TAHOE: STATE OF THE LAKE REPORT 2016

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 2015. 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 and the downturn in clarity, 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 indicator 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? 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, Sudeep Chandra, Bob Coats, Veronica Edirveerasingam, Bill Fleenor, Alex Forrest, Emily Frey, Charles Goldman, Scott Hackley, Tina Hammell, Bruce Hargreaves, Alan Heyvaert, Simon Hook, Zach Hymanson, Amelia Jones, Camille Jensen, Daret Kehlet, Bree Lewis, Anne Liston, Patricia Maloney, George Malyj, Elisa Marini, Tom Mathis, Evan Portier, John Reuter, Bob Richards, Gerardo Rivera, Derek Roberts, Francisco Rueda, Steve Sadro, Goloka Sahoo, Naoki Saito, Heather Segale, Katie Senft, Bill Sluis, Heather Sprague, Lidia Tanaka, Raph Townsend, Alison Toy, and Shohei Watanabe 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 the California Tahoe Conservancy, the Lahontan Regional Water Quality Control Board, the Tahoe Fund, the Tahoe Lakefront Owners Association, the Tahoe Regional Planning Agency, the Nevada Division of Environmental Protection, the Tahoe Water Suppliers Association, the League to Save Lake Tahoe and the Incline Village Waste Not Program. 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.

The 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? What drives movements deep down in the lake? And what are the true to use to describe conditions? The application of these models this year has helped understand the seiche waves that help prevent stagnation of Lake Tahoe's depths.

This annual Tahoe: State of the Lake Report presents data from 2015 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 drivers of variability of water quality around the lake's nearshore regions, the periphyton covering many parts of the rocky shoreline, forest health, new techniques for determining the lake's metabolism, stream water intrusions, the unnoticed seiches waves and the identification of climate change as a driving process in eutrophication.

It is often believed that a poor measure of water quality at one location along Tahoe's nearshore is the result of poor management, a leaking pipe, or a problem waiting for a solution. What the Nearshore Network is showing, using data from around the lake and measured continuously, is that part of what we are experiencing is the normal system behavior. The challenge is to separate those natural signals from the true degradation that is occurring, so that appropriate solutions can be found and implemented in those locations where they are applicable.

A debate around Lake Tahoe is whether the nearshore is actually any worse than it was in the past. In the last two years alone, periphyton levels have significantly decreased. A comprehensive review of all the data on periphyton that TERC has collected over several decades indicated that the trend is not crystal clear. Part of the reason is the way in which periphyton are measured is strongly influenced by lake level, something that has been changing more frequently in recent decades. As lake level rises or falls (sometimes

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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.*

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.1)

several feet in a year), periphyton must re-establish on rocks that may have been in the sun the previous year. Possibly the largest reason for this lack of a clear trend is that the monitoring was initiated after most of the destructive changes at Lake Tahoe had occurred. Whereas the measurement of clarity started in the 1960s, and we witnessed the initial decline followed by the recent 15 year period in which clarity has stabilized, periphyton monitoring has largely been conducted during this more recent, stable period of the lake ecosystem.

Dissolved oxygen in Tahoe's waters is emerging as major topic of concern. It is recognized in many ecosystems around the world that one of the impacts of climate change is the potential for the formation of dead zones, where all the available oxygen has been consumed. Research is being conducted but more needs to be done to better understand what processes are at play to keep oxygen well distributed in the lake's hypolimnion. Are the nutrient reduction strategies embedded in the TMDL sufficient to provide the lake the resilience it needs to withstand even longer droughts in the future? Can studying the lake's metabolism yield new understanding of how warmer water temperatures are changing the conditions at the base of the food web?

2015 saw the continuation of warming and drying conditions for a fourth year at Lake Tahoe. The winter of 2014-2015 had the lowest number of freezing days (24) recorded in over a century of data collection, eclipsing last year's record. Precipitation was close to the long-term average, however the fraction of precipitation that fell as snow was the lowest ever recorded, being only 6.5 percent.

Lake level rose by only 9" during the spring snowmelt, well below the typical seasonal rise. Lake Tahoe was below its rim for almost the entire year, except for one day on December 9, 2015. When the lake is below its rim, outflow via the Truckee River ceases. The lake had a final level of 1.39 feet below the rim at the end of 2015. The outflow from Lake Tahoe to the Truckee River was zero in 2015, owing to the fact that the lake was at or below the lake's rim for the entire year.

The volume-averaged lake temperature increased in 2015 by 0.48 °F (0.26 °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. In the last 4 years the lake has warmed at an alarming rate of over 0.3 °F/year, 15 times faster that the long term warming rate. The average surface water temperature was 53.3 °F (11.8 °C), making 2015 the warmest year yet recorded. The maximum daily summer surface water temperature in 2015 was similar to the previous year, and for the winter-time maximum, it was the warmest surface water temperature observed for the length of the record.

Lake Tahoe did not mix to its full depth in 2015, the fourth consecutive year in which this has occurred. Instead, the maximum depth of mixing was only 262 feet (80 m), reached between February and March. The lack of mixing was due to a fourth year of above average lake stability, driven by the generally warmer weather. The upper 330 feet of the lake stayed stratified for 189 days, three weeks longer than what was typical when the record began.

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.2)

The input of stream-borne nutrients (nitrogen and phosphorus) to the lake was low again in 2015 due to the low precipitation and subsequent run-off. The last four years have all had nutrient and particle loads a factor of four to five below the long-term mean.

Overall in-lake nitrate concentrations have remained relatively constant over the 33 years of record. In 2015, however, the volume-weighted annual average concentration of nitrate-nitrogen reached an all-time high of 20.6 micrograms per liter, exceeding the previous high of 20.0 micrograms per liter set in 2014. This increase is in part due to the record low 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 deep-water mixing allows a continued build-up of nitrate in the deep water. Surprisingly, in-lake phosphorus concentrations which had been on a long term decline, displayed an increase in 2015, to the highest level in the last six years.

Biologically, the primary productivity of the lake has increased dramatically since 1959. In 2015, there was a decrease in primary productivity to 206.1 grams of carbon per square meter, the third successive year of reduced productivity. By contrast the biomass (concentration) of algae in the lake has remained relatively steady over time. The annual average concentration for 2015 was 0.63 micrograms per liter, slightly lower than the previous two years. For the period of 1984-2015 the average annual chlorophyll-a concentration in Lake Tahoe was 0.70 micrograms per liter.

This year the annual average Secchi depth, a measure of lake clarity, continued the long-term halt in clarity degradation. The value for 2015 was 73.1 feet (22.3 m), a decrease of 4.8 feet over 2014, but this 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. Winter (December-March) clarity declined by 7.6 feet to 71.5 feet (21.8 m). The low level of snowfall compared to rain this year caused the water entering the lake to be warmer in 2015, and this introduced fine particles closer to the surface. Summer (June-September) clarity in Lake Tahoe in 2015 was 72.8 feet (22.2 m), a 4.2 foot decline over the value from 2014.

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 Tons
- 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. There was no outflow from Lake Tahoe into the Truckee River in 2015 on account of low lake level.
- 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

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 and watersheds, 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 continuous 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, an educational 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.

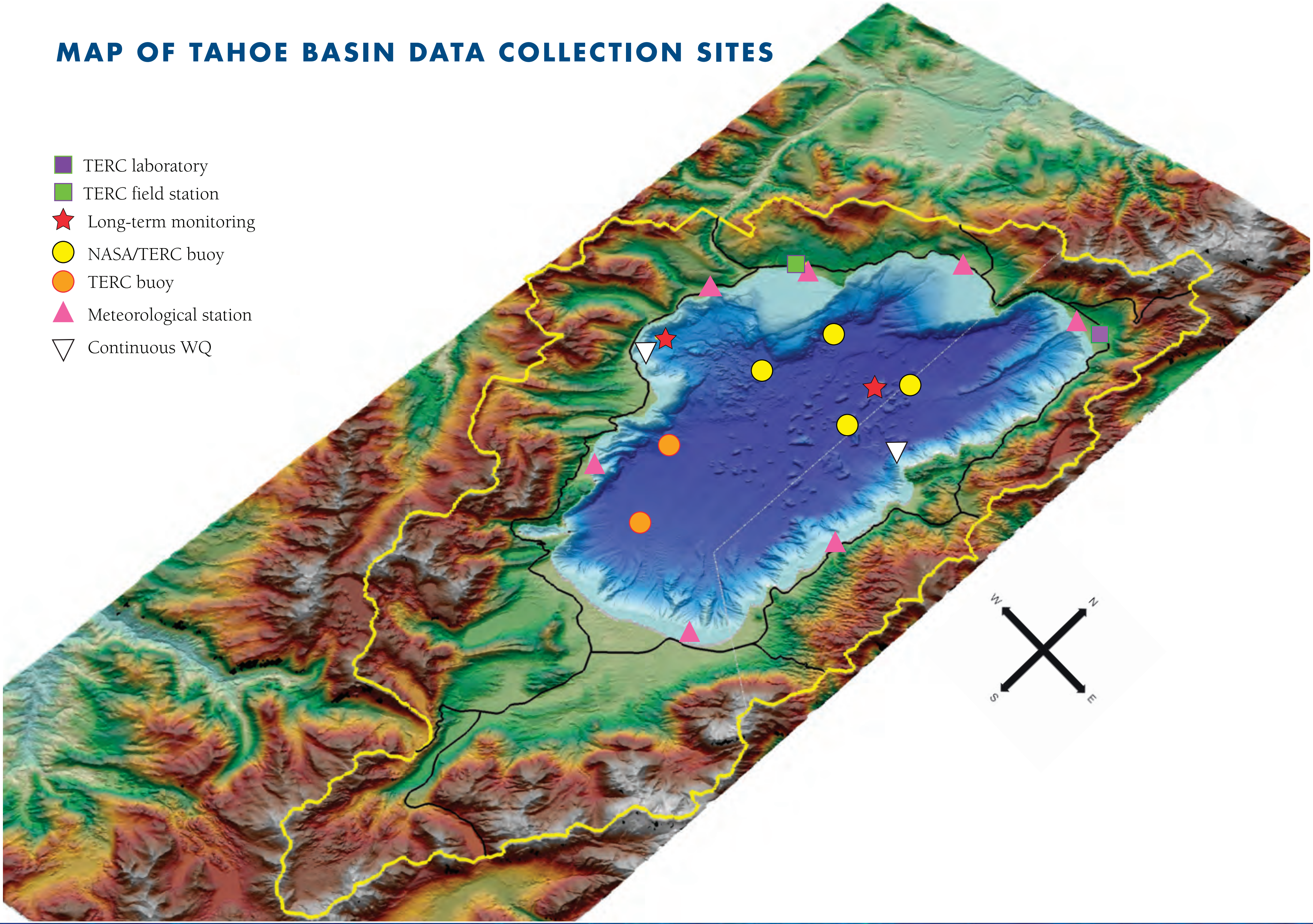
Our secondary laboratories and offices are located on the UC Davis campus at the Center for Watershed Sciences and in Wickson Hall.

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 (http://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 2016

RECENT RESEARCH UPDATES

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RECENT RESEARCH UPDATES

New expertise for emerging challenges

The solutions needed to tackle emerging challenges at Lake Tahoe and other freshwater ecosystems require a multidisciplinary approach. TERC has increased its expertise this year through the hiring of two new faculty members under the UC Davis Hiring Incentive Program.

Dr. Alex Forrest, a former TERC postdoctoral researcher and, more recently, a senior lecturer and researcher at the University of Tasmania in Australia, brings new expertise in the area of autonomous data acquisition to understand the interplay between water motion and its interplay with the lake floor. Alex is known world-wide for the use of autonomous vehicles in extreme environments such as Arctic ice-covered lakes, Antarctic ice shelf cavities, and lakes prone to sudden, catastrophic sediment flows. This experience will help broaden methods to be applied to Tahoe where highly variable conditions mean that conventional data acquisition methods are often difficult to utilize.

Dr. Steve Sadro is a limnologist and ecosystem ecologist interested in how physical, chemical, and biological factors interact to regulate aquatic ecosystems. After nearly a decade in the Pacific Northwest working in coastal and estuarine ecosystems, Steve shifted to study the limnology of mountain lakes, which was the focus of his PhD work at UC Santa Barbara. Since 2006 he has been exploring ecosystem energetic such as carbon and nutrient cycling, terrestrial – aquatic linkages, and food web dynamics in arctic and alpine lakes to better understand how these systems are being affected by climate change and other anthropogenic effects. Steve brings a large-scale perspective that will help put Tahoe in a bioregional and global context.

Dr. Alex Forrest preparing to deploy an autonomous vehicle on ice-covered Lake Kilpisjärvi, northern Finland.

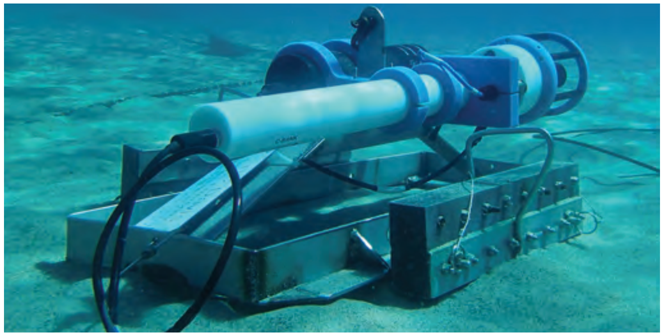
Dr. Steve Sadro preparing to sample Doris Lake, a hot spring-fed lake in the Sierra.

RECENT RESEARCH UPDATES

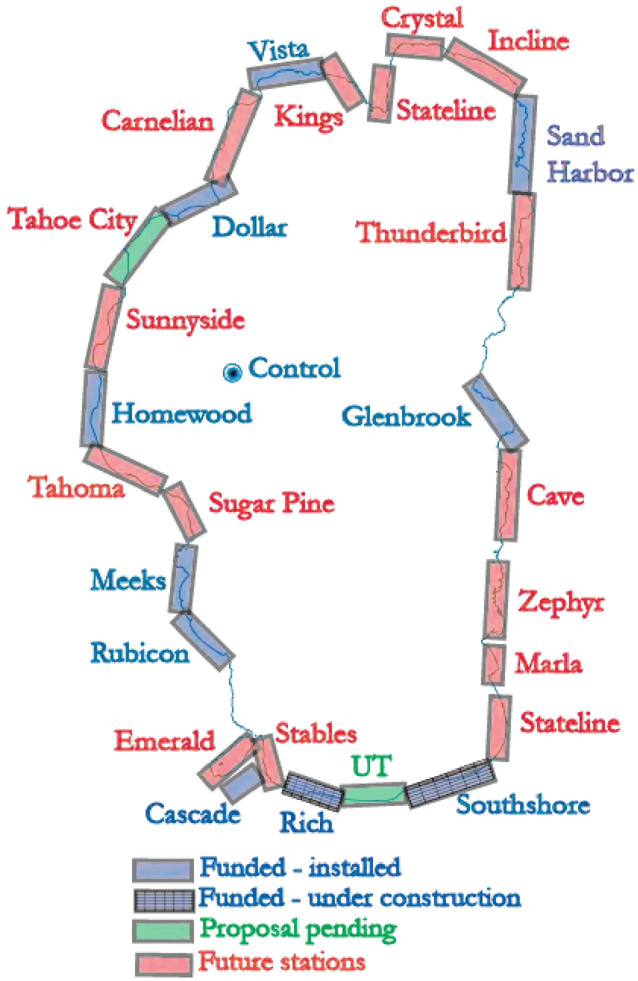
Variability around the shoreline of Lake Tahoe

TERC's Nearshore Network is a system of water quality stations spread around the shallow areas of the lake that continuously measure water quality and physical conditions every 30 seconds, and almost-instantly logs the data to the internet. The current set of stations have been installed with support from private property owners and home-owner associations and are installed at both private docks and public facilities. The map shows the general locations of the existing and under construction stations, as well as potential locations of future stations. Please contact tercinfo@ucdavis.edu if you are interested in funding a future station.

The purpose of the stations is to help understand the variability of conditions in the nearshore around the lake, and to identify the sources of this variability. Until now it has not even been possible to know what "normal" is for most water quality properties. Conditions could be driven by natural lake processes; by pollutant inputs from drains, streams or direct runoff; by accidental releases of contaminants; or by combinations of all of these. Each of these could force a departure from "normal". We now know that "normal" is different, depending on where you are around the lake. Most importantly, the way in which nearshore conditions can be improved depends directly on the underlying causes.



A nearshore station in the shallow water of Lake Tahoe.



Locations of existing and planned nearshore network stations.

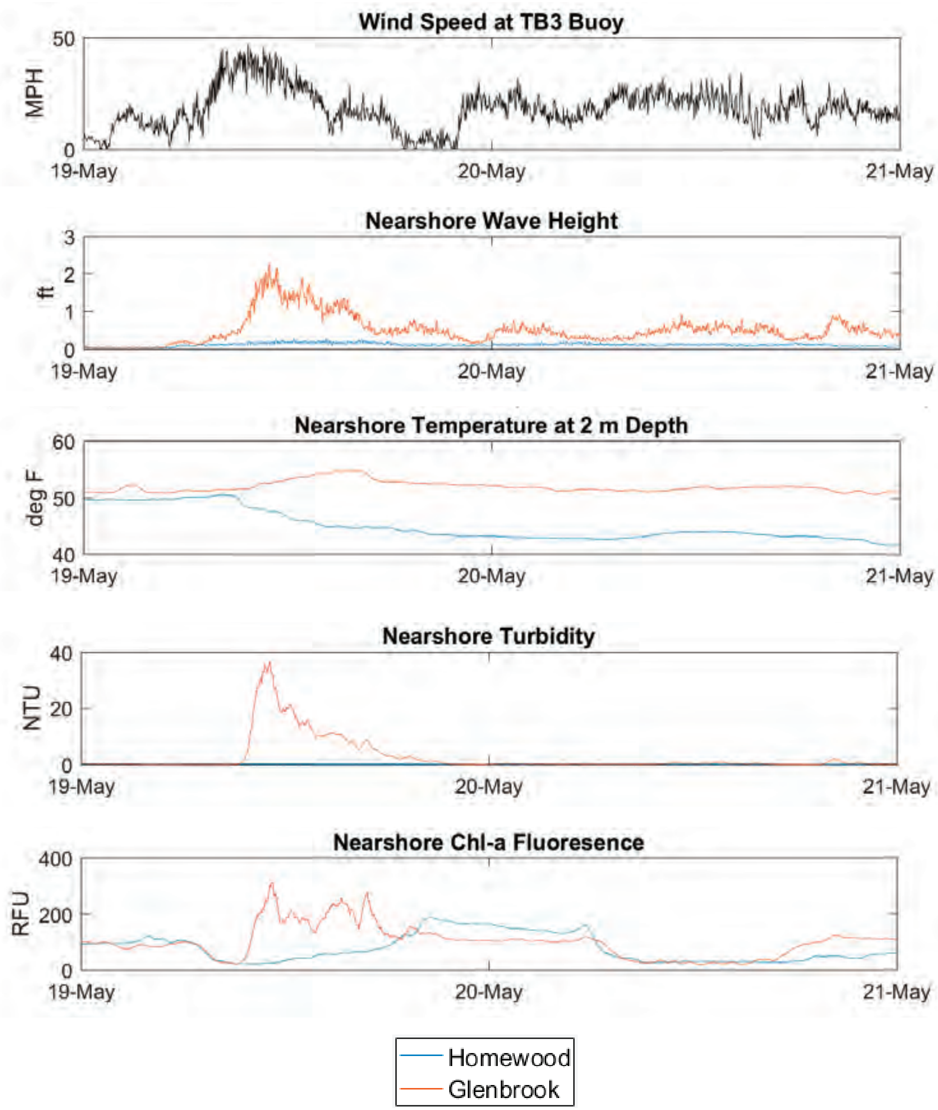
RECENT RESEARCH UPDATES

Variability around the shoreline of Lake Tahoe, continued

Two nearshore stations on opposite sides of the lake clearly show how water quality can vary due to lake processes and position. Strong sustained winds from the west produce "upwellings", a phenomenon in which cool, deep water is brought to the surface on the upwind side, and warm surface water gets blown across the lake. The Homewood station (west side), and the Glenbrook station (east side), both record temperature, conductivity, depth, wave height, chlorophyll (algae concentration), CDOM (dissolved organic material), turbidity, and dissolved oxygen data at a thirty-second interval.

During such an event on 19 May 2016, the water quality consequences at Homewood and Glenbrook can be clearly seen. A westerly wind of 40 mph caused the Homewood temperature to drop for 3 days. Because of the wind direction, 2 foot high waves occurred at Glenbrook (Homewood was sheltered and remained calm), which resulted in resuspension of bottom sediment. This resuspension caused turbidity to exceed 30 NTU (30 times the desired value), while conditions at Homewood were well below the desired 1 NTU maximum turbidity. Chlorophyll levels at Homewood almost doubled due to water from a depth of 60 m, the level of the peak chlorophyll in the lake, rising to the surface.

This was a case where a totally natural set of events produced "poor" water quality at two separate locations. This highlights the need for adequate monitoring to better understand the causes of change and distinguishing between "natural" events and "manageable" events.



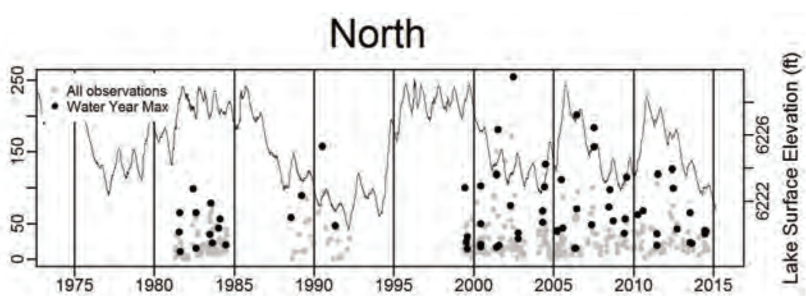
RECENT RESEARCH UPDATES

More or less slime?

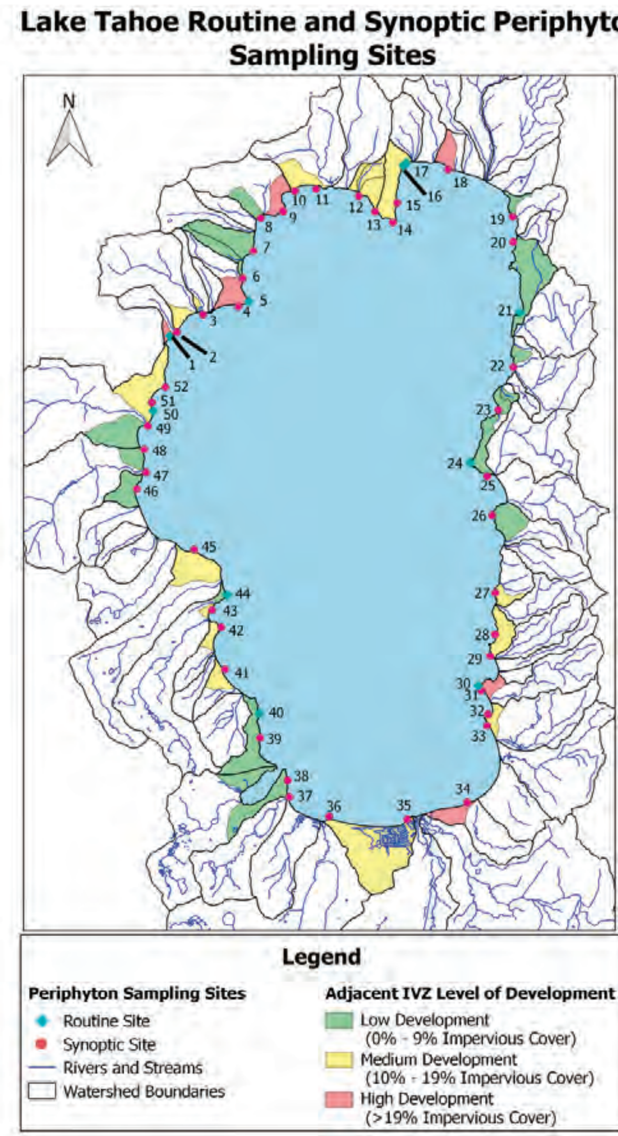
In late 2015, at the request of the TRPA, TERC undertook a review of all the data collected on the status of periphyton, the attached algae on the rocks around the lake that most people refer to as slime. Was there more of it now than there had been in the past? Were some areas naturally worse than others?

TERC has conducted periphyton monitoring in Lake Tahoe since 1982. Monitoring occurred for select periods in the 1980s (1982-85) and 1990s (1989-93). Near-continuous monitoring has occurred since 2000 with a one-year gap in 2004. Periphyton monitoring has primarily focused on measuring levels of algal biomass at six to ten "routine" monitoring sites around the lake. Samples of attached algae for measurement of biomass have been collected from natural rock surfaces at 0.5 m (20 inches) below the water level at the time of sampling. In addition, once each spring an intensive "synoptic" sampling of approximately 40 additional sites is completed. This synoptic sampling is timed to occur when periphyton biomass is believed to be at its spring peak.

With respect to spatial changes, the trends are somewhat definitive, with areas of medium and high development displaying higher levels of periphyton biomass. Whether this is due to the presence of the development itself or whether it is also tied to the fact that development often occurred in areas of flatter land (meadows, wetlands etc.) has yet to be determined.



Chlorophyll-a (in mg/sq. m) for all the North Lake Tahoe sites. The determination of a long term trend is complicated by fluctuating water level and gaps in the data. Even within one year, there are large variations between sites.



RECENT RESEARCH UPDATES

More slime or less slime? continued

Temporal trends during the period of record are either statistically insignificant or very slight. One reason for this may be that given the number of controlling variables (e.g. water level, time submerged, algal type etc.) the data record is still relatively sparse. More likely is that since the monitoring commenced in the mid-1980s, the largest changes to periphyton may have already occurred, just as the largest changes in clarity occurred prior to that time.

There is a large amount of anecdotal data to suggest that extremely low periphyton levels were once the norm for Lake Tahoe's shoreline. Anecdotal data can be quantified, especially if they are accompanied by photographic data. If you have photographs that show the lake's shoreline with or without algae from before the 1990s, we would be interested in seeing them and using them as part of our database. Please contact Scott Hackley (shhackley@ucdavis.edu). If you also wish to contribute to the current database, then please take photos of the shoreline algae using the free app, Citizen Science Tahoe. The finding of few significant trends should not be interpreted as evidence that periphyton are not an important challenge. As stated, the period of measurement occurred after the major land use changes had already occurred and water clarity had been drastically reduced. More importantly, there is growing evidence that the littoral zones of large lakes worldwide – from Lake Baikal to Lake Superior - are degrading at an alarmingly rapid rate.

Cyanobacterial periphyton exposed above water at Rubicon Pt. during low lake level, November, 2015.

Thick, furry coverage of the stalked diatom *Gomphoneis herculeana* at the Pineland site.

RECENT RESEARCH UPDATES

How do we maintain a healthy forest?

The health of the Lake Tahoe Basin's forests is subject to a range of threats, not the least of which are those posed by native insects. With funding from the CalFire Greenhouse Gas Reduction Fund Program, Dr. Tricia Maloney's team is conducting research to provide scientific and practical guidance to enable pest management interventions that benefit the carbon balance of the Basin, help sustain water supply, reduce the frequency and intensity of destructive wildfires, increase forest resiliency to pests and drought, and protect valuable ecosystem services and natural resources. Carbon sequestration in Sierra Nevada forests is highly dependent on the dynamics of insects and pathogens, but it is unclear how the thinning of dense stands and prescription fire interact with outbreak dynamics. Dr. Maloney is currently evaluating fuel reduction treatments for their effectiveness in mitigating bark beetle outbreaks, the spread and intensification of pathogens, increasing forest resiliency to drought, and increasing tree growth rates (and subsequent carbon storage).

Bark beetles feed on inner bark (phloem) and will preferentially attack drought

Resilient seed sources are collected for mountain pine beetle outbreak recovery or post-wildfire restoration.

Dead and dying trees are a familiar sight in the Tahoe basin.

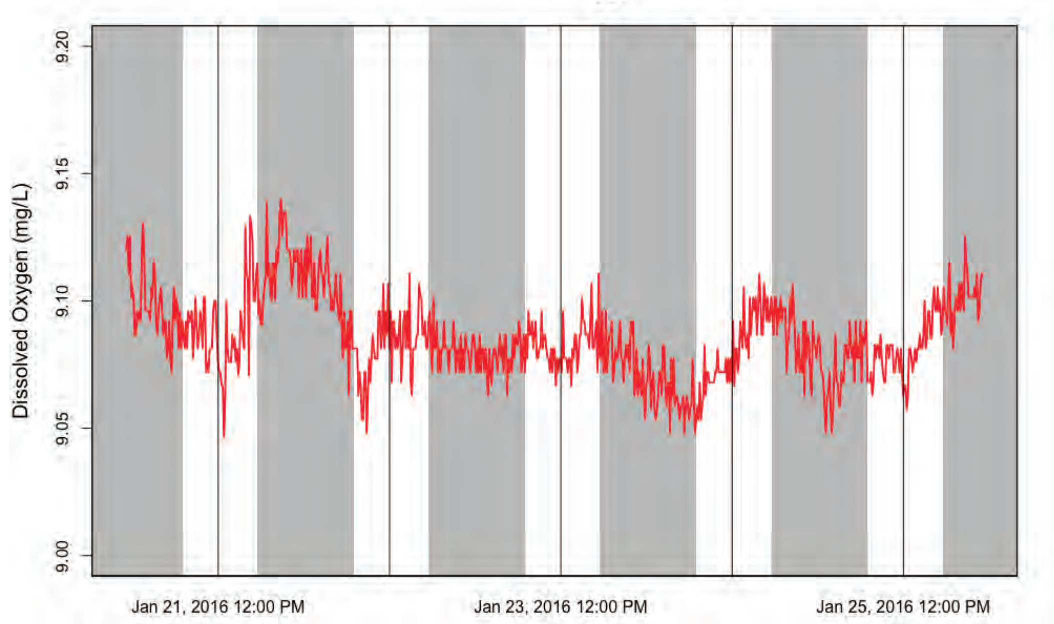
RECENT RESEARCH UPDATES

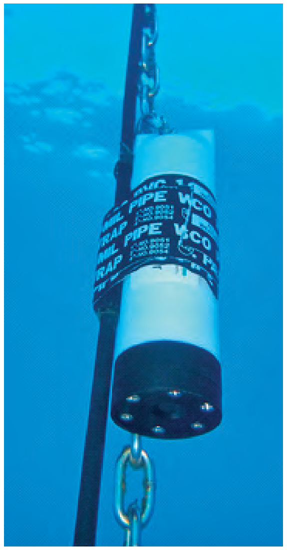
Measuring the metabolism of Lake Tahoe

The metabolism of a lake is typically separated into the primary productivity or PPr (the rate of increase of algal biomass) and respiration (the rate of loss of algal biomass). These are both important parameters for the lake and for CO2 uptake and release. Since the 1960s, PPr at Lake Tahoe has been measured monthly (or more often) using Carbon-14, a technique pioneered by Dr. Charles Goldman. This has shown that the PPr of the lake has been increasing substantially. This method, however, has the limitation that it yields no information on respiration.

In the last few years, rapid response dissolved oxygen (DO) sensors have made it possible to accurately measure changes in DO in the lake. As DO concentrations increase due to photosynthesis (the process whereby algal biomass is produced) and decrease due to respiration, by measuring DO concentration continuously we potentially have continuous measures of both PPr and respiration.

TERC has been testing DO sensors during 2016 to see whether the results are comparable with the highly accurate Carbon-14 results. The figure below shows the variation of dissolved oxygen that occurs during the day-night cycle at a depth of approximately 7 feet. The gray bars indicate night time. During the day DO is seen to increase, and then decrease at night. The smaller scale fluctuations in the measured DO is due to variations in light due to clouds and smoke, variations in nutrient availability due to the complex currents of the lake, and microbial processes. DO sensors are deployed at 8 depths, with the changes at each depth dependent on the light and the nutrient availability.





