UC DAVIS

TAHOE: STATE OF THE LAKE REPORT 2022

Tahoe Environmental Research Center

The UC Davis Tahoe Environmental Research Center is dedicated to interdisciplinary research and education to advance the knowledge of aquatic and terrestrial ecosystems and their interactions within natural and developed Earth systems, and to communicate science-informed solutions worldwide.

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Co-Editors: A. Toy, S. Watanabe

The UC Davis Tahoe: State of the Lake Report 2022 is dedicated to the entire Tahoe community in recognition of their fortitude and resilience in the face of the extraordinary conditions brought on by the wildfires of 2021. Special thanks to the firefighters and other first responders who confronted danger and helped avert what could have been a cataclysmic event for the Tahoe basin.

Tamarak Fire, 2021. Courtesy of L. Bronson, USFS Firefighter and former TERC AmeriCorps member

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TABLE OF CONTENTS

(CONTINUED ON NEXT PAGE)

TABLE OF CONTENTS, CONTINUED

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 and human activity are affecting the lake's clarity, physics, chemistry, and biology. We also present a portion of the data collected in 2021—presenting all of it would be overwhelming. 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 United States and worldwide.

Our goal is to understand the lake's complexity and to use the knowledge gained to provide the scientific underpinnings for ecosystem restoration and management actions. Choosing from those options and implementing them is the role of management agencies that also need to account for a host of other considerations.

This annual report is intended to inform non-scientists about the variables that affect lake health. One indicator of Lake Tahoe's health status—the annual clarity—is reported earlier each year. In this report, we publish many other environmental and water quality factors that serve as other indicators of the lake's condition and help explain the lake's changing clarity. This report sets the context for understanding both the year-to-year changes and those that are observed over decades.

Some of the important parts of this report are the updates on research taking place independently of the long-term monitoring. These updates highlight some of the most exciting and promising findings of work that is still in progress. The new insights gained through this research will help keep Lake Tahoe at the cutting edge of science for years to come. Many of the sections explore new ideas and approaches to address the ever-evolving challenges at Lake Tahoe.

The data we present are the result of efforts by a great many scientists, engineers, students, technicians, and educators who have worked at Lake Tahoe throughout the decades since sampling commenced. I would, however, like to acknowledge (in alphabetical order) the contributions to this year's report by Brant Allen, Karen Atkins, Kian Bagheri, Carmen Bedke, Brandon Berry, Fabian Bombardelli, Mike Bruno, Tom Burt, Samantha Campisi, Luciana Cardoso, Yuan Cheng, Bob Coats, Troy Corliss, Alicia Cortés, Cole Dickson, Stephen Drake, MJ Farruggia, Helen Fillmore, Alex Forrest, Nick Framsted, Susan Frankel, Drew Fredrichs, Scott Hackley, Tina Hammell, Simon Hook, Camille Jensen, Yufang Jin, Melissa Kibbee, Jessica Landesman, Kenneth Larrieu, Anne Liston, Kevin Livingston, Patricia Maloney, Elisa Marini, Jasmin McInerney, Antonina Myshyakova, Aaron Ninokawa, Holly Oldroyd, Anne Nolin, Kanarat Pinkanjananavee (Job), Gerardo Rivera, Steve Sadro, Heather Segale, Katie Senft, Steven Sesma, Noah Shapiro, Samantha Sharp, Roland Shaw, David Smith, Sheri Smith, Adrianne Smits, Micah Swann, Lidia Tanaka, Ruth Thirkill, Raph Townsend, Alison Toy, Sean Trommer, Sergio Valbuena, Aaron Vanderpool, Lindsay Vaughan, Shohei Watanabe, and Erik Young to this year's report. In particular, Shohei Watanabe was responsible for the majority of the data analysis, and Alison Toy led the compilation and layout of the final 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 California Tahoe Conservancy, Lahontan Regional Water Quality Control Board, Tahoe Regional Planning Agency, U.S. Geological Survey, and UC Davis.

Sponsors for current projects include the following: California Natural Resources Agency, California Tahoe Conservancy, Incline Village General Improvement District, Nevada Department of Tourism and Cultural Affairs, Nevada Division of Environmental Protection, Nevada Division of State Lands, Parasol Tahoe Community Foundation, Tahoe Fund, and Tahoe Truckee Community Foundation.

Our monitoring is frequently done in collaboration with other research institutions and agencies. In particular, we would like to acknowledge our collaborators at UC Davis, the Desert Research Institute (DRI), the National Aeronautics and Space Administration (NASA), the National Oceanographic and Atmospheric Administration (NOAA), the Tahoe Resource Conservation District (TRCD), the U.S. Forest Service, (USFS), the U.S. Geological Survey, the University of Miami at Ohio, and the University of Nevada, Reno (UNR).

We are very proud to recognize the funding support for actual production of this annual report from the following organizations: California Tahoe Conservancy, Incline Village Waste Not Program, Lahontan Regional Water Quality Control Board, Lake Tahoe Marina Association, Mountain Workspace, Parasol Tahoe Community Foundation, Tahoe Fund, Tahoe Lakefront Owners' Association, Tahoe Regional Planning Agency, Tahoe Truckee Airport Community Partner, Tahoe Water Suppliers Association, and True Point Solutions. We sincerely thank these organizations for their dedication in supporting science to save the lake.

Sincerelv.

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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 provides a unique tool for understanding ecosystem function and change. It has become essential for decision-making by elected officials and public agencies tasked with restoring and managing the Tahoe ecosystem. This is, in part, because it provides an independent basis for assessing the progress toward attaining 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) is innovating with new approaches to enrich the long-term data record for Lake Tahoe and to address emerging questions. These approaches include real-time measurements at over 25 stations around the basin and remote sensing from autonomous underwater vehicles, satellites, aerial drones, helicopters, and computer modeling tools. These efforts are all focused on quantifying the changes that are happening and, at the same time, understanding what actions and measures will be most effective for control, mitigation, and management in the future. Our newest station was commissioned in June 2022. This real-time thermistor chain and dissolved oxygen sensor, cabled back to shore at Obexers' Marina on the west shore, is now providing data on the internal motions of the lake and the loss of oxygen at a depth of 115 m (380 ft).

This annual Tahoe: State of the Lake Report 2022 presents data from 2021 in the context of the long-term record. While we report on the data collected as part of our ongoing measurement programs, we also include sections summarizing some of the current research that is being driven by the important questions of the day and concerns for the future. These include: the large decline in the populations of many of the lake's zooplankton; the unprecedented change that occurred in both the distribution and taxa of the lake's phytoplankton; the accelerating rate of ecological change in the nearshore, made all the more clear through the use of aerial surveillance; the prevalence of microplastic pollution the lake; the measurement of smoke from distant wildfires using an autonomous underwater vehicle; the launch of a lake condition forecast website, which made it possible for visitors and residents to be informed about potentially life-threatening conditions; and, finally, a summary of some of the work being done by graduate students and researchers at areas outside the Tahoe basin.

The populations of some species of zooplankton, the tiny aquatic animals that live in Lake Tahoe, have declined to extremely low numbers in the last nine months. There may be serious consequences from these changes. Zooplankton occupy the middle of the food web, an important

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"Previous year" for some parameters means data collated in terms of the water year, which runs from October 1 throught September 30; for other parameters, it means data for the calendar year, January 1 through December 31. Therefore, for this 2022 report, Water Year data are from October 1, 2020 through September 30, 2021. Calendar year data are from January 1, 2021 through December 31, 2021.

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.1)

position for regulating algal concentration and providing food for higher-level organisms. The most important decline is that of the *Mysis* shrimp, a non-native species that was introduced to the lake over 50 years ago. Based on past observations, we have reason to believe that this will allow the numbers of *Daphnia* and other small zooplankton that are very effective at cleaning the water to increase. If that occurred, we would expect a large increase in the Secchi depth clarity beginning in 2023. If *Daphnia* abundance persists for two years or more, a large increase in kokanee salmon size could also occur. Eventually, however, the cycle will repeat, and *Mysis* will re-establish and consume the *Daphnia*. Nature does not often present natural whole-ecosystem experiments, but this is precisely what has commenced at Lake Tahoe. At this point in time, there exists a unique opportunity to thoroughly monitor the changes that ensue.

The phytoplankton of the lake are also changing at an unprecedented rate. In 2021, phytoplankton changed their distribution in the water and moved much closer to the surface as summer progressed. There was also a major shift in the phyla present. For the first time on record, the cyanobacteria *Leptolyngbya* sp. was the dominant alga. This is a species that has been shown to be favored by the high nitrogen values present in wildfire smoke.

The nearshore regions of the lake, where millions of people recreate every year, are also at a growing risk. Using aerial imagery from a helicopter, we are now able to quantify the spatial distribution of attached algae and algal mats around the entire shoreline of the lake. Instead of sampling at several fixed locations around the lake, we now sample everywhere. For the first time, we were able to fully capture the vast extent of the periphyton bloom in the northwest of the lake, centered on Tahoe City, and have ground truthing confirmation on the same day.

Wildfires are an increasing presence, even when they are not burning within the basin. Fine particles reduce visibility and cause the air quality to reach dangerous levels that impact public health and the lake in many ways. One way is believed to be the change in phytoplankton species and vertical distribution in the lake as noted above. Using a range of measurements, including those taken by autonomous underwater vehicles, TERC researchers and students have been studying the impacts of the Caldor Fire as part of a larger study through the Tahoe Science Advisory Council.

Microplastics, long recognized as an environmental issue in the ocean, are also present in Lake Tahoe in surprisingly high numbers. Preliminary data from a study between TERC and the UC Davis School of Veterinary Medicine have been able to quantify the types of plastics present throughout the year. The study is currently evaluating the potential for bioaccumulation in

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EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.2)

the lake's organisms.

Meteorologically, the persistent, long-term trends have not changed from year-to-year. However, a changing climate is evident in almost all the long-term meteorological trends, including rising air temperature and the declining fraction of precipitation as snow. The weather experienced in a given year can be far more variable. From March through July 2021, monthly average temperatures were warmer than the previous two years and the long-term average. The monthly average air temperatures for June and July were the warmest ever recorded since 2010. At 15.3 inches, 2021 had less than half the long-term average precipitation and was the third driest year on record. Eight of the last ten years had precipitation at or below the long-term average. Precipitation in every month of the 2021 Water Year was below the long-term average. This, combined with the low precipitation of winter 2022, highlights the long-term drought our region is experiencing.

The water level in Lake Tahoe varies throughout the year due to inflows, outflows, precipitation, and evaporation. In 2021, on account of the dry winter, there was no significant annual rise in lake level. From January through December 2021, overall lake level fell 1.5 feet. It is almost certain that the lake will fall below its natural rim during summer 2022 and stop river outflow to the Truckee River.

Despite year-to-year variability, the annual average surface water temperatures show an increasing trend. For 2021, the average surface water temperature was 53.1 °F making it the third warmest year on record. The overall rate of warming of the lake surface is 0.39 °F per decade. July surface water temperature averaged 68.7 °F, the highest value ever recorded. This was 3.5 °F above the average of 65.2 °F for the 23-year period of record. Lake Tahoe mixes vertically each winter as surface waters cool and sink downward. 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 carries oxygen downward to deep waters, promoting aquatic life throughout the water column. On March 17, 2021, Lake Tahoe was observed to have only mixed to a maximum depth of 492 feet. On February 18, 2022, it mixed to a maximum depth of only 328 feet, the second lowest value on record.

The stability of the lake is an important concept that expresses its resistance to vertical mixing and determines its length of stratification. High stability can mean that oxygen is not transferred to deep portions of the lake, that pollutant bearing inflows enter the lake closer to the surface, and that the types and vertical distribution of phytoplankton change. The length of time that Lake Tahoe is stratified has increased each year, another consequence of climate change. Since 1968, the stratification season length has,

(CONTINUED ON NEXT PAGE)

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.3)

on average, increased by 31 days, effectively increasing the length of summer and decreasing the length of winter. In 2021, the length of the stratified season was 217 days, the second longest period on record.

The reduction of nutrient and fine particle loads to the lake is a fundamental part of the restoration efforts driven largely by the Total Maximum Daily Load (TMDL) program. The stream-borne nitrogen and phosphorus loads from the Upper Truckee River were the lowest on record in 2021, which was in line with the low precipitation for the year. In-lake nitrate and total hydrolyzable phosphorus concentrations increased slightly, partly as a result of the absence of deep mixing in 2021. Surface nitrate levels are particularly low, which could possibly be the result of very rapid uptake by the changed phytoplankton community in 2021. The concentration of fine particles in the surface of the lake has been elevated since the record inflows of 2017. The reasons for the persistence of these particles are an area of current research.

Biologically, the primary productivity of the lake has increased dramatically since 1959. In 2021, it appeared to reach its highest values ever, although the data are currently provisional. By contrast, the biomass (concentration) of algae, as measured by chlorophyll concentration in the lake, has remained relatively steady. Most of the chlorophyll is concentrated in a band at a depth of approximately 150–200 feet, known as the "deep chlorophyll maximum" (DCM). In 2021, the DCM moved higher in the water through summer and fall—something that has never been observed previously. For the first time, cyanobacteria were the most abundant phytoplankton in Lake Tahoe. Diatoms were still the dominant group by volume. Of these, *Synedra* formed the largest percentage of the biomass, accounting for over 90 percent of the diatoms during spring, summer, and fall. Total biomass was three times larger than it was in 2020. The attached algae (periphyton) on the rocks around the lake were near average values in 2021, based on a synoptic survey. As usual, the California side of the lake continued to display higher concentrations of periphyton.

In 2021, the annual average Secchi depth was 61.0 feet (18.6 m). Little changed from the previous year which was reflective of the near-constant values over the last 20 years. The greatest individual value recorded in 2021 was only 79.6 feet (24.2 m) on February 12. The lack of complete vertical mixing of the lake in 2021 is a major reason for this low maximum clarity value. The winter (December–March) clarity value was 71.9 feet (21.9 m). Winter precipitation was well below the long-term average, and such conditions would typically be expected to yield higher clarity values. Summer (June–September) clarity was 54.8 feet (16.7 m), a decrease of over four feet from the previous year. This is above the lowest summer value of 50.5 feet in 2008.

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 second 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: approximately 75 miles (120 kilometers)
- Volume of water: 40 trillion gallons, plus or minus
- The daily evaporation from Lake Tahoe (half a billion gallons) would meet the daily water needs of five million Americans
- The number of algal cells in Lake Tahoe is approximately 30 million trillion, within a few trillion or so
- A single *Daphnia* can consume 100,000 fine particles every hour
- In a bad year, there are over 60 billion *Mysis* shrimp in Lake Tahoe
- In 2022, there are less than three billion *Mysis* shrimp, potentially setting the stage for the rebound of the *Daphnia* population and an improvement in clarity in 2023
- 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 exits at Tahoe City, flows through Truckee and Reno, and terminates in Pyramid Lake, Nevada
- Number of monitoring stations TERC utilizes in the Tahoe Basin: 225
- 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 conducted continuous scientific monitoring of Lake Tahoe, laying the foundation for restoration and stewardship efforts.

TERC's activities are based out of 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, which is 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 R/V John LeConte and the R/V Bob Richards. The R/V Ted Frantz operates out of Clear Lake, California, and the R/V Tom is based in Davis, California. Malyj Manor, a three-bedroom house in Tahoe City, provides short-term housing for students and visiting researchers.

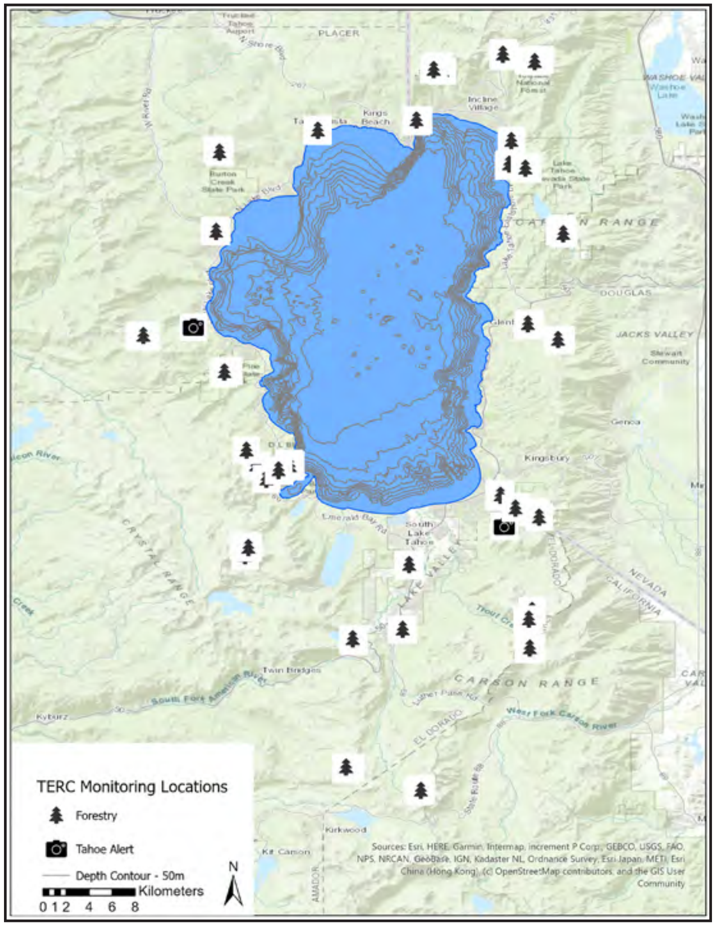
Additional laboratories and offices are located on the UC Davis campus at the Center for Watershed Sciences, Ghausi Hall, and Wickson Hall.

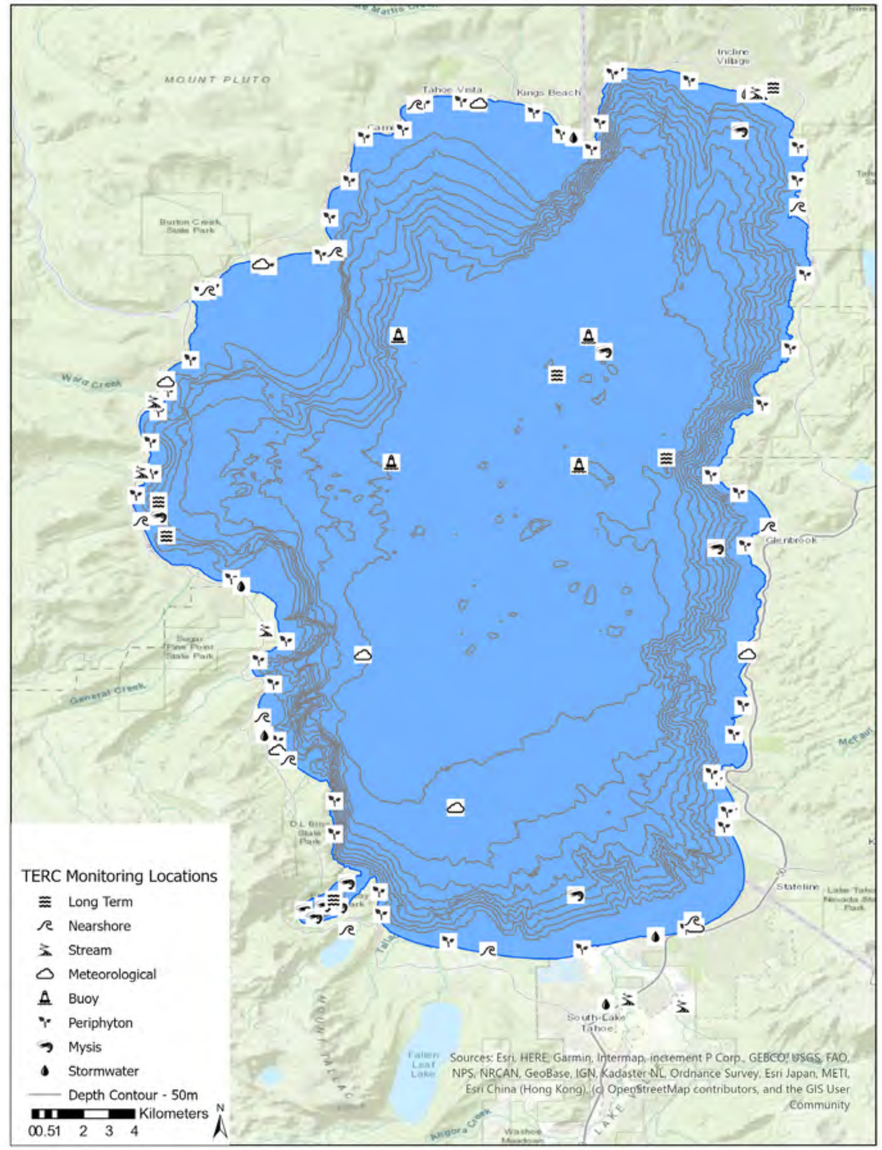
At locations throughout the basin, we have sensors continuously reporting on the health and well-being of the lake and its environs, which all contribute to making Lake Tahoe the smartest lake in the world.

Our website (https://tahoe.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 sensors;
- TERC research publications;
- Exhibits and events at the education centers; and
- Information about supporting our research and learning programs.

TAHOE BASIN DATA COLLECTION SITES





TAHOE: STATE OF THE LAKE REPORT 2022

CURRENT RESEARCH

Current research synthesis

This section of the State of the Lake Report describes ongoing research that is above and beyond the monitoring described in the subsequent sections, although in many cases it is predicated on that monitoring.

The changes to Lake Tahoe that were observed in 2021 and in the first part of 2022 are among the largest and most significant that have been observed in the 54-year data record. These changes are documented in the first three parts of this section, and relate to major shifts in the lake's zooplankton, phytoplankton, and nearshore algae. The extent to which these shifts are inter-related is a focus of our current research. Being able to understand what is driving these changes and what these circumstances may mean for issues like restoring lake clarity, makes them all high-priority research questions.

Clockwise from top right: Atmospheric deposition sampler on Lake Tahoe; a South Lake Tahoe beach covered in green algae and orange coloration associated with iron-oxidizing bacterial activity; Lake sampling never stops because of cold temperatures.
(Photos: B. Berry, S. Hackley, and B. Scholes)

Current research synthesis, continued

The three subsequent sub-sections describe ongoing research projects that TERC scientists and graduate students are currently involved in. They relate to studying the impacts of wildfire smoke on Lake Tahoe following 2021's devastating fires, tracking the spread of invasive Asian clams at Sand Harbor State Park, and collecting and analyzing of microplastics from Lake Tahoe.

We also describe a new tool that has been developed with the help of a team of undergraduate students. The Lake Conditions tool allows the public to access both TERC's real-time lake temperature and wave height data and to get forecasts of lake temperatures, water currents, and wave heights for every three hours over the three following days. We hope that this will prove to be a life-saving tool as people learn how treacherous the lake can be to the unprepared and plan their fun accordingly.

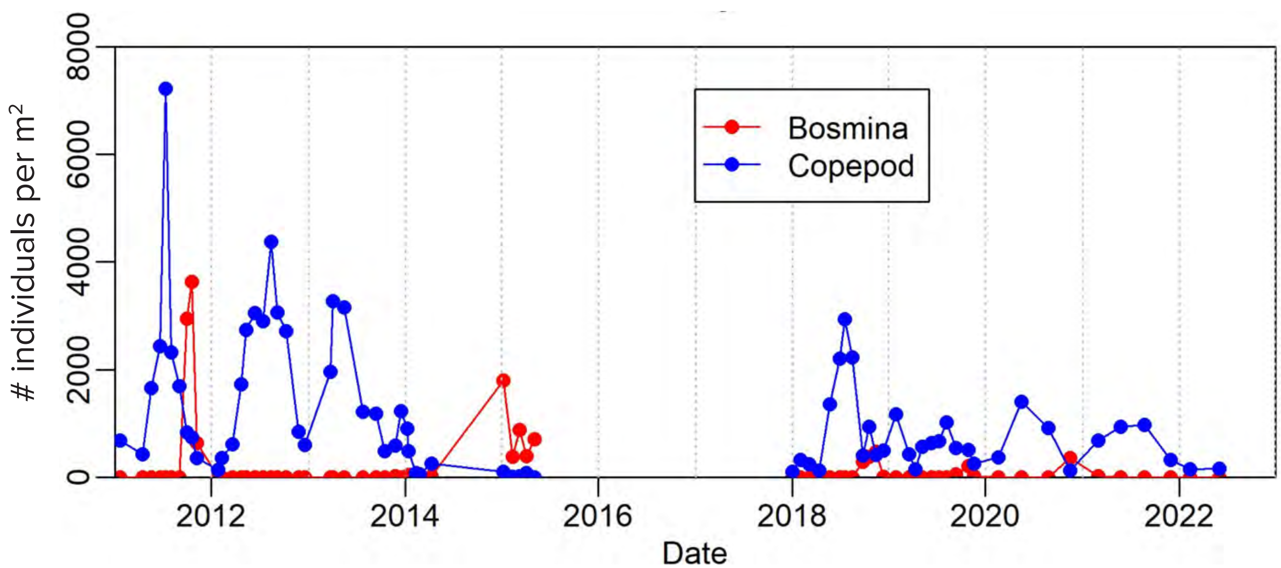
Water conditions can change quickly. Real-time and forecasted conditions are available for surface temperature, currents, and wave height at https://tahoe.ucdavis.edu/lake-conditions. Don't be caught in an unforeseen hazard by making sure to check lake conditions before heading out.
(Photos: N. McMahon and A. Toy)

Dramatic decline of zooplankton species presents an opportunity to study effects on clarity

In September 2021, TERC researchers noticed a decline in the numbers of zooplankton, the tiny aquatic animals that live in Lake Tahoe. As TERC sampling extended into July 2022, we continued to see alarmingly low numbers of some zooplankton taxa.

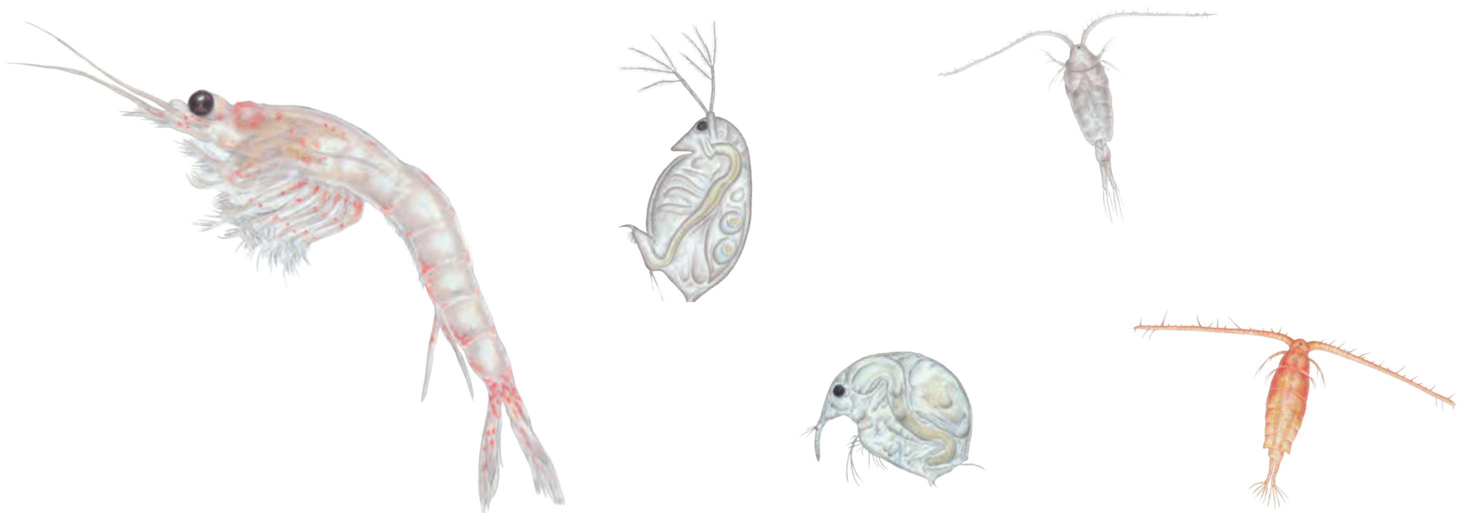
There may be serious consequences from these changes. Zooplankton occupy the middle of the food web and play an important role in the lake ecosystem. They consume algae, some of which reduce water clarity or which might otherwise accumulate in the nearshore regions and beaches. Zooplankton are also a major food source for fish, such as the popular sport fish kokanee salmon.

The panel below shows the abundances (individuals/m^3) of native zooplankton, *Bosmina* (a cladoceran) and the copepods *Epischura* and *Diaptomus* from measurement stations in Lake Tahoe. Since the 1970s, *Bosmina* have rarely been present in large numbers. *Daphnia*, also a native cladoceran, have been even rarer in this period. While seasonal fluctuations exist in all years for the copepods, numbers have been low for several years, especially since 2021. Similar declines are being observed in Emerald Bay.



Dramatic decline of zooplankton species presents an opportunity to study effects on clarity, continued

Over 50 years ago, a non-native zooplankton species, the *Mysis* shrimp, was introduced to Lake Tahoe. Since that time, it has dramatically altered the food web in Lake Tahoe and Emerald Bay, just as it has done in most lakes where it was introduced. One of the consequences of its introduction was the decline of native zooplankton such as *Daphnia*, which *Mysis* preferentially consume. This is important because *Daphnia* are voracious grazers of algae and are considered a harbinger of good water quality.

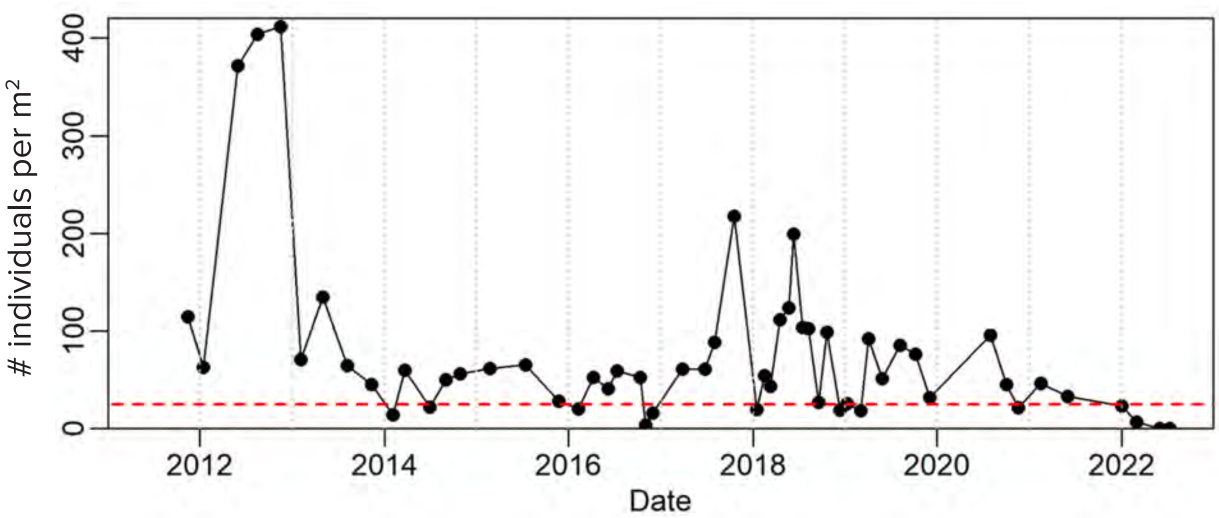


Scientific Illustrations of Lake Tahoe zooplankton from left to right: Mysis shrimp, Daphnia, Bosmina, Epischura, and Diaptomus. (Illustrations: S. Adler)

Dramatic decline of zooplankton species presents an opportunity to study effects on clarity, continued

We saw evidence of this linkage between *Mysis*, *Daphnia*, and water clarity in Emerald Bay. From 2011 to 2014, *Mysis* abundance dropped similarly in Emerald Bay, followed by an increase in *Daphnia* and a dramatic 36-foot increase in clarity. At the same time, the size of kokanee living in Emerald Bay doubled. This was not the case for kokanee residing in Lake Tahoe. When the *Mysis* returned a few years later, the process reversed itself. The *Daphnia* declined, and there was a return to the former lower water clarity. Unfortunately, at that time, the importance of what was happening was not recognized, and very little data beyond Secchi depth were collected to determine the broader changes wrought by the *Daphnia* and the impact of the absence of *Mysis* on the lake ecosystem.

Today, almost ten years later, a similar event may be occuring in Lake Tahoe itself. While a complete data record for *Mysis* since its introduction in the 1960s does not exist, the current extremely low levels are believed to be unprecedented. The red dashed line in the figure below indicates a *Mysis* abundance of 27 individuals per m^2. This level was established based on Tahoe research from the 1970s as the maximum *Mysis* abundance that would allow species such as *Daphnia* and *Bosmina* to again flourish.



Dramatic decline of zooplankton species presents an opportunity to study effects on clarity, continued

At this point in time, we have a unique opportunity to thoroughly monitor the changes that ensue. Based on what we observed in Emerald Bay in the past, we have reason to believe similar changes might occur in Tahoe. With the expected increase in the abundance of *Daphnia* and other small zooplankton, there would be a correspondingly large increase in the Secchi depth clarity. If *Daphnia* abundance persists for two years or more, we anticipate seeing a dramatic increase in kokanee size based on the return of their preferred prey. However, the cycle will eventually repeat; *Mysis* will re-establish and consume the *Daphnia*, and the system will revert to its former, perturbed version.

What should be done? If we just keep monitoring clarity, we will see the end effect. But by investing in more complete monitoring now, we will develop a clearer understanding of the mechanisms linking zooplankton population dynamics with variations in water clarity and other ecosystem properties. This is critical information for developing and improving predictive models. Many questions could be answered:

1) What populations of *Daphnia* and *Bosmina* are required to clear contaminants from the lake?
2) Small algae such as *Cyclotella* have been prevalent since *Mysis* were introduced. Will these algae disappear and allow for a return of larger phytoplankton?
3) What size range of fine inorganic particles do *Daphnia* graze on?
4) What will the effect be on native fish and game fish? This question has already started to be answered. With the help of Tahoe's fishing guides, we are collecting fish stomach contents to record how their diets are evolving.

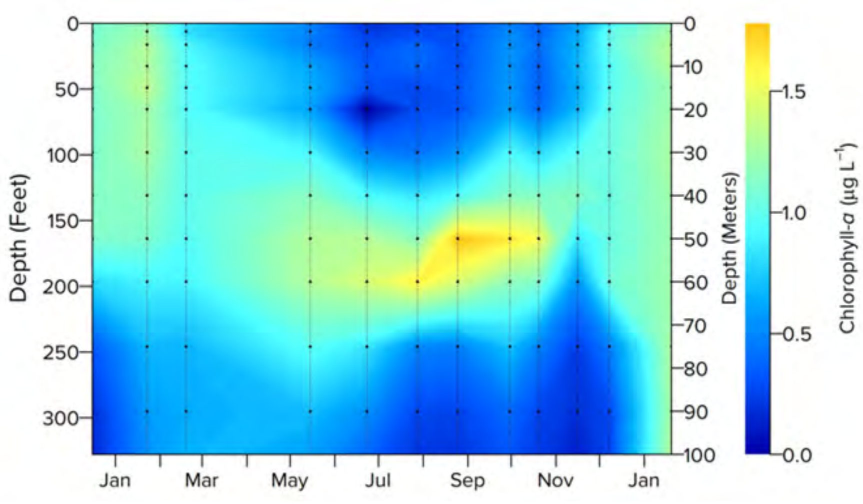
Eventually *Mysis* will return. The real question is whether the absence of *Mysis* from Lake Tahoe will help restore clarity and, if so, is the deliberate removal of *Mysis* in the future warranted? As clarity of Lake Tahoe has shown no sustained improvement for 20 years, this is an opportunity that should not be passed by.

