TAHOE: STATE OF THE LAKE REPORT 2015

UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

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INTRODUCTION

The University of California, Davis has conducted continuous monitoring of Lake Tahoe since 1968, 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, long term change and human activity have affected the lake's clarity, physics, chemistry and biology. We also present the data collected in 2014. The data shown reveal a unique record of trends and patterns – the result of natural forces and human actions that operate at time scales ranging from minutes to decades. These patterns clearly indicate that Lake Tahoe is a complex ecosystem, behaving in ways that cannot always be predicted. This was exemplified this year by the record levels of in-lake nitrate concentrations, despite greatly reduced inflows on account of drought conditions. While Lake Tahoe is unique, the forces and processes that shape it are the same as those acting in most natural ecosystems. As such, Lake Tahoe is an analog for other systems both in the western U.S. and worldwide.

Our goal is to explore this complexity and to use the knowledge gained to provide the scientific underpinnings for ecosystem restoration and management actions. Choosing among those options and implementing them is the role of management agencies that need to account for a host of other considerations. This annual report is intended to inform non-scientists about some of the variables that affect lake health. Previously, only one indicator of Lake Tahoe's health status was widely reported: the annual clarity (often called the Secchi depth, after the instrument used to collect the clarity data). In this report we publish many other environmental and water quality factors that all provide indications of the lake's condition.

This report sets the context for understanding the changes that are seen from year to year and those that are observed over time scales of decades. Is Lake Tahoe continuing to warm? Are the inputs of algal nutrients to the lake declining? How is the drought affecting Lake Tahoe? And, of course, how do all these changes affect the lake's famous clarity and blueness? We also present updates on some of our ongoing research. These new research results highlight some of the most exciting findings of work that is still in progress, and will be reported on fully in the months and years to come.

The data we present are the result of efforts by a great many scientists, engineers, students and technicians who have worked at Lake Tahoe throughout the decades since sampling commenced. I would, however, like to acknowledge (in alphabetical order) the contributions of Brant Allen, Nancy Alvarez, Patty Arneson, Alex Berrian, Emily Blackmer, Fabian Bombardelli, Sudeep Chandra, Bob Coats, Veronica Edirveerasingam, Bill Fleenor, Alex Forrest, Charles Goldman, Scott Hackley, Tina Hammell, Bruce Hargreaves, Alan Heyvaert, Diana Hitchen, Simon Hook, Andrea Hoyer, Debbie Hunter, Peter Hunter, Zach Hymanson, Camille Jensen, Daret Kehlet, Lisa Lacampagne, Jordan Leung, Anne Liston, Patricia Maloney, George Malyj, Tom Mathis, Mark O'Berry, Carley O'Connell, Faye-Marie Pekar, Kelsey Poole, Kristin Reardon, Kristen Reichardt, John Reuter, Bob Richards, Gerardo Rivera, Derek Roberts, Francisco Rueda, Goloka Sahoo, Laynie Saidnawey, Naoki Saito, Lindsey Saunders, Heather Segale, Bill Sluis, Heather Sprague, Ashley Taylor, Raph Townsend, Alison Toy, Warwick Vincent, Shohei Watanabe, Katie Webb, and Kylee Wilkins to this year's report.

Funding for the actual data collection and analysis has come from many sources over the decades. While many additional water quality variables could be tracked, funding ultimately limits what we measure and report on. Current funding for the long-term monitoring and analysis is provided by the Lahontan Regional Water Quality Control Board, the Tahoe Regional Planning Agency, the U.S. Geological Survey and UC Davis. Our 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 Desert Research Institute (DRI), the University of Nevada, Reno (UNR), the National Aeronautics and Space Administration (NASA), and the U.S. Forest Service (USFS). Some data are also collected as part of research projects funded through a variety of sources. Without these data there are many questions that could not even be asked let alone answered.

We are very proud to recognize the funding support for the actual production of this annual report from (in alphabetical order) the California Tahoe Conservancy, the IVGID Waste Not Program, the League to Save Lake Tahoe, the Parasol Tahoe Community Foundation, the Tahoe Area Sierra Club, the Tahoe Fund, the Tahoe Lakefront Owners' Association, the Tahoe Regional Planning Agency, the Tahoe Resource Conservation District, and the Tahoe Water Suppliers Association. We sincerely thank these organizations for their dedication in supporting science to save the lake.

Sincerely,

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EXECUTIVE SUMMARY

The long-term data set collected on the Lake Tahoe ecosystem by the University of California, Davis and its research collaborators is an invaluable tool for understanding ecosystem function and change. It has become essential for responsible management by elected officials and public agencies tasked with restoring and managing the Tahoe ecosystem. This is in large part because it provides an independent basis for assessing the progress toward attainment of Tahoe's restoration goals and desired conditions while at the same time building our understanding of the natural processes that drive the ecosystem.

UC Davis Tahoe Environmental Research Center (TERC) has developed sophisticated computer models that better predict and understand how Lake Tahoe's water moves and how the entire ecosystem behaves. Long-term data sets are an essential element in constantly refining the accuracy of those models and in developing new models as knowledge increases and new challenges arise. These models are used to address a variety of questions: where would a contaminant spill be carried? what are the likely next locations for the spread of invasive species within the lake? will lake oxygen be depleted by climate change? and what will the consequences be? The application of these models this year has helped refine the source of the pollutants that are reducing lake clarity.

This annual Tahoe: State of the Lake Report presents data from 2014 in the context of the long-term record. While the focus is on data collected as part of our ongoing, decades-long measurement programs, we have also included sections summarizing current research on the first ever quantification of Tahoe's blueness, the impacts of the ongoing drought, the water loss from evaporation, results from the first year of operation of TERC's Nearshore Water Quality Network, and the fluctuations of lake temperature and the use of temperature data to create lake music.

While water clarity and lake blueness have long been considered to be one and the same, a newly developed Blueness Index (based on measurements of the wavelength of light leaving the lake) has shown that this is not the case. On the contrary, at times of year when clarity increases, blueness is seen to decrease. In the last three years, Lake Tahoe's blueness has been increasing. What the research is revealing is that while clarity is controlled by fine particulates, blueness is controlled by algal concentration. This new knowledge will help agencies implement programs that will help restore both clarity and blueness.

The largest water loss from Lake Tahoe is from evaporation. Using data collected over the last 14 years in collaboration with NASA-JPL, a newly developed model allows for instantaneous evaporation estimates to be made for the lake. Results show that evaporation from the lake surface during the year equals approximately 51 inches of water, with August being the month of maximum evaporation. One inch of evaporation is equivalent to 3.5 billion gallons.

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[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 2015 report, water year data are from Oct. 1, 2013 through Sept. 30, 2014. Calendar year data are from Jan. 1, 2014 through Dec. 31, 2014.*

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(CONTINUED FROM PAGE 2.1)

New data from the nearshore water quality network shows for the first time just how variable water quality can be. Algal concentrations at different parts of the shoreline can vary by a factor of two, while seasonal variations at the same site can be even greater. During a storm, turbidity increases by a factor of 100 at sites where wave breaking is occurring.

Continuously measured lake temperature data is showing just how variable temperature can be due to oscillations occurring at all depths. These data are also being used to generate the "music" of the lake, the sounds that we would hear if our audible range was large enough. By transforming the recorded frequencies, we can hear the lake's melody for the first time.

2014 saw the continuation of warming and drying conditions for a third year at Lake Tahoe. The winter of 2013-2014 had the lowest number of freezing days (29) recorded in over a century of data collection. Precipitation was only 61 percent of the long-term average. The fraction of precipitation that fell as snow was well below the general downward trend that has been recorded, being only 18 percent. The depth of the April snowpack was the lowest recorded in 100 years of record keeping. Monthly precipitation was well below the long term mean for all months except the summer months of July, August and September, possibly portending a change toward wetter summers.

Lake level rose by only 11" during the spring snowmelt, well below the typical rise. Lake Tahoe fell below the natural rim on October 16, 2014, signaling the cessation of outflow via the Truckee River. The lake had a final level of 0.49 feet below the rim at the end of 2014. The volume-averaged lake temperature increased in 2014 by 0.2 °F (0.11 °C) over the previous year. Following the cooler temperatures of the last decade, 2014 exceeded the long-term trend of increasing temperature. Similarly the annual-averaged surface temperatures were at an all-time high in 2014 at 53.0 °F. The maximum daily surface water temperature in 2014 was significantly warmer than it has been for the last 4 years, and for the winter-time maximum, it was the warmest surface water temperature that has been observed for the length of the record. Other consequences of climate change could also be seen in the rising temperature of the deep waters of the lake. In the last 38 years bottom temperatures have increased by over 1.0 °F.

Lake Tahoe did not mix to its full depth in 2014, the third consecutive year in which this has not happened. Instead, the maximum depth of mixing was only 440 feet (134 m), reached in March. The lack of mixing was due to a third year of above average lake stability, driven by the generally warmer weather. Lake stability (the resistance to mixing) in 2014 was the highest since continuous record keeping began in 1968. The upper 330 feet of the lake stayed stratified for 199 days, almost a month longer than what was typical when the record began.

The input of stream-borne nutrients to the lake was low again in 2014 due to the low precipitation and subsequent run-off. The last three years have all had nutrient and particle loads well below the long-term mean.

Overall in-lake nitrate concentrations have remained relatively constant over the 33 years of record. In 2014, however, the

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.2)

volume-weighted annual average concentration of nitrate-nitrogen reached an all-time high of 20.0 micrograms per liter. This increase is in part due to absence of deep mixing this year; nutrients from the bottom of the lake were not brought up to levels where they can be utilized by phytoplankton. The lack of deepwater mixing allows a continued build-up of nitrate in the deep water. By contrast, in-lake phosphorus concentrations display a downward trend over the same period, having decreased by almost 50 percent.

Biologically, the primary productivity of the lake continued its long-term increase in 2014, with the annual average value of 217.1 grams of carbon per square meter. The reasons for this increase are believed to be linked to a long-term shift towards smaller algal species that have the ability to process nutrients faster. Despite the increase in lake productivity, the concentration of chlorophyll in the lake has remained relatively constant over time. In 2014 there was a continued decrease in the abundance of diatom cells in the lake, down from the peaks experienced in 2009 to 2011. In particular the concentration of Cyclotella was reduced. This small-sized diatom can exert a large influence on lake clarity. Higher numbers of this group over the last six years compared to historical values have been linked to climate change and have resulted in summertime clarity reductions. This year's continued reduction coincided with an improvement in clarity.

Periphyton, or attached algae, on the rocks around the shoreline continues to show variability from site to site. The long-term monitoring program has helped identify those areas of the shoreline that are consistently displaying periphyton levels that are undesirable. Overall conditions in 2014 were greatly improved compared to 2013. In 2014, concentrations were at or below their historic lows at many sites. The two most urbanized sites, Tahoe City and Pineland, were one half to one sixth of their values in 2013. This decrease is not believed to be part of a long term trend, but linked to the low water levels and the reduced nutrient input. TERC's real-time nearshore water quality network will play a crucial role in future efforts to better understand the causes of these changes by creating a link between nearshore water quality and measured meteorology, streamflow and stormwater flow. This understanding will provide a scientific basis for nearshore restoration.

This year the annual average Secchi depth, a measure of lake clarity, continued the long-term halt in clarity degradation. The value for 2014 was 77.8 feet (23.7 m), an increase of 7.6 feet (2.3 m) over 2013, and well above the lowest value recorded in 1997 of 64.1 feet (19.5 m). Year-to-year fluctuations are the norm, and the long-term goal must be seen as attaining a level of clarity which on average meets the basin's standards. Summer (June-September) clarity in Lake Tahoe in 2014 was 78.7 feet (24.0 m), almost a 13 foot improvement over the value from 2013. This coincided with a continued decline in the concentration of small algal cells in 2014, as well as sharply lower stream inflows. Another contributing factor was the shallow depth to which the lake mixed to during the previous winter.

This report is available on the UC Davis Tahoe Environmental Research Center website (http://terc.ucdavis.edu).

ABOUT LAKE TAHOE AND THE TAHOE BASIN

- Maximum depth: 1,645 feet (501 meters), making it one of the deepest lakes 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: 75 miles (120 kilometers)
- Volume of water: 39 trillion gallons
- The daily evaporation from Lake Tahoe (half a billion gallons) would meet the daily water needs of 5 million Americans
- The number of algal cells in Lake Tahoe is approximately 30 million trillion
- All of Tahoe's algae stacked on a football field, would stand 9 feet tall and weigh 15,500 Tonnes
- Number of inflowing streams: 63, the largest being the Upper Truckee River
- Number of large lakes worldwide with annual clarity exceeding Tahoe's: 0
- Number of outflowing streams: one, the Truckee River, which leaves the lake at Tahoe City, California, flows through Truckee and Reno, and terminates in Pyramid Lake, Nevada. Outflow from Lake Tahoe into the Truckee River stopped on October 16. 2014.
- Length of time it would take to refill 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: 55,000 (2010 Census)
- Tourist population: 4.5 million (2010 Lake Tahoe Basin Prosperity Plan)
- Vehicle miles traveled (VMT) on a midsummer's day: about 2,000,000 miles

ABOUT THE UC DAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER (TERC)

The UC Davis Tahoe Environmental Research Center (TERC) is a world leader in research, education and public outreach on lakes, providing critical scientific information to help understand, restore, and sustain the Lake Tahoe Basin and other systems worldwide. Since 1968 UC Davis has undertaken the scientific monitoring of Lake Tahoe, creating the foundation on which to base restoration and stewardship efforts.

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 Tahoe Science Center, a learning resource for K-12 students and learners of all ages, that is free and open to the public.

In Tahoe City, California, we operate a field station (housed in a fully renovated, former state fish hatchery) and the Eriksson Education Center. Tahoe City is also the mooring site for our research vessels, the John LeConte and the Bob Richards.

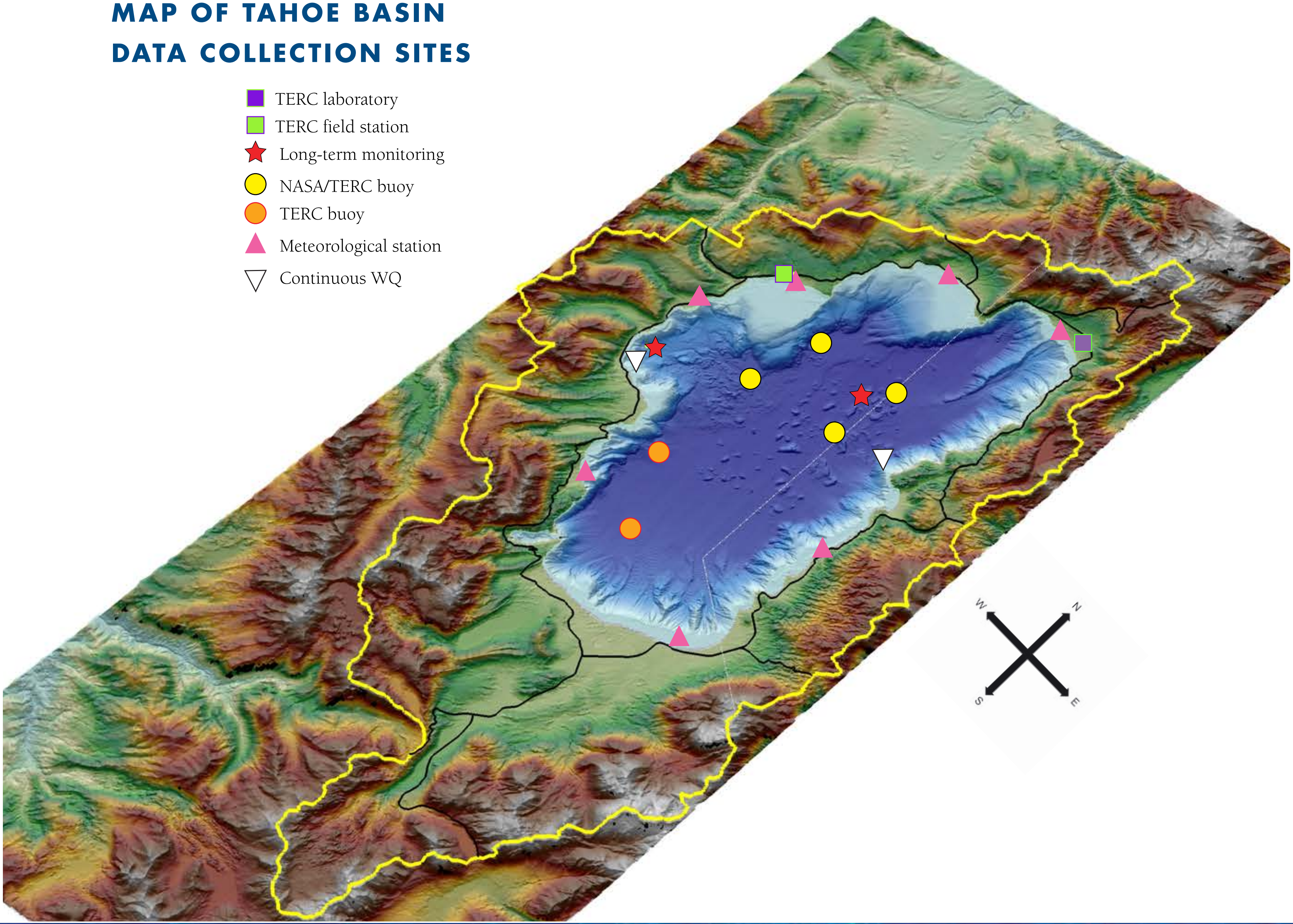
Our secondary laboratories and offices are located on the UC Davis campus at the Center for Watershed Sciences and in Wickson Hall.

At locations throughout the basin, we have sensors continuously reporting on the health and well being of the lake and its environs, making Lake Tahoe the smartest lake in the world.

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

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

MAP OF TAHOE BASIN DATA COLLECTION SITES



TAHOE: STATE OF THE LAKE REPORT 2015

RECENT RESEARCH UPDATES

RECENT RESEARCH UPDATES

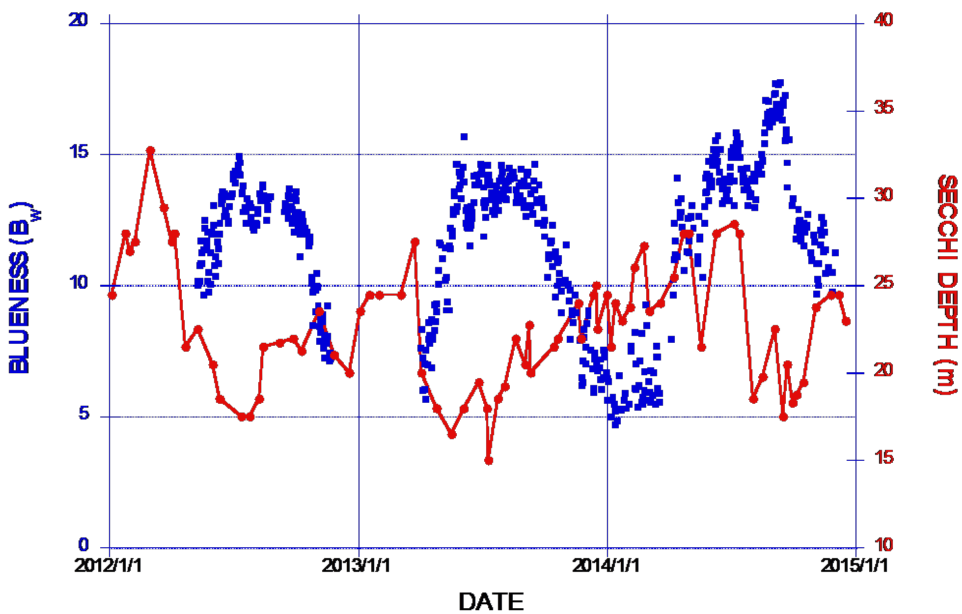
Keep Tahoe Blue or Keep Tahoe Clear?

UC Davis' long-term measurements of decline in Secchi depth readings have been a focal point of advocacy directed at restoring clarity and of restoration efforts themselves. The loss of Tahoe's unique cobalt blue color was at stake among other things. The general assumption was that clarity was synonymous with blueness. But is it?

TERC post-doc Dr. Shohei Watanabe has been leading a collaboration with Laval University, Canada and NASA-JPL to measure the blueness of the lake continuously from one of the research buoys in the center of the lake. Using hyperspectral radiometers that measure the amount of light leaving the lake at each waveband (in other words, the color we observe), he has produced a Blueness Index which provides a unique record of color change in Lake Tahoe.

When the daily average Blueness Index is combined with the measurements of Secchi depth, a surprising result emerges, as evident in the figure below. Blueness and clarity vary opposite to each other. While the clarity is related to the input of very fine particles from the surrounding land, blueness is most strongly related to the algal concentration. The lower the algal concentration, the bluer the lake. The lowest concentration typically occurs in summer when nutrients have been depleted. This is the time of highest particle concentration.

This is good news. We now have an even better understanding of how Lake Tahoe works, and it reinforces the importance of controlling nutrient inputs to the lake, whether from the forest, the surrounding lawns, or even from the air. What is particularly encouraging are the long-term changes. Overall, the blueness has been increasing over the last 3 years and the average annual clarity has stopped declining.



The blueness index plotted against Secchi depth for the last three years. Times of greater blueness occur at times of lower clarity.

RECENT RESEARCH UPDATES

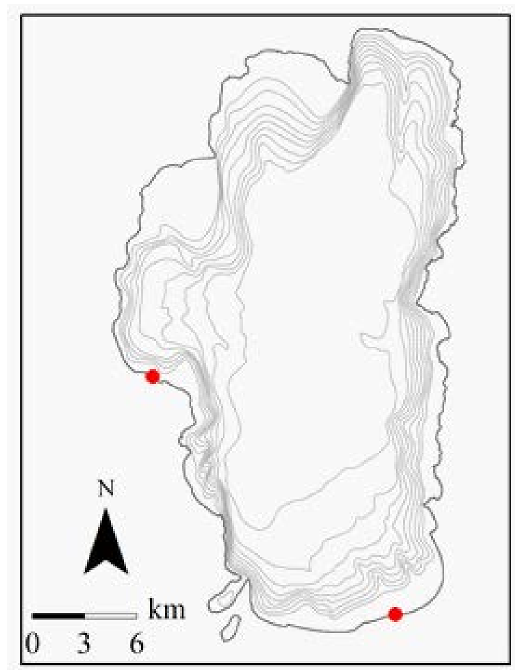
How Low Will it Go?

In 2014, the level of Lake Tahoe dipped below the lake's natural rim, thereby cutting off flow from Lake Tahoe into the Truckee River. When the level next rises above the rim and flow starts again will depend on how wet the next winter is. If it is below average the lake may stay below the rim for another year.

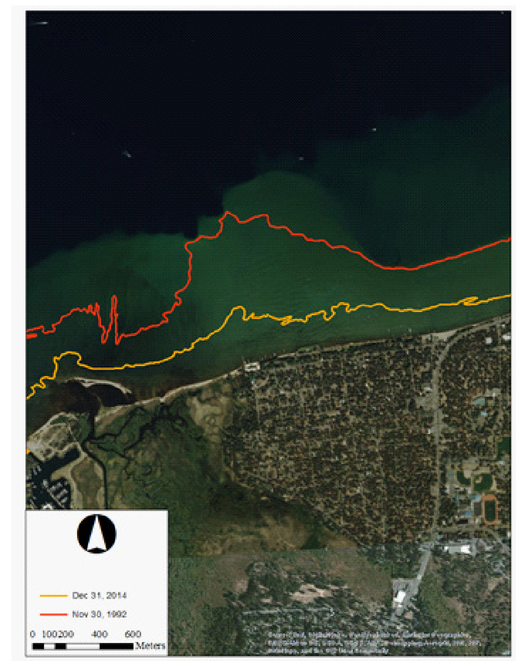
This phenomenon has happened several times in the last 100 years. You can see the record in Section 8.1. The lowest level in the last 100 years occurred on November 30, 1992, when the lake was 2.75 feet below the rim.

One of the consequences of low lake level is that the shoreline moves further out from the land. How far out it will go will depend of the lake level. The figures below show the shoreline location at two sites – Chambers Landing on the west shore and Al Tahoe in South Lake Tahoe. In both figures, the shoreline at end of 2014 and on November 30, 1992 are shown. Where will the shoreline be at the end of 2015?

Chambers Landing pictured with the 2014 shoreline depicted by a yellow line and the 1992 shoreline by a red line.



Chambers Landing is the red dot on the west shore of Lake Tahoe while Al Tahoe can be found at the red dot on the south shore.



Al Tahoe pictured with the 2014 shoreline depicted by a yellow line and the 1992 shoreline by a red line.

RECENT RESEARCH UPDATES

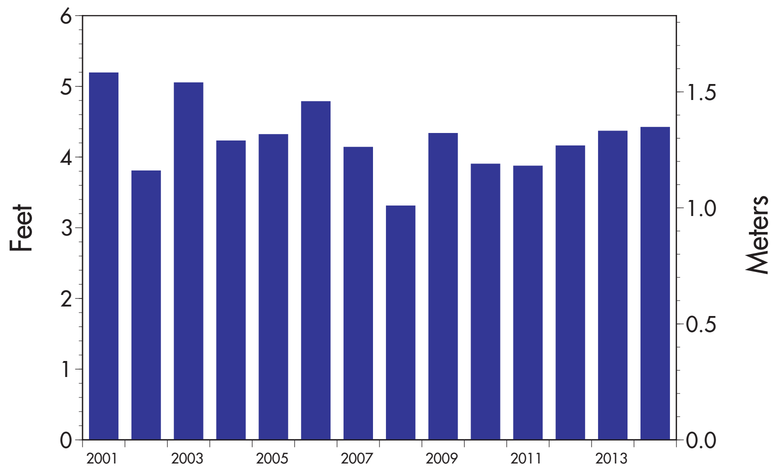
Evaporation from Lake Tahoe

Of the water that leaves Lake Tahoe each year, the largest amount is generally from evaporation from the lake's surface. Because of the size of the lake, the variability of the wind, temperature and humidity across it, and the heat stored in the lake itself, ascertaining how much leaves each day is difficult to quantify.

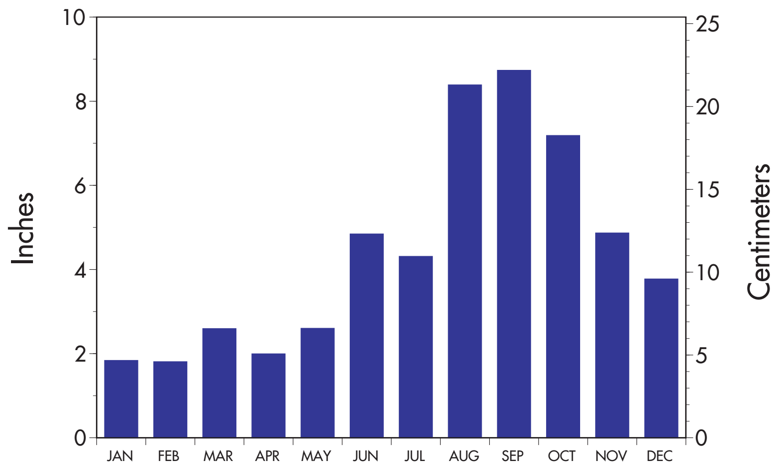
Using the continuous data from all four of the NASA-JPL/TERC research buoys on Lake Tahoe, graduate student Tom Mathis has been able to solve this problem. After creating a sophisticated model that calculates the heat and water loss across the surface based on real-time buoy measurements, Tom is able to calibrate and validate the accuracy of his model using independent water level data.

The figure on the left shows annual evaporation for the last 14 years. Despite some year-to-year variability, the annual evaporation is 4.27 feet (51.2 inches). The figure on the right shows how evaporation varied monthly in 2014. August and September were the months with the greatest evaporation with a monthly loss in excess of 8 inches. During the winter, evaporation fell to just 2 inches per month.

Daily lake evaporation rates will soon be part of TERC's real-time lake data displays around the basin.



The annual evaporation from 2001 to 2014.



Distribution of monthly evaporation during 2014.

RECENT RESEARCH UPDATES

Let's Go Launch a Boat

One of the consequences of the drought and the falling lake level is that launching a boat at Lake Tahoe has become far more difficult. The table below shows the status of Lake Tahoe's public boat launches, as of July 1, 2015. Only three of seven have enough water to remain open. If water level continues to drop, the remaining boat ramps will be threatened.

PUBLIC BOAT LAUNCH	OPERATOR	CURRENT STATUS	PREVIOUS FULL-SEASON CLOSURE	NOTES
Cave Rock Boat Ramp	NV State Parks	OPEN	None	Only one of two boat launch lanes open.
Sand Harbor State Park Boat Ramp	NV State Parks	CLOSED	2000	Frequently has closed for the second half of the season
El Dorado Beach Boat Ramp	City of South Lake Tahoe	CLOSED	2014	Last season fully open was 2010
Coon Street Boat Launch	CA State Parks	CLOSED	Unknown	---
Lake Forest Boat Ramp	Tahoe City PUD	OPEN	Not in past 5 years	Dredged in Spring 2015
Tahoe Vista Recreation Area Boat Launch	North Tahoe PUD	CLOSED	Never closed before	Built in 2009
Ski Beach	Incline Village GID	OPEN	Not in past 20 years	---

Coons Street boat launch in Kings Beach. Photo: E. Blackmer

Tahoe Vista boat launch. Photo: E. Blackmer

RECENT RESEARCH UPDATES

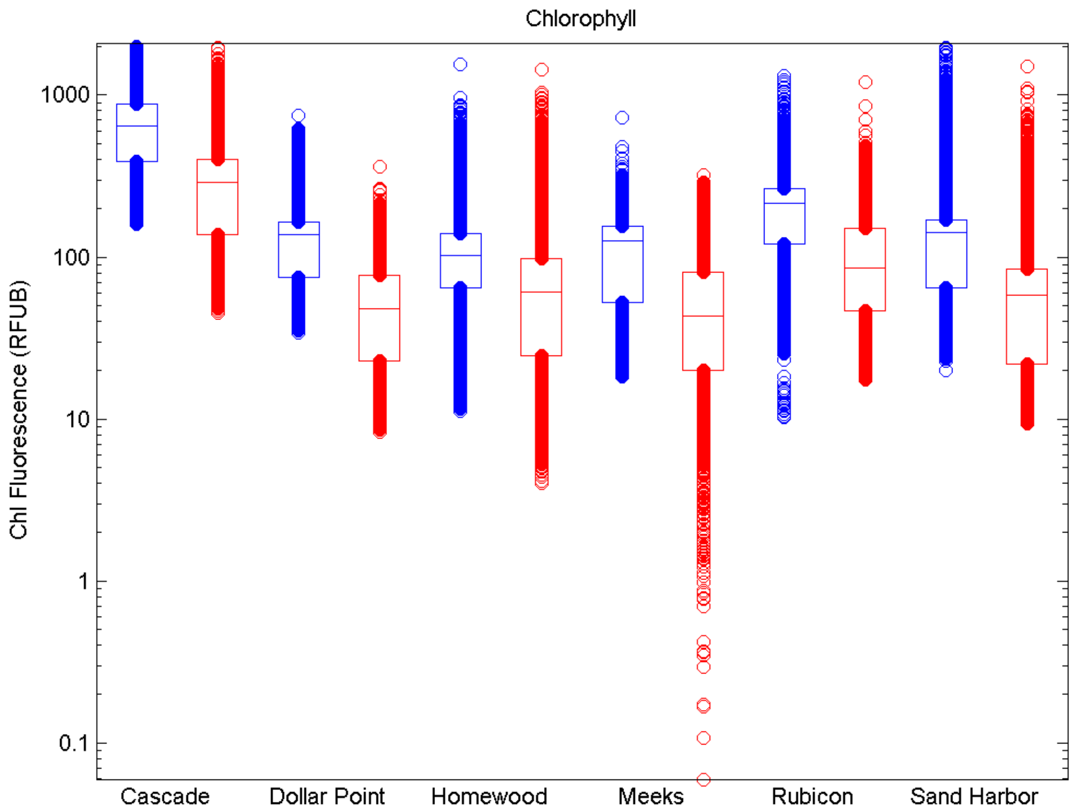
Tahoe's Nearshore Network

In 2014, we established a network of water quality instrument stations at various points on the shoreline around the lake. The program aims to understand the causes of degradation of Lake Tahoe's nearshore and provide the essential data needed to guide restoration and future stewardship.

By June 2015, 7 stations were installed and fundraising for the remaining 13 stations was well underway with individuals, businesses and homeowners' associations around the basin working with TERC on completing the network. Data that is being collected include algal concentrations, turbidity, temperature, wave height and dissolved oxygen concentration. Graduate student, Derek Roberts, is using the results are as the basis for his PhD research project.

What has been learned so far? To start, we now have baseline data for the instrumented sites to know what "normal" and "extreme" conditions are. The figure left shows the distribution of algal concentration (as relative fluorescence units) from six sites for a winter period (1/9/14 – 2/8/14) shown in blue and a spring period (3/21/14 – 4/23/14) shown in red. The line across each box is the median value recorded (from the approximately 84,000 measurements). The upper and lower bounds of the boxes represent the 75th and 25th percentiles respectively, and the symbols represent all values outside this range (the extremes).

