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; 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.

This annual *Tahoe: State of the Lake Report 2021* presents data from 2020 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 future consequences of climate change on the physical environment at Lake Tahoe; the accelerating rate of ecological change in the nearshore, made all the more clear through the use of new approaches and advanced sensing and analysis tools; the emerging and growing prevalence of microplastic pollution in both the watershed and the lake; the impacts of smoke from distant wildfires on Lake Tahoe; the varied impacts of extreme heat and temperature stress on forest health; and finally an introduction to some of the work being done by graduate students and researchers affiliated with TERC.

The future climate change impacts for the Lake Tahoe Basin are substantial. While the projected air temperature increases of 8 °F and the 50 percent reduction of snow by the latter part of the century seem dramatic, what may be more important are the changes that arise on account of this increasing temperature. For example, drought intensity due to both the warming and loss of soil moisture place the Tahoe forests at far higher risk of mortality, insect attack, and wildfire than they are presently. The loss of snow and its replacement by rain will increase peak stream flows by 2–3

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"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 2021 report, water year data are from October 1, 2019 throught September 30, 2020. Calendar year data are from January 1, 2020 through December 31, 2020.

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times their current peaks, placing infrastructure at heightened risk. The rapidly rising lake levels during such events has the potential to exceed the capacity of the dam at the outlet and is likely to result in uncontrolled releases downstream. Lake Tahoe itself will be increasingly prone to stagnation during ever longer, warmer summers with the potential for a loss of oxygen at depth.

The nearshore regions of the lake, where millions of people recreate every year, are also at a growing risk. The largest threat here is the increasing presence of filamentous algae (metaphyton) that wash up on the beaches and decompose. The metaphyton grow, in part, due to the concentration of lake nutrients by the invasive Asian clam, which has been present in Lake Tahoe since 2008. Warmer water and higher nutrient loads expected with future climate change will further exacerbate this growth. Microplastic pollution is also an increasing issue, with much of it being introduced at the shoreline.

Wildfires are an increasing presence, even when they are not burning within the basin. Fine particles which reduce visibility and cause the air quality to reach dangerous levels impact public health and the lake in many ways. The reduction in sunlight during these events changes algal growth and heat transfer within the lake. More importantly, the large reduction in UV radiation is changing grazing patterns by zooplankton within the lake. The impacts of this change are currently being explored through ecological modeling of the lake. Other impacts from wildfires, such as the addition of particles and nutrients to the lake are also the subject of ongoing research.

Meteorologically, the long-term trends that have been prevalent do not change 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, and 2020 was a relatively warm year. The annual average maximum temperature was 58.2 °F, an increase of 3.2 °F from 2019. The 2020 annual average minimum was 32.4 °F, which was 0.9 °F warmer than the previous year. At 20.1 inches, 2020 precipitation was below the long-term average measured at Tahoe City. The low values of 2020 came after just four years of average or above average precipitation. Snow represented 45.1 percent of the 2020 total precipitation.

The water level in Lake Tahoe varies throughout the year due to inflows, outflows, precipitation, and evaporation. In 2020, on account of the dry winter, the annual rise in lake level was very muted. From January through December 2020, overall lake level fell 1.9 feet. Based on historical water level data, it is likely that

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Lake Tahoe will fall below its natural rim in October 2021.

Despite year-to-year variability, the annual average surface water temperatures show an increasing trend. The average temperature in 1968 was 50.4 °F. For 2020, the average surface water temperature was 52.8 °F, warmer than in 2019. The overall rate of warming of the lake surface is 0.38 °F per decade. 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 February 6, 2020, Lake Tahoe's maximum mixing depth was observed to be 476 feet (145 m). This relatively shallow mixing likely contributed to the warmer surface temperatures experienced during winter, and the low winter clarity.

The stability of the lake is an important concept that expresses its resistance to vertical mixing and determines whether it is stratified. 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 changes. In 2020, the stability index was the third highest ever recorded. The length of time that Lake Tahoe is stratified has been increasing each year, another consequence of climate change. Since 1968, the stratification season length has, on average, increased by one month, effectively increasing the length of summer and decreasing the length of winter. In 2020, the length of the stratified season was 200 days.

The reduction of nutrient and fine particle loads to the lake is a fundamental part of the restoration efforts at Lake Tahoe, driven largely by the Total Maximum Daily Load (TMDL) program. The stream-borne nitrogen and phosphorus loads from the Upper Truckee River were generally lower in 2020, in line with the below average precipitation for the year. In-lake nitrate and total hydrolyzable phosphorus concentrations increased slightly, a result of the absence of deep mixing in 2020. 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. By contrast, the biomass (concentration) of algae as measured by chlorophyll concentration in the lake has remained relatively steady. For the period of 1984–2020, the average annual chlorophyll-*a* concentration in Lake Tahoe was 0.70 micrograms per liter. Most of the chlorophyll is concentrated in a band at a depth of approximately 150–200 feet, known as the "deep chlorophyll maximum." The peak in the chlorophyll

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occurred relatively late in the summer of 2020. Diatoms were the most common algal group (60 percent of the cells) in terms of the abundance of individual cells. Of these, *Synedra* formed the largest percentage of the biomass, accounting for over 80 percent of the diatoms during spring, summer, and fall. Although *Cyclotella* was a relatively low fraction of the percentage of the biovolume of diatoms in 2020, it was the second most dominant species in June and July and still had a large impact on clarity due to its tiny size. The attached algae (periphyton) on the rocks around the lake were near average values in 2020, based on a synoptic survey of 53 observations. As usual, the California side of the lake continued to display higher concentrations of periphyton.

In 2020, the annual average Secchi depth was 63.0 feet (19.2 m), almost unchanged from the previous year and reflective of the near-constant values that have been attained over the last 20 years. The highest individual clarity value recorded in 2020 was 81.2 feet (24.8 m) on February 12. The lack of complete vertical mixing of the lake in 2020 is the main reason for this low maximum clarity value. The poorest clarity reading was 50.8 feet (15.5 m) on May 15. While the average annual clarity is now better than the preceding decades, it is still short of the clarity restoration target of 97.4 feet (29.7 m). The winter (December–March) clarity value of 64.0 feet was the lowest winter clarity on record and was 17 feet lower than the previous year. Winter precipitation was below the long-term average and such conditions would typically be expected to yield higher clarity values. The reasons for the low winter values are still not fully understood. Summer (June–September) clarity was 59.1 feet (18.0 m), a loss of over 6 feet from the previous year. This is significantly better the lowest summer value of 50.5 feet in 2008.