(Photo: B. Allen)

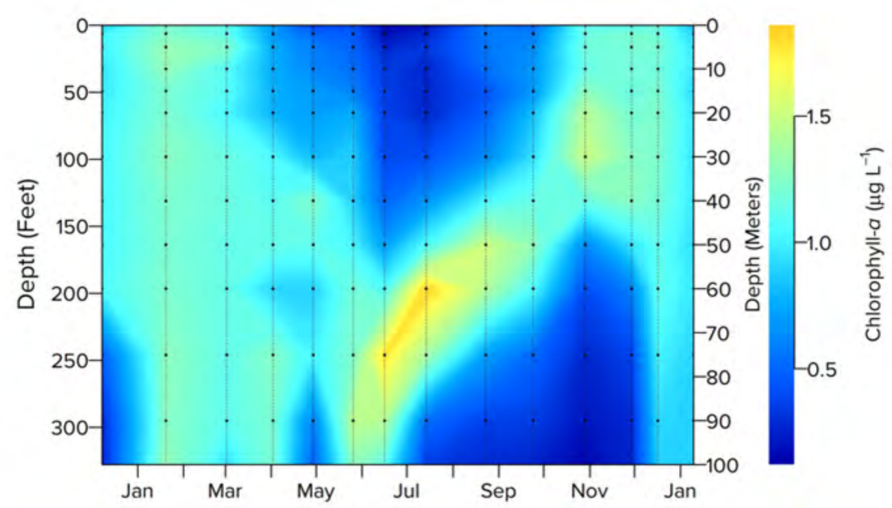
A very different year for Tahoe's phytoplankton

At the beginning of 2021, there was little reason to believe the year would be as unusual as it turned out to be for Lake Tahoe's phytoplankton. One of the first signs came mid-summer, when the Dixie, Tamarack, and Caldor wildfires continuously filled the basin with smoke. TERC researchers found it was taking far longer to filter surface water because the upper 70 feet of the lake appeared to be unusually high in phytoplankton. Due to Tahoe's exceptional clarity, algae are usually concentrated in a band at a depth of 150–250 feet, known as the "deep chlorophyll maximum" (DCM). The figure below for 2020 shows the typical annual pattern of chlorophyll distribution, with the DCM in yellow and orange tones. For 2021, the DCM can be seen starting to form at 250 feet in June and July of 2021, but then it progressively becomes shallower throughout the summer, until fall mixing occurs in late November. This pattern is unlike any previous year.

The cause of this change in phytoplankton distribution may be due in part to the reduction in sunlight and UV radiation that occurred due to wildfire smoke. Phytoplankton need sunlight to photosynthesize, so this upward shift is not unexpected.



2020

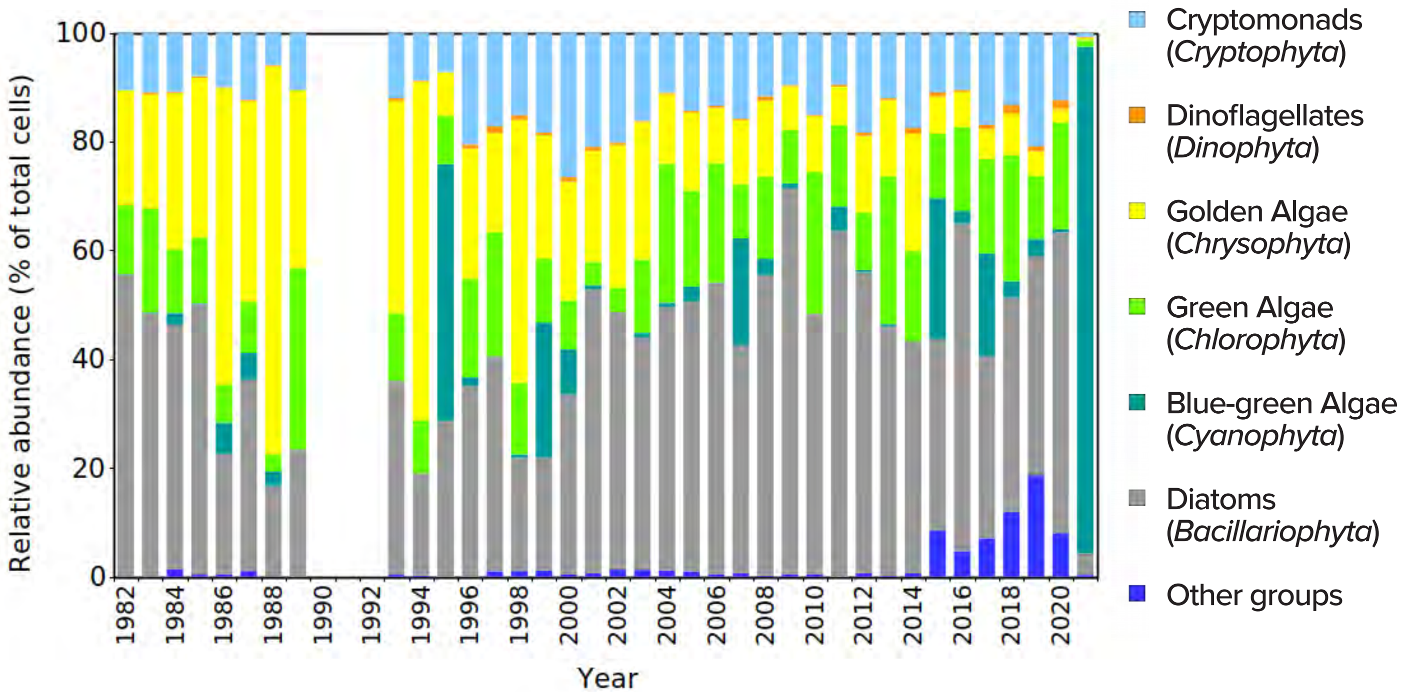


2021

A very different year for Tahoe's phytoplankton, continued

But what was surprisin was the major change in species composition. In 2021, the lake experienced a major bloom of the filamentous cyanobacteria *Leptolyngbya* sp., an alga rarely observed at Lake Tahoe. However, previous research at Tahoe (Mackey et al. 2013[1]) found that *Leptolyngbya* was strongly favored by high Nitrogen:Phosphorus ratios associated with atmospheric deposition, particularly wildfire smoke.

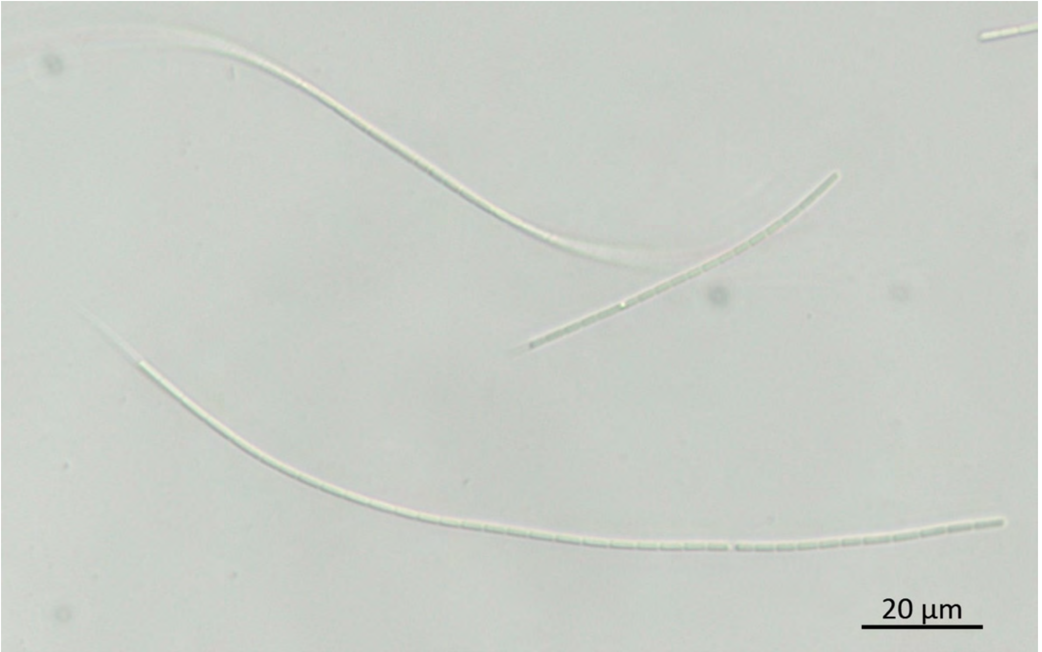
The figure below shows the relative abundance of different phyla of Lake Tahoe algae annually since 1982. The total dominance by *Leptolyngbya* in 2021 is evident based on the number of algal cells. This is the only recorded year in which a single taxon belonging to the cyanobacteria group has so dominated the phytoplankton assemblage.



[1] *Mackey, K. R. M., D. Hunter, E. V. Fischer, Y. Jiang, B. Allen, Y. Chen, A. Liston, J. Reuter, G. Schladow and A. Paytan. 2013. Aerosol-nutrient-induced picoplankton growth in Lake Tahoe, J. Geophys. Res. Biogeosci., 118, 1054–1067, doi:10.1002/jgrg.20084.*

A very different year for Tahoe's phytoplankton, continued

Leptolyngbya are extremely small (which makes them important for clarity). The diameter of the filaments they form are on the order of 1-2 microns. Individual filaments, comprised of dozens of individual cells, can be over 200 microns in length. Their small size also limits their contribution to algal biovolume. Based on biovolume, diatoms still dominated the phytoplankton assemblage in 2021, with *Synedra* being the dominant species in every month (see Fig.10.5 and 10.6).

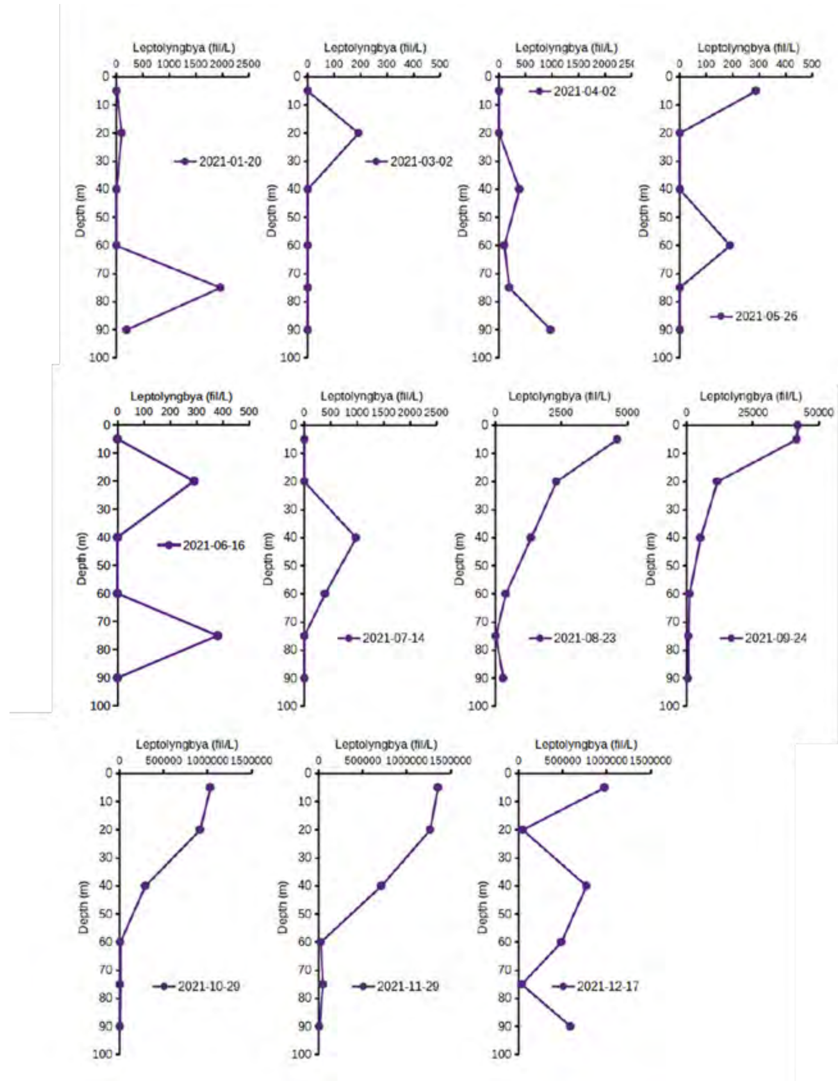


Leptolyngbya filaments from a 2021 Lake Tahoe sample. (Photo: L. Tanaka)

A very different year for Tahoe's phytoplankton, continued

The monthly depth distribution of *Leptolyngbya* in 2021 provides greater detail on the evolution of this algal bloom and its possible cause, as well as accounting for the rising depth of the deep chlorophyll maximum layer.

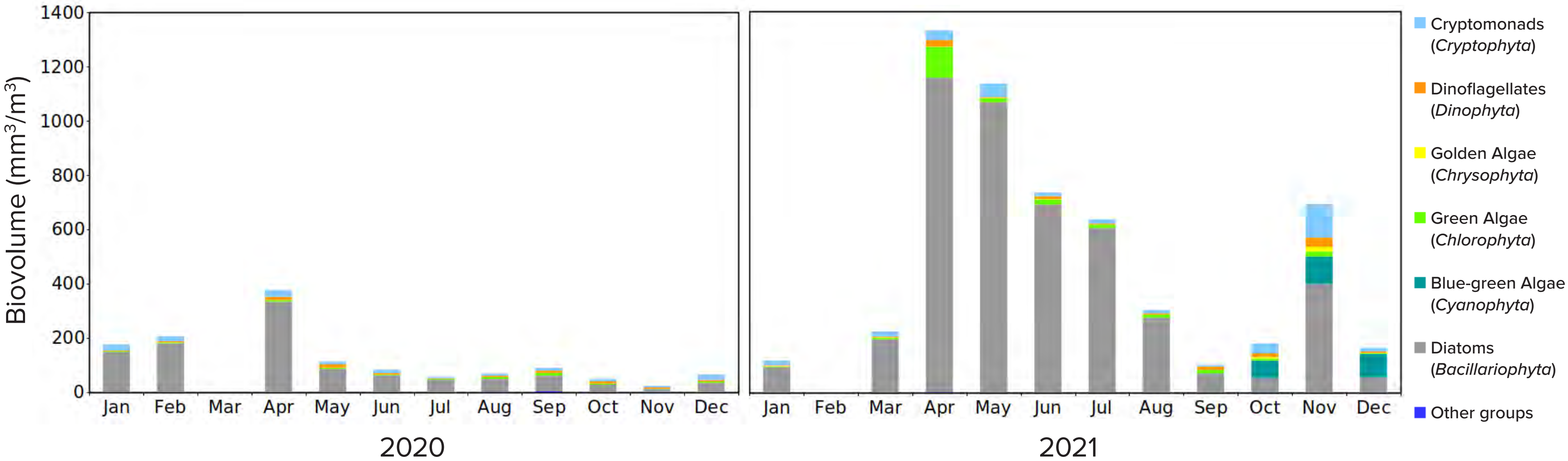
The monthly distributions had low maximum abundances from January through August, with the peak values being less than 5,000 filaments/liter. In the September sampling, peak values increased by a factor of ten, and then from October through November, they increased further by a factor of 30 to approach abundances of 1.5 million filaments/liter. The high abundances were confined to the upper 130 ft (40 m) of the lake. In December, the abundances were still high, but spread through a greater depth due to fall mixing.



A very different year for Tahoe's phytoplankton, continued

A further surprise in the phytoplankton data was the revelation that the biomass of phytoplankton far surpassed the levels that are normally observed in Lake Tahoe. In April 2021, for example, the biovolume was three times higher than the biovolume for April 2020, which itself was double the value from 2019. Most of the increase was due to the presence of the relatively large diatom *Synedra*.

Adding to the mystery is the fact that most of the 2021 high biovolume months preceded the California wildfires and their nutrient-rich smoke by five months. Additionally, 2021 was a year in which stream-derived nutrients were at record low levels. What could explain these data? That is a question that our researchers are currently exploring, while focusing specific attention to the decreasing abundance of *Mysis* that began in spring 2021.



The rapidly evolving shoreline algae

Since 2018, the TERC nearshore algae-monitoring program has been examining the entire shoreline of Lake Tahoe in a novel and powerful way. TERC flies an instrumented helicopter and a drone many times throughout the year in order to capture images and locate the spatial extent of algal blooms and specific hotspots. After each flight, TERC staff and volunteers visit specific locations to take photos and samples to establish the "ground truth" of what was seen from the air. This builds on the traditional method of monitoring, where divers would individually sample a finite number of locations at a depth of two feet, creating a more robust and meaningful dataset. Previous data suggested that the biomass was not changing over the long-term at those fixed sites. With this new method, we are now learning that the areas impacted can change radically from year to year and may be increasing spatially due to the combined effects of warming water temperatures, changing water levels, and the impacts of invasive species, specifically Asian clams.

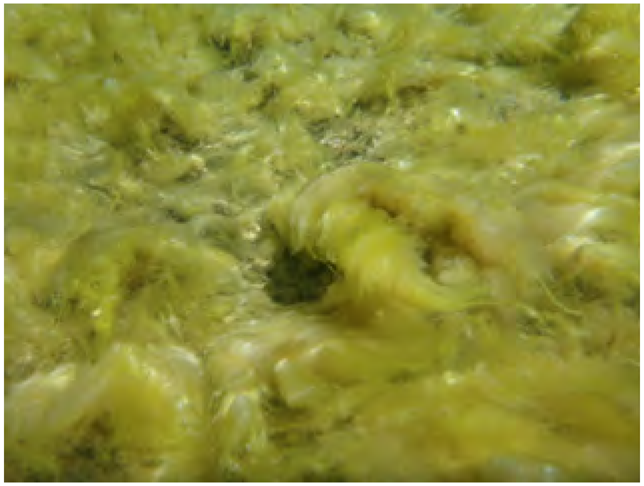
An orthomosaic of individual helicopter images (right) along Northwest shore of Lake Tahoe around Tahoe City from June 1, 2022. The red box shows the area around the inlet to the Truckee River. The yellow and brown coloration is from luxuriant growth of stalked diatoms on rocks and cobbles. (Photos: M. Bruno)

The rapidly evolving shoreline algae

Nearshore algae blooms are a growing ecological threat to the lake, as they seriously degrade water quality and cover large areas of beach with mats of decomposing algae, with certain types being toxic. The blooms also occur where the greatest numbers of people—residents and visitors—directly interact with the lake. To date they have been most prevalent in South Lake Tahoe and Tahoe City. For example, a large and toxic bloom occurred in fall 2021 near the mouth of the Upper Truckee River in South Lake Tahoe, and a much larger bloom of attached algae occurred in spring 2022 along six miles of shoreline at Tahoe City.

By actively monitoring the spatial extent, type, and intensity of nearshore algal blooms, we can better understand the underlying causes of the blooms and develop appropriate mitigation measures. The project also serves as a warning system to alert public and government agencies to these unattractive and potentially dangerous situations and to guide cleanup crews to hotspots.

The aerial monitoring approach was initially developed through funding from State agencies, but for the last three years it has received minimal support. COVID-19 disruptions also interrupted this critical project at the worst possible time—just as some of the largest algal and bacterial blooms were occurring in the lake. Currently, private funding is supporting this program. Learn more about it and how you can help maintain and expand it to include more research into the best cleanup and mitigation methods by visiting https://tahoe.ucdavis.edu/algae

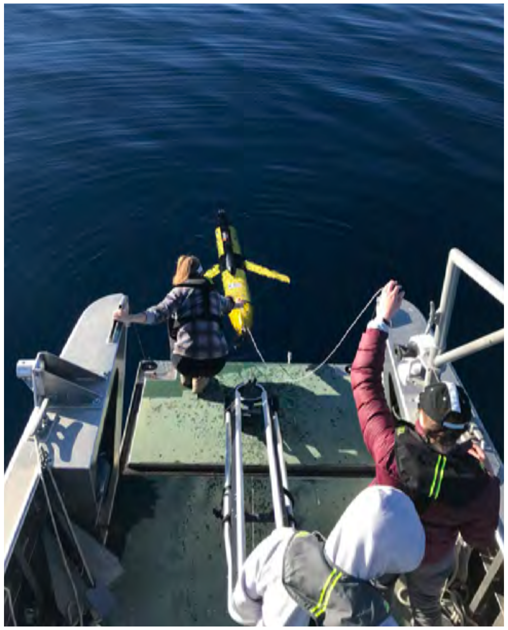


Images of stalked golden diatoms and filamentous green algae on June 1, 2022, during ground-truthing near the outlet of the Truckee River in Tahoe City. Left image underwater and right image from the surface. (Photos: S. Hackley)

Underwater gliders track the fate of wildfire smoke particulates within Lake Tahoe

As part of a Tahoe Science Advisory Council study, TERC's Slocum G2 autonomous underwater glider "Storm Petrel" was deployed to continuously map the distribution of lake water quality variables. The glider measured electrical conductivity, temperature, depth, chlorophyll-*a* fluorescence, dissolved organic matter, and optical backscatter. It was also equipped with a LISST 200X, a laser diffraction instrument used to measure particle size distributions.

The glider was deployed on September 3, 2021, when atmospheric fine particulate matter concentrations from the Caldor Fire in the Lake Tahoe Basin were at peak levels, and it continued to operate until September 25, 2021.

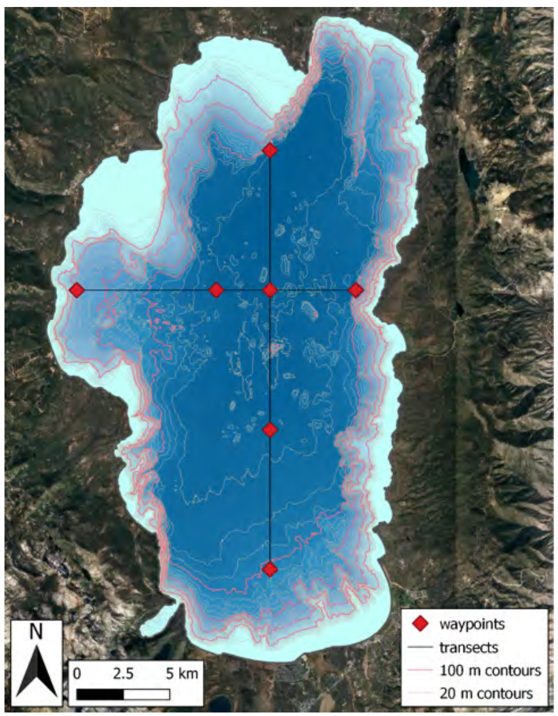


Launching the glider on its monitoring jouney (left) and getting pulled from the lake after completing its Lake Tahoe mission (right). (Photos: B. Berry [left] and B. Allen [right])

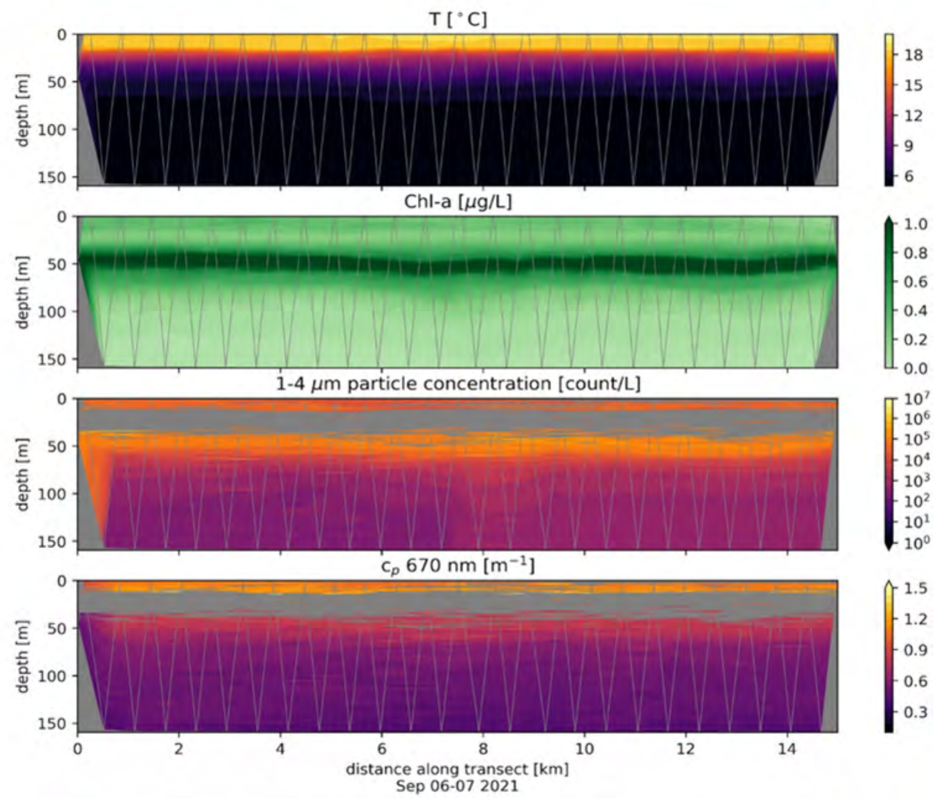
Underwater gliders track the fate of wildfire smoke particulates within Lake Tahoe, continued

The glider was pre-programmed to repeat transects across Lake Tahoe (both East-West and North-South transects). While navigating along the programmed transects, the glider continuously repeated dive/climb cycles between the water surface and 150 m (500 ft) depth.

While data are still being analyzed, preliminary results are showing that the behavior and impacts of particulates from wildfire smoke are more complex than originally thought.



Glider transects and waypoints used for the wildfire study. Bathymetric contours of Lake Tahoe are shown for context.

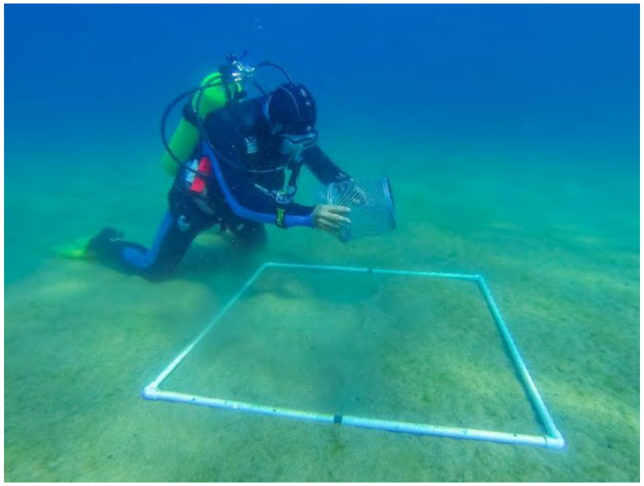


Data from a single west to east transect. The grey lines indicate the yo-yo pattern the glider follows as it traverses the lake.

Tracking the spread of invasive species at Sand Harbor State Park

The invasive bivalve, the Asian clam (*Corbicula fluminea*), was first documented at the southeast corner of Lake Tahoe in 2002. It wasn't until 2012 that the first non-connected population was discovered on the sill of Emerald Bay State Park, California. This was soon followed in 2014 by the discovery of an isolated population at the boat ramp in Sand Harbor State Park, Nevada.

Treatment of Asian clams at Sand Harbor State Park was implemented from 2017 to 2020 in the vicinity of the Sand Harbor Boat Ramp. Following the multi-year control project, a comprehensive survey was conducted in summer 2021 by TERC with funding provided by the Nevada Division of State Lands (NDSL). The goal of the survey was to assess clam density throughout the aquatic portion of Sand Harbor State Park.



TERC researcher, Kian Bagheri, collects clams during the survey at Sand Harbor State Park. (Photos: B. Berry)

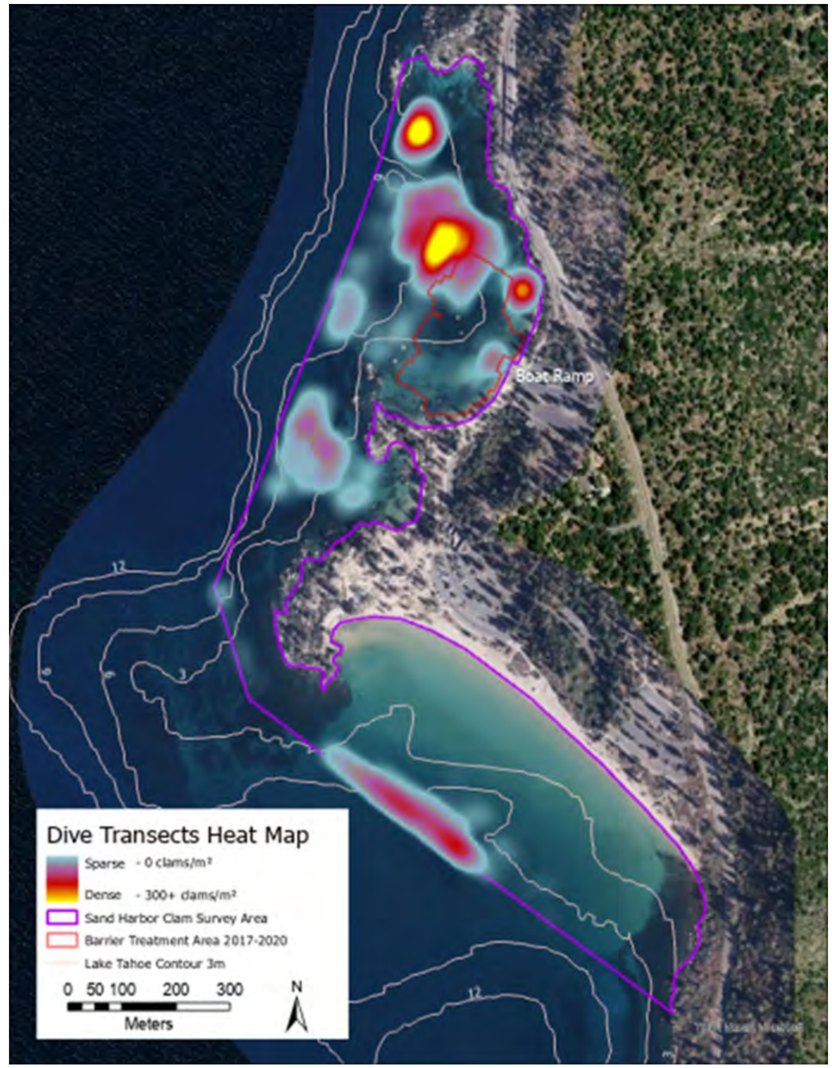
Metaphyton patches observed north of the boat ramp at Sand Harbor State Park. (Photos: B. Berry)

Tracking the spread of invasive species at Sand Harbor State Park, continued

The survey area was approximately 130 acres, and it encompassed the lakeward areas surrounding Sand Harbor State Park. A systematic scuba survey was designed to cover the entire region while simultaneously quantifying clam abundance and distribution. Generally, clams were found distributed throughout the entire survey area at depths greater than 10 ft (3 m). Despite the large area with a viable clam population, densities were generally low (0–30 clams/m^2) except for select areas that contained densities over 100 clams/ m^2. A color contour map of clam population abundance at Sand Harbor is displayed.

An impact of Asian clams at Lake Tahoe is the correlated enhanced metaphyton growth. Metaphyton are unattached drifting patches of green filamentous algae. Metaphyton were observed at Sand Harbor State Park during the surveys. While the extent is still relatively small, numerous metaphyton patches up to 2 feet in diameter were observed over the highest clam densities in the area. An unregulated expansion of the existing clam population would be expected to lead to heavier metaphyton mats over larger areas of Sand Harbor in future years. The timing of and the potential for these mats to create nuisance algae on beaches is unknown.

The clam surveys at Sand Harbor are planned to continue for the next two summers. During this time, TERC will be working with NDSL staff to consider a range of mitigation measures.



Plastics, plastics everywhere

Microplastic pollution is a growing environmental concern, as plastics have become a ubiquitous part of our daily lives. Once released into the environment, larger pieces of plastic often mechanically break into smaller and smaller pieces over time. This has led to increasing concerns about the impact of plastics on the environment, ecosystems, water quality, and human health. In August 2020, TERC began quantifying and characterizing microplastics in the waters of Lake Tahoe. A manta trawl was towed alongside a research vessel to filter plastics from the lake surface. These plastics were then isolated in the lab and analyzed with Raman microspectroscopic imaging to confirm plastic type and chemical composition of particles.

(A) Map of transect locations where microplastic samples were collected. (B) The manta trawl tow net. (C) Particles suspected to be plastic were isolated for subsequent Raman microspectroscopic analysis. (Photos: K. Senft (B) and S. Sesma (C))

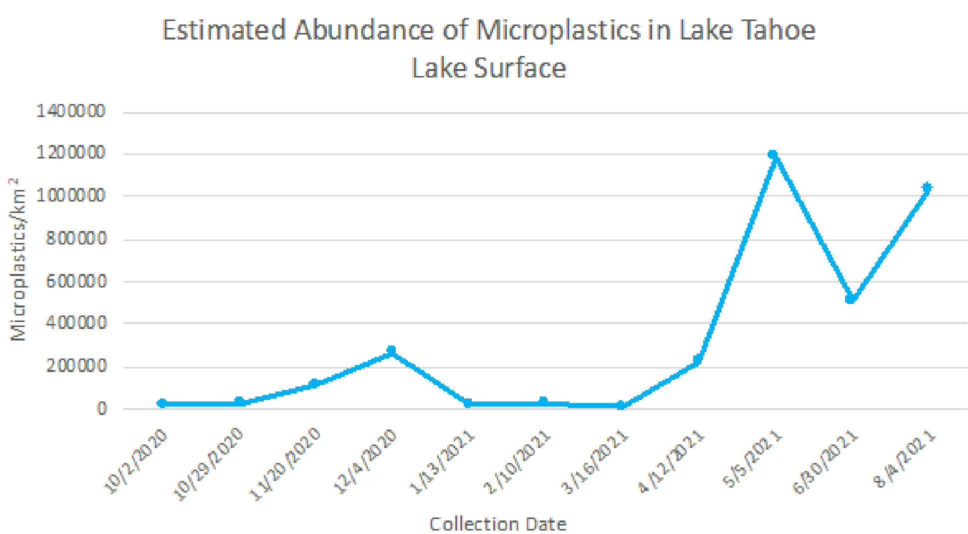
Plastics, plastics everywhere, continued

Preliminary data analysis has shown an average abundance of 312,000 plastic particles per square kilometer at the lake surface during the sampling period, with peak abundances exceeding 1,200,000 particles per square kilometer. Samples collected during May, June, and August had the highest numbers of microplastics at the lake surface.