At all sites, algal concentration is higher in winter, often by a factor of 2 or 3. Cascade Lake (next to Emerald Bay) has the highest algal concentration, while the lowest median concentrations in Spring were in Meeks Bay and Dollar Point. The most extreme low values were on the west shore, due in large part to cold water upwellings.

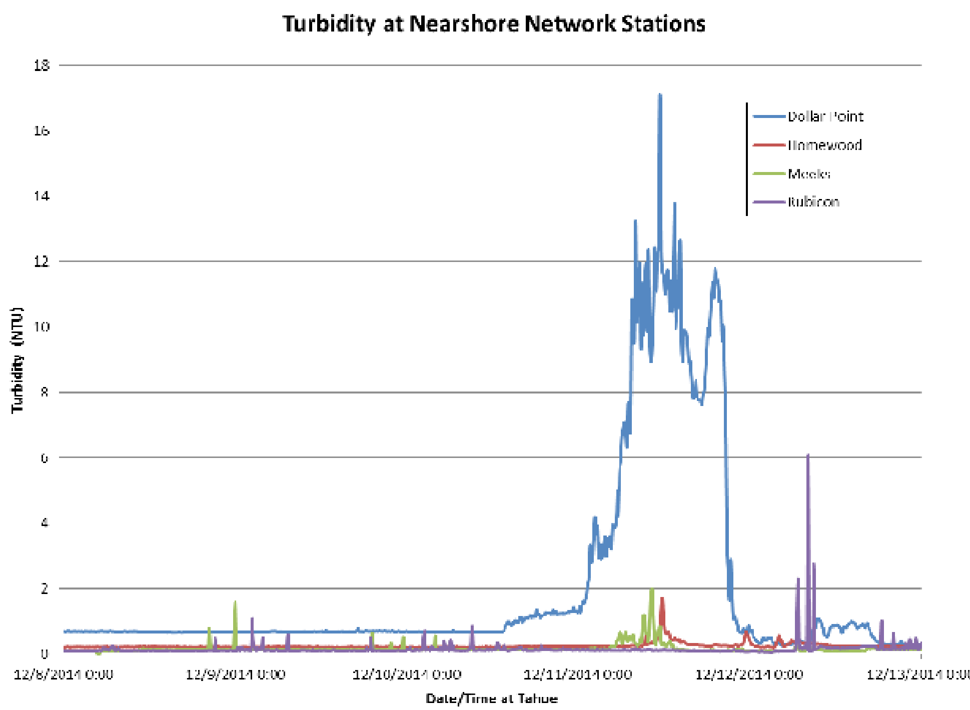


Variation of chlorophyll concentration at six sites in winter (blue) and spring (red). The lines across each box show the median value.

RECENT RESEARCH UPDATES

What Happens to the Nearshore During a Storm

In December 2014, the lake was blasted by two severe windstorms. On December 11, 2014, winds came from the southwest at 40 mph. The first panel shows the impact of the storm on turbidity at four west shore stations. Dollar Point recorded huge increases in turbidity up to 16 NTU (100 times larger than the desired value) in response to the storm, due to the breaking of 4 feet waves on the shore. The other west shore sites were sheltered, and had smaller, short term impacts. Most notable is the abrupt decline in turbidity immediately after the storm, indicating no lasting degradation.



Turbidity at four nearshore stations with strong southwest winds.

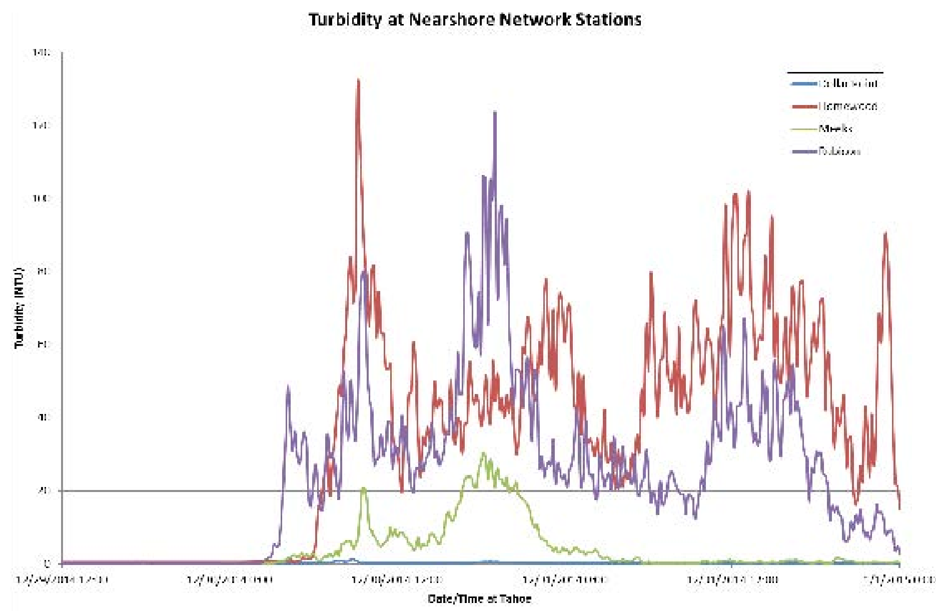
RECENT RESEARCH UPDATES

What Happens to the Nearshore During a Storm, continued

The second storm struck on December 30, 2014. The winds from this storm were lower (25 mph) and blew in from the northeast. For this storm Dollar Point was sheltered and saw almost no change in turbidity. However, Homewood and Rubicon saw turbidity rise to 50-100 NTU, a level that persisted for over 48 hours.

Neither of these events represent degradation of Lake Tahoe. Rather, they inform us of the impacts and duration of natural, albeit extreme, events. Knowing this, we can better recognize and understand the increases in turbidity that arise through poor land use practices.

Locations of the four nearshore stations relative to the wind direction.



Turbidity at four nearshore stations with strong northeast winds.

RECENT RESEARCH UPDATES

How Cold is Lake Tahoe?

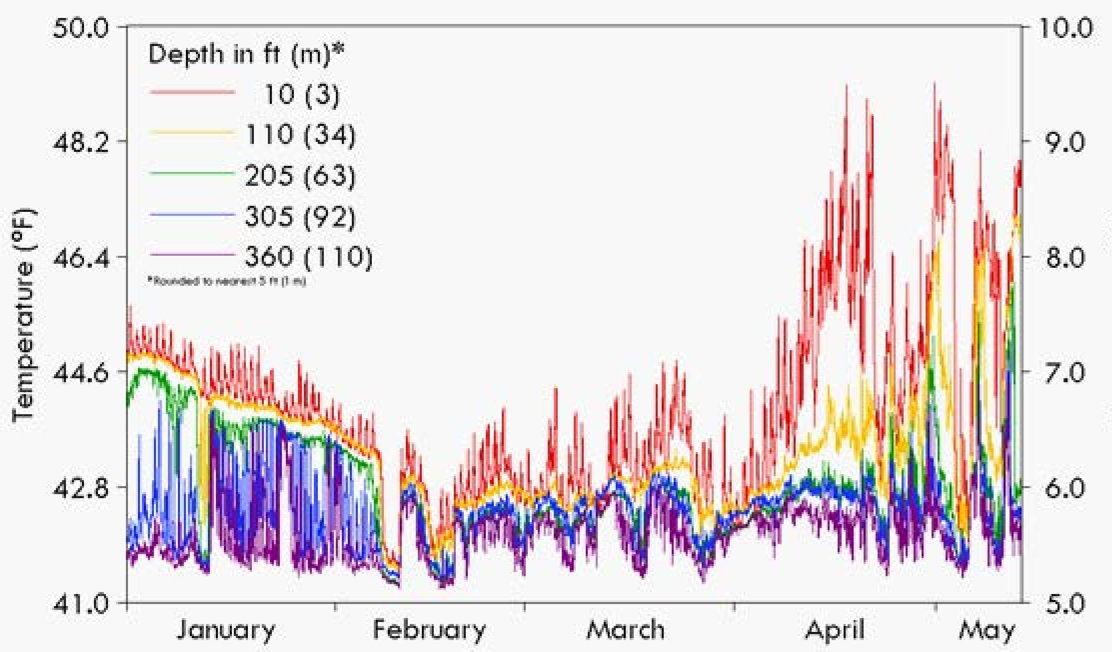
Temperature in the lake is constantly changing in response to the weather, the seasons, and especially the internal motions of the lake itself. A string of 16 high-resolution thermometers (a "thermistor chain") located off Homewood, CA, is providing graduate student Heather Sprague with unique data on Tahoe water temperatures.

Connected to the shore at Obexer's Marina by an underwater cable, data are gathered at 30 second intervals. The figure shows temperatures from just 5 of the instruments for the first 5 months of 2014. The uppermost (red) line shows the temperatures 10 feet below the surface. Here water temperature changes daily in tune with the rising and setting of the sun. Even in winter the water temperature can change 1 °F during the day. In summer, it can be 4 or 5 °F.

At a depth of 110 feet these daily changes are more muted, and we see the seasonal changes more clearly. Temperatures are lowest near the end of March.

Deeper down in the lake (305 and 360 ft.), the temperature fluctuations are again large, with temperature changes in the range of 2-3 °F. While they look like they are occurring daily, these fluctuations are in fact occurring every 19 hours, the result of a curious interaction with the earth's speed of rotation and the size and latitude of Tahoe. Even longer periods and larger amplitude fluctuations take place in the spring. These fluctuations are due to oscillations that travel around the edge of the lake once every 5 days.

The oscillations revealed by measuring temperature are similar to the oscillations that produce musical sounds. Read the next section to see (and hear) how this connection is being made and allowing us to hear the music produced by Lake Tahoe.



Temperature traces at five depths near Homewood, CA.

RECENT RESEARCH UPDATES

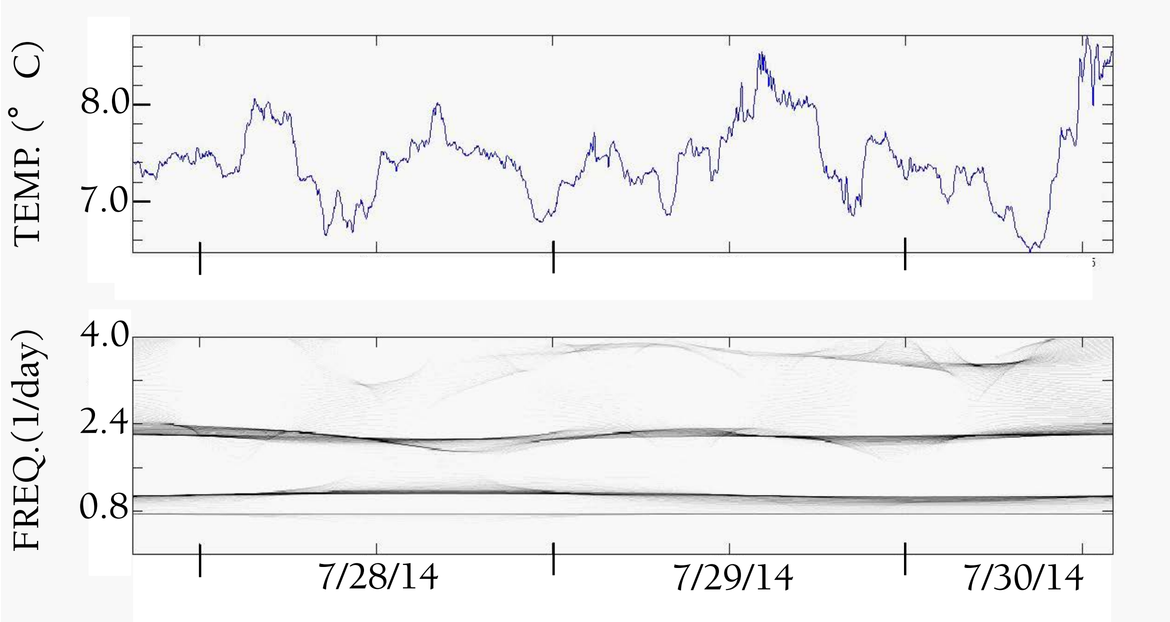
Lake Music

Lake Tahoe is in a constant state of motion. Many of these motions take the form of vertical oscillations. These oscillations vary in size and frequency, and depend on interactions between the temperature difference from top to bottom in the lake, the strength and direction of the wind, and the daily rotation of the earth about its axis. At each depth and on each day, oscillations are changing accordingly.

The temperature record from three days at a depth of 120 feet off Homewood, CA (upper panel), show the oscillations clearly. They are not unlike the vibrations that a plucked guitar string might exhibit. This idea has inspired a collaboration between the UC Davis Department of Mathematics and TERC. With guidance from Dr. Naoki Saito, undergraduate student Jordan Leung and graduate student Alex Berrian have converted Tahoe's inherent music into an audio file. The data used were temperature measurements TERC student Heather Sprague recorded every 30 seconds at 16 depths ranging from 10 feet to 360 feet below the lake surface.

For each temperature recorded, the trend was removed and a sophisticated mathematical procedure called 'synchrosqueezing' was used to generate time-frequency curves (lower panel). Here you can see the major frequencies in the time series and how these change over time. These curves are then mapped to pitches in a music scale in the human-audible range. Each time series is assigned a different musical instrument, with lower pitch instruments such as a double bass used for the deeper parts of the lake and higher pitch instruments such as a violin used for the shallower parts. Each instrument played different notes according to the calculated frequency with volume altered according to the observed trend.

To listen to a sample of lake music based on 14 days of data from 10 ft. below the surface, scan the QR code or simply go to http://terc.ucdavis.edu/local_resources/music/soundsoftahoe_.mp3



The oscillating temperatures recorded over a three-day period off Homewood is pictured above. Converting these oscillations using 'synchnosqueezing' is shown in the lower panel.

Scan QR code (left) to listen to Lake Tahoe's inherent music.

TAHOE: STATE OF THE LAKE REPORT 2015

METEOROLOGY

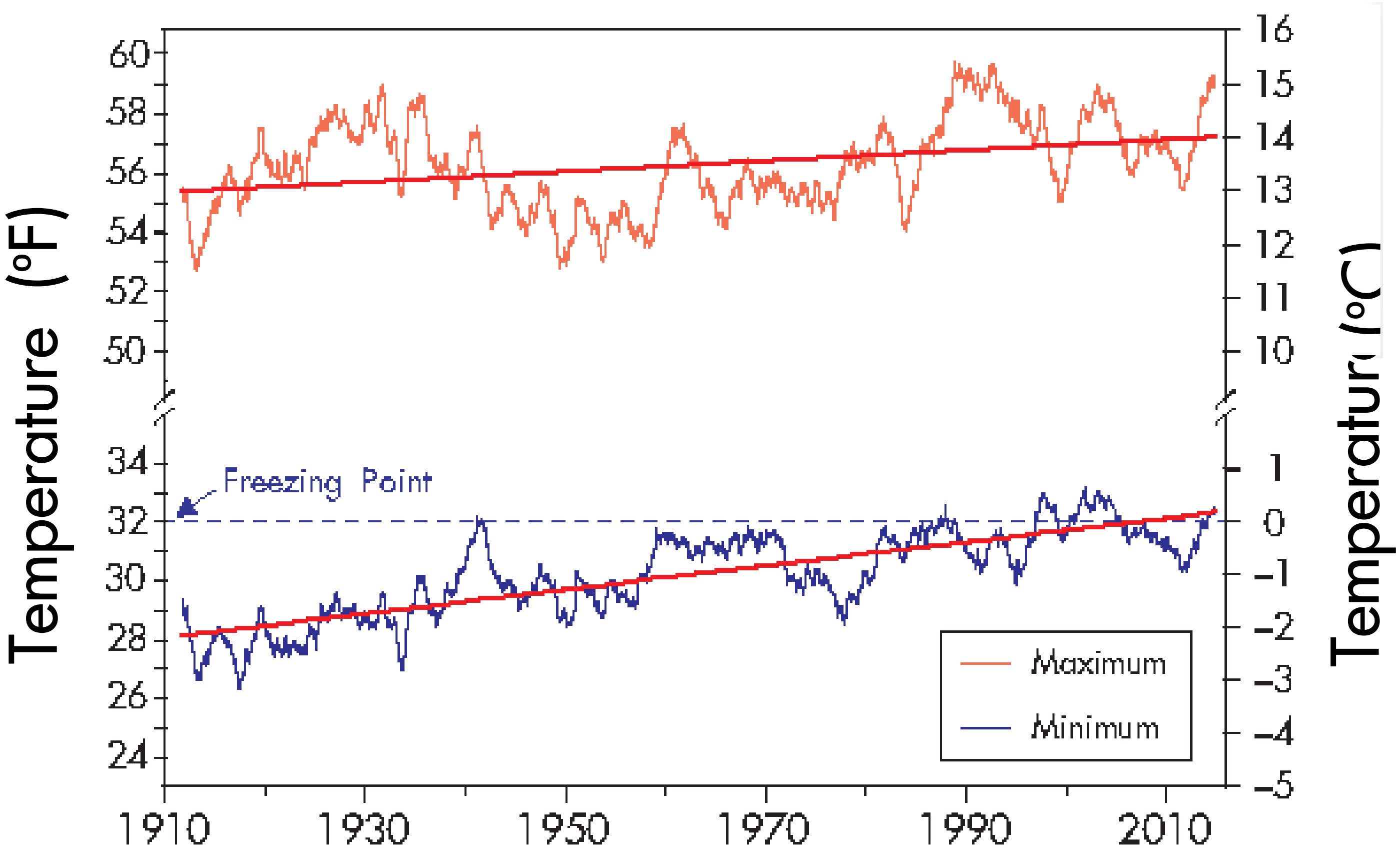
UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

METEOROLOGY

Air temperature

Daily since 1911

Over the last 100 years, the daily air temperatures measured at Tahoe City have increased. The long-term trend in daily minimum temperature has increased by 4.2 °F (2.3 °C), and the long-term trend in daily maximum temperature has risen by 1.8 °F (1.0 °C). The trend line for the minimum air temperature now exceeds the freezing temperature of water, which is strongly suggestive of more rain and less snow, as well as earlier snowmelt at Lake Tahoe. These data have been smoothed by using a two-year running average to remove daily and seasonal fluctuations. In 2014, the average minimum temperature increased by 2.3 °F (1.3 °C) over 2013. The average maximum temperature increased 2.0 °F (1.1 °C) over 2013.

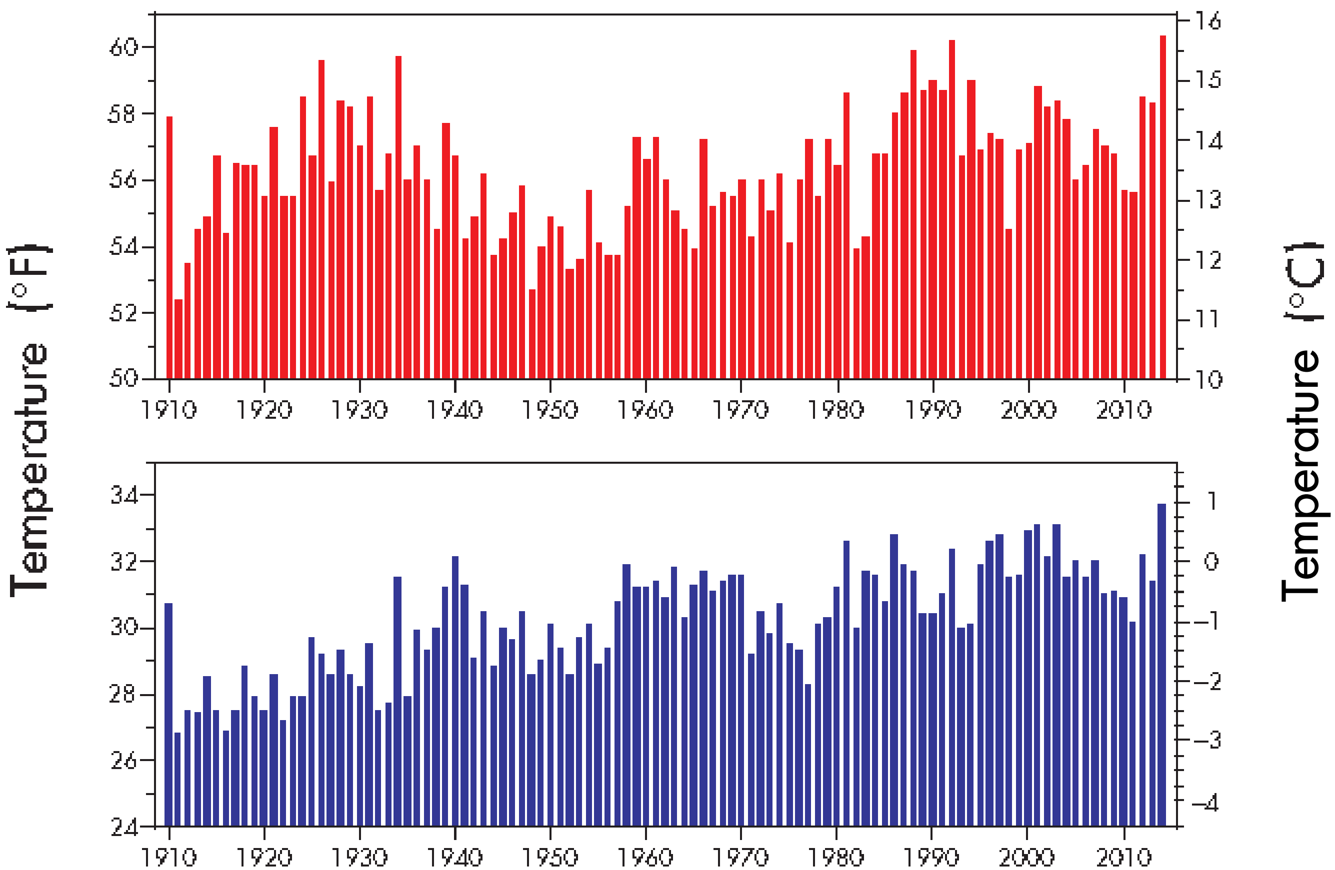


METEOROLOGY

Air temperature - annual average maximum and minimum

Since 1910

Annual average maximum (red) and minimum (blue) air temperatures both increased in 2014. The 2014 annual average minimum was 33.7 °F (0.92 °C) an increase of 2.3 °F over the previous year, and is the highest ever recorded. The maximum temperature was 60.3 °F (15.7 °C) an increase of 2.0 °F over the previous year, and is also the highest ever recorded. The long term means for the minimum and the maximum are 30.2 °F (-0.97 °C) and 56.3 °F (13.5 °C), respectively.



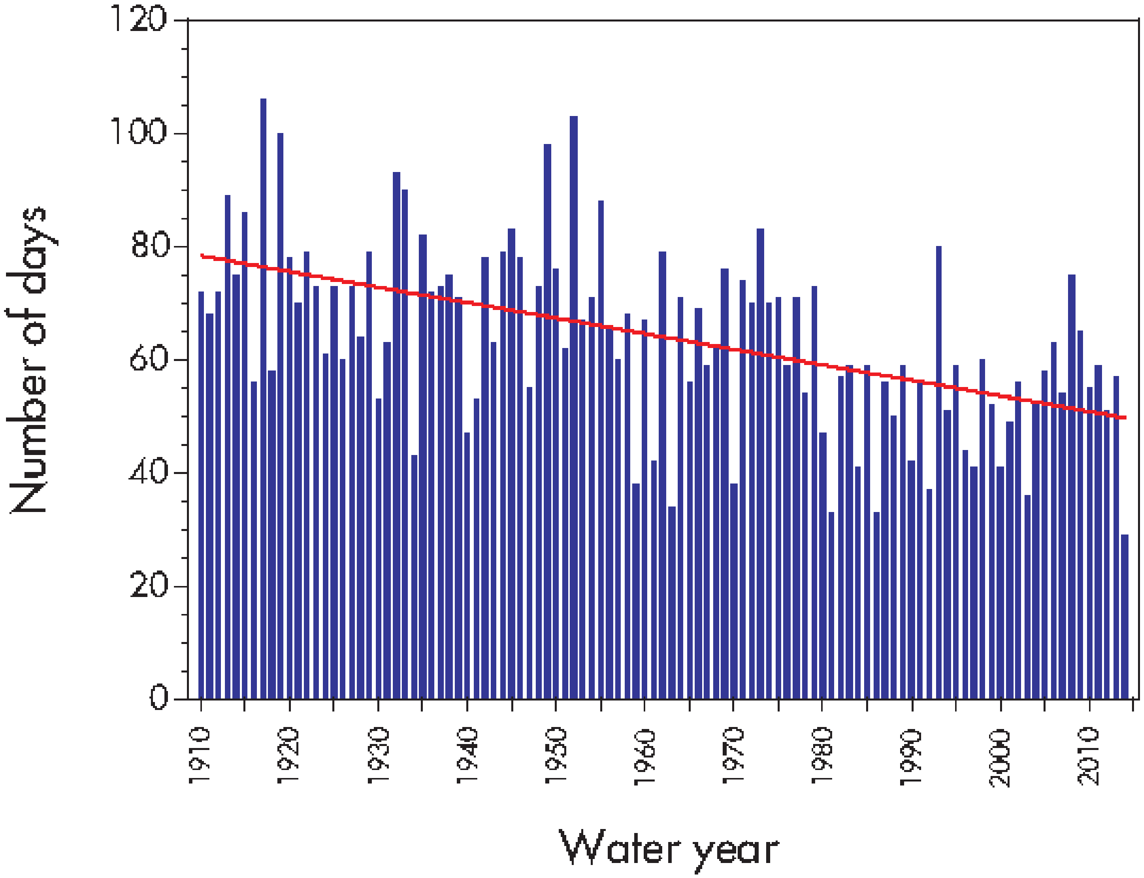
METEOROLOGY

Below-freezing air temperatures

Yearly since 1910

The method used for this analysis sums the number of days with daily average temperatures below freezing between December 1 and March 31 for each Water Year (WY). Although year-to-year variability is high, the number of days when air temperatures averaged below freezing has declined by about 29 days since 1911. In WY 2014, the number of freezing days was 29, the lowest ever recorded.

Note: The Water Year extends from October 1 through September 30.

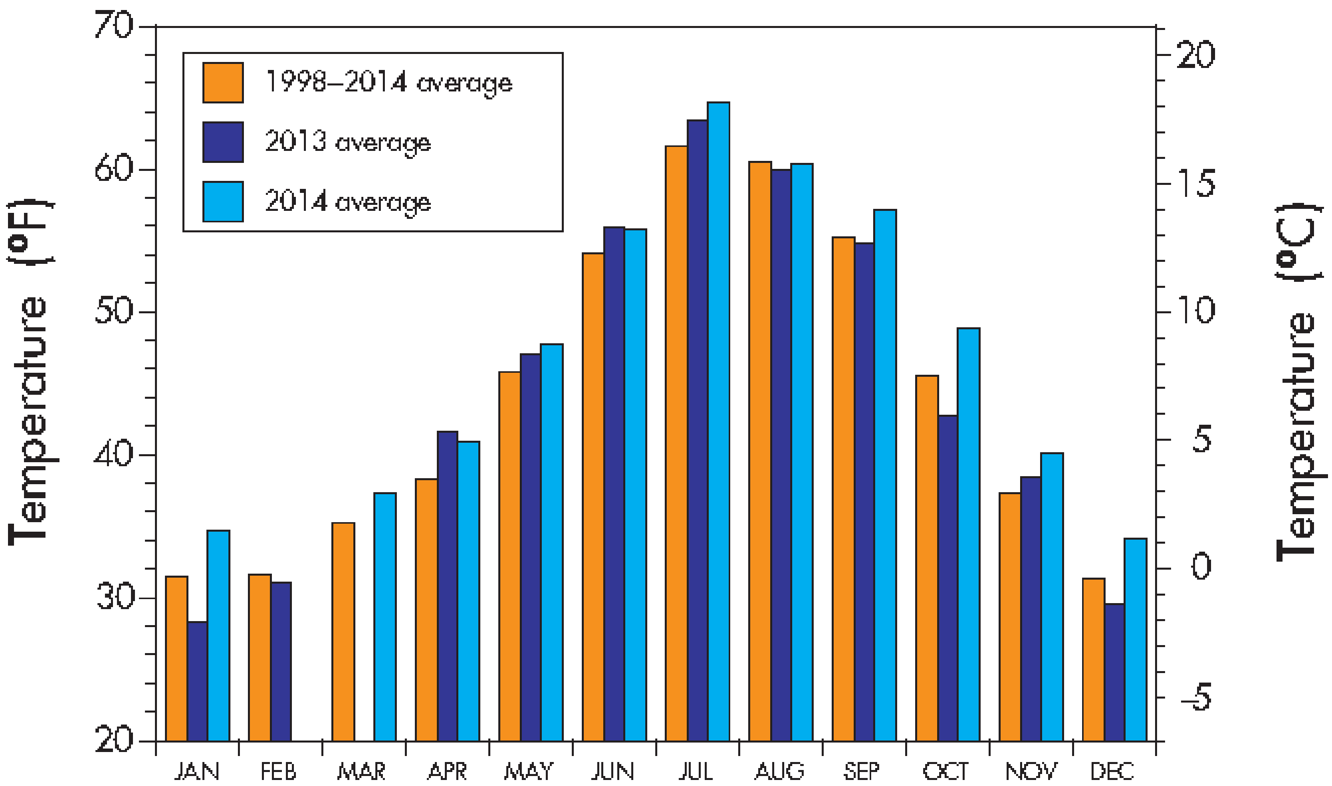


METEOROLOGY

Monthly air temperature

Since 1998

In 2014, monthly air temperatures were distinguished by being warmer than the long-term mean in virtually every month of the year (except August). This trend is consistent with the global trend of 2014 being the warmest year on record. Months with more than 25 percent of days missing were omitted.

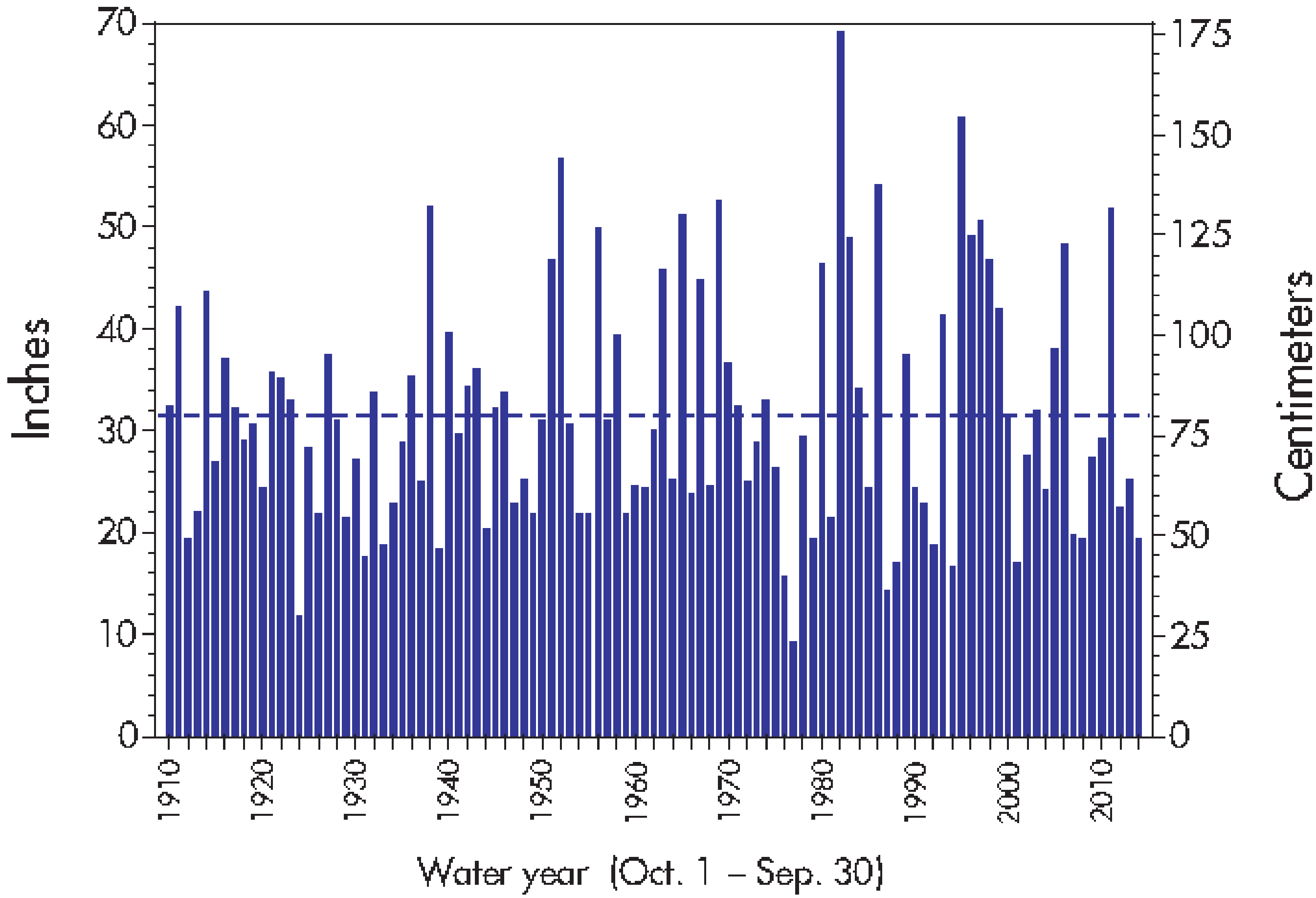


METEOROLOGY

Annual precipitation

Yearly since 1910

From 1910 to 2014, average annual precipitation (water equivalent of rain and snow) at Tahoe City was 31.41 inches. The maximum was 69.2 inches in 1982. The minimum was 9.2 inches in 1977. 2014 was well below average, with 19.32 inches, following the two previous dry years. The long-term mean of 31.41 inches is shown by the dashed line. Generally there is a gradient in precipitation from west to east across Lake Tahoe, with almost twice as much precipitation falling on the west side of the lake. (Precipitation is summed over the Water Year, which extends from October 1 through September 30.)

