EXECUTIVE SUMMARY

The long-term data set collected on the Lake Tahoe ecosystem by the University of California, Davis and its research collaborators is an invaluable tool for understanding ecosystem function and change. It has become essential for responsible management 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 new 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, and aerial drones; and the deployment of a suite of numerical models. 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 2018 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 current research that is being driven by the important questions of the day. These include: the continuing decline of lake clarity during the summer months and a potential ecological approach to restoring it; the vastly different climate that Tahoe basin will experience in the coming decades and what this could mean for current planning and management activities; the direct linkage between the alga *Cyclotella* and clarity; new findings on the physical processes that occur in the lake based real-time measurements in the nearshore; and growing threats to Lake Tahoe's aspens. The impact that TERC's researchers are having at locations far from Tahoe are also highlighted.

Summer clarity has been declining in the long term at Lake Tahoe, and largely offsetting the gains made in winter clarity. With projections of future climate change indicating accelerating warming and earlier runoff from streams, the decline in summer clarity is expected to continue, threatening the progress that has been made in the last 20 years. Recent results suggests that a novel ecological approach, focused on the removal of the Mysis shrimp that was introduced in the 1960s, may be able to restore the lake's native zooplankton, increase the clarity at to levels not seen in decades, and in the process "climate proof" the clarity of the lake. Increased clarity and the return of the native zooplankton carries with it the additional benefits of rapid growth of native fish and a natural impediment to the growth of invasive fish and plants.

Climate change is expected to impact all aspects of the Tahoe basin in the coming decades. The most serious of these changes are likely to be driven by changes in the physical processes, not simply the change in air temperature. The temperature

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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 2019 report, water year data are from Oct. 1, 2017 through Sept. 30, 2018. Calendar year data are from Jan. 1, 2018 through Dec. 31, 2018.

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distribution in the lake will suppress mixing, critical for oxygenation of the deep waters. At the same time, the continuing transition from a snow-based to a rain-based climate will result in the peak stream-flows occurring months earlier than they historically have. Aside from consequences for fish spawning, the loss of snowpack water storage will also mean a drying of the forests and the consequent elevated wildfire risk.

In 2018 the tiny diatom, a type of algal cell, *Cyclotella* again impacted summertime clarity levels. Even though *Cyclotella* biomass was relatively smaller in 2018, its small size and its dominance in the surface waters means that it comprises the largest number of algal cells above the level of the Secchi disk.

Five years ago, a novel monitoring program was commenced with the installation of eleven real-time water quality stations around the periphery of the lake. Over that time, an entirely new set of insights and knowledge about Lake Tahoe have been developed. Aside from quantifying water quality in different parts of the nearshore, we have been able to create predictive tools for turbidity and periphyton sloughing all around the lake, better understand the conditions under which stream inflows mix as they enter the lake, and– most importantly– have discovered a new "wave" that propagates around the boundary of Lake Tahoe. The existence of this wave had previously been inferred, but now the measurements and the model results have confirmed its existence and its importance.

Though the devastation wrought on Tahoe's forests by the recent drought seem to have passed from our memory, new threats to the health of the forests have emerged. The most prominent of these is the threats white satin moth, which is defoliating stands of Aspen in parts of the basin. Some of these trees are considered "heritage trees" as carvings on their trunks can be dated to an earlier era when Basque sheepherders brought their flocks into the basin. With successive cycles of defoliation these trees will eventually die.

Meteorologically, 2018 was a very uneventful year. Air temperature and precipitation were similar to what the long-term trend lines. Similarly, the percentage of snow in the total precipitation was 31.5 percent, almost identical to the previous year, but down from one hundred years ago when it was closer to 50 percent. The snow depth on March 29, 2018 was 121 inches, a very average year, far below the values this year when on March 29, 2019 it was 198 inches.

Lake Tahoe has been warming since regular measurements commenced in 1968. Surface water temperatures in particular have been increasing. For 2018, the average surface water temperature was 53.2 °F (11.8 °C). This is the second warmest surface temperature year recorded. The maximum daily summer surface water temperature was one of the highest observed at 77.5 °F, which was recorded on August 6, 2018. Over the month of July, surface water temperature averaged 67.3 °F, the third warmest July on record. The warming of the surface prevents the lake from fully mixing in winter. In 2018, Lake Tahoe mixed to a depth of 935 feet. This lack of deep

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mixing most likely contributed to the warm surface temperatures, and the continuing buildup of nitrate in the lake.

Nutrient inputs via streams are a major source for nitrogen and phosphorus, and the total load typically varies with the annual precipitation. With 2018 being an average precipitation year, nutrient inputs were closer to average than the previous very wet year. Within the lake, nitrate concentration was at an all-time high of 20.9 micrograms per liter, the result of the seventh successive year in which deep mixing did not occur. Phosphorus, measured as total hydrolysable phosphorus (THP), was at its highest level since 1989 for the same reason.

Biologically, the primary productivity of the lake has increased dramatically since 1959. By contrast, the biomass (concentration) of algae in the lake has remained relatively steady over time. The annual average concentration for 2018 was 0.65 micrograms per liter. For the period of 1984-2018, the average annual chlorophyll-a concentration in Lake Tahoe was 0.70 micrograms per liter. From an abundance viewpoint, diatoms were the most common algal group (60 percent of the cells). Of these, *Synedra* and *Nitzschia* were the most common during every month of the year. *Cyclotella* was a lower fraction of the diatoms in 2018, but it still had a large impact on clarity. The peak biovolume in 2018 was 320 cubic millimeters per cubic meter, almost double the biovolume in the last three years, a reflection of the increase in *Synedra* and *Nitzschia.* The attached algae (periphyton) on the rocks around the lake were particularly heavy in 2018, based on a synoptic survey of 53 observations. This was in part due to the relatively steady water level. Ironically, the four individual sites that are annually used to compare year to year variations were all abnormally low.

In 2018, the annual average Secchi depth was 70.9 feet (21.6 m), a 10.5 foot increase over the previous year. The highest individual value recorded in 2018 was 100.0 feet (30.5 m) on March 6 and the lowest was 50.0 feet (15.2 m) on July 27. The increase this year is attributed to a return to more normal conditions, following the five-year drought and the heavy snow year that ended it. 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. The winter (December - March) clarity value of 73.5 feet was a decrease of 5.2 feet. This was largely the result of the previous year's extremely low clarity conditions. Summer (June-September) clarity was 61.7 feet, an 8.2 foot increase from 2017. The cause of the improvement was a return to more normal summer conditions.

This report is available on the UC Davis Tahoe Environmental Research Center website (http://tahoe.ucdavis.edu/stateofthelake).