

TAHOE:  
STATE  
OF THE  
LAKE  
REPORT  
2009

## CONTENTS

### 1. Introduction

### 2. Executive Summary

### 3. About Lake Tahoe

### 4. About the UC Davis Tahoe Environmental Research Center

### 5. Map of Tahoe Basin data collection sites

### 6. Asian Clams

- 6.1 Lake Tahoe species introduction timeline
- 6.2 Asian clam in Lake Tahoe
- 6.3 Invertebrate composition
- 6.4 Increased algae
- 6.5 Asian clam excretion experiment
- 6.6 Asian clam size distribution by depth
- 6.7 Asian clam lake distribution

### 7. Meteorology

- 7.1 Air temperature (daily since 1910)
- 7.2 Below-freezing air temperatures (yearly since 1910)
- 7.3 Monthly air temperature (since 1998)
- 7.4 Solar radiation (daily in 2008)
- 7.5 Annual precipitation (yearly since 1910)
- 7.6 Monthly precipitation (2007, 2008 and 1910 to 2008 average)
- 7.7 Snow as a fraction of annual precipitation (yearly since 1910)
- 7.8 Shift in snowmelt timing (yearly since 1961)

### 8. Physical properties

- 8.1 Lake surface level (daily since 1900)
- 8.2 Lake surface level (daily since 2005)
- 8.3 Average water temperature (since 1970)
- 8.4 Surface water temperature (yearly since 1968)
- 8.5 Maximum daily surface water temperature (since 1999)
- 8.6 July average surface water temperature (since 1999)
- 8.7 Water temperature profile (in 2008)

8.8 Density stratification (since 1970)

8.9 Depth of mixing (yearly since 1973)

8.10 Upper Truckee vs. Truckee River Mean Daily Streamflow (in 2008)

8.11 Upper Truckee vs. Truckee River Annual Streamflow (since 1980)

### 9. Nutrients and particles

9.1 Sources of clarity-reducing pollutants

9.2 Pollutant loads from 10 watersheds

9.3 Nitrogen contribution by Upper Truckee River (since 1989)

9.4 Phosphorus contribution by Upper Truckee River (since 1989)

9.5 Suspended sediment contribution by Upper Truckee River (since 1989)

9.6 Nutrient concentrations in rain and snow (yearly since 1981)

9.7 Nutrient loads in rain and snow (yearly since 1981)

9.8 Lake nitrate concentration (yearly since 1980)

9.9 Lake phosphorus concentration (yearly since 1980)

### 10. Biology

10.1 Algae growth (primary productivity) (yearly since 1959)

10.2 Algae abundance (yearly since 1984)

10.3 Algae concentration by depth (in 2008)

10.4 Depth of chlorophyll maximum (yearly since 1984)

10.5 Algae group distribution by depth (three days in 2008)

10.6 Algae groups as a fraction of total population (yearly since 1982)

10.7 Algae groups as a fraction of total population (monthly in 2008)

10.8 Nutrient limitation of algal growth

10.9 Shoreline algae populations (yearly since 2000)

10.10 Shoreline algae distribution (in 2008)

### 11. Clarity

11.1 Annual average Secchi depth (yearly since 1968)

11.2 Secchi depth measurements (in 2008)

11.3 Penetration of photosynthetically active radiation (in 2008)

### 12. Education and outreach

12.1 TERC outreach

## INTRODUCTION

The University of California, Davis, has monitored Lake Tahoe for over 40 years, amassing a unique record of change for one of the world's most beautiful and vulnerable lakes. In the UC Davis Tahoe: State of the Lake Report, we summarize how natural variability and human activity have affected the lake's clarity, physics, chemistry and biology. We also present the 2008 data. The data shown here reveal a unique record of trends and patterns – the result of natural forces and human actions that operate over time scales ranging from days to decades. These patterns tell us that Lake Tahoe is a complex ecosystem, and it behaves in ways we don't always expect. While Lake Tahoe itself is unique, the forces and processes that shape it are the same as those that apply in all natural ecosystems. For this reason Lake Tahoe provides an analog for many other systems both in the western US and worldwide.

Our role as scientists is to explore that complexity, use our advancing knowledge to suggest options for ecosystem restoration and management, and help evaluate progress. Choosing among those options and implementing them is the work of those outside the scientific community. The annual UC Davis Tahoe: State of the Lake Report is intended to inform non-scientists about the most important variables that affect lake health. Until recently, only one indicator of Lake Tahoe's health status was widely available: 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) publishes many other indicators of the lake's conditions.

This report is not intended to be a report card for Lake Tahoe. Rather, it sets the context for understanding what changes are occurring from year to year: How much are invasive invertebrates affecting Lake Tahoe? Was Lake Tahoe warmer or cooler than the historical record last year? Are algae increasing? And, of course, how do all these changes affect the lake's famous clarity? The data we present are the result of efforts by a great many scientists, students and technicians who have worked at Lake Tahoe throughout the decades. I would, however, like to acknowledge the contributions of Patty Arneson, John

Reuter, Scott Hackley, Brant Allen, Bob Richards, Marion Wittmann, Sudeep Chandra, Charles Goldman, Monika Winder, Debbie and Peter Hunter, Anne Liston, Tina Hammell, Heather Segale, Bob Coats, Bill Fleenor, Todd Steissberg, Veronica Alambaugh, Simon Hook, Stephen Andrews, Dan Nover and George Malyj.

Funding for this enormous undertaking comes from a great many sources, spanning federal, state and local agencies, as well as UC Davis itself. While many other water quality variables could be tracked, funding ultimately limits what we measure. Current funding for monitoring and analysis is provided by the Lahontan Regional Water Quality Control Board, the Tahoe Regional Planning Agency, the U.S. Forest Service and the U.S. Geological Survey. TERC's monitoring is frequently done in collaboration with other research institutions and agencies. In particular we would like to acknowledge 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 17, 2008

## EXECUTIVE SUMMARY

The long-term data set collected on the Lake Tahoe ecosystem by the University of California, Davis, and its research collaborators is a valuable tool for understanding ecosystem function and change. It has become essential to public agencies tasked with restoring and managing the Tahoe ecosystem, in part because it allows us to monitor progress toward reaching Tahoe's restoration goals and desired conditions.

This annual Tahoe: State of the Lake Report presents 2008 data in the context of the long-term record. While the focus is on data collected as part of ongoing, long-term measurement programs, this year we have also included data related to the discovery of a major invasion of *Corbicula fluminea*, or Asian clam, in Lake Tahoe. If any single factor had to be identified as the most important change in the state of Lake Tahoe in 2008, it would be the dramatic increase of Asian clam. The report also includes data about changes in the algae

composition and concentration, lake clarity and the effects of climate change on snowmelt timing, lake water temperature and density stratification.

The UC Davis Tahoe Environmental Research Center has developed sophisticated computer models that help scientists more accurately predict how Lake Tahoe's ecosystem behaves. Long-term data sets are essential to refine the accuracy of those models. In these times of rapid change, reliable predictive models are indispensable tools for Lake Tahoe Basin resource managers.

This report is available on the UC Davis Tahoe Environmental Research Center website ([terc.ucdavis.edu](http://terc.ucdavis.edu)). Here are some of the highlights presented in the following pages.

### ASIAN CLAMS

- In parts of the southeast of Lake Tahoe, Asian clams now comprise almost 50% of the benthic (sediment-dwelling) organisms (Fig. 6.3) and are present in concentra-

tions greater than 1500 per square meter. (Fig. 6.7)

- The green filamentous algae *Zygnema* is co-located with the beds of Asian clam and is present at concentrations sufficient to be considered a nuisance. High concentrations of nutrients that are excreted by the clams are believed to be driving the growth and accumulation of the large *Zygnema* biomass. (Figs. 6.4 and 6.5)

### METEOROLOGY

The Lake Tahoe ecosystem is highly influenced by meteorology. In the short term, meteorological conditions are expressed as daily variations in weather. In the long term, they are expressed as normal cyclical variations such as wet and dry cycles, and long-term trends related to global climate change.

#### Historical record:

- The nightly minimum temperatures recorded at Tahoe City have increased by more than 4 degrees F since 1910. (Fig. 7.1)

- Days when air temperatures averaged below freezing have generally decreased by 30 days per year since 1910, although 2008 was a cold year with the greatest number of freezing days in the last 16 years. (Figs. 7.2 and 7.3)
- Since 1910, the percent of precipitation that fell in the form of snow decreased from 52 percent to 34 percent. (Fig. 7.7)
- Peak snow melt averages 2 ½ weeks earlier than in the early 1960s. (Fig. 7.8)

#### Previous year<sup>1</sup>:

- Solar radiation in the Tahoe basin was reduced by up to 20% during one week in July on account of smoke from the California wildfires. (Fig. 7.4)
- Precipitation during both 2007 and 2008 was low, with 2008 being the 12th driest year on record in 98 years. (Figs. 7.5 and 7.6)

### PHYSICAL PROPERTIES

Lake Tahoe's physical properties

(CONTINUED ON NEXT PAGE)

<sup>1</sup>"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 2009 report, water year data are from Oct. 1, 2007 through Sept. 30, 2008. Calendar year data are from Jan. 1, 2008 through Dec. 31, 2008.



## EXECUTIVE SUMMARY

### (CONTINUED FROM PAGE 2.1)

are largely a response to external factors, especially meteorology. Physical properties, in turn, determine the environment for all the lake's chemical and biological processes (see next sections).

#### Historical record:

- Water temperature (volume averaged) rose by more than 1 degree F in the past 38 years. (Fig. 8.3)
- Winter surface water temperatures were the coldest measured in the last 10 years, with the lowest maximum surface water temperature of 41.02 degrees F. (Fig. 8.5)
- Density stratification of Lake Tahoe has increased over the last 38 years as surface water warmed due to climate change. (Fig. 8.8)

#### Previous year:

- In 2008, lake level fell to a low of 6223.07 feet in December, within 1 inch of the natural rim. (Fig. 8.2)
- Lake Tahoe mixed all the way to the bottom in 2008, repeating the

deep mixing event of the previous year. (Fig. 8.9)

## NUTRIENTS AND PARTICLES

Lake Tahoe's clarity is determined especially by fine sediment particles, and also by nutrients. Tahoe's urban areas contribute 72% of fine particles, despite representing only 10% of the land base. Nutrients affect lake clarity by promoting algae growth. Off-shore, algae make the water greenish and less clear. Along the shoreline, algae are a problem because it coats rocks with green slime.

The two nutrients that most affect algal growth are nitrogen and phosphorus. These nutrients are measured at various depths at TERC's mid-lake and western lake stations. One form of nitrogen that is readily available to algae—nitrate—enters the lake through stream and urban runoff, groundwater and atmospheric deposition. Phosphorus occurs naturally in Tahoe Basin soils and enters the lake from soil disturbance and

erosion, as well as atmospheric deposition.

#### Historical record:

- Stream inputs of particles, nitrogen and phosphorus are directly linked to the annual amount of precipitation to the annual amount of precipitation via runoff and stream flow. (Figs. 9.3 to 9.5)
- Atmospheric deposition of nutrients, both in concentration and total loads, are also linked to precipitation. (Figs. 9.6 and 9.7)
- Nitrogen concentrations in the lake have remained generally constant for many years. (Fig. 9.8)
- Phosphorus concentrations have been generally declining. (Fig. 9.9)

#### Previous year:

- The watersheds that contributed the most particles and nutrients to Lake Tahoe were the Upper Truckee River, Blackwood Creek, Trout Creek, Ward Creek and Incline Creek. (Fig. 9.2)
- In 2008, the volume-weighted,

annual average concentration of phosphorus was just under 2.0 micrograms per liter (parts per billion); the lowest value since monitoring began in 1980. (Fig. 9.9)

## BIOLOGY

The longest data sets for lake biology come from the base of the food web—the free-floating algae (or phytoplankton). This algae influences the lake's food web, clarity and aesthetics.

#### Historical record:

- Primary productivity, the rate at which algae produce biomass through photosynthesis, has been increasing since 1959. (Fig. 10.1)
- Since 1984, the annual average depth of the deep chlorophyll maximum has declined. (Fig. 10.4)
- Diatoms remain the dominant algal species and provide high quality food for aquatic species. (Fig. 10.6)

#### Previous year:

- Primary productivity in 2008 was

(CONTINUED ON NEXT PAGE)

## EXECUTIVE SUMMARY

### (CONTINUED FROM PAGE 2.2)

- the highest on record. (Fig. 10.1)
- The depth of the maximum chlorophyll concentration decreased in 2008 to a mean of 115 feet. (Fig. 10.4)
  - Periphyton (attached algae) concentrations were similar to values recorded in 2007, with the exception of Zephyr Point, which experienced a 2-3 fold increase to the highest values ever recorded at that site. (Fig. 10.9)

### CLARITY

Clarity remains the indicator of greatest interest for Lake Tahoe because it tracks both degradation and the community's efforts to restore clarity to historic levels. Secchi depth (the point below the lake surface at which a 10-inch white disk disappears from view) has been measured continuously since 1968, and is the longest continuous measure of Lake Tahoe's water clarity.

In 2008, the annual average Secchi depth was 69.6 feet, virtually identi-

cal to the value recorded in 2007. In the last eight years, Secchi depth measurements have been better than predicted by the long-term linear trend. There is statistical support that Lake Tahoe's clarity decline has slowed significantly, and is now best represented by a curve. (Fig. 11.1)

### EDUCATION AND OUTREACH

The public can learn about the science behind Lake Tahoe restoration at TERC's Incline Village education center (the Thomas J. Long Foundation Education Center). In 2008, over 9,200 people participated in our education and outreach activities. (Fig. 12.1)

## ABOUT LAKE TAHOE AND THE TAHOE BASIN

- Maximum depth: 1,645 feet (501 meters), making it the 11th deepest lake in the world and 2nd deepest lake in the United States
- 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: one, the Truckee River, which leaves the lake at Tahoe City, Calif., flows through Truckee and Reno, 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
- Age of the lake: about 2 million years
- Permanent population: 66,000 (2000 Census)
- Number of visitors: 3,000,000 annually

## ABOUT THE UC DAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER (TERC)

The Tahoe Environmental Research Center 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, California, about 90 miles west of the lake.

Our main laboratories and offices are in Incline Village, Nevada, on the third floor of the 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, California, we operate a field station (formerly a state fish hatchery) and the Eriksson Education Center. Tahoe City is also the mooring site for our three

research vessels, the John LeConte, the Bob Richards and the Ted Frantz.

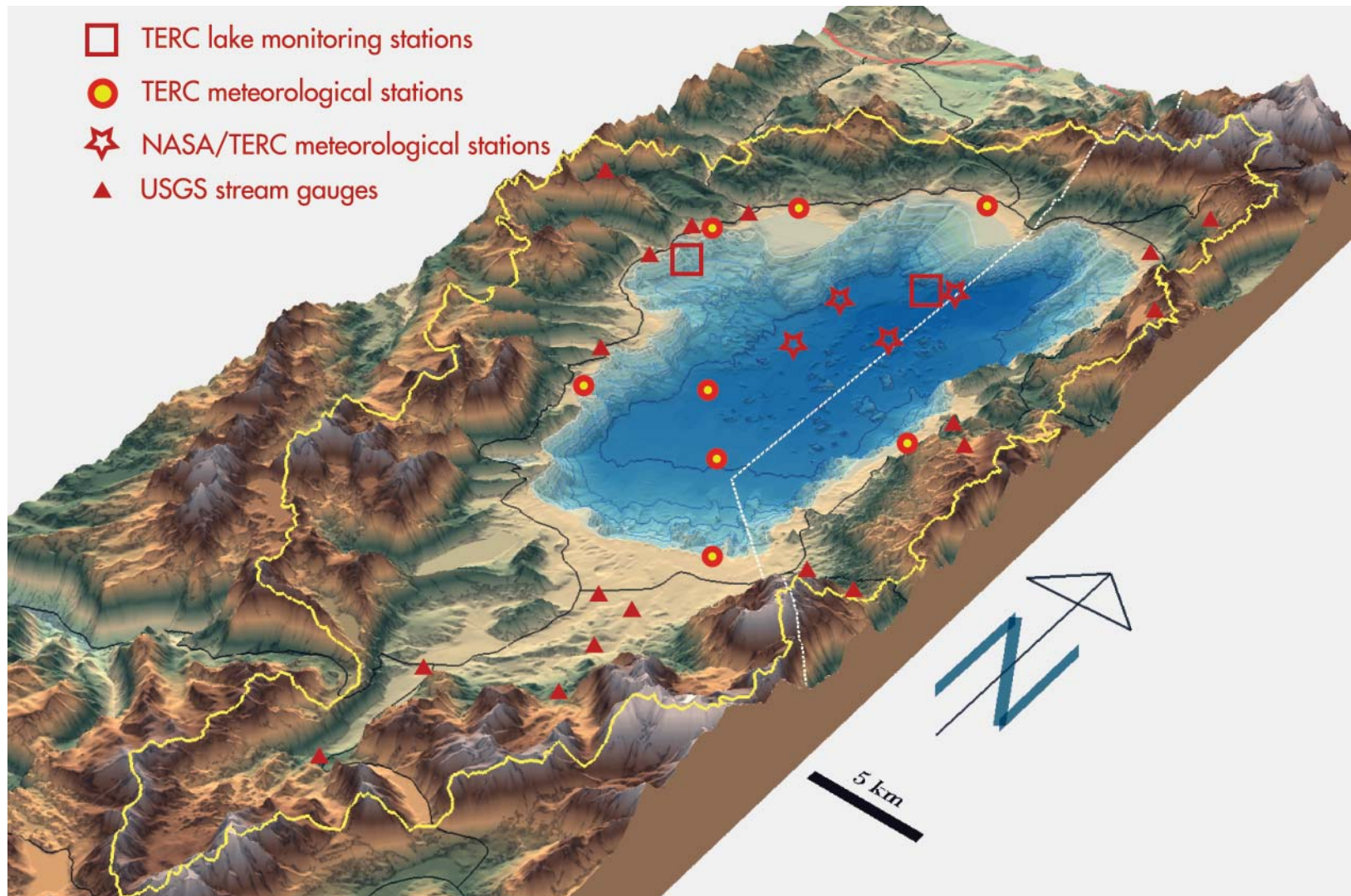
Our secondary laboratories and offices are located on the UC Davis campus at the Center for Watershed Sciences.

Our website ([terc.ucdavis.edu](http://terc.ucdavis.edu)) has more information about our programs, including:

- Information for potential students, staff, faculty, and research collaborators;
- Access to near-real-time meteorological data gathered by our network of sensors;
- A list of publications;
- Exhibits and events at the Education Centers; and
- Information about supporting our research and teaching programs.



## MAP OF TAHOE BASIN DATA COLLECTION SITES



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LAKE  
REPORT  
2009

**ASIAN CLAM**

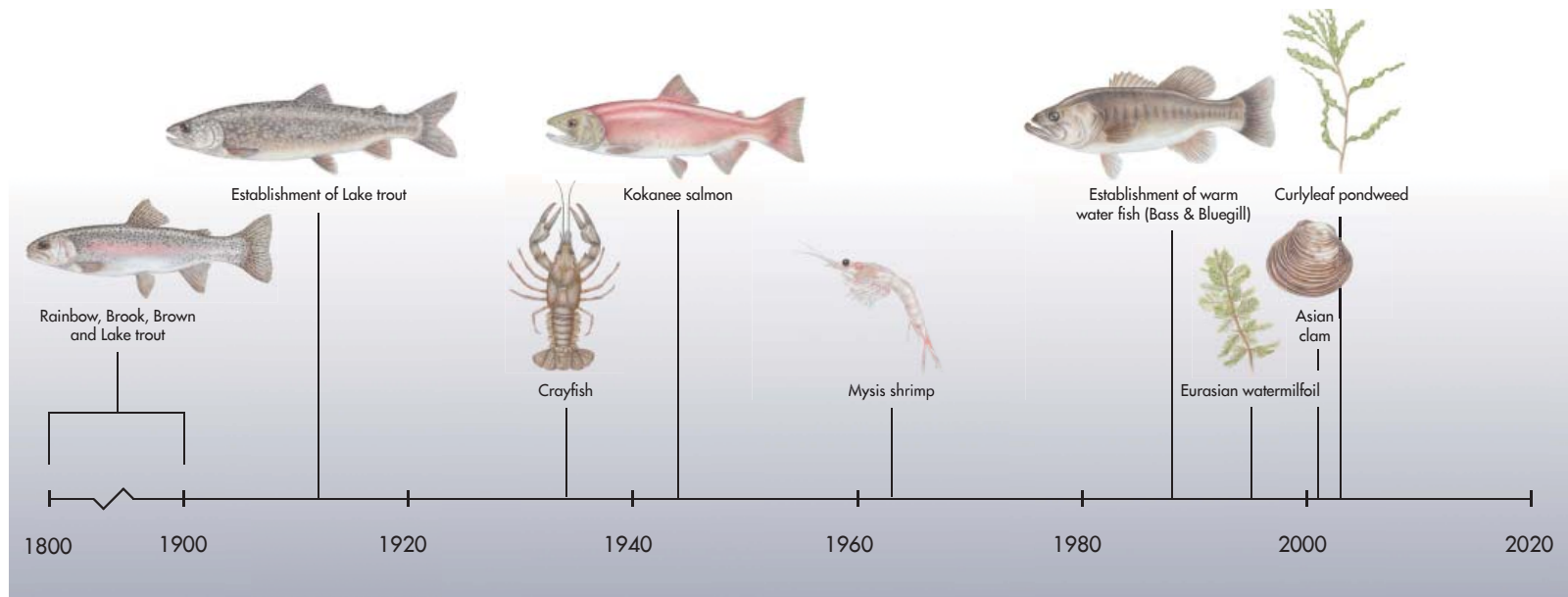
**ASIAN CLAM**

**Lake Tahoe Species Introduction Timeline**

There have been many non-native species introductions since the 1800's to Lake Tahoe—both intentional and unintentional. The lake has been stocked by natural resource agencies with rainbow, brook and brown trout, kokanee salmon, crayfish and mysis shrimp in attempts to boost fisheries. Unfortunately these efforts impacted the Lake Tahoe ecosystem which resulted in the dramatic decline of

the native Lahontan cutthroat trout. Recently, there have been many unintentional introductions of non-native aquatic plants (Eurasian watermilfoil and curly leaf pondweed), warm water fish species such as largemouth bass and bluegill species and one bivalve mollusk, the Asian clam. The consequences of these ecosystem-wide shifts include alterations to: water chemistry through the uptake or

release of excess nutrients, food web structure through resource competition, population dynamics of sports fisheries, as well as decreases in the recreational and aesthetic values of lakefronts, marinas and swimming areas through deposition of nuisance biomaterials (i.e., decomposing plant material, shells, algal blooms).



Research on Asian clam and other aquatic invaders to Lake Tahoe is being done in complete partnership between scientific teams at UC Davis - TERC and the University of Nevada, Reno. Lake Tahoe Species Introduction Timeline developed by Sudeep Chandra, Ph.D. (University of Nevada, Reno) with scientific illustrations by Sarah Adler.



## ASIAN CLAM

### Asian Clam in Lake Tahoe

In spring 2008 UC Davis researchers discovered extensive and often dense beds of an invasive bivalve, the Asian clam (*Corbicula fluminea*) in southeastern Lake Tahoe in nearshore

areas from Zephyr Cove to El Dorado Beach. Observations by researchers at the University of Nevada Reno of small numbers of clams (densities of 3-20 individuals per square meter)

in 2002 suggest that Asian clam may have been in Lake Tahoe for at least 6 years; however, the densities and size of the recently observed beds are much larger than previously reported.



