TAHOE: STATE OF THE LAKE REPORT 2021

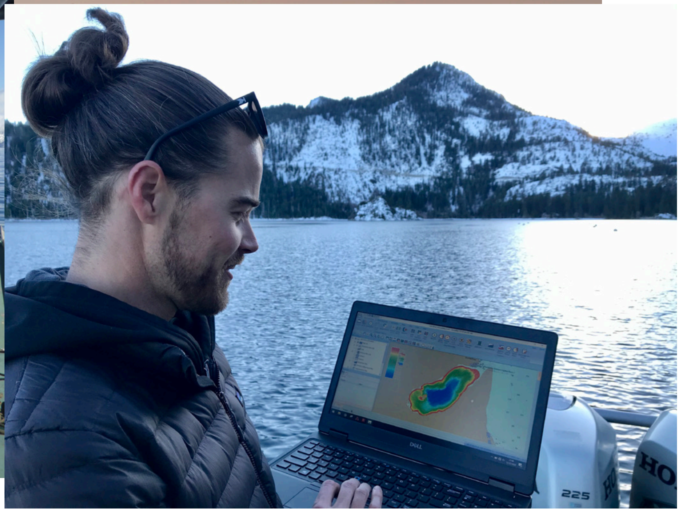
CURRENT DIRECTIONS

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. These monitoring data are an invaluable resource for assessing the impact of changes that have occurred due to anthropogenic factors and to natural variability.

Additionally, we engage in focused and often 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 for context, but it is distinctly separate. The results of this research — conducted by TERC students, postdoctoral researchers, faculty, and staff, often in collaboration with other institutions, companies and agencies — has made Lake Tahoe the smartest lake in the world, and arguably the most influential.



Photos: B. Allen, S. Hackley, and A. Toy

Current Research Synthesis, continued

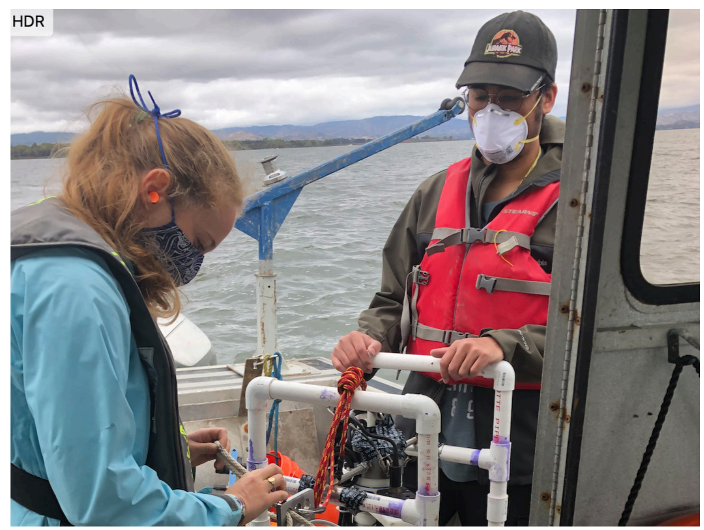
The current research summarized this year covers a broad range of areas, and much of it is the result of work conducted over the last several years. Some of the research is now complete and the results are just starting to have an influence with management and decision-making. Much of it is still underway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

- Climate Change and Some of its Future Consequences at Lake Tahoe: A brief overview of a recently completed modeling study of how climate change may impact the meteorology, hydrology, and processes within Lake Tahoe.
- Lake Tahoe's Nearshore Region: A great many factors are at play in the nearshore of Lake Tahoe. The results from a number of completed and ongoing projects are introduced here. These include the historical changes in attached algae (periphyton), new approaches to understanding periphyton growth under future climate conditions, the emerging concerns of filamentous algae (metaphyton) washing up on beaches, and dramatic changes to water color due to spring snowmelt.
- Plastics pollution at Lake Tahoe and elsewhere is finally gaining the attention it deserves. Here we describe a particularly egregious example of how easily this can occur and the grassroots solutions that are being pursued.

Photos: A. Toy and B. Allen

Current Research Synthesis, continued

- The Impacts of Wildfires on Lake Tahoe: Though there has not been a major wildfire in the Tahoe Basin since the Angora Fire of 2007, the basin is increasingly subject to transported smoke from the rapidly increasing wildfires throughout the west. 2020 was a particularly bad year, and here we consider just two of the impacts that smoke has — the measurable reductions of sunshine (solar radiation) that occurs for many days on end and the reductions of harmful UV radiation. Other impacts, such as the addition of nutrients and particulates to the water itself are part of an ongoing NSF project.
- The high temperatures and drying conditions exacerbated by climate change are having an impact on our forests. In the short-term, there are a range of strategies that TERC is exploring. These include harvesting native seeds that have demonstrated resilience to drought and insect attack, and using these genetically diverse seeds for reforestation in partnership with local and statewide agencies.
- Finally, we present a quick overview of projects that some of our graduate students and researchers are undertaking. Some of these are on topics that may seem far removed from Lake Tahoe, and others are taking place at locations far from the Sierra Nevada. They all, however, impact our understanding of what happens at Lake Tahoe and prepare us for the dramatically different conditions that we will face here in future decades.

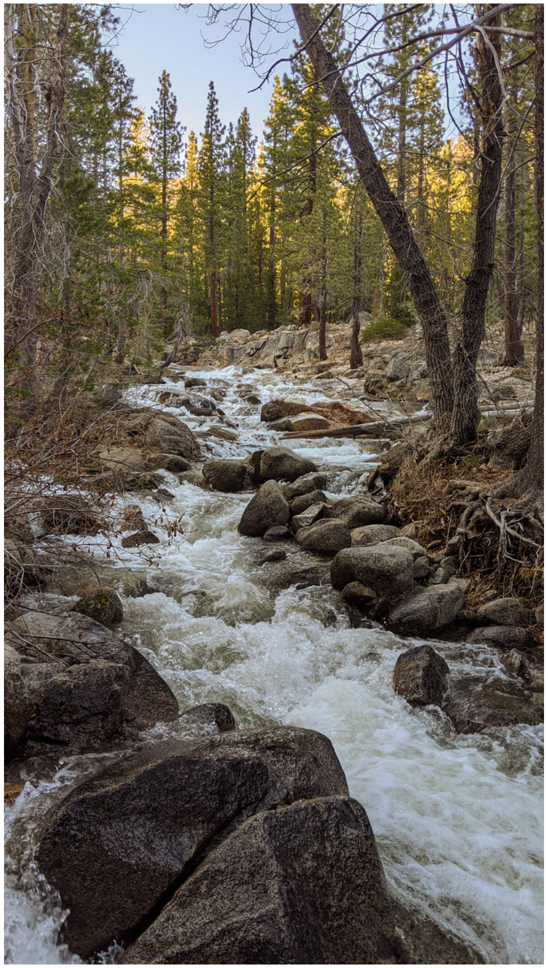


Photos: L. Bronson and M. Swann

Climate Change and Some of its Future Consequences at Lake Tahoe

The signature of climate change is strong in most of the data collected at Lake Tahoe. This is seen, not just in the air temperatures and declining snow fraction, but also in the increasing stability exhibited by the lake as well as the alterations in stream hydrology. Both California and Nevada have recognized the shared urgency of addressing future climate change. To that end, both states now utilize the same set of four future climate prediction models and the same two sets of assumptions about future levels of carbon in the atmosphere known as Representative Concentration Pathways (RCPs). RCP 4.5 and RCP 8.5 are generally recognized globally as suitable planning estimates for lower and higher levels of atmospheric carbon emissions, although current emission rates may in fact exceed those assumed under even RCP 8.5.

With funding from the California Tahoe Conservancy (CTC) a team comprised of Sean Trommer, Goloka Sahoo, Robert Coats, Jack Lewis, Zack Silber-Coats, and Geoff Schladow have been evaluating the changes that Lake Tahoe and its watershed may exhibit, due to climate change, over the period of 2006 to 2100. The evaluation predicted climate model outputs to drive watershed and lake models, and some of the results of those models are presented below. A particular emphasis was placed on quantifying the extreme conditions that climate change is expected to exacerbate. The results here mainly reflect RCP 8.5 as it is more reflective of current carbon emission levels.

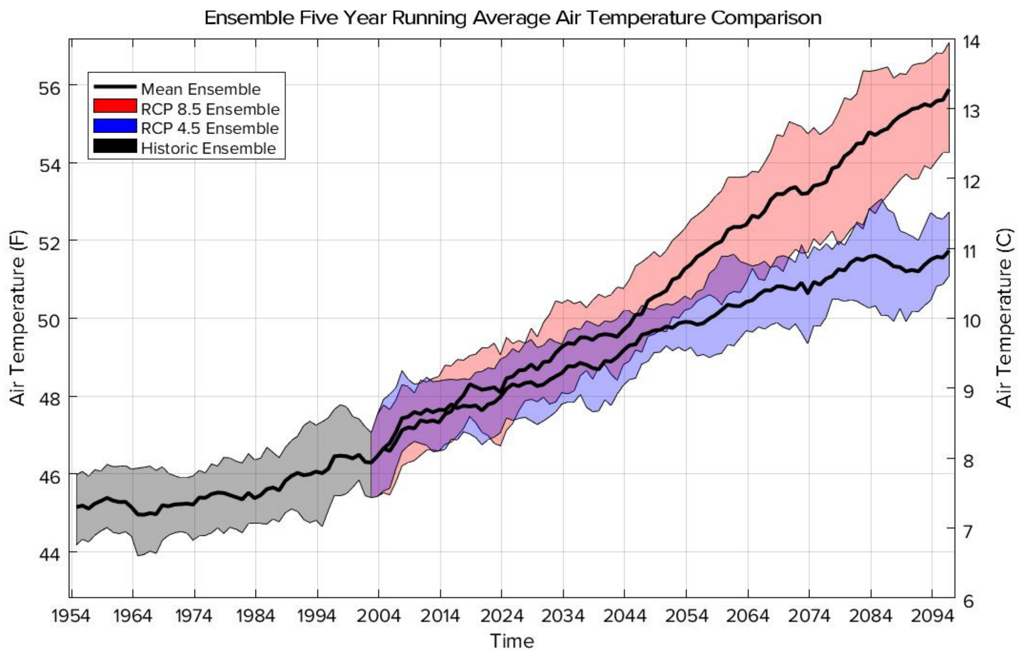


Maximum stream flows are expected to increase throughout the basin as a result of climate change. Photo: A. Toy

Climate Change and Some of its Future Consequences at Lake Tahoe, continued

Air Temperatures

The four climate models are in strong agreement that daytime and nighttime (Tmax and Tmin) air temperatures will continue to increase. The trends for Tmax and Tmin under the RCP 8.5 scenario indicate an accelerating warming trend. From 2006 to 2100, the model ensemble mean indicates an increase of 9.5 °F (5.3 °C) for both Tmax and Tmin at lake level. Note that all model results (the shaded areas) indicate predictions in the range of +/- 1.5 °F.