Raman microspectroscopy was used to identify the synthetic polymer composition (plastic type) of each confirmed microplastic particle. The majority of analyzed plastic particles from surface waters were identified as polyethylene (41 percent) and polypropylene (40 percent) with a smaller proportion of particles identified as polyesters (14 percent). Additional synthetic polymers, including polystyrene, nylon, acrylics, and co-polymer mixtures, were also identified but made up only five percent of all analyzed particles.

Polyethylene is the most widely produced plastic polymer in the world and is used in the production of everything from food packaging and water bottles to plastic bags and toys. Polypropylene is found in carpeting, outdoor furniture, clothing, and upholstery. Most plastic items in our everyday lives are composed of one or both of these plastic polymers.

This work was undertaken as a collaboration between TERC and the UC Davis School of Veterinary Medicine. Funding has been provided by the Nevada Division of Environmental Protection.



The desiccation of Tahoe's forest—the last straw

From Lake Tahoe looking up to the west shore forests, one can see yet another impact of the decadal drought that the western U.S. is experiencing—thousands of dead and dying trees.

Currently in Tahoe, we are seeing areas of moderate-to-high fir mortality. In some locations, incense cedars are being impacted as well. The lack of sufficient water adds to the stress that the trees are enduring and makes them more prone to insect and pathogen attacks.

This trend is also being observed more broadly throughout California and the west. Many of the impacted stands are where tree densities are in excess of the natural carrying capacity, particularly in times of drought.

What is the solution? Nature is currently enacting a solution by killing off some of the excess trees. Unfortunately, the stands of dead trees only compound the fire risk. A better solution may be to more aggressively put into action the various forest management plans that have been developed over the last decade. Neither our current or future climate can support the current tree densities.

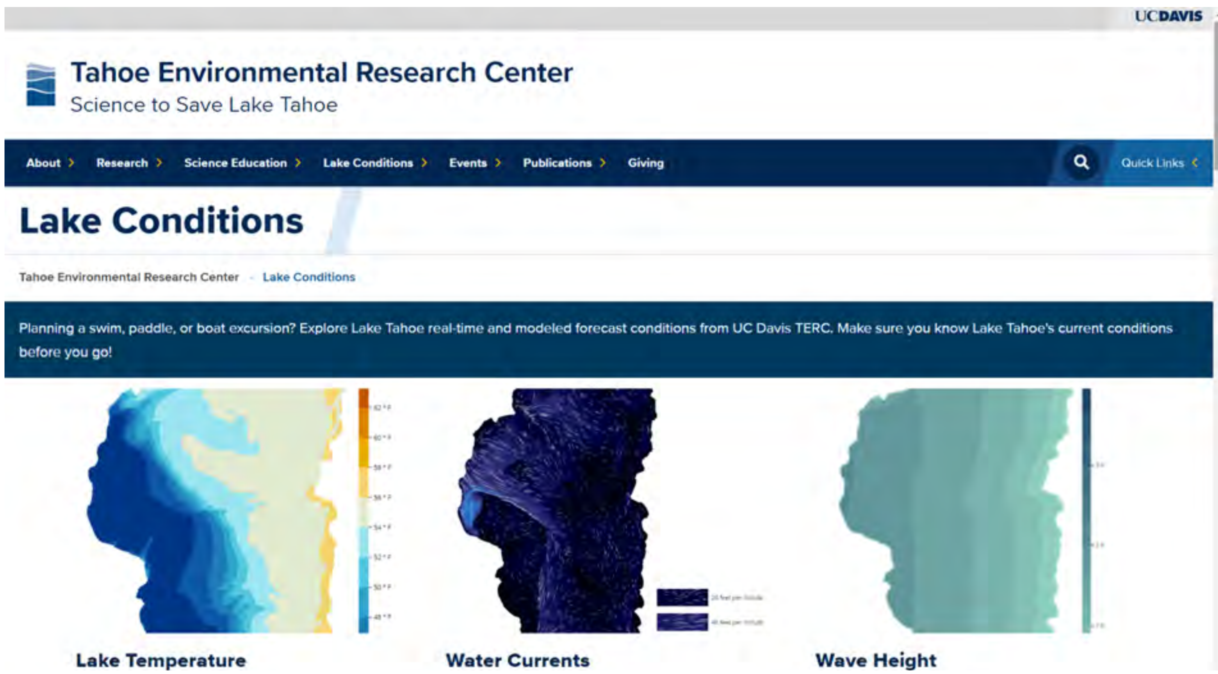
The extent of dead trees on Tahoe's west shore during the TERC 2022 Lake Circumnavigation event. (Photo: G. Schladow)

A stark contrast of dead, dried brown trees. (Photo: A. Toy)

Current conditions webpage

Along with the bliss of being on Lake Tahoe during a hot summer day, there are hidden dangers lurking. The weather in the Sierrra can be fickle and conditions can change quickly, potentially presenting a hazard to the unprepared. But there are other, lesser known dangers, that can also place a swimmer, paddleboarder, or boater in jeopardy.

UC Davis TERC's new online Lake Conditions tool provides both real-time and forecasted water temperatures, wave heights, and water current information. These indicators provide an early warning of some of the major lake hazards that can exist at Lake Tahoe. The Lake Conditions webpage (https://tahoe.ucdavis.edu/lake-conditions) provides a direct link to TERC's temperature and wave measurement stations around the lake. It also provides present conditions and forecasts of water temperature, currents, winds, and waves across the entire lake every three hours for up to three days day into the future.

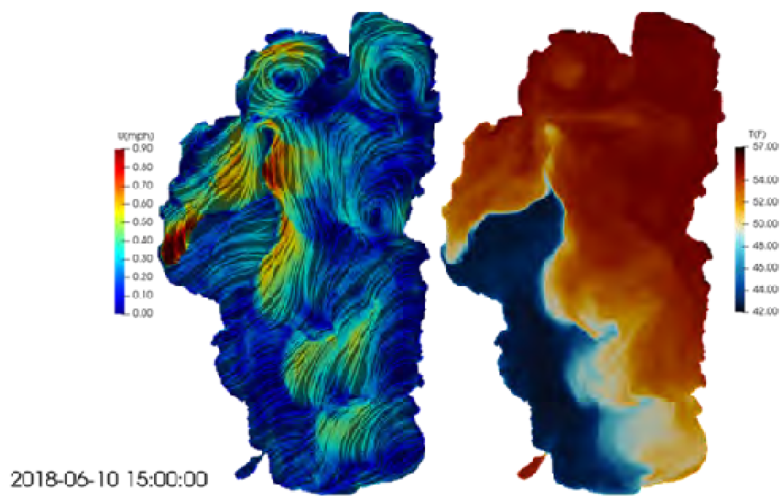


Screenshot from the UC Davis TERC Lake Conditions webpage showing lake temperature, water currents, and wave height.

Current conditions webpage, continued

What are the special hazards to be aware of at Lake Tahoe? During strong, persistent winds the lake may experience an "upwelling." This is when the warm surface water gets pushed downwind and cold, frigid water from deep in the lake rises on the upwind side of the lake. Fortunately, during such windy and rough conditions, very few people venture out on the lake. The real danger comes after the wind subsides and people get back in the water. Because the lake is so massive, the cold upwelled water can remain at the surface for several days before returning to the lake bottom. This may come as an unwelcome and dangerous surprise to people diving off a boat expecting normal warm summer surface waters. To make matters worse, when in the water, people may also experience very strong currents that are generated as the lake returns to its initial state.

The map on the right shows the modeled surface water temperature under calm conditions shortly after an upwelling event. While most of the lake is a brisk 55 °F, the water in the southwest quadrant is a hypothermia-inducing 42 °F. At that temperature, a person in the water could lose dexterity in minutes and lapse into unconsciousness in less than 30 minutes. The map on the left shows the corresponding surface current patterns. The red coloration indicates currents of over 1 mph. That may not seem very fast but imagine falling off a paddleboard into 42 °F water, and while trying to catch your breath, you notice your paddleboard being carried away at 2 feet per second.



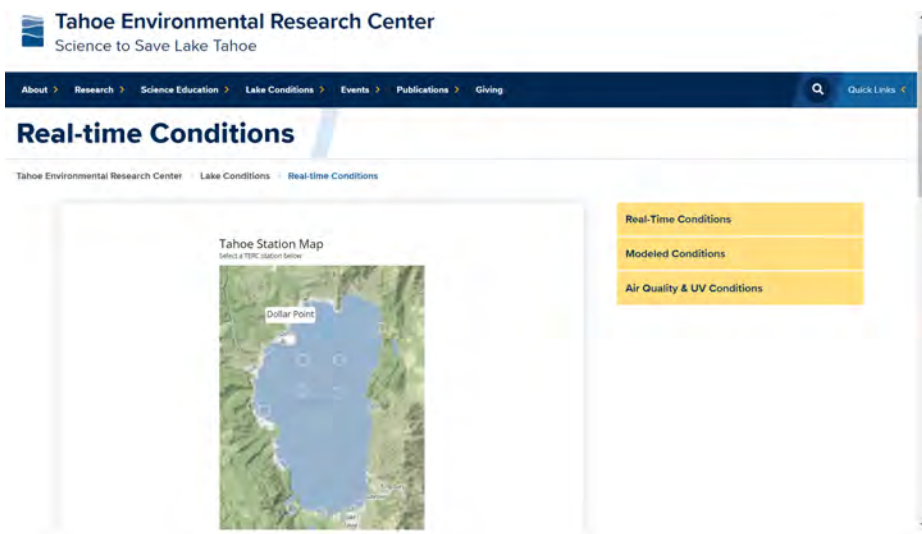
High velocity (>0.7 mph) jets and cold (<42 °F) water temperatures following an upwelling event in Lake Tahoe

Current conditions webpage, continued

The real-time data come from TERC's Nearshore Network of stations located along the shoreline all around the lake. These stations are funded and supported by TERC donors, lakeshore property owners, and the Lahontan Regional Water Quality Control Board. The stations provided valuable research data for the last eight years and are now providing lake users with the most current, up-to-the-minute lake conditions information. Water temperature data from the middle of the lake are also provided from research buoys that are operated in partnership with the NASA Jet Propulsion Laboratory.

The forecast conditions are from computer models developed by TERC researchers. The model for lake temperatures and currents is a complex three-dimensional model that TERC has used on many lakes around the world to better understand complex motions and water quality challenges. Another model, first developed by the U.S. Army Corps of Engineers, was adapted to forecast the wave heights across Lake Tahoe.

A team of UC Davis Computer Science students comprised of Sam Maksimovitch, Julian Nguyen, Suryakiran Santhosh, and Simperpal Whala, created this life-saving resource as part of a two-quarter project with TERC. The models were developed by TERC graduate student Sergio Valbuena and alum Dr. Patricio Moreno. Funding for the project was provided by the Tahoe Fund and UC Davis.



Screenshot from the UC Davis TERC website showing the locations of the real-time sensors.

Find Tahoe Tessie

Tahoe Tessie isn't real, but climate change is.

As part of an alternative approach to climate change education, TERC has been developing the Find Tahoe Tessie app. This app is part of a larger project, "Understanding Change at Lake Tahoe Augmented Reality (AR) Experiences," funded by the Institute of Museum and Library Services. This AR app allows players to place Tahoe Tessie around Lake Tahoe.

The biological stressors that this mythical creature faces are similar to those of aquatic organisms native to Lake Tahoe such as the Lahontan cutthroat trout. Like other organisms, Tahoe Tessie's health is affected by water temperature, dissolved oxygen levels, lake clarity, algal concentrations, and human activity

Using the app, users can compare Tahoe Tessie's health and well-being under future climate scenarios and learn how rising air temperatures can affect many of the variables that aquatic organisms everywhere depend upon.

The app is planned for release in Fall 2022.

See Lake Tahoe's mythical lake creature in augmented reality. Tahoe Tessie isn't real, but climate change is. (Photo: A. Toy)

TAHOE: STATE OF THE LAKE REPORT 2022

METEOROLOGY

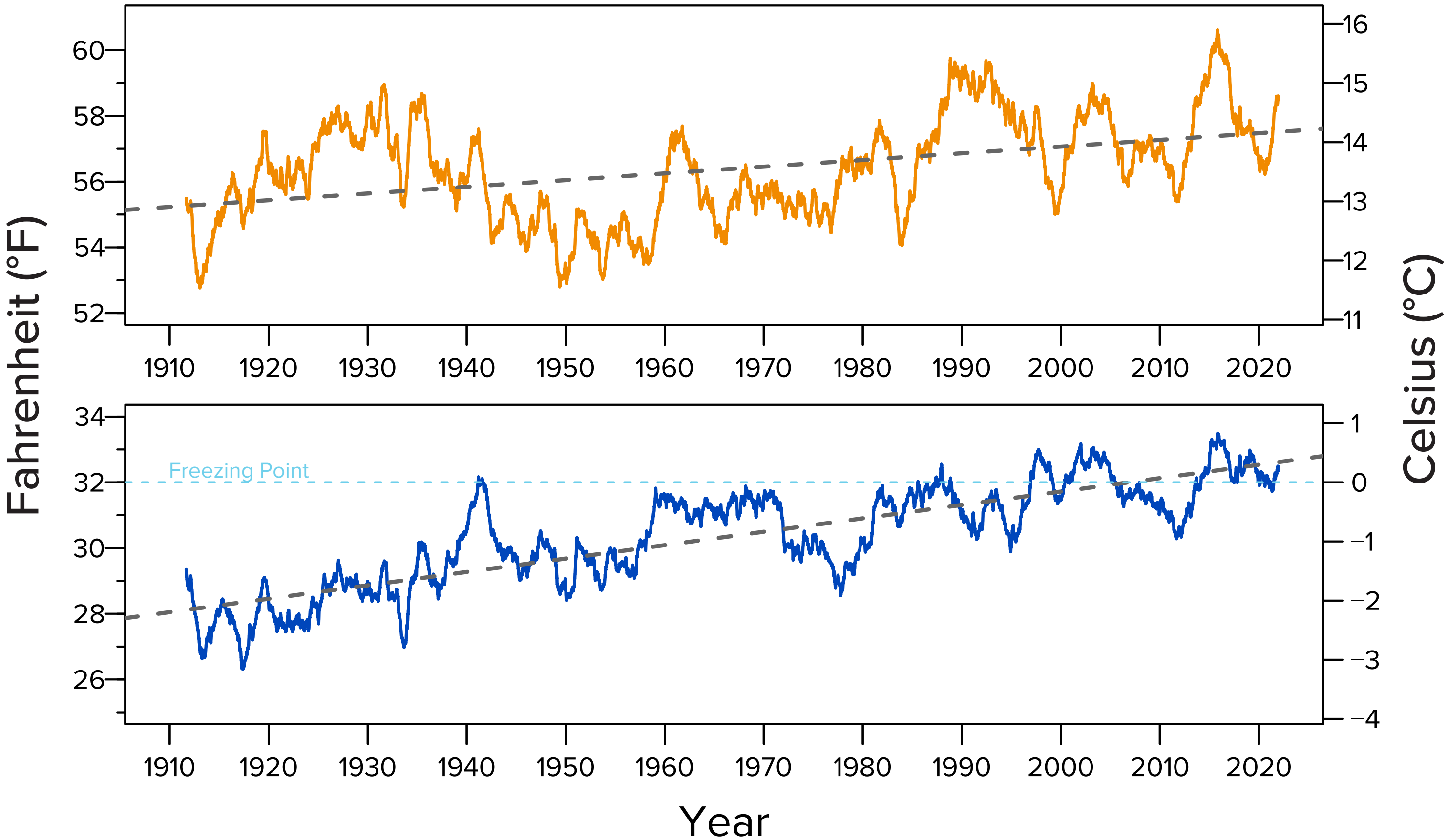
UC DAVIS
Tahoe Environmental
Research Center

Air temperature - smoothed daily maximum and minimum

Daily since 1911

Over the last 110 years, daily air temperatures measured at Tahoe City have increased. The long-term trend in average daily minimum temperature (bottom figure) has increased by 4.50 °F (2.50 °C) and the long-term trend in average daily maximum temperature (upper figure) has risen by 2.25 °F (1.25 °C). The trend line for the minimum air temperature has exceeded the freezing temperature of water for the last 16 years, leading to more rain and less snow as well as earlier snowmelt at Lake Tahoe. These data are smoothed using a two-year running average to remove daily and seasonal fluctuations.

Data source: Long-term NOAA daily maximum and minimum temperatures data set.

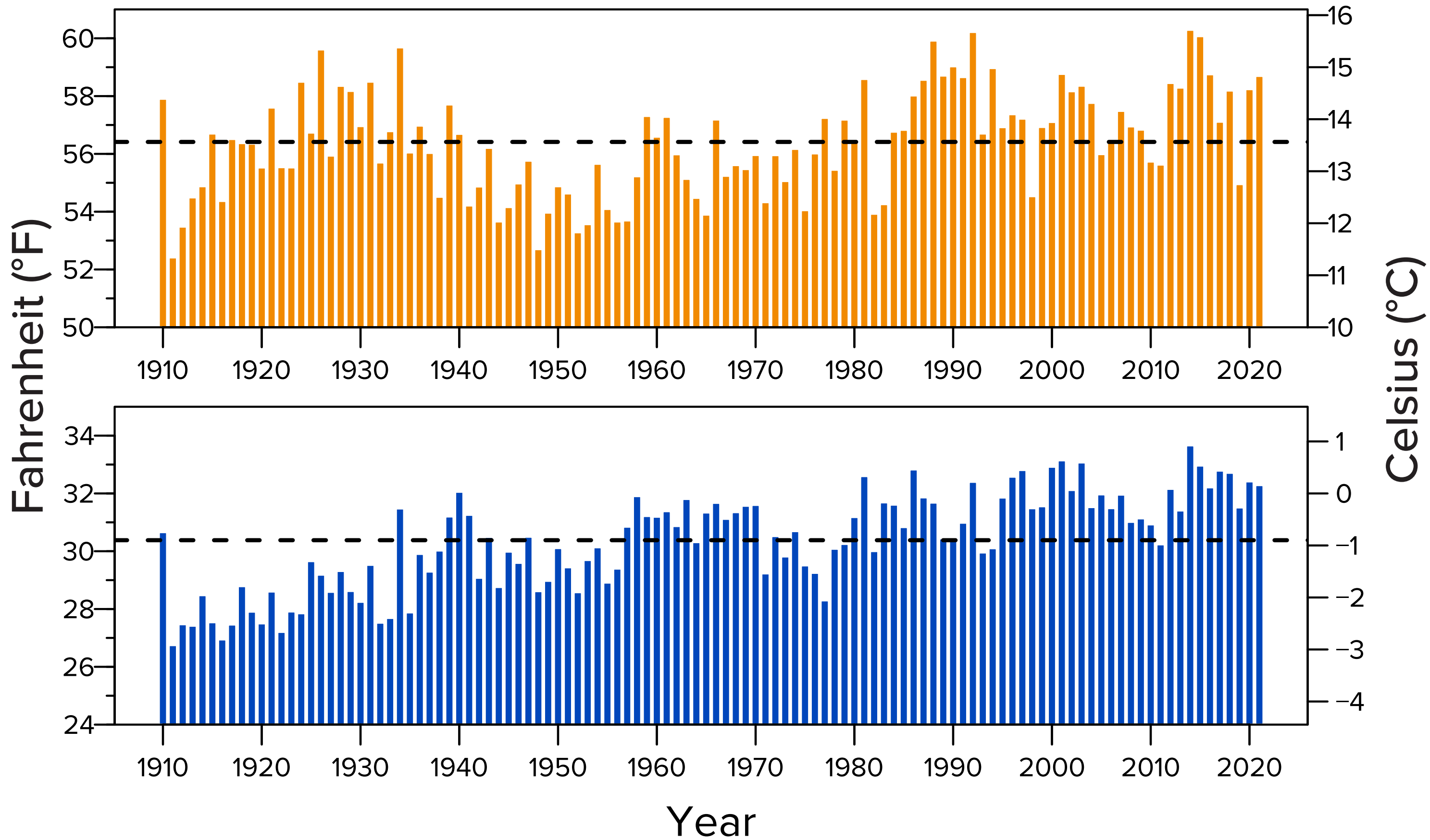


Air temperature - annual average maximum and minimum

Since 1910

Annual average maximum (upper figure) and minimum (lower figure) air temperatures in 2021 were both very similar to the previous year and above the long-term average (dashed line) temperature. The annual average maximum temperature was 58.7 °F (14.8°C), which was 0.4 °F warmer than the previous year. The 2021 annual average minimum was 32.3 °F (+0.2 °C), which was 0.1 °F cooler than the previous year. The long-term averages for the maximum and the minimum are 56.4 °F (13.6 °C) and 30.4 °F (-0.9 °C), respectively.

Data source: Long-term NOAA daily maximum and minimum temperatures data set measured at Tahoe City.



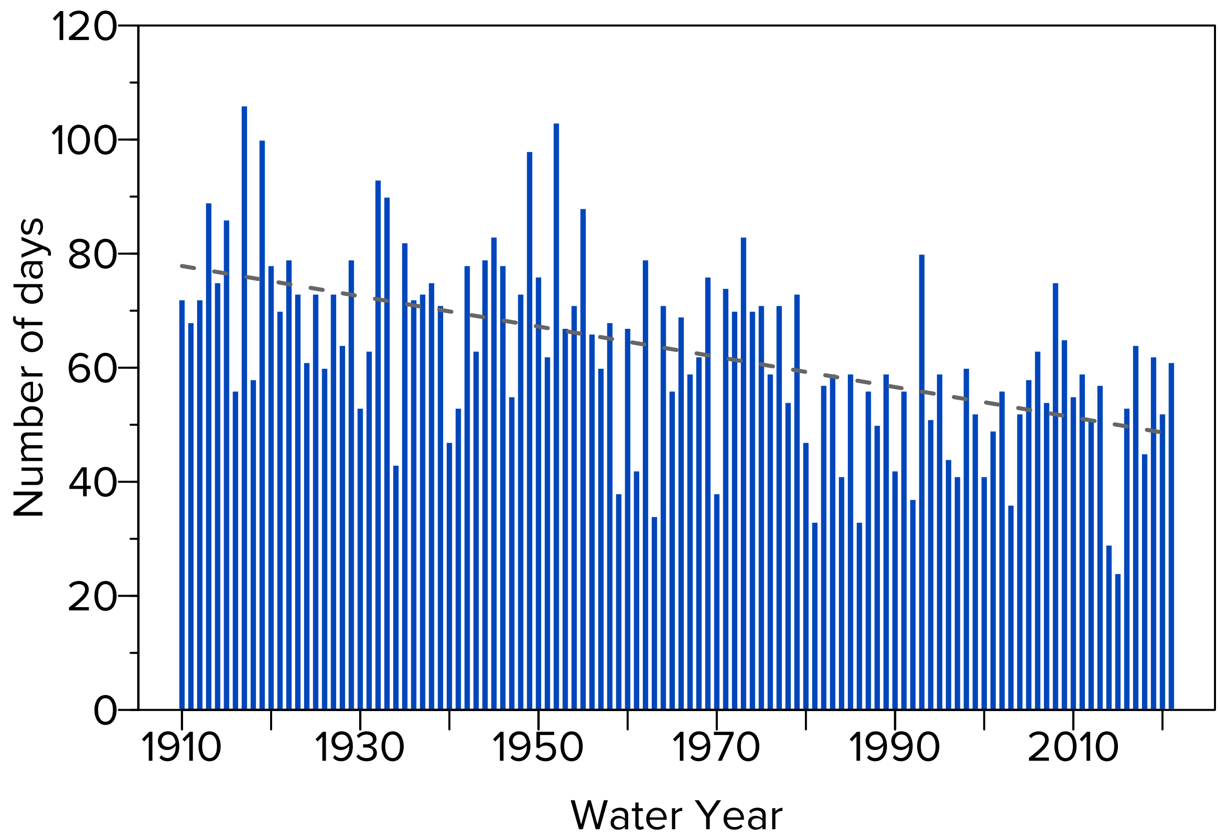
Below-freezing air temperatures

Yearly since 1910

The method used for this analysis sums the number of days with daily average temperatures below freezing between December 1 and March 31 for each Water Year (WY). Although year-to-year variability is high, the number of days when air temperatures averaged below-freezing has declined by over 29 days since 1911. In WY 2021, the number of freezing days was 61, above the declining long-term trend line. This is consistent with the measured air temperatures in 2021.

Data source: Long-term NOAA daily maximum and minimum temperatures data set measured at Tahoe City.

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

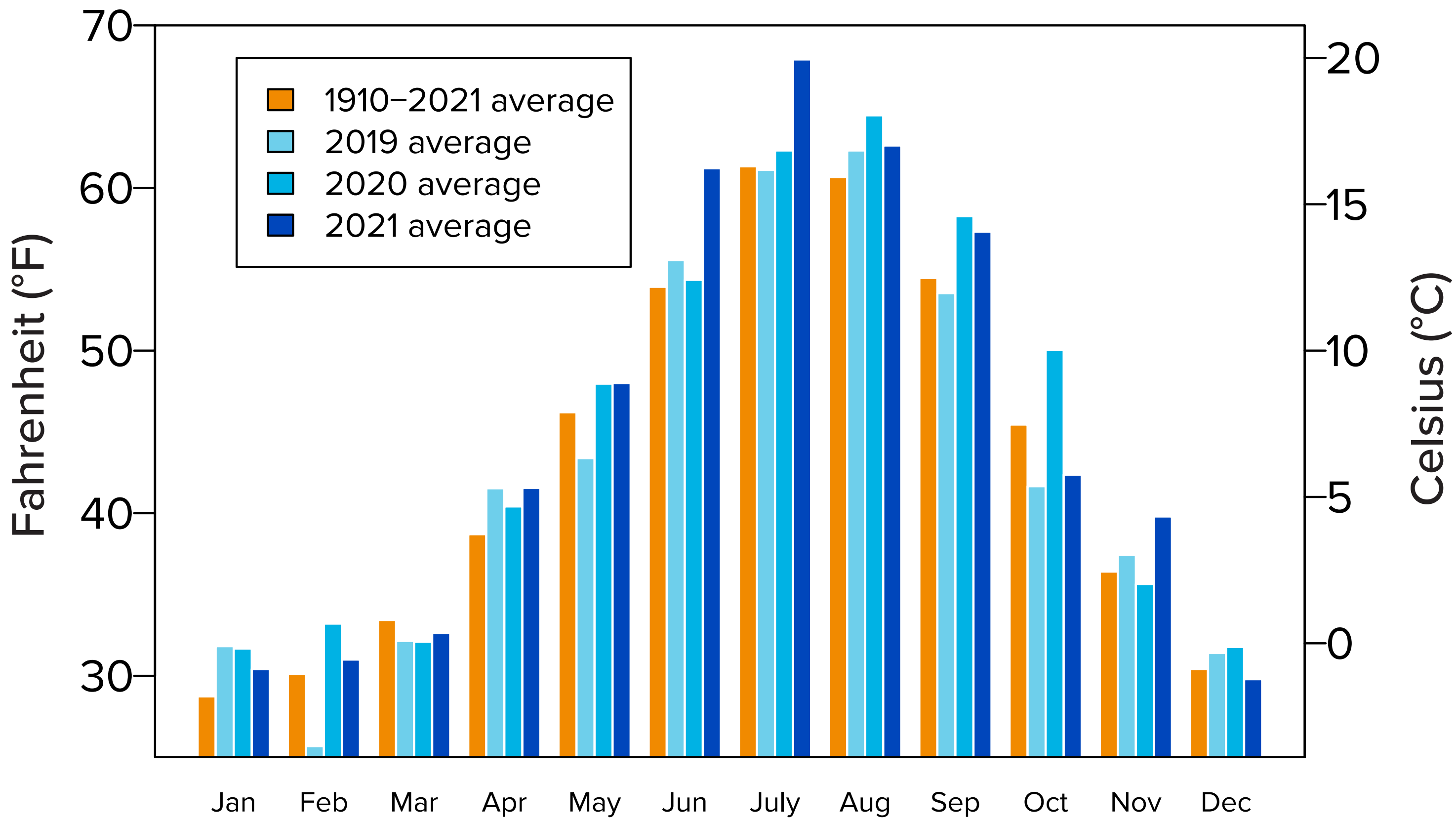


Monthly air temperature

2019, 2020, 2021 and 1910 to 2021

In 2021, monthly air temperatures were similar to 2019 and 2020. However, for the period from March through July, temperatures were warmer than the previous two years and the long-term average. The monthly average air temperatures for June and July were the warmest ever recorded (since 2010). Most of this was due to an increase in nighttime minima.

Data source: Long-term NOAA daily maximum and minimum temperatures data set.

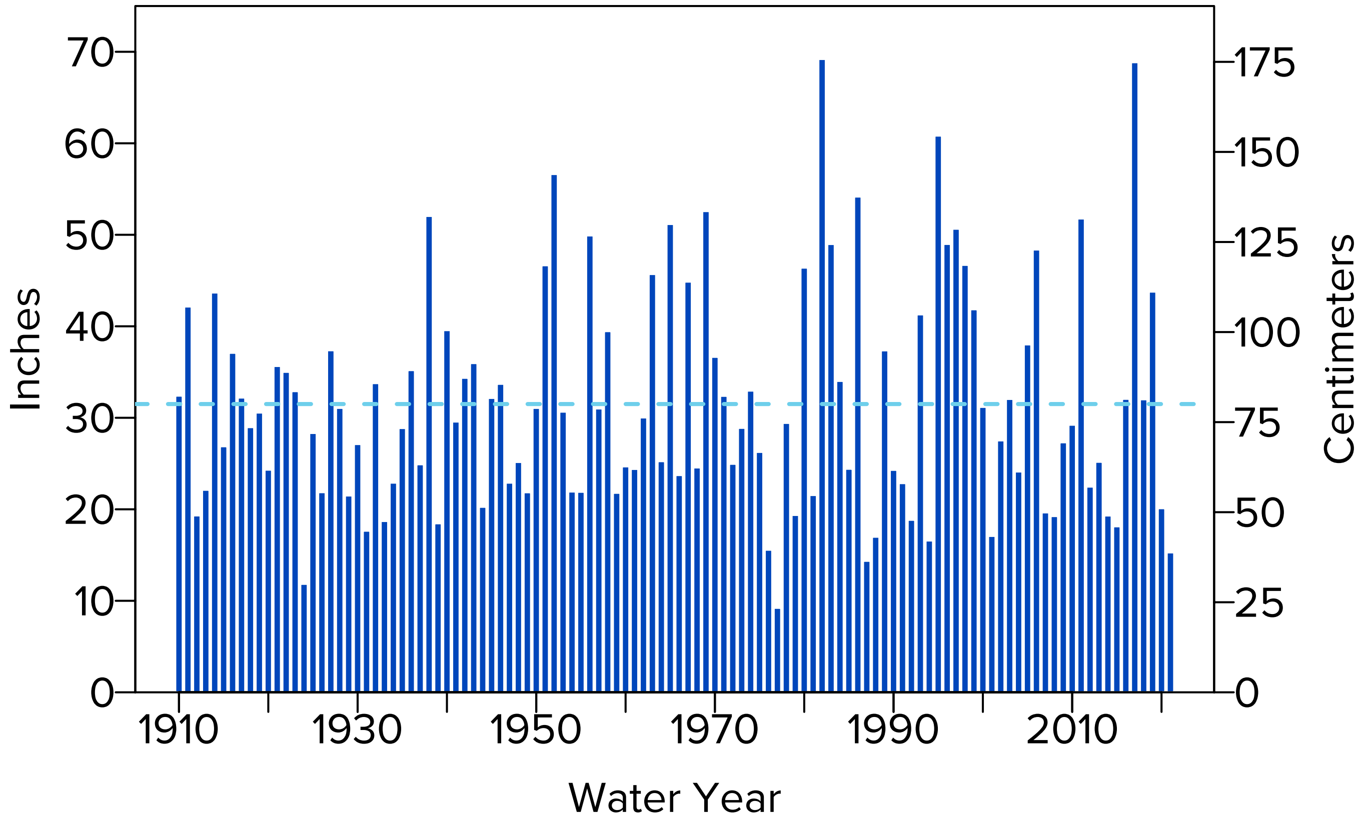


Annual precipitation

Yearly since 1910

From 1910 to 2021, average annual precipitation (water equivalent of rain and snow) at Tahoe City was 31.5 inches. The maximum recorded was 69.2 inches in 1982. The minimum recorded was 9.2 inches in 1977. At 15.3 inches, 2021 was less than half the long-term average (shown by the dashed line) and the third driest year on record. Eight of the last ten years had precipitation at or below the long-term average. This, combined with the low precipitation of winter 2022, highlights the long-term drought our region is experiencing. 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. There is also an increase in precipitation with elevation in the Tahoe basin. Precipitation is summed over the Water Year, which extends from October 1 through September 30.

Data source: Long-term NOAA daily precipitation data set.

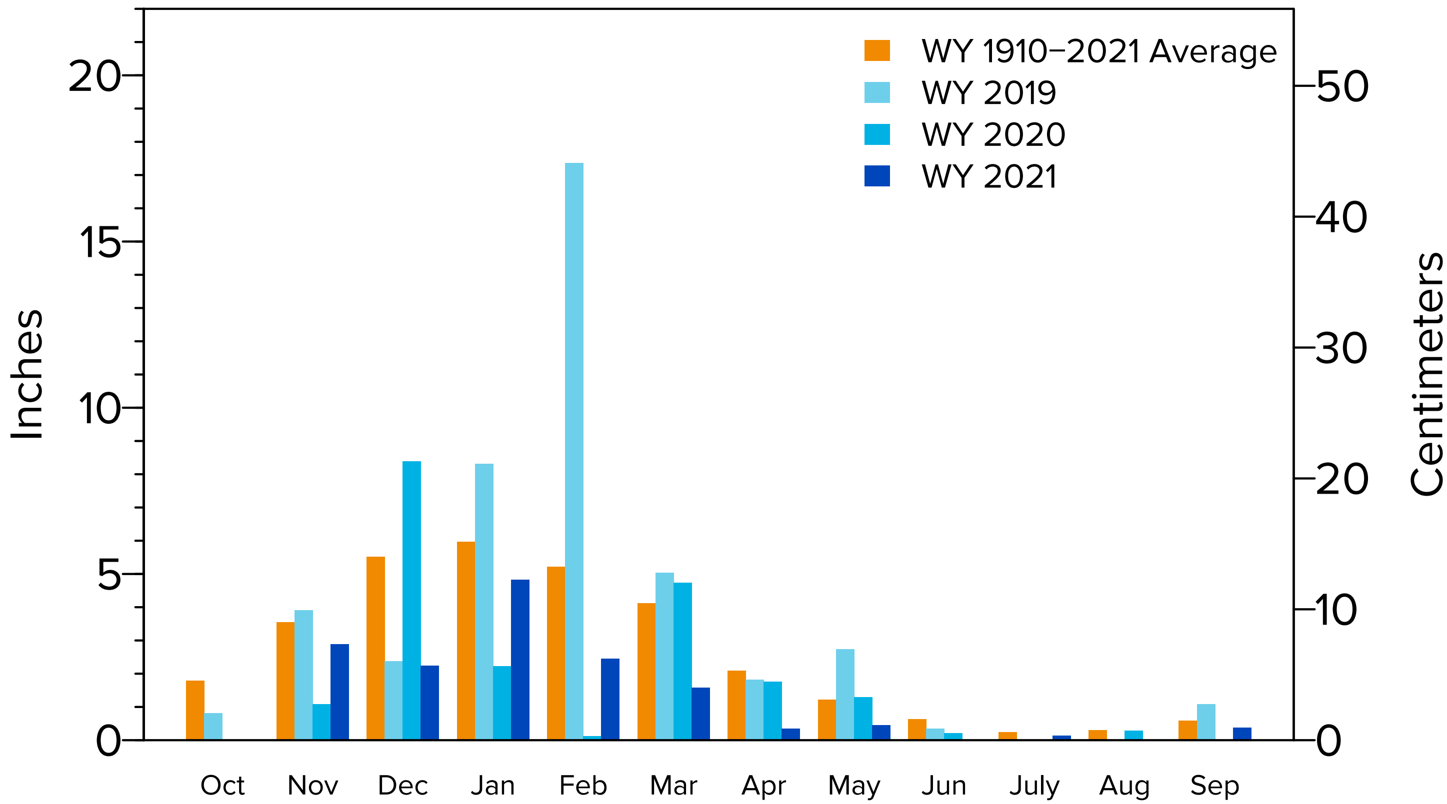


Monthly precipitation

2019, 2020, 2021 and 1910 to 2021

The 2021 Water Year had an annual average of 15.3 inches of precipitation, well below the long-term average of annual precipitation of 31.5 inches at Tahoe City. Precipitation in every month of the 2021 Water year was below the long-term average. The 2021 Water Year extends from October 1 through September 30.

