TAHOE: STATE OF THE LAKE REPORT 2018

CURRENT RESEARCH

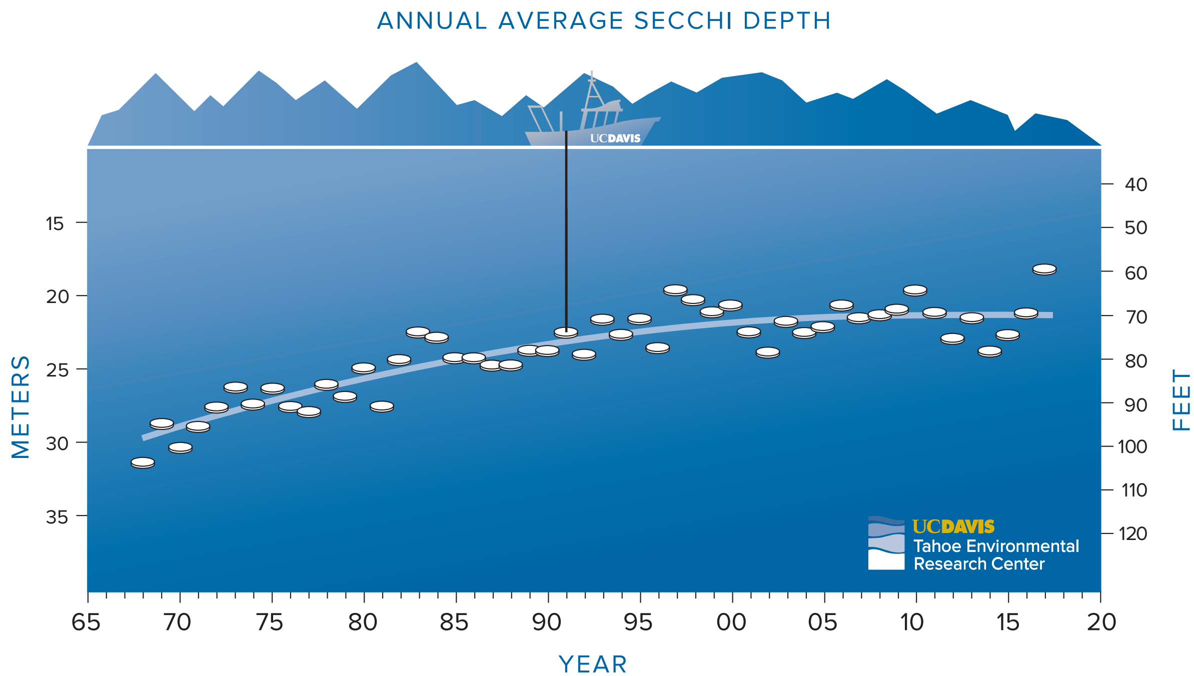
UC DAVIS
Tahoe Environmental
Research Center

CURRENT RESEARCH

Lake clarity in 2017

Annual average Secchi depth

In 2017, 26 individual clarity readings were taken from January through December 2017. The highest value recorded in 2017 was 90.2 feet on March 9, and the lowest was 47.6 feet on October 17 and December 19. The average clarity level for 2017 was 59.7 feet, a 9.5 foot decrease from the previous year, and the lowest level ever recorded. The long-term record of annual average clarity in Lake Tahoe is shown in the figure below.



Long-term annual average clarity in Lake Tahoe.

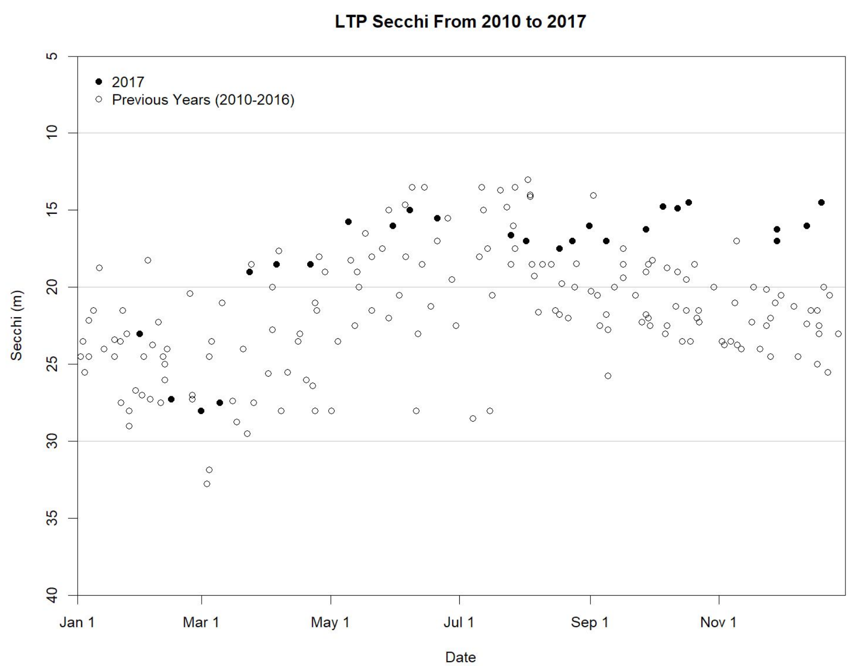
CURRENT RESEARCH

Lake clarity in 2017, continued

Individual Secchi depth measurements

Secchi depth measurements typically follow a seasonal pattern. In summer, clarity is usually at its lowest due to the impacts of spring runoff, warmer temperatures, and long hours of sunlight. As winter approaches, the surface layer of the lake mixes and deepens, diluting the upper layers with clearer, deep water. This clearing through the winter continues until the following spring when the pattern starts again. While no two years are identical, this pattern has long been established.

The year 2017 had a departure from this seasonal pattern. In the figure below, the individual values of Secchi depth are shown for the years 2010 through 2017. The 2010 to 2016 values are shown as hollow circles, while the 2017 values are filled circles. Until September 2017, values generally fell within the historical range. From September through the end of the year, the 2017 clarity values were 10 to 20 feet less than the historical range. It is the Secchi disk values in this four-month period of time that are responsible for the record low clarity of 2017. The usual winter clearing of the water column did not initiate before the end of December.



Individual Secchi depth measurements for 2010-2016 (hollow circles) and 2017 (filled circles).

