TAHOE: STATE OF THE LAKE REPORT 2019

CURRENT DIRECTIONS

UC DAVIS
Tahoe Environmental
Research Center

Current Research Synthesis

Since 1959, UC Davis has been engaged in monitoring the status and health of Lake Tahoe and its watershed. That trove of monitoring data is an invaluable resource for assessing the impact of changes that have occurred due to anthropogenic factors and to natural variability.

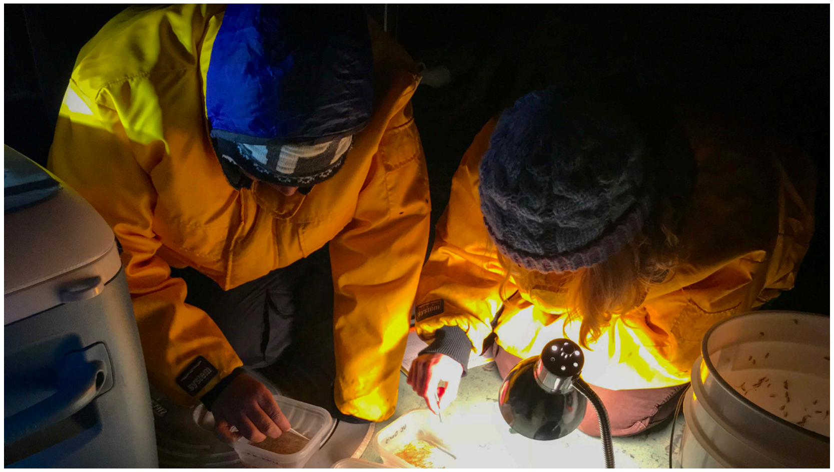
Additionally, we engage in shorter-term research that seek to answer specific questions or to gain understanding of processes and events. This research relies on the long-term monitoring data to provide a context, but it is very much separate. The results of this research – conducted by TERC's students, postdoctoral researchers, faculty, and staff, and often in collaboration with other institutions and colleagues – has made Lake Tahoe the smartest lake in the world, and arguably the most influential.

Photos: J. McInerney, K. Senft, and A. Toy

Current Research Synthesis, continued

This year, our current research synthesis covers a broad range of areas, much of it, the result of work conducted over the last five years. Some of the research is now complete and the results are starting to influence management and decision-making. Much of it is still underway or in its initial stages. The topics we are focusing on are:

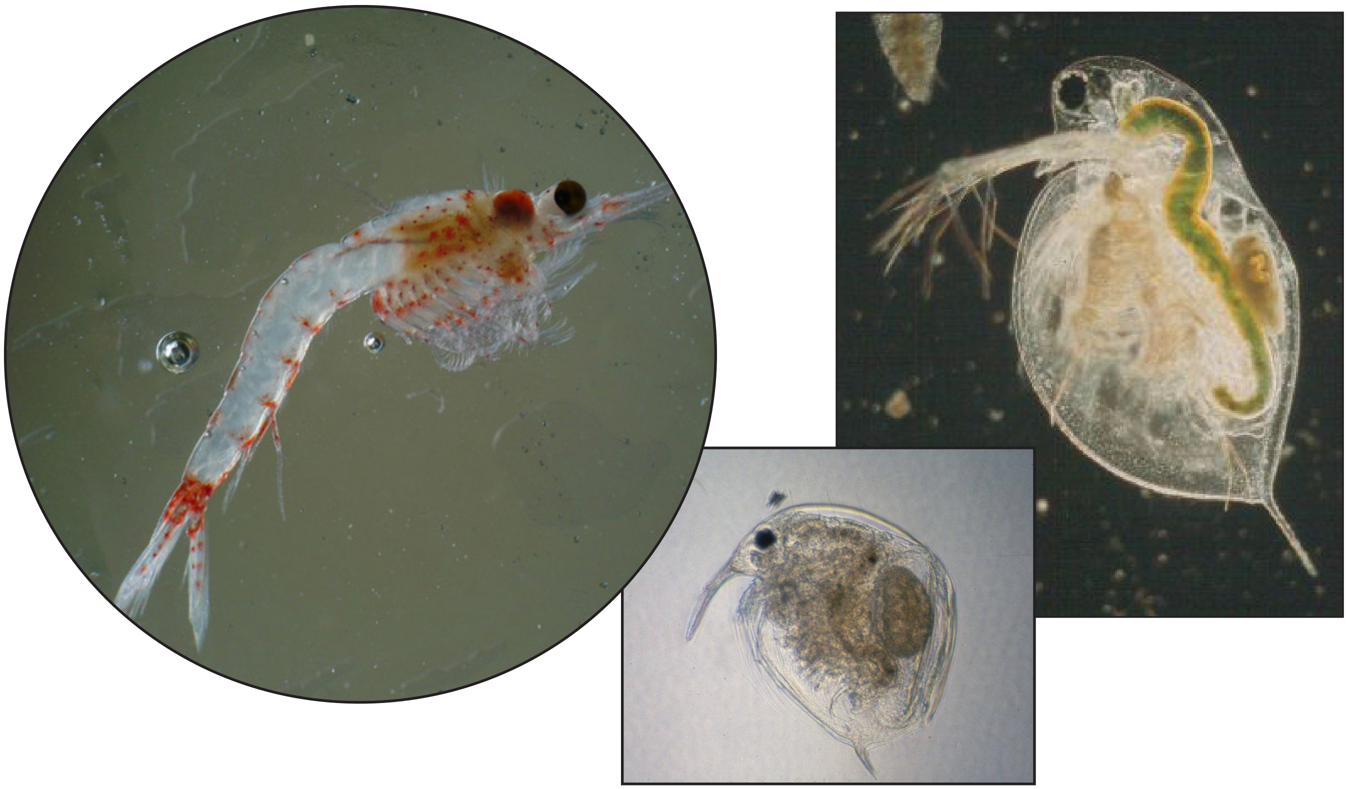
- Are there solutions for avoiding the impacts of climate change on the lake's clarity? Monitoring has shown that removing the introduced *Mysis* shrimp can rapidly restore clarity and could climate-proof it against future changes.
- The future climate of the Tahoe basin and the huge changes in store for the basin's hydrology.
- The continuing impact of the tiny algal cell, *Cyclotella* on the summer clarity at Lake Tahoe in 2018.
- The linkages between the nearshore and the mid-lake regions. This work is the culmination of five years of development of the Nearshore Water Quality Network. Three specific findings are described. These findings include the variations in nearshore turbidity; the detection of lake upwellings and the "Tahoe Wave"; and new revelations about the influence of climate change on the fate of stream water entering the lake.
- The emerging threat to the aspens of the Tahoe basin posed by the white satin moth.
- Lakes and other water bodies are sometimes the final resting place of vessels from a previous era. TERC students are actively searching for these wrecks using advanced technologies both at Tahoe and elsewhere.
- The California Mountain Lake Observatory Network that monitors over 15 lakes throughout the Sierra Nevada. These data can be compared with the long-term Tahoe data.
- Taking the lessons of Lake Tahoe global. What is learned at Tahoe is noticed and applied around the world. This is happening at the Poles and in northern Patagonia in Chile.



