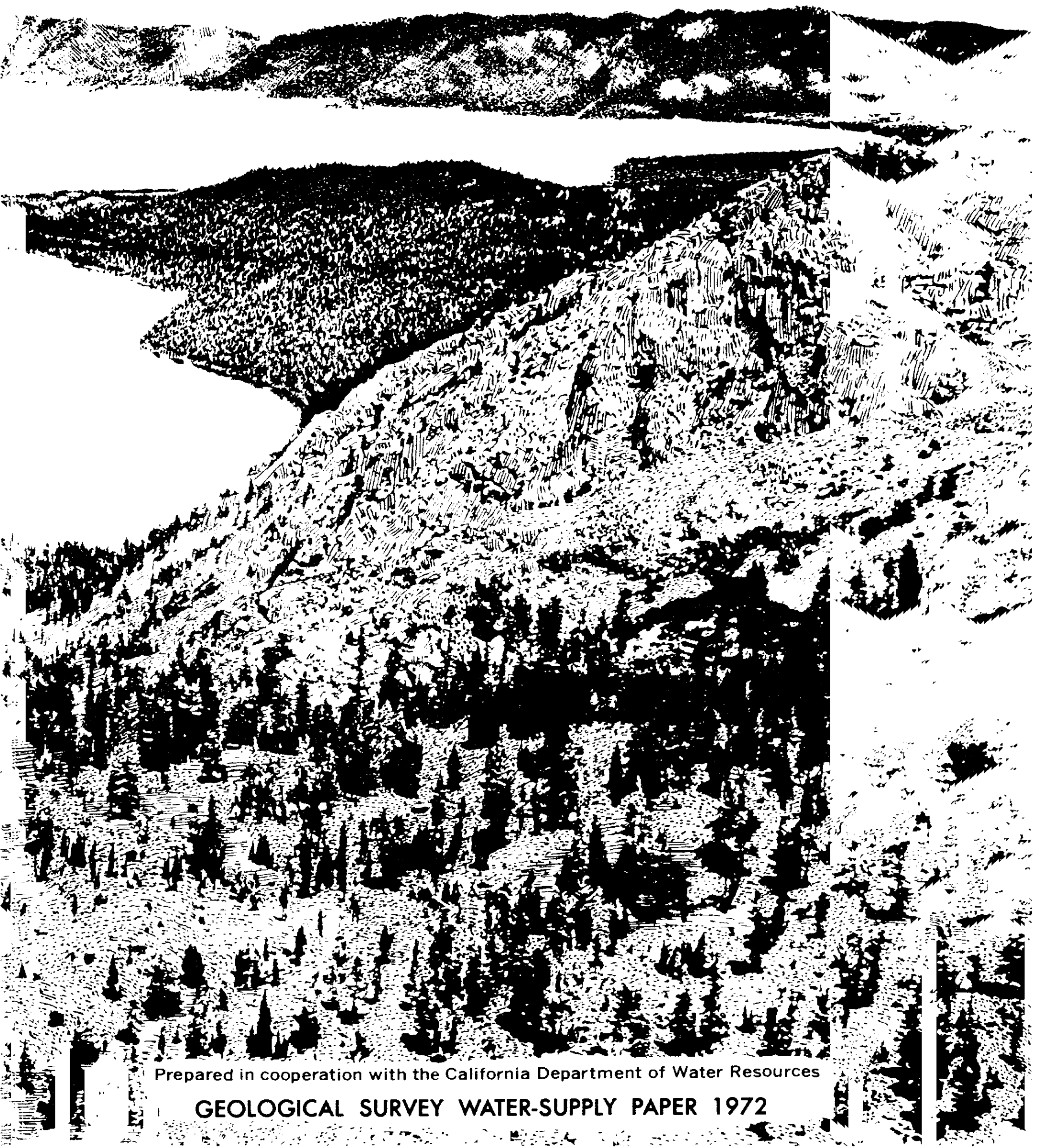
The Lake Tahoe Basin, California–Nevada



Prepared in cooperation with the California Department of Water Resources

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1972

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Looking north-northeast over Fallen Leaf Lake and Lake Tahoe. The community of South Lake Tahoe is near the shore at the end of the lake to the right, and Crystal Bay, at the north end of the lake, is at the extreme left. (Courtesy of Air-Photo Co., Inc.)

The Lake Tahoe Basin, California-Nevada

By J. R. Crippen
and B. R. Pavelka

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By J. R. Crippen and B. R. Pavelka

INTRODUCTION

Lake Tahoe and the mountains that form its basin provide vistas and environments among the most beautiful in the Sierra Nevada. The region offers opportunities for both rest and recreation to suit a great variey of tastes. In addition to the natural beauty of the lake, the shoreline, the mountains, and the streams, there are facilities for almost all related summer and winter sports. These attractions are in a fairly compact region that is within 1 or 2 days driving distance for about 25 million people. The beauty and the recreational facilities of the region attract sightseers, short-time visitors, and seasonal residents in both summer and winter. Others come to visit the casinos that have sprung up in parts of the basin in Nevada.

Tourists and part-time residents provide the major source of income for the area, and the great increase in tourism during the past two decades has had a tremendous impact not only on the economy of the Lake Tahoe basin but also on the environment. Hotels, motels, restaurants, and gas stations mushroomed almost overnight; unfortunately, their presence is somewhat incongruous with an area Mark Twain once called "the fairest picture the whole earth affords." The many privately owned lakeshore properties may lead to a shortage of facilities for public enjoyment of the shoreline. The concentration of commercial development in a few areas near the lake has caused acute traffic congestion during the summer and on winter weekends during the skiing season.

The most immediate problems are waste disposal and consequent pollution, for the lake itself is the terminal for all liquid wastes and contaminants in the basin. Local, State, and Federal agencies are working together seeking ways to control future pollution. Because of the great beauty and purity of the lake, it is unusually subject to despoilment by the introduction of wastes that our way of life produces. Much of the attraction of the basin lies in the opportunity for enjoyment of nature, at once spectacular and pristine.

The rapid growth of tourism and the publicity given to the possibility of pollution of Lake Tahoe have resulted in a great demand for information concerning the lake and its environment. Much has been written about the history of the region; there are technical reports about various aspects of the natural and manmade environments and popular pamphlets describing the local attractions. This report summarizes many facts about Lake Tahoe and its environment and gives special emphasis to the hydrology and the water problems of the region. The report is not a deeply scientific exposition; however, it does contain some technical information that may help in understanding the interplay of geologic, climatic, and hydrologic factors that affect the natural environment of Lake Tahoe and the interactions between man's way of life and his environment. A bibliography is included for those who are interested in more comprehensive studies of the area. Much of the information in this report was derived directly or indirectly from one or more of these references, and some of the opinions expressed here are based on data presented in them.

GEOGRAPHY

LOCATION

Lake Tahoe lies high in the Sierra Nevada, and occupies a valley bounded by the main range of the Sierra Nevada on the west and the Carson Range, an offshoot ridge to the east. It is almost midway between the California gold belt and the gold and silver mining area of Virginia City, Nev. The lake is about 150 miles northeast of the Pacific Ocean at San Francisco's Golden Gate. The California-Nevada State line passes through the lake and divides the basin (including the lake itself and the watershed that contributes to it), so that roughly two-thirds is in California and one-third in Nevada. The basin includes parts of three California counties—El Dorado, Placer, and Alpine—and three Nevada counties—Douglas, Ormsby, and Washoe. Figure 1 shows Lake Tahoe in relation to principal population centers in the region.

FIGURE 1 ~ Principal cities and highways in the vicinity of Lake Tahoe.

PHYSICAL GEOGRAPHY

Lake Tahoe is an irregular oval, about 22 miles long from north to south and 12 miles wide. It lies in the northern part of a basin that is about 40 miles long from north to south, and 10 to 18 miles wide. Figure 2 shows the lake, with lines that indicate its depth, and figure 3 shows the entire drainage basin. Some of the statistics pertaining to the lake and its contributing watershed are:

Surface area of Lake Tahoe	191 square miles (122,000 acres)
Altitude of the surface	6,225 feet above mean sea level
Average depth of water	1,000 feet
Greatest measured depth	1,645 feet
Volume of water in the lake	122,000,000 acre-feet (40,000,000,000,000 gallons)
Area of contributing watershed (exclusive of the lake itself).	315 square miles (202,000 acres)

About 134 square miles of the lake is in California, and 57 square miles is in Nevada.

Statistics on Lake Tahoe show that the volume of water in the lake is exceptionally great in proportion to the surface area. Lake Erie, which has more than 50 times the area of Lake Tahoe, contains less than five times as much water. The water in Lake Tahoe would cover a flat area the size of California to a depth of slightly more than 14 inches. About 150 square miles of the lake is more than 500 feet deep, and 100 square miles is more than 1,200 feet deep. In North America only two lakes are known to be deeper than Lake Tahoe: Crater Lake

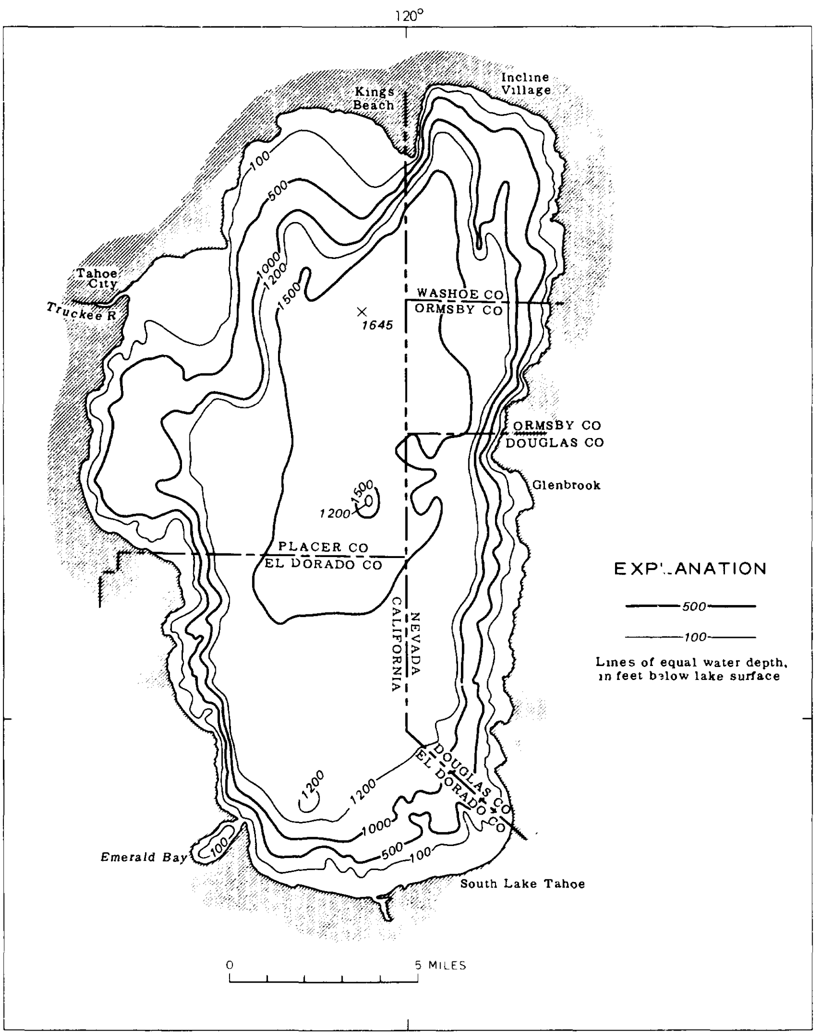

FIGURE 2 ~ Depths of water in Lake Tahoe.

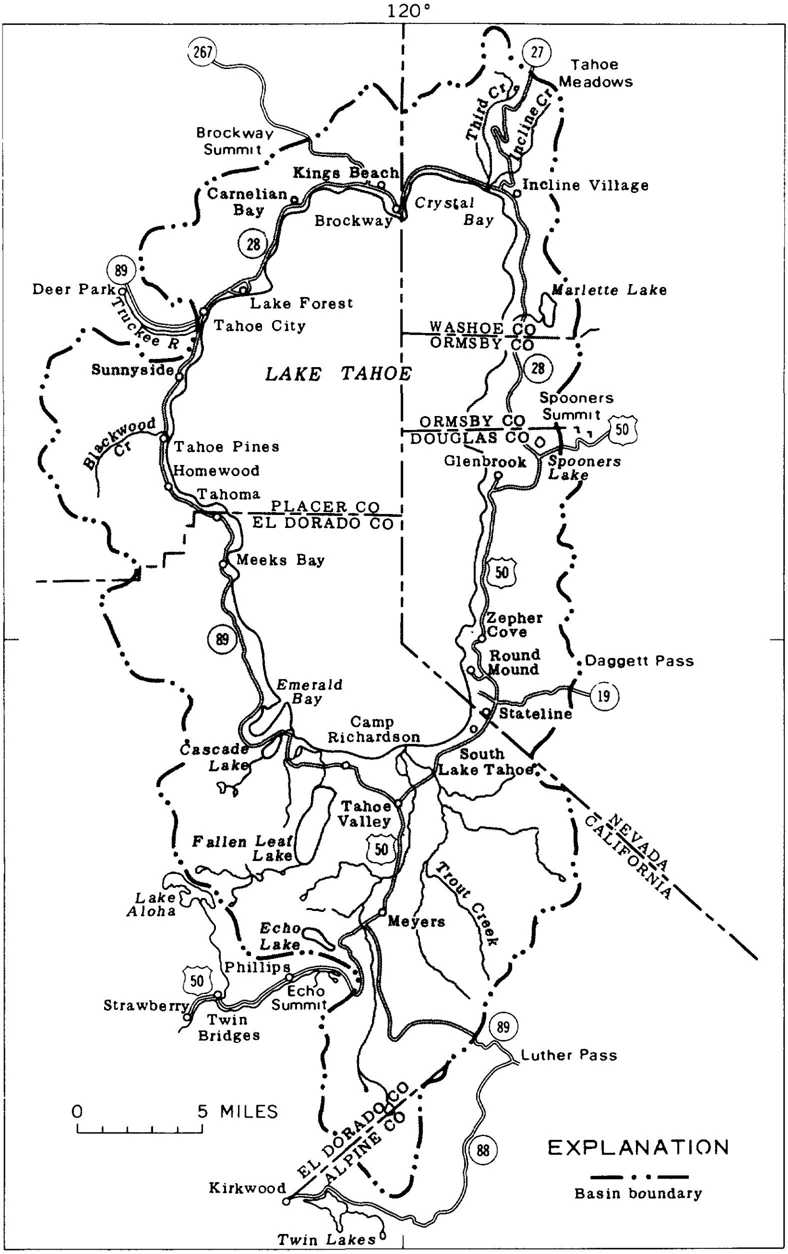

FIGURE 3—The Lake Tahoe basin.

in Oregon (1,930 ft deep) and Great Slave Lake in northern Canada (2,010 ft deep). In all the other continents there are only seven lakes known to be deeper than Lake Tahoe. It is the highest lake of its size in the United States; its only rival, Yellowstone Lake in Wyoming, is

137 square miles in area and the altitude of the lake surface is about 7,735 feet.