Asian clams are relatively small in size, ranging from 1 mm to 55 mm in most systems. In Lake Tahoe, the largest clam only gets to be about 30 mm in size, likely due to colder water temperatures and low calcium and food (algal) availability in the lake.



Asian clams live within the sandy bottom of lakes. They can burrow into the sediments using a strong muscle called a “foot”. Ridges on their shells help them burrow into sediments and stay anchored in the bottom when water currents move across them. Asian clams are capable of both filter feeding and pedal (foot) feeding—drawing from both the water column and the bottom sediments for nutrition. One reason for the Asian clam’s success in a wide range of habitats is that it can effectively filter phytoplankton and bacteria out of the water column and deposit feed when pelagic (lake water) food becomes scarce.



Researchers are currently studying the impacts of the clams to Lake Tahoe. By measuring sediment porewaters (the water between sediment grains on the bottom of the lake) scientists can understand how Asian clams are contributing to the amount of nutrients in the lake bottom, including the deposition of calcium through degrading clam shell matter. These accumulations of high calcium regions may facilitate the invasion of other calcium loving species, such as the quagga or zebra mussel.

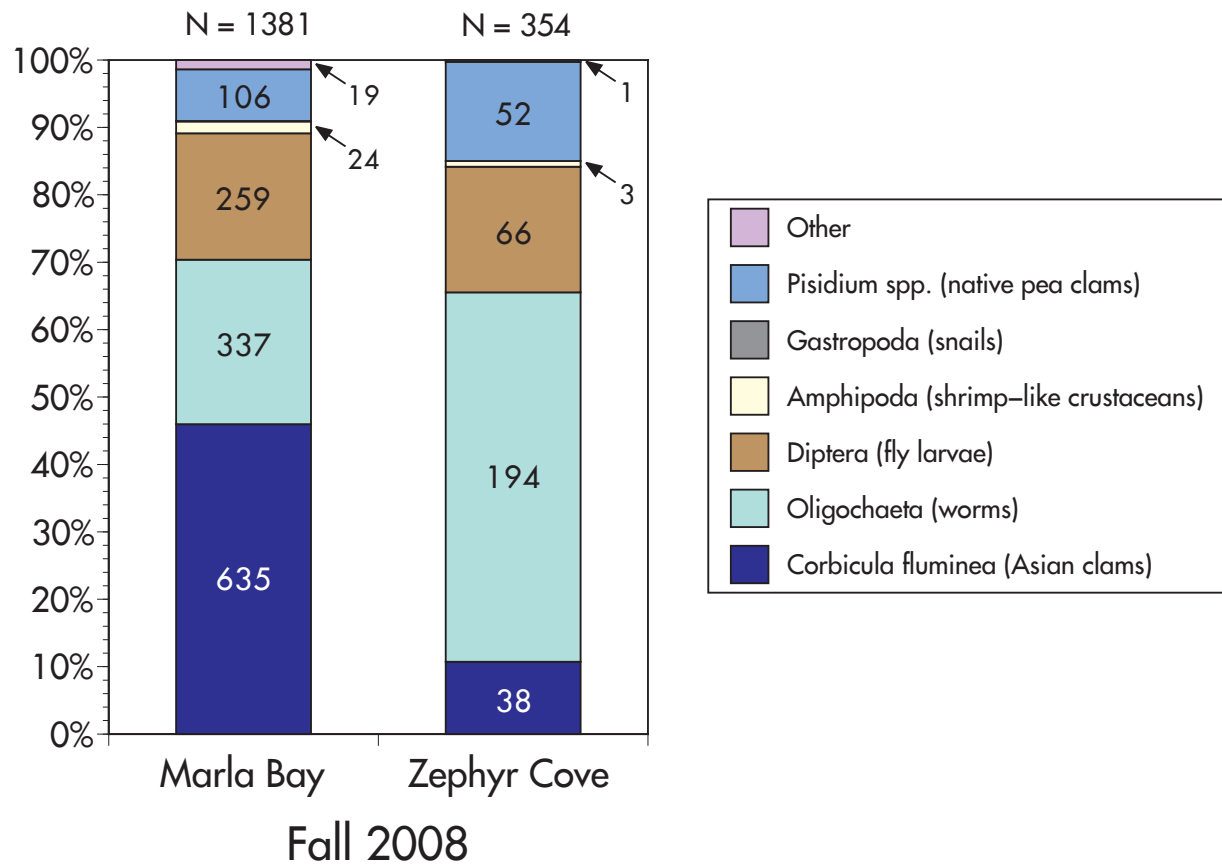
**ASIAN CLAM**

**Invertebrate Composition**

In addition to Asian clams, there are a number of other native benthic invertebrates that live in the sandy bottom of Lake Tahoe. This includes a native pea clam which can get up to 4 mm in length, only ~1/8 as large as the Asian

clam adult. There are also many other snail, worm, and crustacean species that live in the bottom where Asian clam are found. Researchers are currently studying the impacts of Asian clam on other invertebrate species,

such as the possible decrease of benthic biodiversity as a result of Asian clam. In areas where Asian clam densities are high, it has been observed that native pea clam densities are relatively lower.





## ASIAN CLAM

### Increased Algae

Along the southeastern portions of Lake Tahoe during July through September 2008 dense algal blooms of the green filamentous algae *Zygnema* and *Spirogyra* were often co-located

with Asian clam beds. These are both filamentous green algal species, which may exist attached or unattached to substrate, whose accelerated growth in other lakes and reservoirs has been

linked to increased levels of nutrient in the water column, sometimes as a result of bivalve excretion.



The 2008 algal bloom reached estimated densities of approximately 125 mg Chl/m<sup>2</sup>, which is considered to be at or above nuisance levels. The primary bloom extended as significant patches from South Zephyr Point to Elk Point. Additional patches of bright green algae were observed from Zephyr Cove to Timber Cove along the south shore.



Excretion of nutrients by clams is a natural part of their feeding and growth. Nitrogen and phosphorus contained in the clam excretion readily stimulates algal growth. This is one of the most likely sources of nutrients fueling the observed algal growth. Other contributing factors could include smoke and ash associated with wildfires, warming in the nearshore zone, and urban runoff. However, the fact that this bloom of bottom algae persisted for so long supports the idea that clam excretion played an important role.



An extended algal bloom has long lasting impacts on the nearshore condition of Lake Tahoe. Residual dead and dying biomass is washed up onto south shore beaches where it decomposes and influences nearshore water quality.

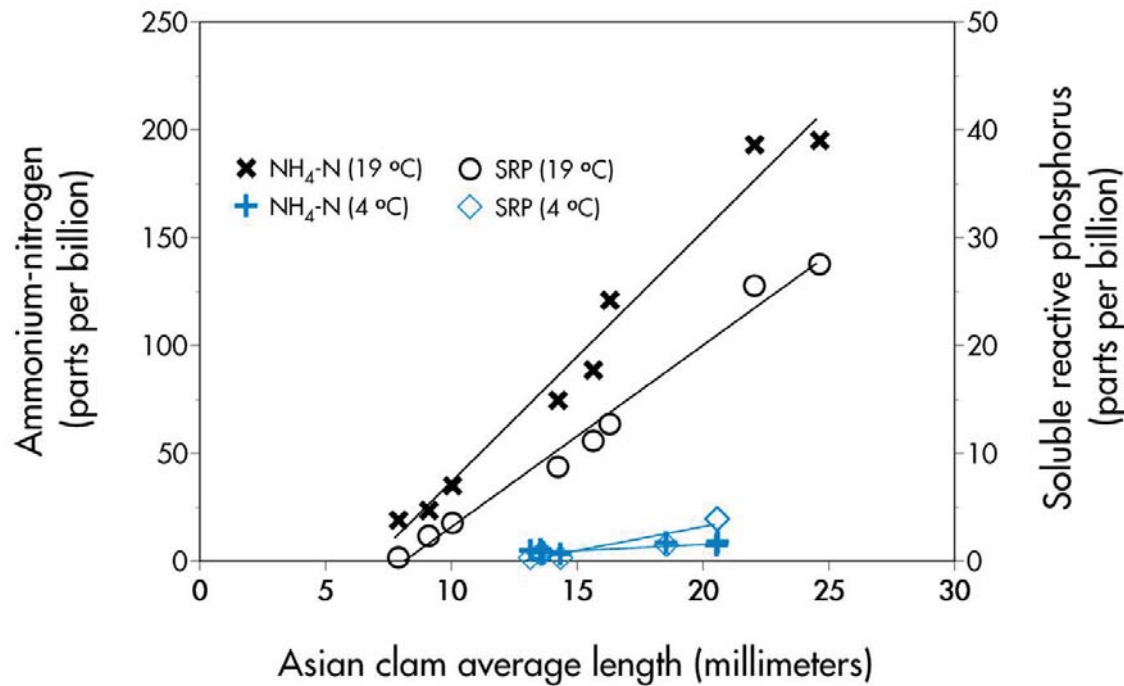
**ASIAN CLAM**

**Asian Clam Excretion Experiment**

Researchers conducted simple experiments to observe the rates of nitrogen and phosphorus excretion by Asian clams. For a 12-hour period, five similarly sized clams were placed in a single beaker containing 250 mL of filtered lake water and incubated at both 19 °C (Lake Tahoe nearshore summer water temperature) and 4 °C

(Lake Tahoe nearshore winter water temperature). Results from the warm temperature (19 °C) experiment show that larger clams excrete more N and P than smaller clams and both excrete more than background concentrations in Lake Tahoe water column. The largest clams in this experiment were approximately 25 mm and excrete at

rates an order of magnitude larger than the smallest clam size class considered here. Furthermore, tests designed to evaluate the impact of clam excretion products on algal growth showed a dramatic (3-fold) increase in phytoplankton biomass over a 7-day incubation period in the laboratory.



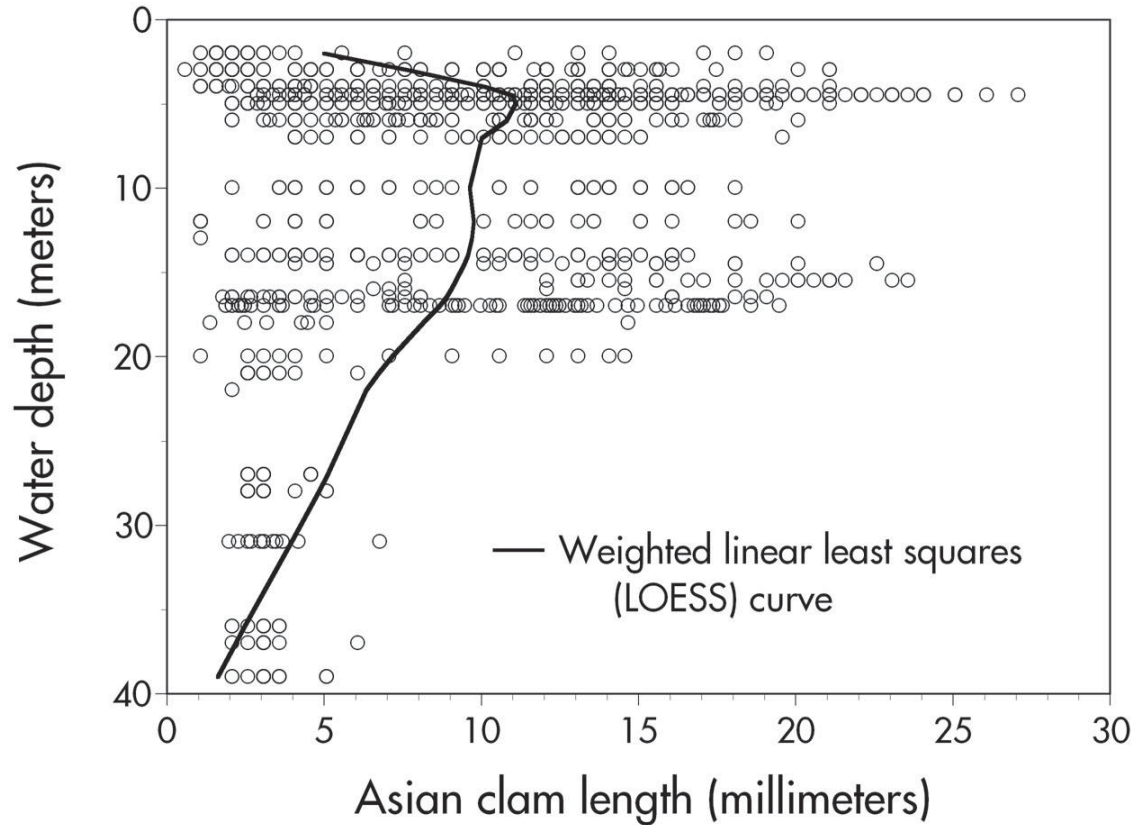
**ASIAN CLAM**

**Asian Clam Size Distribution by Depth**

Asian clam ranges in size from 1 to approximately 30 mm in length in Lake Tahoe. The bulk of the Asian clam populations in the southeast portion of the Lake occur at a 5

meter depth, with a few small-sized individuals occurring down to 40 meter depth. The circles in the figure show the size and depth distribution for individual clams. The solid line

represents a statistical approach to better visualize the complete depth distribution.



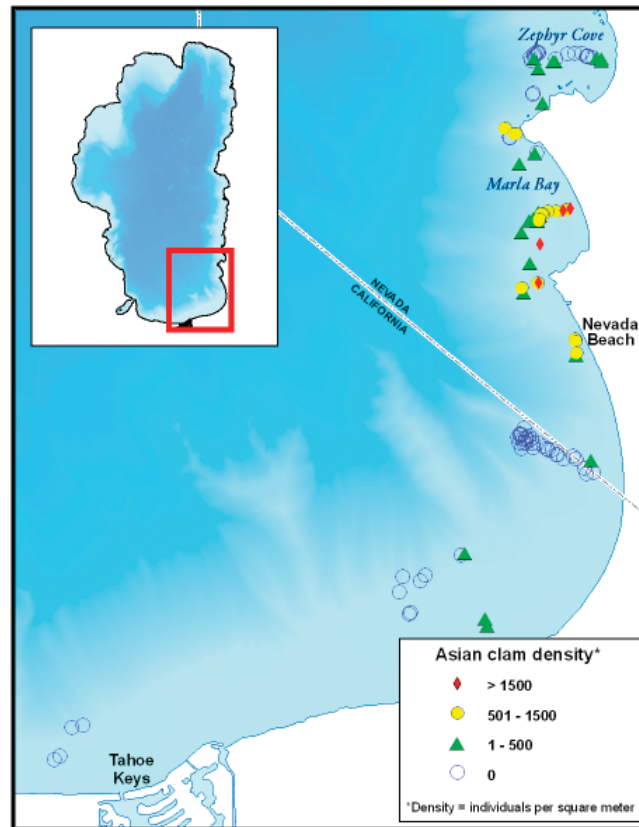
**ASIAN CLAM**

**Asian Clam Size Distribution**

The research teams surveyed the southeastern portion of Lake Tahoe in late summer and early autumn 2008. They found that the highest Asian clam densities occur at Marla Bay and at Elk Point ranging from 1 to 3000

individual clams per square meter. Patchy densities of clams were also observed in Zephyr Cove and east of these areas along the south shore. This survey was carried out using a combination of tools: by deploying a

sediment grab sampler off the side of a boat, along with snorkel and scuba surveys. This is not a comprehensive survey and researchers at UC Davis and University of Nevada, Reno are doing a whole-lake survey in 2009.



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**METEOROLOGY**



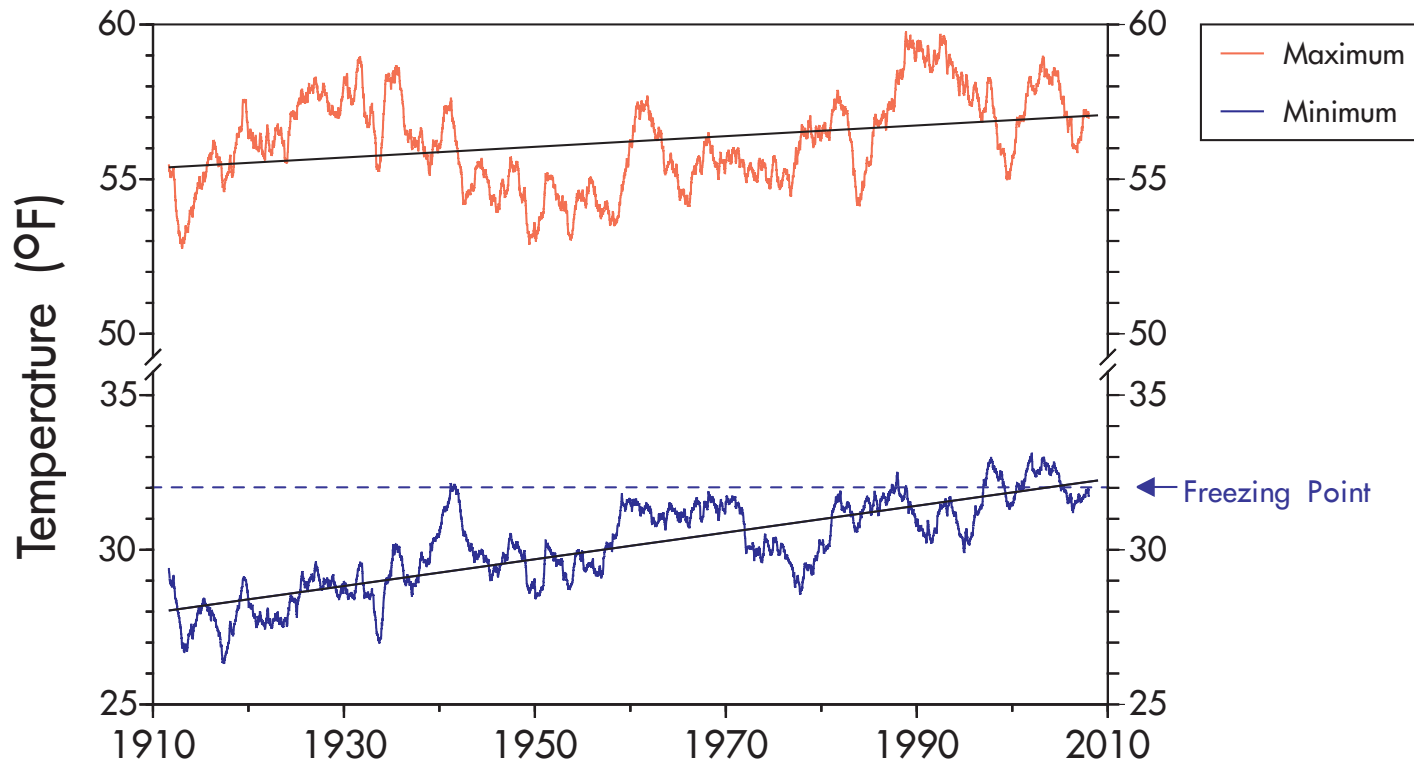
## METEOROLOGY

### Air temperature

Daily since 1910

Daily air temperatures measured at Tahoe City have increased over the 98 years. Daily minimum temperature has increased by more than 4 degrees F, and daily maximum temperature has risen by less than 2 degrees F. The average minimum air

temperature now exceeds the freezing temperature of water, which points to more rain and less snow, as well as earlier snowmelt. These data have been smoothed by using a two-year running average to remove daily and seasonal fluctuations.



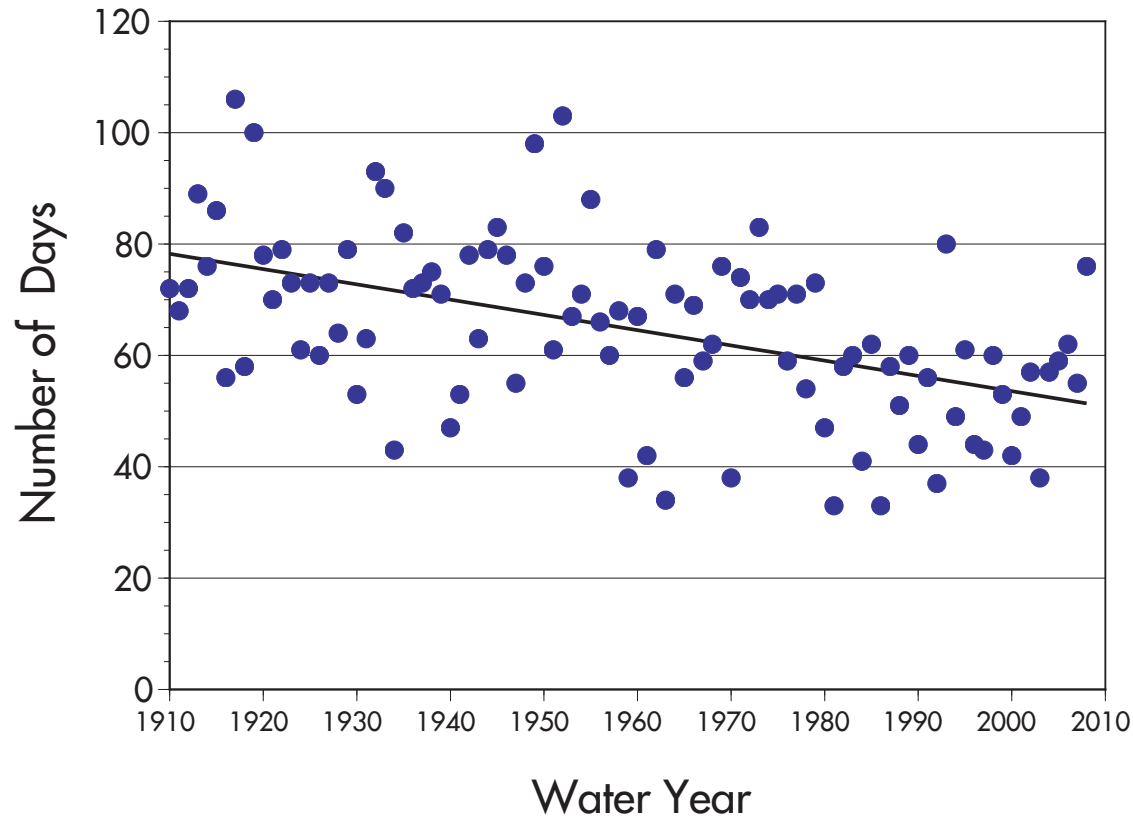
## METEOROLOGY

### Below-freezing air temperatures

Yearly since 1910

Although year-to-year variability is high, the number of days when temperatures averaged below freezing has declined by about 30 days since 1910.

In 2008, the number of freezing days was unusually high at 77. This is close to the average number of freezing days 100 years ago.



