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7

Lake Tahoe Case Study

INTRODUCTION

The Sierra Nevada Ecosystem Project (SNEP) selected the Lake Tahoe Basin as one of several areas deserving special study, as it believes that we have much to learn from the long-history of human use and scientific study of the Basin's resources. In addition, there is much policy and management insight to gain from studying the continuing evolution of its institutions. Appropriately, our study is written along a chronological backbone, from the past to the present and looking to the future of Lake Tahoe. It is important to realize that the SNEP study includes humans as a full-fledged element within the ecosystem, and as such we are interested in various human uses of the ecosystem, changing cultural attitudes and values, and the evolution of human institutions.

Our understanding of the Lake Tahoe Basin ecosystem is still evolving, and this report is only a partial description of what we have learned. There is a need to complete a more thorough analysis of the ecosystem's historical record, which is "locked" in the sediments of Lake Tahoe, its tributaries, and its forest trees, in archives in written and graphic form, and in the beliefs and information handed down by our ancestors. Nevertheless, if all extant information were to be brought together we would have a better, science-based understanding of the history of the Lake Tahoe Basin ecosystem, especially for the last 150 years, than anywhere else in the Sierra Nevada. During the past thirty-five years, research has greatly enhanced our understanding of the relationships between the dynamics of watershed and atmospheric processes and water quality. Based on this research, science-based management has played a greater role in the Lake Tahoe Basin than in any other Sierra Nevada locale.

We also review some of the major legal and policy decisions that led to the current regulatory and resource situation at the Lake Tahoe Basin, and discuss what will be the "cost" to continue to restore damage to this ecosystem. Conserving a resource such as the Lake Tahoe Basin is very expensive, time-consuming, and complex because it is a highly disturbed and fragmented watershed due to a history of early clearcutting and recent rapid urbanization, and because of the pattern of mixed ownership of land. It has required public support, legislative, judicial, and / or regulatory agency action, the cooperation of all levels of government, the involvement of public and private landowners, the involvement of interest groups, an evolving set of regulatory mechanisms and actions, acquisition and restoration programs, and a high level of collaboration between all players to conserve this ecosystem. As the environment and our societal needs and values change, this process must be dynamic, flexible and sustainable. Thus, the history of the Lake Tahoe Basin serves

Sierra Nevada Ecosystem Project: Final report to Congress, Addendum. Davis: University of California, Centers for Water and Wildland Resources, 1996.

Back to CD-ROM Table of Contents

as a valuable and expensive lesson in resource management within a highly sensitive watershed of extraordinary beauty and economic value.

Lake Tahoe has long been recognized as a special place by the Washoe and earlier Native American peoples, by early settlers and explorers, by all levels of government, by conservation agencies and organizations, by the millions of people who visit the Basin every year, and in the economic and fiscal investments that both help draw people to the Basin and enable its management. Today, Lake Tahoe's topographically bound, watershed ecosystem is regulated on a regional basis under a bi-state compact between California and Nevada which created the Tahoe Regional Planning Agency (TRPA) and cooperatively involves various federal, state, and local agencies and non-profit organizations. As such, the Lake Tahoe Basin serves as an historic, evolutionary model with elements of ecosystem management for public and private lands, and affiliated land acquisition, institutional evolution, and consensus building processes. The "state" or what some might term "health" of the ecosystem is monitored through the regular measurement and analysis of many ecosystem components. No doubt, other ecosystem components could be monitored. Nevertheless, land management is evaluated through regular monitoring and reviewed every five years. Restoration activities, resource preservation, land acquisition programs, other capital improvements, and regional land-use planning are some of the means of achieving these thresholds[1], and in the Lake Tahoe Basin this regional management is done through strict regional review of permits, ceilings on the number of permits issued, land coverage regulations, careful resource management, restoration projects, and a cautious eye towards the future in terms of evolving energy, transportation, recreation, housing and other societal needs.

In conducting our evaluation of the Lake Tahoe Basin's ecosystem, we were guided by two questions that we hoped would both inform the other parts of SNEP and contribute to the long-term health of the Lake Tahoe Basin ecosystem:

- What can SNEP learn from what has been done at Lake Tahoe in the ecological assessment, monitoring, consensus building, land-use management and regulation, land acquisition and restoration, and policy development arenas?
- What can SNEP recommend as future needs and directions for the wise science-based assessment, policy formulation, and resource management of the Lake Tahoe Basin, to sustain and improve its ecological health into the future?

While these questions focused on our examination of the Lake Tahoe Basin experience, this report does not contain explicit answers to the questions as stated here. Regarding the first question, the case study team informed other scientists about how the Lake Tahoe Basin experience could help the larger SNEP assessment. Regarding the second question, our recommendations are very general and, for the most part, support the process of cooperation, learning, planning and management that is now underway in the Basin.

The case study team recognized the following premises upfront in our assessment:

- The Lake Tahoe Basin is an important local, regional, state, national and international resource; it is one of the largest, deepest, and clearest mountain lakes in the world and is reknown for its scenic beauty; before the turn of the century, it was discussed as one of the first three potential national parks (i.e., Yosemite, Lake Tahoe and Yellowstone); the major attraction is the large, deep and clear mountain basin lake and the scenic vistas it provides;
- The deterioration of the Lake Tahoe Basin ecosystem is understood to have begun with the influx of large numbers of early settlers ca. 1870, with near stand-replacement logging, alteration of stream courses and flows, resultant erosion, loss of native flora from grazing, elimination of native fisheries, modification of near-shore habitats, and urbanization and recreational development; little is understood about the extent or effects of at least 8,000 years of Native American resource manipulation;
- The Lake Tahoe Basin has a long history of human conflict, litigation, and policy response targeted at development versus environmental preservation; this history has forced discussion between groups with dissimilar interests and goals, resulting in various efforts to better manage the environment built on productive compromise and cooperation;
- Since the early 1980s, the Lake Tahoe Basin ecosystem has been managed using an integrated resource management philosophy, with key thresholds defined for a variety of ecosystem parameters, with these parameters monitored, regulated and reviewed; various on-the-ground components of this management process still need to be implemented;
- The Lake Tahoe Basin ecosystem is still under threat (e.g., lake water continues to decrease in clarity, parts of the forest cover are severely stressed by drought, infestation, and other factors, and air pollution continues to be a concern), the full range of human concerns for the biophysical and human systems are present here (e.g., community well-being, recreation, economic redevelopment, invasion of exotic organisms, wildfire risk, water quality deterioration);
- Continued analysis and discussion are needed to define additional key scientific data needs and monitoring and restoration opportunities; key issues of concern include watershed restoration, erosion, forest fuels reduction and vegetation management, wildlife viability and habitat suitability, and urban-wildland interfere processes; some of these are addressed in other SNEP assessment reports;
- The Lake Tahoe Basin ecosystem provides a window to the future of planning and management of other Sierra Nevada ecosystems in terms of multiple stress, participatory planning, financing, jurisdictional cooperation, and efficacy of efforts.

METHODS EMPLOYED IN THE CASE STUDY DEVELOPMENT

The case study team followed the specific charge given to SNEP as outlined in our May, 1994 Sierra Nevada Ecosystem Project Progress Report, which set a framework for addressing questions and conducting tasks within the project. All SNEP-wide tasks in ecosystem assessment and policy analysis were undertaken in the Lake Tahoe case study and structured as follows:

1. *Assessment of current and historic ecosystem conditions and trends*—Our science-based ecosystem assessment (biophysical and human dimensions) is portrayed in the section titled "Ecosystem Assessment" of this report. We conducted an overview of existing data, as best as possible, with limited time and funding, on the historical and current conditions of the ecosystem's biophysical elements, as well as on changing human uses and needs (i.e., human elements). The purpose was to portray where the Basin ecosystem has been and where it is likely going. We also inventoried and identified the locations of key data, including time-series monitoring data, historical photographs, and geographic information system (GIS) layers, and collected and centralized as many of these data as possible in the SNEP GIS (ARC/Info, Unix-based). In the process of data compilation, we compiled a digital bibliography (using the bibliographic database program EndNote 2) of over 1,200 references. All of this digital information is available through SNEP. The SNEP ARC/Info GIS is available through (1) the Alexandria project at UC Santa Barbara (http://alexandria.sdc.ucsb.edu), (2) the UC Davis GIS Center on campus, and (3) the CERES of the California State Resources Agency (http://ceres.ca.gov/snep/). Select layers and database files are also available on the SNEP CD-ROM under compilation by Mike Diggles of the U.S. Geological Survey, Menlo Park. The bibliographic database for the Lake Tahoe Case Study is also on the CD-ROM as well as available in hard copy, as a Word text file, or as an EndNote 2 bibliographic database file from Deborah Elliott-Fisk (lead author, e-mail dlelliottfisk@ucdavis.edu).

2. *Definition and discussion of management choices set within the framework of policies as defined by evolving institutions*:—Our "Institutional Evolution" part of the case study addresses this objective. Using an historical approach, we compiled information on and reviewed some land-use and resource management regulations and policy formulation for the Lake Tahoe Basin (e.g., policy assessment). We compiled an overview of the salient points and decisions in the institutional history of Lake Tahoe Basin ecosystem management from legal and policy perspectives. We also reviewed the effectiveness of the current ecosystem monitoring network and the TRPA thresholds. The case study team conducted a modest identification of additional monitoring and research needs (e.g., groundwater inputs, lake nutrient budget, air pollution sources, key wildlife inventories) as a basis for further improving science-based management. The purpose was to provide a framework for continued discussion rather than identify specific management options.

3. *Synthesis*—In our final section on the current institutional framework and future needs, we put our analyses in the broader context of SNEP through a discussion of what SNEP can learn from the institutional evolution of the Lake Tahoe Basin's management, and how this information can be carried into SNEP's policy analysis and discussion of new institutional approaches. Furthermore, we discuss the future science-based management needs of the Lake Tahoe Basin in reference to the long-term sustainability of the ecosystem.

As this case study is an independent scientific assessment, we did our best to compile and review all published scientific data on the Lake Tahoe Basin ecosystems, to meet with various individuals and organizations to gain their perspective, and to incorporate the range of opinions as best possible. Although significant contributions of data were made by TRPA and other organizations and individuals, not all of these individuals are authors of this report. All authors of the report either wrote first drafts of various sections of this case study or provided key figures, tables and appendices, and provided key input and critical review of the case study. This is not to be interpreted as a consensus report of all Lake Tahoe residents, stakeholders, and organizations.

ECOSYSTEM ASSESSMENT

In the last fifty years, dozens of authors have written hundreds of books, papers, theses, and articles on Lake Tahoe and its ecosystem. It is appropriate at this point in the Lake Tahoe Basin's history to ask ourselves what we know about the various ecosystem components and processes and their interactions, what we have witnessed and learned over the past 100 plus years following the major deforestation and natural reforestation of the Basin, and whether our perception of key ecosystem parameters and threats and responses to them have changed over time. We discuss herein the ecology of the Lake Tahoe Basin from a historical, evolutionary perspective for both the biophysical and human elements of the ecosystem.

Biophysical Elements

The Physical Setting

The Lake Tahoe Basin lies high in the Sierra Nevada, between elevations of 1,900–3,050 m (6,200–10,000 feet) asl . It includes about 1,300 km^2 (500 mi^2), of which approximately 500 km^2

(192 mi^2) or 38% are covered by the waters of Lake Tahoe (figure 1). The lake reaches a maximum depth of 502 m (1,645 ft) and a mean depth of 313 m (1,027 ft). The depth of the lake is important with respect to nutrient loading and response.

The Basin's climate is one of long cool-to-moderate winters and short moderate-to-warm summers and is a function of the latitude, proximity to the Pacific Ocean, and the elevation of the Basin. Precipitation occurs primarily between October and May, with winter precipitation predominately in the form of snow. Thunderstorms occur sporadically throughout the summer, but do not produce significant amounts of precipitation (Department of Water Resources 1991). There are many local climates within the Basin, due to topographic influences, as well as a pronounced rainshadow effect and decreasing precipitation from west to east across the Basin, with the Carson Range more arid than the main Sierra Nevada crest to the west.

The geologic underpinnings of the Lake Tahoe Basin are typical of the northeastern Sierra Nevada (McGauhey et al. 1963; Crippen and Pavelka 1970). Granitic rocks dominate the bedrock geology and are the surficial rocks of the southern section of the Basin. Late Cenozoic volcanic rocks overlie the granitics in the northern part of the Basin and are dominated largely by basalts and andesites. All of these rocks are extensively faulted. In addition, metamorphic rocks, largely as caprocks, are scattered throughout the Basin.

The rugged topography consists of steep slopes and generally narrow canyons. Glaciation was most pronounced on the west side of the Basin, producing steep sided troughs and serrated mountain peaks, and depositing morainal materials across the lower slope and into the lake itself. The northern and eastern portions of the Basin walls are deeply incised by narrow stream valleys, with gently rolling, hilly terrain in some sections. The southern portion of the Basin and some areas of the lakeshore are covered by extensive glacial moraine and outwash deposits, as well as Quaternary lake deposits (McGauhey et al. 1963; Bailey 1974).

Biota

With the broad elevational range of the Basin, and topography strongly controlling precipitation and temperature, a wide diversity of montane vegetation types occur here, ranging from subalpine to alpine meadow and fell-fields, to coniferous forests and woodlands, riparian forests, Great Basin shrublands, and various wetland communities (figure 2). Soils act as a secondary control to climate of vegetation patterns. A number of plant species of special interest, especially at high elevations and in wetlands, are found here. Although the typical northern Sierra Nevada diversity of tree species is present (e.g., lodgepole pine, red fir, white fir, incense cedar, Jeffrey pine), the relative species composition and density of the forest have changed in the last century, as the co-dominant sugar pine-Jeffrey pine-white fir forests which covered the greater part of the Basin before the logging of the late Nineteenth century were largely lost. Remnants remain on smaller parcels, steeper slopes, and at higher elevations, where red fir, mountain hemlock and other coniferous species co-occur (Bailey 1974).

This diversity of plant communities and vegetation types creates a broad spectrum of wildlife habitats in the Basin. Due to the high density of stream tributaries issuing from the mountain slopes, riparian vegetation makes important habitat contributions here, and this vegetation and the adjacent stream ecosystem are currently the focus of intensive biodiversity inventories on birds, mammals, amphibians, reptiles, terrestrial insects, aquatic insects, vascular plants, mosses, lichens and fungi (Pat Manley, USFS Region 5, San Francisco, 1995). The U.S. Forest Service (USFS), California Tahoe Conservancy (CTC), and University of Nevada, Reno are working collaboratively to design an innovative riparian inventory and monitoring protocol, which they will then apply basin-wide. We find the knowledge on plant and forest structure and dynamics to be incomplete in light of the important role they play in the Basin ecosystem. There is strong interest in manipulating vegetation on the lake's watershed. If this is to be done, there must be monitoring of short-, medium-, and long-term results (e.g., nutrient fluxes from thinning or prescribed burning).

Small birds, waterfowl, upland game birds, raptors, and large and small mammals have lived in the Basin, including willow flycatchers, pileated woodpeckers, bald eagles, peregrine falcons, golden eagles, pine martens, grizzly bear, wolverines, osprey, goshawks, and fishers. Populations of some of these vertebrates have diminished or have been lost completely. In its 1991 evaluation of environmental indicators (Tahoe Regional Planning Agency 1991), TRPA reported that it found no active bald eagle nests in the Basin. In this same year, the USFS did sight juvenile and adult goshawks at Angora Lake. An active nest was also found at Saxon Creek. The TRPA furthermore recommended that cooperating agencies prepare an overall report on wildlife population dynamics.

The native fisheries of the past were diverse including Lahontan cutthroat trout, mountain whitefish, tui chub, Lahontan redside, speckled dace, Tahoe sucker, and Paiute sculpin (Tahoe Regional Planning Agency 1991). Brewer wrote of Lake Tahoe's remarkable fishery in l863 (p. 443): "The lake abounds in the largest trout in the world, a species of speckled trout that often weighs over twenty pounds and sometimes as much as thirty pounds!" Sadly, the Lahontan cutthroat has been lost except at a few isolated spots in the Truckee River drainage. Efforts have been made to restore the native Lahontan cutthroat, especially in the Upper Truckee River watershed in the Meiss Lakes Basin and also in the lower Truckee River below Lake Tahoe's outlet. However, even before cutthroat trout began to decline in the Lake Tahoe watershed, state fish and game departments cooperated to establish a larger sport fishery, first by planting rainbow trout, brown trout, mackinaw (lake trout), brook trout, golden trout and, later, Kokanee salmon. These introductions impacted

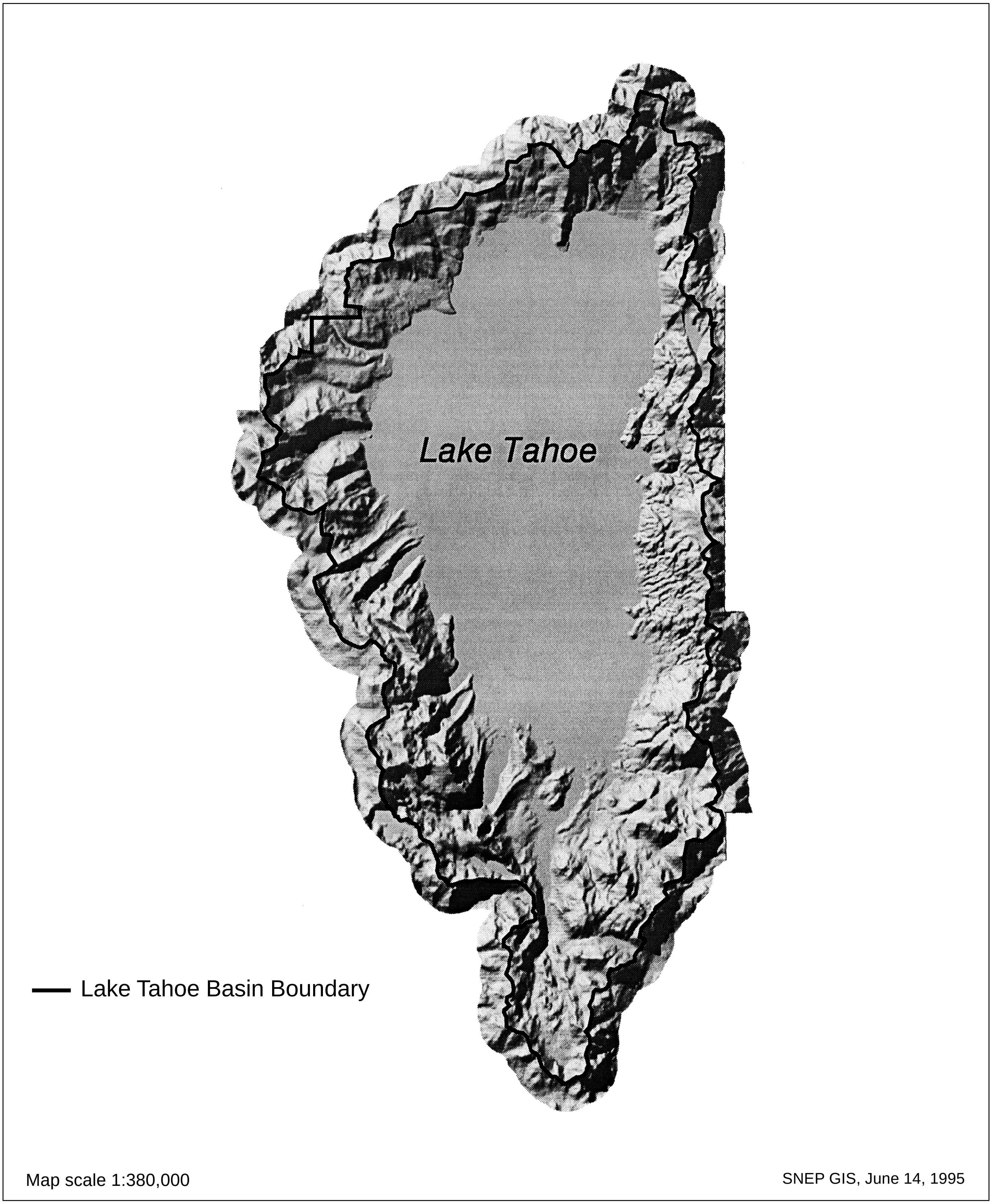


FIGURE 1

Lake Tahoe Basin shaded relief map.

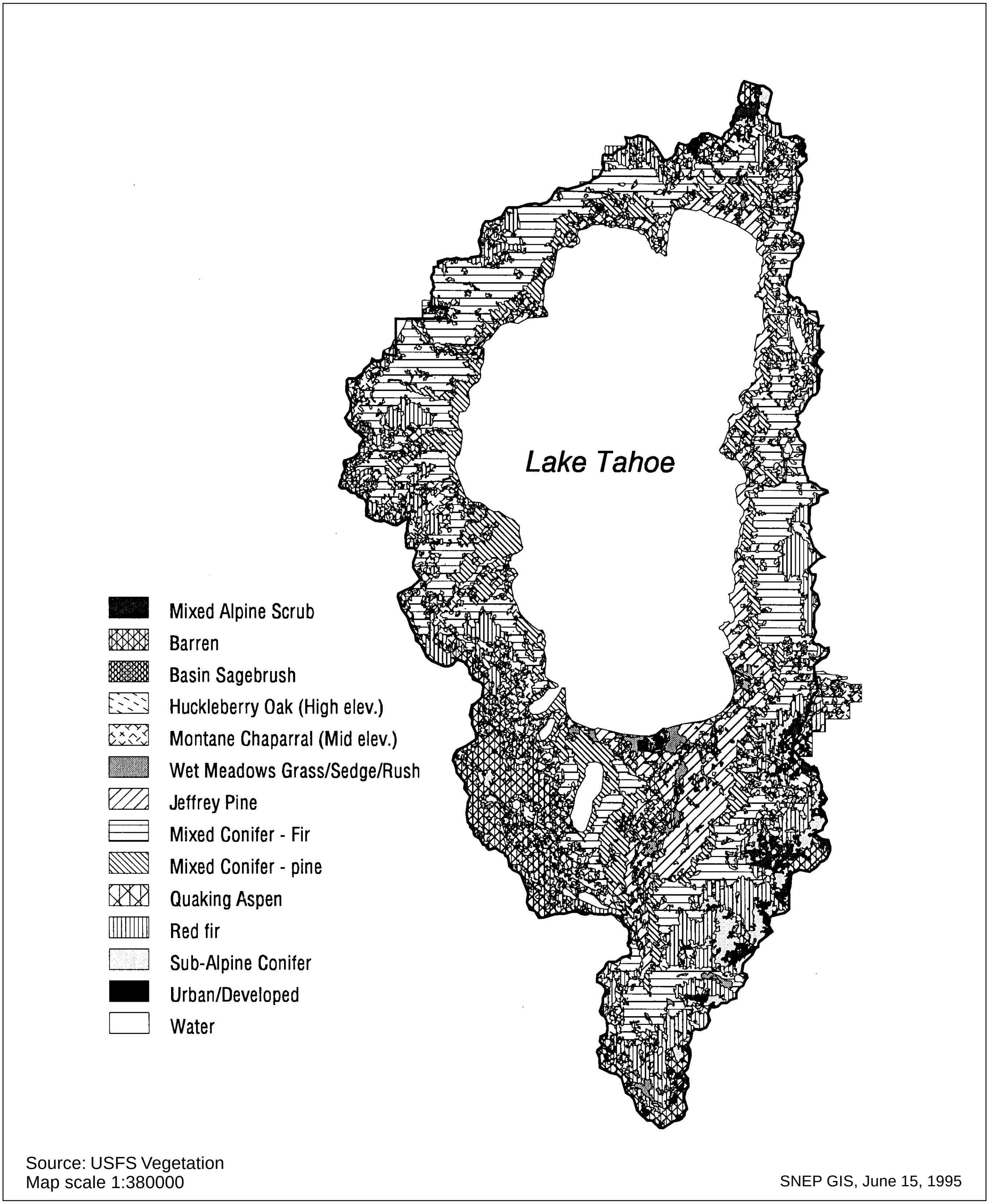


FIGURE 2

Lake Tahoe Basin vegetation map.

the aquatic invertebrates. With a few notable exceptions, such as at Taylor Creek, spawning streams were obstructed by road construction, channelized, devegetated, or all three. Fish survival rates from year-to-year were assured to be low, leading to a policy of annual restocking from hatcheries. Today, Lake Tahoe's fishery consists almost totally of introduced species, although native fish species are present.

In the early years of the post-war era, urbanization of the Basin was accompanied by draining and filling of many wetland areas, a practice that reached its peak in the 1960s with the creation of the Tahoe Keys (figures 3 and 4), a dredged and filled residential development in the region's largest marsh, at the mouth of the Upper Truckee River. Many backshore as well as some nearshore habitats have been modified by road construction, the management of beaches and piers, and other construction. In 1979, the Western Federal Regional Council said that 75% of the Lake Tahoe Basin's marshes, 50% of its meadows, and 35% of its riparian zones had been destroyed since 1900, and also that about 25% of the Basin's marshland had been developed between 1969 and 1979 (Western Federal Regional Council Interagency Task Force 1979).

FIGURE 3

Truckee Marsh in 1930 (current site of Tahoe Keys development). Photo by Dr. Robert Orr, property of California Tahoe Conservancy.

As the human population of the Basin started to grow, suppression of wildfires also became the norm. In the 1920s, public agencies began to regularly fight and extinguish forest fires. Logging occurred through the 1960s, especially along the north shore. In 1947, the mill along the south shore was still the largest employer in the Basin. However, given the Basin's beauty and attraction to visitors, a policy emerged in which timber production was later discouraged. Furthermore, land managers became reluctant to thin or otherwise harvest the forest for fear of damaging water quality or other resources and upsetting environmental groups. The prevailing view of the forest ecosystem in the middle of this century was that, with fire excluded, the ecosystem would take care of and repair itself. The use of prescribed fire in the Basin continued to be debated by many parties. A logic for protecting the Lake Tahoe Basin from fire was put forth based on conservation of watershed values, recreational opportunities, preservation of forest and wildlife habitat, and protection of developed areas valued at many millions of dollars. However, by 1975, the California Tahoe Regional Planning Agency (CTRPA[2]) had adopted a regional plan that recognized the value of prescribed burning (California Tahoe Regional Planning Agency, 1995). The ecosystem effects of prescribed burning were not completely understood, yet fire was recognized as an essential ecological process in the summer-dry forest type of the Basin. Prescribed fire was also recognized as a tool for reducing fuel load in the forest, thereby decreasing the risk of destructive, high-intensity wildfires.

In the last two decades, a broader understanding of the ecosystem has emerged. A drought, starting in the mid-1980s, stressed the overstocked, even-aged forest making white fir, and then the pines, susceptible to insect damage. In 1991, the USFS reported that 300 million board feet of timber were dead or dying in the Basin. Land managers also realized the need to reintroduce fire into the ecosystem, or substitute something else for it to restore forest health.

A better understanding of the role of natural fire in the Lake Tahoe Basin ecosystem is very much needed. Fire histories have been compiled in six California State Parks within the Sierra District of the California Department of Parks and Recreation (Rice 1988; Rice 1990), and three of these parks are within the Lake Tahoe Basin: (1) D. L. Bliss State Park (off Highway 89, 6 miles south of Meeks Bay), (2) Sugar Pine Point State Park (off Highway 89, 1 mile south of Tahoma), and (3) Emerald Bay State Park (off Highway 89, 22 miles south of Tahoe City).

For these fire history studies, slabs were taken out of live and dead trees with fire scars. The forest vegetation at each

FIGURE 4

Tahoe Keys development of the Truckee Marsh, 1978. Photo by Ray Lacey, California Tahoe Conservancy.

site consisted primarily of Jeffrey pine, ponderosa pine, and incense cedar, with white fir also a common overstory tree in the D. L Bliss and Sugar Pine Point State Parks. Some sugar pine is found at Emerald Bay State Park.[3] The studies provide excellent fire history data, but it is difficult to arrive at general conclusions because the spatial component of the fire study is missing. The fire history studies do present average fire intervals by century for each park and they are summarized in tables 1–3 (Rice 1988; Rice 1990).[4] However, to effectively manage using fire, there must be a better understanding of the effects of varying fire intensity, season of burning, and nutrient retention and release. This is currently a major gap in scientific understanding in the Basin.

Before the year 1700, sample size becomes limited and calculations of fire intervals are unreliable. Past logging near these areas has also removed valuable fire scar data. A measure of fire return interval variability would also give more information on the disturbance regime, and the raw data that are provided in the report could be analyzed in this regard.

The data demonstrate that fire is a persistent process in these ecosystems. Fires occurred on the average every five years from 1800–1899, and have occurred on an average of every twenty years from 1900–1990. In the twentieth-century, fire frequency is higher in the Lake Tahoe Basin than for most of the western Sierra Nevada. The change in fire frequency with increased human occupance, however, has resulted in increased tree density and changes in biodiversity of the forest (McKelvey et al. 1996). Shade tolerant species such as white fir have increased in density over shade intolerant species such as Jeffrey pine. The use of prescribed fire generates system impacts that are both beneficial and potentially detrimental from a human perspective, and needs to be carefully dealt with.

TABLE 1

Average fire intervals at D. L. Bliss State Park.

Years	Average Interval (yr.)	Number of Fires
1900–1990	21.5	4
1800–1899	4.6	22
1700–1799	9.3	11
1600–1699	20.0	3
1500–1599	29.0	3

TABLE 2

Average fire intervals at Sugar Pine Point State Park.

Years	Average Interval (yr.)	Number of Fires
1900–1990	18.0	4
1800–1899	6.6	14
1700–1799	8.2	11
1600–1699	19.8	5
1500–1599	29.0	3

TABLE 3

Average fire intervals at Emerald Bay State Park.

Years	Average Interval (yr.)	Number of Fires
1900–1988	8.8	10
1800–1999	3.7	27
1700–1700	4.3	23
1600–1699	6.6	15

The biota of the Lake Tahoe Basin is affected not only by human induced processes, such as fire suppression, urbanization, and pollution, but by natural influences, such as periodic flooding, wildfire, mass movement (e.g., landslides), and droughts. Long-term drought is believed to be responsible for lowering the lake below its natural rim, and in this regard, researchers have found tree stumps as deep as 4.9 m (16 ft) along the south shore of the lake and 12 m (40 ft) along the east shore. The size of these stumps indicates the trees were over 100 years old when they died (Lindström (appendix A). A lake-level decrease of this magnitude would encourage stream entrenchment and wetland modification, accelerated erosion, and sediment transport into the lake.

Further information on natural droughts, altered fire and runoff regimes, and various human impacts are available through the pollen analysis of a mid-lake core collected from Lake Tahoe by the Tahoe Research Group (TRG) (Davis appendix 7.2). The pollen and sediment data attest to historic changes in vegetation and fire in the Basin. During the Little Ice Age (ca. 1850–1890 AD), a decrease in pine and an increase in fir and sagebrush indicates cooler and drier conditions than at the present. A decrease in both pollen and charcoal concentration with settlement of the Basin in the latter nineteenth century is indicative of logging and accompanying erosion during the Comstock era, with acceleration of the sedimentation rate. Decreased wildfire beginning about 1885 is reflected in the reduced charcoal concentration. A subsequent small increase in pollen and charcoal concentration and a brief but sharp decrease in pine pollen percentage appear to be the result of post-World War II development in the Basin. Increased nutrient flow into the lake from accelerated erosion and human pollution is also reflected here by the increases in the planktonic algae *Pediastrum,* and also seen with the expansion of the nearshore littoral zone as represented by sedge pollen (Davis appendix 7.2).