The water in Lake Tahoe is pure and exceptionally clear. All natural water contains dissolved solids, but streams flowing from mountain regions that drain granitic rock, such as makes up much of the Lake Tahoe basin, usually carry less dissolved materials than do lowland streams. Lake Tahoe water contains from 60 to 70 mg/l (milligrams per liter, equivalent to parts per million, by weight) of dissolved minerals—roughly, 1 pound in 1,800 gallons of water. Lake Michigan contains about 120 mg/l, Crater Lake about 80, Lake Superior about 60, and Moosehead Lake in Maine less than 20.

The clarity of the water is well known. Under the proper conditions of natural lighting and surface smoothness, underwater features can be seen at depths of several tens of feet. Scientists sometimes test the transparency of water by lowering a Secchi disk (about the size of a dinner plate and painted black and white). In Lake Tahoe the Secchi disk can sometimes be followed to depths of more than 120 feet. Most streams and lakes contain solid material in the form of small particles of sediment and organic growth that limit visibility to much smaller depths. There is little organic matter in Lake Tahoe, as will be discussed later in this report. Sediment is brought into the lake by the many small contributing streams during winter storms and spring snowmelt, but relatively little sediment arrives from May through September. Because the lake occupies an area that is notably large with respect to the area of the contributing basin, a large proportion of its inflow (about 40 percent) reaches it directly in the form of rain and snow which contain almost no insoluble material.

Lake Tahoe never freezes over, but ice may form at times along the shore in small protected inlets. The water near the surface of the lake generally cools to 40° or 45°F during February or March and warms to 65° or 70°F during August or September. Below 600-700-foot depths the water temperature is always about 39°F.

The lake has about 71 miles of shoreline—42 miles in California and 29 miles in Nevada. The most pronounced irregularity in the shoreline is Emerald Bay, which covers an area of about 460 acres at the southwestern part of the lake. In the bay is Fannette, the only island in Lake Tahoe, 2 or 3 acres in area and rising 60 feet above the lake surface.

The low point of the lake shore is at Tahoe City, Calif., where the Truckee River carries the outflow from Lake Tahoe. The altitude of the lake surface is generally given as 6,225 feet above mean sea level; however, it ranges from 6,223 feet to 6,229 feet, depending on the quantity of inflow and, since 1874, on the operation of gates in a low dam at Tahoe City. The natural level of the outlet of the lake is about 6,223 feet. The quantity of water subject to regulation between the levels of 6,223 and 6,229 feet is about 745,000 acre-feet. The lowest known level of the lake during historic times is 6,221.74 feet in December 1934, and the highest known level is 6,231.26 feet in July 1907; these figures represent a difference in storage of about 1,160,000 acre-feet, less than 1 percent of the total contents of the lake.

The Lake Tahoe basin, which has a perimeter of almost 140 miles (fig. 4), is defined as the land and water area contributing to the outflow from Lake Tahoe. More than 100 miles of the basin boundary is higher than 8,000 feet above sea level, and almost 50 miles is higher than 9,000 feet. Paved highways enter the basin at seven locations—Brockway Summit, Tahoe City (the lowest, alt about 6,230 ft), Echo Summit, and Luther Pass, all in California; Daggett Pass, Spooners Summit, and Tahoe Meadows (the highest, alt 8,570 ft), in Nevada. The Tahoe Meadows road reaches an even higher altitude—about 8,930 feet—at Mount Rose Summit, some 2 miles northeast of the boundary of the Lake Tahoe basin.

The highest peaks on the Lake Tahoe basin rim rise from ridge lines at four locations. West of Fallen Leaf Lake, Calif., is Dicks Peak (alt 9,974 ft). At the southern end of the lake are Stevens Peak and Red Lake Peak, both at an altitude of 10,061 feet. The Carson Range, in a 7-mile crestline south of the Nevada-California boundary, rises to Monument Peak (alt 10,067 ft), Jobs Sister Peak (alt 10,823 ft), and Freel Peak, whose altitude (10,881 ft) is the highest point in the basin and is about 4,650 feet higher than the surface of Lake Tahoe. At the northern end of the basin is a ridge that extends toward Mount Rose, Nev. (which is outside the basin), for about a mile at altitudes of more than 10,000 feet, the highest point being 10,324 feet. Many square miles of the lake bottom lie at altitudes of less than 4,700 feet above sea level. Figure 5 is a topographic map of the basin, and figure 6 is a cross section that showns graphically the great depth of the lake and the flatness of its bed.

Of the 315 square miles of the basin that contributes to Lake Tahoe, about 70 square miles lies at altitudes between 6,230 and 6,500 feet. Almost all the land in the basin that can be used for agricultural or commercial purposes is included in this part. The remainder of the land area lies at these altitudes:

Feet	*Square miles*
6,500 to 7,000	60
7,000 to 7,500	48
7,500 to 8,500	92
8,500 to 10,000	44
More than 10,000	1

Within the basin there are more than 150 ponds having surface areas of from 1 to 20 acres, about 15 having areas of from 20 to 100 acres, and four larger lakes—Cascade (210 acres), Upper and Lower Echo

Aerial view looking northwest over Cascade Lake and Em
outlet of the lake are at the upper right. The mountain
Fannette Island can be seen near the head of the bay, and a
Air-Photo Co., Inc.)

, showing the west shore of Lake Tahoe. Tahoe City and the
ɔnd the far shore of Emerald Bay is almost 9,200 feet high.
ow sandy beach is visible at the lower right. (Courtesy of

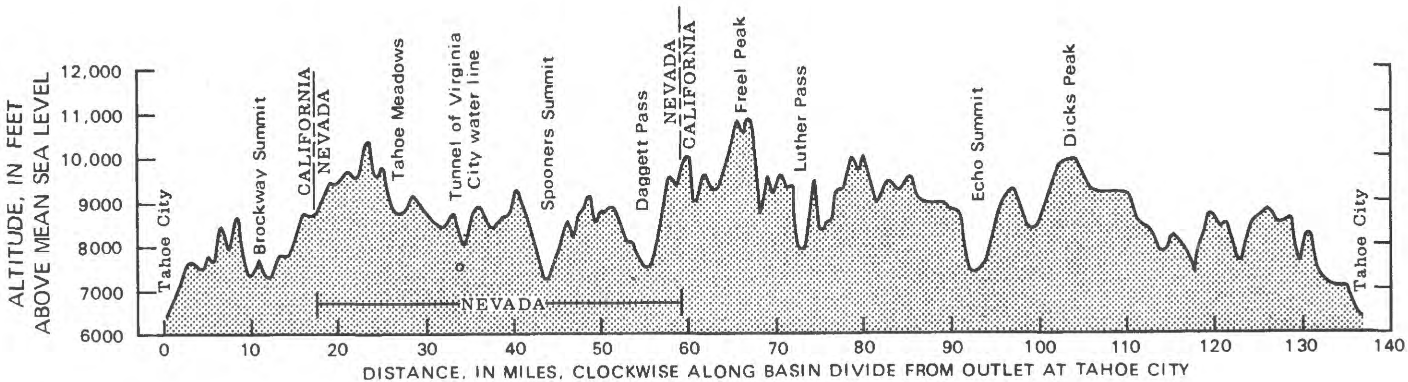

FIGURE 4~ Profile of the perimeter of the Lake Tahoe basin.

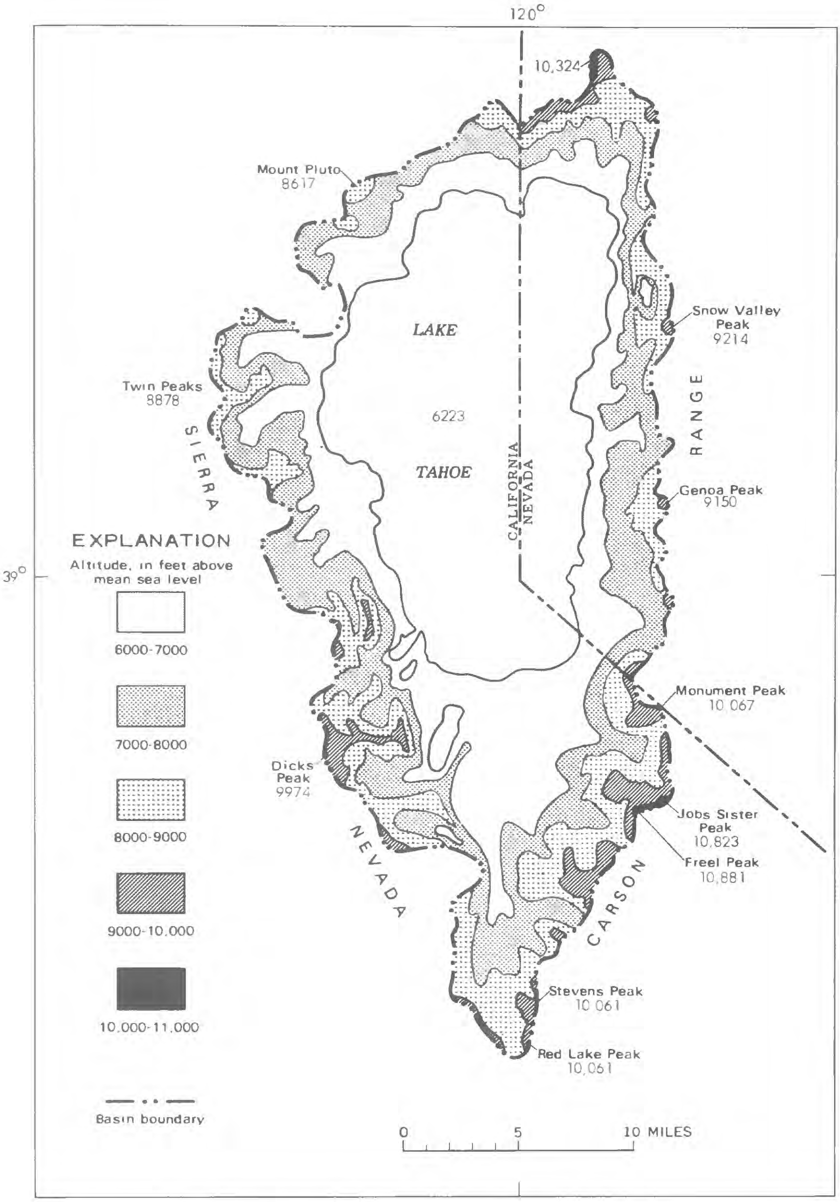

FIGURE 5 ~ Altitudes in the Lake Tahoe basin.

(330 acres together), Marlette (350 acres), and Fallen Leaf (1,400 acres). The total surface area of these lakes is about 5 square miles, therefore about 310 square miles of the basin is truly land surface.

Little of the land surface is level; most of it lies at slopes ranging from gentle and almost imperceptible to very steep. About half the land area of the Lake Tahoe basin has a slope steeper than 20 percent

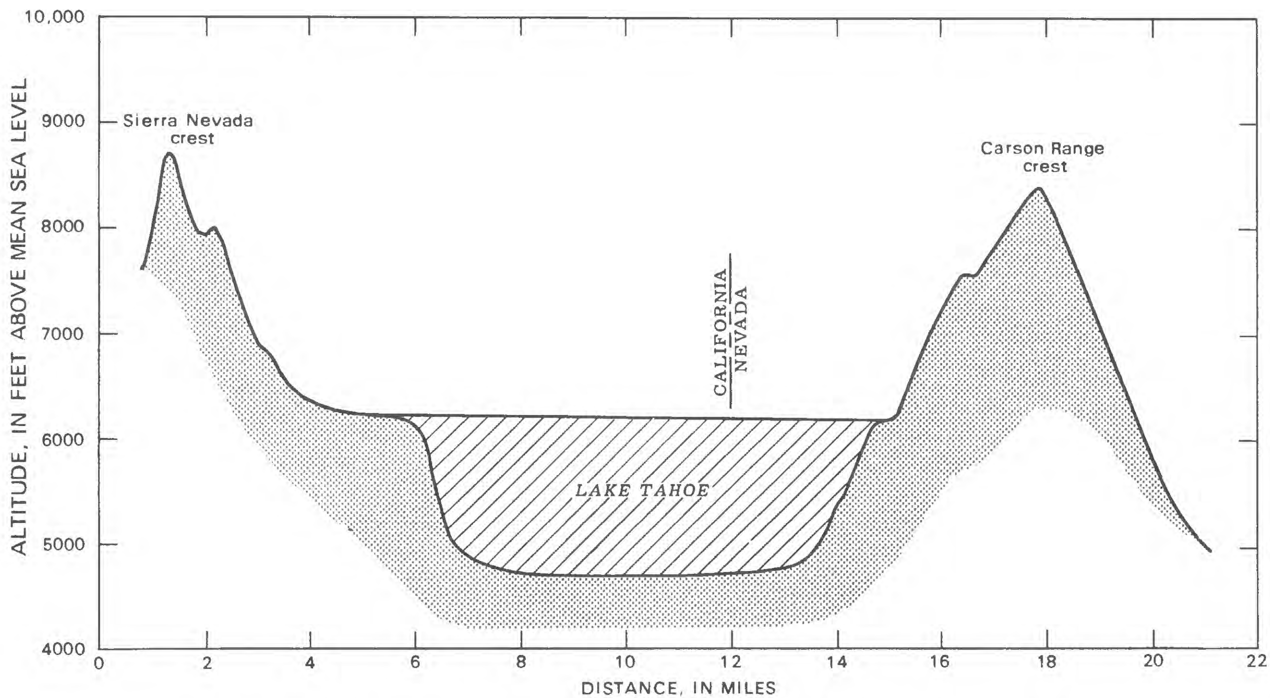

FIGURE 6 ~ Topographic cross section of the Lake Tahoe basin at Tahoma, Calif.