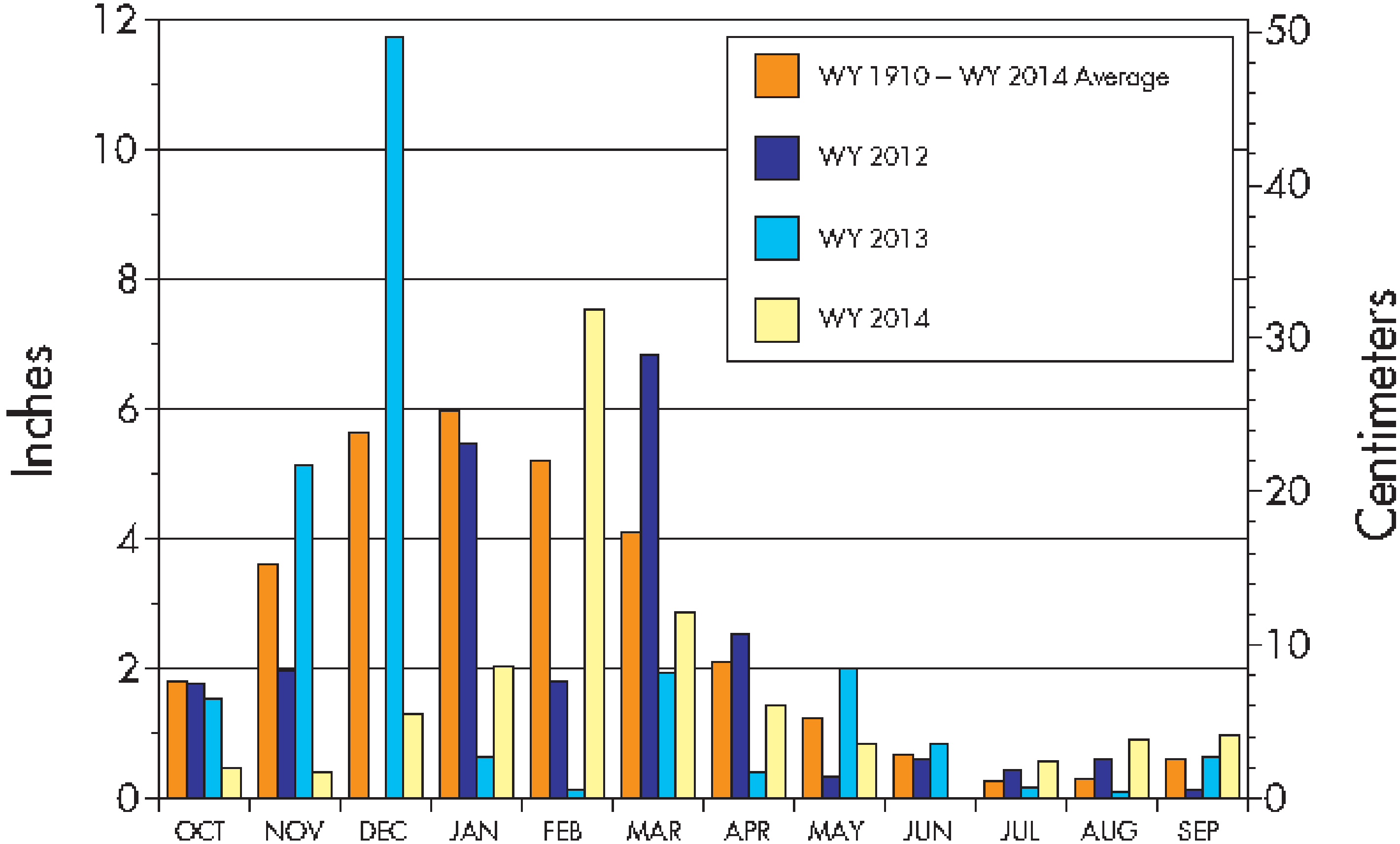


METEOROLOGY

Monthly precipitation

2012, 2013, 2014 and 1910 to 2014

2014 was well below average in total precipitation. This is clearly evident in the comparison of the monthly precipitation with the previous two years and the long-term average. Monthly precipitation in WY 2014 was particularly lower than the long-term average between October and January. The monthly precipitation for Dec-2011 (WY 2012), and Jun-2014 (WY 2014) was 0 inches. The 2014 Water Year extended from October 1, 2013, through September 30, 2014.

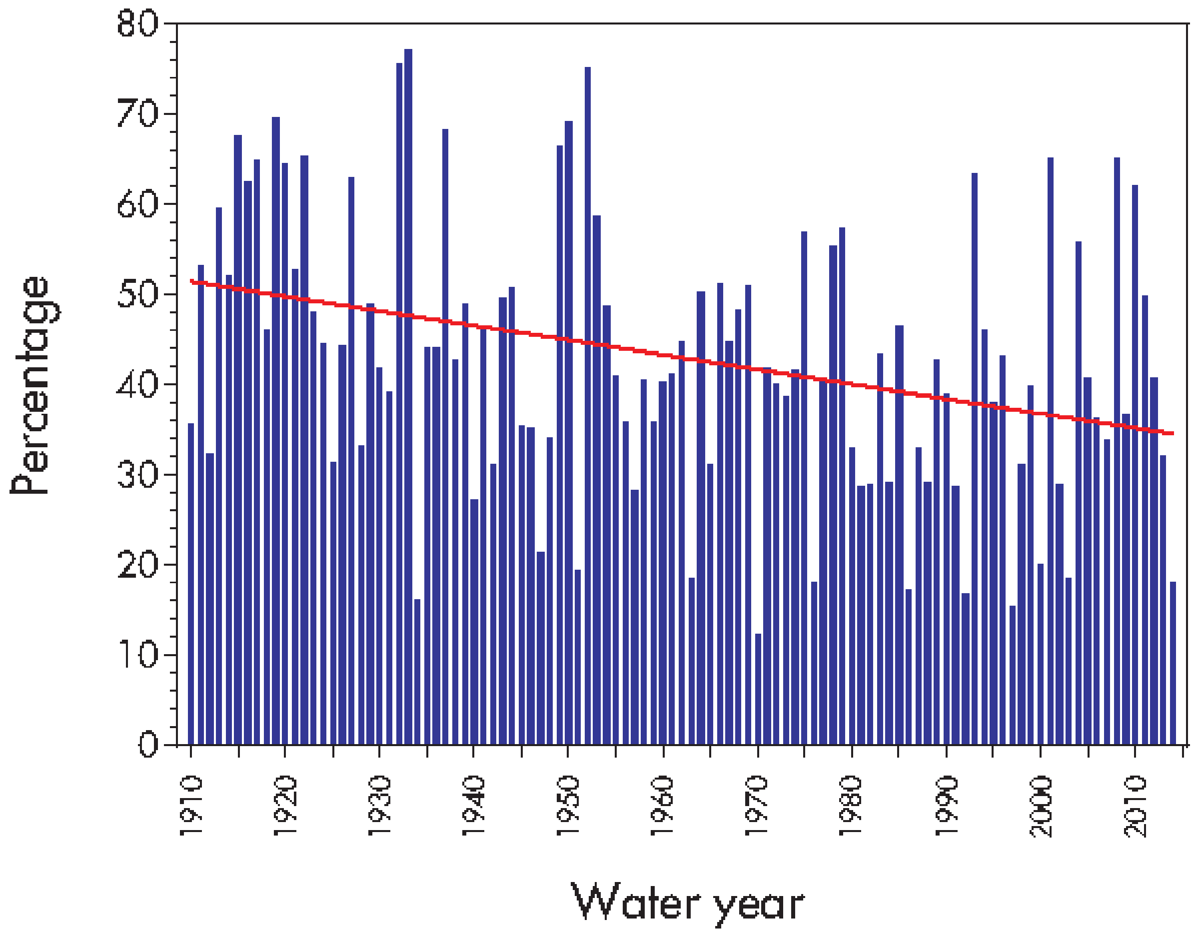


METEOROLOGY

Snow as a fraction of annual precipitation

Yearly since 1910

Snow has declined as a fraction of total precipitation, from an average of 51 percent in 1910 to 34 percent in present times according to the line of best fit. In Tahoe City, snow represented 18 percent of the 2014 total precipitation, one of the lowest values on record. These data are calculated based on the assumption that precipitation falls as snow whenever the average daily temperature is below freezing. (Precipitation is summed over the Water Year, which extends from October 1 through September 30.)

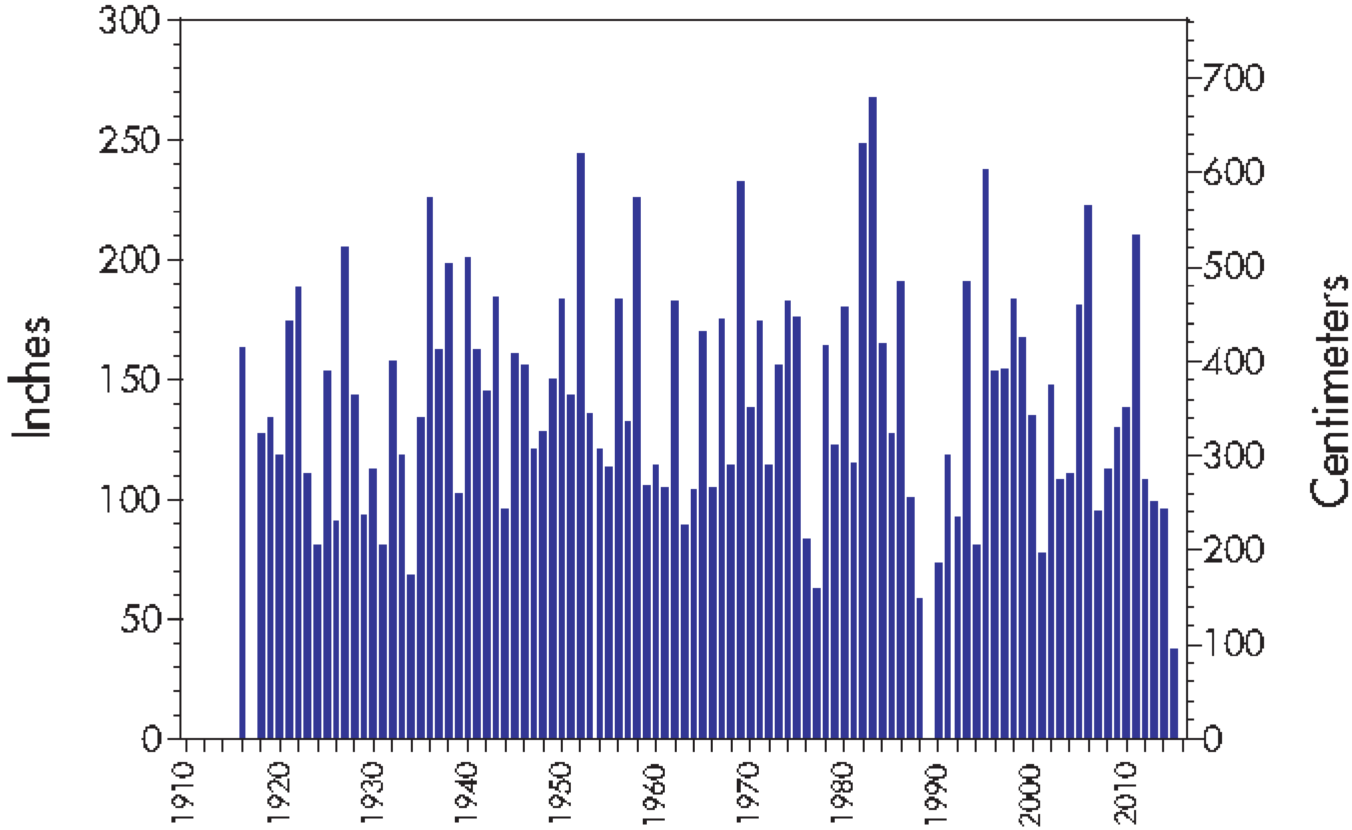


METEOROLOGY

April snowpack

Since 1916

The depth of the snowpack is measured at multiple locations throughout the Sierra throughout the year. Shown here are the readings taken on approximately April 1 for the period 1916 to 2015 at the Lake Lucille Snow Course Station (located in Desolation Wilderness, elevation 8,188 feet, Lat 38.86 Long -120.11) NOTE: April snow depth data are not available for 1917 and 1989. The snow depth on 3/27/2015 was 37 inches, the lowest value ever recorded. The average snow depth over the period 1916-2015 was 142 inches. Data source: USDA Natural Resources Conservation Service, California Monthly Snow Data.



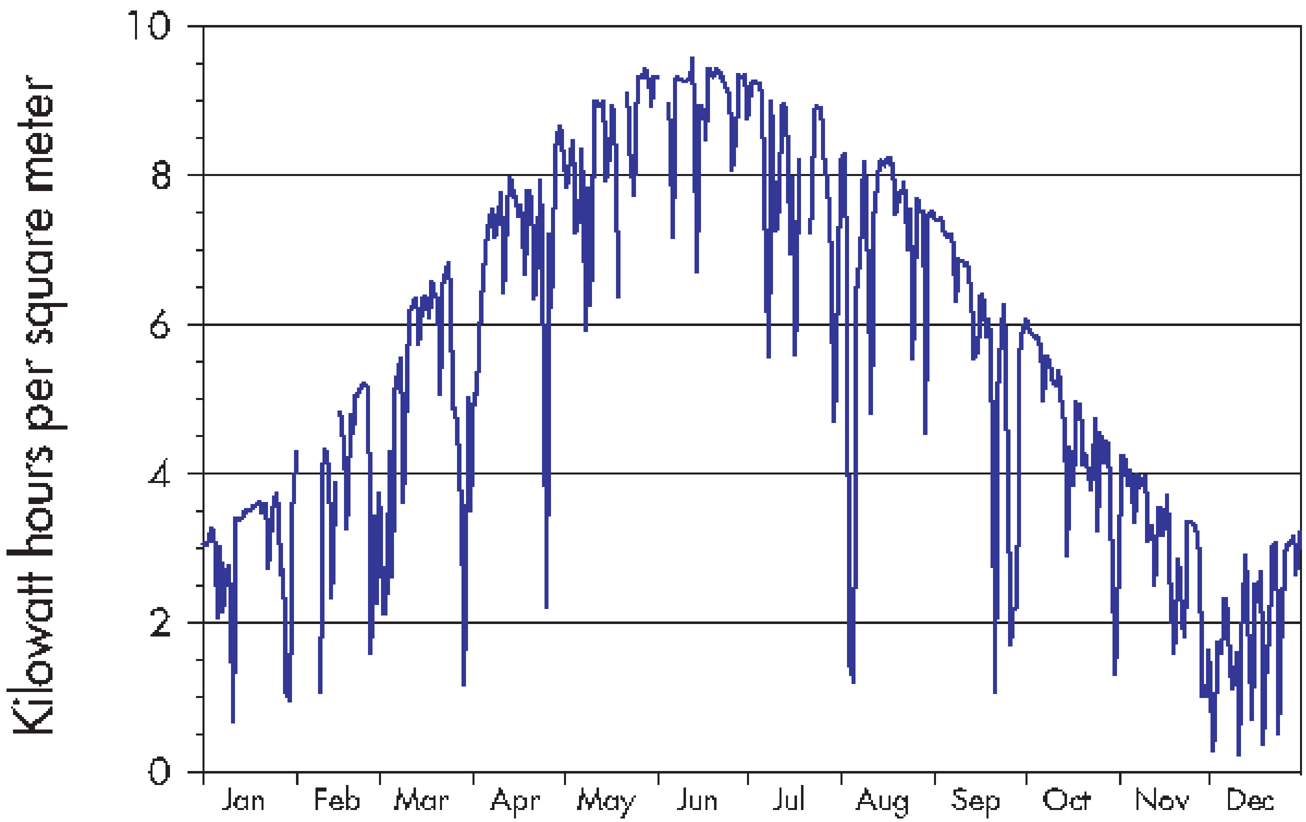
METEOROLOGY

Daily solar radiation

In 2014

Solar radiation showed the typical annual pattern of increasing then decreasing sunlight, peaking at the summer solstice on June 21 or 22. Dips in daily solar radiation are due primarily to clouds. Smoke and other atmospheric constituents play a smaller role. It is noteworthy that solar radiation on a clear day in mid-winter can exceed that of a cloudy day in mid-summer.

The station where these data are collected is located on the U.S. Coast Guard dock at Tahoe City.



TAHOE: STATE OF THE LAKE REPORT 2015

PHYSICAL PROPERTIES

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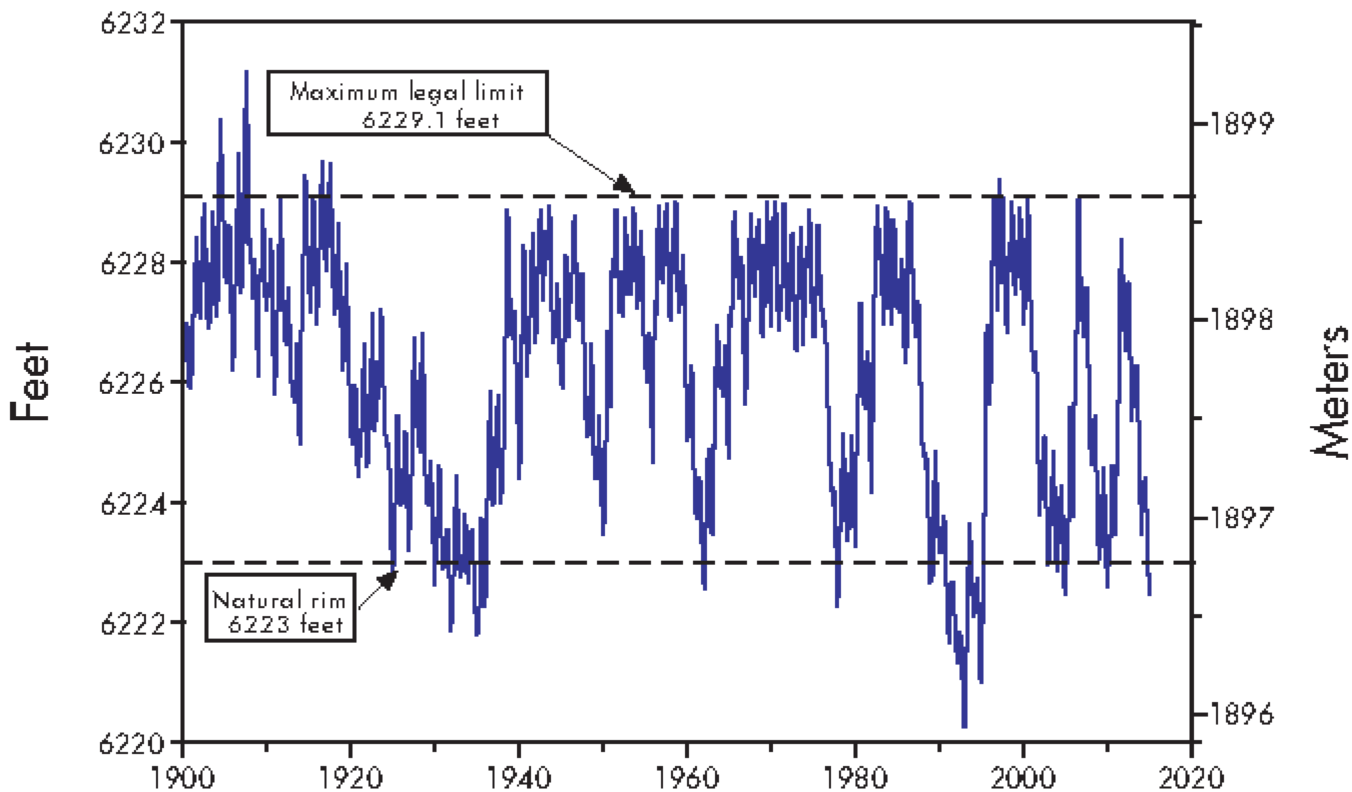
PHYSICAL PROPERTIES

Lake surface level

Daily since 1900

Lake surface level varies throughout the year. It rises due to high stream inflow, groundwater inflow and precipitation directly onto the lake surface. It falls due to evaporation, in-basin water withdrawals, groundwater outflows, and outflow via the Truckee River at Tahoe City. Overall, lake level fell during 2014. The highest lake level was 6224.44 feet from May 23-26, and the lowest was 6222.49 feet on November 28. The natural rim of the lake is at an elevation of 6223 feet. Lake Tahoe fell below the natural rim on October 16, 2014, signaling the cessation of outflow via the Truckee River. Several episodes of lake level falling below the natural rim are evident in the last 114 years. The frequency of such episodes appear to be increasing.

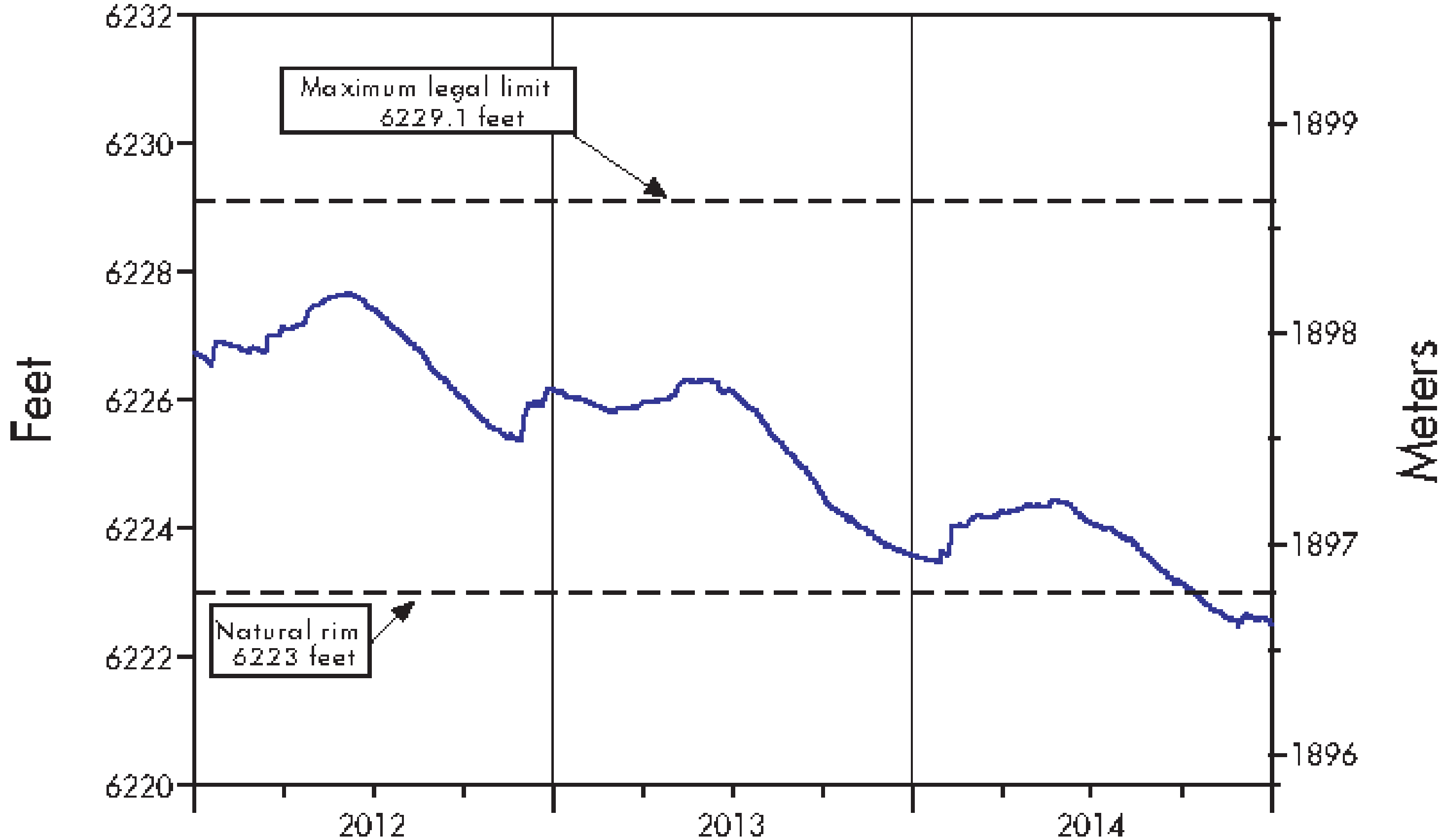


PHYSICAL PROPERTIES

Lake surface level, continued

Daily since 2012

Displayed below is the lake surface data from 2012-2014 extracted from the same data on page 8.1. This more time restricted presentation of recent lake level data allows us to see the seasonal patterns in greater detail. Data clearly show the lake level falling below the natural rim in October 2014 and its final level of 0.49 feet below the rim at the end of 2014. The effects of the drought on overall lake water level is evident.

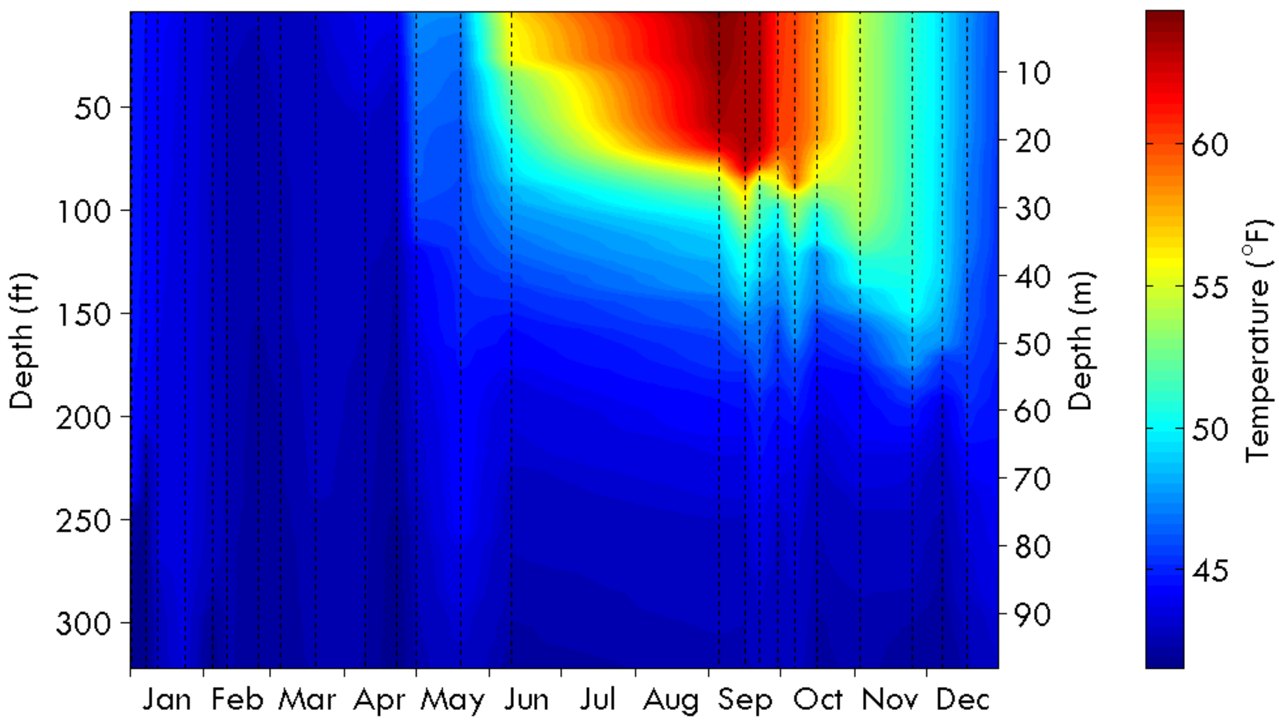


PHYSICAL PROPERTIES

Water temperature profile

In 2014

Water temperature profiles are measured in the lake using a Seabird CTD (conductivity, temperature, depth) profiler at the times indicated by the dashed vertical lines. The temperature is accurate to within 0.005 °F. Here the temperature in the upper 330 feet (100 m) is displayed as a color contour plot. In 2014, the lake temperature followed a typical seasonal pattern. In February-March, the lake surface was at its coldest, while it was at its warmest at the end of August. The beginning of the 2014-2015 winter mixing is evident at the end of the plot, with the surface layer both cooling and deepening.

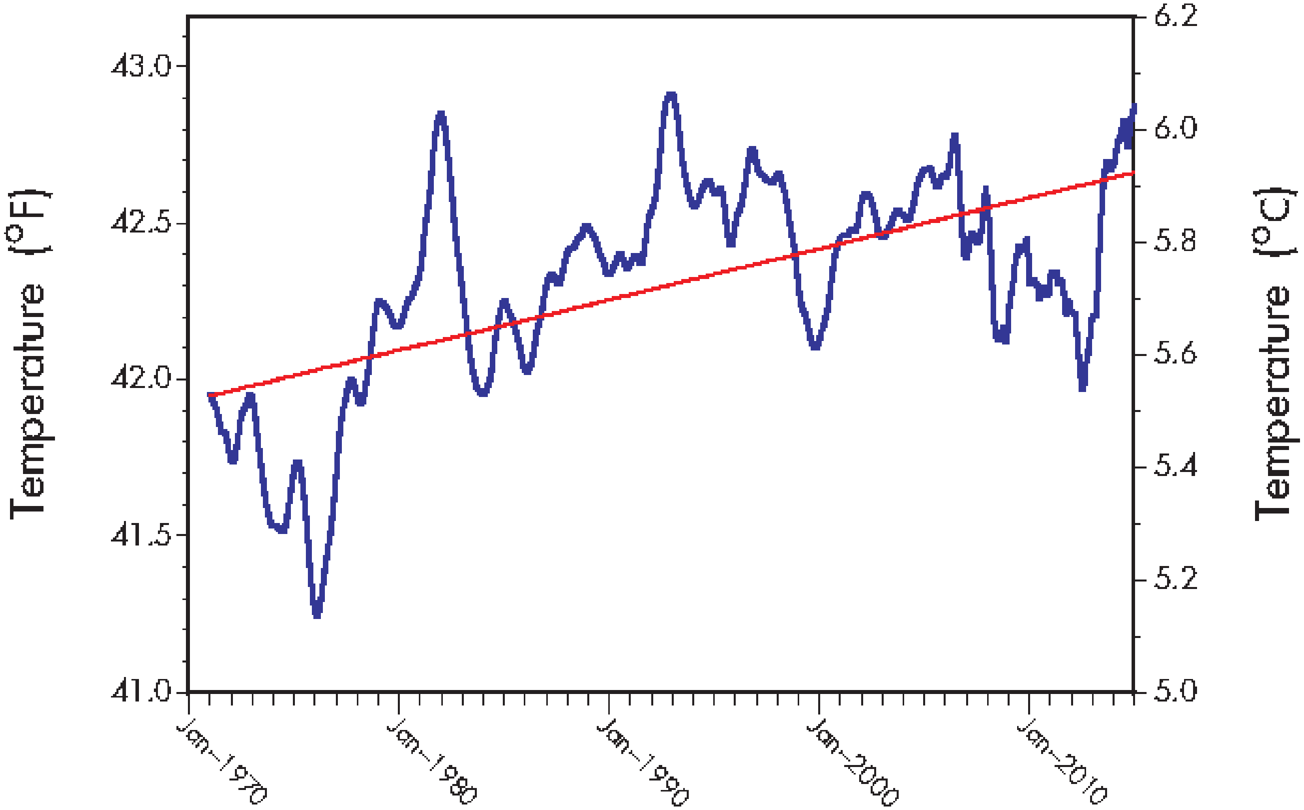


PHYSICAL PROPERTIES

Average water temperature

Since 1970

The trend in the volume-averaged temperature of Lake Tahoe has increased by approximately 0.7 °F since 1970. The annual rate of warming is 0.016 °F (0.0091 °C). The monthly temperature profile data from the lake has been smoothed and seasonal influences removed to best show the long-term trend. Up until the late 1990s the warming rate was considerably greater, but a high number of deep mixing years since 1997 have slowed the warming rate.