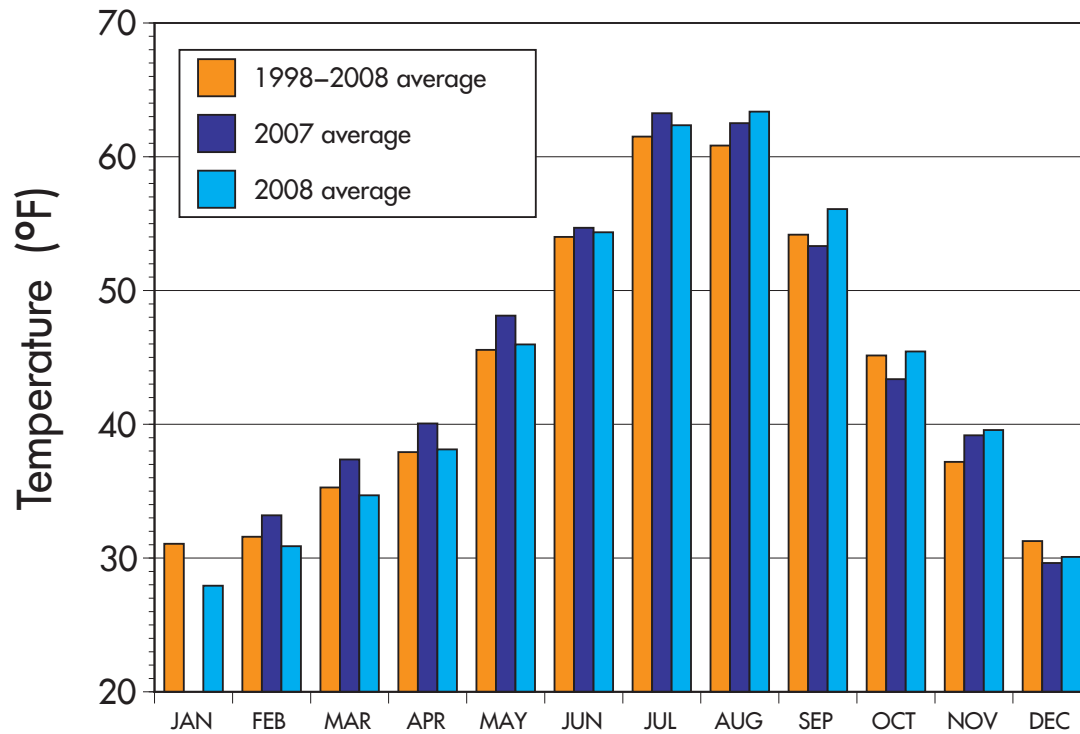
**METEOROLOGY**

**Monthly air temperature**

Since 1998

In 2008, January, February and March were colder than either the previous year or the eleven-year average. Late summer and fall, incorporating the

months of August through November, were significantly warmer than the previous year and the eleven-year average.



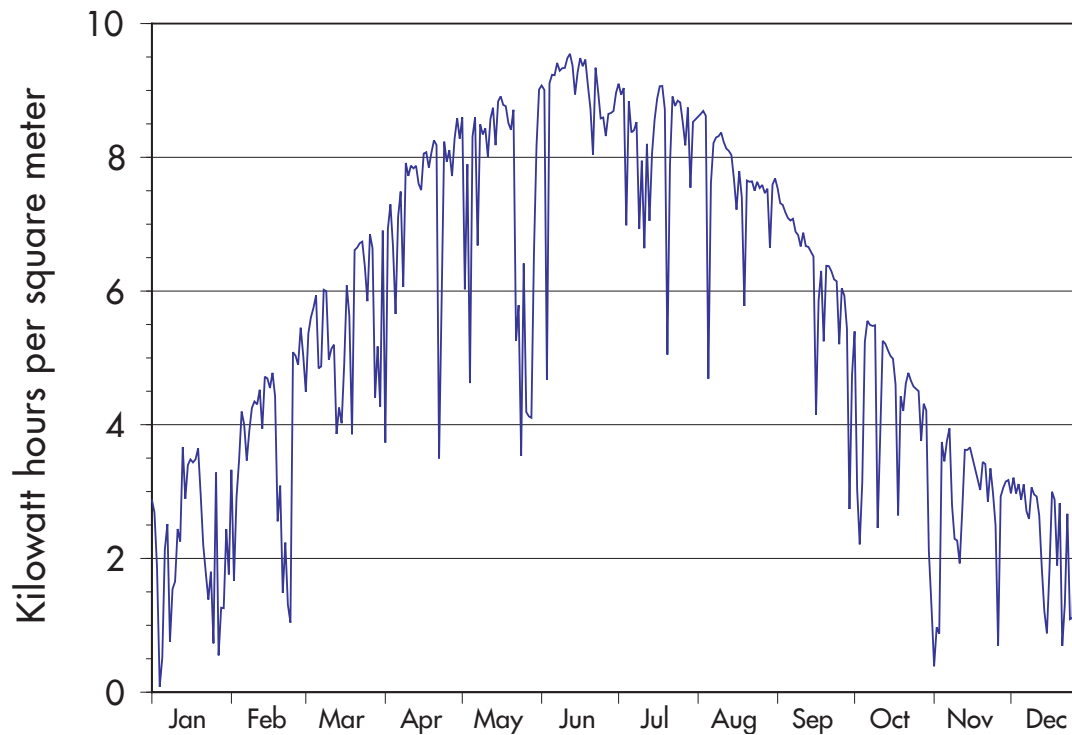
## METEOROLOGY

### Solar Radiation

Daily in 2008

Solar radiation showed the typical annual pattern of increasing then decreasing, peaking at the summer solstice on June 21 or 22. Dips in daily solar radiation are due to clouds, smoke and other atmospheric constituents. The California wildfires that

extended from June 6 to August 29, 2008 had their largest impact on the Tahoe basin for about 1 week commencing on July 9, 2008. An approximate 20% reduction in solar radiation can be seen during that period.



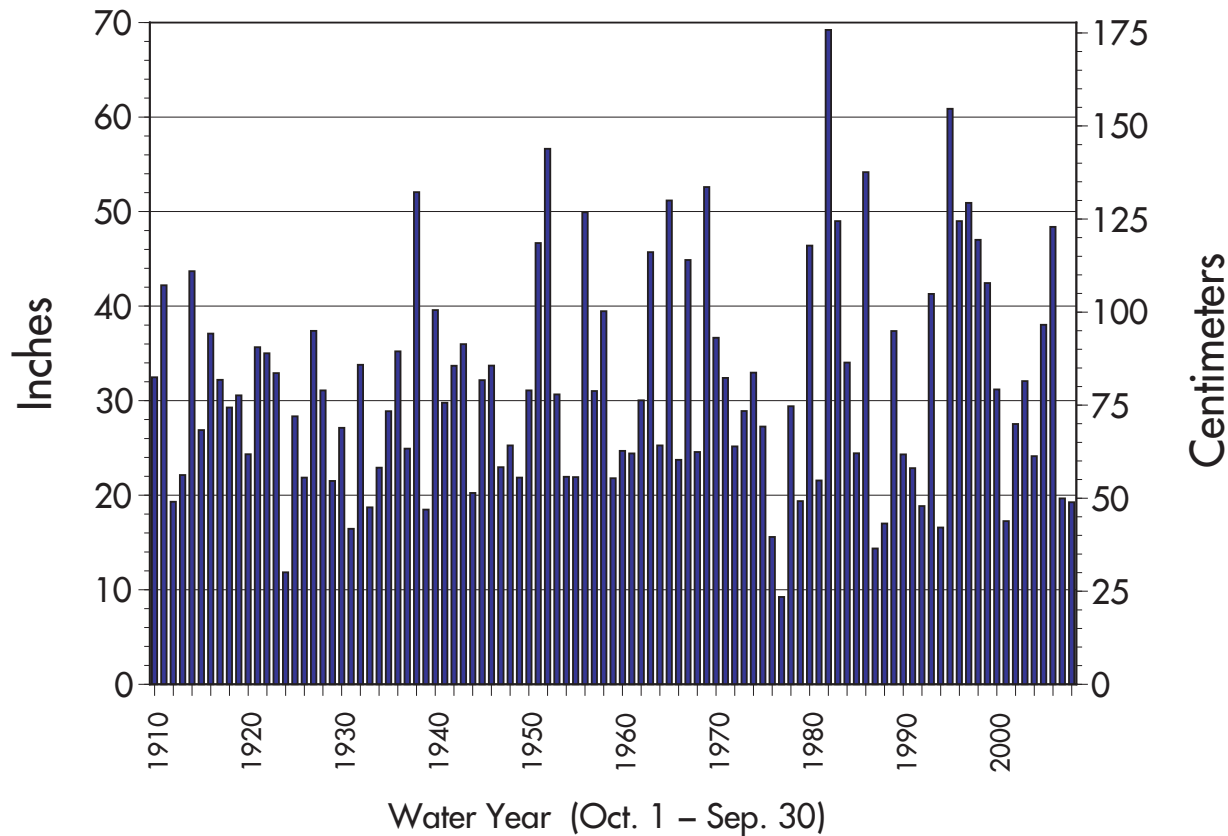
**METEOROLOGY**

**Annual precipitation**

**Yearly since 1910**

From 1910 to 2008, average annual precipitation (water equivalent of rain and snow) was 31.6 inches. The maximum was 69.2 inches in 1982. The minimum was 9.2 inches in 1977. 2008 was the

12th driest year on record, with only 19.3 inches of precipitation. (Precipitation is summed over the Water Year, which extends from October 1 through September 30.)





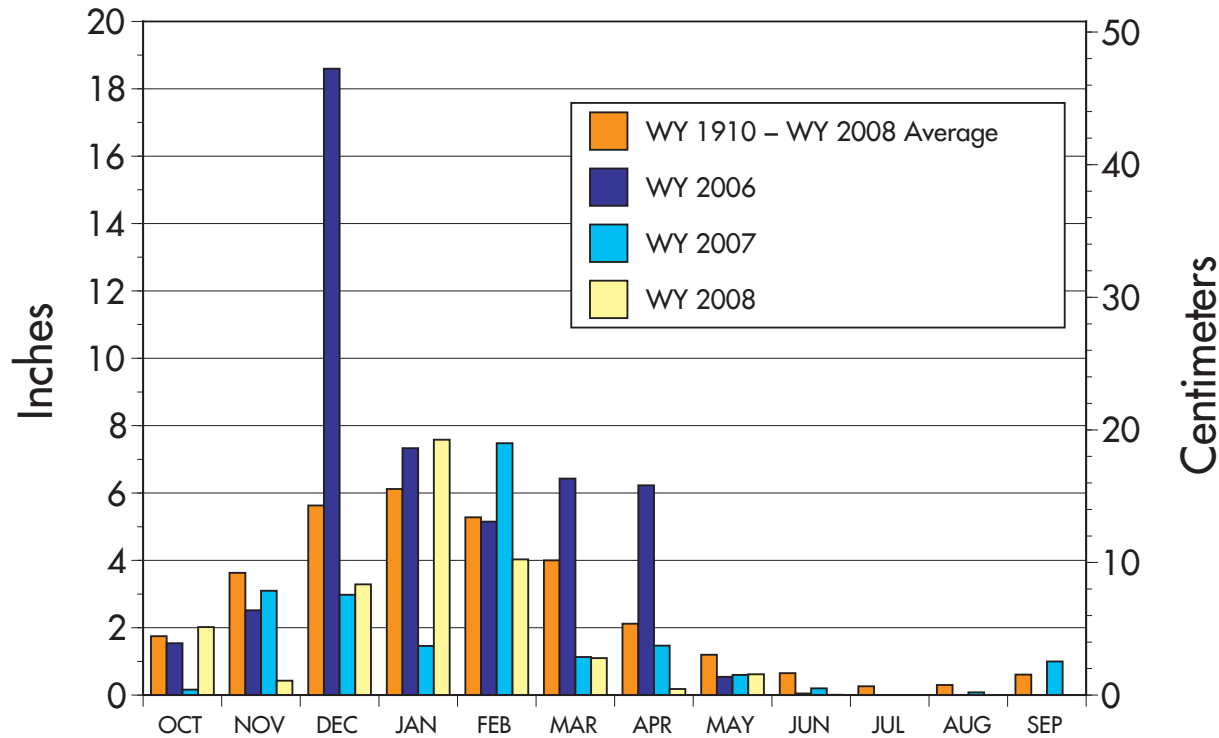
## METEOROLOGY

### Monthly precipitation

2006, 2007, 2008 and 1910 to 2008 Average

2008 was notable as the 12th driest year on record. Annual precipitation barely exceeded the amount received in the month of December 2006. Ten months were drier than the 99-year

historical average and January was by far the wettest month in 2008. The 2008 Water Year extended from Oct. 1, 2007, through Sept. 30, 2008.



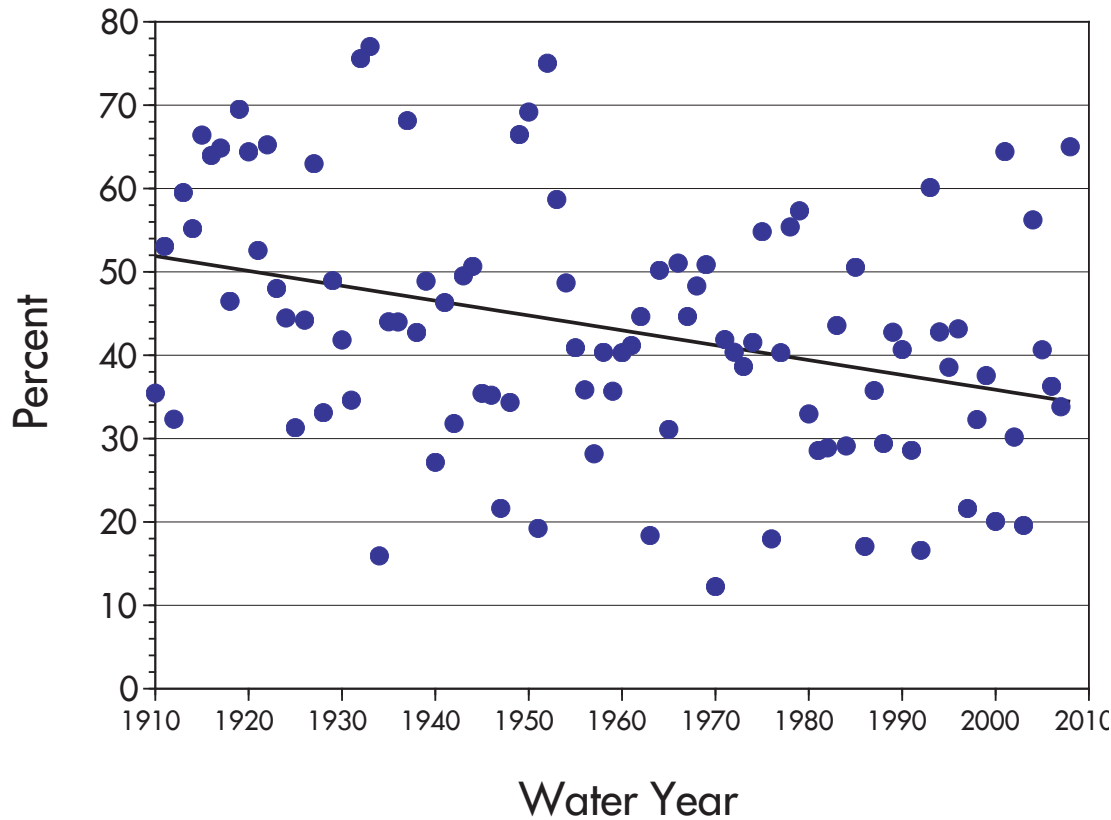
**METEOROLOGY**

**Snow as a fraction of annual precipitation**

Yearly since 1910

Snow has declined as a fraction of total precipitation, from an average of 52 percent in 1910 to 34 percent in present times. In Tahoe City, snow represented 65 percent of 2008 total precipitation, a marked increase over recent years.

These data assume precipitation falls as snow whenever the average daily air temperature is below freezing. (Precipitation is summed over the Water Year, which extends from October 1 through September 30.)



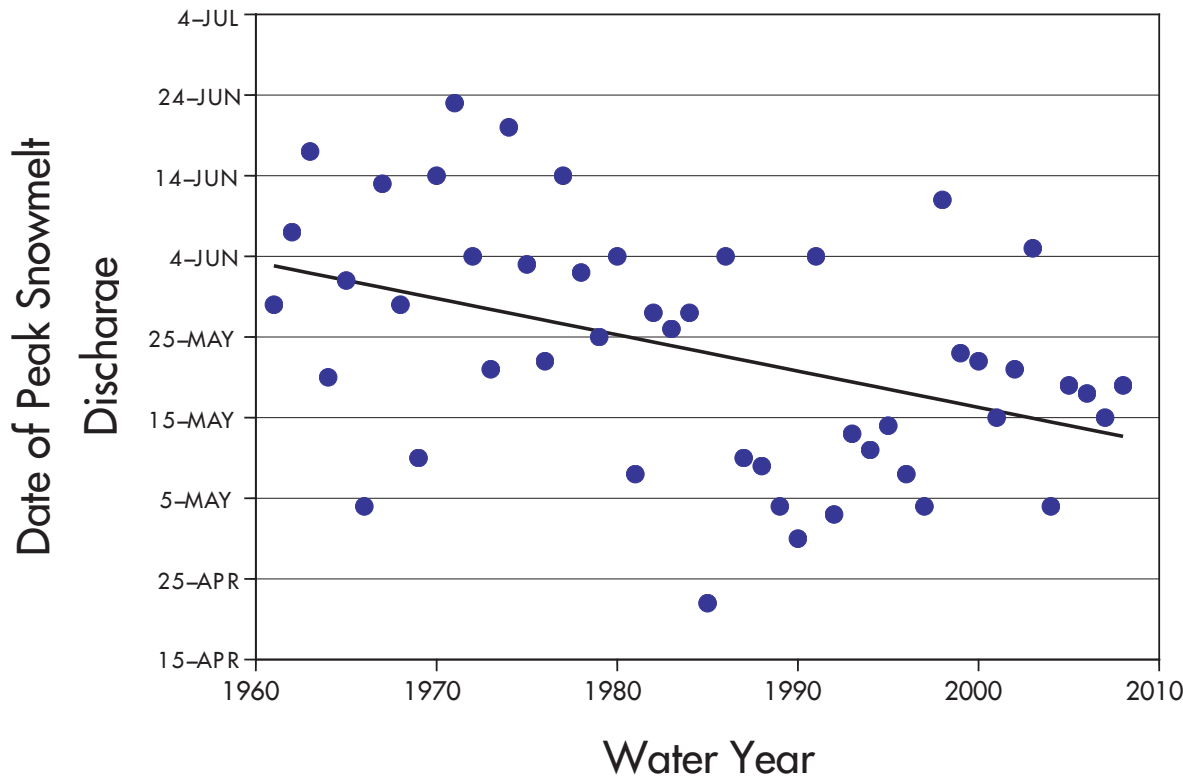
**METEOROLOGY**

**Shift in snowmelt timing**

Yearly since 1961

Although the date on which peak snowmelt occurs varies from year to year, since 1961 it has shifted earlier by an average of 2 ½ weeks. This shift is statistically significant and is one effect of climate change on Lake Tahoe. Peak snowmelt is defined as

the date when daily river flows reach their yearly maximum. Daily river flows increase throughout spring as the snow melts because of rising air temperatures, increasing solar radiation and longer days. The data here are for the Upper Truckee River.



TAHOE:  
STATE  
OF THE  
LAKE  
REPORT  
2009

**PHYSICAL  
PROPERTIES**

## PHYSICAL PROPERTIES

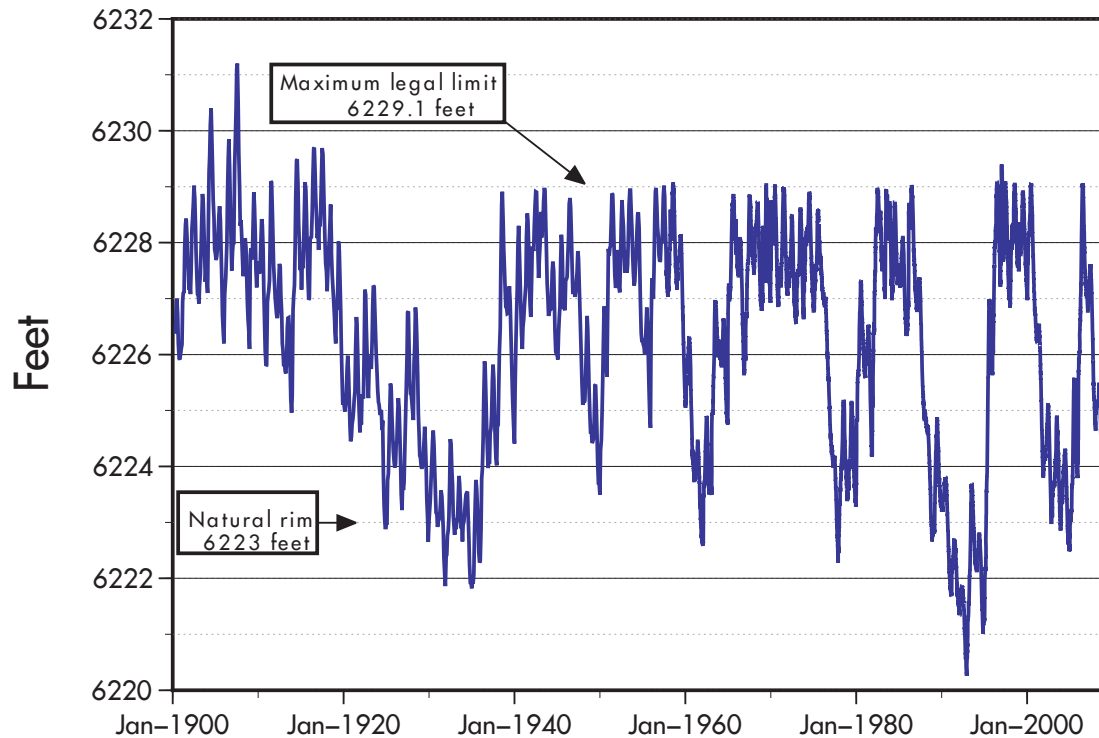
### Lake surface level

Daily since 1900

The lowest lake level on record was 6,220.26 feet on Nov. 30, 1992. Since 1900, lake level has varied by more than 10 feet. Lake level typically alternates between several years with values

close to the maximum, then several years close to the natural rim. This pattern reflects climate wet and dry cycles in the western US. (Lake surface levels are recorded by the U.S. Geological Sur-

vey as height above mean sea level. By law, Lake Tahoe cannot exceed 6,229.1 feet and nor can water be released to the Truckee River when it falls below the natural rim of 6,223 feet.)