Looking north from Crystal Bay, in Nevada, to a 9,600-foot-high mountain ridge that forms part of the northern boundary of the basin.

(that is, 1 ft of rise for each 5 ft of horizontal distance). Such steep slopes are probably too difficult and expensive to develop for any purpose but specialized recreation in the climatic environment of Tahoe. Little development within the basin is on land having a slope of more than 10 percent, and most development is on land having a slope of less than 5 percent. Only about 70 square miles (45,000 acres) of land in the basin lies at slopes gentler than 10 percent, and some 60 square miles of this relatively level land is at the south end of the lake in El Dorado County, Calif., between the State line and Cascade Lake, and along the lakeshore in Placer County, Calif.

GEOLOGY

Much of the geologic history of the Lake Tahoe basin, described in 1897 by Waldemar Lindgren, still remains largely hypothetical. Most of the early geologic history of the basin must be deduced from findings of regional studies of the entire Sierra Nevada, of which the Lake Tahoe basin is only a small part. In these studies, the fossilized remains of plants, animals, insects, and marine life have been analyzed and related to similar findings from other regions, and the ages of minerals have been estimated from the characteristics of their radioactive emissions. All those studies and many others have been considered together, and deductions—some weak and some forceful—have been made. A story encompassing tens of millions of years follows, the story of the rocks of the Lake Tahoe basin.

HOW THE BASIN WAS FORMED

For perhaps 200 million years, during the Paleozoic Era, a shallow sea lay in a broad valley that existed where the Sierra Nevada and the Carson Range now rise. There was a continual very slow movement into the sea of sediment and volcanic material derived from high land to the east. The seabed slowly sank during the era so that the accumulations formed layers on it. Then near the end of the Paleozoic Era, perhaps 250 or 300 million years ago, there was a period of gentle deformation of the earth's crust, and the thick layers of sedimentary and volcanic rocks were bent and broken. This period of deformation probably lasted for 100 to 150 million years and was followed by the Nevadan Revolution, some 150 to 175 million years ago. The Nevadan Revolution was a widespread disturbance of the crust that raised the area and formed a system of mountain ridges somewhat lower than the present Sierra Nevada.

Those ancient ridges were worn down by erosion for 40 to 50 million years and became a relatively low and level plain. Then about 50 million years ago there began a period of great volcanic activity that erupted new rock material into parts of what is now the Lake Tahoe region. Between 25 and 40 million years ago another period of uplift occurred, and it was probably in that period of geologic activity, during the late Tertiary Period of the Cenozoic Era, that the Sierra Nevada was tilted upward and the large block of the earth's crust now partly occupied by Lake Tahoe was dropped below the nearby land surface. From that time onward, the general shape of the Sierra Nevada rise, of the Tahoe trough or graben, and of the Carson Range has been changed only by widespread uplifting of the entire region about 10 million years ago, by erosion, and to a minor extent by additional volcanic activity.

Between the periods of major movements of the earth's crust are periods in which the forces of erosion tend to wear away the mountains and fill the valleys. We are now living in such a period. The landscape is being slowly leveled by many forces but principally by the wearing away of material by water and the movement of the eroded material along stream channels. The early period of the Lake Tahoe basin, after the formation of the valley by the faulting that formed the graben, also saw changes wrought by volcanic activity and the movement of glaciers. The southern end of the graben is its lowest part, and there a lake quickly formed. It was probably much larger and deeper than it is now, and its outflow may have been a short distance east of the present outlet.

The water flowing from the lake eroded the outlet to an altitude corresponding to the present 6,480-foot level rather quickly because the obstructing material above that level was unconsolidated and easily moved. Basalt flows, however, emerged from volcanic vents to block the outlet, and the lake level rose to about the present 6,600-foot level. The water then wore its way through the basalt only to have another flow block the outlet again. When the water cut through this second flow, the general location of the present outlet was established.

The glacial or Pleistocene Epoch began about 2 million years ago and is followed by the Holocene Epoch, the period of time in which we live and the 10,000 or 15,000 years of the immediate past. During the Pleistocene there were four periods of glaciation, and the last glacial retreat of that epoch began about 25,000 years ago. The movement of vast ice sheets in the Lake Tahoe basin was important in forming the landscape we now know. Several times the outlet of Lake Tahoe was blocked by ice and the water rose, once to a height of about 600 feet above its present level. The gouging by glacial ice and the formation of moraines (masses of broken rock fragments and soil deposited by the melting of glacier ice and the outflow of melt water) formed the troughs now occupied by Emerald Bay, Fallen Leaf Lake, Cascade Lake, and many smaller lakes and ponds.

ROCKS AND SOILS OF THE BASIN

As one would deduce from the foregoing geologic history of the Lake Tahoe basin, the rocks that are found near the surface are of many types and ages. The folding and overturning that took place many times during the long periods of geologic activity, and the erosion, deposition, and recementing of rock materials that occurred during geologically quiet periods have left a complex arrangement of layers. Bedding that was originally horizontal can now be found lying at all angles, sometimes completely overturned. Ancient rocks overlie much younger formations in some places.

Rocks now exposed in the Lake Tahoe basin are principally igneous (that is, formed directly by the cooling of molten material) and metamorphic (formed by the alteration of some earlier type of rock principally by pressure and heat). Areas where the various types of rock are found are shown in figure 7.

The metamorphic rocks of Paleozoic age, the oldest exposed rocks in the basin, crop out at a few places on the east and west sides of the basin, mostly at high altitudes. They are the remains of a much larger body that has been intruded by the younger granitic rocks. The granitic rocks, principally of Jurassic and Cretaceous age, and soil derived from them, make up about half the exposed material in the basin. Most of the east side and the southern end of the basin is of granitic origin. Volcanic rocks crop out north and northwest of the lake and at the extreme southern end of the basin.

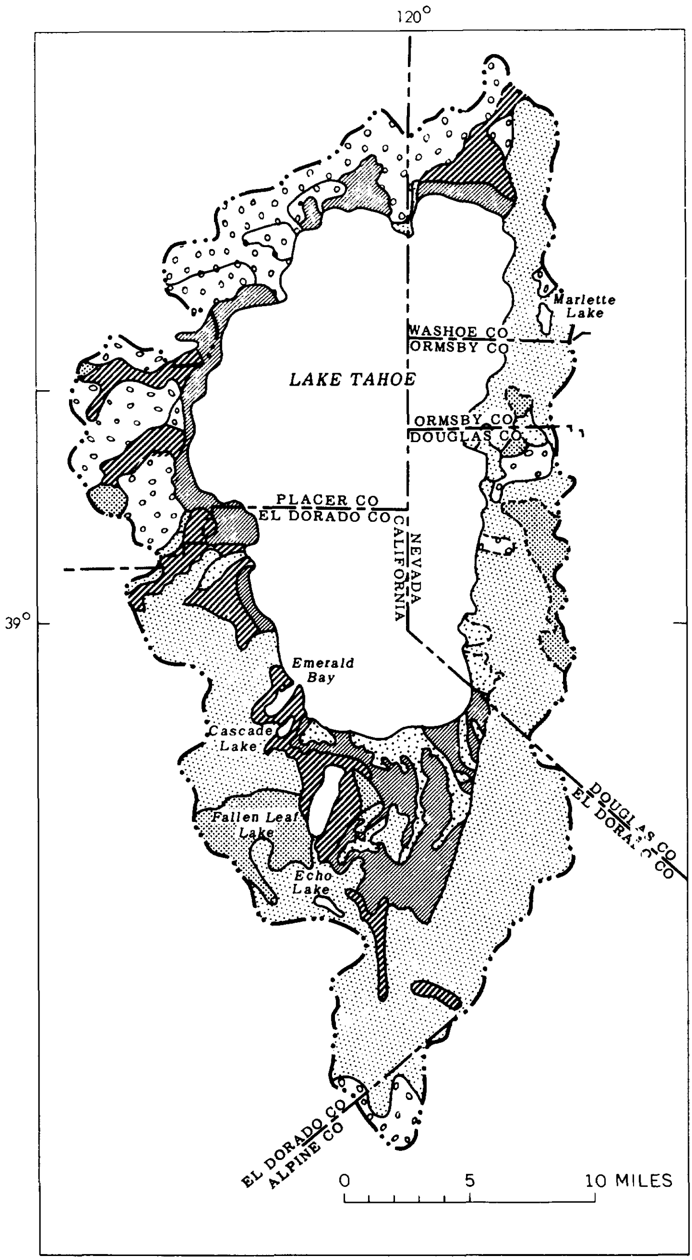

FIGURE 7 ~ Types of rocks in the Lake Tahoe basin.

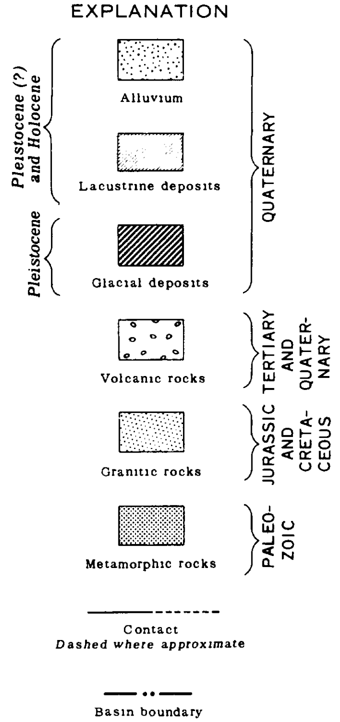

FIGURE 7 ~ Continued.

Soils generally are derived from adjacent rock outcrops and, if undisturbed by other forces, would tend to show the same lines of demarcation between types as do the rocks from which they were formed. However, forces such as gravity, flowing water, wind, or glacial ice were active. Regions such as the Lake Tahoe basin that have a complex pattern of rock outcrops also possess a complex pattern of soil types, and because of soil movement the locations of the soils may not bear a close relationship to the location of the parent rock. However, in general the soils found at the north end of Lake Tahoe are volcanic in nature and soils at the south end are of granitic origin. There are structural fractures in the rock, and there is some deterioration of the consolidated rock mass from weathering and from penetration by deep-rooted vegetation. Because of this, the contact between the soil and the underlying rock is often indistinct. Water can penetrate into coarse soil and fragmented rock easily; it also drains rapidly from these materials unless there are barriers to its movement. Most ground water in the basin is found in valley fills of coarse soil. Soil depths in the Lake Tahoe basin range from thin veneers in the uplands to deposits several feet deep in some bottom lands.

Glacial deposits, principally gravel, sand, and silt, occur at many places near the lakeshore. The retreat of the ice sheets of the glacial epoch has left many rocks and boulders mixed with the gravel and silt at the northern end of the basin. The glacial residue is therefore rather rough and uneven and is not as attractive for development as are some other soils.

Lacustrine deposits, formed under water when the lake surface was at a higher altitude, cover the wide valley floor south of the lake. Alluvium brought down from the mountains by running water underlies the principal stream channels and adjacent areas. The alluvium and lacustrine deposits are probably the most recently formed surface materials and, because of the nature of their origin, form the most level and low-lying land surfaces in the basin. These level areas are attractive for roads, streets, and buildings; by far the greatest part of the development in the basin is within the regions shown (fig. 7) as lake deposits and alluvium.

CLIMATE

There is no single classification that can describe the climate of the Lake Tahoe basin. One can generalize so far as to state that all regions of the basin experience freezing temperatures during the winter and most of the precipitation comes during the winter months. Beyond this, generalization is difficult.

The climatic factors that dominate in establishing the nature of the plant and animal life of a region and that most directly influence human activities are temperature and precipitation. The climate of the Lake Tahoe basin is influenced by marine air moving inland from the Pacific Ocean and by continental airmasses from the interior. Figure 8 shows mean monthly temperatures at Tahoe City as well as those at Sacramento and San Francisco. The moderating effect of the ocean is strongly evident in the San Francisco temperatures, and the effect of altitude difference is shown by comparing temperatures at Sacramento to those at Tahoe City. Sacramento is less than 100 feet above sea level.

Monthly average temperatures tell only part of the story. The range between daytime highs and nighttime lows and the temperature extremes experienced during unusually hot or cold periods are important to our comfort and our choice of activities. Data are available for lakeside locations in the Lake Tahoe basin, but relatively little is known of conditions at higher altitudes. At Tahoe City, these have been observed during a 50-year period:

Highest temperature	94°F	Lowest temperature	−15°F
Mean daily maximum, January	37°F	Mean daily minimum, January	17°F
Mean daily maximum, July	78°F	Mean daily minimum, July	43°F
Mean annual temperature	42.4°F		

On the average, temperatures at Tahoe City drop to or below 32°F on about 220 days of the year. Temperatures at Glenbrook, on the east shore of the lake, are generally 4° or 5° higher than those at Tahoe City. At higher altitudes the mean, or average, temperatures can be roughly estimated by applying the rule-of-thumb correction of a 1° drop for each 300 feet of altitude. The actual temperature at various locations at a given altitude varies, of course, with exposure to wind and sun, and extreme high and low temperatures are both likely to be lower at high altitudes.

Precipitation in the Lake Tahoe basin follows the pattern that prevails along the Pacific Coast from San Diego to Seattle; that is, it is plentiful in the winter and scanty in the summer. However, the bars in figure 8 showing average monthly precipitation indicate that there is more precipitation at Tahoe City than at Carson City, Sacramento, or San Francisco. This is because most precipitation in the region originates with airmasses that move inland during the winter and are forced upward by the rising landmass that forms the Sierra Nevada. Figure 9 shows lines of equal depth of mean annual precipitation in the Lake Tahoe basin. These represent the long-term average and often differ greatly from year to year, but the relation between the quantity of precipitation and the topography is usually the same. The maximum precipitation is at high altitudes in the southwest part of the basin. As the air descends into the basin, precipitation becomes less until the eastward-moving air is again forced upward by the Carson Range.

Most of the precipitation comes during the winter in the form of snow. The long-term average annual snowfall reported by the U.S. Weather Bureau at Tahoe City is 213 inches. At higher altitudes, where precipitation is greater and temperature is lower, snowfall is undoubtedly much more than this. Reports of April 1 measurements show depths of snow on the ground as great as 89 inches at Tahoe City and 244 inches near Echo Lake at an altitude of 8,200 feet in the southwest part of the basin. February, March, and April snow depths are usually between 15 and 45 inches at Tahoe City and between 110 and 190 inches near Echo Lake. On the average, probably at least 50 percent of the precipitation falls as snow at the lowest altitudes in the Tahoe basin, and 90 percent or more does so at altitudes of 8,000 feet or higher.