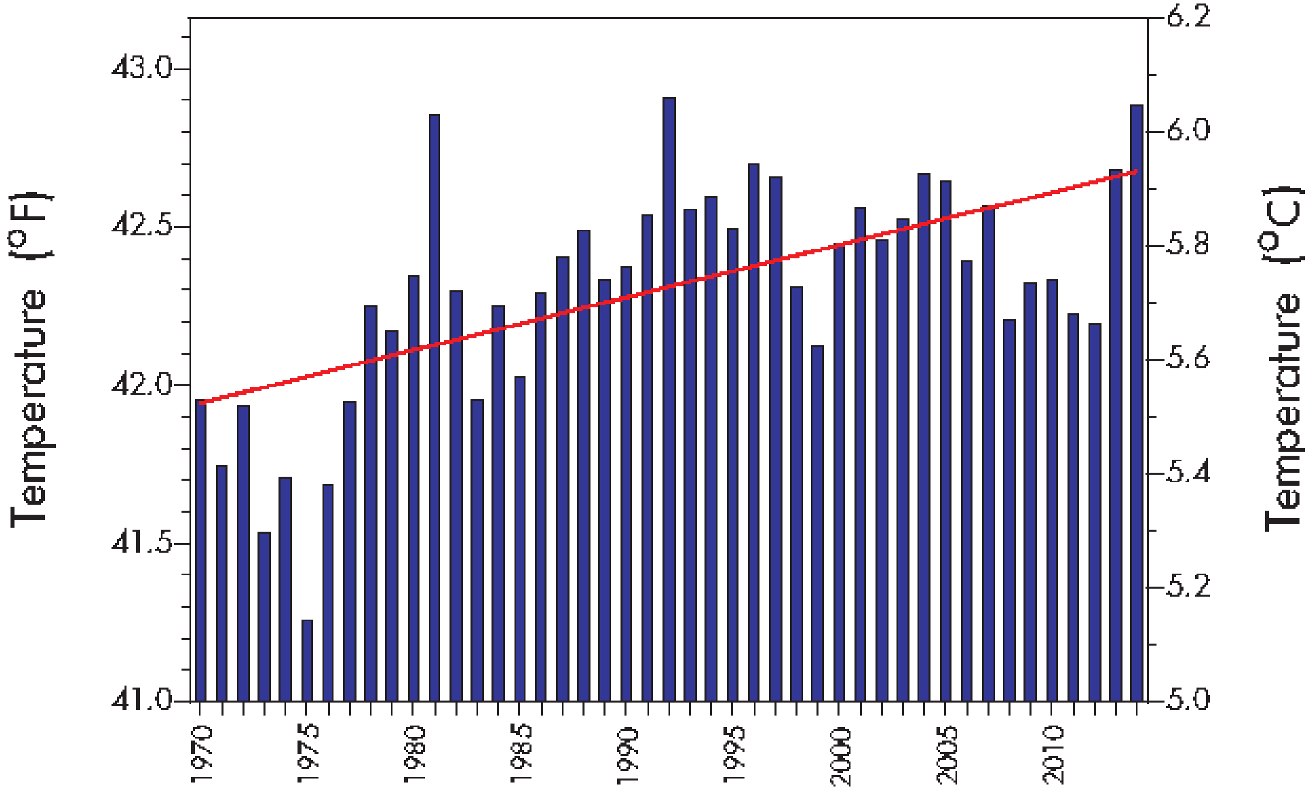


PHYSICAL PROPERTIES

Annual average water temperature

Since 1970

The volume-averaged temperature of the lake for each year since 1970 is shown. In 2014 the volume-averaged temperature increased by 0.2 °F (0.11 °C) over the previous year. The years with the largest decreases in temperature generally correspond to those years in which deep mixing occurred. Years with increases in temperature are often associated with a lack of deep mixing.

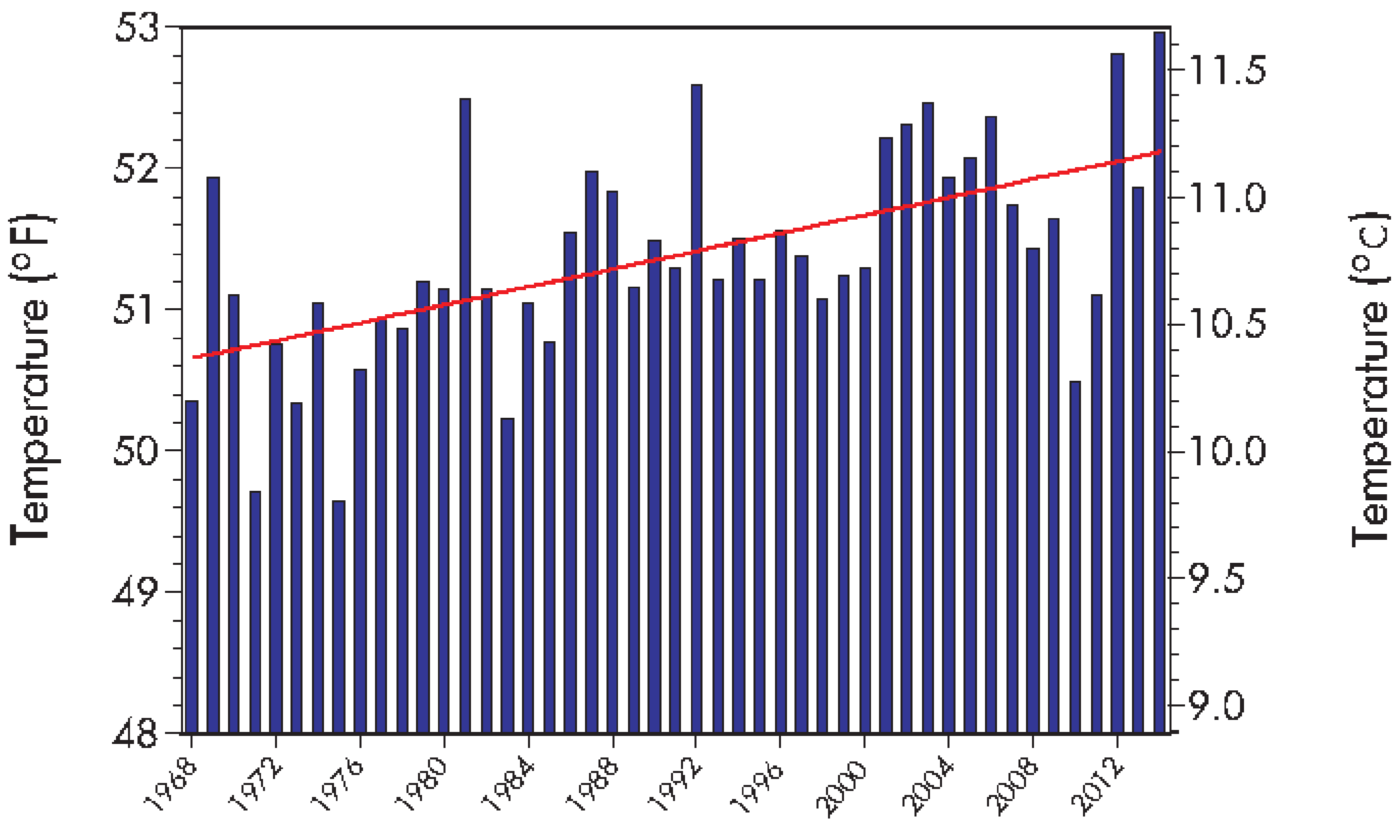


PHYSICAL PROPERTIES

Surface water temperature

Yearly since 1968

Surface water temperatures have been recorded monthly at the mid-lake and index station since 1968 from the R/V John LeConte and the R/V Bob Richards. Despite year-to-year variability, the annual average surface water temperatures show an increasing trend. The average temperature in 1968 was 50.3 °F (10.2 °C). For 2014, the average surface water temperature was 53.0 °F, making it the warmest year yet recorded. The overall rate of warming of the lake surface is 0.032 °F (0.018 °C) per year.

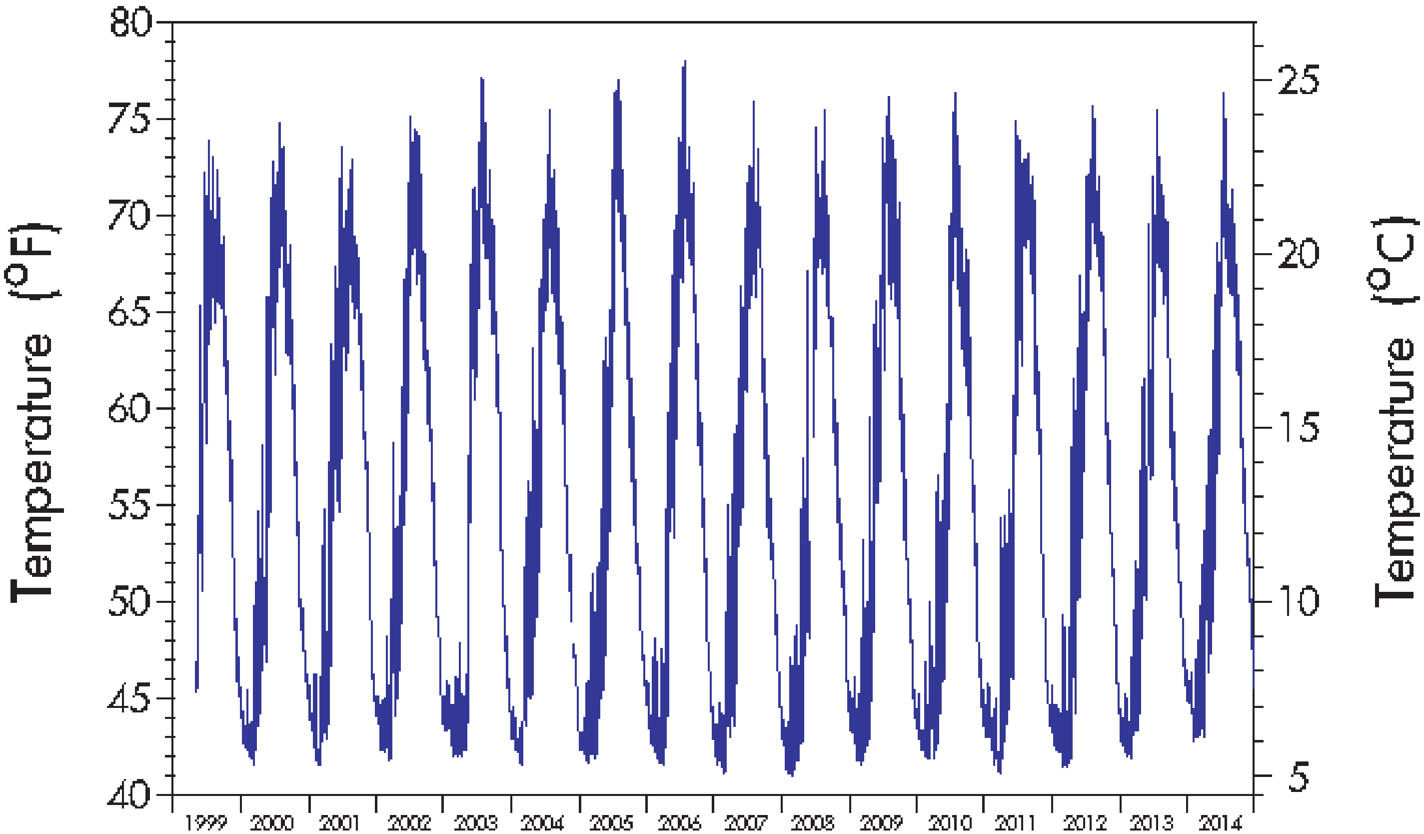


PHYSICAL PROPERTIES

Maximum daily surface water temperature

Surface temperature measured since 1999 every 2 minutes

The maximum daily surface water temperature in 2014 was significantly warmer than it has been for the last 4 years, and for the winter-time maximum, it was the warmest surface water temperature observed since 1999. The highest maximum daily surface water temperature (summer) was 76.33 °F, which was recorded on July 18, 2014. The lowest maximum daily surface water temperature (winter) was 42.79 °F, which was recorded on February 9, 2014. These data are collected in real-time by NASA-JPL and UC Davis from 4 buoys located over the deepest parts of the lake.

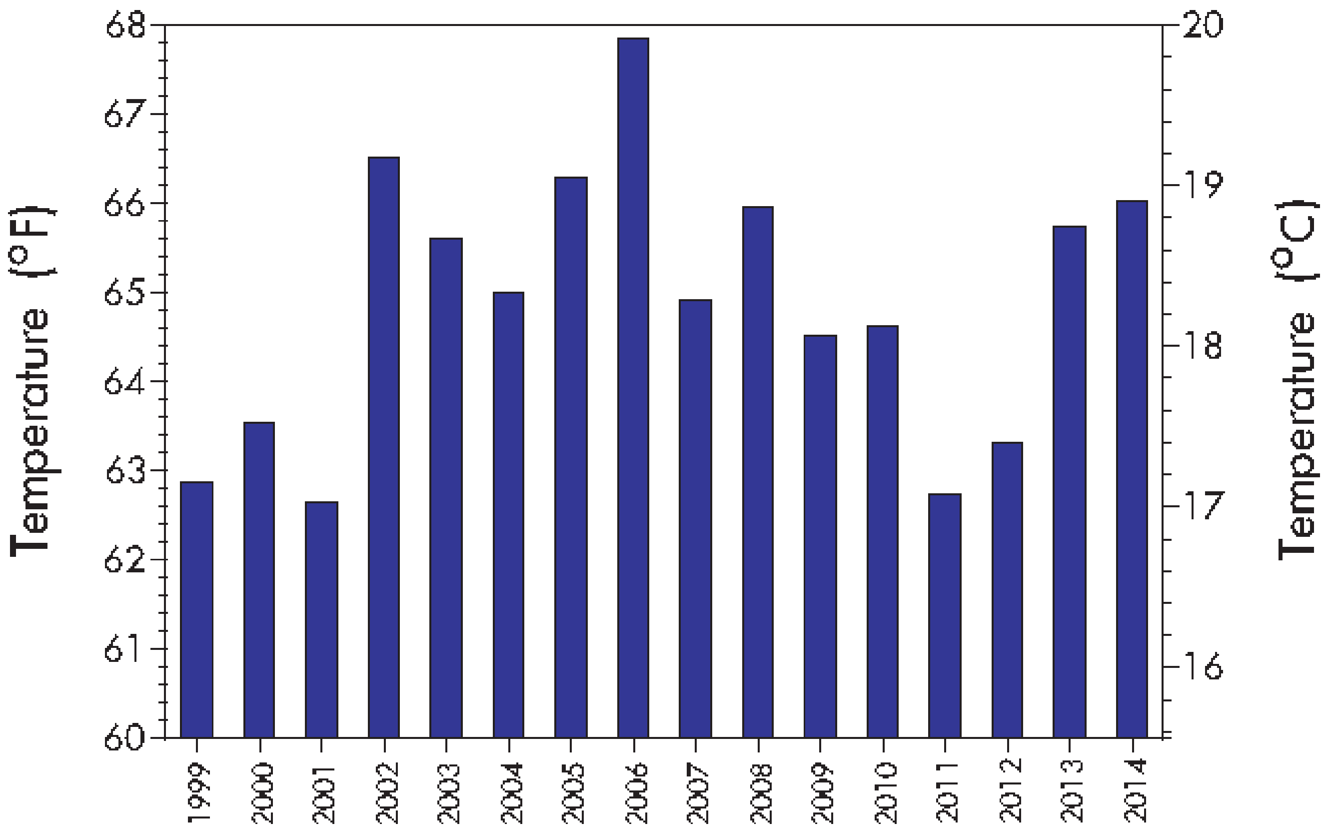


PHYSICAL PROPERTIES

July average surface water temperature

Measured since 1999 every 2 minutes

Since 1999, surface water temperature has been recorded every two minutes from four NASA/UC Davis buoys. Shown here are 16 years of average surface water temperatures in the month of July when water temperatures are typically warmest. In 2014, July surface water temperature averaged 66.0 °F, compared with 62.7 °F in 2011. This increase coincides with the absence of deep lake mixing since 2011. Cooling of the lake surface is necessary to drive the process of deep lake mixing. The average July surface water temperature for the 16 year period is 64.9 °F.

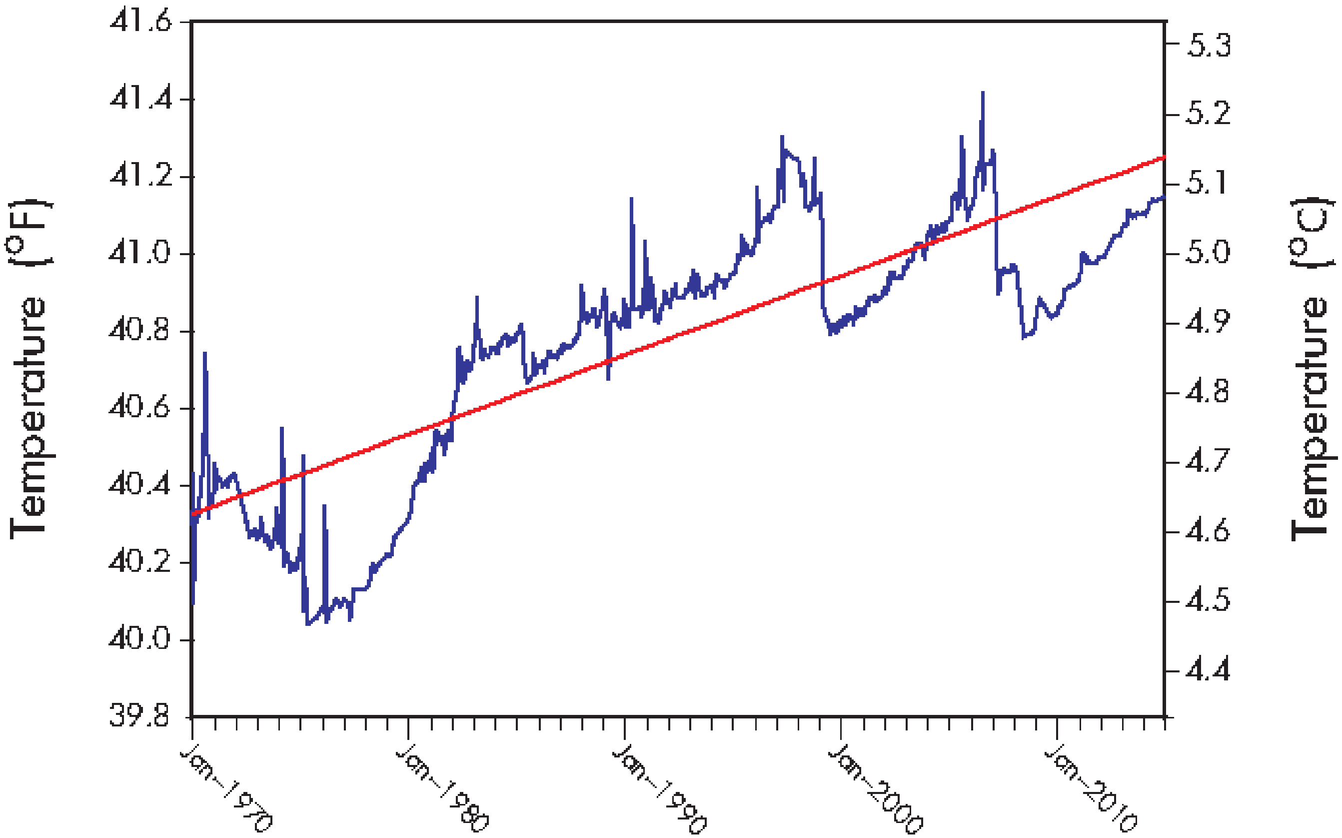


PHYSICAL PROPERTIES

Deep water temperature

Since 1970

The water temperature at a depth of 1,320 feet (400 m) is indicative of conditions in the deeper waters (hypolimnion) of Lake Tahoe. Since 1970 the deep water temperature has increased by approximately 1 °F (0.6 °C), at an annual rate of 0.021 °F (0.011 °C), a rate of warming that is half that of the surface water. This increase has not been steady but is punctuated by occasional drops in temperature. These coincide with times when the lake completely mixes to the bottom, an event which allows a huge amount of heat to escape from the lake. The short spikes of temperature increase are temporary effects caused by motions of internal waves.

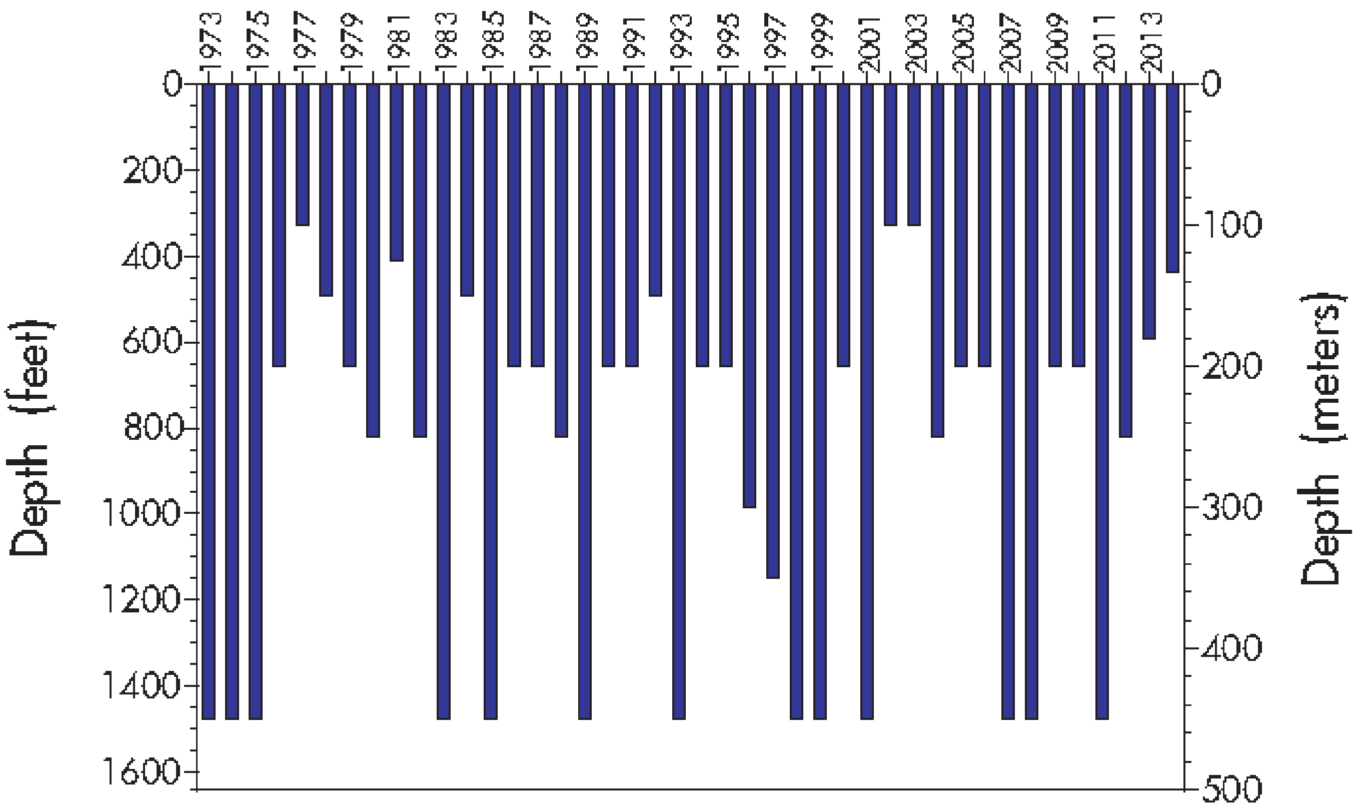


PHYSICAL PROPERTIES

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 and intense cooling of winter helps to determine how deep the lake mixes. Mixing depth has profound impacts on lake ecology and water quality. Deep mixing brings nutrients to the surface, where they promote algal growth. It also moves oxygen to deep waters, promoting aquatic life throughout the water column. The deepest mixing typically occurs between February and March. In 2014, Lake Tahoe mixed to a depth of only 440 feet (134 m). This lack of deep mixing most likely contributed to the warmer surface temperature, the build up of nitrate in lake, and the generally higher clarity. Beginning in 2013, the determination of the depth of mixing has been based on high-resolution temperature profiles rather than nitrate concentration sampled at discrete depths.

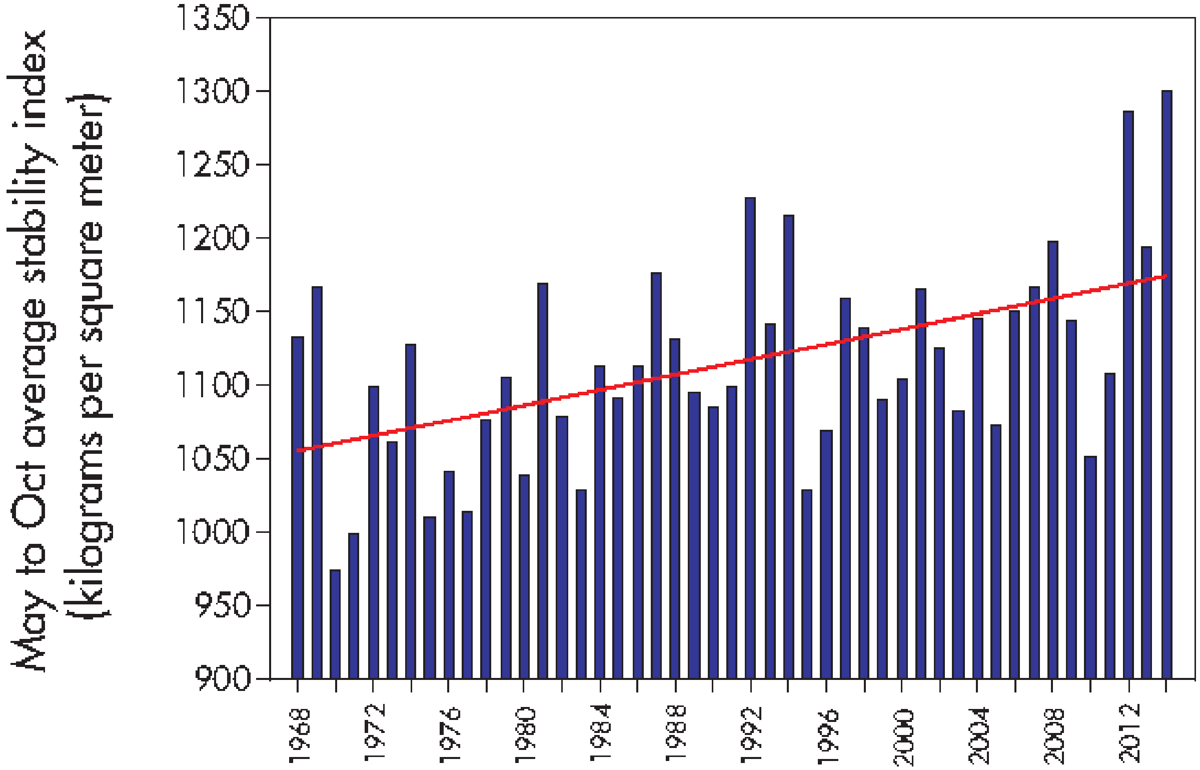


PHYSICAL PROPERTIES

Lake stability

Since 1968

When the lake has a vertical distribution of temperature, it has a corresponding density distribution, with warm and lighter water at the surface, and colder, denser water at depth. The stability index is a measure of the energy required to fully mix the water column when its density is stratified. The average stability index for the upper 330 feet (100 m) of Lake Tahoe is plotted for the period of May through October each year. The values are derived from temperature profiles taken at the Index Station at approximately 10-20 day intervals. There has been an overall increase in lake stability by over 10% in the last 45 years. In 2014, the stability of the lake was the highest recorded for the period of measurement.

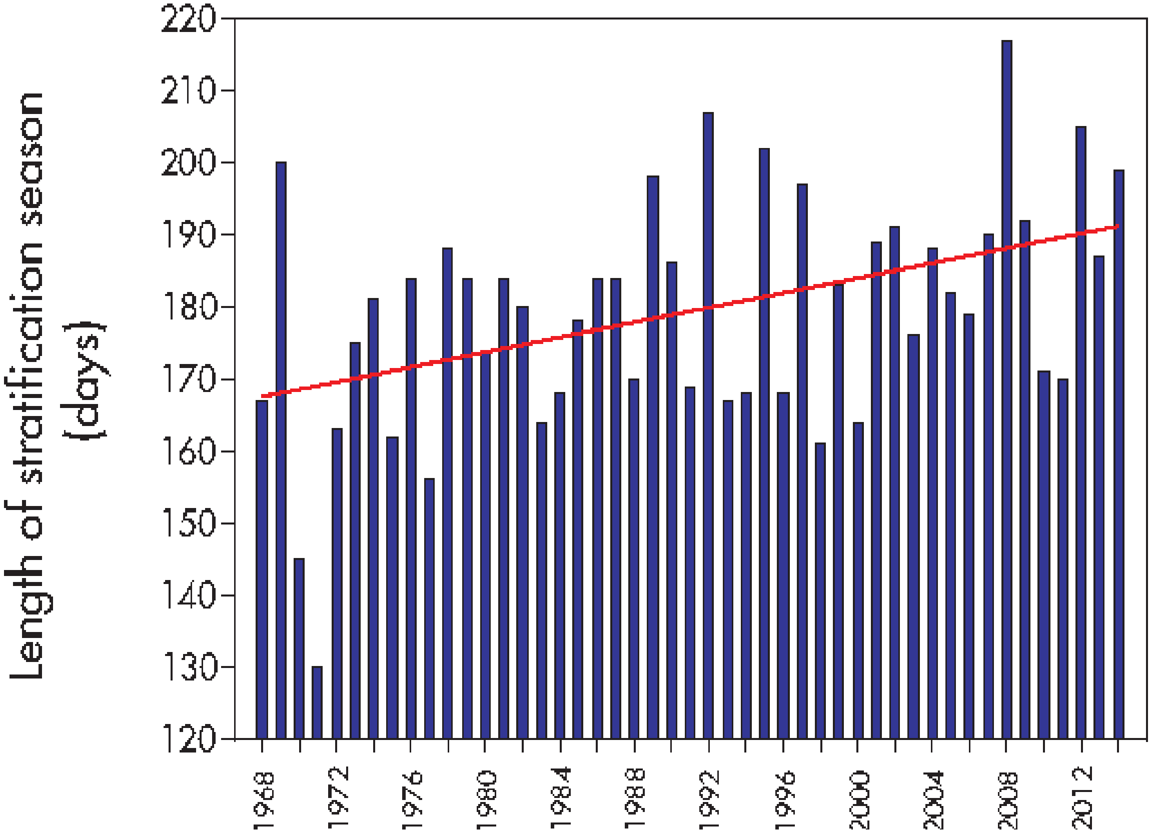


PHYSICAL PROPERTIES

Stratified season length

Since 1968

The stability index, a measure of the energy required to fully mix the lake, can be evaluated for every day of the year. We define the stratification season as the length of time when the stratification index exceeds a value of 600 kilograms per square meter. Since 1968 the length of the stratification season has increased, albeit with considerable year-to-year variation. Overall the stratification season has lengthened by approximately three weeks. In 2014, the length of the stratified season was 199 days.

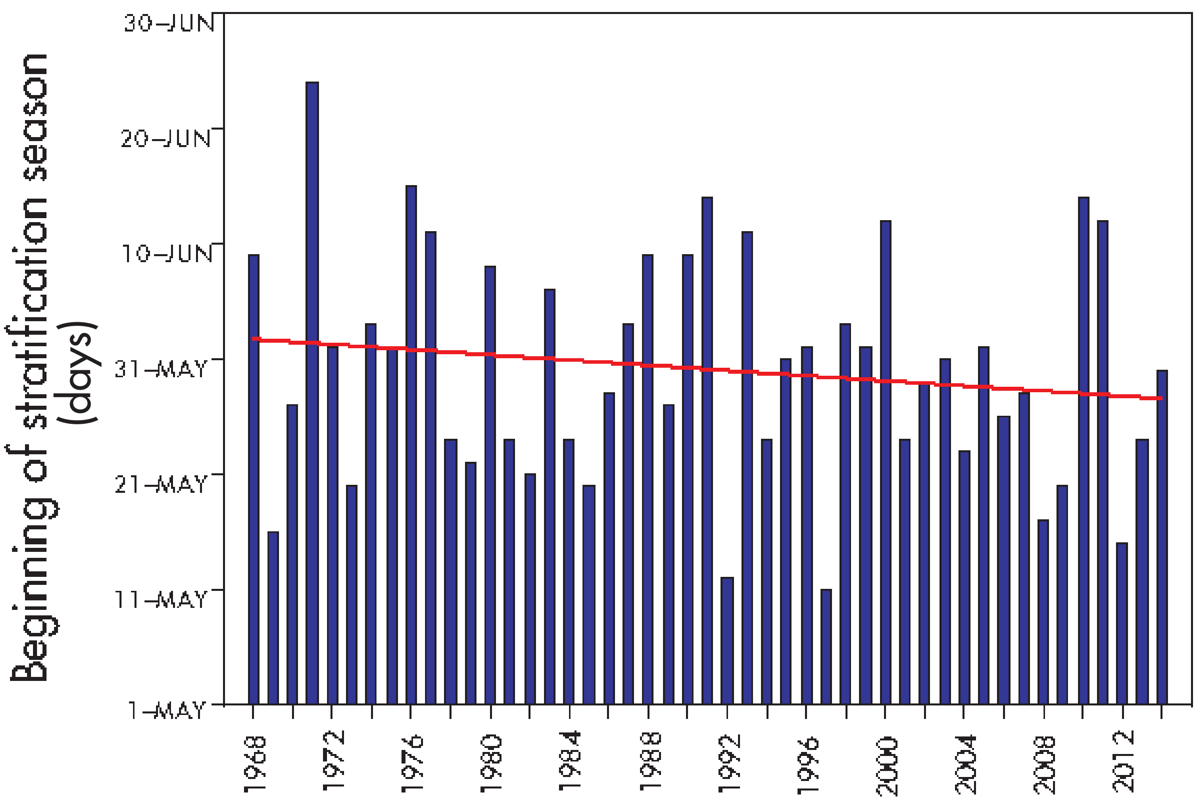


PHYSICAL PROPERTIES

Beginning of the stratification season

Since 1968

The length of time that Lake Tahoe is stratified has been lengthening since 1968. One reason for this is the increasingly early arrival of spring as evidenced by the earlier commencement of stratification. Stratification occurs approximately three days earlier than it did in 1968. The commencement of the stratification season is typically in late May or early June. In 2014 stratification commenced on Day 150 (May 30).