**PHYSICAL PROPERTIES**

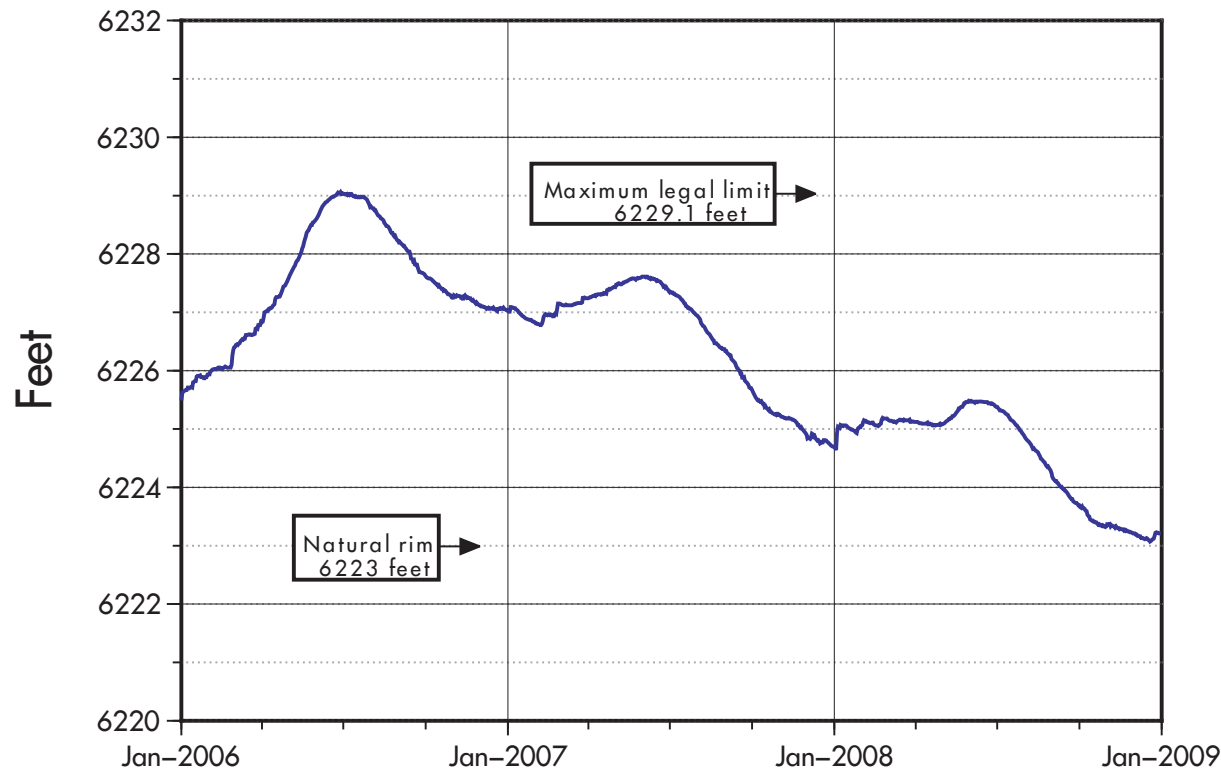
**Lake surface level**

Daily since 2005

Lake surface level varies throughout the year. It rises due to high stream inflow, groundwater inflow and precipitation directly onto the lake. It falls due to evaporation, in-basin

water withdrawals and flow out of the Truckee River. In 2008, dry conditions caused lake level to rise by only 10 inches during snowmelt, compared with several feet in normal runoff

years. The highest lake level was 6225.48 feet on June 2, and the lowest was 6223.07 feet on December 19, less than 1 inch above the natural rim.



## PHYSICAL PROPERTIES

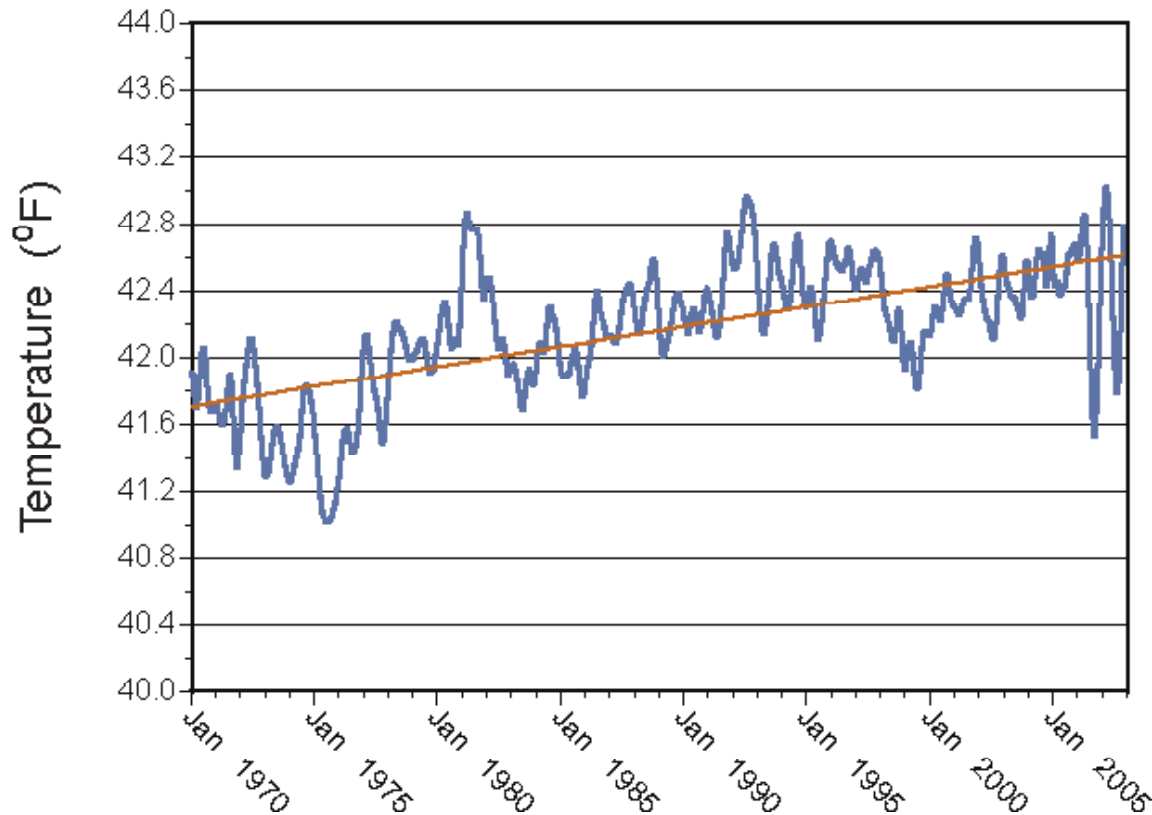
### Average water temperature

Since 1970

The volume-averaged temperature of Lake Tahoe has increased nearly a full degree since 1970, from 41.7 degrees F to 42.6 degrees F. The change in water temperature has affected the density stratification in the lake (Fig. 8.8) with

a subsequent shift in phytoplankton community structure. A published TERC study showed that small-sized diatom species were able to best adapt to the observed decrease in mixing intensity, highlighting the strong link

between climate change, physical processes and species diversity. (The monthly lake temperature profile data in this figure has been smoothed and deseasonalized to best show the long-term trend.)



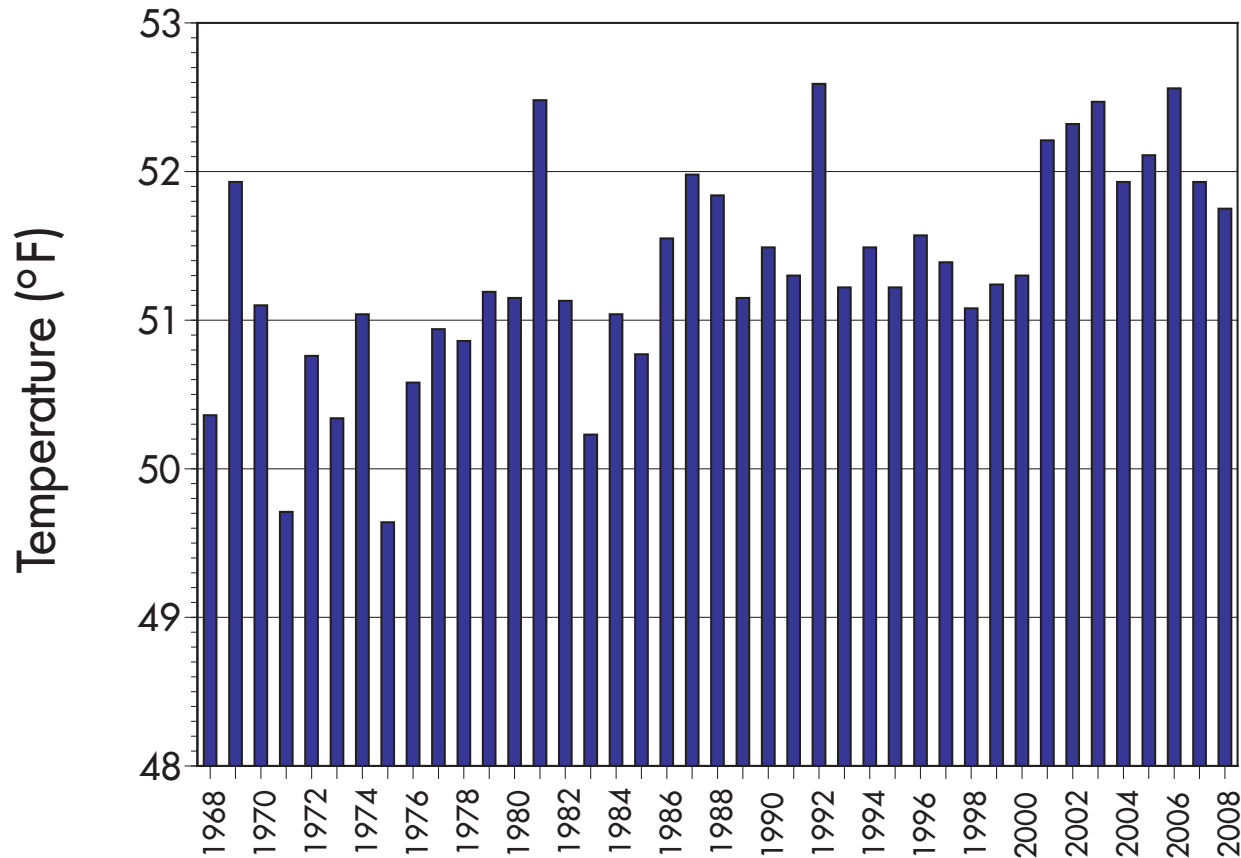
**PHYSICAL PROPERTIES**

**Surface water temperature**

Yearly since 1968

Surface water temperatures have been recorded at the mid-lake station since 1968. Despite year-to-year variability, water temperatures show an increas-

ing trend. The average temperature in 1968 was 50.3 degrees F. For 2008, the average surface water temperature was 51.7 degrees F.



## PHYSICAL PROPERTIES

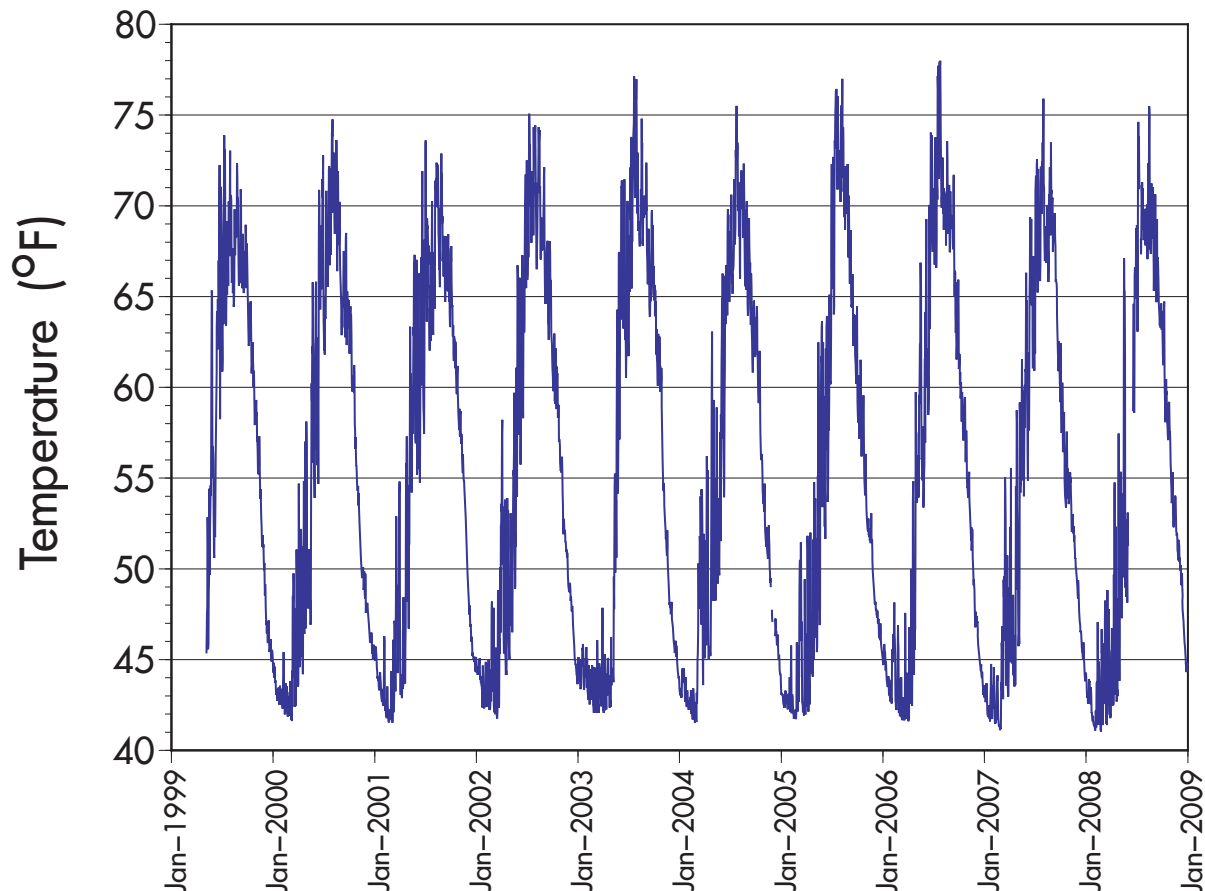
### Maximum daily surface water temperature

Every 15 minutes since 1999

Maximum daily surface water temperatures were similar in 2008 to the 2007 values, although summer surface water temperatures continue to show a long-term increase. Since May 1999,

the highest maximum daily surface temperature was 77.99 degrees F on July 26, 2006. The lowest maximum surface water temperature was 41.02 degrees F on Feb. 25, 2008. In the last

decade, the 28 lowest maximum daily surface water temperatures occurred in 2007 and 2008. This may be attributable to the deep mixing that has occurred in both these years.





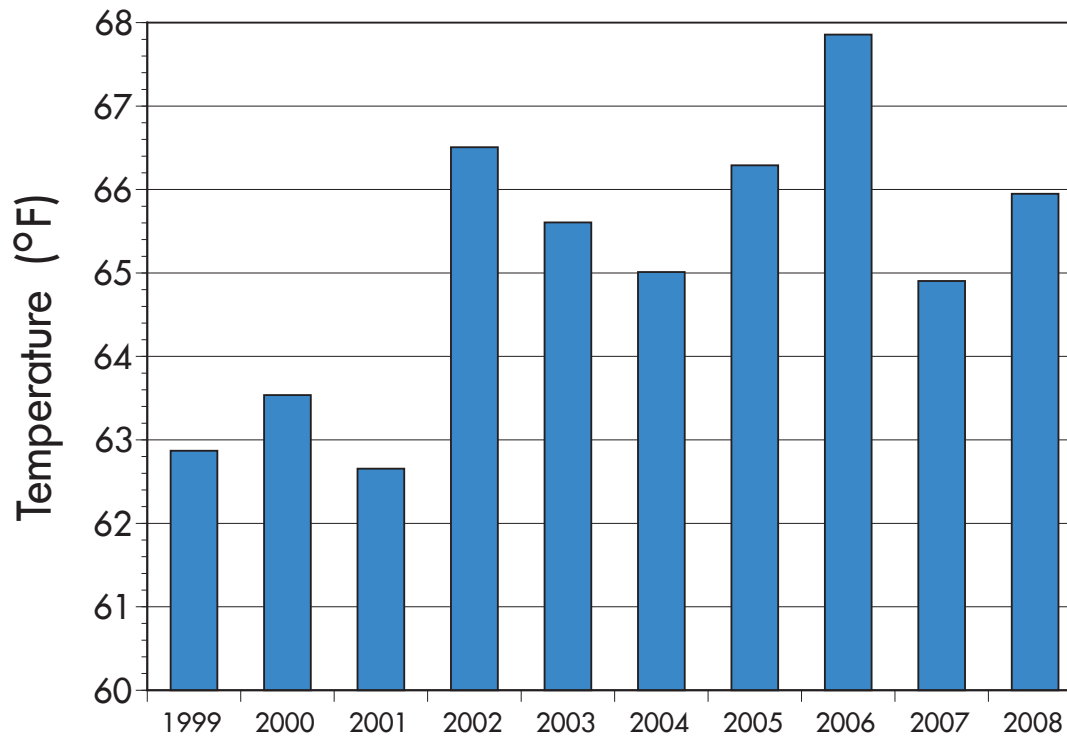
## PHYSICAL PROPERTIES

### July average surface water temperature

Since 1999

Since 1999, surface water temperature has been recorded every two minutes from four NASA/UC Davis buoys. Shown here are ten years of average surface water temperatures in the

month of July when water temperatures are typically warmest. In 2008, July surface water temperature averaged 66 degrees F, 1.1 degrees warmer than in 2007.



## PHYSICAL PROPERTIES

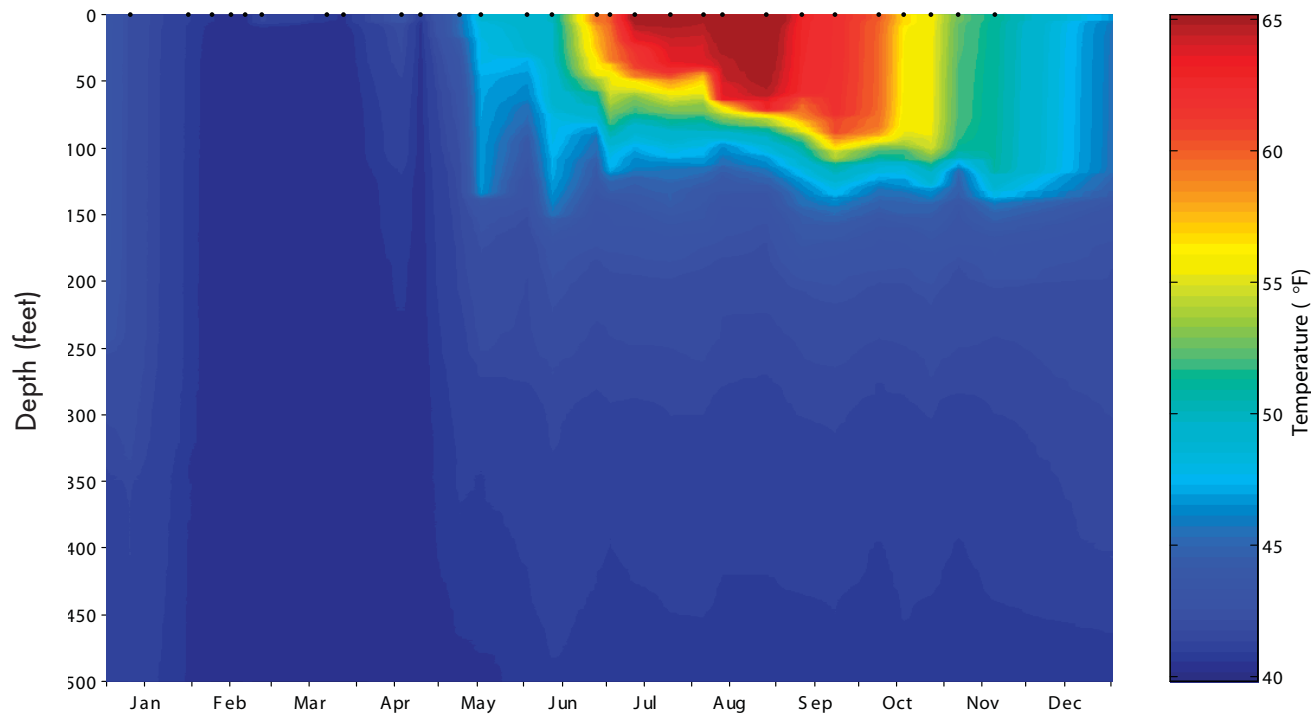
### Water temperature profile

In 2008

Water temperatures are measured at six-inch intervals every two to four weeks to produce Lake Tahoe's thermal profile. In 2008, that profile followed a typical seasonal pattern. In

early March, the lake was coldest with a uniform temperature throughout its depth. This resulted in a complete mixing from the surface to the bottom (1,645 feet), the second successive

year in which this happened. Thermal stratification commenced in May and peaked in late August. From September onwards, the surface layer cooled and deepened.



## PHYSICAL PROPERTIES

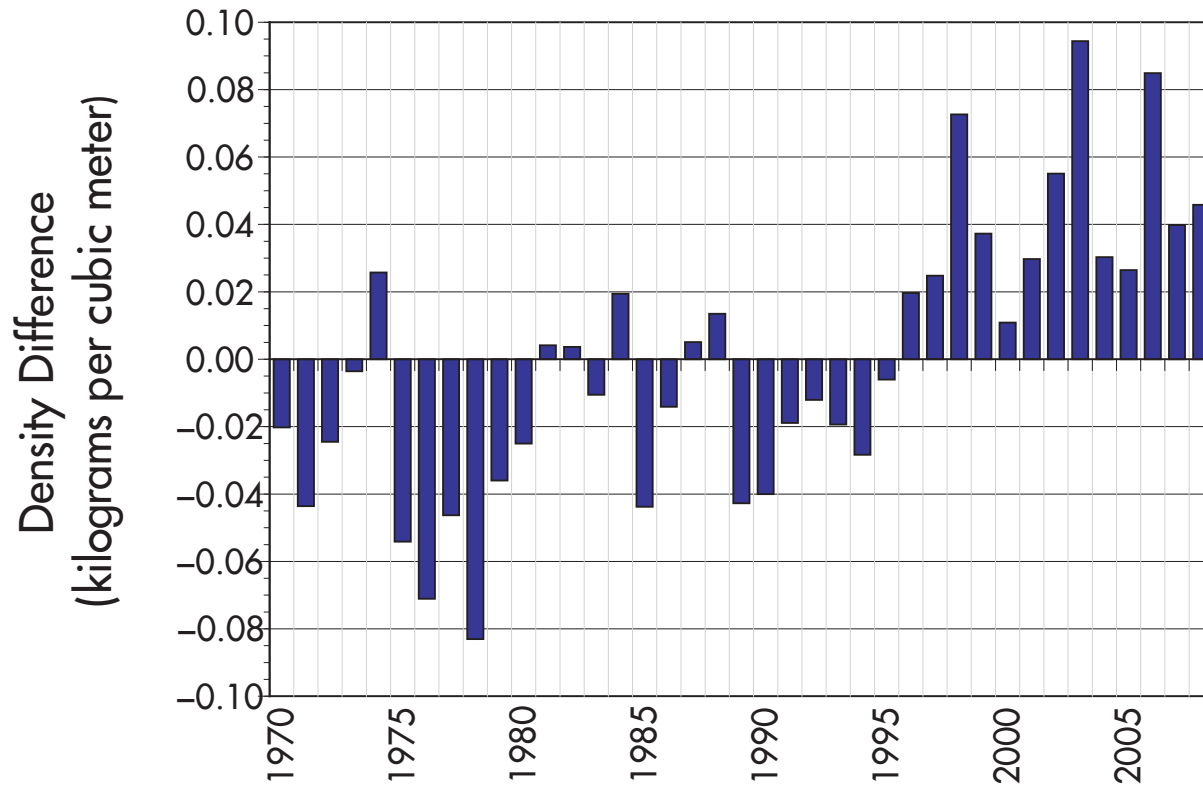
### Density stratification

Since 1970

Density stratification in Lake Tahoe has generally increased since 1970, as shown by the trend below. Each bar represents the annual average density difference between deep (100

to 165 feet) and shallow (0 to 33 feet) water, subtracted from the mean density. Density differences increase as Lake Tahoe's surface waters warm, making them less dense or lighter.

Increasing density stratification causes deep mixing of the lake to occur less frequently.