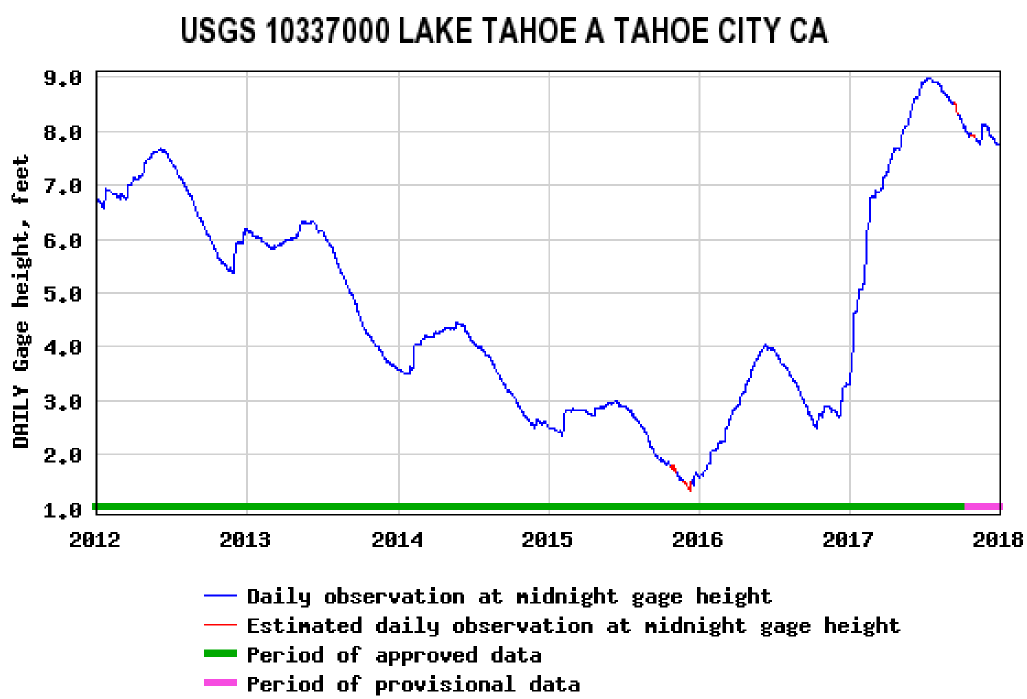
CURRENT RESEARCH

Lake clarity in 2017, continued

Lake level 2012-2018

Based on all the available data, a combination of two extreme climatic and hydrologic events was the primary cause of the unprecedented clarity conditions in 2017. The first key event was the record five-year drought that commenced in 2012. During this time, total precipitation, as well as the fraction of precipitation as snow, was particularly low in the northern Sierra Nevada.

The second key event was the record high precipitation that occurred in 2017 to officially end that drought. Water Year 2017 (Oct. 2016 - Sept. 2017) was California's second wettest and Nevada's seventh wettest in a 122-year record. A lake level rise of six feet in a six-month period in 2017 is shown below.



The overall drop in lake level during the drought years is evident, as is the rapid rise during 2017.

CURRENT RESEARCH

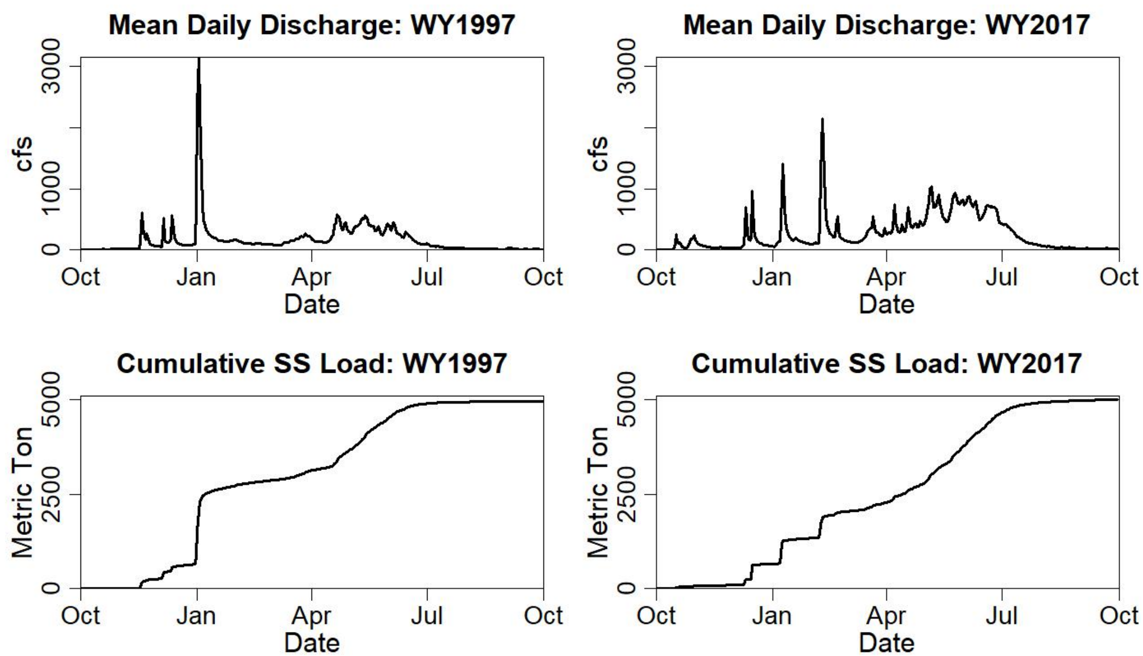
Lake clarity in 2017, continued

Comparing 1997 and 2017

A comparison of 1997, the previous lowest clarity year, and 2017 is illustrative. Upper panels of the figure below compare the flow of the Upper Truckee River for both these years. In 1997, major flooding downstream of Lake Tahoe occurred, as well as low clarity conditions. While 1997 had a larger peak flow, 2017 had more frequent peaks and a more sustained flow well into August.

The lower two panels show the cumulative sediment load and it is evident that 2017 and 1997 had similar loads. In 2017, the load came later in the year when surface warming had already commenced.

These plots are for the Water Year (October 1 – September 30), so 2017 does not include the sediment flux associated with the large rainfall and flow event in November 2017.



The Upper Truckee River in WY 1997 and WY 2017. Upper panels are discharge (cubic feet per second). Lower panels are the suspended sediment cumulative load from October 1st to September 30.

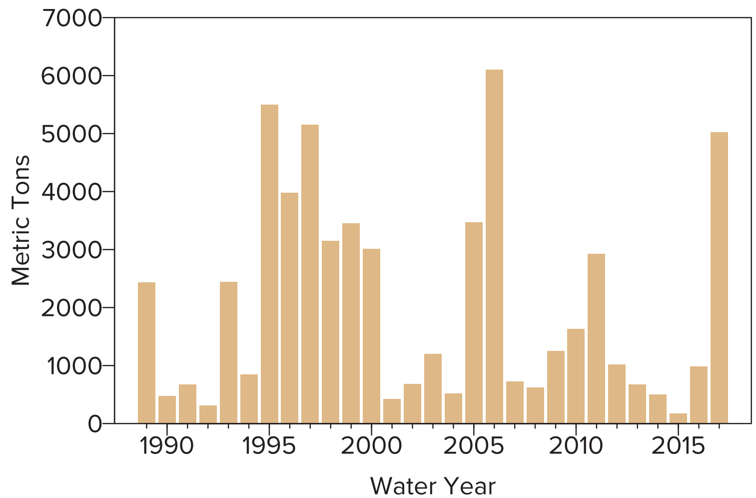
CURRENT RESEARCH

Lake clarity in 2017, continued

Suspended sediment load

The figure below indicates the annual suspended sediment load from the Upper Truckee River to the lake for each water year from 1989 through 2017. The 2017 sediment load in metric tons is larger than the sum of all of the sediment loads for the previous five years combined.

The loads were the direct result of the combination of the extreme drought (2012-2016) that was followed by an extreme wet year. The high and sustained flows in winter 2017 both mobilized accumulated sediment and caused additional erosion within the watershed (see picture below). High flows in 2017 extended into August. Additionally, there was also a late November storm (WY 2018) that added considerable sediment to the lake.



Annual suspended sediment load of Upper the Truckee River to the lake (metric tons).