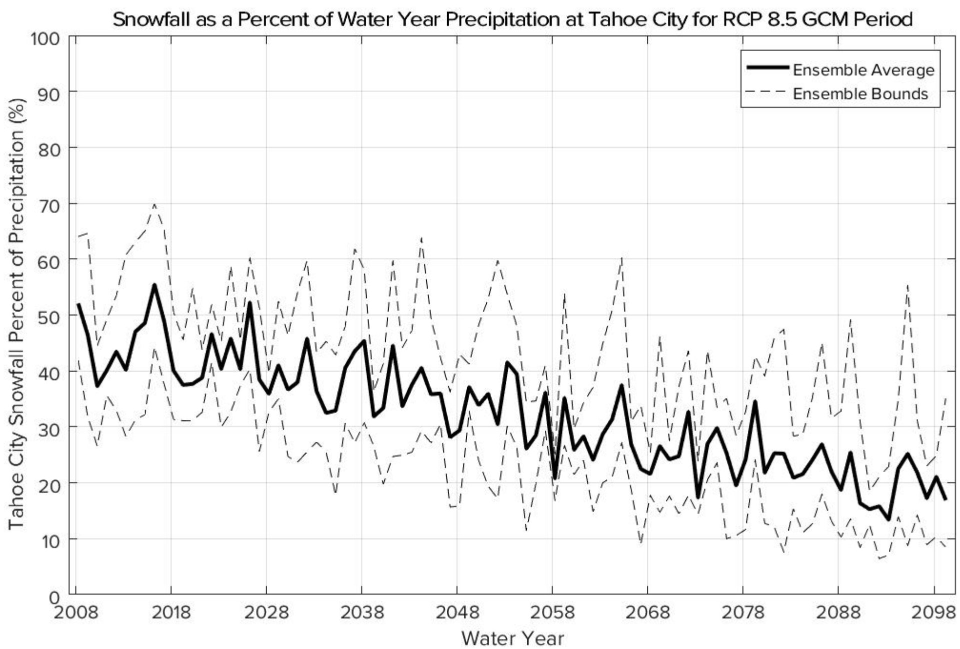


Ensemble five-year running average air temperature and range of variability for the historic, RCP 4.5, and RCP 8.5 scenarios at lake level. The ensemble average for each scenario is shown with a solid black line while the range for all scenarios is shown with a shaded region.

Climate Change and Some of its Future Consequences at Lake Tahoe, continued

Percent of Precipitation Falling as Snow

The results for all model-scenario combinations indicated downward trends in the percent of precipitation falling as snow. Over the past monitoring record, the percent of precipitation falling as snow at Tahoe City has declined at a rate of 1.76 percent per decade. All models under RCP 8.5 predicted a shift at Tahoe City at double the historic trend. For the entire Basin, the average decline rates were only slightly lower than the rates at Tahoe City (at lake level). The ensemble bounds in the figure indicate both the potential magnitudes of extreme years (high and low snow) as well as the expected interannual variability.

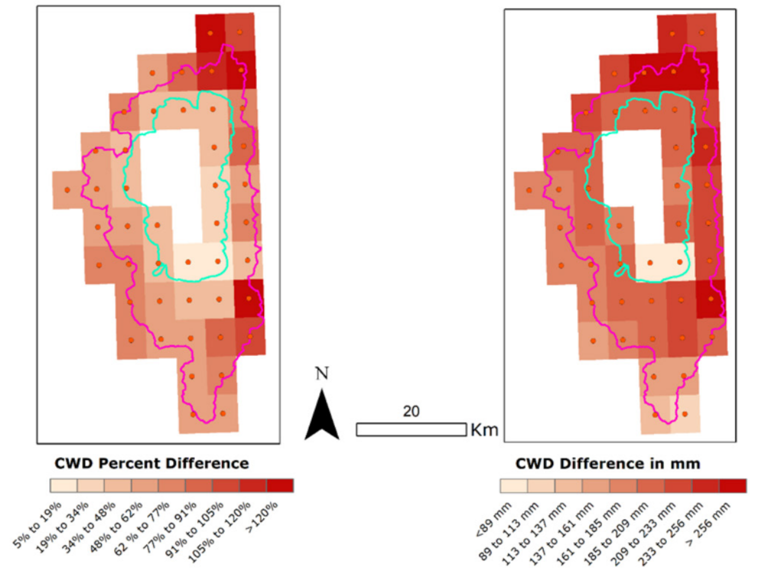


Ensemble average and range (bounds) of snow as a fraction of water year precipitation at Tahoe City for RCP 8.5.

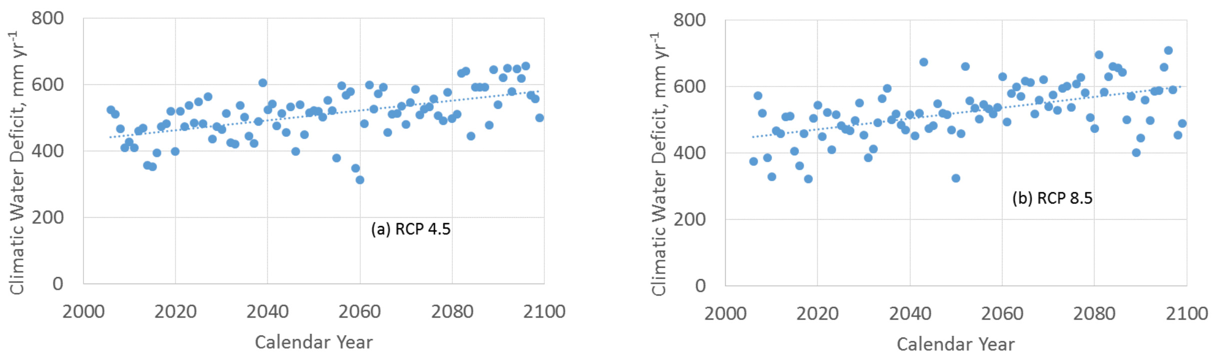
Climate Change and Some of its Future Consequences at Lake Tahoe, continued

Drought Intensity

Drought conditions are expected to intensify in the coming decades. The Climatic Water Deficit (CWD) is the calculated annual evaporative demand that exceeds available water. It integrates climate, energy loading, drainage, and changes in soil moisture in a single variable, and is considered to represent the terrestrial ecological impacts of climate change. There is an upward annual projected CWD trend for both RCP 4.5 and RCP 8.5 for three of the four models (the outlier model also predicts much higher future precipitation which accounts for this result). Spatially, the increase in CWD is higher along the drier east side of the Basin, where soils are relatively poor and Available Water Capacity is low.



The modeled geospatial change in CWD from 1950–2005 to 2070-2099, for the average of the four models under RCP 8.5. On the left is the percent change and on the right is the absolute change in mm per year.



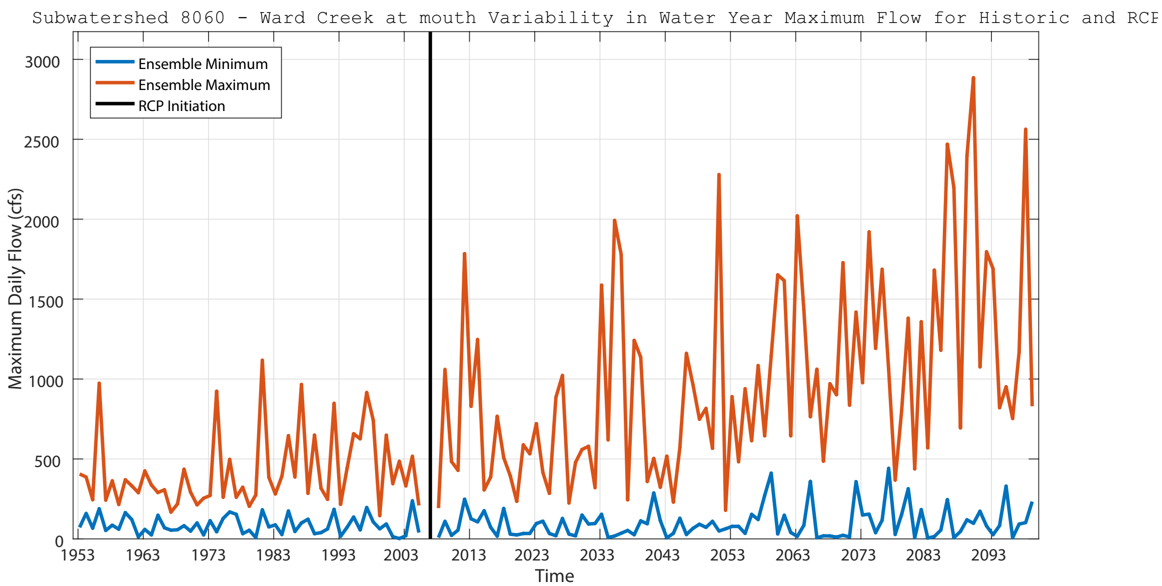
Annual Climatic Water Deficit, averaged across the Tahoe Basin and for all four General Circulation Models. The figure (left) is for RCP 4.5 and the figure (right) is for RCP 8.5.

Climate Change and Some of its Future Consequences at Lake Tahoe, continued

Maximum Daily Stream Flow Rate

Largely on account of more precipitation falling as rain rather than snow and the loss of storage in the snowpack, maximum stream flows are expected to increase dramatically. Similarly, due to the overall drying conditions, the minimum flows are expected to decrease. As an example, the anticipated flow at the mouth of Ward Creek, CA, are shown.