Photos: B. Allen and A. Toy

An Ecological Solution for Tahoe's Clarity

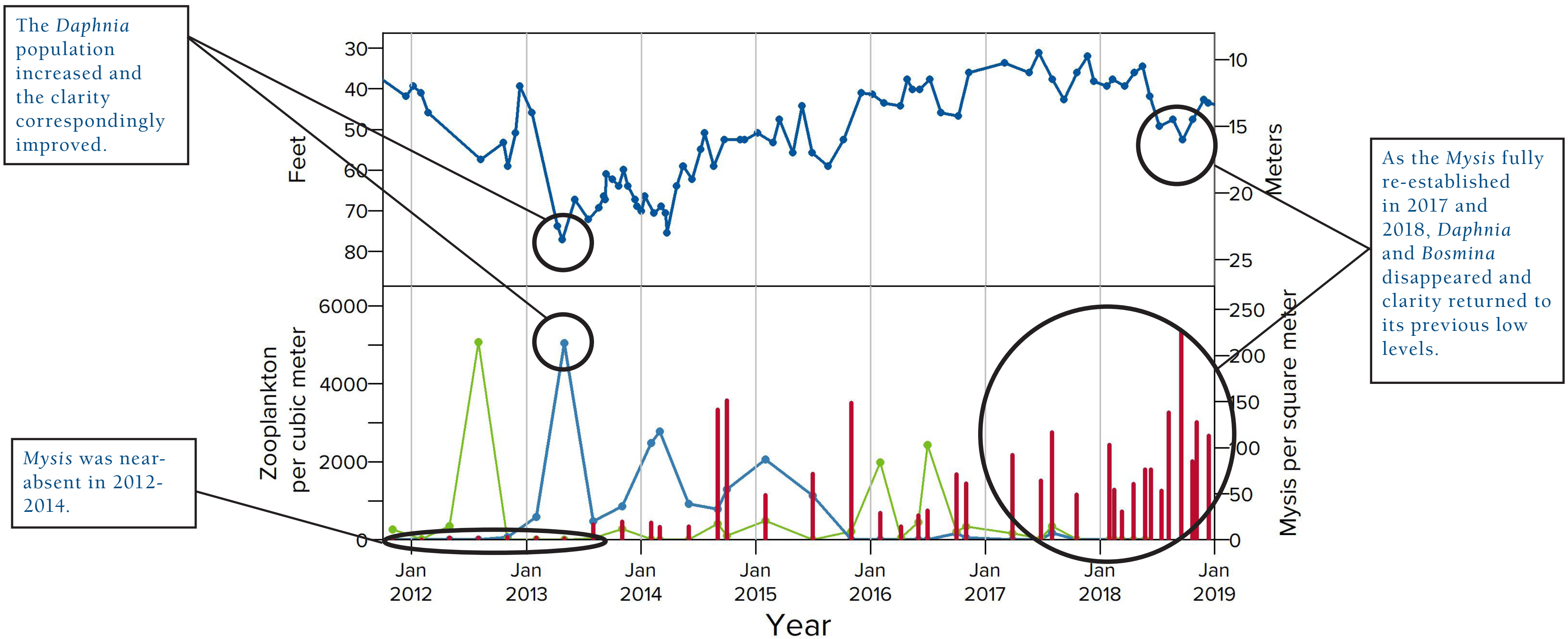
In the 1960s, the California Department of Fish and Game (now California Department of Fish and Wildlife) introduced the non-native shrimp *Mysis relicta* to Lake Tahoe and Emerald Bay as a food source of intermediate size for the lake's trout population. Early TERC monitoring found that this introduction was an ecological tragedy. The *Mysis* would migrate vertically to the depths of the lake to avoid light during the day, and then rise to the surface at night where they would consume native zooplankton, the trout's natural food source. The net result was that the average trout size diminished and the two dominant zooplankton, *Daphnia* and *Bosmina*, largely disappeared from the Tahoe system.



From left to right: Mysis relicta, Bosmina, and Daphnia (not to scale).

An Ecological Solution for Tahoe's Clarity, continued

In 2011, TERC researchers resumed the monitoring of *Mysis* after a break of many years. In Emerald Bay, they initially found that the *Mysis* had disappeared. However, they also found the populations of the native zooplankton, *Bosmina* and *Daphnia*, returning in large numbers. Clearly, they had been heavily predated by *Mysis*, but in the absence of the *Mysis* they could quickly reproduce and re-establish. Such booms and busts in zooplankton communities are not uncommon, but what was startling was the concurrent and dramatic improvement in the clarity of Emerald Bay. In 18 months, clarity increased from 40 feet to nearly 80 feet, a phenomenal rate of clarity improvement.



The connection between clarity and zooplankton is evident when comparing these two panels. The Upper Panel shows Secchi depth readings in Emerald Bay. The Lower Panel depicts concentrations of Bosmina (green), Daphnia (blue) and Mysis (red) in Emerald Bay.

An Ecological Solution for Tahoe's Clarity

These results demonstrate unambiguously that when the invasive *Mysis* shrimp is not present, native zooplankton can return and flourish, and when they do so the clarity rapidly improves to a level not seen in decades. Why does this occur? The native zooplankton have the ability to rapidly ingest small particles and either use them for growth, or excrete them as large fecal pellets. These small particles include the tiny diatom (a type of single-celled algae), *Cyclotella*, which is currently considered the major climate change-induced threat to long-term clarity in Lake Tahoe (see 6.10).

This raised an interesting possibility. Land-use practices and urbanization, which grew rapidly starting in the 1960s, are considered the major cause of clarity decline, and all efforts to restore clarity have been directed at mitigating those impacts. The role that the introduction of *Mysis* had, which occurred at exactly the same time, has never been seriously considered. Could a program to remove *Mysis* rapidly improve the clarity of Lake Tahoe? As their removal ultimately results in a reduction of *Cyclotella*, could this be an ecological approach to "climate proof" Lake Tahoe's clarity?

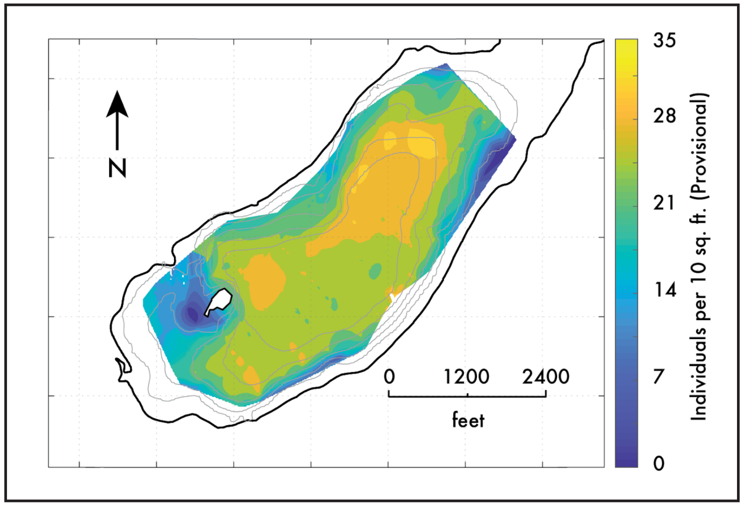
The Research Vessel John LeConte testing the Mysis trawl net in Lake Tahoe in 2018. Photo: B. Allen

An Ecological Solution for Tahoe's Clarity

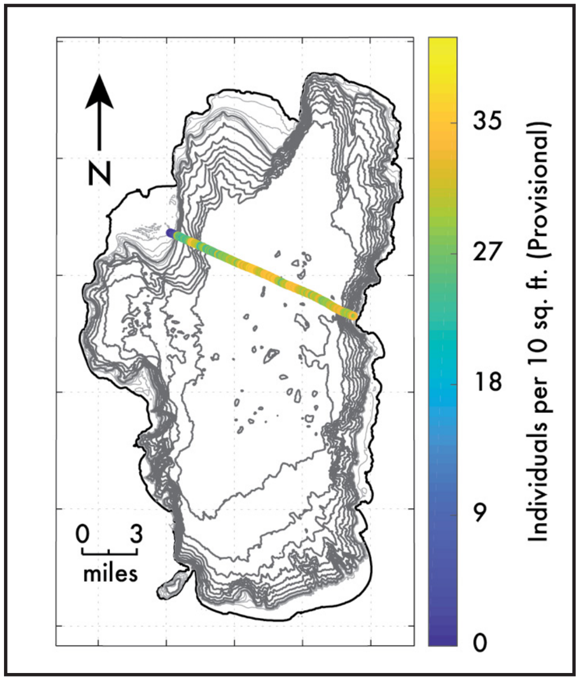
In 2016, a pilot project funded by the California Tahoe Conservancy and the Nevada Division of Environmental Protection sought to answer this question through a small-scale pilot project in Emerald Bay. Using a bio-acoustic echosounder, it was possible to locate the position of *Mysis* in Emerald Bay, quantify them, and remove them with a trawl net. Could *Mysis* populations be reduced to a level at which *Daphnia* and *Bosmina* could thrive?

With one year of the project remaining, the answer appears to be YES! With TERC's research vessel, we can locate and remove *Mysis*, and also provide information on their distribution, size, and concentration in both Emerald Bay and Lake Tahoe. To better characterize the *Mysis* distribution in Lake Tahoe itself, we will use a miniaturized echosounder on our autonomous underwater vehicle.

We are currently designing a full-scale approach for *Mysis* removal and working on the commercialization of the *Mysis* catch. Collaboratively, a team from UNR is investigating the diets of *Daphnia* and *Bosmina* to corroborate that they are removing both fine particles and *Cyclotella*.



The distribution of Mysis in Emerald Bay on May 29, 2019. The gray depth contours are at 50 foot intervals.