## PHYSICAL PROPERTIES

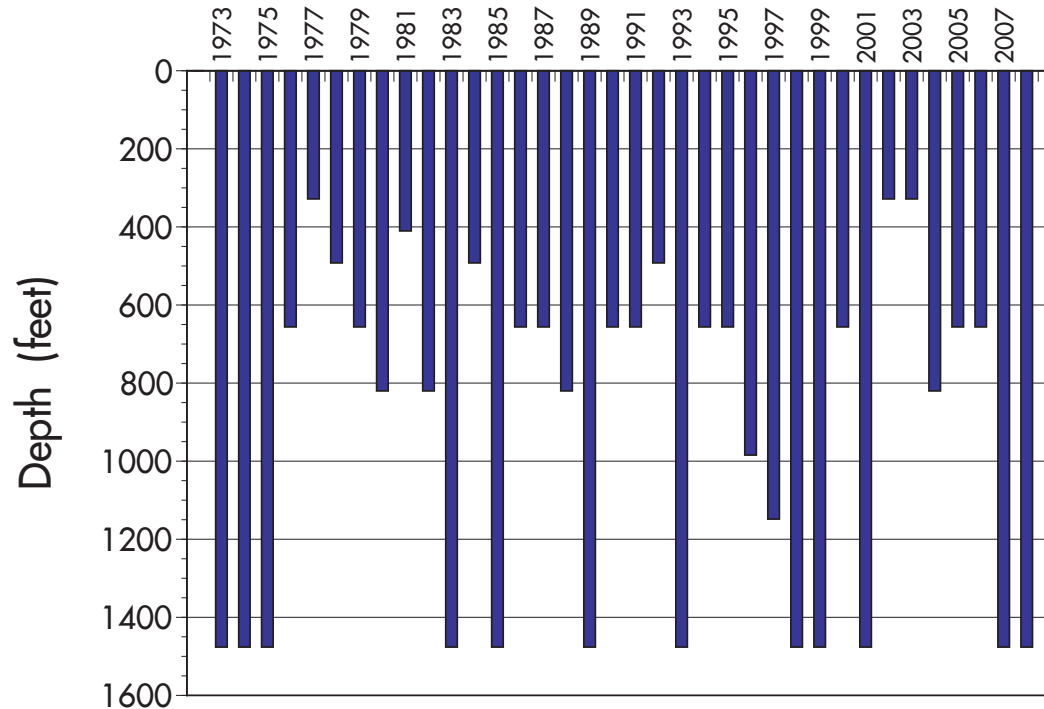
### Depth of mixing

Yearly since 1973

Lake Tahoe mixes each winter as surface waters cool and sink downward. In a lake as deep as Tahoe, the wind energy of winter storms helps to determine how deeply the lake mixes. Mixing depth has profound impacts on lake ecology and

water quality. Deep mixing brings nutrients to the surface, where they promote algae growth. It also moves oxygen to deep waters, promoting aquatic life throughout the water column. The deepest mixing typically occurs in late February to early March.

In 2008, Lake Tahoe mixed all the way to the bottom at the mid-lake station. This was the second successive year of deep mixing. Complete mixing during two or more successive years has only occurred three times since 1973.



**PHYSICAL PROPERTIES**

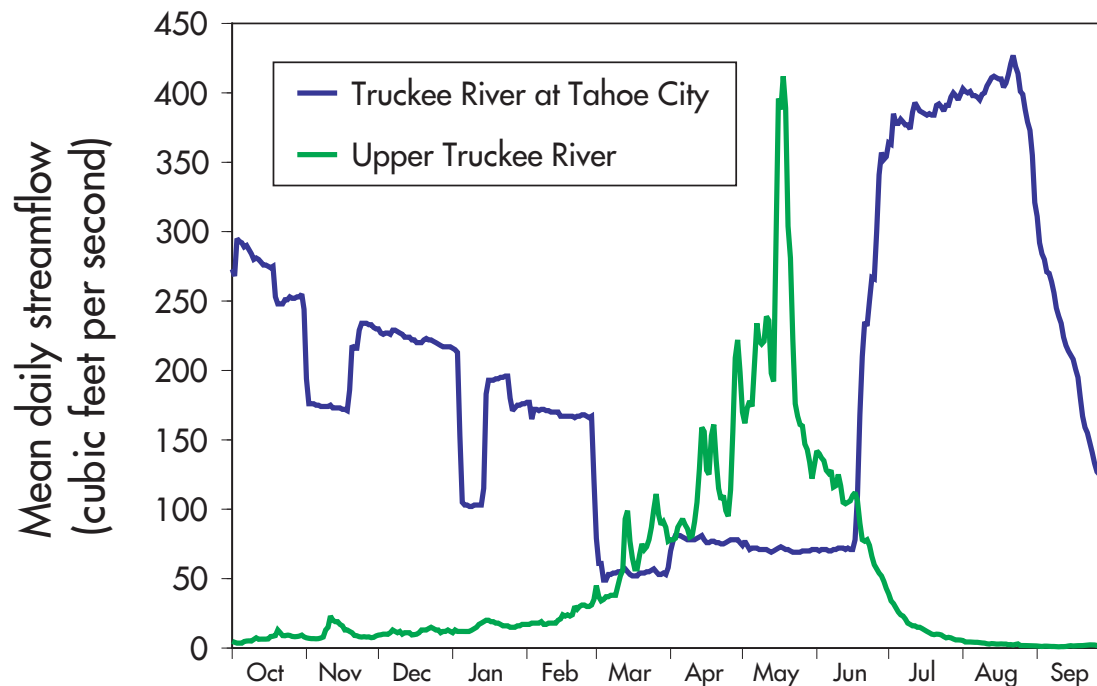
**Upper Truckee River vs. Truckee River Mean Daily Streamflow**

**Water Year 2008**

The seasonal pattern (hydrograph) for the Upper Truckee River, as it flows into Lake Tahoe, was dominated by the annual snowmelt that occurs in the spring. In 2008, discharge peaked

in mid-May. The low measured flow in the period October to February reflects the lack of significant rainfall, common for dry years such as 2008. The annual pattern of flow leaving

Lake Tahoe via the Truckee River at Tahoe City includes natural patterns of drainage into the lake as well as human management of lake level to meet downstream water demands.



**PHYSICAL PROPERTIES**

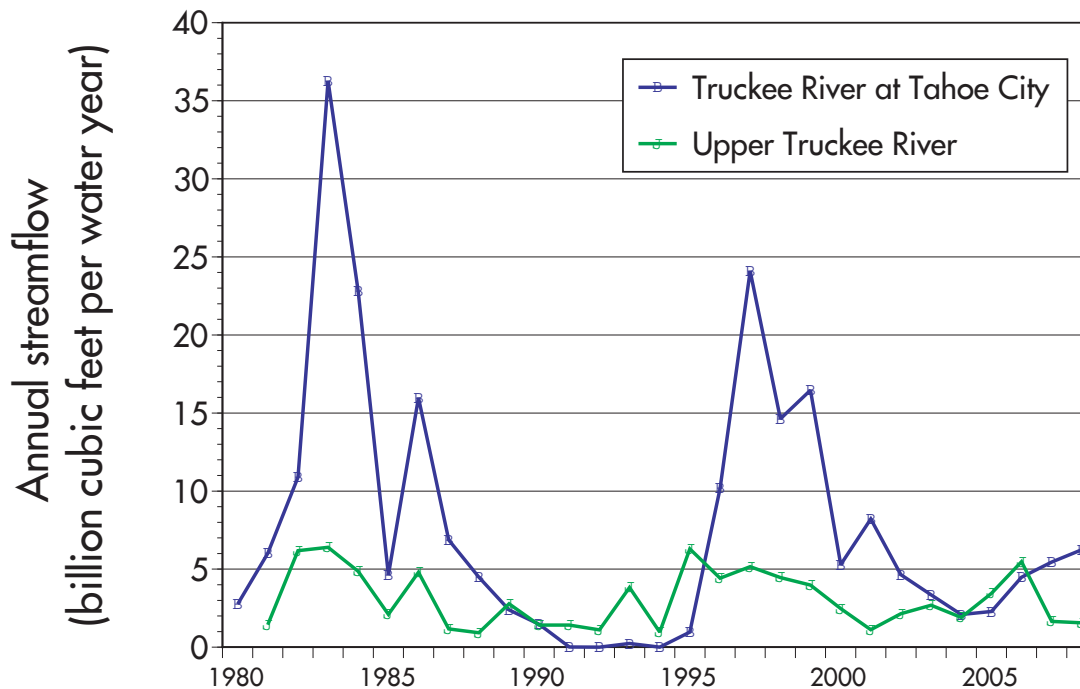
**Upper Truckee River vs. Truckee River Annual Streamflow**

Since 1980

Flow into Lake Tahoe (e.g. Upper Truckee River) and discharge out of Lake Tahoe (Truckee River at Tahoe City) has shown considerable variation since 1980. The large peaks in discharge from the lake correspond

to years when precipitation (and therefore total inflow) was the greatest, e.g. 1982-1983, 1986, 1995-1999. Similarly, the drought-like conditions in the early 1990s and the low precipitation years in the

beginning of the 2000s also stand out. Since many of the pollutants of concern for Lake Tahoe's clarity enter along with surface flow, year-to-year changes in clarity is influenced by precipitation and runoff.





TAHOE:  
STATE  
OF THE  
LAKE  
REPORT  
2009

**NUTRIENTS AND  
PARTICLES**

## NUTRIENTS AND PARTICLES

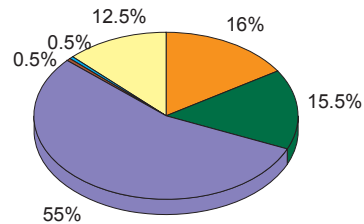
### Sources of clarity-reducing pollutants

Research has quantified the primary sources of nutrients (nitrogen and phosphorus) and particulate material that are causing Lake Tahoe to lose clarity. Extremely fine particles, the major contributor to clarity decline, primarily originate from the urban watershed (72%), even though these areas cover

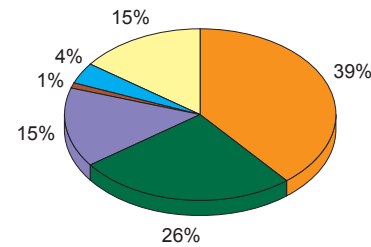
only 10% of the Tahoe basin. For nitrogen, atmospheric deposition is the major source (55%). Phosphorus is primarily introduced by the urban (39%) and non-urban (26%) watersheds. These categories of pollutant sources form the basis of plans to restore Lake Tahoe's open-water clarity by agencies including

the Lahontan Regional Water Quality Control Board, the Nevada Division of Environmental Protection, the Tahoe Regional Planning Agency and the California Tahoe Conservancy. (Data were generated for the Lake Tahoe TMDL Program and this figure also appeared in last year's State of the Lake Report 2008.)

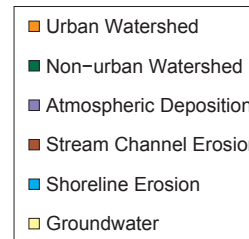
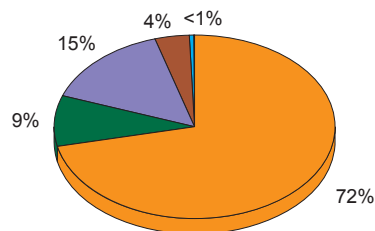
**Total Nitrogen**



**Total Phosphorus**



**Fine Sediment Particles**



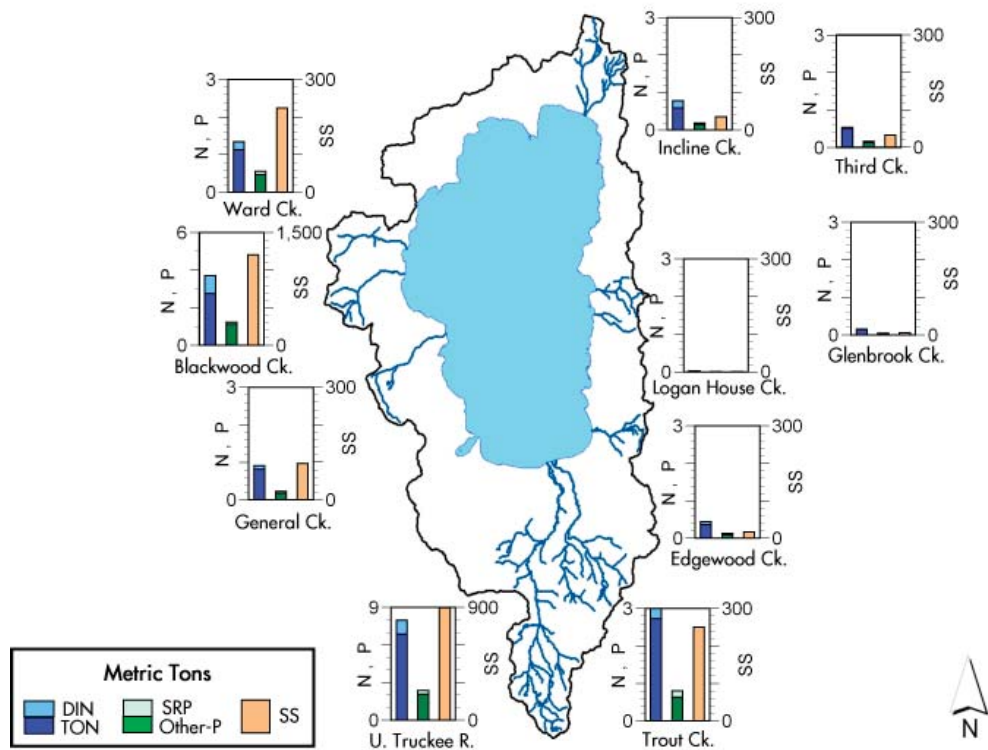
**NUTRIENTS AND PARTICLES**

**Pollutant loads from 10 watersheds**

The Lake Tahoe Interagency Monitoring Program (LTIMP) measures nutrient and sediment input from 10 of the 63 watershed streams – these account for approximately half of all stream flow into the lake. Most of the suspended

sediment contained in the 10 LTIMP streams is from the Upper Truckee River, Blackwood Creek, Trout Creek and Ward Creek, most especially the first two. Over 75 percent of the phosphorus and nitrogen comes from the

Upper Truckee River, Trout Creek and Blackwood Creek. The LTIMP stream water quality program is managed by the U.S. Geological Survey in Carson City, Nevada, UC Davis TERC and the Tahoe Regional Planning Agency.



**NUTRIENTS AND PARTICLES**

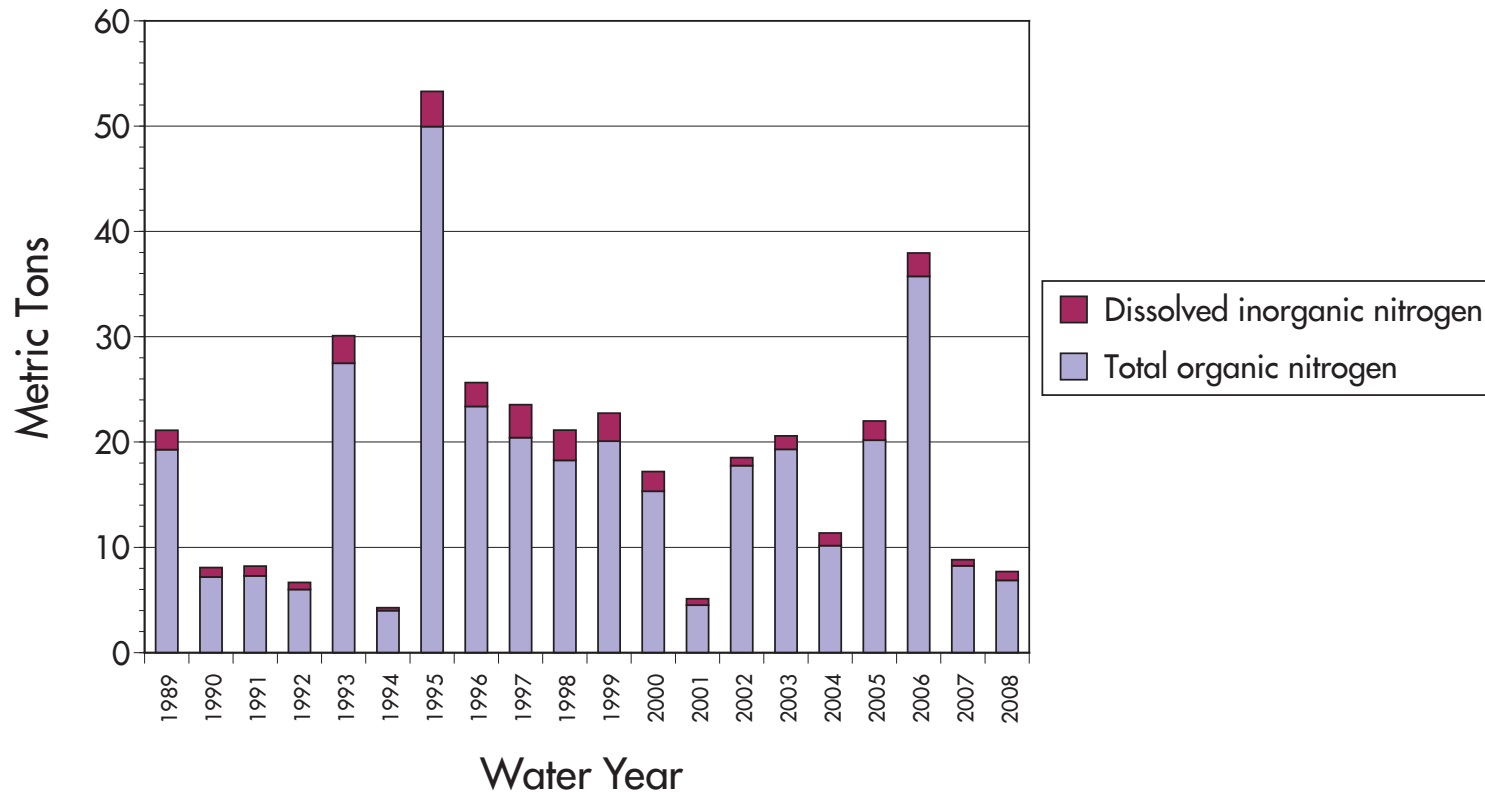
**Nitrogen contribution by Upper Truckee River**

Since 1989

Nitrogen (N) is important because it, along with phosphorus (P), stimulates algal growth. (Fig. 9.1 shows the major sources of N and P to Lake Tahoe) The Upper Truckee River is the largest of the 63 streams that flow into Lake Tahoe, contributing about 25 percent of the inflowing water. The river's contribution of dissolved inorganic

nitrogen (nitrate and ammonium) and total organic nitrogen loads are shown here. The year-to-year variations primarily reflect changes 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. Low rainfall in

2008 resulted in a low nitrogen load. The watershed burned in the Angora Fire (June 2007) drains directly to the Upper Truckee River. 2008 was the first year after the fire and nitrogen load was not elevated as a result of that event. (One metric ton = 2,205 pounds.)



**NUTRIENTS AND PARTICLES**

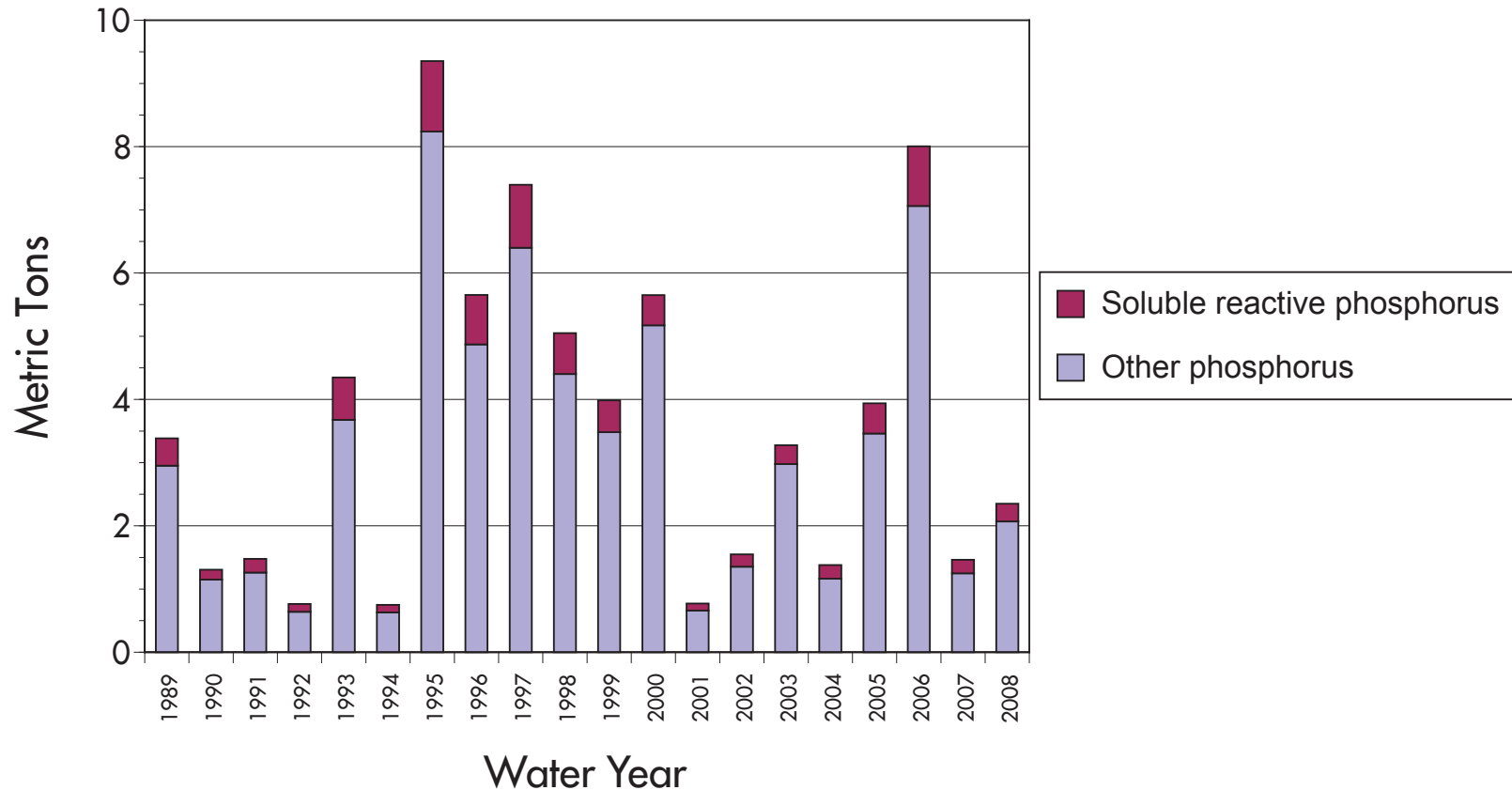
**Phosphorus contribution by Upper Truckee River**

Yearly since 1989

Soluble reactive phosphorus (SRP) is that fraction of phosphorus immediately available for algal growth. As with nitrogen (Fig. 9.3), the year-to-year variation in load largely reflects the changes in precipitation. Low

rainfall in 2008 resulted in a relatively low phosphorus load. Unlike nitrogen and suspended sediment, phosphorus was somewhat higher in 2008 versus 2007. The possible influence of the Angora Fire is being investigated.

Total phosphorus is the sum of SRP and other phosphorus, which includes organic phosphorus and phosphorus associated with particles. (One metric ton = 2,205 pounds.)



