

Environmental Problems Facing Lake Tahoe

The three main environmental problems facing Lake Tahoe include:

1. Loss of water clarity
2. Impact of climate change
3. Impact of non-native species (especially Aquatic Invasive Species)

Other environmental problems include litter, issues with wildlife such as human-bear conflicts, traffic, air quality problems from car exhaust and wood-burning stoves, the impacts of human development, the impact of tourism, and more. However, we will focus on the top three issues.

Loss of Water Clarity

Pollution

Pollution, primarily from the more urbanized areas around the lake, has become a problem for Lake Tahoe. Pollution takes many forms and can include litter, sediment, nutrients, oil and grease, microplastics, and pathogens. Lake Tahoe suffers from increased loads of fine sediment and dissolved nutrients. The nutrient inflows are mostly phosphorus and nitrogen fertilizers which support the growth of free-floating and attached algae. Urban stormwater is the largest source of pollution clouding Lake Tahoe's clear water. When it rains, or as the snow melts, water flows down streets and across parking lots, picking up dirt, road sand, fine particles, and oil, all of which flow directly into storm drains that lead to Lake Tahoe. No wastewater flows into Lake Tahoe, however, so it is protected from tiny microplastic pollution from our washing machines and other sources.

Algal Growth

TERC research has shown that the rate of algal growth has been steadily increasing over the past 50 years. The rate of algae growth in Lake Tahoe has quadrupled since 1959. This trend continues to increase at a rate of approximately 5 percent to 6 percent per year (see annual algal growth chart in the Additional Resources section, at the Lab Exhibit, and in the State of the Lake Report). This increase in growth is believed to be due to a reduction in the size of the phytoplankton in the lake, and a faster turnover rate of nitrogen and phosphorus in the lake. These two nutrients have become unnaturally abundant in the lake because of human-caused (anthropogenic) disturbances. The

primary anthropogenic sources are accelerated erosion, fertilizer use, car exhaust, and urban runoff.

Sediment Erosion

Erosion of soil and sediment occurs naturally by water and wind. Recently, accelerated erosion has been occurring due to human caused disturbances. Driving on roads, motor vehicles on dirt trails, and development are all sources of erosion and soil disturbances. These activities grind up soil and sediment into microscopic particles. The extremely small particles (1 – 10 microns) are especially harmful to water clarity. These small particles get into the lake via the air, storm drains, and tributaries. Some particles are so small that they stay suspended in the water column and are believed to be the major contributor to Lake Tahoe's long-term clarity loss (Swift et al. 2005).

Eutrophication

Eutrophication refers to the effects of an overabundance of nutrients and occurs naturally as part of the overall aging of a lake. The normal life cycle of a lake begins with clear water that becomes progressively browner/greener due to sedimentation and algae growth. Over time, layers and layers of dead organisms and sediment will fill up the lake, turning it into a marsh, and then finally into a meadow. This process normally occurs over millions of years, however, at Lake Tahoe, we are seeing the effects of eutrophication happening at an accelerated rate. This accelerated eutrophication is primarily due to the nutrients and the sediments that are entering the lake at rates higher than what would naturally occur. If we do not make a conscious effort to reduce these inputs, we could witness catastrophic changes within our lifetimes.

Cultural Eutrophication

Cultural eutrophication refers to the acceleration of the natural process of eutrophication by anthropogenic changes. These changes can include such things as disturbed watersheds from roads and urbanization. The pavement, rooftops, and other impervious surfaces shed over 90 percent of all precipitation. Instead of being filtered by the soil, the water runs off the surface rapidly. Surface runoff typically concentrates in ditches and gullies, causing soil erosion. When these higher-than-natural flows reach streams, increased streambank erosion occurs. Cumulatively, these alterations lead to greater loads of fine particles and nutrients to the lake.

Impact of Climate Change

Climate change is one of the biggest threats facing Lake Tahoe. It is causing more precipitation to fall as rain rather than snow. More rain means more floods and stormwater runoff that carries sediment into Lake Tahoe. Climate change is also increasing the lake's water temperature and affecting regional weather patterns in ways that could change the lake's ecosystem and cause more of a decline in the lake's clarity.

Climate change is a complex, overarching factor for many changes occurring at the lake:

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.

Over the last 108 years, daily air temperatures measured at Tahoe City have increased. The long-term trend in average daily minimum temperature has increased by 4.47 °F (2.48 °C) and the long-term trend in average daily maximum temperature has risen by 2.25 °F (1.25 °C). The trend line for the minimum air temperature now exceeds the freezing temperature of water, which is leading to more rain and less snow as well as earlier snowmelt at Lake Tahoe.

Since 1910, snow has declined as a fraction of total precipitation, from an average of 52 percent in 1910 to 32.6 percent.

The average temperature of all the water in Lake Tahoe has increased by approximately 0.94 °F since 1970. The annual rate of warming is 0.19 °F/decade (0.011 °C/decade). Despite year-to-year variability, the annual average surface water temperatures show an increasing trend. The average temperature in 1968 was 50.4 °F (10.2 °C). For 2019, the average surface water temperature was 52.2 °F (11.2 °C), slightly cooler than 2018. The overall rate of warming of the lake surface is 0.37 °F (0.21 °C) per decade.

When the lake has a vertical distribution of temperature, it has a corresponding distribution of density, with warm and lighter water at the surface, and colder, denser water at depth. As the temperature difference increases, the lake is said to become more stable. Increasing stability poses a potential threat to all lakes. The stability index is a measure of the energy required to fully mix the water column when it is density stratified.

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.

For additional details, see the Tahoe: State of the Lake Report at <https://tahoe.ucdavis.edu/stateofthelake> or the Climate Science page of the TERC website at <https://tahoe.ucdavis.edu/climate-change>.

Changes in the Food Web and Aquatic Invasive Species

Changes in the Food Web

Species diversity in Lake Tahoe has been greatly affected by the intentional and unintentional introduction of non-native species, and many communities of both plant and animal life have undergone significant change since studies began. In the case of phytoplankton, these communities have a direct impact on lake clarity. For other species, changes have affected the lake's food web and consequently have altered its fishery.

Introduction of Non-Natives

In attempts to improve Lake Tahoe's fishery, many fish and invertebrate species have been introduced into Lake Tahoe and surrounding waters, most with limited success. These non-natives cause changes in the food web and food web energetics. For example, Mysis shrimp were introduced into Lake Tahoe to provide a food source for game fish; however, they reduced the available food sources for the larger fish by eating many of Tahoe's native zooplankton, such as the Daphnia. Since Daphnia naturally clear the lake through filter-feeding, their population decreases have led to decreases in clarity (Further information found in additional resources).