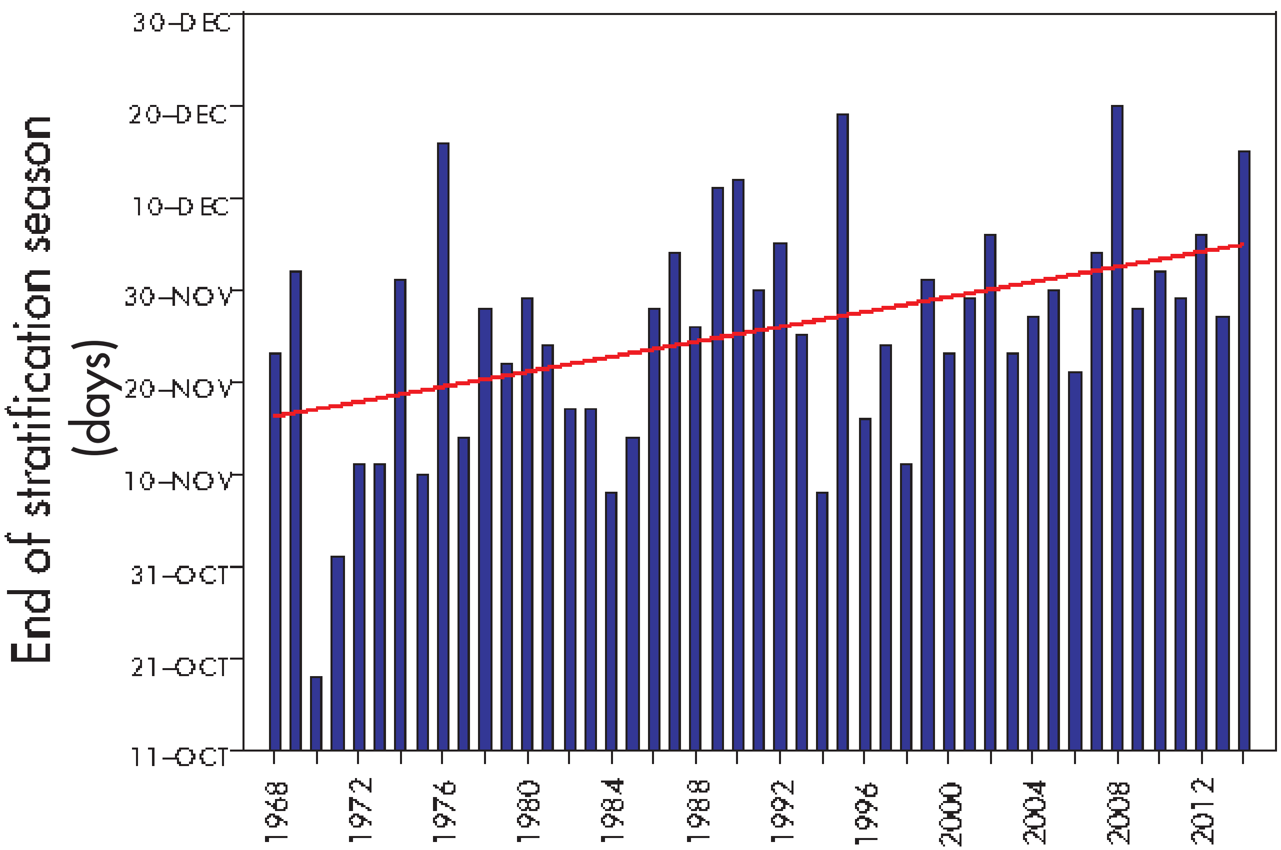


PHYSICAL PROPERTIES

End of stratification season

Since 1968

The length of time that Lake Tahoe is stratified has lengthened since 1968 by approximately three weeks. The end of stratification appears to have been extended by approximately 18 days on average. In other words, the fall season for the lake has been considerably extended. In the late 1960's stratification ended in mid-November. Now it often ends in December. In 2014, stratification ended on Day 349 (December 15) This has important implications for lake mixing and water quality, such as the build up of nitrate at the bottom of the lake.

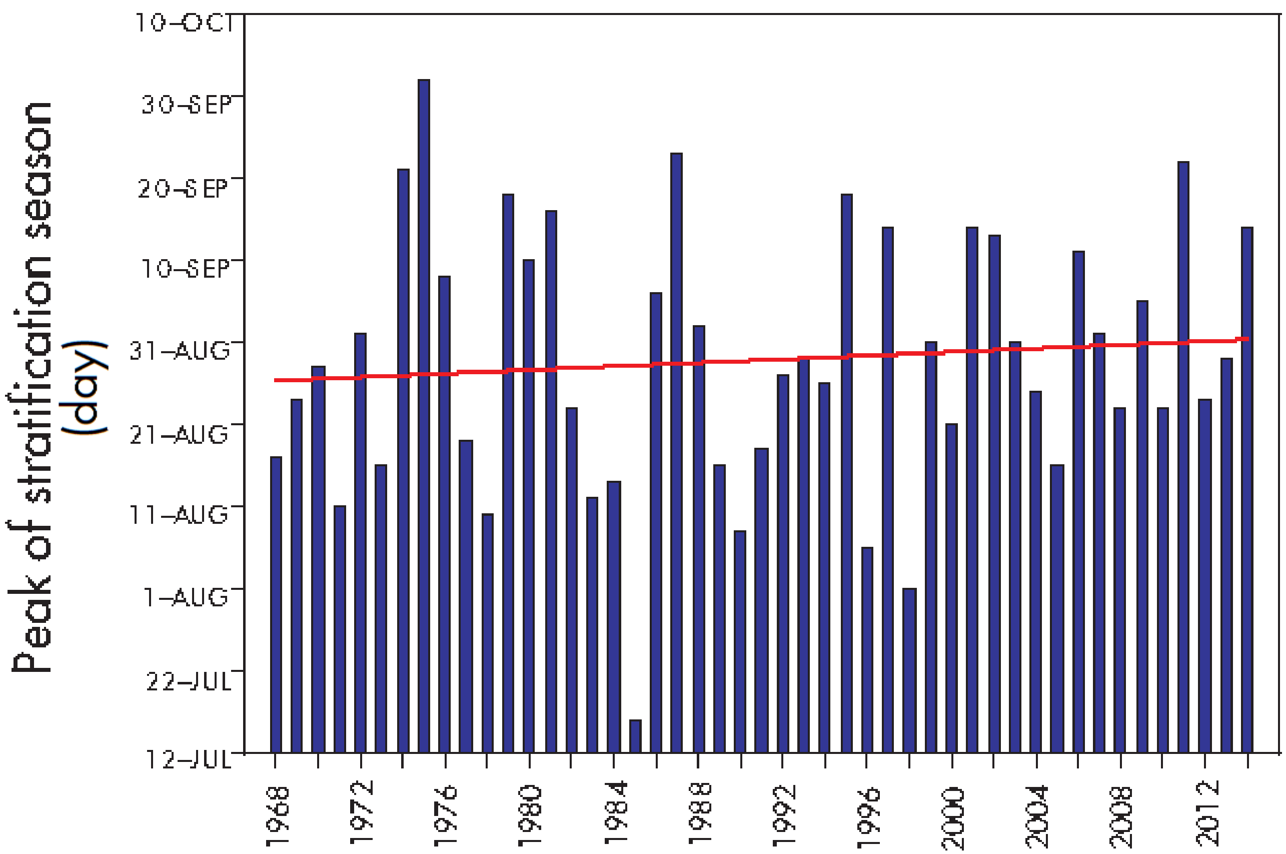


PHYSICAL PROPERTIES

Peak of stratification season

Since 1968

The day of the year when lake stratification reaches its maximum value has been plotted. There is considerable year-to-year variation, but over time there has been only a slight delay in when the peak occurs.



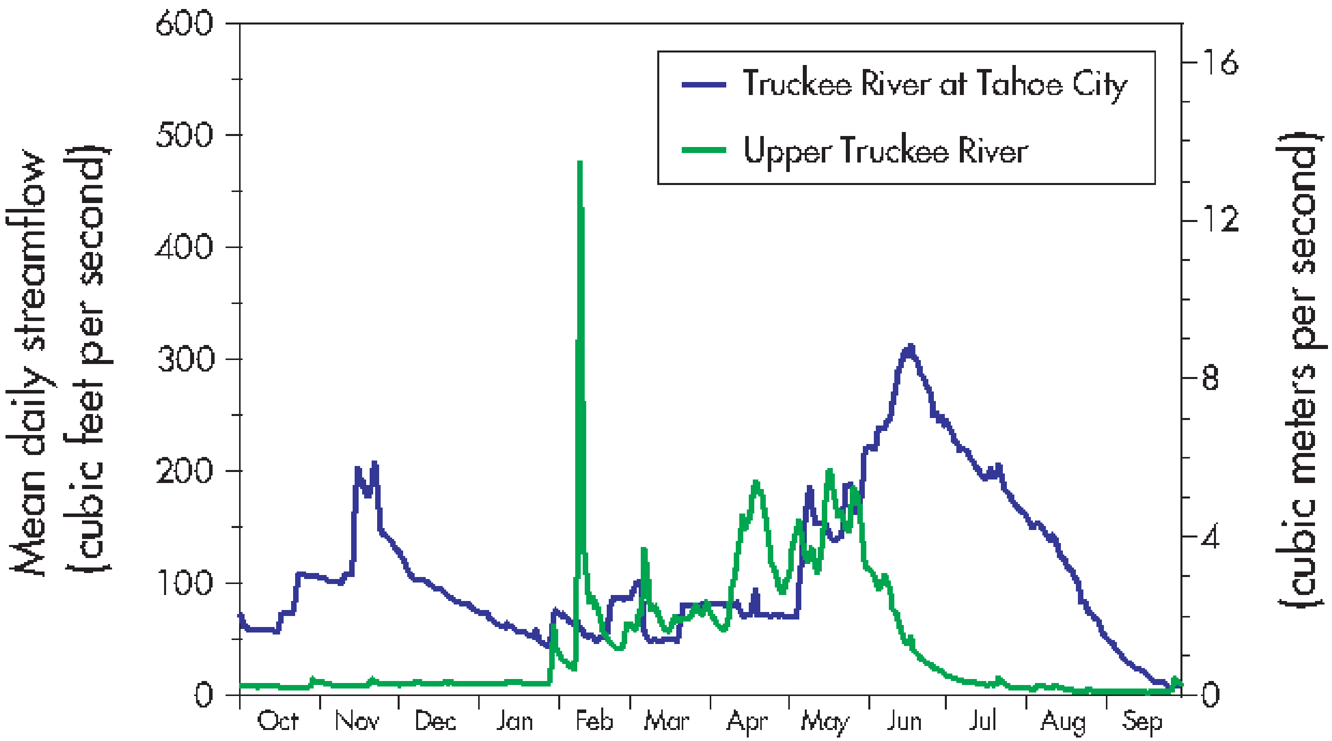
PHYSICAL PROPERTIES

Mean daily streamflow of Upper Truckee River vs. Truckee River

Water Year 2014

The largest stream flowing into Lake Tahoe is the Upper Truckee River. The small peaks in the hydrograph generally represent rain events or short warm periods in winter or spring. The extended seasonal increase (March-May) represents the snowmelt. The peak snowmelt flow was approximately 200 cfs, compared to the long-term average of 300 cfs. The mean daily discharge was 44.3 cfs, compared to the long-term mean of 93.9 cfs

The Truckee River is the only outflow from Lake Tahoe. It is a regulated flow, with release quantity controlled by the Federal Water Master. As a result, the hydrograph has extended times of near-constant outflow. The release rates are set according to downstream demands for water and concerns for flooding. The maximum discharge in 2014 was approximately 300 cfs in mid-June. This is a typical summer time flow rate. What was unusual in 2014 was the steep decline in flow rate in August and September due to the falling lake level. Streamflow data are collected by the U.S. Geological Survey under the Lake Tahoe Interagency Monitoring Program (LTIMP).

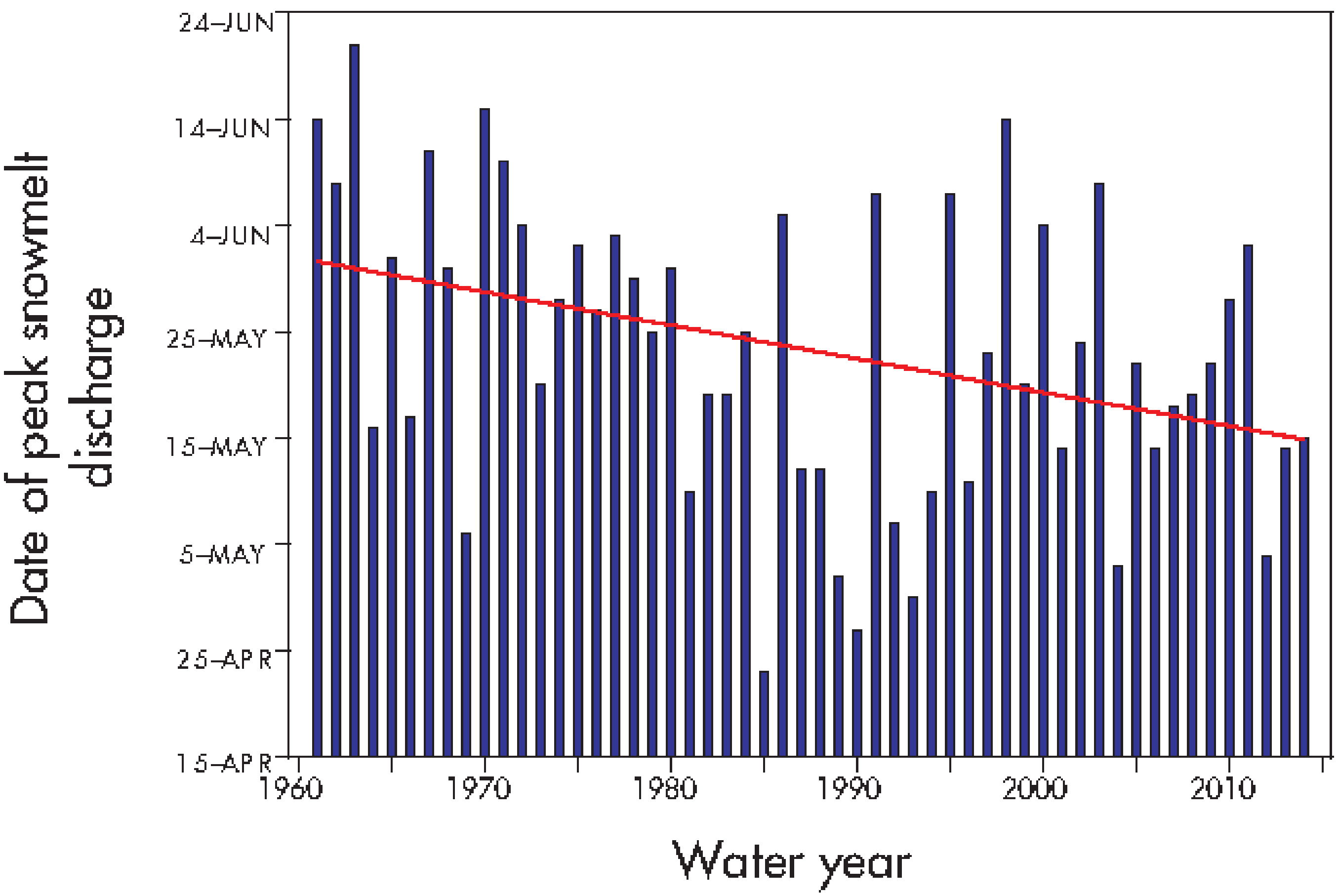


PHYSICAL PROPERTIES

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 an average of over 2 weeks (16.7 days). This shift is statistically significant and is one effect of climate change at Lake Tahoe. Peak snowmelt is defined as the date when daily stream flows reach their yearly maximum. Daily stream flows increase throughout spring as the snow melts because of rising air temperatures, increasing solar radiation and longer hours of daylight. The data here are based on the average from the Upper Truckee River, Trout Creek, Blackwood Creek, Ward Creek, and Third Creek. In 2014 the timing of the snowmelt peak fell on the long-term trend line.

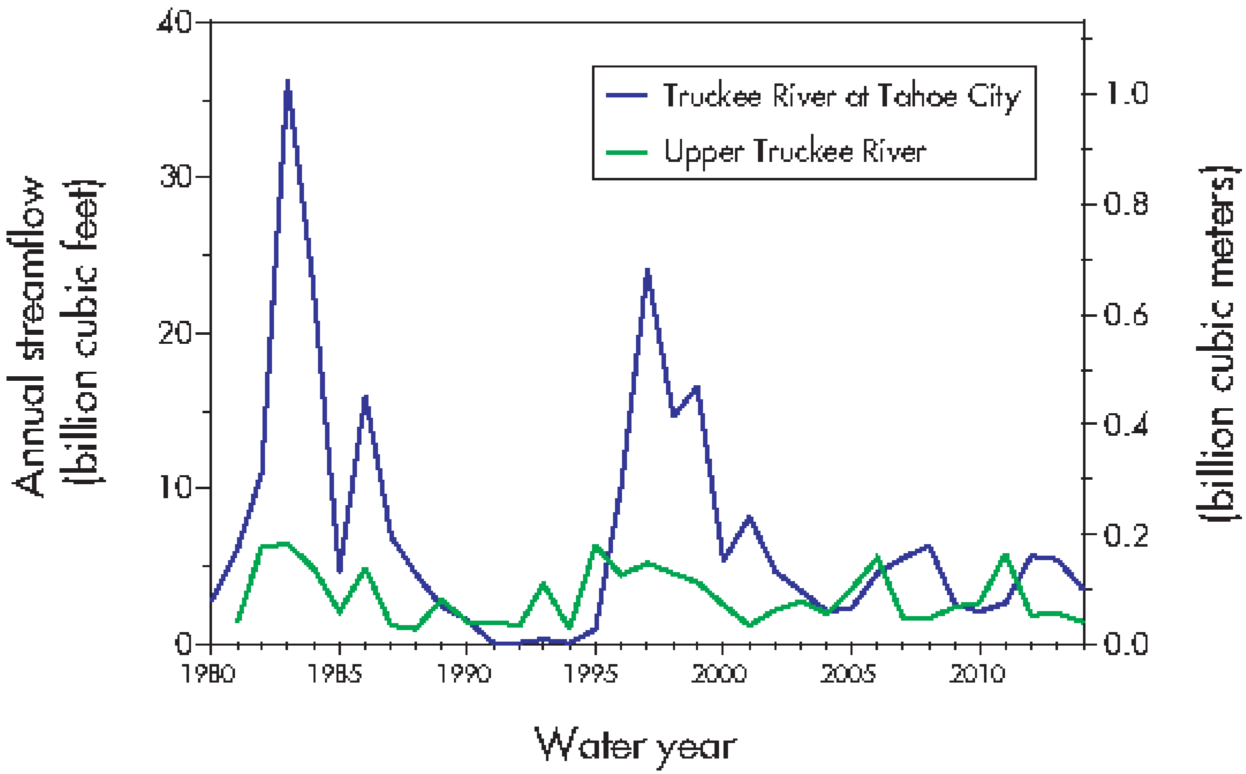


PHYSICAL PROPERTIES

Annual discharge volume for upper Truckee River and Truckee River

Since 1980

Flow into Lake Tahoe (e.g. Upper Truckee River) and discharge out of Lake Tahoe (Truckee River at Tahoe City) have 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 culminating in the current drought year 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 are influenced by precipitation and runoff. The average annual Upper Truckee inflow since 1981 is 3.00 billion cubic feet, while the average annual outflow through the Truckee River is 7.12 billion cubic feet. In 2014 discharges into and out of the lake were well below the long-term averages. The Upper Truckee River inflow volume was 1.40 billion cubic feet. The Truckee River discharge was 3.50 billion cubic feet.

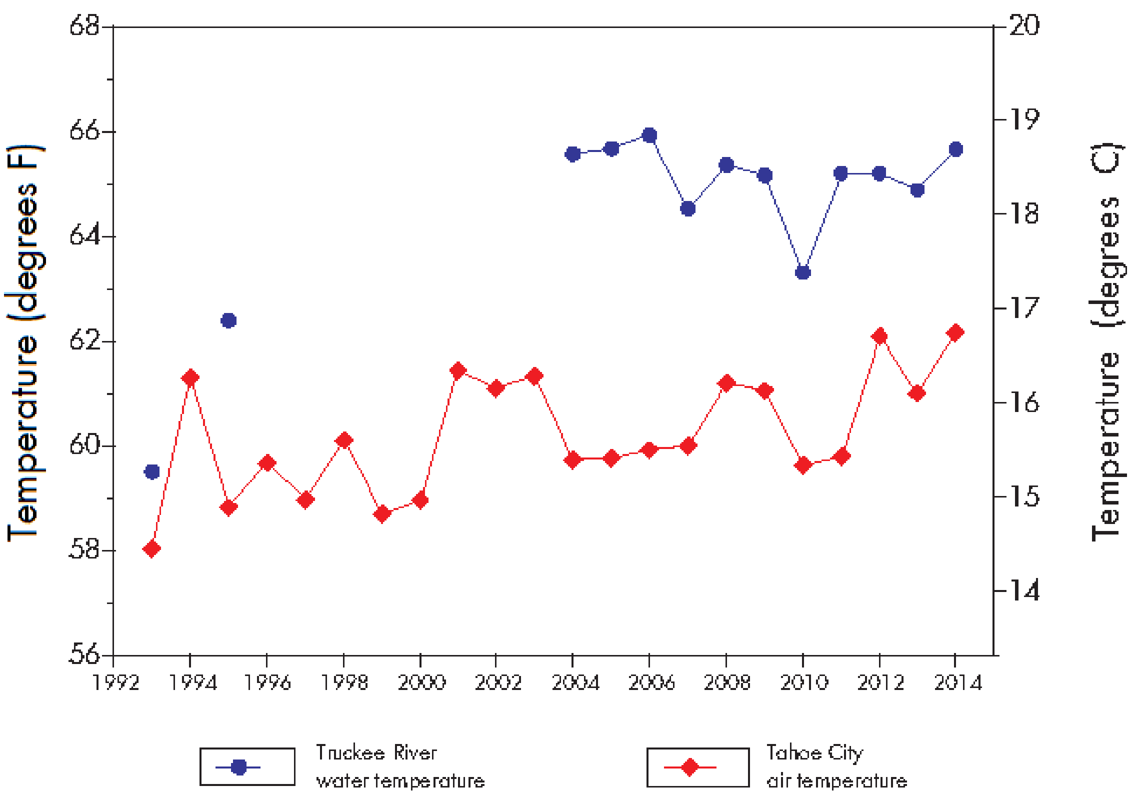


PHYSICAL PROPERTIES

Truckee River July-September water temperatures

Since 1993

Water temperature of the Truckee River as it departs Lake Tahoe in the summer months (July-September) is measured by the U.S. Geological Survey. Data gaps prevent a complete pattern, but the measurements suggest that a 4-5 °F (2.2-2.8 °C) rise in the average temperature may have occurred since 1993. Average air temperatures from Tahoe City for the same period also suggest a temperature rise but at a lower rate. Elevated river temperatures can also negatively impact fish spawning and fish rearing.

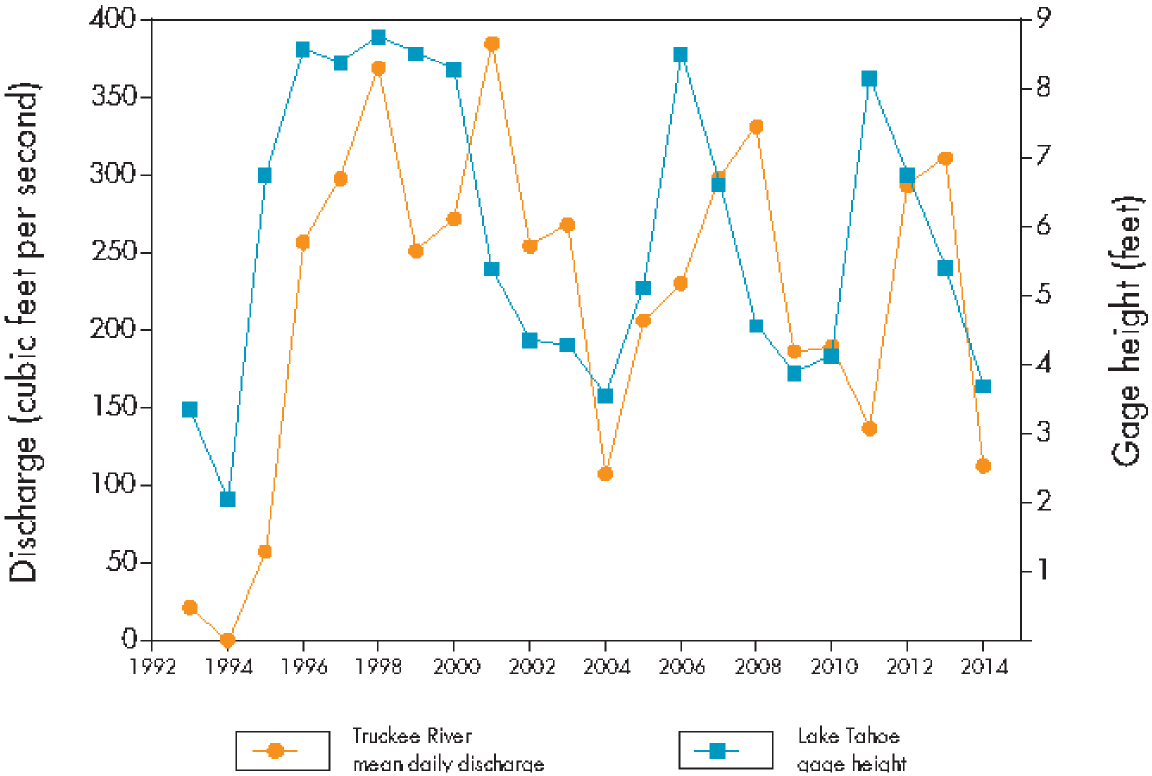


PHYSICAL PROPERTIES

Truckee River summer discharge and lake elevation

Since 1993

Flow rate of the Truckee River as it departs Lake Tahoe in the summer months (July-September) and lake level for the same period is measured by the U.S. Geological Survey. Here the relationship between these two variables is evident, with mean daily river discharge typically showing a one- to two-year lag from the lake elevation. Gage height is measured relative to a datum of 6,220 feet. Release of water from Lake Tahoe is controlled by the Federal Water Master.



TAHOE: STATE OF THE LAKE REPORT 2015

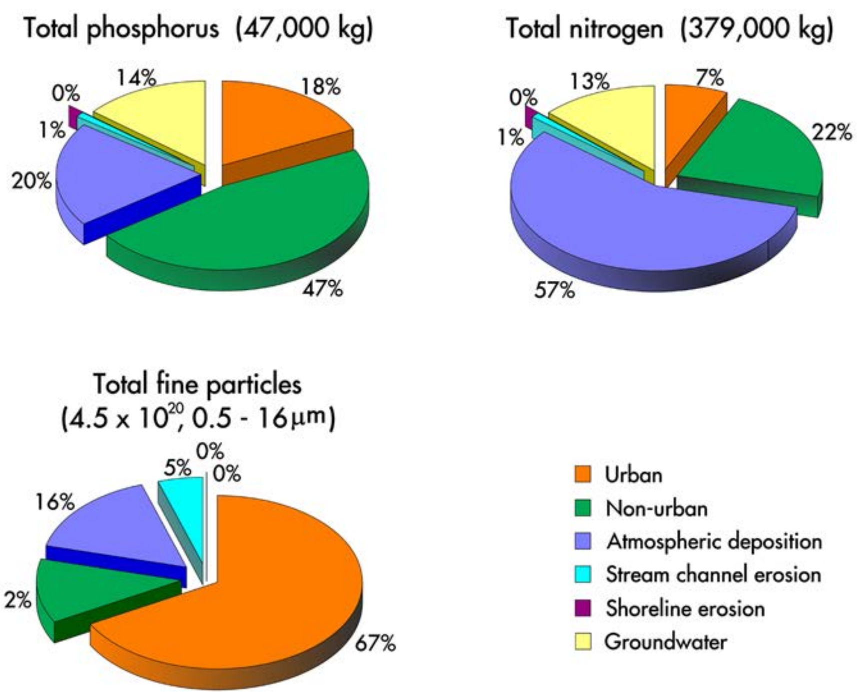
NUTRIENTS AND PARTICLES

NUTRIENTS AND PARTICLES

Sources of clarity-reducing and blueness-reducing pollutants

Research has quantified the primary sources of nutrients (nitrogen and phosphorus) and particulate material that are causing Lake Tahoe to lose clarity and blueness in its upper waters. One of the major contributors to clarity decline are extremely fine particles in stormwater that originate from the urban watershed (67 percent), even though these areas cover only 10 percent of the land area. Part of the atmospheric particle load is from these urbanized areas. For nitrogen, atmospheric deposition is the major source (57 percent). Phosphorus is primarily introduced by the urban (18 percent) and non-urban (47 percent) watersheds. These categories of pollutant sources form the basis of a strategy to restore Lake Tahoe's open-water clarity by agencies including the Lahontan Regional Water Quality Control Board, the Nevada Division of Environmental Protection, and the Tahoe Regional Planning Agency. Data were originally generated for the Lake Tahoe TMDL Program. These results are revised from the original estimates as they are based on a longer time series of monitoring data.

The pie chart representations are based on data from the period 1994 – 2008:
Urban & Non-urban (data from 1994-2008)
Atmospheric, Stream channel erosion, Shoreline erosion, Groundwater (data from 1999-2008)



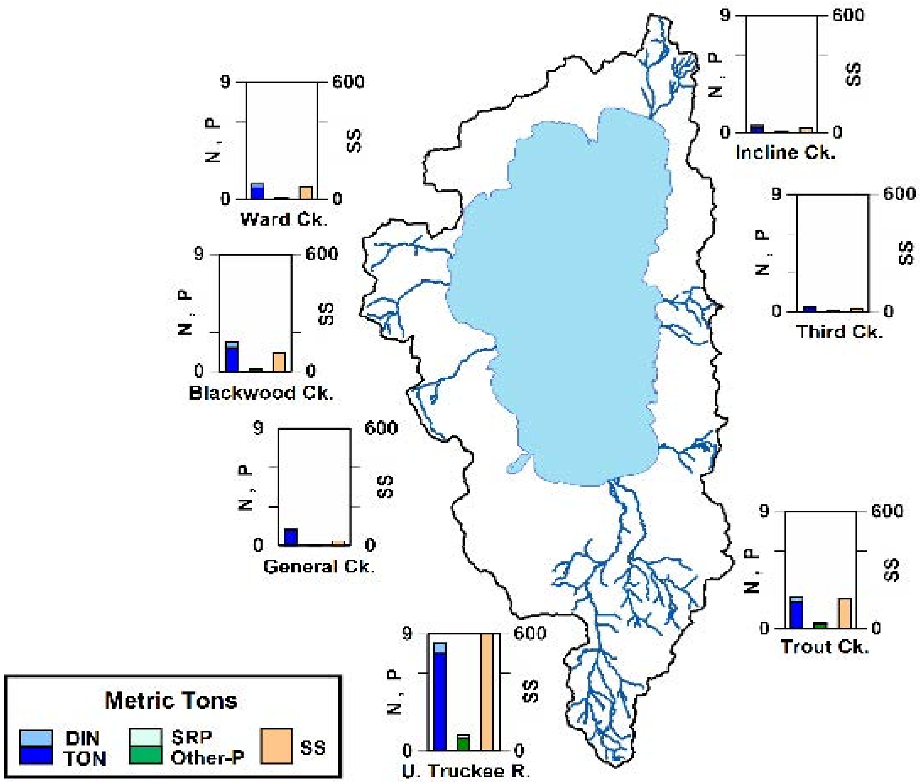
NUTRIENTS AND PARTICLES

Pollutant loads from seven watersheds

In 2014

The Lake Tahoe Interagency Monitoring Program (LTIMP) measures nutrient and sediment input from seven of the 63 watershed streams – a reduction of three streams since 2011. Most of the suspended sediment contained in the 7 LTIMP streams is from the Upper Truckee River, Blackwood Creek, Trout Creek and Ward Creek. Over 75 percent of the phosphorus and nitrogen comes from the Upper Truckee River, Trout Creek and Blackwood Creek. Pollutant loads from the west-side streams were a factor of four lower in each of the last three years, compared with 2011. This was largely due to the drier years that the basin experienced.