**NUTRIENTS AND PARTICLES**

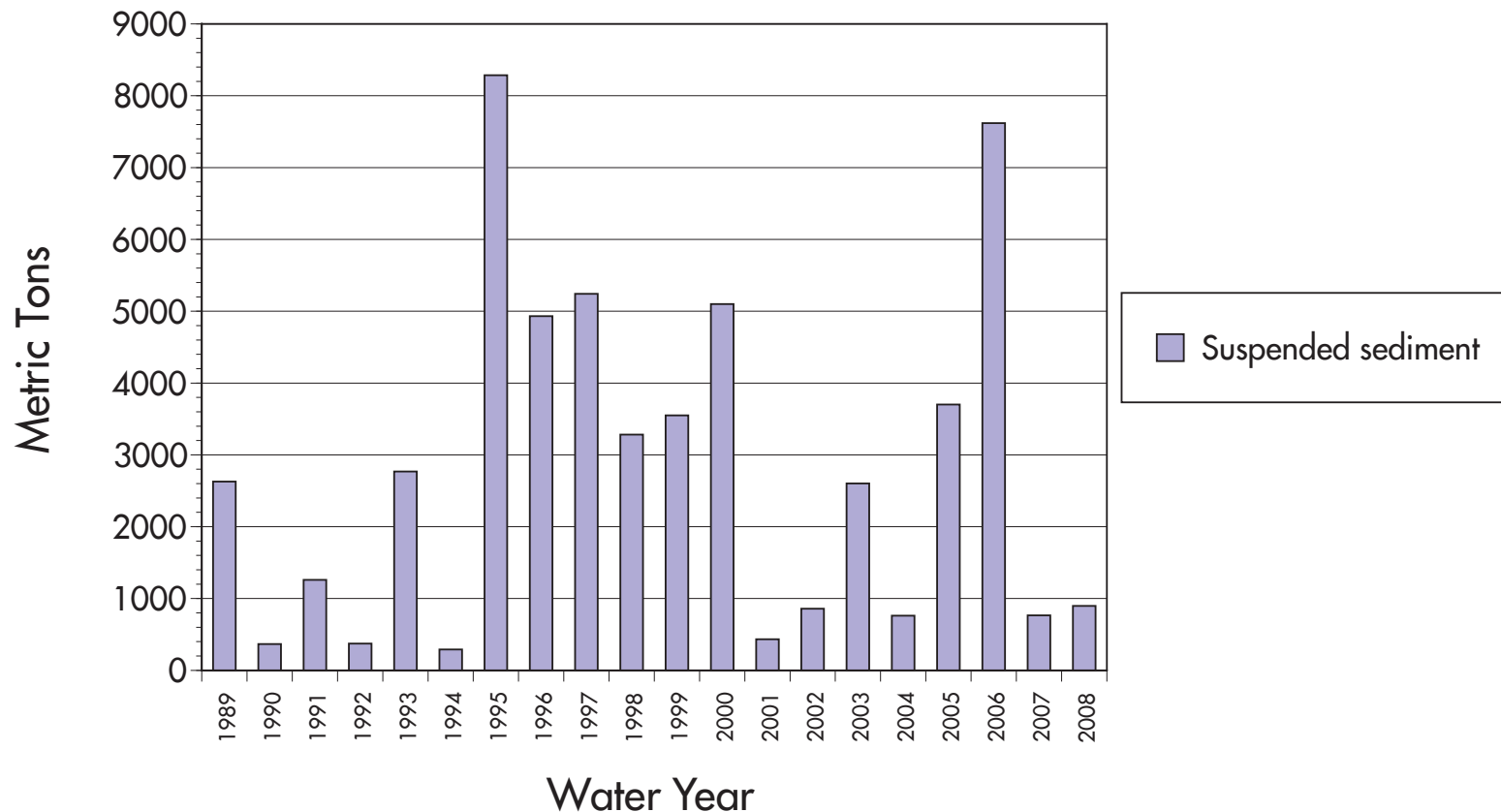
**Suspended sediment contribution by Upper Truckee River**

Yearly since 1989

The load of suspended sediment delivered to the lake by the Upper Truckee is tied directly to precipitation and stream flow. Low rainfall in 2008 resulted in a low suspended sediment load. This and the previous two figures illustrate how greatly

changes in hydrological conditions affect pollutant loads. Plans to restore lake clarity emphasize reducing loads of very fine suspended sediment (less than 20 microns in diameter). As with nitrogen and phosphorus, no large-scale effect of the Angora Fire on

suspended sediment transport to the Upper Truckee River was seen in the first year after the fire. This was most likely the result of the low amount of precipitation that year. (One metric ton = 2,205 pounds.)





**NUTRIENTS AND PARTICLES**

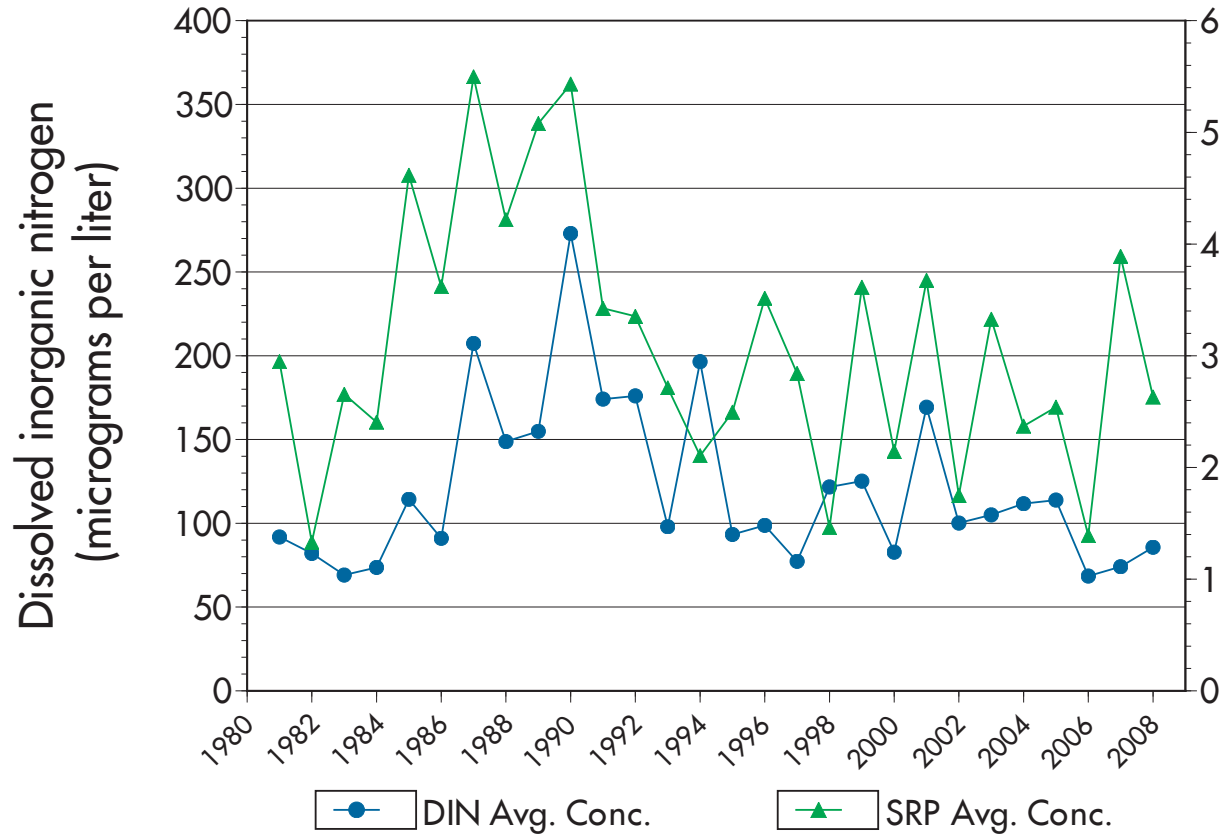
**Nutrient concentrations in rain and snow**

Yearly since 1981

Nutrients in rainwater and snow (called wet deposition) contribute large amounts of nitrogen, but also significant phosphorus, to Lake Tahoe. Nutrients in precipitation have

been measured near Ward Creek since 1981, and show no consistent upward or downward trend. Annual concentrations in precipitation of dissolved inorganic nitrogen (DIN) and soluble

reactive phosphorus (SRP) vary from year to year. In 2008, concentrations of DIN in precipitation remained relatively low, but were close to the average for SRP since the early 1990s.



**NUTRIENTS AND PARTICLES**

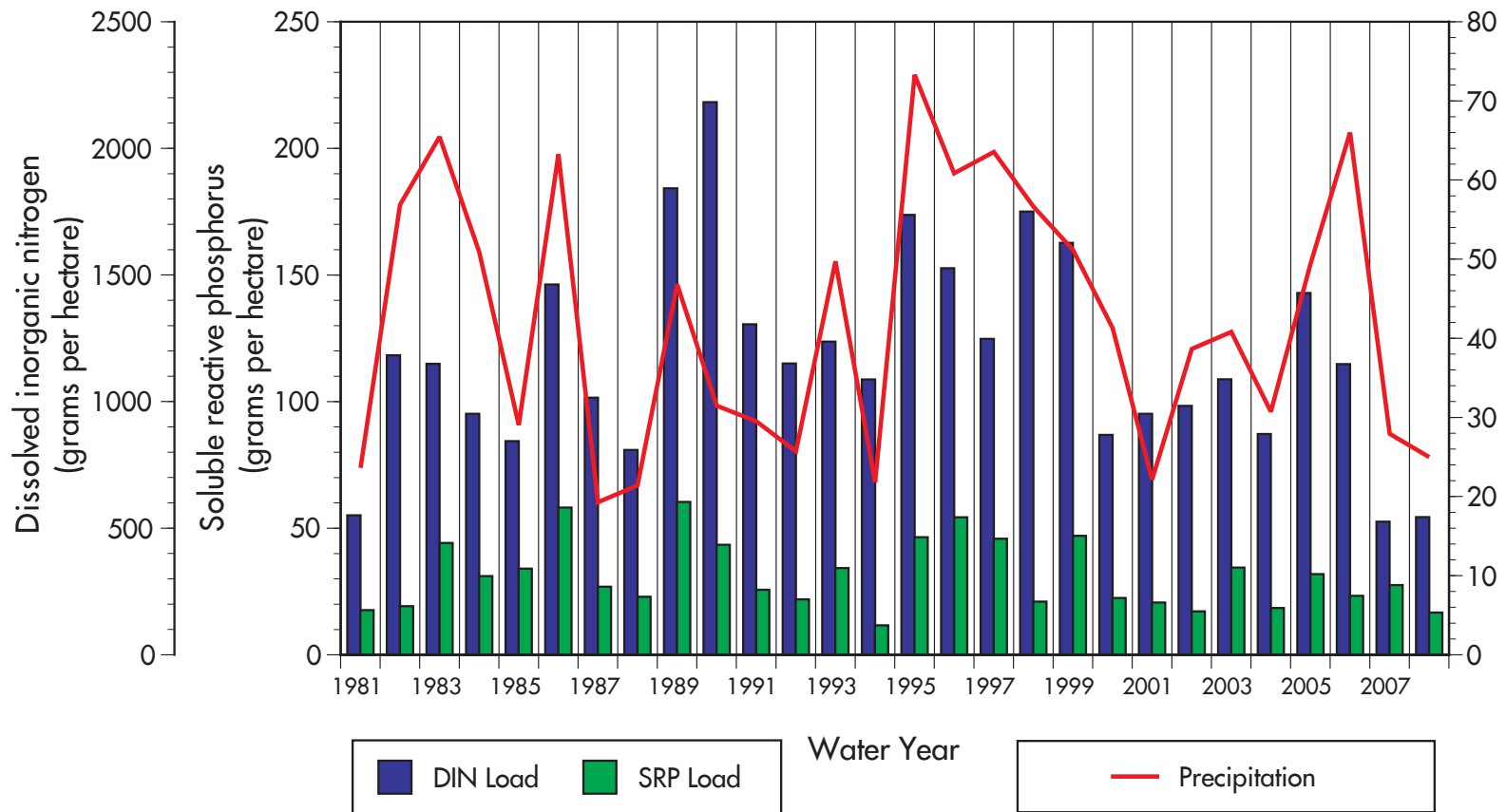
**Nutrient loads in rain and snow**

Since 1981

The annual load for wet deposition is calculated by multiplying the concentration of dissolved inorganic nitrogen (nitrate and ammonium) and soluble reactive phosphorus (in the previous

graph) by total annual precipitation. While nitrogen and phosphorus loads from precipitation have varied from year to year at the Ward Creek monitoring site, no obvious long-term trend

has emerged. In 2008, the phosphorus load was near or slightly lower than the historical average while the nitrogen load was similar to that measured in 2007, the lowest on record.



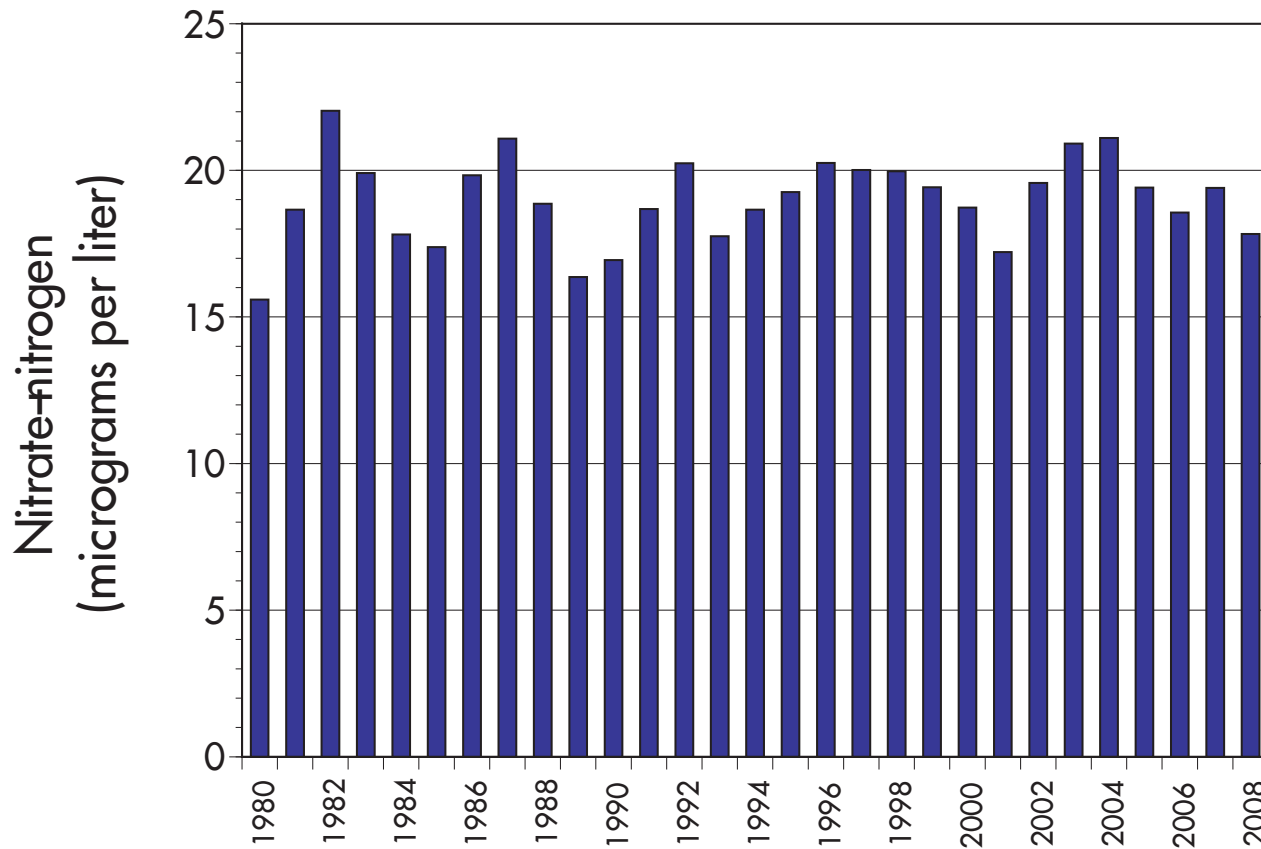
**NUTRIENTS AND PARTICLES**

**Lake nitrate concentration**

Yearly since 1980

Since 1980, the lake nitrate concentration has remained relatively constant, ranging between 16 and 22 micrograms per liter. In 2008, the volume-weighted

annual average concentration of nitrate was approximately 17.5 micrograms per liter (or parts per billion).



## NUTRIENTS AND PARTICLES

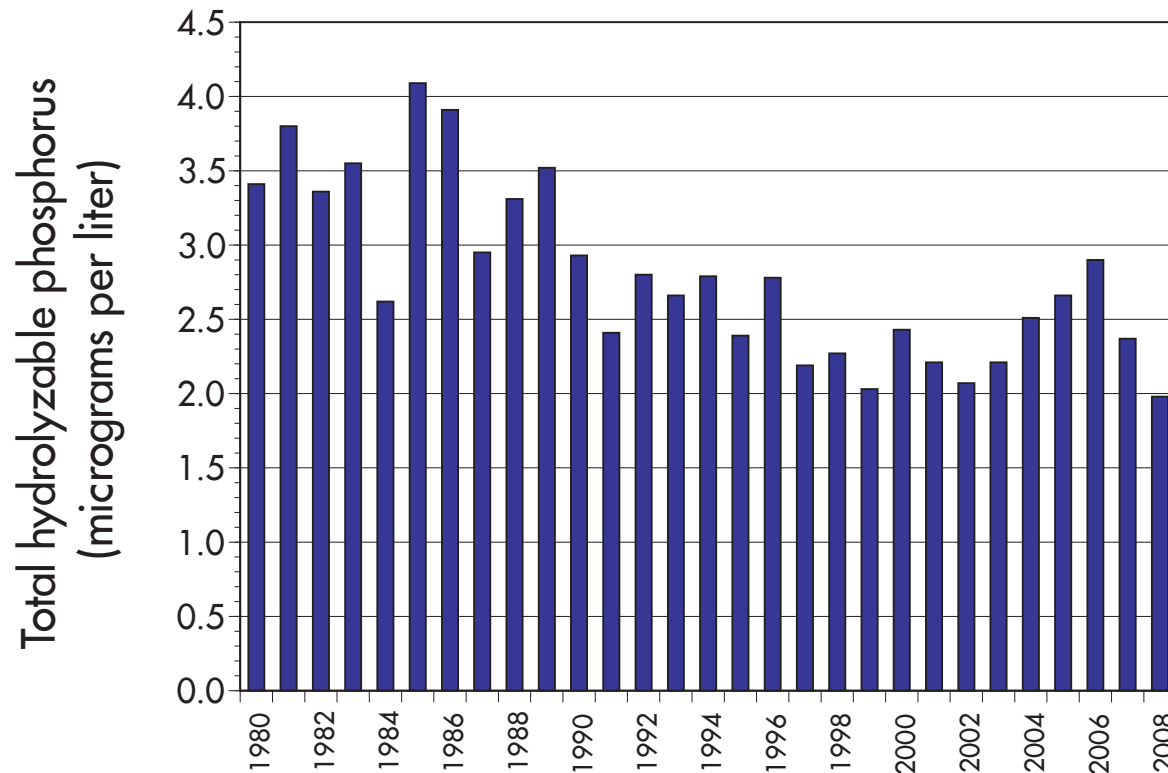
### Lake phosphorus concentration

Yearly since 1980

Phosphorus naturally occurs in Tahoe Basin soils and enters the lake from soil disturbance and erosion. Total hydrolyzable phosphorus, or THP, is a measure of the fraction of phosphorus

algae can use to grow. Since 1980, THP has tended to decline. In 2008, the volume-weighted annual average concentration of THP was just under 2.0 micrograms per liter

and the lowest annual average since monitoring of this parameter began in 1980.



TAHOE:  
STATE  
OF THE  
LAKE  
REPORT  
2009

**BIOLOGY**

## BIOLOGY

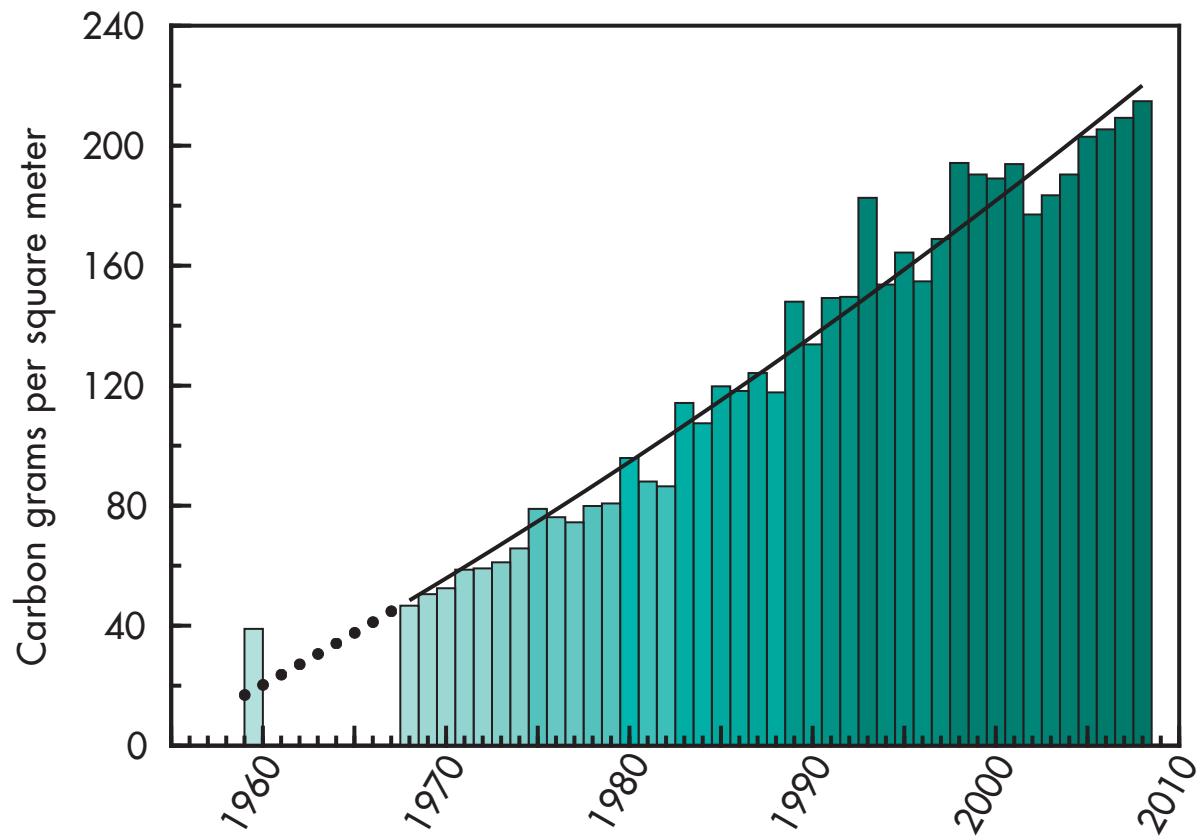
### Algae growth (primary productivity)

Yearly since 1959

Primary productivity is a measure of the rate at which algae produce biomass through photosynthesis. It was first measured at Lake Tahoe in 1959 and has been continuously

measured since 1968. Primary productivity has steadily increased over that time, promoted by nutrient loading to the lake, changes in the underwater light environment and a

succession of algae species. In 2008, primary productivity was 214.8 grams of carbon per square meter.