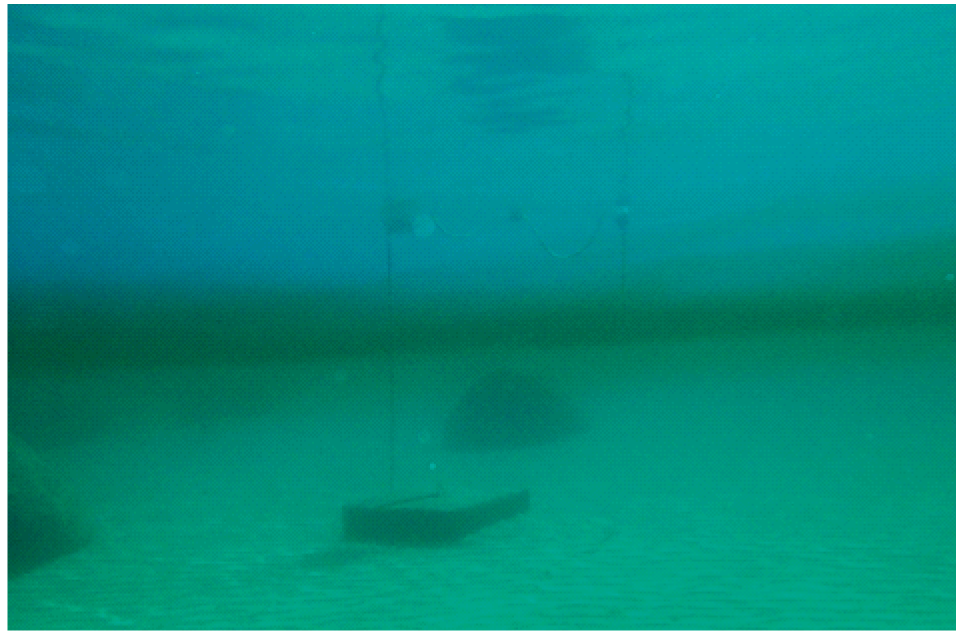
A dissolved oxygen sensor deployed in Lake Tahoe.

RECENT RESEARCH UPDATES

Where does stream water go?

When stream water flows into Lake Tahoe in the spring, it is generally very cold due to the large fraction of snowmelt. As the fraction of snow in our precipitation decreases, it is expected that the stream inflows will enter the lake warmer, and hence less dense. As the density of the lake varies in the spring – lighter at the top and heavier at the bottom – due to the water temperature, it follows that stream inflows will insert themselves at progressively higher levels. Is there any evidence to support this?

The photo below (taken by Brant Allen) shows a rare photo of a stream intrusion in 10 foot deep water in Meeks Bay, taken on April 20, 2016. The anchor and chain of a boat buoy are clearly seen, as are the buoys floating on the surface above. The intrusion is the thin, dark layer seen at mid height in the photo. The layer is approximately 6 feet above the bottom, and has a thickness of about 6-8 inches. A nearby stream was seen to be discharging water that was high in tannins (dissolved organic carbon).



The thin, dark intrusion layer can be seen horizonally cutting through this photo. Photo: B. Allen

Looking down from the boat, the presence of this layer was not detectable. However, such layers have a deleterious impact on the clarity, and would reduce the amount of light and especially of UV radiation that reaches the bottom sediments. High levels of UV radiation are an important factor in suppressing the successful reproduction of invasive fish species and in reducing the growth of invasive aquatic plants such as Eurasian milfoil. Such layers would also produce a reduction in the measured Secchi depth.

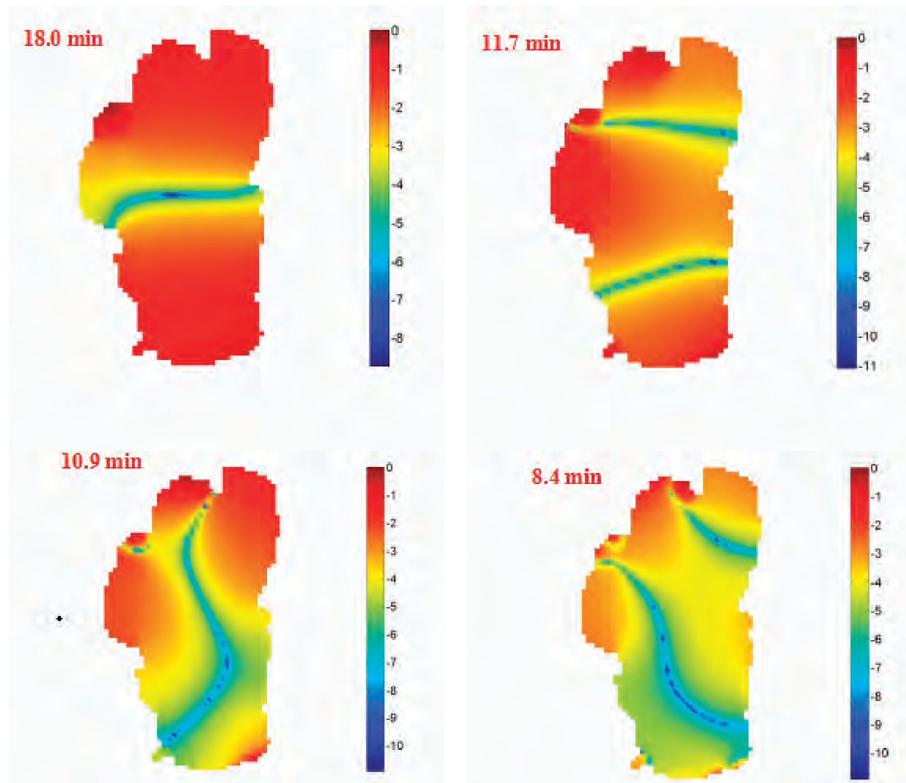
RECENT RESEARCH UPDATES

The waves of Lake Tahoe–more than meets the eye

Sitting on the edge of the lake, one can see the regular breaking of waves on the shore every 2-3 seconds. But the surface of the lake is actually varying more than it seems. Every time the wind blows for a few hours or more, it excites a different kind of wave – a seiche (pronounced say-sh). First observed in Lake Geneva in the late 1800s, seiches are "standing waves" that have much longer periods than the waves we so easily see at the shore. They are unique in every lake and depend on the size and shape of the lake, and the underwater topography.

In Lake Tahoe, we have four dominant seiches, with periods (the length of time it takes a compete oscillation to occur) varying from 18 minutes to about 8 minutes. Seiches are best thought of as a rocking of the entire lake surface, with troughs (nodes) and crests (antinodes). The figure below illustrates the 4 dominant Tahoe nodes, with the blue tones indicating the location and shape of the node, and the red tones indicating the locations of maximum seiche amplitude (the crests).

Can you ever see them? Unlikely, as the maximum amplitude in Lake Tahoe is only 1-2 inches. But they are extremely important. Unlike the wind waves, that are imperceptible at a depth of 20 feet, the motions produced by seiches extend all the way to the bottom of the lake at 1650 feet. The motions they produce through the entire water column are critical in preventing the stagnation of deep water, and helping to redistribute nutrients and oxygen.



RECENT RESEARCH UPDATES

Climatic eutrophication – A Mechanism of Change in Lake Tahoe

In recent years, researchers at Lake Tahoe have been investigating the long-term effects of climate change on lake stability and how that restricts deep water renewal. While this has obvious immediate effects (reducing nutrient renewal in the lake, preventing dissolved oxygen supply from reaching the bottom of the lake, etc.), it also has long-term implications for the health of the lake. In an article in The Conversation (https://theconversation.com/climate-change-could-alter-the-chemistry-of-deepwater-lakes-and-harm-ecosystems-58612), researchers at the lake coined the term climatic eutrophication.

Unlike cultural eutrophication, the accelerated impact of anthropogenic nutrient enrichment on lakes, climatic eutrophication has the potential to affect entire regions by increasing lake water temperatures in both summer and winter. The resulting thermal stratification from these increased temperatures will act as a barrier to winter overturn in the lake and cause nutrients to accumulate in the surface waters. In the near future, this won't drive conditions seen in other shallower lakes such as harmful algal blooms Lake Erie in 2009 but has the potential to fundamentally alter the physics, chemistry and biology of Lake Tahoe.

Harmful algal bloom in Lake Erie, 2009. T. Archer, NOAA/Flickr, CC BY-SA

This process may have serious implications on long-term water supply and ecosystem dynamics on a regional scale (e.g. lakes and reservoirs in the western US, including Lake Tahoe). To understand these implications, and mitigate the risks they impose, it will be necessary for scientists, engineers and policy makers to identify lakes at risk of this phenomenon. The ongoing research at Lake Tahoe is critical for this process as both a localized test case and as being representative of lake systems in the western US and deep lakes worldwide.

TAHOE: STATE OF THE LAKE REPORT 2016

METEOROLOGY

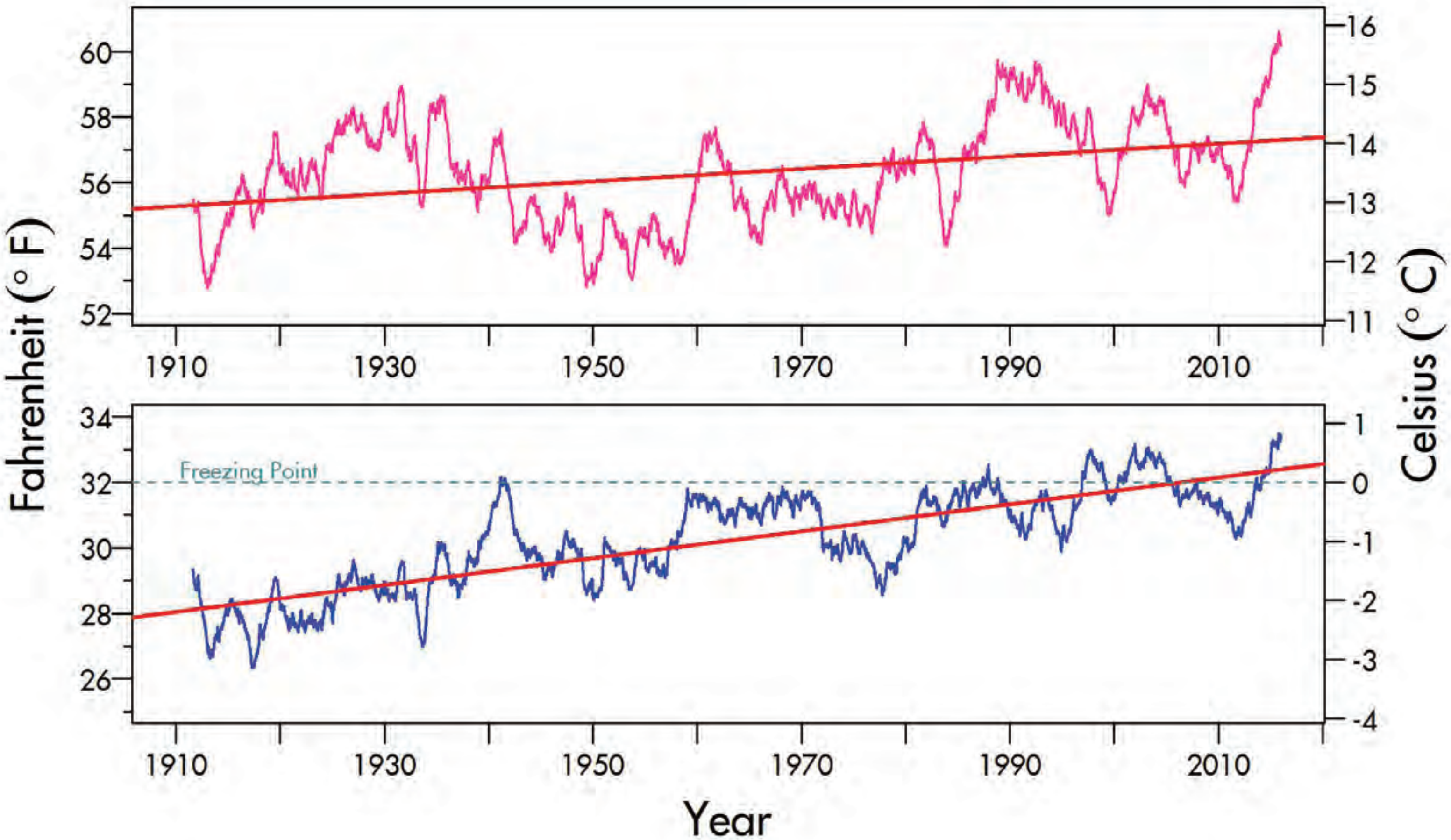
UCDAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

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 average daily minimum temperature (bottom figure) has increased by 4.3 °F (2.4 °C), and the long-term trend in average daily maximum temperature (upper figure) has risen by 2.0 °F (1.1 °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.

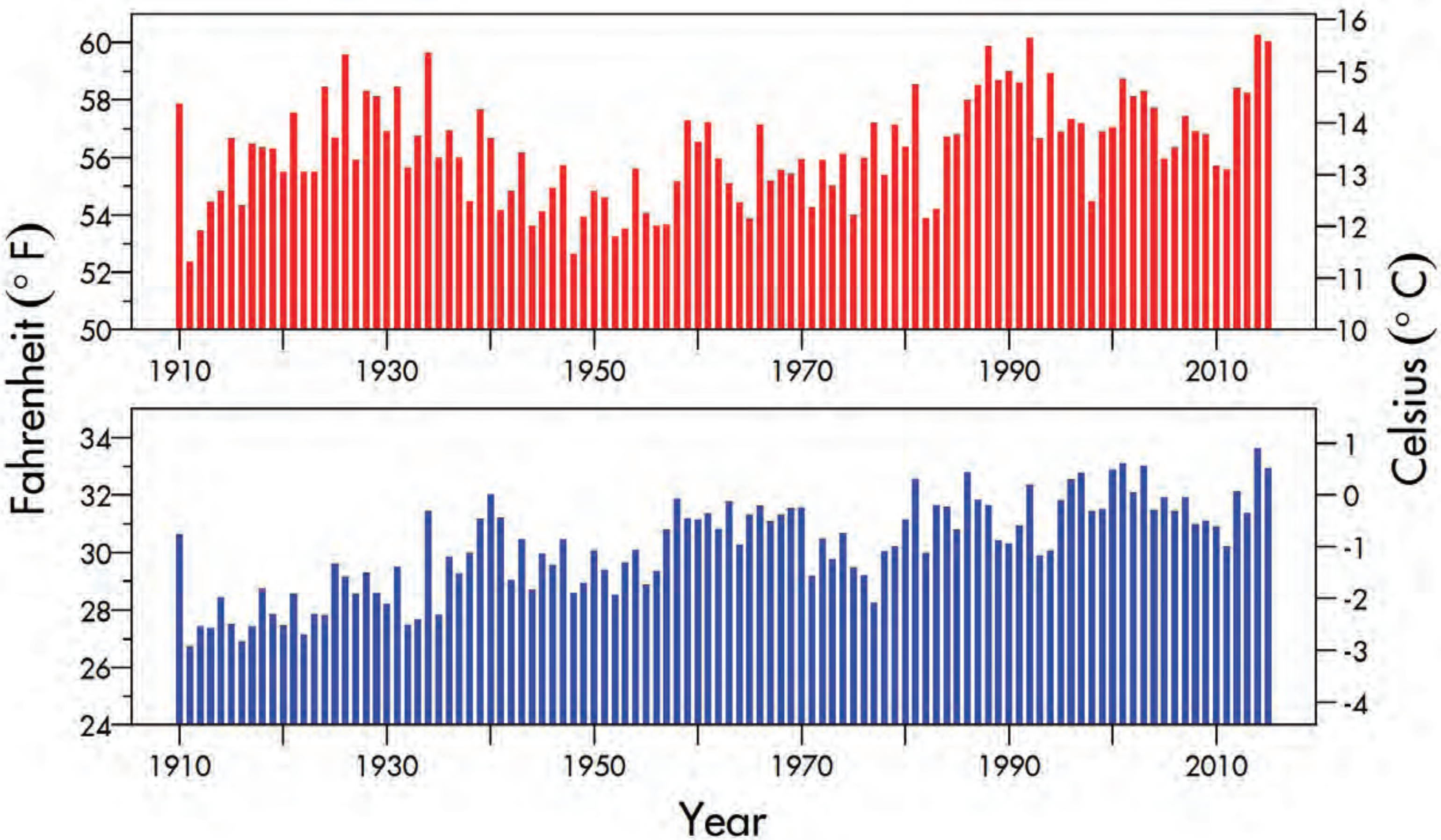


METEOROLOGY

Air temperature - annual average maximum and minimum

Since 1910

Annual average maximum (red) and minimum (blue) air temperatures in 2015 were both well above the long-term average and slightly below the values for the previous year. The 2015 annual average minimum was 33.0 °F (0.56 °C) a decrease of 0.7 °F over the previous year, and is the fourth highest ever recorded. The maximum temperature was 60.1 °F (15.6 °C) a decrease of 0.2 °F over the previous year, and is the third highest ever recorded. The long-term means for the minimum and the maximum are 30.3 °F (-0.96 °C) and 56.3 °F (13.5 °C), respectively.



METEOROLOGY

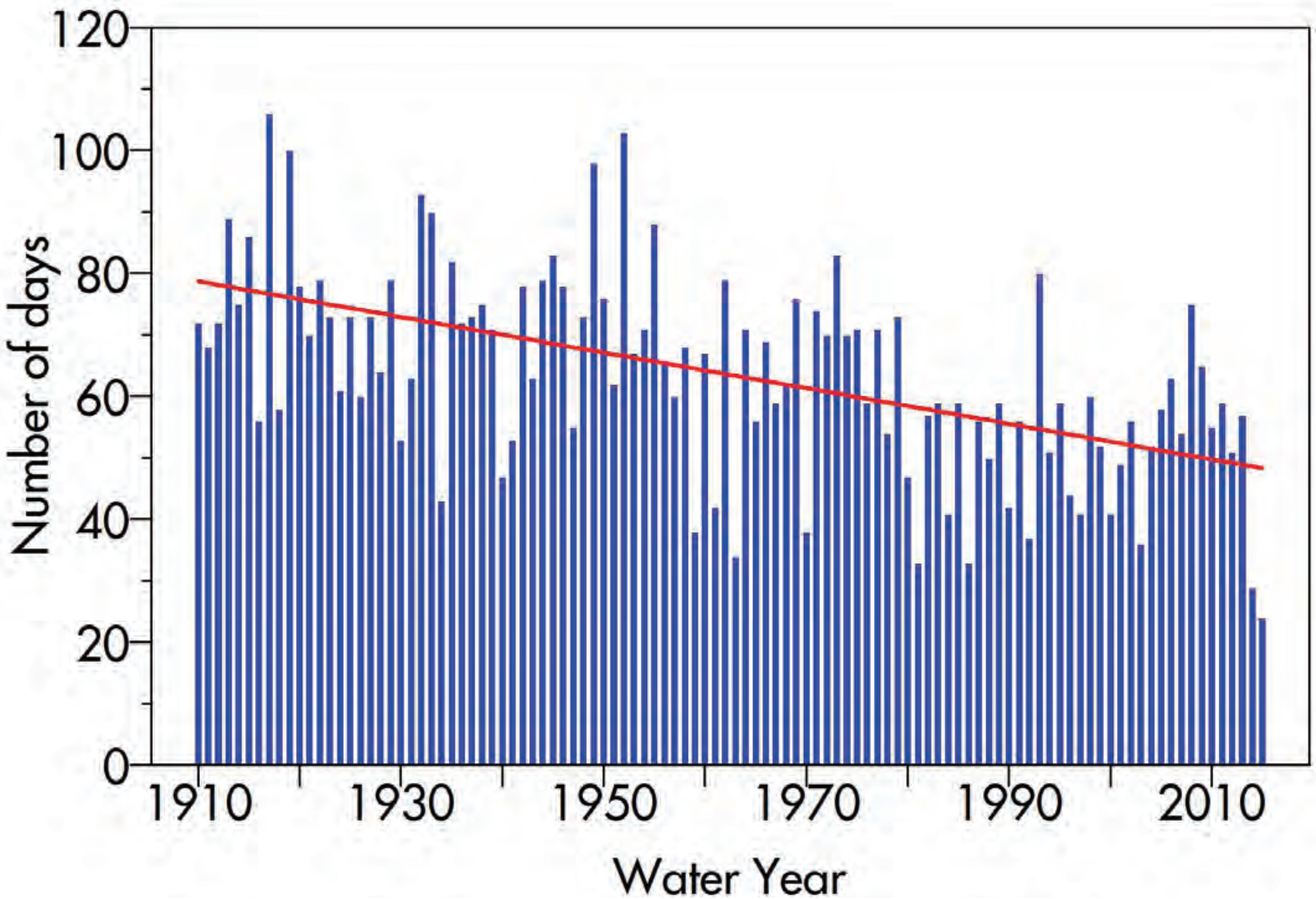
Below-freezing air temperatures

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

when air temperatures averaged below freezing has declined by about 30 days since 1911. In WY 2015, the number of freezing days was 24, the lowest ever recorded.

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

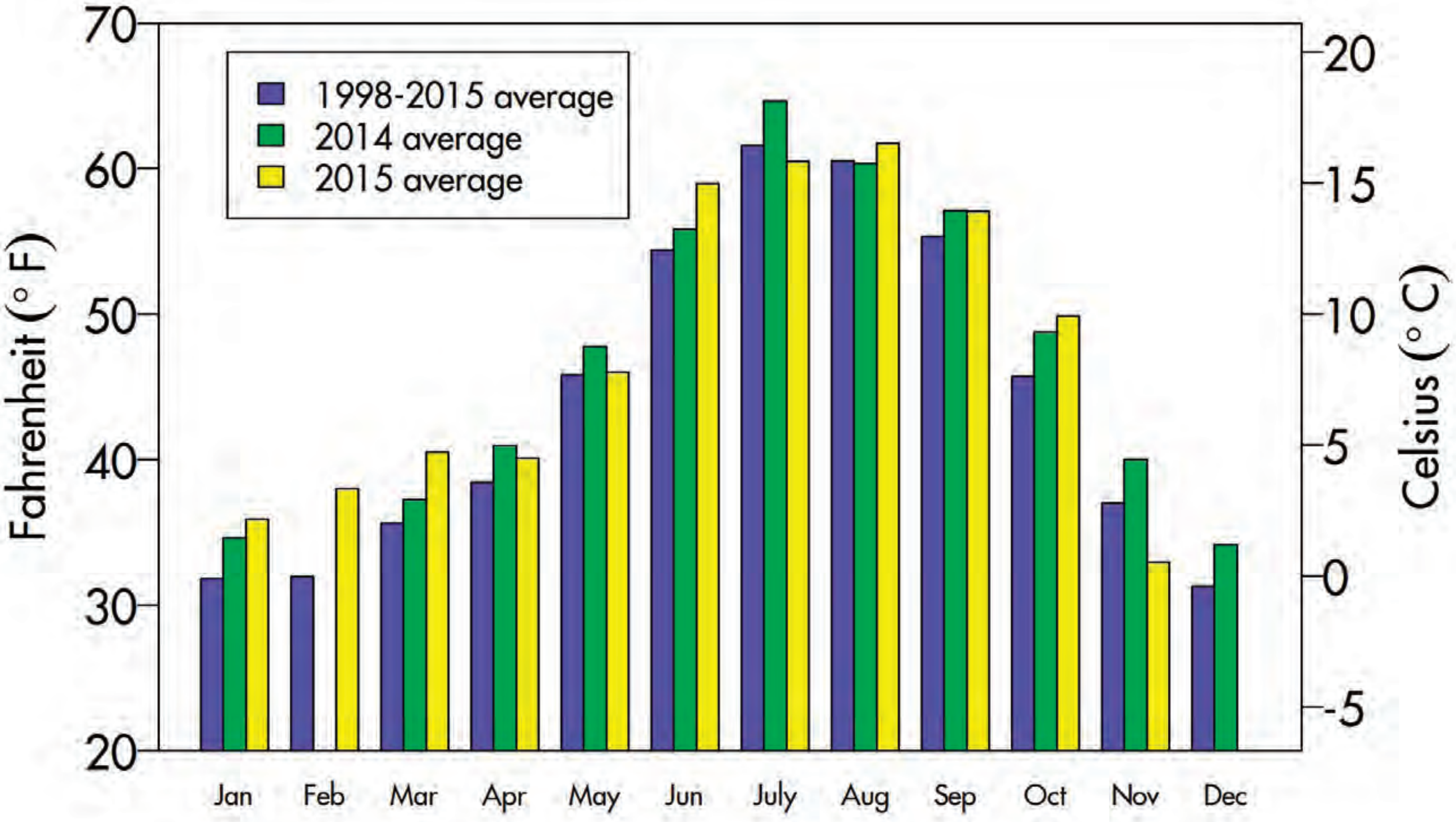


METEOROLOGY

Monthly air temperature

Since 1998

In 2015, monthly air temperatures were distinguished by being warmer than the long-term mean during seven months of the year. This trend is consistent with the global trend of generally warming temperatures. The winter months (Jan-March 2015) were significantly warmer. Months with more than 25 percent of days missing were omitted.

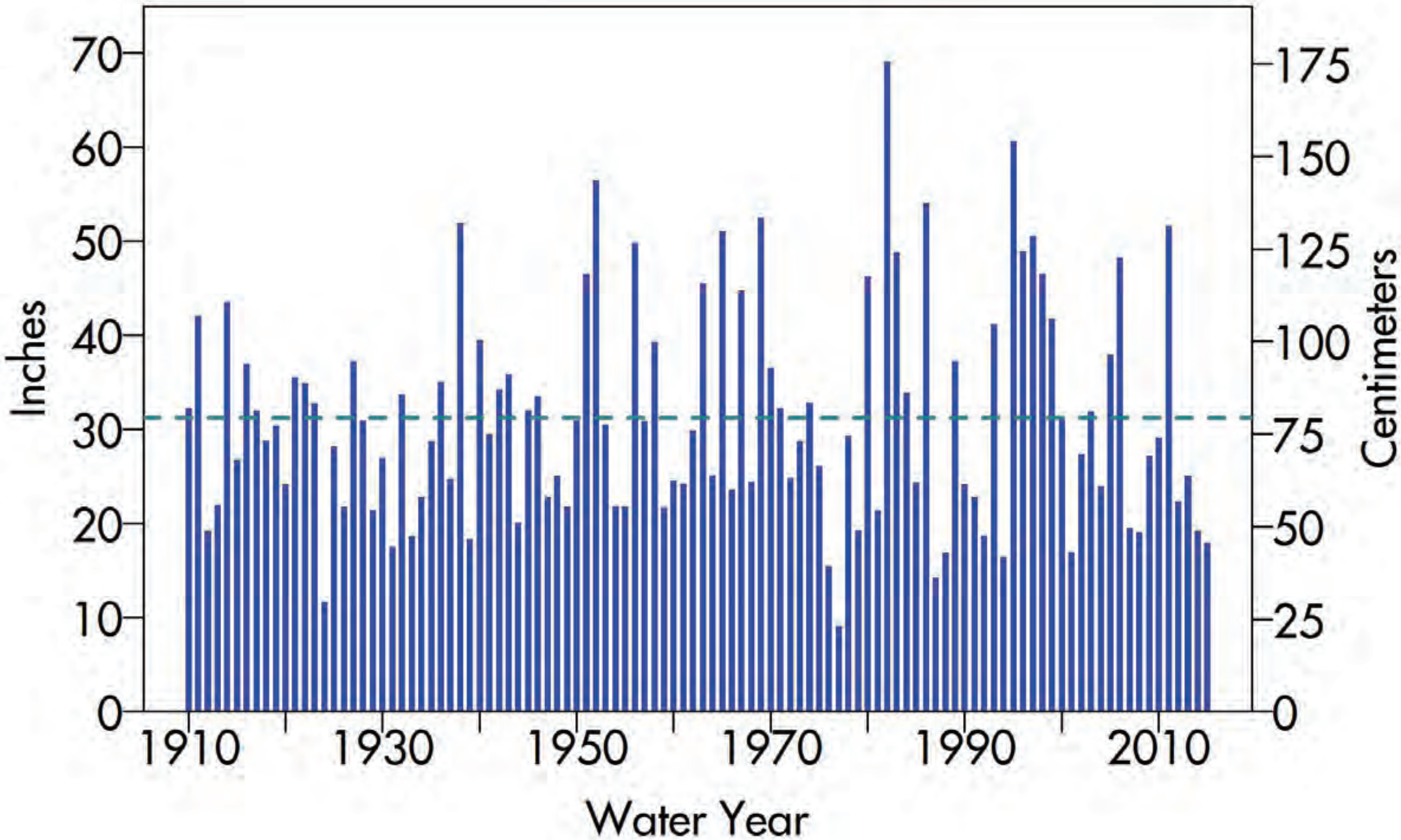


METEOROLOGY

Annual precipitation

Yearly since 1910

From 1910 to 2015, average annual precipitation (water equivalent of rain and snow) at Tahoe City was 31.4 inches. The maximum was 69.2 inches in 1982. The minimum was 9.2 inches in 1977. 2015 was well below average, with 18.1 inches, following the three previous dry years. The long-term mean of 31.3 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.)

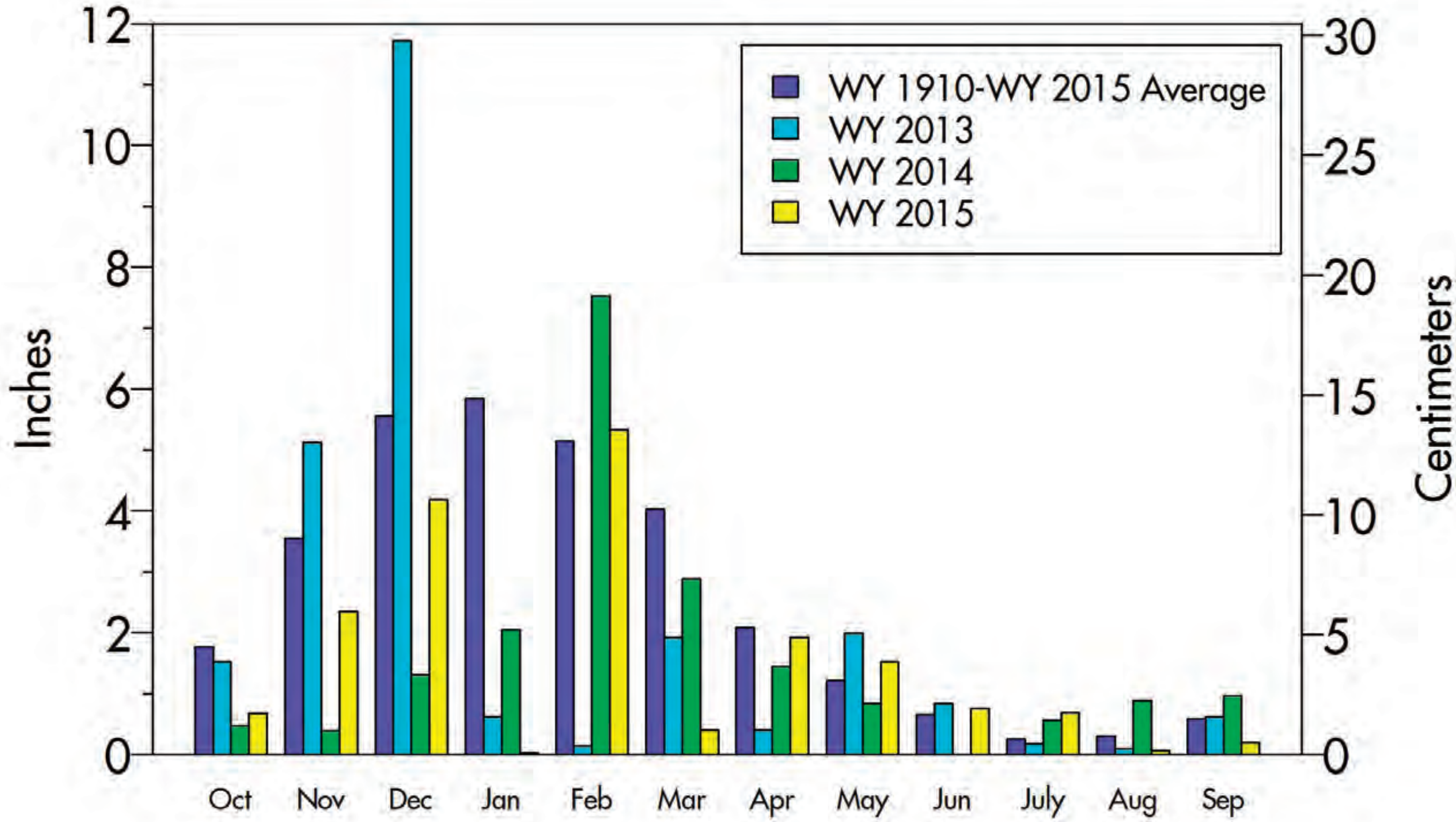


METEOROLOGY

Monthly precipitation

2013, 2014, 2015 and 1910 to 2015

2015 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 2015 was particularly lower than the long-term average during summer, especially August and September. The monthly precipitation for Jun-2014 (WY 2014) was 0 inches. The 2015 Water Year extended from October 1, 2014, through September 30, 2015.