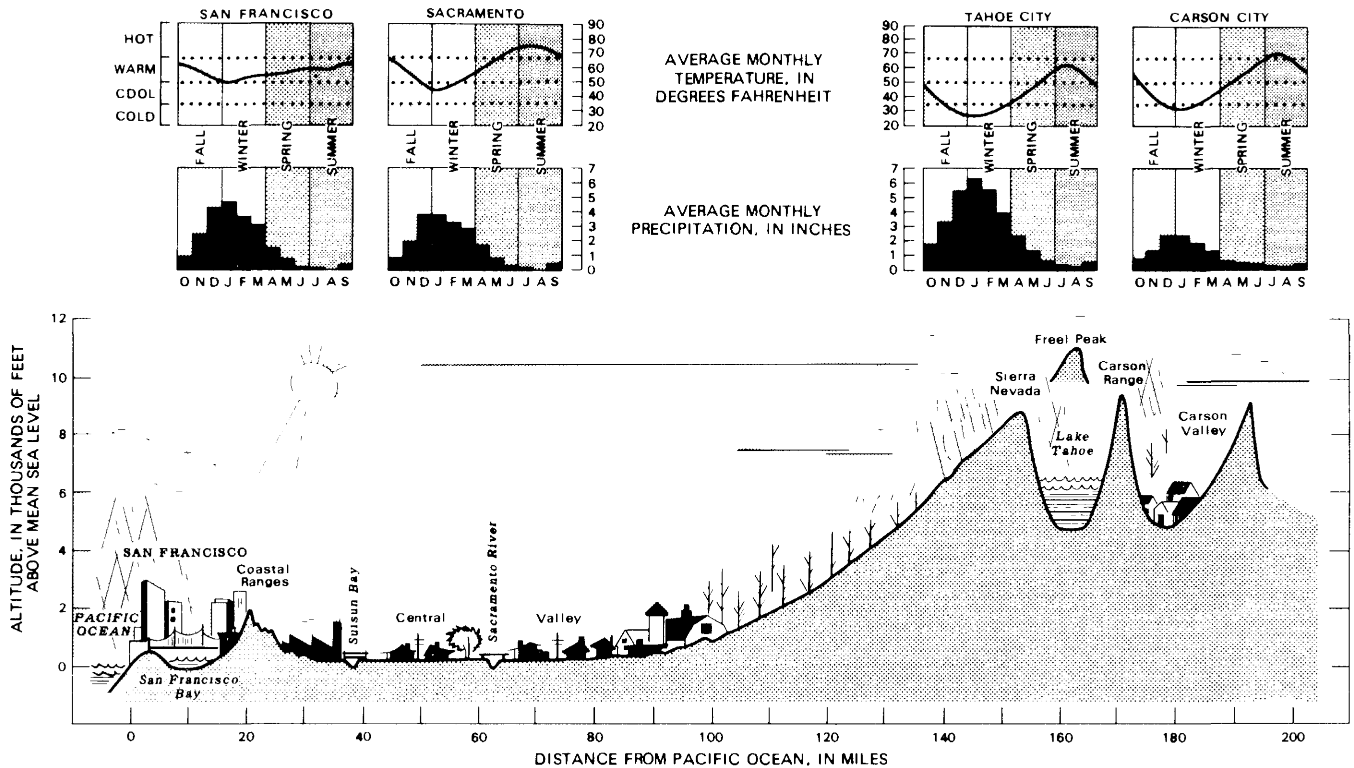

FIGURE 8 ~ Climate and topography from the Pacific Ocean to Carson Valley.

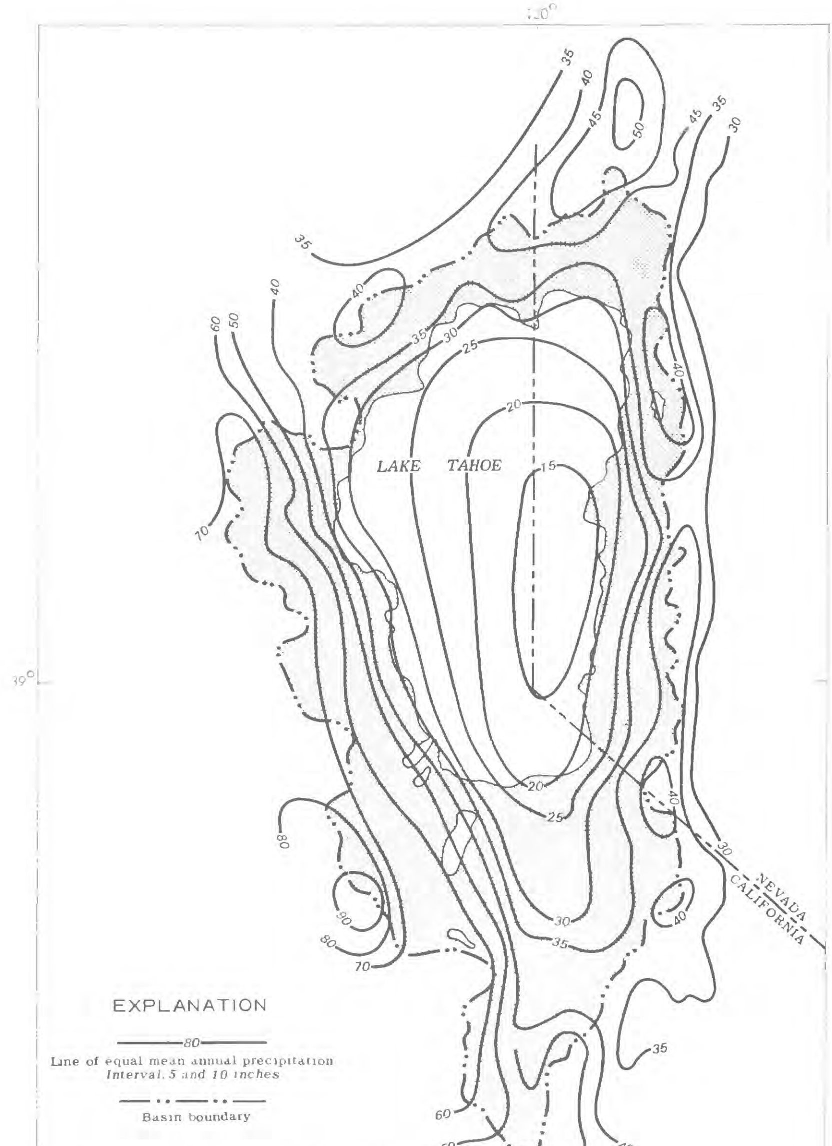

FIGURE 9 ~ Mean annual precipitation in the Lake Tahoe basin.

Forested regions below 8,000 feet in altitude are generally clear of snow by the middle of June, but snow cover may last a few weeks longer after unusually wet winters. By mid-August, winter snow is gone except for the remains of deep drifts that may have formed in sheltered ravines on north-facing slopes. Although some snow may fall on the higher peaks and ridges even during summer months, there is no permanent snowpack or icefield in the basin.

Thunderstorms sometimes occur in the basin, most often in the mountains. They occasionally cause localized flooding.

Prevailing winds are generally from west to east, but local conditions often give them northwesterly or southwesterly directions, and light breezes over the lake itself may blow in any direction. Violent winds are infrequent.

Aerial view of Lower Echo Lake, elevation 7,400 feet, on June 24, 1953. Note the heavy snow cover on the north-facing slope of the ridge south of the lake. Only scattered patches remain on the south slopes of the ridge. U.S. Highway 50, the main route between Sacramento and South Lake Tahoe, is visible at the right.

VEGETATION, FISH, AND WILDLIFE

Probably 95 percent of the trees in the Tahoe basin consists of conifers, mostly varieties of pine and fir. Most forest cover is at altitudes of less than 9,000 feet, although trees and shrubs can thrive at higher altitudes where soil and exposure are favorable. Along much of the lake's shoreline there is a belt of gently sloping land that has soil and moisture conditions favorable to vegetation. Because of this, the lake is surrounded by a belt of pine and fir, interspersed with areas of shrubs and open meadows.

There are many hundreds of acres of the low, hardy scrub brush of mixed varieties, including manzanita, ceanothus, and scrub oak, commonly known collectively as chaparral. Large areas of chaparral cover the slopes facing the lake just north of Emerald Bay. Many slopes that have been laid bare by slides or fire are bordered by chaparral, which can find a foothold rather quickly in soils that are relatively inhospitable.

Grasses and other herbage flourish on fairly level open areas that have a few inches or more of soil, at all altitudes. Their growth occurs while moisture is available after snow cover melts, and they become brown and brittle and go to seed as soil moisture drops below the wilting point during the dry summer. Chaparral, which has a much deeper root system, remains green throughout the summer. There are large areas of grassland south and east of Fallen Leaf Lake. In the same region and in other locations where soils and moisture supply are favorable there are clumps of deciduous brush and small trees. Among the grasses and brush are many flowering plants that at times furnish pleasant scenes of natural beauty amid varied surroundings.

Almost all varieties of wildlife found in the Western United States, can be seen in the Lake Tahoe basin. Deer, bear, mountain lion, coyote, rabbit, raccoon, and a great variety of rodents are common. Deer, rabbit, and woodchuck are probably the most frequently hunted animals. Land birds and water fowl are plentiful, and almost all common varieties nest in the basin or visit it during migrations.

For a few years before the turn of the century there was commercial fishing in Lake Tahoe, and the fish population was greatly depleted. The nutrient supply of the lake water was too low to encourage a rapid revival, so the lake is now stocked with fish, mostly trout from hatcheries, that provide sport fishing. Lake trout, brown trout, and brook trout as well as the native cut-throat rainbow trout and whitefish are caught. Cut-throat trout weighing as much as 35 pounds have been taken from the lake. There are many miles of fishable streams in the basin.

HISTORY

EXPLORATION AND SETTLEMENT

Indians of the Washoe tribe lived in the Lake Tahoe basin long before the first forerunners of European civilization reached western America. Little is known of their way of life. They maintained themselves by hunting and fishing and probably suffered from occasional forays by the Paiutes, who roamed the drier lands to the east. The first recorded sight of Lake Tahoe by anyone other than Indians was on February 14, 1844, by John C. Frémont. With a party of 39 men that included "Kit" Carson, Frémont was on a tour of exploration that had left Kansas City more than 8 months earlier. He had visited Great Salt Lake and the Columbia River, then had turned southward and discovered Pyramid Lake. Perhaps because of stories of a semi-tropical lake lying on the western slopes of the Sierra Nevada, the expedition continued southward and westward, and it was on this leg of the journey that the party sighted Lake Tahoe, probably from Stevens Peak. They did not visit the lake but continued westward and crossed the Sierra through the pass that is now named after Carson. Frémont named the lake "Bonpland," in honor of a noted French botanist. He believed it to be in the headwaters of the American River.

The name "Bonpland" was never popular or widely used. The first official map of the State of California, prepared in 1853, called it Lake Bigler, after the third Governor of the State. Bigler was not considered an attractive name, and ex-Governor Bigler expressed political sympathies that made the name undesirable in 1862, when a new map was in preparation. The map compiler was somewhat versed in the local Indian vocabulary and proposed renaming the lake "Tahoe," variously interpreted as "big water," "high water," or "water in a high place." The name was adopted and retained.

Few travelers crossed the Sierra Nevada until the great migration that followed the discovery of gold in 1848 about 50 miles west and slightly south of the lake, in the South Fork of the American River. In 1849, after news of the discovery, a stream of gold seekers began a trek to California that soon included adventurers, hopeful farmers, and tradesmen and businessmen who sought the freedom and opportunity of a new frontier. All these groups followed the best routes to the goldfields and the rich farmlands and settlements farther west. To them, the Lake Tahoe region was only a barrier in their route, and the easiest journey for most was up the Carson River to its headwaters and over Carson Pass or Johnson Pass (now Echo Summit), 9 miles south of the lake. Others followed the Truckee River upstream from Reno and avoided Lake Tahoe and the steep mountains rising on its west shore by crossing at Donner Summit, north of the lake. Then in 1858, the Comstock lode was discovered 15 miles to the east, at Virginia City, Nev., and Lake Tahoe became attractive as a place of opportunity.

The riches in the Lake Tahoe basin were not gold nor silver but were timber to supply the needs of the Comstock development. The needs were great, for thousands of people were flocking into western Nevada and immense profits could be made by supplying lumber for the region. The thick forests on the slopes surrounding Lake Tahoe were especially attractive, and lumbermen and their followers began to settle in the basin. By 1860, the town of Glenbrook was settled, and in 1861 a sawmill was established there. The first roads were built from the lake to the Carson Valley over Daggett and Spooners passes, and flumes were built to float logs cut high on the Carson Range down to Carson City.

As lumbering progressed on the eastern side of the basin, the supply of large logs began to diminish and cutting began on the west side. The logs were floated across the lake to the mills of Glenbrook. All this activity led to the development of other enterprises; one of the earliest was the supplying of hay for the large number of horses used. Hay was grown in the meadows at the northern end of the lake near the outlet into the Truckee River. In 1860 the 125-ton, 60-foot schooner *Iron Duke* was put into service to carry hay to the south end of the lake. A short-lived mining boom at Squaw Valley, Calif., in 1864 brought many people to the northern end of the lake, and those who settled near the boat landing founded Tahoe City and built two hotels to accommodate visitors and attract tourists. Lake Tahoe was becoming a resort, but as a satellite of the Virginia City-Comstock lode region.

Those were the years of timber construction and steam power, and the steam required wood for fuel. The demand for wood continued to deplete the forests, but the payrolls and the profits from supplying the workers maintained prosperity in the Lake Tahoe basin for 25 or 30 years. Short logging railroads were built near Glenbrook and Incline, Nev., and Bijou, Calif. In 1864 the first steamboat was launched on the lake, a 42-foot, 32-ton wood-burning side-wheel tugboat. Other steam-powered cargo carriers, tugs, and passenger boats served on the lake in the following years. Many of them carried mail and passengers between lakeside communities on a regular schedule. Steamboat transportation served Lake Tahoe until 1934, when the 169-foot vessel *Tahoe* made its last scheduled trip.

Gradually the momentum of the mining boom slowed and the demand for timber lessened. At the same time a few individuals foresaw the possibility of harmful effects from uncontrolled logging, and under these influences lumbering activity diminished. The number of visitors increased, however, especially after a railroad connection between Tahoe City and the main line at Truckee was opened in 1900.

