TAHOE: STATE OF THE LAKE REPORT 2011

RECENT RESEARCH UPDATES

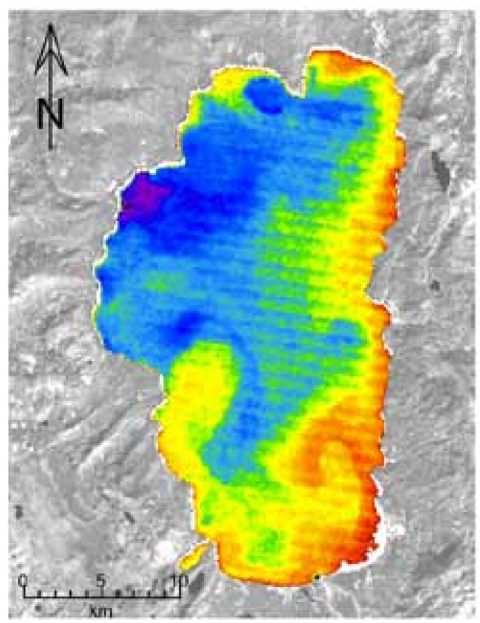
UC DAVIS
TAHOE ENVIRONMENTAL RESEARCH CENTER

RECENT RESEARCH UPDATES

Overview

Each year different research areas emerge as the most topical in the State of the Lake Report. In past years we have focused on topics such as the Angora Fire, Climate Change, and the emergence of Asian clams as a major threat to Lake Tahoe's ecosystem. This year we are stepping back and looking at clarity, the issue that has most symbolized Lake Tahoe in the eyes of the world. The recent changes in lake clarity highlight the complexity of natural systems, and the extent to which monitoring is needed to understand and best protect our natural resources. As a result of the SNPLMA science grant, we are able for the first time to present clarity information from all around the lake. We also introduce the concept of the "trophic status" of the lake. Finally, we provide an update on the continuing efforts of researchers and agencies toward controlling the spread of Asian clams.

The Secchi disk has been used to measure clarity at Lake Tahoe since 1968 with measurements taken every 10-14 days



Satellite images of Lake Tahoe showing areas of different water temperature

Asian clams (Corbicula fluminea)