Erosion gully on a fire road in the Tahoe watershed. Photo: H. Segale

CURRENT RESEARCH

Lake clarity in 2017, continued

Lake temperatures

The drop in the annual Secchi depth is the most obvious in-lake response to these climatic and hydrologic drivers. However, alterations to some of the physical processes in the lake due to a changing climate may have exacerbated the situation. The summer temperatures in 2017 were the warmest on record at Lake Tahoe, almost 4° F higher than the previous three years. As evident in the figure below, the elevated water temperatures extended into September 2017. This increase in the lake's thermal stratification would keep inflow waters and their sediment loads suspended in the upper part of the lake.

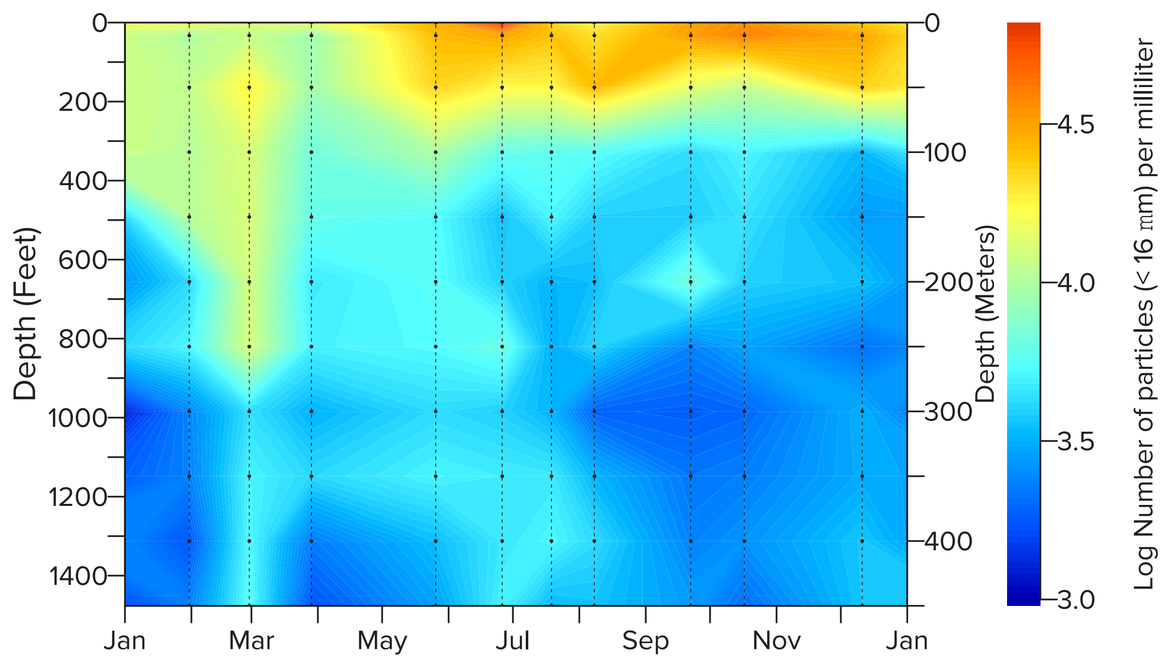
Surface water temperature in 2010 to 2016 (blue) and 2017 (red).

CURRENT RESEARCH

Lake clarity in 2017, continued

Fine sediment distribution

Fine sediment was kept in suspension in the upper part of the lake in the latter part of 2017 as shown in the figure below, where the concentration of fine particles (less than 16 micron diameter) are shown over the full lake depth for 2017. From May until the end of the year, a distinct, high concentration layer of fine particles, those causing the loss in clarity, is evident.



Fine sediment distribution in 2017.

CURRENT RESEARCH

Lake clarity in 2017, continued

Conclusion

In 2017, Lake Tahoe's low clarity was primarily the result of the coincidence of two extreme climatic and hydrologic events. There are likely other factors at play that are producing changes in the behavior and response of the lake, such as the warming of the lake and an alteration to the mixing regime due to the impacts of a changing climate. As such, the clarity value for 2017 may be seen as an anomalous value and should not be considered as representing the underlying long-term trend. Clarity data for the first six months of 2018 appear to confirm this, with the "regular" Lake Tahoe range of clarity readings returning.

Photo: N. McMahon

CURRENT RESEARCH

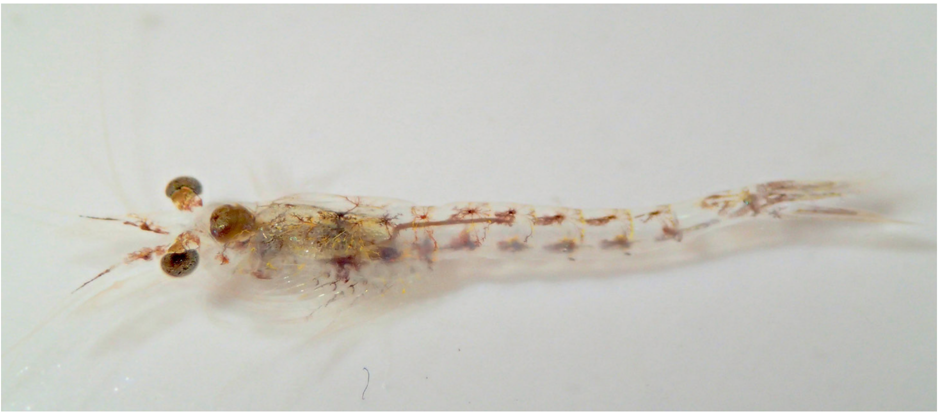
The nexus between invasive species and lake clarity

Pilot project in Emerald Bay

During a six-year study (2011-2016) funded by private donors, TERC researchers were able to chronicle a doubling of clarity in Emerald Bay. This clarity improvement was coincident with the disappearance of the introduced Mysis shrimp and the return of the native zooplankton, Daphnia.

This occurrence presented two intriguing questions. First, were Mysis shrimp having a large impact on clarity through their intense grazing of algae-eating Daphnia? The answer to that appears to be yes. Second, is it possible to harvest Mysis to the point where Daphnia can return throughout the lake and help with the restoration of lake clarity? These answers are being addressed in an ongoing pilot project.

The 2018-2020 pilot project is being funded by the California Tahoe Conservancy and the Nevada Division of Environmental Protection. It entails the location and quantification of the Mysis shrimp in Emerald Bay using echosounding technology, and then removal of Mysis using a custom-designed trawl net. Prior research has shown that the Mysis only have to be reduced by 50-70% for Daphnia to return.



A Mysis shrimp (actual length 1/2 inch).

A Mysis trawl net being tested in Lake Tahoe.