By 1870 there were resort hotels at Brockway and Carnelian Bay, Calif., and Glenbrook, Nev., as well as at Tahoe City. Tahoe City was a center of activity after 1900, for it had shipyard and railroad-shop facilities in addition to serving as the railroad terminal and the transfer point between rail and water facilities.

There was a slow, steady increase in the number of people visiting the Lake Tahoe basin for recreation until World War II. After the war, two factors brought about an explosive increase in both the temporary and the permanent population of the basin. Splendid casinos, offering popular, sophisticated entertainment as well as gambling facilities, were built on the Nevada side of the State line. At the same time, widespread financial prosperity and fast, easy automobile routes put all America on the highway. Lake Tahoe is well known, both because of its attractions and because of well-directed efforts to obtain publicity. Many tourists from distant States visit the lake on their vacation trips in the West, and the major population centers of California are now within a 1- or 2-day drive of the lake. The number of people visiting Lake Tahoe will no doubt continue to increase. Land developers are successfully persuading visitors to buy land for vacation or retirement homes in the basin.

TRENDS IN POPULATION AND LAND USE

The permanent homes within the Lake Tahoe basin are almost entirely on the low-lying gentle slopes along the lake shore. Estimates of the permanent population of the basin at any given time vary widely, probably because of varying opinions as to what constitutes permanency. However, a reasonable estimate of the year-around resident population of the basin in 1965 is about 26,000. By far the largest concentration is in and near the city of South Lake Tahoe, Calif. This community was incorporated in November 1965 and had a population of about 14,000; about 2,000 more persons lived in the adjoining community of Stateline, Nev. The shoreline communities along State Highway 28 in Placer County, Calif., including Homewood, Tahoe City, Carnelian Bay, Brockway, and Kings Beach, had a total population in 1965 of about 4,000. Another 4,000 residents lived along the shores of Crystal Bay, in Nevada. The remaining 2,000 lived in other parts of Douglas County, Nev., and El Dorado County, Calif., mostly near the lake. Thus, except for residents in the vicinity of Meyers, Calif., 5 or 6 miles south of the lake, only a few hundred of the total year-around population lived more than 2 miles from the lake.

The actual number of people within the basin varies greatly from season to season, the greatest number coming on summer weekends and the smallest number, corresponding closely to the residential population, during midweek periods from November through April. The average annual transient population served by the facilities of the basin is probably from two to three times the permanent residential population, and during the busiest month (mid-July to mid-August), the number of people in the basin may be more than eight times the permanent population.

In addition to these periodic variations in basin population, there is a strong trend toward an increase in both permanent and temporary population. The results of many projections vary, but trends indicate that the peak-season population by the year 1990 may be between 350,000 and 500,000, or at least twice the 1965 peak. The projected year-around population is from 80,000 to 100,000.

Most recreational activity in the basin is associated with the lake and its shores, with the casinos that are just over the interstate boundary in Nevada at the north and south ends of the lake, or with skiing facilities. Water sports and recreation are also available at the smaller lakes in the basin, especially at Fallen Leaf and Echo Lakes. There are campgrounds and hiking trails in the mountains that surround the lake, but with the exception of skiers the concentration of people visiting the basin is as strongly associated with lakeshore locations as is the permanent population.

Thus, from the viewpoint of population distribution and land development, the Lake Tahoe basin can be considered as having two rings concentric about the lake: An inner ring rarely more than 2 miles wide in which are most of the roads and streets, homes, and businesses of the residents and most of the recreational activity; and an outer ring of mountainous land, about 240 square miles in area, that is visited by skiers and hikers but otherwise is virtually uninhabited.

The economy of the Lake Tahoe basin, originally based on logging and agriculture, shifted its base to tourism and recreation by the turn of the century. After World War II, and especially during the past decade, the economy of the basin underwent a dramatic boom which increased the pressure for conversion of land to the most immediately profitable uses. Motels, summer homes, shopping centers, and casinos, together with the streets and parking areas needed to serve an almost completely automobile-based and largely transient population, were quickly built. Such uses are appropriate for land with rather gentle slopes. It is therefore probable that the greatest pressures for land development will continue to be in the 70 square miles of relatively low and flat land immediately surrounding the lake, while somewhat less pressure will exist for development of adjacent higher and slightly steeper land.

WATER RESOURCES

HISTORY OF WATER USE

Water is essential to almost all the activities of man. Aside from the obvious needs for household purposes, one probably thinks first of the recreational and esthetic uses of the lakes and streams in the Lake Tahoe basin. These uses, however, were not the first that measured the importance of Lake Tahoe for the surrounding region. Lake Tahoe water flows into the water-hungry semidesert of western Nevada and was valued highly for use in irrigation many years before Lake Tahoe became well known.

The outflow from Lake Tahoe, augmented by drainage from mountain regions to the north and the northeast, forms the Truckee River. In California, the Truckee provides water for power generation and domestic water supplies. In Nevada, the water is used for municipal supply in the cities of Reno and Sparks and for irrigation in the lower Truckee and Carson basins and is important to the economy of a large area. Figure 10 shows the entire Truckee River basin from its origin south of Lake Tahoe to its terminus in Pyramid Lake, Nev., which has no outflow.

During the last hundred years, man's use of water in the Truckee River basin has been marred by water-rights disputes involving not only the citizens of the area, but also the California and Nevada State Governments and the Federal Government. Many of the problems have been solved, but the biggest problem of all remains: providing enough water for domestic use in California and Nevada and for agriculture in Nevada without causing an excessive drop in the level of the lake or harmfully affecting the quality of the water.

The story of large-scale use of water in the Lake Tahoe basin began in 1865 when Colonel A. W. Von Schmidt, an engineer from Prussia, acquired some land at the Truckee River outlet of the lake and was granted the right to build a dam across the river and to appropriate 500 cfs (cubic feet per second—more than 320 million gallons per day) of water. By 1870 Von Schmidt had completed a wooden and rock dam. In 1871 he announced a bold plan to supply San Francisco with water from Lake Tahoe by constructing a tunnel through the

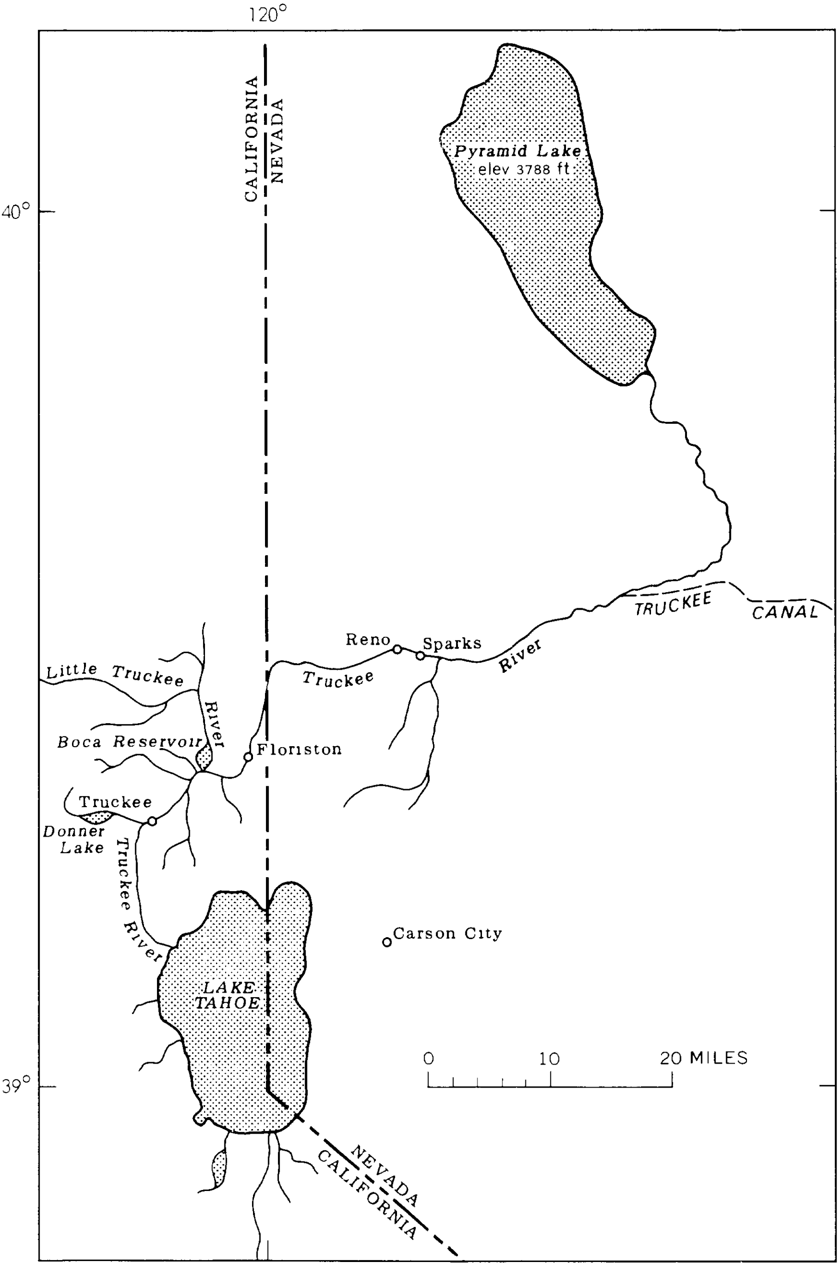

FIGURE 10 ~ The Truckee River.

Sierra Nevada large enough to accommodate both a railroad line and two 6-foot-diameter conduits. The scheme was dismissed as too ambitious and costly; neither the city of San Francisco nor the Central Pacific (now the Southern Pacific) railroad was interested.

In 1870 the California legislature granted the Donner Lumber and Boom Company, a subsidiary of the railroad, exclusive use of the Truckee River between Tahoe City and Truckee, as well as the right to build a dam at the outlet. However, because of Von Schmidt's prior rights to the outlet, the company could not fully implement their plans. Von Schmidt continued to seek acceptance of his idea but was unable to muster enough support and eventually control of the dam passed to the Donner Company.

In 1903 the Donner Lumber and Boom Company demanded a fee from power companies along the Truckee for the privilege of using the water. In response to this demand the Fleishhacker family, who owned two power plants that served pulp and paper mills at Floriston, Calif., about 15 miles downriver from Truckee, purchased the "littoral rights" to the Truckee River outlet from the Donner Company.

Under the Reclamation Act of 1902 the U.S. Bureau of Reclamation of the Department of the Interior initiated a program of supplying water from the Truckee River to agricultural lands in Nevada. The Bureau planned to construct a new dam at the Lake Tahoe outlet to provide greater control over the flow in the Truckee. Not certain that the purchase of "littoral rights" by the Fleishhacker interests was legal, the Bureau over a period of years negotiated with both the Donner Lumber and Boom Company and the Fleishhaker power company in an attempt to firmly acquire the necessary rights. Its efforts were foiled by lakeshore landowners who were opposed to increased discharges from the lake that would result in lower lake levels.

In 1908 the Truckee River General Electric Company, predecessor of the Sierra Pacific Power Company, purchased all the power plants along the Truckee as well as the dam and the adjacent land. The terms of the purchase included an agreement by the power company to maintain an average flow at Floriston of 500 cfs from March 1 to September 30 and 400 cfs for the other months. These required releases became known as the "Floriston Rates." At the time, they assured a sufficient supply of water for power generation in California and for irrigation in Nevada.

In 1908 the Bureau of Reclamation initiated the Newlands Project, named after its principal promoter, Nevada's Senator Francis Newlands. The goal of the project was to supply water for irrigation of a large area of land near Fallon, Nev. In 1909 the Bureau was granted control of the Lake Tahoe dam and gates by the Truckee River General Electric Company. In the agreement the Floriston Rates were reaffirmed, and the Truckee-Carson Irrigation District, created under the auspices of the Bureau, was issued the right to appropriate all surplus water of the Truckee River for irrigation in Nevada. In return, the Truckee River General Electric Company received the perpetual right to divert the Truckee anywhere along its reach as well as the right to locate its installations on any public lands east of the Truckee River watershed. In addition, the Government assumed the responsibility for any damage claims brought against the power company as a result of the agreement. The power company also was granted the right to construct a diversion channel from Lake Tahoe at any point along its shores; however, because of adverse public opinion, this right was never exercised.

In 1915 a Federal court decreed that the U.S. Government had the right to control discharges from Lake Tahoe. In addition, the decree stipulated that the Floriston Rates of flow must be maintained, and the water level of the lake must not be allowed to drop below 6,223 feet above mean sea level.

The Truckee-Carson Irrigation District was granted the right to operate the Newlands Project and the Lake Tahoe Reservoir by the Bureau of Reclamation in 1926. The Bureau also agreed to abstain from additional diversions from the Truckee and Carson Rivers until enough water was available to irrigate 87,500 acres at Newlands, Nev.

The water shortage problems created by a severe drought in the early 1930's led to the Truckee River Agreement in 1935. Parties to the agreement included the Bureau of Reclamation, Truckee-Carson Irrigation District, Washoe County Conservation District, and the Sierra Pacific Power Company. The States of California and Nevada and the Lake Tahoe landowners did not participate in the negotiations. Major provisions of the agreement included:

1. Maintaining the Floriston Rates, except for those periods of low lake levels occurring between November 1 and March 31. During this time the new rates were established at 350 cfs for lake levels between 6,225.5 and 6,226.0 feet and at 300 cfs for lake levels below 6,225.5 feet.
2. Allowing water to be pumped out of the lake for irrigation upon the consent of the Secretary of the Interior or upon the consent of the attorneys general of the States of California and Nevada if the pumping is for sanitary or domestic purposes.
3. Fixing the low-level elevation of the lake at 6,223.0 feet above sea level and the high water level at 6,229.1 feet above sea level.
4. Constructing Boca Reservoir, which has a storage capacity of 40,000 acre-feet, on the Little Truckee River. Boca Reservoir was completed in 1939.

A Federal court decree of 1944 redefined the irrigation rights in the Truckee River basin, affirmed certain water rights of the Pyramid Indians, and clarified the rights of the power plants. Reservoir operating procedures were established, so that the Floriston Rates could be maintained. Finally, the Truckee River Agreement of 1935 was incorporated into the 1944 decree.

Aerial view of the outlet of Lake Tahoe. The dam is below and left of the center of the picture, 100 feet or so upstream from the highway bridge over the Truckee River. Streets in Tahoe City are near the top of the picture.