The red line shows the annual maximum daily flow for the ensemble average for all four GCMs under RCP 8.5. The blue line shows the corresponding minimum annual flows. The main feature that emerges is the overall rise in maximum streamflow, with some years indicating flows in excess of 2500 cubic feet per second (cfs). Such flows would almost certainly result in flooding and infrastructure damage. It is important to bear in mind that the lines are the averages of all four models and are the average daily flows. Individual model results display even greater extremes and substantially higher instantaneous flowrates within a day.

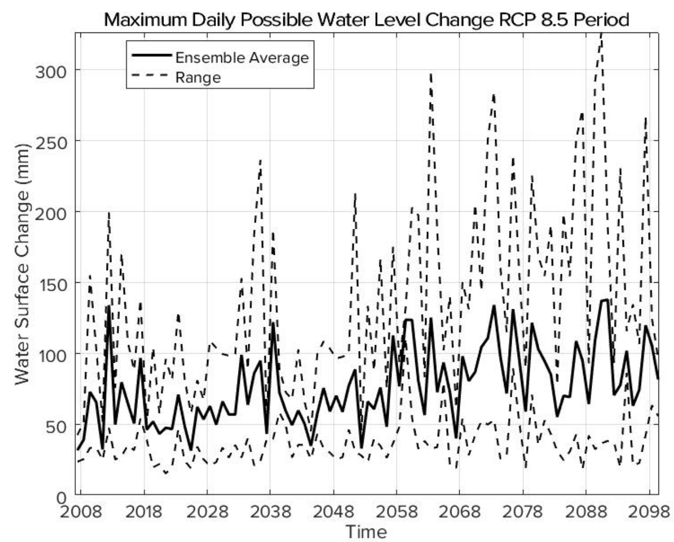


Variability in annual maximum daily flow rates between the four GCMs for Ward Creek under RCP 8.5. The vertical black line separates the modeling of the historical period (to the left) from the modeling based on future climate model projections that began in 2006.

Climate Change and Some of its Future Consequences at Lake Tahoe, continued

Lake Level

It is not possible to predict the future water level of Lake Tahoe as it is very dependent on how releases from the dam at Tahoe City are managed in the future. However, based on the expected peak stream inflows for all streams, it is possible to estimate the potential lake levels in extreme future years. The figure below shows the result for the average of all four climate models under RCP 8.5 and the maximum and minimum values from the full set of models. The results suggest that while the future mean lake level rise is four inches per day, the extreme values of individual models should be the focus of management concerns. Each of the individual model results is based on the current state of knowledge of climate change and hydrology, and must be, at a minimum, considered plausible. Those extreme values are for water level rises as great as one foot (300 mm) per day. With only six feet separating the lake's natural rim and the top of the dam that holds back the water, the risks of overtopping of the dam at increasing frequencies in the future should be taken into consideration with greater urgency. Under those predicted rapid water level increase rates, the release rate of the dam would be insignificant in affecting the rise, and the capacity of the Truckee River unable to accommodate the ensuing release.

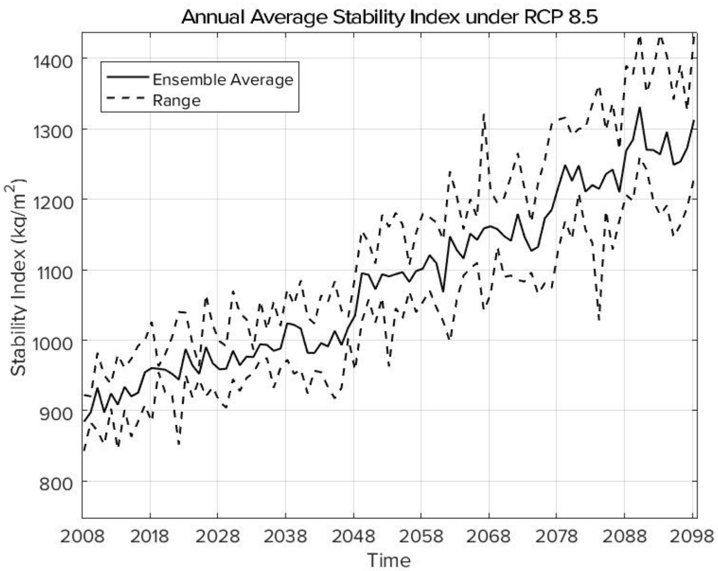


The largest single day water level rise each year under RCP 8.5. Results are shown as both the average value of all four models (solid line) and the maximum range of variability for the individual models (dashed lines).

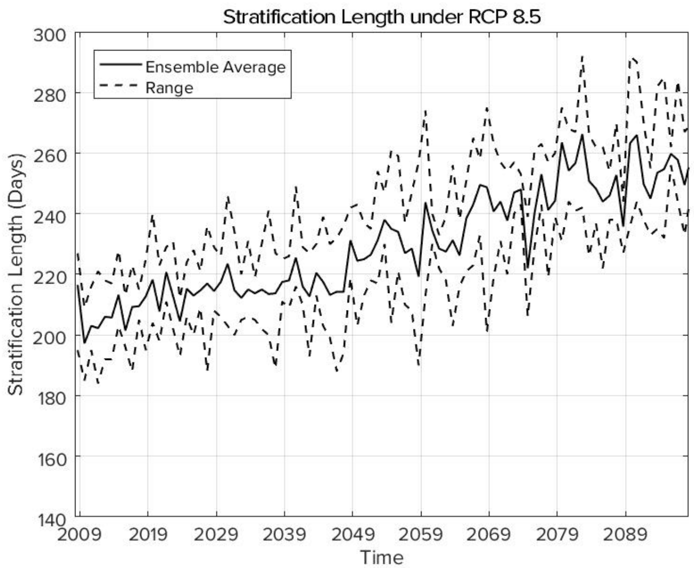
Climate Change and Some of its Future Consequences at Lake Tahoe, continued

Lake Stability

The hydrodynamic stability of Lake Tahoe (its resistance to vertical mixing) has been quantified with the stability index (SI). Under RCP 8.5, the average stability index increases at a rapid rate through the end of the century. While the duration of stratification for Lake Tahoe has increased by approximately 30 days in the last 50 years, the ensemble average length of stratification is anticipated to increase by an additional 50 days under RCP 8.5.



Mean annual average stability index average across all climate models for RCP 8.5 (solid line). Variability between the individual models is shown by the maximum and minimum value for each year (dashed lines).

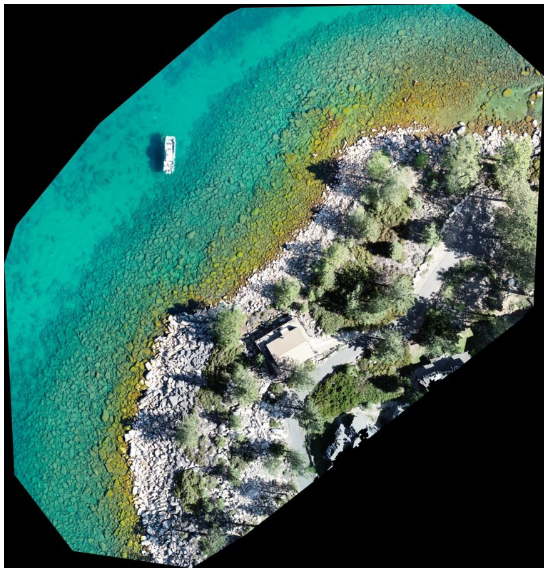


Mean length of stratification across all GCMs for RCP 8.5 (solid line). Variability between the individual models is shown by the maximum and minimum value for each year (dashed lines).

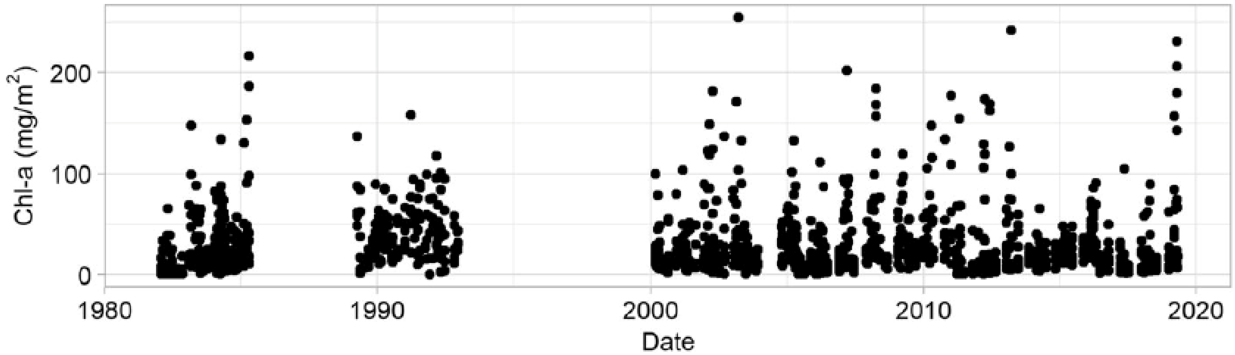
Lake Tahoe's Changing Nearshore Region

The nearshore of a lake is the most complex region. Streams, urban drains, and groundwater enter the lake in the nearshore zone. Most recreation occurs near the shoreline, making it more prone to the introduction of pathogens, non-native species, and other contaminants such as plastics. This complexity exhibits itself through the variations in the rates of change of water quality indicators. Such changes can vary across time scales from decades, seasons, and even to hours and days, making monitoring and research all the more challenging.

In the pages that follow, we summarize some of the research that is being conducted on Lake Tahoe's nearshore and present some of the preliminary findings.



A fringing band of brown, stalked diatoms are attached to rocks at Zephyr Point, NV. Orthomosaic: B. Berry



Periphyton chlorophyll a measured at 20 inches below the surface from all sampling stations showing the long-term stability of periphyton biomass. From: K. Atkins

Lake Tahoe's Changing Nearshore Region, continued

Periphyton – The Historical Record

Periphyton, or the brownish algae attached to the rocks around Lake Tahoe's nearshore, is receiving increasing attention due to anecdotal reports of increasing bloom frequency and severity. Periphyton blooms may be increasing globally in response to climate warming and changes in nutrient inputs to lakes, a pattern that is potentially concerning since they can decrease both water quality and the aesthetic value of nearshore areas.