As the result of fire suppression, past forest harvesting practices (Sudworth 1900; Leiberg 1902), and recent stress, widespread tree mortality is occuring in the Basin today. Insect damage in parts of the forest also occurred in 1921 and 1937. Increased tree density and reduced biodiversity, as demonstrated by the preponderance of white fir, has resulted in the current ecosystem being much more vulnerable to disturbances such as wildfire, drought, insects and disease, whether they are species specific or otherwise.

In the past five years, salvage logging operations have been occurring in the Basin, primarily on the eastern, northern and southwestern sides of the lake, and to a limited extent on the western side. Salvage operations that concentrate on standing dead trees and do not reduce surface fuel loads may increase fire risk in these ecosystems. A comprehensive program that reduces surface fuel load and reduces vertical and horizontal continuity will be required to restore these systems to a state that can incorporate natural disturbance without catastrophe. Maintenance of the desired vegetative matrix will be necessary and will require some combination of thinning of stands, prescribed fire, and mechanical brush treatments. Draft environmental impact statements proposing such treatments are pending by the Lake Tahoe Basin Management Unit (LTBMU), USFS.

The Atmosphere

Clean air and good visual range have been two of the Lake Tahoe Basin's most appreciated values. Lake Tahoe is a high altitude lake at 1,900 m (6,200 ft), and is separated from the Sacramento Valley by the Sierra Nevada divide, ranging from 2,200 m (7,200 ft) at the passes to 3,050 m (10,000 ft) at the summit of the Crystal Range. With the lower ridges to the east, this terrain forms a bowl-shaped basin that develops very strong, shallow subsidence and radiation inversions at all times throughout the year. Even relatively weak local pollution sources can thus build-up to serious levels. Each of the pollutants has its own environmental impacts and cause-effect relationships. In addition, transport of pollutants from the Sacramento Valley occurs during the summer, increasing the concentrations of both ozone and fine particulates such as sulfates, nitrates, and smoke. 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 along a cleaner air stream.

Smoke from natural lightning fires and fires set by the Washoe people occurred in the Lake Tahoe Basin in historic times. Recent studies indicate that smoke played an ecological role in regard to controling pest outbreaks in the forest. Even in the absence of smoke from fires, haze would have been present, as the sun volatilized light-scattering terpene aerosols from the forest during the summer, as it does today. The logging associated with the Comstock era also undoubtedly resulted in smoke from fires and combustion engines. 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. Access improved, almost to today's levels. Urbanization brought with it increased vehicle trips, and the various and widespread Basin amenities generated substantial vehicular traffic. Human occupance 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 (ARB) at many sites around the lake and nearby. The results confirmed the earlier study, showing levels that reached or surpassed those seen in many cities for primary automotive pollutants. This study resulted in designation of the Lake Tahoe Basin as a separate air basin by both California and Nevada, with very stringent standards on carbon monoxide (because of the high altitude) and on visibility (because of the scenery). Regular monitoring of pollutants commenced at South Lake Tahoe, along with studies by the UC Davis Air Quality Group (AQG) in 1976–79. The AQG studies, along with work by the ARB, clarified the nature of the inversions, and the AQC 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 ARB monitoring, these studies documented the dramatic levels of pollutants that occurred in winter under the strong inversion at both the southern and northern ends of the lake.

In 1978, the U.S. Environmental Protection Agency (EPA) designated portions of the Lake Tahoe air basin as a non-attainment area for carbon monoxide. Meanwhile, residential development added many new residents and new homes during the 1970s. The popularity of wood heaters, coupled with the great availability of inexpensive firewood, increased wood smoke emissions dramatically during the heating 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.

By 1994, the TRPA air monitoring had clearly defined the ratio of local-to-transported particulate matter, and coupled it closely to visibility degradation. Cahill et al. (1996) shows the results of four years of air monitoring for fine particulates (figure 5). Based upon Rice's (1988, 1990) studies, 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 a local,

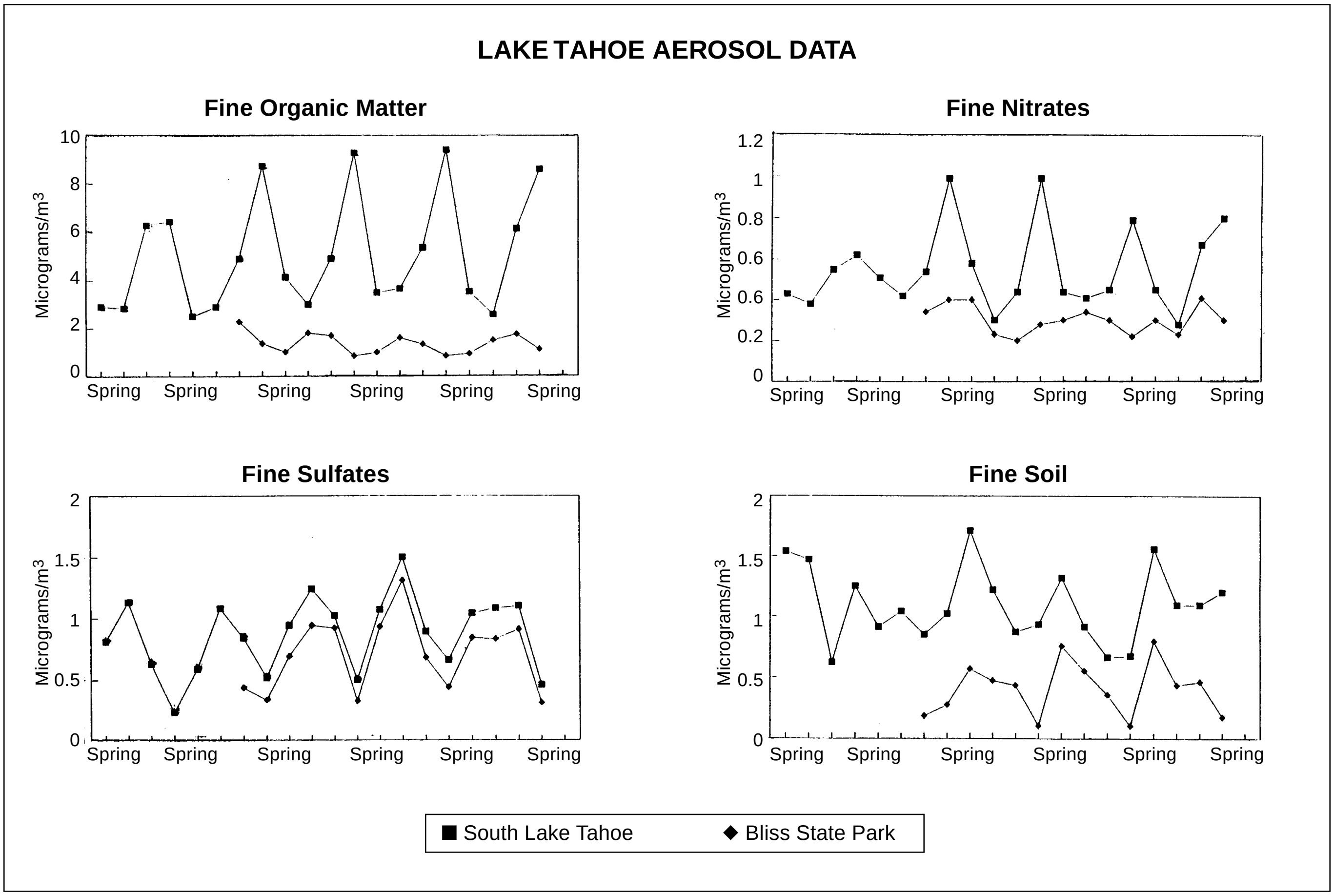


FIGURE 5

Air quality at South Lake Tahoe and Bliss State Park, Lake Tahoe, 1989-1994.

in-basin sources. As with the earlier studies, the Bliss site represents the average pollutant levels present across the entire air basin, upon which are superimposed the local pollutant sources from urbanized areas around the lake, especially at the northern and southern ends. If the two concentrations are the same, then all the pollutant is transported. This situation is the case for fine sulfates. The difference between the Bliss data and the South Lake Tahoe data then represents the local contribution. The winter maxima are both high and mostly local. These concentrations, however, do not extend very far from the urbanized areas, falling off to about one-half of their concentration about a mile away from the sources.

Ozone concentrations are highest during the summer, when sunlight drives the chemical processes that create ozone from airborne hydrocarbons and oxides of nitrogen. Ozone concentrations in the Lake Tahoe Basin were stable during the 1980s, hovering at or slightly above California standards. However, two factors puzzled scientists. First, the Lake Tahoe Basin's highest ozone concentrations were observed in the late afternoon and early evening, 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. Although the Basin generated its share of biogenic and anthropogenic ozone precursors, the resulting ozone was probably appearing somewhere downwind in Nevada.

Analysis of particles in the air improved dramatically after TRPA installed, in the late 1980s, 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) was located at the particulate sampling stations, giving scientists the ability to look simultaneously at particulate matter and its impact on visual range.

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, soil, ammonium sulfate, and ammonium nitrate. The monitors collected small concentrations of industrial metals, indicators of industrial sources not present in the Basin (Tahoe Regional Planning Agency 1991).

The largest concentrations of these metals occurred in the summer, when long-range transport conditions were most likely. The main sources of the particulate organic carbon component are natural terpene emissions in the summer and wood burning in the winter.

Ammonium sulfate is an industrial emission, for which there are no known sources in the Lake Tahoe Basin. Ammonium nitrate (from automobiles, generally upwind of the Basin) represented only 6% of the fine particulate mass. From these measurements, scientists were able to draw two conclusions: long range transport of pollutants from distant urban and industrial sources was definitely occurring, and automobile exhausts were only a small contributor to haze and diminished visual range in the Basin.

In the 1980s, those working to understand the 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 had 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 the idea, as did the nation's interest in acid rain and deposition of nitric and sulfuric acids. Airborne substances undoubtedly played a role in Lake Tahoe's water quality dynamics, but what role, exactly, was unclear.

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 groundwater inputs. This conclusion—even without monitoring data to confirm it—influenced the development of TRPA's threshold standards and subsequent regional plan by causing TRPA to look beyond erosion and runoff control as methods to control cultural eutrophication[5], and by creating an amount of uncertainty as to sources, distribution, and impacts of the airborne fractions.

In the following years, 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. Since deposition is literally a molecular-level phenomenon, monitoring it directly is difficult. Spatial variation in meteorology within the Basin, especially over the lake itself, complicated attempts to measure dry-weather and wet-weather deposition.

In 1990, in expert testimony in the case of *Kelly v. TRPA*, Cahill of AQG summarized what was known about the atmospheric deposition of nutrients to Lake Tahoe. He stated that the decline in the lake's water quality was not primarily due to atmospheric inputs. With abundant nitrogen in the system from various ecosystem sources, phosphorus is now a major influence on aquatic productivity. 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 negligible sources of phosphorus.

In 1991, TRPA published a summary on deposition of airborne algal nutrients on Lake Tahoe. It said that the primary nutrient of concern was nitrogen, commonly found in the air in gaseous form (e.g., NO_2 or nitrogen dioxide) and particulate form (e.g., NH_4NO_3 or ammonium nitrate) (Tahoe Regional Planning Agency 1991). Phosphorus compounds were also found in the air in the particulate form.

Gaseous emissions from local sources appeared to be an important source of atmospheric nitrogen in Lake Tahoe's nutrient budget. Particulate nitrogen from upwind areas appeared to be less important. The report said gaseous emissions of nitrogen compounds (known as "NO_x") from automobiles and other sources react with other substances in the atmosphere and on the ground. The portion not scavenged from the air by other chemicals, vegetation, or other surfaces, including water bodies, changes to particulate in about 24 hours. Because the particles are less than 2.5 millionths of a meter in diameter, they do not settle easily, and are transported downwind.

The report said that most NO_x emissions upwind of the Lake Tahoe Basin change to the particulate form before they reach the Basin, and are easily transported over the Basin by the wind. However, NO_x emissions within the Basin react with vegetation, water surfaces, and other surfaces before they change to the particulate form. These reactions scavenge a portion of the NO_x from the atmosphere. Thus, local NO_x emissions contribute to the lake's nitrogen budget.

Vegetation in the watershed also scavenges NO_x, and some portion of the scavenged nitrogen eventually makes its way into Lake Tahoe. "The reader may wish to think of this process," the report said, "as an area-wide enrichment, or fertilization, of Lake Tahoe and the Tahoe Region by local sources of NO_x" (Tahoe Regional Planning Agency 1991).

Recent analysis of wet and dry deposition has been made based upon a multi-year measurement program by TRG (Jassby et al. 1994). These results favor a larger fraction of the nitrate input from upwind sources, but due to the use of innovative but uncharacterized sample collection, the results are being carefully evaluated for relevance to both dry deposition theory and standard sampling protocols.

The Hydrosphere

Lake Tahoe is unique as a Sierra Nevada high elevation lake in terms of its size and depth. It holds approximately 156 cubic kilometers of water (126 million acre feet). It is 19 km wide (12 mi) and 35 km (22 mi) long, with a surface area of 500 km^2 (192 mi^2). The mean depth of Lake Tahoe is 313 m (1,027 ft), with a maximum depth of 502 m (1,645 ft), making it the 10th deepest lake in the world.

Like most lakes, Lake Tahoe stratifies during much of the year with colder, denser waters staying at the bottom and warmer, lighter waters on top, with little mixing between the layers. However, unlike most temperate lakes, Lake Tahoe does not always turnover annually. The depth and duration of winter mixing are extremely variable (Goldman 1988).

Tributary flows deliver about 370 million m^3 (300,000 acre-feet of water) to Lake Tahoe each year. Nearly half of the surface inflow to Lake Tahoe comes from only four of its sixty-three tributaries: Trout Creek, the Upper Truckee River, Taylor Creek, and Ward Creek. The amount of subsurface groundwater flow entering Lake Tahoe is not known, but is probably not more than about 10% of surface flow (McGauhey et al. 1963). Four estimates of a water balance are known to have been made for Lake Tahoe. The years, methods and assumptions used result in different estimates (table 4).

Estimates of average annual evaporation from the lake surface from these studies range from 338 million m^3 (680 mm) to 551 million m^3 (1,100 mm). These water balance estimates suggest there is a considerable uncertainty in the calculations and much variability between years.

By considering the water budget and the lake's volume, scientists calculate the average residence time of a drop of water in Lake Tahoe at about 700 years. This residence time is an important point in the development of control plans because, for practical purposes, one must think of Lake Tahoe as a nutrient sink not subject to flushing action.

Prior to European contact (ca. 1850) and probably through glacial-interglacial cycles, the level of Lake Tahoe fluctuated naturally, partially controlled by ice dams in the area of what is now the Truckee River outlet. Tree-ring and other data reveal a long-term drought after the last ice age which lasted over a thousand years (Stine 1996). Research in progress by scientists at the University of Nevada Desert Research Institute (T. Kumamato, 1996, personal communication) shows that the level of the lake's surface dropped at least 14 m (46 ft) below its current rim, and conifers grew at an elevation of about 6,200 feet. Further information on mid-to-late Holocene lake-level changes is contained in Lindström (appendix 7.1).

To examine possible increases in rates of sedimentation resulting from the intensive logging and watershed disturbance of the late 1800s, TRG, led by Charles R. Goldman, analyzed sediment cores from the deep portions of Lake Tahoe. They dated biological and physical changes in the cores by measuring the abundance of a radioactive lead isotope. The cores revealed no demonstrable change in Lake Tahoe's algal community that correlated with the logging era. As noted previously, however, Davis' (appendix 7.2) analysis of pollen and charcoal concentration showed increased sedimentation rates following the Comstock era. In the 1950s, however, the relative abundance of some of the phytoplankton (araphidinate Pennales and Centrales) increased dramatically with a corresponding influence on water clarity. This is also reflected in Davis' analysis of the nearshore cores by an increase in *Pediastrum* (appendix 7.2).

Although land disturbance during the Comstock era was extensive, it has been hypothesized that the absence of long-term impacts was due to the fact that logging did not create surfaces as impervious to water percolation and throughflow as pavement and concrete, even though soil compaction undoubtedly occurred, and thus the watershed recovered from logging with the natural wetlands largely intact. An alternative hypothesis is that the climate of this time was such that there were few heavy winter snowpacks with their resulting large amounts of spring runoff that would have delivered higher amounts of sediment to Lake Tahoe in the immediate post-Comstock years. However, hydrologic records show major flooding in Reno in 1867, 1886, and 1900, and four of the ten highest seasonal snowfall amounts from 1879 to the present fell between 1880 and 1895, casting doubt on this hypothesis.

Lake Tahoe's first dam was constructed at Tahoe City in the early 1870s. The dam, which raised Lake Tahoe's average surface elevation by about 2 m (6 feet) caused Lake Tahoe's shoreline to move landward, a phenomenon that had previously occurred only as a result of natural climatic variation. There is little documentation of the ecological effects of this change. One can visualize, however, a period of adjustment in which the lakeshore eroded and new beaches were formed. In the early 1900s, traincar-loads of sand were brought to the Homewood and Sunnyside areas on Lake Tahoe's northwest shoreline to supplement the natural beaches, and this sand eventually moved into the nearshore circulation of the lake.

The impacts of sewage discharge in the Basin are a further concern for the lake's health. Not until the 1950s did the Basin's residents begin to manage their sewage in a collective fashion. The Tahoe City Public Utility District (TCPUD) opened a secondary treatment (e.g., trickling filter) plant in 1954. The North Tahoe Public Utility District (NTPUD) opened a primary treatment plant near Tahoe Vista in 1957.

TABLE 4

Estimates of Lake Tahoe's water balance (in million m^3 of water).

Source	McGauhey et al. 1963	LTAC 1971	Lind and Goodridge 1978	Myrup et al. 1979
Interval (yrs)	unknown	1960–71	1958–77	1967–90
Streamflow into lake	380	459	362	510
Precipitation into lake	253	336	255	388
Evaporation from lake	410	541	338	551
Outflow to Truckee River	217	214	227	368
Change in storage	plus 0.1	plus 40	minus 36	minus 22

The South Tahoe Public Utility District (STPUD) built a secondary treatment (i.e., activated sludge) plant near the confluence of Heavenly Valley and Trout Creeks in 1960, which served portions of the south shore in both California and Nevada, including the Stateline casino district. All of these treatment plants disposed of their treated effluent by application to the land, via spray irrigation or infiltration ponds and trenches.

Still, many populated areas of the Basin were outside the service areas of these facilities, and by the early 1960s there was a significant interest in providing sewage collection and treatment for all the residents and visitors of the Lake Tahoe Basin, to “cure” or at least slow down the onset of cultural eutrophication of Lake Tahoe. The LTAC, with money from the Max C. Fleischmann Foundation, contracted in 1961 with the consulting engineering firm Engineering-Sciences, Inc., which conducted a thorough study under the direction of an expert “board of consultants” to explore possible solutions to the sewage problems of the Basin. The analysis contained in the LTAC’s 1963 report (McGauhey et al. 1963) included a hydrologic budget, a nutrient balance, a detailed analysis of nutrient sources and outflow, and an analysis of the impacts of nutrients on Lake Tahoe (present and future). Despite the fact that it did not have long-term water quality data to rely upon, it concluded that “the amounts of nutrients to be developed in [the] Tahoe Basin with continuing growth of population appear to be sufficient to pose a definite hazard to Lake Tahoe should an appreciable portion of these find their way into the lake.” The study considered “all feasible methods of [sewage] disposal which can protect the quality of the lake and of the Truckee River,” including land disposal, surface disposal, and removal from the Lake Tahoe Basin. However, in 1963 LTAC was considering a land freeze as a moratorium on land-use changes.

In July 1966, the Secretary of the Interior convened a conference at Lake Tahoe, under the authority of Section 10 of the Federal Water Pollution Control Act, for representatives of federal, state, and local agencies concerned with the water quality of the lake. The purpose of the conference was to lay a basis for future action, and give the states and localities an opportunity to take whatever remedial action is possible and practicable under state and local law. The conferees concluded that recognizable long and short-term threats of pollution to Lake Tahoe and the Lake Tahoe Basin existed, primarily from the rapid development of the area. They said that federal, state, and local agencies had been aware of these threats, and that substantial progress had already been made, but that there was an urgent need for the establishment of basin-wide objectives and standards for development and use of the lands and waters, which would include enforcement provisions covering not only the waters of Lake Tahoe but its shoreline developments and the total complex of lands and waters that make up the Basin. They further recommended that all developed lands be included within sewage districts, and that the districts aggressively pursue plans to export sewage effluent from the Basin by 1970, with substantial federal financial assistance.

In 1967, Engineering Sciences, Inc. published another report for LTAC, the purpose of which was to indicate those programs necessary to provide a truly long-range regional plan for solution of the sewerage problem. The report noted that considerable effort had been expended toward the accepted goal of total export of sewage from the Lake Tahoe Basin, but that the effort had been uncoordinated, particularly from a financial point of view.

At the time of the 1967 LTAC (Engineering Sciences, Inc. 1967) report, the Douglas County Sewer Improvement District had a secondary treatment plant under construction for the Nevada portion of the South Shore, and the Incline Village General Improvement District had installed a 1 MGD (million gallons per day) package plant, treating sewage from the commercial area adjacent to Lake Tahoe, with disposal via golf course irrigation and hillside spray irrigation. The report said that, of 93,200 privately-owned acres (37,700 ha) in the Basin, 31,290 acres (12,670 ha) were served by sewer facilities, and of the area within existing sewerage districts, only about 60% of the developments were connected to sewers. It concluded that it was essential that a long-range plan providing for sewage collection and management be adopted.

In 1969, LTAC published another report on eutrophication of surface waters (in general) and Lake Tahoe (specifically). Based on the use of bio-assays of the stimulatory effect of various sources of nutrients on algae, the report examined the expected impacts of sewage effluent on Lake Tahoe. And, with more emphasis than in the earlier LTAC reports, the 1969 report examined the role of other sources of nutrients (i.e., non-sewage) on algal growth in surface waters. The report stated that the assumption that domestic and industrial waste water effluents are the principal source of nutrients was not necessarily valid, and furthermore it addressed not only the ability of sewage effluents to stimulate algal growth (in Lake Tahoe and in receiving waters outside the Lake Tahoe Basin), but also the overall amount of nutrients reaching Lake Tahoe annually from the normal processes of nature and the effect of anthropogenic near-shore and shoreline modifications and activities.

The 1969 LTAC report concluded that all types of sewage effluents stimulated growth of algae in Lake Tahoe, and that human activity in a watershed can increase its normal yield of nutrients. It said that Ward Creek had about the same level of biostimulatory properties as Lake Tahoe, but that Incline Creek and the Upper Truckee-Trout Creek (which drained developed areas) each had about twice the biostimulation of Lake Tahoe.

In 1969, the California legislature added Section 13951 to the State Water Code, requiring the export of sewage effluent from the Lake Tahoe Basin and prohibiting the further maintenance or use of cesspools, septic tanks, or other measure of waste disposal in the Basin after January 1, 1972. The governor of Nevada later issued an Executive Order on January 27, 1971, prohibiting the use of septic tanks in the Basin after December 31, 1972.

By 1975, virtually all wastewaters in the California portions of the Basin were being exported to Indian Creek Reservoir in Alpine County (by STPUD), within the heart of contemporary Washoe-land, and to the Cinder Cone land disposal site, near the Truckee River outside the Lake Tahoe Basin (by TCPUD and NTPUD) while a regional treatment plant at Truckee was under construction. These efforts were supported by an extraordinary funding commitment through federal and state loans and grants.

Progress on exported sewage in Nevada was slower, and the EPA sued Douglas County to enforce water quality standards and the sewering and export of wastewaters from the Basin. In May 1973, the U.S. District Court in Reno enjoined any issuance of building permits by Douglas County after December 1, 1973 until sewage facilities were completed and in operation. Construction of sewer facilities were completed in 1975.

In addition, there was a concern whether there was sufficient treatment capacity to accomodate growth. Even though sewage was being exported, the Lahontan Regional Water Quality Control Board (LRWQCB) imposed a sewer connection ban on utilities on both the north and south shore areas of the California side of the Basin because of a shortage of treatment capacity. This shortage was due to increasing rates of development around the Basin. This ban slowed down the development rate in the Basin. However, the gradual decision to collect and export sewage, which spanned the 1960s, allowed for additional subdivision of land and residential use of the Basin. While it may not have been desirable or possible, even then, to reverse the urbanization of the Basin to protect Lake Tahoe and its surroundings, the decision to sewer and export effectively changed the relevant issues.

However, despite the investment in sewage treatment and export, the productivity of Lake Tahoe continued to increase, and its clarity to decrease. State and regional water quality and planning agencies increased their focus on human-induced erosion in Lake Tahoe Basin as the crucial variable in the lake's water quality trend.

Federal, state, and regional agencies began in-depth studies of the water quality situation, focusing on erosion and diffuse or "non-point" sources of water pollution. Working primarily under the provisions of sections 208 and 303 of the federal act, they developed a series of plans and regulations to control erosion and other sources of pollution (e.g., fertilizer). During the 1970s, the California State Water Resources Control Board (SWRCB) and the LRWQCB based their policies on the premise that erosion and siltation were the primary causes of increased algal growth rates in the lake, and they consistently sought greater protection of environmentally sensitive lands and the implementation of soil-erosion control projects through regional water quality plans (Ingram and Sabatier 1987).

Starting in the late 1970s, California and Nevada renegotiated the Tahoe Regional Planning Compact, under pressure from federal agencies, conservation groups and others, and obtained congressional ratification and presidential approval in December 1980. The revised Compact initiated a new round of water quality investigation and planning. Faced with continuing evidence of water quality degradation, TRPA, with the assistance of a technical advisory panel and a consulting team, worked to model the dynamics of Lake Tahoe's water quality. Charles Goldman and TRG continue to lead the assessment of the lake, with their long-term monitoring of lake clarity (figure 6) and primary algal productivity (figure 7) key long-term evaluations of the lake's health.

After attempting to correlate annual changes in algal productivity and water transparency with annual loads of sediment or nutrients entering Lake Tahoe from tributary streams, with insignificant results, TRPA's consulting team investigated

FIGURE 6

Annual average secchi depth at Lake Tahoe, 1968–94. By Charles Goldman, Tahoe Research Group.

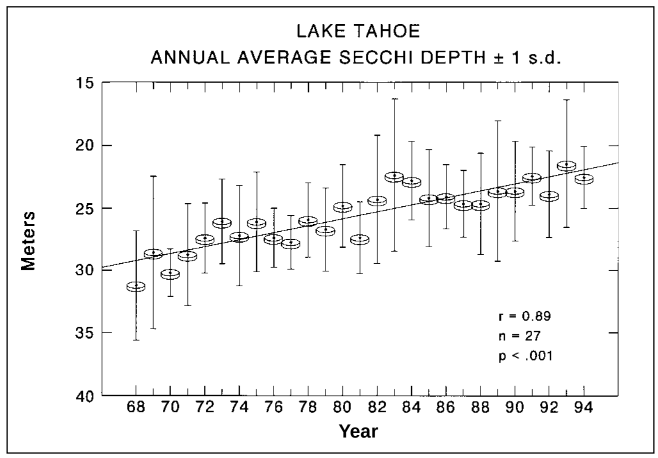
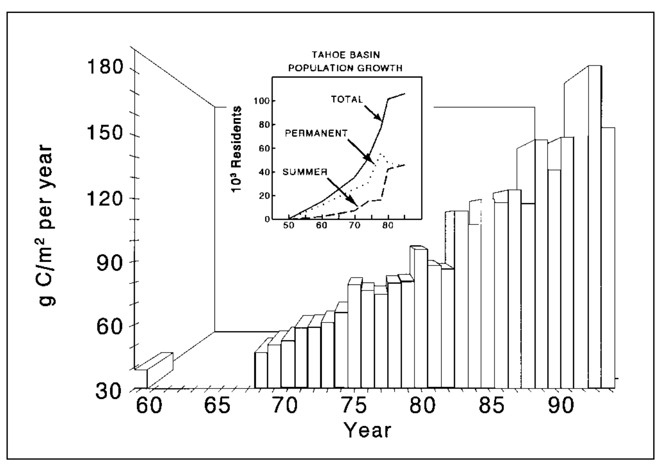


FIGURE 7

Annual algal growth at Lake Tahoe, 1960–94. By Charles Goldman, Tahoe Research Group.



a different cause-effect relationship (Tahoe Regional Planning Agency 1982). They hypothesized that Lake Tahoe's water quality responded not so much to annual inputs of algal nutrients from the watershed and the atmosphere, as to changes in the storage of nutrients in the lake and the amount of annual mixing between the deeper, nutrient-rich waters and the nutrient-depleted surface layer. They found strong statistical support for this hypothesis. In other words, TRPA began to look at Lake Tahoe as a nutrient sink, with a fluctuating, but generally increasing, store of nutrients. Especially in years with extensive mixing, this storage could increase algal productivity in the euphotic surface layer. This conceptual model was a breakthrough for the basin managers, and brought a dose of reality to efforts to control Lake Tahoe's water quality trend. If Lake Tahoe was responding not to short-term (annual) inputs of nutrients, but to longer term (chronic) nutrient loads, there would be no quick fix for cultural eutrophication. In 1982, when TRPA adopted threshold standards, it prefaced them with a statement saying that some environmental components, including water quality, were likely to get worse before they got better. The threshold standards and the subsequent regional plan contained objectives and programs to control nutrient loads to Lake Tahoe from runoff, fertilizer, damage to wetlands, and airborne sources.

During the 1980s, the state and regional agencies continued to refine the conceptual model, and to study and monitor water quality at both surface water and groundwater sampling sites (figure 8), as well as atmospheric contributions of nutrients. This monitoring system is relatively extensive throughout the Basin. In 1988, TRPA amended the state- and federally-approved water-quality management plan ("the 208 plan"), again introducing an updated conceptual model related to water quality.

Although those interested in protecting Lake Tahoe's water quality knew that runoff, particularly from urbanized areas, carried higher-than-natural loads of nutrients and stimulated algal production in Lake Tahoe, there was much debate as to what, exactly, in the watershed caused these problems. In the 208 plan amendments, TRPA emphasized that both empirical and experimental evidence indicated that the natural watershed normally released very few nutrients to the lake. Urbanization, TRPA said, "short-circuited" the watershed's natural functions, causing both the accelerated release of nutrients from the watershed and the diminution of its cleansing capacity.

Thus, from the beginnings of concern for Lake Tahoe's water quality in the 1950s, to the present time, the working hydrologic models of Lake Tahoe and its watershed evolved. Starting with a concern for controlling algal stimulation from sewage, the model grew to include concern for atmospheric sources of nutrients, erosion and runoff from land-use practices, and hydrologic modifications and acceleration of natural watershed processes. Research continues by a number of groups, including the U.S. Geological Survey (USGS), University of Nevada, USFS, TRG, and others. Through these studies we will continue to learn more about the functional links between the atmosphere and the terrestrial watershed to the lake.

