TAHOE: STATE OF THE LAKE REPORT 2007

UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

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INTRODUCTION

The monitoring of Lake Tahoe for nearly 40 years by the University of California, Davis, has resulted in a unique record of change in one of the world's most beautiful and endangered lakes. In this new public report, we summarize that record of the impacts of recent human activity on the water's clarity, temperature, chemical makeup and biology.

The trends revealed here tell us that Lake Tahoe is a very complex system, and its long-term behavior is not always as expected.

Our job in the scientific community is to understand that complexity and use our understanding to recommend ecosystem restoration and management options. Choosing among those management options, and implementing them, is the work of the non-scientific community.

This new UC Davis *Tahoe: State of the Lake Report*, which we intend to produce annually, is intended to give the non-scientific community more information about the variables that matter most to lake health.

Until now, only one measurement of Lake Tahoe's health status has been widely available to the public: the annual clarity report (often called the Secchi depth, after the instrument used to collect the clarity data). In the *Tahoe: State of the Lake Report*, the UC Davis Tahoe Environmental Research Center (TERC) will publish many more measurements of lake conditions.

The report is not intended to be a scorecard for the lake. Rather, it will provide a context for understanding what changes are occurring on a year-to-year basis: Was Lake Tahoe warmer or cooler than the historical record last year? Are algae increasing in concentration? And, of course, how do all the changes impact the lake's famous clarity?

The data we present are the result of the efforts of a great many scientists, students and technicians who have worked at Lake Tahoe throughout the decades—so many that it is not possible to list them all. (A partial listing is available at terc.ucdavis.edu.) Similarly, the funding that has been required to maintain this effort has come from a great many sources, spanning federal, state and local agencies.

TERC's monitoring is frequently done in collaboration with other research institutions and agencies. In particular we would like to acknowledge the role of the U.S. Geological Survey (USGS), the National Aeronautics and Space Administration (NASA), the Desert Research Institute (DRI) and the University of Nevada, Reno (UNR).

We hope you find this report helpful. I welcome your comments.

Sincerely,

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August 14, 2007

ABOUT LAKE TAHOE AND THE TAHOE BASIN

- Maximum depth: 1,645 feet (501 meters), making it 11th deepest lake in the world, second deepest lake in the USA
- Average depth: 1,000 feet (305 meters)
- Lake surface area: 191 square miles (495 square kilometers)
- Watershed area: 312 square miles (800 square kilometers)
- Length: 22 miles (35 kilometers)
- Width: 12 miles (19 kilometers)
- Length of shoreline: 72 miles (116 kilometers)
- Volume of water: 39 trillion gallons
- Number of inflowing streams: 63, the largest being the Upper Truckee River
- Number of outflowing streams: 1, the Truckee River, which leaves the lake at Tahoe City, Calif., flows through Reno, Nev., and terminates in Pyramid Lake, Nev.
- Average residence time of water in the lake: about 600 years
- Average elevation of lake surface: 6,225 feet (1,897 meters)
- Highest peak in basin: Freel Peak, 10,891 feet (3,320 meters)
- Latitude: 39 degrees north
- Longitude: 120 degrees west

ABOUT THE UC DAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER (TERC)

The Tahoe Environmental Research Center (formerly the Tahoe Research Group) is a year-round UC Davis program of research, education and outreach in the Tahoe Basin.

TERC's activities are based at permanent research facilities in the Tahoe Basin and at the university's main campus in Davis, Calif., about 90 miles west of the lake.

Our main laboratories and offices are located on the campus of Sierra Nevada College in Incline Village, Nev., on the third floor of the new Tahoe Center for Environmental Sciences building. On the first floor, we operate the Thomas J. Long Foundation Education Center, a learning resource that is free and open to the public.

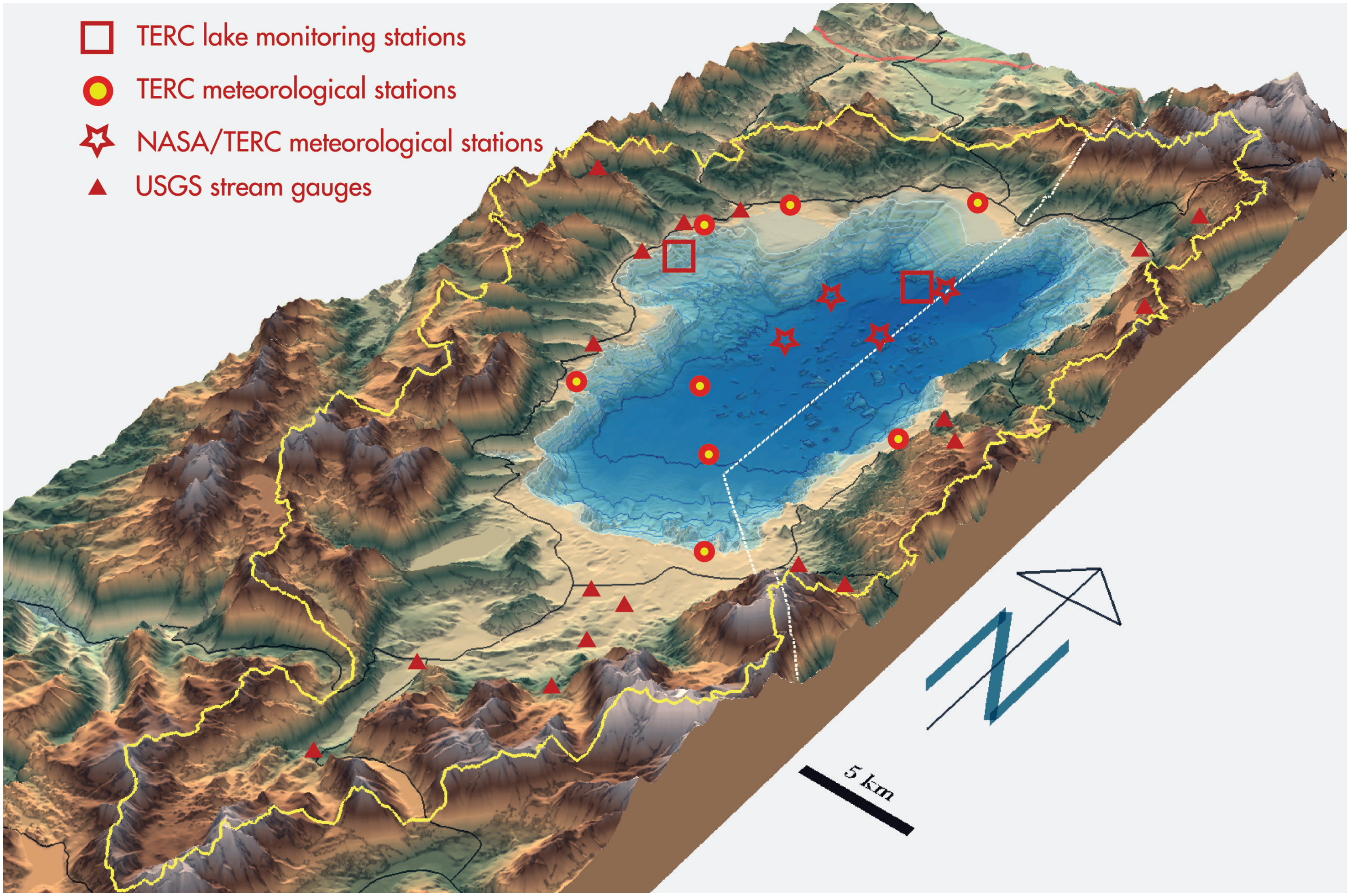
In Tahoe City, Calif., we are currently renovating our former home, an old fish hatchery, and converting it into a field station. Tahoe City is also the mooring site for our two research vessels, the John LeConte and the Ted Franz.

Our secondary laboratories and offices are located on the Davis campus in the Center for Watershed Sciences building.

Our Web site at terc.ucdavis.edu has much more information about our programs, including:

- Information for potential students, staff and faculty members, and research collaborators;
- Access to near-real-time meteorological data gathered by our sensor network;
- Exhibits and events at the Education Center;
- The fish hatchery renovation; and
- How to help support our research and teaching programs.

MAP OF TAHOE BASIN DATA COLLECTION SITES



EXECUTIVE SUMMARY

Long-term data sets are invaluable: They are the key to understanding ecosystem function and change.

The long-term data set on the Lake Tahoe ecosystem that has been collected over nearly 40 years by the University of California, Davis, has become essential to public programs of ecosystem restoration and management in the Tahoe Basin.

The data reveal a unique record of trends and patterns — the result of both natural forces and human actions that have occurred over many time scales ranging from days to decades. They tell us that Lake Tahoe is a complex ecosystem, and its behavior is not always as expected.

The UC Davis Tahoe Environmental Research Center has developed sophisticated computer models that are helping scientists better predict that behavior. The long-term data sets are being used to refine the accuracy of those models. In these times of rapid change, reliable predictive models are essential tools for Tahoe Basin resource managers.

In this and future annual State of the Lake reports, we will present data for the previous year[1] placed in the context of the long-term record and arranged in the subject areas of meteorology, physical properties, nutrients, biology and clarity. In future years, we will update the data in these subjects and hope to add new ones.

The entire report is available online at http://terc.ucdavis.edu. This Web site also contains the homepage for the UC Davis Tahoe Environmental Research Center and summarizes our current activities.

Here are some highlights of the data presented in the following pages.

METEOROLOGY

The Lake Tahoe ecosystem is in large part controlled by the meteorological conditions to which it is exposed. In the short term, these are expressed as the day-to-day variations in the weather that can, for example, produce a series of storms that will result in high stream flows and pollutant runoff into the lake. In the long term, these are expressed as normal cyclical variations, as well as abnormal variations related to global warming.

The most significant trend in the meteorology data is the record of climate warming.

Historical record:

- The nightly minimum temperatures recorded at Tahoe City have displayed an upward trend, with an overall increase of more than 4 degrees F. (Fig. 6.1)
- The number of days with average air temperatures below freezing has decreased by 30 days per year. (Fig. 6.2)
- The fraction of snow in the total precipitation has decreased from 52 percent to 34 percent. (Fig. 6.6)

Previous year:

- The number of freezing days was 62. (Fig. 6.2)
- The annual average air temperature was 56.1 degrees F. (Fig. 6.3)
- March 2006 was the coldest month in the past 8 years, with an average air temperature of 27.4 degrees F. (Fig. 6.3)
- Precipitation at Tahoe City was 48.4 inches, higher than the annual average of 32.4 inches. (Fig. 6.4)
- The wettest month in the water year was December 2005, with 18.6 inches (water equivalent), making it the ninth wettest month since 1911. (Fig. 6.5)
- The fraction of snow in the total precipitation was 37.4 percent. (Fig. 6.6)

PHYSICAL PROPERTIES

Lake Tahoe's physical properties are largely a response to the external factors that are imposed upon it, especially meteorology. In turn, the physical properties determine the environment in which all the lake's chemical and biological processes (see next sections) take place.

Historical record:

- Average lake surface water temperature has risen by more than 1 degree F. in the past 35 years, and was 52.6 degrees F. in 2006. (Fig. 7.2)

(CONTINUED ON NEXT PAGE)

[1]*"Previous year" for some parameters means data collated in terms of the water year, which runs from October 1 through September 30; for other parameters, it means data for the calendar year, January 1 through December 31. Therefore, for this 2007 report, water-year data are from Oct. 1, 2005 through Sept. 30, 2006. Calendar-year data are from Jan. 1, 2006 through Dec. 31, 2006.*

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 5)

- Surface water temperatures in July have risen by 5 degrees F. in the past 7 years. July 2006 was the warmest on record, with an average temperature of 67.8 °F. (Fig. 7.4)
- The highest recorded surface water temperature occurred on July 26, 2006: 78 degrees F. (Fig. 7.3)

Previous year:

- Lake surface level was generally high. The lowest lake level for the year was 6225.49 feet on Jan. 1. (Fig. 7.1)
- The annual cycle of mixing in Lake Tahoe extended to a depth of 650 feet in 2006, approximately one third of the total depth. (Fig. 7.6)
- Throughout the year, dissolved oxygen concentration in the surface water was between 90 and 100 percent of the saturation limit. (Fig. 7.8)

NUTRIENTS

Overgrowth of algae is a problem in Lake Tahoe. It coats rocks on shorelines, making them green and slimy. And offshore, it contributes to making the water greenish and less clear.

The two nutrients that most affect algal growth in Lake Tahoe are nitrogen and phosphorus. These nutrients are measured at various depths at both the Mid-lake and Index stations. One form of nitrogen—nitrate—enters the lake via stream runoff, urban runoff, groundwater and atmospheric deposition (falling out of the air). Phosphorus naturally occurs in Tahoe Basin soils and enters the lake via soil disturbance and erosion.

UC Davis research has found that, while Lake Tahoe algae are more responsive to increases in phosphorus than nitrogen, the greatest response occurs when both are added.

Historical record:

- Nitrogen concentrations in the lake have remained generally constant for many years. (Fig. 8.1)
- Phosphorus decreased to a minimum in 1999 and since has shown an increasing trend. (Fig. 8.2)
- Stream inputs of both nitrogen and phosphorus are directly linked to the amount of annual precipitation.

Previous year:

- Atmospheric inputs of both nitrogen and phosphorus in 2006 were relatively low.

BIOLOGY

The aspects of lake biology that have been measured for the longest times are those elements at the base of the food web – the algae (or phytoplankton) and the zooplankton (microscopic aquatic animals that graze on algae). Algae and zooplankton affect clarity and overall lake aesthetics, as well as influencing the entire lake food web.

