

RECENT RESEARCH UPDATES



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New expertise for emerging challenges

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

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

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



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



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





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Variability around the shoreline of Lake Tahoe

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

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



A nearshore station in the shallow water of Lake Tahoe.



Locations of existing and planned nearshore network stations.



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Variability around the shoreline of Lake Tahoe, continued

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

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

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





RECENT RESEARCH UPDATES More slime or less slime?

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

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

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



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

Lake Tahoe Routine and Synoptic Periphyton Sampling Sites Legend **Periphyton Sampling Sites** Adjacent IVZ Level of Development Routine Site Low Development (0% - 9% Impervious Cover) Synoptic Site Medium Development Rivers and Streams (10% - 19% Impervious Cover) Watershed Boundaries **High Development** (>19% Impervious Cover)



RECENT RESEARCH UPDATES More slime or less slime? continued

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

There is a large amount of anecdotal

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



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



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



RECENT RESEARCH UPDATES How do we maintain a healthy forest?

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



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



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



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



RECENT RESEARCH UPDATES Measuring the metabolism of Lake Tahoe

The metabolism of a lake is typically separated into the primary productivity or PPr (the rate of increase of algal biomass) and respiration (the rate of loss of algal biomass). These are both important parameters for the lake and for CO₂ uptake and release. Since the 1960s, PPr at Lake Tahoe has been measured monthly (or more often) using Carbon-14, a technique pioneered by Dr. Charles Goldman. Monitoring has shown that the PPr of the lake has been increasing substantially. This method, however, has the limitation that it yields no information on respiration. In the last few years, rapid response dissolved oxygen (DO) sensors have made it possible to accurately measure changes in DO within the lake. Because DO concentrations increase due to photosynthesis (the process whereby algal biomass is produced) and decrease due to respiration, by measuring DO concentration continuously we potentially have continuous measures of both PPr and respiration.

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





A dissolved oxygen sensor deployed in Lake Tahoe.



RECENT RESEARCH UPDATES Where does stream water go?

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

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

Looking down from the boat, the presence of this layer was not detectable. However, such layers have a deleterious impact on the clarity, and would reduce the amount of light and especially of



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

UV radiation that reaches the bottom sediments. High levels of UV radiation are an important factor in suppressing the successful reproduction of invasive fish species and in reducing the growth of invasive aquatic plants such as Eurasian water milfoil. Such layers would also cause a reduction in the measured Secchi depth.



RECENT RESEARCH UPDATES The waves of Lake Tahoe - more than meets the eye

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

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

Can you ever see them? Unlikely, as the maximum amplitude in Lake Tahoe is only 1-2 inches. However, they are still extremely important. Unlike the wind waves, that are imperceptible at a depth of 20 feet, the motions produced by seiches extend all the way to the bottom of the lake at 1645 feet. The motions they produce through the entire water column are critical in preventing the stagnation of deep water and helping to redistribute nutrients and oxygen.





RECENT RESEARCH UPDATES Climatic eutrophication - A Mechanism of Change in Lake Tahoe

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

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

This process may have serious



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

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