In 1955 the States of California and Nevada each created interstate compact commissions to formulate recommendations for solving water and sewage problems in the entire Truckee River basin. The more important recommendations made by the commissions for the Lake Tahoe basin included the following:

1. Pumpage from the lake should not exceed 34,000 acre-feet per year, and return flow from such pumpage should not be transported from the basin.
2. Transbasin diversions should not be changed. (There are three transbasin diversions from the Lake Tahoe watershed, amounting to approximately 5,000 acre-ft annually. The Marlette Lake diversion in Nevada supplies water for domestic use in Virginia City. Diverted water from Third Creek, also in Nevada, is used for irrigation in Washoe Valley. About 2,000 acre-ft is diverted annually from Echo Lake into the South Fork of the American River.)
3. Sewage or sewage effluent should not be discharged directly into Lake Tahoe, unless the quality of the discharge is such that it will not impair the quality of lake water.
4. Waste effluents should not be exported unless an equal amount of water is imported.

Opponents of these recommendations argue that the Lake Tahoe basin might be faced with a serious water shortage if annual pumpage from the lake were limited to only 34,000 acre-feet.

There is also opposition to the recommendation that the export of effluents from the basin be delayed until an equal amount of water can be imported, based on the conviction that effluents must be exported immediately to preserve the purity of the lake. With the aid of Federal and State funds, the planning and construction of transbasin pipelines for exporting sewage effluent was under way in 1967.

HYDROLOGY

Hydrology is the study of the waters of the earth, their occurrence, distribution, and movement. The hydrology of the Lake Tahoe basin that will be described here is concerned with the water brought to the basin as rain or snow, its movement within the basin, the forces that act upon it, and its manner of leaving the basin.

Hydrology is not as yet an exact science. The study of forces and factors involved in the behavior of water in the environment includes atmospheric physics, hydraulics, chemistry, and biology. The quantities involved are tremendous; a winter storm that brings 2 inches of water to the basin in 2 or 3 days as rain or snow carries more than

70 million tons of moisture. At the same time the destiny of each molecule of water entering the environment is uniquely determined by the physical and chemical interactions to which it is exposed. Obviously, we can only generalize about those quantities and forces. The random variations that exist in nature from place to place and from time to time make precise measurements rather pointless. We can only gather records of data that most directly concern us and use that information to describe what we consider to be the important characterisics of hydrology.

Data that have been gathered in the Lake Tahoe basin include snow depths and water contents, total precipitation (rainfall plus the water equivalents of snowfall), evaporation of water from a standard 4-foot diameter pan, and temperature. Precipitation, evaporation, and temperature data have been gathered at only a few points, mostly near the lake. The most accurately measured data, however, are the outflows from the lake into Truckee River. These have been measured since 1901, and daily as well as annual flows are known to within a few percent. Records of the level of water in the lake have also been kept, and therefore variations of the amount of water in storage are known.

The tabulation of quantities of inflow of water to a region and of the quantities leaving the region and the routes by which they leave is called a hydrologic budget. Figure 11 is the estimated annual hydrologic budget of the Lake Tahoe basin. The value shown for average annual change in storage is really meaningless because a drop of 7 inches in lake level during the 66 years would change storage by 70,000 acre-feet and would be interpreted as an average annual change of 1,000 acre-feet. Changes in storage of more than 70,000 acre-feet during single years are frequent.

The story of figure 11 is amplified by the information in table 1, statistics of the annual hydrologic budget of the Lake Tahoe basin. The table shows the mean value (that is, the average of all estimated or observed annual events), the median (the value between the highest half and the lowest half of events), the standard deviation (a measure of scatter; for example, about two-thirds of the years had outflow of between 52,000 and 290,000 acre-ft, determined by subtracting 119,000 acre-ft from or adding it to the mean of 171,000 acre-ft), and the greatest and smallest estimated or observed annual values. Because of the relative ease of measurement, the values of outflow of water from the lake are much more accurate than any of the other components of the budget. The values of average annual precipitation and water loss pertaining to land and water surfaces may be in error by several percent. The same is true of the precipitation lines of figure 9 and of the component values suggested for individual years in the specific instances that are cited in this report; however, because their integrated residual in the form of changes in storage and outflow are

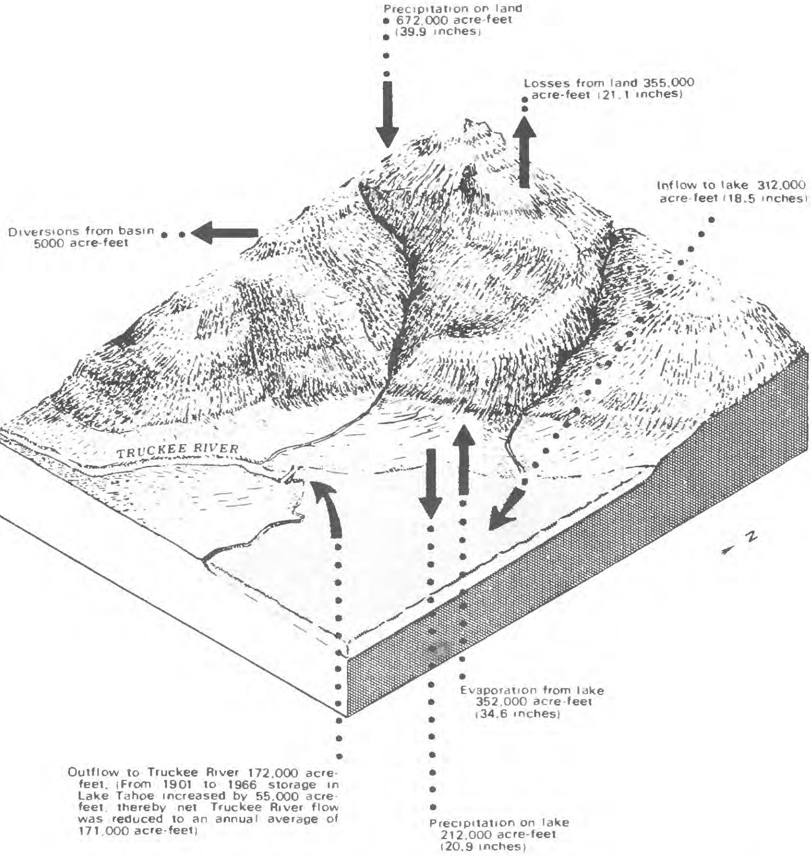

FIGURE 11 ~ Estimated annual hydrologic budget of the Lake Tahoe basin.

known rather precisely, the relative magnitudes of the components, one to another, cannot be greatly in error.

The annual diversion of 5,000 acre-feet, mentioned in the section, "History of Water Use," is from Echo Lake, Marlette Lake, and Third Creek. The losses from land of 355,000 acre-feet include evaporation from small lakes and streams, in addition to evaporation from moist soil surfaces, and from transpiration, the process by which plants utilize water. After these losses, probably a little less than half the water that falls on the land reaches the lake in the form of streamflow or underground seepage. The lake also receives precipitation directly on the lake surface. It loses water to the air by evaporation, and the residual flows over the dam and through the gates at Tahoe City into the Truckee River or is retained to increase the amount of water stored in the lake. Losses from the lake by underground flow or seepage are probably very small or nonexistent.

TABLE 1 ~ *Estimated statistics of the anunal hydrologic budget of the Lake Tahoe basin, 1901–66*

Component	Mean	Median	Standard deviation	Maximum	Minimum
Runoff to lake, after diversion . . . . inches . .	18.5	17.0	8.0	41.5	4.6
Precipitation on lake . . do . .	20.9	20.5	4.2	35.0	12.8
Evaporation from lake . do . .	34.6	35.2	3.3	39.5	28.2
Net runoff from basin [1] . . acre-feet . .	172,000	155,000	205,000	767,000	[2] —194,000
Outflow to Truckee River [3] . . do . .	171,000	152,000	119,000	657,000	4,700
Range in stage . . . . feet . .	2.27	1.97	.94	4.9	.8

[1] Represents outflow to Truckee River if year-end lake level were always the same.
[2] Negative value reflects excess of evaporation from the lake over the sum of inflow and precipitation on the lake.
[3] Outflow as it actually occurred.

NOTE.—0.3 inch of runoff is diverted from the basin and therefore does not reach the lake. Highest lake stage: 6,231.26 ft, July 1907. Lowest lake stage: 6,221.74 ft, December 1934.

As shown in table 1, the components of the hydrologic budget vary greatly from year to year. During the wet water year [1] from October 1, 1906, to September 30, 1907, inflow to the lake from the land was 698,000 acre-feet, and precipitation on the lake was 356,000 acre-feet. Of this input of 1,054,000 acre-feet, 287,000 acre-feet was lost by evaporation, 657,000 acre-feet flowed down the Truckee River, and 110,000 acre-feet remained in the lake. In contrast, during the dry water year 1924, only 78,000 acre-feet reached the lake from the land and 130,000 acre-feet by direct precipitation; 402,000 acre-feet was lost by evaporation and 178,000 acre-feet was released to the Truckee River. Because of the low total inflow, storage in the lake was diminished by 372,000 acre-feet. The extreme changes in lake storage were the decrease just described, in water year 1924, and an increase of 419,000 acre-feet in water year 1938.

An important aspect of hydrology, in addition to quantity, is timing because the growing season is the period when both man and nature have the greatest need for water. The Lake Tahoe basin has the same seasonal variation in precipitation as does the entire region west of the Sierra Nevada; that is, winter precipitation and summer dryness. The timing of inflow to Lake Tahoe is also affected by the fact that much of the precipitation input to the basin is in the form of snow, awaiting release by the melting that occurs in late spring and early summer. Thus most of the 212,000 acre-feet average inflow from direct precipitation upon the lake comes during the months December to

[1] The period October 1 to September 30 of the following year is by convention called the water year. It is selected as the period most convenient for hydrologic computation.

March, while much of the 312,000 acre-feet runoff from the land area is often delayed until the months of April to July. These inflows, when considered as components of the net input to the storage and discharge regimen of the lake, are modified by evaporation from the lake surface. The evaporation loss is relatively small during the damp, cool winter months and is greater during the late spring and summer (the melt period).

August, September, and October are months of little precipitation, negligible snowmelt, and high evaporation. Therefore the 9 remaining months can be considered the inflow period and can in turn be separated into the 5-month winter period, November to March, when most precipitation arrives but when there is little melting of snow and the 4-month melt period, April to July, when there is much less precipitation but more snowmelt and evaporation. The variations in timing and magnitude of net input to the lake can be demonstrated by data from the unusually dry and unusually wet years 1961 and 1965:

	Winter period	*Melt period*
1961 net input:		
Time	Jan. 24–Mar. 31	Apr. 1–June 13
Percent	29	71
Thousand acre-feet	28	70
1965 net input:		
Time	Dec. 19–Mar. 31	Apr. 1–Aug. 17
Percent	60	40
Thousand acre-feet	333	226

Net input is the sum of Truckee River outflow plus increase in storage in Lake Tahoe. The 1961 melt period was rather short, while in 1965 a severe storm in December caused both heavy wintertime runoff into the lake and a prolonged period of snowmelt. Before and after the periods shown, evaporation loss from the lake was generally greater than inflow.

The variation of annual precipitation from place to place has been discussed in the section "Climate" and is shown by figure 9. Inflow to the lake generally varies in location in proportion to the quantity of precipitation received by the various contributing streams. Inspection of figure 9 shows that the south and west parts of the basin, especially the areas draining towards Emerald Bay and Fallen Leaf Lake, receive the most precipitation; that region therefore contributes a large part of the inflow. Of the inflow to Lake Tahoe from land areas, 80 to 90 percent is from California.

The slopes of the Lake Tahoe basin are drained by many streams; by far the greatest flow is from three that enter the south end of the lake. These are, from east to west, Trout Creek, Upper Truckee River, and Taylor Creek. Together they drain about 36 percent of the land area of the basin and yield from 40 to 45 percent of the runoff. These and other selected basins are shown in figure 12.

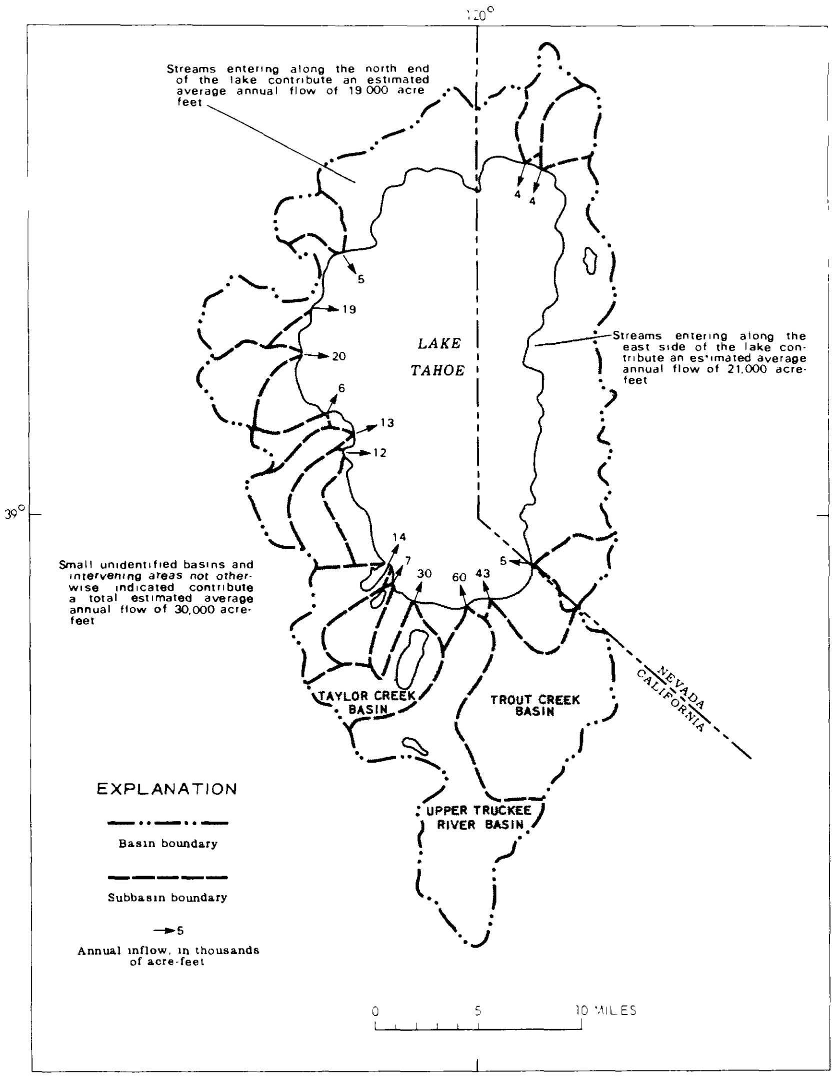

FIGURE 12 ~ Principal subbasins contributing to Lake Tahoe and their estimated average annual flow.