Invasive Species

During the last 130 years, numerous non-native fish, invertebrates, and plants have been introduced to Lake Tahoe. Invasive species such as Asian clams, Eurasian watermilfoil, Curly-leaf pondweed, and fish species such as largemouth bass, smallmouth bass, bluegill, and carp are now found regularly in Lake Tahoe. Whether intentional, accidental, or illegal, these species introductions have had profound negative effects on the lake's native food web and have greatly altered native habitats. Current management efforts are

aimed at preventing the introduction of Quagga or Zebra mussels into the lake. Mandatory boat inspections are currently required for all boats entering the lake to prevent spread of invasive species.

Other Concerns

Destruction of Wetlands

Lake Tahoe historically had natural wetlands that acted as filtration systems to remove excess nutrients from stream water before the runoff reached the lake. This is one of the many reasons for Lake Tahoe's famously clear and pristine water. Unfortunately, the value of wetlands was not fully known before the heavy development that began in the mid-1950s. For example, the Tahoe Keys was built on one of the largest wetlands in the Lake Tahoe basin. Research has shown that the wetlands of South Lake Tahoe used to remove tons of sediment and nutrients. The detrimental impact of this development can be easily seen during heavy rainstorms when plumes of sediment cause the water to turn cloudy.

Forest Health

The numbers of dead and dying trees throughout Tahoe and the Sierra Nevada are increasing due to a combination of drought stress, insect attack, wildfire, and disease. This carries direct implications for fire safety, biological diversity, and carbon sequestration. Learn more about forest health from the TERC Forest and Conservation Lab at <https://tahoe.ucdavis.edu/forests>.

TERC Research Activities in the Lake Tahoe Basin

Researchers at Lake Tahoe have been gathering data since 1958 and have produced one of the longest continuous data sets available for a sub-alpine lake. This long-term record along with the research and analysis of these data contributes to the knowledge base on sub-alpine lakes worldwide and to the well-being of Lake Tahoe itself.

Ongoing Research and Monitoring

An ongoing monitoring program is essential to water quality protection in the Lake Tahoe region. The goal of monitoring is to characterize water quality and the degree of support for beneficial uses on both temporal and spatial scales. 'Baseline' data can be used to set standards for water bodies that currently do not have site-specific standards. 'Trend' information defines the need for, and allows prioritization of, restoration and/or regulatory actions. Monitoring can also document compliance with permit conditions and the success (or failure) of remedial activities. The UC Davis Tahoe Environmental Research Center has been an active member and committed partner in the Lake Tahoe Interagency Monitoring Program or "LTIMP." The mission of LTIMP is to develop integrated water quality research and monitoring strategies to support regulatory, management, planning, and research activities within the Lake Tahoe Basin.

Current Monitoring Projects

Lake Tahoe Profile Monitoring

This is conducted every 7-10 days to determine changes in lake clarity and water column properties. This includes conducting Secchi disk measurements at the mid-lake and index station (off west shore near Homewood), measurements of primary productivity (see the section on primary productivity sampling), profiles of temperature, conductivity, dissolved oxygen, light transmission, and light attenuation using a "Seabird- SBE25," profiles of particle size and concentration using a LISST-100X, and water sampling for nutrient analysis and phytoplankton counts from discrete depths. Zooplankton samples are collected using a net pulled from 150 meters depth up to the surface, and then stored and counted in Davis. These include species such as Diaptomus and Epischura.

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Primary Productivity Monitoring

This occurs every 30 days to measure the amount of algae that make up the basis of the food web in Lake Tahoe. Water samples are collected from the surface down to 105 meters using a Van Dorn sampler for varied depth collection. Samples are then split into glass bottles, injected with an isotope of Carbon (C14), and then sent back down to the depth in which they were collected. After the samples are allowed to incubate for four hours, measurements can determine how much of this “labeled” carbon was taken up by the algae. This measures the instantaneous growth rate of algae.

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Monitoring of Periphyton

Brant Allen, Katie Senft, and Brandon Berry regularly don their wetsuits to collect samples of the attached algae that grows along Tahoe’s shoreline. Attached algae, or periphyton, are good indicators of localized nutrients entering the lake. Researchers from TERC snorkel sections of the shoreline to monitor levels of periphyton growth around the lake five times per year by collecting it from submerged rocks at nine routine sites and measuring chlorophyll content to estimate algal biomass. An additional 25 sites are visited during the heaviest spring growth to provide more detailed information on distribution each year. Researchers have been studying the attached algae in the shore zone of Lake Tahoe for the past 37 years, one of the longest datasets available for a lake like Tahoe.

While the steady loss in lake clarity is sometimes difficult to visualize, the seasonal proliferation of periphyton is an easily observed by the public. This green “ring around the collar” appears as a troubling sign to those expecting a pristine Tahoe aesthetic. Thick, green or white expanses of periphyton biomass often coat the shoreline in portions of the lake during the spring. When this material dies and breaks free, beaches can be fouled with decaying organic matter that washes onshore. The nearshore periphyton can significantly affect the aesthetic and beneficial uses of the shore zone. The purpose of the periphyton-monitoring task is to assess the levels of nearshore periphyton growth around the lake.

Periphyton, algae attached to submerged rocks, has been found all over Lake Tahoe, and anecdotally was reportedly seen in increasing amounts since the 1960s. However, a TERC

study published in 2021 found that periphyton biomass has not increased since monitoring began in the 1980s and may actually have decreased at many sites. The conflict between scientific measurements and public perception may partially be explained by the delay between Tahoe Basin development and the start of periphyton monitoring. Much of the change in shore zone algae may have occurred prior to 1980. If periphyton growth has not been increasing in the last four decades, why is it that so many people report mounds of rotting algae building up on Tahoe's beaches in low water years? TERC scientists believe that this is the result of increased amounts of metaphyton—stringy, floating clumps of algae. These have appeared simultaneously with the arrival of invasive Asian clams and are a focus of ongoing study.

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Stream Monitoring

TERC and USGS researchers visit long-term stream monitoring stations to collect water samples and make measurements throughout the year. These collections are part of the Lake Tahoe Interagency Monitoring Program (LTIMP), which measures nutrient and sediment input from a portion of the basin's 63 streams. Brandon Berry and Raph Townsend conduct regular sampling monthly with more frequent sampling during the spring runoff and rain events. Water samples are analyzed for nutrients, suspended sediment, temperature, fine particles, and dissolved oxygen. Information from this monitoring is used to estimate the annual nutrient loads from streams and to discern trends in tributary water quality. Fine particles contributed from tributaries and other sources have a significant direct negative impact on lake clarity. The Lake Tahoe Interagency Monitoring Program (LTIMP) evaluates the status and trend of stream input (loading) of sediment and nutrients. As watershed restoration efforts carry on into the future, continued stream monitoring is important to evaluate program effectiveness, detect changes in the response of stream water quality, and support simulation monitoring used for management decisions.