Historical record:

- Primary productivity, or the rate at which algae produce biomass through photosynthesis, has been increasing since 1959. (Fig. 9.1)
- Since 1984, we have not seen a clear, long-term trend in phytoplankton abundance. (Fig. 9.3)
- Since 1984, the average annual depth for deep chlorophyll maximum (the depth in Lake Tahoe where the highest chlorophyll concentrations occur) declined by approximately 45 feet. (Fig. 9.5)

Previous year:

- Primary productivity in 2006 was the highest on record, at five times the 1959 level. (Fig. 9.1)
- The deep chlorophyll maximum occurred at a depth of 117 feet. (Fig. 9.5)
- Periphyton (attached algae) concentrations in 2006 were average. The two sites with the most periphyton were near the two more urban areas. (Fig. 9.9)
- Zooplankton concentrations in 2006 were the lowest recorded since 1998. Epischura concentrations were unusually low but the rarely seen Bosmina were present. (Fig. 9.10)

CLARITY

Clarity remains the parameter of greatest interest at Lake Tahoe because of its role as the leading indicator of lake degradation and the community's efforts to restore clarity to historic values. Secchi depth (the point below the lake surface at which a 10-inch white disk disappears from view) is the longest continuous measure of water clarity at Lake Tahoe. Secchi measurements began in 1968.

- In 2006, the Secchi depth was 67.7 feet, a reduction of 4.7 feeet from the previous year. The year's high precipitation (see Fig. 6.6), and the resulting high urban runoff and stream flow, largely account for this decrease. (Fig. 10.1)

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METEOROLOGY

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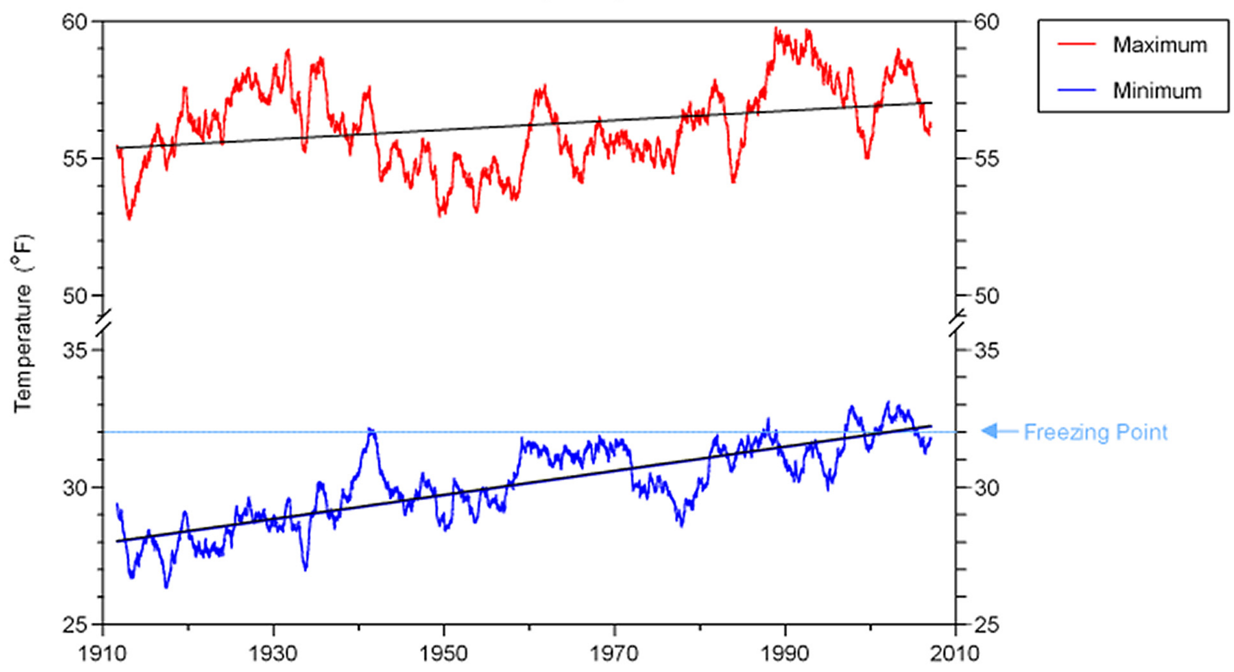
METEOROLOGY

Air Temperature

Yearly since 1911

Daily maximum air temperatures show less than a 2 degree F increase over the 95-year record. Daily minimum temperatures show an increase of more than 4 degrees F. The average minimum air temperature is now approaching the freezing point of water, which points to the likelihood of more rain and less snow, as well as earlier snowmelt.

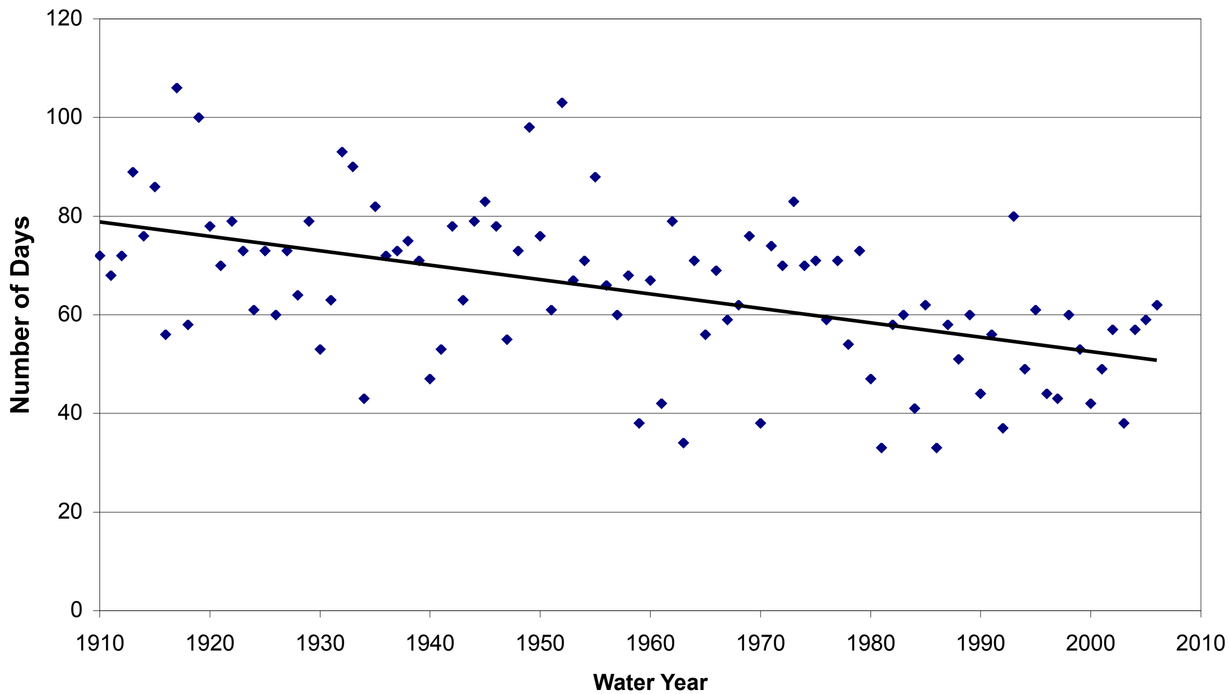


METEOROLOGY

Below-freezing air temperatures

Yearly since 1910

While there is clearly a lot of year-to-year variability, the overall trend (solid line) shows a general decrease in days below freezing since 1910. In 2006 the number of freezing days was 62.

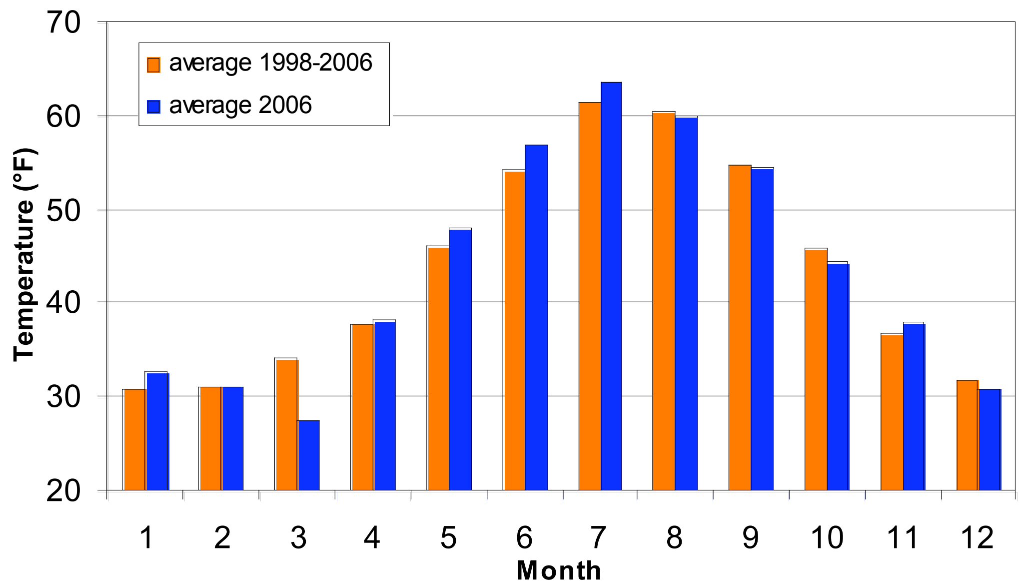


METEOROLOGY

Air temperature

Monthly, 2006 vs. 1998-2005

June and July 2006 had the highest monthly average air temperatures recorded for the eight-year period. March 2006 had the lowest monthly average air temperature recorded.

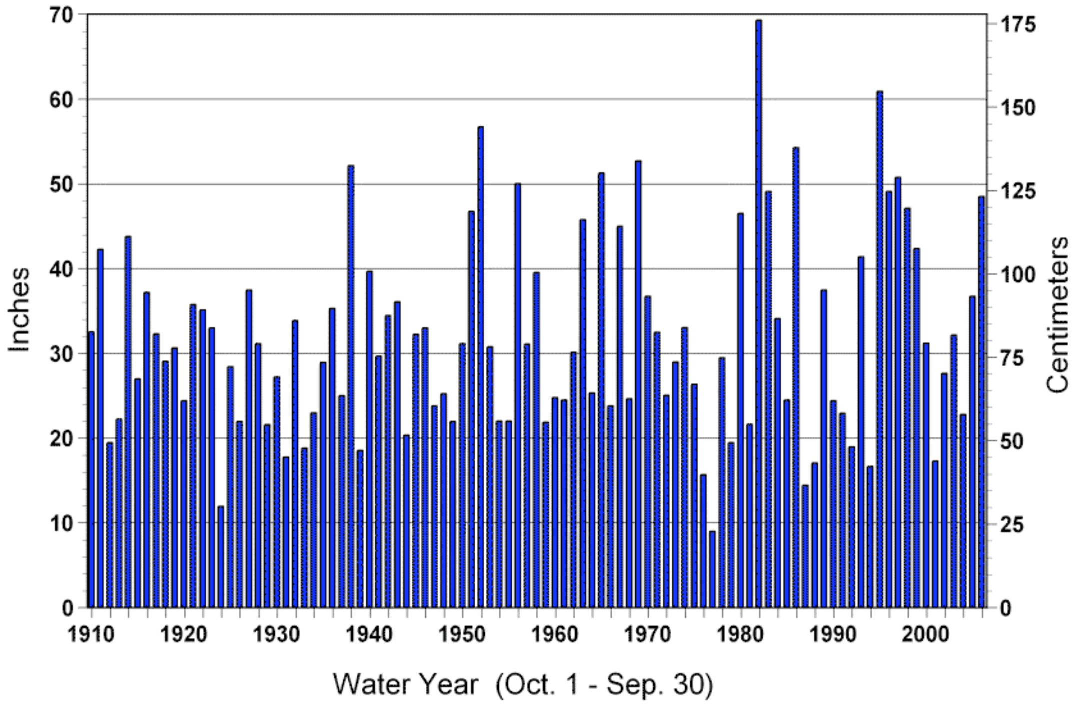


METEOROLOGY

Precipitation

Yearly since 1910

The average annual precipitation (water equivalent of rain and snow) over the entire time period was 32.4 inches. The maximum was 69.2 inches in 1982. The minimum was 8.9 inches in 1977. Precipitation for the 2006 water year was 48.4 inches.