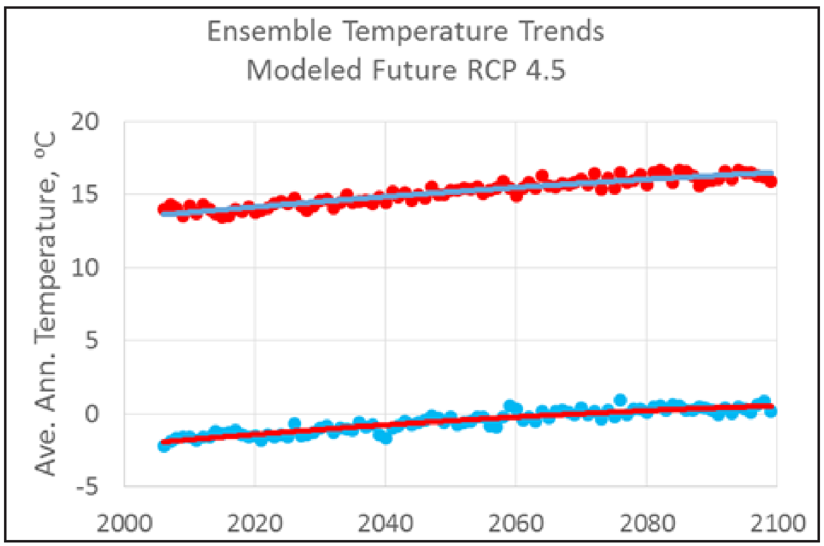
The distribution of Mysis shrimp along a transect of Lake Tahoe on November 13, 2018. Note the patchiness of the Mysis distribution across the deep portion of the lake.

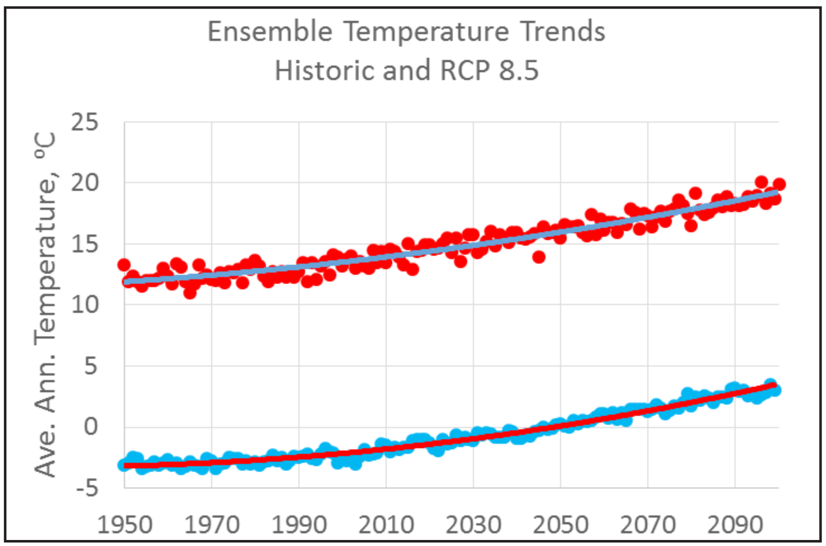
Future Climate Conditions

With support from the California Tahoe Conservancy, TERC has developed projections of future climate conditions and indicators specific to the Lake Tahoe Basin that serve as a resource to agencies and stakeholders. The projections are based on four General Circulation Models (GCMs) and two emission scenarios from the Intergovernmental Panel on Climate Change (IPCC) Assessment Reports.

For the Lake Tahoe Basin, the GCM results were statistically downscaled to an approximately 4-mile pixel size. Just two of the ICPP CO_2 emission scenarios (RCPs) were used, as they were considered to span the range of currently plausible CO_2 scenarios. RCP 4.5 is considered to be at the lower end of what we may experience, while RCP 8.5 is considered to be at the higher end.

Temperature projections have the highest degree of certainty of any of the forecast climatic variables. The average of all 4 models' maximum and minimum annual air temperatures are shown through the end of the century for both RCP 4.5 and RCP 8.5. Under RCP 4.5, both minimum and maximum temperatures increase by 2-3°C (3.6-5.4 °F) from 2010 – 2100. Under RCP 8.5, minimum and maximum temperatures are projected to increase by more than 5°C (9 °F) (Figure on the right), with the shape of the curves indicating an accelerating warming rate.



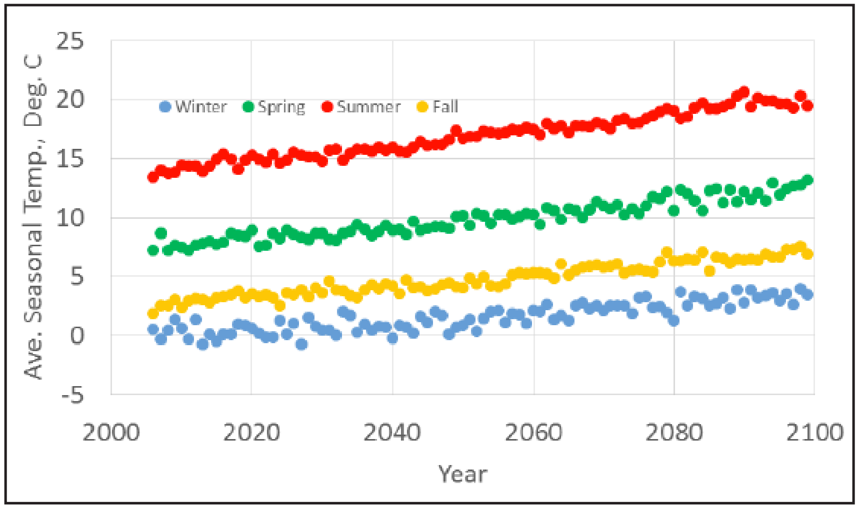


Basin-wide averages of annual maximum daily (Red) and minimum daily temperature (Blue), for RCP 4.5 (left) and RCP 8.5 (right).

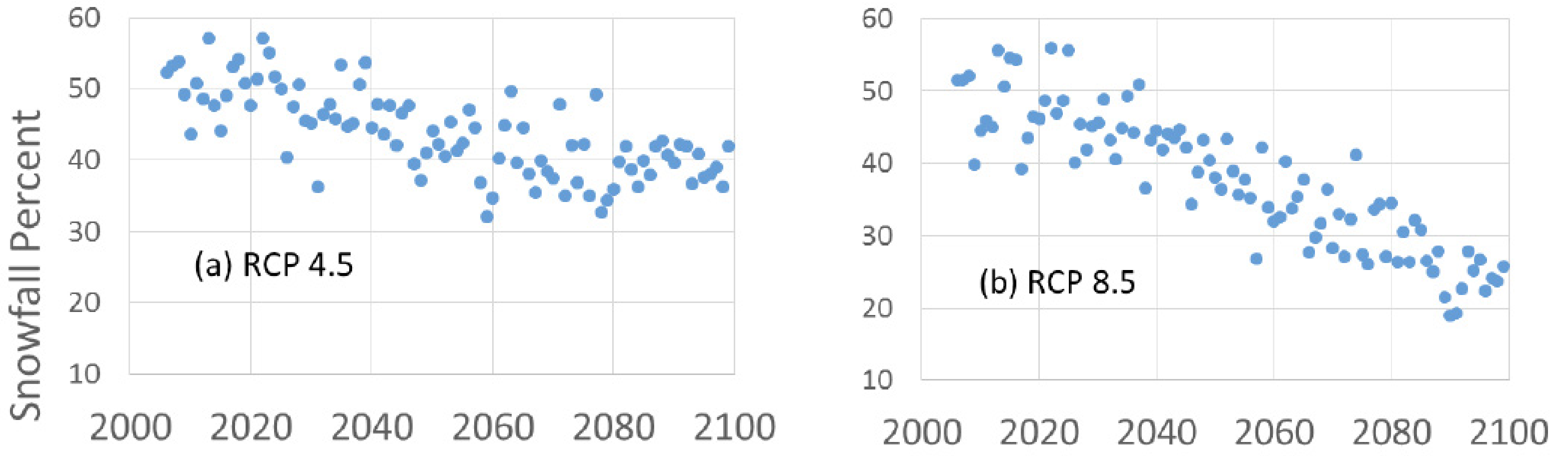
Future Climate Conditions, continued

Annual average and basin-wide averaging, while effective in showing the overall trends, don't reveal the changes that are expected in different seasons. The figure (top right) shows average warming trends for average daily temperature by season under RCP 8.5. The warming rate is highest in the summer (1.2 °F/decade) and lowest in the winter (0.7 °F/decade).

Total precipitation in the Lake Tahoe Basin is not expected to change significantly through 2100, however the fraction of snow and location of the snow level will change. The two figures (bottom right) shows the declining percent of precipitation falling as snow, averaged over the Lake Tahoe basin, under the two emissions scenarios.