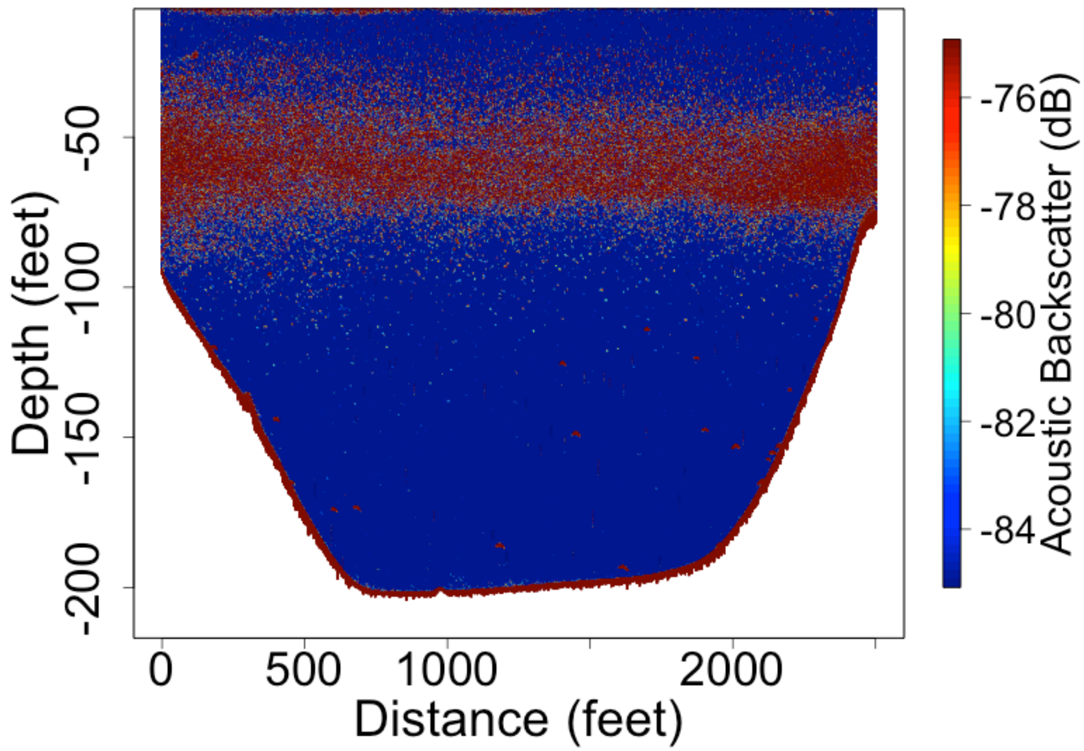
CURRENT RESEARCH

The nexus between invasive species and lake clarity, continued

Pilot project in Emerald Bay

While this sounds simple enough, the real challenge is presented by the daily, vertical migration that the Mysis shrimp undertake. To avoid predation, Mysis spend daylight hours on the lake bottom, and then swim toward the surface at night. The figure below produced by a Biosonics Echosounder shows the location of the discrete band of Mysis shrimp in Emerald Bay close to midnight. This image shows researchers precisely the depth at which the trawl net needs to be maintained in order to intercept the largest concentrations of Mysis shrimp during nighttime removal.

While undertaking this research is proving to be arduous, the potential it holds for restoring lake clarity is tremendous.



An echogram showing the location of a band of Mysis shrimp in Emerald Bay at midnight, The peak of their distribution is at a depth of 60 feet.

CURRENT RESEARCH

Project UPWELL

A collaboration on lake physics

In the spring of 2018, TERC graduate student Derek Roberts led a collaboration of researchers from UC Davis Civil and Environmental Engineering, Bodega Bay Marine Laboratory, Stanford University, and the University of British Columbia in a first-of-its-kind experiment in the nearshore region of a lake. The overarching goal of UPWELL (**U**pwelled **P**elagic **W**ater **E**xchange driving **L**ittoral **L**imnology) experiment, was to document the rising and falling of deep, nutrient-rich water on Lake Tahoe's west shore, and to ascertain its impact on the growth of algae on shoreline rocks (periphyton).

A 1.5 mile wide "measurement curtain" was installed in the lake from the shoreline toward the center of the lake. Pre-programmed instruments were deployed at seven moorings along the curtain, the shallowest near the shoreline at 7 feet and the farthest offshore at almost 900 feet depth. Temperature, current velocity, and dissolved oxygen measurements were taken every 30 seconds in order to resolve the upwellings that were driven by the strong spring winds. An autonomous, underwater glider was used to collect data along the shoreline to examine how variable the upwelling was along the west shore. Water samples were taken for nutrient concentrations before, during, and after upwelling events.

One of TERC's real-time Nearshore Water Quality Stations (right) with a newly installed Acoustic Doppler Anemometer (left) for turbulence measurements during UPWELL. The instruments were at 6.5 feet depth. Notice the heavy periphyton growth covering the rocks. Photo: B. Allen

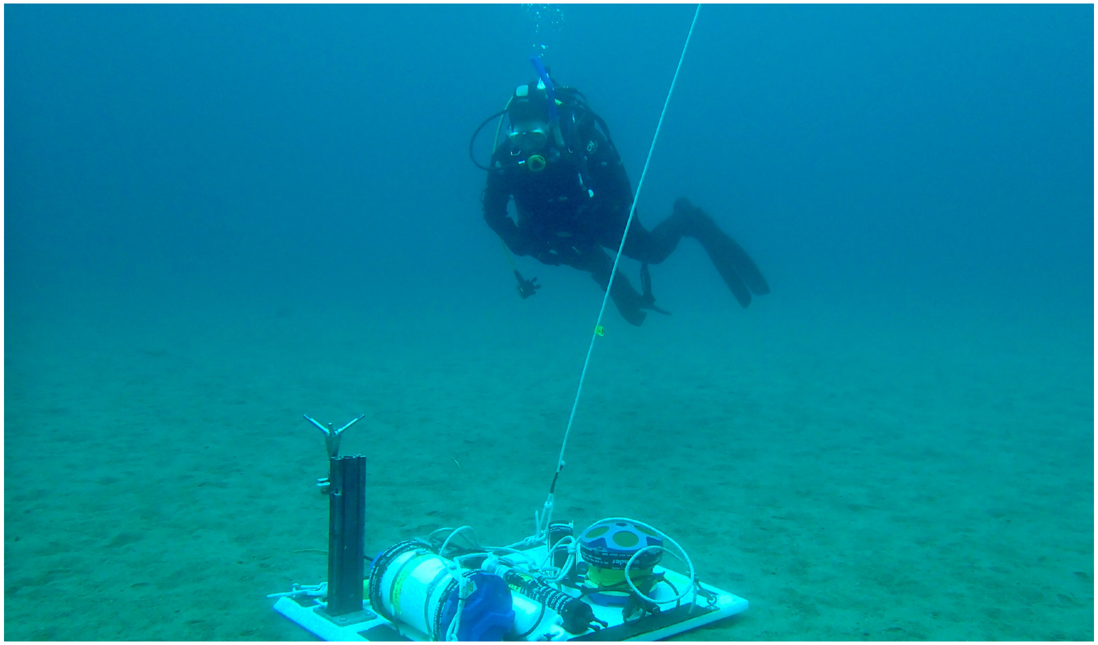
CURRENT RESEARCH

Project UPWELL, continued

A collaboration on lake physics

The experiment was motivated by data from the TERC Nearshore Network of water quality instruments. The network has shown that an upwelling event can bring water 1,000 feet deep, up to the surface of the lake, but how this process stimulates periphyton growth is not well understood.

The instruments were recovered and the data were downloaded in June 2018, and for the next six months these data will be analyzed in great detail. But even after an initial look, it is clear that our understanding of upwelling dynamics has been advanced. The experiment was able to document two major and two minor upwelling events. During the major events (May 31 and June 9), water from as deep as 500 feet rose to the surface along the west shore in a matter of several hours, dropping west shore temperatures to a frigid 40° F while the east shore remained a balmy 57° F. The upwelling ended with a rapid transition to a downwelling. After the wind died down, the cold water rushed back down the west slope of the lakebed and warm water from the east shore surged back across the lake surface. The speed of this water was in excess of 2 feet per second (1.5 mph).