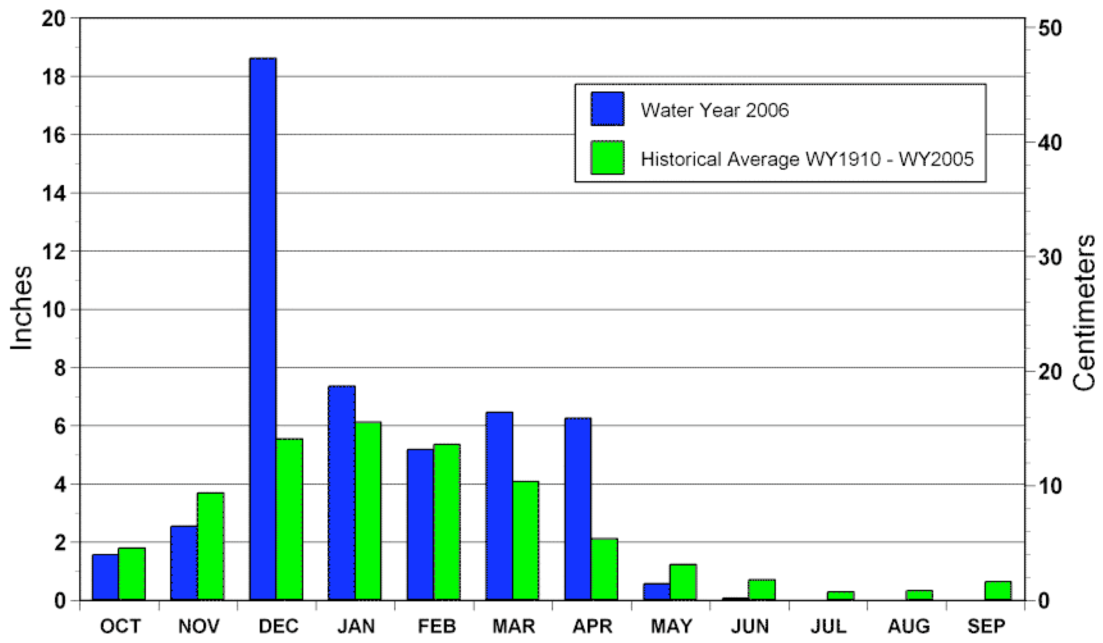


METEOROLOGY

Precipitation

Monthly, 2006 vs. 1910-2005

2006 was notable for the extremely wet December and the absence of significant precipitation in July, August and September.

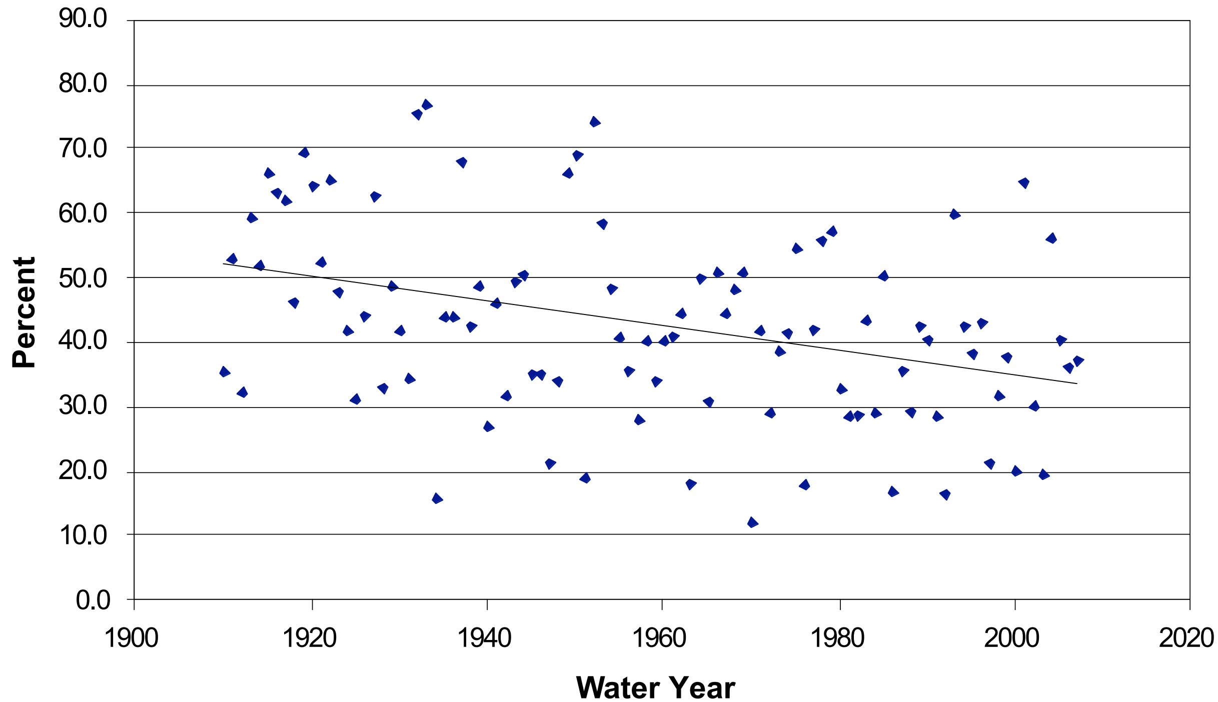


METEOROLOGY

Snow as a fraction of annual precipitation

Yearly since 1911

There is a downward trend in the fraction of total precipitation that falls as snow, from 52 percent in 1911 to 34 percent this year. (Based on precipitation records from Tahoe City, and defining snow as precipitation falling on a day when the average daily air temperature is below freezing.)



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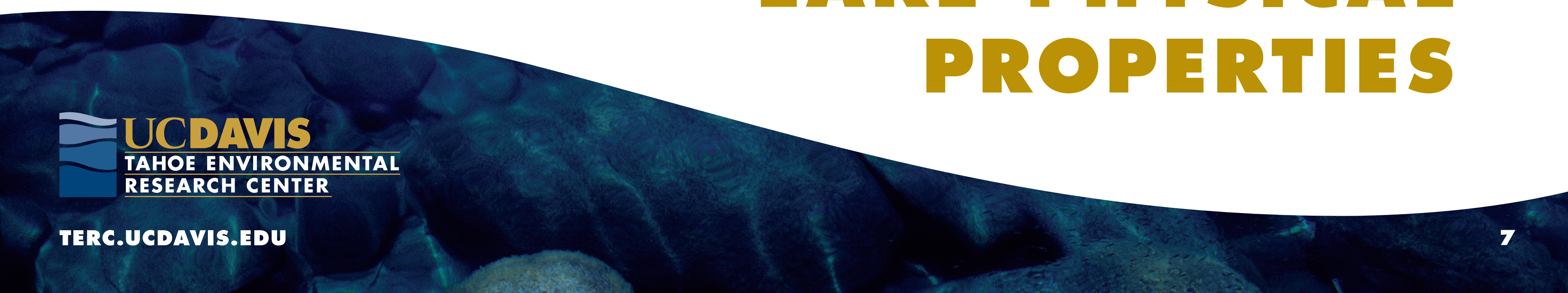
LAKE PHYSICAL PROPERTIES



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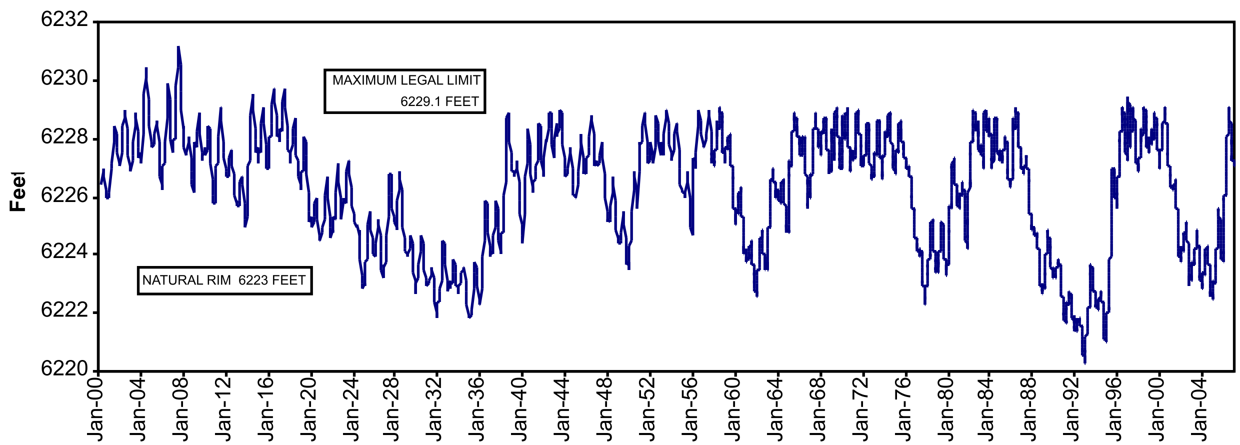
LAKE PHYSICAL PROPERTIES

Lake surface level

Yearly since 1900

Lake surface levels are recorded by the U.S. Geological Survey and reported as height above mean sea level. By law, the level of Lake Tahoe cannot exceed 6,229.1 feet, so it is kept there or lower by releasing water into the Truckee River from the dam at Tahoe City. On the other hand, water releases are not permitted when the lake surface level falls below the natural rim at 6,223 feet. The lowest lake level on record was 6,220.26 feet on Nov. 30, 1992. In 2006, the lowest lake level was 6,225.49 feet on Jan. 1, and the highest was 6,229.06 feet on June 28.

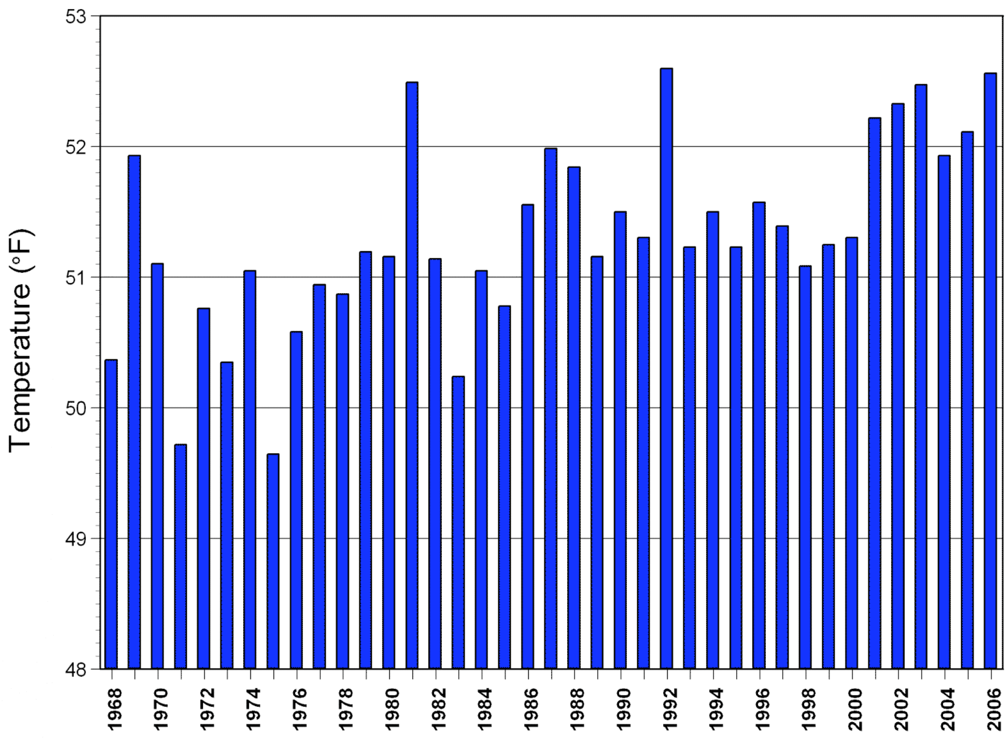


LAKE PHYSICAL PROPERTIES

Surface water temperature

Yearly since 1968

Surface water temperatures have been recorded at the Mid-lake Station since 1968. Despite year-to-year variability, there is an overall trend of rising water temperature. The average temperature since 1968 was 51.3 degrees F. For 2006, the average surface water temperature was 52.6 degrees F.

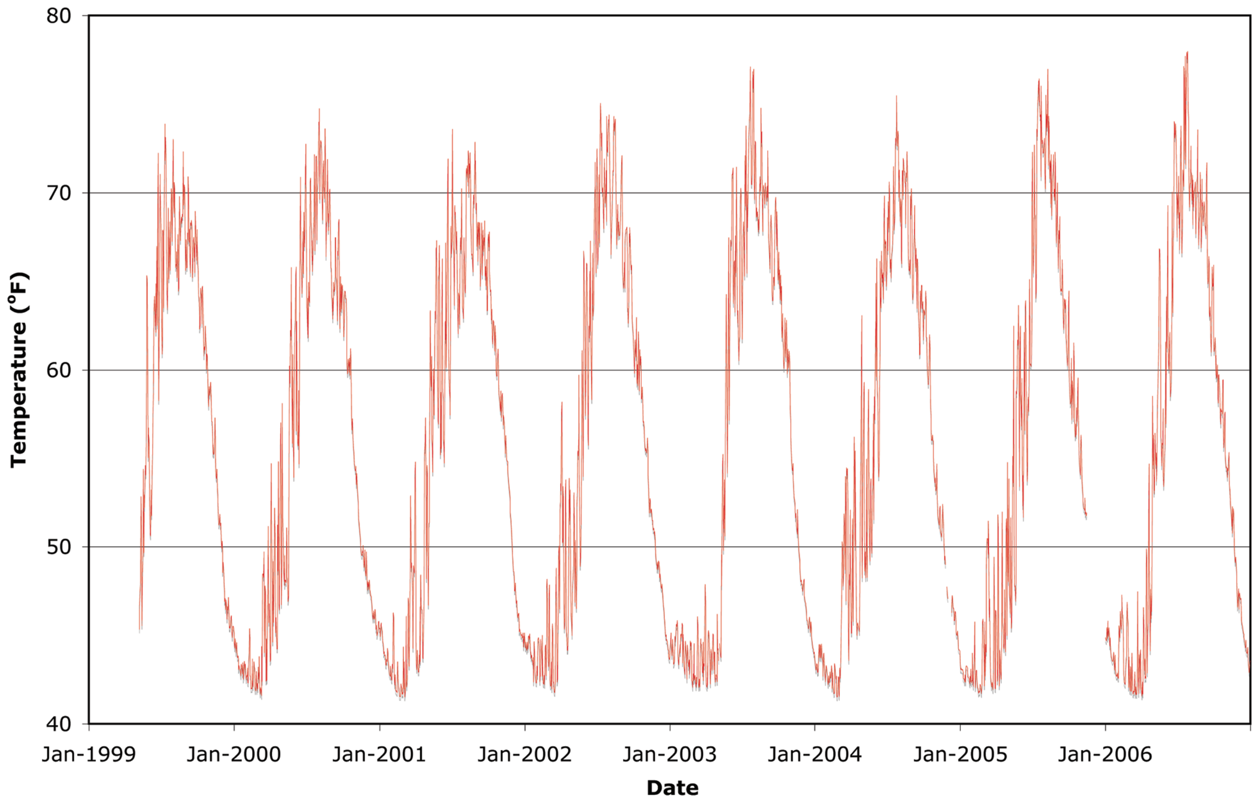


LAKE PHYSICAL PROPERTIES

Maximum daily surface water temperature

Since 1999

Winter maximum surface water temperatures have not increased noticeably but summer maximums have, with 2006 having the highest recorded surface water temperature: 78 degrees F. on July 26.