Human History and Use

The Lake Tahoe Basin has a long history of human use and misuse. Such settings of great physical beauty often evoke passionate human responses from both conservation and exploitation perspectives. With a long history of Native American occupance and a relatively brief but extraordinarily resource-extractive association with early settlers, the Basin has been both enshrined and desecrated. "A fundamental question arose early in Tahoe's history that continues unanswered to this day: to whom does Tahoe belong, and how should it be used?" (Strong 1984, p xiv).

Humans have been an integral part of the Lake Tahoe Basin ecosystem for at least the last 8,000 years. In the broadest terms, the archaeological signature of the Lake Tahoe Basin marks a trend from hunting-based societies in earlier times to populations that were increasingly reliant upon diverse resources by the time of historic contact (Elston 1982; Elston et al. 1977; Elston et al. 1994). The shift in lifeways may be attributed partially to factors involving changes in climate and population, and a shifting subsistence base. The Pre-Archaic lifeway (prior to 7,000 years ago) involved sparse populations, high residential mobility, and non-intensive plant food processing and storage. Pre-Archaic sites are nearly absent in the Lake Tahoe Basin and reflect the incipient occupation of the area soon after the retreat of Sierra Nevada glaciers 14,000 to 10,000 years ago.

During the succeeding Archaic lifeway (within the last 7,000 years), prehistoric populations increasingly exerted their influence in altering the landscape and affecting fauna and flora through a gradual decrease in overall mobility, increased land-use diversity, a broadened diet, and intensified resource procurement. This period is correlated with mid-Holocene warmth and prolonged drought, punctuated by intervals of increased moisture. Extreme aridity prior to 5,000 years ago (and more recently around 700 and 500 years ago) is marked by tree stumps submerged far below the current shoreline of Lake Tahoe and other nearby lakes (Lindström 1985 1990; Lindström and Bloomer 1994; Lindström appendix 7.1). Changing environments imposed critical limits on prehistoric land use, allowing for year-round residence in the Basin at some times and prohibiting even seasonal occupation during other time periods. It is conceivable that even during severe droughts, Lake Tahoe and its tributary lakes and streams could have sustained resource-rich habitats, especially relative to the desiccated lowlands. Persistent droughts may have stressed lowland habitats and resulted in population "squeezes." Meanwhile, ameliorated climates in the uplands may have opened new subsistence-settlement opportunities, as groups expanded their seasonal circuits and intensified use of the highcountry. Such population shifts or expansions are

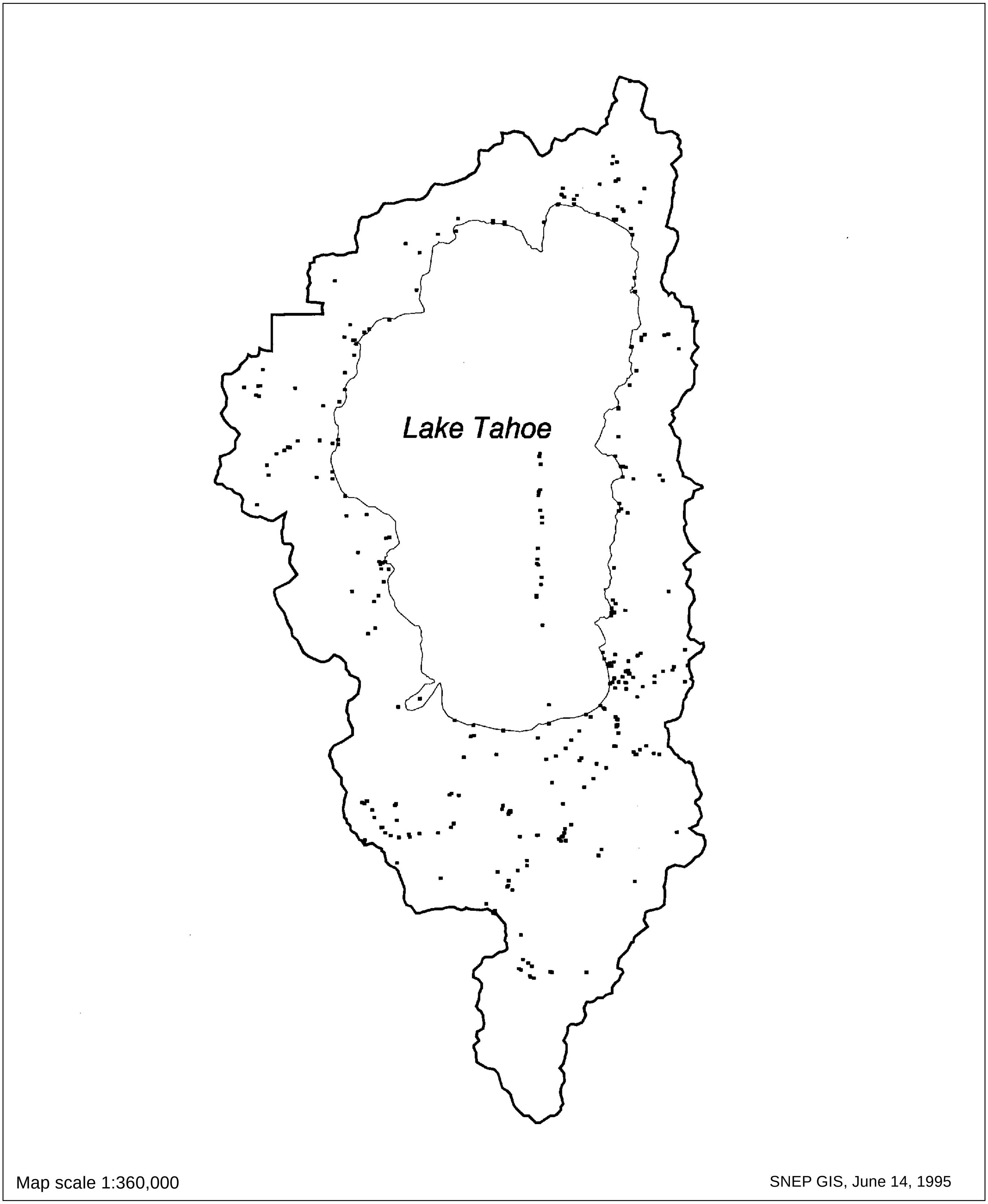


FIGURE 8

Hydrological monitoring sites in the Lake Tahoe Basin, 1995. (SNEP GIS project).

reflected archaeologically in the location and composition of upland sites. More intensive and long-term use of the Lake Tahoe Basin uplands during dry (i.e., xeric) intervals within the last 1,000 years is tentatively documented (Lindström 1982, Lindström and Bloomer 1994).

The last 1,300 years of the Archaic period may represent the initial phase of the Washoe ethnographic pattern and the onset of their long tenure in their known area of historic occupation. Nearly 75% of the tested archaeological remains in the Lake Tahoe Basin represent this latter period of human history (Elston et al. 1994), and it is reasonable to conclude that most of the anthropogenic effects on the Lake Tahoe Basin landscape date from this time period.

Washoe territory extended along the eastern Sierra Nevada front from Honey Lake to the north, south to Topaz Lake, eastward to the Virginia Range, and westward into the western Sierra Nevada foothills. The Lake Tahoe Basin held a central place in the Washoe economic and spiritual world. Washoe culture, residential patterns, social structure, subsistence, and religion have been studied by ethnographers over the past eighty years in an effort to reconstruct pre-contact patterns (Barrett 1917, Dangberg 1918–1922, d'Azevedo 1956, 1971, 1985, 1986a, 1986b, 1991, 1993, Downs 1961, 1971a, 1971b, 1966; Freed 1963, 1966; Freed and Freed 1963a, 1963b; Lowie 1939; Nevers 1976; Siskin 1983; Price 1963a, 1963b, 1980). Most recently, Rucks (1995) reviewed literature relevant to Washoe ground stone-milling technology and discussed residential mobility, egalitarian social structure, land and resource ownership and sharing, resource management, and Washoe world view in relation to their potential effects on the Lake Tahoe Basin ecosystem.

The pre-contact Washoe were hunter-gatherer people. While fish were the single most abundant and predictable staple in the diet (d'Azevedo 1980; Lindström 1992), with piñon pine and acorn providing important storable winter foods, the Washoe were dependent upon a vast array of plant and animal life from a varied and diverse ecosystem. The deliberate management of wild plant and animal resources and their habitats, in order to enhance their quality and quantity, is a practice not typically attributed to hunter-gatherers. Yet, recent research provides compelling evidence for significant levels of resource manipulation by hunter-gatherer populations. Horticultural practices such as burning, weeding, pruning, copicing, and selective harvest, were major elements of tribal subsistence strategies (Anderson 1993; Anderson and Nabhan 1991; Blackburn and Anderson 1993; Fowler 1994; McCarthy 1993; Rucks 1995). Furthermore, these horticultural practices were augmented by the generative and constraining power of human language, ideology, religion and world view. The mental culture was as dynamic a part of the human environment as optimal economic choice. Both realms exerted selective pressure over the consequences of human resource exploitation and management.

The degree to which the Washoe engaged in a highly interactive system that actually changed floral and faunal patterns over time requires further research. The detection of anthropogenically altered landscapes in the Lake Tahoe region is made difficult by relatively lower indigenous population densities at higher elevations than in the adjoining foothills and, perhaps, by the higher incidence of lightning-caused fires here in relation to human-set fires. However, it is clear that Washoe natural resource manipulation was extensive, continual and sustained over a 1,300-year period, and that it integrated cultural traditions and beliefs (Rucks 1995). Washoe ideology incorporates ethics for sharing resources with a spiritual connection to and responsibility for the land, plants, and animals (Rucks 1995). For the Washoe, harvesting entails ritual that demonstrates respect and gratitude for the resource, while their conservation practices help ensure a sustained yield in years to come.

The Lake Tahoe region encountered by early settlers had been subject to Washoe land use for at least 1,300 years. However, early settlers viewed indigenous land management as creating, according to their perceptions, a "natural, un-improved, and un-owned landscape." Lacking agriculture per se, the Washoe were perceived as passive in their relationship with the environment. Over-emphasis of Washoe technological and social simplicity and conservatism, residential mobility and impermanence, egalitarian social structure, and lack of private ownership has been used through time to justify taking land and resources from people that never "owned" them in the first place. While the Washoe were a relatively informal and flexible political collectivity, Washoe ethnography suggests a level of technological specialization and social complexity uncharacteristic of their surrounding neighbors in the Great Basin. Sedentism and higher population densities, concepts of private property, and communal labor and ownership may have developed in conjunction with their residential and subsistence resource stability (d'Azevedo 1986a; Lindström 1992).

After European contact ca. 1848, the Washoe were largely displaced from their traditional camps and fishing grounds. However, families continued to trek to the lake, gathering seeds, making baskets, speaking their language, and raising their children. They negotiated living arrangements with the dairies, logging operators, and resorts, working as domestics, laborers and game guides, and as such maintaining a remnant of their past lifeway and culture while their leaders continued to struggle for political and social reforms and request land and protection for their resources. After the passage of the General Allotment Act of 1887, 160 acre (65 ha) 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 (d'Azevedo 1993). Although lands around Lake Tahoe and in fertile valley floors had been petitioned, none were included in the land allotment. A few decades later, the tribe's corporate charter was ratified (1936), a Tribal Council formed, and a constitution adopted, thus achieving federal recognition under the provision of the Indian Reorganization Act of 1934.

In 1970 the tribe's land claims case, initiated in 1951, was finally settled, awarding them approximately $5 million of the $42.3 million in funds requested as compensation for their lost homeland of approximately 10,000 square miles surrounding the Lake Tahoe Basin. The federal government described the loss of the Washoe's lands as encroachment, with substantial evidence that the Nevada portion of their territory was overrun by miners, settlers and others with the approval of the United States government; by the end of 1862, the tribe had lost all ot its lands due to encroachment (U.S. Indian Claims Commission, 1959–1970).

Euro-American Era

The European culture superimposed upon the existing Lake Tahoe Basin ecosystem during the mid-ninteenth century stands in sharp contrast to indigenous land-use practices. Comstock-era logging and water management, sheep grazing, and a booming recreational economy within the last 150 years resulted in disruption of the landscape. Between the 1840s and 1880s, early settlers largely displaced the Washoe and their traditional land-use practices from the Lake Tahoe Basin. Although the period of contact can be said to have begun with Fremont's sighting of Lake Tahoe in 1844, there was no significant presence in the Basin until the Comstock Lode silver discovery of 1859 (the California Gold Rush of 1849–50 having been confined almost entirely to lower elevations on the western slope of the Sierra Nevada). Impacts were immediate and dramatic. The mines of western Nevada promised great wealth, but the surrounding terrain offered neither water nor timber. The Lake Tahoe Basin, a mere 24 km (15 mi) to the west, offered a seemingly endless supply of both. Early settlers, with their western ideology, viewed the Basin as a God-given resource waiting to be tapped. The July 7, 1859 *Alta California*, a San Francisco daily newspaper, boasted "at present, the timber and lumber capabilities of the borders of Lake Tahoe seem illimitable (Goin 1992)." The lake and its environs were assessed primarily in terms of their economic output. Raymond (1992) writes, "changes that would be deplored today, such as clear-cutting slopes for timber, were acclaimed by a nineteenth-century society that celebrated human dominion over nature."

Timber Harvest

During the Comstock era from 1859 largely through the 1880s, large amounts of lumber were needed for the construction and operation of the Virginia City mines. It has been said that the mines of the Comstock Lode are literally the tombs of the Sierra Nevada forests (Lord 1883). Although logging extended from the east slopes of the Carson Range and south through the Carson River watershed, these areas were rapidly depleted of their timber and harvesting was directed to the Lake Tahoe Basin. About two-third's of the Basin's forest were cut between 1860 and 1930, and the most accessible forests were extensively logged (Robert Harris, LTBMU, SUFS, South Lake Tahoe, CA, 1996, personal communication). By 1861, a large mill was operating at Glenbrook on Lake Tahoe's eastern shore. Cutting spread to the north and south shores, and finally to the west side. Large-scale timber operations began after 1867 with the invention of the V-flume system for transporting wood to staging areas. The 1869 completion of the transcontinental railroad, which had arrived in Truckee in 1868, also created additional demand for timber (Strong 1984; Raymond 1992). With the technology of mills, railroads, and flumes, loggers transported 33 million board feet per year to lumber yards in the Carson City and Virginia City area. During peak periods, as much as 72 million board feet of Lake Tahoe Basin lumber were milled annually (Eissmann 1990). In a 20-year period, loggers took about $80 million worth of lumber from the Basin. The Carson and Tahoe Lumber and Fluming Company produced 750 million board feet and one-half million cords of firewood between 1873 and 1898 alone.

As this demand for lumber increased, systematic lumbering quickly took its toll on forest resources. The result was "virtual deforestation of large portions of the Tahoe Basin by the 1890's" (Raymond 1992, p 15). By 1898, the last of the Comstock era mills had closed for lack of available wood, leaving behind a drastically altered ecosystem (Raymond 1992). Jeffrey pine and sugar pine were targeted and the resulting second growth forest, increasingly dominated by white fir, was a prelude to today's dying stands.

This deforestation is documented in the forest surveys conducted in the early twentieth century (Sudworth 1900; Leiberg 1902) (figures 9 and 10). Both the Sudworth and Leiberg surveys covered portions of the Lake Tahoe Basin (McKelvey and Johnston 1992), with Leiberg's (1902) work concentrated in portions of the northern Basin in Forest Reserves, and Sudworth's (1900) work in those areas that were portions of the southern and eastern forests. The extensive timber removal they documented suggests that both mammals and birds needing a structurally complex (i.e., with numerous large downed trees, snags, and deep litter) or closed forest may have become locally extinct, or at least population sizes decreased dramatically.

Commercial Fishing

Commercial fishing began in Lake Tahoe with the opening of the Comstock mines in 1859. The Carson Valley and Virginia City were the initial markets. Later, San Francisco, Chicago, and New York imported fish from Lake Tahoe. In the 1870s, about twenty-five operators fished Lake Tahoe in the summer, and the Washoe also fished in the Upper Truckee River and other tributaries to Lake Tahoe. As early as 1856, a private hatchery at Tahoe City and later two hatcheries of the California Fish Commission produced fry for Lake Tahoe. As an example of the volume of commercial fishing that occurred here, in October 1880, operators took 70,000 pounds of trout from Lake Tahoe. By 1904, eighty fishing boats worked the lake.

By the time that the California legislature banned commer-

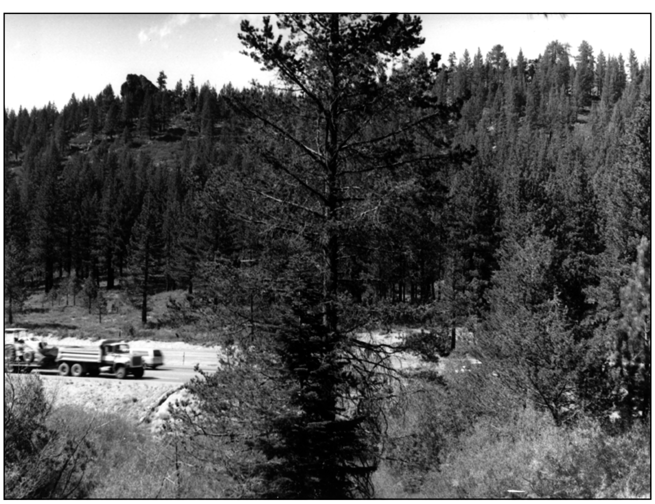
FIGURE 9

Looking north at the Comstock Fluming operation in 1876. Elevation 7,200 feet. Location Spooner Summit, Carson City Rural Area, Nevada. Nearly all trees in the lightly stocked presettlement stands had been cut. Note conifer reproduction. Photography taken by C. E. Watkins, with credits to the Nevada State Railroad Museum. Contributed by George E. Gruell.

cial fishing in the Lake Tahoe Basin in 1917, the fishery was severely depleted (Strong 1984; Hinkle and Hinkle 1949). The cutthroat trout population has never recovered from the heavy fishing of the Comstock era. In addition, dam construction, disturbance of spawning grounds and obstruction of spawning runs, pollution of streams with sawdust, exotic disease,

FIGURE 10

Repeat photograph on August 21, 1992 of Figure 9 site on Spooner Summit. Photo taken from the only opening in the vicinity of the original camera point that afforded a reasonably clear view. State Highway 50 bisects the midground. Densely stocked second growth Jeffrey pine is dominant on the southerly slope. Photo taken and contributed by George E. Gruell.



and competition from introduced species almost sealed the demise of the native cutthroat trout by 1938 (Townley 1980; Lindström 1992).

Grazing

Along with logging and fishing, grazing was also a component of the resource extraction system in the early years. In the early part of the Comstock era, commercial hay production reached over 800 tons annually. Thousands of head of livestock were driven through the Basin to market in Virginia City. At least thirteen commercial dairies also operated at Lake Tahoe in the 1870s, making use of all the Basin's meadows (Hinkle and Hinkle 1949; Strong 1980). Thousands of sheep were grazed extensively within the Basin for a period that extended forty years after the Comstock era. Washoe elders who continue to gather basket materials, berries and medicinal plants on Basin lands relate that sheep are particularly remembered as the final blow to valued plant resources in the Basin. From 1865 through the 1890s, millions of sheep were trailed from California to the mining camps of the Great Basin and railheads in the plains (Douglass and Bilbao 1975). Bands averaged 1,000–1,500 ewes (Mallea-Olaetxe 1992).

In his forest inventories, Sudworth (1900) also noted that sheep grazing in the Lake Tahoe Basin was ubiquitous, and that in some areas all of the grass and shrubs had been consumed by sheep. The spatial pattern is noted by Sudworth as follows: "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." (Sudworth 1900, pp. 554–555).

Grazing and trampling by sheep greatly reduced tree regeneration. In many cases, areas that were difficult or impossible to reach by cattle and sheep had abundant tree regeneration, but healthy, regenerating forests were the exception basin-wide (Sudworth 1900). Fires set by sheep herders also affected the response of these systems to grazing. It was common for sheep herders to set fire to high-elevation meadows and shrublands when they left for the year (Sudworth 1900). The herders also burned many large downed trees, since they were viewed as an obstruction to the herds: "Fallen timber forms troublesome barriers to driving sheep along regular routes and the herders set fire to these logs, usually as they are leaving 'fed out' range, in order that the way may be open on their return. 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, pp. 555–556)

Fires of this frequency and extent certainly affected these ecosystems. Regeneration of all plants would be difficult in such a fire regime since establishment would be almost impossible unless the plants were in protected, isolated areas. The season of burning by the herders also would have a large impact on these systems. Fires did occur during diverse seasons pre-historically, but the compression of most fires to a limited season would adversely affect the biodiversity of the Basin.

Intensive sheep grazing of Basin meadows and slopes cleared of their forests by Comstock-era logging continued in the 1920s and 1930s (J.Mallea Olaetxe, personal communication 1993). Grazing after the 1930s was continued by grazing allotments, with each permittee having access to a specific range normally not shared with others.

The Lake Tahoe Basin's strategic proximity to both the Mother Lode and the Comstock Lode further promoted related development in transportation infrastructure, market hunting and fishing, tourism, and urban development, which brought profound changes in the Basin's ecosystem. During the Comstock era, multiple streams were channeled and their water diverted to flumes for transport of logs downstream. Miles and miles of flumes were constructed to move cordwood to Glenbrook and lumber from Spooner. The impacts of this activity on stream resources is not well documented.

Water Resources

After the Comstock Lode silver boom collapsed, water resources provided the next natural resource of great economic value. Pursuit of out-of-basin, alternative uses of Lake Tahoe's water posed a subsequently serious threat to the ecosystem. The lake itself is a vast reservoir situated at the edge of the Great Basin, and its high elevation offered unique opportunities for gravity-flow diversions to nearby desert lands.

Early out-of-basin diversions were constructed at Echo and Marlette lakes. The Echo Lake diversion on the west side of the Basin, constructed in 1876 by a company that was a predecessor to the Pacific Gas and Electric Company, tunneled water under the Sierra Nevada crest to the American River Basin, augmenting supplies to the western Sierra Nevada foothills and Sacramento. The Marlette Lake diversion on the east side of the Basin, an inverted siphon constructed in 1873, delivered 6,600,000 gallons per day to the mines of Virginia City (Department of Water Resources 1991).

An example of human attempts to control water resources can be found in the efforts to turn Lake Tahoe into a reservoir for Virginia City or San Francisco, an idea put forward by Colonel Von Schmidt. Recognizing the agricultural potential of western Nevada's desert lands, Senator Francis G. Newlands pursued construction of a new dam at Lake Tahoe's outlet along the northern shore to ensure a constant water supply into Nevada for irrigation purposes, thus opening hundreds of thousands of acres for irrigation downstream. His efforts culminated in the passage of the Federal Reclamation Act of 1902, and, ultimately, construction of the Newlands Project. The Bureau of Reclamation aimed to encourage settlement and economic development of the west by providing sufficient water to "make the desert bloom." Nevada's Newlands Project, the first major project completed under the authority of the Reclamation Act, remains the single largest appropriator of Lake Tahoe Basin water today. Construction of this dam converted Lake Tahoe into a draw-down reservoir. Later efforts (ca. 1938) by Nevada to receive permission to tunnel through the Carson Range to obtain Lake Tahoe's water were never approved.

In 1969, California and Nevada agreed to the Interstate Compact on the Truckee, Walker, and Carson River systems, which limited water withdrawals for use in the Lake Tahoe Basin. Although the U.S. Congress never ratified the compact, it remains in effect as a policy agreement between the two states. As a result of litigation in federal court over water use and water rights in the Truckee River system, the court appointed a federal water master to manage the dam at the outlet to the Truckee River at Tahoe City. The reservoir portion of Lake Tahoe above the elevation of 1,897 m (6,223 ft) asl remains an important source of water for the Truckee-Carson Irrigation District and the Reno-Sparks area. A federal statute which allotted Truckee River water was passed in 1991, however, implementation of the bill is still the subject of review.

The Lake Tahoe Basin's incredible wealth of various water resources and its strategic proximity to other resources and amenities justified the investment of a significant amount of capital in transportation to and through the Basin. The Placerville Road was constructed between Placerville and Virginia City in the 1850s and followed earlier emigrant and wagon routes through the Basin. The opening of the Central Pacific Railroad in 1868, with connections to the lake's northshore by stage in the 1860s and by rail in 1900 (Lake Tahoe Railway and Transportation Company) fostered tourism and promoted the development of year-round communities even after the demise of timber harvesting and grazing activities. In addition, with the difficulty of overland travel within the Lake Tahoe Basin, steamships became a key part of the transportation network as early as 1864.

Conservation Ethic

While resource extraction was taking its toll on the Basin around the turn of the century, the United States was also witnessing the beginnings of a conservation ethic. Prior to the 1890s, popular culture had largely maintained the early Judeo-Christian ethic of wilderness as an evil, dark, foreboding menace that needed to be tamed by humankind before its fruits could be harvested. With the onset of a conservation ethic, a new philosophy emerged wherein the natural environment could be appreciated (Nash 1982). This emergent philosophy of conservation of natural and scenic resources, promoted by the likes of Emerson, Thoreau, and Muir, quickly came to play a major role in the public's perceptions of, and attitudes toward Lake Tahoe. Increasingly, the Lake Tahoe Basin was being viewed as a resource to be preserved rather than exploited.

Although the resource exploitation ethic remained dominant during the latter half of the nineteenth century, there was a notable increase in popular support for resource preservation, particularly with respect to scenic quality. As early as 1859, the San Francisco press was reporting that Lake Tahoe would soon become beyond all doubt, one of the most interesting and agreeable resorts for pleasure and amusement on the borders of the Pacific. Perhaps the most frequently cited summation of Lake Tahoe's beauty came in 1861 when a young Mark Twain wrote ".. at last the Lake burst upon us—a noble sheet of blue water lifted six thousand three hundred feet above the level of the sea, and walled in by a rim of snow-clad mountain peaks that towered aloft full three thousand feet higher still! As I lay there with shadows of the mountains brilliantly photographed upon its still surface, I thought it must surely be the fairest picture the whole earth affords." (Twain, 1861 pp. 120-121)

The late 1800s saw a steady increase in the public's perception of Lake Tahoe as a recreational resource. Early lakefront resorts flourished at Tahoe City, Glenbrook and Tallac. In 1900, the Lake Tahoe Railway opened between Truckee and Tahoe City, allowing wealthy San Francisco residents to travel to the shores of Lake Tahoe in less than nine hours (Scott 1957). From Tahoe City, the luxurious steamer *Tahoe* ferried passengers around the lake to ports at Carnelian Bay, Brockway, Glenbrook, Tallac, and Emerald Bay. In ever increasing numbers, these visitors helped establish a new direction in American tourism. Historian John Sears describes this new direction with a melding of recreational tourism and the wilderness ethic as playing an important role in shaping a new American identity. "People visited famed natural sites as if they were shrines, where solemn reflection and adoration were the prescribed responses. In this regard, Tahoe was no exception. Nineteenth century tourists came to the Lake to experience its restorative powers, to see its sights, and to be spiritually uplifted amidst its well known beauties" (Sears 1989).

For much of the next century, the name Lake Tahoe would become increasingly associated with both the beauty of natural landscapes and recreational tourism. As a result, there was a pronounced popular and political movement to set aside lands for the enjoyment of future generations. In 1883, the California legislature created the Lake Bigler Forestry Commission to specifically address the problems of over-harvesting of timber in the Lake Tahoe Basin. The study called for the protection of the lake and its surrounding land for tourism. 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. Objections to land transfers that would ultimately profit the Central Pacific Railroad prevented further action to create protection for the Lake Tahoe Basin (Pisani 1977). Further protective legislation followed in 1889 and again in 1894 which prohibited sawdust dumping in streams and lakes. The federal presence at Lake Tahoe changed in 1899 when 15,198 ha (37,550 ac) were set aside from the public domain by presidential proclamation as the Tahoe Forest Reserve, areas where the resources—timber, watershed, and forage were to be used but not to the detriment of the reserve itself. Forest Reserves were transferred in 1905 from the Department of the Interior to the Department of Agriculture, where the Bureau of Forestry became the U.S. Forest Service. In 1907 forest reserves were renamed national forests (Steen 1992). From this modest beginning, today the three national forests, Eldorado, Tahoe, and Toiyabe make up 77% of the Lake Tahoe Basin land area. Three distinct efforts to designate the Basin a national park were also pursued unsuccessfully in 1900, 1912, and 1918.

The high percentage of ownership and development on private lands in the Basin dramatically changed land-use patterns in the Lake Tahoe Basin after 1900, especially with regard to increased recreation through the promotion of camping, hunting, fishing, winter sports activities, and the construction of summer homes (Beesley 1995; Markley and Meisenbach 1995). Large tracts of land remained privately-owned, particularly along the lakeshore, until the USFS began acquiring tracts in the 1930s.

Tourism and Recreation

Lake Tahoe represented an idyllic vacation getaway to an ever more mobile and affluent society. The first passable road around the lake was completed in 1935. Having severely depleted timber resources, landowners were quick to capitalize on the automobile and the new economic opportunity recreation provided. San Francisco newspapers proclaimed that Lake Tahoe would soon become a popular destination resort for thousands of vacationers. Author Douglas Strong summarizes the sentiment of the day by quoting an editorial in the *Call*, "...until now there has been no systematic exploitation of the real estate of the Lake shore. California (has) a duty to open the Lake Tahoe region to people from less favored regions." (Strong 1984, p. 39)

In the early part of the twentieth century, recreational tourism remained the domain of the wealthy elite. Transportation was primarily by train or boat, and travel time was often lengthy (Nash 1982). At Lake Tahoe, summer resorts and small subdivisions characterized urban development from the turn of the century through World War II. Following the war, however, California's population boomed, and the middle class expanded at an unprecedented rate. Private automobiles became available to large numbers of people, allowing them access to recreational areas that had previously been inaccessible. Highway 50 from Sacramento to the south shore of Lake Tahoe was completed. At Lake Tahoe, as elsewhere in the United States, use of the private automobile led to the decline of railroads and steam-powered boats and the proliferation of roads, roadside attractions, and motor courts.

Casinos also came into being at this same time. In 1931, the Nevada legislature decided to allow open gambling operations so that gambling could be licensed, taxed, and policed. Games of chance were permitted and counties were authorized to collect a tax. During the 1930s and 1940s, the gambling industry changed rapidly, especially after 1945 when wartime travel restrictions ended; Las Vegas and Reno's gambling enterprises boomed. At Lake Tahoe's Stateline and North Shore, a number of smaller-scale imitations of the Las Vegas gambling clubs came into existence. For example, the Wagon Wheel was opened in 1946 along with a number of other small clubs. In 1955, William Harrah purchased the Gateway Club and opened Harrah's hotel-casino at Lake Tahoe. Harrah's began year-round operations in 1957, expanding on what had been a summer business.

The expansion of winter recreation, culminating in the hosting of the 1960 Winter Olympic Games at Squaw Valley, truly fostered the establishment of permanent year-round communities in the Lake Tahoe Basin. Seasonal communities of summer homes were slowly converted to year-round housing for resort employees. Recreational tourism and the expansion of a number of casinos both on the south and the north shores provided the main sources of local employment.