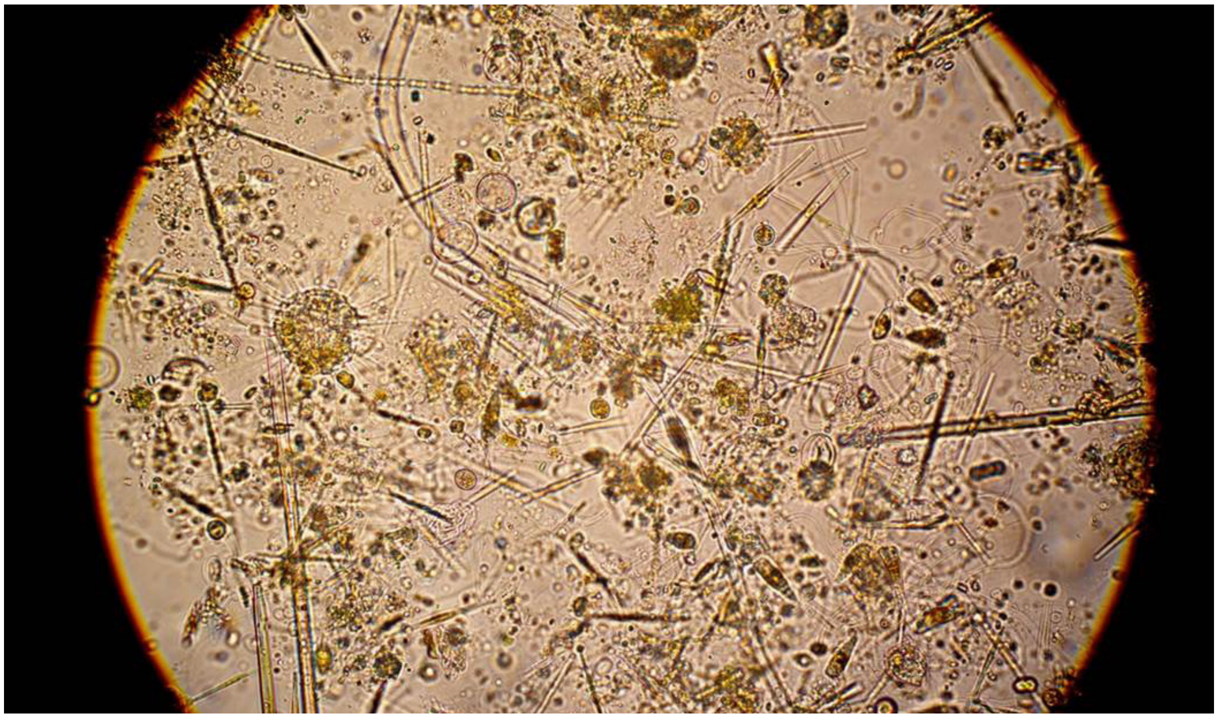
A diver inspects UPWELL instruments at 33 feet depth. The Acoustic Doppler Current Profiler (right) measures currents between the bottom and the surface. The Acoustic Doppler Velocimeter (left) measures current turbulence near the bottom. Photo: B. Allen

CURRENT RESEARCH

Where does the nearshore end?

Periphyton diversity

Periphyton, or attached algae, can make lake rocks slippery and green. To help understand the distribution of conditions that favor growth, TERC graduate student Karen Atkins deployed growth surfaces for periphyton at different depths and distances from the shore. The periphyton colonized and grew on the surfaces during two months of spring, their peak growing season. At the end of the experiment, the taxonomy and quantity of algae was assessed from nearly 80 substrate surfaces.



An example of the diversity of the alga in a periphyton sample. Those shown here include *Golenkinia, Cyclotella*, *Gomphoneis*, and *Synedra*. The diameter of the view is approximately 0.6 mm. Photo: K. Atkins

CURRENT RESEARCH

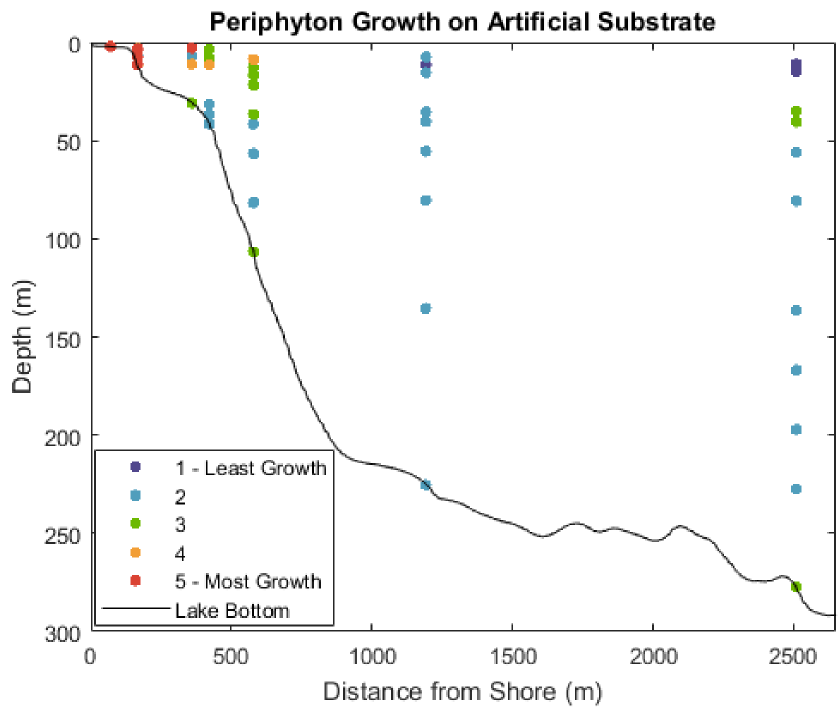
Where does the nearshore end?, continued

Periphyton growth

The outcome of a visual growth assessment is shown below. A rating of 5 indicates that the algae colonizing the substrate grew to a large mass that included filamentous strands. By contrast, surfaces exhibiting a rating of 1 had no visible algae and did not feel slick with a biofilm.

The results showed that periphyton growth is highest at the surface, toward the nearshore. The growth toward the surface was not unexpected, as the periphyton require light to photosynthesize. What was surprising was the Level 3 growth at depths down to 40 m (130 feet). Also surprising was the observation that conditions favoring high growth (Level 3 and 4) extend to over 500 m (1,650 feet) from the shore, corresponding to a depth at this west shore site of about 100 m (330 feet).

These findings help researchers better understand the sources of nutrients that are driving excess periphyton growth in the nearshore. With this information we can better advise agencies about the best strategies for managing the nearshore environment.



The dots indicate the locations of deployed growth surfaces coinciding with individual UPWELL instruments. The colors refer to the degree of growth.

CURRENT RESEARCH

Forest health

Ecology and evolution

The iconic sugar pine experienced mortality in large parts of the Tahoe Basin during the recent drought. What are some of the ecological and evolutionary consequences of this?

There will likely be shifts in species composition and structure, as well as genetic shifts.