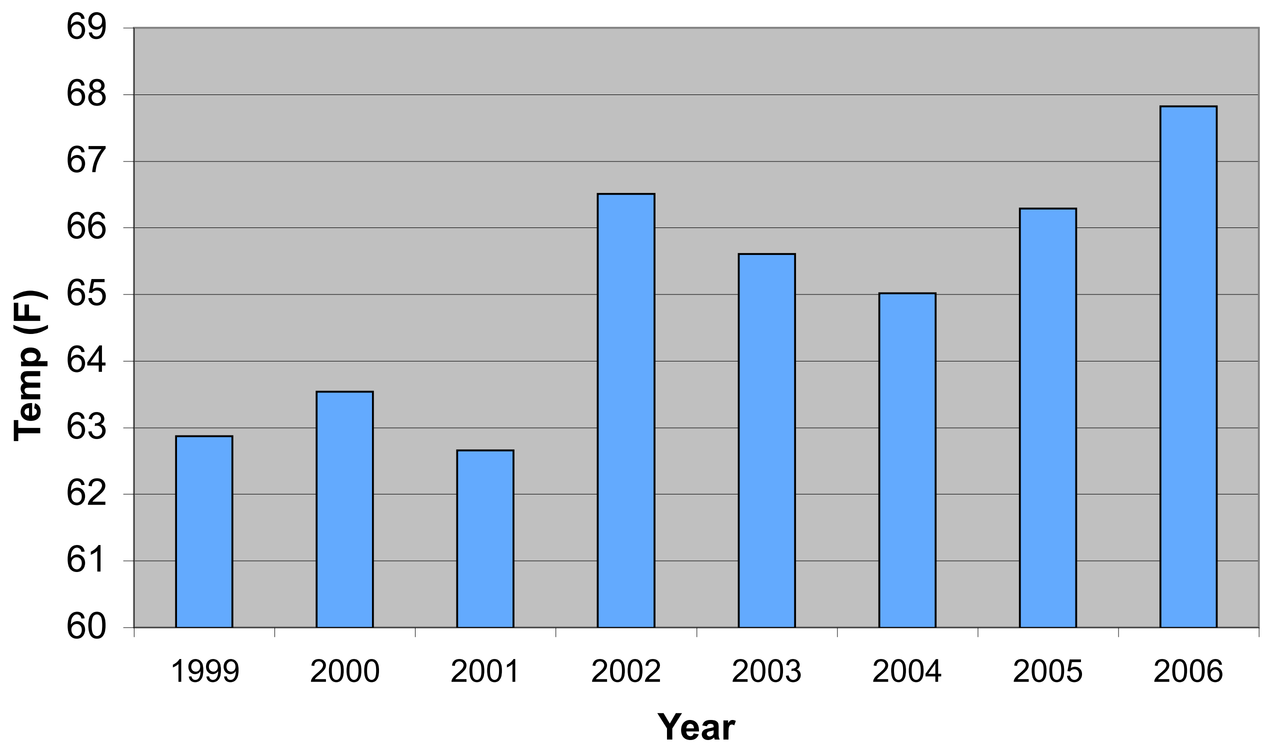


LAKE PHYSICAL PROPERTIES

July surface water temperature

Since 1999

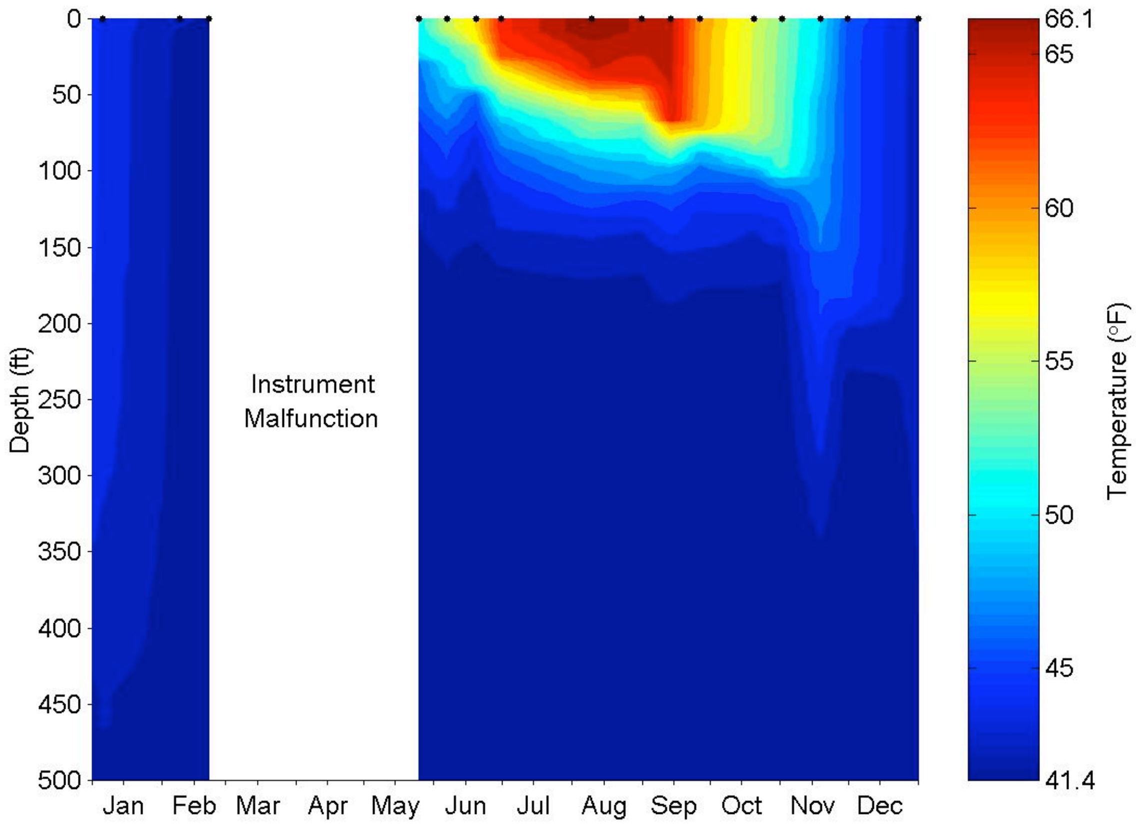
Since 1999, surface water temperature has been recorded every two minutes from four NASA/UC Davis buoys. Here are average surface water temperatures for eight years for the month of July, the month with the warmest water temperatures. 2006 had the warmest July on record, with an average surface water temperature of 67.8°F.



Water temperature profile

In 2006

At the near-shore Index Station, water temperatures at various depths are measured every two to four weeks to produce Lake Tahoe's "thermal profile." In 2006, that profile followed a typical seasonal pattern. From June into November, surface water warmed to a depth of about 70 feet. The highest temperatures occurred in July at the very surface.

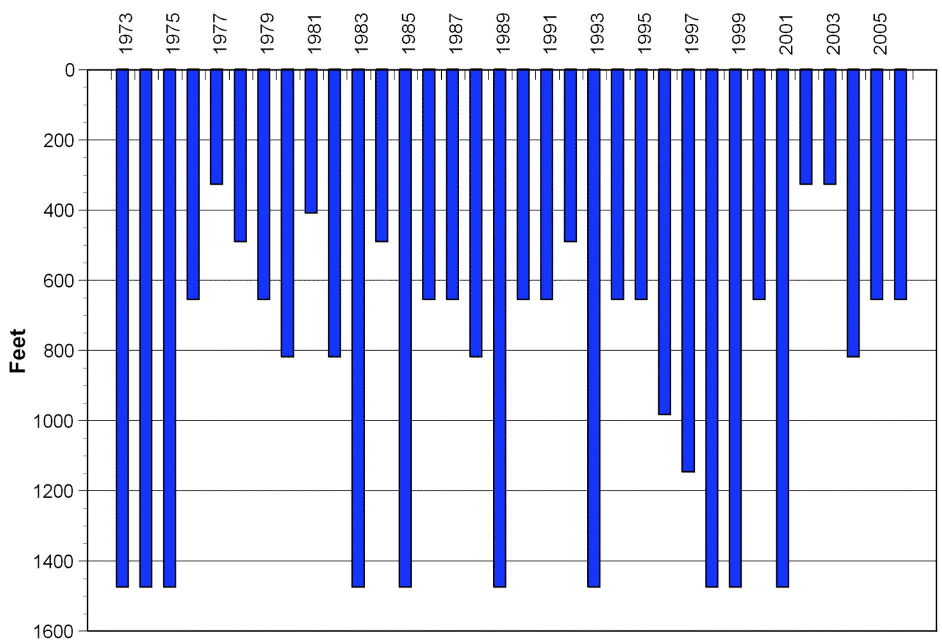


LAKE PHYSICAL PROPERTIES

Depth of mixing

Yearly since 1973

Cold water sinks, so each winter the surface waters of Lake Tahoe mix downward. The depth to which mixing occurs has profound ecological and water-quality impacts. Deep mixing brings nutrients to the surface, where they promote the growth of algae. And it takes oxygen to deep waters, which promotes aquatic life at all depths of the lake. The deepest mixing typically occurs in late February. In 2006, Lake Tahoe mixed to a depth of 650 feet.