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Atmospheric Deposition Monitoring:

Atmospheric deposition of nitrogen (and to a lesser extent phosphorus) is an important source of nutrients to the lake. TERC currently monitors atmospheric deposition at one station within the Tahoe basin. The station is located on the research buoy TB1 in the middle of the lake. Approximately every 10 days, TERC researchers exchange a bucket located on top of the buoy which is partially filled with deionized water and collects atmospheric deposition occurring onto the lake (as rain, snow, and "dry" deposition of gaseous and particulate material). At the end of the collection period, the water is analyzed by TERC labs to estimate the atmospheric deposition of nitrogen and phosphorus to the lake surface. Bulk deposition data is collected from the buckets and a passive plastic-lined PVC sampler, located on the buoy to collect wet and dry precipitation. Atmospheric deposition data from the lake buoys have provided important information on atmospheric deposition directly to the lake surface. The atmospheric deposition-monitoring program provides ongoing information on nutrient loading via this important source of nutrients to the lake.

Monitoring of atmospheric deposition is also important for understanding its role in the degradation of the lake and for use in watershed management. Atmospheric deposition contributes about 55% of the total nitrogen, 15% of the total phosphorus, and 15% of the total fine (<20 μ m) particles to the lake, all of which influence clarity.

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Current Research Projects

In addition to the routine monitoring that is undertaken by TERC, there are a variety of ongoing, ever-changing research projects funded by national and state agencies. These are in areas as diverse as invasive species control, lake currents, remote sensing of lake water quality, sediment resuspension dynamics, lake food webs, computer modeling, landslide risk, and wetlands performance. TERC's graduate students, post-doctoral scholars, visiting scientists and our professional staff, conduct this research. Details of many of these projects are included on TERC's webpage at <https://tahoe.ucdavis.edu/lake-science>.

Meteorology of Lake Tahoe

Knowing the meteorology that drives motions and heat exchange in a lake is an essential component of understanding its behavior. Since the 1990s, TERC has been installing and operating a series of real-time weather stations around the lake to provide this data.

Meteorology Stations

Six meteorological stations are located on land in the watershed surrounding Lake Tahoe. The data collected from these stations have multiple uses. UC Davis researchers are investigating lake circulation, clarity loss, and other environmental changes. Too many nutrients in the water were once thought to be a problem, but in the past few years we started finding that fine sediment has a larger effect on clarity. The satellite data enable TERC scientists to see temperature changes across the entire lake, making it possible to understand lake circulation and its effect on the transport of fine particles. Data from the buoy stations and satellites will enable graduate students and researchers to study the physical processes that contribute to Lake Tahoe's unique clarity and build computer models to categorize and understand these processes.

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NASA's Jet Propulsion Laboratory and UC Davis TERC Research Buoys

Researchers from the Tahoe Environmental Research Center maintain a network of real-time meteorological and lake temperature stations on the water and on land. Along with collaborators from NASA's Jet Propulsion Laboratory (JPL), TERC has a network of six research buoys and rafts on Lake Tahoe. Serving as research stations, these vessels provide information that ensures Earth-observing satellites are measuring the Earth's

surface temperature correctly. Several environmental satellites, including Terra, Landsat, Aqua, and Envisat, fly over Lake Tahoe to collect data, with about six satellites passing by each day. NASA and UC Davis scientists have been collaborating to collect data on Lake Tahoe and to validate the data gathered by the environmental satellites since 1999.

Each research buoy has a radiometer that can measure the lake's surface temperature to within 0.05 of a degree, a temperature sensor trailing in the water that measures the lake's temperature at depth, and meteorological equipment that determines air temperature, wind speed and direction, pressure, relative humidity, and net radiation. Air samplers and deposition samplers have also been added to the research stations. Deposition samplers enable scientists to measure the amount of nitrogen and dust falling into the lake from the atmosphere. These buoys monitor both temperature variations and atmospheric fluxes above and below the air-water interface, which is primarily used by NASA to calibrate and validate thermal infrared data from satellites and aircraft, but also facilitates a wide range of scientific studies on the physics of lakes and other inland water bodies.

Three-Dimensional Modeling of Lake Tahoe

Three-dimensional computer models allow researchers to study the complex motions that take place within a lake, and to play “what-if” scenarios to understand the impacts of changing conditions. In recent years, our models of Lake Tahoe have progressed from being able to resolve features down to 200 m (660 feet) from only 20 m (66 feet). TERC's three-dimensional model Si3D is currently being used to understand the transport of invasive species such as Asian clam larvae, pathogens, and other contaminants within Lake Tahoe.

The complex patterns produced by the interactions of the wind, the complex shape of Lake Tahoe and the earth's rotation are key to knowing where contaminants are likely to build up or be transported.

Modeling Lake Clarity

Dynamic Lake Model with Water Quality (DLM-WQ) includes a physical process based one-dimensional hydrodynamic model and newly developed sub-modules to simulate turbulent diffusion transfer, fine particle dynamics, dissolved oxygen, phytoplankton, zooplankton, nutrients (species of nitrogen and phosphorus), and Secchi depth. Although

the hydrodynamic model is one-dimensional, lake outflows and turbulent mixing due to stream inflows are treated two-dimensionally. The model parameterizations are derived from the extensive field and laboratory experimental data.

DLM-WQ simulates the temporal changes in the temperature and water quality distributions in lakes/reservoirs and the lake water level. Because boundary-forcing inputs to the DLM-WQ include time-series weather variables, inflow volumes (stream and intervening zones), and associated physical, chemical and biological characteristic of the water, lake outflows, groundwater fluxes, atmospheric deposition, and shoreline erosion, it is used for development of TMDL, monitoring TMDL, operation and management of the lake, and assessments of climate change impacts.

Keep Tahoe 450 nm - Measuring Lake Tahoe's "Blueness"

Lake Tahoe's deep cobalt blue color is of great ecological and economic value and a focus for lake management strategies of the region. While water clarity has been scrutinized and routinely measured for more than five decades, the blueness of the lake had never been quantified scientifically, until 2014. In collaboration with NASA-JPL and the Université Laval, Québec, Canada, TERC has developed the blue water index (Bw) to quantify Lake Tahoe's blueness. This objective measurement of water color enables us to conduct continuous monitoring of Lake Tahoe's color as well as the color of other oligotrophic lake waters.

The color monitoring from 2012 to 2014 revealed that Lake Tahoe's iconic blueness is most closely related to algae, not fine inorganic sediments that can be directly correlated to lake clarity. The general assumption that lake clarity is tied to blueness has driven advocacy and management efforts in the Lake Tahoe Basin for decades. However, these findings show that at times of the year when clarity increases, blueness decreases, and vice versa. This is due to the seasonal interplay of sediment, nutrients, and algal production as the lake mixes.

Development of models estimating lake water blueness from the input of water quality data is currently underway. The model will help us determine past and future lake colors that reflect changing environmental conditions of the region.

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Measuring Metabolism

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 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. This 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 in the lake. Dissolved oxygen 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.

Forest Health

The health of the Lake Tahoe Basin's forests is subject to a range of threats, including 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).