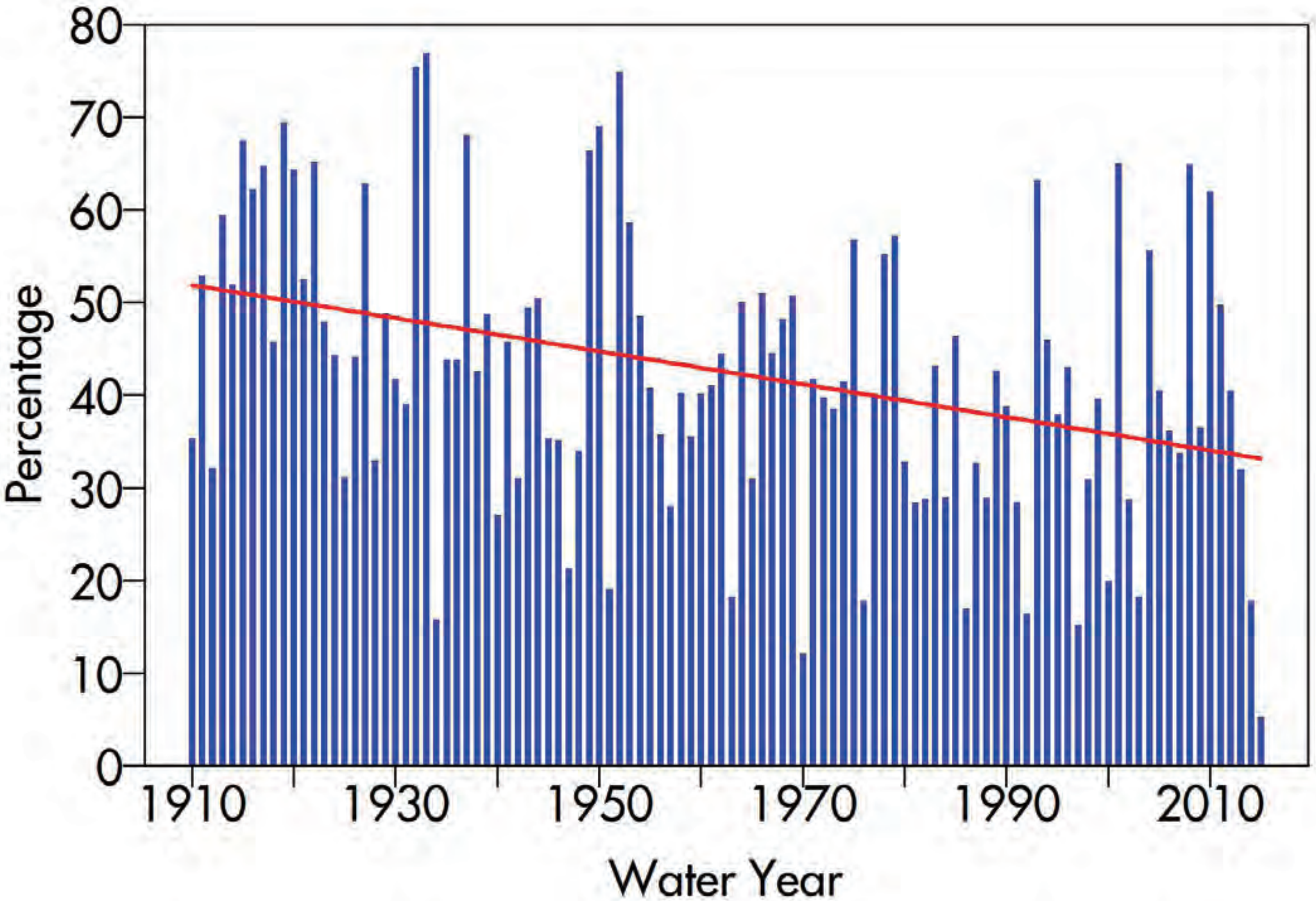


METEOROLOGY

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 33 percent in present times according to the line of best fit. In Tahoe City, snow represented 5.4 percent of the 2015 total precipitation, the lowest value 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.)

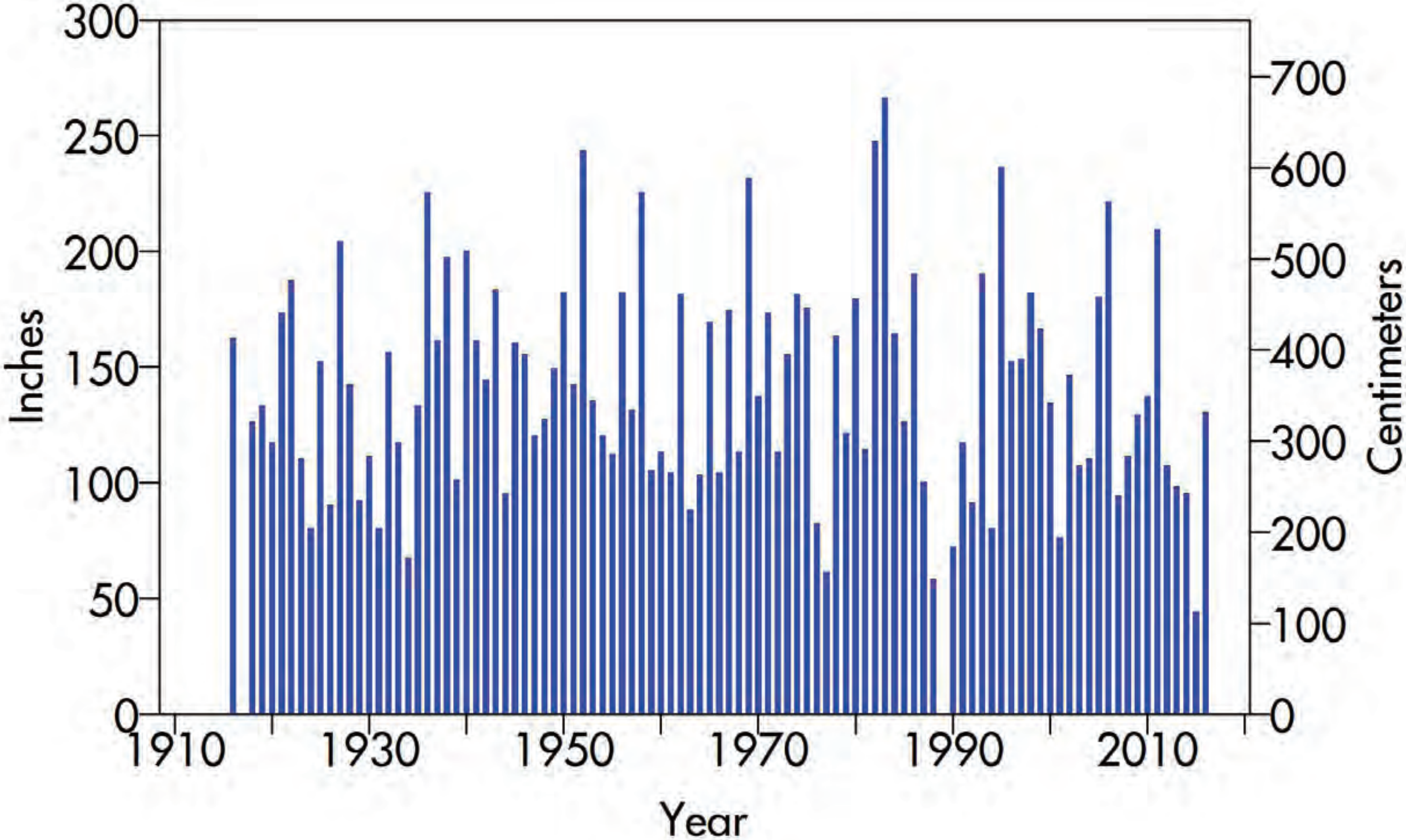


METEOROLOGY

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 2016 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 April 1, 2016 was 131 inches, representing a more normal year compared to the record low value in 2015. The average snow depth over the period 1916-2016 was 142 inches. Data source: USDA Natural Resources Conservation Service, California Monthly Snow Data.

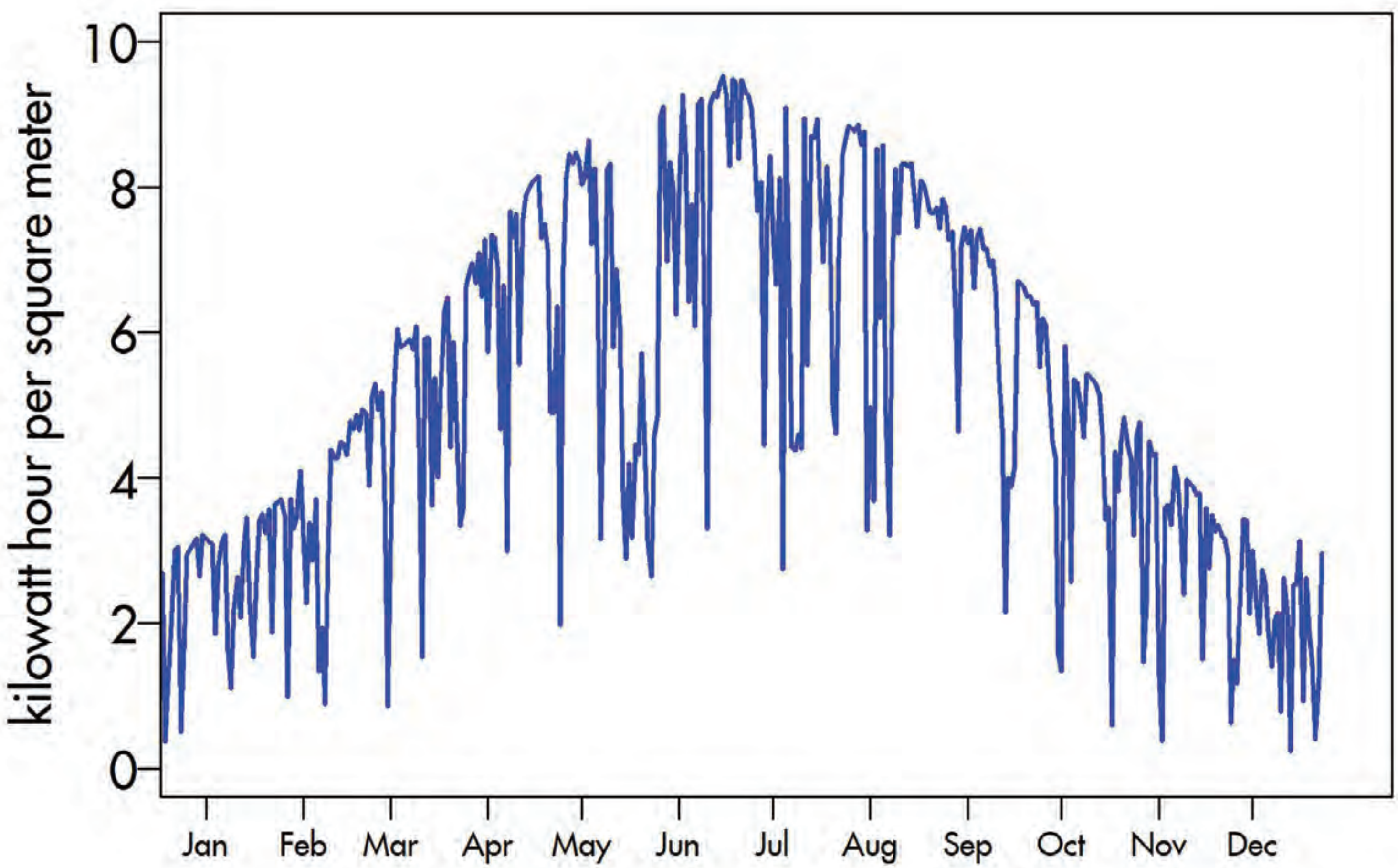


METEOROLOGY

Daily solar radiation

In 2015

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 2016

PHYSICAL PROPERTIES

UC DAVIS TAHOE ENVIRONMENTAL RESEARCH CENTER

PHYSICAL PROPERTIES

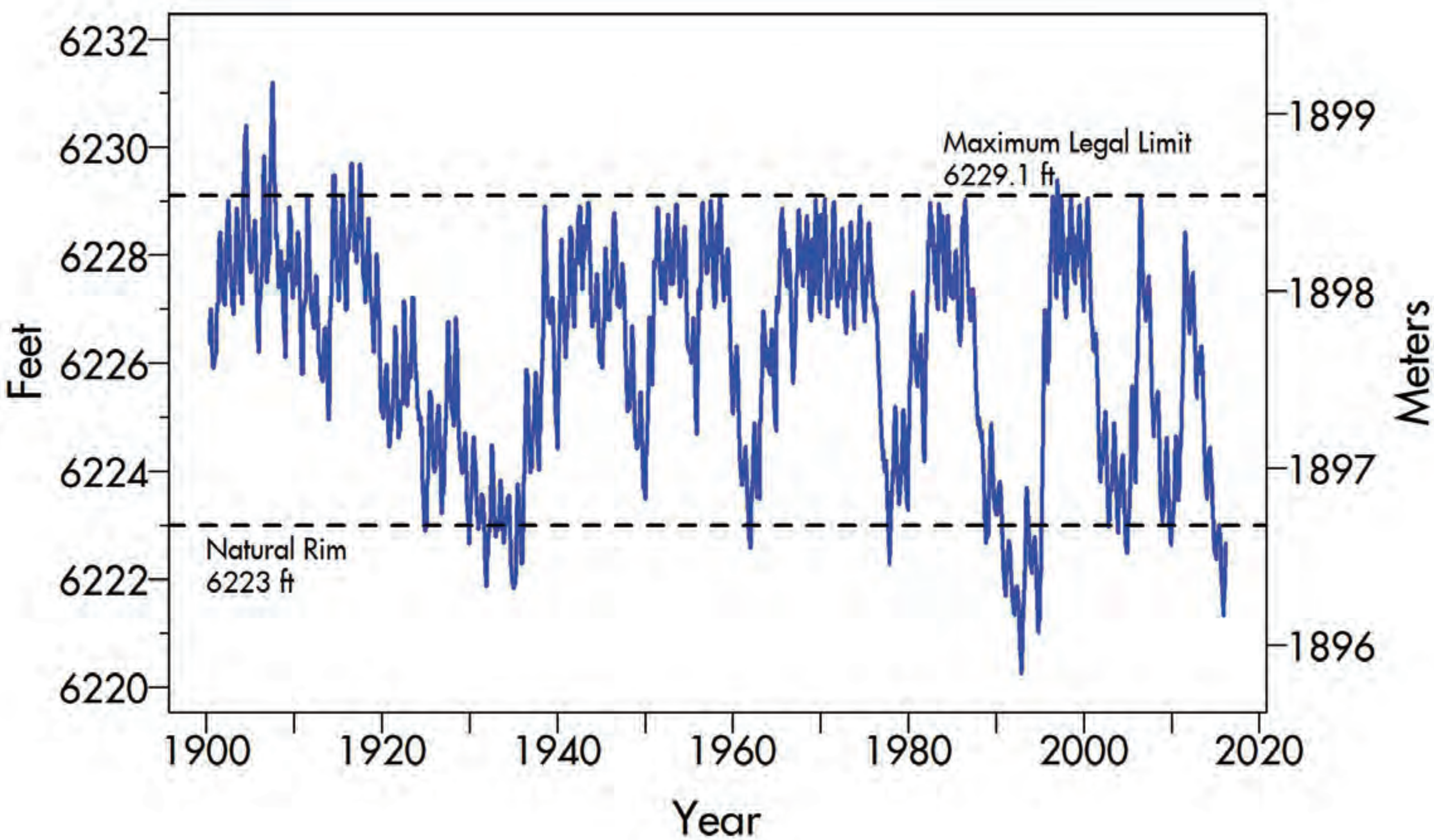
Lake surface level

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 by about 9 inches during 2015. The highest lake level was 6223.01 feet on June 10, and the lowest was 6221.33 feet on December 9. The natural rim of the lake is at an elevation of 6223 feet. Lake Tahoe was below its rim for almost the entire year, except for one day on December 9, 2015.

When the lake is below its rim, outflow via the Truckee River ceases. 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.

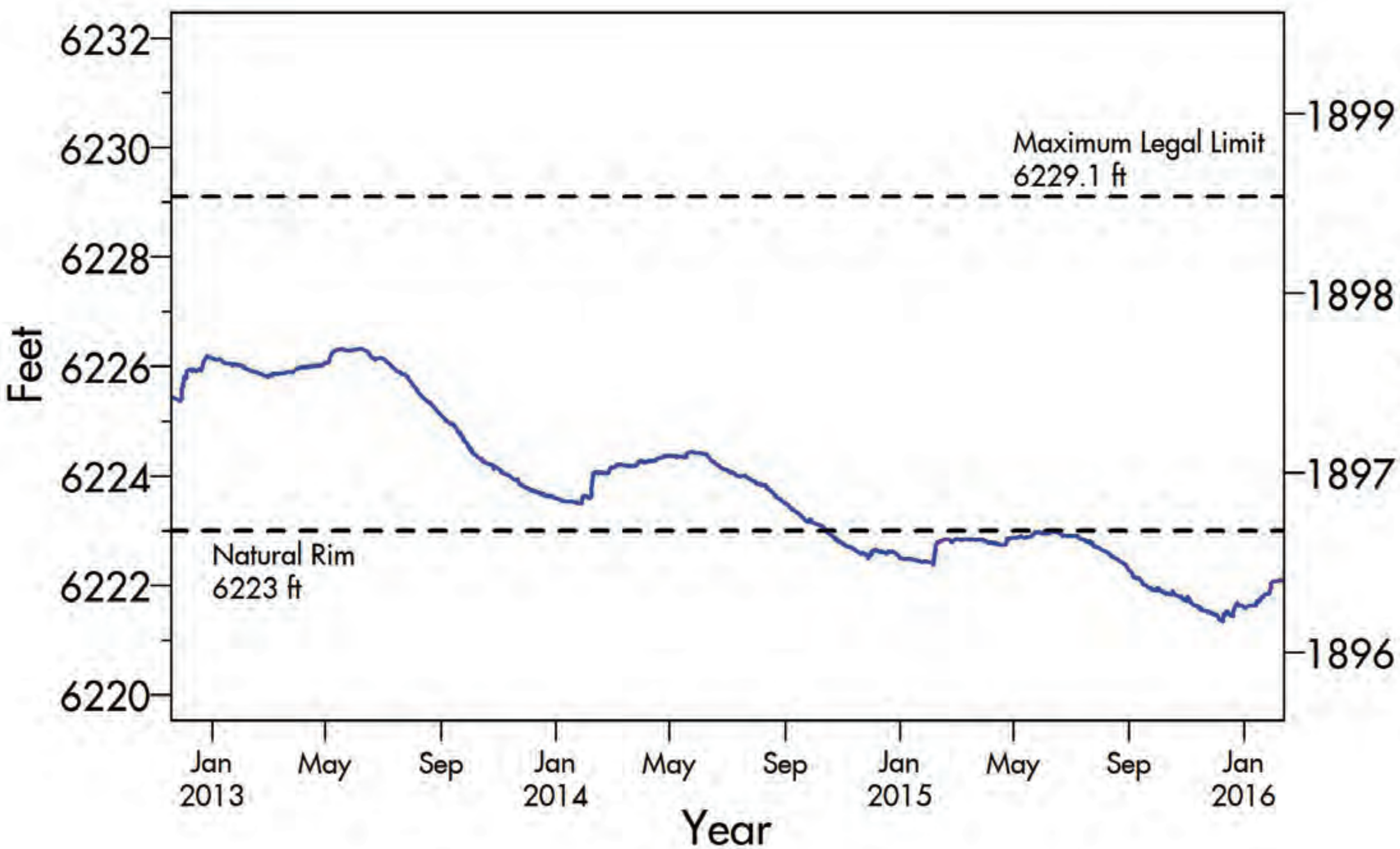


PHYSICAL PROPERTIES

Lake surface level, continued

Daily since 2013

Displayed below is the lake surface data from 2013-2015 extracted from the same data on page 8.1. This more time restricted presentation of recent lake level data allows us to see the annual patterns of rising level and falling level in greater detail. Data clearly show the lake level falling below the natural rim in October 2014 and its final level of 1.39 feet below the rim at the end of 2015. The effects of the drought on overall lake water level is evident.

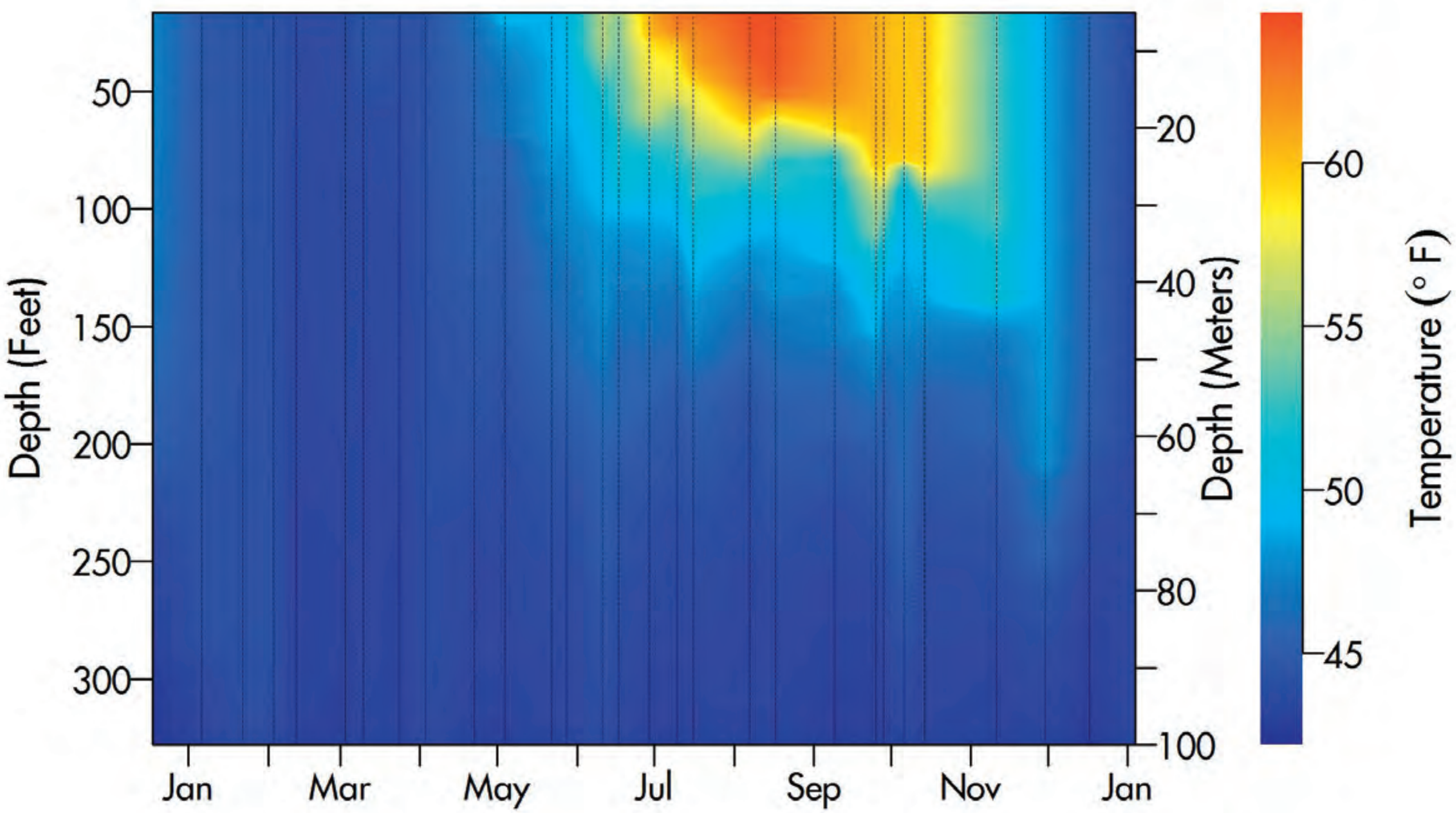


PHYSICAL PROPERTIES

Water temperature profile

In 2015

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 2015, 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 deepening of the warm water zone toward the end of the year is the result of winter mixing, a process that is important in bringing oxygen to the deeper parts of the lake.

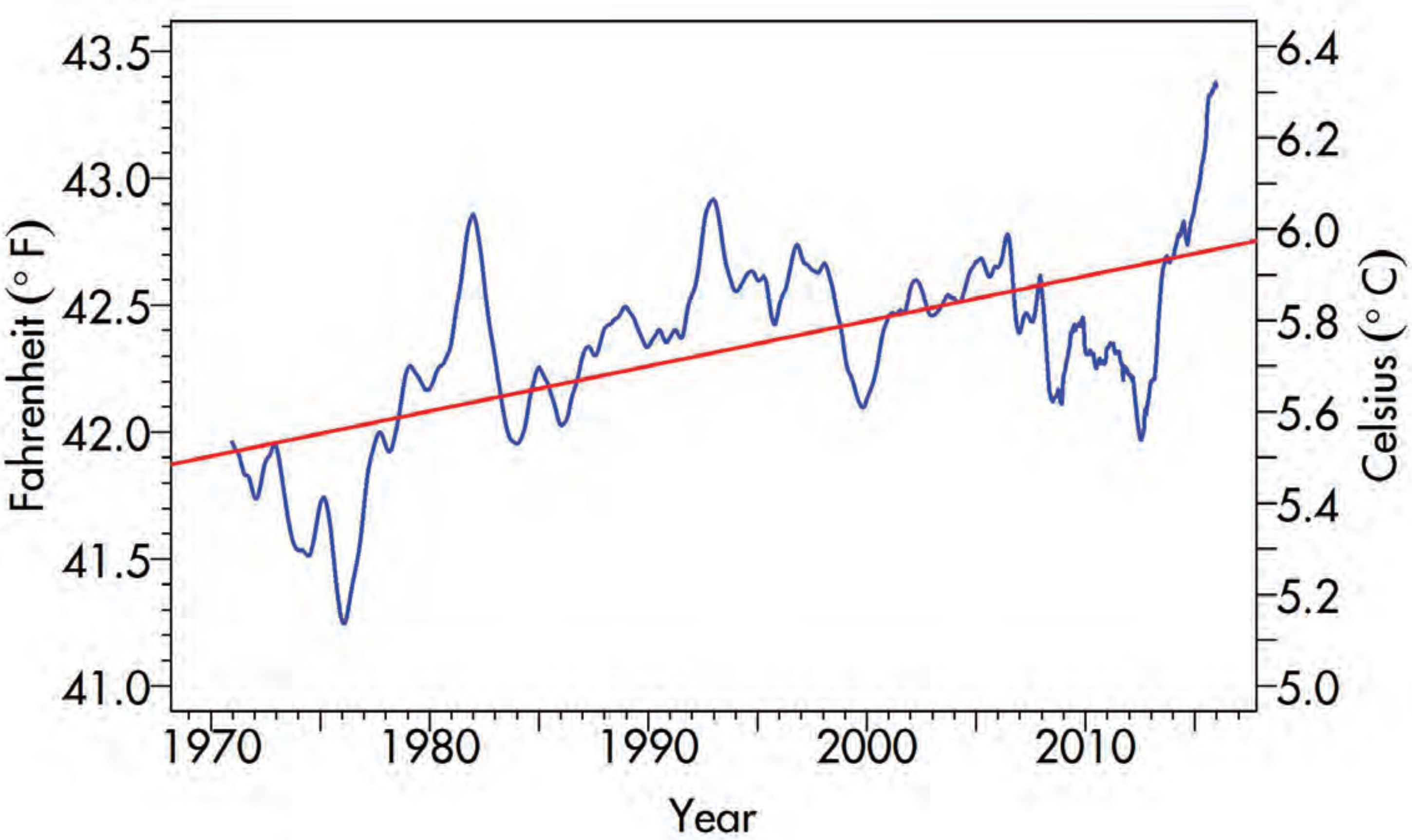


PHYSICAL PROPERTIES

Average water temperature

Since 1970

The trend in the volume-averaged temperature of Lake Tahoe has increased by approximately 0.8 °F since 1970. The annual rate of warming is 0.018 °F/year (0.01 °C/year). The monthly temperature profile data from the top to the bottom of 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 high, but a high number of deep mixing years between 1997 and 2011 caused the lake temperature to cool. Since that time, warming has accelerated to its highest recorded rate.

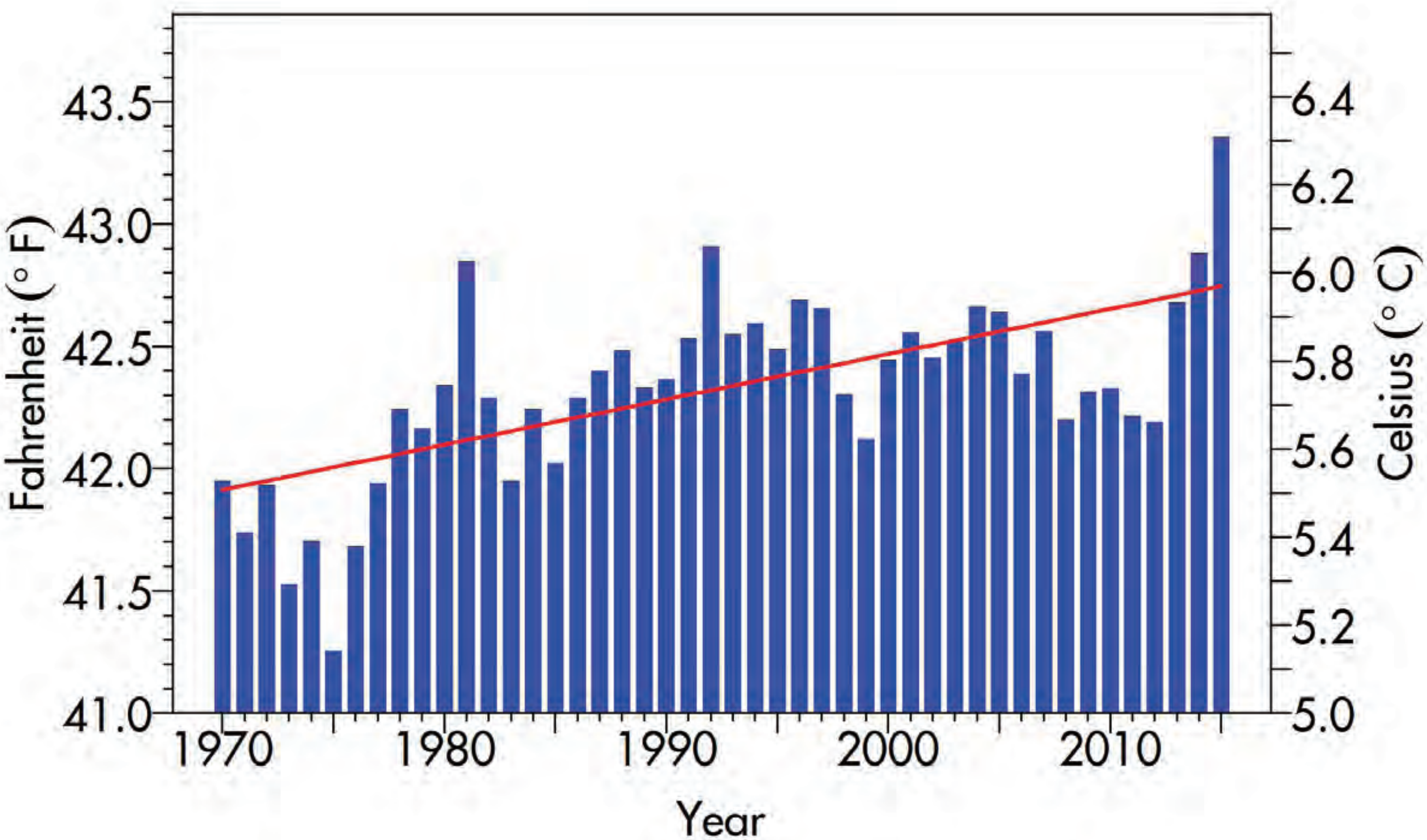


PHYSICAL PROPERTIES

Annual average water temperature

Since 1970

The volume-averaged temperature of the lake for each year since 1970 is shown. In 2015 the volume-averaged temperature increased by 0.48 °F (0.26 °C) over the previous year. In the last 4 years the lake has warmed at an alarming rate of over 0.3 °F/year, 15 times faster that the long-term warming rate. Increases in temperature generally correspond to those years in which deep mixing did not occur. This year deep mixing was the shallowest ever recorded.