Data source: Long-term NOAA daily precipitation data set.

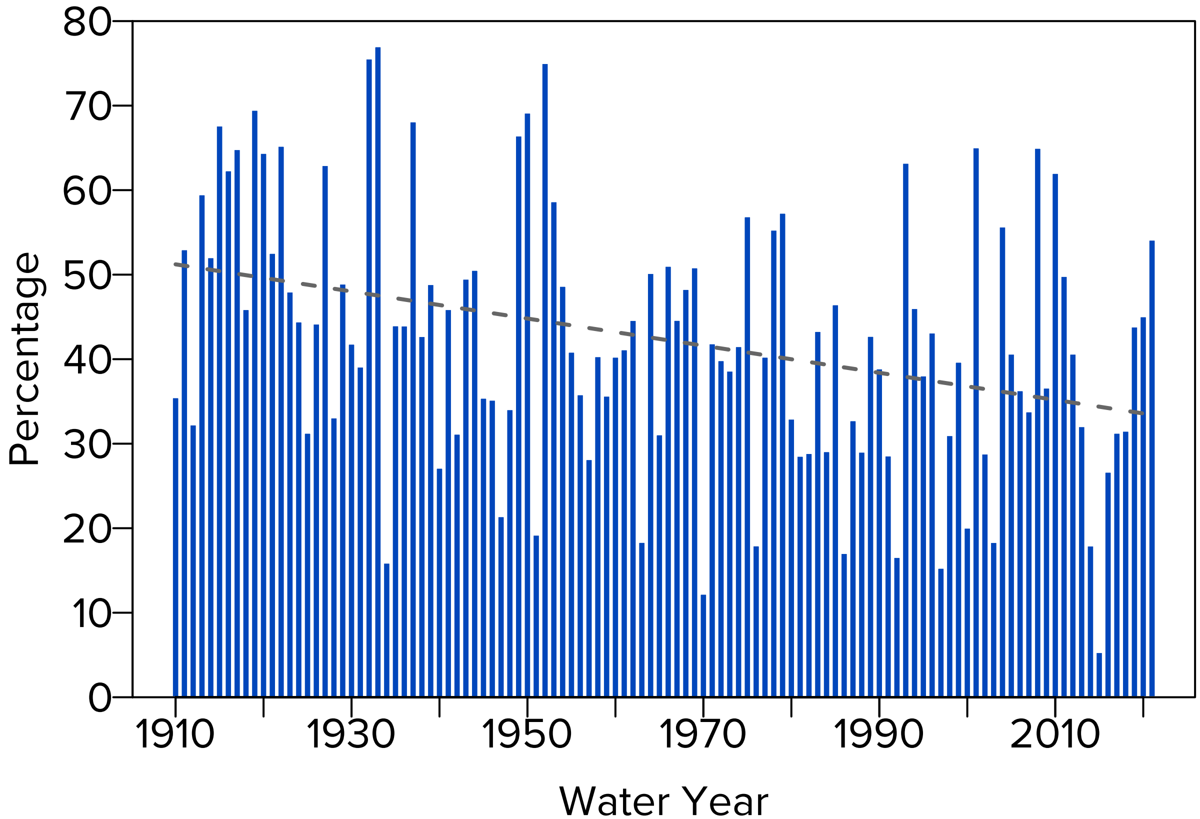


Snow as a fraction of annual precipitation

Yearly since 1910

Snow has declined as a fraction of total precipitation, from an average of 52 percent in 1910 to 33 percent in 2021, according to the trend line. In Tahoe City, snow represented 54.2 percent of the 2021 total precipitation, although the extremely low precipitation likely played a role in that figure, and it should not be interpreted as having long term significance. These data are calculated based on the assumption that precipitation falls as snow whenever the average daily temperature (the average of the daily maximum and minimum temperatures) is below-freezing. Precipitation is summed over the Water Year, which extends from October 1 through September 30.

Data source: Long-term NOAA daily air temperature and precipitation data sets.



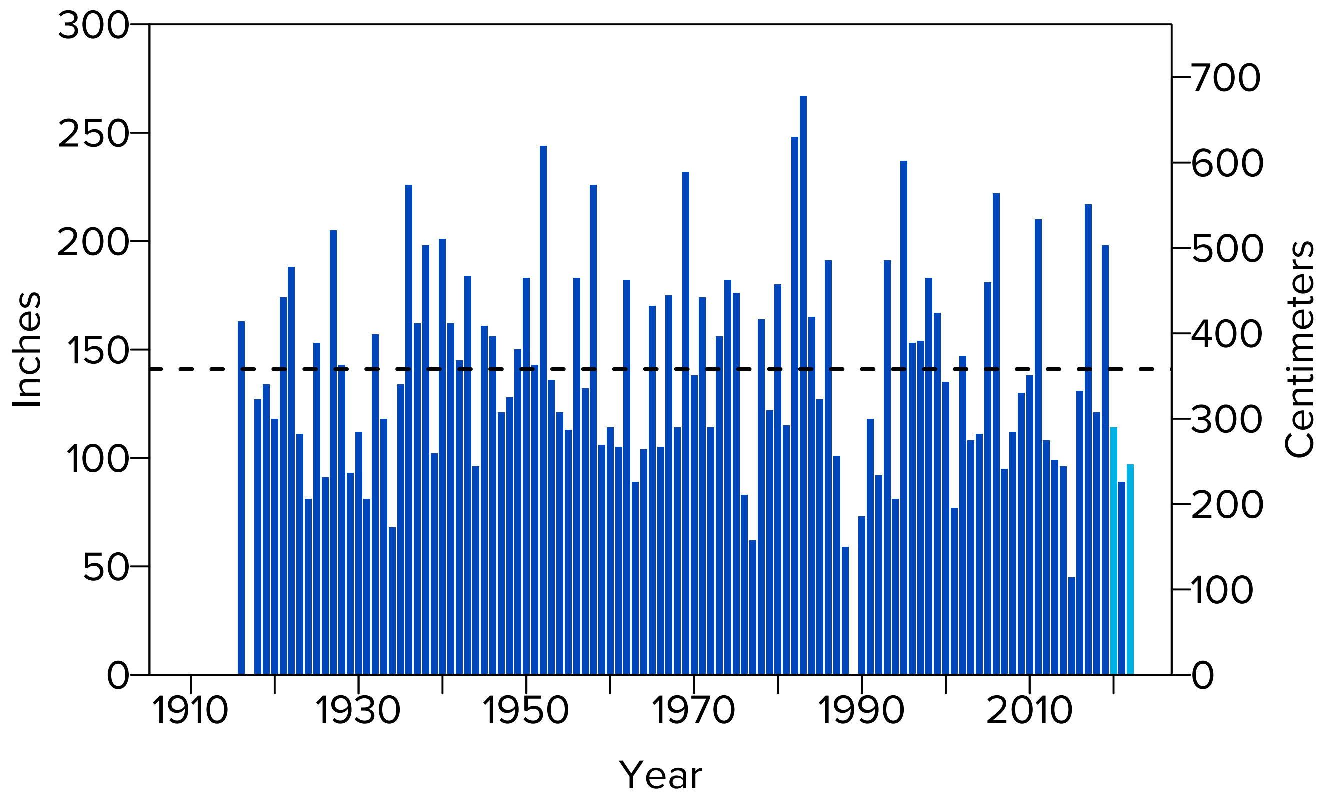
April snowpack

Since 1916

The depth of the snowpack is measured over the year at multiple locations throughout the Sierra. Shown here are the readings taken on approximately April 1 since 1916 at the Lake Lucille Snow Course Station (located in Desolation Wilderness, elevation 8,188 feet (Lat. 38.86 deg. Long. -120.11 deg.). Note: April snow depth data are not available for 1917 and 1989. In 2020 and in 2022, the April snowpack readings at Lake Lucille were not made due to storm conditions. Instead, the values were estimated by correlation with values made at the Rubicon #1 snow course. The correlation estimates are shown with the lighter blue columns.

For March 30, 2022, the value was 97 inches. The largest amount on record was 267 inches on April 5, 1983. The average snow depth (shown by the dotted line) over the period 1916-2022 was 141.7 inches.

Data source: USDA Natural Resources Conservation Service, California Monthly Snow Data.

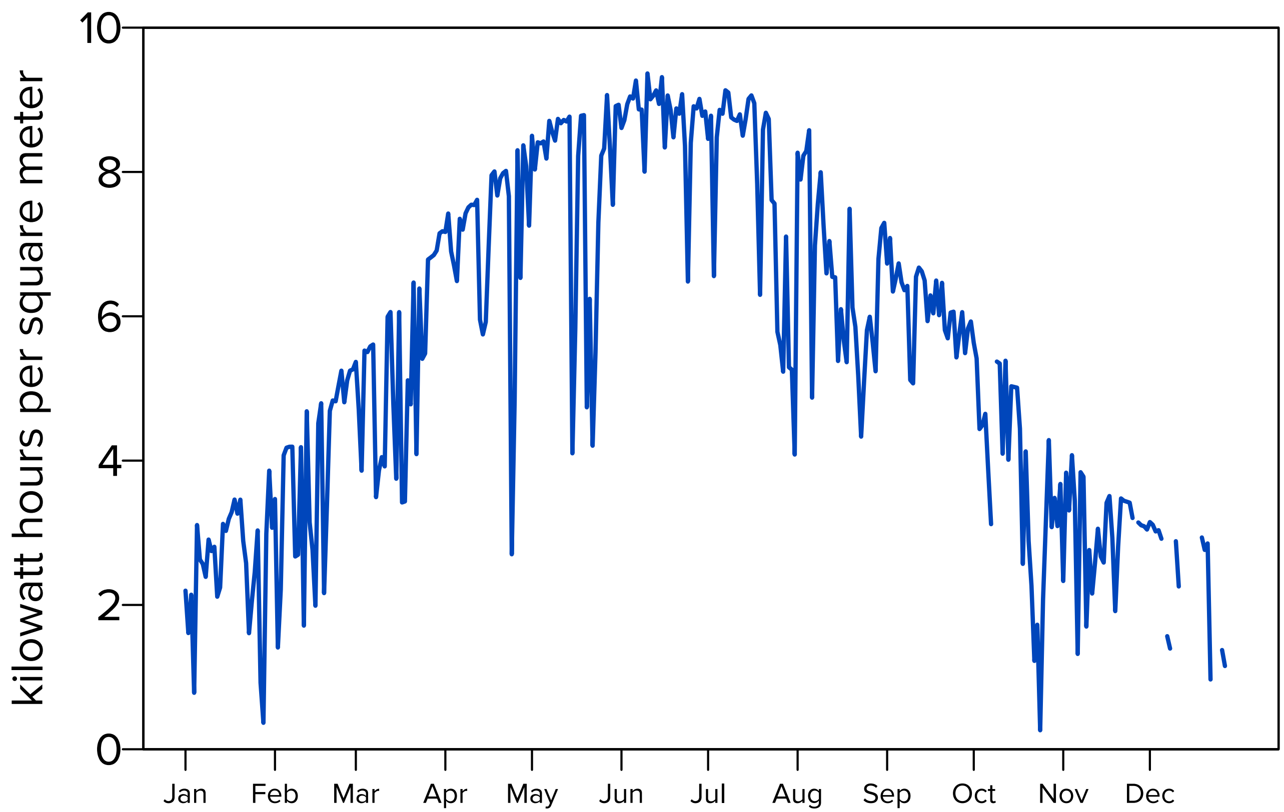


Daily solar radiation

In 2021

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

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



TAHOE:
STATE
OF THE
LAKE
REPORT
2022

PHYSICAL PROPERTIES

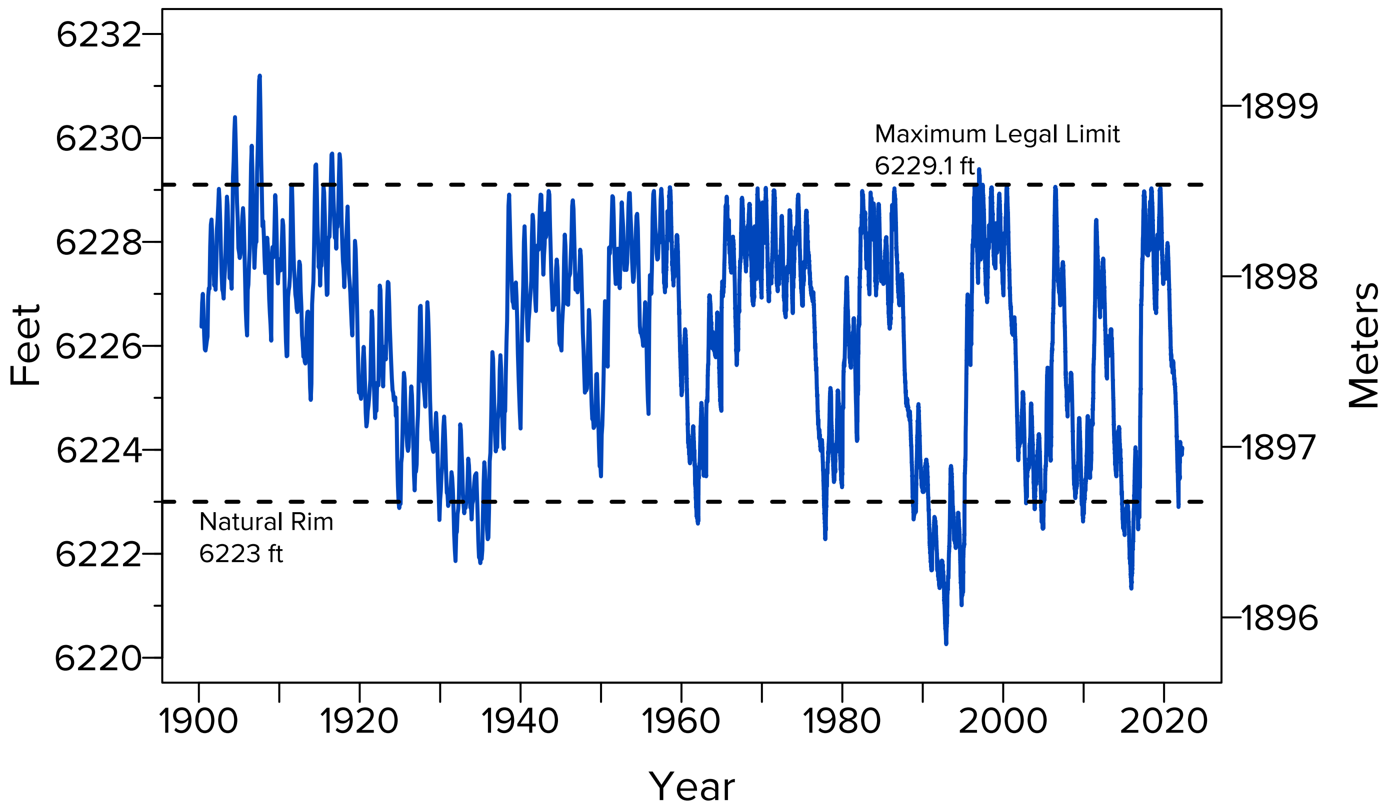
UC DAVIS
Tahoe Environmental
Research Center

Lake surface level

Daily since 1900

Lake surface level varies throughout the year. Lake levels rise 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 outflows via the Truckee River at Tahoe City. In 2021, the highest lake level was 6,225.71 feet on February 13, and the lowest was 6,222.90 feet on October 19. The natural rim of the lake is at an elevation of 6,223 feet. Lake Tahoe fell below its rim on October 13 but rose back above it on October 24. When the lake was below its rim, outflows via the Truckee River ceased. Several episodes of lake level falling below the natural rim are evident in the last 114 years. The frequency of such episodes appears to be increasing. The lowest lake level on record is 6,220.26 feet on November 30, 1992.

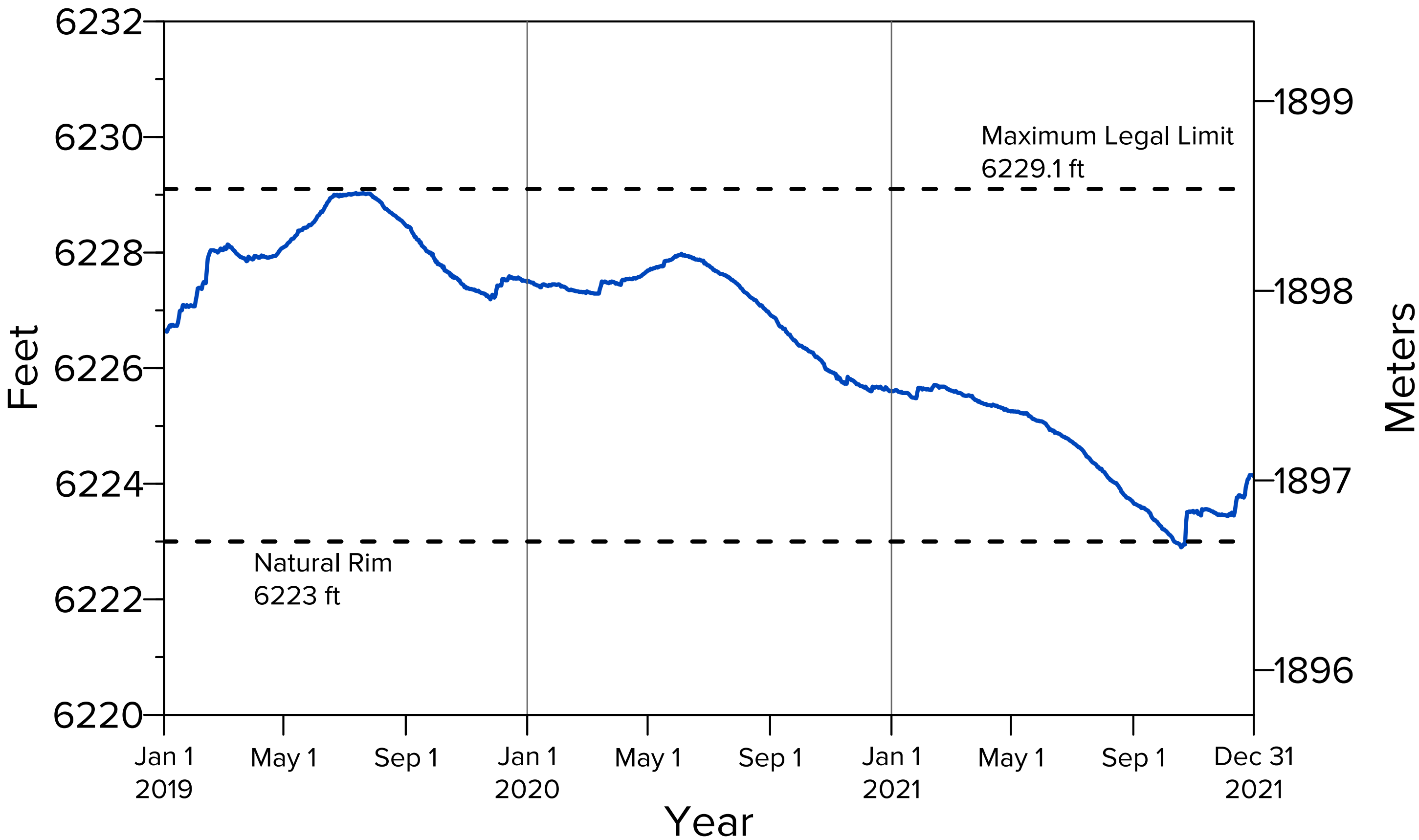
Data source: US Geological Survey level recorder in Tahoe City.



Lake surface level

Daily since 2019

Displayed below is a subset of lake surface data extracted from the same data as in Fig. 8.1 for the most recent three years from 2019–2021. This more time-restricted presentation of recent lake level data allows us to see the annual patterns of rising and falling lake level in greater detail, particularly as we head towards a return to drought conditions and low lake levels. In 2021, on account of the dry winter, the winter and spring rise in lake level was virtually nonexistent. The mid-October snow in 2021 produced a sudden jump in lake level, but overall from January through December 2021, overall lake level fell 1.5 feet.
Data source: US Geological Survey level recorder in Tahoe City.



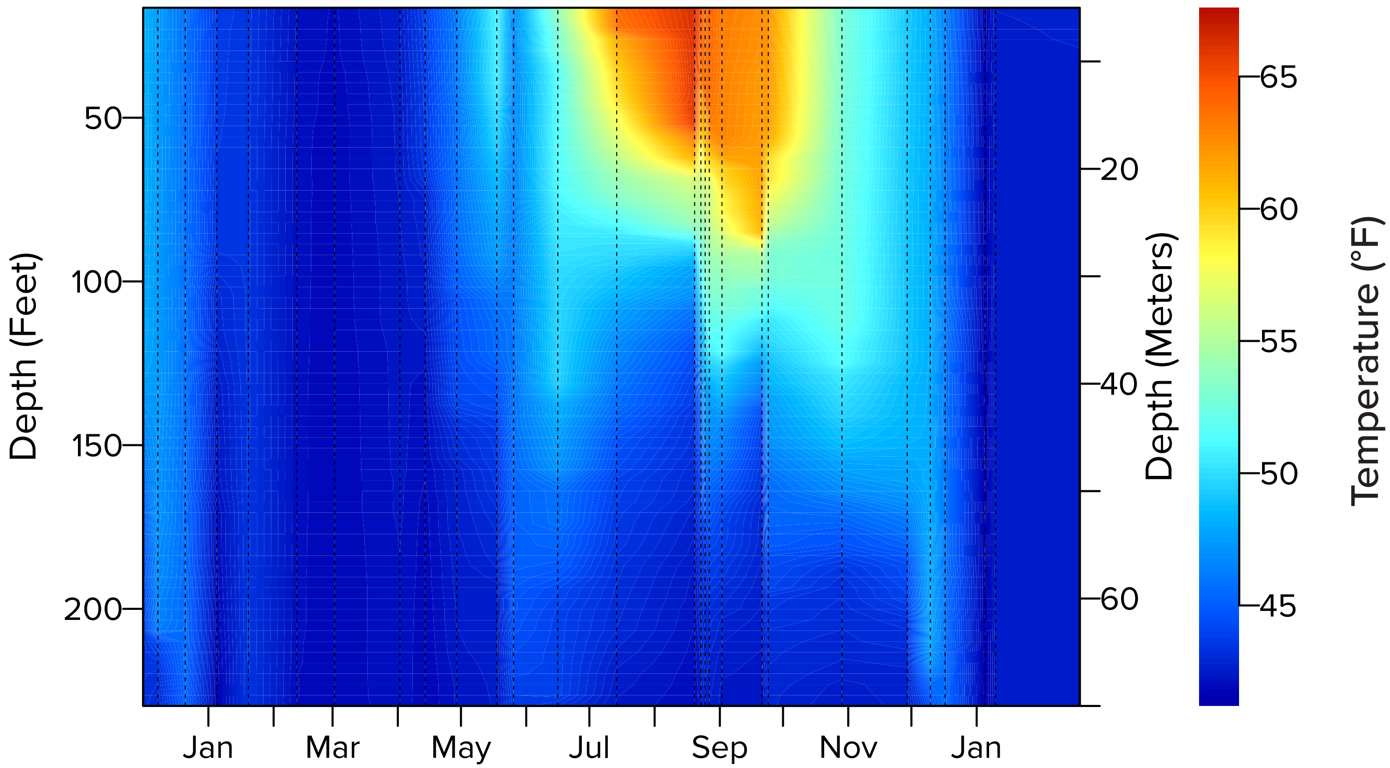
Water temperature profile

In 2021

Water temperature profiles are measured in the lake using a Seabird CTD (conductivity, temperature, depth) profiler on the days indicated by the dashed vertical lines. The intensification of the sampling frequency in August and September was part of the effort to capture the impacts of the extremely smokey conditions being experienced at Lake Tahoe. The temperature is accurate to within 0.005 °F. The vertical distribution of water temperature is a very important lake attribute, as it represents lake density, with warmer, lighter water trapped at the surface during the summer months. Here, the temperature in the upper 230 feet (70 m) is displayed as a color contour plot. In the early part of 2021, the lake temperature followed the typical seasonal pattern. In February and March, the lake surface was at its coldest, while it was at its warmest in August.

In 2021, the upper portions of the lake cooled earlier than in comparison to most years. This was in part due to the blockage of solar radiation by the smoke which engulfed the basin. The continued cooling of the surface water toward the end of the year is part of the normal cycle of winter mixing, a process that is key to bringing oxygen to the deeper parts of the lake.

Data source: TERC lake monitoring.

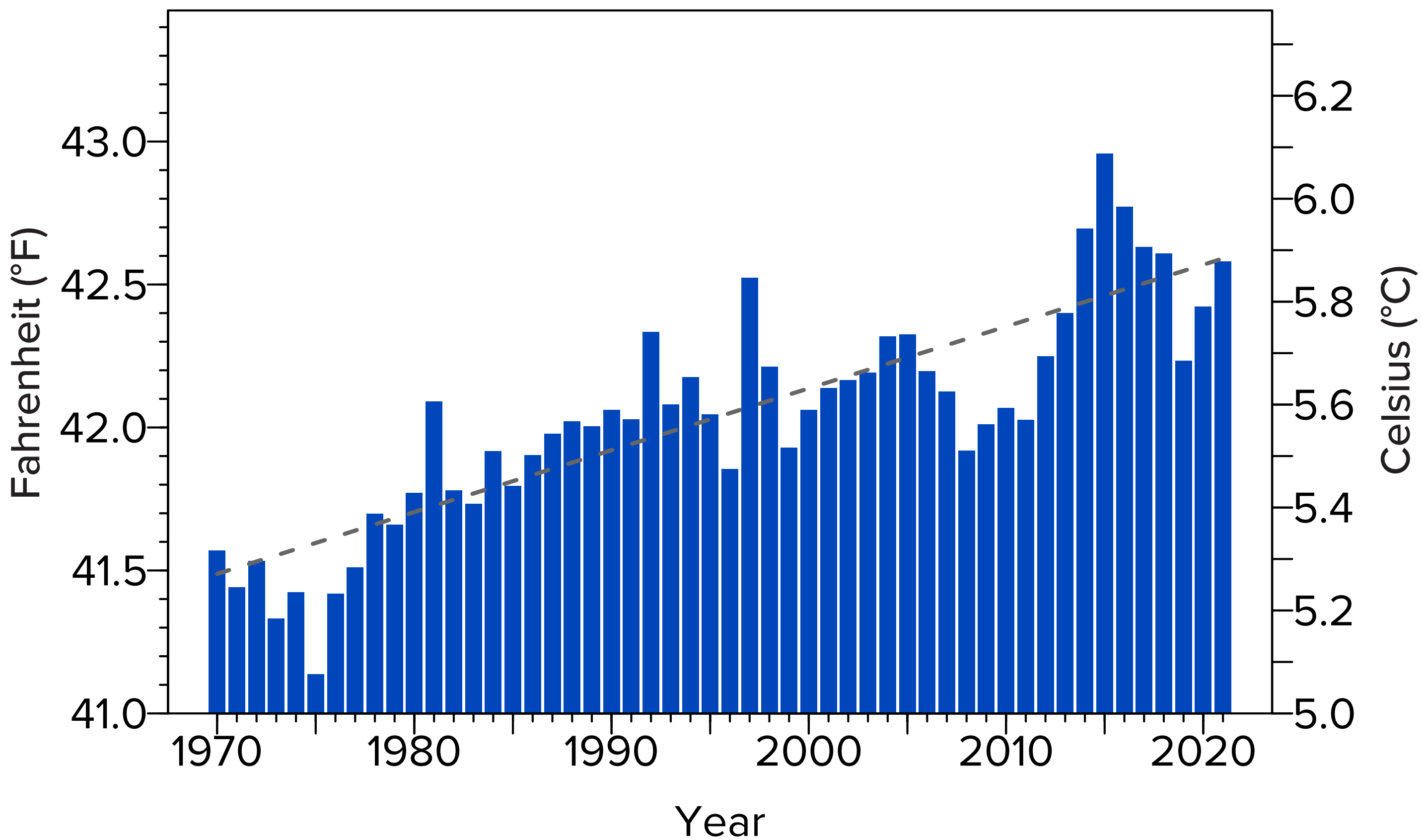


Annual average water temperature

Since 1970

The volume-averaged temperature of the lake for each year since 1970 is shown. The trend line indicates that water temperature has increased by approximately 1.1 °F (0.61 °C) since 1970. The annual rate of warming is 0.22 °F/decade (0.12 °C/decade). The monthly temperature profile data from the top to the bottom of the lake has been smoothed, and any seasonal influences were removed to best show the long-term trend. Up until the late 1990s, the warming rate was high, but there were still a relatively large number of deep mixing years between 1997 and 2011, and additionally, the top to bottom mixing in 2019 caused the average lake temperature to cool. Despite that, the longer-term warming trend appears to be returning with the 2021 average temperature of 42.6 °F (5.9 °C)

Data source: TERC lake monitoring.

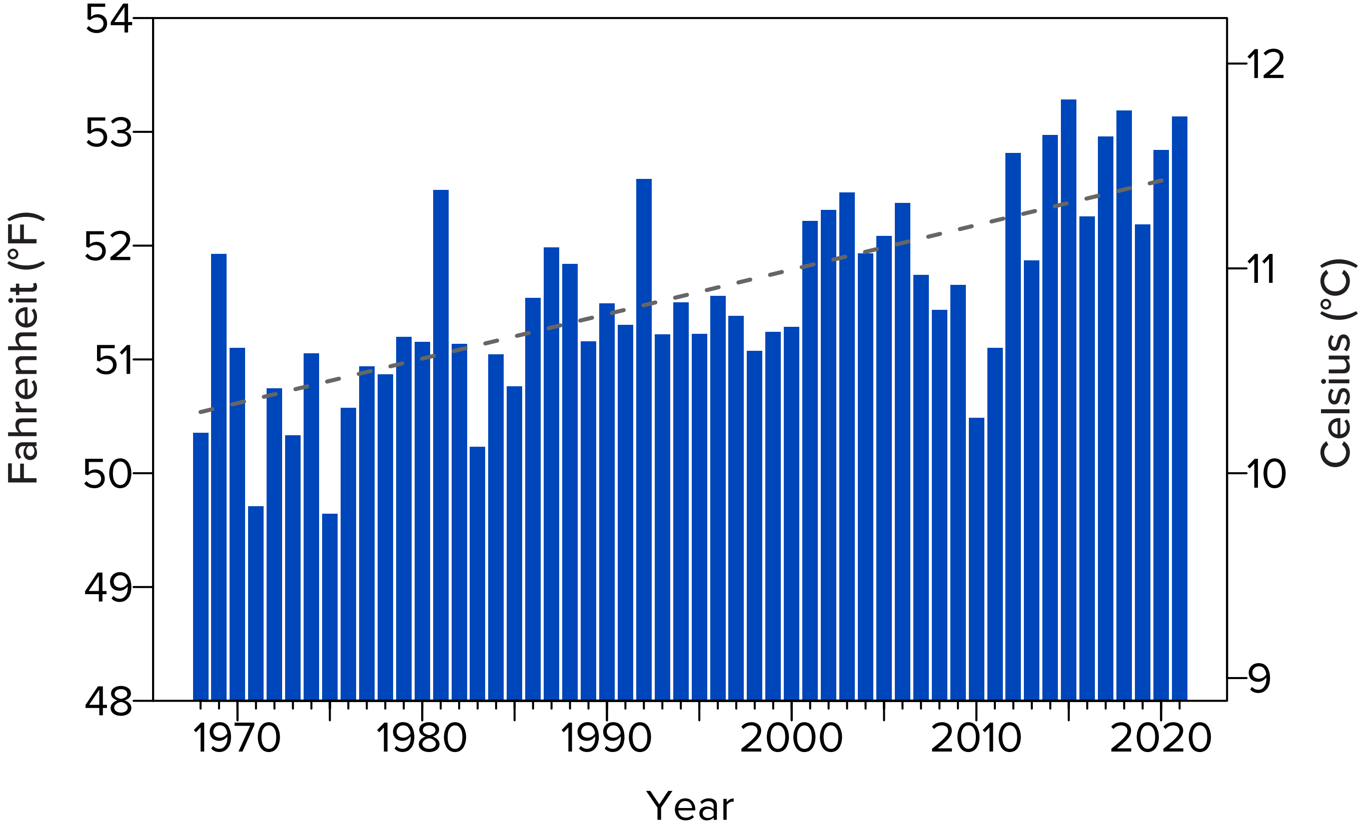


Annual surface water temperature

Yearly since 1968

Surface water temperatures (technically at a depth of 5 feet) have been recorded monthly at the Mid-lake and Index stations from TERC's research vessels since 1968 and from four buoys since 2007. Despite year-to-year and longer cyclical variability, the annual average surface water temperatures show an increasing trend. The average temperature in 1968 was 50.4 °F (10.2 °C). For 2021, the average surface water temperature was 53.1 °F (11.7 °C), making it the third warmest year on record. The overall rate of warming of the lake surface is 0.39 °F (0.22 °C) per decade.

Data source: TERC lake monitoring.