The TERC Forest and Conservation Biology Lab headed by Patricia Maloney was featured in the LA Times for efforts to restore Tahoe's native sugar pine forests after repeated drought and pine bark beetle infestation. Since 2016, members of Maloney's lab have been collecting thousands of seeds from trees that survived these devastating events. In the TERC lathe house, located at the Tahoe City Field Station, they have raised approximately 10,000 seedlings. These seedlings are part of a large planting effort

referred to as “assisted regeneration.” These mighty little trees carry genetic information passed down from surviving trees, with the hope that this is the key to survival of impending future events of longer droughts and more intense infestations. This past November, Maloney’s team planted between 4,000 and 5,000 of the seedlings raised for the project. Almost half of these trees were tagged to study how they fare in the future and whether the traits they were selected for have successfully prepared them for changes in our climate. Check out the LA Times article here:

<https://www.latimes.com/california/story/2019-11-18/sierra-trees-climatechange-adaptation-lake-tahoe>

In 2021, the team will be studying the 100 surviving “mother” sugar pine trees from the Lake Tahoe Basin that were the seed sources for a sugar pine reforestation project in 2019–20. The team wants to determine if these survivors carry genes and plant traits that will allow them to be more resilient to future drought and bark beetle outbreaks. A drought stress experiment will address the drought-bark beetle interaction in which a control group will be watered, and another group will be exposed to simulated drought or dry-down conditions. Pre- and post- analyses will allow the lab to assess water efficiency and chemical defenses and identify mechanisms underlying the trees’ varied responses to drought and bark beetle pressure—an important interaction that remains largely unexplored. Having just gone through the second dry winter in a row, this research is now extremely timely.

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Nearshore Monitoring

Starting in 2014, TERC established a network of water quality instrument stations at various points on the shoreline around the lake. The program aims to understand the causes of the degradation of Lake Tahoe's nearshore and provide the essential data needed to guide restoration and future stewardship.

As of June 2018, nine stations were installed around Lake Tahoe, including an additional station on Cascade Lake, which feeds into Lake Tahoe. Each nearshore sensor station consists of a Turner Designs C3 Submersible Fluorometer measuring turbidity, algal concentration, and dissolved organic material, along with an RBR maestro CTD measuring water temperature, conductivity, lake level, and wave height. An underwater cable supplies power to each station and returns data, which are displayed as near real-time and can be accessed via the internet.

The nearshore is a very ecologically productive area of the lake, and the quality of this area is more likely to affect a visitor's impression of Lake Tahoe. Moreover, unlike the deep portion of the lake, the nearshore is subject to sudden erratic changes in water quality. These changes occur in response to storms, inflows from streams and storm drains, local erosion, or drift from other parts of the lake. Every part of the nearshore responds differently. The Nearshore Network will allow scientists and agencies to better understand the causes of degradation, implement projects to mitigate degradation, and determine appropriate and meaningful threshold standards for nearshore conditions.

Using a helicopter and a drone, as well as good old-fashioned sampling from the lake, TERC developed a rapid, accurate, and economical approach to monitor the near-shore. In a project funded by the Nevada Division of State Lands, the team developed a way to image the entire shoreline using a helicopter in less than 90 minutes and image specific bays in detail in only ten minutes. The final product is a set of maps that give highly precise measurement of metaphyton that is calibrated with data taken at lake level. It is also now possible to use the same approach to quantify periphyton, the attached algae on rocks, and rooted plants, some of which are invasive. Researchers are still trying to determine what has spurred the recent growth of metaphyton in certain areas of the lake. The evidence is pointing to the fact that growth is tied to nutrient inputs from the excretion produced by Asian clams. This excretion has over 100 times higher nutrient levels than the lake water and metaphyton are frequently found in the same areas.

Upwelled Pelagic Water Exchange Driving Littoral Limnology (Upwell) Experiment

Spring upwelling events are common between late May and early June. Variable spring weather conditions combine with a weakly stratified lake to generate upwelling. Before this period, the lake is typically vertically mixed; there is no “two-layer” response to strong winds. After mid-June, stratification strengthens, and strong winds become rare; upwelling is uncommon.

During Spring of 2018, a large experiment along the west shore of Lake Tahoe was conducted. The overarching goal of “Project UPWELL” is to characterize the physics of seasonal upwelling and to quantify the role of this process in internal nutrient loading to the nearshore and surface waters. Sustained wind events during weak spring stratification have been observed to induce upwelling of deep, cold water along the upwind shore of Lake Tahoe. These spring storms typically follow the prevailing southwesterly wind pattern, causing upwelling along the west side of the lake. The

experiment detailed in this document aims to generate a rich dataset for quantifying the upwelling and post-upwelling responses of a large lake to sustained spring wind events. This project is a collaboration between TERC UC Davis Civil and Environmental Engineering, UC Davis Bodega Marine Lab, and Stanford University.

Controlling Invasive Shrimp to Improve Water Clarity in Lake Tahoe

A research team led by TERC director Geoff Schladow, civil and environmental engineering professor Alex Forrest, and environmental science and policy professor Steve Sadro, launched a pilot project to test and optimize a strategy to improve water clarity in Emerald Bay and Lake Tahoe. The team aims to reduce the abundance of Mysis shrimp, one of Lake Tahoe's most ubiquitous invasive species, to levels where they no longer impact the ecosystem of the bay. If the number of Mysis is reduced, native zooplankton species will be able to recover to levels not seen since Mysis was established in the 1950s. This could lead to a significant improvement in water clarity – one of the long-term goals for the lake.

A local nonprofit group led by a UC Davis School of Management alum plans to begin trawling for Mysis experimentally in the fall of 2021. Their plan is to remove enough Mysis to allow the lake clarity to return. They will process the removed Mysis and turn them into dog treats for sale in the Tahoe Basin. Learn more about the “Shrimply Blue” project at <https://shrimplyblue.org/>.

Environmental Robotics

Alex Forrest, a TERC researcher and assistant professor of civil and environmental engineering is heading up the UC Davis Environmental Robotics Laboratory. The goal of this group is to use emerging technologies, either autonomous or semi-autonomous, to study environmental water problems in lakes and oceans. From the Arctic to the Antarctic, his group has tackled issues in a broad range of hostile environments. Dr. Forrest is currently working with a broad range of equipment including:

- Storm Glider, an autonomous underwater glider that uses buoyancy differences to extend observations from hours to days or weeks at a time. With its maiden flight in Antarctica in 2017 to examine melting of ice shelves, it is currently deployed in Lake Tahoe to examine physical mixing processes associated with internal waves. In 2018, it is off to Lake Geneva to be used to collect turbulence data and how that relates to lake ecosystem health.