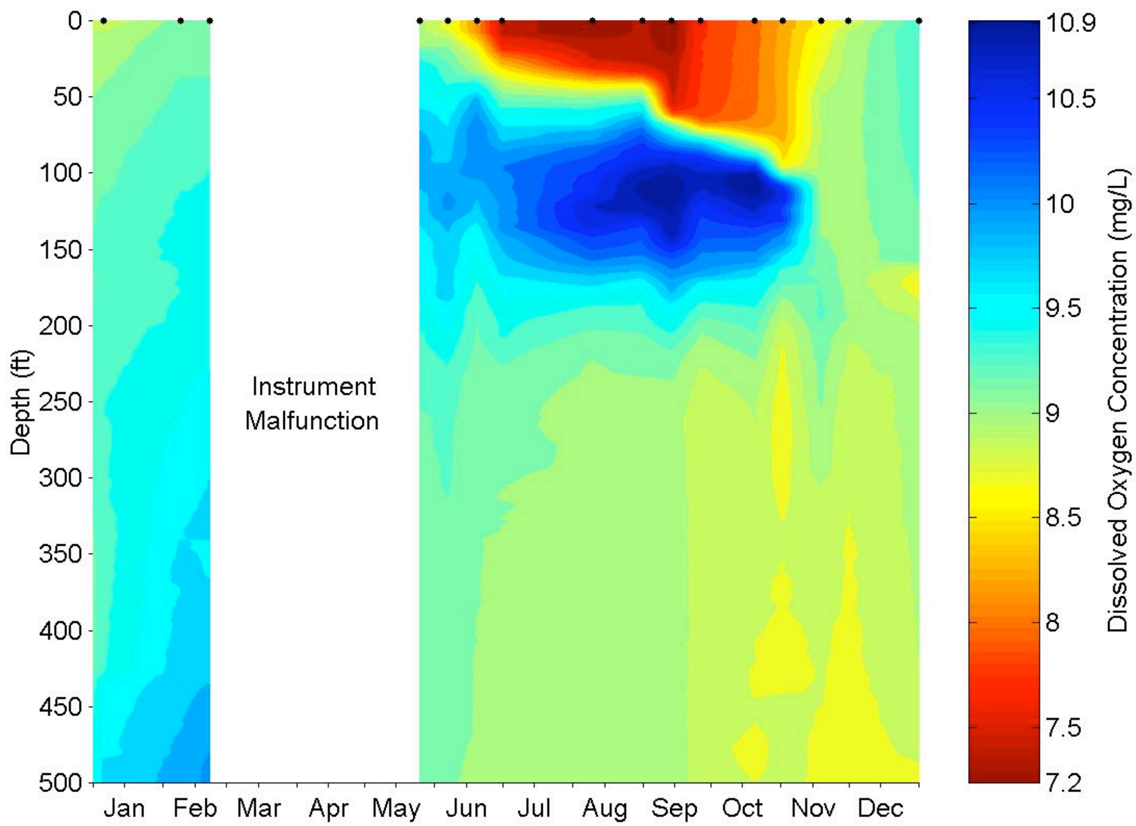


LAKE PHYSICAL PROPERTIES

Dissolved oxygen profile by volume

In 2006

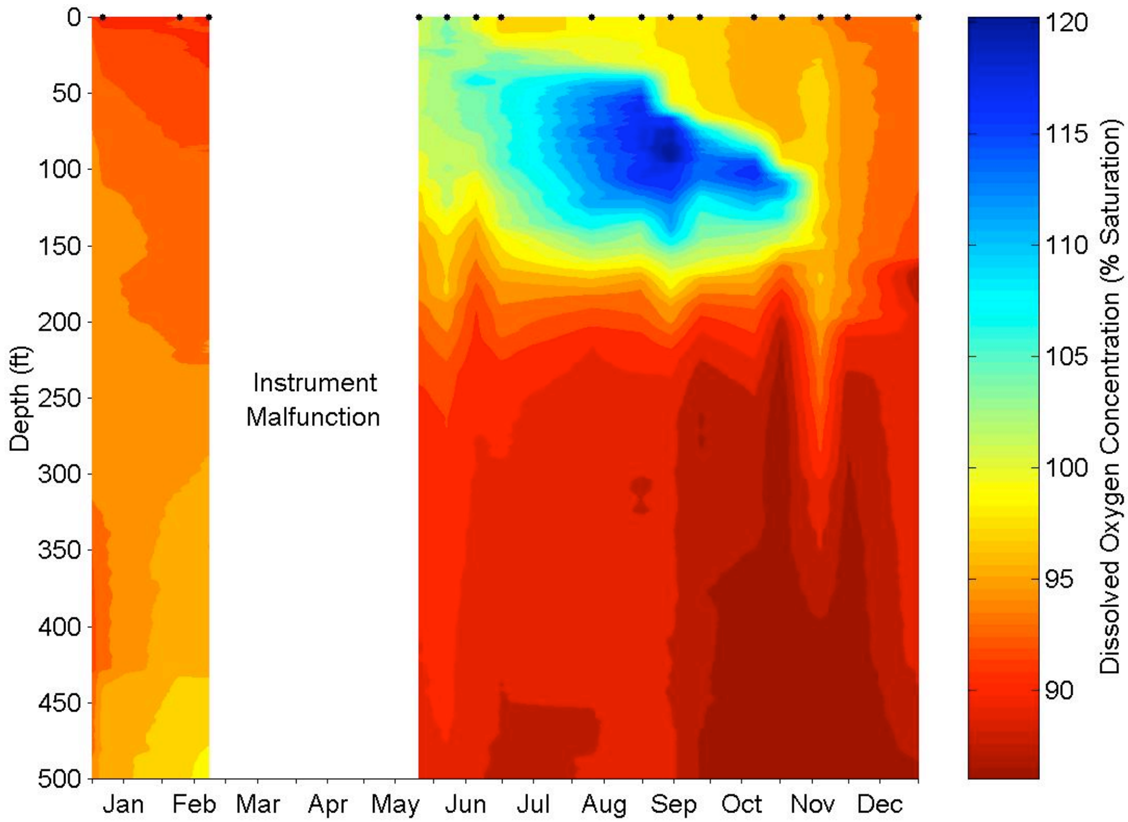
Dissolved oxygen is essential to plant and animal life in the lake. The concentration of dissolved oxygen at various depths is measured every two to four weeks at the Index Station. Here are the seasonal changes in the lake's dissolved oxygen profile. The highest dissolved oxygen concentration was at a depth range of 100-150 feet during the summer and fall, due to oxygen production by algae within the deep chlorophyll maximum (*see Biology Section*). The lower dissolved oxygen concentration at the surface during the summer and fall was due to reduced oxygen solubility in the warm surface water.



Dissolved oxygen profile by degree of saturation

In 2006

Concentrations of dissolved oxygen at various depths are shown here in terms of the percentage of maximum saturation. In 2006, the highest dissolved oxygen concentration occurred in late summer and was supersaturated (above 100 percent of saturation). Even the lower dissolved oxygen concentration at the surface during the summer and fall was close to saturation.



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LAKE NUTRIENTS

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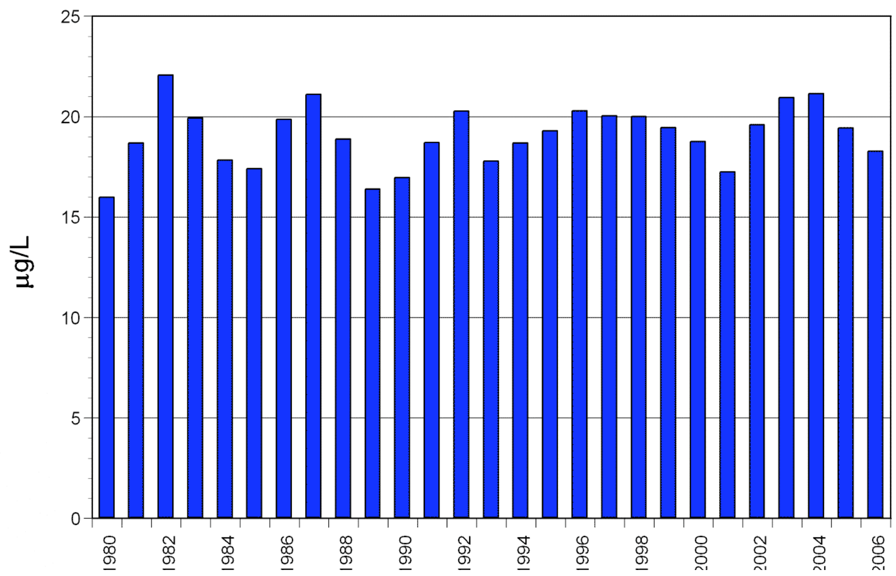
LAKE NUTRIENTS

Lake nitrate concentration

Yearly since 1980

Nutrients, which promote algal growth, are measured at various depths at the Mid-lake and Index stations. One nutrient, nitrate, enters the lake via stream runoff, urban runoff, groundwater and atmospheric deposition (falling out of the air). Since 1980, nitrate concentration has remained relatively constant. In 2006, the volume-weighted annual average concentration of nitrate was 18.2 micrograms per liter (or parts per billion).

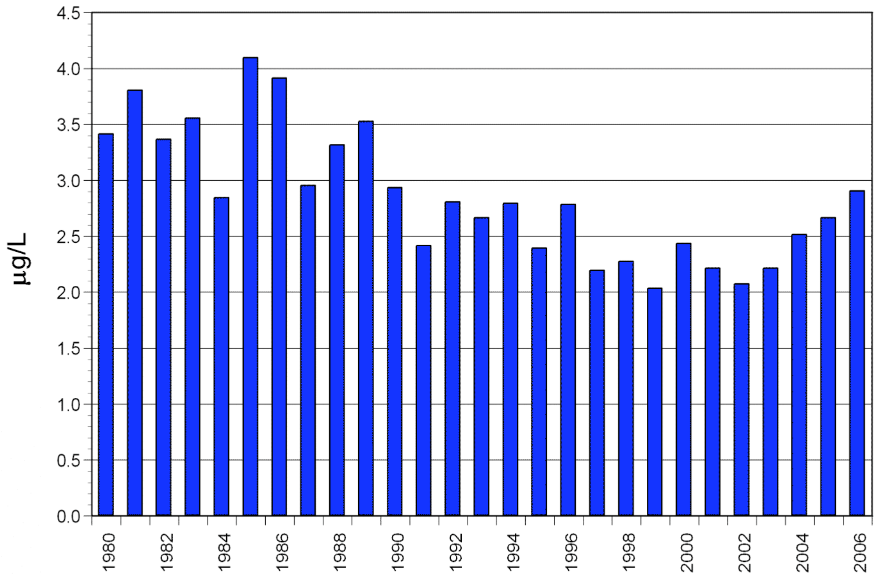


LAKE NUTRIENTS

Lake phosphorus concentration

Yearly since 1980

The fraction of phosphorus that can be used by algae is called total hydrolyzable phosphorus, or THP. Phosphorus naturally occurs in Tahoe Basin soils and enters the lake via soil disturbance and erosion. Since 1980, THP has tended to decline. In 2006, the volume-weighted annual average concentration of THP was 2.9 micrograms per liter (or parts per billion).

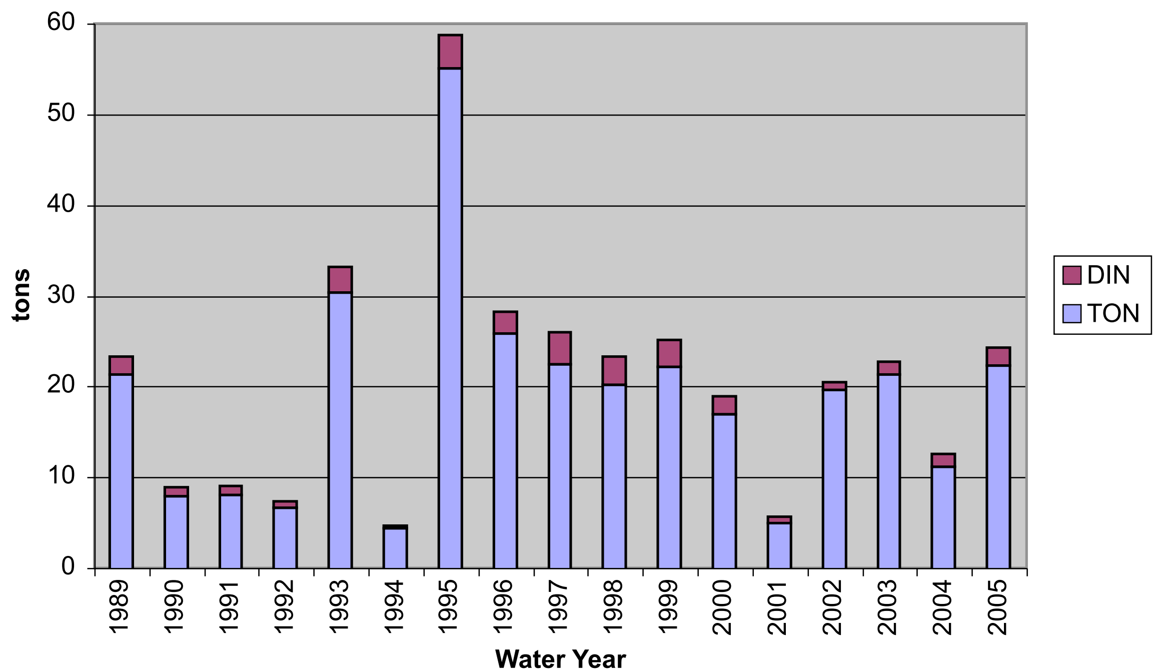


LAKE NUTRIENTS

Nitrogen contribution by Upper Truckee River

Since 1989

The Upper Truckee River is the largest of the 63 streams that flow into Lake Tahoe, contributing approximately 25 percent of the inflow. Here the river's contribution (load) of dissolved inorganic nitrogen (nitrate + ammonium, abbreviated DIN) and total organic nitrogen (TON) are shown. The year-to-year variation in load reflects the year-to-year variation in precipitation. For example, 1994 had 16.6 inches of precipitation and a low nitrogen load, while 1995 had 60.8 inches of precipitation and a very high nitrogen load.

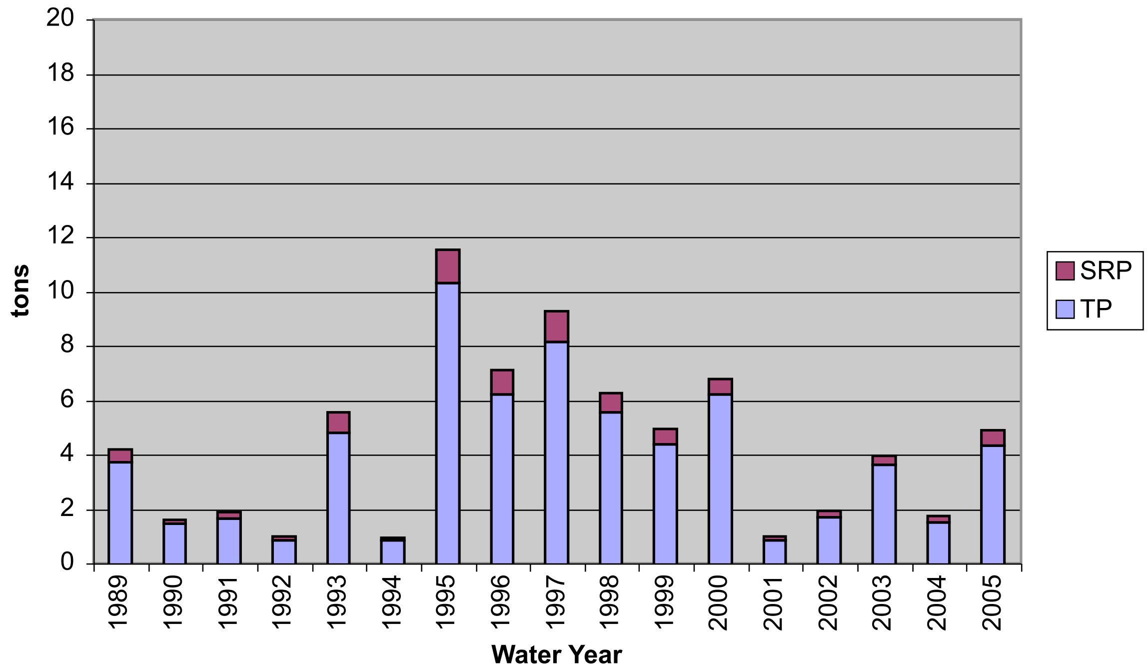


LAKE NUTRIENTS

Phosphorus contribution by Upper Truckee River

Yearly since 1989

Here, the river's load of soluble reactive phosphorus and total phosphorus are shown. Dissolved inorganic nitrogen (nitrate + ammonium, abbreviated DIN) and total organic nitrogen (TON) are shown. As with nitrogen (Figure 8.3), the year-to-year variation in load reflects the year-to-year variation in precipitation.