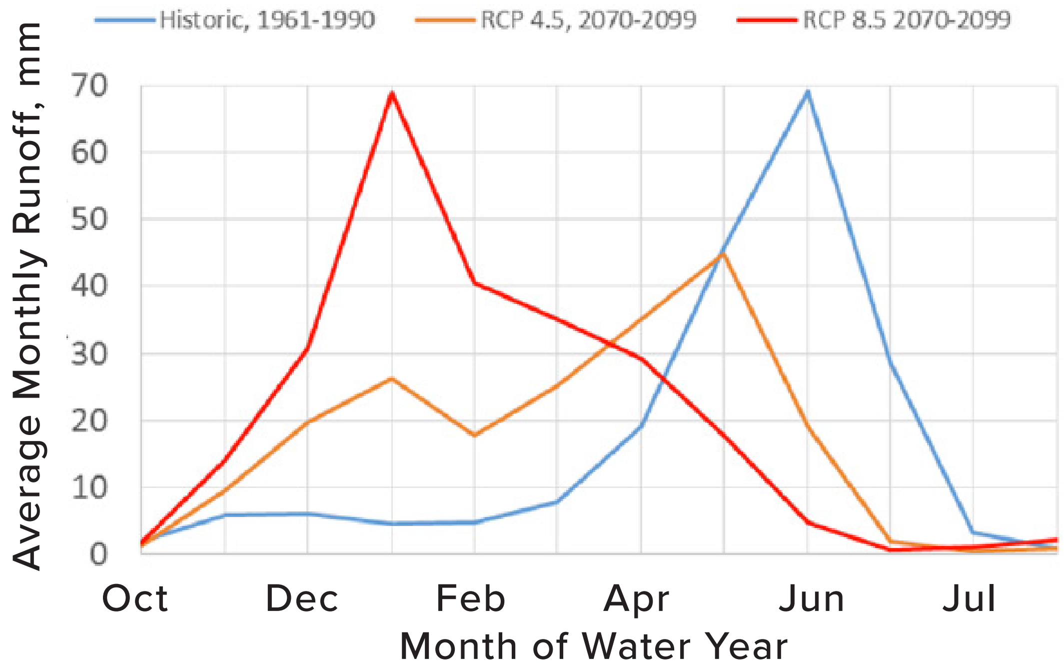
Average daily temperature by season, 2000 – 2100, under RCP 8.5.



Projected future percent of precipitation falling as snow in the Tahoe basin under (a) RCP 4.5 and (b) RCP 8.5.

Future Climate Conditions, continued

In the Lake Tahoe Basin, little trend in runoff magnitude was observed under either scenario. However, the timing of runoff will change dramatically. Figure shows the shift in monthly runoff from mean of the modeled historic conditions to the mean of the 2070-2099 period, under RCP 4.5 and RCP 8.5. The month of maximum runoff shifts from May to June under RCP 4.5, and to January under RCP 8.5. Under RCP 8.5, the negligible values of late summer flow will approach the time of year where we currently experience the highest flows. This phase alteration of the hydrology of the streams may have large ecological consequences. The average magnitude of peak runoff for the historic data and projected data under RCP 8.5 are similar, although instantaneous flow rates are likely to increase significantly. The shift in runoff is most likely related to the transition from a snowfall to a rainfall regime, with an increase in rain-on-snow events.



Historic and projected timing of monthly runoff in the Tahoe basin. Note: the x-axis spans the water year; the first month of a water year is October.

Size Really Does Matter

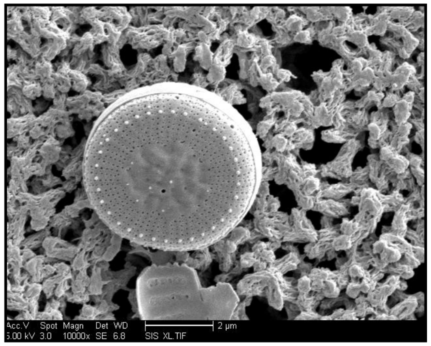
The Role of *Cyclotella* in Lake Tahoe's changing summer clarity

One of the known consequences of climate change is the warming of the surface of Lake Tahoe. As the lake water warms, it thermally stratifies, which reduces the natural action of the wind to stir the lake and keep algal cells suspended in the high light region of the lake. When stirring is reduced, algal cells will sink.

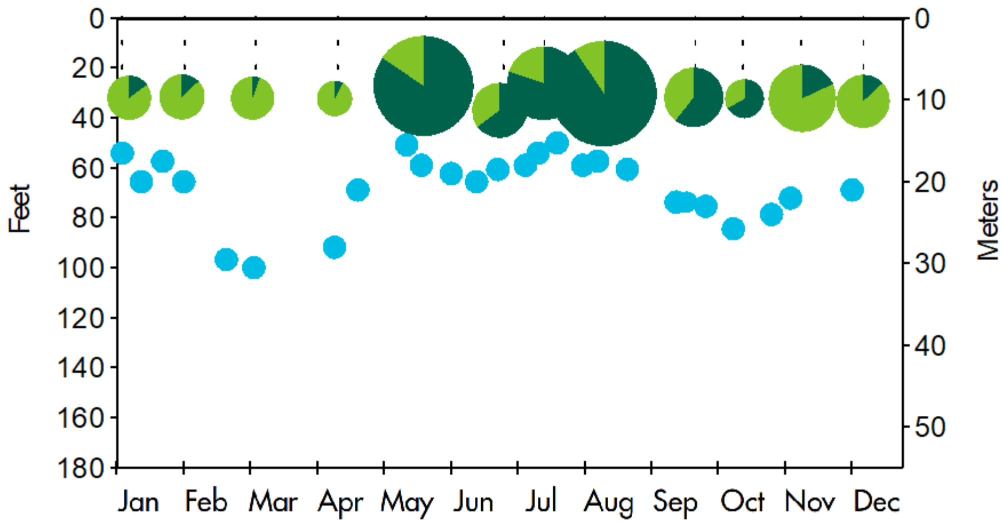
Why is size important? On account of their smaller volumes, *Cyclotella* sink far slower than larger phytoplankton – up to 100-1000 times slower – allowing them uncontested access to the nutrients and light needed for growth. Also due to their small size (less than 4 micron or 0.1 thousandths of an inch in diameter), they scatter light and reduce the measured Secchi depth value, just like fine inorganic particles. In 2018, even though clarity had returned to its recent range, following the record low values of 2017, the impact of *Cyclotella* on summer clarity was abundantly clear as evident in the Figure right.

From late May through September, the low Secchi depth coincided with high abundance of *Cyclotella*.

It is becoming very evident that the improvement in Tahoe's summer time clarity is intimately linked to controlling the development of *Cyclotella* blooms.



Cyclotella gordonensis



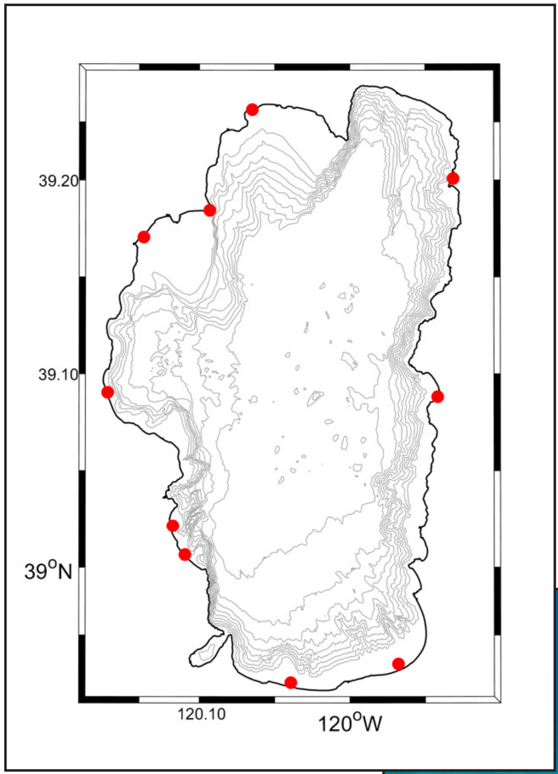
Secchi depth measurements at the LTP station (pale blue dots) in 2018. The pie charts indicate the relative contribution of Cyclotella (dark green) to total phytoplankton assemblage smaller than 20 µm (excluding picoplankton smaller than 1 µm, chain forming algae, detritus and empty cells. Each pie chart represents the combination of algal counts from samples taken from 5 m (16.5 ft) and 20 m (66 ft) depth.