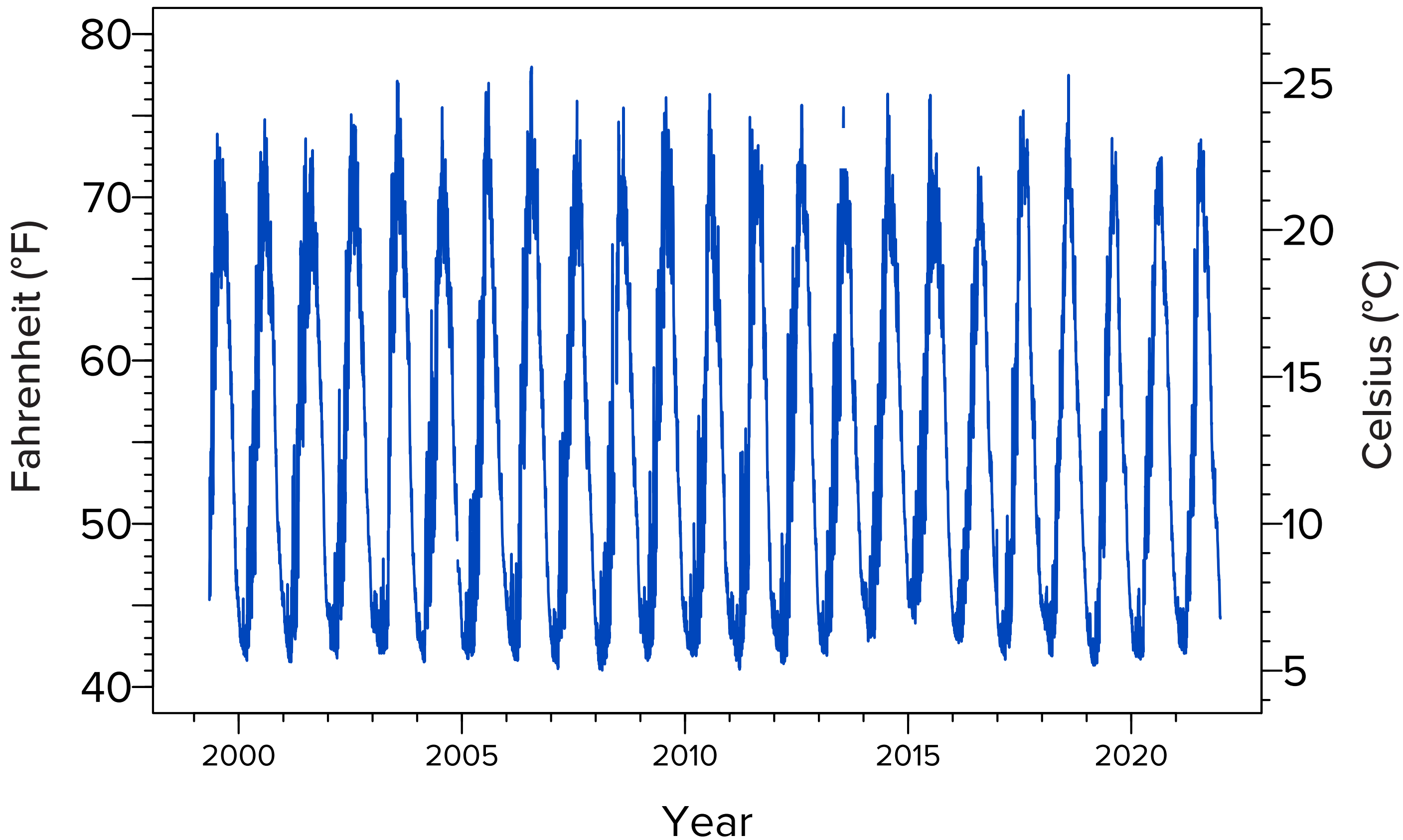


Maximum daily surface water temperature

Surface temperature measured since 1999 every 2 minutes

The maximum daily surface water temperature follows a logarithmic pattern, with the temperature being in equilibrium with the air temperature and other meteorological variables. The highest maximum daily surface water temperature (summer) was 73.5 °F (23.1 °C), recorded on July 24, 2021. The lowest maximum daily surface water temperature (winter) was 42.0 °F (5.6 °C), which was recorded on March 10, 2021. This was relatively warm, due in part to the absence of deep mixing.

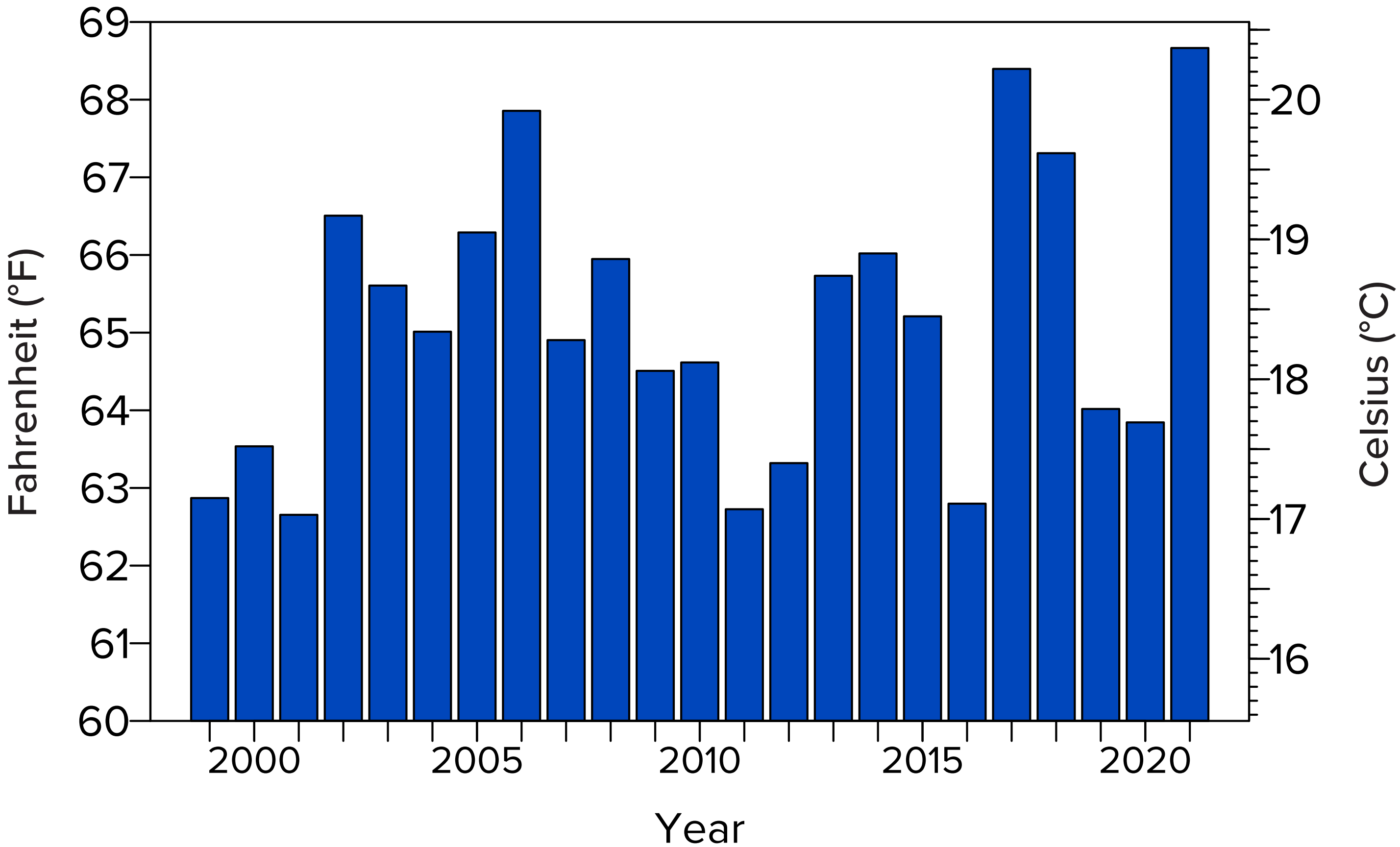
These data are collected from thermistors at a depth of 5 feet (1.5 m) that are attached to four buoys located over the deepest portions of the lake. The highest daily value from among the four buoys is considered as the daily maximum.



July average surface water temperature

Measured since 1999 every 2 minutes

Surface water temperature has been continuously recorded since 1999 from four NASA/UC Davis buoys in the center of the lake. Shown here are 23 years of average surface water temperatures in the month of July when water temperatures are typically at their warmest and the greatest number of people are recreating on the lake. In 2021, July surface water temperature averaged 68.7 °F (20.4 °C), the highest value ever recorded. This was 3.5 °F (1.9 °C) above the average of 65.2 °F (18.4 °C) for the 23-year period of record. These data are collected from thermistors at a depth of 5 feet (1.5 m) that are attached to four buoys located over the deepest portions of the lake



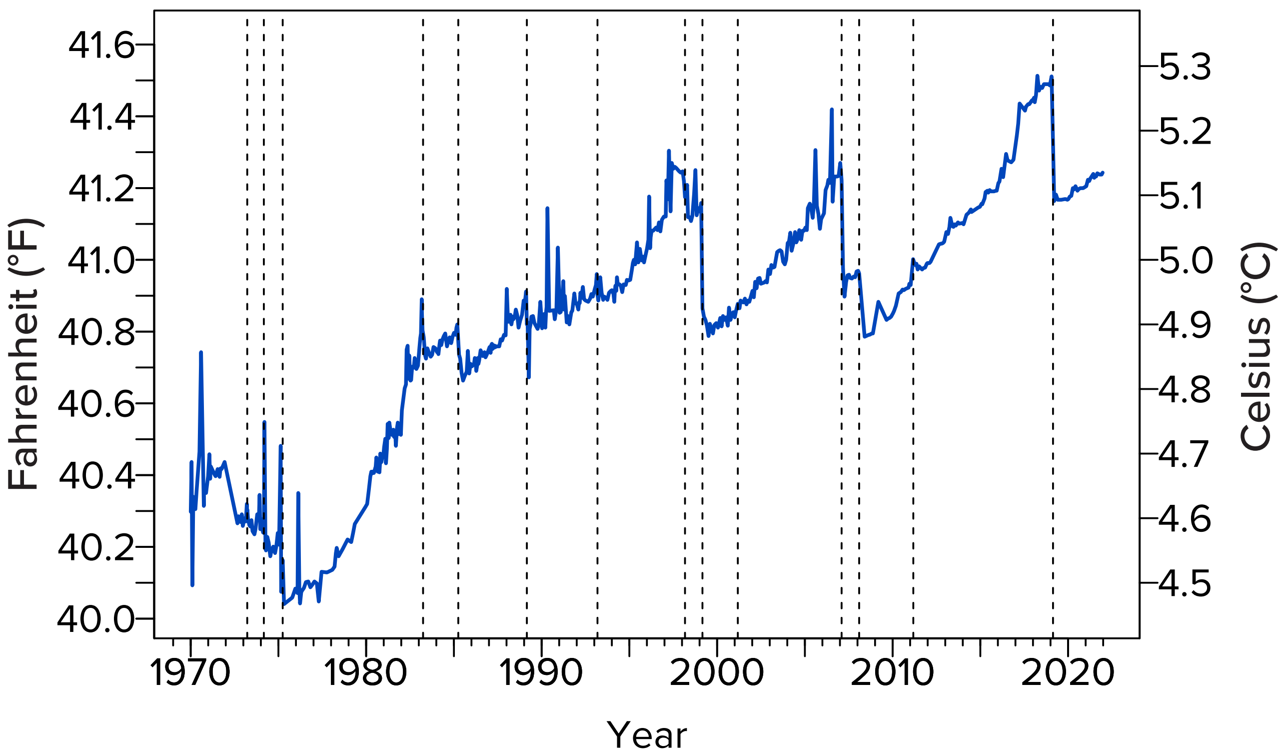
Deep water temperature

Monthly 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. The deep-water temperatures show a complex pattern of warming and sudden cooling. During deep mixing events (shown by the dashed vertical lines), the temperature can drop precipitously over a short period of time, although these drops are generally less than 0.3 °F. The mechanisms behind the heating of the bottom water when deep mixing does not occur is an area of current research. Generally, bottom temperatures are warming.

In 2021, there was no deep mixing (see Fig. 8.9) and water temperatures rose slightly. Between the last two deep mixing events in 2011 and 2019, the rate of water warming was 0.07 °F/year. During the deep mixing of 2019, the water temperature fell over 0.3 °F in just a few weeks. Complete vertical mixing is an event that allows a huge amount of heat to escape from the lake. The short spikes of temperature increase during the warming phases are temporary effects caused by the motions of internal waves and other lake motions in the hypolimnion.

Data source: TERC lake monitoring.

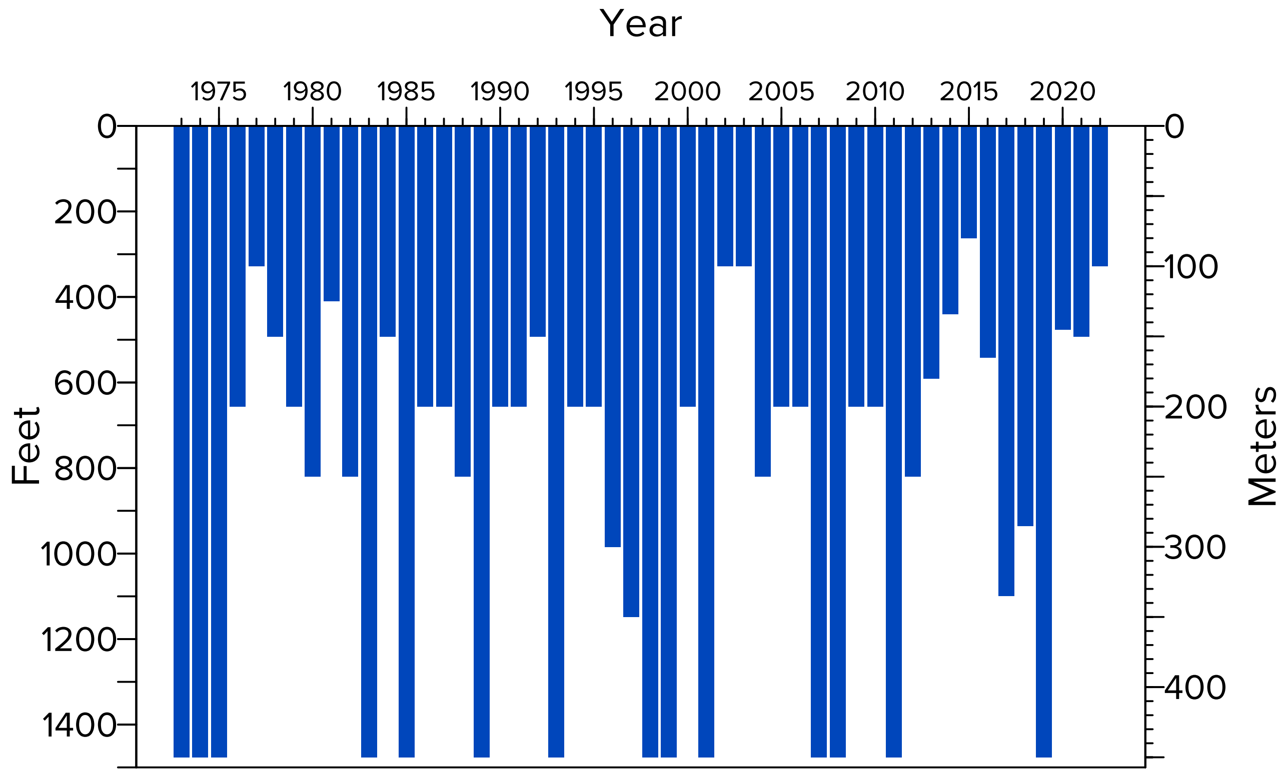


Depth of mixing

Yearly since 1973

The water of Lake Tahoe vertically mixes each winter as surface waters cool and sink downward. In a lake as deep as Tahoe, the intense cooling of winter helps to determine how deep the lake mixes vertically. Mixing depth has profound impacts on lake ecology and water quality. Deep mixing brings nutrients to the surface, that promote algal growth. It also carries oxygen downward to deep waters, promoting aquatic life throughout the water column. The deepest mixing typically occurs between February and March. On March 17, 2021, Lake Tahoe was observed to have mixed to a maximum depth of 492 feet (150 m). This relatively shallow mixing likely contributed to the warmer surface temperatures experienced during winter. On February 18, 2022, Lake Tahoe was observed to have mixed to a maximum depth of only 328 feet (100 m), the second lowest value on record. Since 2013, the depth of mixing has been determined with more accurate high-resolution temperature profiles rather than nitrate concentration sampled at discrete depths. Continuous temperature measurements off Glenbrook provided additional confirmation.

Data source: TERC lake monitoring.



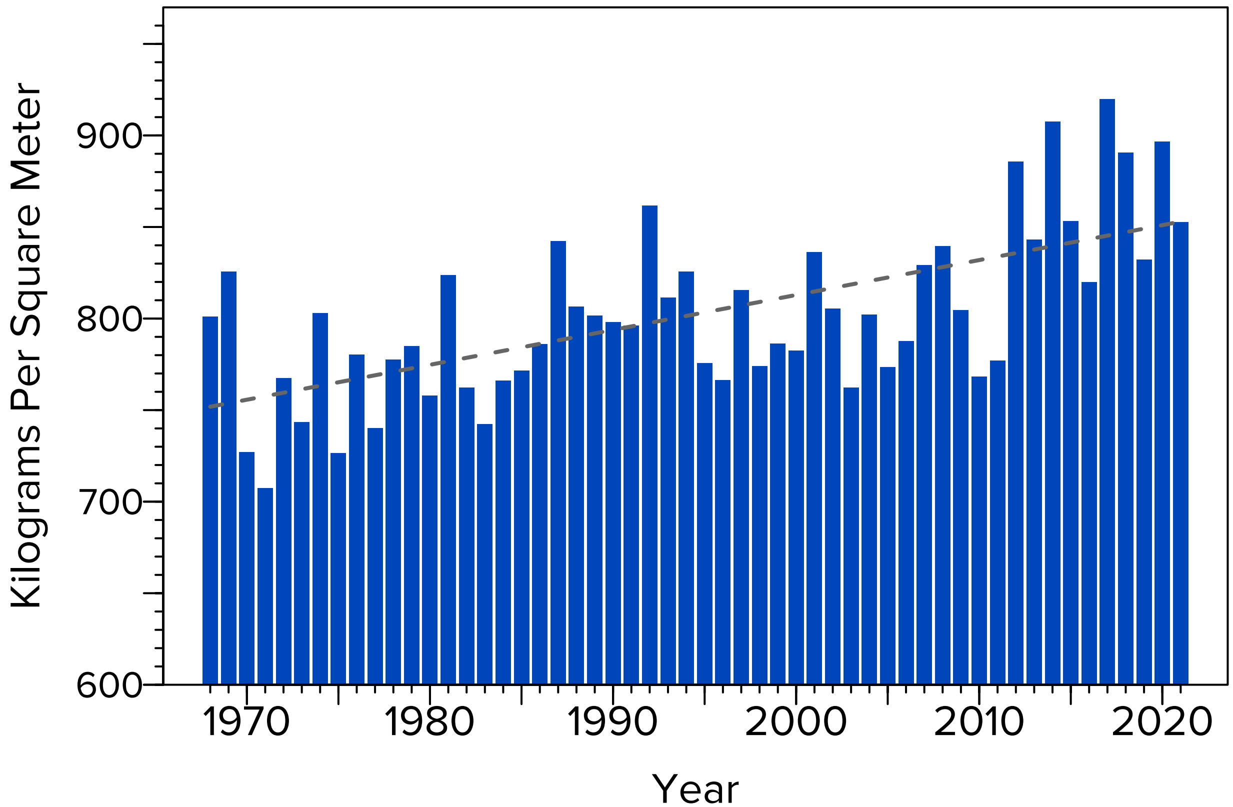
Lake stability index

Since 1968

When the lake has a vertical distribution of temperature, it has a corresponding distribution of density. Warm and lighter (less dense) water stay suspended at the surface above the colder and denser water below. As the temperature difference between top and bottom increases, the lake is said to become more stable.

Increasing stability poses a potential threat to all lakes. The stability index is a measure of the energy required to fully mix the water column when it is density 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- to 20-day intervals. There has been an overall increase in lake stability by 13.4 percent in the last 53 years.

Data source: TERC lake monitoring.

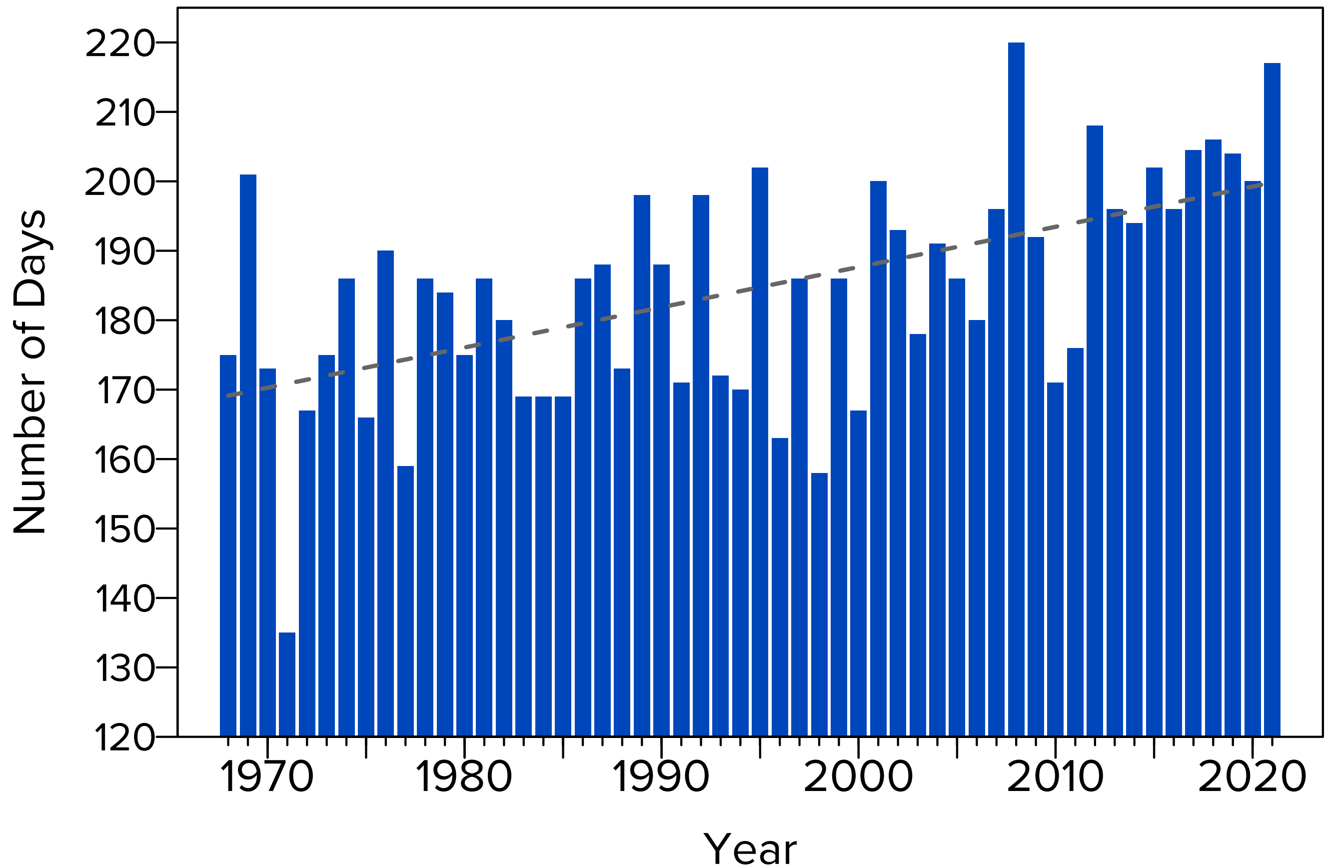


Stratified season length

Since 1968

The stability index, a measure of the energy required to mix the lake, can be evaluated for every day of the year. We define the stratification season as the number of days when the stratification index exceeds a value of 600 kilograms per square meter. Since 1968, the length of the stratification season has increased by 31 days, albeit with considerable year-to-year variation. In 2021, the length of the stratified season was 217 days, the second longest period on record.

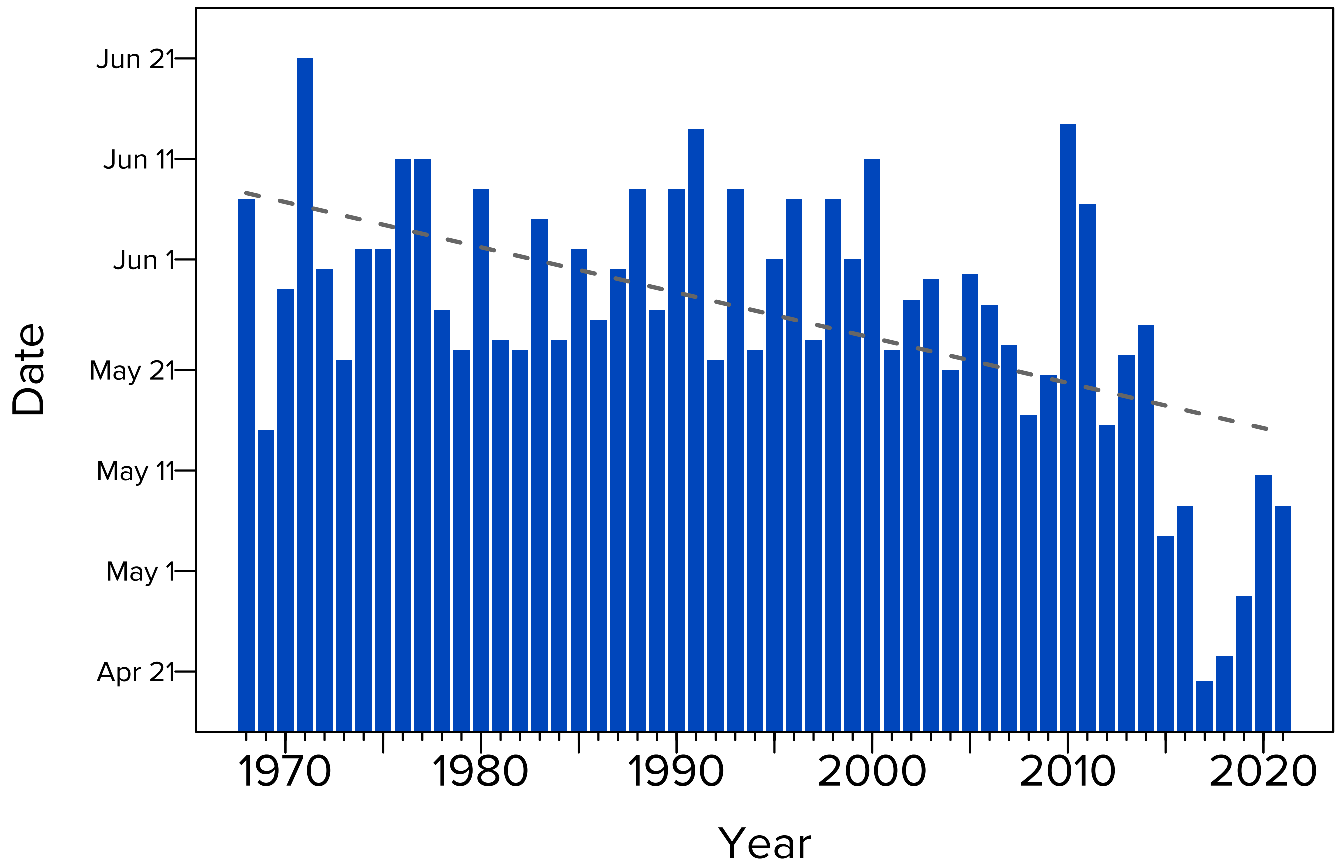
Data source: TERC lake monitoring.



Beginning of the stratification season

Since 1968

The amount 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 24 days earlier than it did in 1968. The commencement of the stratification season is typically in May or early June. In 2021, stratification began on May 7 (Day 128).
Data source: TERC lake monitoring.

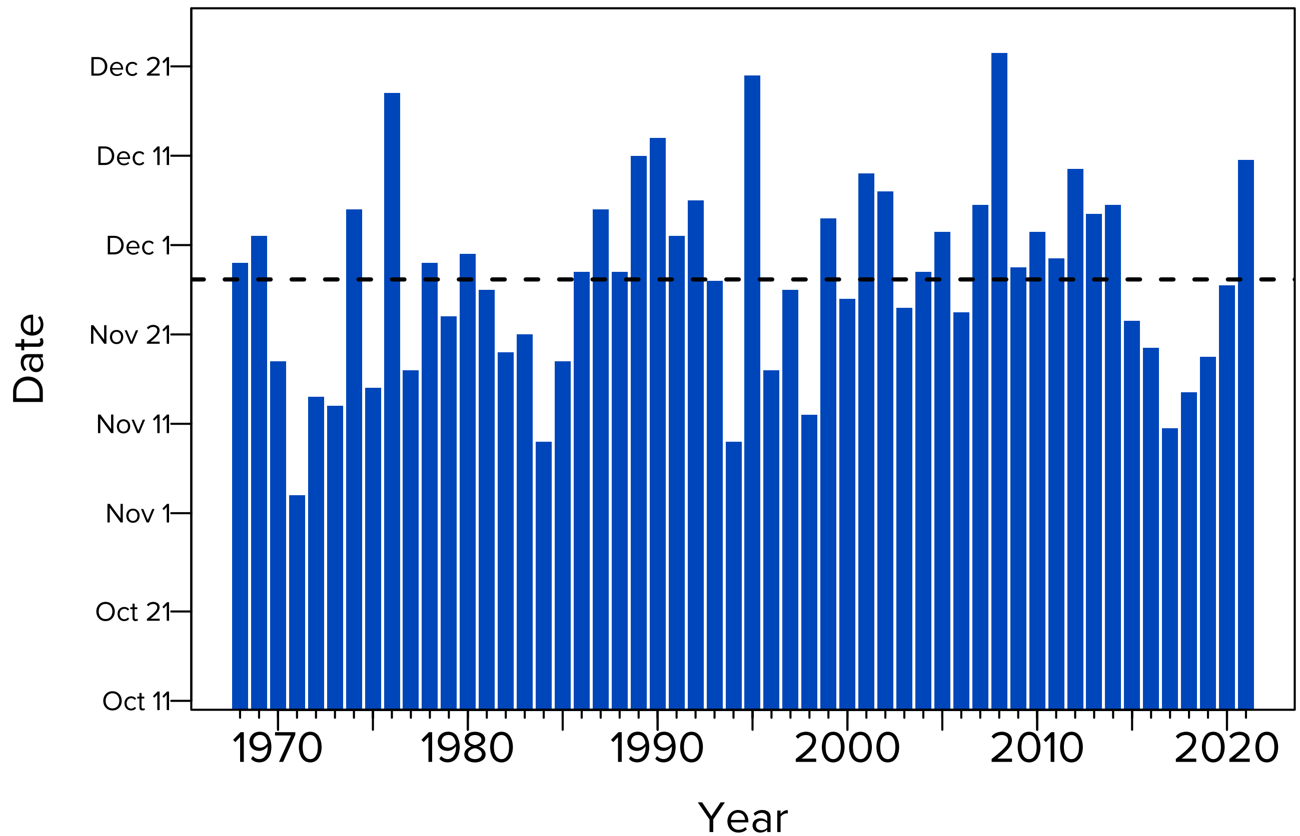


End of stratification season

Since 1968

The amount of time that Lake Tahoe is stratified has lengthened by a month since 1968. The end of the stratification season has been extended, but not as much as the onset of stratification (See Fig. 8.12). Over the 53-year record, the end of stratification has been extended by approximately one week. This can have important implications for lake mixing and water quality, such as the buildup of nitrate at the bottom of the lake. The dashed black line indicates the long-term average end of stratification date.

Data source: TERC lake monitoring.

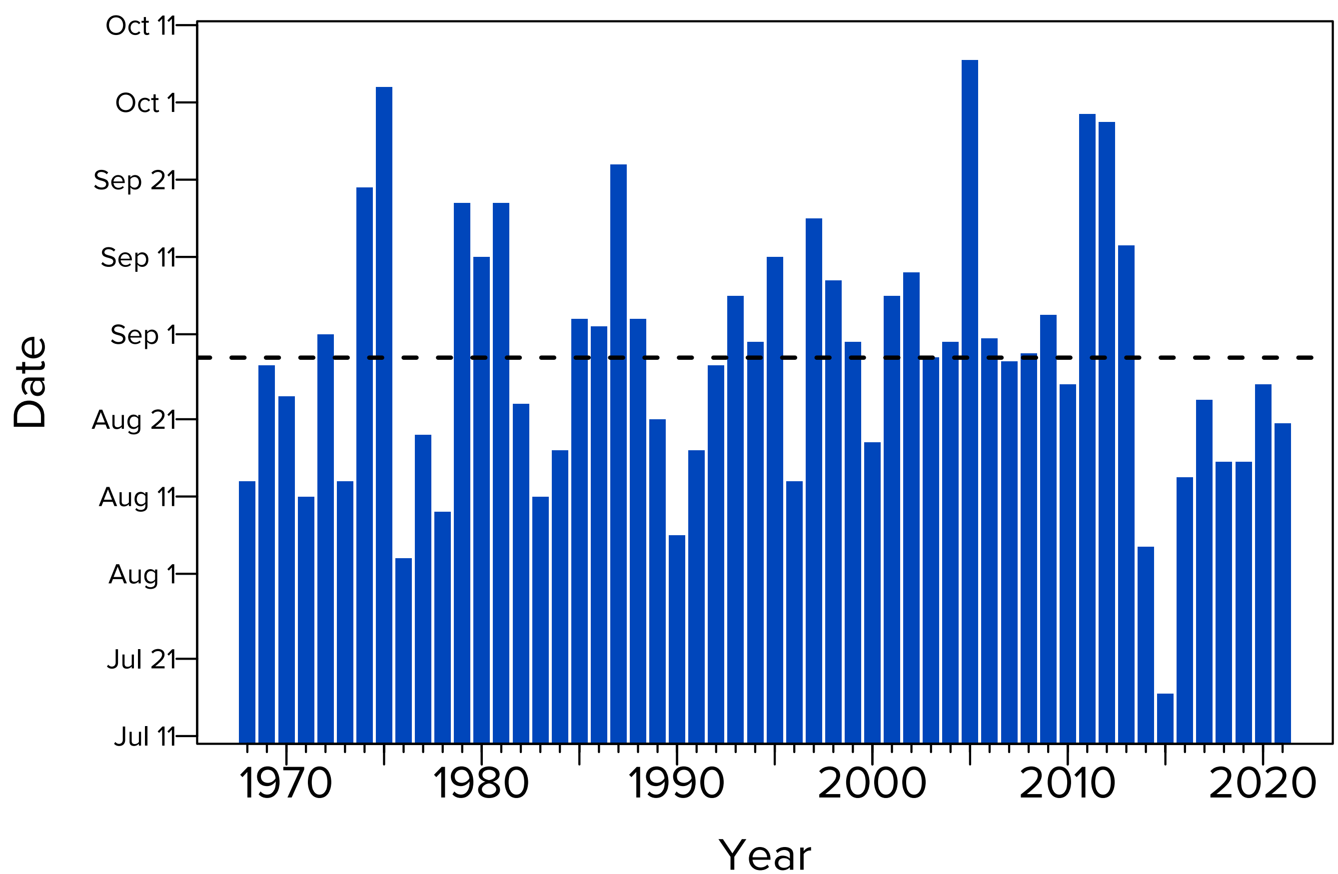


Peak of stratification season

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 no statistically significant change in when the peak occurs. In 2021, the peak occurred on August 20.