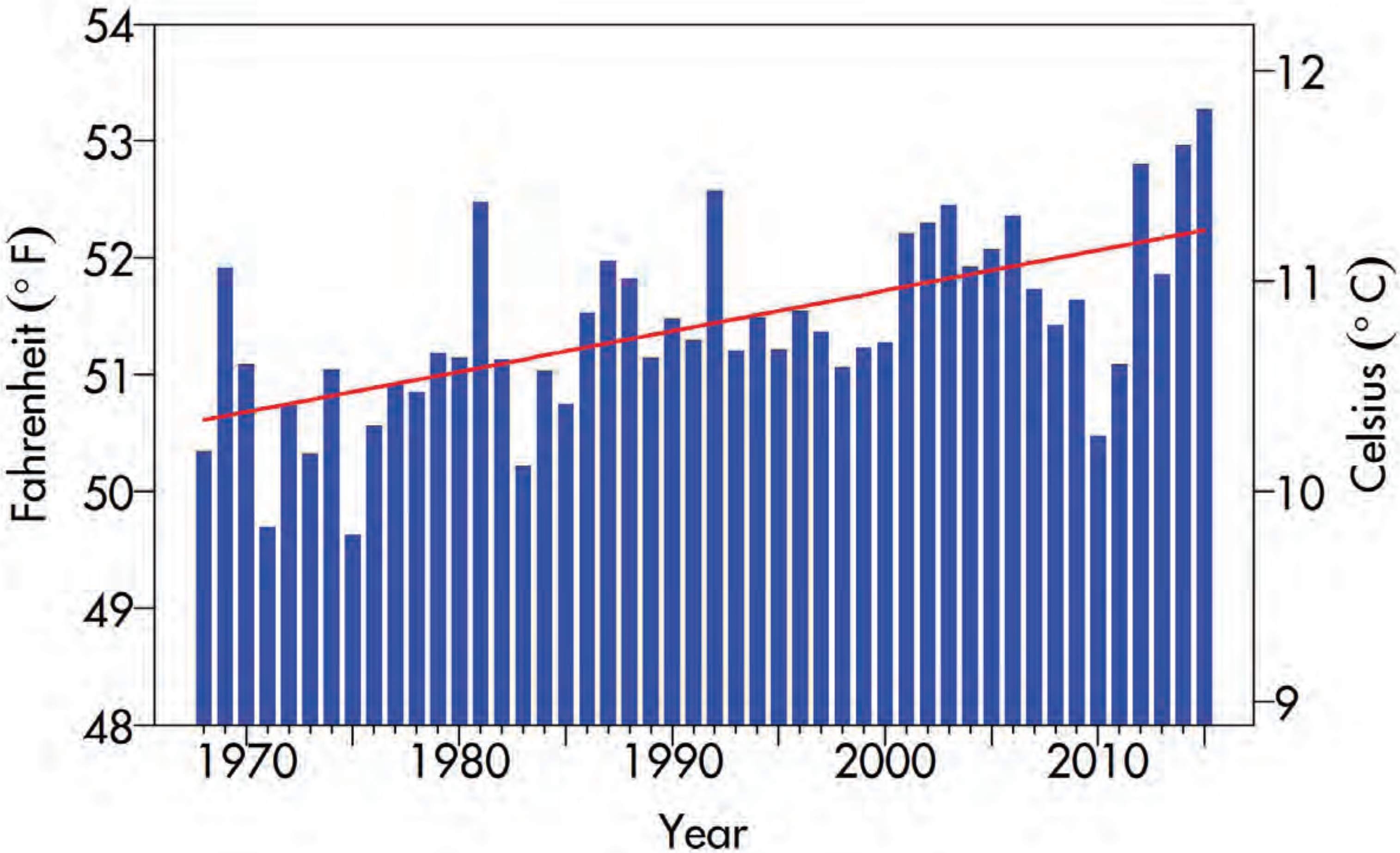


PHYSICAL PROPERTIES

Surface water temperature

Yearly since 1968

Surface water temperatures have been recorded monthly at the mid-lake and index stations 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 2015, the average surface water temperature was 53.3 °F (11.8 °C), making it the warmest year yet recorded. The overall rate of warming of the lake surface is 0.035 °F (0.019 °C) per year.

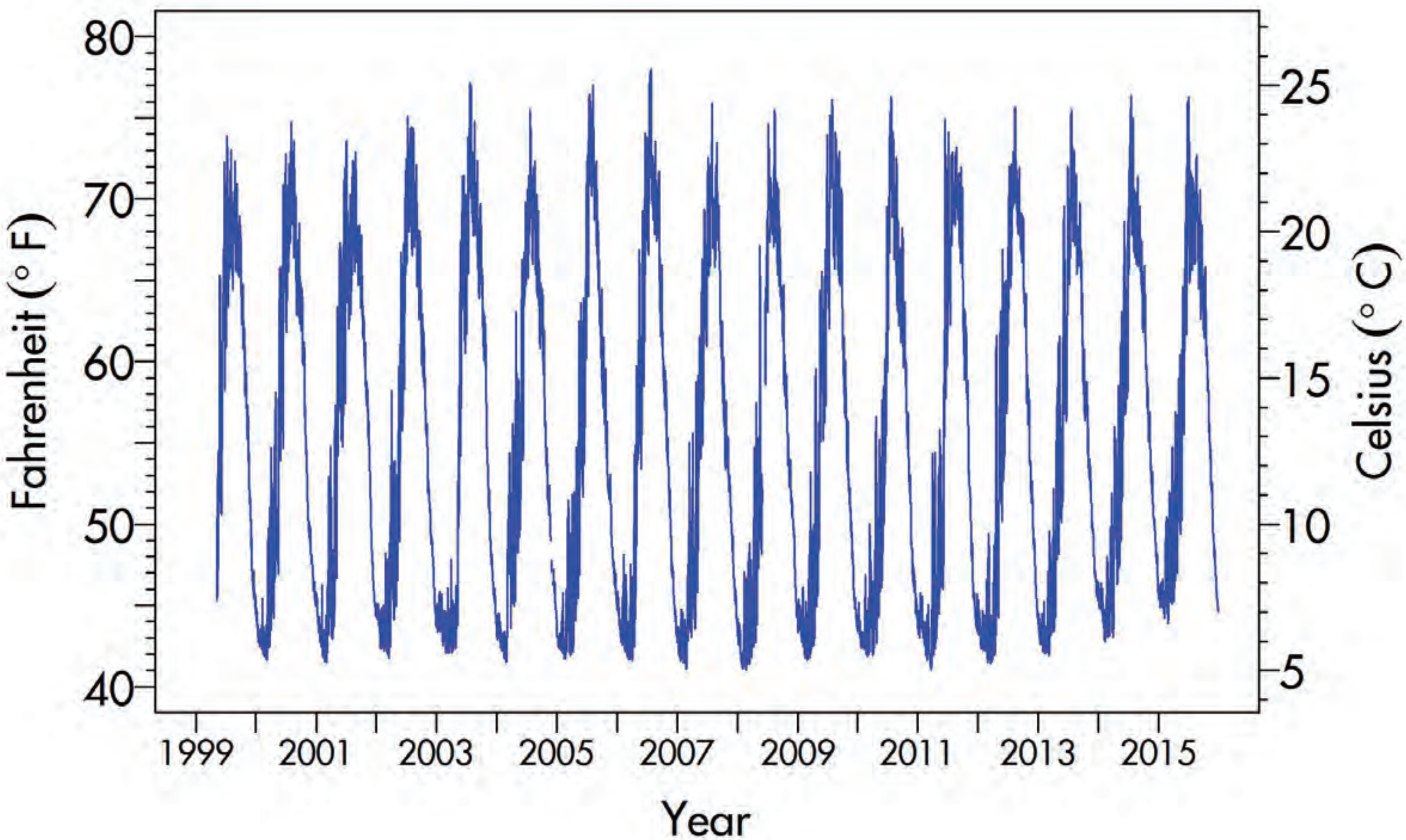


PHYSICAL PROPERTIES

Maximum daily surface water temperature

Surface temperature measured since 1999 every 2 minutes

The maximum daily summer surface water temperature in 2015 was similar to the previous year, 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 76.26 °F, which was recorded on July 2, 2015. The lowest maximum daily surface water temperature (winter) was 43.90 °F, which was recorded on March 1, 2015. These data are collected in real-time by NASA-JPL and UC Davis from 4 buoys located over the deepest parts of the lake.

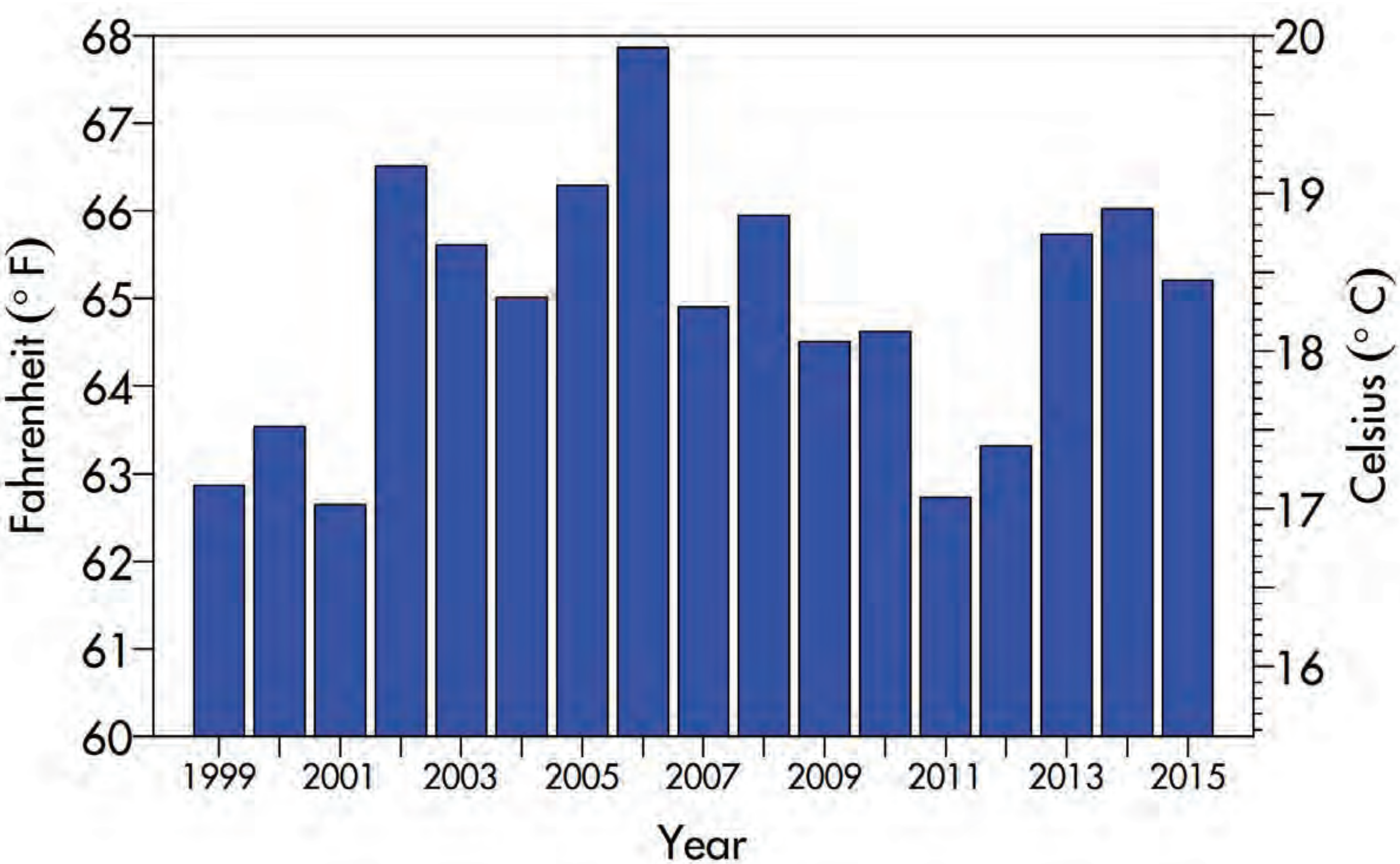


PHYSICAL PROPERTIES

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 17 years of average surface water temperatures in the month of July when water temperatures are typically warmest. In 2015, July surface water temperature averaged 65.2 °F. The warmest July temperatures were 67.9 °F in 2006. The average July surface water temperature for the 16 year period is 64.9 °F.

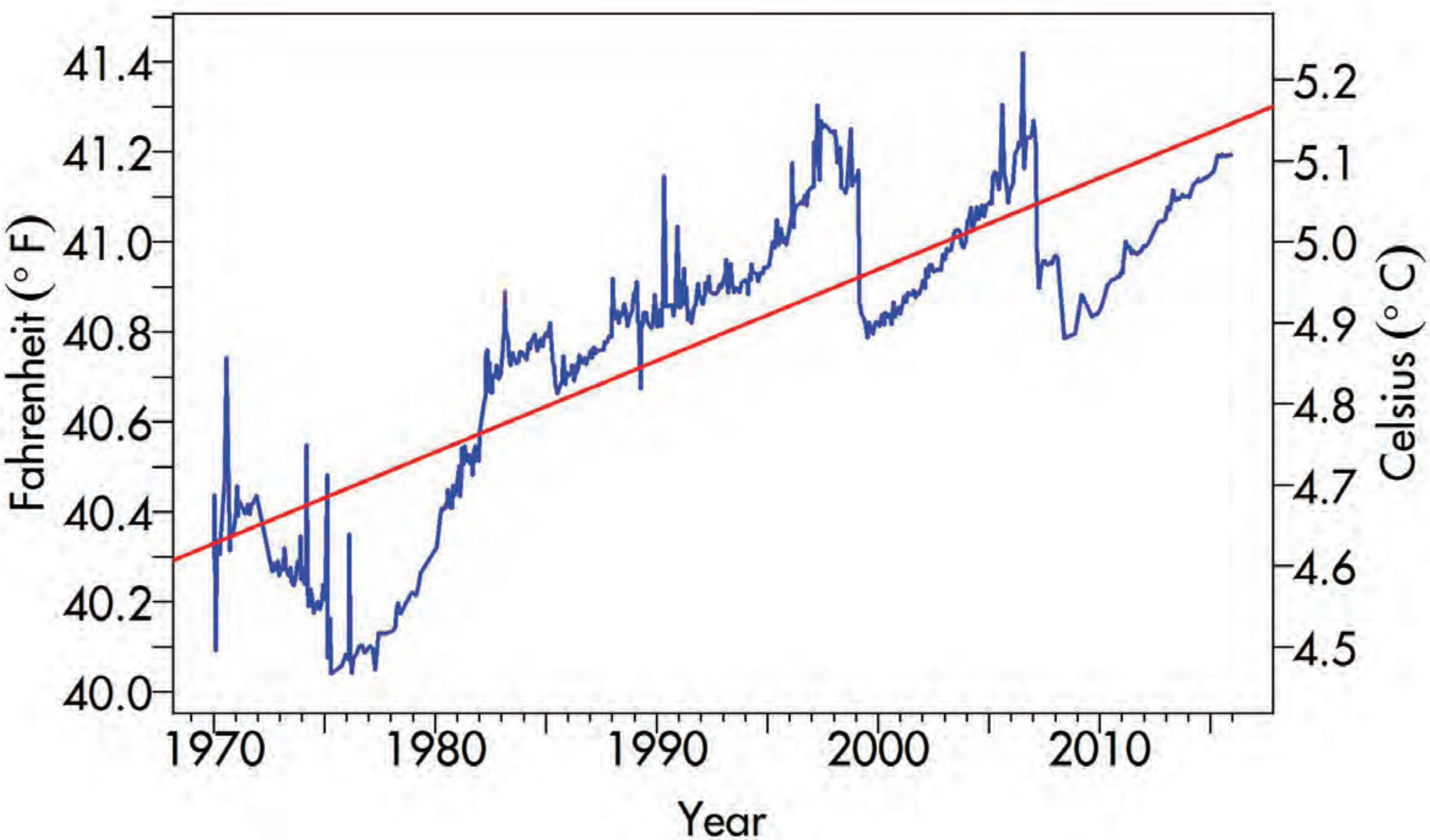


PHYSICAL PROPERTIES

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 0.020 °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.

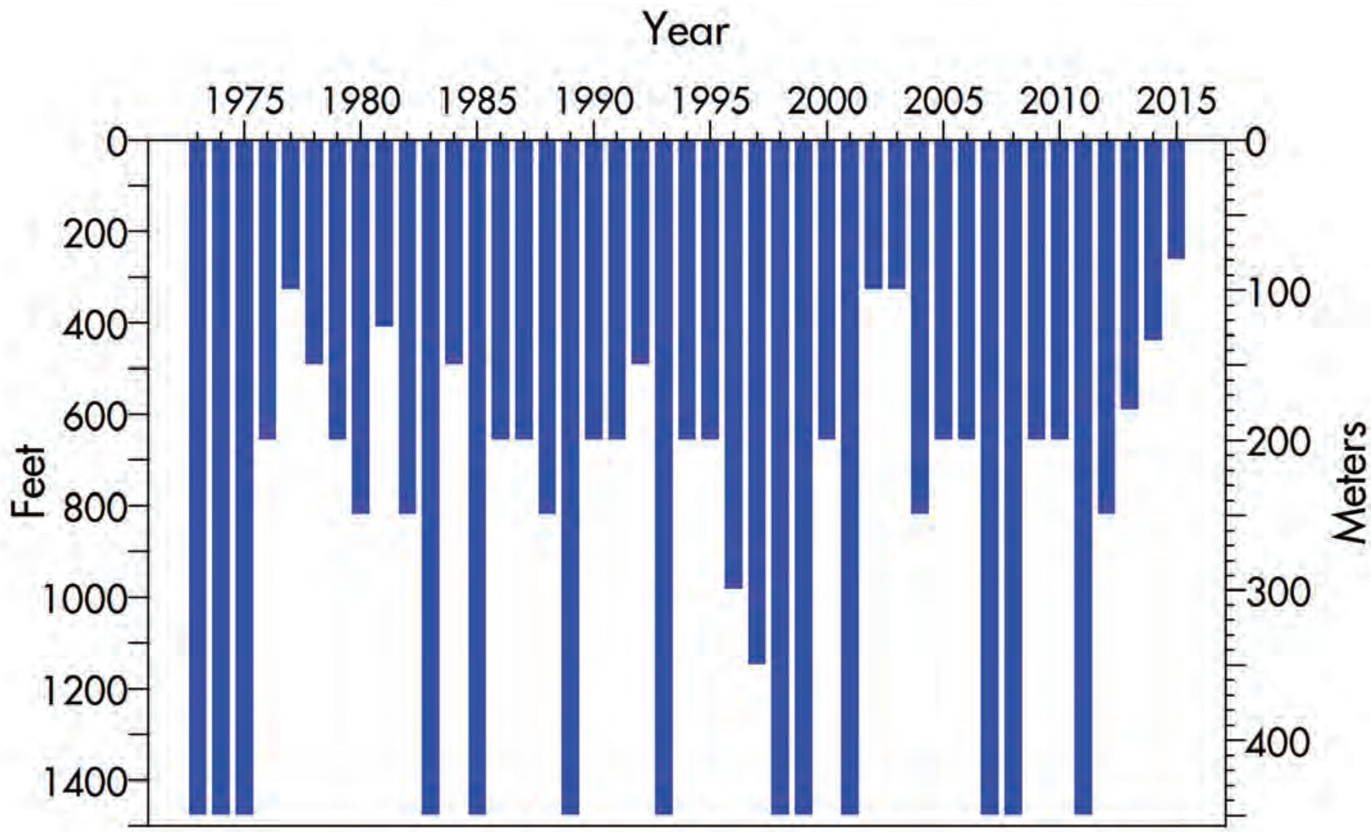


PHYSICAL PROPERTIES

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 2015, Lake Tahoe mixed to a depth of only 262 feet (80 m). This lack of deep mixing most likely contributed to the warm surface and bottom temperature, the continuing buildup of nitrate in the 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.

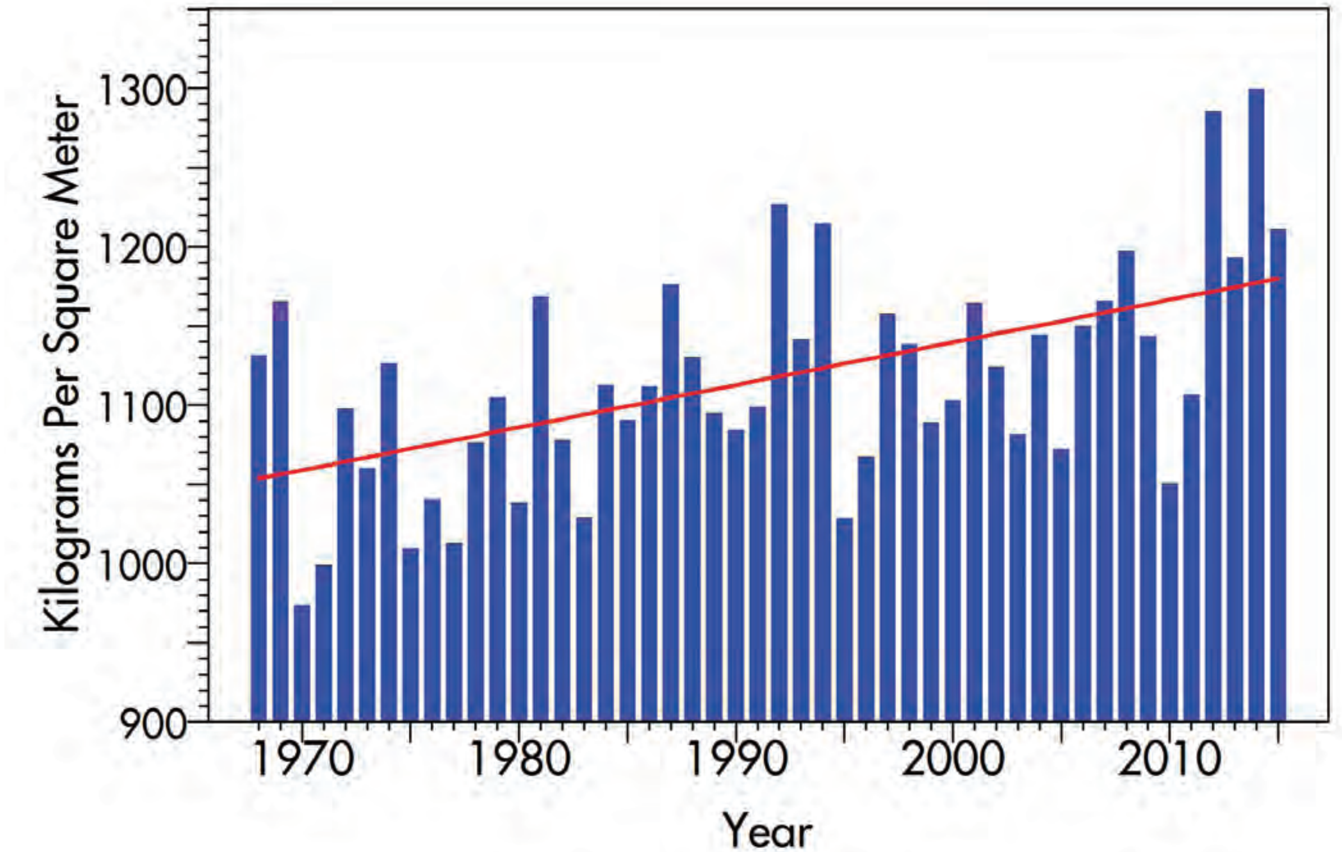


PHYSICAL PROPERTIES

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 2015, the stability of the lake fell, but it was still above the long-term rate of increasing stability.

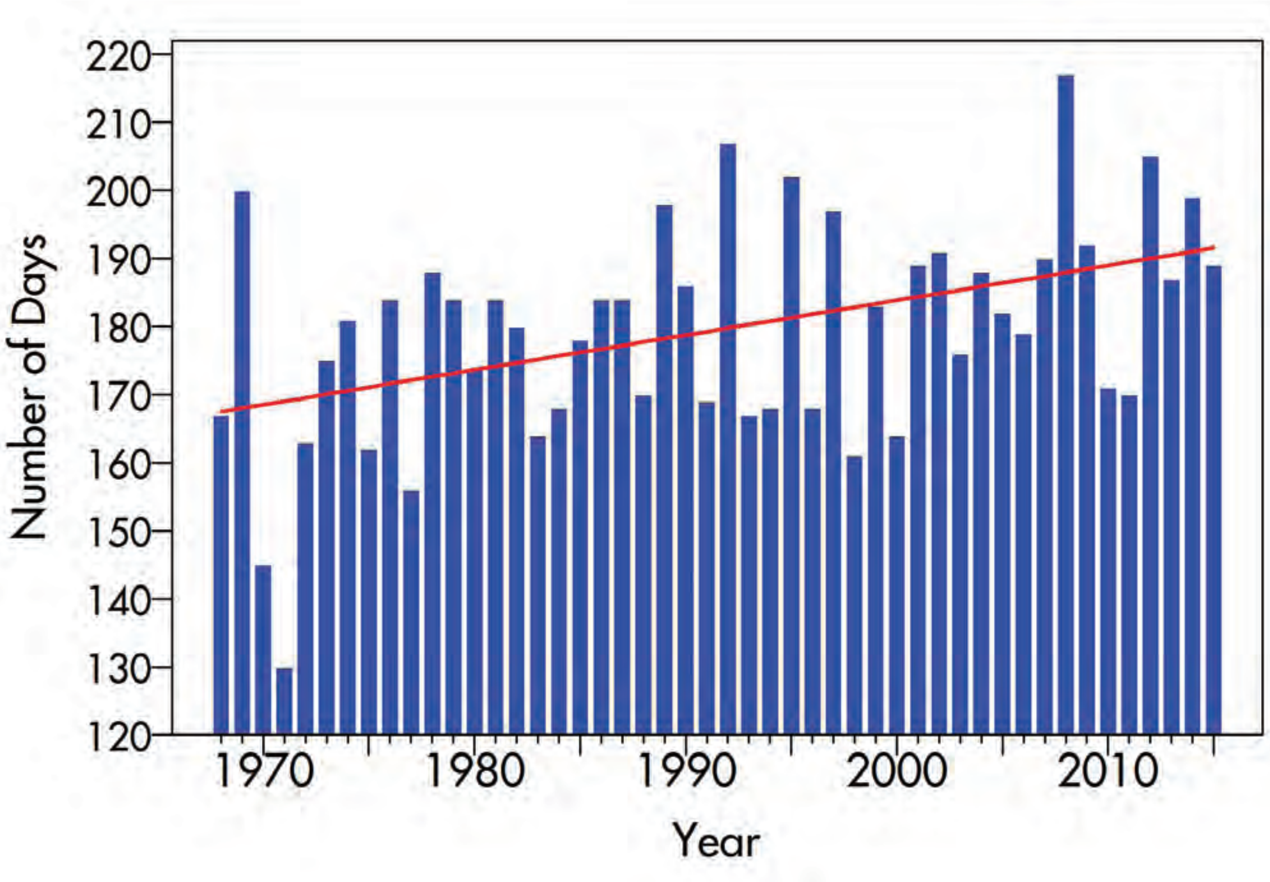


PHYSICAL PROPERTIES

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 2015, the length of the stratified season was 189 days.

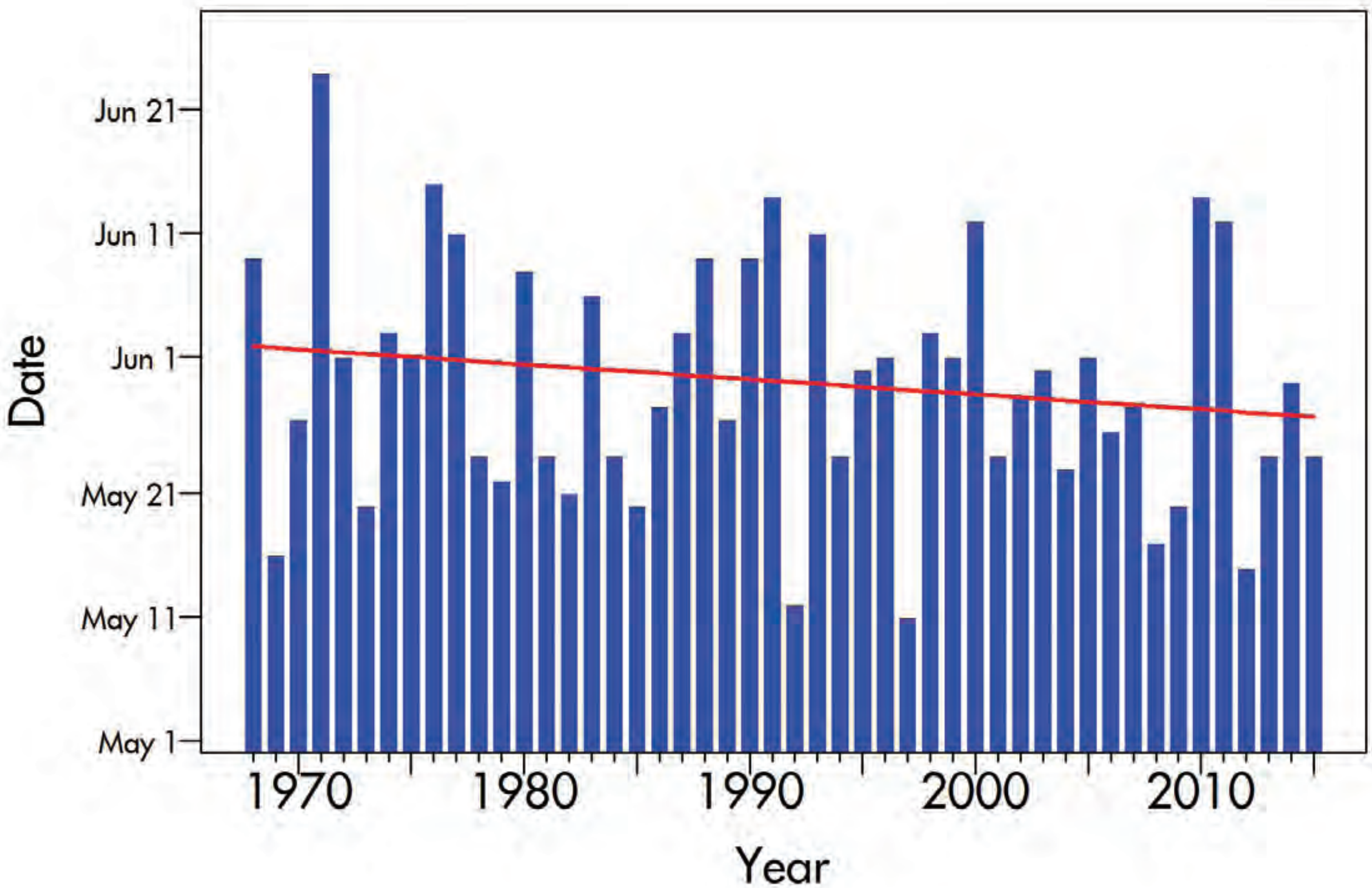


PHYSICAL PROPERTIES

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 2015 stratification commenced on Day 144 (May 24).

