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 large part because it provides an independent basis for assessing the progress toward attainment of 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 increasingly using innovative approaches to enrich the long-term data record for Lake Tahoe. These include real-time measurements at over 25 stations around the basin; remote sensing from autonomous underwater vehicles, satellites, aerial drones; and computer modeling tools. These tools 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.

This annual *Tahoe: State of the Lake Report* presents data from 2019 in the context of the long-term record. While we report on the data collected as part of our ongoing, decades-long 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 progress being made toward the clarity and ecosystem restoration through the harvesting of *Mysis* shrimp and their use as high-grade dog treats; the metaphyton and periphyton growth that impact the lake's nearshore; efforts toward the understanding and the replanting of genetically resilient trees to replace the thousands of sugar pines lost in recent years; underwater robotic instruments to study harmful algal blooms; microplastic pollution; the under-recognized dangers that can be avoided when recreating on Lake Tahoe; and the reciprocal lessons that are being learned by studying deep lakes in Patagonia.

In the last eight years we have been trying to reconcile the connections between the introduction of *Mysis* shrimp in the 1960s, the long-term ecological record for Lake Tahoe, and the experiences of researchers at many lakes across the world. Finally, a consistent picture is emerging for Lake Tahoe. The available data suggest that *Mysis* were responsible for not only the removal of the *Daphnia* (the cleaners of fine particles from the lake), but also for the removal of large algae. This dual impact appears to have created a niche for the dominance of *Cyclotella*, allowing it to increasingly exert an impact on lake clarity, particularly in summer. The experience from Emerald Bay suggests that this may be reversible if *Mysis* are removed.

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[1]*"Previous year" for some parameters means data collated in terms of the water year, which runs from October 1 through September 30; for other parameters, it means data for the calendar year, January 1 through December 31. Therefore, for this 2020 report, water year data are from Oct. 1, 2018 through Sept. 30, 2019. Calendar year data are from Jan. 1, 2019 through Dec. 31, 2019.*

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Experimentation with advanced technologies yields new insights about processes impacting the lake and the surrounding forests. The challenge is in maintaining long-term data records that may have commenced decades ago, while at the same time incorporating new approaches to enrich the monitoring data. This was the goal with our experimentation with UAV and helicopter surveys for metaphyton and periphyton monitoring. Combining remote sensing with traditional diver-based surveys will provide better estimates of interannual differences, and through that an understanding of potential agency actions. Similarly, the use of autonomous underwater vehicles to study harmful algal blooms is a forward-looking approach to an issue that is impacting other lakes increasingly, although not yet a problem for Lake Tahoe.

Wildfire and drought will continue to impact the health of Tahoe's forests. Through our efforts to establish a common garden and understand the plant traits of the most resilient trees in the basin, we are part of a broader effort to preserve and enhance our forests. Working with the California Conservation Corps we have already replanted thousands of trees in the most impacted areas.

Microplastics are of concern everywhere. While others are focused on the sources of the plastic, our researchers are looking for where they are showing up in the lake and in the water we may one day drink. Multi-depth surveys, analysis of biota, and sediment analysis are all being conducted. In parallel with this, an extensive public education effort was launched in partnership with the Tahoe Water Suppliers Association and Raley's supermarkets.

While lake physics may seem esoteric, it is at the core of much of what we see and experience at Lake Tahoe. This especially applies to recreational pursuits such as paddleboarding. Most years there are fatalities at Tahoe during what may seem like a benign sport in an idyllic location. Some of the unseen dangers are explained in this year's report.

Finally, there is also the opportunity to pass on lessons learned at Tahoe and to gain new perspectives from other communities. This is the motivation of a growing collaboration with Patagonian foundations, researchers, industries, and government agencies. Tahoe has a lot to share with the world, but also a lot still to learn.

Meteorologically, the long-term trends that have been prevalent do not change year-to-year. 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. 2019 was a cold year, colder in every month of the year except April compared to

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2017 and 2018. February was particularly cold with the monthly average air temperature being 4.4°F below the long-term average, making it the coldest February since 1956. Precipitation at Tahoe City was 43.8 inches, 12 inches above the average for the last 110 years. February was also the wettest month. 43.9 percent of the precipitation at Tahoe City fell as snow.

The water level in Lake Tahoe varies throughout the year due to inflows, outflows, precipitation, and evaporation. In the last three years it has been generally high due to the average to above-average precipitation. On July 1, 2019, the lake peaked at 6229.03 feet above mean sea level, less than one inch below its maximum legal limit.

Lake Tahoe has generally been warming since regular measurements commenced in 1968. In the last four years, the average water temperature (top to bottom) has cooled from its record warmest year in 2015. Its coolness this year can be partly explained by the fact that it mixed all the way to the bottom for the first time in eight years. During that mixing, the water temperature at the bottom of the lake fell by over 0.3°F in just a few weeks. July surface water temperatures were also significantly cooler. In 2019, the July surface average temperatures were 64.0°F, compared with 68.4°F in 2017.

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. The length of time that Lake Tahoe is stratified each year has been increasing, 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 2019, the stratification season length fell almost exactly on this long-term trend line, despite the cooler than average year.

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 above average, in line with the above average precipitation for the year. Both were well below the record loads from 2017. In-lake nitrate concentrations have displayed an increasing trend since 1980. In-lake total hydrolyzable phosphorus concentrations, after declining from 1980 to 2010, have been showing an increasing trend over the last decade. The reasons for these trends are not fully understood at the present time. The distribution of nitrate and total hydrolyzable phosphorus throughout the lake was radically

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different in 2019, on account of the deep mixing that occurred in March. Over the previous eight years, a high concentration layer of both had accumulated at the bottom of the lake.

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 over time. The annual average concentration for 2019 was 0.88 micrograms per liter. For the period of 1984-2019, the average annual chlorophyll-*a* concentration in Lake Tahoe was 0.70 micrograms per liter. The reason for the jump in 2019 is believed to be due to the infusion of nutrients due to deep mixing after a prolonged break, and the above average stream inflows. Most of the chlorophyll is concentrated at a depth of approximately 170 feet, known as the "deep chlorophyll maximum." From an abundance of individual cells viewpoint, diatoms were the most common algal group (60 percent of the cells). Of these, *Synedra* and *Nitzschia* formed the largest percentage of the biomass during every month of the year. *Cyclotella* was a low fraction of the diatoms in 2019, but it still had a large impact on clarity due to its extremely small size and large numbers. There were two peaks in biovolume – in May and September. The September peak of over 500 cubic millimeters per cubic meter, was far larger than most years. The attached algae (periphyton) on the rocks around the lake were particularly heavy in 2019, based on a synoptic survey of 53 observations. This is believed to be due to the relatively steady water level and the higher nutrient levels. The California side of the lake was especially high, although Zephyr Point in Nevada has its second highest value on record.

In 2019, the annual average Secchi depth was 62.7 feet (19.1 m), an 8.2 foot decrease over the previous year. The highest individual value recorded in 2019 was 112.0 feet (34.0 m) on February 19 and the lowest was 36.1 feet (11.0 m) on May 8, coinciding with a bloom of the tiny algal cell *Cyclotella*. The decrease in clarity in 2019, was the result of a combination of factors including the deep mixing of the lake, above average stream loads, algal blooms, and the impact of lake stratification. While the average annual clarity is now better than in 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 81 feet was only slightly below the long-term mean of 84 feet. Summer (June-September) clarity was 53 feet (16.2 m). This is the fourth lowest summer value, with the lowest being in 2008. Summer is typically the season of lowest clarity values.