The LTIMP stream water quality program is supported by the U.S. Geological Survey in Carson City, Nevada, UC Davis TERC and the Tahoe Regional Planning Agency. Additional funding in 2014 was provided by the California Tahoe Conservancy and the Lahotan Regional Water Quality Control Board.



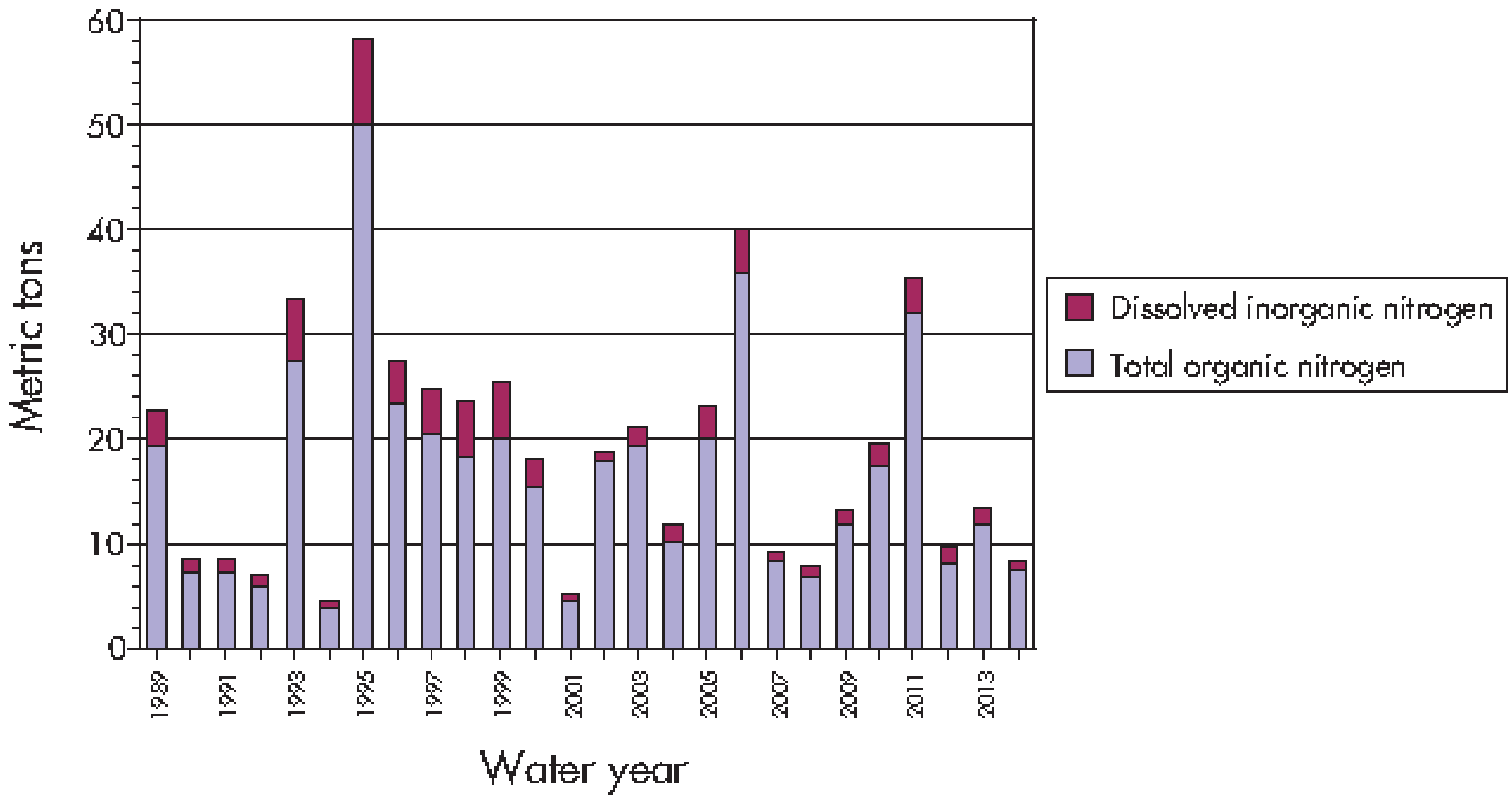
N = Nitrogen
P = Phosphorus
DIN = Dissolved Inorganic Nitrogen
SRP = Soluble Reactive Phosphorus
TON = Total Organic Nitrogen
SS = Suspended Sediment

NUTRIENTS AND PARTICLES

Nitrogen contribution by Upper Truckee River

Yearly since 1989

Nitrogen (N) is important because it, along with phosphorus (P), stimulates algal growth. 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 16.59 inches of precipitation and a low nitrogen load, while 1995 had 60.84 inches of precipitation and a very high nitrogen load. 2014 had 19.32 inches of precipitation, following 2013 with 25.19 inches and 2012 with 22.48 inches. (One metric ton = 2,205 pounds.)

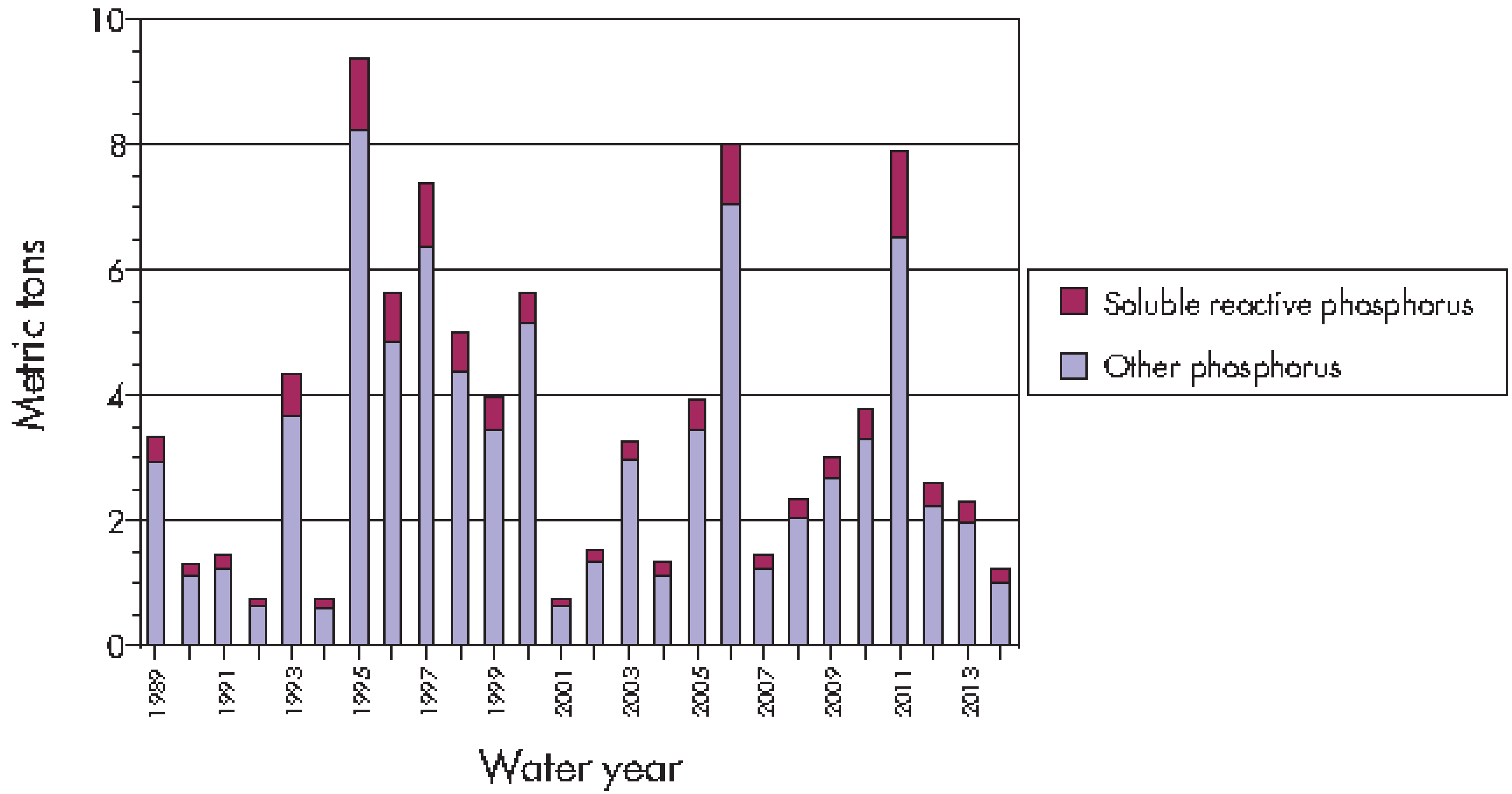


NUTRIENTS AND PARTICLES

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. Below average precipitation in 2014 resulted in a factor of six reduction of the phosphorus load over 2011, the last wet year. Decreasing nutrient inputs is fundamental to restoring Lake Tahoe's iconic blueness. 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.)

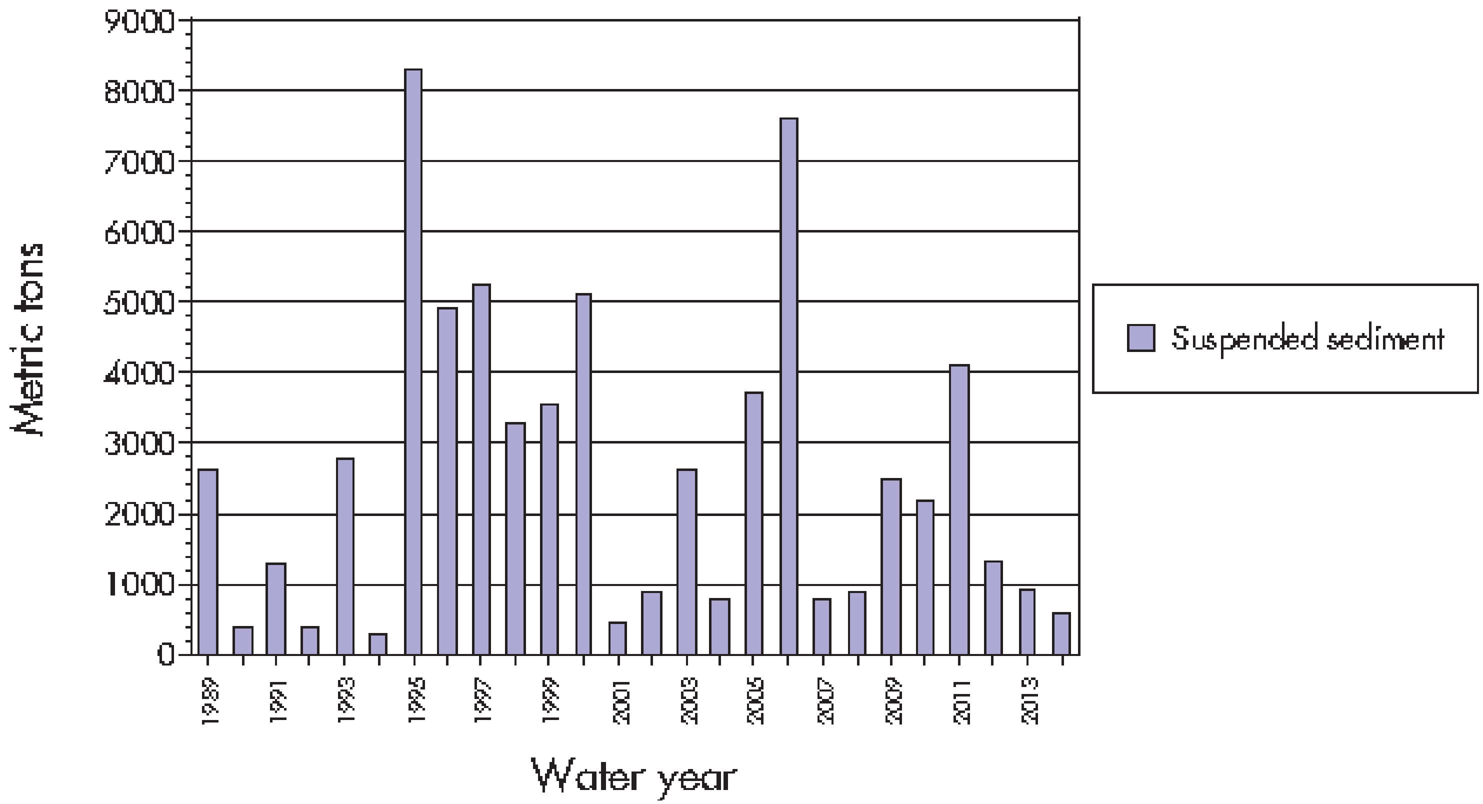


NUTRIENTS AND PARTICLES

Suspended sediment contribution by Upper Truckee River

Yearly since 1989

The load of suspended sediment delivered to the lake by the Upper Truckee is related to landscape condition and erosion as well as to precipitation and stream flow. Certainly, inter-annual variation in sediment load over shorter time scales is more related to the latter. Below average precipitation in 2014 resulted in a factor of seven decrease of the suspended sediment load compared with 2011. This and the previous two figures illustrate how greatly changes in hydrologic conditions affect pollutant loads. Plans to restore lake clarity emphasize reducing loads of very fine suspended sediment (less than 20 microns in diameter) from urbanized areas. Efforts to restore natural stream function and watershed condition focus on reducing loads of total sediment regardless of size, as well as restoration of habitat for plants and wildlife.



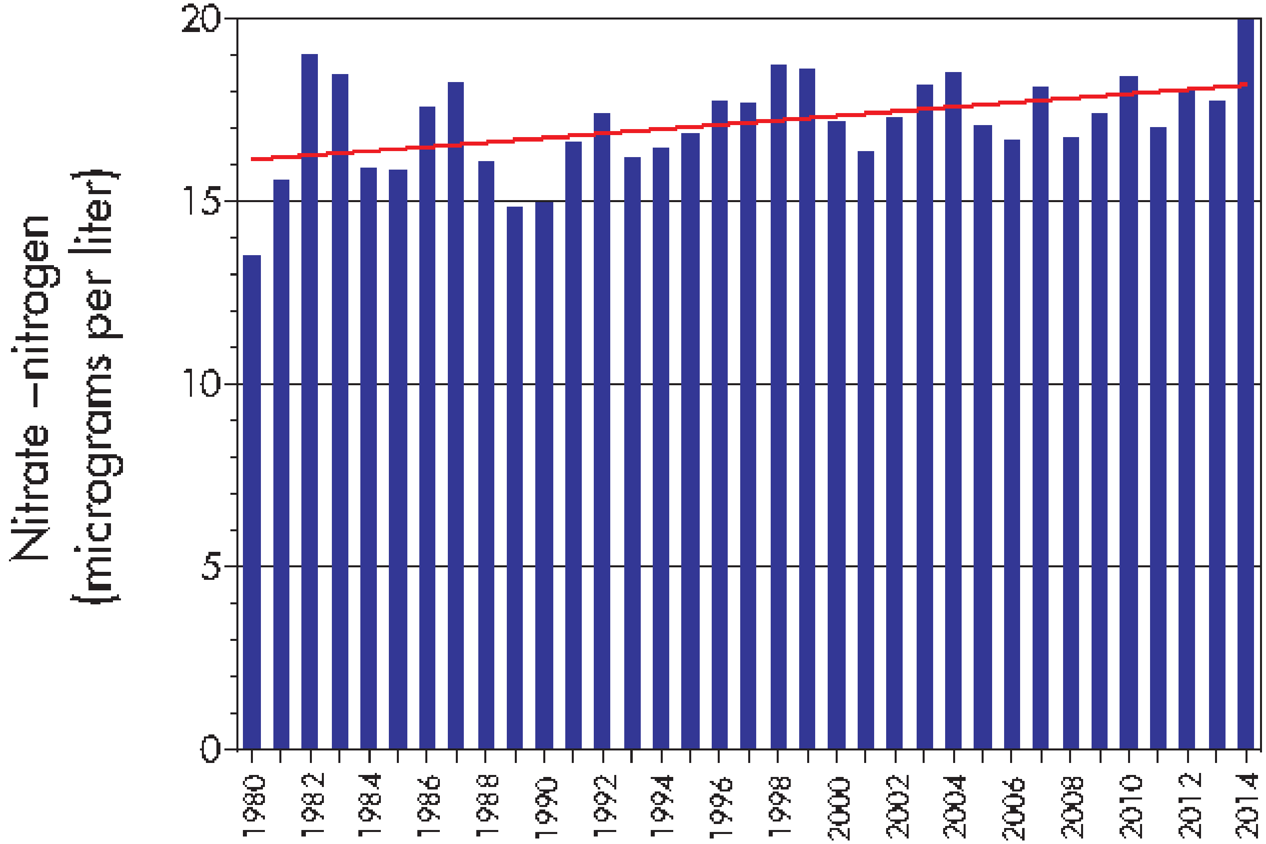
NUTRIENTS AND PARTICLES

Lake nitrate concentration

Yearly since 1980

Since 1980, the volume-weighted annual average concentration of nitrate-nitrogen has remained relatively constant, ranging between 13 and 19 micrograms per liter. In 2014, the volume-weighted annual average concentration of nitrate-nitrogen reached an all-time high of 20.0 micrograms per liter. This increase is in part due to the absences of deep mixing this year, allowing for a continued build up of nitrate in the deep water.

Water samples are taken from the R/V John LeConte at the MLTP (mid-lake) station at 13 depths from the surface to 450 meters. The nutrient analysis is performed at the TERC laboratory in Incline Village, Nevada.

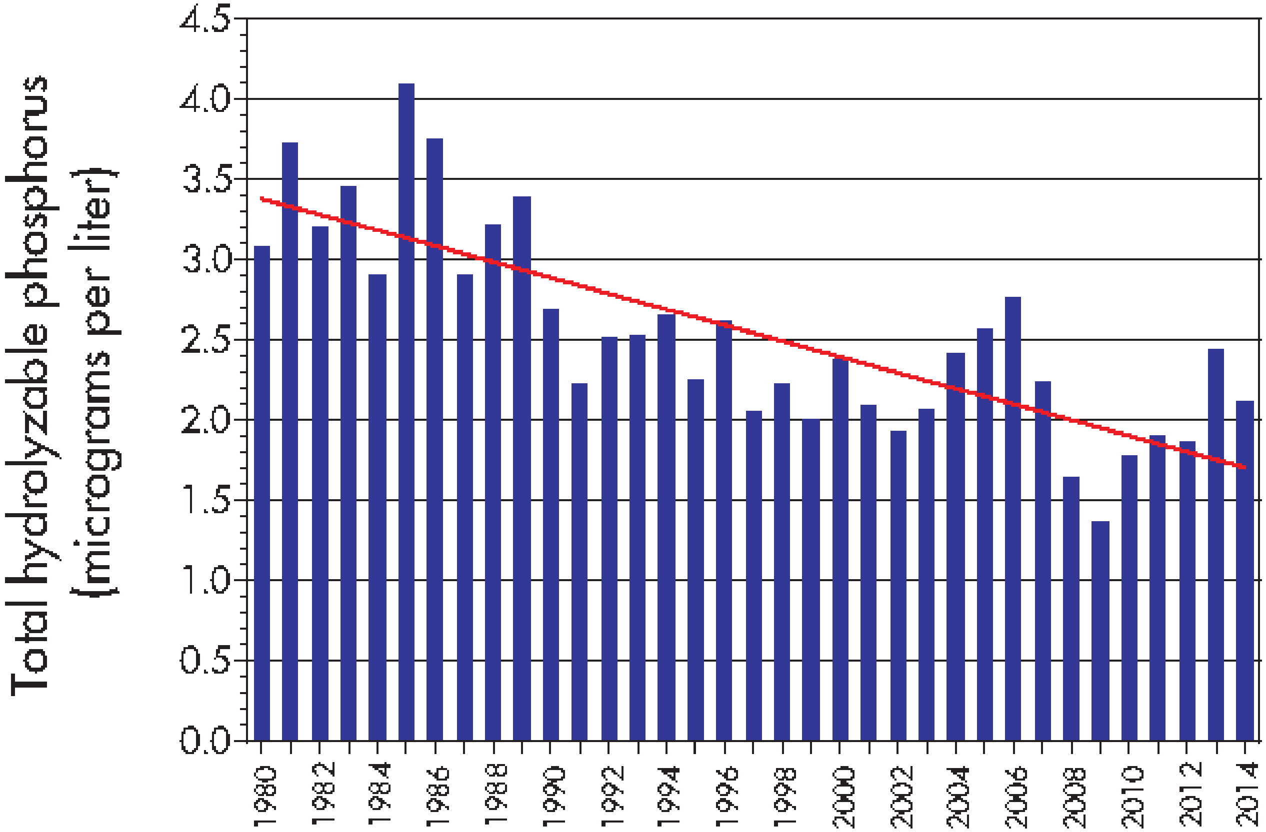


NUTRIENTS AND PARTICLES

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 that algae can use to grow. It is similar to the SRP that is measured in the streams. Since 1980, THP has tended to decline. In 2014, the volume-weighted annual average concentration of THP was approximately 2.1 micrograms per liter, a decrease over the previous year. Water samples are taken from the R/V John LeConte at the MLTP (mid-lake) station at 13 depths from the surface to 450 meters. The nutrient analysis is performed at the TERC laboratory in Incline Village, Nevada.



NUTRIENTS AND PARTICLES

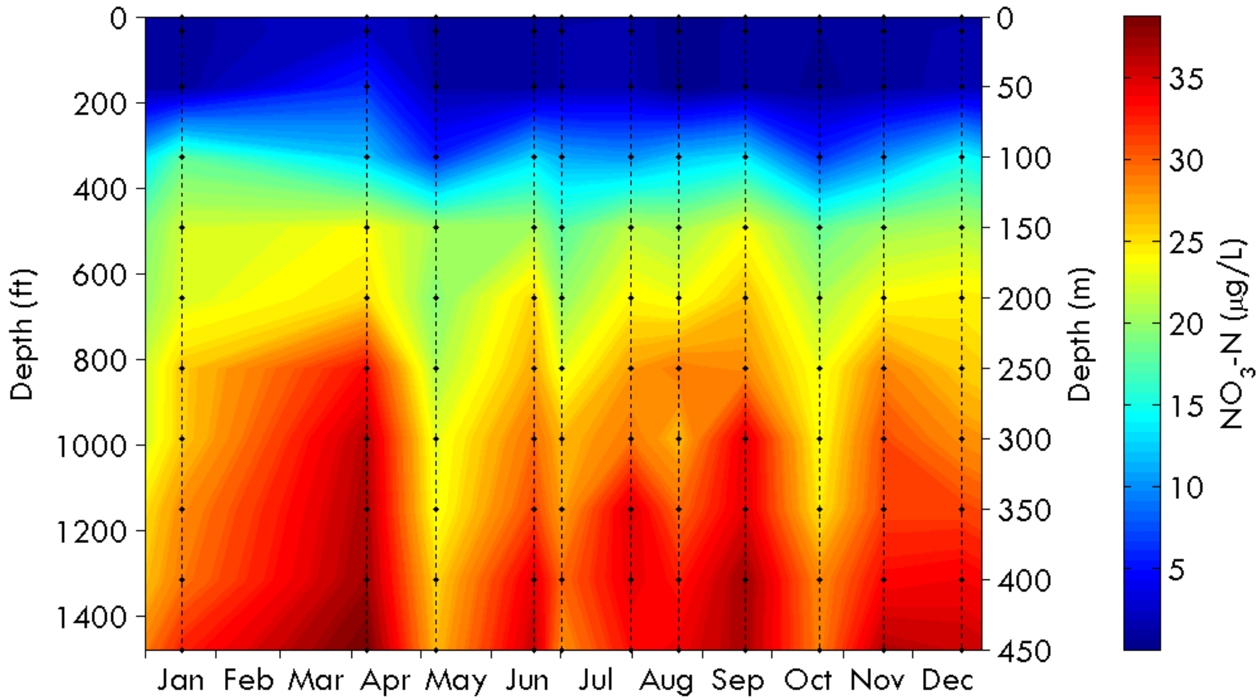
Nitrate distribution

In 2014

Water samples are collected approximately every month (on dates indicated by the dashed lines) at 13 depths (indicated by the dots) at the middle of the lake, and analyzed in the TERC laboratory for nutrient concentrations. Here the nitrate concentration is shown in the form of color contours.

Most evident in this figure is the vertical distribution of nitrate. Concentrations below a depth of about 350 feet are generally high. The surface waters, where there is sunlight to enable algae to grow usually have low concentrations of nitrate. Although most of the nitrate enters at the surface through atmospheric deposition, it is rapidly used up by the algae. As algae sink and decompose, the nitrate they consumed reappears deep in the lake. At these depths, however, there is insufficient light for algae to grow and to use these nutrients.

Deep lake mixing will bring the deep nitrate back to the surface. 2014 was a year with very shallow mixing, extending to only 400 feet, and so most of the nitrate remained trapped in the deep water. The annual nitrate concentration at 1485 feet was a record high value of 34 micrograms per liter.



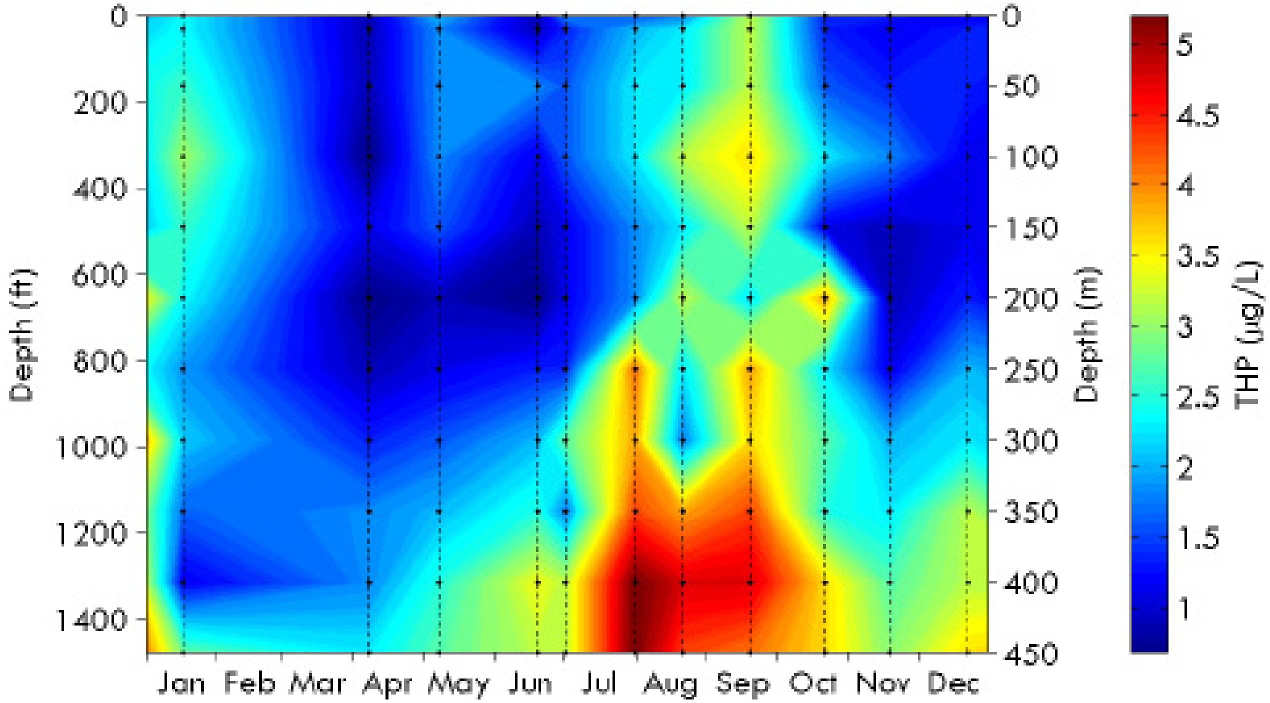
NUTRIENTS AND PARTICLES

Orthophosphate distribution

In 2014

Water samples are collected approximately every month (on dates indicated by the dashed lines) at 13 depths (indicated by the dots) at the middle of the lake, and analyzed in the TERC laboratory for nutrient concentrations. Here the total hydrolyzable phosphorus (THP) concentration (the fraction of phosphorus that can be readily used by algae) is shown in the form of color contours.

Unlike nitrate distribution, there is little vertical distribution of THP. Phosphorus mainly enters the lake in association with fine particles during runoff events. Because of the low snowmelt volumes in 2014, there were very low concentrations of phosphorus at the surface in Spring, with available phosphorus rapidly taken up by algae. The high concentrations of phosphorus deep in the lake during summer are the result of algae sinking and then decomposing. Eventually the THP attaches to particles and settles to the lake bottom.



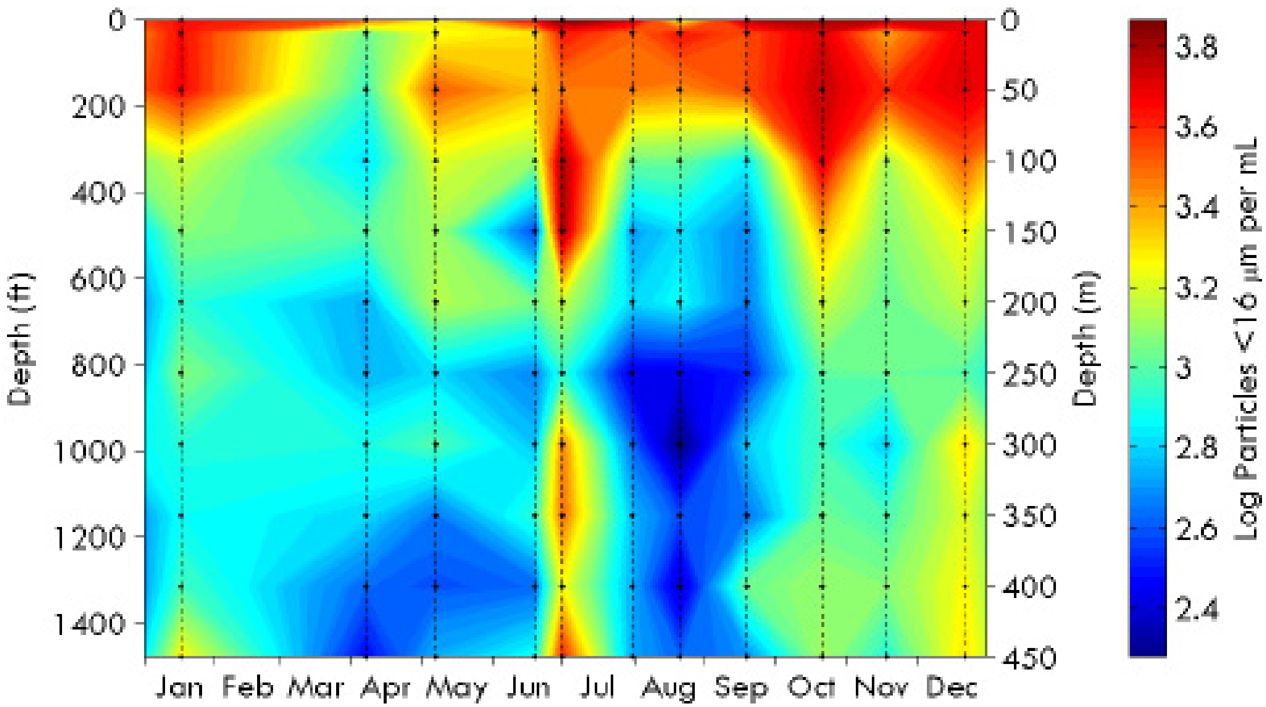
NUTRIENTS AND PARTICLES

Fine particle distribution

In 2014

Water samples are collected approximately monthly (on dates indicated by the dashed lines) at 13 depths (indicated by the dots) at the middle of the lake, and analyzed in the TERC laboratory for the concentration of fine particles in 15 different bin sizes. Here the distributions of the finest particles (in the range of 0.5 to 8 microns) are shown in the form of color contours.

Clearly evident in the figure is that the highest concentrations of fine particles (red tones) are concentrated in the upper part of the lake. In the early part of the year (winter), when clarity is generally highest, surface concentration of particles is the lowest. The particle concentration is highest after July, which coincides with the annual variation in Secchi depth this year. The fine particles gradually clump together (aggregate) which causes them to have less impact on clarity and allows them to more rapidly settle to the lake bottom.