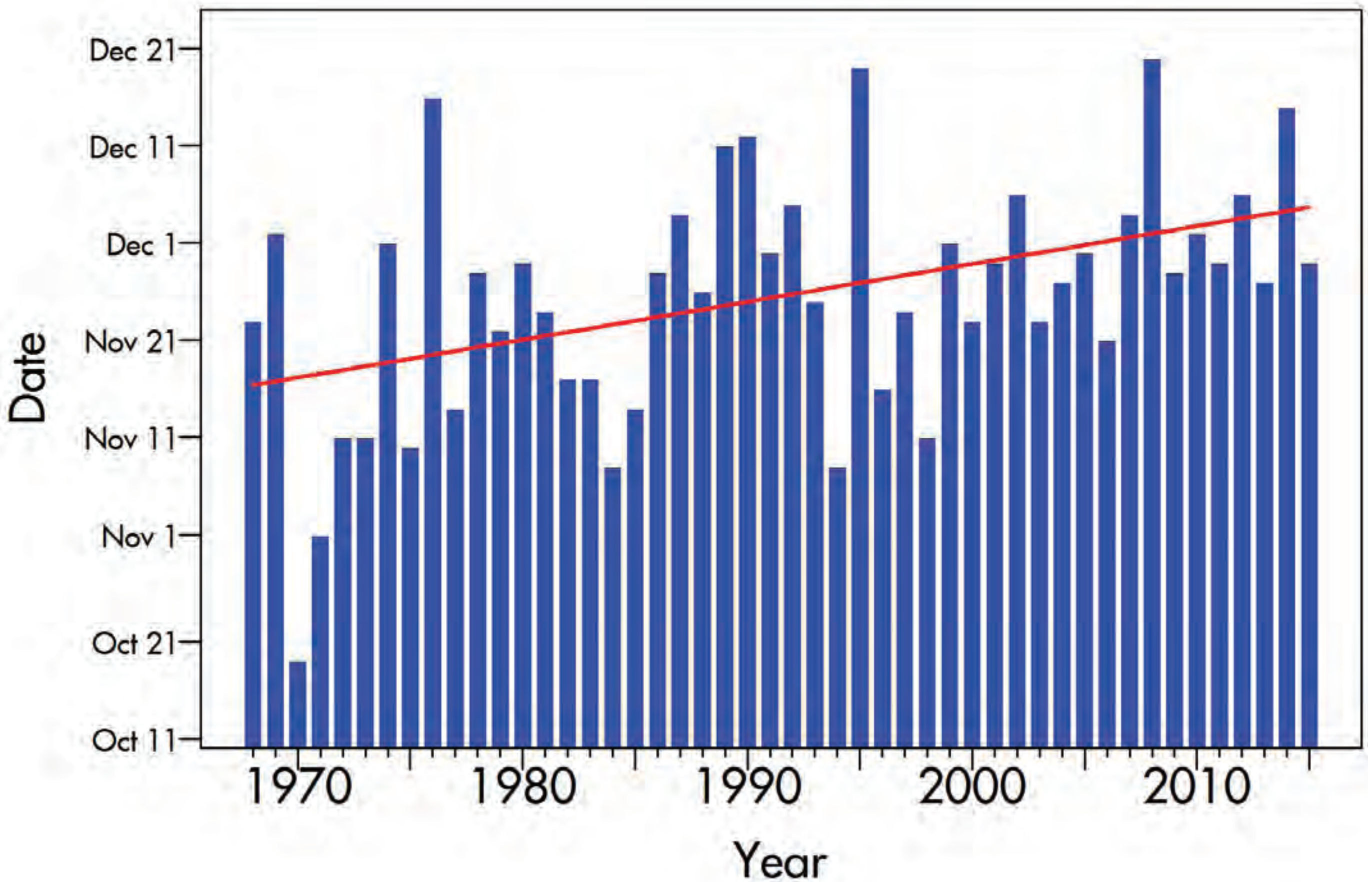


PHYSICAL PROPERTIES

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 2015, stratification ended on Day 333 (November 29) This has important implications for lake mixing and water quality, such as the buildup of nitrate at the bottom of the lake.

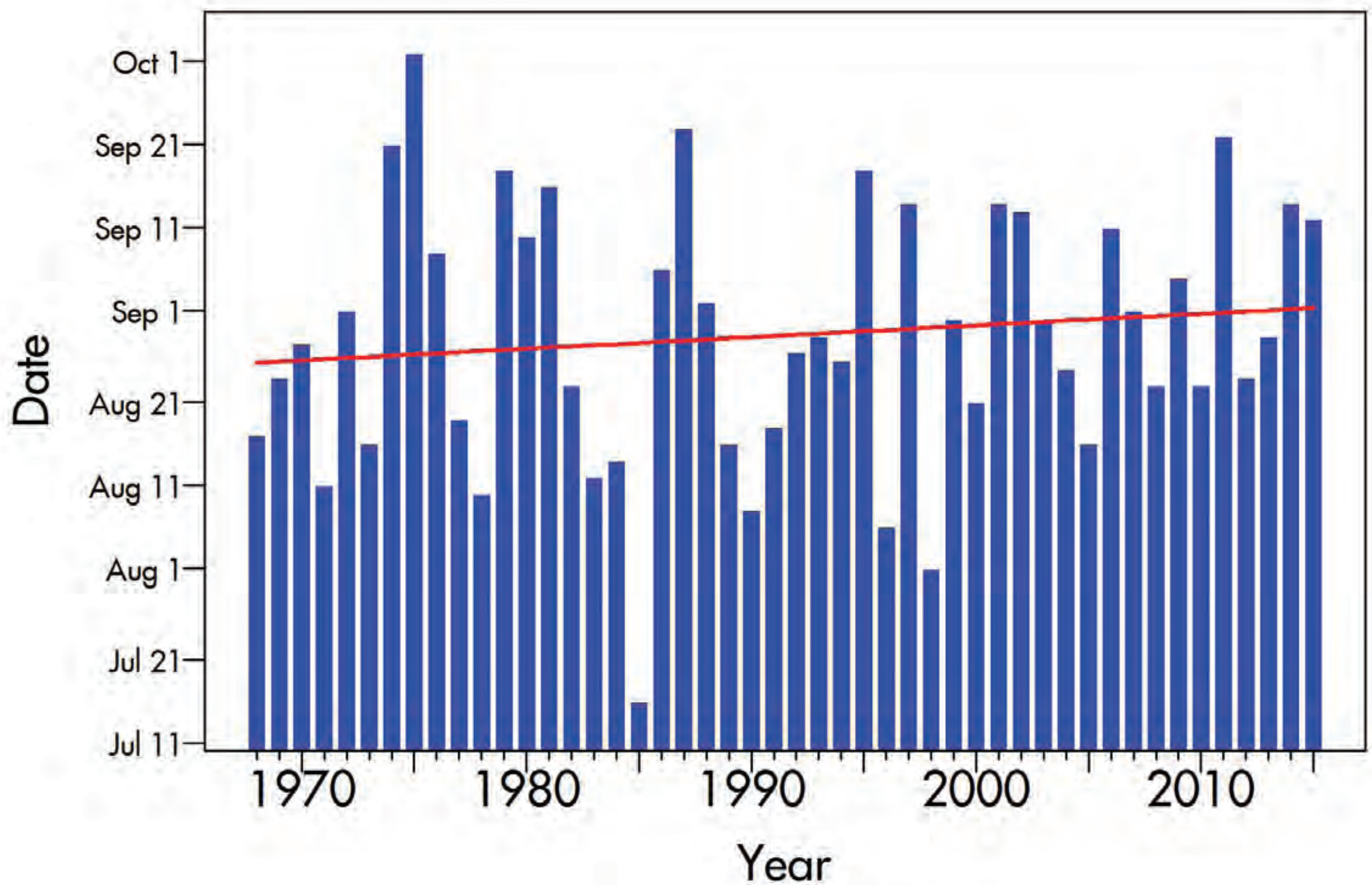


PHYSICAL PROPERTIES

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. In 2015 the peak occurred on September 12, over a week later than the long-term trend would have indicated.



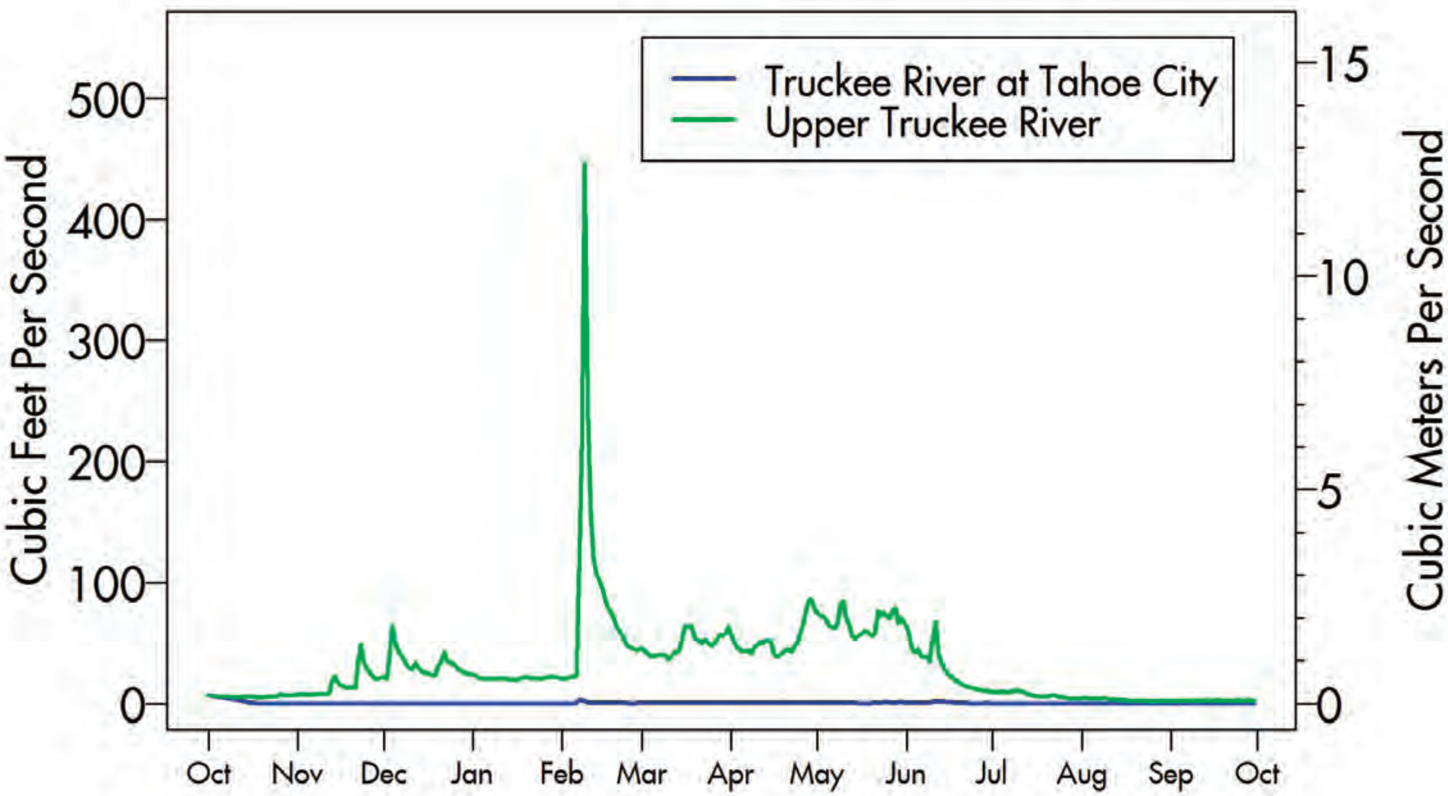
PHYSICAL PROPERTIES

Mean daily streamflow of Upper Truckee River vs. Truckee River

Water Year 2015

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 446 cfs, compared to the long-term average of 300 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. Typical maximum summer discharge is approximately 300 cfs in mid-June. In 2015 the lake level was below the lake's rim for almost the entire year, so outflow was essentially zero. Streamflow data are collected by the U.S. Geological Survey under the Lake Tahoe Interagency Monitoring Program (LTIMP).

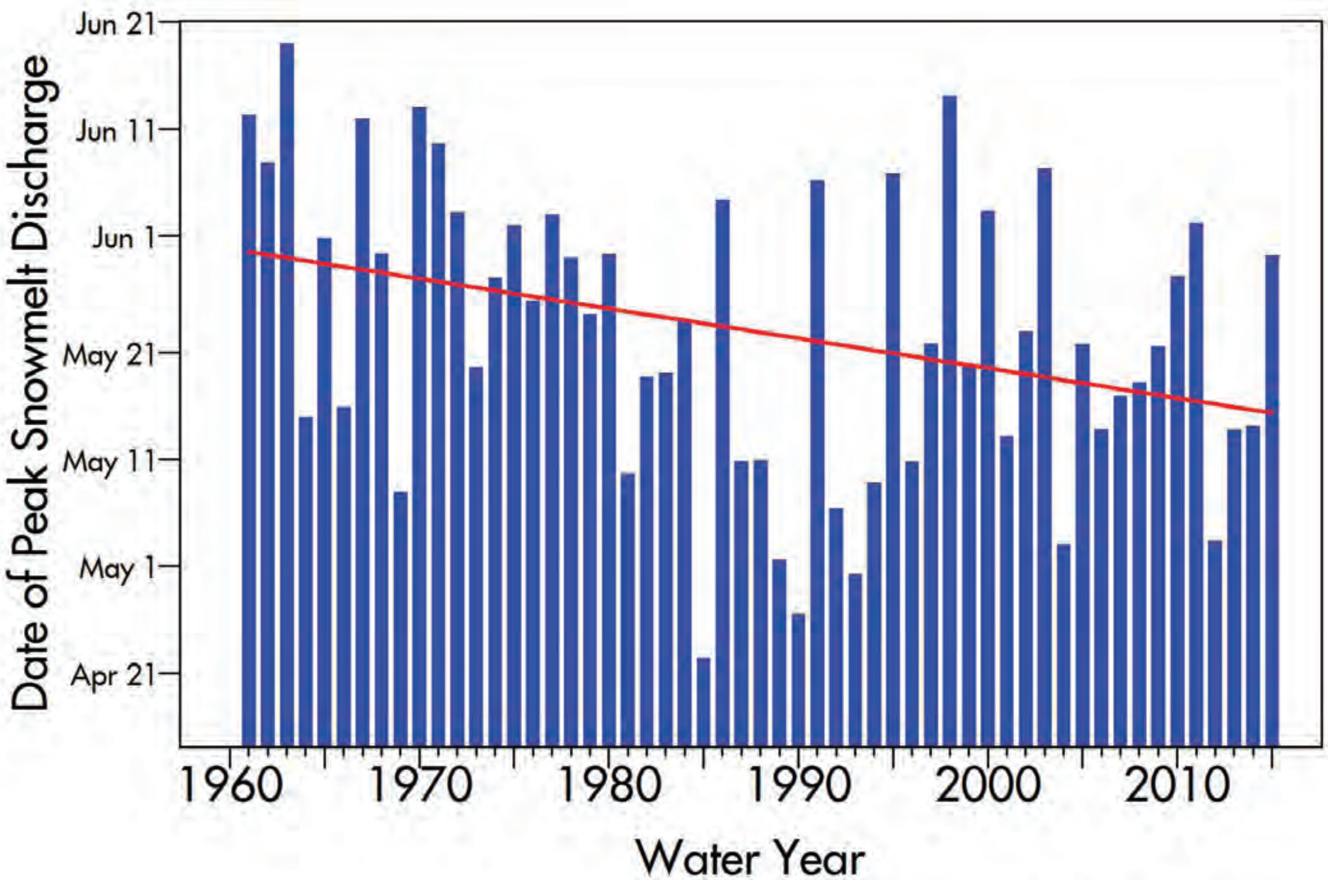


PHYSICAL PROPERTIES

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 (15 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 2015 the timing of the snowmelt peak fell above the long-term trend line.

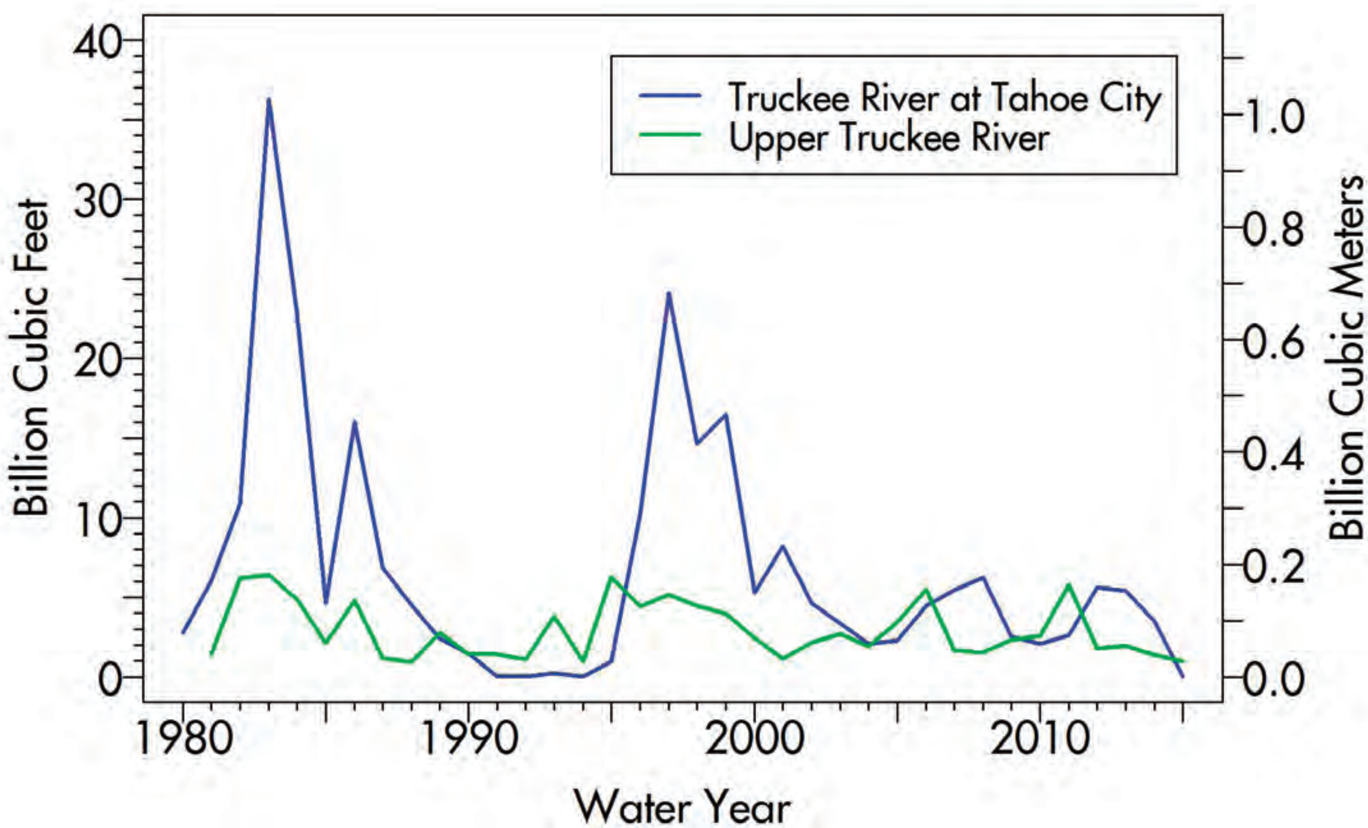


PHYSICAL PROPERTIES

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 2.94 billion cubic feet, while the average annual outflow through the Truckee River is 6.92 billion cubic feet. In 2015 discharges into and out of the lake were well below the long-term averages. The Upper Truckee River inflow volume was 0.96 billion cubic feet. The Truckee River discharge was zero.

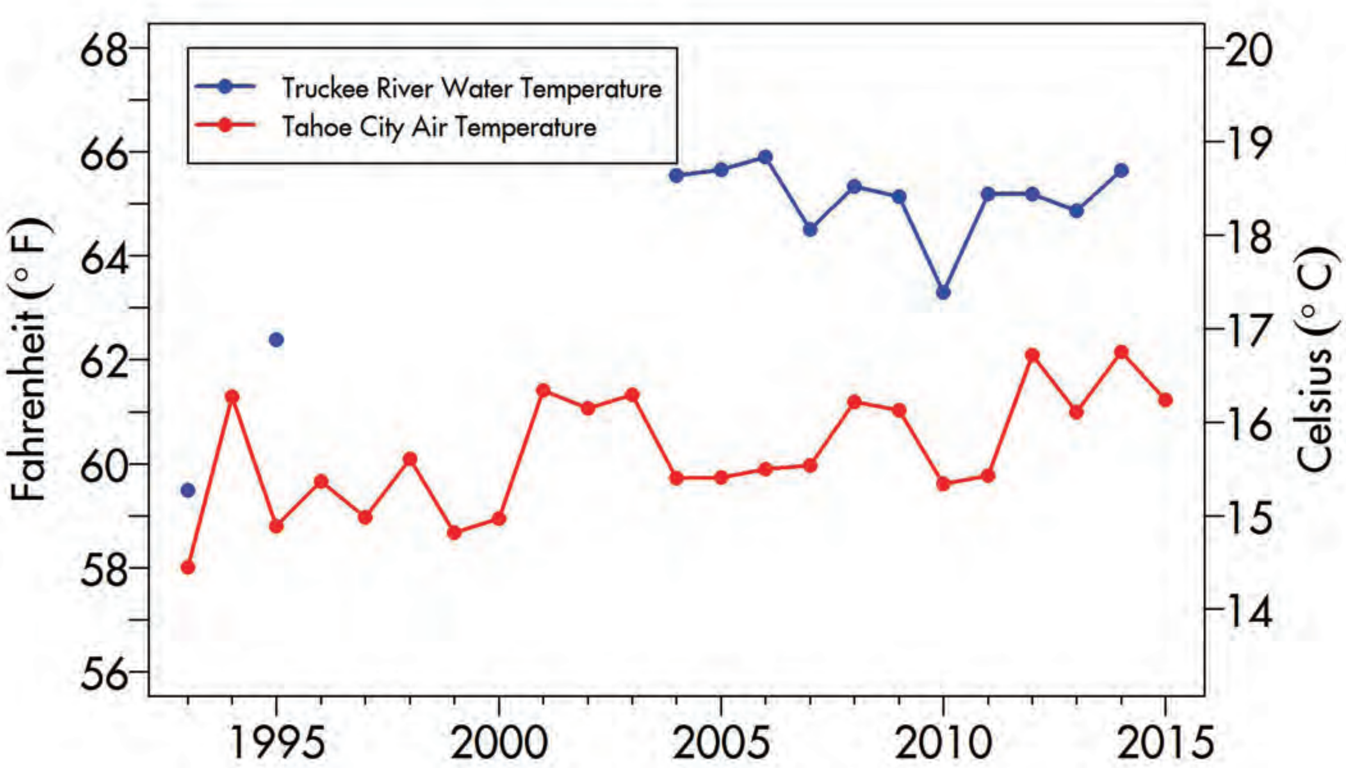


PHYSICAL PROPERTIES

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. In 2015 there was no flow released to the Truckee River from Lake Tahoe, so an average water temperature could not be calculated.

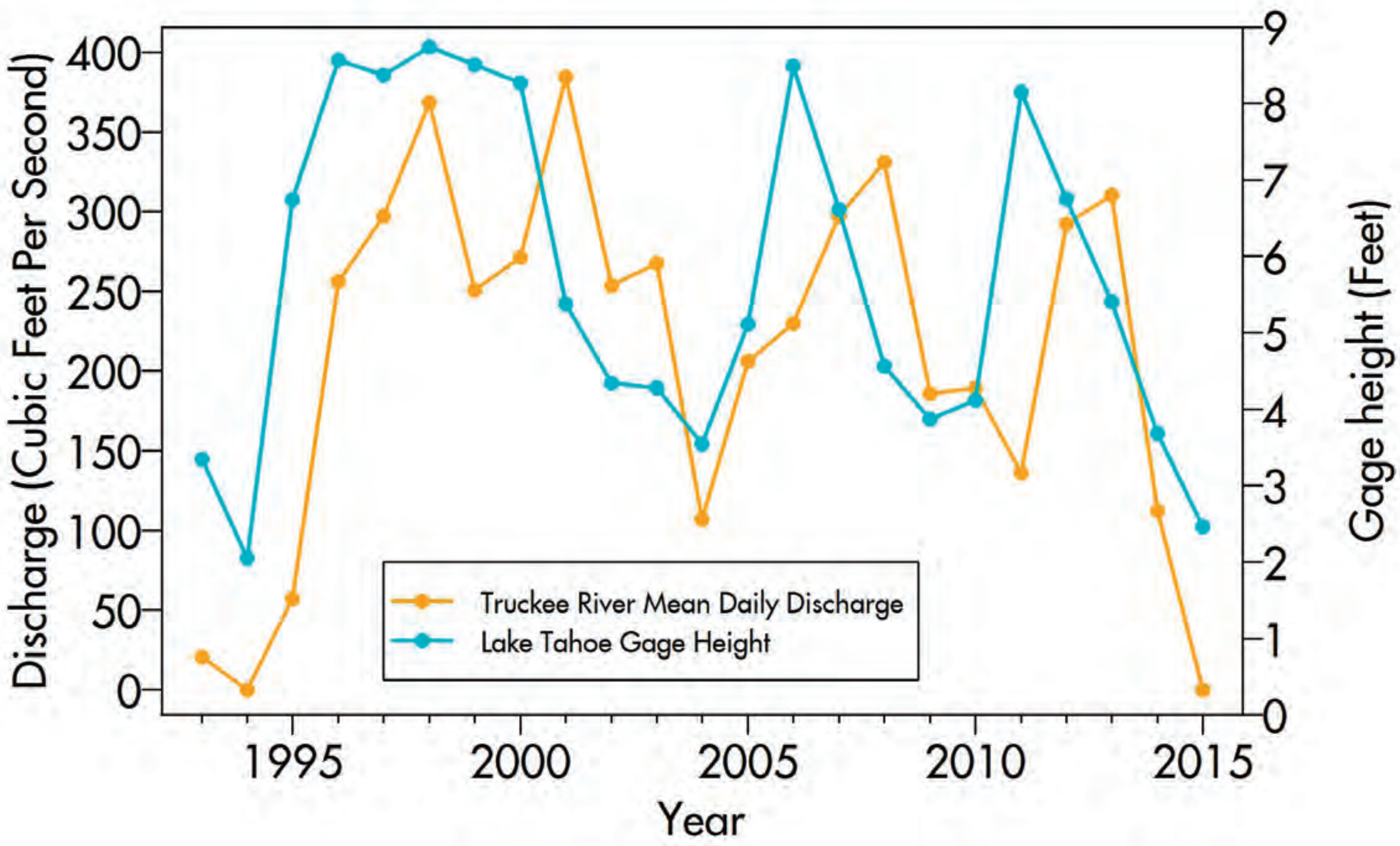


PHYSICAL PROPERTIES

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 2016

NUTRIENTS AND PARTICLES

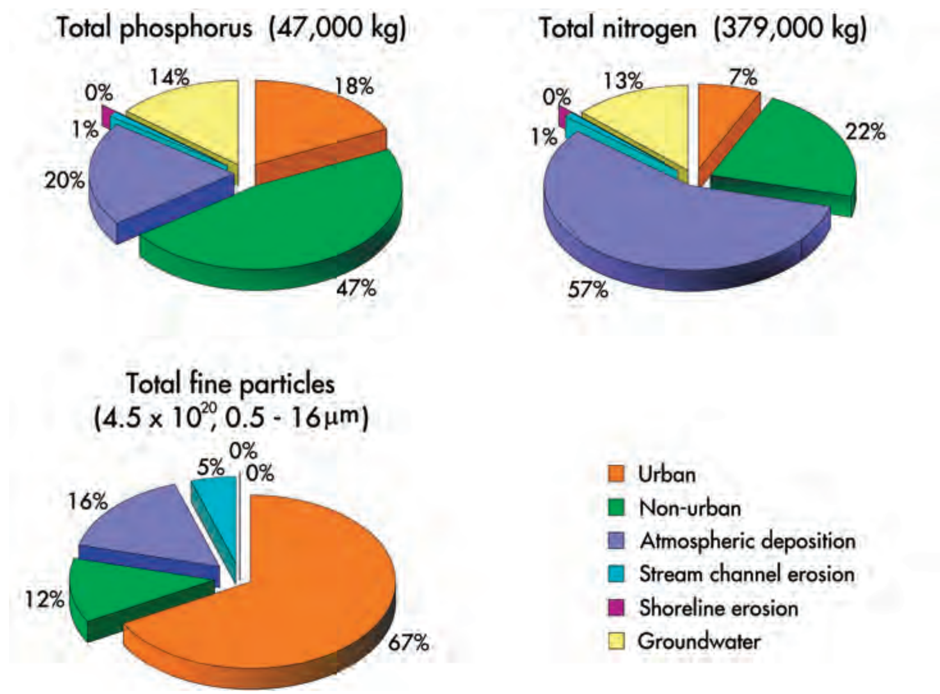
UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

NUTRIENTS AND PARTICLES

Sources of clarity-reducing and blueness-reducing pollutants

In 2015

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 basin's 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.