- UBC-Gavia, a self-propelled autonomous underwater vehicle, has just been loaned to UC Davis from the University of British Columbia (Canada) and is currently being returned from Australia where it was being used to train the Royal Australian Navy.
- In addition to these autonomous platforms, the team has been working with TERC to develop a suite of ship-mounted sensors to resolve fine-scale organisms in the water column (e.g. Mysis) as well as imaging the lakebed with acoustic imagery. Work with this equipment is currently in the demonstration phase and it is planned for much broader deployments in the upcoming years. The use of underwater remote sensing and spatial analysis leverages Forrest's research experience with autonomous underwater vehicles, or AUVs, as data collection platforms to study areas such as large-scale shorelines or beneath ice shelves. Once this equipment has been tested, the team aims to use these and similar platforms in the future in the rest of Lake Tahoe that cannot be surveyed using boat-based techniques and other lakes and oceans around the world.

More broadly, Forrest and his team use AUVs and other emerging technologies to identify problems in environmental fluid mechanics, map the bottom of our lakes and oceans and use these tools to identify the fate and propagation of invasive species within a given ecosystem.

Microplastics

TERC scientists, headed by TERC researcher Katie Senft, are sampling throughout the water column and the sediments of Lake Tahoe to investigate the fate of microplastics in the iconic lake. Microplastics are smaller than five millimeters and pose a threat to aquatic ecosystems and potentially to human health. The researchers will also sample municipal water treatment facilities to assess the potential for human health impacts. The team is also looking into Kokanee salmon stomach contents and Asian clams tissue to determine the impacts of microplastics on the lake's biota. The samples taken in the field are processed in the laboratory, first by TERC chemist Steven Sesma, to separate the plastics by size class then by UC Davis scientist Dr. Jenessa Gjeltrema, who uses Raman microspectroscopy to determine the composition of the very smallest microplastic particles. Scientists from Desert Research Institute (DRI) are collaborating with TERC to study the threat microplastics pose to the entire Lake Tahoe Basin. DRI is studying the inputs—*inflowing streams, accumulation on snow, storm drains, and even dryer vents*, while TERC is researching the distribution and fate of microplastics once they have entered the lake. See the infographic above to see the different sampling methods used

for these projects. The collaboration of efforts will ultimately provide a more complete picture of the sources of microplastics and their impacts. This is one of the first investigations of microplastics in lakes and it will also inform future pollution mitigation strategies.

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Aquatic Invasive Species Control

Curlyleaf Pondweed

This aquatic invasive weed chokes out waterways and is increasing in density in Lake Tahoe. It reproduces via vegetative shoots called turions, which are extremely resilient and hard to kill. TERC utilizes a combination of field and laboratory surveys and experiments to understand the relationship between curly-leaf pondweed population biomass, asexual reproduction (via turion production), and management using bottom barriers. This research assesses plant density in South Lake Tahoe, measures habitat quality, installs three types of barriers to test the impacts on plant biomass and turion viability, and the collection of turions from both control sites and from under barriers to quantify germination rates in a lab setting. The goals of this study are to understand the impact of curly-leaf pondweed on Lake Tahoe's littoral zone ecology and the potential for non-chemical treatment using benthic barriers to reduce both macrophyte biomass as well as turion viability.

Asian Clams in Emerald Bay

Low densities of non-native Asian clams were discovered on the sandy sill entrance of Emerald Bay in 2010. Asian clams compete with native species for resources and can harm water quality. In the fall of 2012, five acres of rubber bottom barriers were placed over the clam beds to reduce/exterminate the clams and prevent them from moving further into the bay. UC Davis and the University of Nevada, Reno researchers monitor the effectiveness of the barriers for clam mortality, changes in dissolved oxygen concentrations under the barriers, and impacts on native aquatic invertebrates. The barriers were removed in the fall of 2014, effectively killing 90% of the clam population in the bay. Researchers are now studying other methods of eradicating clams (e.g. electric rakes, bottom-scraping machines).

State of the Lake

Please see the State of the Lake Report at <http://tahoe.ucdavis.edu/stateofthelake/> for more information about how Lake Tahoe is changing and current research efforts. In the UC Davis Tahoe: State of the Lake Report, we summarize how natural variability, long-term change, and human activity have affected the lake's clarity, physics, chemistry, and biology. We also present the data collected in the previous year. The data reveal a unique record of trends and patterns – the result of natural forces and human actions that operate at time scales ranging from days to decades.

Each year, new research areas emerge in the State of the Lake Report. In past years, we have highlighted topics such as the Angora Fire, climate change, and the emergence of Asian clams as a major threat to Lake Tahoe's ecosystem.

Lake Tahoe Facts

How did Lake Tahoe form?

Three to five million years ago, the valley that would become the Tahoe Basin sank between parallel fractures in the Earth's crust as the mountains on either side continued to rise. A shallow lake began to form in the resulting valley. Two to three million years ago, erupting volcanoes blocked the outlet, forcing the lake to rise hundreds of feet above its current elevation, and eventually eroding down to near its current outlet. Between one million and 20,000 years ago, large masses of glacial ice covered the west side of the Tahoe Basin. Current geologic theory suggests an earthen berm (moraine) left by a receding glacier near Squaw Valley acted as a dam, causing the lake level to rise and then draw down rapidly when the dam catastrophically failed. Between 21-12 thousand years ago, a portion of the West Shore collapsed into the Lake causing a massive, submerged landslide and tsunami, widening the Lake by three miles, and creating McKinney Bay.

How high is the Tahoe Basin?

The surface of the Lake is at an elevation of 6,225 ft. above historical sea level. The surrounding mountain peaks vary from 9,000 to nearly 11,000 ft. Only 16 other large lakes in the world are higher.

How pure is the Lake and why?

The water is 60 parts per million (ppm), 99.994% pure, making it one of the purest large lakes in the world. The Lake owes its extraordinary purity to the relatively small watershed, a large amount of precipitation falling directly on the lake's surface, the dilution effect of the massive volume of water it contains, and purification of runoff by adjacent wetlands.

See below comparisons, (the lower the ppm, the purer the water):

Lake Tahoe	~60 ppm
Typical tap water	~200-400 ppm
Purified water	<10 ppm
Mineral (spring?) water	~250 ppm
Distilled water	~1 ppm

Why is the Lake so blue?

The lake water appears blue as other color wavelengths in the light spectrum are absorbed and blue light is reflected back. Its depth, clarity, and lack of algae also contribute to its particular blueness. In addition, under the right conditions, the Lake surface can reflect the color of the sky.

How clear is the water?

Clarity is determined by measuring the water depth at which an eight-inch diameter white disk disappears from view. In 2019, the annual average Secchi depth was 62.7 feet, far less than the maximum 105 ft. of clarity measured in 1968. While the clarity of Tahoe is decreasing, it is still much clearer than other lakes, such as Lake Shasta (often noted for its muddy, brown water).

How large and deep is the Lake?