Recent PhD graduate Karen Atkins has published a research article that summarized UC Davis' data on periphyton on rocks collected over the last 40 years from around the entire shoreline. While there were large year-to-year variations, for the entire period of monitoring, the periphyton biomass has not increased around Tahoe, a result that has surprised many. The most likely reason is that a large increase occurred in the 1960s and 1970s prior to the commencement of monitoring. This is consistent with the memories of many long-time residents, who recall "gin clear" boulders on the shoreline during the 1950s and 1960s.

Despite this long-term consistency in the biomass of periphyton, Lake Tahoe may still be changing. For example, in the last two years, TERC researchers have made new observations. Mysterious underwater "rings" have appeared on rocks at several locations around the lake. This new phenomenon may be an area for future UC Davis research.

Stalked diatoms attached to shoreline rocks. Photo: B. Allen

"Rings" have been observed near the shoreline at many sites around Lake Tahoe. Photo: B. Allen

Lake Tahoe's Changing Nearshore Region, continued

Periphyton – Current Research on Factors Regulating Growth

Measurements and modeling of the impact of climate change suggest that the nearshore environment will be changing at an ever-increasing rate in future decades. The expected warming water temperatures and earlier influx of high stream nutrient concentrations will definitely drive changes in the lake biota.

In order to better understand the impact of these factors on periphyton blooms in Lake Tahoe, PhD student Nick Framsted is examining the role of temperature, nutrients, and their interactive effects on periphyton metabolic rates. By measuring changes in dissolved oxygen in sealed incubation chambers containing rocks collected from the nearshore, he is quantifying the rates of gross primary production (GPP), ecosystem respiration (ER), and net ecosystem production (NEP). These metabolic rates provide information about periphyton growth and growth efficiency.

Laboratory setup for periphyton metabolism experiments. Photo: N. Framsted

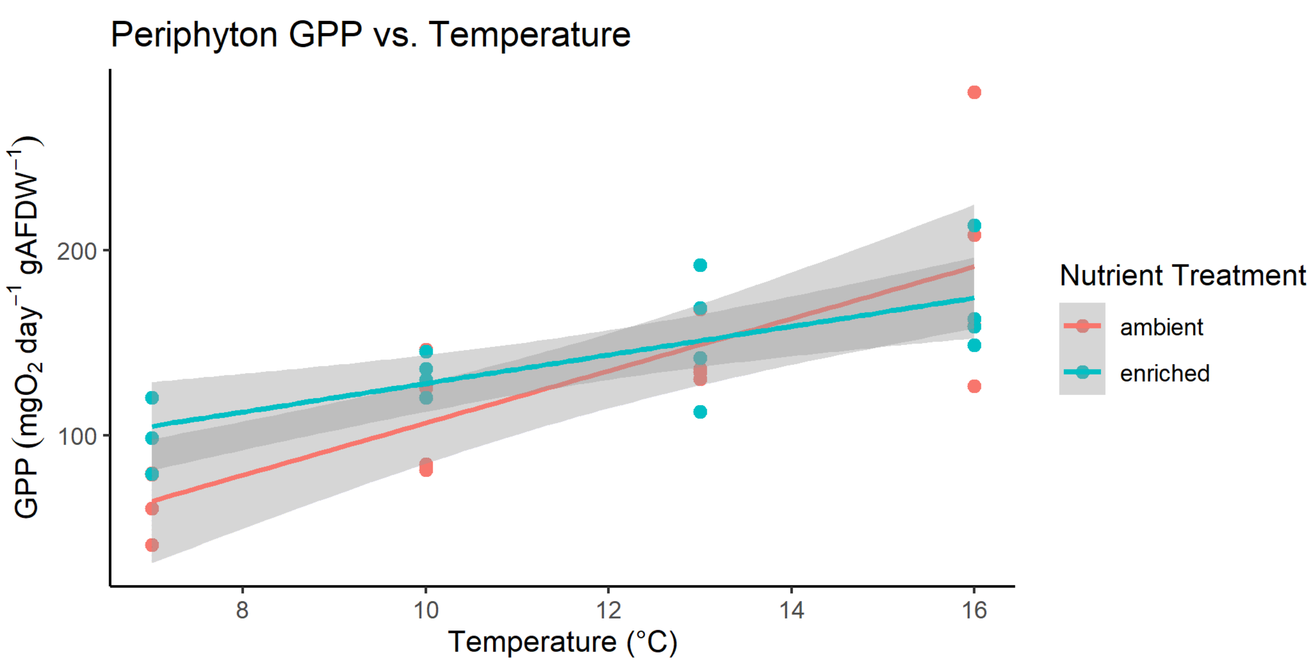
Lake Tahoe's Changing Nearshore Region, continued

Periphyton – Current Research on Factors Regulating Growth

Each season, a set of samples are analyzed at the seasonal mean water temperature and at a series of warmer temperatures going up to 10 °C above the ambient to simulate warming from climate change. Nutrient concentrations are also varied between current values (ambient) and augmented levels (enriched), to simulate nutrient loading associated with increased runoff or other anthropogenic sources.

Preliminary data from the 20/21 winter indicate that temperature significantly increases metabolic rates in periphyton. While nutrients appear to stimulate increased GPP, the relative effect of temperature is larger.

More experiments will be conducted to test for interactive effects and to determine if this trend varies across seasons. By providing a mechanistic understanding of periphyton growth responses, these results will allow us to predict future algal growth rates under climate change scenarios and help develop management strategies for Lake Tahoe.



Preliminary data showing the impact of temperature increases on gross primary productivity. From: N. Framsted

Lake Tahoe's Changing Nearshore Region, continued

Metaphyton

In the last 15 years, an increasing length of Lake Tahoe's shoreline has been impacted by the growth of excessive amounts of metaphyton. The south and southwest shores are the most heavily impacted. Unlike attached periphyton, metaphyton are unattached, green filamentous patches of algae that accumulate along the bottom of the lake close to the shoreline. Research show that metaphyton is often collocated with non-native Asian clams, and its growth is fueled by the highly-concentrated nutrients in the excretions of the clams. Depending on lake depth and the local currents, metaphyton have the potential to be washed up on shore where they form deep beds of decomposing organic matter. The public concern about increasing periphyton degrading the nearshore may actually be the result of the increasing quantities of metaphyton on the beaches.

By using a combination of satellite, helicopter and drone imagery, as well as in situ sampling to ground-truth species abundance, TERC researchers and collaborators are able to quantify the changing areal distribution of metaphyton as well as the causes of its growing impact.

Sampling patches of metaphyton on Lake Tahoe's south shore. Note the clam shells on the sandy bottom. Photo: B. Allen

Regan Beach in 2014, a year of low water level, when washed up metaphyton were common. Photo: S. Hackley

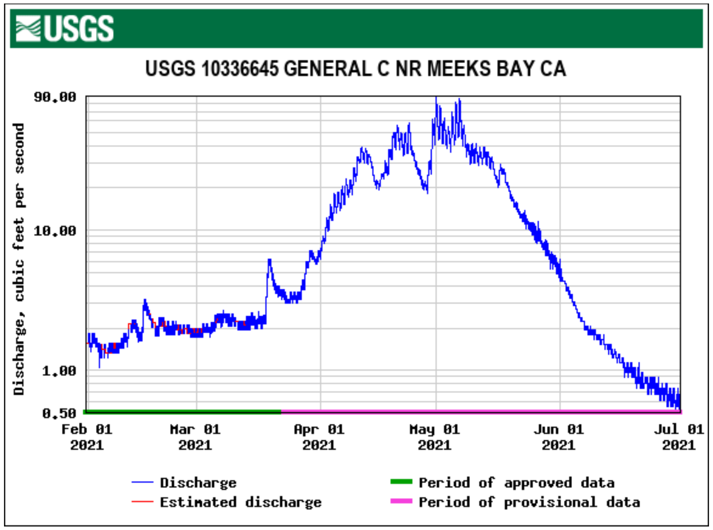
From top left, clockwise: Andy Wong launching a multispectral drone from R/V Bob Richards; cameras mounted on a helicopter; Brandon Berry completing a metaphyton drone survey: an orthomosaic image produced from the individual helicopter images.

Lake Tahoe's Changing Nearshore Region, continued

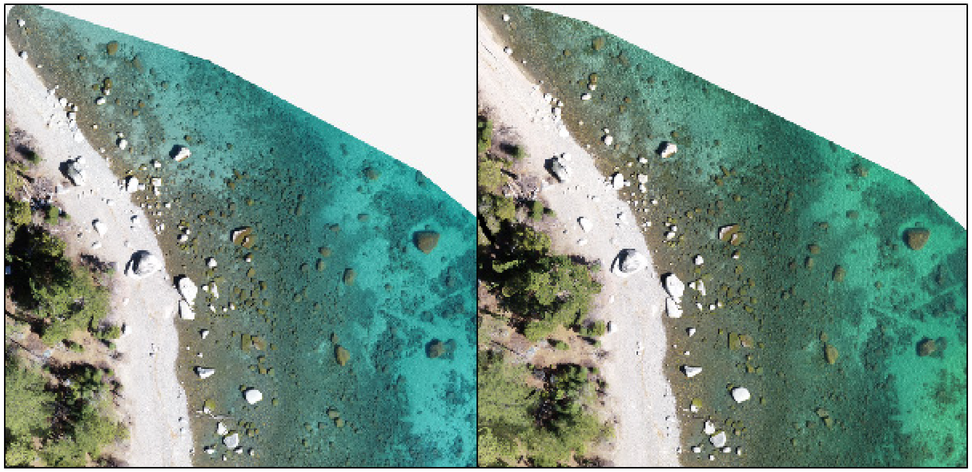
Nearshore Water Quality

The water quality in the nearshore is prone to very rapid changes. TERC's Nearshore Network of real-time sensors has shown that most afternoons, when winds blow from the southwest, wave breaking on the east shore elevates turbidity levels well above ambient standards. This highlights the challenges that regulators face in setting meaningful standards.