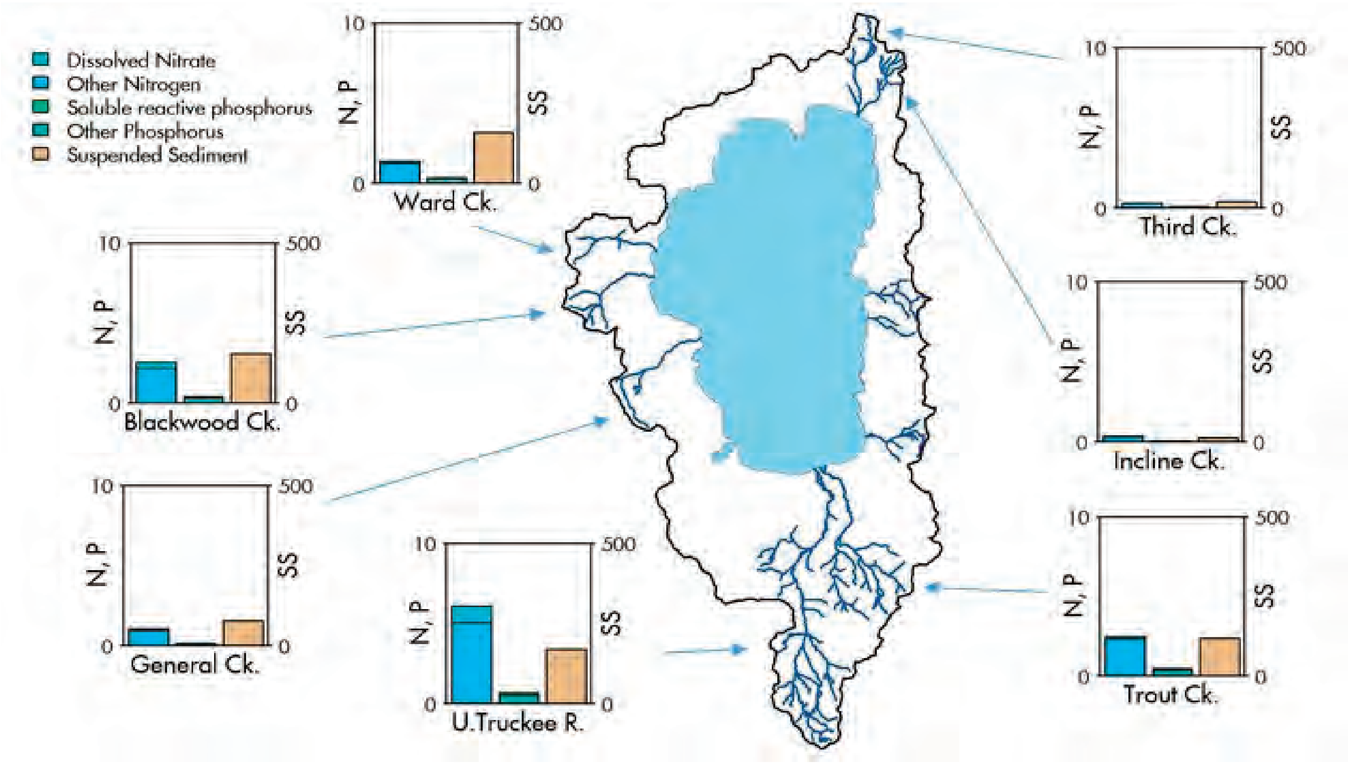
NUTRIENTS AND PARTICLES

Pollutant loads from seven watersheds

In 2015

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. The vast majority of stream phosphorus and nitrogen comes from the Upper Truckee River, Trout Creek, Blackwood Creek and Ward Creek. Pollutant loads from the west-side streams were a factor of four to five lower in each of the last four years, compared with 2011. The suspended sediment was either lower than or similar to last year's values. The notable exception to this was Ward Creek and Blackwood Creek in California. All these reductions were largely due to the effects of the drought.

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 2015 was provided by the California Tahoe Conservancy and the Lahontan Regional Water Quality Control Board.

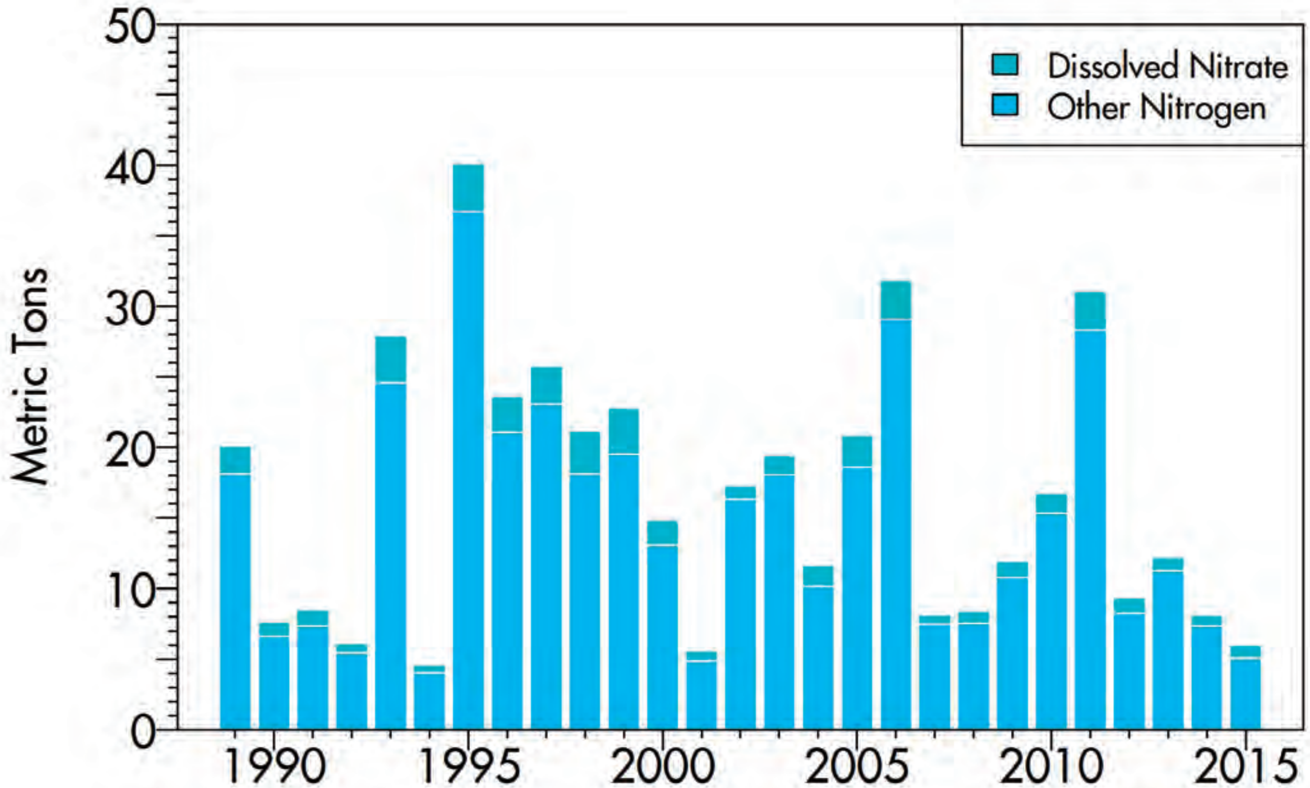


NUTRIENTS AND PARTICLES

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 nitrate and the remainder of the total nitrogen load 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. 2015 had 18.1 inches of precipitation, following 2014 with 19.3 inches, 2013 with 25.19 inches and 2012 with 22.48 inches. The average annual precipitation is 31.4 inches. (One metric ton = 2,205 pounds.)

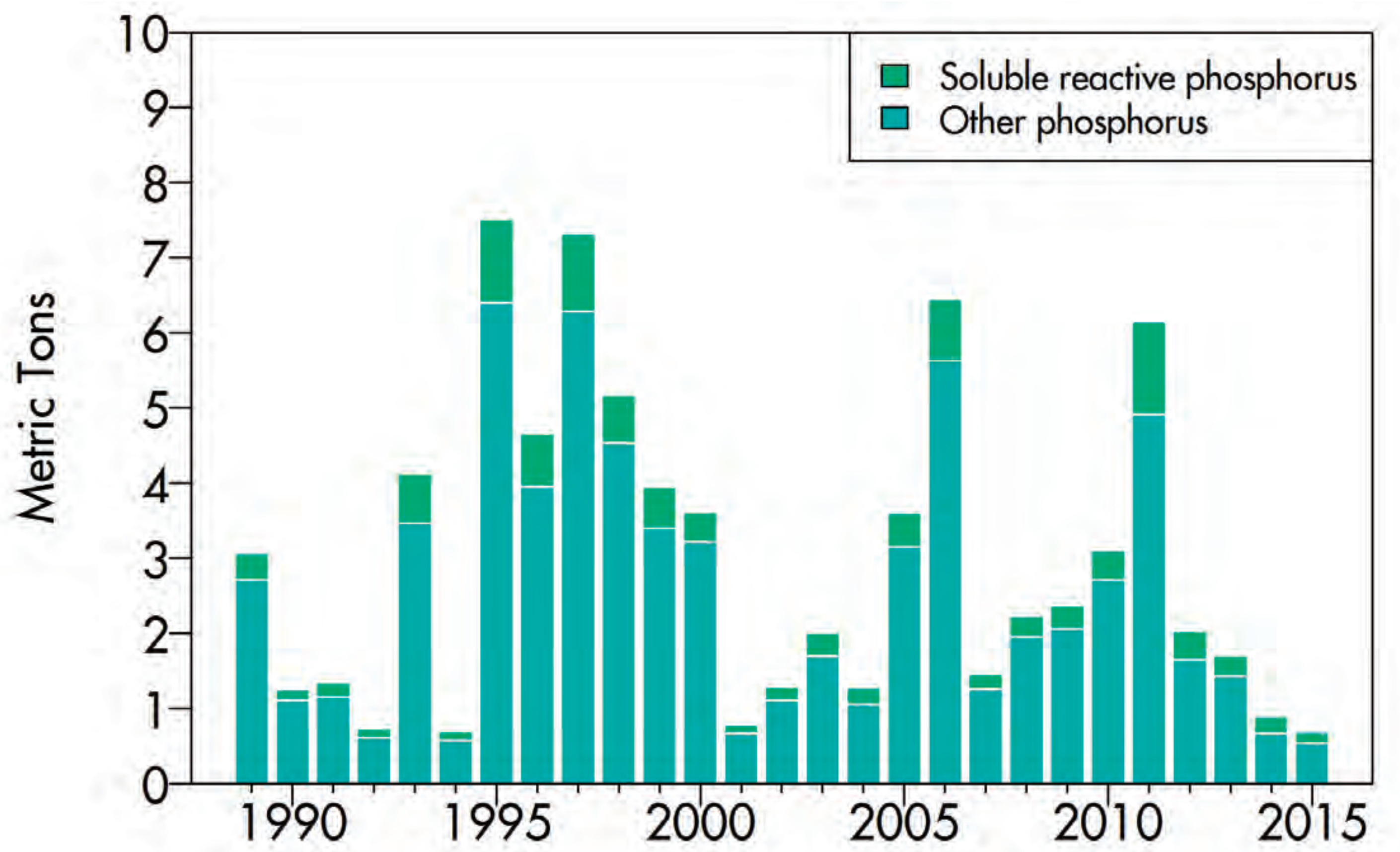


NUTRIENTS AND PARTICLES

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 2015 resulted in a factor of eight 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.)

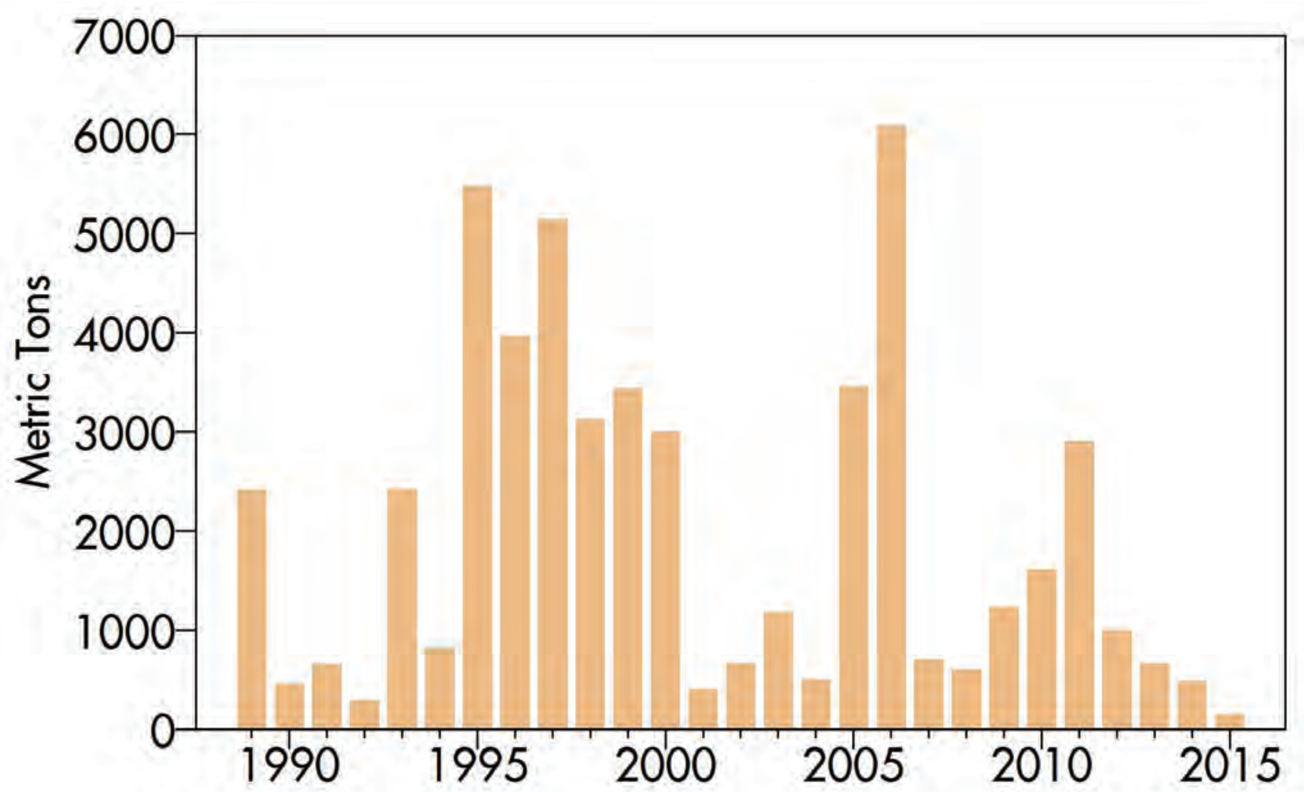


NUTRIENTS AND PARTICLES

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. 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. In 2015 the suspended sediment load from the Upper Truckee River was the lowest ever recorded at 170 Tons. The highest load ever recorded was 6100 Tons in 2006.

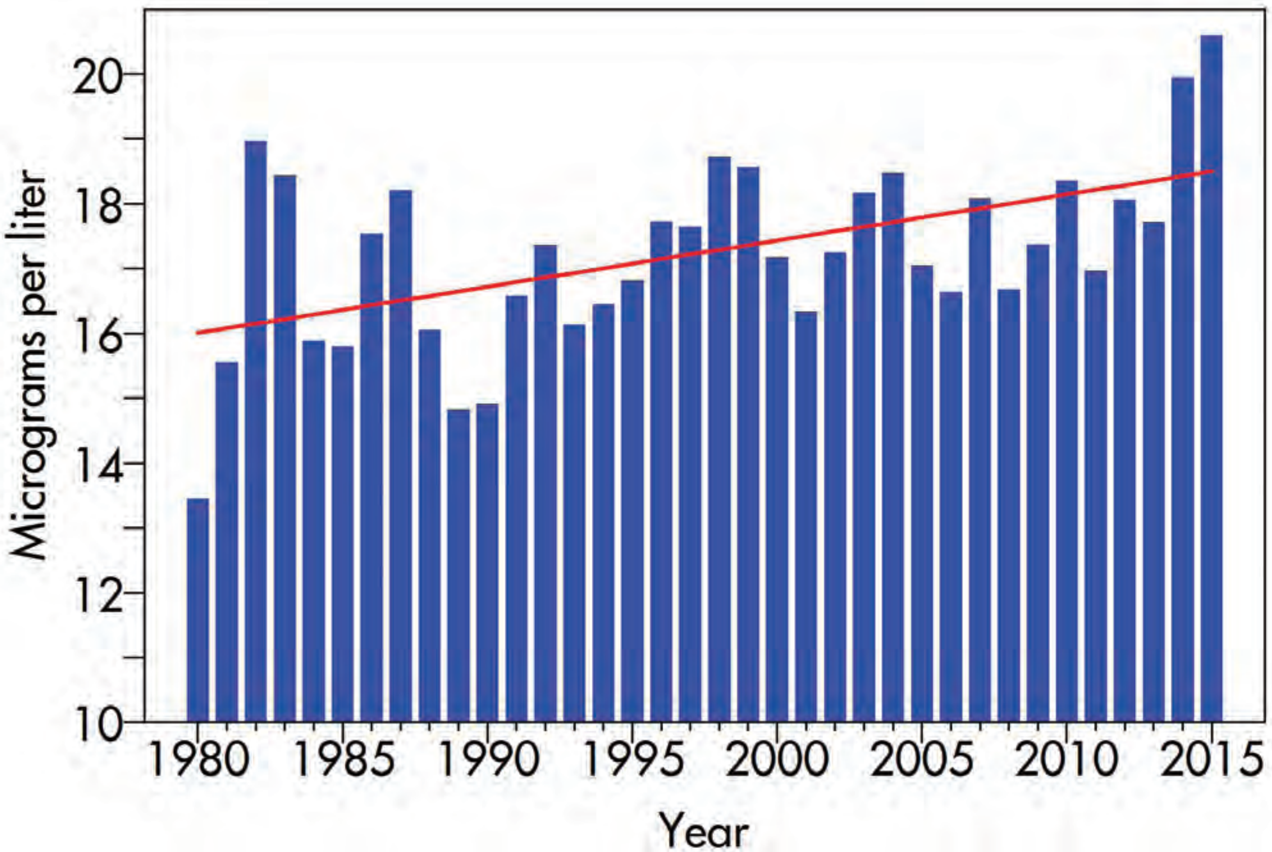


NUTRIENTS AND PARTICLES

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 2015, the volume-weighted annual average concentration of nitrate-nitrogen reached an all-time high of 20.6 micrograms per liter. This increase is in part due to the fourth successive year in which deep mixing did not take place, allowing for a continued buildup 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.

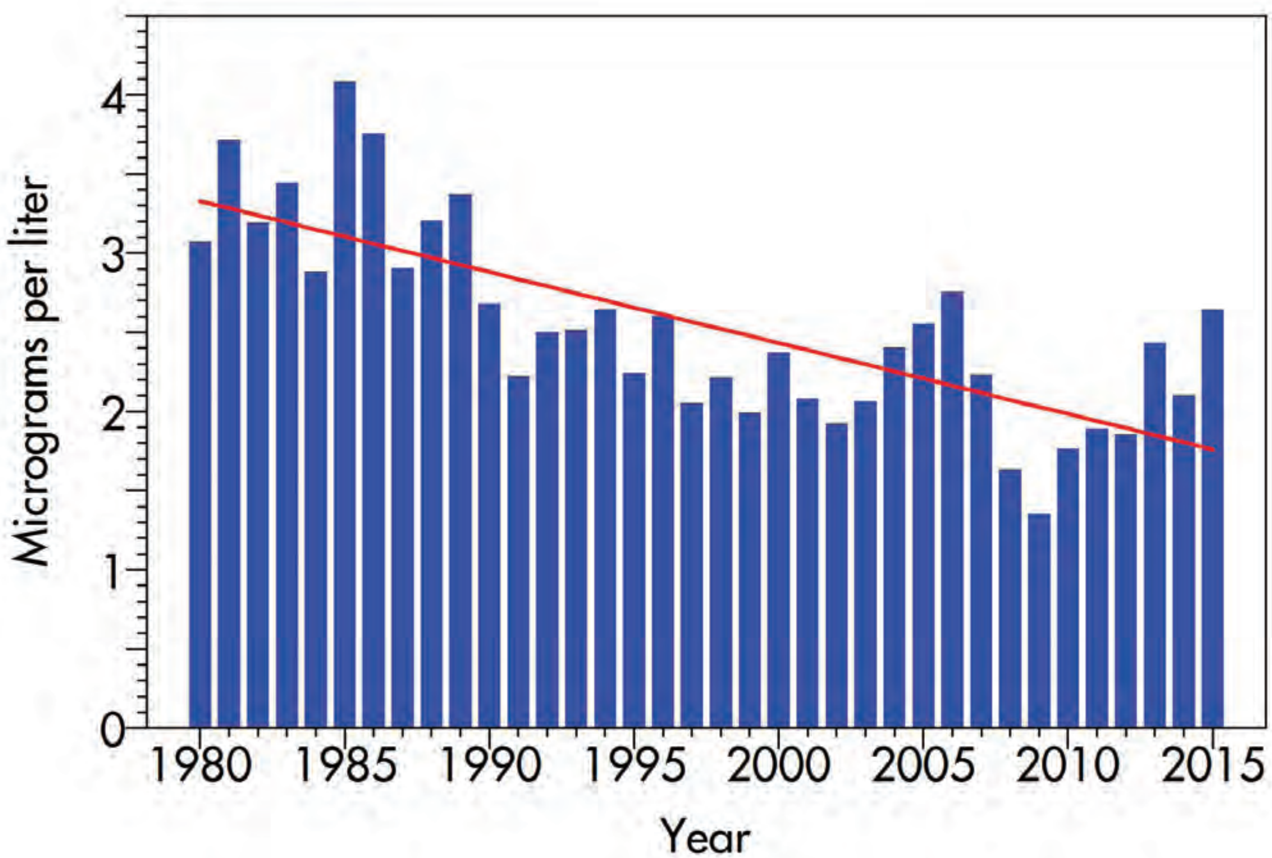


NUTRIENTS AND PARTICLES

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, although in the last six years the values have been increasing toward levels that were present in the 1990s. In 2015, the volume-weighted annual average concentration of THP was approximately 2.65 micrograms per liter, the highest level in the last six years. 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

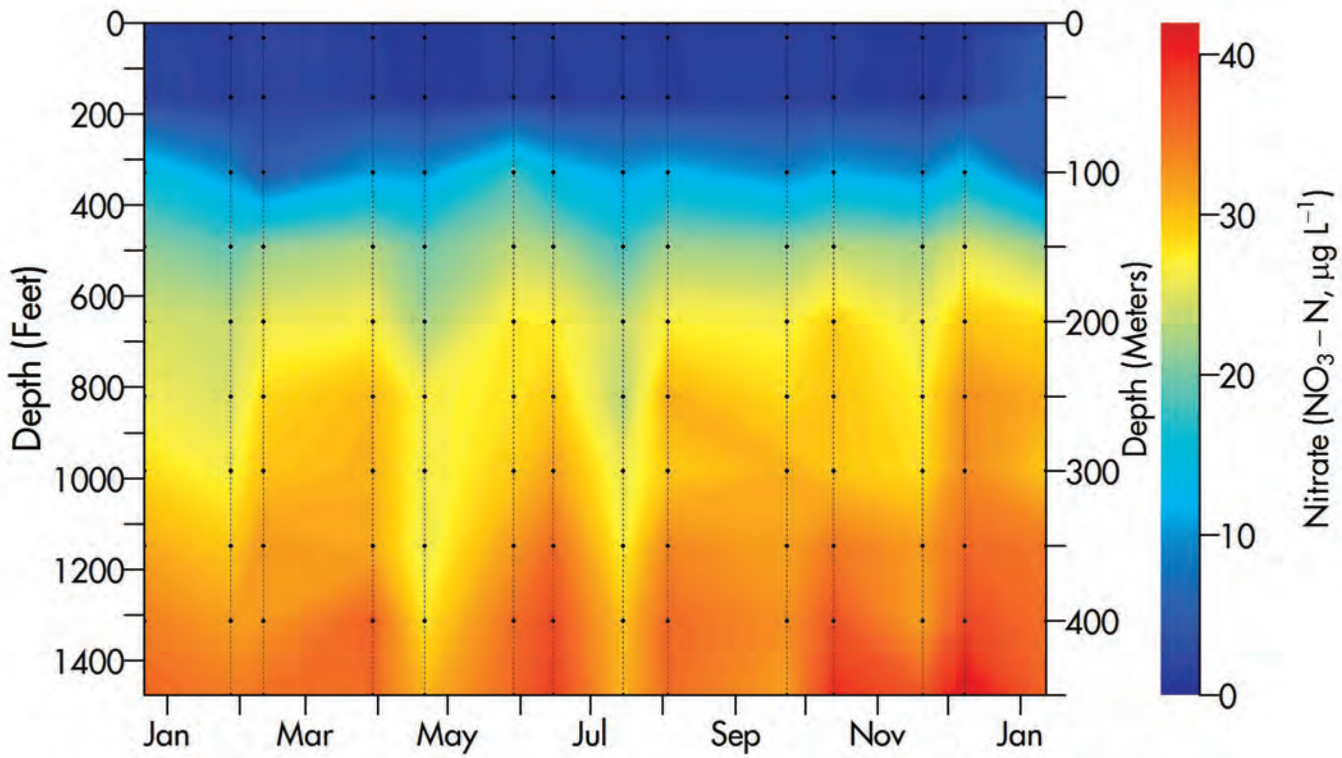
Nitrate distribution

In 2015

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 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 taken up by the algae and surface concentrations are generally low. 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. 2015 was a year with record low mixing, extending to only 262 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 41.8 micrograms per liter.



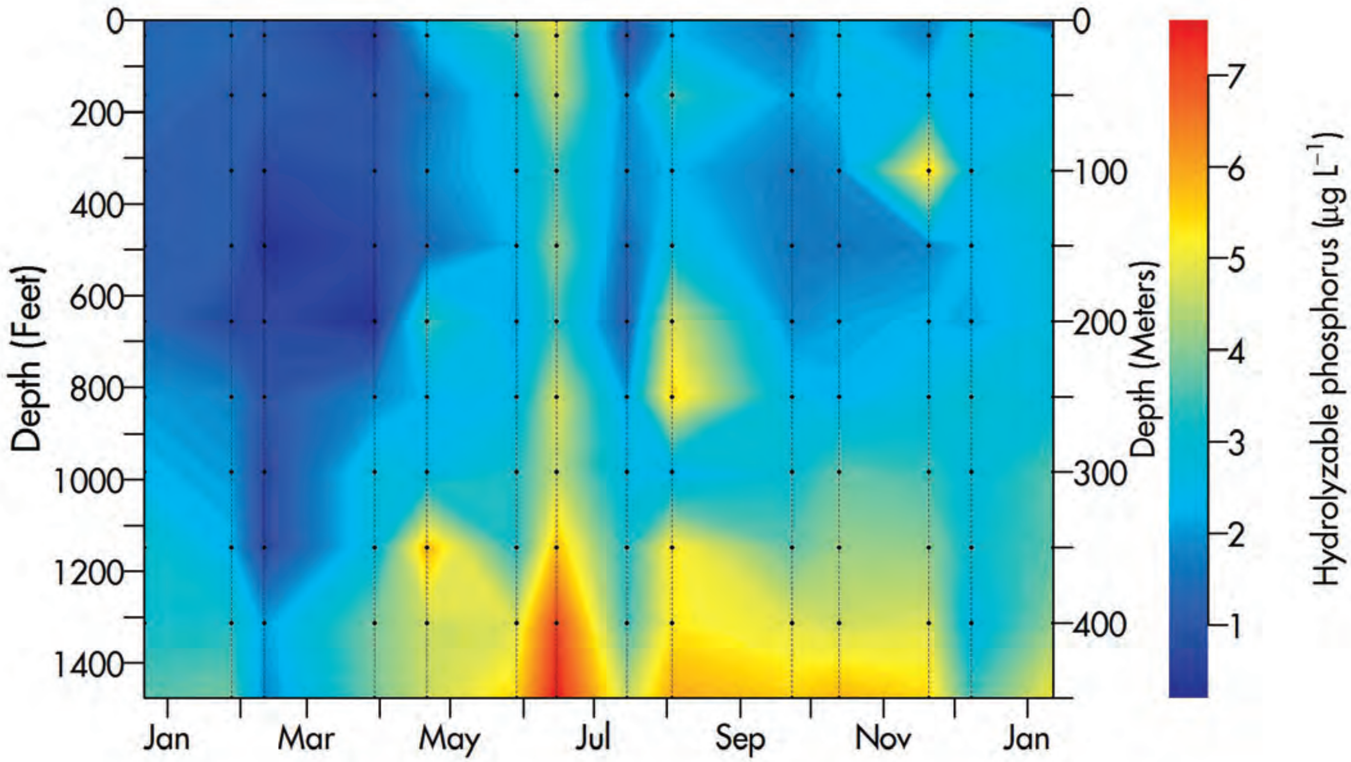
NUTRIENTS AND PARTICLES

Orthophosphate distribution

In 2015

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 variation of THP. Phosphorus mainly enters the lake in association with fine particles during runoff events. Because of the low snowmelt volumes in 2015, 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. The highest recorded value of 7.55 micrograms per liter was at a depth of 1476 feet.