The Lake's surface is 22 miles long by 12 miles wide and 191 square miles (122,200 acres) in area. The shoreline length is 75 miles. The average depth is 1,000 ft. A maximum depth of 1,645 ft. Lake Tahoe is the second deepest lake in the USA, third deepest in North America, and the 16th deepest in the world (previously listed as the 11th deepest lake in the world before finding the depth of under-ice lakes and other unknown lakes' depths).

How much water is in the Lake?

The Lake holds about 40 to 41 trillion gallons of water, enough to cover the state of California to a depth of 14 ½ inches. Between the regulated high and low water levels, the volume of water in Tahoe can vary by 243 billion gallons. Tahoe is the largest lake by volume above 600 ft. elevation in the USA.

Where does the water come from?

Snowmelt from 63 tributaries in the 315-sq. mi. watershed adds 65% of the water. Another 35% falls as precipitation directly on the Lake. Typically, 212 billion gallons of water enter the Lake this way each year.

Where does all the lake water go?

About one-third of it flows into the Truckee River through the dam at Tahoe City for downstream use. Any remaining water flowing to the river terminates at Pyramid Lake. The remaining two-thirds of water evaporates from the surface at an annual average rate of 0.1 inches per day. In a normal year, Lake Tahoe will see a net rise of 15 inches from spring runoff.

What is the weather like?

The average high temperature is moderate, ranging from the high 20s in winter to the 80s in summer. At least seven months per year, daily maximum temperatures reach the outdoor comfort zone. Sunshine occurs over 75% of the time during daylight hours each year, which amounts to roughly 270 sunny and partly cloudy days. From November through March, 78% of the yearly precipitation occurs, mostly as snowfall. Typically, at lake level in Tahoe City, 14 ft. of snow falls over winter and accumulates to a maximum snowpack depth of 2.8 ft.

The chance of getting more than 0.1 in. of precipitation between the May 1 and October 15 is 10% or less.

How cold is the Lake?

Below an average depth of 600 ft., water temperature is a near-constant 40°F. During July and August, the surface temperature can reach 75°F. In the coldest months, the lake surface temperature lowers to 40°F.

Does the Lake ever freeze?

The main body of Lake Tahoe does not freeze. The stored heat in the Lake's massive amount of water compared to its relative surface area prevents the Lake from reaching freezing temperature under the prevailing climatic conditions. On rare occasions, Emerald Bay has developed full or partial ice cover, and thin ice sheets can form on shallow nearshore waters under very cold and calm conditions.

Does pollution endanger Lake Tahoe?

Tahoe has lost about one-third of its world-renowned clarity since 1968. The major component of clarity loss is fine particles, with nearly three-quarters originating from development-impacted watersheds. Another important pollutant is nitrogen, over one-half of which comes from atmospheric fallout created by vehicle exhaust and pollution blown in from surrounding urban areas. A third critical pollutant is phosphorus, with disturbed and natural watersheds contributing two-thirds of the load. All wastewater is treated and exported from the Tahoe Basin. In 2020, microplastics were found in Lake Tahoe.

Interesting Facts

- The name Tahoe comes from a mispronunciation of the Washoe name for Lake Tahoe, *da ow a ga*, which means, “edge of the lake.”
- The Lake Tahoe water surface averages 6,225 ft. above historical sea level.
- The Lake water appears blue due to absorption of all other colors in the light spectrum and reflection of the remaining blue light back to an observer.
- At Tahoe City, an average of 14 ft. of snow falls, accumulating to a snowpack depth of 2.8 ft.
- The elevation of Carson City, Nevada is 85 ft. higher than the deepest part of Lake Tahoe.
- If Sears Tower, the tallest building in the USA, were dropped into Lake Tahoe at its deepest point, the top would still be submerged by 194 ft. of water.
- By volume, Lake Tahoe is the sixth largest natural lake in the USA, the largest lake over 600 ft. in elevation in the USA and the 17th largest lake in the world at or above this elevation.
- The average daily evaporation of water from the lake surface would serve the daily needs of 3.3 million Americans.
- Lake Tahoe is nominally 22 miles long and 12 miles wide with 75 miles of shoreline and a surface area of 191 square miles.
- Lake Tahoe’s surface water temperature varies between 75°F in summer to 40°F in winter.
- Over a 40-year period, loggers clear-cut 95% of the forest to supply lumber for Virginia City, Nevada mines and the transcontinental railroad.
- The Lake contains about 40 to 41 trillion gallons of water – enough to cover the State of California to a depth of at least 14 ½ in.
- Ancestral Native Americans began inhabiting the Tahoe region as far back as 10,000 years ago. The Washoe Tribe occupied the Tahoe Basin for 1,300 years preceding the 20th Century.
- Lake Tahoe is 3-5 million years old and is the result of faulting and volcanism.
- A dam at Tahoe City on the Lake’s surface outlet regulates the upper 6.1 ft. of Lake Tahoe above the low water mark.
- In 1861, Mark Twain hiked 12 miles from Carson City to Lake Tahoe in search of a timber claim, camped on the North Shore, and accidentally started a wildfire.
- The first recorded sighting of Lake Tahoe was by Brevet Captain John Fremont and his topographer, Henry Preuss, on February 14, 1844 from Red Lake Peak near present day Carson Pass.

- Each year, Lake Tahoe fills with 212 billion gallons of water from 63 streams and direct precipitation on the surface of the lake.
- Tsunamis up to 300 ft. high have occurred on Lake Tahoe in the past 15,000 years.
- Due to global warming, Lake Tahoe surface water temperature has increased an average of 1.6°F since 1968.
- The surface elevation of Lake Tahoe is in the sub-alpine zone.

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Protecting Lake Tahoe

Learn from Science

50 years of research has shown that Lake Tahoe is threatened by loss of water clarity, an increase in non-native species, changes in the food web, and risk of catastrophic wildfires. Research allows for wise public policy decisions as Lake Tahoe provides a living laboratory for studying freshwater lakes and their ecosystems.

Think Blue

Consider how your actions will affect the lake and surrounding watershed. Never dump anything into the storm drains. The underground storm drain system leads directly to roadside ditches, streams, and eventually to the lake.

Prevent soil erosion by covering bare soil in your yard, by staying on trails, and by parking in designated areas. Fertilize wisely – Fertilizers contain the nutrients (nitrogen and phosphorus) that feed plants, including algae, which harm the lake. Pick up after your pet.

Be Green

Ride a bike, take public transportation, walk, or carpool – excessive automobile use degrades air quality and contributes to the decline in Tahoe's clarity.

Consider low-impact recreational opportunities like hiking, biking, kayaking, and cross-country skiing.

Reduce your ecological footprint – increasing open space on private property helps the lake. Conserve energy and recycle.

Conserve water, it is a limited resource.

Practice Good Stewardship of Lake, Land and Sky

Do not purchase single-use plastics.

Do not litter. Dispose of trash properly.

Be careful with fire.

Stay on trails and avoid fragile areas – straying from the trail causes excessive erosion.