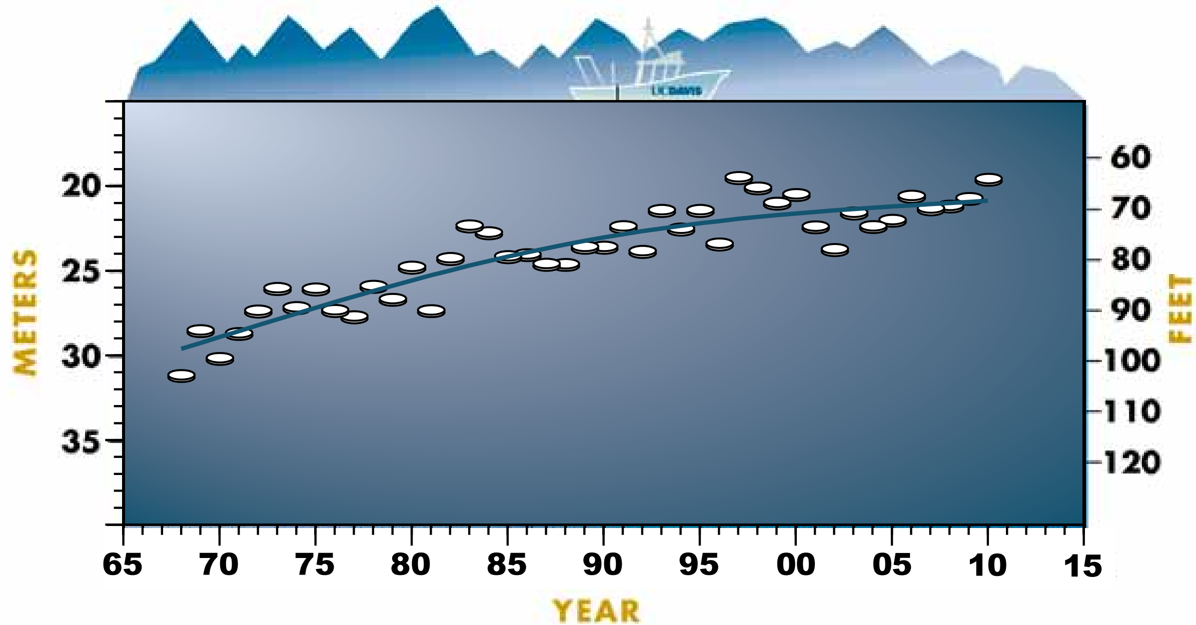
RECENT RESEARCH UPDATES: CLARITY

Lake Tahoe clarity 1968 - 2010

2010 was a low year (less clear) for annual average Secchi depth, with the depth of 64.4 feet measured from the surface being the second lowest ever recorded (the lowest was 64.1 feet in 1997). It represents a decrease of 3.7 feet from the previous year. It is important to understand the possible causes and to see what they tell us about past actions and future investments. Long-term monitoring data, such as that summarized in the State of the Lake Report, provides part of the information needed, but not all. Some of the critical knowledge gaps are in the monitoring of urban stormwater flows, where an independent and comprehensive monitoring program needs to be established to evaluate the status and trends of this important source of fine sediment and nutrients.

Even though 2010 was less clear, the overall trend of a slowing decline in clarity continues. Looking at the long-term record, interannual clarity changes of this magnitude are common. Over 50 percent of the 43 years with Secchi depth measurements have seen interannual differences (both positive and negative) in excess of this year's change. Insights into the status and trends of lake transparency are evident by examining both the long-term winter and summer Secchi depth values as well as the individual Secchi depths for recent years.