Another source of nearshore water quality change is from streams. General Creek, on the west shore of Lake Tahoe, is one of the most pristine streams in the basin with most of its watershed being part of Sugar Pine Point State Park and Desolation Wilderness. The creek discharges into the lake at Sugar Pine Point State Park. The two images below, taken 16 days apart in April 2021, show how spring runoff from General Creek can cause the water color to change from blue to green. The image on the left from April 6 occurred when General Creek's discharge was 16.2 cubic feet per second (cfs), while the image on the right from April 22 was for a discharge of 41.2 cfs. The peak discharge in 2021 was 64.2 cfs on May 6. The addition of dissolved organic material plus nutrients that stimulate algal growth were sufficient to change the nearshore waters from blue to green.



Runoff hydrograph for General Creek from the USGS NWIS database.



Orthomosaic images of the nearshore at Sugar Pine Point on April 6, 2021 (left) and April 22, 2021 (right). Photo: B. Berry

Tahoe's Plastic Problem

"There is a great future in plastics. Think about it. Will you think about it?". If you are old enough to remember the movie *The Graduate* from 1967, then you will no doubt recall those lines. The plastics of the future are now the plastics of the present, and it is not all great. Take a recent example from Moon Dunes Beach in Tahoe Vista, when thousands of tiny polystyrene pellets littered the shoreline. The source — a Big Joe Pool Petz Noodle Butterfly, sold across the country at multiple large box stores.

Discovered by TERC staffer Alison Toy, her social media posts quickly alerted over 50,000 people and by the next morning, thanks to the help of the community, most of the pellets were quickly cleaned up. Most, but not all, the others were carried away by the currents where they have either been ingested by fish and birds or are breaking down into even tinier pieces to become microplastic pollution.

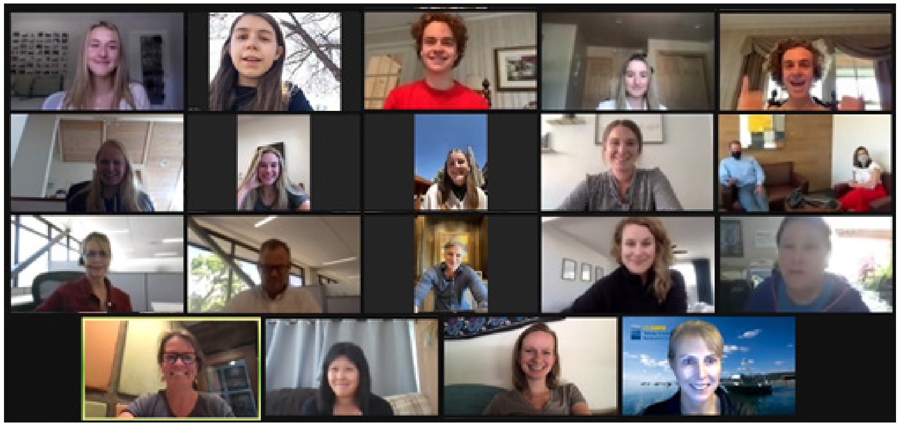
A Big Joe Pool Toy found punctured on Moon Dunes Beach. Photo: A. Toy

Thousands of polystyrene pellets from the Big Joe Pool Toy litter the shoreline. Photo: A. Toy

Tahoe's Plastic Problem, continued

Clearly, there are a few irresponsible people who simply leave their mess behind, be it a Big Joe or the trash from their day at the lake. But it is also irresponsible, with today's awareness, for businesses such as Costco, Target, and Walmart to sell items like these in the first place. It does not take much imagination to see how destructive these pellets could be in any environment.

How can we start to change this culture? TERC and other nonprofit partners have worked with local high school students to foster the transition of knowledge about plastic contamination to action. The students surveyed local stores and assessed plastic problems that businesses could readily address. After the students presented their findings to the Raley's grocery stores executive team, Raley's agreed to create lasting, sustainable change at their stores by eliminating plastic straws and plastic silverware by switching to paper and reusable options. A range of additional actions are also being considered. There is still a long way to go, but with increased awareness and the engagement of the next generation we are making real progress in the Tahoe Basin.



Envirolution Club Members Jade Bullock, Sophia Phillips, Ben Anderson, Lily Murnane, Evan Anderson, Kili Lehmkuhl, Alani Powell, and Amelia Swanson presented their plastic assessment via Zoom to Raley's Executives Sarah England, Mark Koppang, Chelsea Minor, Laura Croff, Kevin Konkel, Keith Knopf, and Megan Riggs; all under the guidance of Madonna Dunbar (TWSA); Ashley Phillips (SWEP); and TERC Educators Alison Toy, Elise Matera, and Heather Segale. Photo: E. Matera

The Impacts of Wildfires on Lake Tahoe

While 2020 will always be remembered as the year of COVID, it was also the year of incredible wildfires impacting California and the western United States. In California there were almost 10,000 "incidents" including five of the six largest wildfires ever recorded in California. A total of over 4.1 million acres burned, double the previous annual record.

While there were no significant fires within the Tahoe basin in 2020, the impacts of the fires in the western states were experienced by all in the Basin. For much of August and September, visibility was poor and air quality ranged from unhealthy to hazardous.

Despite being many miles away, wildfires continued to smother the Tahoe-Truckee area including Martis Valley off of highway 267. Photo: N. McMahon

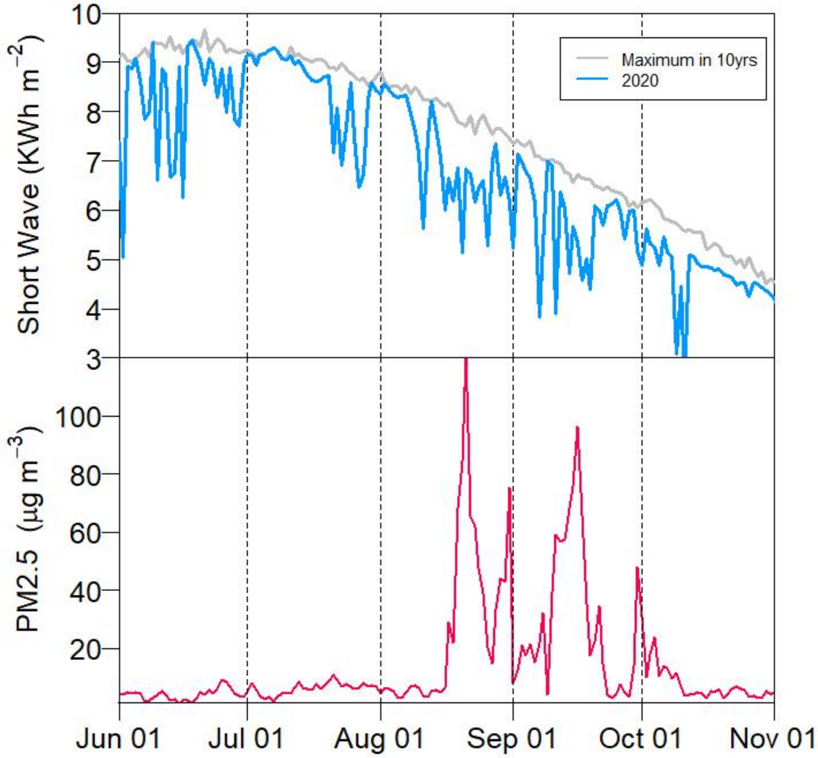
TERC researchers diligently continue data collection despite less than desirable air conditions. Photo: K. Senft

The Impacts of Wildfires on Lake Tahoe, continued

The blue line in the figure shows the daily average shortwave (solar) radiation based on 10-minute readings at TERC's long-term station at the US Coast Guard pier at Lake Forest in June through November 2020. The gray line is the maximum value of the daily average value shortwave radiation from the previous 10 years (2010–2019). Focusing on June and July, one can see that there are obvious "dropouts" in the 2020 values, relative to the long-term maximum values. These dropouts are normal and represent the impacts of cloudy days. Comparing any individual year with the long-term average would yield a similar looking plot, with low periods interspersed with returns to the long-term maximum.

The months of August and September are different. Here, the dropouts are larger and longer, and for almost the entire period the short-wave radiation is below the long-term average. On some days the radiation is reduced by 50%. This sustained reduction in solar radiation is the direct result of wildfire smoke generated hundreds of miles away.

The red graph shows the concentration of PM2.5 particles measured in Tahoe City by the California Air Resources Board. PM2.5 are inhalable fine particles with diameters of 2.5 micrometers and smaller, that have been linked to a number of health problems. The EPA's national standard for PM2.5 is 12 micrograms per cubic meter.



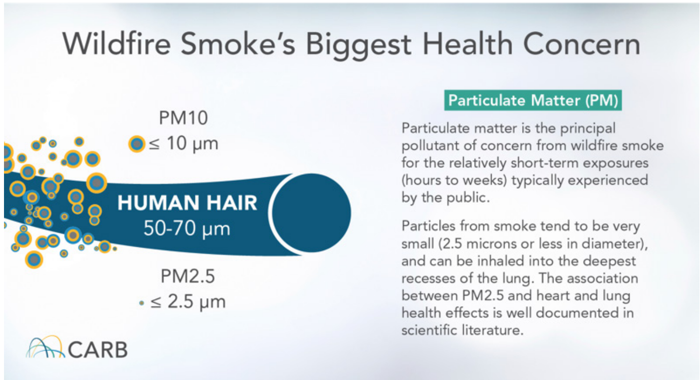
The top graph shows the measured daily solar radiation at Lake Tahoe (blue) compared with the maximum of the last 10 years. The bottom graph shows the measured PM2.5 from CARB station in Tahoe City, CA. Peaks show the impact of wildfire smoke from areas outside the Tahoe basin.

The Impacts of Wildfires on Lake Tahoe, continued

The data for the months of June and July have values below this standard, with some days even approaching zero. From August 13 through October 8, however, the data show the impacts of wildfire smoke. Hardly a day was below the standard, with most days PM2.5 concentrations exceeding 50 micrograms/per cubic meter.

What would the lake health impacts from wildfires be? There are two aspects to this. First there are impacts from the reduction of shortwave radiation and UV radiation described above, and second, there are the additions of smoke and ash constituents to the water.