Three New Insights from the Nearshore Network

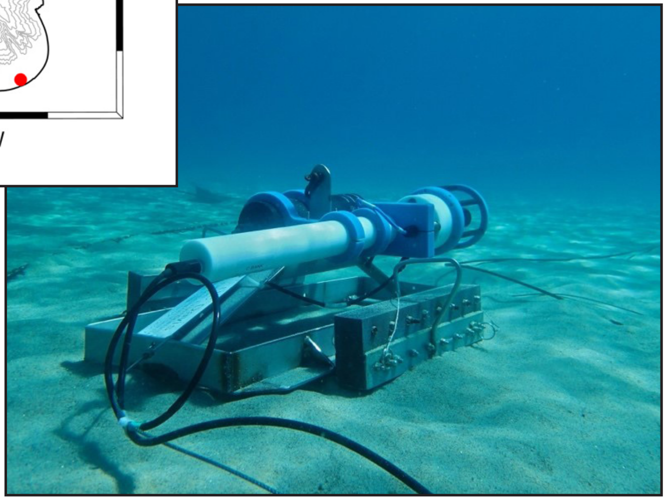
In 2014, TERC installed the first Nearshore Water Station at Homewood, California. Since then, an additional ten Stations have been added all around Lake Tahoe and in adjacent Cascade Lake. The idea was simple – work with property owners who have direct access to the lake, install underwater cables from their docks to an instrument located in seven feet of water, and monitor water quality every 30 seconds. The measurements provide the data needed to distinguish water quality around the lake.

That has been achieved, but more importantly the data have revealed a new understanding of processes that occur lake-wide and in the nearshore. The following pages will highlight some of this new knowledge.

We thank those who have financially supported this project and/or provided access to their docks, the Glenbrook Homeowners Association, and the Lahontan Regional Water Quality Control Board.



The red dots indicate locations of Nearshore Stations around Lake Tahoe



A Nearshore Station on the sandy bottom at Rubicon, CA. Photo: B. Allen

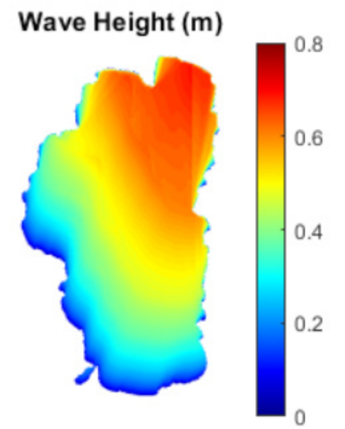
Three New Insights from the Nearshore Network

1. Predicting Sediment Resuspension in the Nearshore

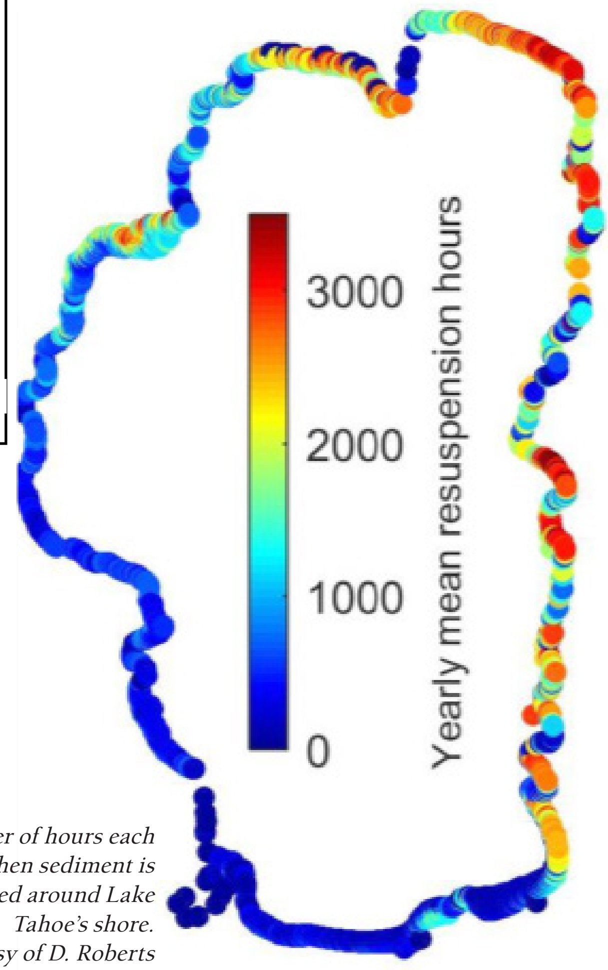
Data from the stations allowed the establishment of the relationship between the water's turbidity (cloudiness) and the measured wave height. Similarly, a relationship was developed between wind strength and wave height. Combining this information in our Wind-Wave model produced a tool for predicting turbidity at any point along Tahoe's shore for any combination of wind speed and direction.

We have learned that most of the east shore of Lake Tahoe exceeds turbidity standards over 40% of the time. This is not due to the inflow of any contaminants, but simply natural waves breaking on the downwind side of the lake and resuspending lake sediments. This new tool allows for a more informed discussion of what turbidity standards should be around the lake, that will both serve to protect the lake and not unduly restrict activities.

The same forces that cause sediment resuspension and turbidity, also impact the algae attached to rocks around the lake. The wave-induced forces help to "slough" algae off the rocks. This information is forming part of our periphyton modeling. The boxed figure displays a typical wave height distribution for Lake Tahoe in response to the prevailing south-west winds.



Courtesy of D. Roberts and P. Moreno



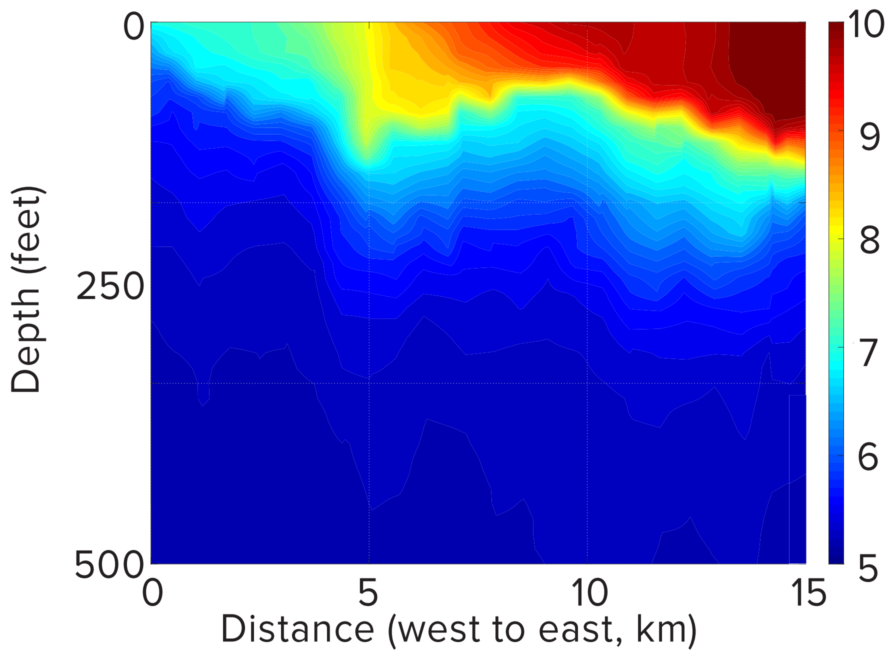
The number of hours each year when sediment is resuspended around Lake Tahoe's shore. Courtesy of D. Roberts

Three New Insights from the Nearshore Network

2. Upwelling and the "Tahoe Wave"

When strong winds blow across the surface of the lake, warm surface water gets blown downwind, typically warming the beaches on the east shore. At the same time, cold water rises up from the depths to replace this water, resulting in what is referred to as an upwelling. Under extreme wind conditions, these upwellings can be as large as 600 feet high. As the cold water rises in the west it simultaneously brings up nutrients from deep in the lake, that can stimulate algal growth.

The Nearshore Network has allowed us to readily see when these upwellings occur and their magnitudes. Typically, with southwest winds, water temperatures drop suddenly on the west shore and rise on the east shore. As shown in the Nearshore station data below, temperature differences as large as 18 °F (10 °C) can occur within a few hours.