Is climate change already exerting a selective pressure for drought resilient forest trees? In our reforestation of sugar pine, we purposefully chose those sugar pine trees that survived drought and avoided attack by mountain pine beetle.

Mountain pine beetles (pictured above) are responsible for killing sugar pine above Crystal Bay, Nevada (pictured to the right). Photos: P. Maloney

CURRENT RESEARCH

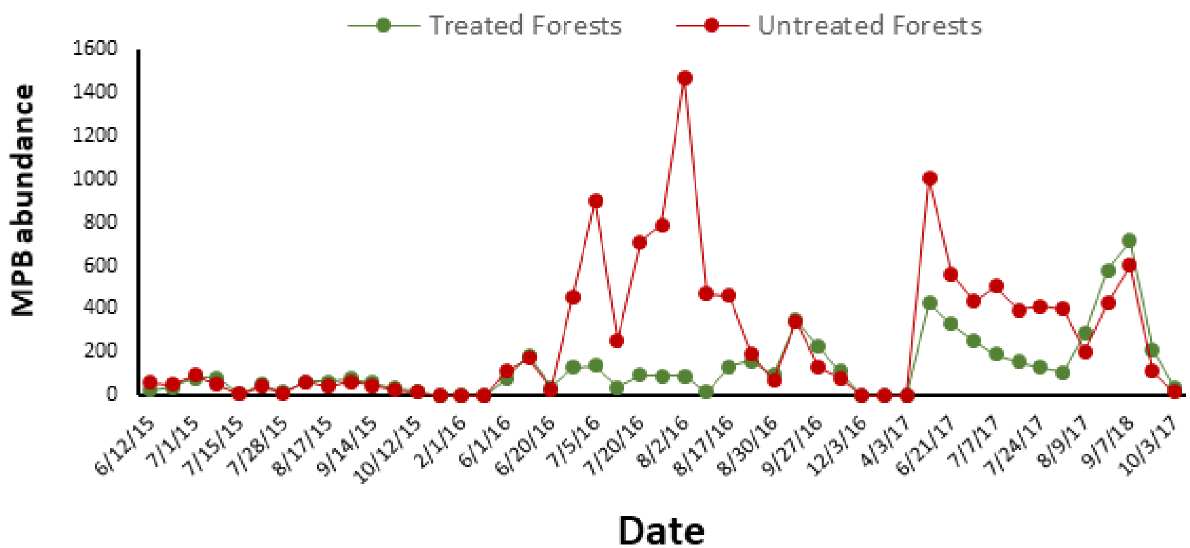
Forest health, continued

Host-bark beetle interactions

Mountain pine beetle (MPB) numbers (abundance) peaked in 2016 in the Lake Tahoe Basin. Bark beetles such as MPB are known to preferentially attack drought-stressed trees. Trees have a physical-based defense by producing resin or "pitching out."

Tree chemistry can either defend against bark beetle attack or aid beetles in locating a suitable host tree. When trees in the Sierra Nevada are drought stressed, they can emit chemicals such as ethylene that signal tree vulnerability when detected by MPB. TERC's forest biology lab is exploring the relationships between tree physiology, water-use efficiency, and susceptibility to MPB. Preliminary findings show that sugar pine trees that are more water-use efficient, and perhaps better adapted to drought, survived the recent MPB outbreak. In contrast, those sugar pines killed by MPB utilized water less efficiently and were most susceptible to MPB attack.

Forest surveys have shown the value of active forest management. Stands that receive no treatments such as thinning or prescribed fire had much higher numbers of MPB compared to stands that received treatments.



The impact of forest treatments on the abundance of MPB.

A sugar pine "pitching out" a mountain pine beetle. Drought-stressed trees are limited in their ability to do this. Photo: P. Maloney

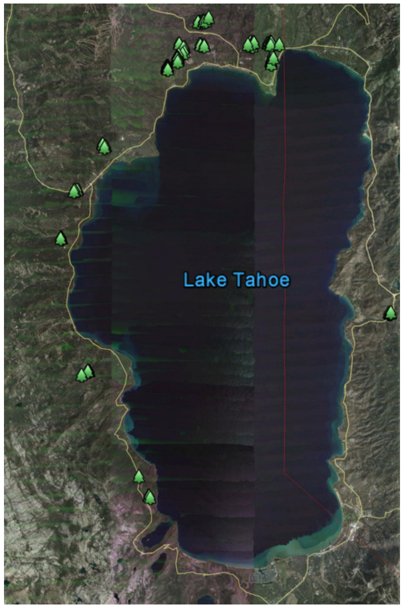
CURRENT RESEARCH

Forest health, continued

Reforestation

One solution to drought-mediated mortality is to reforest stands for bark beetle outbreak resilience. Despite high levels of sugar pine mortality, there were numerous surviving sugar pine trees on the north shore of the Lake Tahoe Basin. In September 2017, TERC's forest and conservation biology lab collected from 100 local and diverse seed sources mainly on the North Shore of Lake Tahoe. The seeds were germinated at the USDA Forest Service Placerville Nursery. The seedlings will be relocated to our Tahoe City Field Station in spring 2019.

Sugar pine reforestation will allow us to improve sugar pine population and facilitate sugar pine regeneration in mountain pine beetle impacted stands. This work is supported by the Tahoe Fund and the California Tahoe Conservancy.



Sites of seed collections.

Collecting cones at Incline Lake. Photo: P. Maloney

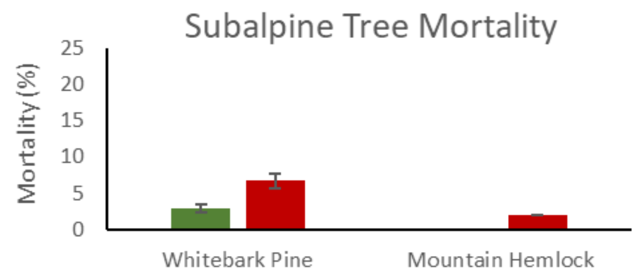
Sugar pine seedlings at Placerville nursery. Photo: P. Maloney