Under natural conditions the streams entering Lake Tahoe carry an average of 100 to 250 mg/l of suspended sediment, as do most streams in the Sierra Nevada. This is equivalent to about 0.13 to 0.34 ton of sediment per acre-foot of inflow, or 40,000 to 100,000 tons per year, on the average. Some of the sediment settles in the lake, and the Truckee River probably carries away not more than 0.06 to 0.13 ton per acre-foot, or 10,000 to 25,000 tons per year. This indicates that perhaps 50,000 tons of sediment are deposited in Lake Tahoe each year, enough to reduce the average depth of the lake by 1 foot in about 3,200 years. The activities of man in the basin probably increase the volume of sediment entering the lake, and some of this material is undoubtedly deposited on the lake bottom. However, our knowledge of the quantities involved and of their trends is not complete enough to justify an estimate of the long-range effect.

Lake Tahoe water contains some 60 to 70 mg/l of minerals in solution. Most streams in the area that have been studied contain similar concentrations of dissolved solids, so it is reasonable to assume that streamflow entering and leaving the lake has the same characteristic; studies of Truckee River water show about the same concentrations. These values, converted to weights, show that about 30,000 tons of dissolved solids per year on the average enter the lake in streamflow and about 17,000 tons leave it. Precipitation and fallout of soluble dust from the air can be conservatively estimated to add another 1,000 tons per year of dissolved solids, so that the net increase of minerals in Lake Tahoe is probably about 14,000 tons per year. If all this material remained in solution, concentration of dissolved solids would increase about 10 mg/l in 100 years; however, there are several physical, chemical, and biological processes that remove solutes from the water, and therefore the actual increase in concentration is considerably slower. The dissolved solids in both the streams and the lake are in the form of ions, mostly bicarbonate, silica, calcium, sodium, sulfate and chloride.

In addition to suspended sediment and dissolved minerals, flowing water carries organic material derived from the environment through which it passes. This material ranges in size from floating tree trunks, through decaying leaves and bark, down to particles too small to see. If conditions are favorable the organic material eventually decays to form gases and adds to the dissolved mineral content of the water. The processes and products of decay are important to the biology of a stream or lake, and the density and character of aquatic life are dependent upon the physical and chemical characteristics of the water.

Lake Tahoe receives organic material from the streams that feed it. Because of the great volume of water in the lake, the incoming water remains there a very long time, and the processes of decomposition are given the opportunity to operate more completely than in a smaller lake. Also, about 40 percent of the water annually entering the lake comes as precipitation and is almost completely free of organic material. Moreover, in the past there has been a low supply of nutrients to the lake, therefore biological productivity of the lake has been inhibited. For these reasons, under the natural regimen the lake as a whole is almost completely free of the disagreeable side effects that accompany an overabundant supply of organics, such as objectionable odor, taste, or color of the water.

LIMNOLOGY

Limnology is the scientific study of bodies of fresh water, with special reference to plant and animal life. In this section Lake Tahoe is described as an example of the family of lakes, and its unique characteristics as an individual are examined in terms of lakes in general. Limnology and hydrology are thoroughly intertwined; therefore, this and the preceding section are closely related.

Lakes originate in many ways. Glacial movement sometimes scoops out a trough that may fill with water and become a lake; Fallen Leaf Lake is an example of such action. Glacial debris, landslides, or volcanic outflows can obstruct valleys and create lakes. The ground surface can subside, either because of the removal of soluble underlying rock by water or because of crustal movements of the earth, and provide a basin that will fill until water finds a point of overflow. Lakes form in the craters of inactive volcanoes and in the oxbow-shaped troughs left behind when a river changes its course. Lake Tahoe has been affected by many of these phenomena. As mentioned in the section, "How the Basin Was Formed," the Tahoe valley itself was formed by the sinking of a massive block of the earth's crust during a period of geological instability. The level of the lake and the location of its outflow have been affected by glacial action, by lava flows from volcanic vents, and undoubtedly by landslides. Because of the predominating influence of crustal sinking in its formation, Lake Tahoe is considered a magnificent example of a graben lake. Many large lakes have been formed in this manner, among them the two deepest known: Baikal, in Siberia (greatest known depth about 5,700 ft), and Tanganyika, in Africa (4,800 ft). Pyramid Lake, into which the Truckee River flows, is a graben lake about one-fifth as deep as Lake Tahoe.

Although Lake Tahoe is not among the large lakes of the world in surface area, it is the 14th largest natural fresh-water lake in the United States, excluding the Great Lakes. The combination of area, depth, and altitude, together with the relatively small area of contributing basins, creates a unique situation. The great volume of the lake, about 122 million acre-feet, results in a relatively slow flushing action by the water that flows through. Flushing time, sometimes called self-purging time, must be measured on the basis of outflow from the lake; water losses by evaporation tend to concentrate impurities rather than to remove them. The flushing time of Lake Tahoe computed thus (dividing volume by annual outflow) is roughly 700 years; this compares to some 185 years for Lake Superior, having 97 times the volume of Lake Tahoe; about 10 years for lakes Chelan, Wash., Seneca, N.Y., and Sebago, Maine; and 2.6 years for Lake Erie, having more than four times Lake Tahoe's volume. Thus the flushing action resulting from the passage of water is much slower in Lake Tahoe than in most lakes, and the time of residence of a given mass of water, together with all the organic and inorganic material carried by the water, is relatively long. This long residence probably has some effect upon the dissolved minerals; it can be very important to the fate of organic materials, and it allows the settling of a large part of the incoming sediment. Because flushing time is dependent upon the complete exchange of water in the lake and because it is unlikely that all the water involved in vertical mixing processes within the lake passes through the inflow-outflow system of the lake at a uniform rate, it is probable that the true flushing time for Lake Tahoe is considerably longer than 700 years.

The clarity of water can be measured in several ways. The most common method that provides a basis for comparison from place to place is by noting the depth to which a Secchi disk can be followed. Results of this method are subject to a rather wide range of error, however, because of differences among observers, differences in the condition of the water surface, and differences in conditions associated with the incoming light at the water surface. The transmission of light through water can be measured more objectively by use of a hydrophotometer, a device that is relatively free of such errors. Hydrophotometer readings taken at Lake Tahoe indicate that, in general, between depths of about 30 to 500 feet, 90 percent of incoming light is extinguished by 120 or 130 feet of water. Hydrophotometer readings and Secchi disk readings in other lakes show that the waters of Lake Tahoe are among the clearest water found in nature anywhere in the world.

Water temperature is an important characteristic of a lake. Its variation from time to time and its role in creating vertical currents are very significant in determining the nature of biological activity. Lake Tahoe, like most lakes, frequently has three strata or layers of water of differing temperature characteristics; the vertical extent of these layers varies with weather conditions, especially wind, and with the amount of heat added to or removed from the water within the lake. The layering fades out of existence as autumn winds and low temperatures cool the surface of the lake, and there may be mixing of water within the upper 500 feet or so of the lake because of density currents arising from temperature differences and agitation by the wind.

The three layers of water are most clearly defined during late summer and early fall. At that time there is an upper layer of relatively warm water, called the epilimnion, in which temperature decreases very slowly with depth. The temperature of the epilimnion in Lake Tahoe may sometimes slightly exceed 70°F, and the layer sometimes extends to depths as great as 75 feet. In shallow protected parts of the lake, water temperatures may be somewhat higher than the prevailing temperature of the epilimnion.

Below the epilimnion, from March or April to November or December, is another layer that varies in vertical thickness as the season advances and sometimes may reach to a depth of 250 feet. This is the region in which temperature decreases much more rapidly as depth increases, and in a typical late summer period it may exhibit a decrease in water temperature from 65°F at a depth of 35 feet to 45°F at 180 feet. This zone of rapid temperature change is called the thermocline; in shallower lakes the thermocline occupies a much narrower range of depths and the temperature gradient is necessarily much steeper.

Below Lake Tahoe's thermocline lies another layer, the hypolimnion, in which temperature again changes but slowly with depth. The hypolimnion exists as a separate zone only during the summer period when temperatures in the epilimnion are markedly higher than those at greater depths; thus the upper boundary of the hypolimnion corresponds to the lower boundary of the thermocline, and the mutual boundary in Lake Tahoe is very indefinite. The warmest temperatures of this deep layer are probably about 50°F in late summer. Very few readings have been made of water temperatures in Lake Tahoe at depths greater than 500 feet; the few data that are available indicate that, the year around, the temperature of this deep water is very close to 39°F, the temperature at which water has its greatest density. Professor C. R. Goldman, of the University of California at Davis, has conducted studies that include the collection of data from great depths in Lake Tahoe. He concluded (1965, p. 1053) that the lake is "monomictic"; that is, the water is mixed completely to the bottom once each year. This conclusion is supported by data of temperature and chemical gradients and by the fact that the water is nearly saturated with oxygen throughout the depth of the lake.

The oxygen content of the water is another factor in establishing the nature of a lake. In general, water in Lake Tahoe contains from 7 to 11 parts per million of dissolved oxygen, existing as molecules intermixed with the molecules of water. This represents a healthy condition because there is great capacity for eliminating organic impurities; low oxygen content is usually reflected by the presence of organic material that is only partially decomposed, a condition resulting in disagreeable color, odor, or taste and in a loss of transparency of the water. The dissolved oxygen in Tahoe seems to range from 90 to 105 percent of saturation throughout the upper 500 feet of the lake and varies in concentration chiefly with temperature and depth.

In water containing the relatively low concentrations of dissolved solids that are present in Lake Tahoe, biological activity depends strongly on the presence of oxygen, the prevalence of favorable temperatures, the clarity of the water which allows light necessary for photosynthesis to penetrate, and the availability of nutrients, especially nitrate and phosphate. Almost all water, including that of Lake Tahoe, contains microscopic organisms called plankton. Plankton includes plants, such as algae, and animals, such as protozoa. The plants thrive on nitrate and phosphate, and when these substances are present in the proper quantity and proportions, algae grow and multiply rapidly, sometimes experiencing bursts of growth called "blooms" that produce clouds of greenish algae. Under some circumstances, live algae growths can cause unpleasant characteristics to appear in water, similar to those associated with partially decomposed organic material.

In the normal regimen of a lake, the algae propagate and then die at a moderate rate, and the dissolved oxygen contained in the lake water is sufficient to support decomposition of the dead algae as well as all the other organic material that is continually entering the lake. If the volume of algae increases beyond some critical point, however, oxygen may be depleted by the decomposition of dead algal cells and other organic material in the water. When this occurs, the water may become colored by the undecomposed material, and the taste and odor of the water may be affected. The entire process—that of enrichment and the chain of events culminating in increased organic content—is called eutrophication.

Eutrophication proceeds most rapidly in shallow lakes that receive large amounts of plant nutrients. Algae grow most bountifully where light is present, and little light reaches the bottom of deep lakes. Lake Erie, which is rather shallow and receives nutrients in great volumes, has reached a high degree of eutrophication while none of the other and deeper Great Lakes shows such advanced signs of enrichment. It is likely then that under natural conditions, eutrophication of Lake Tahoe would be a long-time process. However, it is possible that the phase of eutrophication that is accompanied by the widespread appearance of algal blooms near the surface could be initiated in the near future if phosphate and nitrate, found in great quantity in sewage and fertilizers, continue to be injected into the lake.

From the preceding description of eutrophication, it is obvious that under the natural regimen of Lake Tahoe conditions favorable to small localized algal blooms might exist in some parts of the lake. Such blooms do in fact occur and have been observed in shallow, sheltered coves where organic material has been deposited and the circulation of water from the main body of the lake is restricted. Undoubtedly, such situations arose before man affected the lake. It is probable that, regardless of the true extent of change due to the entry of man, phenomena such as algal blooms now are more quickly detected and more widely publicized because of the widespread attention that has been directed to Lake Tahoe.

There has been much study of the eutrophication of lakes and streams but the process is very complex and involves many chemical and biological interactions so there remains much that is unknown. Most authorities now believe that accelerated eutrophication might begin in Lake Tahoe with the addition of nitrate and phosphate and that the phosphorus now in the lake is present in concentrations that are almost critical so that an increase in nitrogen could trigger the process.

CONTAMINATION

In terms of geologic time, Lake Tahoe, like all lakes, is doomed to a short life; however, its life expectancy is much longer than that of most other lakes because of its great depth. Lake Tahoe will probably remain as a large body of water long after many other lakes have been emptied by geological processes or have become filled with sediment to form marshes or solid land. It is possible, however, for man to introduce contamination that can make at least some aspects of the lake less pleasing than they have been in the past. The history of our treatment of other lakes and streams gives ample proof that our refuse can defile such beauty quickly and easily and that it probably will do so unless safeguards of some type are adopted.

Fortunately, in the Lake Tahoe basin, there is little evidence of such obvious befouling of the environment as is found in large industrial areas—the great clouds of smoke from factory chimneys, the spreading oozing heaps of slag, the windrows of trash that collect at hedges and fences, and the floating scum and solids that appear in ponds and streams. Probably there never will be smoke clouds or slag heaps in the region; there is little likelihood that heavy industry will find the basin to be an economical site. There are other and more subtle processes of contamination, however, and these are the threats that are feared.

Metropolitan region planners generally consider that on the average each person imposes about 120 gallons of sewage and 4 pounds of rubbish daily on his environment. Sewer lines, treatment facilities, and trash collection systems are usually planned to handle such an output. In the Tahoe basin, however, much of the population is transient and does not use as much water as would the same number of permanent residents, and there is little industry. For these reasons the per capita use of water in the Tahoe basin can be assumed to be somewhat lower, perhaps 90 gallons per day in 1965 and 100 gallons per day by 1990. Thus the quantities of refuse and sewage that were produced in 1965 and may be produced in 1990 in the basin can be summarized by these estimates:

Period	1965			1990		
	Population [1]	Sewage, in millions of gallons	Rubbish, in tons	Population [1]	Sewage, in millions of gallons	Rubbish, in tons
Daily, slack season	26,000	2.3	52	90,000	9	180
Daily, average	53,000	4.8	110	170,000	17	340
Daily, peak season	170,000	15	340	420,000	42	840
Annual total		1,700	40,000		6,200	124,000

[1] Middle range of estimates from several sources made during 1960–66.