Population Growth

Eventually, what had been the seasonal student labor work force, typically single and relatively transient, was replaced by a more stable blue collar work force. Public school enrollment at South Lake Tahoe reflects this increase in population and the number of permanent residents in the Basin: 47 students in 1945, 460 in 1955, 4,432 in 1965, 5,145 in 1990, and 5,717 in 1994 (Strong 1984; Susan O'Connor, Bilingual Program Coordinator, Lake Tahoe Unified School District, telephone conversation March 15, 1995).

As Strong states, "No one had proposed or consciously planned that the Lake Tahoe Basin become urbanized: but a multitude of individual and governmental decisions—and the attraction of Tahoe's scenic wonders—inevitably flooded the Basin with people (Strong 1984, p. 197)." In the years between 1960 and 1980, the Basin's population grew five-fold and the number of houses increased from 500 to 19,000 (Strong 1984). By 1970, more than 49,000 subdivided lots had been created and hundreds of miles of roads had been built to serve the new subdivisions.

It should be noted that the Washoe pattern of seasonal employment in the Basin for resorts, sawmills, and dairies, and their independent selling of baskets and other crafts to tourists, continued to provide both a living and a means of continuing traditional activities in the Basin, including plant collection, until after the 1940s. As population in the Basin increased in the 1950s, Washoe people felt further alienated and excluded by privatization and development, and very few continued to visit the area annually, much less use plant resources (Rucks 1995). Recently, Washoe people and tribal government policies have focused on reestablishing a presence at Lake Tahoe, and although they are not residents, they must be considered an increasingly vocal stakeholder (Washoe Tribal Government 1994).

The Lake Tahoe Basin's population appears to be undergoing demographic changes parallel to those of the United States population as a whole, albeit several decades later. The ninteenth century population of the Lake Tahoe Basin was seasonal and ethnically diverse, thanks to demands for French-Canadian lumberjacks, Chinese-American cordwood cutters, flumesman, teamsters, and cooks, Basque sheep herders, and Washoe domestics, game guides, dairymen and haycutters. After this initial period of concentrated resource extraction, development of recreational opportunities drew a primarily white Euro–American population. Only much later in the 1970s did the Basin's population change once again from being primarily white to becoming ethnically diverse, with in-migration from Asian and Latin American populations among others. Again, school enrollment data clearly illustrate this; as recently as 1977, non- and limited-English speaking students accounted for only 0.02% of the student population, but by 1994, this figure had risen to 17% (Susan O'Connor, Bilingual Program Coordinator, Lake Tahoe Unified School District, telephone conversation March 15, 1995).

Today, the Lake Tahoe Basin is home to more than 60,000 permanent residents. The population is culturally and ethnically diverse, and an increasingly accurate reflection of the U.S. population. In the city of South Lake Tahoe (the Basin's only incorporated city), minorities now account for more than 35% of the population (U.S. Bureau of the Census 1991), which is considered a conservative estimate according to city officials. Also, despite a long-standing perception of wealth and exclusivity, 63% of the households in South Lake Tahoe qualify as low income by federal standards (i.e., defined as earning 80%, or less, of the county median income).

The Lake Tahoe Basin economy's continued evolution from one based on resource-extraction to one centered around the resource-dependency of recreation brought with it a parallel transformation in popular perception of the region. Unlike the mining, lumber, and water resource booms of the past, the new recreation economy is dependent upon the sustained health of the ecosystem. Visitors to the Basin expect a beautiful environment, and permanent residents and business interests are increasingly aware of their economic dependence on recreation and the visiting public's perception of a healthy environment. By 1990, recreation had developed into a $1 billion economy employing more than 20,000 people. More than 200,000 tourists visit the Basin on peak holidays and visitor days are estimated to exceed twenty-three million annually (Ray Lacey, California Tahoe Conservancy, memo to SNEP, February 11, 1995).

"Tourism in various guises (has) become Tahoe's principal economic asset. Paradoxically, however, the boom has also produced a host of new difficulties, in their own ways as disturbing and disrupting as the conflicts over how and where to use the water, or the physical devastation of the lumbering. Tahoe in the twentieth century has come to be dominated economically by a tourism industry that depends directly upon the landscape. Yet that landscape is increasingly imperiled by its own successes, by the environmental pressure of large numbers of tourists, and the growing population that exists, at least in part, to serve them" (Raymond 1992, p. 18).

Transportation System

The transportation system within the Basin continues to be the focus of improvements. The TRPA is charged by its Compact to develop a transportation plan for the Lake Tahoe region. This plan is to integrate all the elements of a regional transportation system. The TRPA is designated as the Regional Transportation Planning Agency (RTPA) for the state of California within the Lake Tahoe region. As the RTPA, TRPA is required to revise or update a regional transportation plan every two years.

The Compact also states that the goal of transporation planning shall be to reduce, to the extent feasible, air pollution which is caused by motor vehicles. Transportation and air quality planning by TRPA is for the express purpose of attaining or maintaining the applicable federal, state, local, and TRPA threshold standards for transportation and air quality. Although recent data show attainment with the National Ambient Air Quality Standard for carbon monoxide (CO), the Lake Tahoe region is still considered a non-attainment area for CO until a maintenance plan is completed and implemented. The California and TRPA standards for CO have been exceeded, but 1995 data show a large improvement, and the possibility of attainment. Violations of ozone standards occur at times, but are not consistent. The region is currently classified as non-attainment-transitional for the California one-hour standard. The TRPA adopted an integrated Regional Transportation Plan-Air Quality Plan which addresses these issues.

Serving the resident and visitor populations are both public and private transportation systems that include bus transit, shuttles, demand-responsive transportation services, air transportation services, and a local and regional highway network. The main feature of the transportation system in the region is a network of state and federal highways that surrounds Lake Tahoe, with seven primary entrances from outside the region. The majority of traffic to the region is from California, with most of the traffic travelling U.S. Highway 50 to reach the area on the south shore. A single highway circles the lake. In many areas, expansion of the highway system is constrained by natural features and environmental concerns. The region experiences lengthy periods of traffic congestion along U.S. Highway 50 on the south shore, and on California Highway routes 28 and 89 near Tahoe City on the north shore.

The Lake Tahoe region is also served by the South Lake Tahoe Airport. Portions of the region are served by bicycle facilities and water-borne excursion services. Several private shuttle systems are in operation to serve recreational uses. Public transit is provided on the north shore of the region by the Tahoe Area Regional Transit bus system, which is operated by Placer County. Public transit on the south shore is provided by the city of South Lake Tahoe, which contracts the operation of the South Tahoe Area Ground Express transit system.

The Regional Planning Compact also created the Tahoe Transportation District (TTD). The TTD was given the responsibility for implementing transportation plans and programs developed by TRPA. The TTD may acquire, own, and operate public transportation systems serving the Lake Tahoe region and provide access to convenient transportation terminals outside of the region. The TTD is governed by a board of directors representing the counties within the region, the city of South Lake Tahoe, and the Directors of both the California Department of Transportation (Caltrans) and the Nevada Division of Transportation (NDOT).

For recent planning projects, TRPA has been utilizing a public-private partnership approach to assist in achieving environmental benefits. Examples of this would be the development of the Coordinated Transit System on the south shore, assisting with the implementation of the trolley systems on both the north and south shores, and facilitating completion of the Lake Tahoe Bikeway 2000. By working with local groups, both public and private, these programs are more easily implemented.

Despite these apparent conflicts between use and environmental protection, there is reason to be encouraged. The emerging alliance between recreational tourism and a sustainable economy has brought a renewed understanding of environmental interdependence. Environmental protection measures adopted by TRPA have sought to incorporate principles of carrying capacity and ecosystem management. Indeed, the most basic tenets of TRPA policies revolve around "the carrying capacity of the land in the Tahoe Basin in relation to its ability to tolerate use without sustaining permanent damage" (Strong 1984, p. 199). No less importantly, publicly mandated programs in both California and Nevada are acting to carry forward these policies. Programs initiated pursuant to the California Lake Tahoe Acquisitions Bond Act, the Nevada Tahoe Basin Act (both approved by voters), and the federal Santini-Burton Act are collectively seeking to ensure a balance between public and private uses through the acquisition and restoration of sensitive lands throughout the Basin.

Precedent-setting codes established by TRPA and acquisition and restoration strategies implemented by the USFS, CTC, and Nevada Division of State Lands, have not only shaped resource protection and development policy, they have also heightened public awareness. Today, residents and visitors seem to be at least somewhat aware of the delicate balance of their immediate environment, and recognize both the social and economic benefits of maintaining those balances for future generations. As stated by Raymond (1992, p. 21): "For modern residents, the dilemma is a serious one. If Tahoe no longer offers visitors the chance to experience untrammeled nature, or some reasonable facsimile thereof, then all the recreational variety offered by casinos and ski runs may be insufficient to sustain its tourist economy."

Emerging Socio-Political Vision

Upon contact with the early settlers, the Washoe lifeway was irrevocably changed in the Lake Tahoe Basin. Although the Washoe vigorously defended their fishing rights (Downs 1966), and protested the loss of their land base, their claim to any portion of the Basin was subservient to the now dominant foreign culture.

Confrontation over appropriate, uses of the Basin can be traced to the beginning of the era when logging was opposed by conservationists. Through the latter half of the nineteenth century and the twentieth century, environmental issues became increasingly polarized: resource extraction versus conservation; development versus protection of water quality; livestock grazing versus watershed protection; local versus state versus federal; and public versus private interests. Administrative responsibilities between the two states, counties, federal and state agencies, and public and private lands fragmented the ability to deal with issues in a cohesive manner. These tensions led to the realization that Lake Tahoe's problems needed to be addressed regionally, and ultimately played a role in the creation of TRPA, as well as a number of well-defined special interest groups.

The USFS began its first land-use planning for national forest lands in 1950. The first cross-jurisdictional land-use planning effort designed to address the use and preservation of the many valued ecosystem components was the Lake Tahoe Regional Planning Compact, adopted in 1969 and revised in 1980 by the states of California and Nevada with the consent of the United States Congress. The Compact identified the need to create a balance between the natural environment and human use of the Basin. Under the Compact, city, county, state, and federal governments came together to collectively address land-use planning, environmental regulation, and ecosystem restoration and monitoring.

The early years under the Compact can best be characterized as a period of controversy and crisis, with tensions and acrimony among the many parties. After much debate and discussion, the plan was approved, but only after many delays and federal pressure. The early Compact was ineffective in stemming the tide of development already underway, and contained near fatal flaws of (1) a dual majority[6] of both states for denial of a project and (2) a sixty-day automatic approval provision if TRPA failed to act, without TRPA conditons.

Subsequent to the initial adoption of the Compact, the federal Lake Tahoe environmental assessment (Western Federal Regional Council Interagency Task Force 1979) demonstrated that the Basin's environmental quality had measurably declined between 1970 and 1978. This degradation occurred even though environmental mitigations had been implemented for new projects, and indicated that it was not effective to mitigate individual actions due to cumulative effects from past disturbances. The council's evaluation concluded that Compact should be revised, or the Compact goals would be non-attainable. The TRPA ad hoc committee report concluded that Compact revision was necessary to correct the dual majority and to expand the membership and change voting rights. County governments were reluctant to pay for their share of administration costs, and asked the states to make contributions equal to the total county contribution. They also continued to challenge the constitutionality of the Compact. Federal agencies offered both strong support for TRPA and sharp criticisms when the bi-state efforts failed to meet Compact objectives. Direct financial contributions came from Housing and Urban Development (HUD) through 701 Planning Grants, EPA 208 Grants, and by resource publications and professional staff by the Soil Conservation Service and the Forest Service. EPA, HUD, U.S. Army Corps of Engineers (COE), USFS, and other federal actions were coordinated through the presidential appointee to TRPA and the Western Federal Regional Council. Extraordinary federal actions included moratoriums on FHA loans, pier and lake construction permits, development on national forest lands, and the required grant coordination of HUD's 701 planning with EPA's 208 waste treatment planning. The state of California was dissatisfied with TRPA's performance and created the California Tahoe Regional Planning Authority (CTRPA). The TRPA also faced a number of legal challenges at this time, including inverse condemnation lawsuits. There was a perception that private property rights were threatened by CTRPA, TRPA, and other regulations, and previously approved subdivisions were under threat to be downzoned. The majorities on the TRPA and CTRPA boards of directors switched from local to state control between 1969 and 1978 (Sabatier and Pelkey).

The TRPA was beset with financial insecurity, lawsuits questioning its constitutionality, uncertainty of legal liability of board members, and conflicts between local control and bi-state interests, and was, therefore, off to a shaky start. The TRPA requested a federal grant to speed up acquisitions of land in the Basin. In August, 1970, TRPA requested all federal, state, and local agencies to use all predictable means and measures to implement their authority to help protect the environmental qualities of the Basin. By 1973, TRPA had $260 million in claims and $35 million in lawsuits filed against it. By 1973, with all the default approvals of casino expansions and a north shore mall, conservationists withdrew their support of TRPA. Local governments balked at enforcing conditions emposed by TRPA on approved projects. There was a series of legal tests between the TRPA and the counties before the issue was resolved; TRPA actions were enforcable. The counties had no choice but to enforce TRPA conditions.

Efforts to revise the Compact touched off a major struggle between the states, with the two governors leading the battle. Finally, a negotiated agreement was signed by both states under the threat of federal intervention. The 1980 revised Compact mandated that TRPA establish environmental thresholds and carrying capacities, first, and then devise a plan to achieve those thresholds. Some limits were put on further development until a new regional plan was adopted.

No sewage plant expansion (except for Douglas Co. 1) would be allowed, nor would new casinos, yet existing casinos could expand and new casino permits were still valid. A Lake Tahoe Transportation District was established to better coordinate transportation needs. The Compact required an environmental impact statement. The TRPA board was expanded and a dual majority vote was required for project approval, otherwise projects were rejected outright.

In 1982, TRPA adopted a comprehensive set of environmental threshold carrying capacities that were considered necessary to maintain the significant scenic, recreational, educational, scientific, and natural values of the region. A new regional plan was required to meet the thresholds.

In 1984, TRPA adopted a regional plan for the Basin. It was a product of a very difficult process. Futher, it was short-lived because the State of California and the League to Save Lake Tahoe successfully obtained federal court injunctions against implementation of the plan on the grounds that it would not achieve thresholds and that the environmental impact statement was inadequate (*People* of the State of California ex rel. John K. *Van de Kamp* v. *Tahoe Regional Planning Agency* [9th Cir. 1985] 766 F. 2d 1308). The plantiff's success in this pivotal case set the stage for a consensus process which resulted in the adoption by TRPA of a revised general plan in 1987 and a revised regional water quality management plan in 1988. The consensus process resulted in a dramatic change in the manner in which problems were addressed the Lake Tahoe Basin by placing an emphasis on consensus and collaborative efforts rather than on litigation and conflict.

The adoption of the revised regional plan in 1987 did not remove the tensions in the Basin. As Sabatier and Pelkey (1990) point out, TRPA's regulations are viewed by many as an unjustified intrusion on private property rights and usurpation of local government's authority to regulate land uses. This tension manifests itself in several ways. Certainly, there continues to be litigation which seeks to overturn TRPA regulations. To date, TRPA's regulatory structure has largely been upheld. The courts have upheld the applicability of the Compact's provisions to local government [*People* ex. rel. *Younger* v. *El Dorado* (1971) 5.Cal.3d 480]. In a significant case, a Nevada court validated the scientific and legal underpinnings of TRPA's 1987 regional plan with regard to its water quality provisions [*Kelly* v. *Tahoe Regional Planning Authority*, 855P.2d 1027 (Nev. 1993)]. The Nevada Supreme Court unanimously upheld that decision. In another case, which will soon go to trial, landowners are claiming that TRPA's adoption of the regional plan resulted in the deprivation of property without just compensation (*Tahoe Sierra Preservation Council* v. *TRPA*). The tension furthermore manifests itself in legislative attempts to amend the Compact in such a manner as to change representation or require locally elected representatives on TRPA's board and to increase legislative oversight.

Cooperative management of the Lake Tahoe Basin has improved in the last decade with the maturation of the Compact, as most interested parties are working together to accomplish Compact goals. While the early years relied heavily upon the USFS, other federal agencies, and consultants to provide the scientific expertise needed to develop the Basin plans, today the states, local governments, and various public groups are heavily involved in restoration, monitoring, and land-use planning, with much more responsibility accepted at the local level. In the Lake Tahoe Basin, it seems that the formation of TRPA in 1969 was vital in furthering collaborative efforts to better manage the Lake Tahoe Basin ecosystem. As a federally sanctioned planning body, TRPA provided a credible forum for public debate and accountability. The TRPA had jurisdiction, by design, over the environmental and economic unit of interest: the Lake Tahoe watershed. As such, many cause and effect relationships could be effectively addressed. The marriage of ecosystem research and monitoring with policy formulation and community and regional planning allowed TRPA and other organizations to at least address the sustainability of the Lake Tahoe Basin ecosystem from all biophysical and socio-economic dimensions, and made the Lake Tahoe Basin a model for regional planning.

At Lake Tahoe, the Compact and the formation of TRPA allowed the many interest groups to come together to focus their energies on ecosystem goals and appropriate land-use practices, and then to focus on key areas of agreement as a group. The interest groups, along with the leadership of key individuals, need to be recognized for the important perspectives they bring to the table. The League to Save Lake Tahoe remains a powerful force within the Basin, with a membership of over 4,000 individuals who reside both inside and outside the Basin. Groups such as the Lake Tahoe Economic Crisis Committee have sought to retain local control in the Basin and protect private property rights. The Tahoe-Sierra Preservation Council, organization founded in 1980, is the leading representative of area property and business owners, also focusing on the protection of private property rights, but supporting a broad range of efforts, including the various land acquisition programs. These and other special interest groups are long-standing, respected members of the community, and effective and well organized voices for their respective views.

Collaborative, consensus groups aimed at bridging what may be gaps between the Basin's many special interest groups, especially on the conservation versus economic sides, have formed in recent years. These groups have evolved through time in response to conflict over the 1984 plan for the Basin, TRPA's proposal for consensus, redevelopment agreements, and the identification of parameters and processes that need to be more fully addressed. Collaboration between various players in the Basin has occurred to more efficiently use knowledge and resources, to improve communication between those with various viewpoints, as a way to bring public and private interests together to address tasks that exceed individudal capacities, and to form a united voice on key issues.

One of the first of these collaborative groups was the Tahoe

Transportation Coalition (TTC) which was formed in 1989. This coalition of business and environmental groups was brought together to provide input on transportation planning issues and to secure legislative support and funding for the Basin's transportation needs. Recently, the group was successful in procuring $2.5 million from Congress to help coordinate transportation systems on the south shore of Lake Tahoe.

Another of these collaborative groups is the Tahoe Truckee Regional Economic Coalition (TTREC) formed in 1992. This group was borne out of a growing consensus that the natural environment of the Lake Tahoe Basin is its greatest economic asset. Under the name the Economic Round Table, the first informal group held monthly discussions, began to build a database of economic indicators, and sponsored conferences on the economic issues facing recreational resort communities. In 1992, the Economic Round Table became TTREC. The TTREC's goal, as stated in its vision statement, is to ensure the long-term harmonious enhancement of our natural and human environment, historical and cultural heritage, and the overall quality of life for residents and visitors. As such, TTREC is working to sustain the ecological and economic vitality of the Basin in parallel fashion.

The Tahoe Coalition of Recreation Providers (TCORP) is a special interest group that formed about the same time (in 1991) in recognition of recreation as the foundation of the Basin's billion dollar economy. The TCORP recognizes that this recreation is largely dependent upon the user's perception of the Lake Tahoe Basin's environmental quality or health. The TCORP is working across jurisdictional boundaries to promote regional coordination and cooperation of recreational activities that reflect both functional human and environmental units. Its unified approach is fostered by the sharing of information and coordinated planning. Recreation providers, both public and private, use TCORP as a clearinghouse for information to the recreation community. According to Co-Chair Linda Eissmann, Senior Planner with the Nevada Division of State Parks (personal communication 1995), TCORP believes that dynamic, regional recreation planning may be the single most important mechanism we have to coordinate the principles of environmental sustainability with a strengthened recreational tourism economy.

In 1991, the Forest Health Consensus Group (FHCG) was formed by TRPA out of a growing concern for the rapid rate of mortality in timber stands. Agencies and the public shared interest in assessing the need to reintroduce logging and natural fire regimes while recognizing the need for strict watershed protection. A consensus has been achieved that the pre-settlement condition of the forest is the desired future state of the forest in the Basin. Currently, the FHCG is working to define the means for achieving this desired condition.

The Washoe Tribe of Nevada and California has undertaken collaboration with the regional land-management agencies, particularly the USFS. The Washoe, like many other groups, strongly support management of a human landscape that is ecologically sustainable. The tribal government's comprehensive land-use plan includes goals to: "acquire a tribal land base in the Lake Tahoe Basin, once at the heart of their territory"; to revitalize Washoe heritage and cultural knowledge, including the harvest and care of traditional plant resources; to "interact with agencies and governments in aboriginal areas to preserve" archaeological sites and traditional properties; and, specifically, to return Cave Rock, a prominent landmark and spiritual site on the east shore, to Washoe ownership (Washoe Tribal Government 1994, pp. IV-9).

A most recent addition to the growing list of collaborative groups is the Tahoe Center for a Sustainable Future (TCSF). Incorporated in 1994, TCSF's mission is to provide information, support, education, and training to individuals, agencies, organizations, communities, and regions who are concerned about and / or working toward environmental preservation, or restoration and sustainable development. As defined by the TCSF, sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Implicit in this definition are environmental protection, preservation and remediation, as well as human needs.

The TTC, TTREC, TCORP, and TCSF emphasize the evolving local and regional goal of the sustained health of the environment as a foundation for economic viability. Sharing of knowledge and resources has provided the foundation for trust. While individual special interest groups and factions retain their respective positions, those positions are increasingly linked to the same information base. Interpretive differences remain, but the common knowledge base creates a degree of openness and trust that was heretofore absent.

Reflecting this collaborative spirit and a growing appreciation of the inter-relationship between environmental and economic needs in the region, is a strong public / private sector commitment to redevelopment and restoration within the Basin as a means of achieving the environmental thresholds, regional planning goals, and economic development objectives. The regional plan places an emphasis on redevelopment as a means to concentrate new commercial development in existing commercial areas and to install larger-scale water quality improvements, such as recreated wetlands, and public access improvements, such as trails. The city of South Lake Tahoe has taken the lead in using this mechanism to redevelop the casino corridor and the Ski Run areas on the south shore through a $300 million program. Similarly, Placer County is also establishing a redevelopment program on the north shore. As a precursor to this redevelopment effort, Placer County has been using TRPA's community planning process to install transportation, water quality, and commercial improvements at Tahoe City.

There is also an expanded emphasis on restoration of the natural environment and provision of additional recreational facilities which complement on-going soil-erosion grant and public access programs. There is a broad based public / private partnership to obtain funding for major stream and wetland restoration and soil-erosion control projects, such as the Upper Truckee River and Wetland Restoration Project in California and the General Creek and Spooner Summit projects in Nevada. This partnership was instrumental in placing bond acts in both Nevada and California for water quality purposes on the November 1996 ballots.

There is also a growing commitment to complete regional trail systems. For example, TRPA has called for the completion of a bikeway around the lake by the year 2000.

INSTITUTIONAL EVOLUTION

Just as the Lake Tahoe Basin ecosystem has evolved, and our human use and understanding of it, so have the institutions that have overseen management of the Basin. The institutional history of the Lake Tahoe Basin has similarities to and differences from other regions of the western United States. Washoe use and management of the Basin was replaced by early settlers' cultural practices that were much more intensive and year-round. Our federal and state institutions supported settlement of the Basin and extractive resource use through the latter half of the nineteenth century. With the overharvesting of resources such as timber, fish, and fodder, and an increasing interest in recreation in the high mountains, institutional focus shifted to the provision of local services for both residents and tourists, and along with this, water resources use, both in-basin and downstream. As it became evident that environmental quality was declining, perhaps to the detriment of the high-quality recreational experience the Basin supplied, institutions further shifted their concern to gaining better scientific information on the ecology of the lake system, environmental stewardship of it, and regional sustainability. Today, 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 to private land ownership in the Basin. The following sections explore the evolution of this institutional framework based the assessment of the Lake Tahoe Basin ecosystem, land-use planning and management, and accompanying land acquisition and environmental restoration.

Ecosystem Assessment: Independent and Interagency Efforts

Early scientific assessments of the Lake Tahoe Basin were conducted in the late 1800s, largely by individual scientists, not institutions or interagency groups. These early scientists included Charles Burckhalter of the U.S. Naval Observatory, J. N. LeConte of the University of California, and naturalist John Muir. During the first half of the 1900s, little scientific information was published on the Lake Tahoe Basin, but with a renewed interest in science and natural resources after World War II, scientific research by federal and state resource management agencies and university scientists increased sharply. Studies included investigation of the hydrology and aquatic resources of the Lake Tahoe Basin in the late 1940s and 1950s by the California Division of Water Resources, the California Department of Fish and Game, the Nevada State Engineer, the Nevada State Department of Health, the U.S. Bureau of Reclamation, the USFS, and COE.

Interest by federal and state agencies in the Lake Tahoe Basin's natural resources fostered expanded scientific research and ecological monitoring. The first significant, multidisciplinary assessment of the entire Lake Tahoe Basin ecosystem (aquatic and terrestrial components) was done by LTAC (McGauhey et al. 1963) to specifically address the eutrophication of Lake Tahoe. Based on various biophysical technical analyses, including a review of nutrient sources, impacts, and sinks, these data provided justification for the decision to prohibit the discharge of wastewater within the Lake Tahoe Basin. This early study was extraordinary and set the stage for regional resource planning in the Basin. Like the ecological assessments which followed, it provided detailed information necessary to understand at least the partial ecological impacts of human activities, define priorities for future actions, and redirect the institutional decision-making process and structure. Management concerns were addressed across jurisdictional boundaries, which proved key.

Charles Goldman (University of California, Davis) and his colleagues published the first of many reports on the limnology of the lake in 1963 (Goldman 1963). Air quality monitoring in the Basin also began in the 1960s, as the National Air Pollution Control Administration measured ozone concentrations at South Lake Tahoe and Incline Village during 1967 and 1968. Monitoring of the lake ecosystem was thus clearly underway.

In 1972, TRPA, USFS, and LTAC helped to obtain a grant from the National Science Foundation to establish coordinated research efforts in the Lake Tahoe Basin. The TRPA had found that research was scattered among myriad federal and state agencies, universities, independent organizations, and individuals, and that there was little, if any, regional coordination. The TRPA had also discovered that the research community as a whole had little knowledge of the overall needs of the Lake Tahoe Basin management authorities, and the potential research users were also poorly informed about available research findings. The Lake Tahoe Research Coordination Board in two years (1) published a compilation of past and on-going research and a comprehensive listing of research needs for the Basin, (2) hosted well attended public seminars on research results, and (3) began a review of proposed research projects.

The University of California was the primary academic institution active in the Lake Tahoe Basin in the 1970s. The

SWRCB, LRWCB, the Nevada Department of Conservation and Natural Resources, CRTPA, and TRPA conducted many valuable analyses of their own, yet relied heavily on TRG for monitoring of Lake Tahoe's water quality and, by the mid-1970s, monitoring of streams. The USGS served as an important cooperator in much of this monitoring and data management. As an independent scientific research group, TRG received grants from the National Science Foundation, the Fleischmann Foundation, the Federal Water Pollution Control Administration (later EPA), the SWRCB (through a voter-approved bond act), and other entities to support its monitoring and research efforts at the lake. Goldman remains the "father" of Lake Tahoe ecological research, with a very active program of study for over thirty years.

In regards to air-quality monitoring, the ARB, the Nevada Division of Environmental Protection (NDEP), and the EPA became actively involved at Lake Tahoe in the 1970s. The ARB published reports on air pollution potential and ozone patterns, and NDEP conducted monitoring in support of its air quality planning efforts.

Broad ecosystem assessments were published in the early 1970s by TRPA and the USFS as a series of short reports which became known as the "pastel studies" (because of the colored paper on which they were printed) on a wide variety of ecosystem components (e.g., Tahoe Regional Planning Agency N.d.a, N.d.b, 1971; Tahoe Regional Planning Agency and U.S. Forest Service 1971a, 1971b, 1971c; Smith 1971; Tahoe Regional Planning Agency Committee on Water Distribution N.d.). In 1975, the EPA completed The *Lake Tahoe Study* as requested by the ninety-second Congress. Recommendations in the report included (1) designating the Lake Tahoe Basin as an area of national environmental significance, (2) establishing environmental thresholds, (3) encouraging the states to consider modifications to the Tahoe Regional Planning Compact (e.g., removal of the dual majority), and (4) developing a coordinated federal policy for Lake Tahoe. The report addressed the Lake Tahoe Basin "ecosystem," relating development activities to "first impacts" and "resultant impacts." It reviewed intergovernmental activities, collaborative relationships with TRPA, and presented a problem analysis as well.

In the late 1970s, the Western Federal Regional Council, composed of the western regional offices of the federal land and environmental agencies, pulled together monitoring data on multiple elements of the environment, including wildlife, vegetation, fish, and other parameters for the *Lake Tahoe Environmental Assessment* (Western Federal Regional Council Interagency Task Force 1979). The assessment used an enormous amount of scientific data aggregated into a model which provided a cumulative evaluation of the causes of changes from 1970 to 1980. The model categorized variables as causal forces, internal subsystems, internal flows, and outputs. This report influenced the amendment of the Tahoe Regional Planning Compact and helped establish ecological threshold-based planning in the Basin. The TRPA *Environmental Impact Statement for the Establishment of Environmental Threshold Carrying Capacities* (Tahoe Regional Planning Agency 1982) provided these environmental standards for attaining the Compact goals. Environmental impacts were generalized into three categories: resources management, resources development, and infrastructure. The report was reviewed by TRPA and state and federal agencies. Significant adjustments were made to federal policy and the groundwork was laid for further evaluation of the Compact leading to revision and adoption of thresholds.

The 1982 TRPA EIS lists basin-wide goals for water quality, water quantity, soil conservation, air quality, noise, vegetation preservation, wildlife, fisheries, recreation, and scenic resources. Natural resources are described in some detail, and degradational cause and effect relationships are identified. Environmental consequences of implementing the proposed thresholds are described as needed for environmental protection, and evaluated for physical-biological impacts and their social and economic environmental consequences.

It is evident here that significant institutional shifts in monitoring, research, and technical evaluation occurred in the 1980s. The adoption and ratification of the revised TRPA Compact in December 1980 heightened interest in research. In 1980, the Lake Tahoe Interagency Monitoring Program (LTIMP) published the first of many annual water quality reports covering Lake Tahoe and five of its tributary streams. The TRG still carried out the bulk of the actual water-quality monitoring through grants from the National Science Foundation, but at least twelve federal, state, and regional agencies provided professional assistance and additional funds for the LTIMP monitoring efforts. The LTIMP evaluated atmospheric deposition and streamflow as sources of nutrients to the lake as well. In the early 1980s, the USGS working with TRG also began to monitor tributary water quality and groundwater quality, with a particular interest in sediment transport. All efforts were coordinated with LTIMP to avoid overlap and promote consistency, while best coupling monitoring to scientific research.