Past research from the King Fire in Yosemite in 2014 has shown that there are impacts even without visible signs of ash falling on the lake. Wildfire smoke transported from far away reduced both solar radiation and UV radiation, just as they did in 2020. The research showed that a reduction in the UV radiation alone, by just 9% from one day to the next, resulted in a 14 ft. upward shift in the location of zooplankton in the lake. This changed the location at which grazing was taking place which could impact both the lake clarity as well as the overall foodweb. Additionally, UV reductions also decrease the potential for solar disinfection of waterborne parasites.

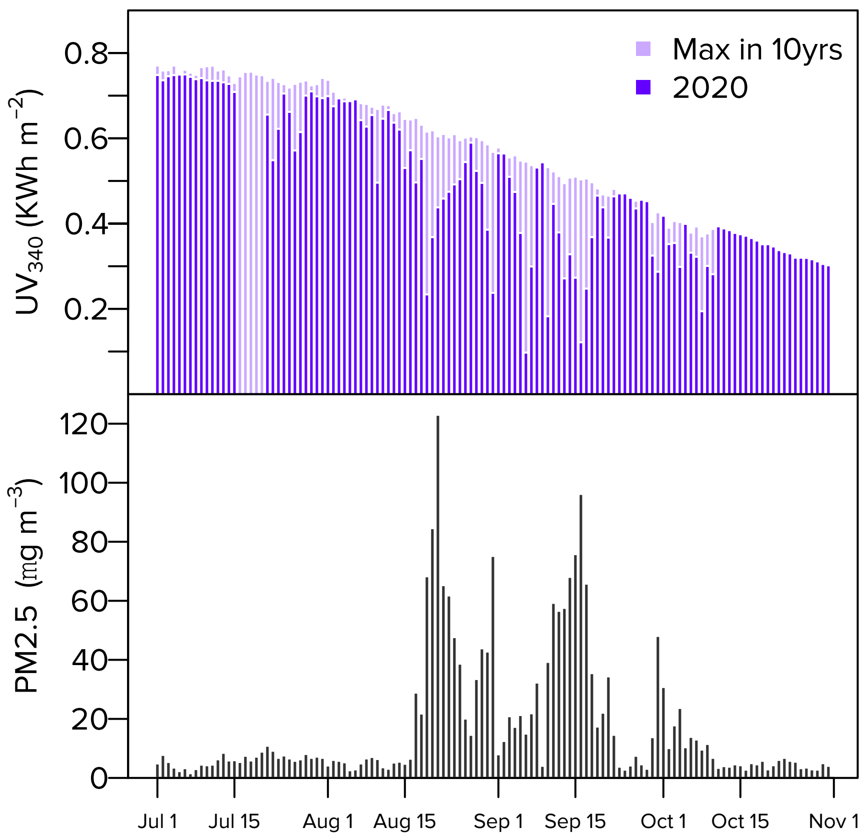


Source: https://ww2.arb.ca.gov/wildfire-smoke-health

While ash may not be visible, the very fine particulate matter in the air causes Tahoe's blue hues to take on new tones.
Photo: A. Toy

The Impacts of Wildfires on Lake Tahoe, continued

In 2020, the UV reductions are far greater than those recorded in 2014. The figure shows the maximum daily UV recorded in the previous 10 years, plotted alongside the 2020 daily UV. During July, August, and September, due to the high PM2.5 concentrations, daily UV was significantly depressed for over 10 days at a time with reductions of up to 80% below normal values.



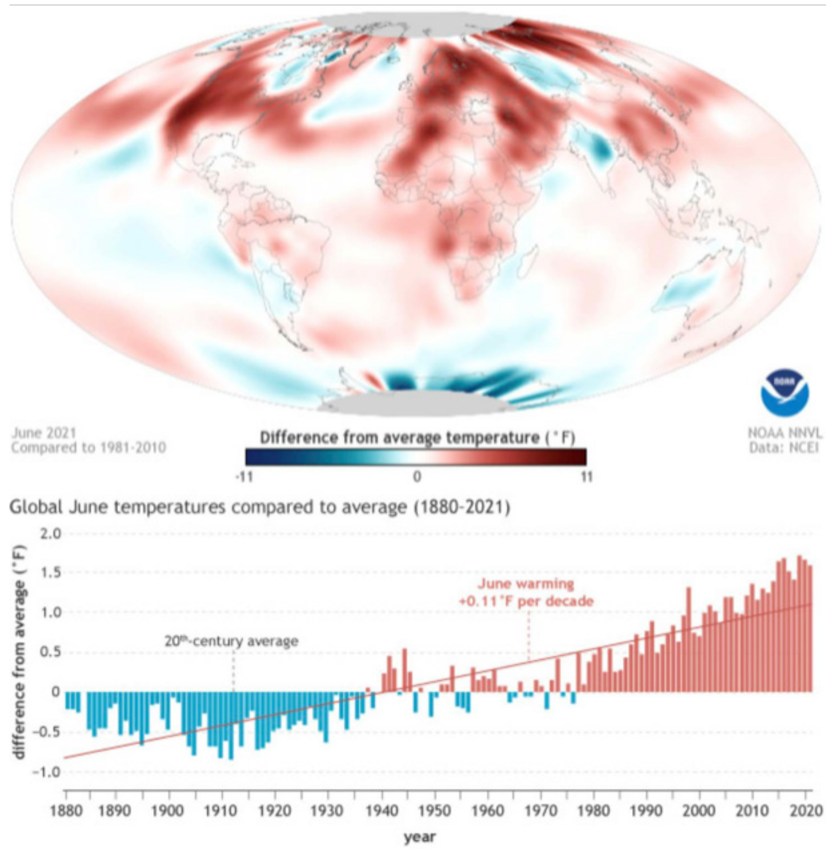
The impacts of this 6-week reduction in UV and in solar radiation on the lake food web are unknown as concurrent measurements on the zooplankton vertical distributions were not taken. However, as large wildfires are likely to be a part of our ever-lengthening summers for many years to come, it is likely that there will be significant changes occurring to the lake biota

The second aspect, the addition of fine particles, nutrients, toxic chemicals and other smoke constituents is an even more complex issue. Most deposition occurs on the land and continues to be washed into the lake many months after the fires have been extinguished when winter returns. TERC, along with collaborators at the University of Nevada, Reno, and Crater Lake National Park, have been funded by the National Science Foundation to research the impacts of direct particle deposition on lakes from the 2020 fires in the western United States. Though still ongoing, the research is looking at a range of over 20 lakes of different sizes, latitudes, and altitudes. The team is using direct in-lake sampling, autonomous underwater gliders, and spaceborne remote sensing to address the problem.

Extreme Heat and Temperature Stress of Tahoe Forests

According to NOAA's National Centers for Environmental Information (NCEI), June 2021's global surface temperature was 1.58 °F (0.88 °C) above the 20th century average of 59.9 °F (15.5°C) — the fifth-warmest June in the 142-year record. June 2021 was the 45th consecutive June and the 438th consecutive month with temperatures above the 20th-century average. Much of the western United States experienced an extreme heat event in that particular month.

TERC's Forest and Conservation Biology Lab is proactively working to understand and manage extreme heat and drought impacts both in the Tahoe Basin forests and throughout California.



Global June temperatures from NOAA/NCEI. Source: https://www.climate.gov/news-features/understanding-climate/june-2021-was-fifth-warmest-record

Extreme Heat and Temperature Stress of Tahoe Forests, continued

Amplifying Resilience to Drought Using Local and Genetically Diverse Seed

Land managers are at a critical juncture in the management of resources for adaptation and uncertainty. In particular, the selection of seed and source material, either local or non-local, for restoration has become a fundamental and much-debated decision. Given the scale of ecosystem disturbance, there is an urgent need to procure native seed across taxonomic groups to secure the diversity and local adaptation in wild populations. TERC's Forest and Conservation Biology Lab has developed restoration strategies using the progeny of local and diverse sugar pine "survivors" from the 2012–2016 drought to promote forest resiliency against drought in the Lake Tahoe Basin. This approach can serve as a model to many other terrestrial ecosystems throughout California.

The lab is studying important plant traits of 100 surviving "mother trees" of sugar pine from the Lake Tahoe Basin to determine, through a common garden study, if these "survivors" carry unique genes that give rise to plant traits such as water-use efficiency, plant defense chemistry to bark beetles, phenology, and resource partitioning. Such traits will allow them to be more resilient to drought and bark beetle outbreaks. This work is funded by the California Tahoe Conservancy.

Initial height measurements.
Photo: C. Jensen

Sugar pine seedlings arranged in four experimental blocks.
Photo: C. Jensen

Extreme Heat and Temperature Stress of Tahoe Forests, continued

Amplifying Resilience to Drought Using Local and Genetically Diverse Seed, continued