**BIOLOGY**

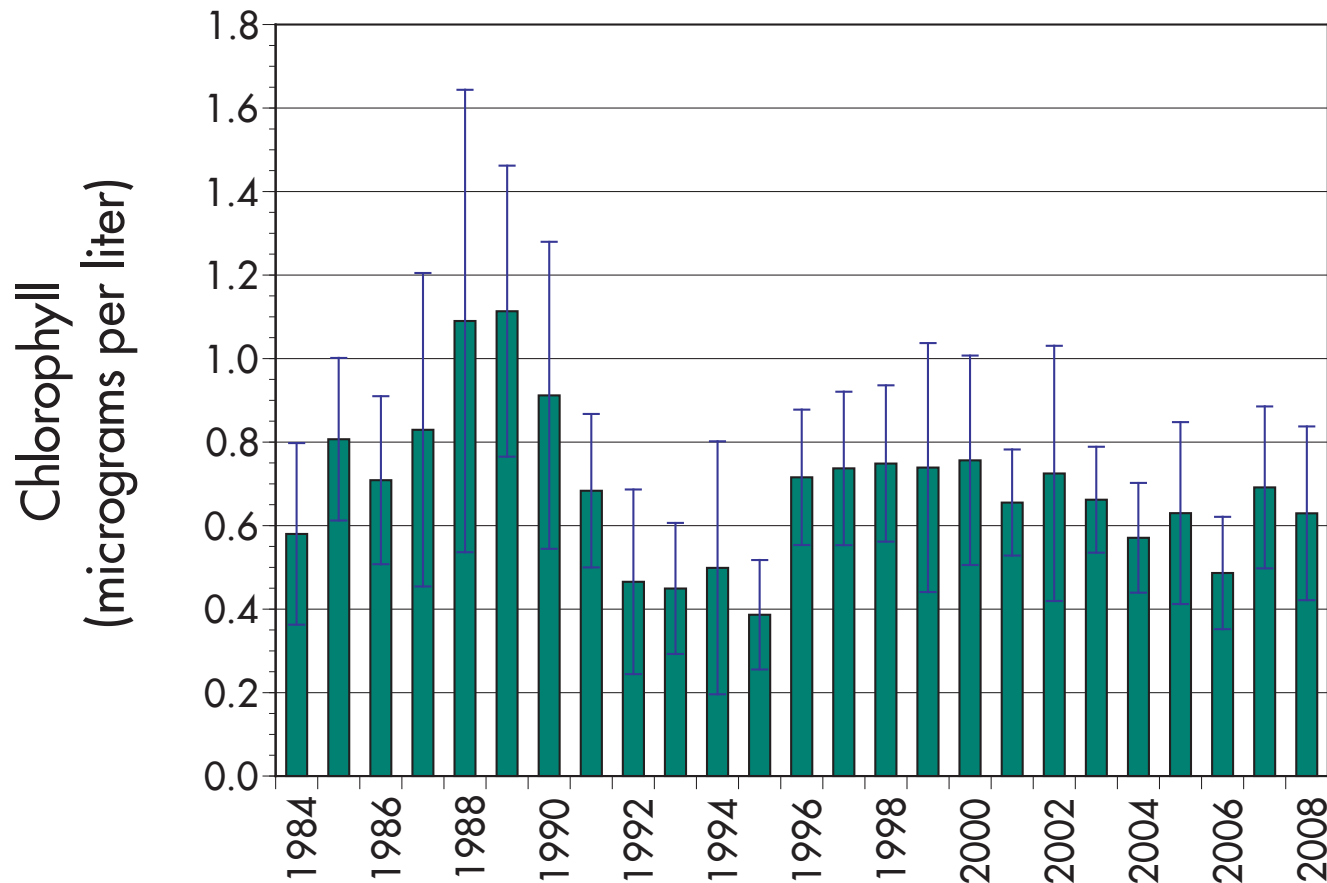
**Algae abundance**

Yearly since 1984

The amount of free-floating algae (phytoplankton) in the water is determined by measuring the concentration of chlorophyll a. Chlorophyll a is a common measure

of phytoplankton biomass. Though algae abundance varies annually, it does not show a long-term increase. The annual average value for 2008 was 0.63 micrograms per liter. The average

annual chlorophyll a level in Lake Tahoe has remained relatively uniform since 1996.



## BIOLOGY

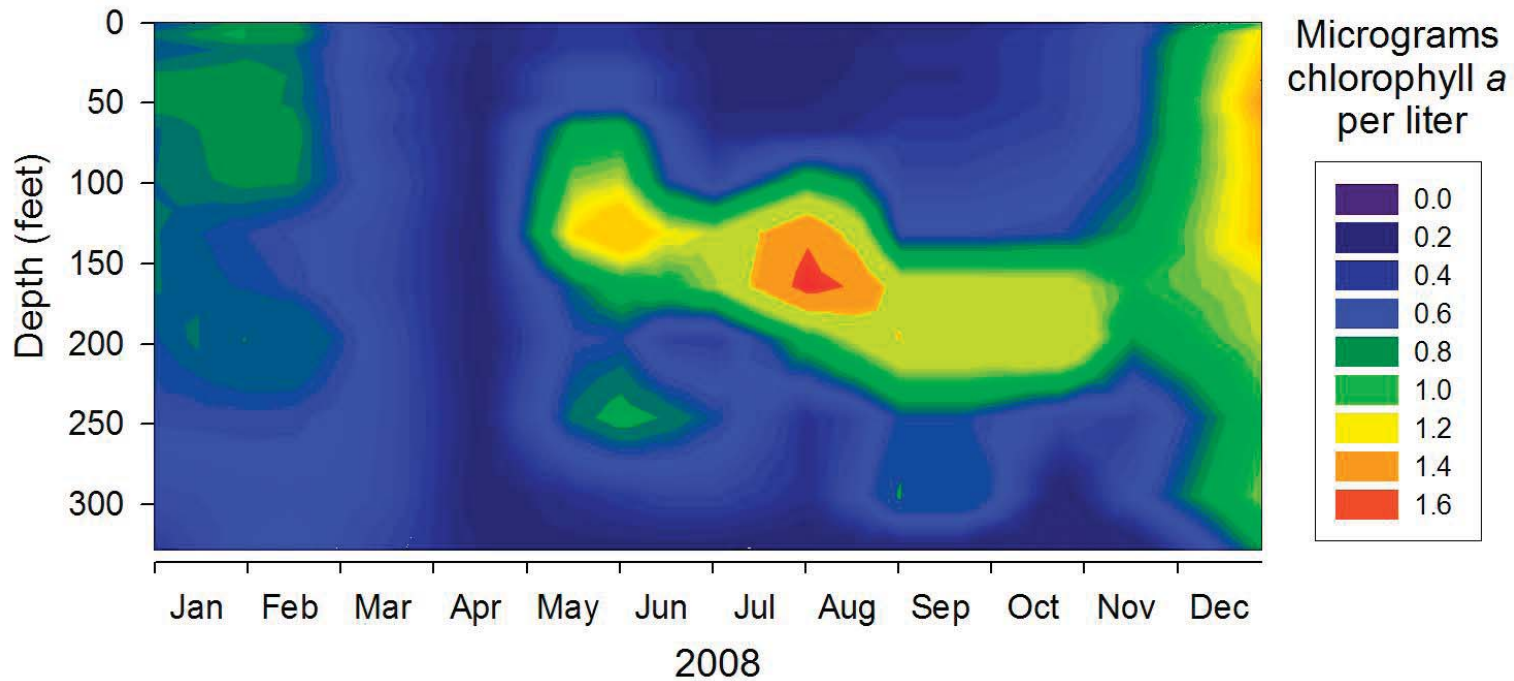
### Algae concentration by depth

In 2008

The highest concentrations of algae (as measured by chlorophyll a concentration) occur in summer between the 100 and 200-foot depths. This discrete layer, known as the

deep chlorophyll maximum, forms in spring and persists until winter mixing redistributes algae. In 2008, winter mixing began in late-November and early-December. The deep chlorophyll

layer is below the Secchi depth (Figs. 11.1 and 11.2), and does not influence lake clarity until winter mixing relocates chlorophyll into the range of the Secchi disk (50 to 80 feet).



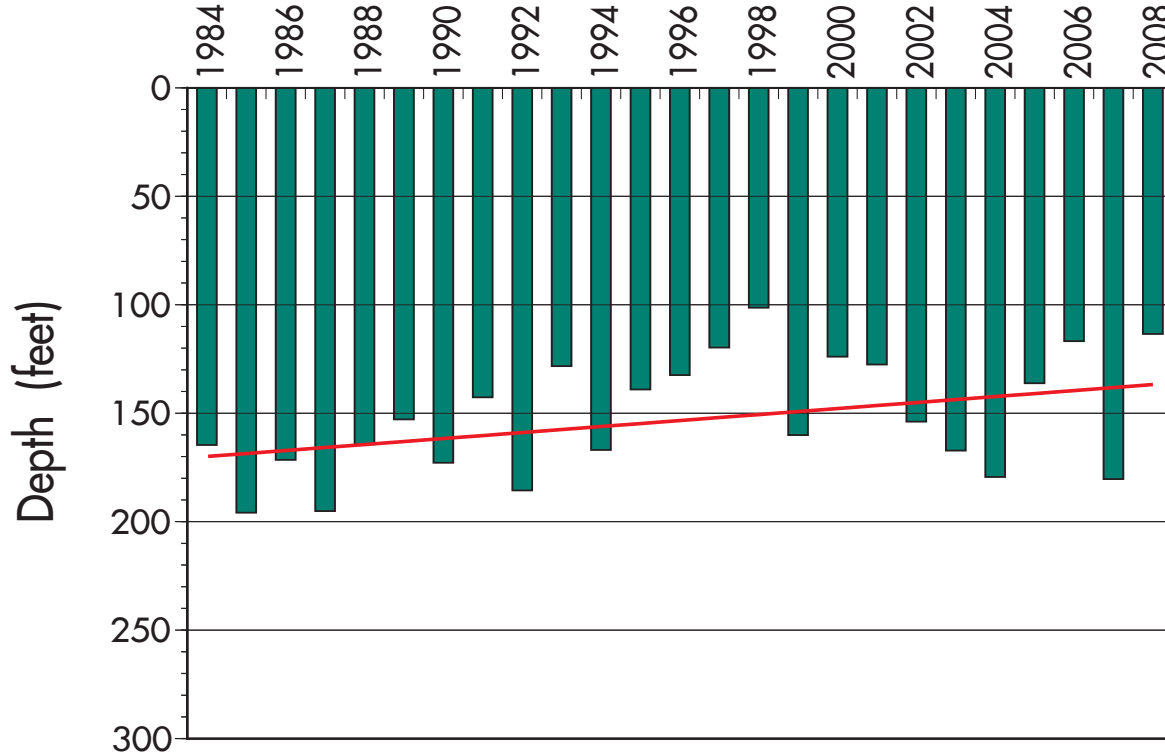
**BIOLOGY**

**Depth of chlorophyll maximum**

Yearly since 1984

The depth at which the deep chlorophyll maximum occurs varies from year to year. In 2008, the deep chlorophyll maximum was relatively shallow at about 115 feet. The deep

chlorophyll maximum depth has generally been getting shallower over time, a trend believed to be linked to the decline in water clarity.



## BIOLOGY

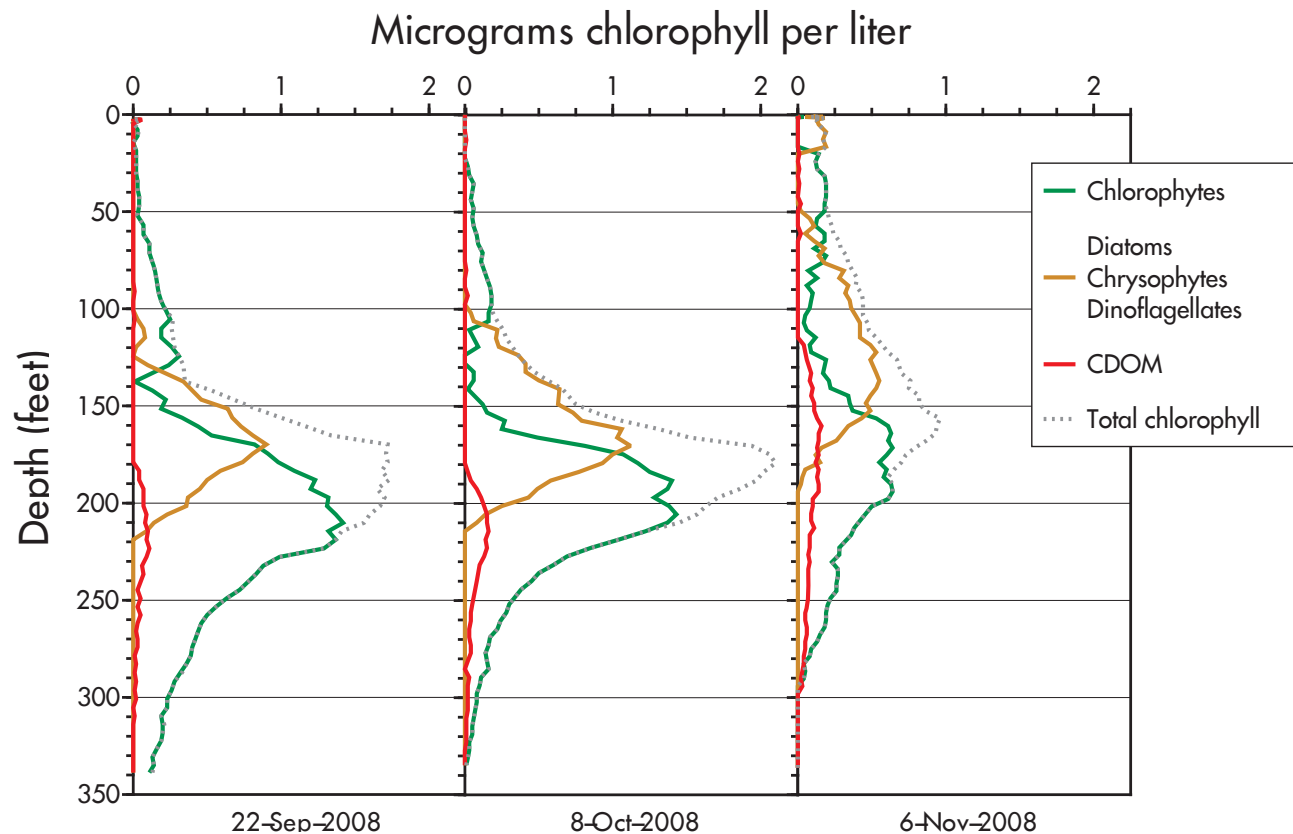
### Algae group distribution by depth

Fall 2008

Lake Tahoe supports many types of algae. Different groups grow at various depths below the lake surface, depending on their specific requirements for light and nutrient resources. The three profiles shown below focus on the September-November period when the

deep chlorophyll layer is beginning to break down as mixing in the upper water column commences (refer to Fig. 10.3 and compare similar dates). Two algal groups, chlorophytes, or green algae, and diatoms were dominant at this time of year. Notice the separation in depth

between these two groups with the chlorophyte peaks occurring about 50 feet lower. This type of vertical separation is common in lakes as different algae coexist by occupying a unique depth range and thereby avoiding direct competition for resources.



**BIOLOGY**

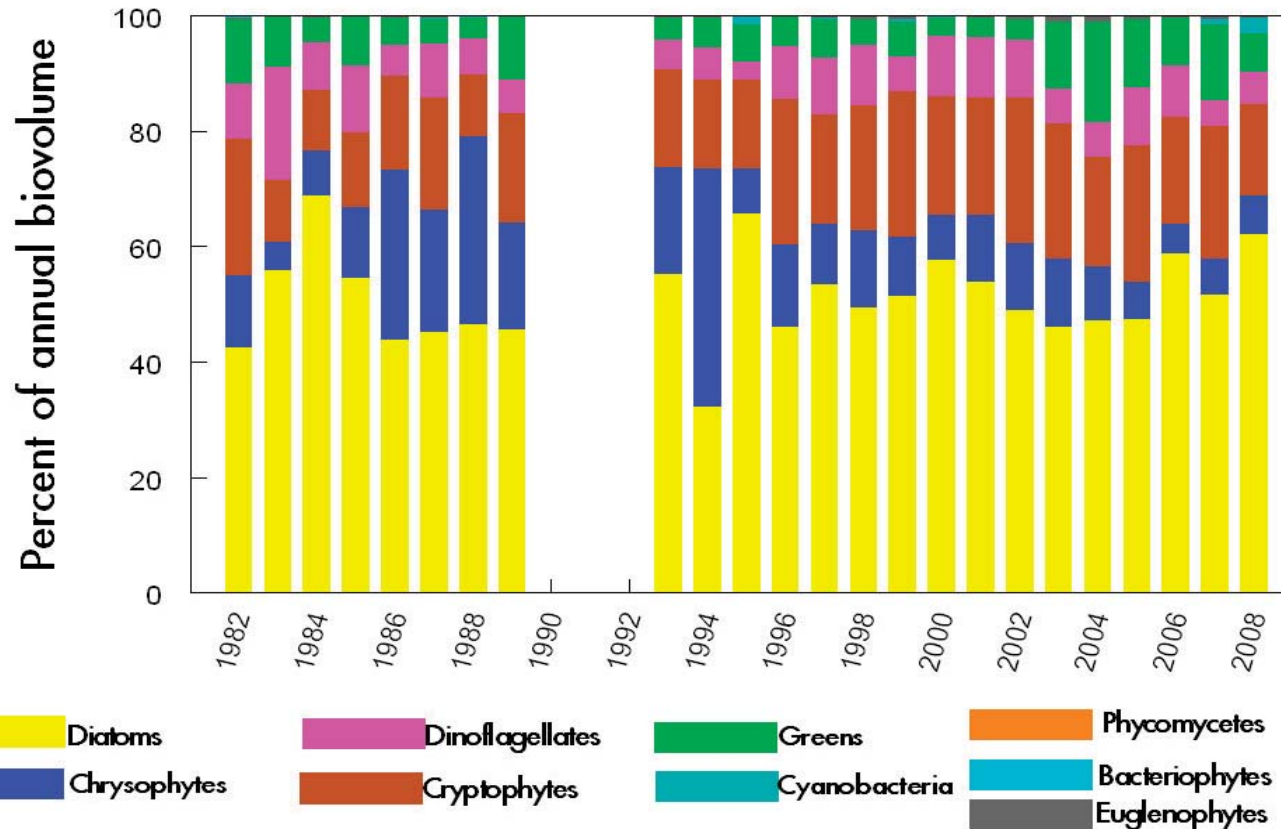
**Algae groups as a fraction of total population**

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 60 percent of the total biovolume each

year. Chrysophytes and cryptophytes are next, comprising 10 to 30 percent of the total. Since 2003 and including 2008, the chlorophytes, or green algae, have increased in abundance, and

the relative contribution of each of the major algal groups has remained relatively uniform.



**BIOLOGY**

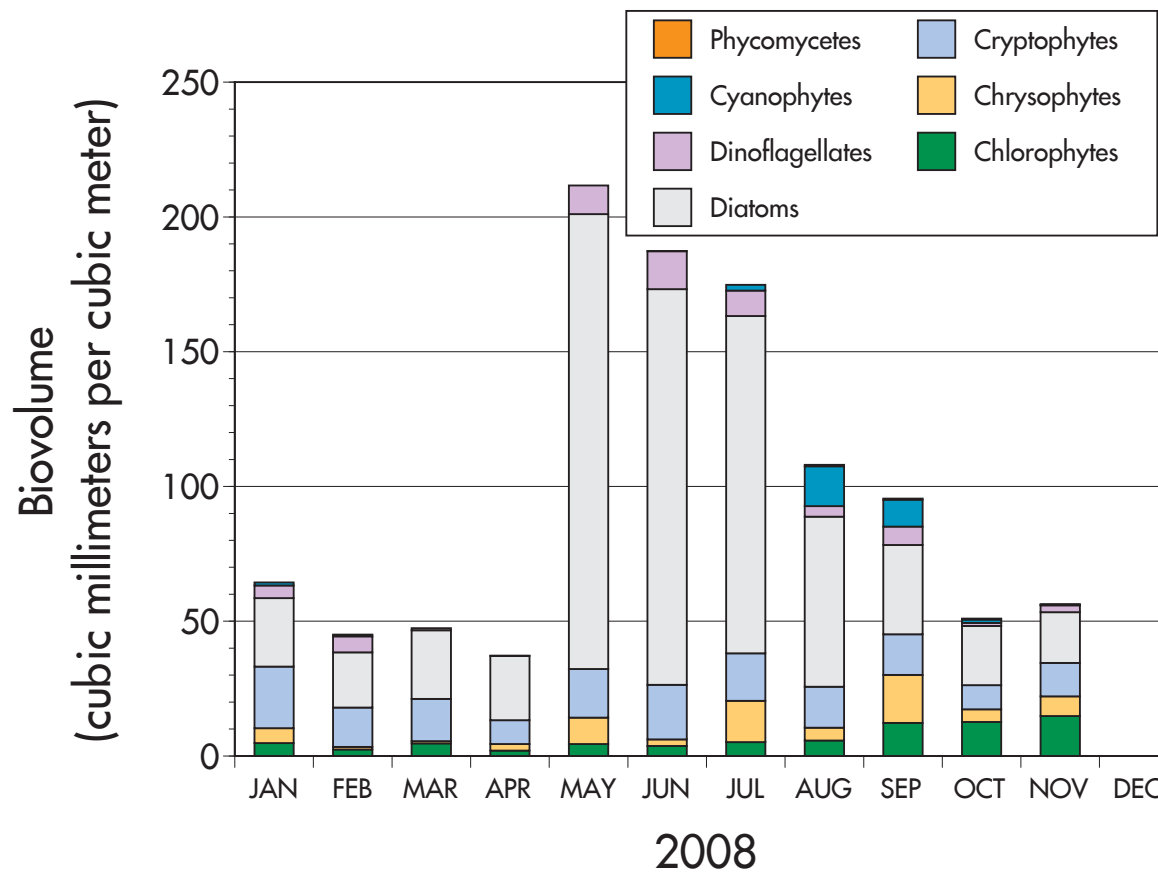
**Algae groups as a fraction of total population**

Monthly in 2008

Algae populations vary month to month, as well as year to year. In 2008, diatoms again dominated the phytoplankton community, especially

in May-July when their biovolume was high. While the relative importance of the chlorophytes (green algae) increased in the fall, their biovolume

did not peak as dramatically in 2008 as it did in 2007.