Practice "Leave No Trace" outdoor ethics: "Pack it in, pack it out."

Protect sensitive areas such as stream zones and meadows. Respect plants and wildlife.

Start in Your Backyard: Tahoe Locals Have Responsibilities

Complete the required Best Management Practices (BMPs) and Defensible Space projects on your property.

BMPs improve water quality by reducing soil erosion and capturing polluted water before it enters Lake Tahoe. The intent of BMPs are to help designed landscapes better mimic the natural ecosystem, reducing the amount of dirt and sediment that flows into Tahoe.

- Typical BMPs include armored drip line under roof eaves, slotted channel drains in driveways, slope stabilization, and infiltration basins.
- Pave your driveway. Sediments from compacted dirt driveways wash into the nearest storm drain and into Lake Tahoe during rainfall or snowmelt.
- For more information about BMPs, visit www.tahoercd.org (California) or www.ntcd.org (Nevada).

Due to years of fire suppression and mismanagement, Tahoe's forests have become densely populated which puts us at high risk for high-intensity fires that destroy neighborhoods, impact watersheds, and take human lives; therefore, it is important to implement defensible space practices to increase the likelihood of your home's survival.

- Rake your pine needles! Rake them in the spring; let them fall in the fall.
- Thin trees. Trees less than 14 inches in diameter can be removed without a permit as one-step to creating defensible space.
- Trim low limbs and thin brush. These limbs and brush or "ladder fuels" allow fire to travel along the forest floor and to climb into the forest canopy.
- Maintain a 5-foot noncombustible zone. Keep a fire safe buffer free of combustible material around structures year-round to combine erosion control with wildfire defense practices.
- For more information on defensible space, visit www.tahoelivingwithfire.com

Keep it Native

Use native and adapted plants that are easier to maintain and require little irrigation and fertilizer.

Never plant non-native invasive ornamentals on your property. Invasive weed infestations can permanently alter the environment and cost millions of dollars to manage, making early detection and rapid response the most effective tools in the fight against invasive weeds.

Watch out for hoary cress, Dalmatian toadflax, spotted knapweed, and Scotch broom. For a complete list of priority weeds, visit www.tahoeinvasiveweeds.org.

Watch out for invasive aquatic species such as Quagga mussels, Zebra mussels, New Zealand mud snails, Eurasian watermilfoil, and Curly-leaf pondweed, which hitch rides on boats, trailers, and equipment. Check boat propellers, bilge, and bait buckets to help prevent the spread of invasive species that can have devastating long-term effects on Lake Tahoe and its streams. Ensure your boat is clean, drained, and dry after every outing, and have your boat inspected before launch. For more information, visit www.tahoeboatinspections.com.

Protect Native Wildlife

Never feed bears or leave food out for pets, or wild creatures, to lure them up close for that perfect photo. Bears and other animals will return in an attempt to get another free meal after you have gone home. Often the next visitor has to deal with a problem that you may have created.

Dispose of your trash in bear-proof containers. Do not overfill or stack garbage outside of the container. Be sure that the latches engage after closing the door. If bear-proof containers are not available, store your garbage in your garage or indoors until trash day. Put your trash out on the morning it will be picked up, not before.

Conserve. Clearly.

Everyone has a role to play to protect Tahoe's clarity.

Support the Lake Tahoe Environmental Improvement Program (EIP).

- The EIP consists of hundreds of projects that are designed to restore Lake Tahoe's clarity and environment.
- Write to your elected officials to let them know the EIP is important for preserving Lake Tahoe for future generations.

Lights Out!

Point your home's outdoor lights down so that they do not cause light pollution and dim the night's starry skies.

Use energy-efficient bulbs outside and inside to conserve energy and turn off outdoor lights when not in use.

Watch the Volume!

Enjoy the tranquil beauty of the region by choosing non-motorized options such as kayaking, sailing, biking, or walking.

Be considerate - Please let others enjoy peace and quiet, especially in the forest. Remember that carbureted 2-stroke engines are not allowed on motorboats or watercraft on Lake Tahoe because they pollute. There is also a 600-foot no-wake zone to help reduce boating noise, to prevent shoreline erosion, and to help protect wildlife.

Get Involved

Volunteer for a program, organization, or effort to protect the Tahoe Basin.

Participate in local citizen monitoring or restoration efforts – citizens can collect valuable information about water quality and assist in restoration projects.

Use the Citizen Science Lake Tahoe app to record your observations and contribute to the science of the nearshore environment.

Support the Tahoe Environmental Research Center and other research institutions by contributing financially -- including cash contributions to the donation box for specified research projects, or through in-kind contributions.

Lake Tahoe: Four Decades of Change

By Charles R. Goldman, Distinguished Professor Emeritus of Limnology, UC Davis Fall 2006

General John Fremont first observed Lake Tahoe and his tired group of cavalry from a mountaintop located southwest of the lake. Since that time of those early western settlers, development for the next century proceeded slowly with stagecoaches and summer visitors finding their way gradually to the shore of the lake. When Mark Twain visited Lake Tahoe, he was extremely impressed by its cobalt blue waters and commented in his book, Roughing It, that the lake was the “fairest sight the whole earth affords.”

Once the discovery of gold and silver in the Comstock Lode at Virginia City was made, the first of the major disturbances of the Lake Tahoe basin occurred. This was the clear cutting of most of the Tahoe basin’s timber to shore up the mines of the Comstock. The timber was required for the boxed scaffolding that supported the mineshafts as the miners went ever deeper into Nevada’s earth. When the mines ran out of silver, most of the old growth timber in the Lake Tahoe basin was also gone. White fir and brush grew back in dense, overcrowded stands that have created a major fire hazard in the basin today. This period of re-vegetation was important, however, in slowing the high soil erosion rates, which characterized the peak logging period. The high losses of soil, which is chronicled in the sediments, dropped back to less than a quarter of those that occurred during that time of excessive lumbering activity.

Lakes are, in fact, reservoirs of history in the sense that they are able to record in their bottom sediment, an indelible record of what has occurred on the land, in the air, and in the water. Sawdust from the sawmills at Glenbrook along the east shore is still perfectly preserved in the sediment samples extracted from the lake bottom. A unique chemical record also exists in the sediments from the ethyl lead used in gasoline as well as mercury from the California gold rush and various sources of industrial atmospheric pollution. Even the fossil remains of invertebrates and fish scales can provide forensic evidence of the past glacial history of Lake Tahoe.

With the return of forests to the basin, Tahoe recovered its pristine quality as one of the clearest large lakes in the world. John le Conte, in 1887, measured the lake’s transparency at over 100 feet. This lake revival provides the hope that the lake can once more recover from the current period of high development activity. Over seventy percent of the Tahoe basin is US Forest Service land under the control of the Federal government. Despite this dominant ownership, there was ample room for extensive development around the lake

shore. Post World War II construction of roads and buildings, for the most part, had proceeded using the flatland technology of the less sensitive lower elevations. Adding to this situation, the problems associated with development on steep slopes contributed to the degradation of the fragile soils and the limited vegetation cover of the sub-alpine Tahoe basin.