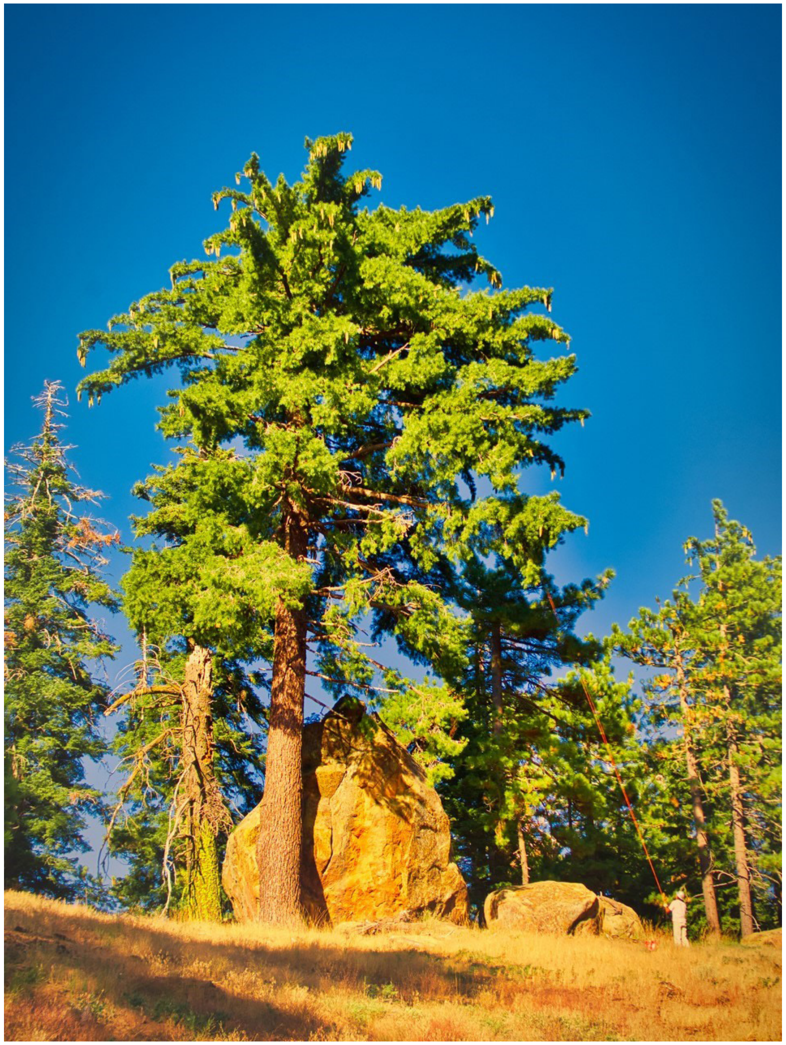
Our ecological and genetic studies with sugar pine and other five-needled white pines provide valuable information regarding seed material for restoration and reforestation. The work to date is providing strong evidence that using local and diverse seed sources promotes forest resiliency and provides "insurance" against climate change. We are at a tipping point, facing an unprecedented loss of California wildlands and all the associated ecosystem services they provide. Collections from extant plant populations and individuals that have proved to be resilient to anthropogenic and natural stressors should be prioritized for seed collection. Novel restoration strategies guided by a better understanding of how native plants evolve in response to selective pressures such as drought and temperature stress hold the potential to increase not only the pace and scale of ecosystem restoration, but to amplify population resiliency to contemporary pressures and stressors.

A view of Tahoe Forests and Lake Tahoe. Photo: A. Toy

Extreme Heat and Temperature Stress of Tahoe Forests, continued

Ongoing Native Seed Collections

California is a biodiversity "hotspot" and given the scale and extent of wildland loss there is an urgency for procuring native germplasm across taxonomic groups to secure the diversity and local adaptation found in wild populations. As part of this effort, the Forest and Conservation Biology lab continues to make cone and seed collections from sugar pine, western white pine, and other forest tree species throughout California, Nevada, Oregon, and northern Baja Mexico for gene conservation, restoration, and seed-banking.



Tom Burt (bottom right) making a gene conservation collection from a population of sugar pine at Toro Peak in the Santa Rose Mountain Range in southern California. Photo: T. Corliss

A Smattering of Tahoe-Related Research Projects

Every year, UC Davis TERC students and researchers work on a range of research projects, either directly at Lake Tahoe, that draw upon the results of the long-term data at Lake Tahoe, or that can be directly applied to environmental restoration at Lake Tahoe. The following pages highlight some examples of that work in 2020.

The broad range of research taking place at meso-eutrophic Clear Lake. Though very different than Lake Tahoe, contrasting the two lakes helps us better understand the underlying processes. Photo: M. Swann and K. Pinkanjananavee

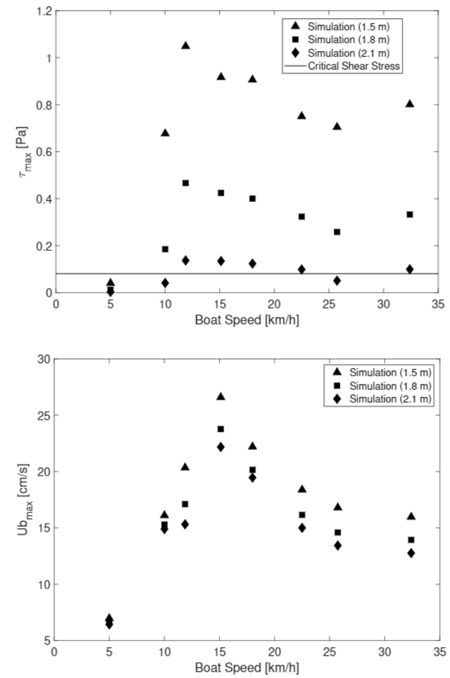
A Smattering of Tahoe-Related Research Projects, continued

Sergio Valbuena - Impacts of Boat Wakes in the Nearshore Zone

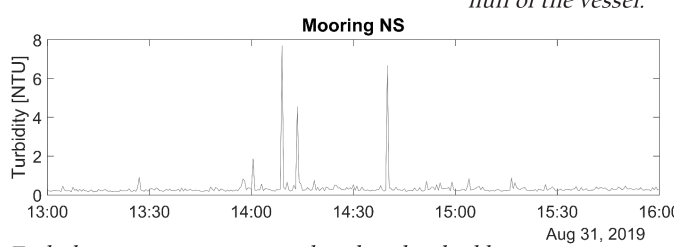
No-wake zones are common in most lakes, yet their scientific basis is poorly understood. The combination of shallow water depths and high boat activity results in complex flows and waves that have the potential to resuspend sediment and nutrients from the lake bed. To this end, a field campaign was undertaken in 2019 where multiple wave and turbidity sensors were used to characterize the lake bed-sediment interaction during summer. Field observations recorded instantaneous turbidity changes associated with boat activity. Turbidity was observed to return to baseline values within five minutes of boat passage. Boat-induced wave impacts were estimated using the wave measurements for a specific range of boat characteristics. Boat wakes accounted for approximately 30% of the total wave activity registered on the south shore of Lake Tahoe. The boat-induced wave contributions to sediment resuspension overall were low in comparison to the wind forcing effects on the wave generation.

Lastly, numerical simulations of propeller wash from boats were conducted. Using a range of boat speeds and water depths it was concluded that boats exceeding a speed of 5 mph (8 km/h) can induce sediment resuspension at depths as great as 3 m (10 feet), with the peak resuspension at a speed of 10 mph (15 km/h).

Sergio prepares instruments to measure boat wake impacts. Photo: G. Schladow



(Top) Shear stress estimations at different water depths for boats at different speeds. (Bottom) Estimated water velocity induced by boat passage underneath the hull of the vessel.



Turbidity increases associated with individual boats.

A Smattering of Tahoe-Related Research Projects, continued

Micah Swann – A Tale of Four Lakes

Micah's research centers on the threats posed to lake ecosystems from declining dissolved oxygen in their deep waters, and the role that climate change and land-use may play in this. The four lakes that are at the core of his work are Lake Tahoe (CA-NV), a high altitude oligotrophic lake with strong development pressures over the last 60 years; Clear Lake (CA) a hyper-eutrophic and severely impacted lake in California's coastal range, with a long history of human development, agriculture, and mining; and two near-pristine lakes in Northern Patagonia, Lake Llanquihue and Lake Ranco, which are seeking to emulate practices at Lake Tahoe in anticipation of impending development pressure and climate change.

Each lake is different, both from the perspective of its limnology and its anticipated future trajectory. In order to inform his study, Micah has been collecting and analyzing field data, while running three-dimensional lake models using current and predicted future conditions. In the next 12 months, he will be spending considerable time in Chile, working through the lake advocacy NGO Chile Lagos Limpios.

The funding for Micah's research has come from the California Department of Fish and Wildlife, UC Davis Global Studies, the Eivind Lange Fellowship, the ARCS Foundation, California Lake Management Society (CALMS), and the Boyd Foundation.

Micah retrieving instrument mooring from the depths of Clear Lake. Photo: R. Thirkill

A Smattering of Tahoe-Related Research Projects, continued

Samantha Sharp – Observing Harmful Algal Blooms from Space

Samantha studies cyanobacterial (harmful algal) blooms using a combination of hyperspectral satellite data and in situ hyperspectral measurements. While previous research in this area of study enables the detection of cyanobacteria, Samantha is seeking to build on this by additionally differentiate between individual cyanobacterial groups. This is important as not all cyanobacteria are toxic. With the exception of locations such as the Tahoe Keys on occasion, harmful algal blooms have not been an issue of concern at Lake Tahoe. However, this may change in the future as warming lake temperatures and increasing nutrient concentrations move the lake toward conditions favoring cyanobacteria.

An important part of this research is to better understand the measurement of algae within water using fluorescence. When algae and cyanobacteria receive light energy in excess of the amount required for photosynthesis, they dissipate this energy as heat through a process known as non-photochemical quenching (NPQ). This causes a daytime reduction of fluorescence and, therefore, results in an under-estimation of the biomass of algae and cyanobacteria. This is a particularly severe issue at Lake Tahoe, where the clear water allows NPQ to occur to depths in excess of 60 ft. Through continuous 24-hour sampling from a site off Homewood (CA), Samantha seeks to develop a correction for NPQ that can be used at Lake Tahoe and other high clarity lakes.

Samantha's funding is provided through a NASA Graduate Fellowship.