TAHOE: STATE OF THE LAKE REPORT 2015

BIOLOGY

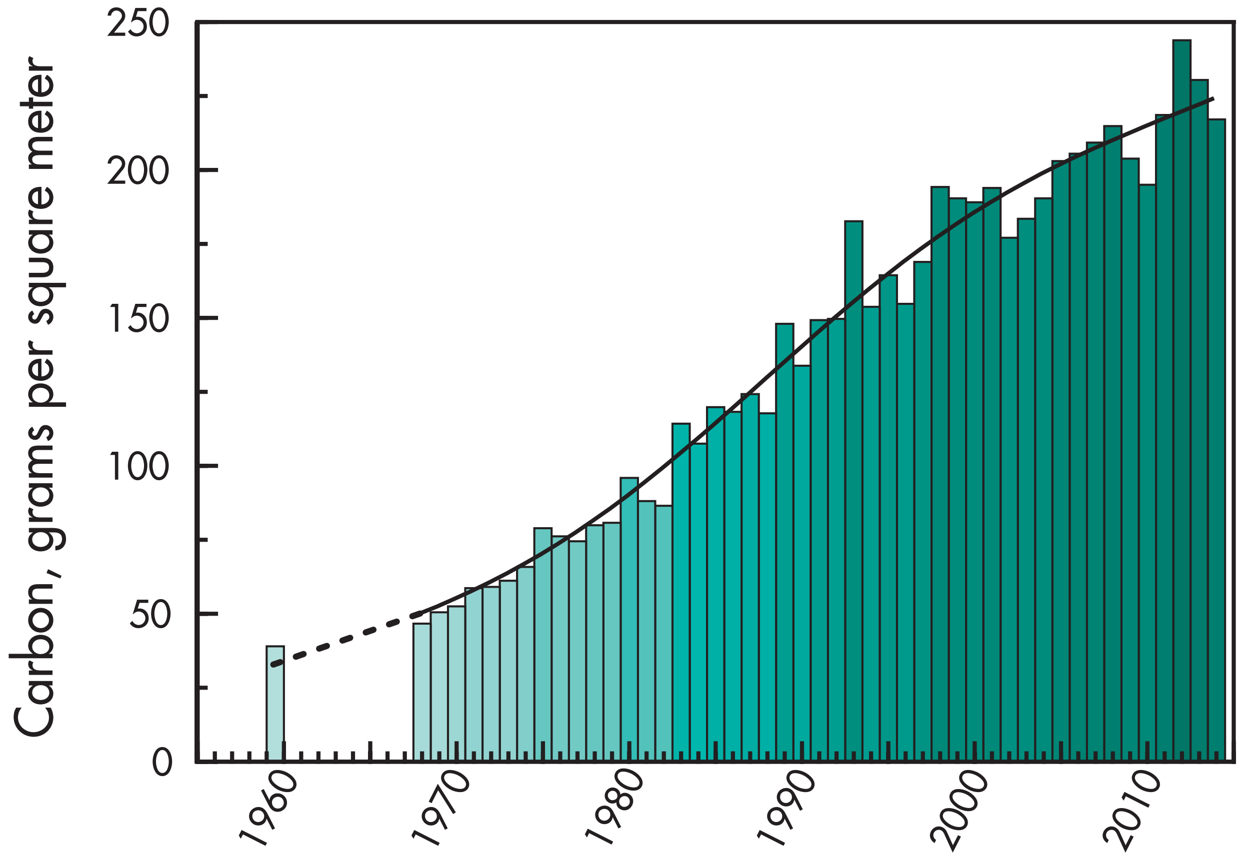
UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

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. Supported by nutrient loading into the lake, changes in the underwater light environment, and a succession of algal species, the trend shows primary productivity has increased substantially over time. In 2014, there was a slight decrease in primary productivity to 217.1 grams of carbon per square meter.

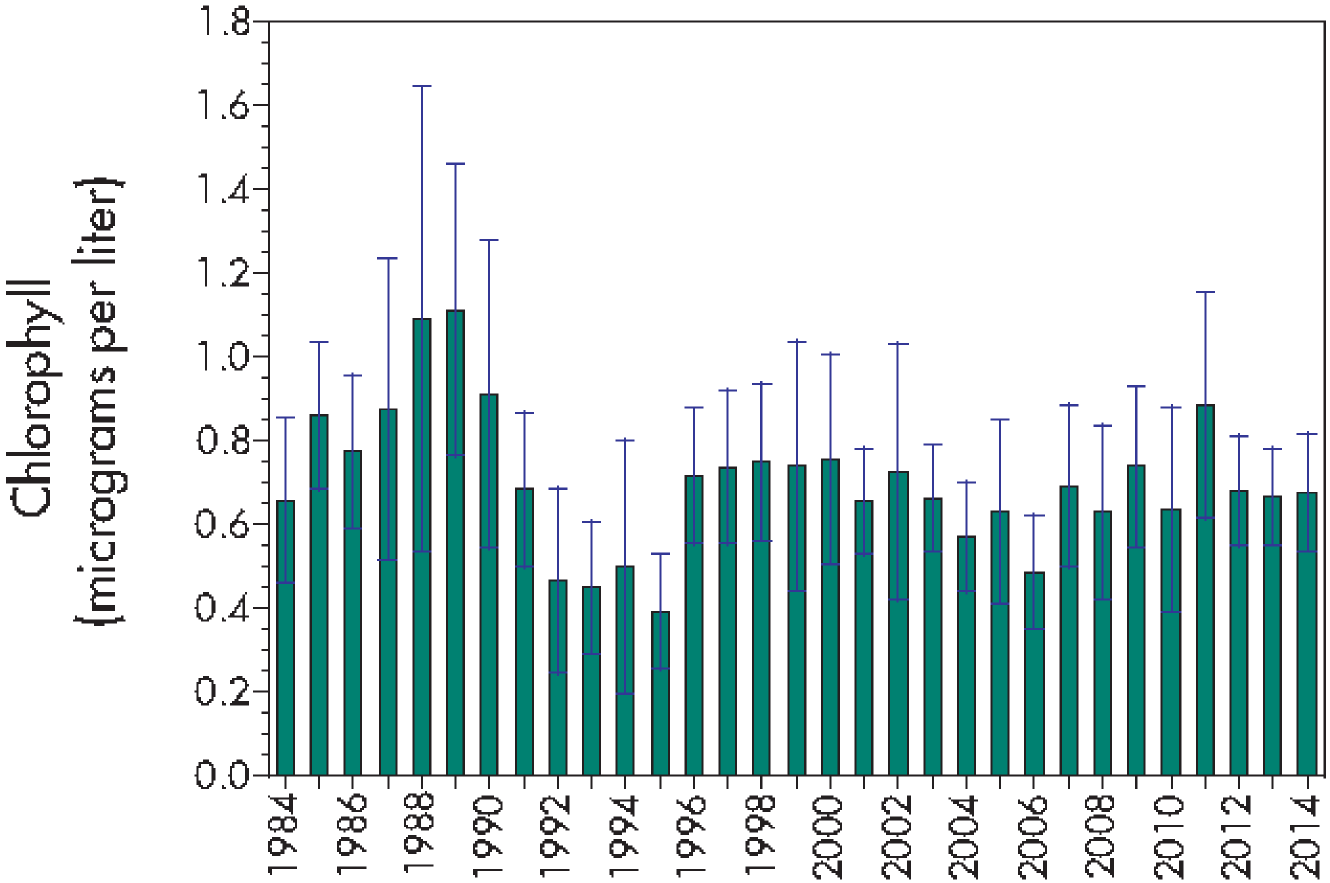


BIOLOGY

Algae abundance

Yearly since 1984

Algae (phytoplankton) are the base of the Lake Tahoe food web, and essential for lake health and the well-being of the entire ecosystem. The amount or biomass of free-floating algae in the water is determined by extracting and measuring the concentration of chlorophyll-*a*, a photosynthetic pigment that allows plants to absorb energy from the sun. Though the value varies annually, it has not shown a significant increase since measurements began in 1984. The annual average concentration for 2013 was 0.67 micrograms per liter. The average annual concentration for 2014 was 0.68 micrograms per liter, virtually identical to the previous two years. For the period of 1984-2014 the average annual chlorophyll-*a* concentration in Lake Tahoe was 0.70 micrograms per liter.



BIOLOGY

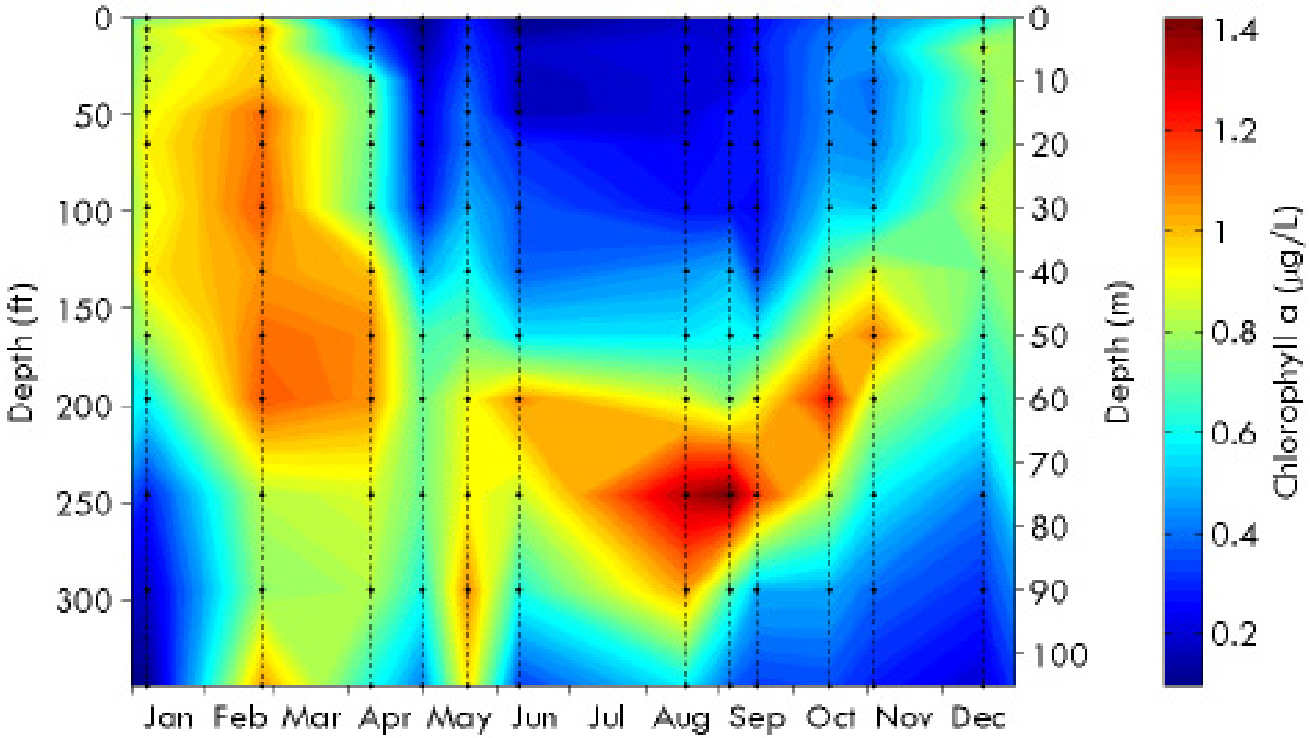
Chlorophyll-*a* distribution

In 2014

The distribution of algae (measured as chlorophyll–*a*) is the result of a combination of light availability, nutrient availability, mixing processes, and to a lesser extent, water temperature. This figure shows color contours of chlorophyll-*a* concentration down to a depth of 350 feet. Below this depth concentrations are near zero due to the absence of light.

Lake Tahoe has a "deep chlorophyll maximum" in the summer that is in the range of 150-300 ft. At that depth the light and nutrient conditions are most favorable for algal growth. The depth of the deep chlorophyll maximum increased in 2014 because of improved lake clarity.

In the early part of the year, the algae were distributed over a greater depth range because of the mixing processes that were occurring. With the onset of thermal stratification in spring, the algae were confined to a discrete band. Throughout the year concentrations decreased as nutrients were depleted. In November and December, the commencement of mixing again redistributed the algae over a broader depth range.

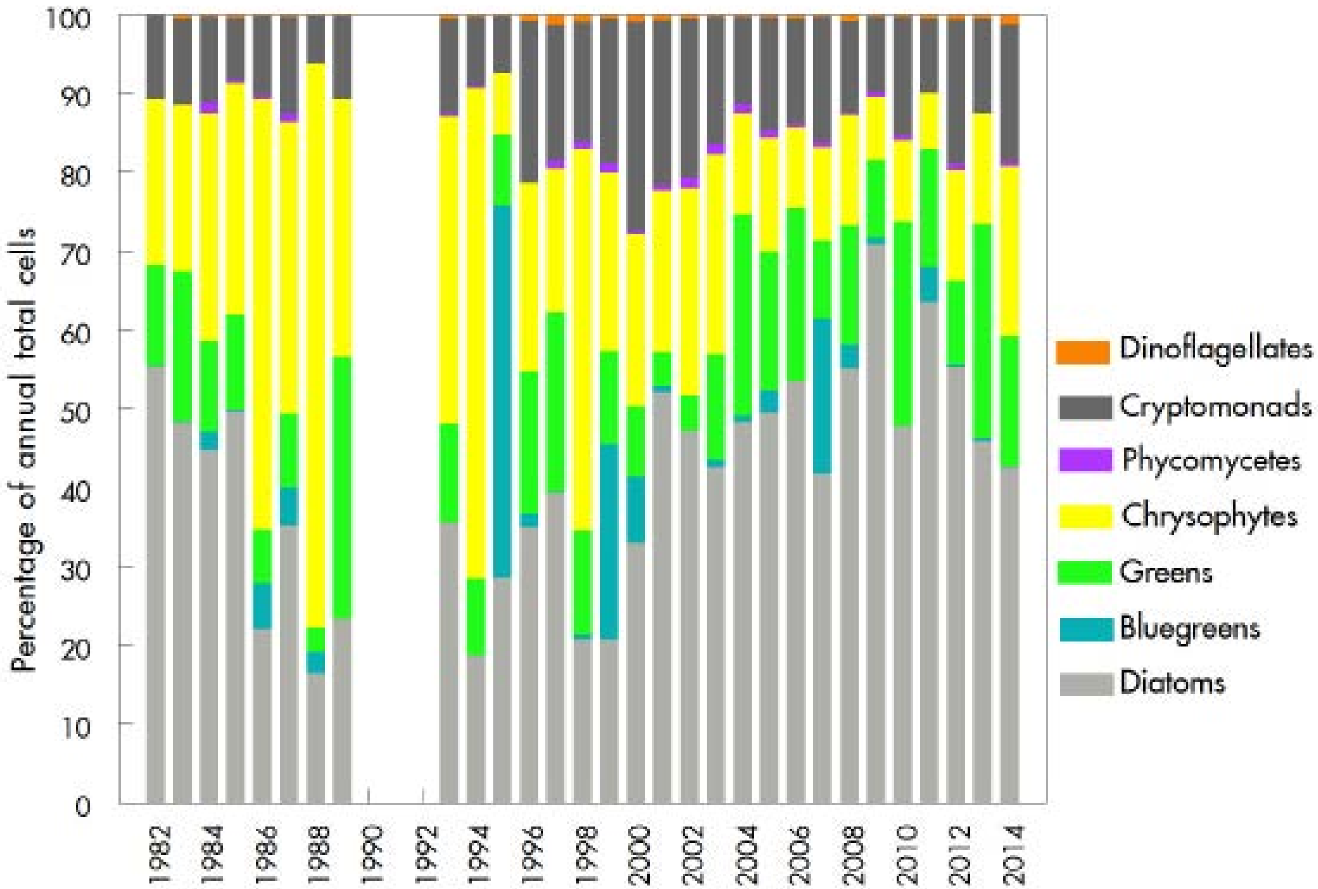


BIOLOGY

Annual distribution of algal groups

Yearly since 1982

The amount of algal cells from different groups varies from year to year. Diatoms are the most common type of alga, comprising over 40 percent of the total abundance of algal cells in 2014. Chrysophytes, cryptomonads and green algae are next, each comprising less than 20 percent of the total. While the proportion of the major algal groups show a degree of consistency from year-to-year, TERC research has shown that the composition of individual species within the major groups is changing, both seasonally and annually, in response to lake conditions.

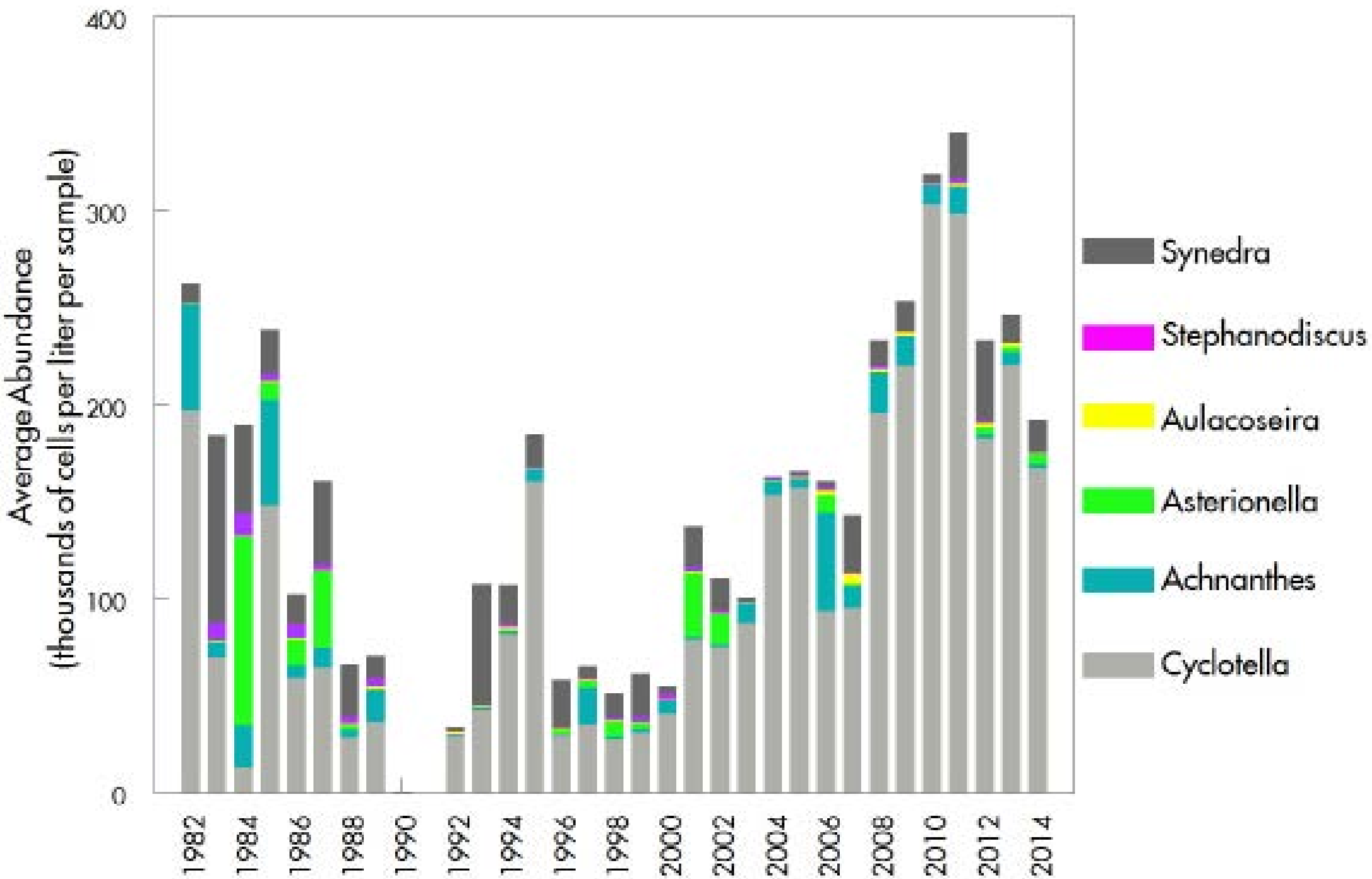


BIOLOGY

Abundance of dominant diatom species

Yearly since 1982

Diatoms have been the dominant algal group at Lake Tahoe for all but a few years since 1982. Diatoms are unique in that they are enclosed within a cell wall made of silica, called a frustule. Here the dominant diatom species at Lake Tahoe between 1982 and 2014 are shown. Huge inter-annual variations are evident, both in the overall abundance and in the relative composition. Generally, *Cyclotella gordonensis* is the dominant diatom species in Lake Tahoe. The recent increase in *Cyclotella gordonensis* that peaked in 2010 and 2011 markedly reduced clarity in those years.

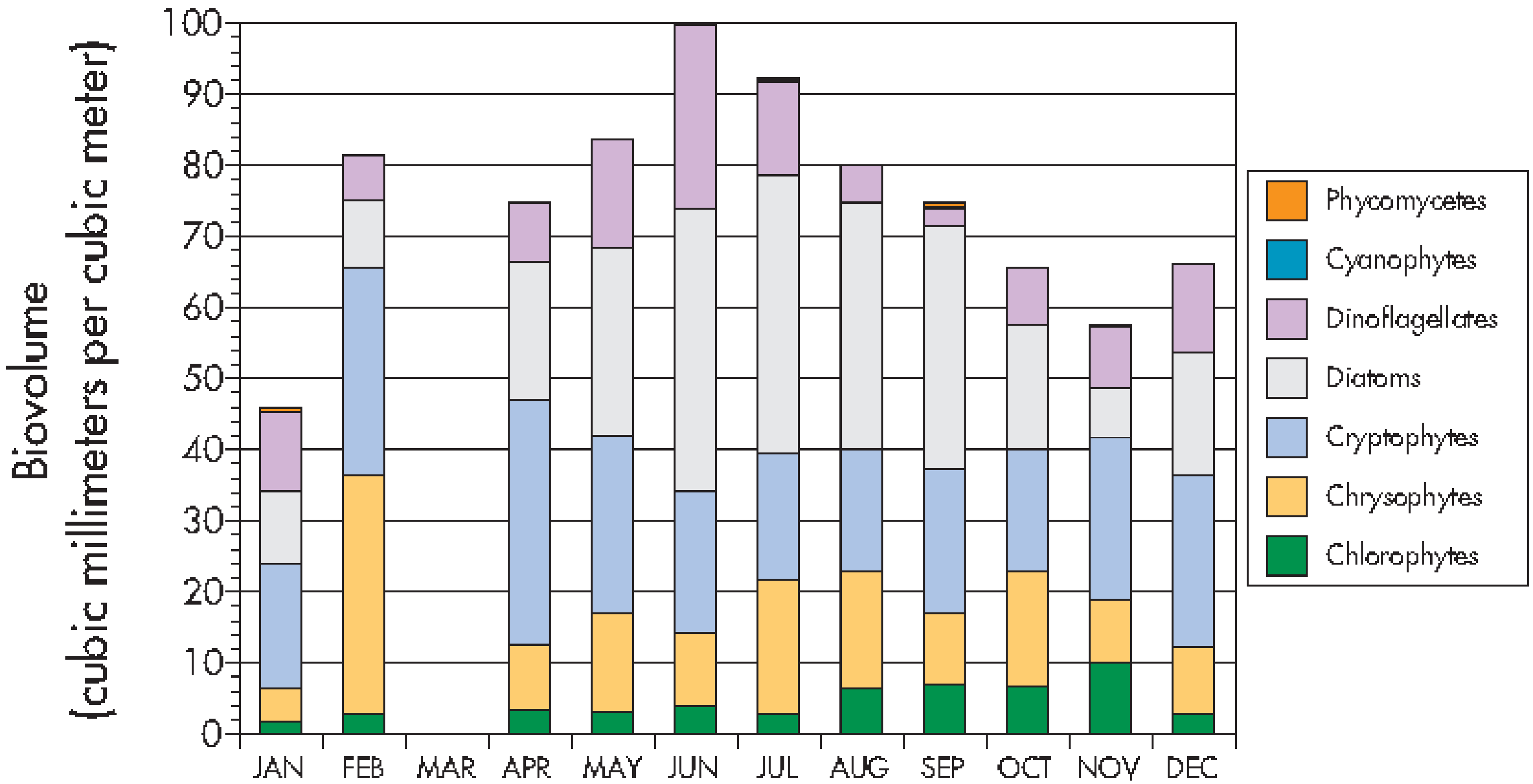


BIOLOGY

Algal groups as a fraction of total biovolume

Monthly in 2014

The biovolume of algal populations vary month to month, as well as year to year. In 2014, diatoms again dominated the biovolume of the phytoplankton community, especially in the summer. Diatom concentrations peaked in April and May (the “spring bloom”). Even at the peak of the bloom, algal cells occupied only one ten-millionth of the water in the lake. The peak biovolume in 2014 (100 cubic millimeters per cubic meter) was five percent lower than the peak in 2012.

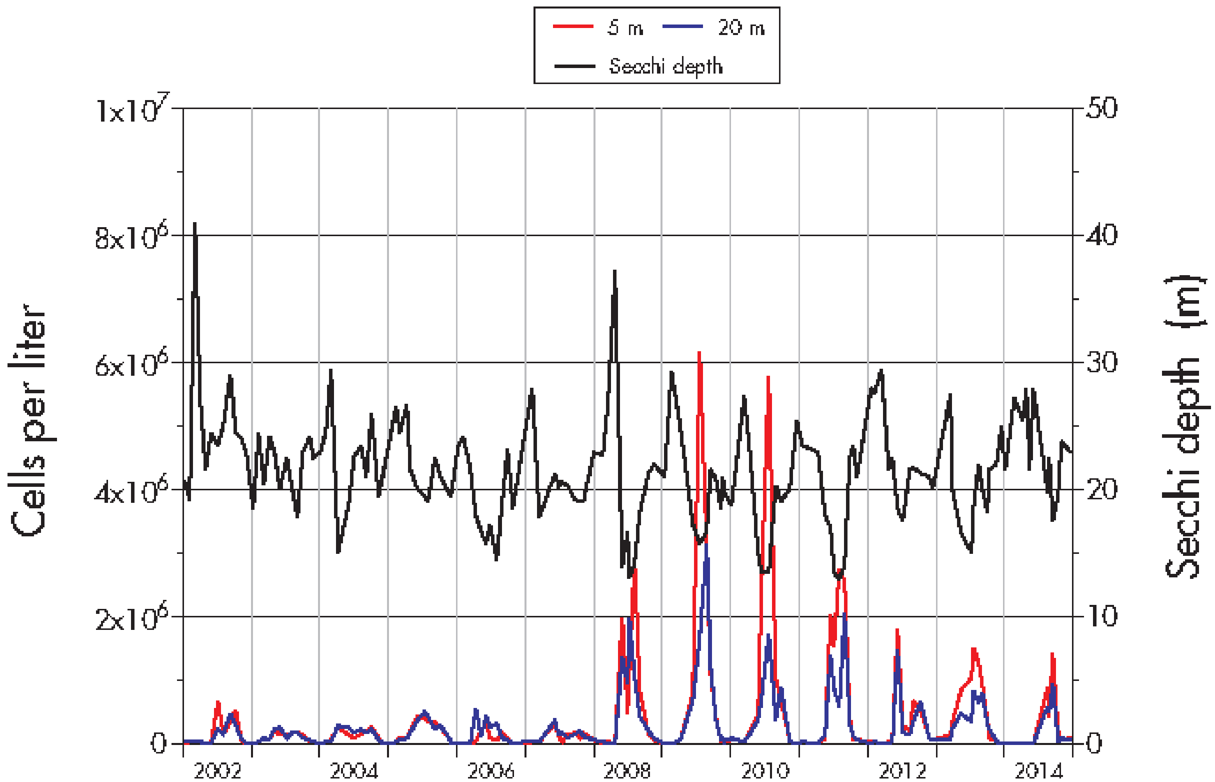


BIOLOGY

Predominance of *Cyclotella spp.*

From 2002 through 2014

In 2008, one species of algae, *Cyclotella gordonensis*, started to dominate the make-up of algae at Lake Tahoe. The cells range in size from 4-30 microns in diameter. During the summer, the smallest cells, 4-5 microns, control the community in the upper euphotic zone. This size range, which is the same as the inorganic particles, is ideal for light scattering. The growing numbers of *Cyclotella* between 2008-2011 were believed to be in large part responsible for the major decline in summer clarity in those years. In 2014 the concentration of *Cyclotella* cells continued to decrease, and in particular the duration of bloom conditions was lower than in the past. The blue and red lines below indicate the concentrations of *Cyclotella* at depths of 66 feet (20 m) and 16.5 feet (5 m) respectively. The black lines indicate the individual Secchi depths taken since 2002. The summer decrease of Secchi depth coincides perfectly with the increase in *Cyclotella* concentration.

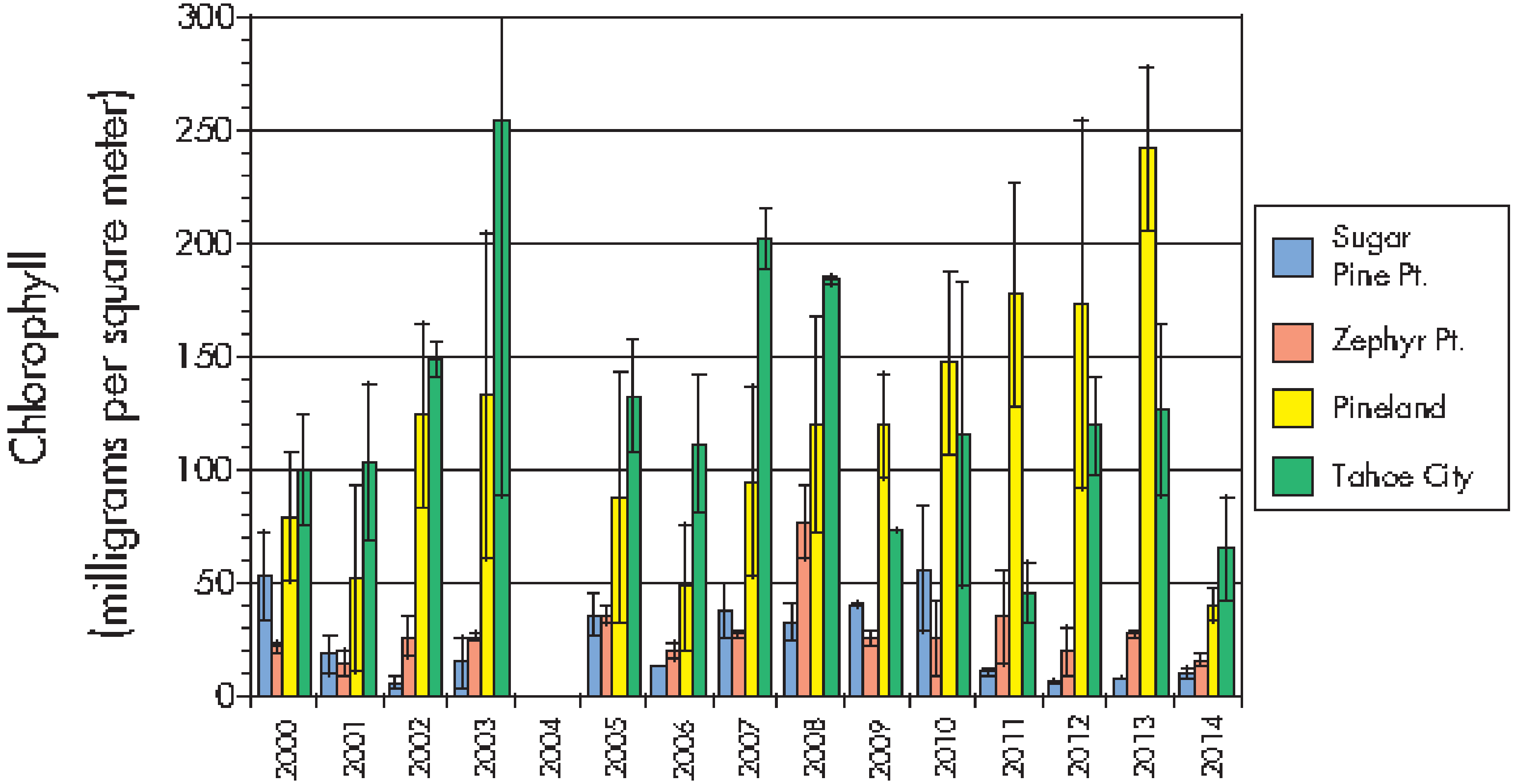


BIOLOGY

Shoreline algae populations

Yearly since 2000

Periphyton, or attached algae, makes rocks around the shoreline of Lake Tahoe green and slimy, or sometimes like a very plush white carpet. Periphyton is measured eight times each year, and this graph shows the maximum biomass measured at four sites for the period from January to June. In 2014, concentrations at the four sites shown were at or below their historic lows. The two most urbanized sites. Tahoe City and Pineland, were one half to one sixth of their values in comparison with 2013. While monitoring periphyton is an important indicator of near-shore health, these data do not shed information on what is controlling year-to-year changes. The Nearshore Network (see Recent Research, Section 6) is intended to provide deeper insight on the factors controlling periphyton growth.