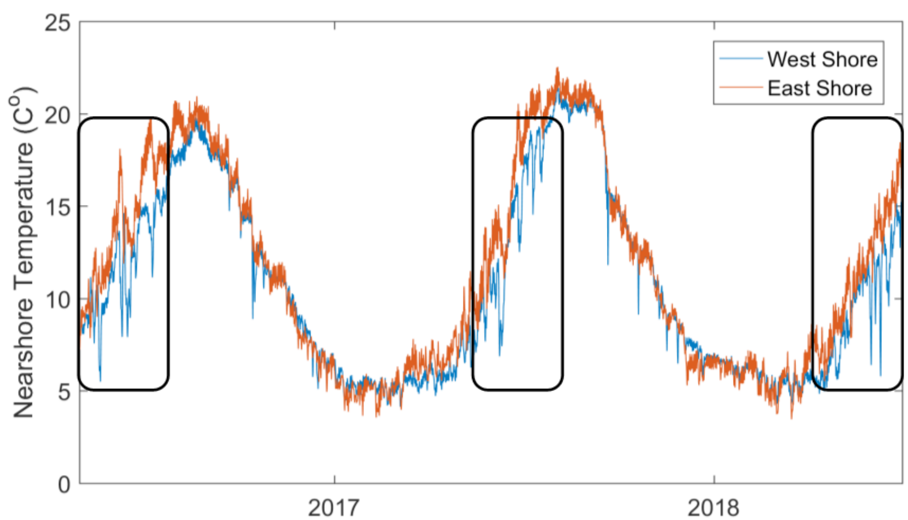
An upwelling at Lake Tahoe, as measured by an autonomous glider. Wind was generally from left to right. The figure shows a lake cross section with Homewood to the left and Glenbrook to the right. This upwelling has an amplitude of 160 ft. Courtesy of K. Lee

Three New Insights from the Nearshore Network

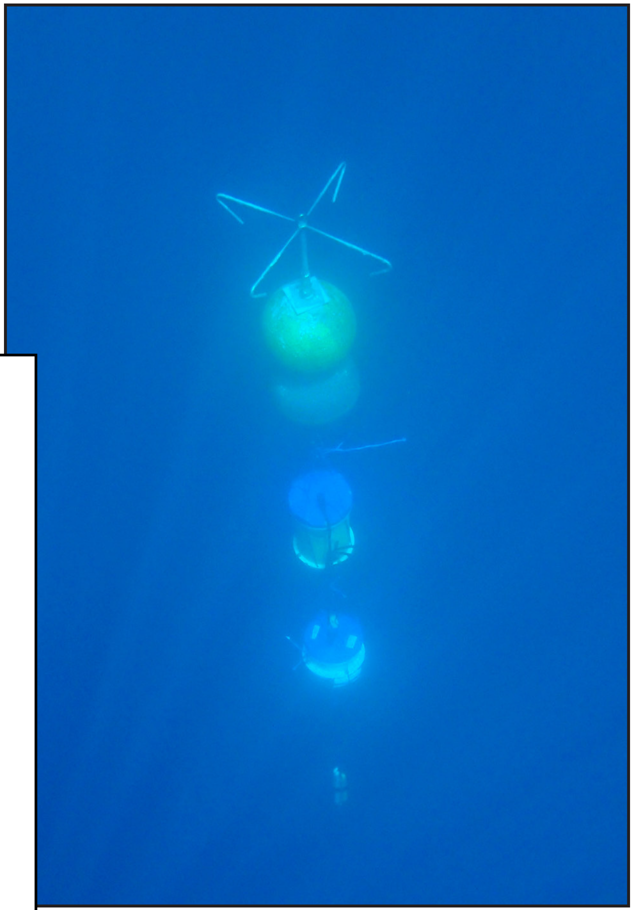
2. Upwelling and the "Tahoe Wave", continued

This happens numerous times in the spring (indicated by the boxed areas on the figure) when temperature stratification is small and less energy is required to move the lighter, warmed surface waters.

To better understand this ubiquitous process, a multi-University experiment was conducted in 2018. A "curtain" of temperature and velocity instruments were installed across the lake. What we found was truly remarkable. The first discovery was that the upwelling process itself occurred gradually and slowly built up energy on the east side of the lake.



Nearshore temperatures from Homewood (blue) and Glenbrook (red) show the magnitude and the frequency of upwelling events. Courtesy of D. Roberts



A chain of temperature and velocity instruments that was one of many used to compose a five-mile wide "curtain" of instruments stretching across Lake Tahoe. Photo: B. Allen

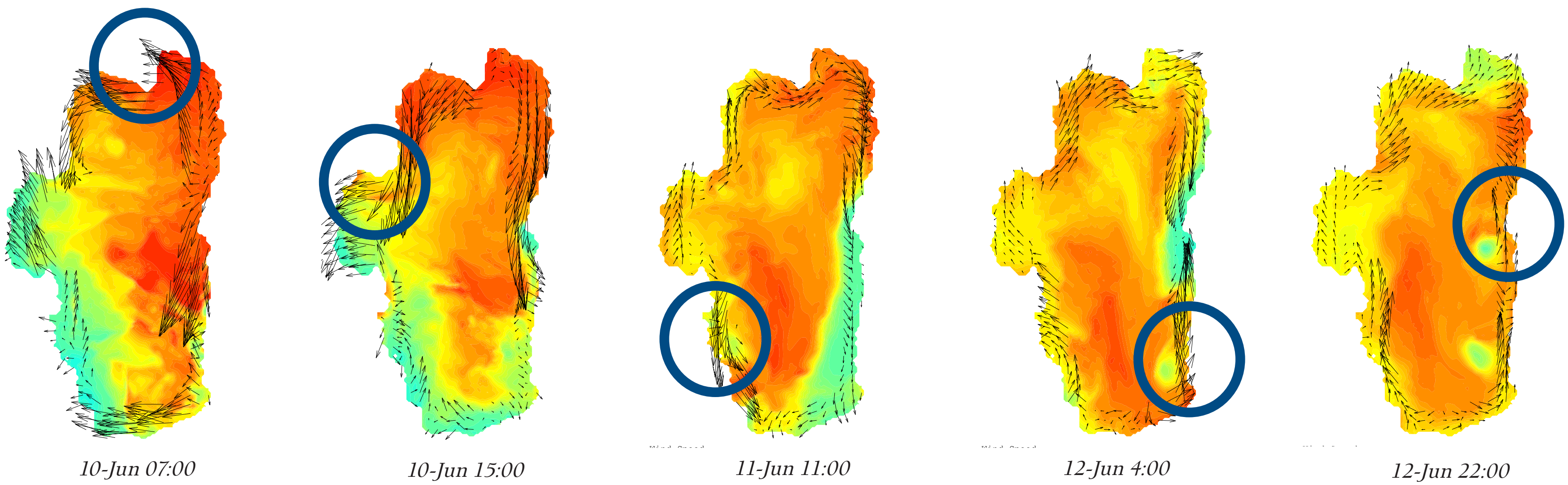
Three New Insights from the Nearshore Network

2. Upwelling and the "Tahoe Wave", continued

When the wind dropped, all that energy was released very suddenly, producing high velocity (2 ft/sec and larger) flows as the water rushed back across the lake. This returning water produced an even larger "downwelling" on the west shore.

Most remarkable of all, is that the accumulation of warm water on the north-east shore simultaneously initiates a trapped internal wave (or Kelvin wave). Due to the earth's rotation, this wave– the "Tahoe Wave"– is forced to hug Tahoe's shoreline as it travels counter-clockwise around the entire lake in a journey of 4-5 days. As the front of the wave moves by, it produces strong, jet-like currents along the coast. Once it passes, those currents are reversed.

The role these currents have on nearshore water quality is still being studied.



Images from a computer simulation of a Kelvin wave traveling around Lake Tahoe following the upwelling of June 10-11, 2018. The colors show water temperature at a depth of 66 feet. The current velocities indicated by black arrows are shown in the nearshore region. The progress of the high velocity jet produced by the front of the wave is indicated with a blue circle. Courtesy of K. Lee

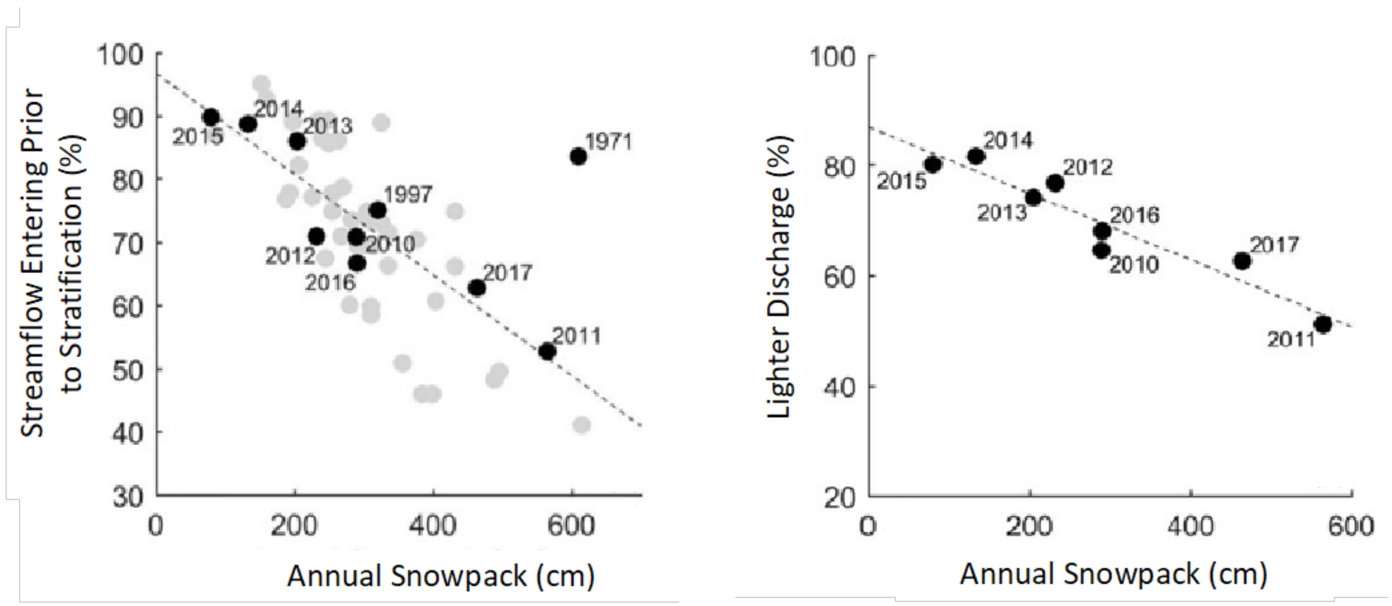
Three New Insights from the Nearshore Network

3. Climate change and lake clarity

The changing climate has affected many aspects of Lake Tahoe. These changes raised the following key question: what effect could climate change have on clarity? The Nearshore Network is helping us address this question as well.