By 1987, facing decreases in the federal and SWRCB money that had largely supported LTIMP, TRPA, the USGS, and TRG pooled their resources. The USGS and TRG scientists collected the bulk of the water-quality data. Together, the agencies expanded the stream monitoring network from its initial five stations to about thirty stations by the end of the decade. The TRG continued to operate the Jean LeConte research vessel for lake-wide monitoring, as they do to the present. The scientific work of TRG and LTIMP was, and is, the backbone of water-quality planning efforts in the Basin.

During the 1980s, significant advances were made in air-quality monitoring. The ARB and NDEP established permanent stations to measure carbon monoxide, ozone, and particulate matter. Pitchford and his associates at the EPA's Las Vegas laboratory conducted their baseline visibility research, published in 1984. In 1987, Thomas Cahill of the Crocker Nuclear Laboratory, University of California, Davis, conducted a six-month study of fine particulate concentrations along the south shore and at Ward Valley. In 1989, TRPA installed the first of its two visibility and particulate monitoring stations, in coordination with the national air quality improvement program of the EPA and the National Park Service. The TRG installed a wet/dry deposition sampler near the mouth of Ward Creek in 1983, and starting in 1986, deployed anchored buoys at four lake stations to measure bulk atmospheric deposition in open collectors.

Furthermore, in the 1980s it became apparent that there was a lack of data on the effectiveness of land remediation efforts, including the use of best management practices (BMPs) and evaluation of large-scale erosion control and wetland restoration projects. To judge their effectiveness, pre-project monitoring and post-project monitoring were undertaken, but not for the long-term, which is often beyond the financial capacity of the agencies implementing the projects. In the Lake Tahoe Basin, the onset of land remediation projects coincided with an eight-year drought cycle, starting in the middle-1980s. We know that even under ideal conditions, reductions in sediment and nutrient yields resulting from remediation of disturbed areas may not appear for a decade or more (Byron and Goldman 1989). One research report on the effectiveness of BMPs in the Lake Tahoe Basin is available (White et al. 1978) and serves as a late 1970s baseline reference for the Basin. However, additional research is needed on BMPs effectiveness coupled to watershed-scale erosion and sediment/solute transport.

An additional data acquisition effort initiated during the 1990s was the collection of economic data under the auspices of the Economic Round Table and its successor, the TTREC. This group is building a database on the human dimensions of the Lake Tahoe Basin ecosystem.

At present, most of the monitoring programs established in the 1980s continue, with refinements. Financing of the monitoring programs with their cost of over $1 million per year may be difficult to sustain. To save money, the agencies involved have postponed data analysis, preferring to expend what funds they have to collect long-term data; this strategy has created a condition described as “data rich and information poor.”

Land-Use Planning and Regulation

In 1985, as a function of litigation (*People* ex. rel. *Van de Kamp* v. *Tahoe Regional Planning Agency*) and agency directives, TRPA embarked on a revision of the regional plan and worked to resolve the on-going conflict through a consensus workshop process. This process was not to be a compromise between TRPA and the plaintiffs in the litigation, but rather a consensus among all parties in the Basin. There were many reasons for the participants to agree to this process, including (1) realization that the court could, in effect, stop development in the Basin, (2) litigation is a situation where everyone loses, (3) the need to identify a stable, long-term and workable solution, and (4) the realization that a building moratorium could lead to Nevada pulling out of the Compact.

A core group of the key stakeholders was formed and an outside expert facilitator was hired to run the workshop meetings and, with the help of the core group, identified twenty-five separate entities and agencies to participate in the consensus building process. By design, the invitees included a very broad cross-section of interests, as well as a representative of every entity perceived to hold veto power over any eventual agreement (table 5).

The workshop process consisted of frequent one- and two-day sessions on key issues by the identified participants . Using interest-based negotiating techniques, the group explored options, considered each others’ needs, and gained information and insight on the planning and regulatory problems of the Basin. The workshop planning and meetings extended over a year from the time that TRPA gathered political support to initiate the effort in the spring of 1985. The first full workshop meeting was in August 1985 with the final full workshop meeting in April 1986, with a total of thirty-two meetings.

The workshop participants compiled and addressed a list of twenty-seven issues within six major areas of concern: (1) the rate of residential and commercial development, (2) the allocation of development rights by county, (3) the new/revised land classification system for residential and commercial development, (4) protection of sensitive lands, (5) community control of the planning process, and (6) balance between environmental protection and economic growth.

TABLE 5

Members of the Lake Tahoe Basin Consensus Building Workshop.

American Association of University Women
California Attorney General
Incline/Crystal Bay Advisory Board
Lahontan Regional Water Quality Control Board
League of Women Voters
League to Save Lake Tahoe
Nevada Attorney General
Nevada Division of Environmental Protection
North Tahoe Advisory Council
North Tahoe Public Utility District
Sierra Club
South Tahoe Gaming Association
Tahoe Basin Association of Governments
Tahoe City Advisory Council
Tahoe Regional Planning Agency
Tahoe Shorezone Representation
Tahoe Sierra Board of Realtors/Incline Village Board of Realtors/North Shore Advisory Council*
Tahoe Sierra Preservation Council
Tahoe Transportation District
Tahoe-area Chambers of Commerce*
Tahoe-area Resource Conservation Districts*
Tahoe-area Utility Districts*
TRPA Advisory Planning Commission
U.S. Environmental Protection Agency
U.S. Forest Service (LTBMU)

*Groups of stakeholders represented by a single individual in the workshop.

Based on the progress made in the workshop through the spring of 1986, the parties involved in the litigation decided to approach Federal District Court Judge Edmund Garcia with a plan to lift the then imposed development moratorium for the summer construction season. He approved a stipulated agreement among the parties authorizing a 1986 summer building season, consisting of 300 residential permits and certain other projects. This ended a four-year development moratorium.

Subsequent to the adjournment of the full workshop, a smaller group of participants met from 1986 through early 1987 to work out the details of the TRPA Code of Ordinances and Plan Area Statements. The membership of this small group varied from meeting to meeting based on the issue under discussion, but the main participants were TRPA, the Tahoe Sierra Preservation Council, the League to Save Lake Tahoe, and the California Attorney General.

In 1987, a full settlement agreement was reached, based on TRPA's adoption of the Code of Ordinances and Plan Area Statements implementing the consensus plan. Judge Garcia dismissed the lawsuits initiated by the State of California and the League to Save Lake Tahoe. The consensus plan with amendments is still in place and being implemented today.

The consensus approach initially utilized to settle the 1984 litigation has led to a number of cooperative and collaborative efforts. The focus is on finding areas of agreement and then acting on them as a group. With the regional plan finally in place, in 1988 TRPA revised the water quality management plan ("208 plan") to conform to the settlement, and obtained state and EPA approval. The TRPA also issued a transportation plan, and transportation planning became a major institutional focus. In the Consensus Building Workshop, the main planning issues had been related to land-use planning, development on sensitive lands, and protection of water quality. With those issues settled, and traffic counts showing increasing reliance on the private automobile, interest in transportation planning increased. A group of private parties, including the Chambers of Commerce, the Lake Tahoe Gaming Alliance, Heavenly ski resort, and the League to Save Lake Tahoe, formed TCC to provide input to the transportation planning process. The coalition was instrumental in bringing a Rural/Urban Design Assistance Team, from the American Institute of Architects to Lake Tahoe in 1989 to study transportation issues and make recommendations. At about the same time, a group of private and public organizations in North Tahoe and Truckee formed a transportation management association, the first to be established in the Basin.

In keeping with the cooperative spirit of the Consensus Building Workshop, planning proceeded for redevelopment in South Lake Tahoe near the state-line. The city commenced its redevelopment program in order to upgrade its visitor accomodations. As a result of the Urban Land Institute's review of the regulatory program, the city realized that its motel and hotel accomodations were not attractive to visitors who wish to have more expensive accomodations. Additionally, the redevelopment process provided an opportunity to readjust land uses in an area and to incorporate public improvements such as water quality improvements and trails. In support of this effort, the city obtained an amendment to the state's redevelopment law which allowed it to begin the process by making a finding of environmental degradation instead of the usual finding of social blight. This finding reflected, in part, the environmental objectives of the project. A pre-development agreement involving the city, the California attorney general's office, the League to Save Lake Tahoe, TRPA, and others resulted in adoption of a plan and the issuance of permits for two major redevelopment projects: the Embassy Suites hotel, which opened in late 1991, and a hotel proposal at Ski Run Marina which has since been converted into a timeshare resort project which is scheduled to be constructed in the summer of 1996. This redevelopment program has resulted in improved aesthetics and water-quality treatment in the redevelopment area and in having California redevelopment law amended to include environmental degredation as a justification for redevelopment.

In the late 1980s, local governments and TRPA embarked upon a process of community planning for up to twenty-four designated commercial nodes around Lake Tahoe. Planning for these areas had been contentious. Implementation has moved slowly and has remained difficult due to competition between local areas, uncertainty regarding economic viability, and high costs of mitigation measures. Some participants felt that commercial areas should be governed by the same rules and regulations as other areas, while other participants felt they should be given a free hand to plan for the future without interference from TRPA. The consensus plan embraced the concept of a local-regional-community partnership, with incentives to property owners to participate.

In the present decade, the consensus approach developed in the 1980s has continued in effect throughout the Basin. The coalitions formed in the late 1980s continue to contribute to the transportation and recreation planning processes. Community planning also continues, albeit slowly.

In 1990, TRPA also began a complete evaluation of the threshold standards and the regional plan (Tahoe Regional Planning Agency 1991). The resolution adopting the threshold standards in 1982, and every major plan document after that date, called for evaluations of the thresholds and the regional plan at least every five years. However, TRPA's first comprehensive evaluation did not occur until 1991. Under the terms of the Compact, TRPA may not implement a regional plan that will not achieve and maintain the environmental threshold standards, and may not approve any project that is inconsistent with the standards. Thus, periodic evaluations are important if TRPA is to continue to implement the regional plan and approve additional activities in the region. The evaluation was also of interest to the plaintiffs in the plan-related litigation, who needed to know that the consensus plan was being implemented, and to private property and development interests, who wanted orderly growth under the regional plan to continue, rather than face another moratorium. The *1991 Evaluation Report* (Tahoe Regional Planning Agency 1991) concluded that the regional plan needed to be strengthened in several areas. Specifically, TRPA made immediate changes in its Code of Ordinances (e.g., strengthening controls on emissions from wood heaters) and agreed to a schedule for development of additional automobile use disincentives (e.g., a parking ordinance). Given the magnitude of the problems, however, these changes focused on relatively minor issues and details.

While for twenty-five years, the vast majority of planning activity in the Lake Tahoe Basin had been directed at land-use planning, water-quality protection, transportation, and related issues, the forests of the Basin were gradually succumbing to the combined stresses of insects, drought, overstocking, and fire suppression. By the early 1990s, the dying forest stands, many which were believed to have high fuels loads with risk of wildfire, had become perhaps the Basin's most contentious planning issue. There was no shortage of blame, but there was a notable shortage of solutions on which the key institutions could agree. As such, in 1991, TRPA convened a Forest Health Consensus Group (FHCG), modeled after the Consensus Building Workshop of the previous decade, to attempt to develop a consensus plan for forest management. Local groups are working with the USFS to devise small-scale fuel reduction strategies for neighborhoods and similar areas. A draft EIS document by the LTBMU is currently under review for treatment of fuels and fire hazard in the forests of the northern part of the Basin.

It is difficult to assess the sustainability of the current use of the consensus approach in the Lake Tahoe Basin. Certainly, there are examples (e.g., export of sewage) where a consensus has been reached in the past. These efforts were followed by periods of contentiousness. However, the current emphasis on consensus has produced significant results. This appears to be a function of greater acceptance of both resource protection objectives and the means to achieve capital planning and outlay programs and authority.

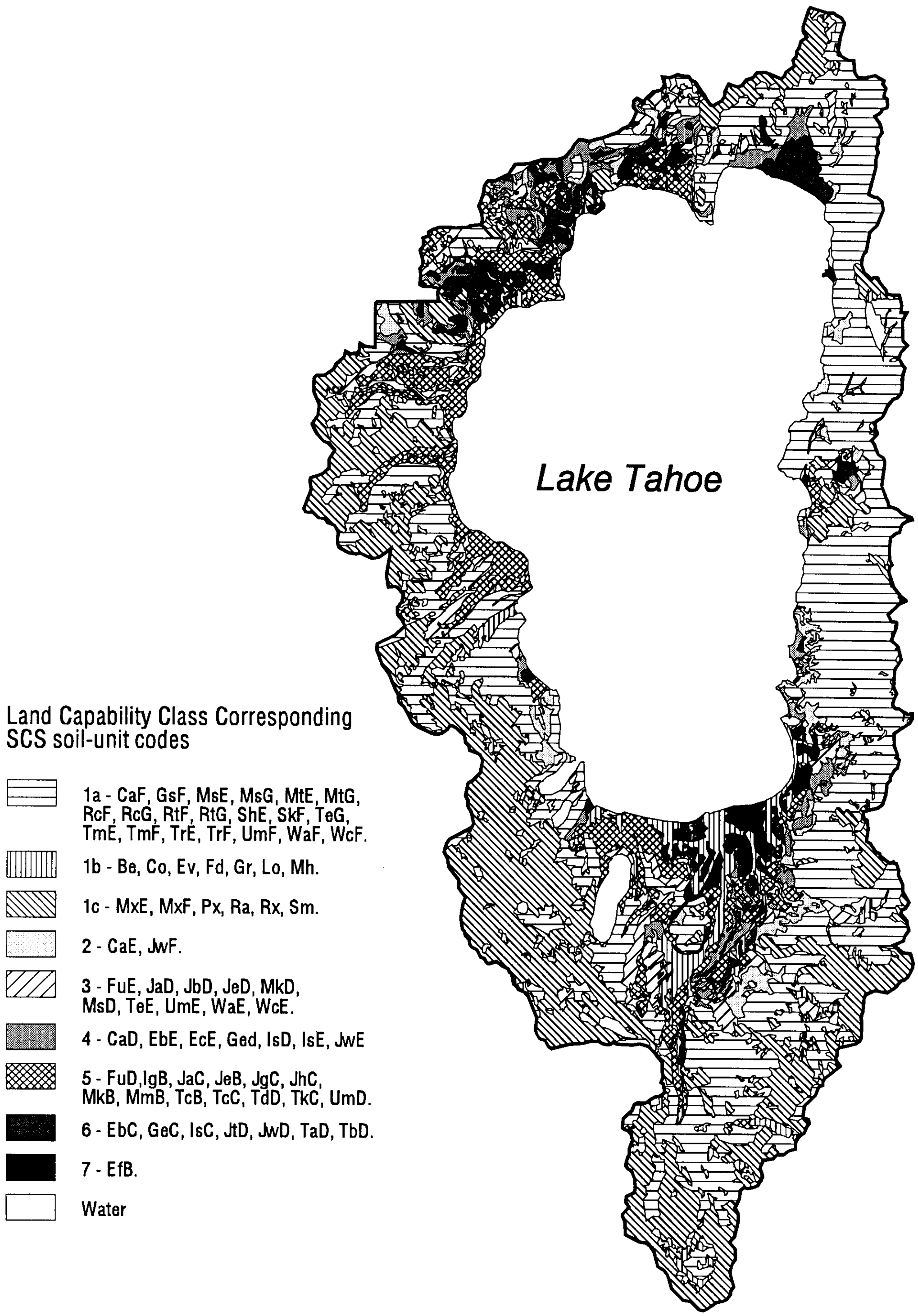
As in the past, litigation is creating uncertainty. There are two sets of cases which may significantly affect TRPA's regulatory programs. Two regulatory taking cases [*Tahoe-Sierra Preservation Council* v. *Tahoe Regional Planning Agency* (U.S. District Court, D. Nev.) have been consolidated in the U.S. District Court in Reno, Nevada. This litigation challenges the constitutionality (i.e., taking of land without just compensation) of the TRPA building restrictions on environmentally sensitive lands under both the 1984 and 1987 regional plans. Currently, the parties are exploring settlement through meditated negotiations. In *Suitum* v. *Tahoe Regional Planning Agency* (U.S. Court of Appeals for the Ninth Circuit), the owner of a wetlands parcel has challenged the constitutionality of TRPA's regulations which preclude development of the parcel. The court dismissed the appeal on the ground, that the landowner had failed to take advantage of the multiple transfer of development programs available under the regional plan. On appeal, the Ninth Circuit of Appeal has upheld the District Court decision. Decisions which are adverse to TRPA could dramatically alter the manner in which environmentally sensitive lands are regulated in the Lake Tahoe Basin.

Public Land Acquisition, Restoration and Management Activities

Another important resource management strategy in the Lake Tahoe Basin is the acquisition of additional public lands, restoration of their natural environments, and their on-going management. Such activities are especially important in areas such as the Lake Tahoe Basin where there is a fine-scale mix of private and public land ownership and uses, where significant natural values are being adversely impacted by rapid growth, and where the overall objective is to improve environmental quality.

These activities serve a number of resource management objectives. In the Lake Tahoe Basin, acquisition activities provide the land and resource base to achieve public objectives (e.g., environmental thresholds) and to incorporate ecosystem dynamics into management strategies and practices. Specifically, acquisition activities are important because they seek to prevent further disturbance of environmentally sensitive lands and wildlife habitat, and provide opportunities for restoration and the construction of public access facilities. Research has shown that disturbance of environmentally sensitive lands (e.g., Bailey Land Capability Classes 1–3) (figure 11) and stream environment zones (SEZs) significantly increases concentrations of nitrate, total phosphorous and suspended sediment in streams, stimulating algal productivity (Byron and Goldman 1987), and decreases wildlife habitat as well. Acquisitions can help prevent further disturbance to wildlife habitat. Disturbance of wildlife habitat has reduced both the number and variety of wildlife in the Basin (TRPA 1982). Due to historical settlement patterns, most of the shoreline is privately-owned (Strong 1984). Consequently, acquisition is also needed to expand recreational opportunities in order to accommodate existing public demand for recreation. Acquisition programs give landowners an opportunity to sell their land for public purposes and to receive fair compensation for it.

In the Lake Tahoe Basin, site improvements are critical to increase the capacity of public lands to function naturally while supporting public uses. Erosion-control improvements are needed to control the release of phosphorous and other nutrients from disturbed areas. Public access improvements are needed to allow recreational opportunities at existing and new sites, to enhance the visitor's experience, and most importantly to minimize environmental damage caused by overuse. Trails are needed to connect existing facilities in order to lower reliance on the automobile to travel from one facility to another. Activities such as stream and riparian restoration are needed to provide additional habitat for wildlife and fish.



Source: Bailey (1974), SCS
Map scale 1:360,000

SNEP GIS, June 15, 1995

FIGURE 11

Bailey land capability classes as mapped for the Lake Tahoe Basin. (SNEP GIS project).

Site improvement activities also support local and regional planning activities and provide private sector jobs.

Land management activities strive to maintain natural functions and provide public access opportunities, to enable the development of new restoration techniques and management strategies, and to protect public health and safety. The following discussion outlines the evolution of these types of activities at Lake Tahoe.

Public Land Acquisition

There has been a long, approximately 100 year history of acquisition or reservation of land for public purposes in the Lake Tahoe Basin. Land acquisition activities reflect, in large part, the evolutionary changes in public agency policy with regard to recreation and environmental protection and the availability of purchase funds.

The initial blueprint of ownership and land uses within the Basin was set by federal policy. With the original public domain, the government disposed of land in the Lake Tahoe Basin in the second half of the nineteenth century under the prevailing national policy to encourage settlement and economic development of the American West (Fink 1991). Land was disposed of to private owners for agricultural, timber, and resort uses, and for the development of the transcontinental railway.

Toward the end of the nineteenth century, the federal government began to shift policy from disposal of public lands to retention for park and conservation purposes (Fink 1991). The creation of the Tahoe Forest Reserve in 1899 was a manifestation of this policy. It marked the beginning of an extraordinary effort to reserve lands for public purposes, which has resulted in federal ownership of 77% of the Lake Tahoe Basin (figure 12).

Acquisition of public lands by the USFS has been extensive. The original national forest land in the Basin has been increased to the present 77% or 63,200 ha (158,000 acres) and 21 km (11 miles) of shoreline through land exchanges and, more recently, through direct purchase under the Land and Water Conservation Fund Act of 1965 and the Santini-Burton acquisition program. Two sizable land exchange transactions added significant acreage to public land in the Basin: (1) in 1936, the Carson & Tahoe Timber and Flume Company exchanged 3,147 ha (7,776 acres) of cut over and uncut timber land in the Upper Truckee River area, and (2) in 1950-51, the Pope Baldwin exchange added 1,425 ha (3,523 acres) of prime lakeshore land in the Fallen Leaf Lake and South Lake Tahoe areas, two key subregions of recreational activity. Three significant land purchases occurred after the passage of the Conservation Fund Act in 1965: (1) the Whittell Estate (Dreyfus) lands on Nevada’s east shore comprising some 4,219 ha (10,425 acres) for $10.6 million in 1972, which added 10.5 km (6.5 mi) of shoreline to public ownership, (2) the Fibreboard Corporation lands, 4,096 ha (10,121 acres) for $9.9 million in the northwest sector of the Basin, in 1974, and (3) the Meeks Bay land from Hewlett in 1974 for $3.0 million, adding 261 ha (645 acre) including 1,014 m (3,328 ft) of shoreline with 549m (1,800 ft) of excellent beach.

Although the LTBMU of the USFS was formed in April, 1973 to provide uniform management of national forest lands in the Basin, these lands legally remain a part of three proclaimed national forests: Eldorado, Tahoe, and Toiyabe.

In the early 1970s, TRPA staff and the USFS Planning Team for the Basin prepared a Public Lands Priorities Map, which was an inventory of private lands which, if acquired, would serve a useful public purpose. Lands were evaluated for such factors as public use, manageability (size), watershed protection, wildlife and scenic value, and development pressure. The cost was estimated to be well over $100 million for direct purchases and land exchanges of high-priority lands.

After more than fifty years of effort, the USFS land acquisition program is more than 95% complete. Current federal ownership now stands at 77% of the 83,065 ha (202,250 acres) landbase, with the ratio between public and private ownership effectively reversed from the situation in 1900.

Given the strong federal interest in the Lake Tahoe Basin, the states did not play an active role in acquisition during most of the nineteenth century. In California, however, there was a concern that clear-cut removal of timber was severely damaging the beauty of the region. In 1883, the Lake Bigler Forest Commission urged the federal government to acquire private lands in the Basin and to transfer management responsibilities to the states for park purposes (Strong 1994).

Near the end of the nineteenth century, California began to establish a state park system. In 1899, the first park site, Tahoe State Park, was set aside at Tahoe City (Strong 1984). During the late 1920s, the state park movement expanded, and in 1927, the California legislature approved a $6 million bond act for acquisition of lands, including property in the Lake Tahoe Basin, to be included in the state park system (Strong 1984). This action started a largely bond-funded acquisition program, which over the next sixty years resulted in the acquisition of about 2,430 ha (6,000 ac) and creation of state parks such as D.L. Bliss and Sugar Pine Point. These acquisitions are important recreational lands and core areas of biological diversity because of their large size.

Nevada established its first state park in the Lake Tahoe Basin at Sand Harbor in 1958 (Strong 1984). In 1961, there was an attempt to create a bi-state park, as recommended by an Interstate Commission, through the establishment of the Lake Tahoe Park Interstate Park Authority. The proposal was sparked by a realization that Nevada had the land and California had the funds and the likely user group. This proposal was the first attempt to establish a bi-state authority in the Lake Tahoe Basin but failed in the Nevada legislature (Fink 1991). In 1964, the Nevada legislature did pass a park bill which allocated funds for the acquisition of a large undeveloped stretch of shoreline owned by George Whittell. In 1967, Nevada acquired 3,024 ha (5,000 ac) which became the foundation of a 5,260 ha (13,000 ac) Lake Tahoe Nevada State Park (Strong 1984).

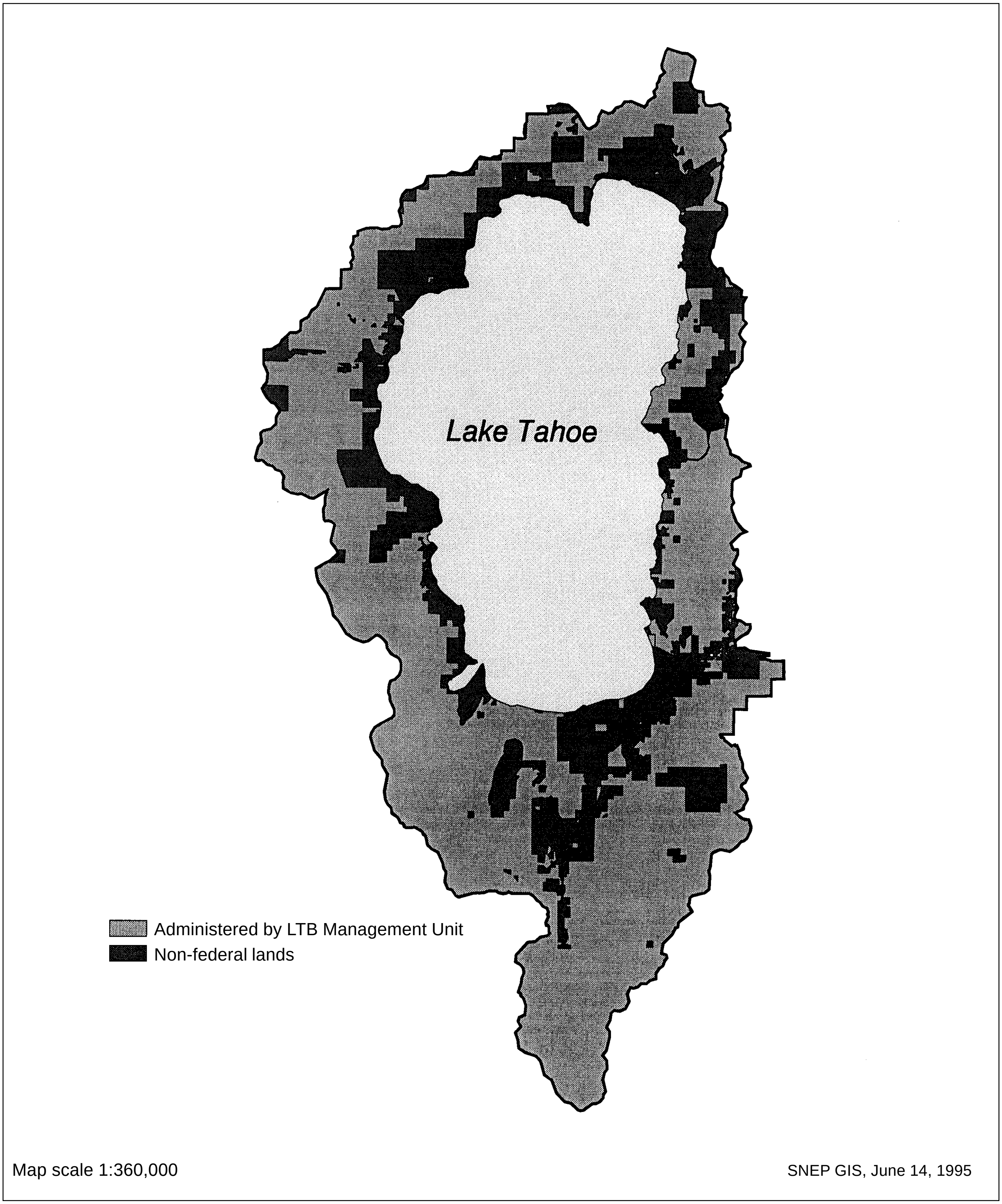


FIGURE 12

Federal land ownership (noted here as lands administered by the LTB Management Unit, USDA-Forest Service) in the Lake Tahoe Basin. (SNEP GIS project).

The states' efforts to acquire land (over 7,690 ha [19,000 ac]) for state parks complemented the USFS efforts to acquire larger parcels of land for recreation and conservation purposes. These acquisitions, totalling 52,600 ha (130,000 acres), formed the landbase for large-scale ecosystem protection.

The rapid urbanization of the Lake Tahoe Basin in the 1950s also dramatically influenced the scope and type of land acquisition within the region. Urbanization, fueled by a increasing demand for recreation, resulted in the creation of over 49,000 parcels and the development of 11,300 ha (28,000 acres) (Ingrum 1986). The Lake Tahoe Basin's population grew fivefold from 1960 to 1978 (Fink 1991). This urbanization fragmented the Basin's ecosystem into thousands of parcels of different qualities, and resulted in rapid deterioration of air and water quality, wetland function, and wildlife viability (Fink 1991). Loss of these natural values focused attention on the urban areas, whereas previously, the focus of conservation was on the wildland mountains, forests, and portions of the shoreline. It became evident that urban activities affected the natural areas, and as such, the practice of preserving of natural areas while allowing development of urban areas was no longer a sound method of resource management.

Monitoring made the impact of urbanization on water quality in particular very clear. In the late 1950s, the focus was on the disposal of sewage on lands within the Basin. Sewage export was ordered in both states by 1966 and was accomplished by 1975 (Fink 1991). During the 1960s, the role of stream-borne nutrients to water quality of the lake began to be examined. In the 1970s, studies showed that the occurrence of free-floating algae (planktonic) and attached algae (periphyton) were closely related to urban development (Goldman 1989). Research showed that a direct positive relationship existed between increased urban land coverage and land disturbance and decreased water quality (Goldman 1989). It also became more evident that most nutrients spurring algal growth in the lake resulted from non-point sources such as disturbed soils, enhanced runoff over impervious surfaces, air pollution, and destruction of natural vegetation and wetlands (Goldman 1989). Point sources such as golf courses which were regularly fertilized were also identified as potential nutrient sources (Goldman 1989).

With the pursuit of regional management strategies during the 1970s, there was a growing recognition of the need for an expanded basis of land acquisition. The call for expanded and accelerated federal and state acquisition efforts came from the League to Save Lake Tahoe, TRPA, Western Federal Regional Council (1979), and SWRCB (1980). The call for expanded acquisition efforts, including small subdivided parcels in already developed areas, resulted from recognition that the remaining undeveloped environmentally sensitive lands needed to be protected in order to prevent introduction of additional nutrients to the lake, to provide future opportunities to restore the nutrient-removal capacity of natural systems, to provide an equitable alternative to landowners, and to relieve pressure on the planning process. This proposal was an extraordinary shift in policy because the acquisition of this type of parcel was previously considered too expensive and controversial, because the parcels were thought to be too difficult to manage. However, increasing scientific evidence pointed out the value of these small pieces of the ecosystem. They were thought to perform important ecosystem functions, including being important in the maintenance of the clarity of Lake Tahoe.

During the 1980s, three federal and state acquisition programs were established primarily to acquire environmentally sensitive urban lots. The procurement of funding sources was key to implementation of these programs. In 1980, the federal Santini-Burton program was established, in part, for the acquisition of environmentally sensitive lands. The USFS has made substantial progress in implementing this program. It has expended $99.1 million for the acquisition of 3,479 parcels involving 4,582 ha (11,322 acres) in both states (Marlow 1996).