In the late 1950s, when the value of wetlands was not well understood, the Dillingham Corporation was allowed to construct a marina development by digging up the Pope Marsh. This single largest wetland in the Sierra Nevada was transformed into an extensive marina development at the south end of the lake known as the Tahoe Keys. In so doing, the important filtering capacity of Pope Marsh was lost forever. To make things worse, the major tributary to the lake, the upper Truckee River, was canalized along the east side of the Tahoe Keys. Because of this, nutrients and sediment are directly delivered to the lake without the filtering benefits of the former wetland. The Keys became a habitat whose water was warmer than that of the lake and has served as refuge for a number of invasive plants and animals.

Unfortunately, over the years, people transported aquarium plants and fish to the Keys. Rather than taking them home at the end of the summer, they dumped them into the Keys. These invasive species, now exemplified by the spread of the notorious waterweed *Eurasian watermilfoil*, have gradually spread from the Keys to other areas around the lake. Warm-water fish introduced to the Keys have been able to move with the *Eurasian watermilfoil* to the new, warmer microenvironments that the weeds have created. Other invasive fish, particularly the cold water tolerant Smallmouth Bass, may eventually threaten the very existence of the native minnow, trout, and salmonid populations.

The invasion of these exotic organisms will be further aided by the gradual warming of the lake. Tahoe's enormous volume of 156 cubic kilometers of water has already increased a half of a degree in temperature over the last twenty years through climatic change and global warming. Unfortunately, this warming trend appears very likely to continue.

Although development along the lakeshore was slowed by World War II, the construction of casinos at the state line on both the north and south ends of the lake, together with a developing summer boating and winter ski industry, Tahoe gradually attained the status of a resort destination. So popular is the lake in summer that it is not unusual to record a million vehicle-miles around the lake in a single day. Selection of Tahoe for the 1960 Winter Olympics gave it global publicity and greatly increased the visitor traffic to the

basin. The beauty of Lake Tahoe is now world renowned, but like most of the world's lakes, human impacts are gradually taking their toll.

Since my studies began in 1959, the lake has lost a third of its remarkable transparency and algal growth rate has increased by about five percent per year. Small particles of dust and sediment remain suspended in the water column for years adding to the gradual but relentless transparency loss. Air pollution is no stranger to the Tahoe basin and nitrogen pollution of the lake is greater from the atmospheric deposition than it is from stream water input.

The limnology studies, which started in 1959, were instrumental in convincing a consulting group of eminent civil and environmental engineers in the 1960s to require the total export of both treated and untreated sewage from the Tahoe basin. Although the availability of a basin wide sewage system was probably stimulation for additional near-shore development, had this export not been achieved, the clear water picture that appears at the beginning of this article would not have been possible. A major factor in achieving the sewage diversion was the growing realization that Tahoe was revered for its remarkable cobalt blueness and that keeping Tahoe blue was a difficult, but achievable goal.

An extremely effective activist group, the League to Save Lake Tahoe, was instrumental in passing the scientific data collected by the Davis faculty of the University of California's Tahoe Research Group to the public at large. This translation of scientific data to layman's terms was particularly important. As the League's membership grew, so did the public's awareness of the growing threats to Lake Tahoe's water quality. "Keep Tahoe Blue" bumper stickers began to appear all across the states of California and Nevada. Another important activist, Alfred Heller, published a journal entitled "Cry California" which dealt with the many contemporary problems of the state. This provided the author with an opportunity to publish two articles on the plight of Lake Tahoe and compare it with the nearly undeveloped great Siberian Lake Baikal. Some years later, the Tahoe Baikal Institute was founded to provide student exchange between the two lakes each year.

Reflecting on the important decisions that have been made since my arrival at Lake Tahoe in 1958, several stand out; creation of the Tahoe Regional Planning Agency, for example, brought a lake divided by two states and five different counties, various municipalities, agencies, and local governments under a single central authority. I accompanied League to Save Lake Tahoe leaders in successful meetings with governors Paul Laxalt of Nevada and Ronald Reagan of California to urge creation of the gestate agency, to be charged

with protecting the lake's unique environment. This Federal mandate was unpopular in some circles, since it imposed Federal control of an area split by two states and five counties, but it provided an essential unification of purpose. The objective was simply to preserve the environmental quality by regulating future development and repairing the damage that had already been done. Federal Judge Garcia issued a landmark decision to halt the development in the basin for two years until control measures could be adequately established to protect the resources.

I have participated in successfully defending the Tahoe Regional Planning Agency from various legal assaults over the years. Strong scientifically based arguments have been the decisive factor in winning these cases for the Agency. A milestone event that greatly influenced the future of Lake Tahoe was a political meeting at the Lake in 1997, referred to as the "Lake Tahoe Summit". Both President Bill Clinton and Vice President Al Gore attended this meeting at Lake Tahoe at the invitation of Nevada's well-known Senior Senator Harry Reid. As Director of the Tahoe Research Group, I had the opportunity to show both the President and the Vice President, first hand, the condition of Lake Tahoe from aboard our University of California research vessel, the "John le Conte". They spent almost an hour aboard, examining the lake's water quality before returning to shore to sign a declaration for Lake Tahoe's protection. This event was unique for a President and Vice President of the United States and was fully covered by newspapers and worldwide television. The Tahoe Summit has now become an annual event. A few years later, when President Clinton was on a post-Presidential speaking tour at the Davis Campus of the University of California, he began his speech by saying how he remembered this lake expedition and getting his biology course from me!

I was invited to accompany J.T. Ravize', an outstanding Tahoe color photographer, when he displayed his photographic artistry and his wife's poetry in Washington D.C., at the U.S. Senate Rotunda. The exhibition was instrumental in focusing attention in the nation's Capital on one of the country's most valuable and scenic resources.

Senior Senators Harry Reid of Nevada and Dianne Feinstein of California have continued their essential leadership in championing the cause of helping to protect Lake Tahoe from further degradation. To further this cause, in the fall of 2006, the UC Davis Tahoe Environmental Research Center will be moved into a new world-class facility to support research and help provide the important science-based decisions for management of the Tahoe basin for this and future generations. Over a century and a half of development and environmental abuse have occurred since the western settlers first knew the lake. Tahoe remains an extraordinarily beautiful and remarkably clear lake. It is one of the West's

most treasured resources. We have now moved beyond most of the conflicts of the past and it is generally agreed between developers and conservationist alike that everyone loses if Tahoe's water quality and scenic beauty is allowed to deteriorate. There has been a growing public understanding of the value of this unique natural resource and a growing willingness to do whatever is necessary to protect Lake Tahoe for this and future generations.