The warming air temperatures have been decreasing the fraction of snow in our precipitation from 50% to 30% over the last 100 years. It has also been advancing the timing of peak streamflow into the lake. At the same time, the lake has been warming and stratifying earlier.

We have been able to explore the relationship between the snowpack, the lake's temperature stratification, and the conditions of the streams as they enter the lake. The data are showing two important trends: (1) As the annual snowpack decreases, more of the stream inflows enter the lake before thermal stratification; and (2) As the annual snowpack decreases more of the stream inflow is warmer relative to the lake and therefore buoyant or lighter than the lake's surface water.

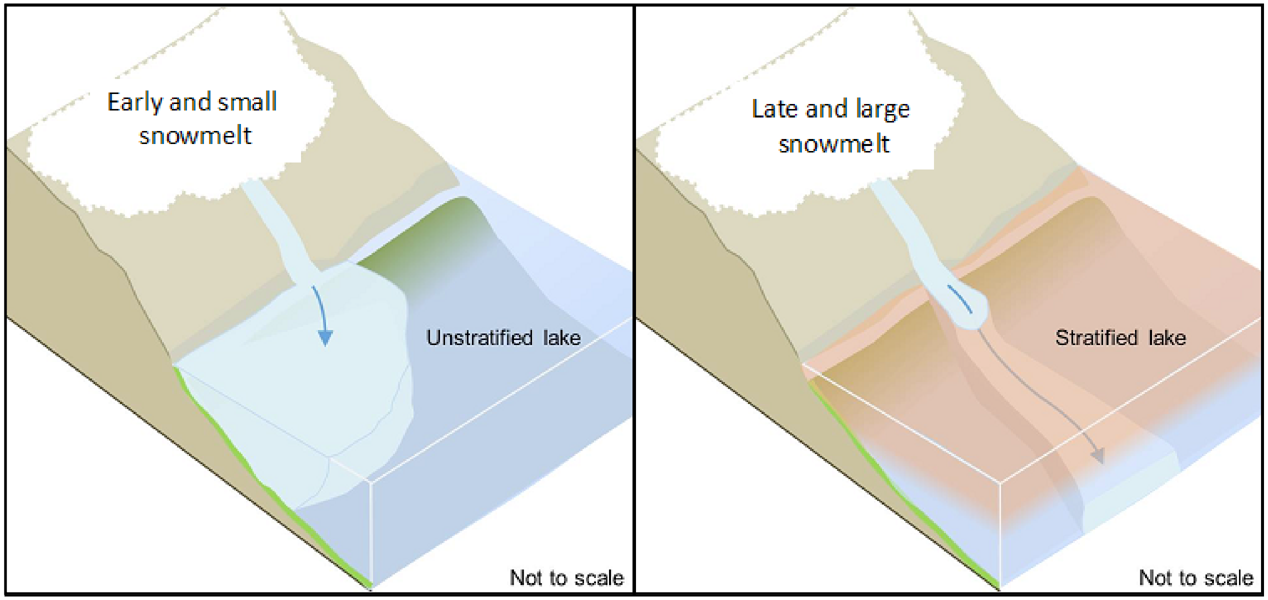


The relationship between snowpack size, the amount of inflow prior to lake stratification and the percentage of the streamflow that is lighter than the surface lake water. Courtesy of D. Roberts

Three New Insights from the Nearshore Network

3. Climate change and lake clarity, continued

The consequence of this is troubling. As the snowpack continues to decrease in the future, it would seem that there is an increasing tendency for inflows not to plunge, but to mix into the surface water. This not only places nutrients high in the photic zone, encouraging algae to grow, but also introduces fine particles above the historical Secchi disk depths. Both impacts have the potential to diminish clarity.



Schematic showing the surface mixing of early and small snowmelt years into a homogeneous lake (left), compared with a late and large snowmelt plunging deeply into a thermally stratified lake. Courtesy of D. Roberts

Forest Health

Heritage Aspens and the Threat of White Satin Moth

In 2011, white satin moth (*Leucoma salicis*) was first detected in North Canyon within the Lake Tahoe Nevada State Park. The moth's (caterpillar's) preferred hosts are native aspen trees (*Populus tremuloides*). Since 2011, the moth has spread northward and southward. Currently, there are numerous aspens stands that are experiencing severe defoliation as a result of these moths.

Some of these highly defoliated stands are in heritage sites that document the rich history of Basque sheepherding and resource management in the Lake Tahoe Basin.

The TERC Forest and Conservation Biology team has been surveying stands around the Lake Tahoe Basin. Through this process they have identified the presence of the moth in a new location on the west shore– in the lower Blackwood Canyon area.

We are quantifying levels of defoliation in aspen stands throughout the Lake Tahoe basin, as well as examining host chemistry which may be an indicator of white satin moth susceptibility or tolerance. Additionally, we will be developing early detection monitoring and conservation strategies for aspens in the basin.

An adult white satin moth. Photo: A. Toy

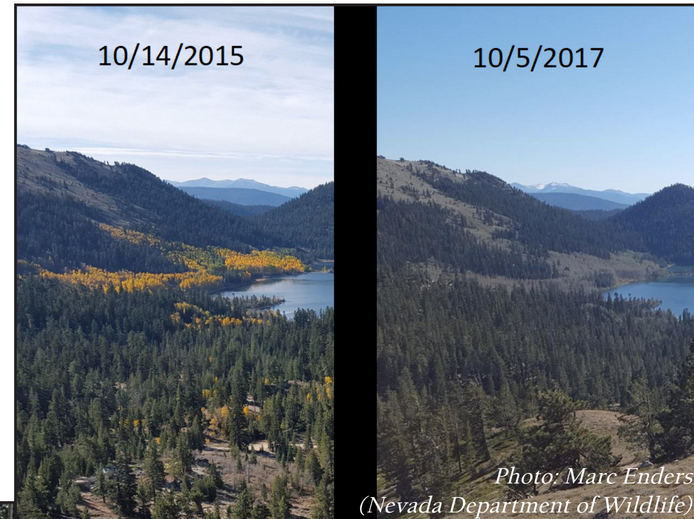


Photo: Marc Enders (Nevada Department of Wildlife)

Basque tree carving on aspen in the Genoa/ Montreal Canyon area. Photo: P. Maloney

The larval caterpillar stage of the white satin moth. Photo: A. Vanderpool

The Secrets Held in Lakes

On November 24, 1918, two French minesweepers, the *Inkerman* and the *Cerisoles* were lost in Lake Superior on their maiden voyages from Thunder Bay, Ontario. It is believed that they now lie 900-1000 feet below the surface.

One hundred years later, researchers from TERC partnered with the University of Delaware and the Great Lakes Research Center at Michigan Technological University to use new sonar mapping techniques to try find their final resting places. Starting with a large search area of 150 square miles, the team managed to cover a quarter of the area in a week of mapping.

While they did not find the target wrecks, they did locate another previously undocumented wreck lying at a depth of 400 feet. Our current plan is to return to this site with a Remotely Operated Vehicle (ROV), to dive to the vessel, and to collect high definition images and videos of the wreck. Plans are also being made to use Autonomous Underwater Vehicles (AUVs) to map this site in greater detail.

The experience gained on this mission will be put to good use in TERC's plans to find the S.S. Meteor, which was scuttled in Lake Tahoe on April 21, 1939. We will also use an AUV with side scan sonar.

Our AUVs have also been used in a collaboration with the Royal Australian Navy (RAN) and the Australian Maritime College Search (AMCS). In 2017, TERC and AMCS started developing a training program for the RAN to use AUVs to detect underwater mines.

Emerging underwater technologies are changing the way we conduct research in all types of aquatic environments. Lakes are ideal testing grounds as they provide conditions that are generally more benign to work in than the open ocean. Lake Tahoe is particularly well-suited as its great depth is representative of ocean conditions.