During the 1980s, the voters in California and Nevada approved environmental bond acts in 1982 and 1986, respectively. These actions were consistent with a national trend toward greater involvement by states, using bond-funded acquisition programs to deal with environmental protection (Fink 1991). The development of such programs is understandable in light of the states' traditional responsibility for land-use regulation. The programs were developed independently by each state. Previous attempts to establish a bi-state park authority and a basin-wide Tahoe Conservancy agency in 1973 were not approved by Nevada. Consequently, these programs evolved separately, unlike the successful effort to establish a bi-state land-use regulatory agency (i.e., TRPA).

The California 1982 bond act provided $85 million of funds for the acquisition and management of undeveloped property for the purposes of protecting the natural environment, providing public access opportunities, and preserving wildlife habitat (Tahoe Area Land Acquisitions Commission 1983). Upon approval of the bond act, the Tahoe Area Land Acquisitions Commission (TALAC) was formed to advise the governor and the legislature on the implementation of the bond act program. After a series of public hearings, TALAC recommended the use of a conservancy model. Conservancies in both the non-profit and state agency sectors were created to affirmatively deal with resource needs and to resolve land-use conflicts in a regional and more decentralized manner. They represented attempts to adapt institutional structure to regional ecosystems. The CTC was established only for the California side of the Lake Tahoe Basin because it could be designed under California law, with amendments to the original legislation, to be a regionally-based and locally headquartered agency with broad authorities to accomplish a range of objectives, and with a governing board which reflected a balance of state, local, and federal entities necessary to successfully implement its programs (Tahoe Area Land Acquisitions Commission 1983). The activation of a regional agency was also thought to be desirable because it would be more responsive to landowners and management concerns as it was based in the region; it would have shorter lines of communication and fewer levels of decision-making than a typical state-wide agency. The conservancy model also placed an emphasis on the resolution of land-use conflicts (Machida and Gussman 1988).

Prior to the authorization of CTC, the State of California completed the acquisition of the 310 ha (770 ac) Lake Country Estates for the purpose of resolving land-use litigation. This action was a precursor of the state's interest in using the CTC to resolve land-use conflicts in the Lake Tahoe Basin through acquisition. To date, it has settled five major long-standing lawsuits against regulatory agencies through "willing-seller" acquisitions.

The CTC is continuing to implement its acquisitions program. The CTC has been able to expand the scope of its programs to include (1) the acquisition and improvement of developed and undeveloped property to prevent disturbance of environmentally sensitive lands, (2) the restoration of degraded lands through erosion control, watershed restoration, and transfer of development rights and mitigation programs, (3) the provision of new or expanded access facilities to the lake and other natural areas, and (4) the protection and enhancement of wildlife habitat. Pursuant to these programs, it has authorized the expenditure of over $92 million for the acquisition of over 5,000 parcels of land involving over 2,830 ha (7,000 ac) (California Tahoe Conservancy 1996). Mitigation credit, or transfer of development rights, has been provided for over 2,300 private and public projects (California Tahoe Conservancy 1996). It should be noted that the numbers for these two programs include CTC grants to the USFS; therefore, there is some double-counting in both programs.

In Nevada, the voters approved a $31 million environmental bond act in 1986. Of this amount, approximately $23 million was allocated for acquisitions and $8 million for soil-erosion control projects. Nevada also used a commission (Commission for Land Acquisition in the Tahoe Basin) to recommend the parameters of a program to the governor and the legislation. The commission recommended utilization of an existing governmental entity, the State Lands Division (Division) to acquire land under the bond act program. Recently, the Division received authorization to establish a mitigation bank similar to California's program. To date, the Division has acquired 497 parcels involving approximately 85 ha (212 ac) (Pam Wilcox, Director, Division of Lands, State of Nevada, interview March 12, 1996).

Non-profit land trust organizations have also played a prominent role in assisting public land acquisition programs in the Lake Tahoe Basin. Generally, these organizations secure options to acquire land, if public acquisition funds are unavailable, and sell land to public agencies when funds become available. For example, the Trust for Public Land has assisted the USFS and CTC in acquiring 156 parcels (over 360 ha [900 acres]), including the USFS's Secret Harbor project involving 1,070 m (3,500 feet) of shoreline in Nevada (David Marlow, Lands Oficer, LTBMU, interview March 13, 1996).

With the increase in public land ownership and associated land uses over the past 100 years, several significant trends are apparent: (1) the percentage of private and unclaimed lands decreased to only 12% of the landbase, with the high percentage of public, non-urbanized lands offering significant cooperative resource management opportunities between the USFS, state parks, conservancy lands, utility / improvement districts, and Natural Resources Conservation Service (NRCS) / Resource Conservation Districts; (2) opportunities to achieve and maintain TRPA's environmental thresholds are significantly dependent on publicly managed lands, especially thresholds involving wetland restoration, sediment reduction, fish and wildlife habitat, recreation, and vehicle miles traveled; federal, state, and local programs and budgets are an integral part of helping the Basin meet the environmental thresholds; (3) availability of publicly owned lands is also a critical component in meeting community needs for transportation and utility corridors, administrative sites, integrated erosion-control sites, and community recreation sites.

Site Improvements

The USFS, state agencies, local governments, and non-profit organizations are involved in a range of site improvement programs, as the work only begins with acquisition activities. Many different ecological improvements are underway, including better routing and construction of trails, restoration of converted meadows to include natural wetland functions, and revegetation and rewatering of streamside zones.

During the first seventy years of this century, the public sector's investment in site improvements was directed towards transportation, development of water supplies, fire protection, sewage treatment, and recreational improvements, all increasing the accessibility of the Basin for humans. During the past fifteen years, a substantial investment in preserving water quality and protecting the environment has been made as well.

In 1980, the federal Santini-Burton program was also established, with a focus on erosion-control and wetland-restoration projects. In 1980, both states also established erosion-control grants programs. Many agencies have cooperated in implementing soil-erosion control and wetland-restoration projects in the Basin. A combination of federal, state, and local funds were procured to fund substantial grant programs. These funds are administered by the USFS, CTC, LRWQCB, and TRPA. The primary implementation agencies are local governments. Their involvement began in 1979 when Washoe County implemented the Upper Fairview project. The involvement of local government has been critical in these programs because of their ownership of street rights-of-way and project development, implementation, and management capabilities.

All of the local governments (El Dorado County, city of

South Lake Tahoe, Placer County, Washoe County, Douglas County) and public utility districts (STPUD, TCPUD, NTPUD, Incline Public Utility District) are currently implementing projects. The Tahoe Resource Conservation District, in conjunction with NRCS, is providing technical and planning assistance to many of these entities

In addition to local governmental efforts, the state transportation agencies (CalTrans and NDOT), state park departments, and resource management agencies (e.g., USFS, CTC) are implementing projects on their properties.

Between 1977 and 1992, federal, state, and local agencies have invested approximately $90 million in erosion-control and SEZ site-improvement restoration projects (TRPA 1992; U.S. Forest Service 1996). Of this total, the states provided 60%, the federal government provided 31%, and local sources contributed 9% of the funding. These totals do not include land acquisition costs. State contributions have been substantial, with the Nevada contributing approximately $16.2 million (TRPA 1992), and since 1980, California contributing a total of $40 million for soil-erosion control and SEZ restoration site improvement grant projects through the SWRCB ($13.2 million) and the CTC ($26.9 million) (California Tahoe Conservancy 1994). This investment is helping to restore the Lake Tahoe Basin's landscape. As an example, local governments have revegetated more than 47 ha (115 acres) of land, restored 26 ha (65 acres) of disturbed wetlands, and constructed more than 11 k (70 miles) of roadside drainage facilities to control erosion and restore the watershed through grants by CTC. Since the initiation of the Santini-Burton program, the USFS has awarded $16.2 million in grants for seventy-six projects.

The CTC and Department of Parks and Recreation (DPR) are conducting site improvement activities under public access and wildlife programs. Public access site-improvement funds are being used to construct hiking, biking, and cross-country ski trails (with 45 km [28 miles] of trails acquired or constructed to date) and trailheads; the construction and expansion of parks and support facilities such as restrooms and parking areas; and the installation of interpretive facilities. The wildlife site-improvement funds are being used to restore streams and offshore habitat areas, marshes, and riparian areas and to meet the special habitat needs of the bald eagle, peregrine falcon, and osprey. These projects are being implemented directly by the agencies or through grants to federal, state, and local agencies and to non-profit organizations. To date, CTC has authorized the expenditure of $5.8 million for public access site-improvement projects and $2.7 million for wildlife enhancement projects. In total, CTC has authorized a total of $41 million for site improvement projects (California Tahoe Conservancy 1996).

The states are also actively managing their properties to the extent feasible with available funds. To a large extent, site-improvement planning still needs to be completed for state properties. For example, acquisition has provided opportunities to build new parks. However, the construction of the parks will depend on the provision of additional funding. During the interim, the natural resources of the sites are being restored. In terms of CTC, acquisition activities are still ongoing. The CTC management efforts are involved in managing over 4,000 parcels including thousands of subdivided lots. Management is especially challenging because many of the parcels are located in developed neighborhoods where there is great potential for unauthorized uses.

Resource restoration projects are being undertaken by both DPR and CTC. The DPR is undertaking a number of projects to preserve and enhance biodiversity at state parks within the Basin (Catherine D. MacDonald, California Department of Parks and Recreation, telephone conversation, December 31, 1996). Reflecting its ownership pattern, CTC is focusing on restoring smaller parcels, improving forest resources, and planning and implementing site improvement projects (e.g., Kings Beach Access Project) under all of its programs. A priority is being placed on forestry management projects because of the urgency to deal with both fuel reduction needs near subdivisions and forest enhancement needs. Approximately 200 management projects have been undertaken, with restoration of more than 460 ha (1,140 acres) of key habitat areas and 23 km (14.3 miles) of streamside zones for riparian and fisheries habitat purposes (California Tahoe Conservancy 1996). Additional funding will be required to do larger projects. The CTC is also participating in basin-wide coordination efforts between public agencies and private parties such as TCORP and several public and private coordination efforts such as Mt. Watson study group in Tahoe City.

Since the early 1980s, the USFS has also conducted a broad range of management activities. The USFS has made substantial investments in recreation improvements, watershed restoration, wildlife and fishery improvements, and forest health needs. Over $5 million, including partnership funding, has been committed in master planning of the Heavenly Ski Area, the Tallac Historic Site restoration and interpretation, renovation of the Stream Profile Chamber, and renovation of resorts. An additional $5 million has been expended on the restoration of 1,400 ha (3,500 acres) of USFS lands. With partnership funding, the USFS has restored approximately 182 ha (450 acres) of wildlife habitat and 13 km (8 miles) of stream (which benefited 130 km [80 miles] of stream systems) and conducted a riparian assessment of 480 km (300 miles) of streams in the Basin.

Since 1989, the USFS has placed a priority on forest health and reducing fire hazards. In order to comprehensively deal with these needs, it has provided leadership in three coordination efforts:

1. TRPA's Forest Health Consensus Group, which is seeking a consensus among public agencies and interested groups on long-term forest health goals;
2. The Lake Tahoe Unified Steering Group for Forest Health Assessment and Protection, which is coordinating the

implementation of projects and the dissemination of information; and

3. The Tahoe Re-Green program, which is coordinating the removal of dead and dying trees and the creation of defensible space on private, state, and federal urban lots.

The USFS is undertaking activities at various scales. Through planning and contract activities, it is undertaking large-scale removal of dead and dying trees and thinning on approximately 8,100 ha (20,000 acres) (with a total of 2,020 ha [50,000 acres]) identified as in need of treatment) in order to regain long-term forest health, treat its urban lots, and create a defensible space fuels profile zone along 13 km (8 miles) of urban interface.

Several resource management activities have been implemented in the Lake Tahoe Basin. These activities are needed to sustain both the natural ecosystem and the human communities dependent upon it. Although more needs to be done, these efforts are beginning to transform the Basin's landscape.

A VIEW TO THE FUTURE AND BROAD LESSONS ON ECOSYSTEM MANAGEMENT

Future Needs and Directions for the Lake Tahoe Basin Ecosystem

Even though there is a long and complex history of human use, scientific assessment, and evolving institutional management of the Lake Tahoe Basin, we have identified future needs and directions to help sustain and even improve the ecological health of this system. This includes addressing the needs listed below.

Monitoring—It is clear to most Basin institutions that a broad and sustained science-based monitoring program of many ecosystem elements is required to track the ecological health of the Lake Tahoe Basin ecosystem and the many values which are dependent upon it. Although the lake itself acts to integrate various ecosystem changes, and reflects these through its water quality and primary productivity, there can be tremendous lags between cause and effect, and as such measuring various biotic and physical components of watersheds are crucial. Streams may store sediment for decades, with only catastrophic or above normal events resulting in transport into the lake. The declining health of the forest itself is a serious issue and one that needs to be better monitored and assessed. Lake Tahoe Basin managers must work with TRPA to address the fullest possible suite of atmospheric, hydrologic, biotic, and geologic indicators and processes to monitor. The TRG, LTIMP, the USGS, the University of Nevada, the USFS ecosystem management group and other experts should be consulted.

Research—Monitoring and research are not the same, although many long-term research projects and programs collect data that can be used for long-term monitoring of the state of or change in any ecosystem element, condition, or process. The key here is asking the right research questions to best address the health of the Lake Tahoe Basin ecosystem, identifying the key variables to be monitored as a part of these programs, and then obtaining the funding necessary to support research. Unfortunately, research has one of the lowest priorities for funding in the Lake Tahoe Basin. Research funding should have a high priority. Due to the multi-year nature of most ecosystem research projects, it is often difficult to integrate and sustain their funding in annual agency budgets, yet the results of long-term research should be central to guiding expenditure of restoration funds in particular. We encourage Lake Tahoe Basin institutions to design a process to further address these needs. Biogeochemical cycling and the nutrient budget of the entire Lake Tahoe Basin ecosystem are an obvious target for further research, especially as this relates to manipulation of watershed vegetation. This gap in knowledge is addressed by various research groups from the University of Nevada, University of California, Davis, USGS, TRPA, the USFS, the LRWQCB and others.

The Forests—We have discussed herein the historical evolution of the forest ecosystem through the Comstock era to the present. The history of the Basin's changing forests is coming together with more and better information from pollen cores, from knowledge of the spatial-temporal pattern of historical fires and logging and the response of forest types to decades of disturbance, and from climate change research. The extent to which understanding history can effectively guide future management is unclear. The USFS estimates that 25–40% of the standing timber in the Basin is now dead, with impacts on associated plants, wildlife, and microbiota. The FHCG describes more open forests as being a desirable future condition. Most of those who informed the case study team believe that the current "dense and dying" forest structure increases the risk of large wildfires. These several observations work together to argue for a program of forest thinning, selective removal of dead trees, prescribed burning, or other treatments of residual fuels. However, the case study team was not able to find evidence that there is a complete understanding of the ecological effects of these forest treatments. This is especially true with regard to how different forest treatments, alone or in combination, will increase or decrease the flow of nutrients to the lake. This gap in understanding was mentioned importantly as an opportunity to link terrestrial and aquatic research toward a coordinated forest structure and lake clarity management program.

The role of forests in settled and urban parts of the Basin has yet to be understood in spite of research elsewhere that examines the role these trees play in (a) the movement of fire between buildings and trees, (b) energy consumption in buildings, (c) air pollution concentrations in the Basin, (d) the timing and quality of urban runoff, and (e) the containment or spreading of forest insects and disease. Chemical fluxes from anthropogenic sources must be understood as they move into and through the urban forest canopy, into and through the soil system, into and through the riparian systems, and into the lake. Given the critical place of forests in the Basin ecosystem—regarding fire, nutrient flux, wildlife, and aesthetics—comprehensive knowledge that combines urban and wildland forest components is far from being achieved.

The LTBMU believes that reaching and then maintaining forest health through pre-fire suppression activities must be a goal. Others believe that the highest priority for forest management must be directed to sustaining high water quality.

Transportation—A portion of the Basin's environmental problems can be traced in large part to its ill-conceived transportation system; a system which has resulted in tremendous land conversion, displaced wetlands, increased erosion and sedimentation, barriers to fish migration, the production of haze, carbon-monoxide hot-spots, and noise. Serious attention, with the necessary political will, needs to be directed to the creation of a public regional transportation system, much as some of the national parks have investigated.

Housing—Lake Tahoe's evolution from a summer resort community, with resort and service staffing largely provided by college students, to a year-round recreational destination staffed by low-wage-earners, largely minorities, has resulted in a housing crisis in which too many people compete for too few affordable accommodations. New approaches need to be undertaken at Lake Tahoe to meet the needs of all segments of the evolving and diversifying economic community.

Institutional mechanisms such as the non-profit Tahoe-Truckee Housing Development Corporation (Ruth Frishman, Esq., Founder, Tahoe-Truckee Housing Development Corporation, 1995) can be used to help deal with housing problems. Joint ventures among non-profits such as this program and a developer and a local government are very common, and it may be possible to nurture such working relationships in the Lake Tahoe Basin. Progress on defining and finding affordable housing is being made. As an example, a desire to provide affordable housing has been expressed by the city of South Lake Tahoe in its "Renaissance 90" report (as well as by Truckee, Nevada County, and others). The city of South Lake Tahoe and a private developer recently completed a 28-unit affordable housing project, the Tahoe Pines, near the Bijou School and an older affordable housing project, Chateau Bijou. This $3.4 million project was paid by grant funding from HUD home funds via the State of California, along with money from the developer, whom applied for and received California and federal tax credits. The city of South Lake Tahoe is also operating a housing rehabilitation program, where owners of single-family homes who meet certain income requirements can receive easy-term, low-interest loans. This loan fund is capitalized by a Community Development Block Grant from the State of California. It should be noted that the South Tahoe Redevelopment agency is required, by law, to participate in housing programs. A portion of the tax increment revenues must be used for housing, and the Agency must replace any displaced affordable housing within four years.

Provision of Washoe Presence in the Lake Tahoe Basin—The Washoe were forced out of the Basin in the last 100 years. The Washoe filed a land claim in 1951 that was not settled until the 1970s. However, there has never been any serious discussion about giving pieces of the lakeshore system, which they so value, back to them. From an ecosystem management context, it is appropriate for this discussion to proceed. Washoe gatherers can share information and reintroduce practices that once contributed to sustainable meadow ecosystems. Collaboration between tribal elders and the USFS encouraging traditional plant use and horticulture has already demonstrated the value of human dimensions of the natural system. Restoration projects are obvious targets for further collaborative activities along these lines.

Heritage Resources—To describe the biological, physical, and cultural / social conditions that existed in the past, land managers are using prehistorical data sources. Archaeological remains provide verification that is independent of the shorter, written record and as such needs to be preserved, conserved and appropriately managed to improve our understanding of the dynamics of past, current, and future ecosystem trends that will help us sustain the quality of the Lake Tahoe Basin ecosystem.

Increased Investments—The demand in the Lake Tahoe Basin for money to support sound ecosystem management is staggering. Identified water-quality and wetlands needs alone are enormous. How can funds be acquired to support the publicly-adopted goal of lake water-quality restoration and affiliated concerns? It costs a tremendous amount on a recurring basis to repair and restore past detrimental land-use changes alone. Hundreds of millions of dollars have been spent in the last fifteen years on public and private land restoration, and the restoration process is not complete. Due to tremendous land subdivision and mixed land ownership, it has been necessary to manage and restore lands on a very small scale, parcel by parcel, with the responsibility to restore the land on its owner. Mitigation banks play an important role here, and the existence of the CTC and Nevada Division of State Lands have created basin-wide mechanisms for mitigation and subsequent restoration. Further steps need to be taken to restore land-use impacts on all private property, and education has to be a part of this effort.

Lake Tahoe is the single most important recreation component of the Sierra Nevada economy (Stewart 1996). Thus, the expenditure of funds to sustain the high environmental quality of the Basin is well justified. More work needs to be done on whether or not the design of assessment or fee mechanisms, such as those who benefit the most economically from Lake Tahoe's environmental assets also pay the greatest share of sustaining the ecosystem, would be of benefit.

Learning from the Lake Tahoe Experience

Several important lessons for SNEP have been identified from this case study of the Lake Tahoe Basin ecosystem, and we believe that SNEP and its users can benefit and learn from them in order to better manage the future of the Sierra Nevada.

It Takes Time and Effort to Create a Unified Vision—Without a unified core of opinion leaders and coalition building, the solutions to complex ecological problems are difficult to identify, much less achieve. It has been learned from the Lake Tahoe Basin experience that there must be equality among players for trust to be built that, in turn, allows the group to move forward. In the Lake Tahoe Basin, it is evident that what began as a bottom-up process with the concern of conservation-minded citizens who brought the issue of environmental degradation to the attention of public officials, became successful as shared goals were identified with state, regional, and federal officials. New laws were written and enforced. There was and continues to be a consensus process in that the many agencies and public work with TRPA to enforce the thresholds and standards for the Lake Tahoe Basin.

The Consensus Building Workshop of 1985 through 1987 brought together stakeholders who had been battling for years, but who had much in common and great creative energy once they learned to work together. The workshop created new options, and it produced innovative programs like Individual Parcel Evaluation System, land banking, and transfers of development rights (including land coverage, building allocations, future development rights, and existing development). Perhaps the workshop was just an example of an idea whose time had come, but it is a process that appears to be a transferable model. It is important to recognize that key forces may come from the inside or outside of the region of concern; in the Lake Tahoe Basin, it was a combination of both, with TRPA leadership providing the forceful yet respected guidance to bring external and internal groups together.

Litigation Is Costly—Lake Tahoe has a long history of clashes and litigation between the development and conservation communities. Many of the issues which have been addressed by the courts have been narrowed and focused in the litigation process. Many would see this as beneficial. However, it is important to try to change the culture from a litigious one to one of consensus. This change in culture has begun in the Lake Tahoe Basin.

Threshold-Based Planning Shows Promise for Ecosystem Management—The concept of threshold-based planning found in the 1980 revisions to the Compact for water quality, air quality, soil conservation, biota, noise, recreation, and other environmental parameters created a favorable environment for planning and management by authorizing the stakeholders to set their goals up front. This adaptive management process requires environmental baseline data. The planning that follows, however contentious, benefits greatly from these "lofty goals" and a shared horizon, as a former TRPA board member dubbed them. The TRPA regional plan moves forward in five-year strides, long enough to allow the plan to work without constant fiddling, but short enough to allow all of the involved institutions to monitor, evaluate, and make adjustments. Finally, ongoing programs figure out a way to survive and some flourish within this framework.

It is very important that this process be flexible and able to adapt to and accommodate the needs of the resource, especially as it responds to episodic environmental change that may not be predictable. It is also important that the regulatory institution (TRPA) has the strength as a "legal hammer" to be effective. It is important to also recognize that various local, state, and federal agencies worked to see the creation of TRPA, and that many parties gave up their sole regulatory authority. The legal hammer of TRPA provides conservation interests with the ability to require TRPA to follow the law, which enabled the consensus.

Land Aquisition and Restoration Programs Are of Great Value—The USFS and the Santini-Burton land acquisition program made great contributions by setting aside and managing thousands of acres of land for the public use. In addition, with the support of the voters and their respective state governments, California and Nevada have contributed greatly to the well-being of the Lake Tahoe Basin with their lands programs, centered in the CTC and the Nevada Division of State Lands. Certainly, there are questions about these programs, but it would be difficult to conceive of the best management programs for the Lake Tahoe Basin today without them. Today, more than 85% of the Basin lands are in public ownership. With land mitigation and subsequent ecological restoration, BMPs need to be well quantified, evaluated for their cost effectiveness, reported upon, and further implemented.

Redevelopment Is A Tool—Redevelopment activities are certainly of local economic value and are applicable to the Lake Tahoe Basin and other urban centers in the Sierra Nevada. Because the Lake Tahoe Basin is geographically defined, and land values are intrinsically high, the recycling and reuse of "improved" property is an appropriate avenue for economic development and environmental protection.

Ecological Monitoring Is Costly But Extremely Valuable—Ecological monitoring enables enforcement of TRPA standards and thresholds while providing a better understanding of the ecosystem. It is a $1 million per year program with many agencies contributing their expertise and funds. The true need for funds probably $2 million per year. Monitoring must be well coordinated among all parties and addressed at the interagency level, and should also be driven by and complement research needs and objectives. With the high cost of monitoring and further data analysis, optimal sampling theory should be used in the design of a data collection system, where the level of data needed across space and time is carefully evaluated. For example, long-term extensive, less detailed monitoring will allow the detection of trends, whereas local, intensive, detailed monitoring allows one to answer site-specific questions. Selection of the proper parameters and processes for monitoring is especially crucial in judging the effectiveness of restoration projects at varying scales.

In the Lake Tahoe Basin, monitoring is done to enforce thresholds. It becomes important to select a reference year or period (e.g., 10- to 30-year mean or mode) to use as the baseline for trend analysis. For the Lake Tahoe Basin, 1974 was selected as the reference year for many of the indicators, based on available data. There were ten years of data for a narrow set of parameters prior to 1974 to serve as a reference basis.

Long-Term Ecological Research is Valuable—Much discussion focuses today on the natural range of variability of ecosystems or their historic variability, as managers strive to identify acceptable ecosystem conditions in the hope that the system will be self-sustaining or sustainable with targeted inputs. Long-term data exist for thirty or more years for some ecosystem elements, especially the lake itself. Significant collaboration has occurred among university, agency, and independent scientists, and some of this research has linked studies of the atmosphere with the forest, the lake, and the human system. However, further ecosystem and long-term research remains to be initiated and better integrated. Many historical references and materials exist for the Lake Tahoe Basin, including photographs, writings, and some early inventory information (e.g., Bliss special collections noting number and sizes of trees logged). Other information will soon become available (e.g., with the publication of George Gruell's repeat photography). Valuable information can also be gained by obtaining oral histories from long-time residents whose personal observations provide information on land-use and ecosystem change. However, the tremendous set of historical information has not been thoroughly researched. Furthermore, historical data are present in lake and stream sediments, in cave deposits, and in tree-rings.

Lastly, it is important to make all research data available to everyone, so they can study, understand, use, and learn from it. As such, a central research base and program in the Lake Tahoe Basin would be very profitable to scientists, managers, and the public. Natural building blocks for this program include TRPA database and staff, the Special Collections of the University of Nevada, Reno, the TRG and AQG, the University of Nevada and its Desert Research Institute, the scientists of the California Fish and Game, DPR, and DWR, and CTC, members of the Washoe Tribal Organization, the USFS LTBMU and Pacific Southwest Research Station scientists, the USGS, and others. As indicated previously, the process of defining a long-term ecosystem research program has begun through the involvement of TRG with TRPA and LRWQCB.

Coalitions, Partnerships and Education—The Lake Tahoe Basin community and the ecosystem of which it is a part have benefited from a number of very positive public-private partnerships and coalitions which have formed over the last thirty plus years, including TTREC, TCORP, various transportation management associations including the TTC, and the Tahoe Center for a Sustainable Future. Partnerships of these types are being formed in other regions of the Sierra Nevada. It has been evident in the Lake Tahoe Basin that widespread public support is crucial for financing for various ecosystem purposes. Public support for and acceptance of land restoration and multi-jurisdictional land/resource planning and management has largely been sustained in the Lake Tahoe Basin over this time period. The need for further education on ecosystem analysis and management, and database analysis and management, has been identified and the Tahoe Center for a Sustainable Future, is working with many parties to fulfill this need.

Applicability of the Experience in the Lake Tahoe Basin to Ecosystem Management in the Sierra Nevada

A considerable amount of legislation, time, staff, and funds has been directed towards the management of the Lake Tahoe Basin ecosystem. Insights from this thirty year plus history may shed light on what may benefit others as we strive to better manage Sierra Nevada ecosystems.

How much do we need to know to manage an ecosystem?—A substantial quantity of literature has been written on the Lake Tahoe Basin, and there is considerable data on many elements of the ecosystem. However, it is clearly recognized that there is a great deal more to learn in order to better manage the ecosystem. For example, there is not a comprehensive nutrient budget for Lake Tahoe. Although much is known about stream-borne nutrients, there is a need to know more about the deposition of nutrients from the atmosphere and their relative contribution to the nutrient budget. Complex biogeochemical processes will also take many years of study.

When is enough known? Obviously, it could be argued that there is always insufficient information. However, significant resources have been committed to approaches in the Lake Tahoe Basin based on the "best available knowledge" of the time. In terms of our experience, it appears the key is to collect what is known and to distribute this information to the public and agencies in a integrated and understandable manner. This compilation is an important starting point. This activity was performed in the Lake Tahoe Basin, in part, with the release of key ecological assessments, including the LTAC (McGauhey et. al., 1963) report; the Western Federal Council Environmental Assessment Report (1979); TRPA's Environmental Threshold Study (1982); TRPA's Regional Plan, the "208" plans (California State Water Resources Control Board 1980; Tahoe Regional Planning Agency 1977, 1988); and various TRG efforts (e.g., goldman 1974, 1981; Byron and Goldman 1986). Review of these works has enabled identification and discussion of what we do and do not know. The process has allowed participants to develop a level of trust because everyone has access to the same information. The SNEP GIS, database and report (Sierra Nevada Ecosystem Project 1996) should provide other valuable sources of scientific information both to the Basin and the entire Sierra Nevada.

How do you define the objectives of ecosystem management?—In the Lake Tahoe Basin, the answer in part could be characterized as a combination of improving certain attributes of the region (e.g., water quality), sustaining other attributes (e.g., wildlife habitat), and minimizing or mitigating the damage caused by certain activities (e.g., transportation). In attempting to achieve these objectives, there is an overall goal of achieving an equilibrium between the human and the natural environments. Environmental threshold standards help monitor progress in terms of meeting objectives. It has been argued that these environmental objectives are optimistic on the one hand and unachievable on the other, or at least difficult to achieve in a highly fragmented ecosystem. There is also a concern that the thresholds may be inadequate targets for sustaining the health of the ecosystem. The need to reclaim or restore the damaged ecosystem has resulted in extraordinary efforts to manage relatively small units of it. Implementation of ecosystem management in the Lake Tahoe Basin has proven to be extremely complex and costly. However, there is a relatively high degree of acceptance of the objectives as goals even if there is skepticism about their feasibility. Along with this, there must be an on-going public process to refine and expand the goals, and scientists and managers must work together to inform the public about this need. In the Lake Tahoe Basin, there has been a series of processes to accomplish this, including administrative processes (e.g., USFS studies), legislative hearings (Z'berg hearings in California in 1960s), approval of the bi-state Compact in 1969 and its amendments in 1980, approval of the environmental thresholds in 1982, the consensus process which led to the adoption of the 1987 plan, voter approval of bond acts, and the five-year review of progress in meeting the thresholds. It is important that the public feel it can participate and will be given an opportunity to influence decision making.

In addition, for ecosystem management to work as a concept, and in order to obtain ongoing support, its objectives need to include socio-economic values and concerns along with environmental objectives.