Data source: TERC lake monitoring.

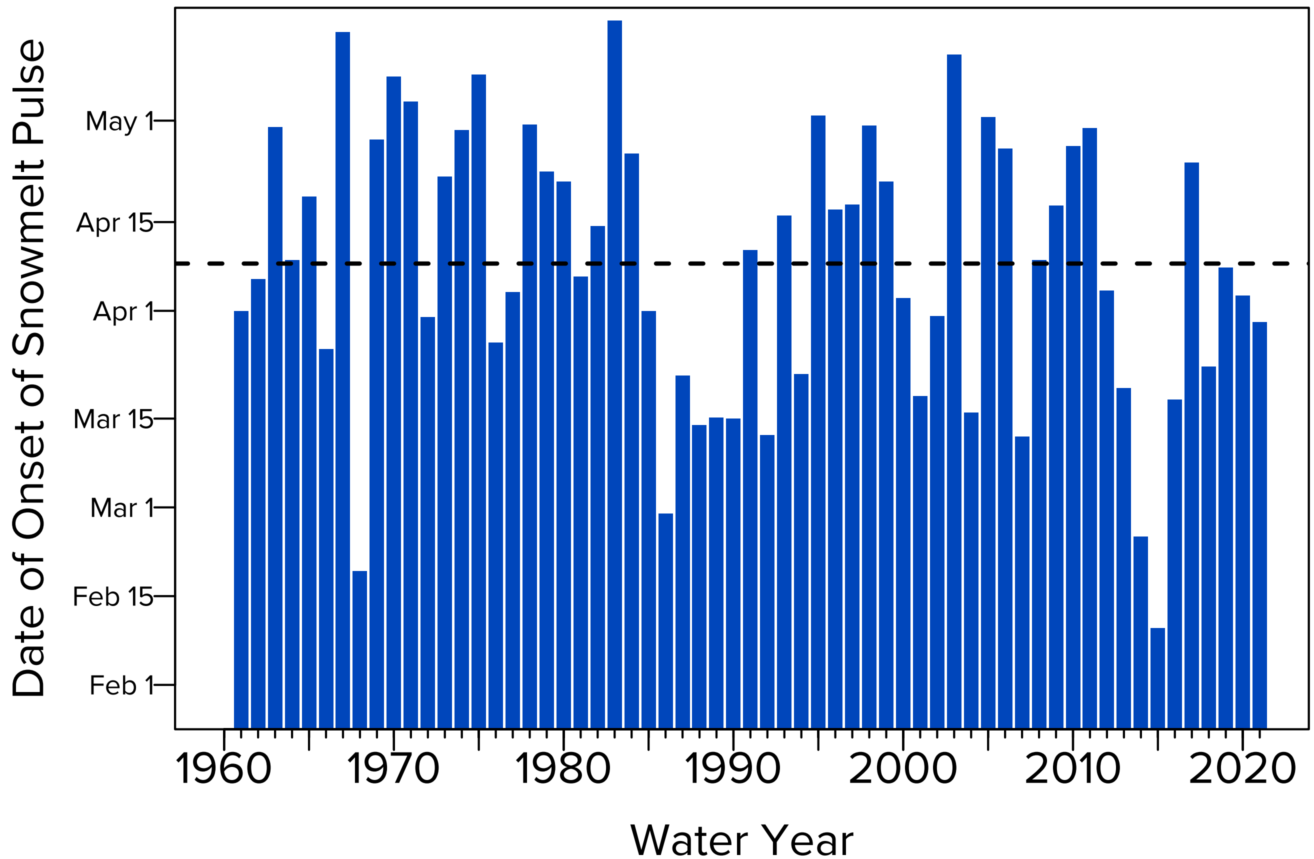


Onset of snowmelt pulse

Yearly since 1961

Although the date on which the onset of snowmelt commences varies from year to year, since 1961 it has shifted earlier by an average of over 17 days. The snowmelt pulse is calculated and averaged for five streams—the Upper Truckee River, Trout Creek, Ward Creek, Blackwood Creek, and Third Creek. This shift is statistically significant and is one effect of climate change at Lake Tahoe. In 2021, the date of the onset of snowmelt was March 30 which, according to the regression line, was earlier by 17 days than it was in 1961. The onset of the pulse is calculated as the day when flow exceeds the mean flow for the period January 1 to July 15. In the past, the peak of the stream hydrograph was used to estimate this metric.

Data source: U.S. Geological Survey stream monitoring.



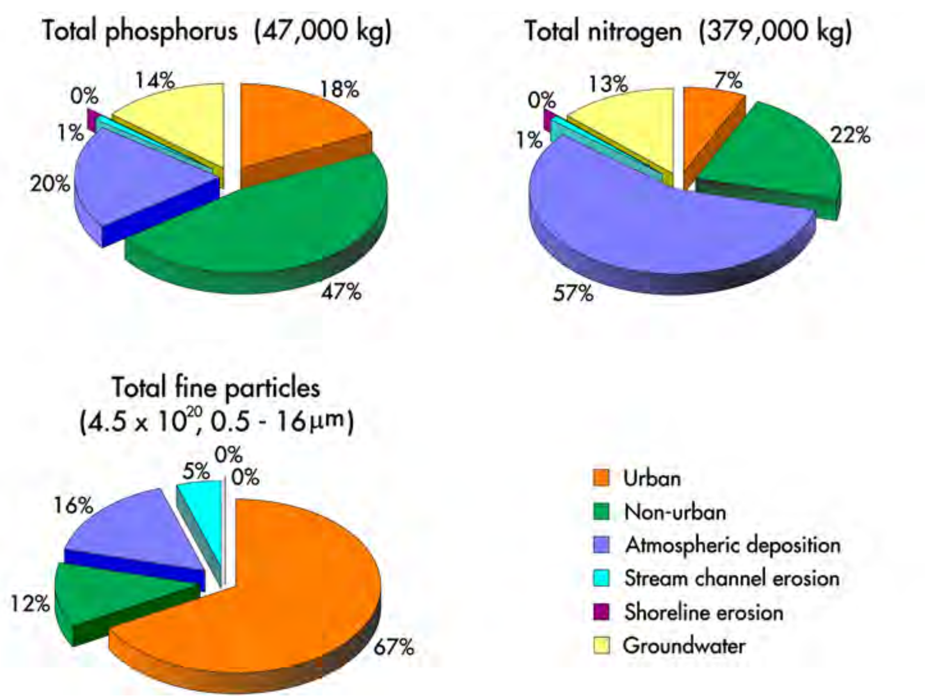
TAHOE:
STATE OF THE LAKE
REPORT
2022

NUTRIENTS AND PARTICLES

UCDAVIS
Tahoe Environmental
Research Center

Sources of clarity-reducing and blueness-reducing pollutants

Research has quantified the primary sources of nutrients (nitrogen and phosphorus) and fine particulate material that are causing Lake Tahoe to lose clarity and blueness in its upper waters. One of the primary contributors to clarity decline is extremely fine particles (in the size range of approximately 1–5 microns) in stormwater that originate from both the urbanized watersheds and the streams that drain the majority of the basin's land area. 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 management agencies, known as the Lake Tahoe Total Maximum Daily Load (TMDL) Program.



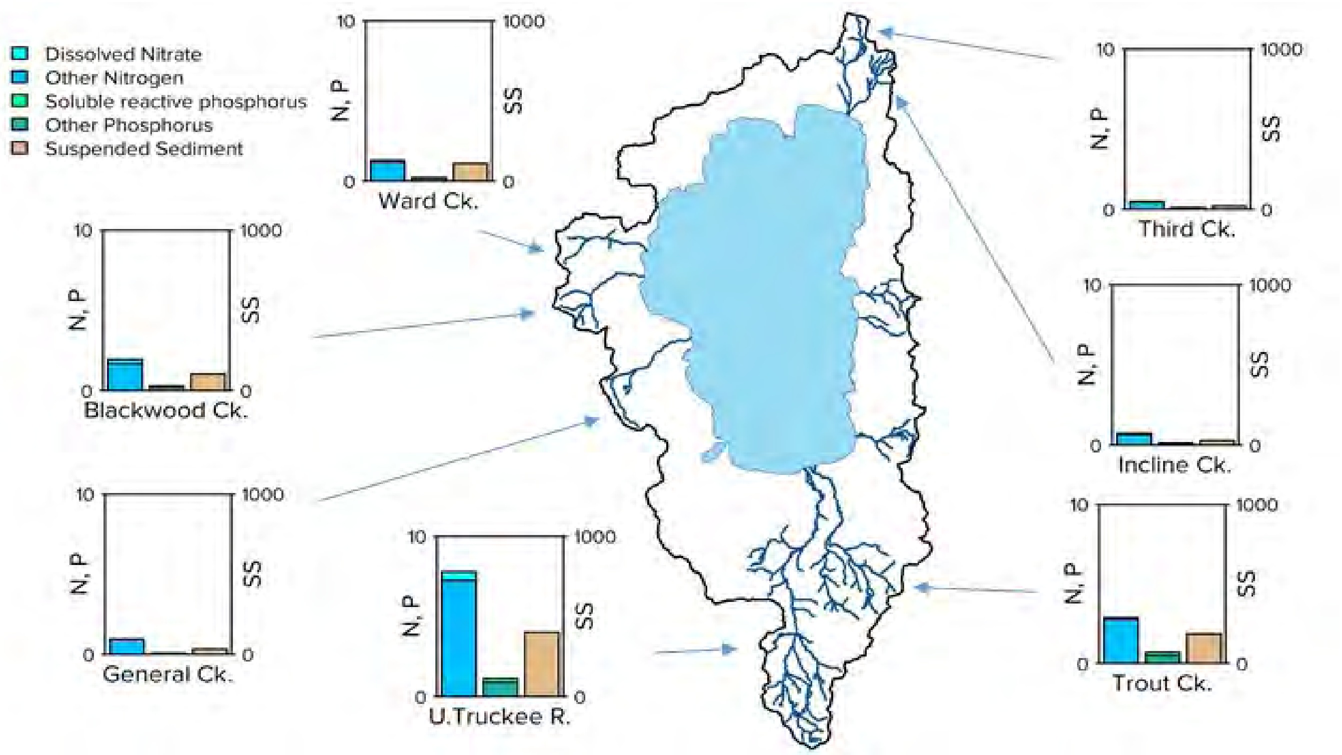
Pollutant loads from seven watersheds

In 2021

The Lake Tahoe Interagency Monitoring Program (LTIMP) measures nutrient and sediment input from seven of the 63 watershed streams. The streams are the Upper Truckee River, Trout Creek, Incline Creek, Third Creek, Ward Creek, Blackwood Creek, and General Creek. In 2021, the majority of stream phosphorus and nitrogen, as well as suspended sediments, came from the Upper Truckee River. This is often the case, but in some years, smaller streams, such as Incline Creek and Blackwood Creek, can also be significant contributors.

It should be noted that suspended sediments as represented in these data include all sediment sizes and is measured by weight. For clarity, it is the number of fine particles (in the range of 1–5 microns) that is important. These particles make up a very small fraction of the suspended sediment, but largely control lake clarity.

The LTIMP stream water quality program is supported by the Lahontan Regional Water Quality Control Board, the Tahoe Regional Planning Agency, the U.S. Geological Survey, and UC Davis TERC. TERC and the U.S. Geological Survey jointly collect and analyze the stream data.

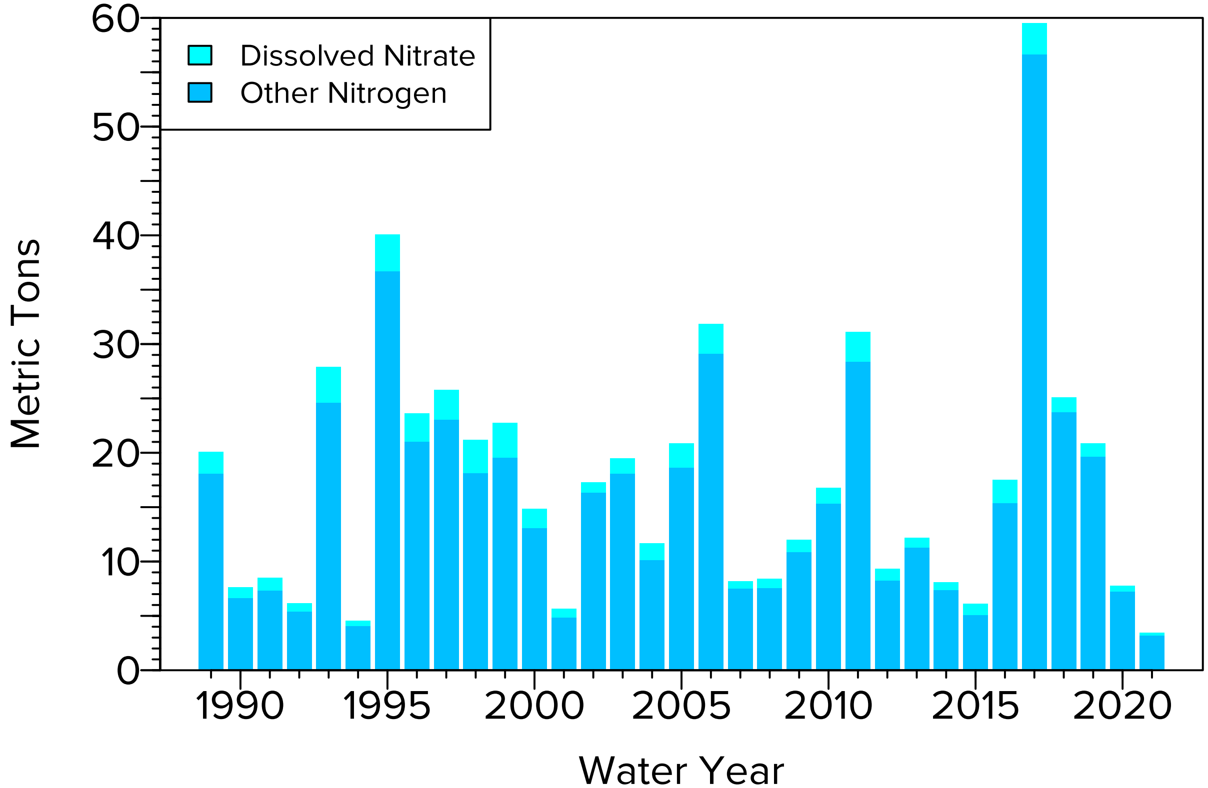


Nitrogen contribution by Upper Truckee River

Yearly since 1989

Nitrogen (N) is important because it, along with phosphorus (P), stimulates algal growth. The Upper Truckee River is the largest of 63 streams that flow into Lake Tahoe, contributing about 25 percent of the inflowing water. The river's estimated contribution of dissolved nitrate and the remainder of the total nitrogen load are shown here. Over the 32 years of record, the percentage of nitrate to total nitrogen has been in the range of 5–14 percent. The year-to-year variations primarily reflect changes in precipitation. For example, 1994 had 16.6 inches of precipitation and a low total nitrogen load of 4.6 MT, while 2017 had 68.9 inches of precipitation and a record high total nitrogen load of 59.5 MT. In 2021, there were only 15.3 inches of precipitation and the lowest ever total nitrogen load from the Upper Truckee River of 3.5 MT, likely due to the record low stream flows. The nitrate load was 0.26 MT. The long-term mean annual total nitrogen load is 17.5 MT/yr while for nitrate it is 1.6 MT. (One metric ton (MT) = 2,205 pounds.).

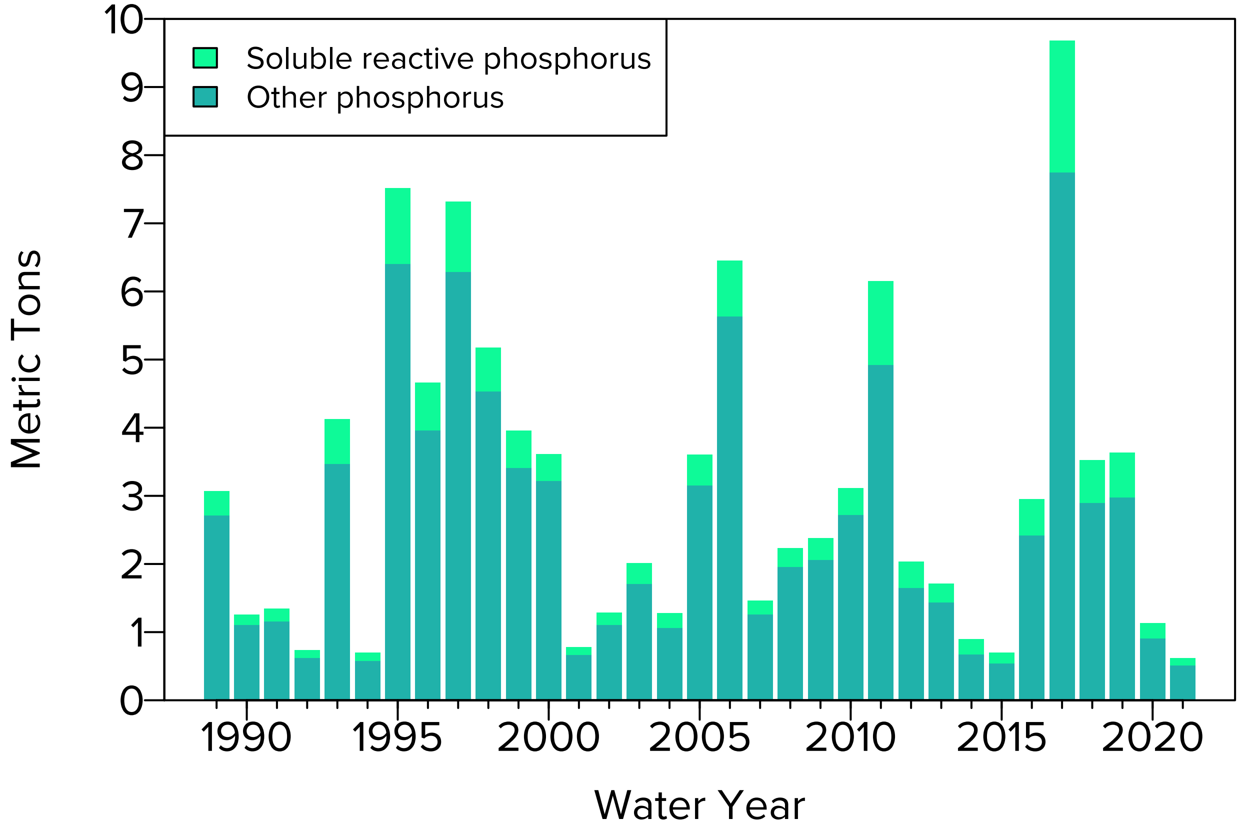
Data source: TERC and U.S. Geological Survey stream monitoring.



Phosphorus contribution by Upper Truckee River

Yearly since 1989

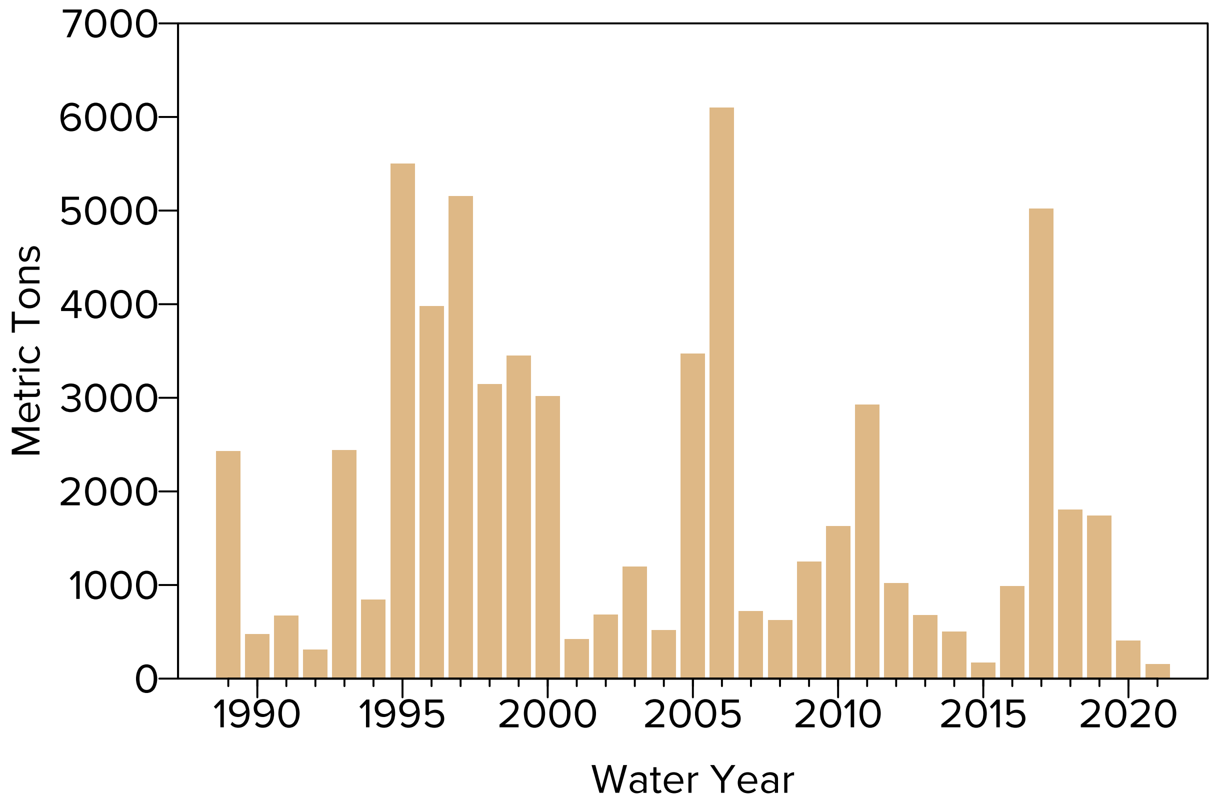
Soluble reactive phosphorus (SRP) is the fraction of total phosphorus immediately available for algal growth. As with nitrogen (Fig. 9.3), the year-to-year variation in estimated loads largely reflects the changes in precipitation. Low precipitation in 2021 resulted in a total phosphorus load of 0.62 MT and SRP load of 0.10 MT, the lowest values on record, likely due to the record low stream flows. These compare with the long-term averages of 3.1 and 0.47 MT respectively. Over the 32 years of record, the percentage of SRP to total phosphorus load has been in the range of 11–25 percent. Decreasing nutrient inputs are 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 (MT) = 2,205 pounds.). Data source: TERC and U.S. Geological Survey stream monitoring.



Suspended sediment contribution by Upper Truckee River

Yearly since 1989

The load of total suspended sediment delivered to the lake by the Upper Truckee River is related to landscape condition and erosion as well as to precipitation and stream flow. 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 (in the size range of 1–5 microns in diameter) from urbanized areas. By contrast, efforts to restore natural stream function, watershed condition, and restoration of habitat for plants and wildlife, focus on reducing loads of total sediment regardless of size. In 2021, the estimated suspended sediment load from the Upper Truckee River was 153 MT. The highest load ever recorded was 6,100 MT in 2006. The average annual load is 1,922 MT. (One metric ton (MT) = 2,205 pounds.). Data source: TERC and U.S. Geological survey stream monitoring.



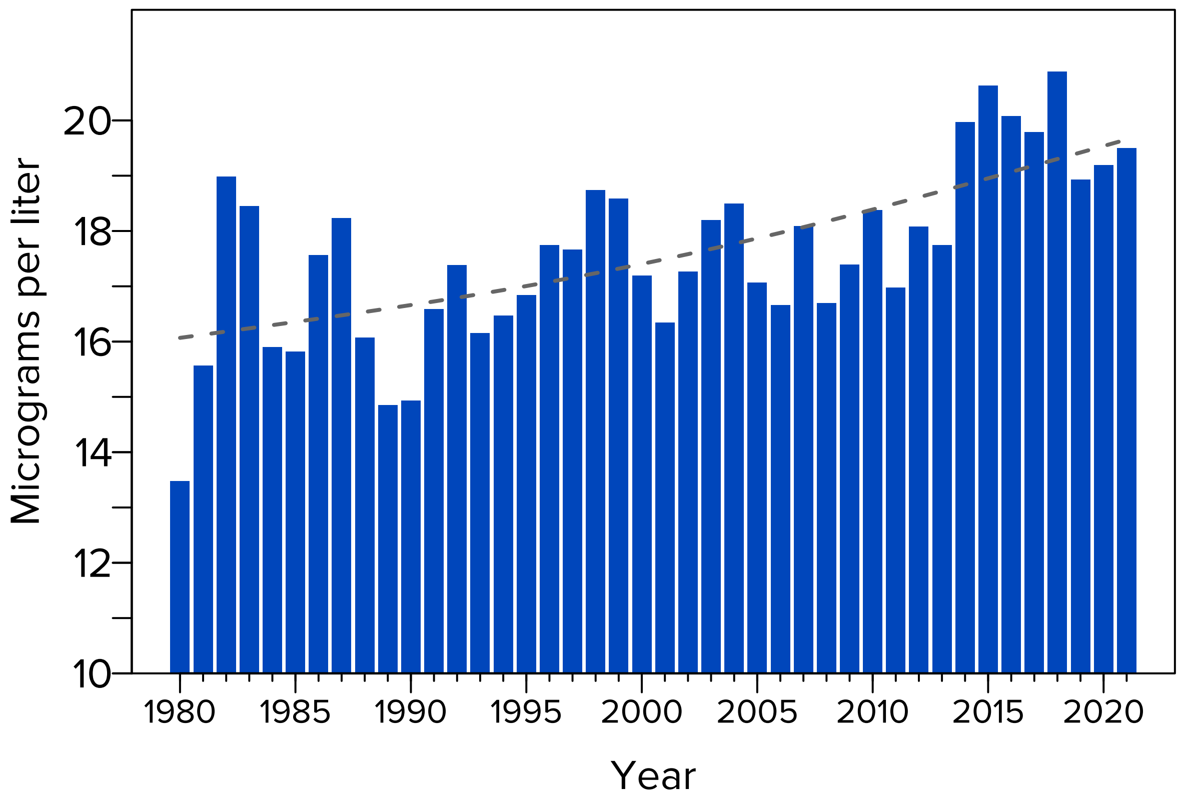
Lake nitrate concentration

Yearly since 1980

Until 2012, the volume-weighted annual average concentration of nitrate-nitrogen had remained relatively constant year-to-year, ranging between 13–19 micrograms per liter. Since that time, however, the lake's nitrate concentration has been increasing, as evident in the trend line produced with a Generalized Additive Model. In 2021, the volume-weighted annual average concentration of nitrate-nitrogen was 19.5 micrograms per liter. In 2019, lake nitrate concentration declined due to the deep mixing that redistributed the nitrate built up at the bottom of lake for the previous eight years and made it available for algal uptake. In 2021, with only shallow mixing, nitrate has recommenced accumulating, resulting in an increase in lake nitrate concentration.

Another factor in the last several years is the additional atmospheric nutrient loading due to wildfire smoke engulfing the region. The impact of the 2021 wildfires is the subject of an ongoing study. Water samples are taken at the Mid-lake station at 13 depths from the surface to 1,480 feet.

Data source: TERC lake monitoring.



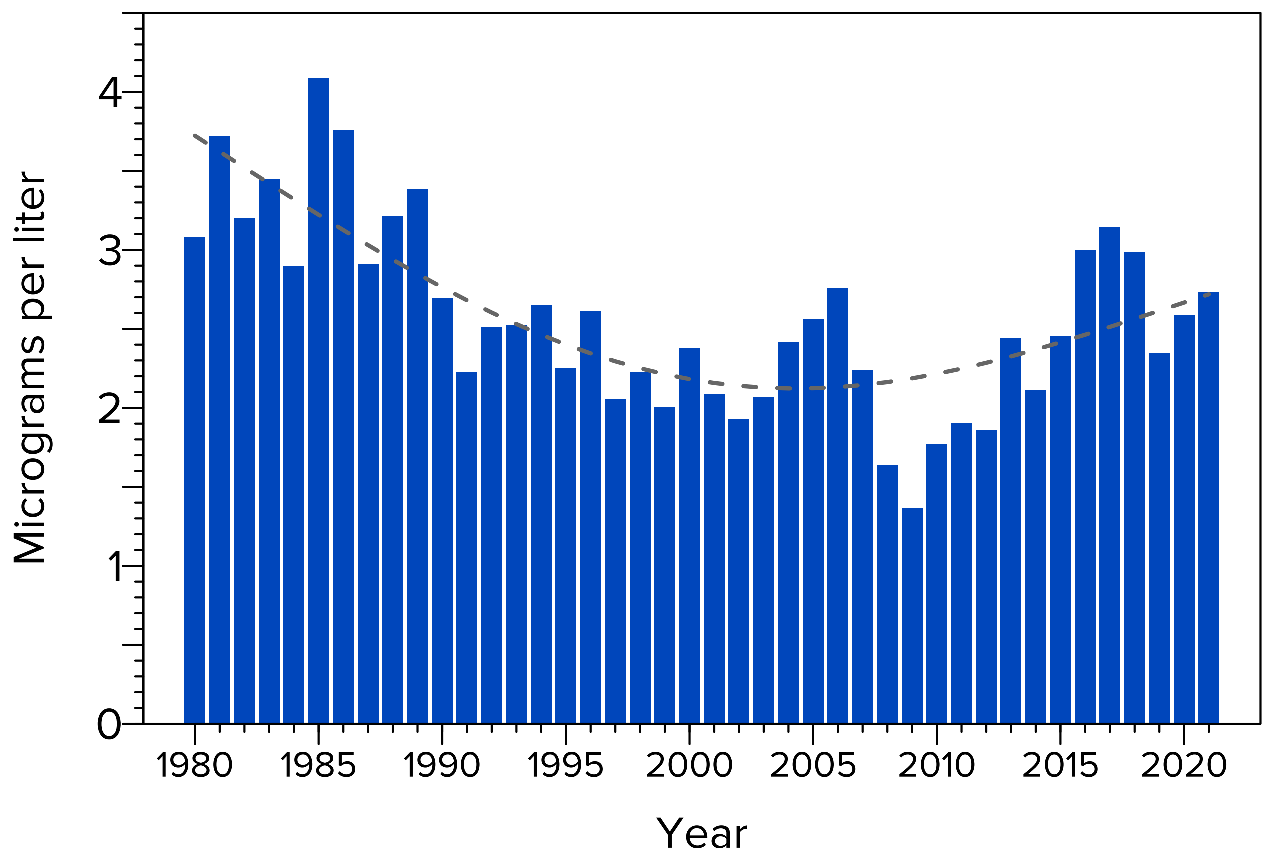
Lake total hydrolyzable phosphorus concentration

Yearly since 1980

Phosphorus naturally occurs in Tahoe Basin soils and enters the lake from soil disturbance and erosion. Total hydrolysable phosphorus (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 declined, although in the last 17 years the values have been increasing. In 2021, the volume-weighted annual average concentration of THP was 2.73 micrograms per liter. Another factor in the last several years is the additional atmospheric nutrient loading due to wildfire smoke engulfing the region. The impact of the 2021 wildfires is the subject of an ongoing study. Water samples are taken at the Mid-lake station at 13 depths from the surface to 1,480 feet.

Data source: TERC lake monitoring.



Lake fine particle concentration

Yearly since 2009

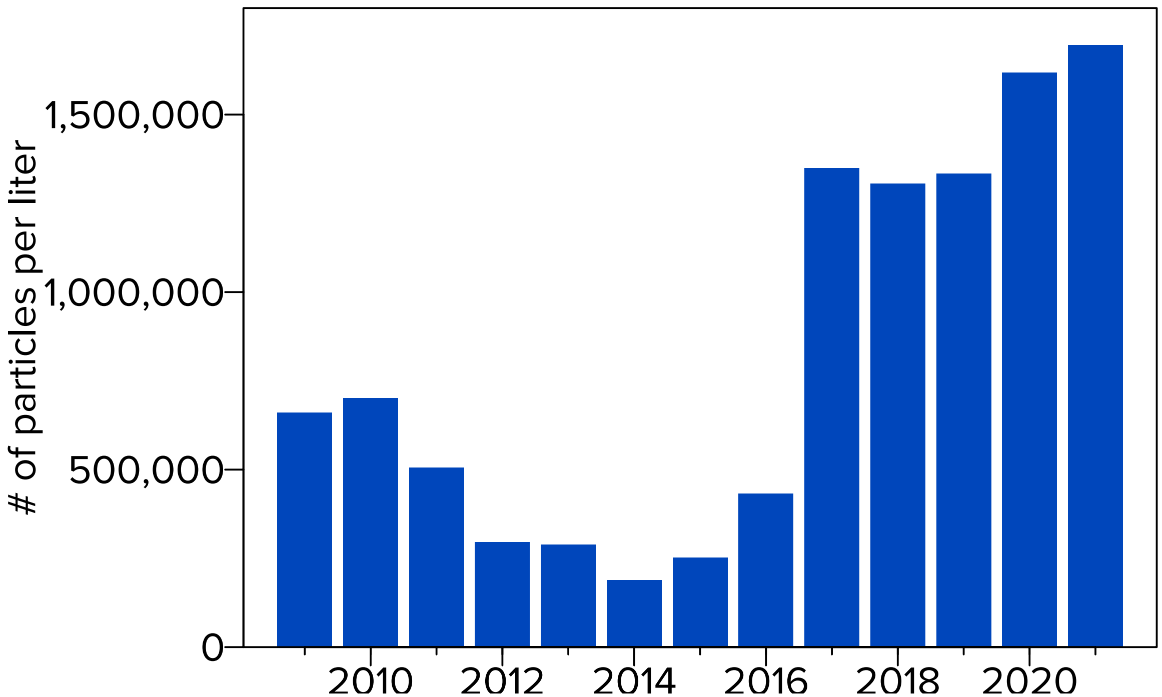
Fine particles in the size range of approximately 1–4 microns are principally responsible for the attenuation of visible light and the consequent loss of lake clarity. As particles in this size range settle slowly, their removal from the lake depends in large part on their aggregation into larger particles. The settling rate of a particle depends on the square of its diameter, so larger, aggregated particles will settle disproportionately faster.

In 2017, a historically wet year, there was a large increase in fine particles delivered to Lake Tahoe from the streams in the watershed. This would account for the steep change in concentration evident between 2016 and 2017. What is harder to explain is the continued high average concentration since that time. The last two years, both of which were low precipitation years, displayed an increase in particle concentration beyond the 2017 level.

In 2021, the mean particle concentration was the highest ever observed. Particles from wildfires in 2021 may be considered a potential source of the additional particles, although the peak of in-lake particles occurred prior to the peak in atmospheric particles. A preliminary analysis comparing rates of aggregation of lake particles, suggests that aggregation rates have not changed significantly over the period of the record.

Water samples are taken monthly at the MLTP (mid-lake) station at 13 depths from the surface to 1,480 feet.