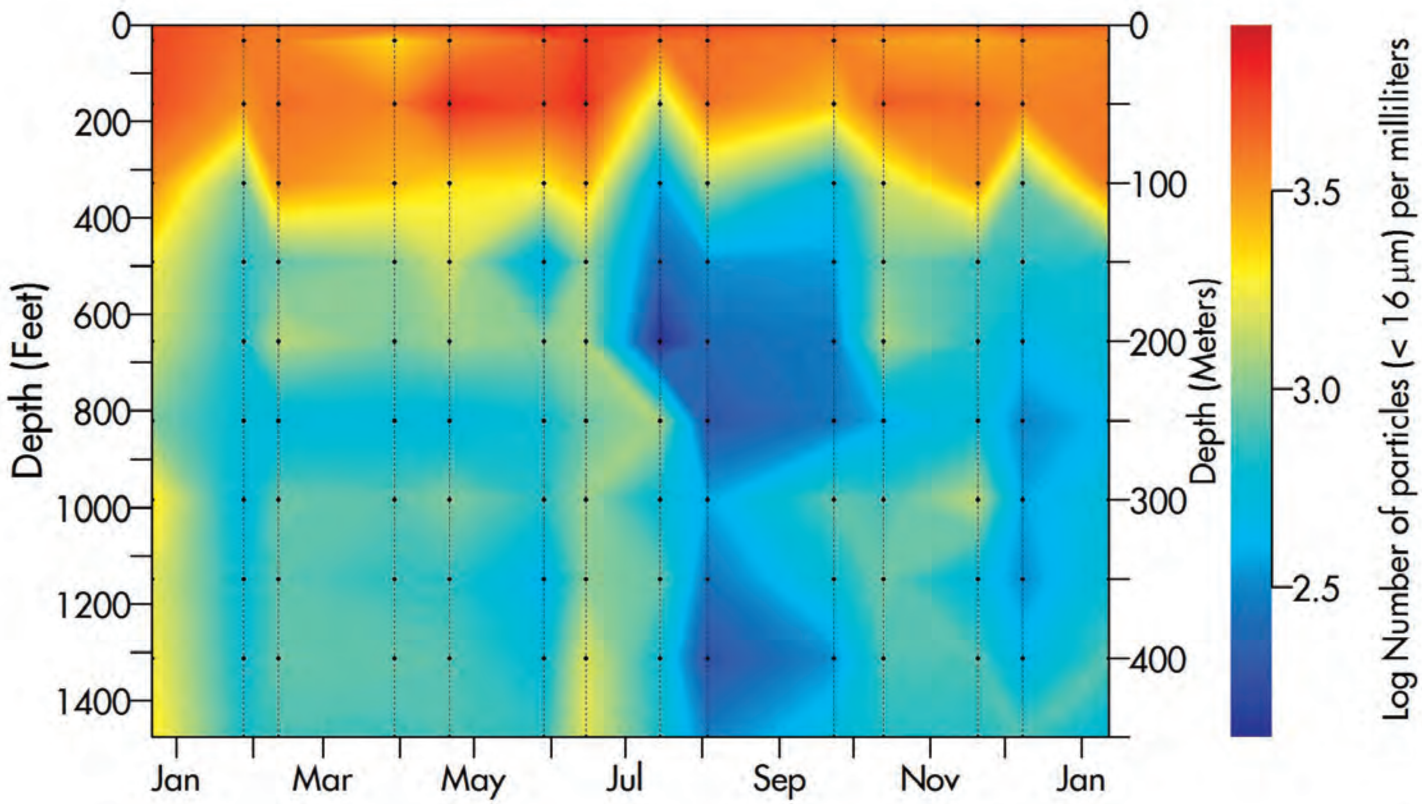
NUTRIENTS AND PARTICLES

Fine particle distribution

In 2015

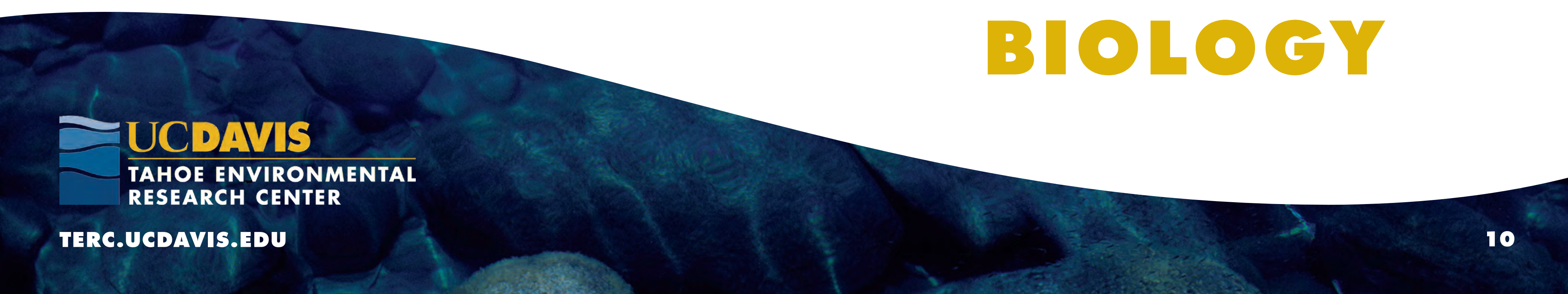
Water samples are collected approximately monthly (on dates indicated by the dashed lines) at 13 depths (indicated by the dots) at the middle of the lake, and analyzed in the TERC laboratory for the concentration of fine particles in 15 different bin sizes. Here the distributions of the finest particles (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 2016

BIOLOGY



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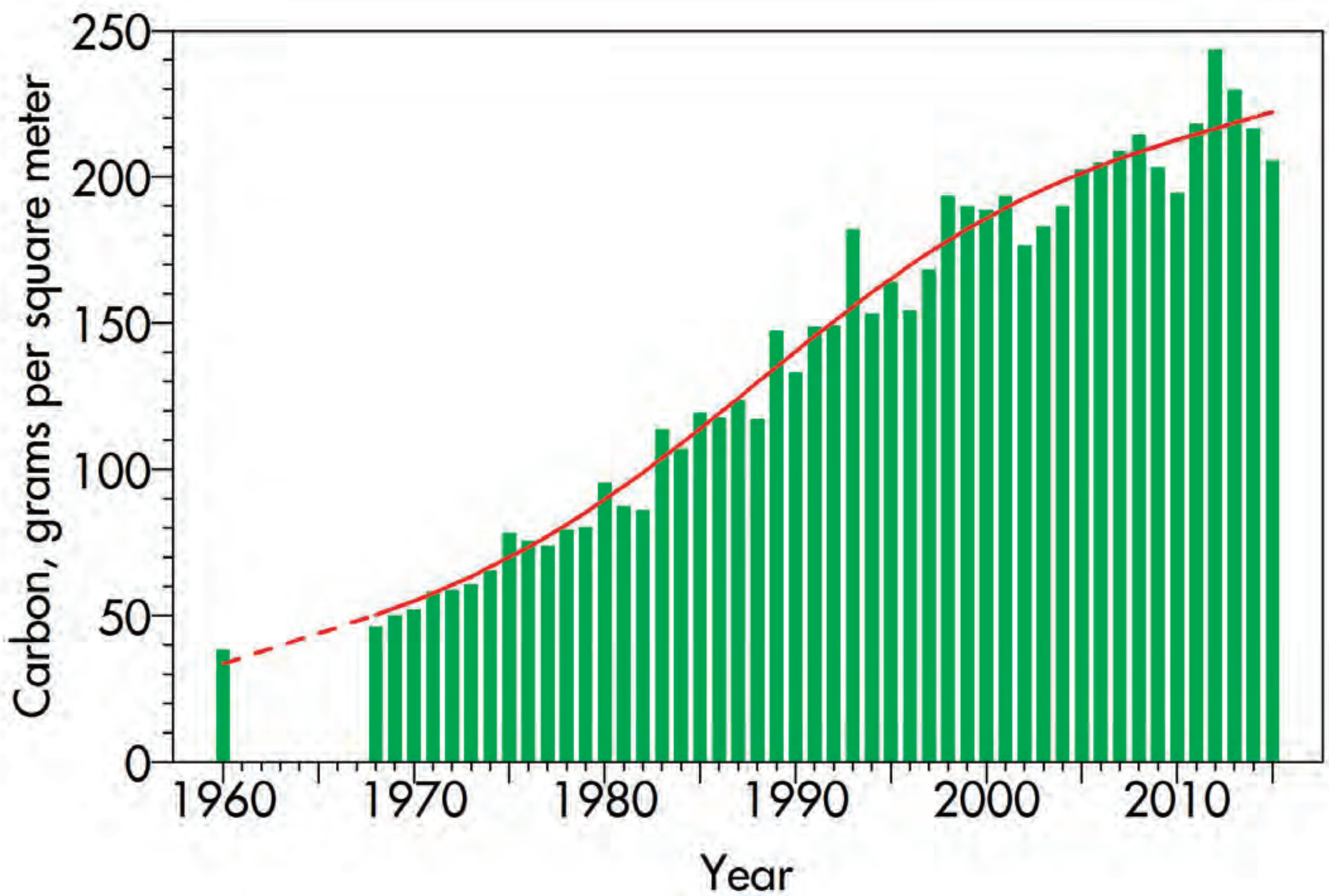
BIOLOGY

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 2015, there was a decrease in primary productivity to 206.1 grams of carbon per square meter, the third successive year of reduced productivity.

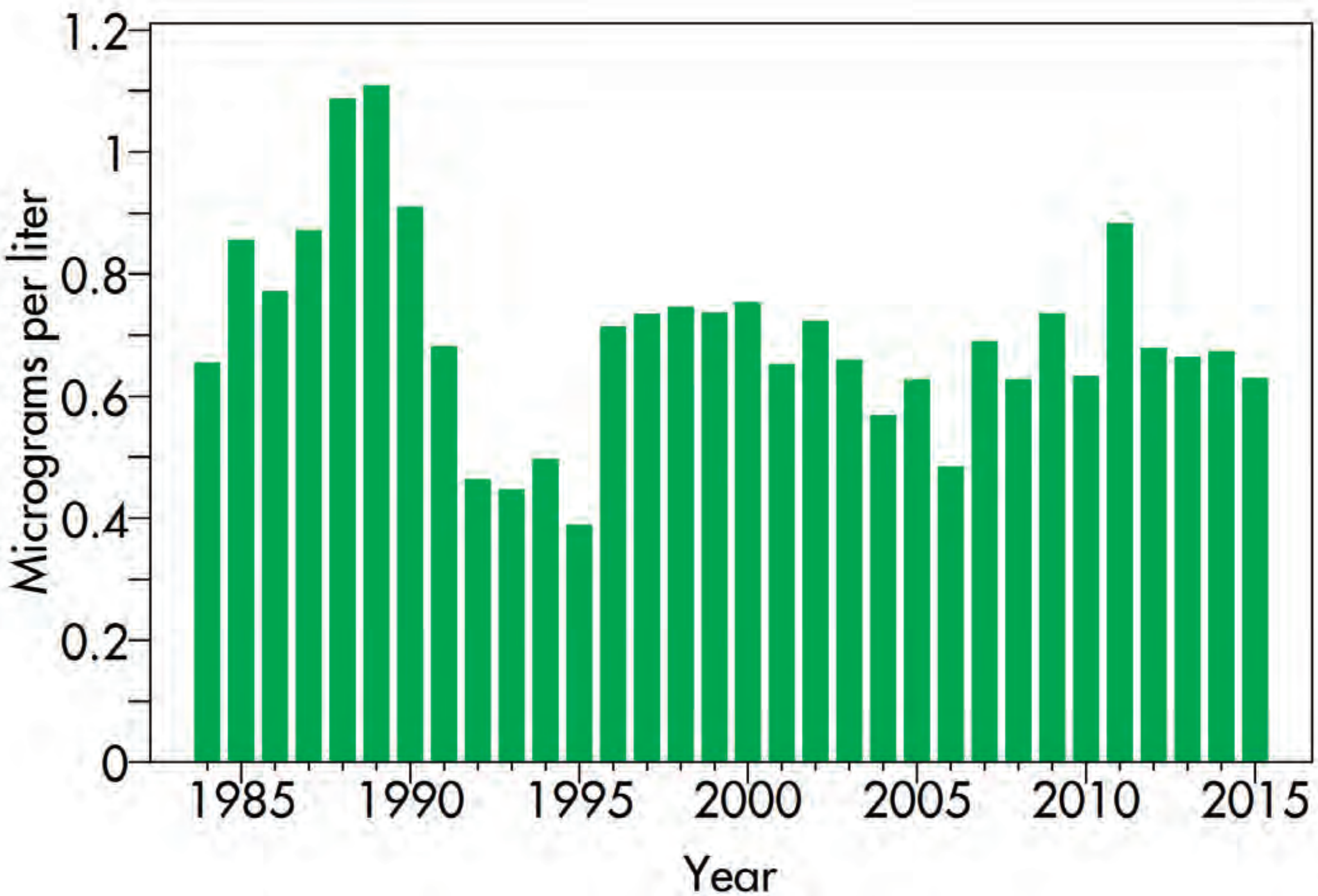


BIOLOGY

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 convert 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 2015 was 0.63 micrograms per liter, slightly lower than the previous two years. For the period of 1984-2015 the average annual chlorophyll-a concentration in Lake Tahoe was 0.70 micrograms per liter.



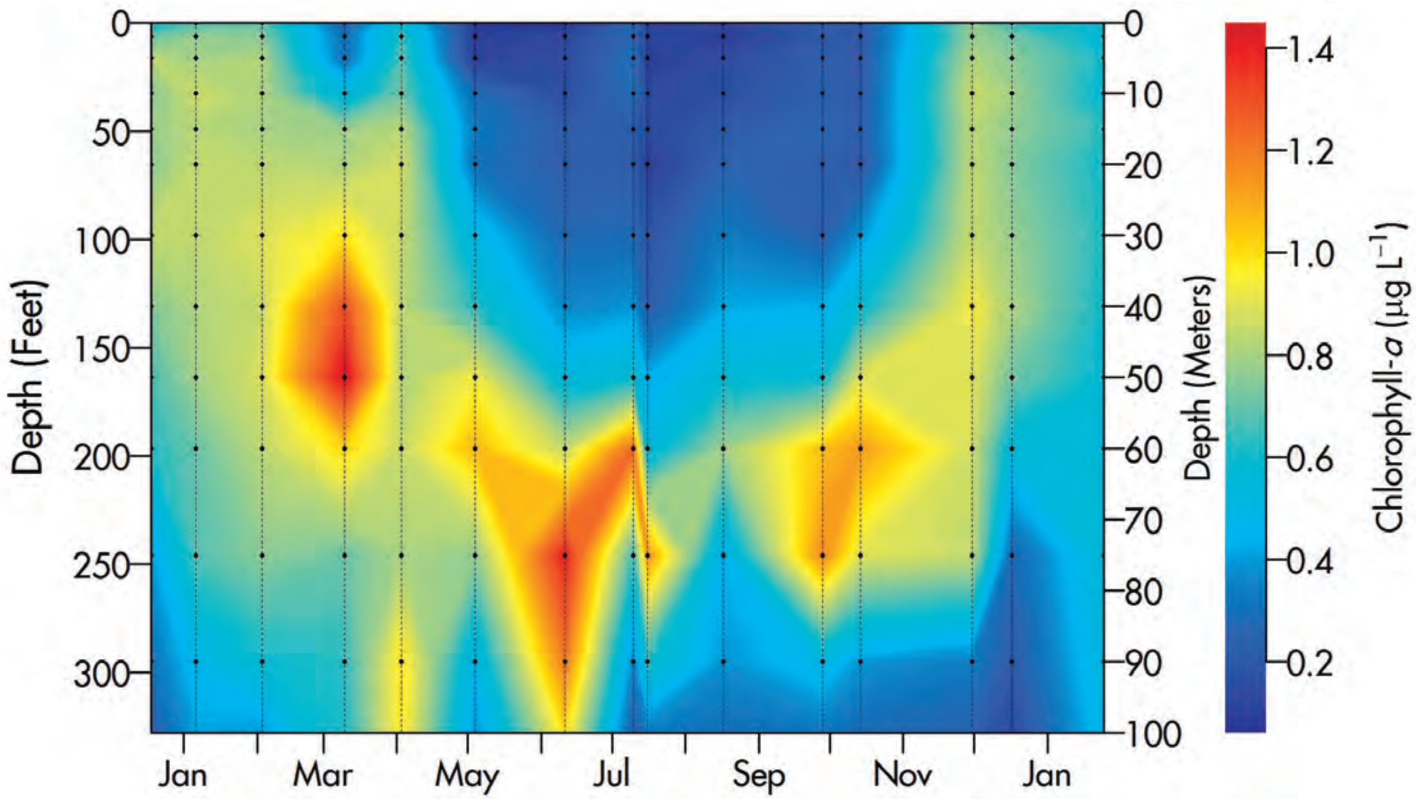
BIOLOGY

Chlorophyll-*a* distribution

In 2015

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 chlorophyll-a concentrations are near zero due to the absence of light. Lake Tahoe has a "deep chlorophyll maximum" in the summer that occupies the range of 150-300 ft. in the water column. In that depth range the light and nutrient conditions are most favorable for algal growth.

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.

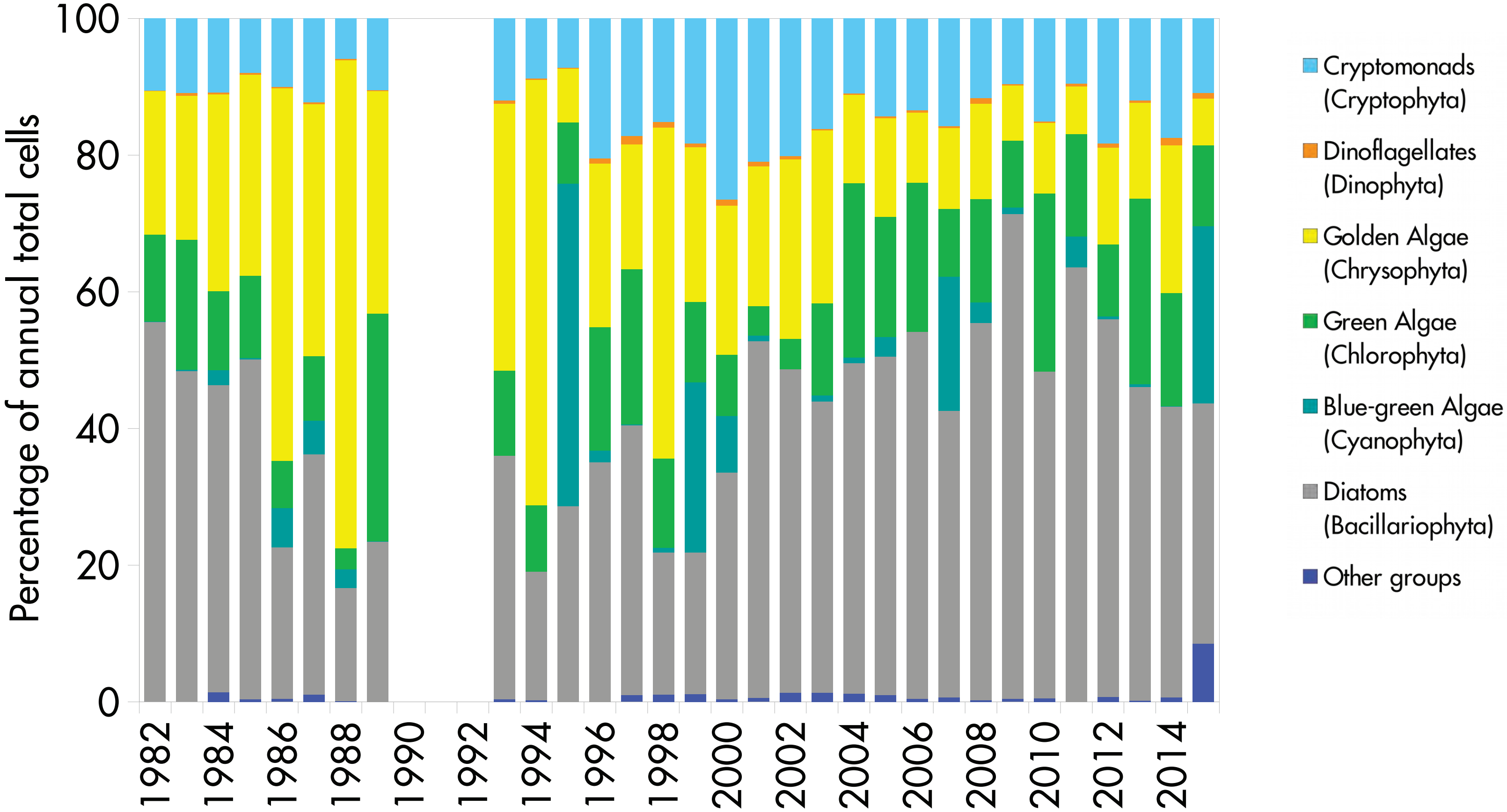


BIOLOGY

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 approximately 40 percent of the total abundance of algal cells in 2015. Surprisingly, blue-green algae (cyanobacteria) were the next most prolific group. Blue-greens only occasionally appear in Lake Tahoe in significant numbers. In 2015 they were 20% of the cells. While the proportion of the major algal groups show a degree of consistency from year-to-year, the composition of individual species within the major groups is changing, both seasonally and annually, in response to lake conditions.

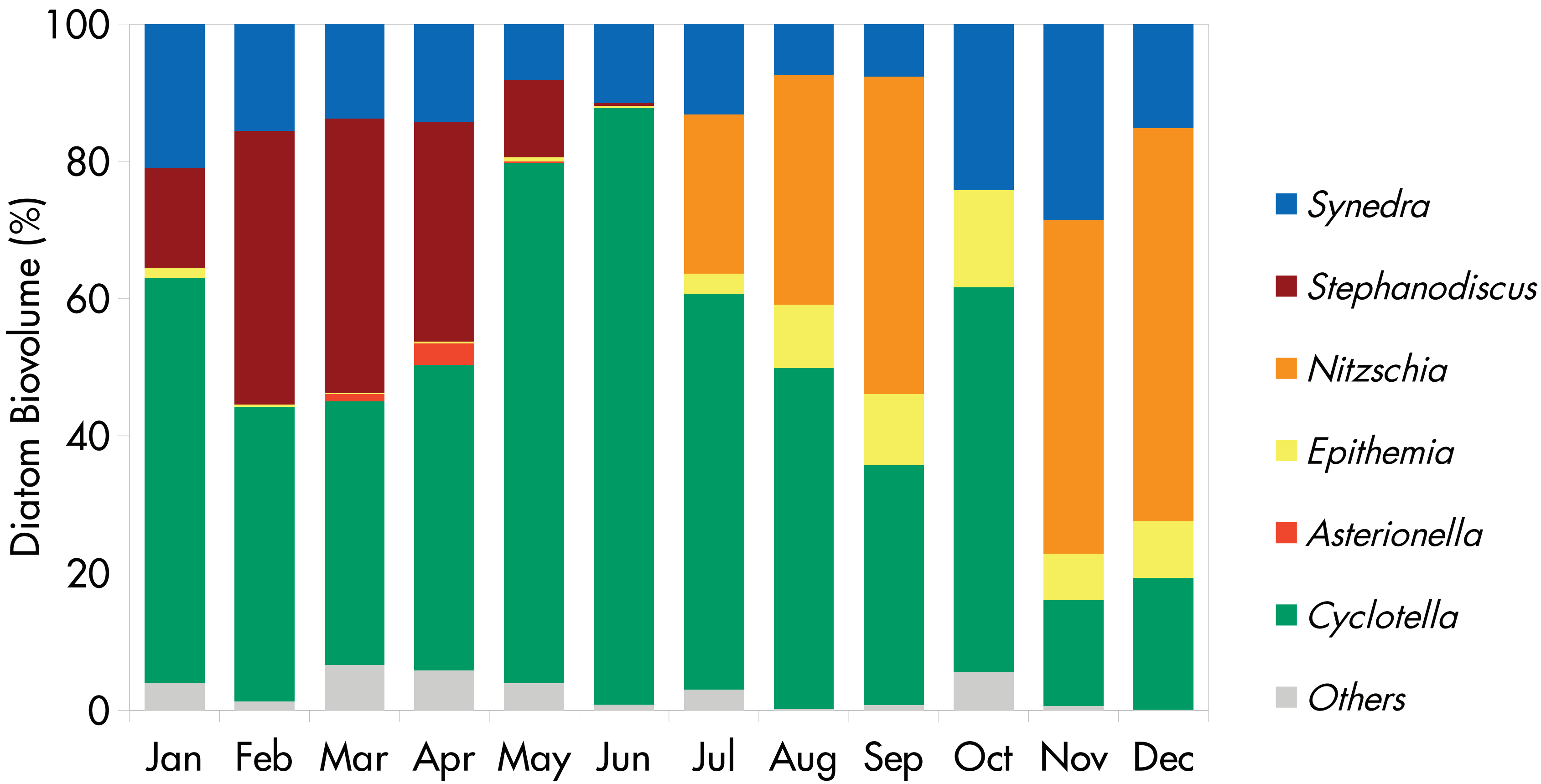


BIOLOGY

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 2015 are shown. Huge inter-annual variations are evident in the relative composition. Generally, Cyclotella gordonensis is the dominant diatom species in Lake Tahoe, although it is not as dominant as it has been in previous years.

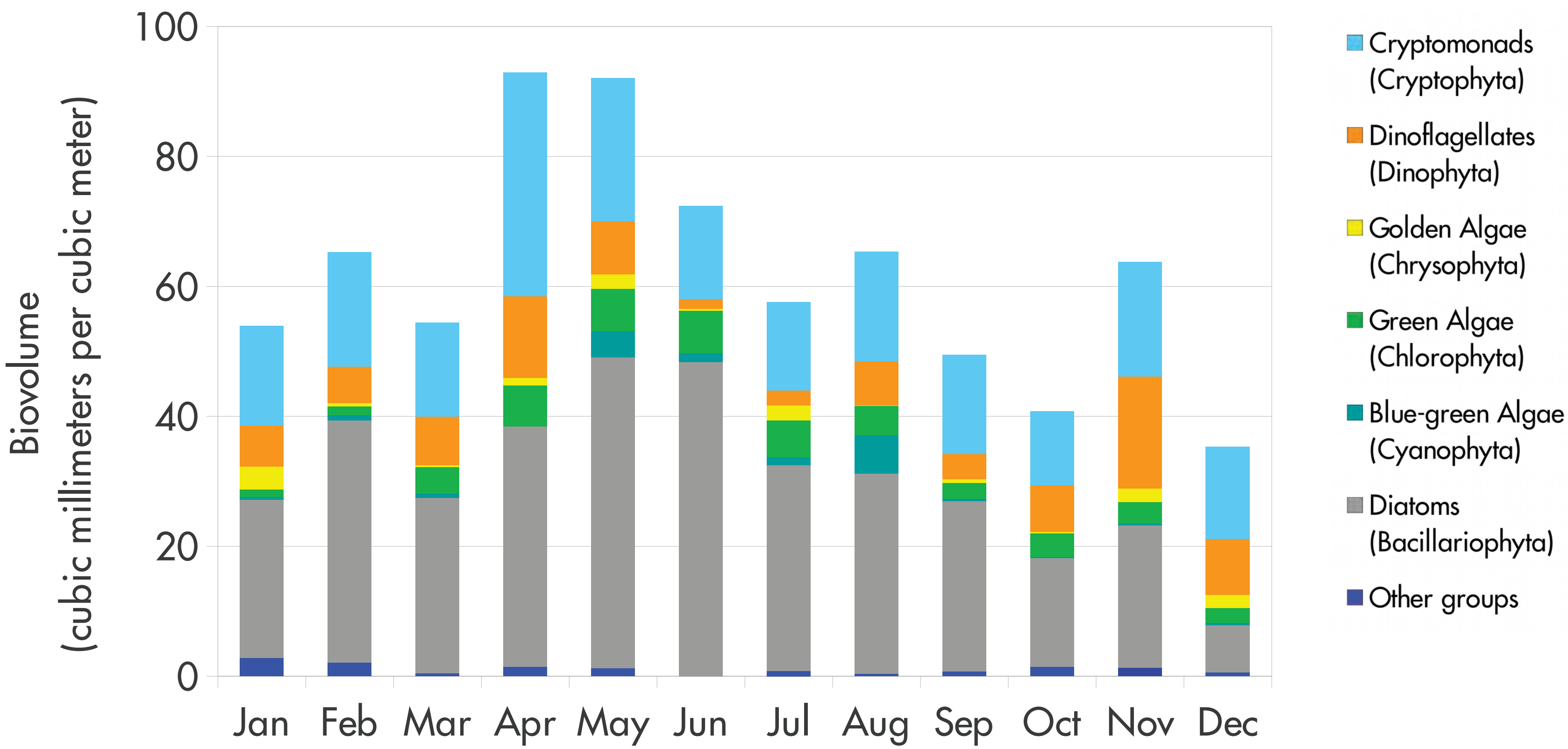


BIOLOGY

Algal groups as a fraction of total biovolume

Monthly in 2015

The biovolume of algal populations vary month to month, as well as year to year. In 2015, diatoms again dominated the biovolume of the phytoplankton community, especially in the summer. The peak in the biovolume occurred earlier in 2015, occurring in April and May. Note that the biovolume of blue greens is close to zero, despite their large fraction of the individual cell counts. Even at the peak of the bloom, algal cells occupied only one ten-millionth of the water in the lake. The peak biovolume in 2015 (90 cubic millimeters per cubic meter) was ten percent lower than the peak in 2014.

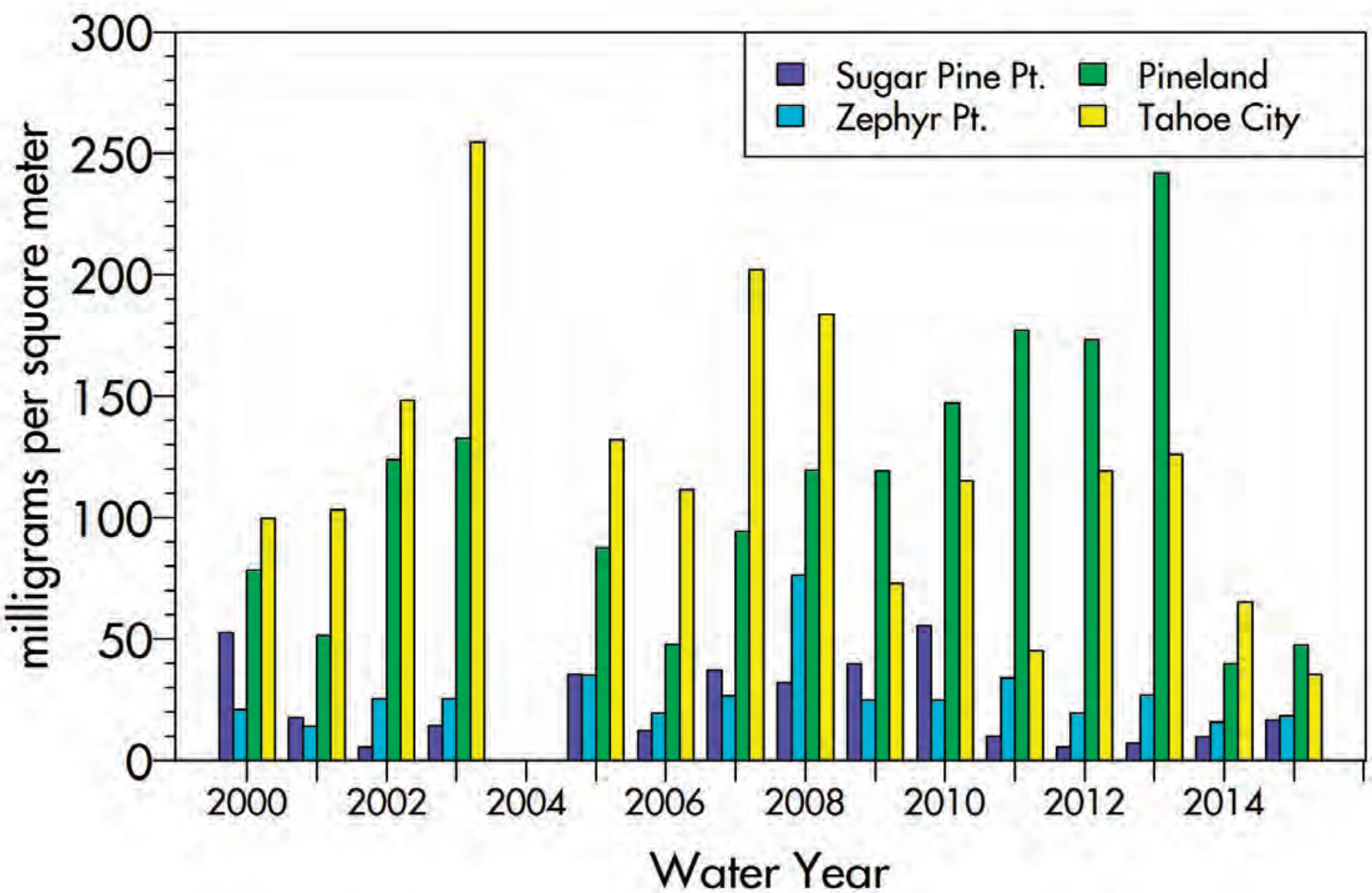


BIOLOGY

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 five to eight times each year, and this graph shows the maximum biomass measured at four sites for the period from January to June. In 2015, concentrations at the four sites shown were at or below their historic lows for the second year in a row. 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.



BIOLOGY

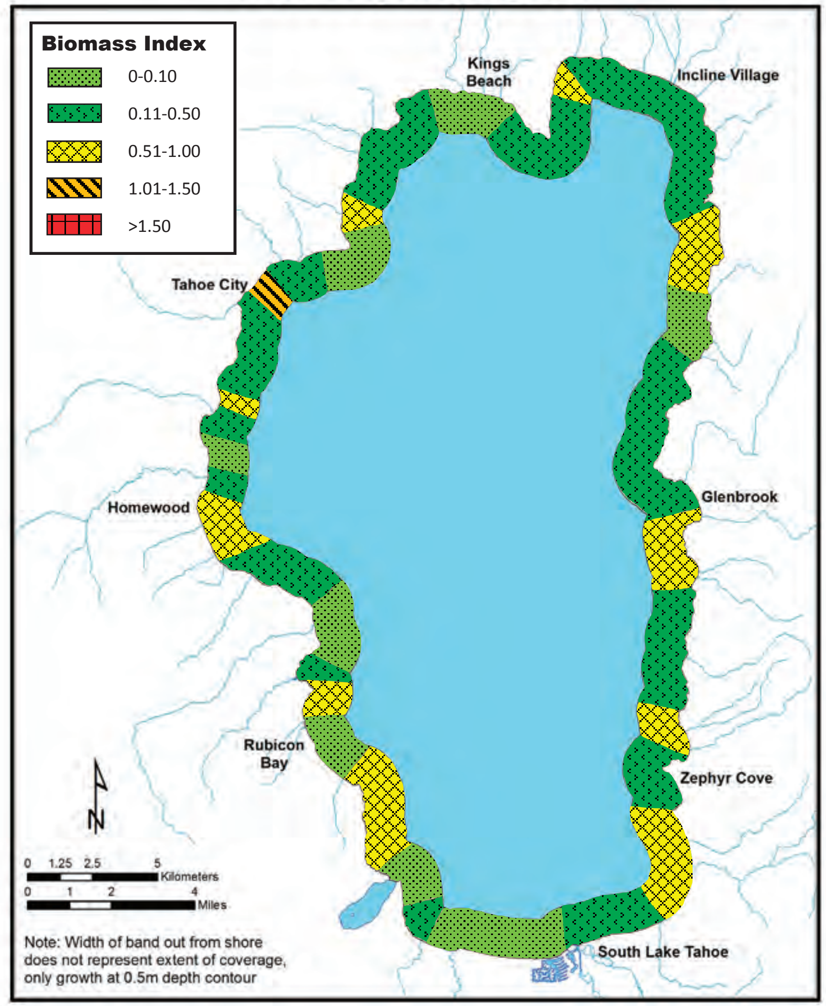
Shoreline algae distribution

In 2015

Periphyton biomass was surveyed around the lake during the spring of 2015, 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. The PBI had fewer very high occurrences (PBI > 1.5) in 2015, possibly due to the low lake levels that prevailed. Instead there was a greater number of moderate areas (PBI = 0.51 -1.0), especially on the east shore. As lake level falls during low lake level years, the 1.5 ft. measurement depth is increasingly dominated by blue-greens at many sites including the east shore sites resulting in moderate biomass index values (in contrast, the east shore often has relatively low growth of algae at higher lake levels).