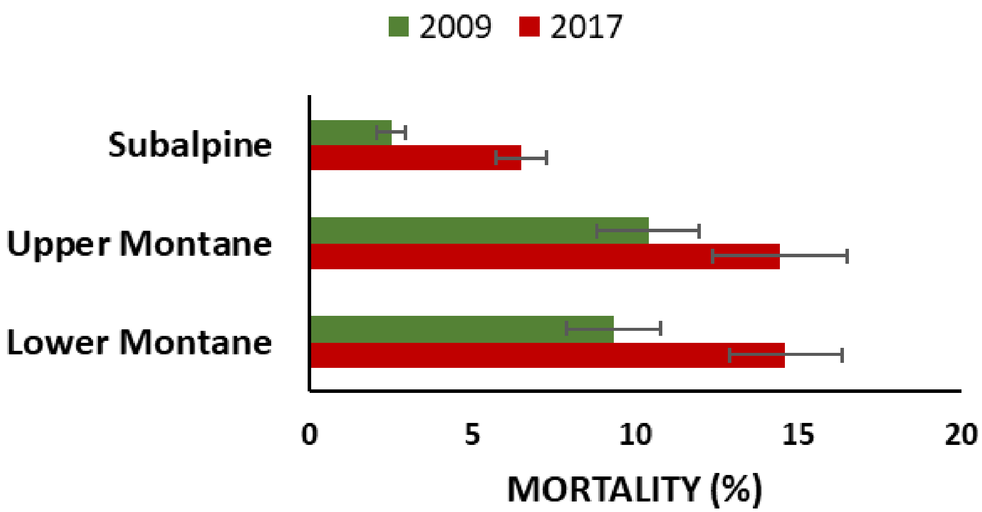
CURRENT RESEARCH

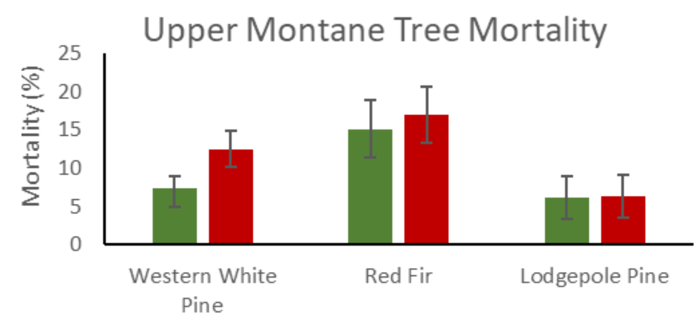
Forest health, continued

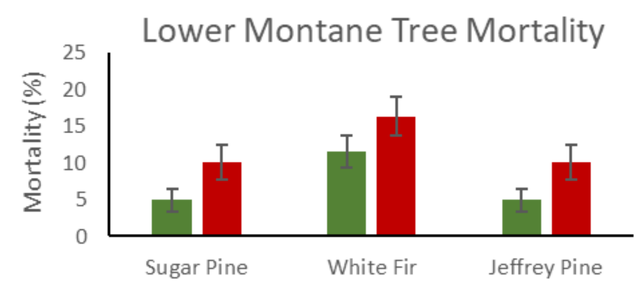
Tree mortality

In 2017, TERC's forest and conservation biology lab resurveyed a network of 84 long-term monitoring plots in the Lake Tahoe Basin to determine tree mortality across three elevation zones. On average, we found a 5% increase in cumulative tree mortality across all three elevation zones in between the two survey periods (2009 & 2017). Average tree mortality increased from 9% to 15%, 10% to 14%, and 2% to 6% in lower montane, upper montane, and subalpine forests, respectively. Primary causes of mortality were bark beetles, pathogens, and drought stress.









CURRENT RESEARCH

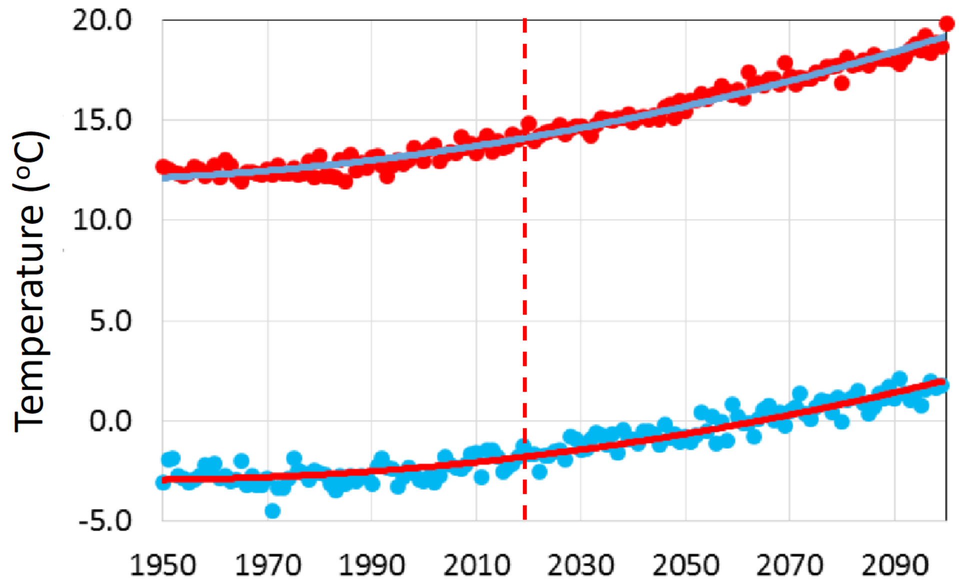
This is not your grandparents' climate

Climate modeling - air temperature

As part of its ongoing focus on climate change impacts on the Lake Tahoe watershed, TERC has been analyzing sets of future climate scenarios. The climate scenarios were produced by a research team from the Southwest Climate Center (SWC) as part of the project "Development, delivery, and application of data on climate extremes for the southwestern United States."

TERC's team of Goloka Sahoo, Robert Coats, Zack Coats, Jack Lewis, Mariza Costa-Cabral, and Geoff Schladow have been working with funding support from the California Tahoe Conservancy. The project will provide a set of climatic and hydrologic conditions for the Tahoe basin that capture the range of extreme events possible in the next one hundred years, based on the SWC projections. The information will assist in the planning and design of watershed restoration and stormwater projects.

The initial results are showing that the Lake Tahoe basin will be considerably warmer in the future. The figure below shows the average of daily maximum temperatures and minimum temperatures, averaged by year across the Basin for the modeled historic (1950-2005) period and the modeled future (2006-2100) using the future carbon scenario RCP 8.5. The results suggest a 9 °F (5 °C)rise in air temperature between now (dashed vertical line) and the end of the century for the maximum and a 7 °F (3.9 °C) rise for the minimum temperatures.



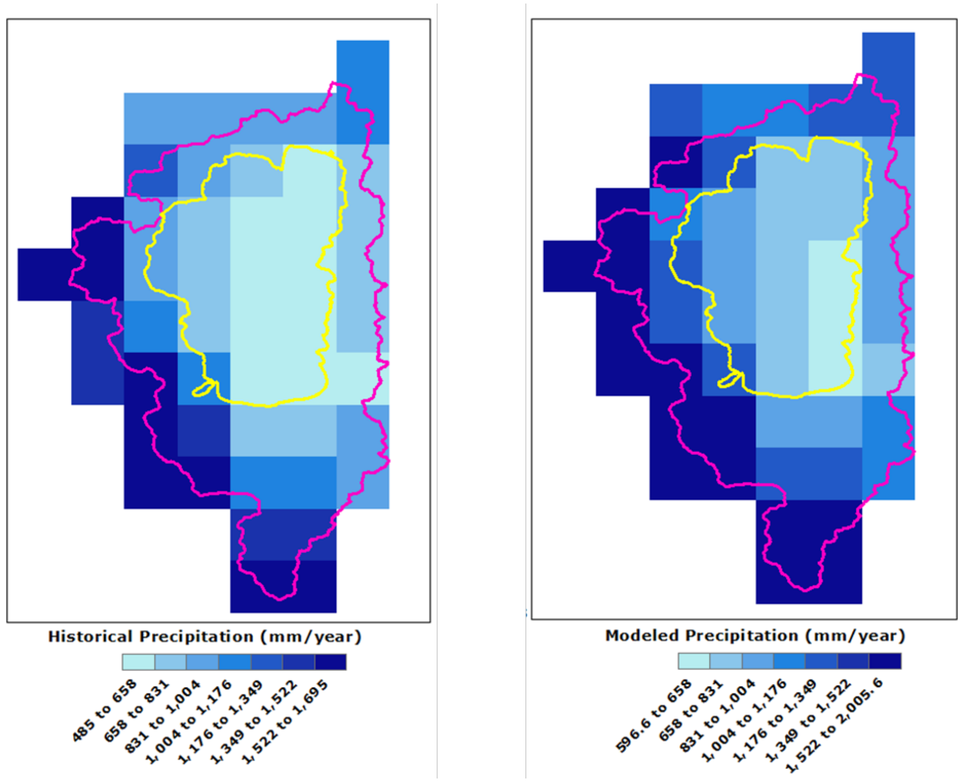
The trend of maximum and minimum temperatures averaged over the Tahoe Basin under RCP 8.5 for an ensemble of four models.