Data source: TERC lake monitoring.



Nitrate distribution

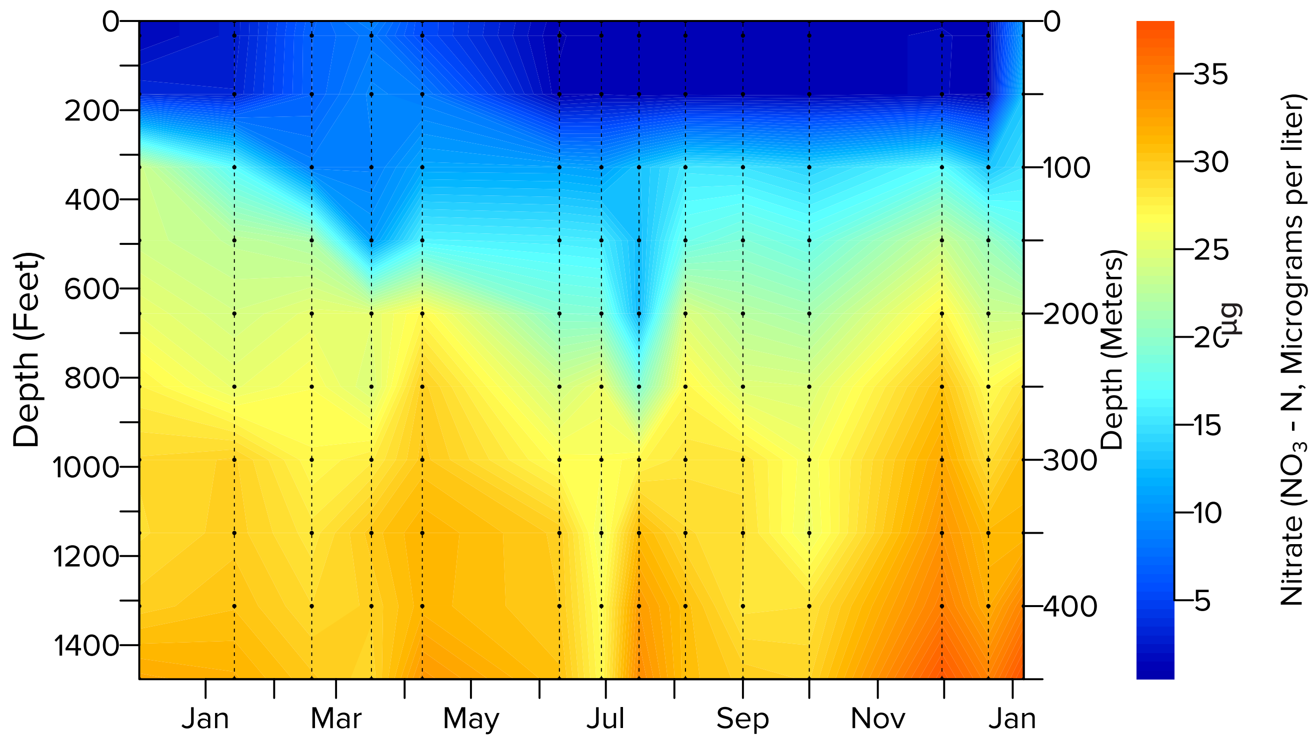
In 2021

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 persistence of the high nitrate region in the lower part of the lake. It is evident that the limited extent of deep mixing in 2021 did not homogenize the nitrate distribution. Instead, a “nitricline” is evident between depths of 300 and 600 feet throughout the year.

Although most of the introduced nitrate enters at the surface through atmospheric deposition, it is rapidly taken up by the algae and surface concentrations remain 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 use these nutrients.

Data source: TERC lake monitoring.



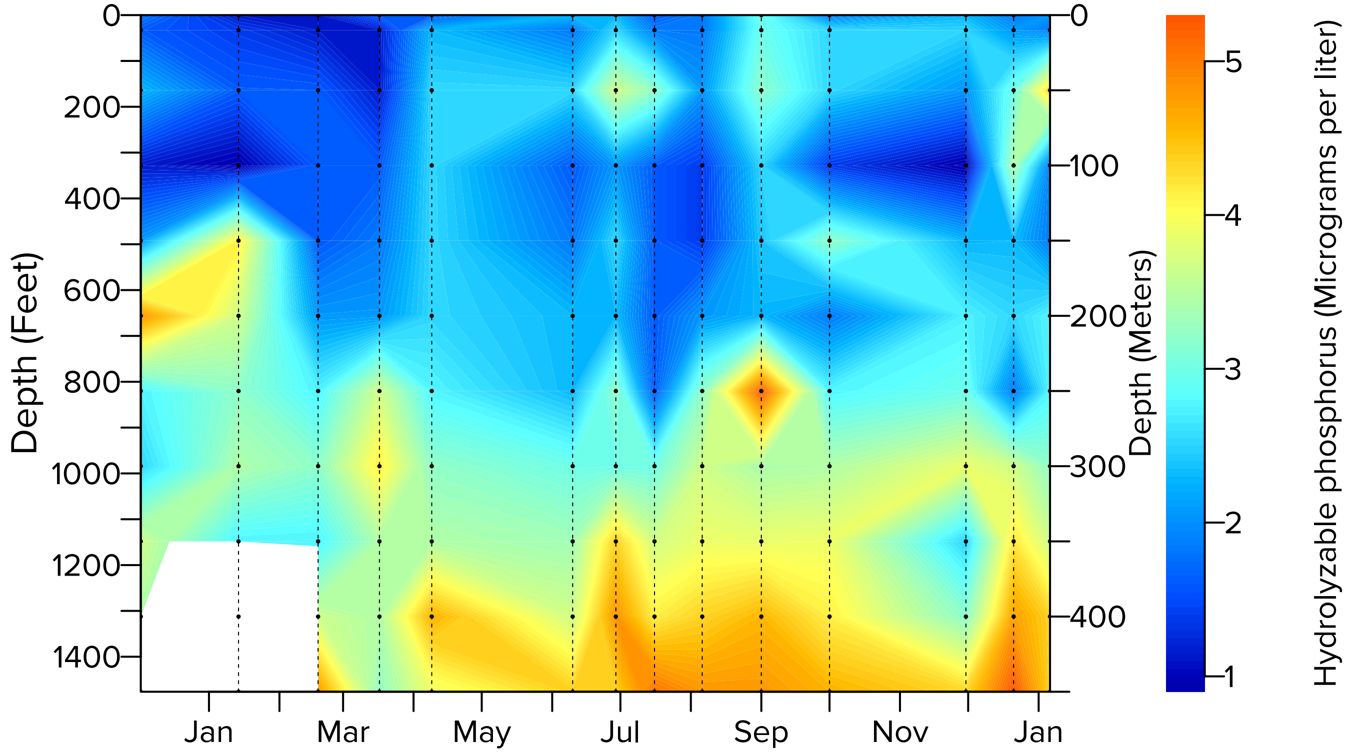
Total hydrolyzable phosphorus distribution

In 2021

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. These samples are analyzed in the TERC laboratory for nutrient concentrations. Here the total hydrolysable phosphorus (THP) concentration, the fraction of phosphorus that can be readily used by algae, is shown in the form of color contours. The white gap at the beginning of the year indicates the loss of the bottom two samples from the January sampling.

Phosphorus mainly entered the lake in association with fine particles during runoff events in April through June, however elevated surface levels in July through September may have been associated with atmospheric deposition associated with wildfire smoke. The relatively elevated values near the surface in spring and summer suggest that in 2021, nitrogen was the nutrient that limited algal growth, rather than phosphorus during that time. The elevated concentrations of phosphorus deep in the lake throughout the year were the result of the absence of deep mixing in 2021.

Data source: TERC lake monitoring.



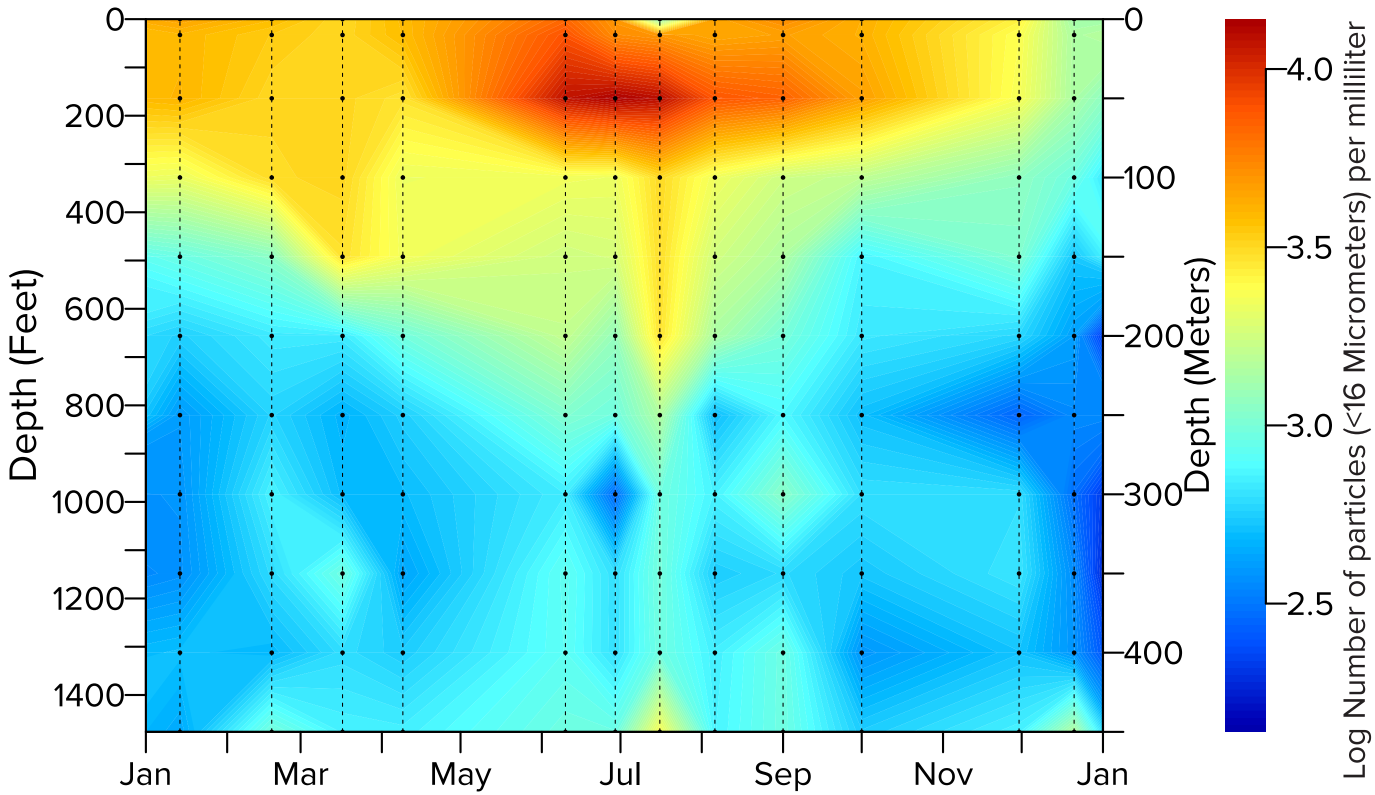
Fine particle distribution

In 2021

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 fine particles (in the size range of 1–4 microns) are shown in the form of color contours. Particles here can be both inorganic particles such as clay or silt or organic particles such as very small algal diatom particles.

Unlike the nutrients in Figs. 9.8 and 9.9, fine particles are in low concentrations deep in the lake throughout the year. The entry of particles in the upper part of the lake (above 300 ft) associated with spring snowmelt is evident in May through July. The extension of high concentrations near the surface through September may be associated with wildfire smoke. The particles do not decrease in the upper layer as quickly as nitrogen or phosphorus, as they are not taken up by algal growth. The fine inorganic particles gradually clump together (aggregate) which allows them to more rapidly settle to the lake bottom.

Data source: TERC lake monitoring.



TAHOE:
STATE OF THE LAKE
REPORT
2022

BIOLOGY

UC DAVIS
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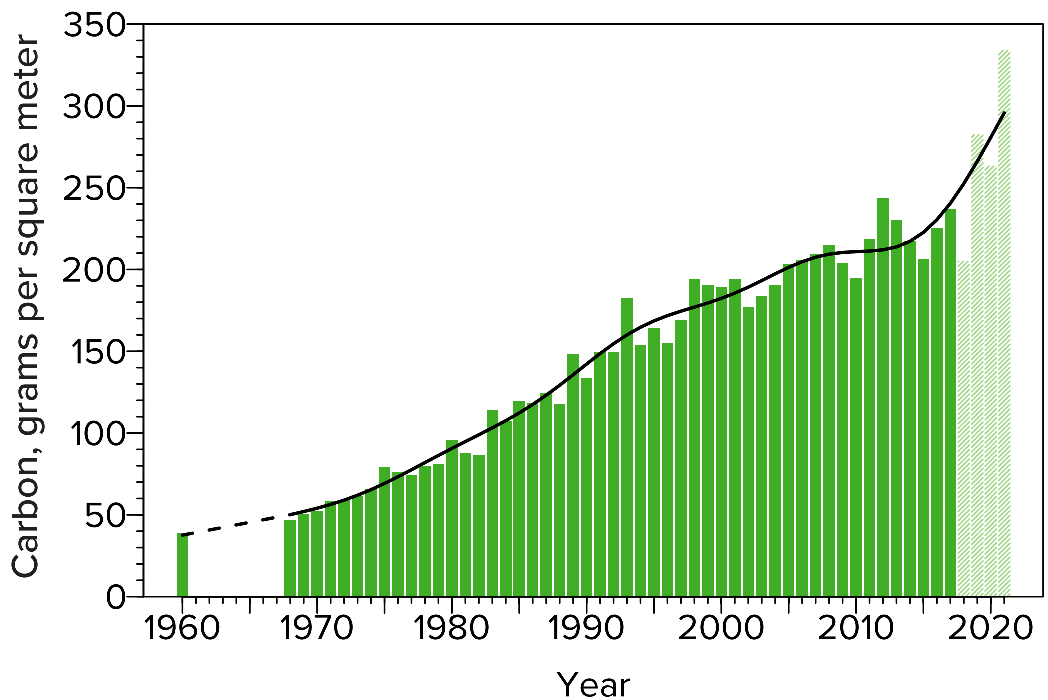
Algae growth (primary productivity)

Yearly since 1959

Primary productivity is a measure of the rate at which algae produce biomass (carbon) 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 that primary productivity has increased substantially over time. Data since 2018 are considered "provisional" due to changes in instrumentation and methodology that are under review.

As plotted, the data show that there has been a six-fold increase in primary productivity over the last 50 years. In 2021, primary productivity attained an all-time high annual value of 334 mg of carbon per m^2, an increase of 20 percent over the previous highest year in 2019. In 2021, the measured primary productivity was a maximum in April at a depth of 30 m (100 ft). From July through December, the peak productivity was always above 20 m (66 ft). While significant uncertainties remain, the increase in primary productivity in 2021 is believed to be associated with a combination of environmental factors that favored the seasonal dominance of the pennate diatom *Synedra*, the major biomass contributor, and the filamentous cyanobacteria, *Leptolyngbya* sp. which was the most abundant species in this particular year.

Data source: TERC lake monitoring.

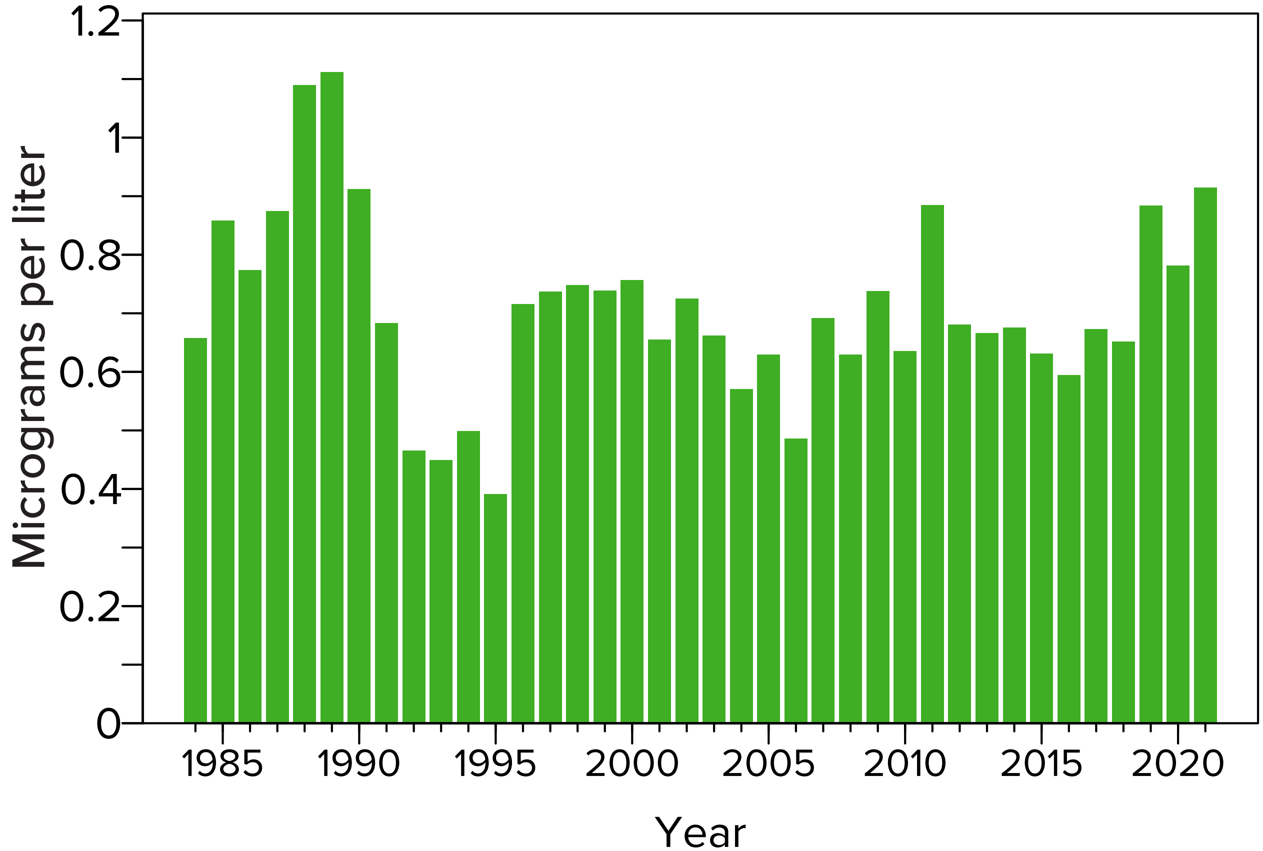


Phytoplankton chlorophyll

Yearly since 1984

Phytoplankton (Algae) are the base of the Lake Tahoe food web and essential for lake health and the well-being of the entire ecosystem. One measure of 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 shown remarkable consistency over the last 25 years, and 2021 maintained this pattern. The average annual concentration for 2021 was 0.91 micrograms per liter. For the period of 1984–2021 the average annual chlorophyll-a concentration in Lake Tahoe was 0.71 micrograms per liter.

Data source: TERC lake monitoring.

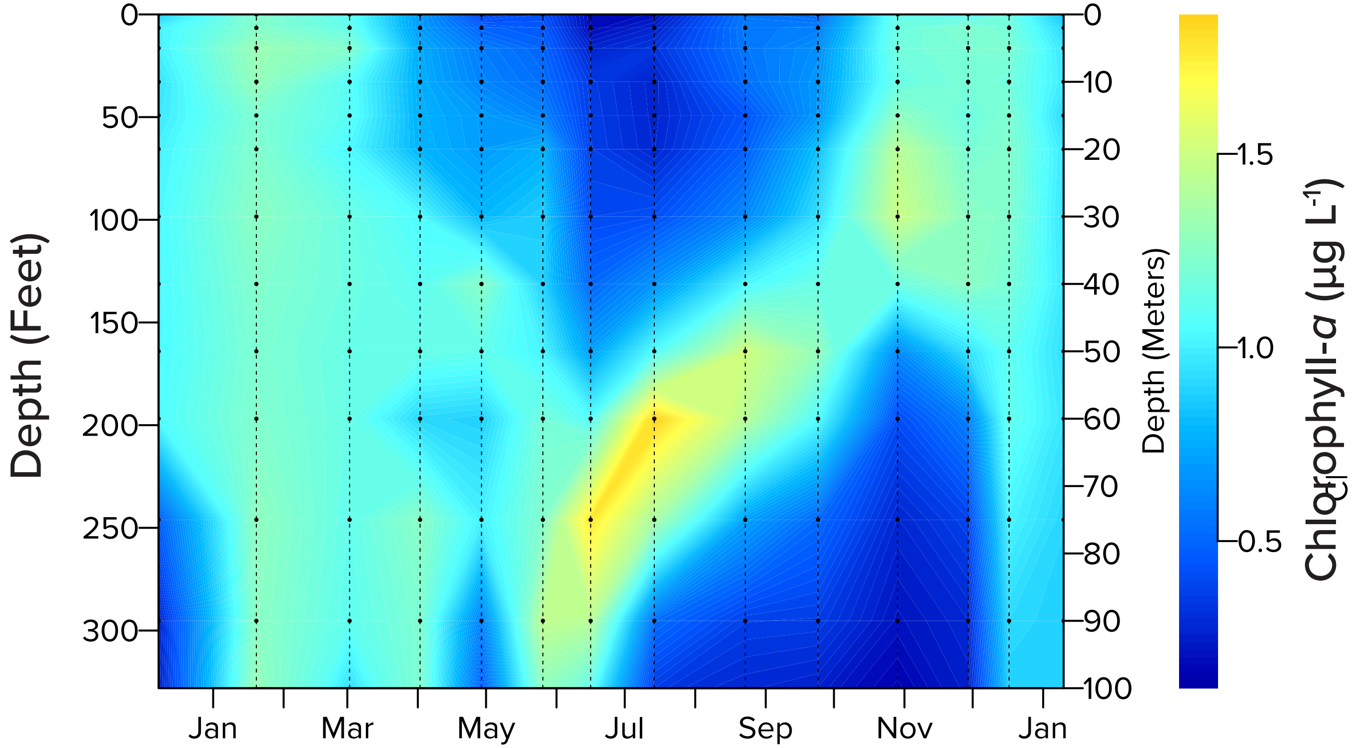


Chlorophyll-*a* distribution

In 2021

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 to a depth of 350 feet. Below this depth chlorophyll-a concentrations are near zero due to the absence of light. Lake Tahoe generally has a "deep chlorophyll maximum" (DCM) in the summer that occupies the range of 150–300 feet in the water column. In that depth range, the light and nutrient conditions are most favorable for algal growth.

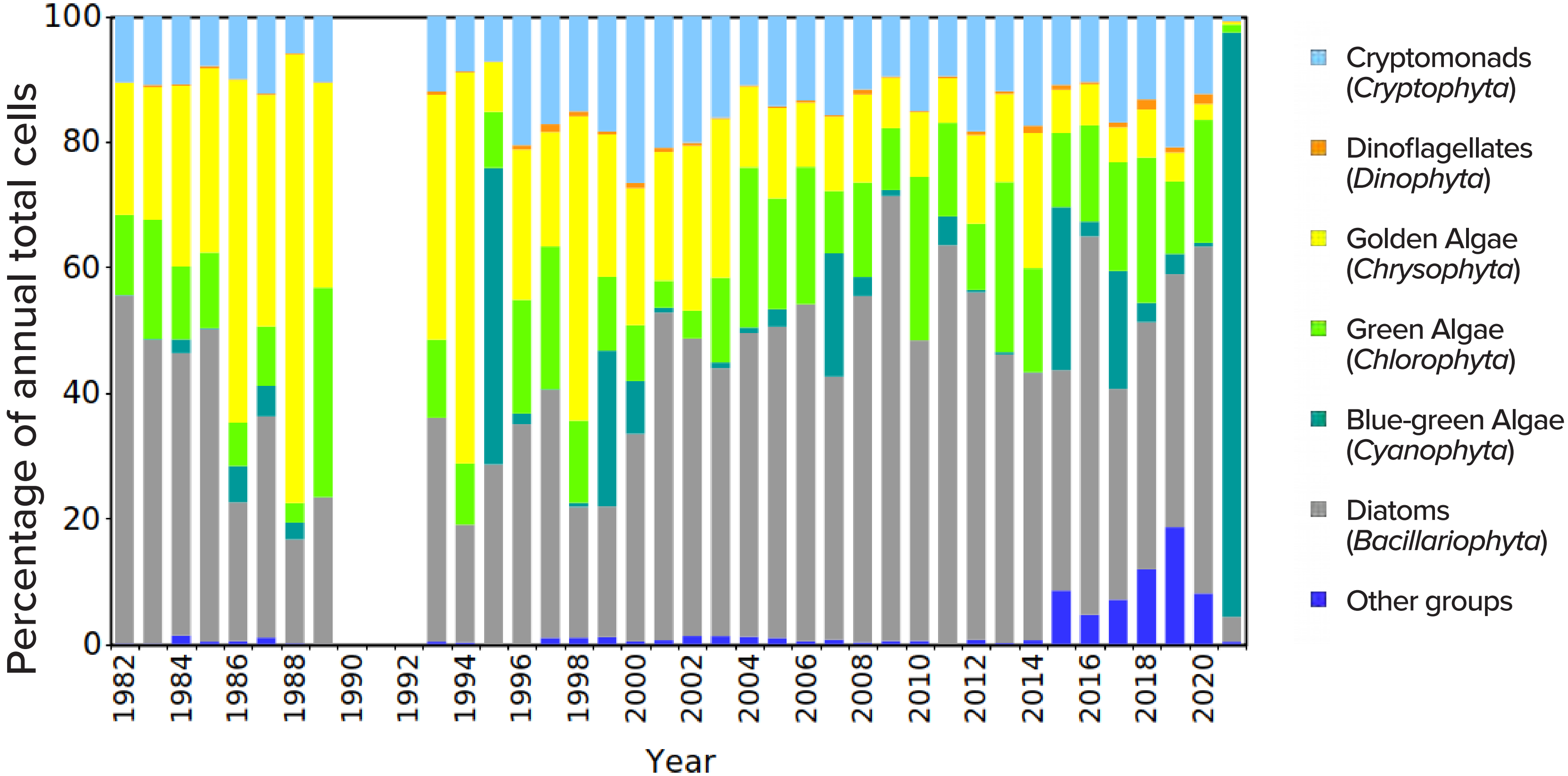
In 2021, this pattern changed significantly. The DCM started to form at 250 ft in June and July of 2021, but then progressively became shallower throughout the summer, until fall mixing in late November. This pattern is unlike any previous year. The cause of this change may be due in part to the reduction in sunlight and UV radiation that occurred due to wildfire smoke. Phytoplankton need sunlight to photosynthesize, so such an upward shift is not unexpected. There was also a major change in the relative abundance and species composition, with the emergence of the filamentous cyanobacteria *Leptolyngbya* sp., observed between September and December.



Annual distribution of algal groups

Yearly since 1982

There are six major taxonomic groups represented in the phytoplankton from Lake Tahoe. The total number of algal cells from different groups varies from year to year. Diatoms are generally the most common type of algae. In 2021, there was a major shift in the phytoplankton composition, with an abrupt increase in the abundance of the cyanobacteria *Leptolyngbya* sp. extending from September through the end of the year. This was the only year on record in which a single taxon belonging to the cyanobacteria group dominated the phytoplankton assemblage. *Leptolyngbya* is a simple filamentous genus that in Lake Tahoe includes an extremely narrow species, generally with cells 1–2 microns wide, which makes them important for clarity. Individual filaments display a visible sheath comprising of dozens of individual cells and can be over 200 microns in length.
Data source: TERC lake monitoring.

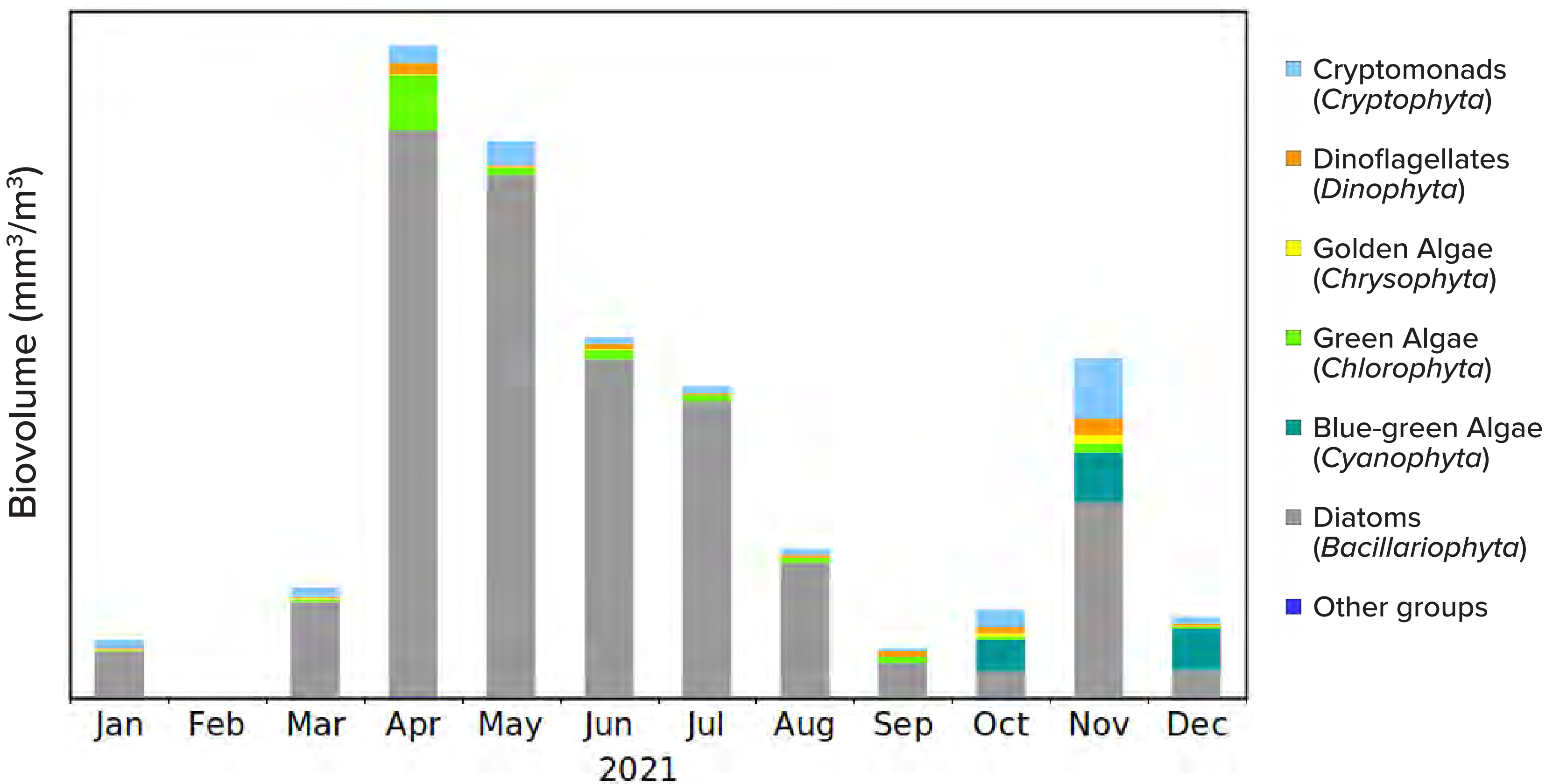


Algal groups as a fraction of total biovolume

Monthly in 2021

The total biovolume of different algal genera vary month to month as well as year to year. In 2021, despite the fact that cyanobacteria dominated algal abundance on the basis of the number of individual cells, diatoms again dominated the biovolume (proportional to the mass) of the phytoplankton community in every month. The peak in the monthly average biovolume occurred in April and May 2021. This "spring bloom" is a typical occurrence in Lake Tahoe and many other lakes. The peak biovolume in 2021 was over 1300 cubic millimeters per cubic meter, six times the usual peak biovolume. There was also a smaller "fall bloom" in November.

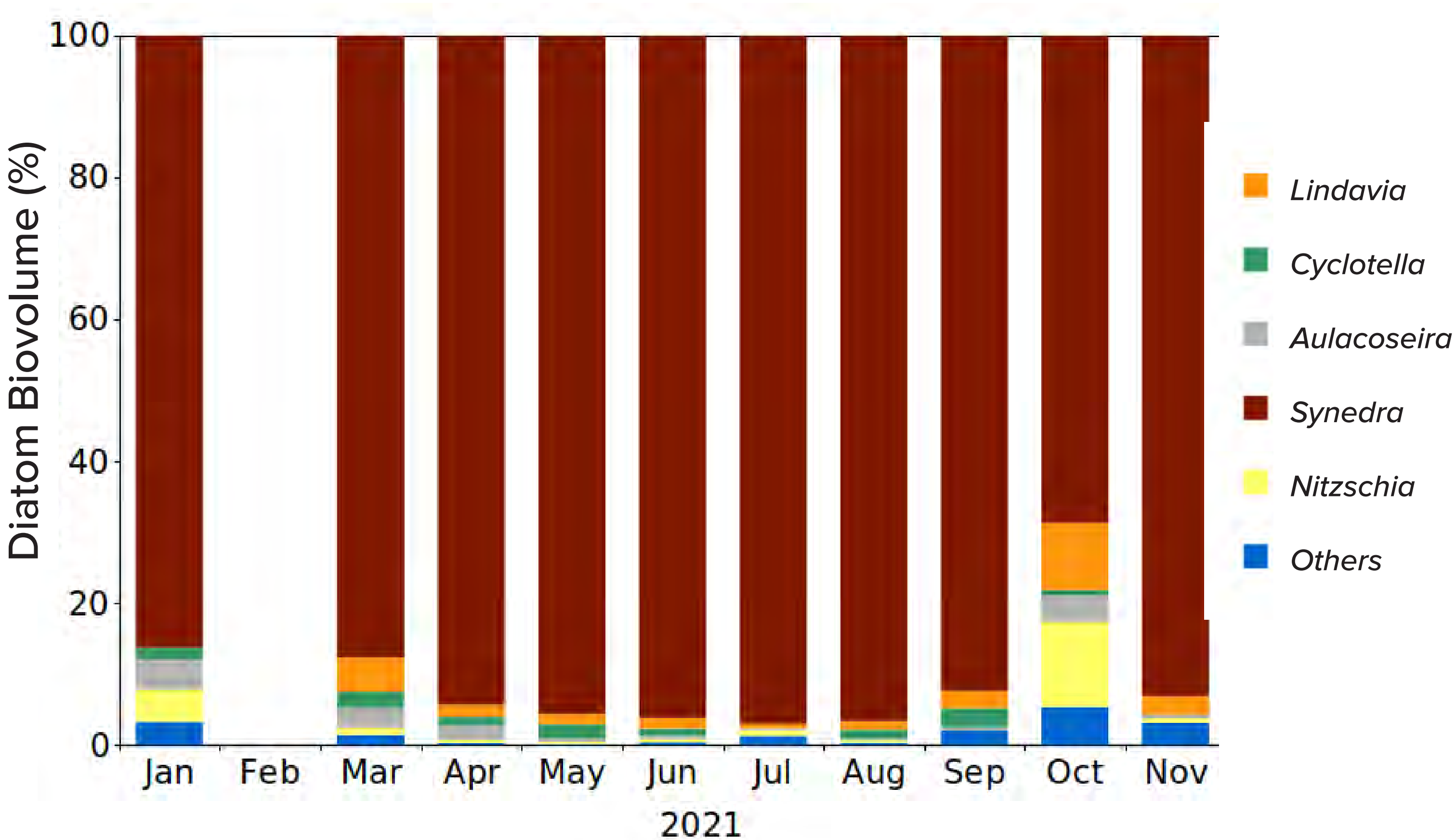
Data source: TERC lake monitoring.