How should you approach ecosystem management?—The Lake Tahoe Basin ecosystem is an urbanized and disturbed ecosystem. It has a mixture of public and private uses. The pressures to conserve and to utilize resources compete. There is a substantial investment of private and public capital. Extraordinary efforts are being undertaken to preserve the ecosystem. From this, three primary components to ecosystem management and its success to date in the Lake Tahoe Basin are becoming apparent. The attributes of disturbance, urbanization, and complexity are similar to those of other Sierra Nevada ecosystems. The post–SNEP process will determine to what extent these three components can be successful parts of adaptive management of these other ecosystems.

First, monitoring and research have played a key role in assessing the condition of some elements of the ecosystem and in establishing some cause and effect relationships. Long-term datasets over thirty years in length established by Charles Goldman and other scientists have been critical in documenting the progressive eutrophication of Lake Tahoe. This research formed the foundation of many of the programs currently being implemented. These activities are critical in establishing baseline information, to document changes to the ecosystem, and to establish cause and effect relationships. This approach should be highly beneficial for the rest of the Sierra Nevada. Similar long-term datasets exist for other select ecosystems in the Sierra Nevada, including some of our national parks sites, ecological reserves and field stations, and Mono Lake.

Second, the establishment of a regional land-use planning and regulatory approach was critical in integrating resource information and reflecting this information in a basin-wide land-use plan. The scale of the approach facilitated comprehensive and integrated planning which crossed jurisdictional lines. The approach was used to establish environmental thresholds to guide land-use planning. As noted earlier, a five-year review process has been built into the assessment process in order to allow regional plan adjustments. Additionally, the approach unified land-use planning on both public and private lands. For a major part of the Lake Tahoe Basin's history, there seemed to be an assumption that public land acquisition and management would largely control the ecological future of the lake and that urban uses would have relatively little impact on the environment (Fink 1991). The effects of urbanization on water and air quality and wildlife quickly illustrated the need to plan for all the components and ownerships within the Basin. Cross-jurisdictional land and resource planning is absolutely crucial to the sucess of ecosystem management, although it is difficult to conceive of a similar regulatory system for other areas of the Sierra Nevada. It also appears to be important to integrate public and private property in these larger approaches—if only to distribute burdens and responsibilities in a more equitable manner.

Third, land acquisition, site improvement, and wetland restoration programs have proven useful in reclaiming a resource base, restoring the natural biodiversity, and enhancing the capacity of existing public lands to perform a range of natural functions (e.g., maintenance of water quality). These programs help the ecosystem heal and restore the capacity to absorb at least some of the future impacts. They also provide a choice and mechanism for compensation to landowners and a means to achieve local and regional planning objectives.

Land acquisition programs may not be necessary and feasible in some areas because of concerns related to the loss of property tax revenues. However, they may be appropriate in resolving land-use conflicts or providing an opportunity for achieving a desirable public objective (e.g., public access). Site improvement and wetland restoration programs, however, may be needed in many areas. These programs should meet broad ecosystem objectives or in some cases react to individual project proposals. Additionally, they are a means of diversifying the local economy and providing jobs.

How do you sustain ecosystem approaches?—There are certain assumptions which need to be stated in ecosystem management. First, the status or condition of the ecosystem and the functional relationships of ecosystem components take a long time to define. Second, the systems will be constantly changing in response to a changing array of inputs. Third, there will be a need to adapt to these changes in perpetuity. Fourth, it will take time, expertise, and money to continually adapt to changing needs and circumstances.

In the Lake Tahoe Basin, it could be argued that these assumptions have proven valid. In response, these various approaches have been institutionalized through statutory or administrative policies and through the provision of funds and staff. These activities may ensure that these functions can be performed over long periods of time. The LTIMP was organized to help consolidate, coordinate, and fund certain monitoring efforts. The TRPA was created to regulate land uses. The USFS created a special management unit (LTBMU) to more effectively collaborate basin-wide and to acquire and manage lands. The states of California and Nevada established independent programs designed to regulate land uses, acquire and / or manage the resources. Administratively, these units were designed to function within the environmental boundaries of the Basin. The CTC is an example of adapting an administrative model to meet the needs of the region.

It should be noted that the institutionalization of these approaches has made it possible to exert leadership at critical times during the Basin's history. For example, the USFS played a critical role in providing support and expertise with the design of the Bailey Land Capability System (Bailey 1974) in the formative years of TRPA.

A second response has been the commitment of funding sources to these programs. Funding limits these approaches. During the past thirty years, a substantial amount of money has been committed to support these programs. Due to the goals of the programs (e.g., to improve the environment of the Basin) and institutional requirements, these approaches are expensive to implement and maintain. Over the years, hundreds of millions of dollars (e.g., Santini-Burton and state voter approved bond acts) have been committed. In recent years, funds have been reduced for almost all of the programs. However, the institutionalized approaches provide a means to marshall and prioritize the use of existing resources and to seek additional funds.

A third response has been the development of specialized programs to meet the complex needs of ecosystem management in the Lake Tahoe Basin (e.g., mitigation and transfer of development rights programs). Additionally, the institutionalization of the approaches has made it possible to allocate time and resources to develop new techniques (e.g., biotechnical erosion control) and refine technologies (e.g., the use of videography to help establish wildlife habitat relationships) to meet the needs of the region.

A fourth response has been to develop more participatory and inclusive processes. Resource protection efforts have been highly controversial and litigious. Conflict existed in the legislature, Congress, the courts, TRPA, the chambers of local government, and in local establishments over the proper management of the Lake Tahoe Basin's valued resources.

The culture of these approaches has changed overtime due to the influence of many factors. A key factor was the use of the consensus process by TRPA to secure adoption of the regional plan in 1987. This process set the stage for a number of other processes which are consensus based (e.g., the forest health consensus) and cooperative (e.g., South Lake Tahoe Redevelopment). Additionally, the availability of funds for acquisitions and site improvements has provided the basis for cooperative projects (e.g., South Lake Tahoe Redevelopment) and helped resolve litigation. Third, there is a growing appreciation within the private and public sectors that cooperation is needed to achieve both agendas, as there are not enough fiscal or political resources in either sector to fully achieve their own objectives. Consequently, both sectors need to share the financial burden and the responsibilities. Finally, there is a recognition that the public must become a part of the decision-making process in order to sustain support for these approaches. Ultimately, this public involvement is the only way to sustain regional ecosystem management here or elsewhere.

SUMMARY

These findings are the interpretations of the SNEP Lake Tahoe case study team. They reflect varying degrees of consensus among the team members because they are inferences from the gathering of many fragments of information and team members represent a range of scientific disciplines and institutional perspectives. However, it is our conclusion that these findings will illuminate the continued management of the Lake Tahoe Basin ecosystem and, perhaps even more importantly, will inform the bioregional planning and management of the Sierra Nevada and its different and unique subregions.

Understanding the Ecosystem

The public and private organizations and institutions responsible for the stewardship of the Lake Tahoe Basin ecosystem have a very good knowledge and understanding of the structure and function of the terrestrial and aquatic components of the ecosystem, and of the atmospheric and anthropogenic fluxes through the ecosystem. We believe that this level of understanding is higher than for most other ecosystems of this size and ecological and institutional complexity in the United States.

More than thirty years of cooperative scientific investigations and management actions, coupled with detailed ecological monitoring, have generated more data and information about this ecosystem than for any other area of comparable size in the Sierra Nevada. However, critical weaknesses in the understanding of ecosystem processes still exist for several major components, including the major plant communities, and especially the forest systems. Ecological mapping is far from complete, as is the study of stand dynamics, understory and soil components and processes, etc. Thus, it is unclear how specific forest stands and plant communities may respond to certain land management or natural disturbances. Several components of aquatic ecosystems also remain incompletely understood, including the full biogeochemical inputs, throughputs and outputs for the lake and the Basin, and the general ecology of fens, springs, and pools. Air pollution and dry and wet deposition of these substances into the Basin and lake are not fully understood, although our knowledge is much better than that at other sites. These voids in our knowledge are largely due to a lack of funding, as various formal studies have been proposed to study all components of biogeochemical system. Riparian corridors and the many benefits they provide to the regional ecosystem are also incompletely studied from biological (e.g., wildlife, aquatic biota, vegetation) and physical (e.g., soil formation, sediment budget, decomposition) perspectives. Paleoecological reconstructions are very incomplete. Although recent studies by Jassby et al. (1994) and Davis (1996 [appendix 7.2]) have shed light on the roles of late-nineteenth century logging and post-World War II road and home building, the human impacts of the last 150 years are not fully understood as potential causes of diminishing lake clarity and ecosystem degradation. The nature and extent of the surviving archaeological record of the Lake Tahoe Basin is unknown. No one knows exactly how many prehistoric and historic sites exist as only a small percentage of the area has been systematically surveyed. The potential significance of the extant archaeological record in modeling the past, present, and future of the regional ecosystem is promising. However, if the archaeological data are not collected before the record becomes too fragmentary to interpret due to site loss, one of the most important keys to understanding humans as a part of the Basin ecosystem will be lost.

There is no institution that determines the priority of investment for gathering knowledge across the ecosystem, such as a science-management advisory board might provide. This absence hinders a trans-organizational approach to setting information and scientific priorities for the ecosystem as a whole.

Thus, in spite the wealth of information and a relatively high level of understanding of the Lake Tahoe Basin ecosystem compared to other ecosystems, knowledge is not at the level where causes and effects are fully understood. It is not known how the lake's ecology has responded to the history of climatic fluctuation and sediment-nutrient flux to the lake from natural and human causes, nor how much sediment and critical nutrients will flow to the lake with different management actions on the watershed (e.g., additional construction, restoration, forest thinning, or burning [either prescribed or uncontrolled]).

Managing the Ecosystem

The Lake Tahoe Basin management experience is one of the best, and longest term, examples of adaptive ecosystem management in the world. A coalition of public and private organizations cooperate in the gathering of data to determine whether the ecosystem is meeting a set of performance standards, termed thresholds. There is a growing commitment to obtain the best scientific understanding to modify these standards and determine the validity, relevance, and usefulness of the monitoring data.

Restoration of ecosystem elements has been modified as further knowledge is gained, with science and engineering used to guide restoration efforts. This approach is consistent with the concept of adaptive ecosystem management in that monitoring is a component of every project. The feedback link could be improved, however, to solicit better analysis of data from the restoration projects and feed it back into adaptive management methods.

Land acquisition and subsequent restoration activities by public agencies have reduced ecosystem degradation locally, and are believed to have decreased the rate at which lake clarity is diminishing. With an incomplete understanding of system lags, it still appears to be a positive step in decreasing ecosystem degradation.

Management of the Basin's forests is hindered by a lack of understanding of how wildland and urban forests interact in terms of insect and disease migration, fire behavior, pollution flux from air to canopy to soil and water, and wildlife habitat gradients. More research is well justified on these forest systems.

Although regulation of land development may have slowed ecosystem degradation and has provided time to establish a better understanding, and to restore certain elements, of the ecosystem, the coalition of steward organizations continue to develop the best processes to guide the range of human uses to sustain critical ecosystem elements and processes. Whether they will be able through time to halt the decline in lake clarity and environmental deterioration is yet unknown, partially as a function of the slow rate of some ecosystem processes. The management perspective thus must be long-term in nature, and the players patient yet willing to act when necessary to reverse deleterious actions and processes.

Applying This Knowledge to the Greater Sierra Nevada

The accuracy with which ecosystem structure and function is defined greatly helps to focus management issues and narrow the debate which, in turn, nurtures institutional cooperation and coordination. The Lake Tahoe Basin has sharp watershed boundaries, and the large, geographically dominant lake with its visible decline in water clarity and pronounced shoreline impacts focused the issues. In other Sierra Nevada ecosystems with less sharply-defined boundaries and less visible ecosystem changes, efforts to comprehend and manage loss of ecosystem quality, however defined, may be more difficult.

The Lake Tahoe Basin's human history is representative of most Sierra Nevada ecosystems. The criticism that the Lake Tahoe Basin is unique and therefore unrepresentative of the rest of the Sierra is unwarranted. Lake Tahoe is especially useful as an example of the many ecosystems undergoing change from prior logging activities, fire suppression, forest overstocking and declining forest health, degradation of riparian corridors and wetlands, restoration activities, recreational impacts, declining air quality, and the many forms and impacts of urbanization. Because all Sierra Nevada ecosystems are candidates for adaptive management, the Lake Tahoe Basin provides a model for the selection of ecosystem performance standards, the generation and use of technical scientific data, institutional collaboration, and land-use regulation while protecting private property rights.

Lake Tahoe exemplifies how actions in one ecosystem have important consequences in other ecosystems which, subsequently, provide feedbacks that may modify structure and function in the original ecosystem. This interaction is a process applicable to all Sierra Nevada ecosystems. Land-use regulation in the Lake Tahoe Basin has shifted land development to Truckee and the Reno-Carson City area. Population growth in these nearby areas influences wildlife, and increases day use in the Lake Tahoe Basin, subsequent automobile use and pollution, and other processes.

The Lake Tahoe experience provides valuable information on ecosystem protection and restoration costs that are applicable to other Sierra Nevada ecosystems. Restoration is at least several times more expensive than protection, and this study strongly suggests that pre-development studies may substantially reduce restoration costs post-development. The more complete the understanding of all ecosystem processes is up-front, the better environmental planning can be done, minimizing ecological impacts and reducing the cost of their mitigation.

ACKNOWLEDGMENTS

We thank the many individuals who met with our case study team, either collectively or individually, and who provided us with valuable data and perspective, including members and staff of the California Department of Parks and Recreation, California Tahoe Conservancy, Lahontan Water Quality Board, League to Save Lake Tahoe, Tahoe Regional Planning Agency, U.S. Forest Service, and others. We thank five anonymous reviewers for their valuable comments on a draft of this paper, as well as members of the SNEP Key Contacts Group and the SNEP Science Team. Editorial assistance provided by Chris Sparks, Maureen Davis, and Erin Fleming is greatly appreciated. Maureen Davis worked as special research assistant during the final phases of this work.

NOTES

[1]Thesholds are defined by the Tahoe Regional Planning Agency. According to the TRPA Code of Ordinances (adopted May 27, 1987), environmental threshold carrying capacities are environmental standards 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. Such standards shall include but not be limited to standards for air quality, water quality, soil conservation, vegetation preservation and noise.

[2] The California Tahoe Regional Planning Agency was established as a land use and regulation planning body, and put in place to regulate private land use within the California portion of the Lake Tahoe basin in addition to the actions being taken by TRPA.

[3]As such, the vegetation is not homogenous in the three parks, although in the fire history analysis by Rice, the parks are treated as having similar ecosystem characteristics. There are also major differences in elevation both within and between parks as well as differences in aspect. [Note: To analyze the past disturbance regimes more thoroughly, these studies should have stratified the sample areas by vegetation type, slope and aspect. The locations of each sampled tree should be presented and groups of trees with similar ecosystem characteristics (e.g., vegetation type, elevation, slope, aspect) should be used to produce a composite fire interval. It is also fundamental to record the size of the area that has been sampled in fire history work. The areas should be stratified ecologically and care must be taken to choose and record the sampling sites.

[4]Composite fire return intervals should also be given for each distinct region. This summarizes all of the fire dates in an area that has similar ecological characteristics and gives more accurate information on the past disturbance regimes. Composite fire intervals have been calculated for each park but the fire scar samples may have come from areas in the park with different ecological characteristics.

[5]The cultural eutrophication of Lake Tahoe refers to increasing the productivity (primarily of plankton and nearshore, benthic plants) of the lake, with a subsequent decrease in water clarity, due to increased nutrient inputs to the lake from human alteration of the terrestrial system and the atmospheric loading of pollutants.

[6] The lack-of-dual-majority rule (also known as the "deemed-approved" rule) required a rejection by a majority of both state's TRPA delegations to reject a project. If, after 60 days, no action was taken, the project was deemed approved. During the 1970s, TRPA oversaw a period of rapid growth, including the construction of four casino-hotel towers on the south state line. Much of this growth was "deemed approved" under the dual-majority rule. This rule was considered a fatal flaw to the 1969 Compact because it allowed the local delegates from either state delegation to veto a denial for a project (i.e., approve). The 1980 revision of the Compact eliminated this rule and increased the membership of each state's delegation to seven members, including four from outside the Basin.

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APPENDIX 7.1

BY SUSAN G. LINDSTRÖM
Truckee, CA

Lake Tahoe Case Study: Lake Levels

The surface elevation of Lake Tahoe has stood considerably lower than the present for long periods of time (Lindström 1990). The magnitude of drops in the level of Lake Tahoe is supported by existing paleoenvironmental evidence, by a series of radiocarbon dates on tree stumps drowned by the rising waters of Lake Tahoe, by submerged archaeological features in the lake, and by historical documentation of lower lake levels. These data have implications for local and regional paleoclimatic and archaeological trends.

Tahoe's lake level is naturally controlled by a narrow sill at the northwest corner at Tahoe City, where water spills over into the Truckee River. The elevation of this natural sill is 6,223 feet. However, since the early 1870s, Lake Tahoe's fluctuations have been artificially regulated within a six-foot range by the construction of a series of small dams at its outlet. Official measurements, maintained since 1900, show fluctuations about two feet below and eight feet above Tahoe's natural sill elevation (figure 7.A1). The legal elevation of Tahoe's lake surface is established at 6,229.10 feet. Its average post-dam surface elevation is 6,225 feet. The lake's highest known surface elevation, set in July 1907, reached 6,231.26 feet (Crippen and Pavelka 1972:7). Since 1900, official measurements record numerous drops below the level of the natural sill. The lowest recorded level of the lake surface, at 6,221.68 feet, was reached in November 1991 (*Tahoe World* 11 / 15 / 91). Drought during the last several years has either stopped Tahoe's flow into the Truckee River altogether or reduced it to a mere trickle.

Compelling evidence of Tahoe's substantially lower lake levels comes from tree stumps submerged far below Tahoe's natural sill (Harding 1965; Lindström 1985, 1990). To date, a total of twenty-one stumps have been inventoried along the south shore zone between Emerald Bay and Stateline at elevations down to 16 feet below its natural rim. Stumps have also been reported along Tahoe's north and west shores, but, as yet, they are undated. Recent seismic surveys of Lake Tahoe's bottom have detected more rooted stumps in 30 to 40 feet of water along Lake Tahoe's east shore (Kumamoto *et al* 1994; Rose, personal communication 1994); exact location and absolute dating await further research. Tree-ring counts on some submerged stumps indicate ages up to 150 years, suggesting a low-stand of at least this long, in order for these trees to become established and grow to this age. Most of these stumps are well preserved. Some of the deeper ones are up to 10 feet tall and 3.5 feet across. The stumps located farthest below Lake Tahoe's rim probably have not been exposed long to air since they were first submerged; otherwise, they would since have decayed. Stumps range in age between 4,250 and 5,510 radiocarbon years ago or 4,846 and 6,304 calibrated radiocarbon years ago (table 7.A1). Fifteen radiocarbon dates, representing eleven separate stumps, suggest a correlation between the elevation and age of these stumps. The oldest stumps are generally from the deepest water. However, data are few and their analysis runs the risk of misinterpretation due to limited sample size. Pending further research, existing evidence could support either an overall rise in the level of Lake Tahoe after 5,510 years ago, during which time the surface elevation did not reach the present natural sill elevation until after about 4,200 years ago, or fluctuating lake levels between 6,300 and 4,200 years ago (figure 7.A2).

Subsequent rises in the level of Lake Tahoe are documented by palynological evidence indicating the formation of a marsh along the lower reaches of Taylor Creek due to a rise in ground water levels between about 5,000–4,000 years and before 2,900 years ago (West l985). A diatomite deposit, indicative of an open water environment, is documented at Taylor Marsh around 2,800 years ago and suggests another rise in the level of Lake Tahoe (West l985). A further wet interval is suggested within the last 1,100 years by the presence of a buried A-horizon in association with a sand lens near Taylor Creek, marking a rise in the level of Lake Tahoe and the deposition of lake deposits (Blackard l985).

In addition to tree stumps in Lake Tahoe, submerged stumps have been dated in other lakes within the upper

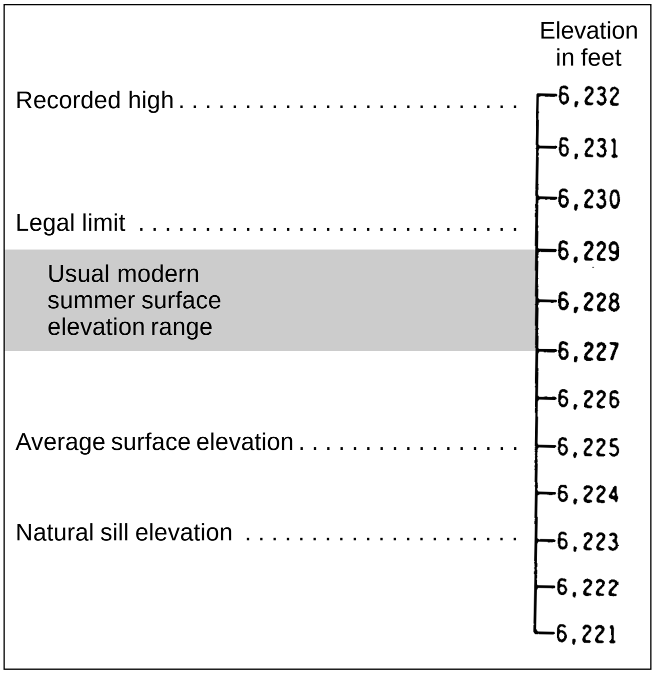

FIGURE 7.A1

Historic elevations of Lake Tahoe. (after Lindström 1990:147, fig. 2)

Truckee River drainage. These document fluctuating lake levels within the last 1,000 years or so, a period that appears to be punctuated by alternating intervals of cool-moist and warm-dry periods. A period of substantial drought between 1,100–900 years ago and again around 700–500 years ago is represented by a cluster of ten submerged stumps in Independence Lake dating around 600 years ago (Beta-32857, 690+/-50 radiocarbon years, 669 calibrated radiocarbon years, Lindström 1990). In addition, several submerged tree stumps, located up to 30 feet below the present day sill of Donner Lake, offer complimentary evidence of a pronounced drought about 500 years ago (Beta-70013, 490 +/- 50 radiocarbon years or 517 calibrated radiocarbon years; Beta-70014, 460 +/- 60 radiocarbon years or 510 calibrated radiocarbon years). Other submerged stumps south of the Tahoe Sierra in Tenaya Lake (Yosemite National Park) have been radiocarbon dated at 915 years ago and 670 years ago (Stine 1992). Stumps rooted within the bed of the West Walker River with radiocarbon dates of 920 years and 660 years lend further support for these two major medieval period droughts (Stine 1992, 1994).

During historic times, receding waters have exposed numerous archaeological features along and below the elevation of Lake Tahoe's natural rim. Bedrock milling features and portable milling slabs occur lake-wide. Their discovery bears upon archaeological studies within the Lake Tahoe Basin in that evidence of lakeshore prehistoric occupation during low water periods may remain beneath Lake Tahoe's historic artificially high water level. Consequently, archaeological site inventories which focus above contemporary lake levels may underepresent the use of Tahoe's lakeshore by prehistoric populations.

The archaeological record in the Lake Tahoe Basin is augmented by a rich Native American oral tradition that provides a glimpse of the changing physical world in which prehistoric peoples lived. The Washoe have enjoyed a long tenure in their known area of historic occupation and their legends are of equal antiquity. Through the antics of the "Weasel Brothers," for example, an unconventional commentary and explanation for observed fluctuations in the level of Lake Tahoe and its tributaries is provided (Dangberg 1927; Lowie 1939).

The widespread presence of submerged tree stumps is suggestive of larger-scale climatic trends in the Lake Tahoe Ba-

TABLE 7.A1

Radiocarbon ages of submerged tree stumps at Lake Tahoe.

Elevation in feet[a]	Laboratory Number	Location	Radiocarbon Years B.P.	Calibrated Years B.P.[b]
6,210.87	Beta-33878	Baldwin Beach	5,510 ± 90	6,304
6,218.64	Beta-32851	Emerald Bay	4,980 ± 80	5,730
6,220.70	Beta-13654	Tallac	4,870 ± 60	5,640
6,222.75	LJ-503	Tallac	4,790 ± 200[c]	5,527
6,218.64	Beta-32852	Emerald Bay	4,720 ± 70	5,380
6,219.00	Beta-33879	Baldwin Beach	4,650 ± 70	5,324
6,222.50	Beta-32847	Al Tahoe	4,610 ± 90	5,313
6,223.25	Beta-32848	Al Tahoe	4,610 ± 90	5,313
6,223.25	Beta-32846	Al Tahoe	4,580 ± 60	5,300
6,220.70	Beta-13655	Tallac	4,520 ± 60	5,197
6,222.50	Beta-32849	Al Tahoe	4,500 ± 60	5,126
6,222.70	LJ-604	Tallac	4,460 ± 250[c]	5,149
6,222.50	Beta-32850	Al Tahoe	4,370 ± 80	4,931
6,222.75	LJ-605	Tallac	4,250 ± 200[c]	4,846

[a] 6,223.00 feet is elevation of natural sill of Lake Tahoe.
[b] University of Washington, Quaternary Isotope Lab Radiocarbon Calibration Program, 1987, Rev. 1.3.
[c] Harding 1965.
(after Lindstroöm 1990: 151, table 1.)

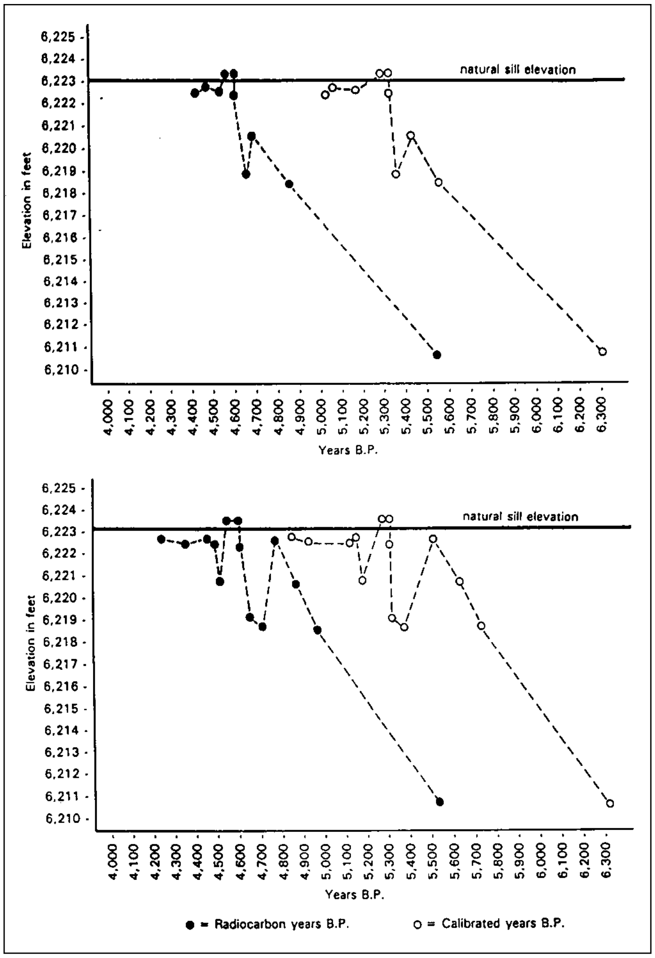

FIGURE 7.A2

Relationship between radiocarbon years and calibrated years versus elevation of stumps. Upper: dates from 10 stumps are plotted (averaging multiple dates taken from the same stump); lower: all 14 dates are plotted individually. (after Lindstroöm 1990:152, fig. 6)

sin. However, the tectonic histories of these lake basins must also be considered (Benson and Thompson 1987; Harding 1965), along with the sedimentological composition of their respective sills (Born 1972; Hardman and Venstrom 1941; Lindström 1990) and lake bottoms (Goldman and Byron 1986), their surface and submarine geomorphology (Birkeland 1965; Davis et al. 1974; Harding 1965), the palynological (Adam 1967; West 1985) and pedological (Blackard 1985) characteristics of adjoining wetlands, and stream run-off studies (Hardman and Reil 1936). If lake level changes prove to be climatically induced, the discovery of a growing body of evidence elsewhere in the Truckee River drainage is anticipated. Localized data from the Lake Tahoe Basin will modify and add significant detail to the larger regional model of climatic change within the last 10,000 years.

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Pollen Analysis of a Mid-Lake Core from Lake Tahoe, California: Historic Vegetation Change

SUMMARY

Routine pollen analysis was performed for forty samples spanning 300 mm of a mid-lake core taken Aug. 1981, from Lake Tahoe (39º N, 120º W, elev. 1899 m), Placer County, California. At the surface, the pollen assemblage is dominated by pine (80%), fir (6%), oak (3%), and sagebrush (3%). Wetland and aquatic environments are represented by sedge (4%) and *Pediastrum* (2%). Time control is provided by 2 radiocarbon dates: 1.12±0.1 fraction modern at 45-50 mm (AA-17171P) and 14±54 yr B.P. (Before A.D. 1950) at 85-90 mm (AA-17172P). Cool-dry climate during the Little Ice Age (140 - 300 mm) is indicated by lower pine (76%) and by greater fir (10%) and *Artemisia* (4%). Historic changes are evident above 100 mm, where the pollen concentration drops from over 1,000,000 to less than 600,000 grains cm^{-3}, and charcoal drops from 730,000 to 410,000 grains cm^{-3}. A second event at 40-50 mm is accompanied by a lesser increase in pollen and charcoal concentration and a sharp, brief drop of pine percentages. It is followed (above 40 mm) by increased percentages of sedge (from 1% to 4%) and *Pediastrum* (from 0% to 2%). The two events probably resulted from human activity in the Lake Tahoe watershed: the first due to logging and erosion following the gold rush, the second due to post-WWII logging and municipal development. Following the first impact, the increased flux of clastic sediment into the lake accelerated the sedimentation rate and decreased the pollen concentration. Fire suppression beginning in 1885 is reflected in reduced charcoal concentration. After 1950, housing construction and pollution increased nutrient flow to the lake and stimulated the growth of planktonic algae including *Pediastrum,* and sediment deposition or lake level increase expanded the littoral zone, reflected in the expansion of sedges.

INTRODUCTION

Setting

Lake Tahoe is a large (500 km^2) deep (502 m max.) lake in the eastern Sierra Nevada of California and Nevada (Goldman 1988). It has a comparatively small (800 km^2) watershed draining crystalline rocks. The oligotrophic lake is gradually becoming polluted through addition of iron and nitrogen (Goldman 1988). Sewage is diverted from the watershed, so the primary sources of pollutants are fertilizer, leaky sewer pipes, and atmospheric deposition following forest fires (Goldman et al. 1990). The lake phytoplankton composition is dominated by diatoms. The species composition has changed during the historic period, with mesotrophic *Fragilaria crotonensis* increasing in response to pollution (Goldman 1988), and overall species diversity increasing as well (Hunter et al., 1990).

The Lake Tahoe watershed is forested—primarily by pines: ponderosa (*Pinus ponderosa*), Jeffrey (*P. jeffreyi*), and sugar (*P. lambertiana*) pine. Juniper (*Juniperus occidentalis*) and oak (*Quercus kelloggii*) are abundant in openings and toward lower elevation. Lodgepole pine (*P. murrayana*), fir (*Abies concolor, A. magnifica*) and mountain hemlock (*Tsuga mertensiana*) are common in moist habitats and at upper elevation. On exposed, rocky slopes sagebrush (*Artemisia* spp.) dominates (Adam 1967).