CURRENT RESEARCH

This is not your grandparents' climate, continued

Climate modeling - precipitation

Under the influence of climate change, the expected difference in the Lake Tahoe Basin's precipitation will be small, but statistically significant. Despite this increase in precipitation, the projected warmer air temperatures will mean that there will be less snow, continuing the historic measured trend (see page 7.7). The figure below compares the modeled historical precipitation 1950 to 2005 on the left, to the mean of a four-model ensemble of expected precipitation from 2070 to 2099 on the right. The expected rain shadow is present in both, with higher precipitation evident on the west side of the lake.



The modeled historical precipitation from 1950 to 2005 is on the left. The predicted precipitation from 2070 to 2099 is on the right. Both represent the mean values from a four-model ensemble.

CURRENT RESEARCH

This is not your grandparents' climate, continued

Climate modeling - climatic water deficit

The basin will also be drier in the coming decades. The "climatic water deficit" (CWD) is a measure of the amount of additional water that would have evaporated or transpired had it been present in the soil.

The figures below show the differences in CWD for the period 1950-2005 to the period 2070-2099. CWD can be seen to increase throughout the basin, and by over 100% on the north and east sides of the basin.

As the CWD increases, it leads to a drying of the forest soils and added stress to the forest. Such stress makes trees more prone to disease and insect attack, as well as increasing the wildfire hazard.

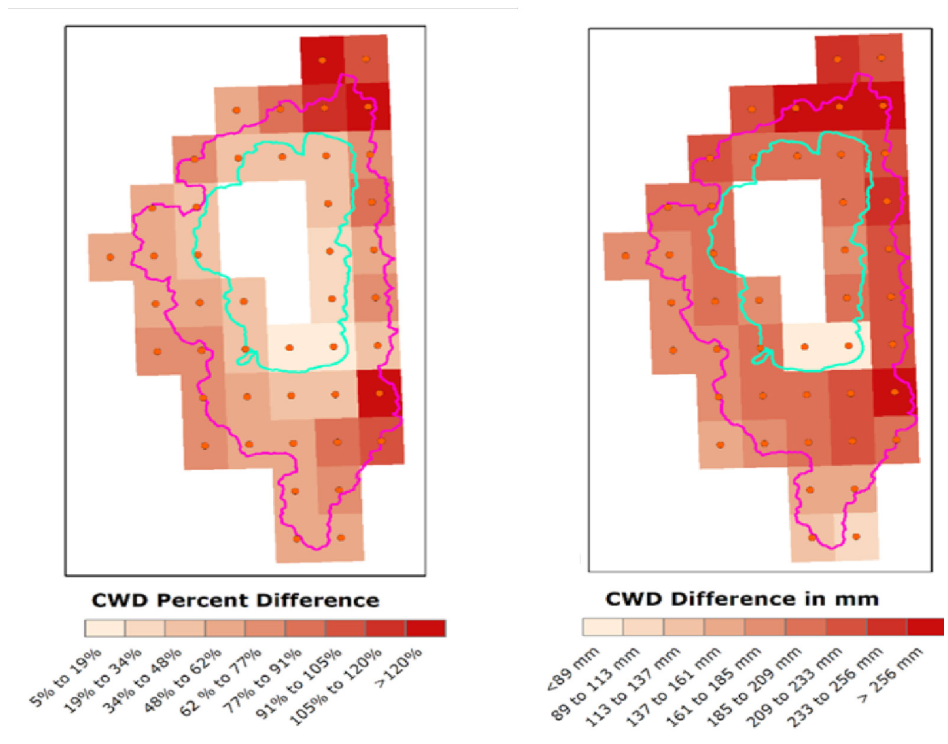


Figure 3 The difference in the spatial distribution of "climatic water deficit" (CWD) between the period 1950-2005 and 2070-2099.

CURRENT RESEARCH

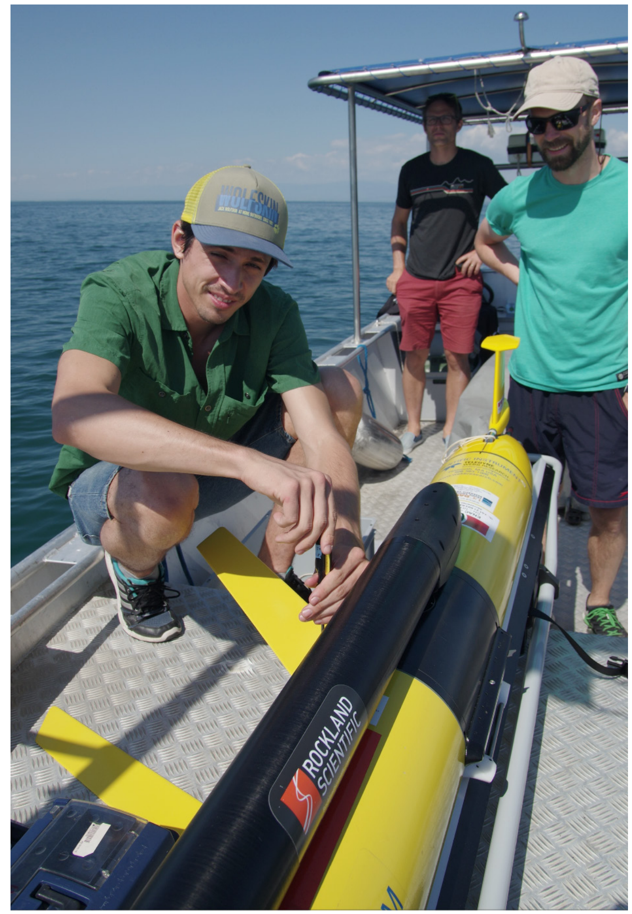
What goes around, come around

A comparative study of two lakes

Gyres, or large-scale circulations, occur in Lake Tahoe and other large lakes. They are important because they can rapidly transport contaminants across the lake. How much they dilute contaminants requires an understanding of turbulence.

Researchers from TERC, led by Alex Forrest, are collaborating with the École Polytechnique Fédérale de Lausanne (EPFL, Switzerland) to measure turbulence in gyres in Lake Geneva using the UC Davis underwater glider. A newly acquired Rockland Scientific Microstructure sensor, mounted to the front of the glider, provides the very rapid measurements (512 measurements per second) of temperature which can be used to determine the turbulence level.

Next summer the measurements will be repeated in Lake Tahoe as the second part of this comparative study. Lake Geneva is where François-Alphonse Forel founded the field of limnology. Forel corresponded with John LeConte, the first limnologist at Lake Tahoe and the first professor hired by the University of California.



Oscar Sepúlveda mounting the microstructure package onto the glider at Lake Geneva. Photo: A. Bahr