Abundance of dominant diatom species

Monthly in 2021

Since regularly monitoring commenced in 1982, diatoms have been the dominant algal group at Lake Tahoe for all but a few years. Diatoms are unique in that they contain a cell wall made of silica, called a frustule. The dominant diatoms at Lake Tahoe in 2021 are shown below. Normally there are large variations in the relative composition by month. In 2021, *Synedra* was dominant in terms of biovolume, forming over 80 percent of the diatom biovolume during every month except October. Although *Cyclotella* was a relatively low fraction of the percentage of biovolume of diatoms in 2021, this was a year in which the total algal biovolume was exceptionally high.
Data source: TERC lake monitoring.

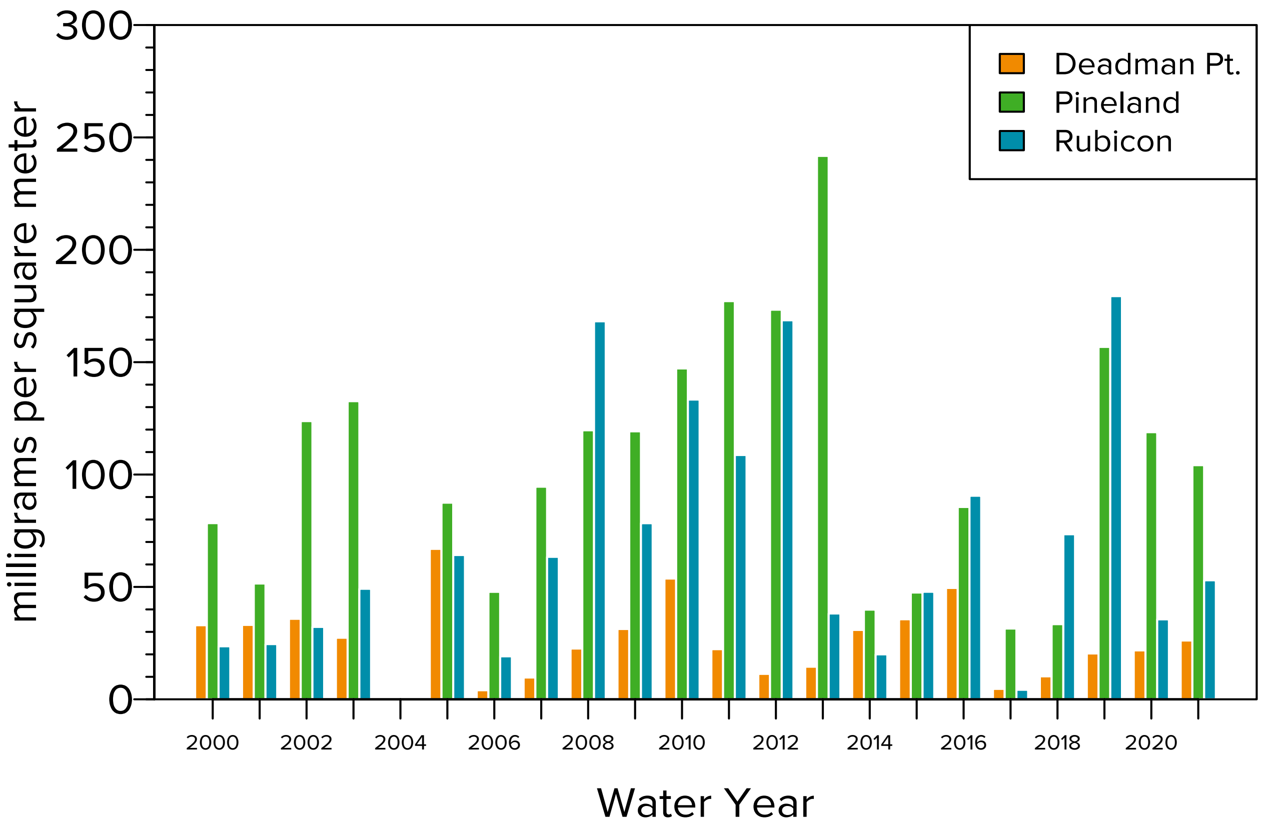


Peak shoreline algae concentrations

Yearly since 2000

Periphyton, or attached algae, makes rocks around the shoreline of Lake Tahoe green and slimy, or they sometimes form a very plush white carpet after being sun-bleached. This graph shows the maximum biomass measured at 1.5 feet (0.5 m) below the surface at three sites from January to June. In 2021, concentrations at the Deadman Pt. and Pineland sites were very close to their long-term average, while Rubicon was 26 percent lower than the long-term average. Monitoring periphyton is an important indicator of near-shore health. In the last four years, TERC has been using whole-lake aerial to better represent the spatial extent of periphyton blooms. See Figure 6.11 for more details.

Data source: TERC lake monitoring.



Shoreline algae distribution

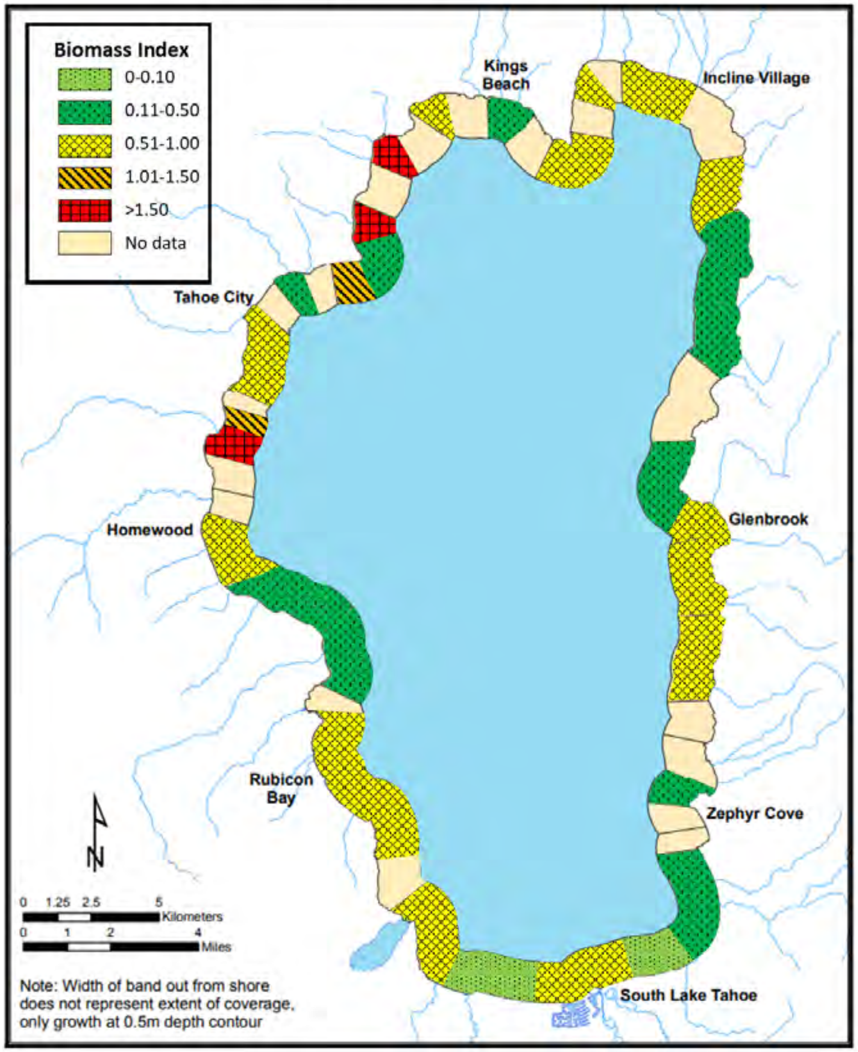
In 2021

Periphyton biomass was surveyed around the lake over a three-week period during the spring of 2021, when it was estimated to be at its annual maximum. Over 50 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 assess levels of periphyton. 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. There were fewer sites with a high PBI in 2021 than the previous year. The majority of the high PBI sites were on the California side. Compared to previous years, this is considered a near-average year. Most of the east shore had relatively low growth. This is in part a reflection of the high wave activity that causes the periphyton to slough, as well as generally lower amounts of precipitation and runoff along the east shore.

Data source: TERC lake monitoring.

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 2021



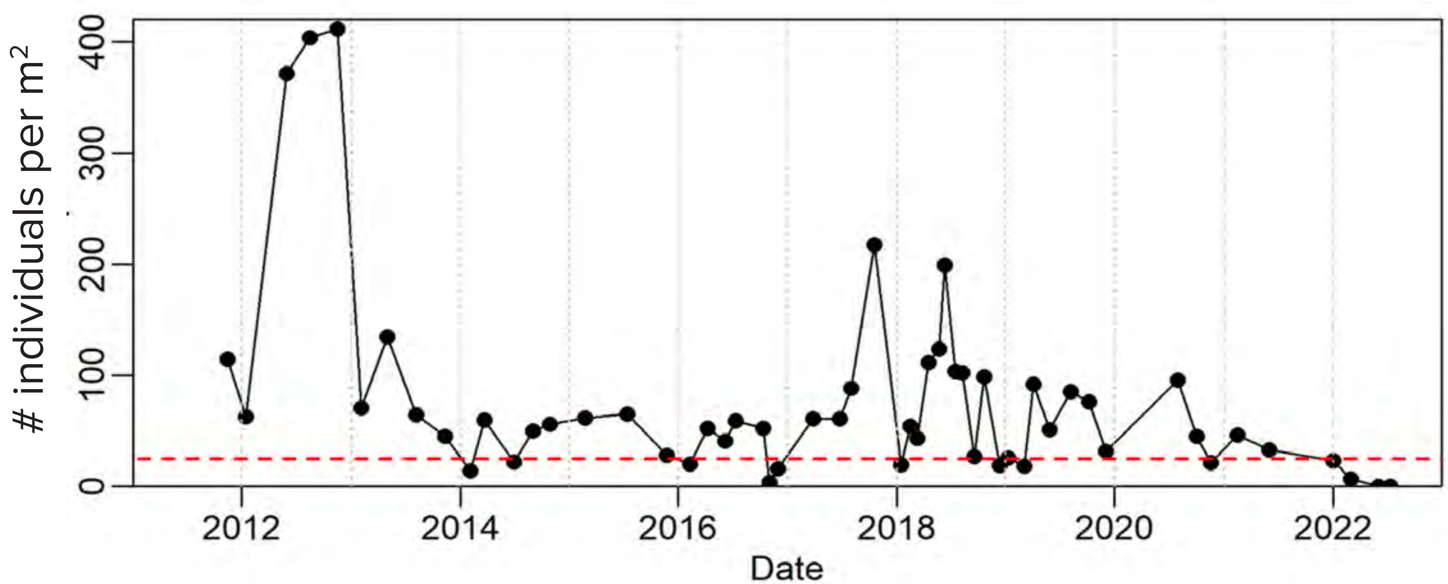
Mysis population

Since 2012

Mysis shrimp were introduced to Lake Tahoe in the 1960s in an attempt to improve the size of game fish in the lake. The intended result did not occur and instead the *Mysis* upset the existing lake food web. Within four years of their introduction, they had decimated the populations of the native *Daphnia* and *Bosmina*. Since that time, these zooplankton are rarely observed. *Daphnia* and *Bosmina* were once an important food source for native minnows, which in turn provided food for kokanee salmon and rainbow trout.

Research on *Mysis* essentially stopped in the 1980s. Since 2012, regular surveys have recommenced in Lake Tahoe and in Emerald Bay, albeit at a minimal scale, funded by philanthropic gifts. Because *Mysis* migrate to the lake bottom during the day, sampling occurs at night. The sampling net is pulled vertically in Lake Tahoe at 3-month intervals from three sites: South Shore Deep (200 m), LTP Index (100 m) and MLTP (200 m). Since early 2022, sampling has increased to monthly intervals

The *Mysis* densities (number of individuals collected divided by the net opening area) in Lake Tahoe show large variability. The red dashed line at 27 individuals per m^2 represents the *Mysis* population level below which *Daphnia* and *Bosmina* can reestablish. During 2021, values were slightly above that threshold. In 2022, however, the numbers have fallen far below that threshold and are currently in single digits. As *Mysis* in Lake Tahoe generally exhibit three to four year classes, the absence of all classes suggest that it may take several years for the Mysis population to rebuild. It is expected that *Daphnia* and *Bosmina* will return in 2023, potentially bringing a significant increase in lake clarity.



TAHOE: STATE OF THE LAKE REPORT 2022

CLARITY

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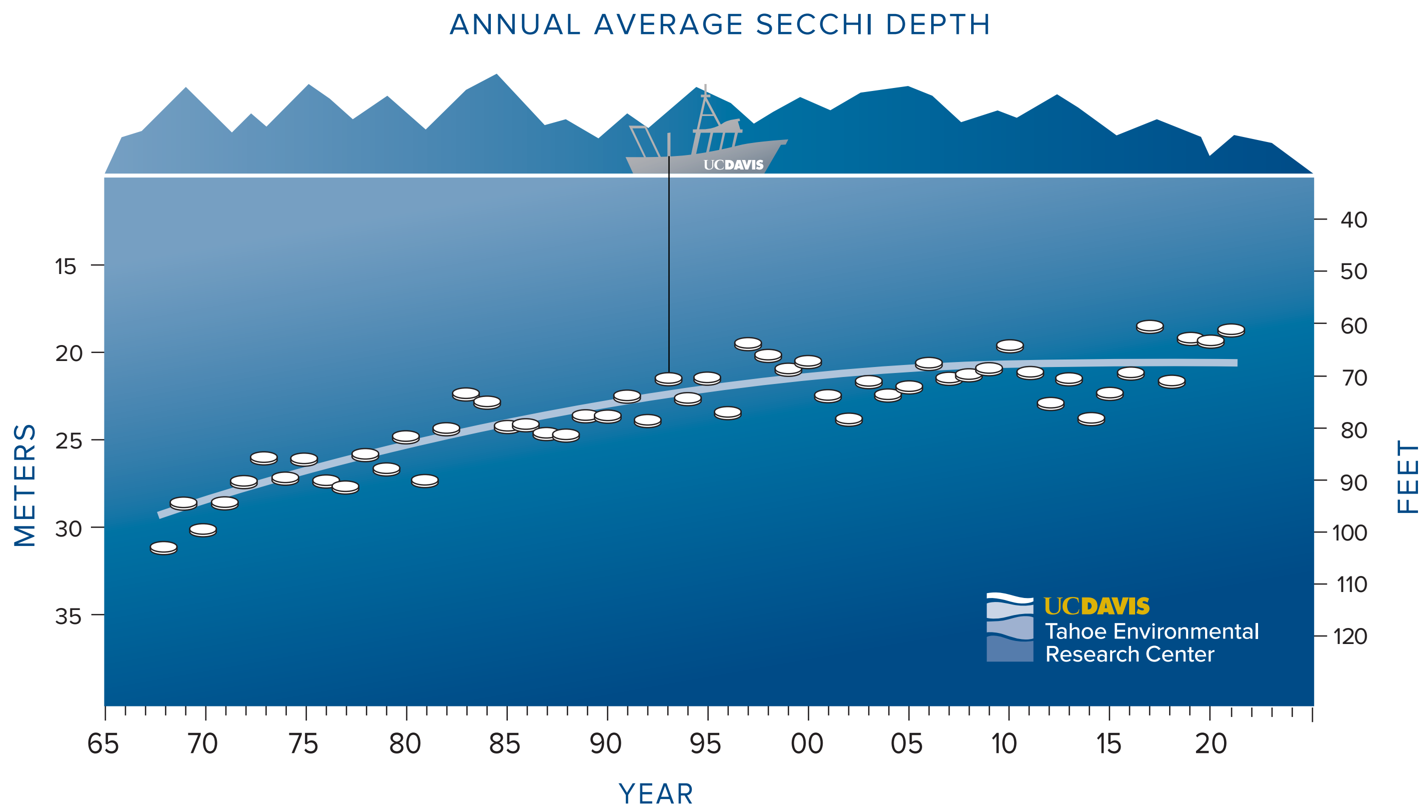
Annual average Secchi depth

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 2021, the annual average Secchi depth was 61.0 feet (18.6 m), little changed from the previous year and was reflective of the near-constant values that have been attained over the last 20 years. The greatest individual value recorded in 2021 was only 79.6 feet (24.2 m) on February 12. The lack of complete vertical mixing of the lake in 2021 is a major reason for this low maximum clarity value. The worst clarity reading was 45.9 feet (14.0 m) on May 26. The clarity in 2021 was the result of a combination of factors including the absence of deep mixing of the lake and the impact of lake stratification. The clarity restoration target of an annual Secchi depth of 97.4 feet (29.7 m) set by federal and state regulators, is a goal that agencies and the Tahoe Basin community continue to work toward.

Data source: TERC lake monitoring.



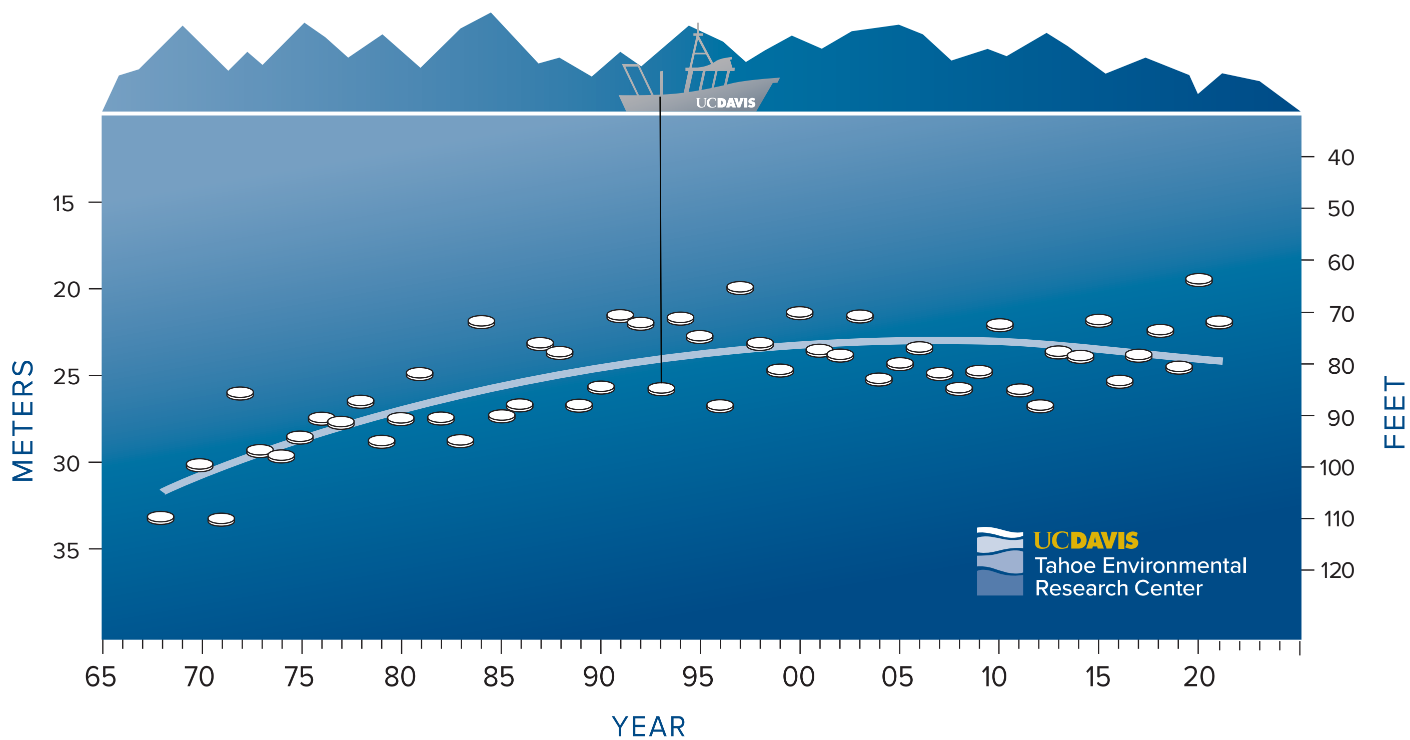
Winter Secchi depth

Yearly since 1968

Average winter Secchi depth was 71.9 feet (21.9 m), based on seven readings between December 2020 and March 2021. Winter precipitation was far below the long-term average and such conditions would typically be expected to yield higher clarity values. The reasons for the low values are still not fully understood.

Data source: TERC lake monitoring.

WINTER AVERAGE SECCHI DEPTH

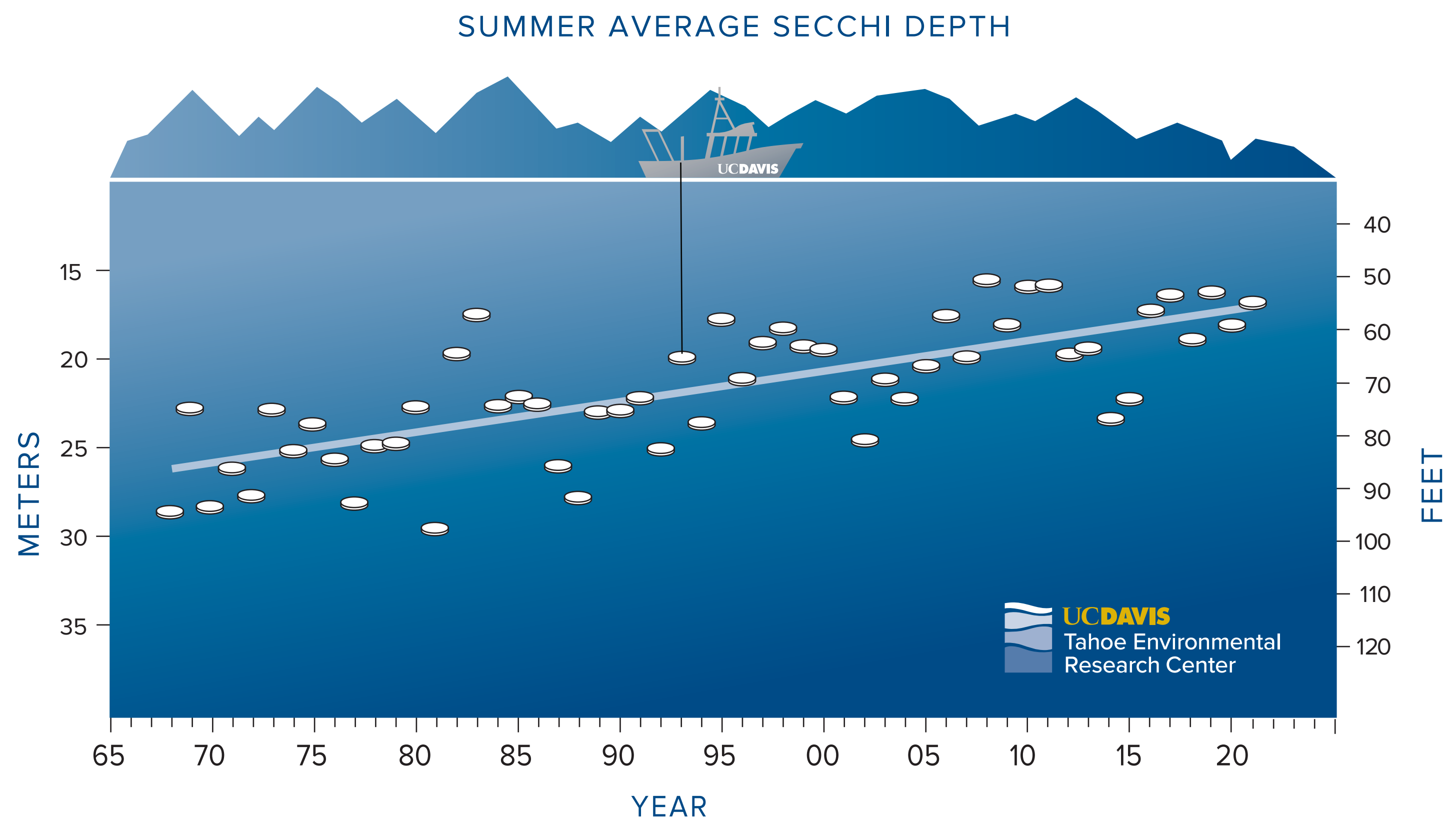


Summer Secchi depth

Yearly since 1968

Summer (June–September) clarity in Lake Tahoe in 2021 was 54.8 feet (16.7 m), a decrease of over 4 feet from the previous year. This is significantly above the lowest summer value of 50.5 feet in 2008. Summer is typically the season of poorest clarity. The long-term summer trend is dominated by consistent degradation. In the past two decades, scientists have observed a divergence in winter and summer clarity. In the winter months, lake clarity has not decreased significantly while in summer, clarity continues to decline. The cause of this divergence is currently under review, but factors related to changing lake stratification and food web changes are believed to play important roles.

Data source: TERC lake monitoring.

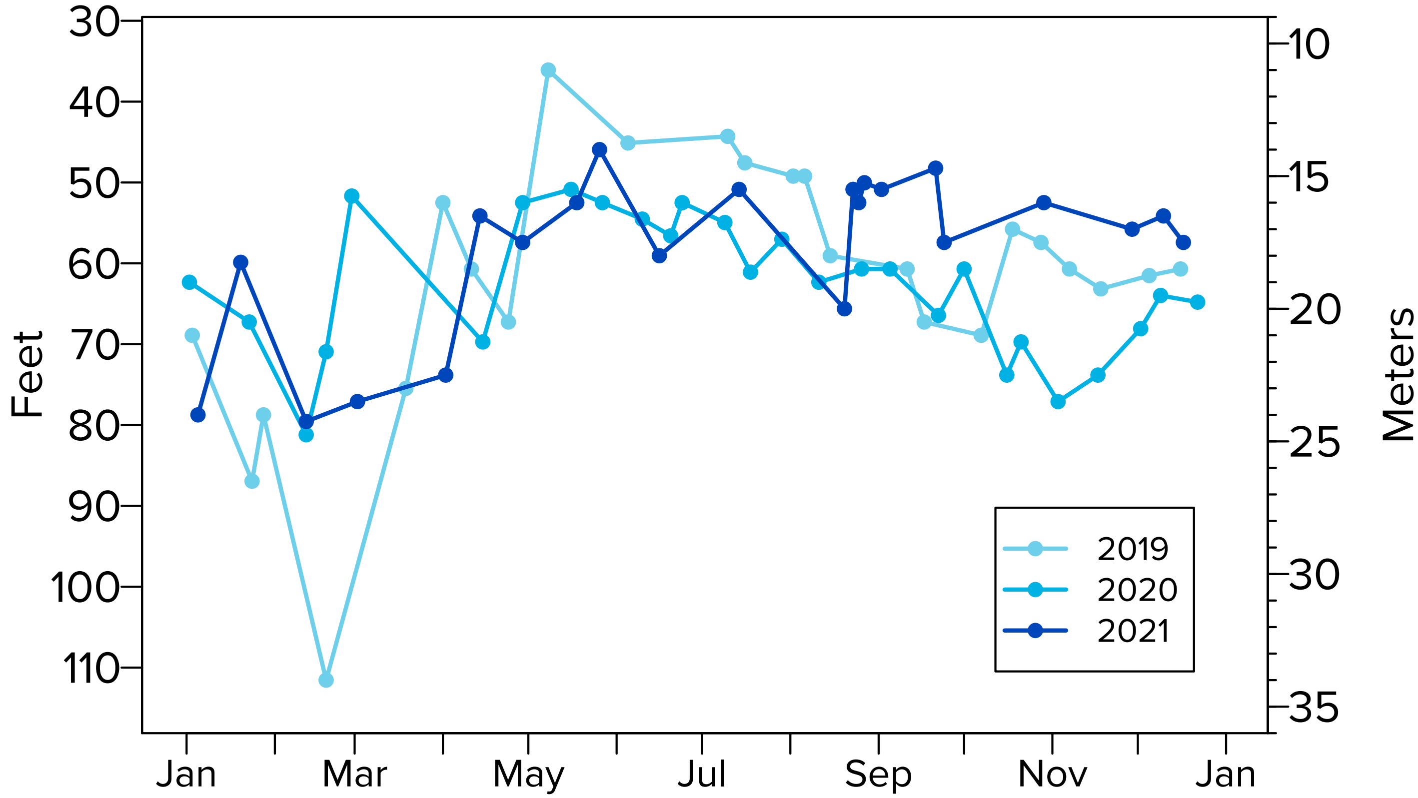


Individual Secchi depths

2019, 2020, 2021

Here, the individual Secchi depth readings from the Index station on the west side of the lake for 2019, 2020, and 2021 are plotted. Secchi values can be seen to sometimes vary considerably over short time intervals. This figure clearly shows that for the first eight months of the year, the 2021 values generally fell into the range of the 2019 and 2020 values. However, for the last four months of the year, Secchi depth values were consistently below the values of the previous two years. This is likely in part due to the effects of the wildfire smoke in the basin during this period.

Data source: TERC lake monitoring.



TAHOE:
STATE
OF THE
LAKE
REPORT
2022

EDUCATION AND OUTREACH

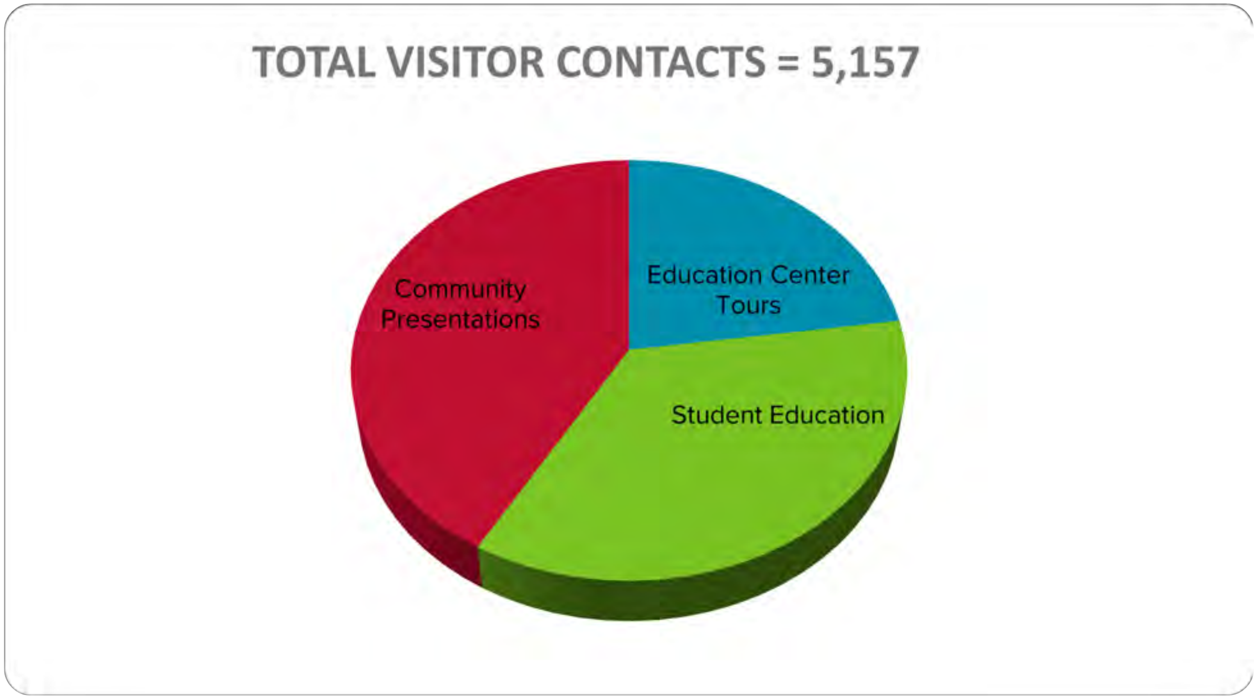
Education and outreach

In 2021

Achieving healthy aquatic and terrestrial ecosystem conditions requires education and outreach to provide science-based information to people of all ages and backgrounds and to foster responsible action and stewardship.

In 2021, TERC interacted with 5,157 visitors through tours, field trips, and lectures. The TERC education team engaged 1,865 students during 86 field trip sessions (some in-person and some virtual) teaching about Lake Tahoe, the aquatic food web, forest health, and climate change. TERC also continued educating the public through online lectures, community presentations, and in-person outdoor programming. In 2021, we hosted 9 lectures with a total of 790 attendees bringing science-rich content to the community. This represented a 60% increase over the previous year at the Tahoe Science Center as we began the transition back to in-person programming.

The TERC Education Team completed the American Alliance of Museums "Museum Assessment Program" for Education and Interpretation as part of our commitment to striving for excellence and meeting standards and best practices in the museum field.



Educational exhibits

Plans for 2022

In 2022, the Tahoe Science Center will install new video exhibits to educate the public and provide updated information about the important science at Lake Tahoe. There will be three new videos on the research vessel exhibit and four new videos on the laboratory exhibit.

A new Underwater Lake Tahoe exhibit will open in 2022 with a mural painted by local artist Susie Alexander. This lounge area will allow visitors to enter the underwater Lake Tahoe environment and discover the various organisms and habitats. Additional elements will include activities, videos from our Underwater Research YouTube playlist, and augmented reality features.

During the winter, TERC partnered with Palisades Tahoe and Protect Our Winters to target skiers and snowboarders to increase action to combat the negative effects of climate change to Lake Tahoe's snowpack with the Save Our Snow (https://tahoe.ucdavis.edu/saveoursnow) educational campaign. This project includes two Instagram filters, a carbon reduction calculator, and a pledge to reduce emissions program.

All programs and outreach efforts aim to increase engagement with residents and visitors. Our goal is to expand the public's awareness, knowledge, and understanding of environmental issues at Lake Tahoe. This increased understanding of the importance of science and research for providing solutions to these challenges will help us to meet those challenges locally and globally.

New docent Brooke Ahmed uses updated Tahoe Science Center videos to teach visitors about the geologic history, environmental issues, and the current research being conducted by UC Davis.
Photo: A. Toy

Muralist Susie Alexander in front of the Underwater Lake Tahoe mural, the latest exhibit installment to the Tahoe Science Center slated for Augmented Reality enhancements in 2022.
Photo: H. Segale

Program Manager Alison Toy and AmeriCorps members Jesse Landesman and Noah Shapiro spend Earth Day discussing ways to reduce individual carbon emissions by 1 ton per year, culminated by choosing the grand prize winner for a Palisades Tahoe season pass.
Photo: H. Segale