ANNUAL AVERAGE SECCHI DEPTH

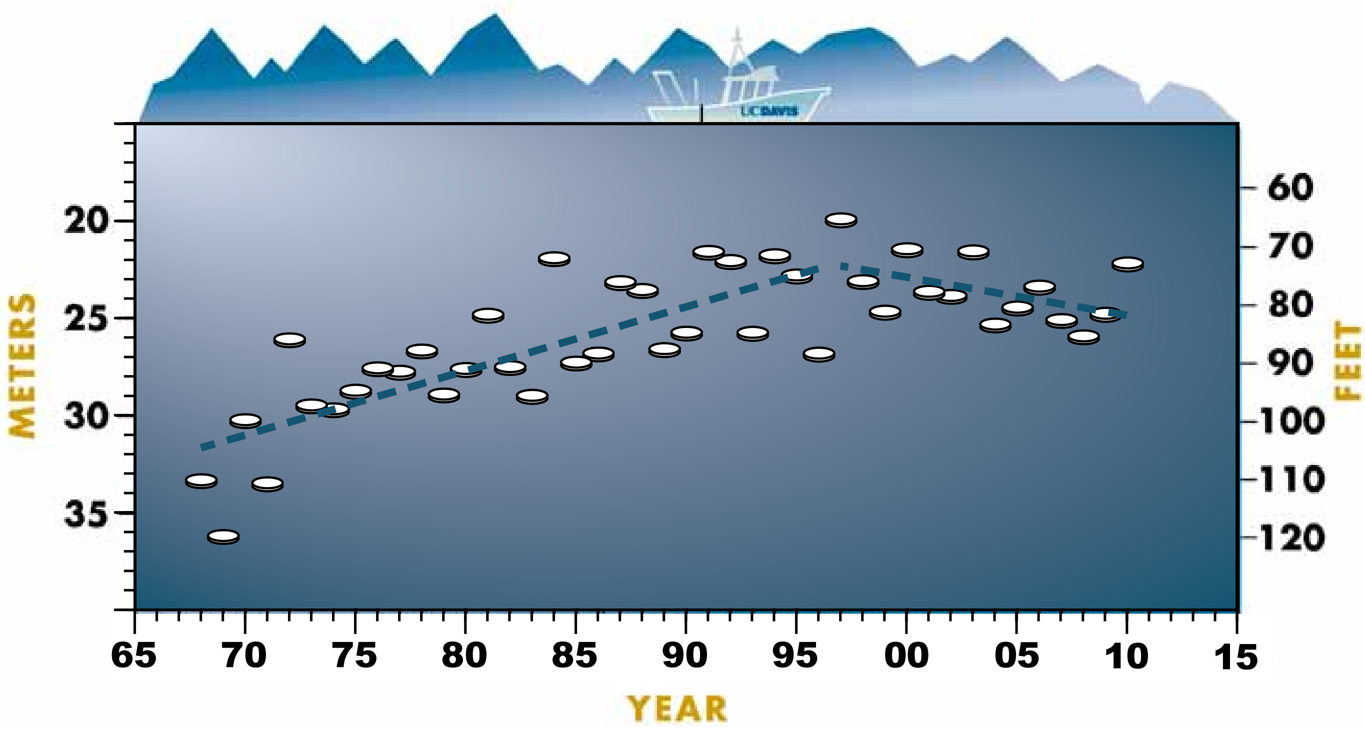


RECENT RESEARCH UPDATES: CLARITY

Winter clarity

Annual winter (December-March) Secchi depth measurements from 1968 to the present indicate that the long-term decline in winter clarity at Lake Tahoe is beginning to show an improvement (dashed lines). The reasons behind this are not fully understood. One hypothesis is that there has been a reduction in the load of fine particles from urban stormwater. Urban stormwater is the largest source of fine particles to Lake Tahoe, and generally enters the lake in winter. A comprehensive, regional urban stormwater monitoring plan is needed to determine if recent capital investments in stormwater projects have indeed reduced these loads.

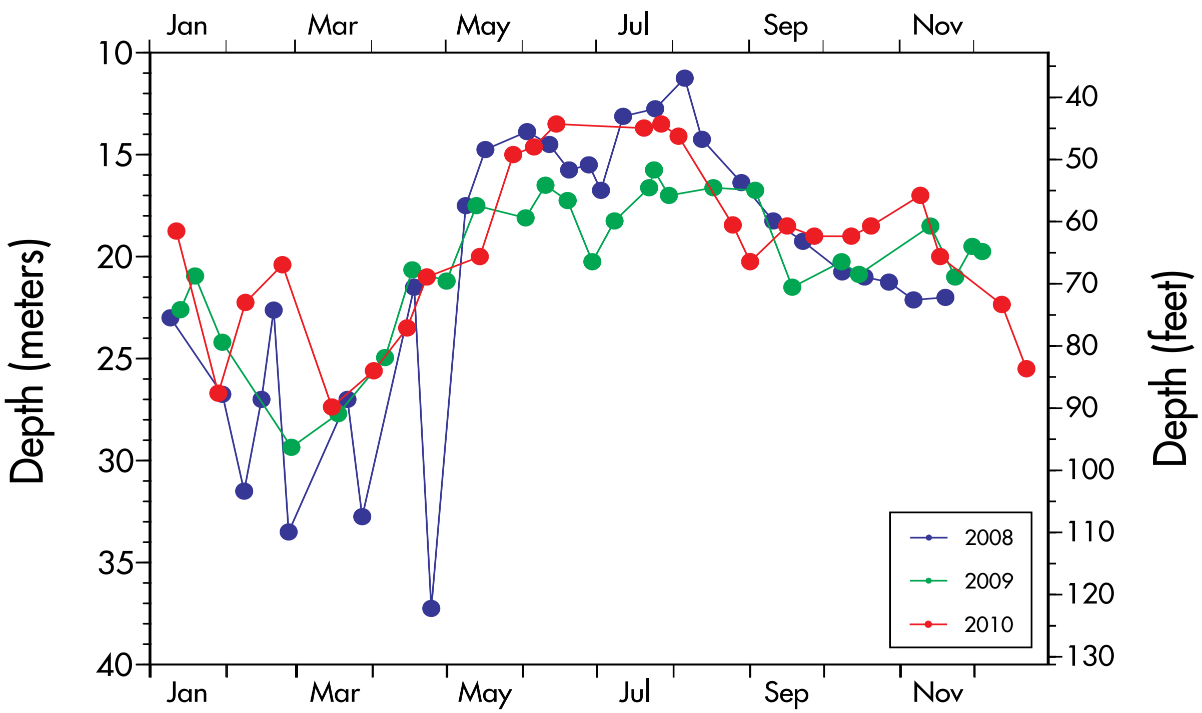
WINTER SECCHI DEPTH



Winter clarity, continued

Of the last three years, 2008 had the greatest winter Secchi depths, with two measurements in February exceeding 97 feet, the California water quality standard. These high clarity events are the result of circulation patterns called "upwellings", when westerly winds cause clear bottom water to rise up to the surface. In early spring of 2008 there were two additional upwelling events. By contrast, 2010 had no upwelling events that affected the annual average measurement.