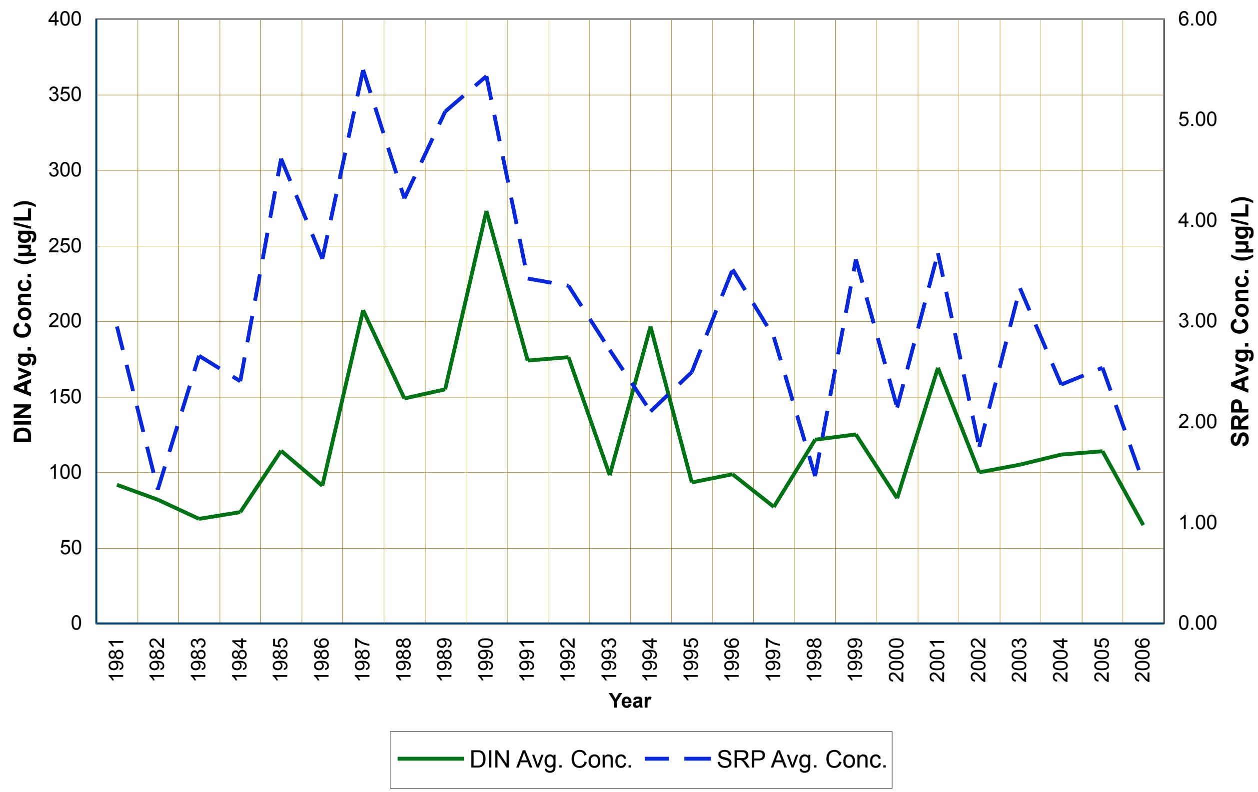


LAKE NUTRIENTS

Nutrients in rain and snow

Yearly since 1981

Nutrients dissolved in rainwater and snow (called wet deposition) make a significant contribution to the nutrients in Lake Tahoe. Since 1981, wet-deposition nutrients have been measured near Ward Creek. This figure shows the year-to-year variation in dissolved inorganic nitrogen (DIN) and soluble reactive phosphorus (SRP) in the precipitation. Overall, there has been no consistent trend in the measurements. 2006 had relatively low concentrations of both DIN and SRP.



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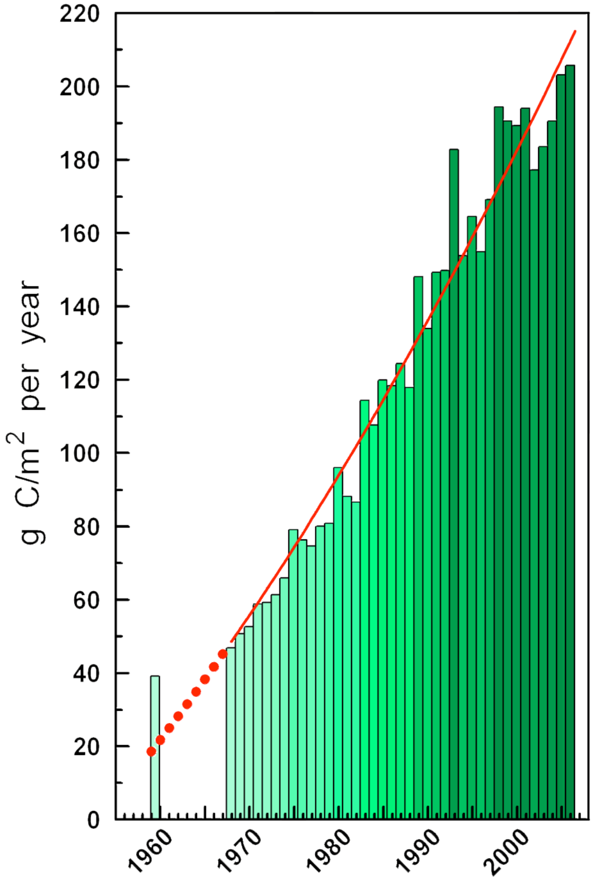
LAKE BIOLOGY

LAKE BIOLOGY

Algae growth (primary productivity)

Yearly since 1959

Primary productivity (PPr) is a measure of the rate at which algae produce biomass through photosynthesis. At Lake Tahoe, it has been measured since 1959. PPr has increased nearly continuously over that time, probably because of growth-promoting changes in the lake's nutrient load, light environment and algae species. In 2006, PPr was 206 grams of carbon per square meter (g C/m²).

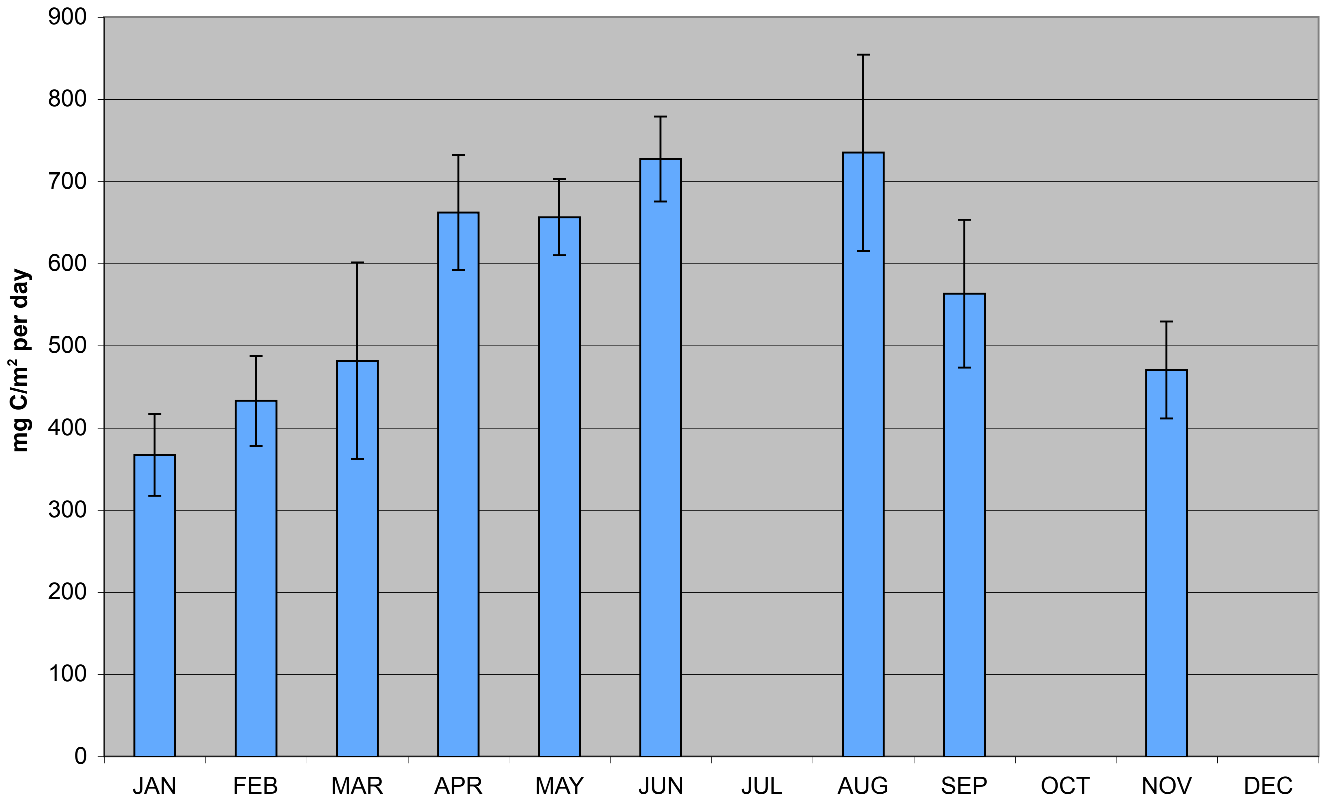


LAKE BIOLOGY

Algae growth (primary productivity)

Monthly in 2006

Primary productivity varies through the year as nutrient availability, light conditions and water temperatures vary. The 2006 monthly data show the typical peak during summer months. (Measured in milligrams of carbon per square meter per day.) (Data not available in July, October and December.)

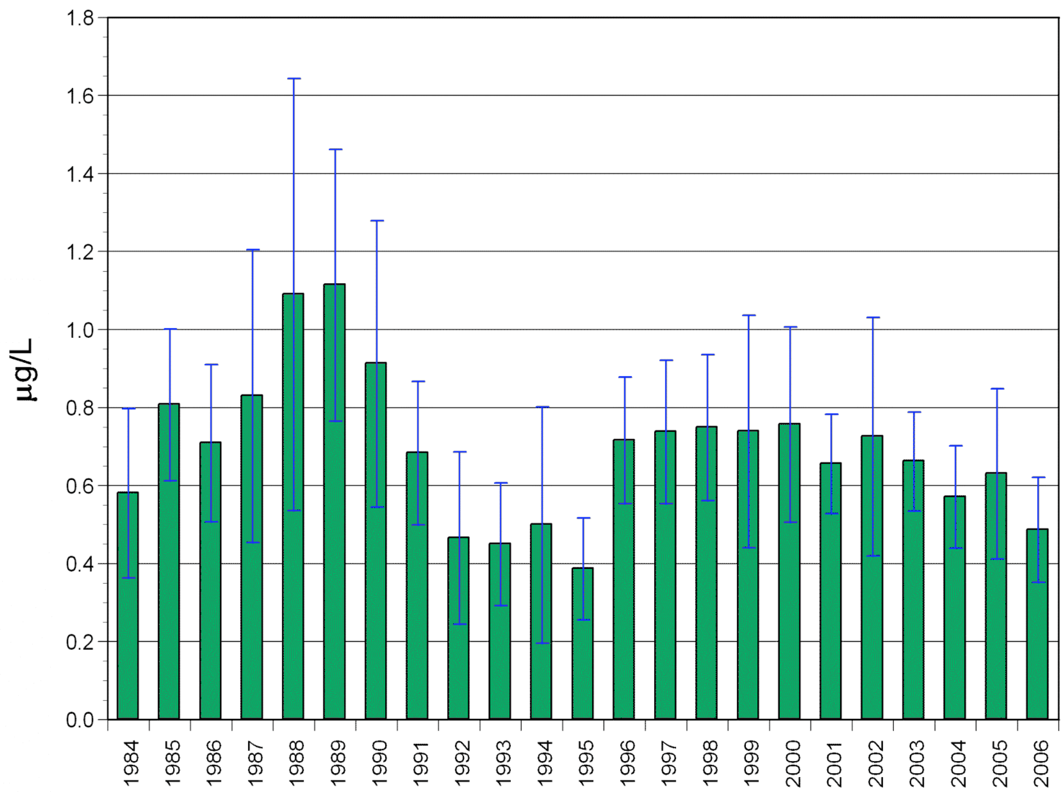


LAKE BIOLOGY

Algae abundance

Yearly since 1984

The amount of free-floating algae in the water is calculated by measuring the concentration of chlorophyll *a*. Though algae abundance varies annually, there has been little to no overall increase over the long term. Since measurements began in 1984, the annual average has been 0.69 micrograms of chlorophyll *a* per liter of water (or, 0.69 parts per billion). The annual average value for 2006 was 0.49 micrograms per liter.