History of the Watershed

The Lake Tahoe Basin was one of the first areas of the Sierra Nevada to experience the impact of historic settlement; with exploration beginning in 1827 (Brooks 1977), accelerated impact during the gold rush of 1847, and with extensive logging from 1856–80 (Sudworth 1900). The logging focused primarily on the ponderosa and sugar pine, which were used for the trans-Sierra railroad, and for constructing the mines and mining camps to the east. Muir (Wolfe 1938) visited the area in 1888 and mentioned extensive “fallen burnt logs or tops of trees felled for lumber.”

The logging practices resulted in extensive erosion of the uplands and sedimentation in streams (Pisani 1977). Introduced grazing animals were likewise credited with accelerating soil erosion (Wagoner 1886). Impact in the Lake Tahoe Basin area was so extensive that Muir advocated giving the water of Lake Tahoe to San Francisco to spare more pristine areas of the Sierra Nevada (Jones 1965).

Settlement and municipal construction in the Lake Tahoe watershed accelerated due to tourism permitted by the completion of the Central Pacific Railroad in 1869. The cities of Tahoe City and Glenbrook were founded soon after the railroad had crossed the Sierra Nevada. Growth was slow, however, until paved all-weather highways were completed in 1947. Legalized gambling in Nevada accelerated development on the eastern margin of the lake after 1931, as did the development of winter sports after ca. 1945 (Strong 1984).

Human impact of the Lake Tahoe Basin intensified after World War II, when the U.S. Forest Service (USFS) dramatically increased the extent of logging in the northern Sierra Nevada, and the formation of a Resort Owners Association resulted in extensive municipal development on the Lake Tahoe shore (Strong 1984).

Fire suppression in the Sierra Nevada began with the creation of the California State Board of Forestry in 1885 (Wagoner 1886) and was expanded in 1907 with the creation of the USFS. Show and Kotok published a document in 1924 concluding that *all* fires damaged timber sales and were to be suppressed. This was followed by the Clark McNary Act, offering funding to state agencies for fire suppression (Pyne 1982).

Previous Palynological Investigations

Analysis of the contemporary pollen rain began with Adam's (1967) study. The close correlation of pine percentages with elevation is a unique feature of the Sierra Nevada (Adam 1967; Anderson and Davis 1988). Fir and mountain hemlock pollen are most abundant at upper–mid elevations on both sides of the Sierra Nevada; and oak (*Quercus*) pollen dominates the foothills of the western Sierra Nevada while, *Artemisia* pollen dominates the eastern Sierra Nevada foothills (Adam 1967; Anderson and Davis 1988).

Pollen analysis of prehistoric vegetation change of the Sierra Nevada began with Adam's (1967) analysis of Osgood Swamp, just south of Lake Tahoe. During the late Glacial and early Holocene, the pollen diagram is characterized by high *Artemisia* percentages (40%); during the Holocene by increased pine, fir and oak; and by increased fir pollen during the last 3 Ka. A similar sequence is recorded at mid-elevations in the western Sierra Nevada at Balsam Meadow (Davis et al. 1985), Exchequer Meadow (Davis and Moratto 1988), and Startkweather Pond (Anderson 1990).

There have been no previous palynological investigations of historic environmental change in the northern Sierra Nevada. However, tree-ring analysis of the western Sierra Nevada (Graumlich 1993) records lower temperature during the Little Ice Age (*ca*. A.D. 1450–1850). Precipitation is more variable than temperature in the tree-ring record, but it is generally lower than today during the late eighteenth and nineteenth centuries, with drought periods from 1806–61 and 1910–34 (Graumlich 1993).

METHODS

The sediment samples provided by Earl Byron (letter of transmittal, 11/24/89) were taken at 5 mm intervals in the upper 50 mm of the core and at 1 cm intervals from 50–300 mm. Routine pollen extraction (table 7.A2) included addition of 1 *Lycopodium* tracer tablet to permit calculation of pollen concentration. The sediment samples were weighed dry (table 7.A3), and the drying resulted in extensive crumpling that prohibited identification of the pine pollen beyond the generic level. The sample labels in table 7.A3 and figure 7.A5 are the upper depth for each sample interval; e.g., the 0–5 mm sample is labeled "0 mm."

Identifications are based on the University of Arizona Geosciences Department reference collection. The pollen sum (divisor) for all types is > 300 grains of upland pollen counted per sample. Charcoal counts were tallied for pollen-size (> 15 µm) fragments. Most charcoal fragments were wood-type, with large bordered pits. Herbaceous-type charcoal was rare.

The pollen sequence was zoned using the CONISS algorithm (Grimm 1987) using the untransformed percentages of the upland pollen types. The clustering algorithm is based on minimizing the within-cluster sum of squares for stratigrapically-adjacent groups of samples.

TABLE 7.A2

Extraction Procedure

a. Add weighed sample to ca. 5 ml water with detergent, agitate 10 min.
b. Swirl solution and screen (180 micron mesh, stainless steel)
c. Transfer to 50 ml test tubes, rinse, add 10 ml 10% HCl
d. Add 1 *Lycopodium* tablets (batch # 710961, 13,911 grains/tablet)
e. Transfer screened solution to 50 ml nalgene test tubes
f. Add 10 ml conc. HCl, mix, add 30 ml H_2O, mix centrifuge, decant, water rinse
g. Add 40 ml HF overnight or 1 hr in boiling water bath centrifuge, decant, water rinse,transfer to 15 ml glass tubes
h. Acetolysis* centrifuge, decant, water rinse
i. Add 10 ml 10% KOH 2 min. boiling water bath centrifuge, decant, water rinse with hot water until clear
j. Stain with safranin "O"
k. Transfer to labeled 1 dram shell vials
l. Add a few drops of glycerin

*Acetolysis
1. 5 ml glacial acetic acid centrifuge and decant
2. Stir sample, add 5 ml acetic anhydride (volumetric dispenser)
3. Add 0.55 ml H_2SO_4 to acetic anhydride solution (volumetric pipet),mix, centrifuge, decant into glacial acetic acid
4. 5 ml glacial acetic acid centrifuge and decant

TABLE 7.A3

Pollen Percentages, Lake Tahoe, Placer County, California.

DEPTH (mm)	0	5	10	15	20	25	30	35	40	45
AGE yr (1995)	13	15	18	21	24	26	29	32	35	38
POLLEN SUM	304	301	306	304	302	306	307	303	303	305
TRACERS	34	13	17	10	7	13	12	22	8	27
Sed wt. (mg)	3101	3126	3106	3138	3098	3136	3132	3112	3126	3118
Sed vl. (.1ml)	5	6	9	10	10	8	1	11	10	10
CONC (1000 gr/cc)	62	190	224	423	600	266	356	211	527	157
CHARCOAL (1000 gr/cc)	15	42	93	179	411	92	115	113	193	208
Abies	6.6	6.3	6.2	11.2	5.3	5.9	1.3	3.0	7.3	10.2
Cercocarpus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cupressaceae	2.3	0.7	1.6	1.0	1.3	1.0	2.3	3.0	3.0	5.6
Pinus total	79.6	87.7	80.7	80.3	81.8	81.0	91.2	86.8	76.2	62.0
Populus	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudotsuga	0.0	0.3	0.0	0.0	0.3	1.3	0.3	0.3	0.0	0.7
Quercus	3.9	2.3	3.3	3.3	3.3	5.6	0.3	1.0	2.3	5.9
Tsuga mertensiana	0.0	0.0	0.0	0.0	0.3	0.7	0.3	0.3	0.7	0.0
Ambrosia	0.0	0.0	0.0	0.0	0.3	1.0	0.3	0.0	1.3	0.0
Artemisia	3.6	1.0	4.2	2.6	3.3	1.3	2.0	4.3	4.6	8.2
Ceanothus	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Chenopod.-Amaranthus	1.3	1.0	0.3	0.3	0.0	1.0	0.3	0.3	0.3	0.7
Ephedra	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ericaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rosa	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Sarcobatus	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	1.3
Arceuthobium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Eriogonum	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Gramineae	0.3	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.7	1.6
Labiatae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leguminosae	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.7	0.0
Liguliflorae	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liliaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Linanthus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Compositae	0.3	0.0	0.0	0.3	0.3	0.3	0.0	0.7	0.0	0.0
Pedicularis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polemoniaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ranunculus	0.0	0.7	0.7	0.0	0.7	0.0	0.0	0.0	0.3	0.3
Umbelliferae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DETERIORATED	1.6	0.0	1.3	1.0	2.3	1.0	1.0	0.3	2.3	2.6
Botryococcus	1.6	4.0	2.0	4.3	3.3	3.3	1.0	2.0	1.7	1.3
Pediastrum	2.3	1.7	2.6	3.6	1.7	1.6	1.0	1.0	2.0	2.3
Spirogyra	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Fern Spores	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fungal Spores	7.6	7.3	4.6	9.2	4.6	3.3	4.2	6.3	6.3	0.3
Sporormiella	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Acer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.7	0.3	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.3
Betula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyperaceae	4.3	3.7	6.2	5.9	6.3	5.2	2.6	2.0	2.3	1.3
Isoetes	1.0	0.3	2.0	1.0	1.7	0.7	0.0	0.0	0.3	2.0
Platinus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Potamogeton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salix	0.7	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.3
Typha-Sparganium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Charcoal	24.3	21.9	41.5	42.4	68.5	34.6	32.2	53.5	36.6	132.1

DEPTH (mm)	50	55	60	65	70	75	80	85	90	95
AGE yr (1995)	46	55	64	73	82	91	100	109	118	127
POLLEN SUM	306	304	302	302	306	310	310	304	306	305
TRACERS	3	9	12	14	11	12	11	27	16	10
Sed wt. (mg)	3140	3066	3098	3106	3109	3077	3140	3114	3100	3104
Sed vl. (.1ml)	12	13	11	11	15	10	16	14	12	14
CONC (1000 gr/cc)	1419	604	382	323	608	359	616	223	327	606
CHARCOAL (1000 gr/cc)	468	395	205	72	288	131	403	118	229	467
Abies	7.8	8.2	6.6	5.0	8.8	4.2	6.8	7.9	4.9	5.9
Cercocarpus	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cupressaceae	2.6	2.3	2.6	0.7	0.3	1.3	0.0	0.3	0.0	3.6
Pinus total	82.7	80.3	78.5	86.1	83.3	85.2	87.1	84.5	89.2	79.7
Populus	0.3	0.3	0.7	3.0	0.0	0.0	0.0	0.0	0.0	0.0
Pseudotsuga	0.0	1.0	0.7	1.0	1.0	0.3	0.6	1.0	0.3	1.0
Quercus	1.0	2.3	1.0	2.3	2.3	1.9	1.9	1.6	2.0	2.0
Tsuga mertensiana	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0

continued

TABLE 7.A3 continued

Ambrosia	0.0	0.0	0.3	0.0	0.7	0.3	0.0	0.0	0.0	0.0
Artemisia	4.2	2.3	6.0	1.3	1.3	2.9	1.9	2.3	2.6	4.6
Ceanothus	0.7	0.3	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0
Chenopod.-Amaranthus	0.0	1.0	1.0	0.0	1.0	0.0	0.0	1.0	0.3	1.0
Ephedra	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0
Ericaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Rosa	0.0	0.0	0.3	0.7	0.0	0.0	0.0	0.0	0.0	0.0
Sarcobatus	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0
Arceuthobium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Eriogonum	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Gramineae	0.3	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.3
Labiatae	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leguminosae	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liliaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Linanthus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Compositae	0.3	0.3	0.0	0.3	0.0	0.6	0.3	0.3	0.0	0.7
Pedicularis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polemoniaceae	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ranunculus	0.0	0.3	0.3	0.0	0.0	1.0	0.3	0.0	0.0	0.3
Umbelliferae	0.3	0.0	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0
DETERIORATED	0.0	0.3	1.7	1.3	0.7	1.3	0.6	0.3	0.3	0.7
Botryococcus	1.0	3.6	1.3	2.0	4.2	0.6	5.2	3.0	2.3	0.3
Pediastrum	0.3	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spirogyra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fern Spores	0.7	0.0	0.0	0.0	0.0	0.3	0.3	1.3	0.0	0.0
Fungal Spores	3.9	2.0	3.6	7.6	2.0	11.6	1.0	2.3	5.9	4.6
Sporormiella	1.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0
Acer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Alnus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Betula	0.3	0.0	0.0	0.3	0.0	0.3	0.0	0.3	0.0	0.0
Cyperaceae	2.6	2.0	2.6	0.0	0.3	0.0	0.0	2.0	0.3	1.3
Isoetes	0.7	0.7	0.3	1.0	2.0	0.0	0.3	0.3	0.0	0.7
Platinus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potamogeton	0.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salix	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Typha-Sparganium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Charcoal	33.0	65.5	53.6	22.2	47.4	36.5	65.5	53.0	69.9	77.0

DEPTH (mm)	100	110	120	130	140	150	160	170	180	190
AGE yr (1995)	136	154	171	189	207	225	243	261	279	296
POLLEN SUM	305	303	305	305	305	303	313	303	305	302
TRACERS	1	6	8	7	7	7	11	11	12	21
Sed wt. (mg)	3112	3116	3074	3131	3067	3123	3063	3131	3102	3138
Sed vl. (.1ml)	17	16	15	15	19	15	16	21	15	15
CONC (1000 gr/cc)	4243	1054	849	849	1061	843	622	843	530	300
CHARCOAL (1000 gr/cc) 2671	856	726	1024	727	607	578	849	456	374	
Abies	2.6	8.3	6.9	9.5	7.5	12.2	11.8	11.2	10.8	8.9
Cercocarpus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cupressaceae	2.0	2.0	2.0	0.0	2.6	0.3	1.3	0.7	2.0	2.3
Pinus total	83.0	82.5	79.0	80.7	81.0	72.3	75.1	74.3	75.1	71.2
Populus	0.0	0.0	0.0	0.3	0.3	0.7	0.0	0.7	0.0	0.7
Pseudotsuga	0.0	0.3	0.7	0.7	0.3	0.3	0.0	0.3	1.0	0.7
Quercus	4.3	1.7	2.0	3.6	3.3	4.0	3.2	2.6	1.6	5.0
Tsuga mertensiana	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ambrosia	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.3	0.0	0.3
Artemisia	4.9	3.3	5.6	2.3	2.0	5.3	4.5	5.6	4.6	5.6
Ceanothus	0.3	0.0	0.0	0.3	0.0	0.0	0.0	0.3	0.0	0.0
Chenopod.-Amaranthus	0.0	0.0	0.0	1.6	1.6	2.0	0.0	0.7	0.7	1.3
Ephedra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
Ericaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sarcobatus	0.0	0.7	0.0	0.3	0.3	0.0	0.0	0.3	0.0	0.7
Arceuthobium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eriogonum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gramineae	0.3	0.0	1.6	0.0	0.7	0.7	0.6	1.0	0.3	0.3
Labiatae	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3
Leguminosae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liliaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0
Linanthus	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0
Other Compositae	1.0	0.3	0.7	0.0	0.3	1.3	1.3	1.0	1.3	0.3
Pedicularis	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.3	0.0
Polemoniaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

TABLE 7.A3 continued

Ranunculus	0.3	0.3	0.3	0.3	0.0	0.0	0.3	0.7	0.3	1.3
Umbelliferae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3
DETERIORATED	1.3	0.7	1.3	0.3	0.0	1.0	1.3	1.0	1.3	1.0
Botryococcus	1.3	2.3	3.9	0.7	1.0	1.0	1.0	3.0	1.3	0.0
Pediastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spirogyra	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fern Spores	1.0	0.0	1.0	0.7	0.3	0.3	0.3	0.0	0.0	0.7
Fungal Spores	3.6	10.2	7.2	1.3	4.3	13.9	3.2	5.3	7.9	17.5
Sporormiella	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0
Acer	0.3	0.3	0.7	0.0	0.7	0.0	0.0	0.0	0.0	0.0
Alnus	0.0	0.0	0.0	0.0	0.3	0.0	0.3	0.0	0.3	0.0
Betula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyperaceae	1.6	1.3	0.3	0.0	1.0	1.7	0.6	1.7	0.7	1.3
Isoetes	1.6	1.3	0.0	0.0	0.3	1.0	2.2	1.0	1.0	1.7
Platinus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potamogeton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salix	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.3
Typha-Sparganium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Charcoal	63.0	81.2	85.6	120.7	68.5	71.9	93.0	100.7	85.9	124.5

DEPTH (mm)	200	210	220	230	240	250	260	270	280	290
AGE yr (1995)	314	332	350	368	386	404	421	439	457	475
POLLEN SUM	304	310	303	318	309	307	305	304	304	308
TRACERS	5	15	18	7	18	7	7	8	15	5
Sed wt. (mg)	3113	3071	3079	3115	3110	3105	3065	3111	3126	3073
Sed vl. (.1ml)	18	18	22	20	16	15	20	20	17	19
CONC (1000 gr/cc)	1410	539	527	1106	391	854	1061	1057	470	1428
CHARCOAL (1000 gr/cc) 1057	435	471	696	563	643	1210	1262	454	1326	
Abies	11.2	11.9	10.2	11.6	12.0	6.5	5.6	7.6	10.2	10.4
Cercocarpus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cupressaceae	2.6	2.6	1.3	1.3	0.6	1.3	1.0	0.7	1.6	1.0
Pinus total	73.4	75.2	78.5	73.6	75.7	81.4	82.6	76.3	78.6	75.3
Populus	0.0	0.3	0.3	0.3	0.0	0.0	0.7	0.7	0.0	0.0
Pseudotsuga	0.3	1.3	0.0	0.6	1.3	0.0	0.7	1.0	0.3	0.6
Quercus	4.6	1.9	2.6	5.0	3.2	3.3	3.0	4.3	2.6	6.8
Tsuga mertensiana	0.7	0.0	0.7	0.3	0.0	0.0	0.0	0.0	0.3	0.0
Ambrosia	0.3	0.0	0.3	0.0	0.0	0.0	0.7	0.0	0.3	0.6
Artemisia	4.3	4.8	5.0	5.7	2.9	4.9	3.9	6.6	2.3	2.3
Ceanothus	0.0	0.0	0.0	0.0	0.0	0.3	0.3	0.0	0.0	0.0
Chenopod.-Amaranthus	0.7	0.3	0.0	0.6	0.3	1.3	0.3	0.3	0.7	0.6
Ephedra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ericaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rosa	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sarcobatus	1.0	0.0	0.0	0.0	0.3	0.0	0.7	0.0	0.3	0.0
Arceuthobium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Eriogonum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Gramineae	0.3	0.3	0.3	0.0	1.0	0.0	0.0	0.3	0.7	0.6
Labiatae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Leguminosae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liguliflorae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Liliaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Linanthus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Other Compositae	0.3	0.6	0.0	0.3	1.0	0.0	0.3	2.3	0.3	1.0
Pedicularis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Polemoniaceae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ranunculus	0.3	0.6	0.7	0.6	0.0	0.0	0.0	0.3	0.3	0.0
Umbelliferae	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
DETERIORATED	0.0	0.3	0.3	0.3	1.6	1.0	0.7	0.3	1.3	0.6
Botryococcus	0.3	0.3	4.0	2.5	2.3	5.5	2.6	1.3	3.6	1.0
Pediastrum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Spirogyra	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fern Spores	1.3	0.6	0.0	1.3	1.3	0.7	0.7	1.0	0.7	0.6
Fungal Spores	11.8	2.9	5.3	3.1	5.5	1.6	4.9	8.6	5.9	6.2
Sporormiella	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0
Acer	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0
Alnus	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Betula	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cyperaceae	1.3	0.3	0.3	0.3	1.9	1.0	1.0	1.0	0.0	0.3
Isoetes	0.0	1.3	1.0	2.2	0.3	0.3	0.0	0.0	0.0	0.6
Platinus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Potamogeton	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Salix	0.0	0.3	0.3	0.0	0.3	0.0	0.3	0.0	0.7	0.0
Typha-Sparganium	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Charcoal	75.0	80.6	89.4	62.9	144.0	75.2	114.1	119.4	96.7	92.9

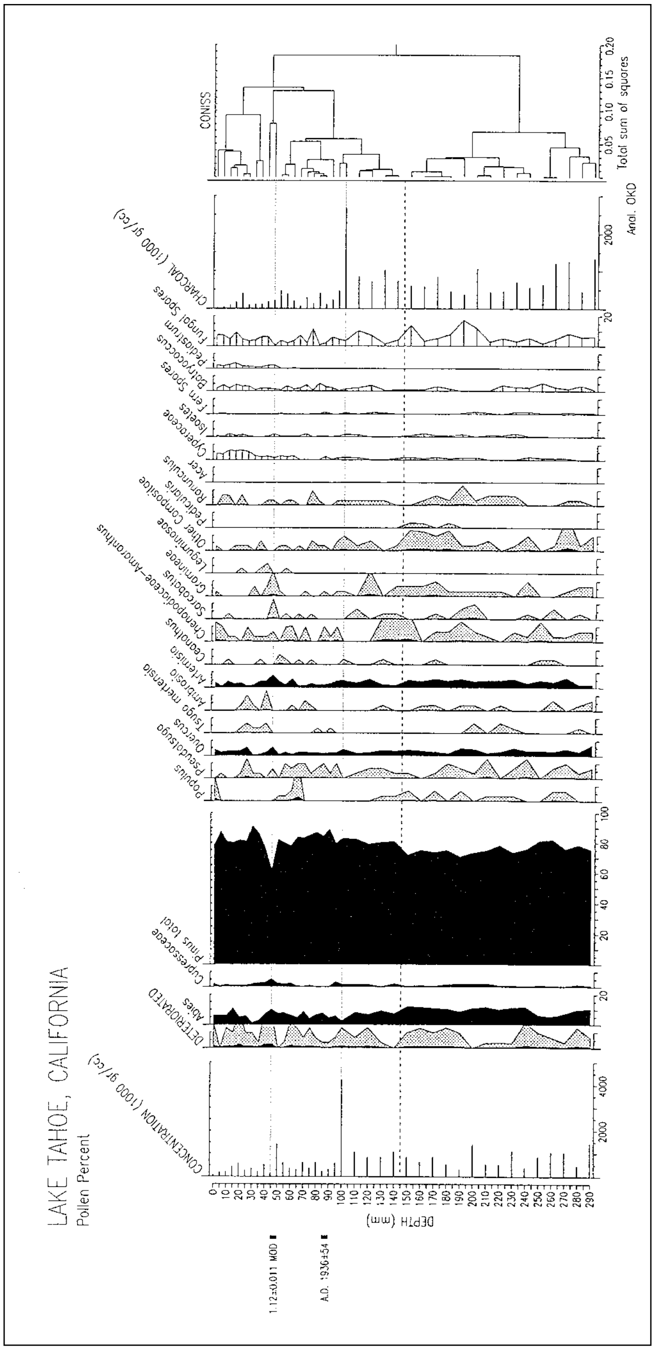

FIGURE 7.A3

Percentage pollen diagram for Lake Tahoe, Placer County, California. Only abundant types shown. Types included in pollen sum are filled curves, aquatic and wetland types (histogram-curves) are not included in pollen sum (divisor for calculation of percentages). Shaded curves are 10X exagerations, added to show trends of rare types. CONISS cluster diagram is based on untransformed pollen percentages of upland types. Solid horizontal line at 145 mm marks the major division produced by CONISS analysis. Dotted lines at 100 and 45 mm are positions of initial historic disturbance and post WWII disturbance, respectively.

RESULTS AND INTERPRETATION

Pollen concentration of the Lake Tahoe samples is very high (reaching 4,000,000 grains cm^{-3}) and preservation is excellent except for crumpling. The pollen spectrum is similar to the upper samples at Osgood Swamp (Adam 1967), and is typical for contemporary pollen samples from upper elevations of the Sierra Nevada (Adam 1967; Anderson and Davis 1988). The CONISS clustering algorithm divides the diagram into lower (undisturbed) and upper (historic human impact) halves. The lower zone has higher percentages of fir, oak, *Artemisia,* and Chenopodiaceae-*Amaranthus* than the upper. Significantly, the break comes at between 140 and 150 mm, prior to the beginning of historic disturbance at 100 mm.

The upper pollen zone (> 140 mm) is punctuated by two events at 100 and at 50 mm, each associated with peaks in pollen concentration (figure 7.A3). These ages of these events are determined by AMS ^{14}C dates on the pollen preparations at 45-50 mm and 85-90 mm. Sample AA-17171P (45–50 mm) is dated 1.1195±0.0106 fraction modern — 12% above the 1950 “standard” due to atmospheric testing of nuclear weapons (Nydal and Lovseth 1970). This ^{14}C enrichment was reached in AD 1957 or 1958 (figure 7.A4; Burchuladze et al. 1989; Nydal and Lovseth 1970). Sample AA-17172P (85–90 mm) is dated 14±54 yr B.P. (Before A.D. 1950) considering the atmospheric “enrichment,” the range of probable ages is 1955–1882.

Following the first event, the pollen concentration drops from an average of over 1,000,000 grains cm^{-3} in the lower core to less than 600,000 grains cm^{-3}, and charcoal concentration drops from 730,000 to 410,000 grains cm^{-3}. The pollen and charcoal concentration increases between 60–50 mm, then steadily declines toward the surface, reaching a low of 62,000 grains cm^{-3} at the surface.

The concentration peak (1,419,000 grains cm^{-3}) at 50 mm is followed by a brief, sharp drop of pine percentages from 80% to 62%. This event is followed by increased percentages of sedge (from 1% to 4%) and *Pediastrum* (from 0% to 2%).

INTERPRETATIONS

The two events at ca. 100 and at 40–50 mm appear to result from human activity in the Lake Tahoe Basin: the first due to logging and erosion following the Comstock era, and the second due to post–WWII logging and municipal development. I attribute the increased pollen concentration associated with each event to a pulse of erosion of pollen-laden soil-surface material into the lake. However, this pulse is not associated with elevated percentages of deteriorated pollen or fungal spores, as has been observed elsewhere in association with historic erosion (Bradbury and Waddington 1973; Davis et al. 1977).

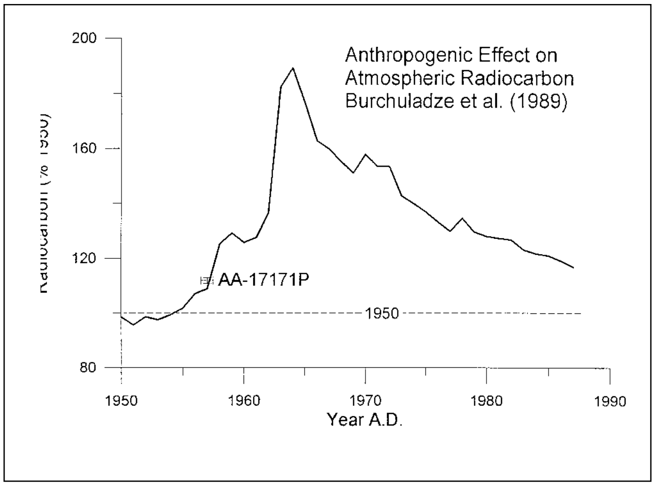

FIGURE 7.A4

Comparison of the ^{14}C content (1.1195 ± 0.0106 fraction modern) of sample AA-17171P (45-50 mm) with the atmospheric ^{14}C enrichment due to the testing of nuclear weapons (Burchuladze et al., 1989). Plotted age for sample AA-17171P is 1957 A.D.

The palynological events beginning at 100 cm can be ascribed to environmental impacts between 1850 and 1900. Increased rates of soil erosion, due to the combined effects of logging, livestock ranching, and road construction permanently increased the flux of clastic sediment into the lake. This accelerated deposition increased the overall sedimentation rate and decreased the pollen concentration (figure 7.A3). The increased pollen concentration from 60–50 cm implies a temporary reduction in the sedimentation rate, possibly due to decreased erosion during the early twentieth century.

Also associated with the 100-cm event is the abrupt reduction of charcoal percentages. Fire suppression, beginning in the late nineteenth century, produced lower fire frequency reflected in reduced charcoal concentration. The approximate halving of charcoal percentages does not necessarily indicate a halving of the regional fire frequency. The reduction is probably greater, because transport of charcoal to the lake should have increased during the historic period due to surface erosion from the watershed. The pollen concentration peak and pine percent minimum at 40–50 mm appear to reflect extensive logging. Erosion of soil-surface material resulted in high pollen concentration and logging reduced the pine percent.

The results of the zonation by CONISS have an important implication for the scale of vegetation change resulting from historic impact. Because the primary division among zones comes at between 140 and 150 mm, rather than at 100 mm (coincident with the beginning of historic disturbance), palynological changes due to natural (or at least prehistoric) causes are as important as man-caused vegetation modifications to the overall variation in the pollen diagram (figure 7.A3). The higher percentages of fir, oak, *Artemisia,* and Chenopodiaceae-*Amaranthus* in the lower zone are consistent with cooler, drier climate during the late eighteenth and nineteenth centuries as demonstrated in the tree ring data (Graumlich 1993).

The pollution of Lake Tahoe after 1950 appears to have increased the abundance of *Pediastrum* in the lake, just as it stimulated the growth of certain other algae. Although not specifically mentioned by Hunter et al. (1990) as increasing in abundance, *Pediastrum* makes its first appearance in the fossil record at 50 cm and increases to a maximum of 3.6% at 15 cm. Although *Pediastrum* seems to reflect the historic impact on the pelagic lake ecosystem, other aquatic plants do not. Neither the planktonic algae *Botryococcus* nor spores of the benthic quillwort *Isoetes* show consistent trends in the core (figure 7.A3). The unchanging *Isoetes* percentages indicates that the reduced transparency of the lake (Goldman 1988) has not yet effected the growth of this bottom-dwelling plant.

The expansion of sedge pollen percentages from 2% at 35 mm to 6.3% at 20 mm shows historic impact on the littoral ecosystem. The sedge expansion could be a response to either fertilization (pollution) of the littoral habitat, or to expansion in the extent of that habitat. Because the sedge percentages correlate with the *Pediastrum* percentages above 50 cm, both may reflect the same forcing (i.e., increasing nutrients). Alternatively, human activities may have increased the extent of the littoral zone through the progradation of the deltas *via.* erosion of sediment from the watershed, or through artificially increasing the level of the lake.

Finally, because atmospheric deposition of nutrients following forest fires is known to provide limiting nutrients to the lake (Goldman et al. 1990), the reduced charcoal frequency above 100 cm implies reduced nutrient loading to the lake. The total nutrient flux surely has been greater in the historic period, due to soil erosion, sewage input, and fertilizers; but the relative contribution of fire-related atmospheric-deposited nutrients probably has been less.

CONCLUSIONS

1. Elevated percentages of fir (10%) and *Artemisia* (4%) pollen below 140 mm indicate cool dry climate during the Little Ice Age.

2. Pollen and charcoal concentrations decrease above 100 cm due to soil erosion and fire suppression.

3. Above 45 cm, municipal construction and lake pollution produce further declines in pollen concentration, and effect the modification of the lake environment as shown by increased *Pediastrum* and sedge percentages.

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Back to CD-ROM Table of Contents