**BIOLOGY**

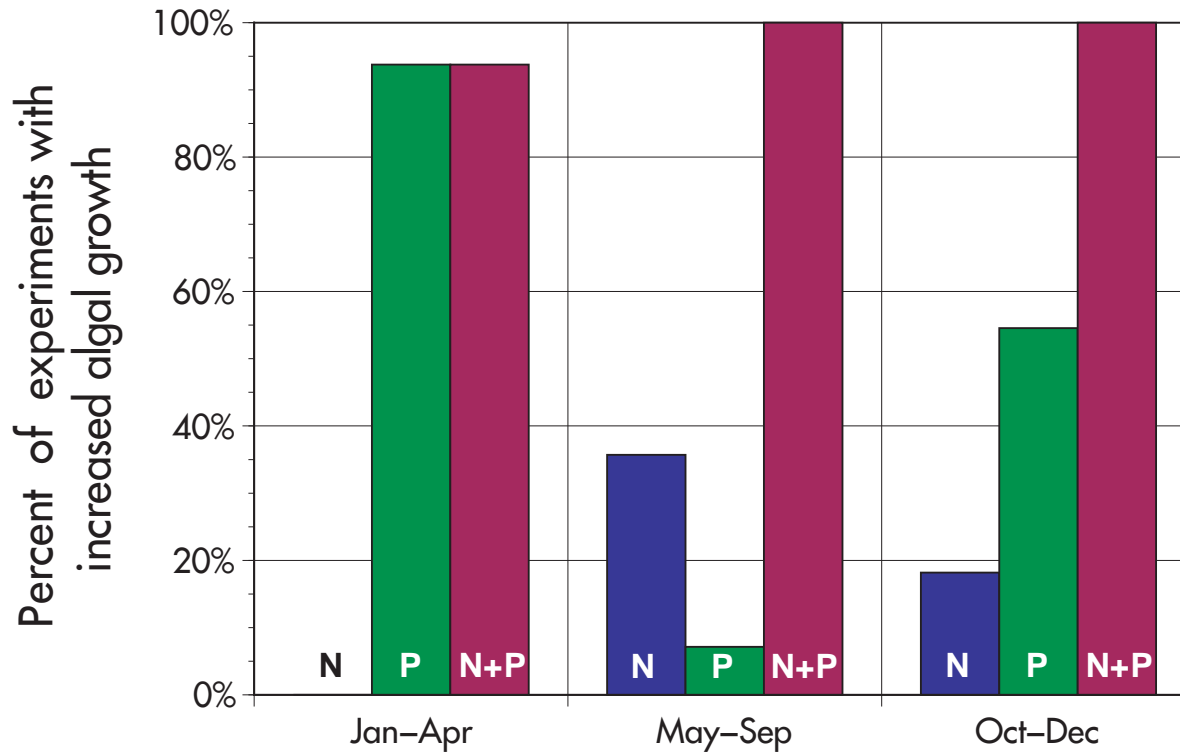
**Nutrient limitation of algal growth**

**In 2008**

Bioassays determine the nutrient requirements of phytoplankton. Nutrients are added to lake water samples and algal biomass is measured. These tests document both seasonal and long-term changes in nutrient limitation. Phytoplankton response to nutrient addition for the period 2002-2008

is shown in the panels below. Between January and April, algae were limited by phosphorus (P), not nitrogen (N), when added alone. When added together, stimulation nearly always occurred. From May to September, N added by itself was more stimulatory, but the lake was co-limited, as shown

by the greater response to adding both nutrients. P was more stimulatory from October to December, but co-limitation was again the dominant condition. These results highlight the role of nutrients in controlling algal growth. They also underscore the synergistic effect when both are available.



**BIOLOGY**

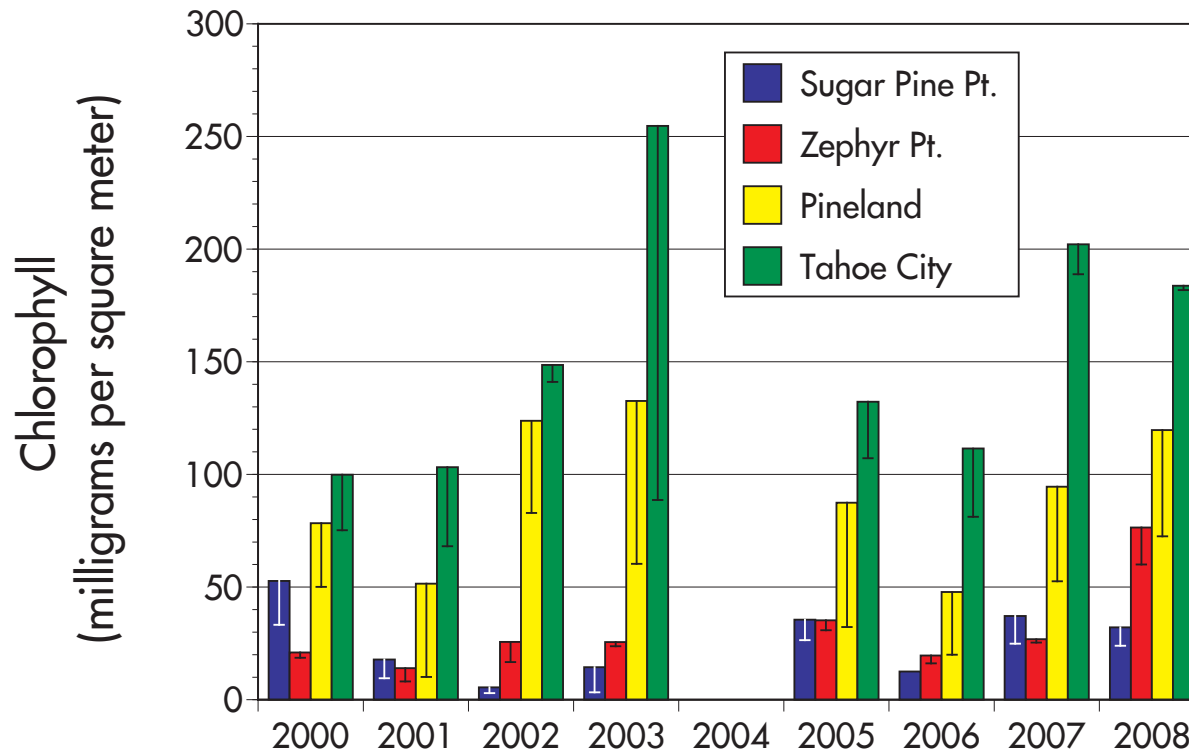
**Shoreline algae populations**

Yearly since 2000

Periphyton, or attached algae, makes rocks around the shoreline of Lake Tahoe green and slimy. Periphyton is measured eight times each year, and this graph shows the maximum biomass measured at four sites. In 2008, concentrations were near or

above average. The two sites with the most periphyton (Tahoe City and Pineland) are closest to urban areas. Peak annual biomass at the less urbanized Zephyr Point site was about 2-3 times higher than found previously. To date, no statistically

significant long-term trend in maximum periphyton biomass has been detected at these locations. However, the higher biomass at the more urban sites has been dramatic year after year.



**BIOLOGY**

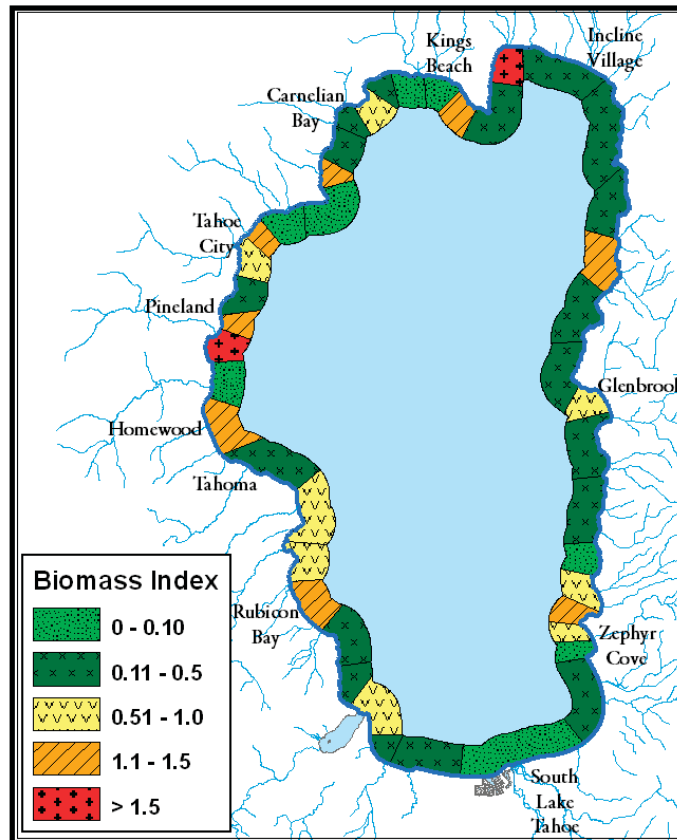
**Shoreline algae distribution**

**In 2008**

Periphyton biomass was surveyed around the lake during the spring of 2008, when it was at its annual maximum. Nearly 45 locations were surveyed by snorkel in 1.5 feet of water. A Periphyton Biomass Index

(PBI) was developed as an indicator to reflect what the casual observer would visually detect looking into the lake from the shoreline. The PBI is defined as the percent of the local bottom area covered by periphyton

multiplied by the average length of the algal filaments (cm). Zones of elevated PBI are clearly seen. (The width of the colored band does not represent the actual dimension of the onshore-offshore distribution.)



TAHOE:  
STATE  
OF THE  
LAKE  
REPORT  
2009

**CLARITY**

**CLARITY**

**Annual average Secchi depth**

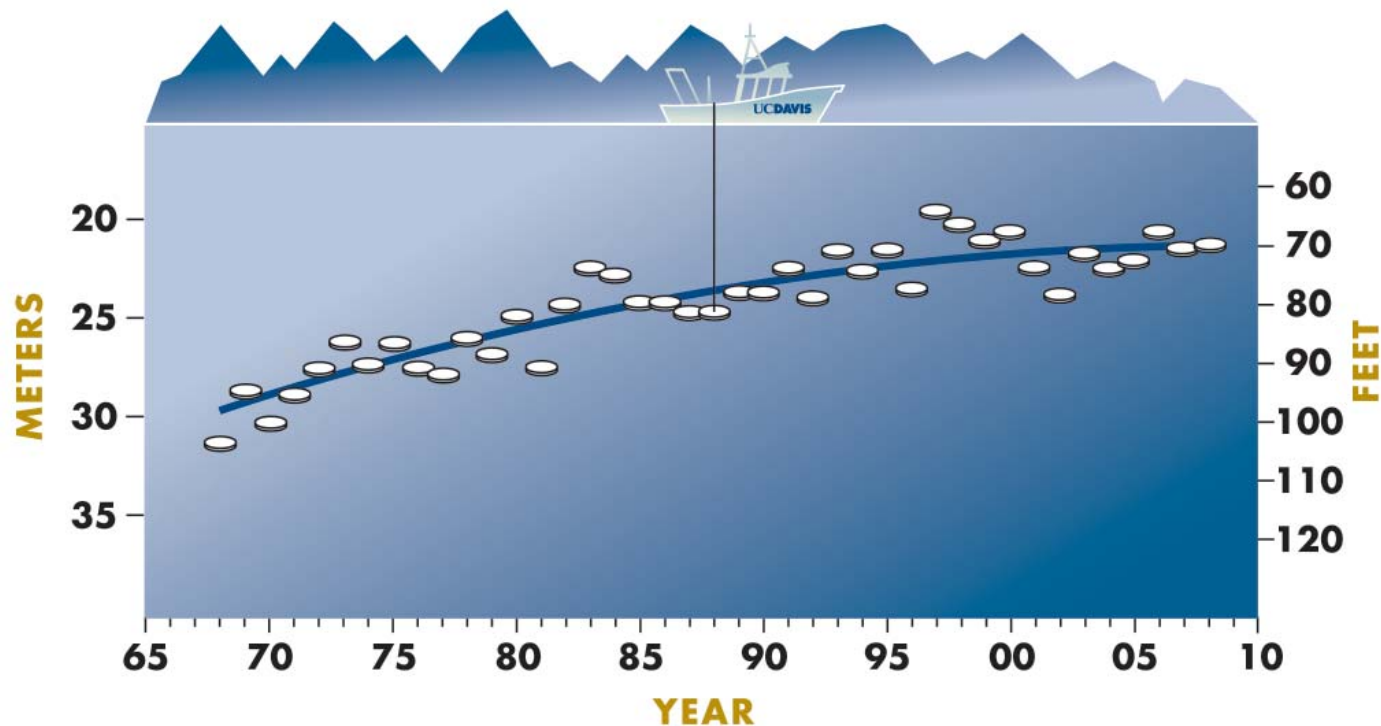
Yearly since 1968

Secchi depth (the point below the lake surface at which a 10-inch white disk disappears from view) is the longest continuous measurement of Lake Tahoe clarity. The annual Secchi depth is the average of 20 to 25 readings made throughout the year. While lake clarity has improved for brief periods since

1968, the overall long-term trend has shown a significant decline. In the last eight years, Secchi depth measurements have been better than predicted by the long-term linear trend. Statistical analysis suggests that the decline in Lake Tahoe's clarity has slowed, and is now better represented by the curve

below than a straight line. In 2008, the Secchi depth was 69.6 feet and virtually the same as 2007. With the exception of 2005 and 2006, precipitation has been low during the past 8 years. The response of the Secchi depth to a series of normal and above normal years will be very instructive.

**DECLINE OF WATER CLARITY AT LAKE TAHOE**



**CLARITY**

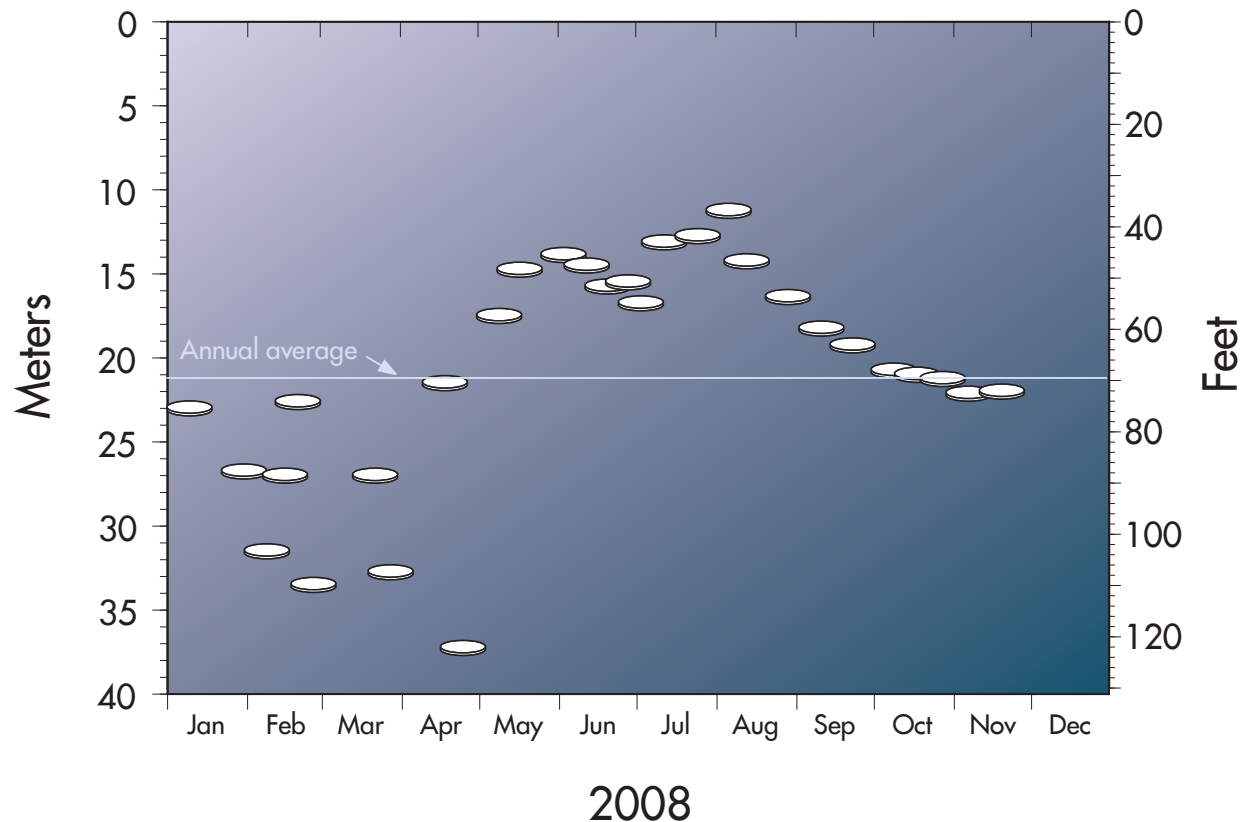
**Secchi depth measurements**

**In 2008**

Secchi depth has a strong seasonal feature which was clearly expressed in 2008. The deepest Secchi depth readings (the clearest water) typically occur in winter and 2008 was no exception. In 2008, the deepest reading was 122 feet on April

24th, while the lowest (37 feet) was measured on August 5th. This represents an 85 foot swing in clarity this year. A Secchi depth in Lake Tahoe of 37 feet is uncommonly low and the reduced readings in July and early August could have resulted

from smoke transported into the Tahoe basin from significant regional wildfires that began in late June. The annual average Secchi values (Fig. 11.1) represent the most robust indicator of the status and trend in Lake Tahoe clarity.



## CLARITY

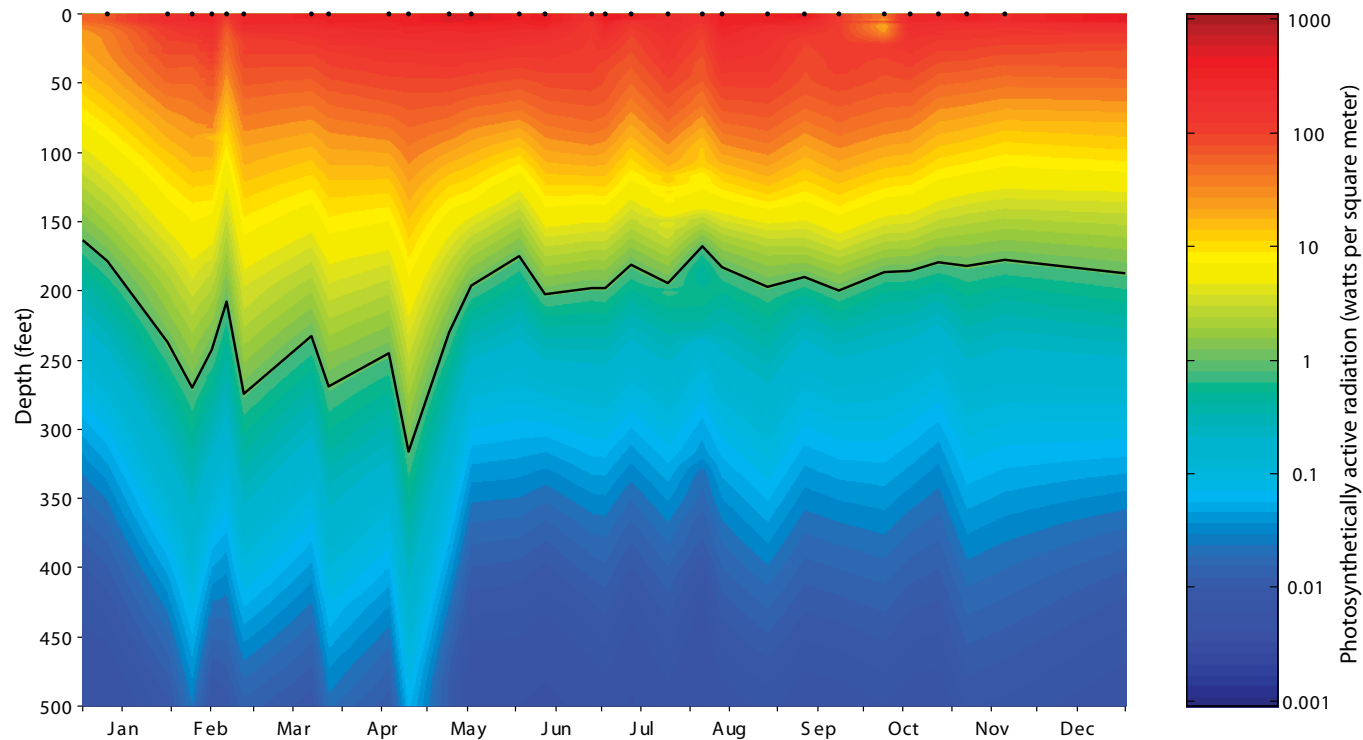
### Penetration of photosynthetically active radiation

In 2008

Photosynthetically active radiation (PAR) is that part of solar radiation spectrum that is utilized in photosynthesis. The black line below shows the depth at which PAR is 1% of its level on the lake surface, known as the euphotic depth. PAR penetration

varies throughout the year, but is often deepest in the summer when the sun is highest in the sky. In 2008, the euphotic depth increased in February and March, corresponding to the onset of deep mixing when clear bottom water is brought to the surface (Fig.

8.9). 2008 was the second year in succession when deep mixing occurred. This year, the maximum Secchi depth reading was 122 feet on April 24th, which also corresponded to the occurrence of the maximum PAR penetration.





TAHOE:  
STATE  
OF THE  
LAKE  
REPORT  
2009

**EDUCATION AND  
OUTREACH**

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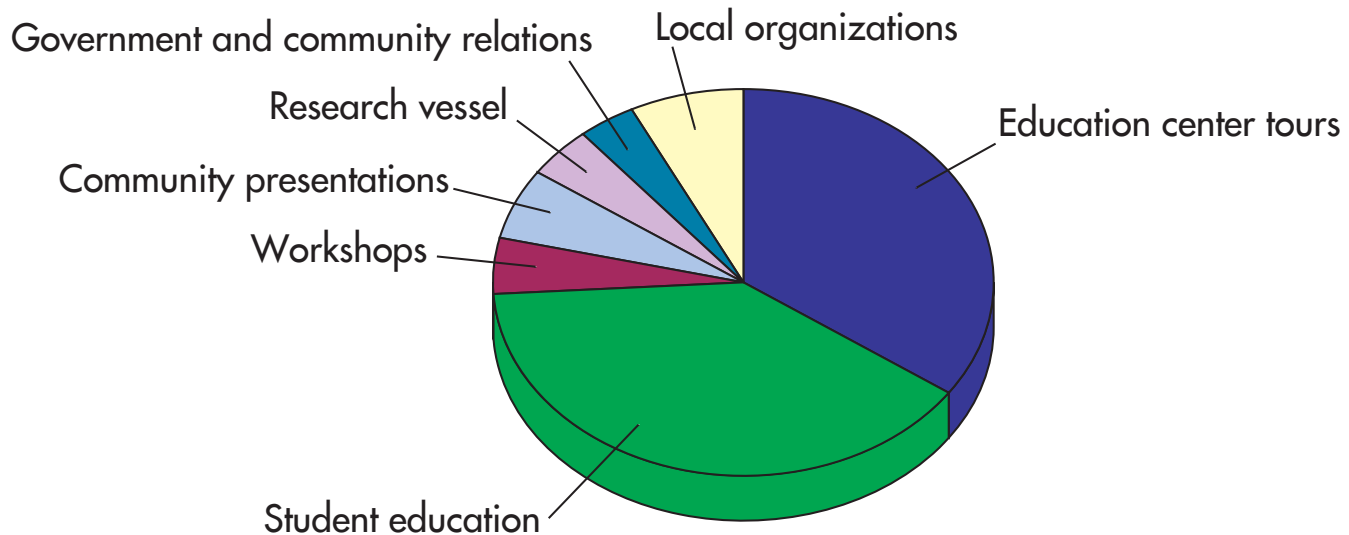
**TERC outreach**

**In 2008**

Part of TERC's mission is education and outreach. During 2008, TERC recorded over 9,200 individual visitor contacts. The majority represented student field trips and visitors to the Thomas J. Long Foundation Education Center at Incline Village. In addition, TERC hosts monthly public lectures and workshops, makes

presentations to local organizations and takes a limited number of visitors out on our research vessels. TERC organizes and hosts annual events and programs including Children's Environmental Science Day, Science Expo, Youth Science Institute, Trout in the Classroom program, Project WET workshops, Summer Tahoe

Teacher Institute and a volunteer docent training program. TERC also partners with numerous groups to deliver education in the Tahoe basin. In 2008, these included AmeriCorps, COSMOS, Sierra Watershed Education Partnerships (SWEP), Space Science for Schools, Young Scholars and many others.



**TOTAL NUMBER OF CONTACTS: 9211**