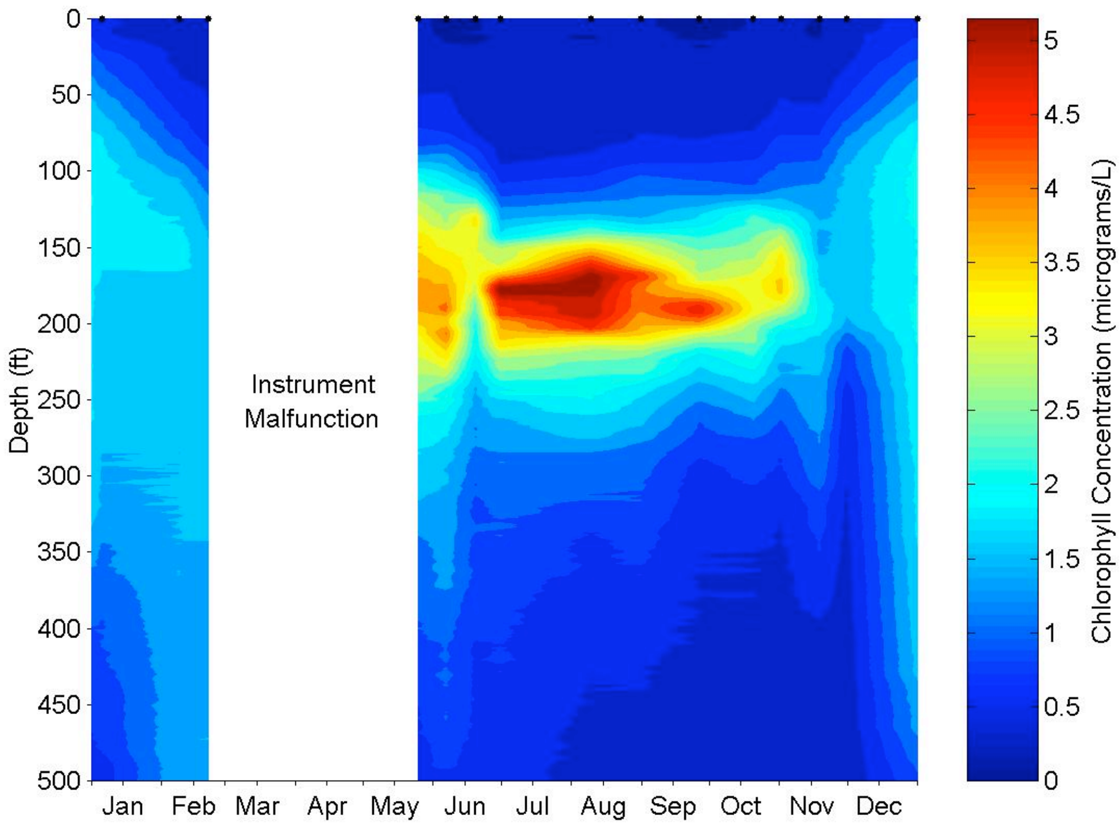


LAKE BIOLOGY

Algae concentration by depth

In 2006

The highest concentrations of chlorophyll *a* occur in summer at about 100 to 200 feet below the lake surface. This is known as the deep chlorophyll maximum.

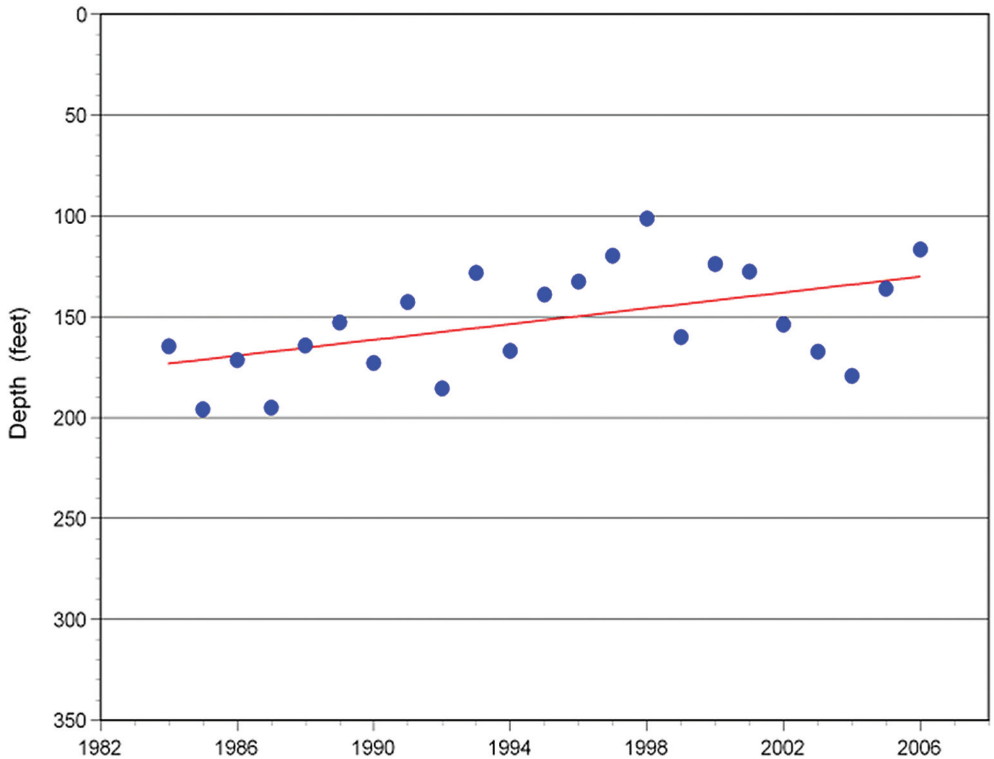


LAKE BIOLOGY

Depth of chlorophyll maximum

Yearly since 1984

The depth in Lake Tahoe where the deep chlorophyll maximum occurs varies from year to year. Since 1984, the average annual depth declined by approximately 45 feet. In 2006, the depth was 117 feet.

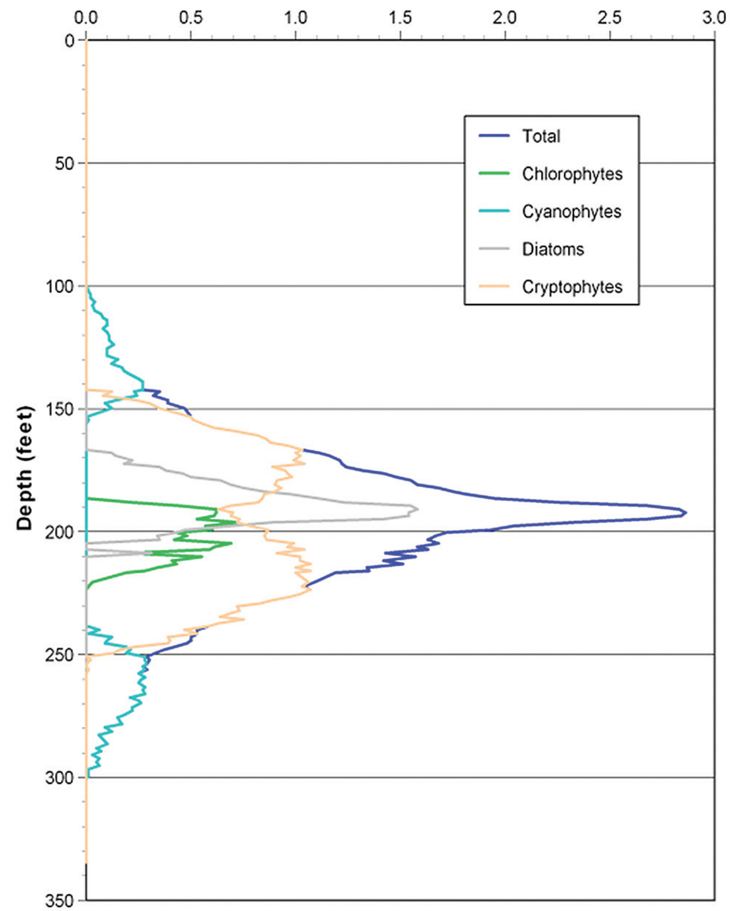


LAKE BIOLOGY

Algae group distribution by depth

A single day in 2006

Algae groups prosper at various depths below the lake surface. This profile from Sept. 26, 2006, shows that cyanophyte populations peak near the surface, cryptophytes at about 155 feet, chlorophytes at 185 feet and diatoms at 200 feet.

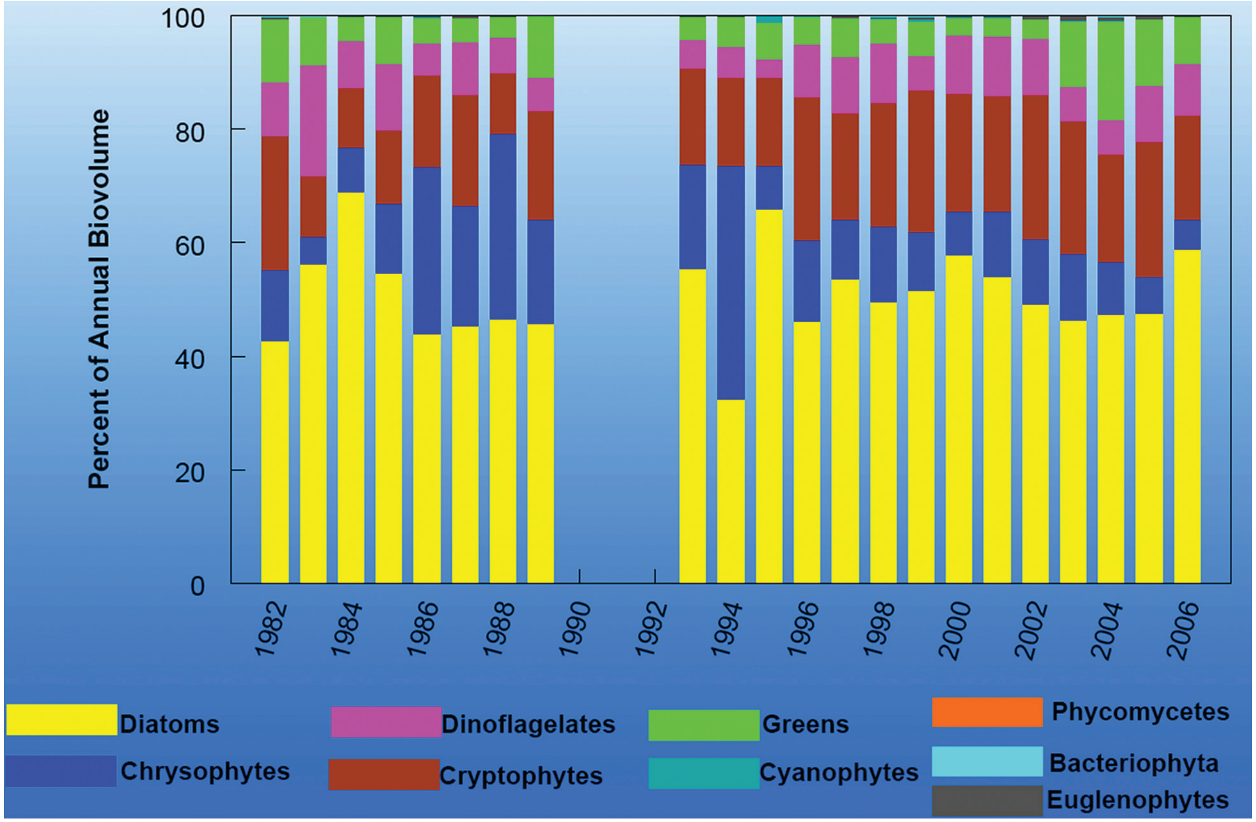


LAKE BIOLOGY

Algae groups as a fraction of total population

Yearly since 1982

The population, or biovolume, of algal cells from different groups varies from year to year. Diatoms are the most common type of alga, comprising 40 to 50 percent of the total biovolume each year. Chrysophytes and cryptophytes are next, comprising 10 to 30 percent of the total.