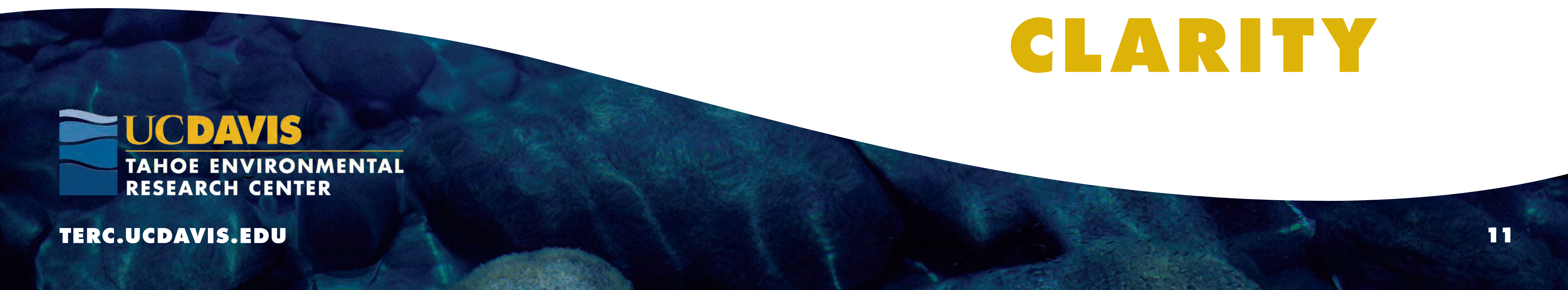
Note: The width of the colored band does not represent the actual dimension of the onshore-offshore distribution. Similarly, its length does not represent the precise longitudinal extent.

Distribution of Periphyton Biomass at 0.5m Depth, Spring 2015



TAHOE: STATE OF THE LAKE REPORT 2016

CLARITY

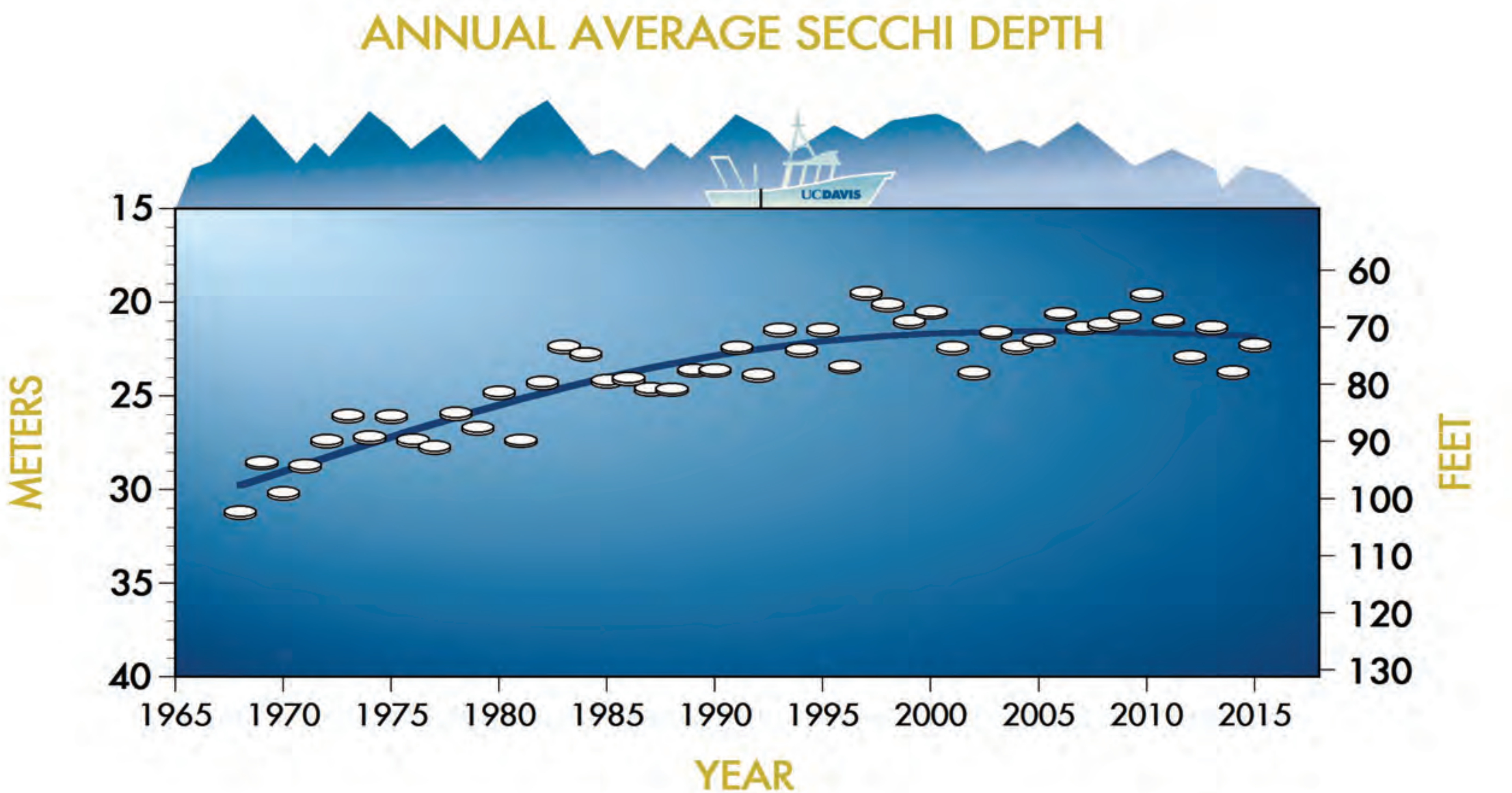


CLARITY

Annual average Secchi depth

Yearly since 1968

The Secchi depth is the depth at which a 10-inch white disk, called a Secchi disk, remains visible when lowered into the water. In 2015, the annual average Secchi depth was 73.1 feet (22.3 m), a 4.8 foot decrease from the previous year but still over 9 feet greater than the lowest average of 64.1 feet (19.5 m) recorded in 1997. The annual average clarity in the past decade has been better than the prior decade. The highest individual value recorded in 2015 was 86.6 feet on April 22, and the lowest was 59.9 feet on February 3. The decline this year is part of the year-to-year variability that has always characterized conditions at the lake. While the average annual clarity is now better than in preceding decades, it is still short of the clarity restoration target of 97.4 feet set by federal and state regulators, a goal agencies and the Tahoe Basin community continue to work toward.

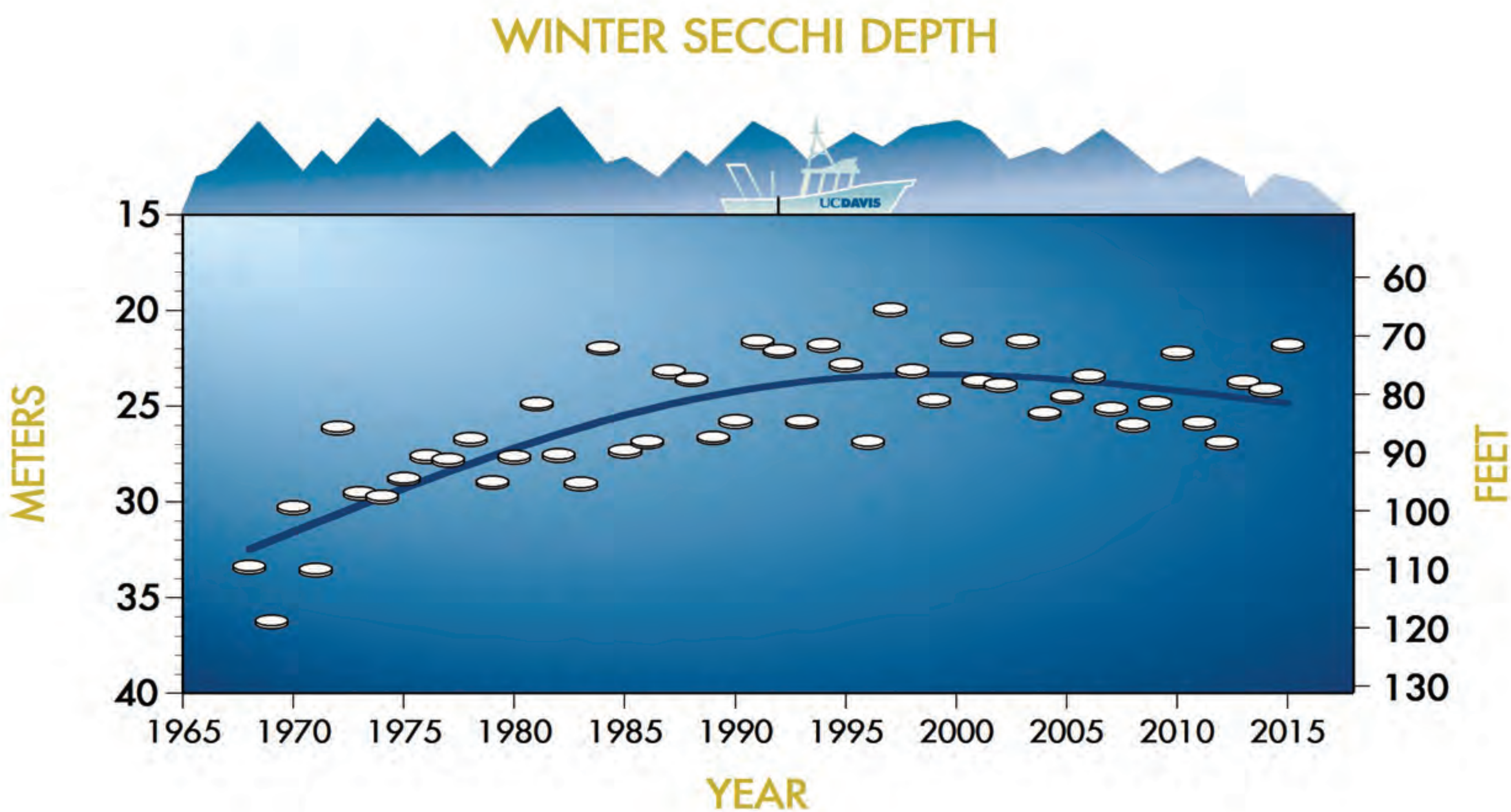


CLARITY

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 2015, winter clarity declined by 7.6 feet. The winter average of 71.5 feet (21.8 m) was still well above the worst winter average, 65.6 feet (20.0 m), seen in 1997. The low level of snowfall compared to rain this year caused the water entering the lake to be warmer in 2015, and this introduced fine particles closer to the surface.

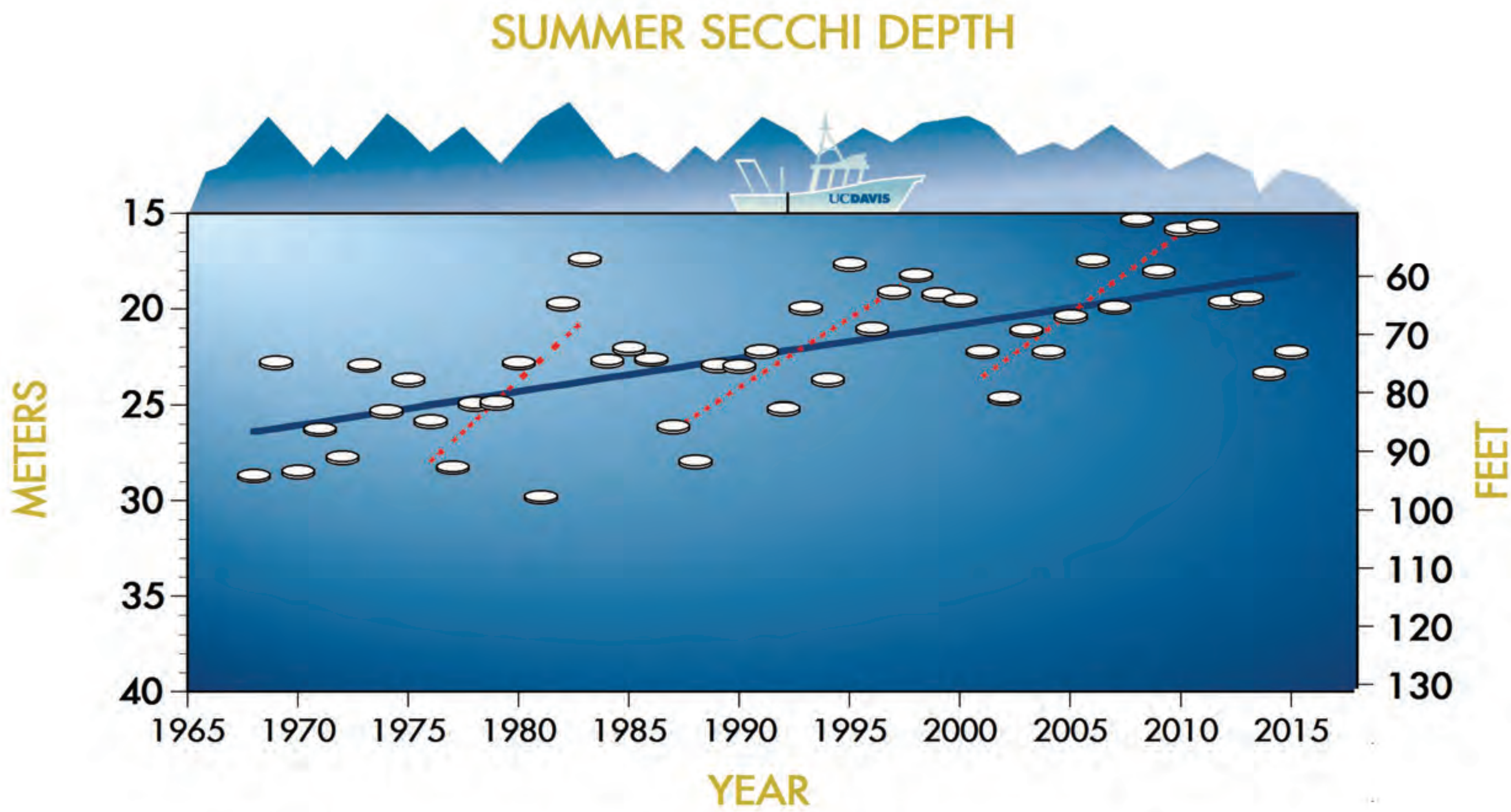


CLARITY

Summer Secchi depth

Yearly since 1968

Summer (June-September) clarity in Lake Tahoe in 2015 was 73.1 feet (22.3 m), a 4.8 foot decline from 2014. A contributing factor may have been the very low water levels in the lake, which exposed muddy shelves around the periphery of the lake. 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.



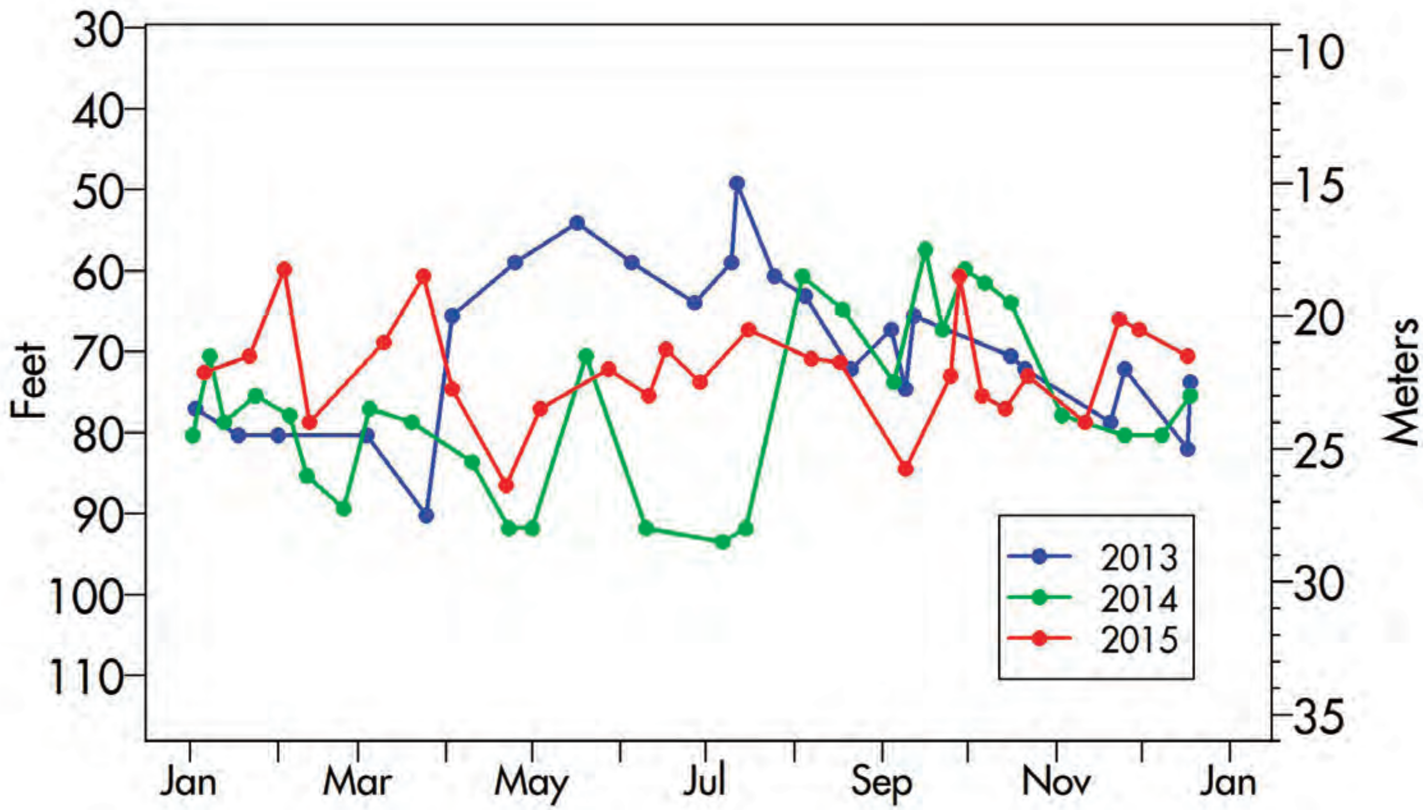
CLARITY

Individual Secchi depths

2013, 2014, 2015

Here, the individual Secchi depth reading from the Index station on the west side of the lake for 2013, 2014 and 2015 are plotted. For 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 and 2015 represented a departure from this long established pattern. In 2015 some of the lowest Secchi depths occurred in winter.

Secchi values can be seen to sometimes vary considerably over short time intervals. This is evident in February and October, 2015, where Secchi depth changed 19.5 feet and 15 feet respectively between consecutive readings. Such short-term variability is common in lakes. In these cases the sudden change is due to episodes of strong wind.

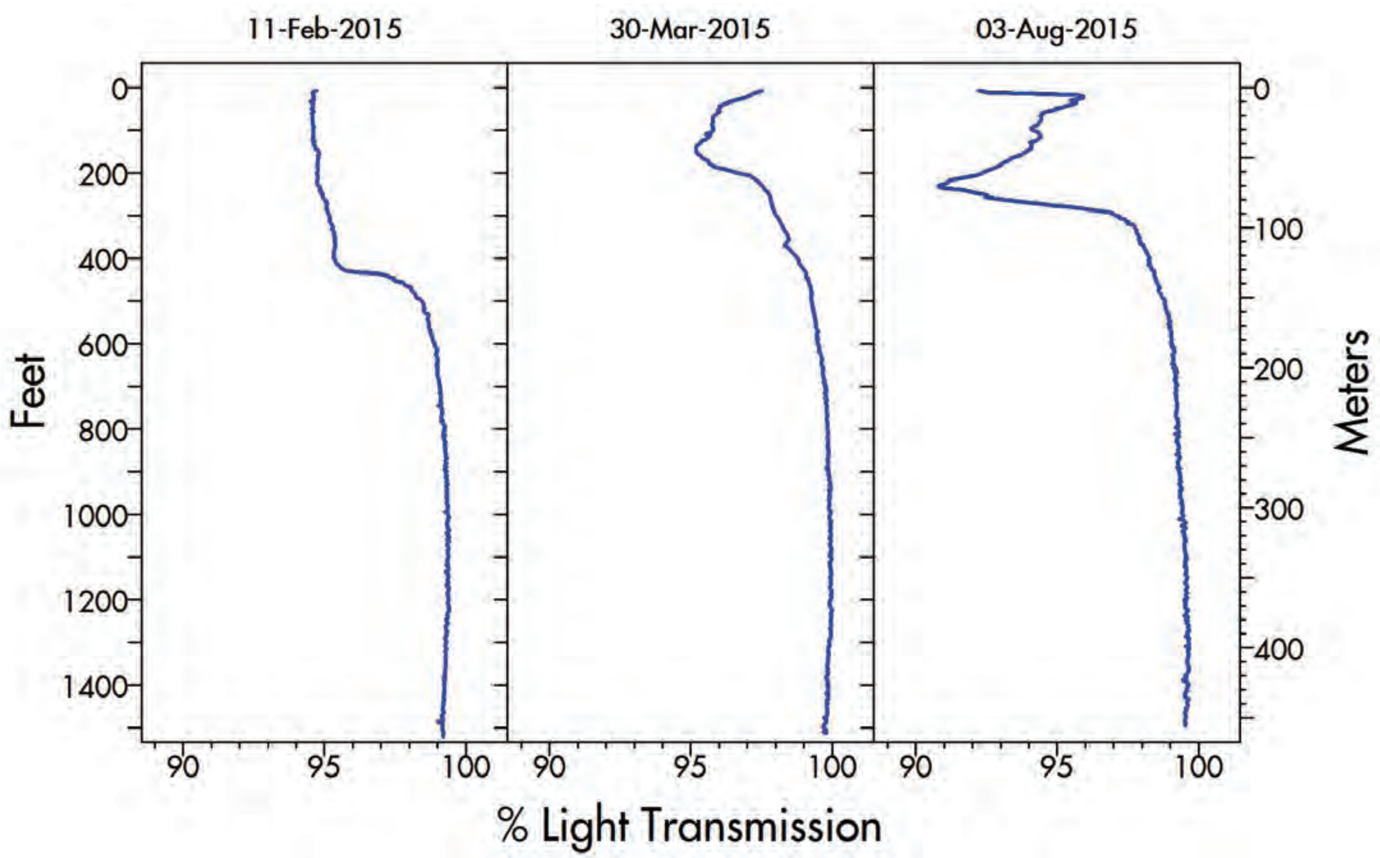


CLARITY

Light transmission

In 2015

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 2015. The first two panels, taken either side of the time of maximum vertical mixing, indicate that the lake has not fully mixed. In all three panels the less clear water (lower percent transmission) is toward the surface, whereas the deeper water is much clearer (higher percent transmission). 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 2016

EDUCATION AND OUTREACH

UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

EDUCATION AND OUTREACH

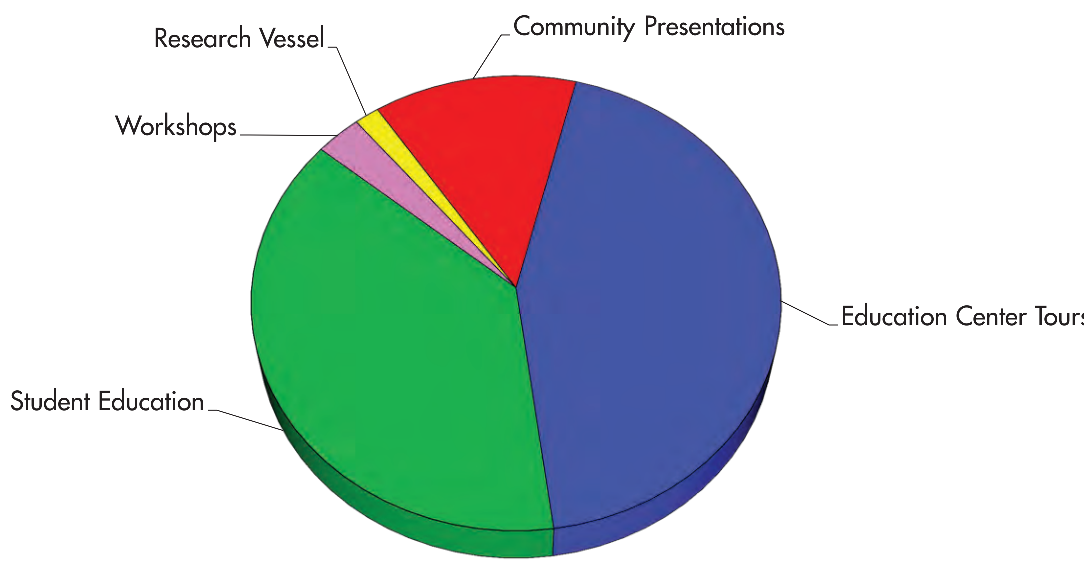
TERC education and outreach

In 2015

Part of TERC's mission is education and outreach. Our public, K-12, teacher professional development, and volunteer programs are designed to provide science-based information about the Lake Tahoe region in order to foster responsible action and stewardship.

During 2015, TERC recorded 12,344 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 2015, 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: 12,344

EDUCATION AND OUTREACH

TERC educational exhibits

In 2015

Each year, TERC works to improve our exhibits and increase the offerings available. During 2015 we developed a new exhibit, a mobile app, curriculum, games, and a 3-D movie that aids in our mission to provide engaging exhibits and interactive hands-on educational activities. Interactive touchscreens for the new "Lake Tahoe in Depth" exhibit allow visitors to examine real-time conditions all around the lake. The "Citizen Science Tahoe" app allows anyone using a smart phone to report conditions they see at the beach. New curriculum, such as the algal growth experiment, teaches students about nutrients that affect the blueness of Lake Tahoe. A game called "Pollution Adds Up," teaches students about the cumulative impacts of non-point source pollution. Finally, TERC's newest 3-D movie "Let's Go Jump in the Lake" is now available for viewing at the Tahoe Science Center.

Visitors view real-time lake conditions (photos, live camera views, weather, and activities) in the "Lake Tahoe in Depth" exhibit now available at the Tahoe Science Center. This project was funded by the Institute for Museum and Library Services, Nevada Division of Environmental Protection, and the North Lake Tahoe Resort Association. Photo: A. Toy

Education-specific funding allows TERC to enhance our education programs and develop new activities. Funded by the Nevada Division of Environmental Protection, the activity 'Pollution Adds Up' has students identifying different sources of pollution and learning about the cumulative impacts of non-point source pollution on a waterbody. Photo: A. Toy

Now showing: TERC's newest 3-D movie "Let's Go Jump in the Lake" is finally here! Take a guided trip into Lake Tahoe, meet the creatures living in the lake, and witness the physical changes a lake experiences over the course of a day, a season, and a year.

EDUCATION AND OUTREACH

TERC educational exhibits, continued

In 2015

TERC's augmented reality (AR) sandbox exhibit, originally developed as part of an National Science Foundation grant, has spread far beyond its home in our Tahoe Science Center. This spring, a new portable version went to Washington, D.C., where it was featured at the White House Water Forum, the USA Science and Engineering festival, and a Center for National Science Funding event at the Congressional Rayburn Building.

Since debuting in 2014, the three original AR sandboxes—located at TERC, the Lawrence Hall of Science, and ECHO Lake Aquarium and Science Center—have inspired over 150 users across the globe to build their own sandboxes. Used as an educational tool, AR sandboxes can teach students and visitors about geomorphology, topography, hydrology, and landforms. Experience the AR sandbox in person at the Tahoe Science Center or visit www.ARsandbox.org to learn more.

Portable augmented reality (AR) sandbox exhibit on display at the USA Science and Engineering Festival in Washington, D.C. Oliver Kreylos, Heather Segale and Geoff Schladow were special invitees to represent the National Science Foundation at the event.
Photo: Sherry Hsi

The portable AR Sandbox exhibit's final home was the Howard University Middle School, where it will be a permanent feature in Mrs. Hardeen's sixth-grade science class. The hand over ceremony was attended by NSF administrators, D.C. education officials, and the trustees of Howard University.

More than 150 AR Sandboxes have been developed following the original LakeViz3D model. These include sandboxes at schools, universities, research centers, government organizations, museums, and science centers. The AR Sandbox is being used to investigate and teach a wide array of topics, including geology, soil science, hydrology, energy and mineral exploration, forestry, seismology, military operations, coastal engineering, regional planning, and disaster preparedness.

EDUCATION AND OUTREACH

TERC educational programs

In 2015

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.

Groups visit TERC for informal science education programs on water, geology, ecology, and biology. Pictured here, are future California Naturalists learning what makes an educator great and the importance of landscaping with native plants at the Tahoe City Demonstration garden. Photo: A. Toy

Students witness the early life stages of a Lahontan cutthroat trout as part of the Trout in the Classroom program. Students release their Lahontan cutthroat trout fry into Incline Creek in hopes that they will thrive in their native Lake Tahoe. Photo: A. Toy

Students in the Youth Science Institute (YSI) are exposed to a variety of science, technology, engineering, and math fields, including fish dissection, medicine, chemistry, robotics, engineering, and computer coding. In the above photo Joanna Koch MD teaches Andrew Bourke how to perform basic medical procedures. Photo: E. Portier

EDUCATION AND OUTREACH

TERC educational programs, continued

In 2015

Each year we train new volunteer docents at our annual June Docent Training. Volunteer docents become local experts and lead public 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.

TERC's "Citizen Science Tahoe App," launched in August 2015, encourages beach-goers to take a couple of minutes to report beach and lake conditions. The information is shared with scientists and provides a more in depth look of conditions around the lake. Photo: A. Toy

Doug Graham and Larry Patzman are two of TERC's newest volunteer docents. During docent training they joined boat captain Brant Allen on the research vessel John LeConte and viewed Tahoe's native zooplankton. Photo: A. Toy

TERC creates new science activities to enhance student interest in citizen science. In the "Algal Bloom Experiment" students discover that nutrients stimulate algal growth in Lake Tahoe water. Students learn that by reporting algal growth through the "Citizen Science Tahoe" app officials are more likely to pinpoint sources of nutrient pollution. Photo: B. Lewis

EDUCATION AND OUTREACH

TERC special events

In 2015

TERC hosts monthly lectures throughout the year on various environmental issues, new scientific research, and related regional topics of interest. Recent topics have included, "Gratitude Works! How Gratitude Heals, Energizes, and Transforms Lives", "The Physics of Snow", and "Exploring Mars with Curiosity."

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).

At the 11th annual Physical Science Expo students learn about light mixing using their hands and other items to block out colored light to create different colored shadows. Photo: A. Toy

This year was the first ever Science Expo to be held in South Lake Tahoe on the Lake Tahoe Community College campus. A student pictured here uses a Van de Graaff generator to learn about the flow of electrons. Photo: A. Toy

Scientists and organizations from the Tahoe basin participate in TERC's annual Children's Environmental Science Day to make this a community event that builds knowledge, encourages conservation, and develops partnerships. In 2015, Commons Beach in Tahoe City became the new location for this fun, family event. Photo: N. McMahon

The UC Davis Tahoe Environmental Research Center is a global leader in research, education, and public outreach on lakes that provides critical scientific information to help understand, restore, and sustain the Lake Tahoe Basin and other systems worldwide.

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