BIOLOGY

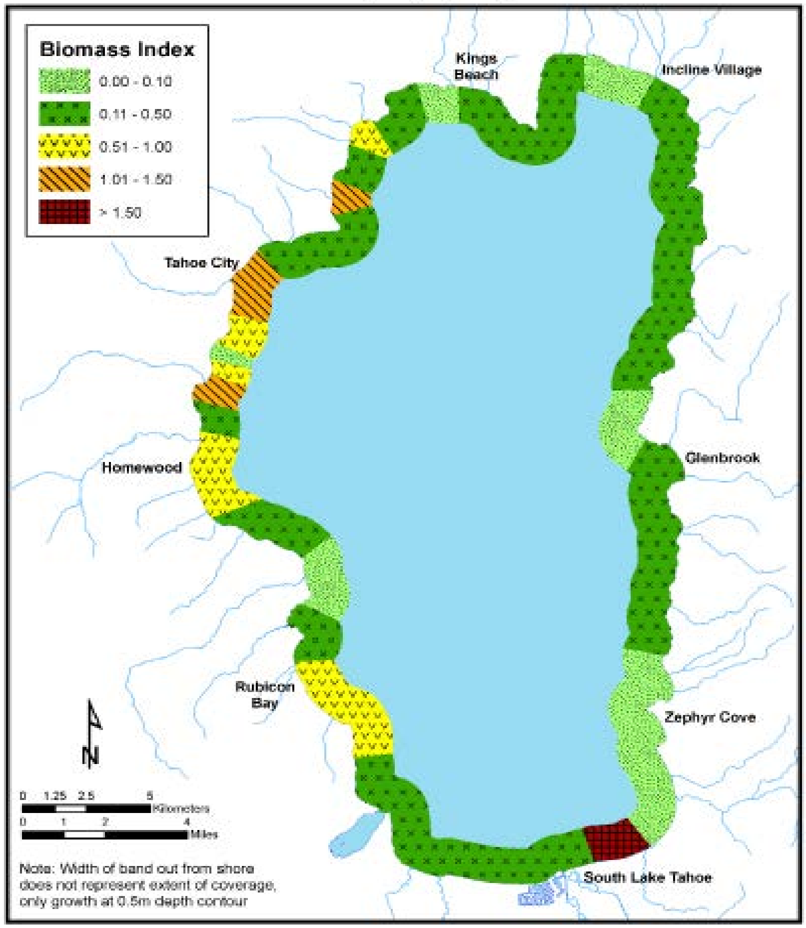
Shoreline algae distribution

In 2014

Periphyton biomass was surveyed around the lake during the spring of 2014, when it was at its annual maximum. Nearly 45 locations were inspected by snorkel survey in 1.5 feet (0.5 m) of water. A Periphyton Biomass Index (PBI) is used 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 fraction of the local bottom area covered by periphyton multiplied by the average length (cm) of the algal filaments. Zones of elevated PBI are evident, particularly near South Lake Tahoe, and to a lesser extent this year in the north-west. Overall conditions in 2014 were greatly improved compared to 2013 and most results from the last 14 years. Low lake level largely accounts for this.

Note: The width of the colored band does not represent the actual dimension of the onshore-offshore distribution. Similarly, its length does not represent the precise longitudinal extent.

Distribution of Periphyton Biomass at 0.5m Depth, Spring 2014



TAHOE: STATE OF THE LAKE REPORT 2015

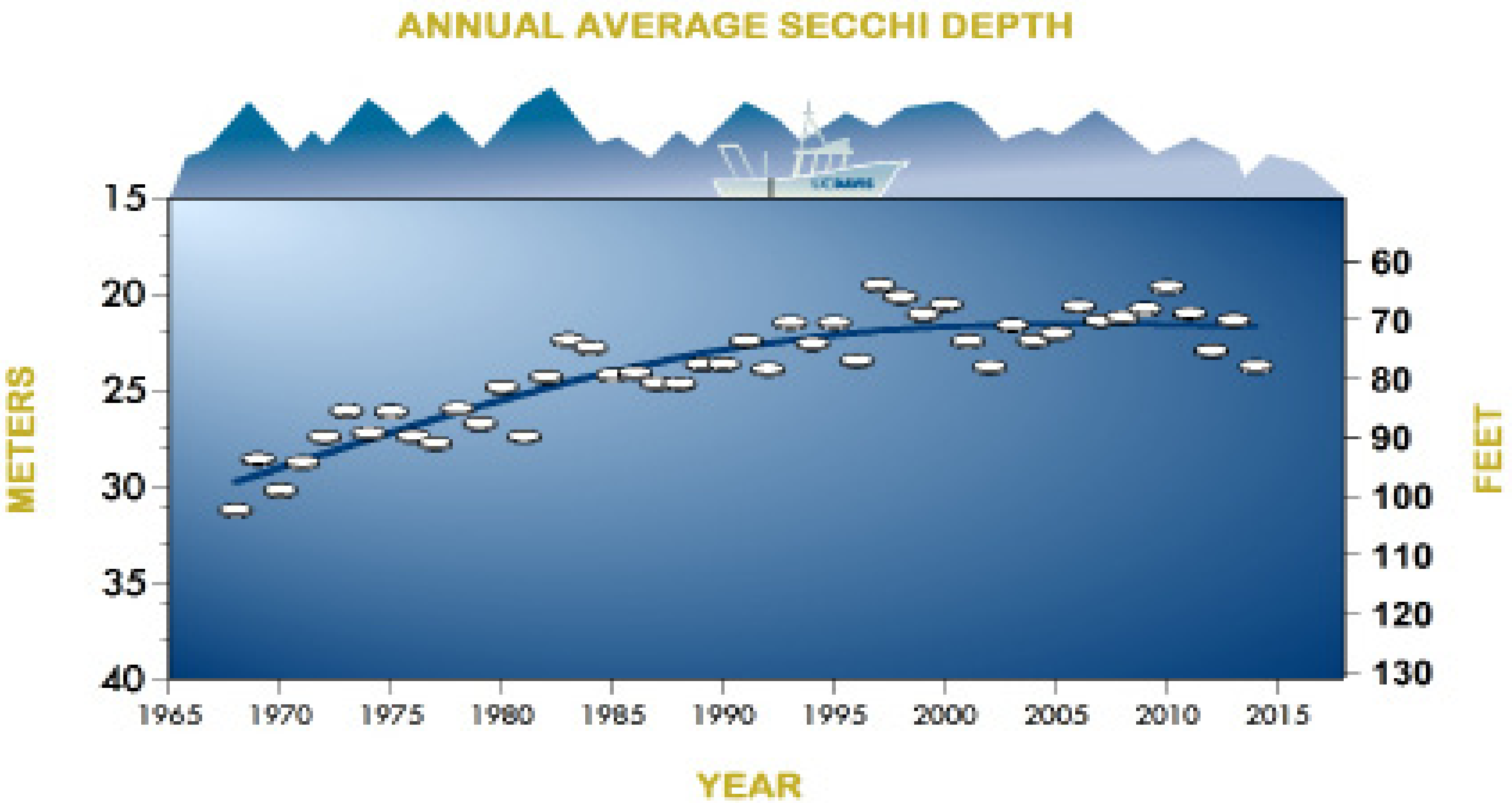
CLARITY

CLARITY

Annual average Secchi depth

Yearly since 1968

In 2014, the annual average Secchi depth was 77.8 feet (23.7 m), an increase of 7.6 feet over the previous year and well above the lowest value recorded in 1997 of 64.0 feet (19.5 m). The annual average clarity in the past decade has been better than the prior decade. The highest individual value recorded in 2014 was 93.5 feet on July 7, and the lowest was 57.4 feet on September 16. It is important to understand the causes behind clarity change and to evaluate past actions and future investments. Computer modeling tools have been developed to provide this information.

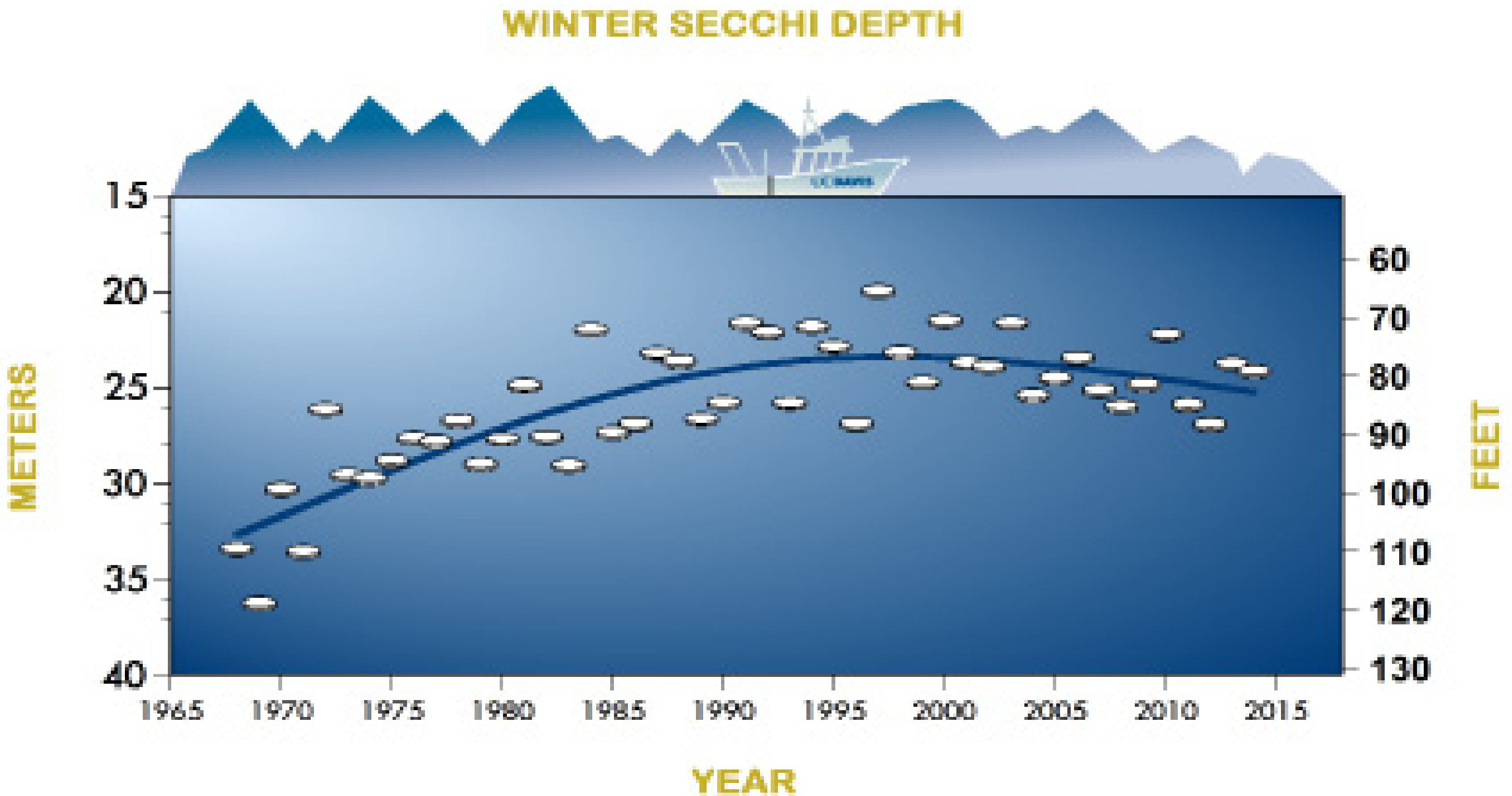


CLARITY

Winter Secchi depth

Yearly since 1968

Annual winter (December-March) Secchi depth measurements from 1968 to the present indicate that winter clarity at Lake Tahoe is showing definite improvement. In 2014, winter clarity improved by one foot, continuing the long-term pattern of improvement since 1997. The winter average of 79.1 feet (24.1 m) was well above the worst winter average, 65.6 feet (20.0 m), seen in 1997. The below average stream inflows on account of the drought were a significant factor in the improvement. However, there are other factors behind the overall improvement in winter clarity that are not fully understood.

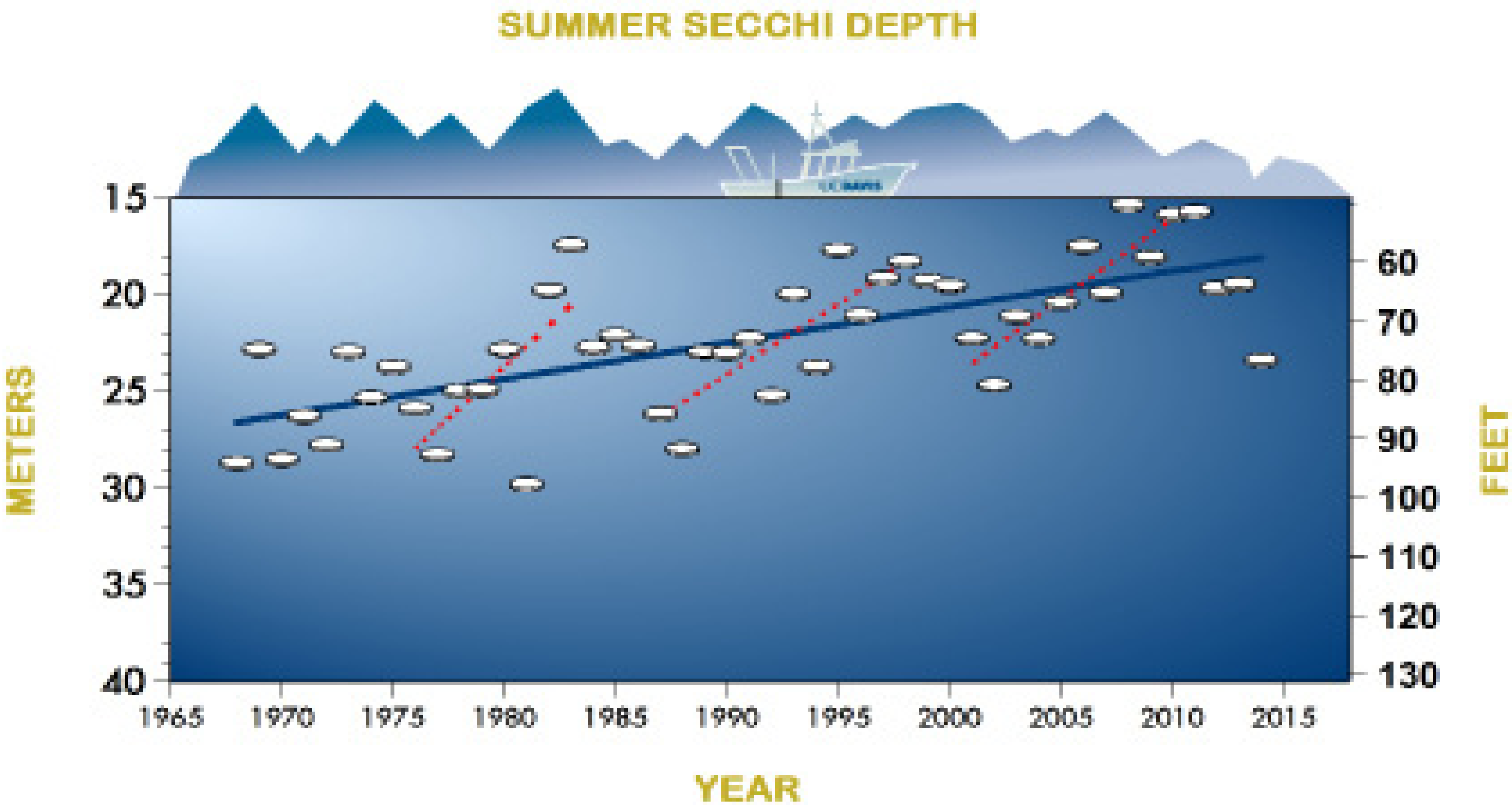


CLARITY

Summer Secchi depth

Yearly since 1968

Summer (June-September) clarity in Lake Tahoe in 2014 was 76.8 feet (23.4 m), almost a 13.1 foot improvement from 2013. This coincided with a continued decline in the concentration of small algal cells in 2014, as well as sharply lower stream inflows. Another contributing factor was the shallow depth to which the lake mixed to during the previous winter. The summer trend is dominated by a consistent long-term degradation but with a noticeable 10-15 year cyclic pattern. The red dashed lines are linear regressions for the periods: a) 1976 to 1983, b) 1987-1998, and c) 2001 to 2011. The most recent improvement may be a continuation of this cyclical trend. The reasons behind this periodicity are being investigated.



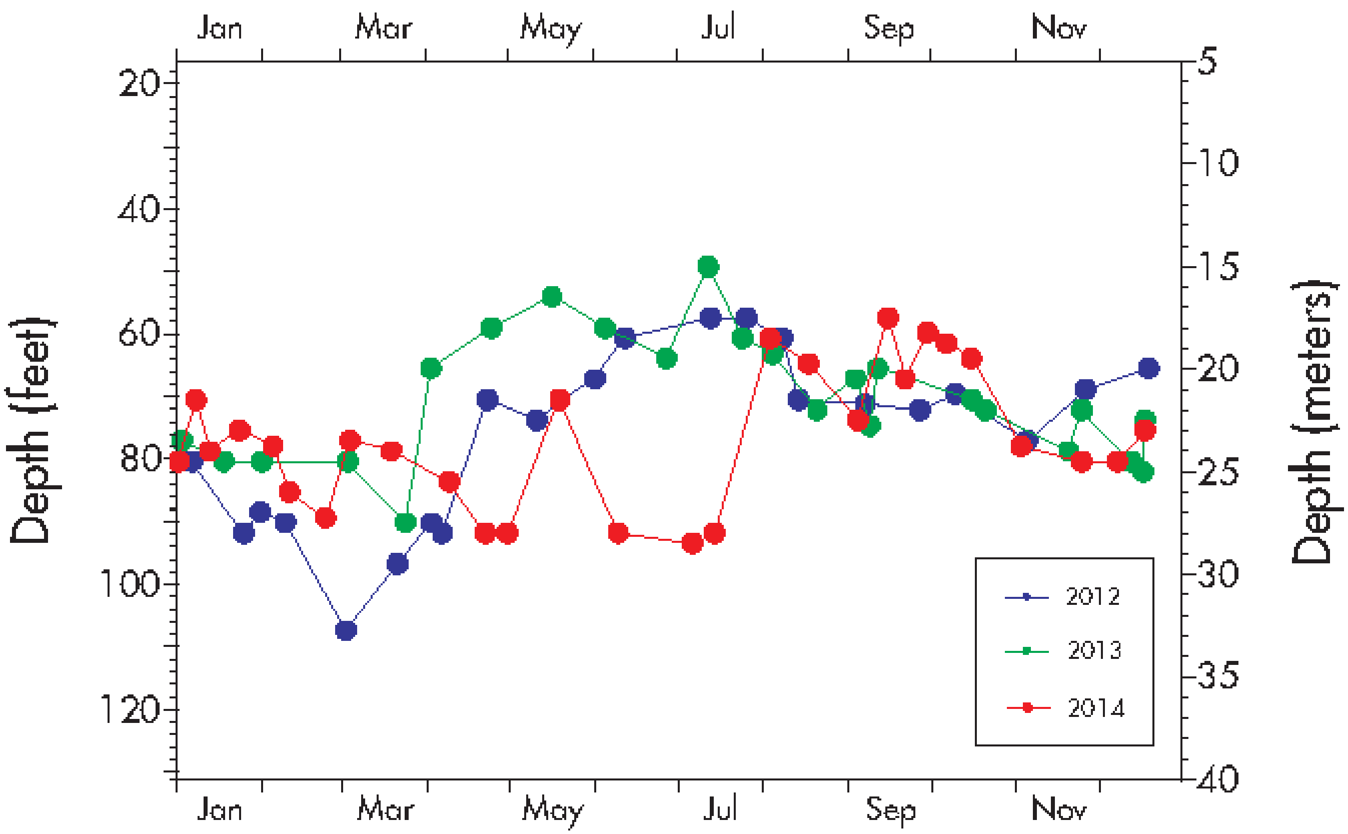
CLARITY

Individual Secchi depths

2012, 2013, 2014

Here, the individual Secchi depth reading from the Index station on the west side of the lake for 2012, 2013 and 2014 are plotted. For 2012 and 2013, there is a distinct seasonality – Secchi depth is generally higher in the fall and winter months, and lowest in the spring and summer. The maximum Secchi depth often occurs around the time of deepest mixing (March). 2014 represented a departure from this long established pattern. This year some of the largest Secchi depths occurred in spring and summer.

Secchi values can be seen to sometimes vary considerably over short time intervals. This is evident in May 2014, where Secchi depth decreased from 92.0 feet (28.0 m)to 70.5 feet (21.5 m)and back again. Such short-term variability is common in lakes. In this case the sudden decrease is likely due to a wind-driven downwelling that concentrates the less clear surface water in the vicinity of our measurement location.

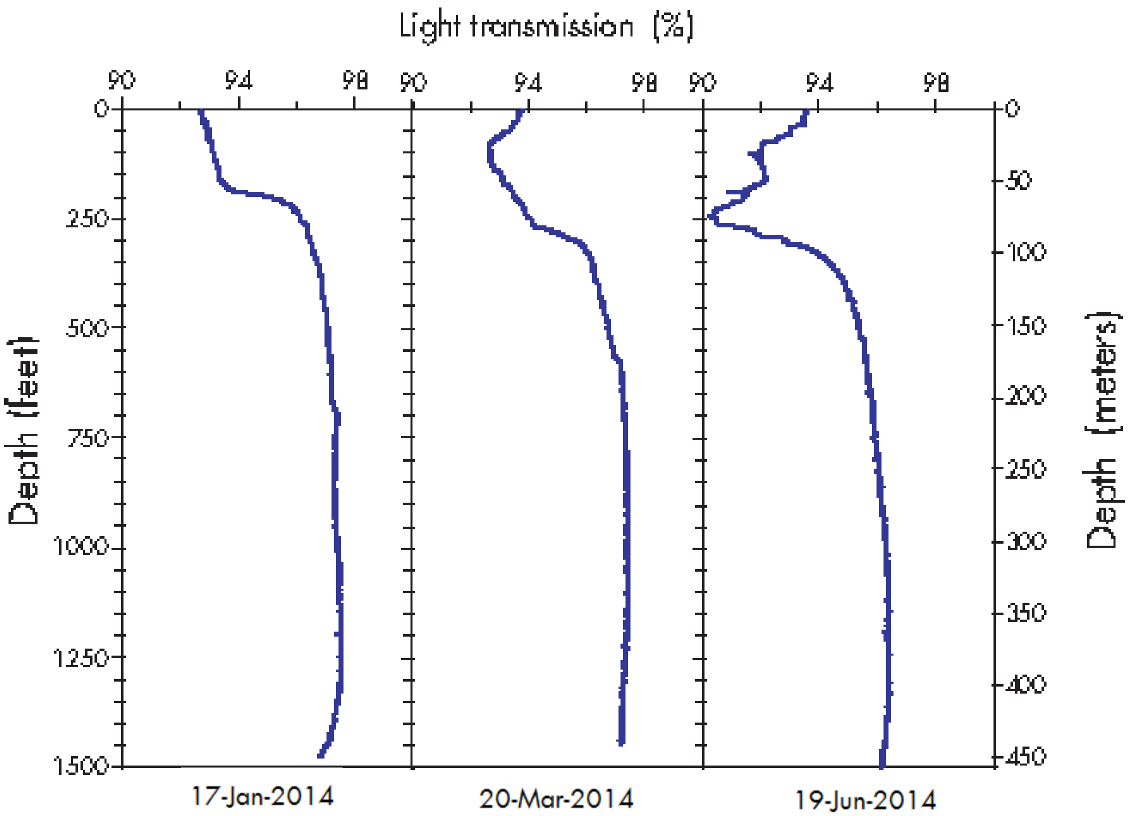


CLARITY

Light transmission

In 2014

A light transmissometer emits a specific wavelength of light and measures the percentage of that light transmitted over a 10 inch path. Clearer water results in a higher percentage of light transmission. Here, the light transmission measured at every depth in the lake is shown at three times in 2014. The “steps” in transmission at 200 feet and 300 feet in the first two panels indicate the depth of active lake mixing on January 17 and March 20 respectively. Here the less clear water (lower percent transmission) is toward the surface, whereas the deeper water is much clearer (higher percent transmission). The panel for June 19 shows the typical summer pattern, with the lowest light transmission in the thermocline, where fine particles become trapped. The reason for the high light transmission in deep water is that fine particles aggregate into larger particles that rapidly settle out in the deep water. Large particles do not scatter light as much as fine particles.



TAHOE: STATE OF THE LAKE REPORT 2015

EDUCATION AND OUTREACH

UC DAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER

EDUCATION AND OUTREACH

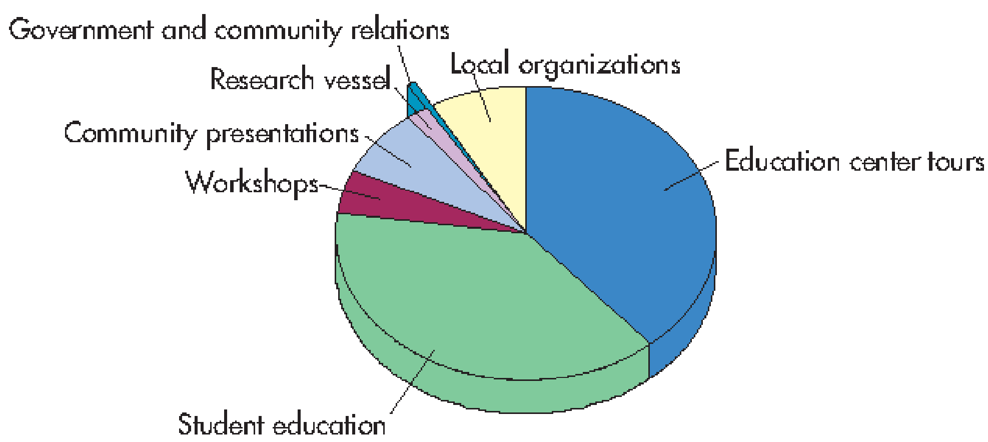
TERC education and outreach

In 2014

Part of TERC's mission is education and outreach. Our public, K-12, teacher professional development, and volunteer programs are designed to spark the imagination and curiosity of our visitors and participants and to sow the seeds of stewardship for our vital, yet fragile, freshwater ecosystems.

During 2014, TERC recorded 12,701 individual visitor contacts. The majority represented student field trips and visitors to the Tahoe Science Center (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 teacher training program, Project WET workshops, Summer Tahoe Teacher Institute, and a volunteer docent training program.

TERC also partners with numerous groups to deliver environmental science education in the Tahoe basin. In 2014, these included AmeriCorps, Lake Tahoe Outreach Committee, North Tahoe Environmental Education Coalition, Sierra Nevada College, Sierra Watershed Education Partnerships (SWEP), South Tahoe Environmental Education Coalition, UC Davis Young Scholars, and many others.



TOTAL NUMBER OF CONTACTS: 12,701

EDUCATION AND OUTREACH

TERC educational exhibits

In 2014

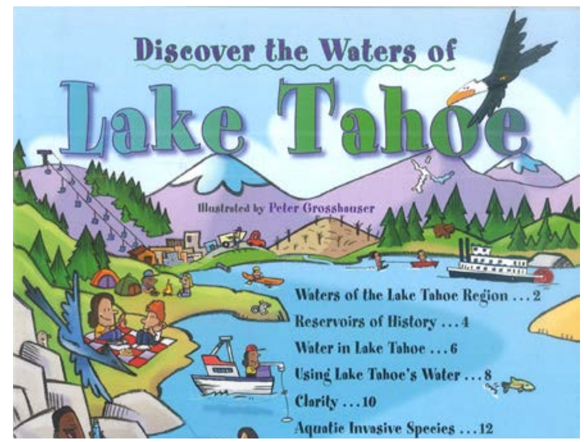
Each year, TERC works to improve our available exhibits and increase the offerings available. During 2014, we planned an “extreme makeover” for the Tahoe Science Center together with the UC Davis Office of Strategic Communications. Graphic designers worked to develop a new look for the science center, which was implemented and installed in 2015.

During 2014, we also worked with the UC Berkeley Lawrence Hall of Science to develop two new interactive iPad applications: “Healthy and Unhealthy Lakes” and “DIY Lake Science.” Additionally, we developed curriculum for the Seiche Wave and Density Flow Model which is available on 3dh2o.org.

“Discover the Waters of Lake Tahoe” is a student- and teacher-tested activity booklet created with the Project WET Foundation to teach children about the fascinating water science of Lake Tahoe.

“Healthy and Unhealthy Lakes” and “DIY Lake Science” apps were developed with the UC Berkeley Lawrence Hall of Science. Photo: A. Toy

Education and outreach team members Carley O’Connell and Diana Hitchen use cold blue water and hot yellow water to explain how changes in temperature and density lead to seasonal lake stratification and lake mixing. Photo: A. Toy



Together with Project WET and Nevada Division of Environmental Protection, TERC helped create and distribute “Discover the Waters of Lake Tahoe” an activity booklet for children ages eight to twelve.

EDUCATION AND OUTREACH

TERC educational programs

In 2014

In addition to providing education center tours for the general public, the TERC Education Team provides high quality informal science education to more than 4,700 third- through eleventh-grade students by hosting over 100 field trips each year.

Other K-12 educational programs include Trout in the Classroom, coordinated in partnership with Sierra Watershed Education Partnerships, which is designed to teach students about the ecology, biology, and history of trout and other aquatic life. This year, we raised Lahontan cutthroat trout in an aquarium in the science center. Students from schools around the region also raised trout for release into local waterways.

A small group of select high school students participated in the annual Youth Science Institute from January through May. Through this after school program participants work with scientists, conduct experiments, and share science activities with other students.

School groups visit for informal science education programs on water, geology, ecology, and biology. Pictured here, students are collecting and analyzing water samples from nearby Incline Creek. Photo: A. Toy

Students excitedly release their Lahontan cutthroat trout and wish them well as they swim off into the lake as the final lesson of the Trout in the Classroom program. Photo: A. Toy

Youth Science Institute participants from high schools around the region conduct multiple science activities over the 16-week after school program. Photo: A. Toy

EDUCATION AND OUTREACH

TERC educational programs, continued

In 2014

Each year we train new volunteer docents at our annual June Docent Training. Volunteer docents become local experts and lead tours at our two science centers. Volunteers also participate in garden work each year to make the Tahoe City Field Station's native plant demonstration garden a beautiful community resource.

Visitors that come to our science centers can view exhibits, watch 3-D movies, and participate in citizen science by conducting water quality monitoring and investigating plant phenology. Public participation in scientific research is educational for adults and children and provides useful data for scientists.

Additionally, for the past several years, TERC has hosted a summer Tahoe Teacher Institute for educators from both California and Nevada aimed at enhancing science, technology, engineering, and mathematics (STEM) education.

At the Tahoe Science Center volunteer docent Alan Castator teaches visitors about lake sediment coring and how these sediment cores provide insight into the environmental history of the lake. Photo: A. Toy

Volunteer docents attend multiple training workshops to build a foundation for providing lively and educational science tours for visitors of all ages at our two science centers. Photo: A. Toy

As part of the Nevada Tahoe Teacher STEM Institute, teachers from all over Nevada learn fun, new, hands-on science activities. Photo: A. Toy

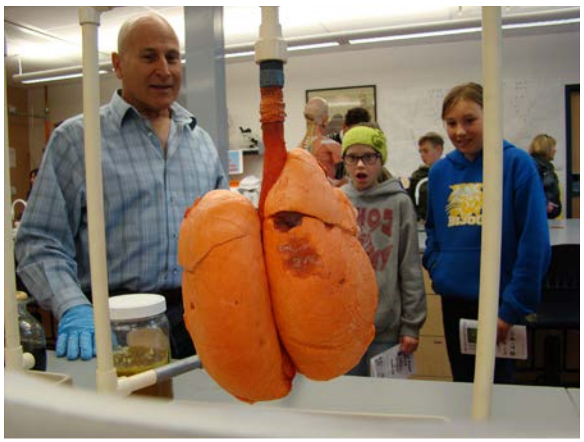
EDUCATION AND OUTREACH

TERC special events

In 2014

TERC hosts monthly lectures throughout the year on various environmental issues, new scientific research, and related regional topics of interest. Recent topics have included, “Your Ideal Canine Companion”, “Stem Cell Treatments for Inflammatory and Traumatic Diseases”, “Mountain Weather and Climate”, and “AlertTahoe: A 21st Century Approach to Firefighting in the Tahoe Basin.”

Special events hosted annually include Project WET training workshops (February), Science Expo (March), Garden workshops (June - August), Summer Teacher Institute (July), and Children’s Environmental Science Day (August).



The annual Science Expo held each March brings in more than 1,000 third-, fourth- and fifth-grade students for hands-on science activities that cover a different theme every year. In 2015, the theme was “Life Science and Health”. Next year the theme will be Physical Science. Photo: A. Toy

Public lectures are held monthly at our Incline Village location. Sponsors and private donations help make these events free to the community. Photo: A. Toy

Children’s Environmental Science Day is held annually each August with hands-on science activities designed for kids ages four and up. Scientists and management agencies from the Tahoe basin participate to make this a community event that builds knowledge and develops partnerships. Photo: A. Toy