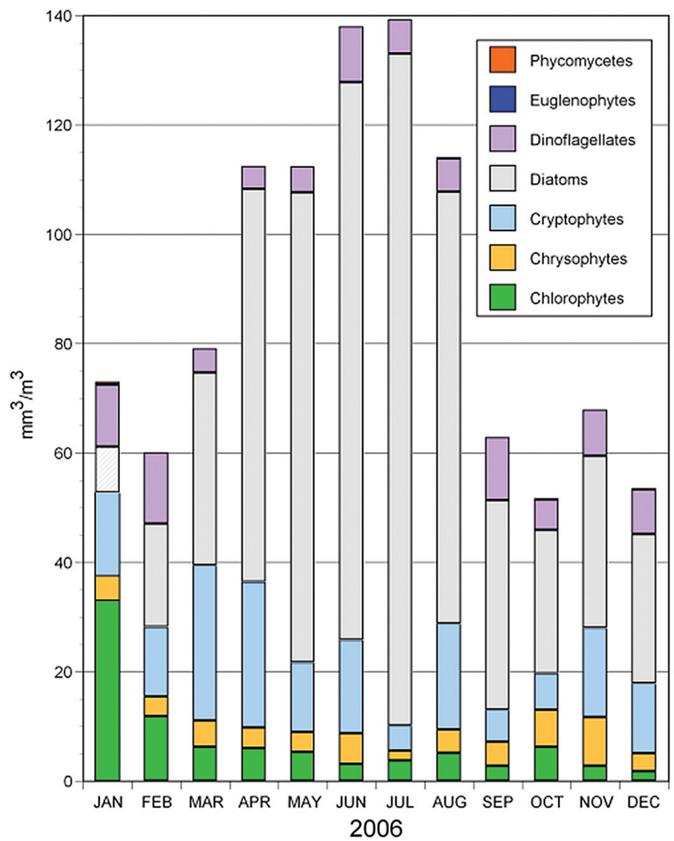


LAKE BIOLOGY

Algae groups as a fraction of total population

Monthly in 2006

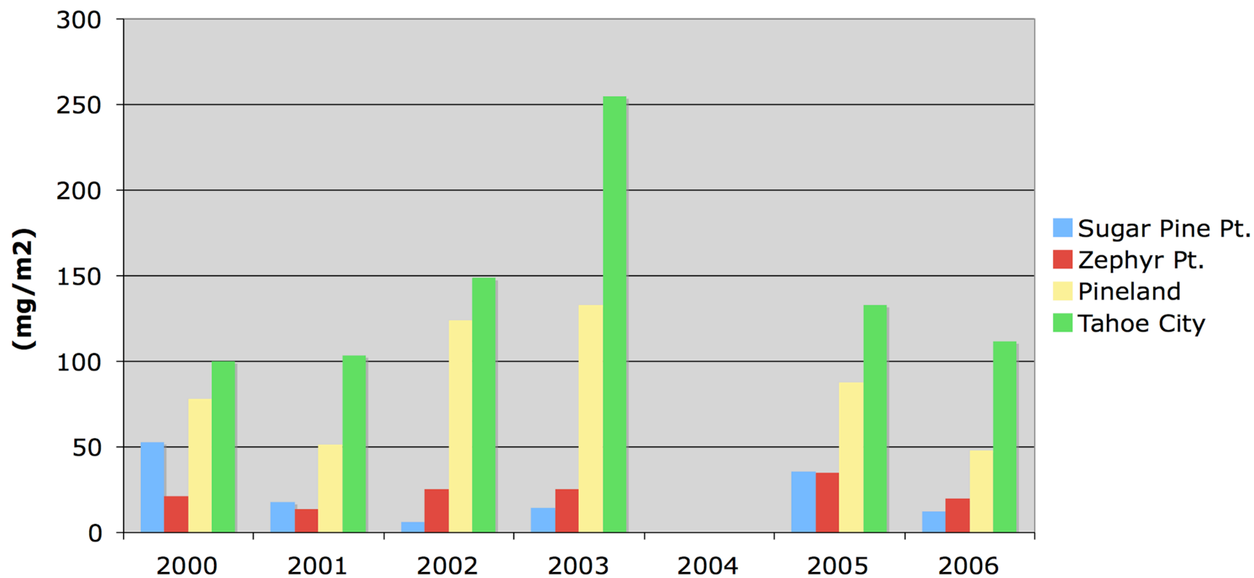
Just as group population varies year to year, it also varies from month to month. Diatoms increase through spring and peak in summer. Chlorophytes peak in winter, while dinoflagellates are present in small numbers all year. (Measured in cubic millimeters per cubic meter.)



Shoreline algae populations

Yearly since 2000

Periphyton, or attached algae, coat many of the rocks around the shoreline of Lake Tahoe. Periphyton is measured eight times each year, and this graph represents the maximum measured at each of the four sites shown. Concentrations in 2006 were average. The two sites with the most periphyton were near the two more urban areas. (Measured in milligrams per square meter.)

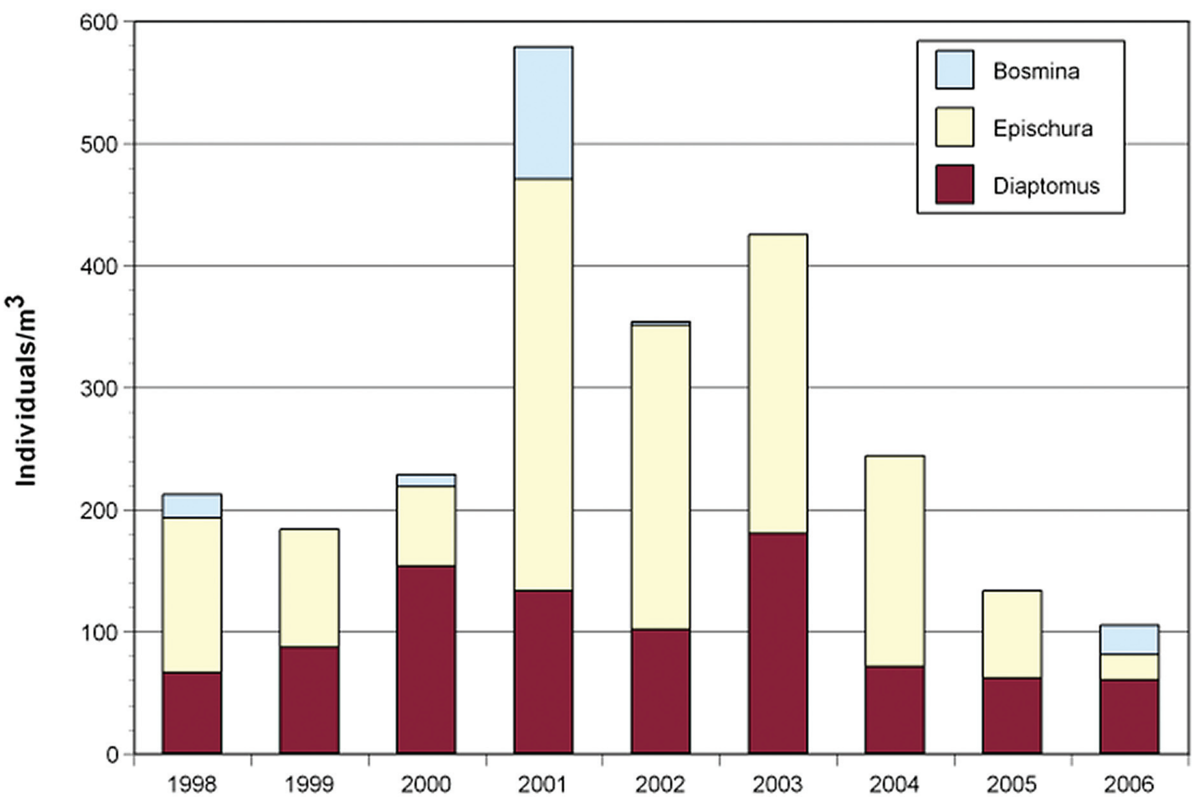


LAKE BIOLOGY

Zooplankton population by genus

Yearly since 1998

Numbers of zooplankton (microscopic aquatic animals that graze on algae) vary from year to year. Since the introduction of the mysid shrimp, the Lake Tahoe zooplankton population has been dominated by *Epischura* and *Diaptomus*. In some years, *Bosmina* are also present, typically in small numbers. Last year had the lowest measured zooplankton biovolume since 1998. (Measured in individuals per cubic meter.)

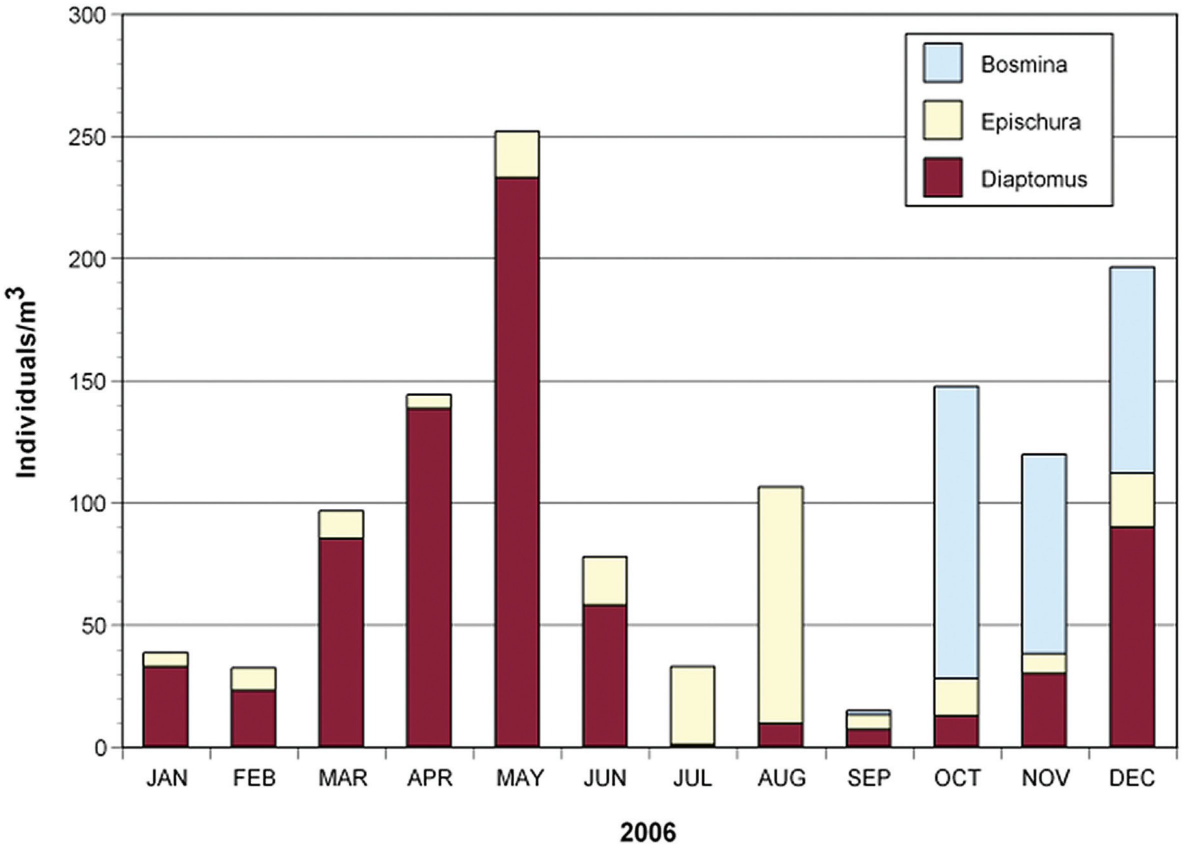


LAKE BIOLOGY

Zooplankton population by genus

Monthly in 2006

During 2006, *Diaptomus* was the dominant zooplankton during the winter and spring. In summer *Epischura* was dominant, and *Bosmina* was present in unusually large concentrations during the fall.



TAHOE: STATE OF THE LAKE REPORT 2007

LAKE CLARITY

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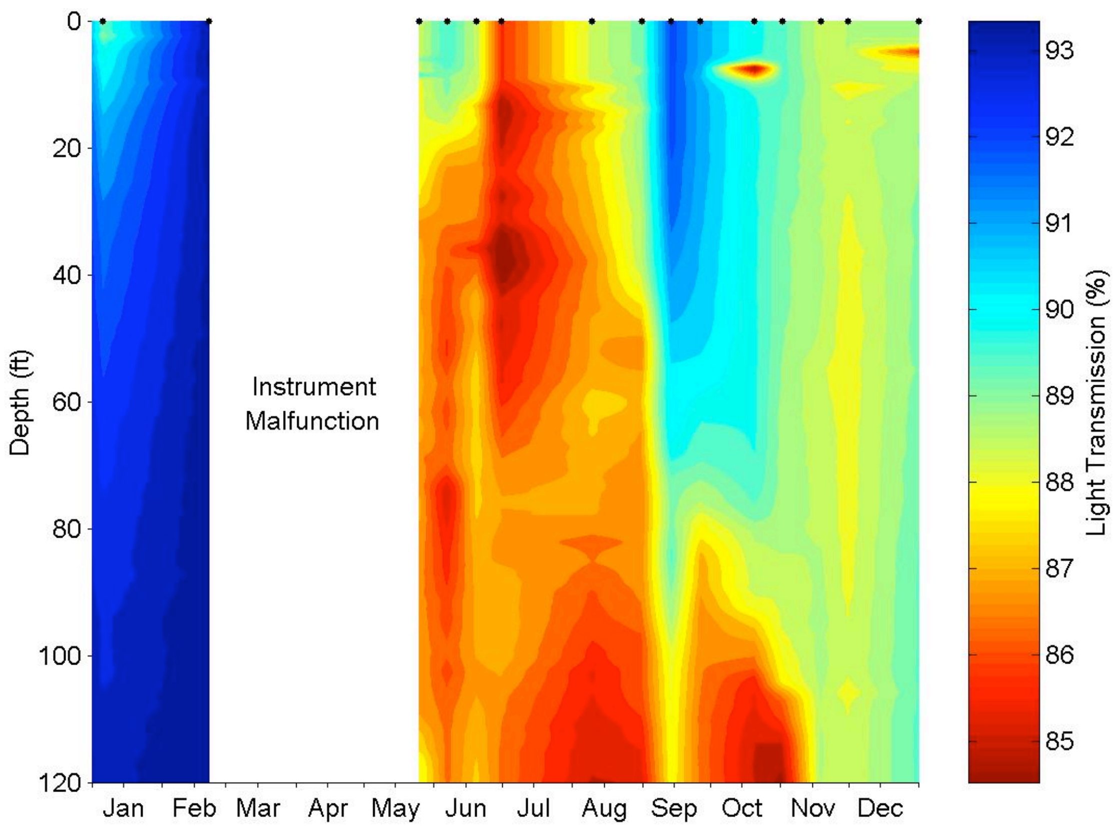
TAHOE ENVIRONMENTAL RESEARCH CENTER

LAKE CLARITY

Light transmission

In 2006

Light transmission is measured at various depths to produce a clarity profile. Last year was typical: The lowest light transmission occurred in summer, with the minimum values (less than 85 percent transmission) in the upper 50 feet. As usual, the highest light transmission (more than 92 percent) occurred in winter (when mixing brings clearer water up to the surface).



LAKE CLARITY

Average Secchi depth

Yearly since 1968

Secchi depth (the point below the lake surface at which a 10-inch white disk disappears from view) is the longest continuous measure of water clarity at Lake Tahoe. The annual Secchi depth is composed of approximately 25 readings throughout the year. While there have been periods of years when lake clarity has improved, there has been an overall long-term decline. In 2006, the Secchi depth was 67.7 feet, a reduction of 4.6 feet from the previous year. The year's high precipitation (Figure 6.5), and the resulting high urban runoff and stream flow, largely account for this decrease.