Obviously, if more than 6 billion gallons of sewage and 120,000 tons of refuse are to be released into the Lake Tahoe basin each year, we must try to determine whether they will harm the environment. If they will, we must choose a course of action that will produce the least harm.

Both rubbish and sewage are sources of pollution that can adversely affect Lake Tahoe. In addition to unsightly remains, they introduce minerals and organic substances that may upset the aquatic community that has developed under the natural regimen. Chief among these harmful substances are phosphate and nitrate, which are abundant in fertilizers; therefore, water that has passed over or percolated through fertilized soil adds to the nutrient load that enters the lake. However, chemical and biochemical processes within the soil tend to decrease the quantity of phosphate and nitrate that are contributed by fertilizers.

Little can be done to reduce the amounts of nutrients that enter Lake Tahoe from the undeveloped parts of the basin. It would probably be harmful to stop that contribution even if it were practicable to do so; the well-balanced cycle of microscopic life that has existed in the lake is necessary to the existence of desirable characteristics. It is an overabundance of activity that is to be avoided, and the greatest potential for creating such an overabundance is in the probable increase in sewage.

Most of the sewage from the larger communities in the basin is now treated before being released, although overloads and breakdowns of equipment have occasionally allowed untreated sewage to enter the lake. Before the influx of visitors and residents that began about 1950, the amount of sewage entering the lake was not believed to pose a serious problem. The only effects of human activity that are clearly defined are an occasional increase in coliform organisms in some popular beach areas, especially at the south end of the lake, and local increases in turbidity when construction activity has introduced sediment into the lake.

Many plans have been proposed for avoiding the contamination of Lake Tahoe by sewage. All plans call for the complete capture and subsequent treatment of all sewage originating within the basin. The degree of treatment differs according to the ultimate disposal of the effluent as envisioned by each plan. Treatment methods are known that, although expensive, will produce an effluent of such high quality that it would meet generally accepted standards for drinking water, but even then the concentrations of nitrate might be unacceptable as inflow to the lake. Distillation of the sewage would leave only pure water, of course, but it would be prohibitively expensive.

The plan that seems most practical, and that has been adopted, is to treat the sewage thoroughly in order to produce an effluent of drinking-water quality and to pump the effluent through pipelines to streams outside the basin. This would involve the export, by 1990, of perhaps 19,000 acre-feet each year and therefore would require that the outflow of the lake be lessened by that amount or that water of acceptable quality be imported to supply the deficiency. The export destinations that are planned are the headwaters of the Carson River, for sewage originating at the south end of the lake, and the Truckee River, for sewage from the northern region. Sewage from regions along the east and west shores of the lake can be routed to one or the other of these export systems. The southern export route might require a total pumping lift of well over 1,000 feet, while the northern route would be almost level and therefore require much less pumping.

The solution by treatment and export is expensive, but not prohibitively so; local, State and Federal groups are agreed on the need for preserving the purity of Lake Tahoe, and there will be cooperation from each of these sources. Probably the greatest difficulties to be surmounted are those created by the tangle of conflicting jurisdictions and by prejudices. Laws, court decisions, and agreements of the past have established attitudes concerning water rights that are not always in accord with the maximum benefits that can be obtained, while even the most complete purification cannot remove from some peoples' minds the stigma sometimes associated with water that has once been sewage. The resolution of these difficulties requires sessions of patient discussion leading to mutual understanding. Some authorities have suggested that the creation of a regional agency with jurisdiction over water-associated matters in the area affecting the Tahoe basin may be the most practical way to bring this about.

Construction activity of almost every nature can affect the lake adversely. In addition to the introduction of sediment, nutrient transport is likely to be accelerated by the disruption of the natural ground cover. Here again, cooperation on a regionally uniform basis is necessary. It may be that guidelines can determine the nature and location of construction and logging activity and perhaps the timing, on the basis of optimum use of the lake and its environs.

Boaters, too, can introduce undesirable contaminants to the lake. Proposals for the reduction of pollution arising from boat use include the sealing of sanitary facilities and periodic inspection to insure that neither human wastes nor grease and oil leakage can reach the lake.

Rubbish and garbage can be removed from the basin by truck to some point of disposal. It is highly probable that, within the next few decades, garbage and the solid residue of sewage treatment plants can be economically converted to serve as fuel, fertilizer, or raw materials for reprocessing. Until such a time, however, some suitable disposal site must be used.

To summarize: Eutrophication is part of the natural evolution of a lake. Geologically speaking, lakes are temporary features of the landscape. In terms of human history, however, they are long lived and can be enjoyed by many generations. If mankind is careless in his treatment of a lake, he can speed up eutrophication to the point that the desirable characteristics of the lake can be adversely affected within decades. In the case of Lake Tahoe, there are indications that rapid and unpleasant changes in the lake may be imminent. The cooperative efforts of all those who are associated with the basin of Lake Tahoe can prevent this catastrophe. The means of forestalling that day are obvious and are within our reach: we have only to stop the uncontrolled inflow of everyday waste products into the basin.

MAPS OF THE BASIN

Many road maps of California and Nevada include an enlarged insert showing travel routes to and around Lake Tahoe. Much greater detail is shown on the topographic maps of the 15- and 7½-minute series that are published by the U.S. Geological Survey. The 15-minute-series quadrangle sheets have a scale of about 1 inch to 1 mile. They portray landforms by means of altitude contours and also show roads, trails, buildings, water features, and political boundaries. Most of the basin is also mapped in the 7½-minute series at a scale of 1 inch to 2,000 feet; four of the map sheets of the 7½-minute series are needed to include the area shown on one of the 15-minute-series sheets. Figure 13 shows the names and locations of the maps of the two series that include Lake Tahoe and its immediate vicinity.

The lake is also shown on maps of the 1:250,000 series (about 4 miles to 1 inch) that are published by the Survey. Lat 39° N. and long 120° E. form boundaries for maps of this series; these coordinates inter-

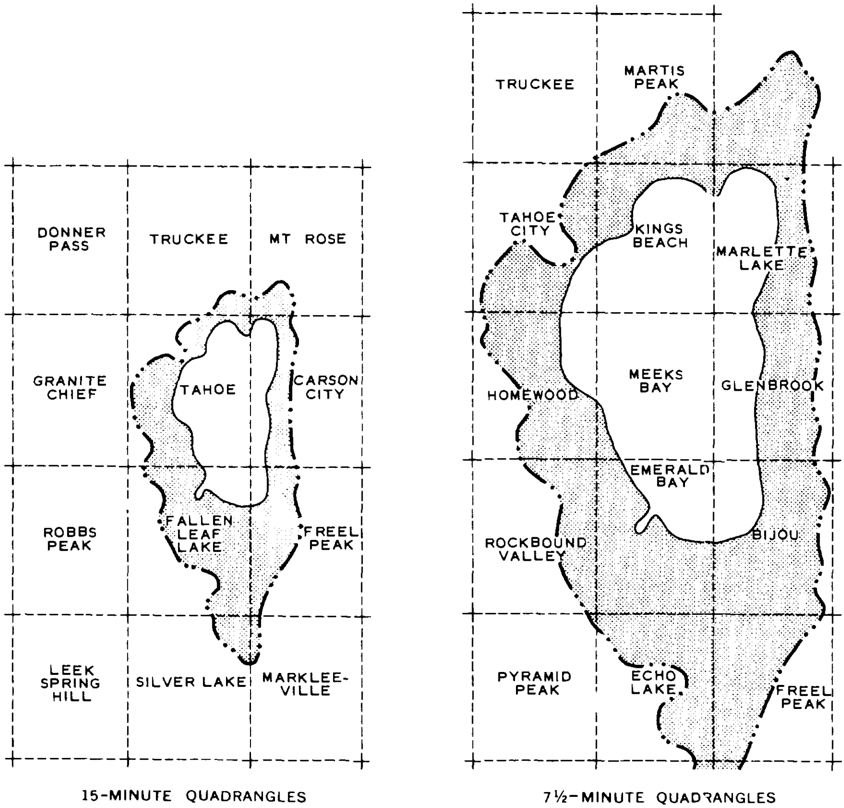

FIGURE 13 ~ Index to Geological Survey maps of the Lake Tahoe basin.

sect within the lake; therefore, four map sheets are required to show the entire lake and its vicinity. Those four sheets—Chico, Sacramento, Reno, and Walker Lake—portray a region extending more than 200 miles from east to west and 140 miles from north to south, with Lake Tahoe at the center.

Chart 5001, issued by the U.S. Coast and Geodetic Survey, is primarily intended as an aid to navigation on Lake Tahoe. The chart is published at a scale of 1:40,000 (about 1.58 inches per mile) and includes contours, landmarks, streams, and roads within a distance of about 2 miles of the shoreline. The chart shows soundings throughout the lake and bears symbols indicating the nature and location of navigational aids and hazards to the boatman.

OUTSTANDING LAKES OF THE WORLD

Lake Tahoe is well known throughout the Nation because of its many attractions. It is considered by many to rank among the world's beautiful scenes. To those seeking recreation it offers many choices. To the more technically minded, it is interesting because of its geology and topography and the extraordinary clarity and depth of the lake itself. Because this report may be read by some who have an interest in lakes in general, a list of selected lakes throughout the world is presented here.

The first 11 lakes named are the largest in the world in terms of surface area. The other lakes have been chosen because one or more of their characteristics may be of interest. The list includes the 12 deepest known lakes in the world, and the lake whose surface is the lowest (the Dead Sea). The highest lake in the world is not known; however, aeronautical charts indicate that there probably are lakes of at least 10 square miles in area at altitudes of more than 19,000 feet on the Tibetan plateau.

There is no precise definition to establish how large a body of water must be to be called a lake. There are many "ponds" that are larger than nearby "lakes," but by usage in most regions, a permanent natural body of water of more than 1 square mile in area is generally called a lake.

The surface areas of lakes are generally determined from maps, while their depths, and therefore their volumes, must be found by soundings. There are many lakes in regions that are not easily accessible and are little known. Advances in aerial mapping have increased our knowledge of many remote areas in recent years, and therefore such information as the existence of lakes, and sometimes even their surface areas and altitudes, in almost unexplored regions are known with a remarkable degree of accuracy. Knowledge of depths and volumes is much more uncertain. Little is known of the depths of the dozens of very high lakes in the Tibetan plateau, and many lakes in southern South America are as yet unsounded. Even in more accessible and familiar regions, soundings may be too few to permit a really accurate estimate of the volume of a lake or to insure that the greatest depth thus far measured is truly the maximum depth of the lake.

For these reasons, data from even some lakes bearing well-known names may be uncertain. Standard reference volumes differ from one

Lake	Area (sq mi)	Maximum known depth (ft)	Rank, by depth	Volume (millions of acre-ft)	Altitude of water surface above or below (—) mean sea level (ft)	Location
Caspian Sea	168,000	3,100	3	64,000	—92	U.S.S.R.–Iran
Superior	31,800	1,300		9,730	602	United States–Canada
Victoria	26,600	260		2,660	3,720	Central Africa
Aral Sea	24,000	220		780	174	U.S.S.R. (Asia)
Huron	23,000	750		3,700	581	United States–Canada
Michigan	22,400	920		4,650	581	United States
Tanganyika	13,100	4,800	2	15,700	2,535	Central Africa
Great Bear	12,300	450			512	Canada
Baikal	12,200	5,700	1	18,700	1,490	U.S.S.R. (Asia)
Nyasa	11,900	2,300	4	6,810	1,550	Central Africa
Great Slave	11,600	2,010	6	1,500	490	Canada
Titicaca	3,000	920			12,600	Peru–Bolivia
Issyk Kul	2,300	2,300	5	1,410	5,400	U.S.S.R. (Asia)
Great Salt	950	35		30	4,210	United States
Tengri Nor [1]	850				16,200	Tibet
Dead Sea	363	1,315		113	—1,330	Israel–Jordan
Salton Sea [2]	360	45		6	—232	United States
Geneva	224	1,020		73	1,230	France–Switzerland
Manasarovar [3]	215	270		22	15,100	Tibet
Hornindalsvatn	196	1,690	9	98	174	Norway
TAHOE	191	1,645	10	122	6,225	United States
Matana	63	1,940	7	32	1,260	Indonesia (Celebes)
Chelan	55	1,600	12		1,100	United States
Lighten [1]	50	220			16,830	Tibet
Sarez	40	1,640	11		10,800	U.S.S.R. (Asia)
Crater	21	1,930	8	10	6,180	United States

[1] Among the highest lakes of comparable size.
[2] The lowest lake of appreciable size in the Western Hemisphere.
[3] Outflow is tributary to the Indus River. Lake has long been regarded by Hindus as a sacred pilgrimage goal.

another in the surface area they ascribe to such familiar lakes as Great Slave and Victoria. The lakes that are known as the largest in area, in volume, and in depth are so outstanding that it is unlikely that further data will displace them from their top rank in those characteristics, but the relative rankings of lakes farther down the list are much less certain.

Among the lakes that at times rank with the greatest in area are some that fluctuate in size, as the vagaries of climate dictate, and vanish or almost vanish during dry periods. Outstanding examples are Eyre, in Australia, and Chad, in Africa. Lake Eyre filled in 1950 to cover an area of about 3,400 square miles, but it was completely dry in 1953. Lake Chad has varied in area from about 3,800 square miles to almost 10,000 square miles. Eyre is the sump for a drainage basin of about 500,000 square miles, much of which has a mean annual rainfall of less than 5 inches. Chad, too, is the terminus of flow for an immense desert basin.

Lake Sarez, in the Pamir Mountains of central Asia, is of special interest because of the way in which it was formed. It is not outstanding in size; in area it is roughly equal to Eagle Lake in California or Lake George in New York. It is outstanding, however, in its combination of great altitude and depth—10,800 feet and 1,640 feet, respectively. Lake Sarez was formed by a huge landslide on February 18, 1911, that dammed the Murgab River to a height of more than 2,400 feet above the valley floor. The water rose slowly for 23 years and the level has been fairly stable since 1934. Outflow is by seepage through the dam at about 500 feet below the lake surface.

Lakes in the United States were tabulated and discussed in some detail by Bue (1963), and probably the most comprehensive source of information relative to lakes throughout the world is Hutchinson (1957).

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