EXECUTIVE SUMMARY

The long-term data set collected on the Lake Tahoe ecosystem by the University of California, Davis and its research collaborators provides a unique tool for understanding ecosystem function and change. It has become essential for decision-making by elected officials and public agencies tasked with restoring and managing the Tahoe ecosystem. This is, in part, because it provides an independent basis for assessing the progress toward attaining Tahoe's restoration goals and desired conditions, while at the same time building our understanding of the natural processes that drive the ecosystem.

The UC Davis Tahoe Environmental Research Center (TERC) is innovating with new approaches to enrich the long-term data record for Lake Tahoe and to address emerging questions. These approaches include real-time measurements at over 25 stations around the basin and remote sensing from autonomous underwater vehicles, satellites, aerial drones, helicopters, and computer modeling tools. These efforts are all focused on quantifying the changes that are happening and, at the same time, understanding what actions and measures will be most effective for control, mitigation, and management in the future. Our newest station was commissioned in June 2022. This real-time thermistor chain and dissolved oxygen sensor, cabled back to shore at Obexers' Marina on the west shore, is now providing data on the internal motions of the lake and the loss of oxygen at a depth of 115 m (380 ft).

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

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

(CONTINUED ON NEXT PAGE)

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

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.1)

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

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

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

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

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

(CONTINUED ON NEXT PAGE)

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.2)

the lake's organisms.

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

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

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

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

(CONTINUED ON NEXT PAGE)

EXECUTIVE SUMMARY

(CONTINUED FROM PAGE 2.3)

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

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

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

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