UCDavis and TERC student Micah Swann on R/V Agassiz ready to search for sunken ships in Lake Superior.

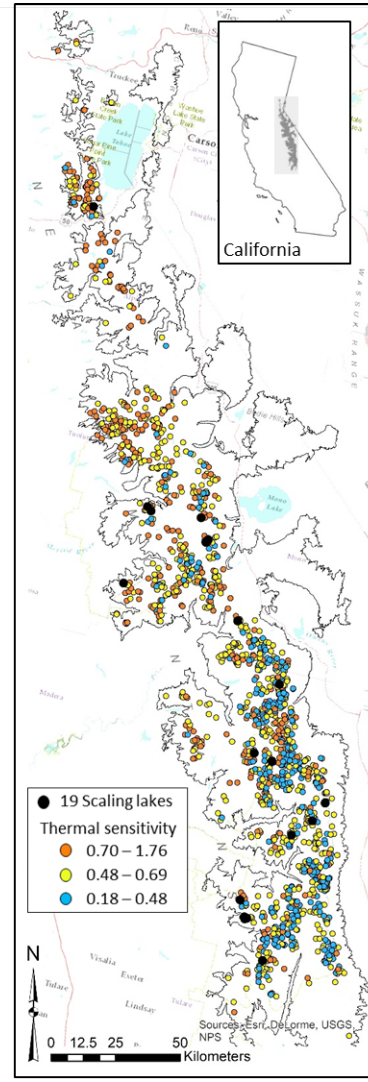
The view from the classroom while deploying an AUV with the Royal Australian Navy in Lake St. Clair, Tasmania, Australia.

Taking the pulse of small lakes throughout the Sierra Nevada

There are over 14,000 lakes and ponds throughout the Sierra Nevada– most of these waterbodies are small and nestled in remote high-elevation catchments, accessible only by foot. In addition to being a vital component of California's water storage network, these lakes are ecological "hotspots" in the environment. By processing carbon and nutrients that wash into them, they provide critical ecosystem services, including supporting the organisms that live within and around them.

Research at the Emerald Lake long-term study site in Sequoia National Park shows that air temperatures in high elevation catchments are warming faster than lower elevation sites such as Tahoe. Despite this, no long-term trend in lake warming has been detected. This is because of the role of winter snowpack in regulating lake temperature. Years with deep winter snowpack mitigate the other climate warming effects on small lakes. The Figure right shows the general sensitivity of small Sierra lakes to declining snowpack has been determined.

Sierra lakes field crew hiking above Hetch Hetchy reservoir on their way to sample a Yosemite lake. Photo: S. Sadro



Research has demonstrated the importance of snow in regulating water temperatures in small lakes. Our current network of lakes is being used to understand the role of snowpack. Figure is adapted from Sadro et al. Limnology and Oceanography Letters 2018.

Taking the pulse of small lakes throughout the Sierra Nevada

These results provided the inspiration for the California Mountain Lake Observatory Network– a network of over 15 lakes located throughout the mountain range, each instrumented with high-frequency sensors to measure temperature and other water quality parameters with the accuracy necessary to make stronger predictions. We chose lakes spanning gradients in all factors that are expected to modulate the effects of climate: latitude, elevation, lake size and depth, and local topographic relief. The network was initially deployed during the summer of 2017. Every summer since then, a field crew backpacks anywhere from 5 to 20 miles to reach each lake, spending 4-5 days at each site downloading instruments, conducting experiments, measuring the productivity of the nearshore and open water areas of the lake, and collecting water samples for water quality analysis. This research will help us understand the mechanisms through which climate affects the physical, chemical, and biological conditions of these lakes, and allow us to develop models to more accurately predict specific lake responses to climate change.

Deployment of a mooring in a Yosemite lake. Photo: E. Suenaga

Benthic chambers measure productivity of the nearshore sediments in a small Sierra Nevada lake in August 2018. Photo: E. Suenaga

TERC Globally

UC Davis and TERC are transferring the lessons and approaches that are being developed at home to the far corners of the world to address the big problems of our time. Current projects in Antartica, Canada, and Chile illustrate the global implications of Tahoe research.

A fragment of the Petermann Glacier melting in the Baffin Sea, Photo: Canadian High Arctic (2011).

Lake Panguipulli nestled at the base of Volcan Shosheunco is in a state of rapid transition due to development pressures. Photo: G. Schladow

TERC Globally

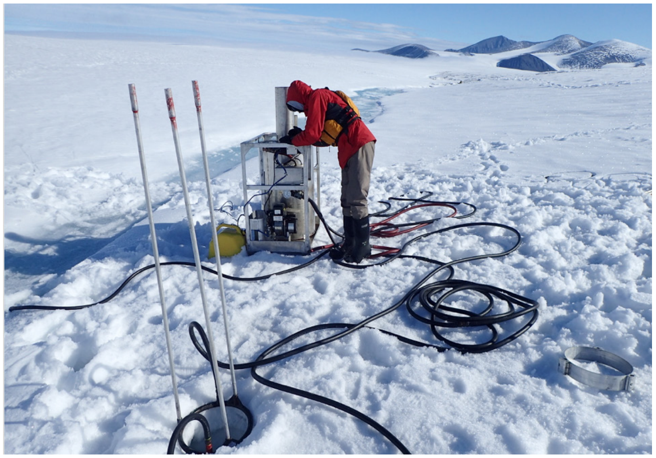
Melting of Polar Ice

The cryosphere, the frozen parts of the Earth, is melting at an unprecedented rate. While the scientific community is trying to predict this rate, it has consistently underestimated how quickly these remote areas are changing. These changes have implications for global weather patterns, sea level rise, and ecosystem management.

What causes large ice shelves to collapse? Researchers from UC Davis and TERC have partnered with the University of British Columbia and Carleton University to study the Milne Ice Shelf, the last remaining Canadian ice shelf in northern Ellesmere Island. In recent years, a subglacial channel has formed draining melted freshwater out to the Arctic Ocean. To understand the heightened flow, we have adapted methods that we are using at Lake Tahoe, installing instruments in this channel to measure temperature, salinity and flow velocities throughout the year. Initial results are showing that the outflow underneath the ice shelf is occurring on a year-round basis, not just during the summer as initially hypothesized, and is melting the polar ice faster than initially expected.

The same processes are believed to be occurring in Antarctica. To study them, a team from UCDavis and TERC, the École Polytéchnique Fédérale de Lausanne (Switzerland) and the Korean Polar Research Institute (KOPRI) have mounted a special turbulence sensor on an underwater glider to go beneath the much larger Nansen Ice Shelf in Antarctica. This glider has been deployed in Lake Tahoe for the last 2 years.

In the span of nine days, the glider completed a 50 mile return trip under the ice shelf, a location impossible to survey without this type of technology. This is the third time that our glider has been run under an Antarctic ice shelf; however, it was the first time in which we measured turbulence. These new measurements will contribute to a better physical understanding of the causes of accelerated polar melting.



Installing instruments in the subglacial channel on the Milne Ice. Photo: J. McInerney

Calibrating the glider compass at Jang Bogo Station, Antarctica. Photo: J. McInerney

TERC Globally

Managing the Lakes of Northern Patagonia, Chile

The symbiotic relationship that has evolved over 50 years between Tahoe management agencies and scientists often goes unnoticed at home. But around the world, Lake Tahoe is seen as a shining example of how lake management has been informed and guided by science. Chile, a country that is geographically very similar to California, is recognizing that its pristine northern Patagonia lakes are now prone to the risk of increased development and visitation, the same challenge that Tahoe faced over 50 years ago. Building on Tahoe's lesson, they are looking to partner and to rapidly transfer the knowledge acquired at Tahoe and apply it in Chile.

TERC, along with the Tahoe Regional Planning Agency and the League to Save Lake Tahoe, are engaged in bringing "the Tahoe Process" to the northern Patagonia lakes. Through a newly formed Foundation, Chile Lagos Limpios ("Chile Clean Lakes"), we are bringing the concept of research informing government and stakeholder action to Chile. A consortium of Chilean universities, as well as local and national stakeholders, are also part of the endeavor.

The first monitoring station was installed at Lake Panguipulli by TERC in December 2018. Another nine lakes will also be outfitted with instrumentation in 2019. The data from these instruments, along with data from frequent water quality sampling, will accomplish two things. First, it will be the initiation of a long-term data set, that will help evaluate how each lake is changing and the underlying causes. Second, it will permit the development of new predictive models that will enable Chilean agencies to understand the impacts of management practices and the future impact of factors such as climate change on the lakes.

Lake Panguipulli, the first northern Patagonia lake that has been instrumented. Photo: G. Schladow

Installation of the first monitoring station at Lake Panguipulli. Photo: D. Middlebrook)