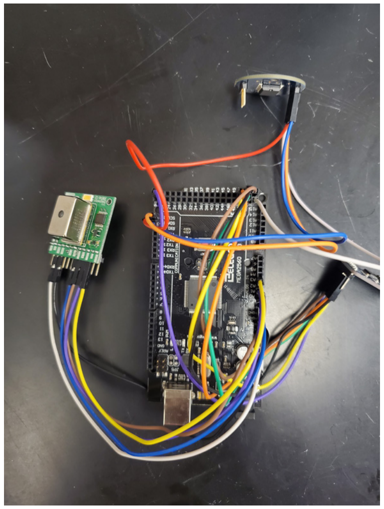
Samantha sampling for cyanobacteria in Clear Lake, CA. Photo: M. Swann

A Smattering of Tahoe-Related Research Projects, continued

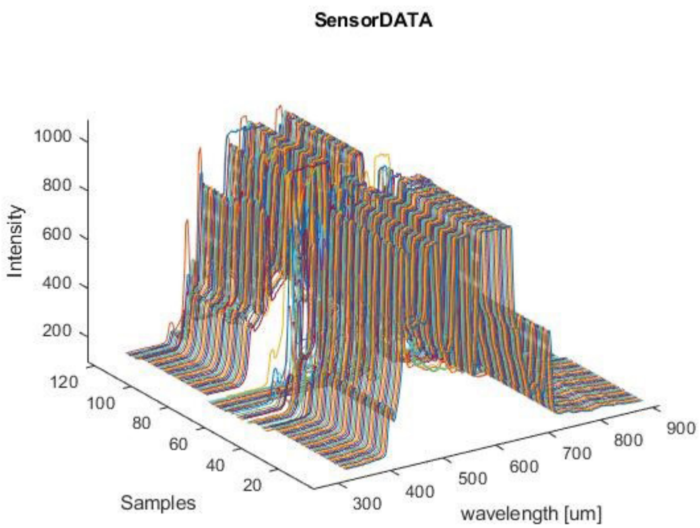
Kanarat (Job) Pinkanjananavee - Rapid and Affordable Cyanobacterial Detection

Job is developing an in situ spectrophotometer for identifying cyanobacteria genera that could ultimately provide an early warning system for harmful algal blooms (HABs). HABs are currently estimated to cost the U.S. economy up to $1B annually. Using a Hamamatsu C12880MA mini-spectrometer with an Arduino mainboard, the software is currently being tested. Trial deployments may commence as early as fall 2021, with the likely test location being Clear Lake (CA), a lake known for extremely large (and toxic) cyanobacterial blooms. If the development is successful, instruments could be deployed in Tahoe and elsewhere in 2022.

Job's funding is from the U.S. Bureau of Reclamation.



Job's spectrophotometer prototype out of its protective casing. Photo: K. Pinkanjananavee



Sample spectrophotometer output from a Clear Lake test deployment.

HABs out at Clear Lake. Photo: K. Pinkanjananavee

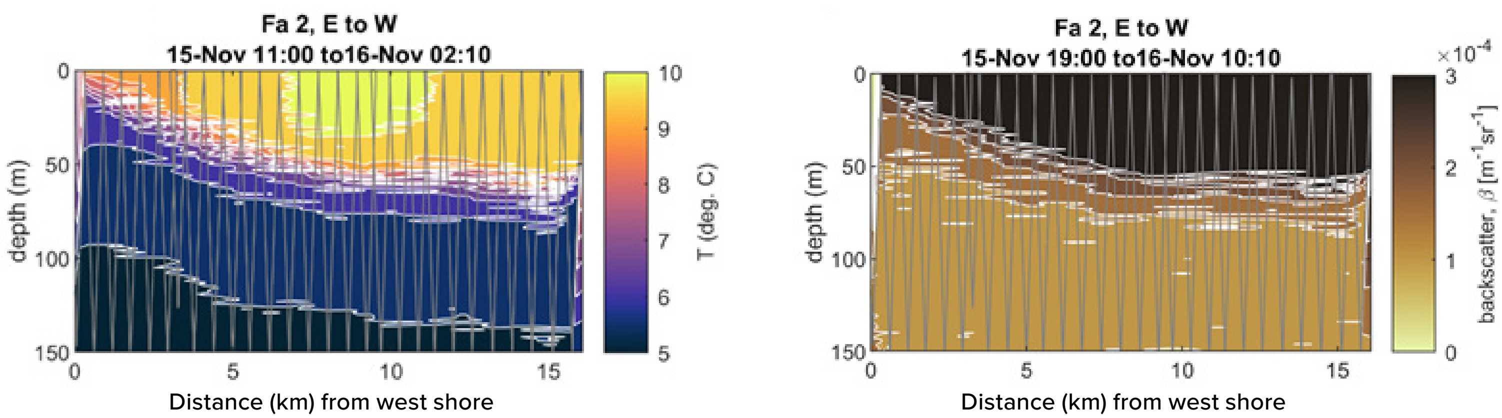
A Smattering of Tahoe-Related Research Projects, continued

Jasmin McInerney – The Art of Measuring Lakes Autonomously

Jasmin's research interests are centered on understanding lake physics using autonomous underwater gliders as a primary measurement tool. Jasmin has deployed gliders in Antarctica, Lake Superior, Lake Geneva and of course, Lake Tahoe. Gliders have the great advantage of being able to run using a very small amount of power, as they utilize their buoyancy to propel themselves. At Lake Tahoe, for example, the glider can run for up to a month, travelling back and forth across the lake while at the same time plunging and rising over 500 feet. It can do this day and night and during intense weather when traditional boat surveys would be dangerous.

In Lake Tahoe Jasmin has been investigating the inter-seasonal variation of internal waves and their effect on suspended particulate matter and chlorophyll distribution. Internal waves are large amplitude waves that arise within the lake due to the variation of temperature with depth. The figure below shows an internal wave that is rising (upwelling) on the west shore. In this example, the images show the impact of an internal wave moving clear (low backscatter) water from the depths of the lake to the surface. The clear water in this case contains very few particles and can help to improve the Secchi depth of the lake. Unfortunately these clear, bottom waters also contain high concentrations of nutrients. When the nutrients are brought to the surface, they can stimulate algal blooms.

The funding for Jasmin's research comes from the Korea Polar Institute and the Robert L. Wiegel Scholarship for Coastal Studies.



Temperature contours (left) and optical backscatter contours (right) on a west-east transect in fall 2017. The grey lines indicate the glider path. The horizontal axis is distance (km) from the start point near Homewood on the west shore.

A Smattering of Tahoe-Related Research Projects, continued

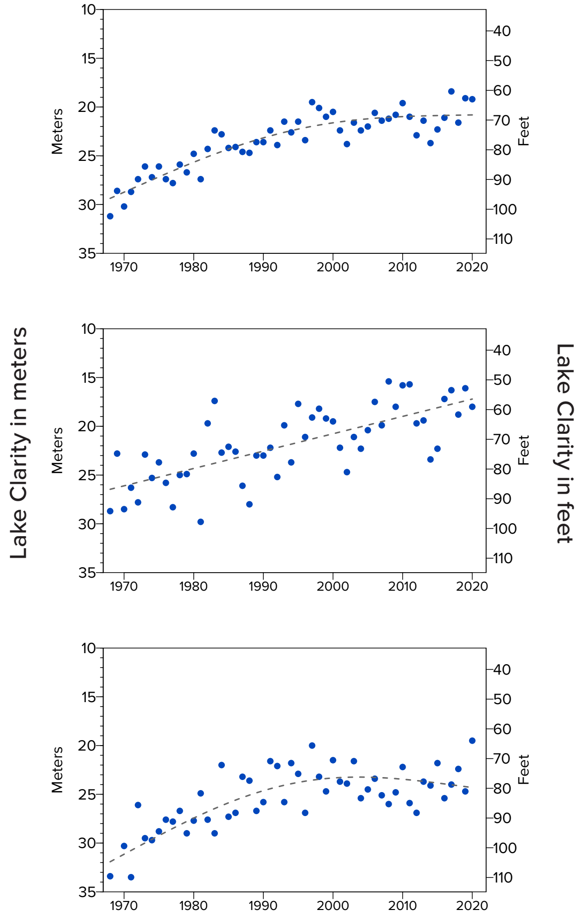
Alicia Cortés (TERC), Shohei Watanabe (TERC), and Lidia Tanaka (TERC) - Understanding Seasonal and Long-Term Clarity Trends

During 2020, an interdisciplinary team of researchers from UC Davis (TERC), the U.S. Geological Survey, and the Desert Research Institute investigated the drivers of seasonal and long-term clarity trends. The work was conducted on behalf of the Tahoe Science Advisory Council (TSAC).

The analyses conducted by the TERC researchers showed that clarity is controlled predominantly and negatively correlated with the in-lake density of fine inorganic and organic particles in suspension (with diameters in the range of 1.0–4.76 microns). The origins of these fine particles are from small diatoms (*Cyclotella*) that have proliferated in the lake in recent decades and external loads of fine sediments primarily from urban areas.

In-lake physical processes also influenced seasonal and historic trends, with the depth of winter mixing having a significant impact on seasonal trends. Clarity improves during the winter as a result of deep mixing. Increases in lake temperatures due to climate change have resulted in the lake becoming stratified earlier and remaining stratified longer. The increase in temperatures at the surface of the lake, combined with changing stream temperatures affect the insertion depths of incoming stream flows.

Regarding biological drivers of clarity, in addition to the negative impact of large numbers of *Cyclotella* on fall and summer clarity, the reappearance of zooplankton species like *Daphnia* in the absence of the predator *Mysis* shrimp is expected to contribute positively to both seasonal and annual clarity due to the ability of *Daphnia* to remove both inorganic and organic fine particles.



Lake clarity during annual (top), winter (middle) and summer (bottom) periods. The dashed trend line is produced using a generalized additive model.

A Smattering of Tahoe-Related Research Projects, continued

Holly J. Oldroyd (UC Davis), Stephen Drake (UNR), and Anne Nolin (UNR) - Snowmelt and Hydro-meteorology

For the last three winters at the Sagehen Field Station outside of Truckee, CA a study has been underway to understand various types of snowmelt events. Such events are critical for understanding water balances and informing water resource management decisions. Several factors make predicting and quantifying water loss from the snowpack challenging. These are related to natural variations in the landscape, such as tree cover and topography, that cause significant differences in ablation (snow loss) processes over spatially small scales. Understanding these processes is critical for developing hydrologic and meteorologic models at much larger scales.

One important process is water loss from the snowpack to the atmosphere through evapo-sublimation. This can account for as much as 25% of the seasonal snow loss. In the 2019 and 2020 campaigns, the team deployed several "flux towers" along a transect between dense forest and open meadow. The findings indicated large differences in fluxes across horizontal distance, vertical heights, and surface types. Clear-sky evapo-sublimation rates increased with wind speed and were often at a maximum near midday when solar energy was at its peak. Evapo-sublimation rates were greatest in the snow-covered forest canopy but were constrained by the lower wind speeds within the forest.

The models that are being developed through this research have direct impact to the water balance within the Tahoe basin. The fraction of the snowpack that provides water to the lake, streams, and soil is the balance of what is left after evapo-sublimation. As forest density changes with landscape-scale forest thinning, and as climate change exerts meteorological changes, having the ability to predict the impact of evapo-sublimation on water availability will allow for improved water resource management.

Eddy-covariance flux tower and spatial variations in snowpack and snowmelt. Photo: S. Drake