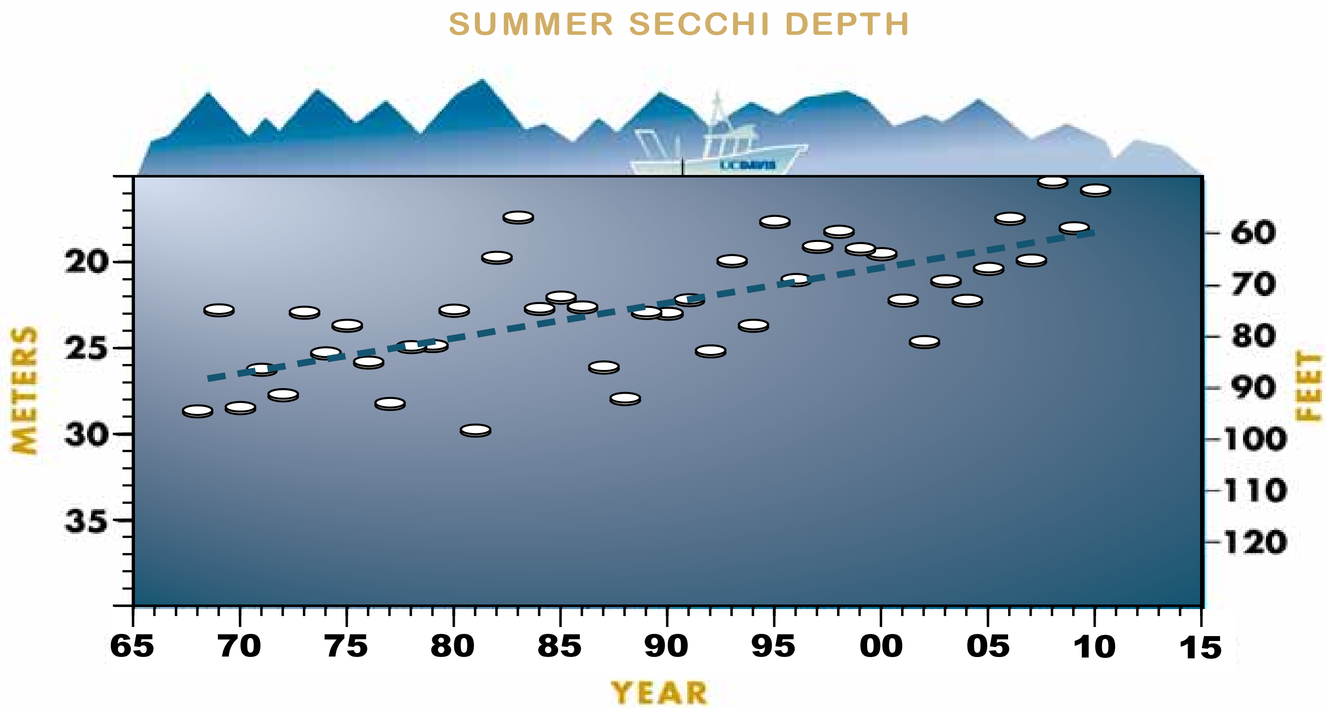
A second factor in the lower (less clear) winter clarity in 2010 was the absence of deep mixing (see Page 8.9). In 2010, the lake only mixed to a depth of 550 feet, slightly less than the 700 feet that occurred in 2009 and considerably less than the complete 1,645 foot mixing that occurred in 2008. The deeper the mixing, the greater is the dilution of the upper waters, leading to improved winter clarity. The two low Secchi depth measurements in February-March 2010 are likely a consequence of the lack of deep mixing.



RECENT RESEARCH UPDATES: CLARITY

Summer clarity

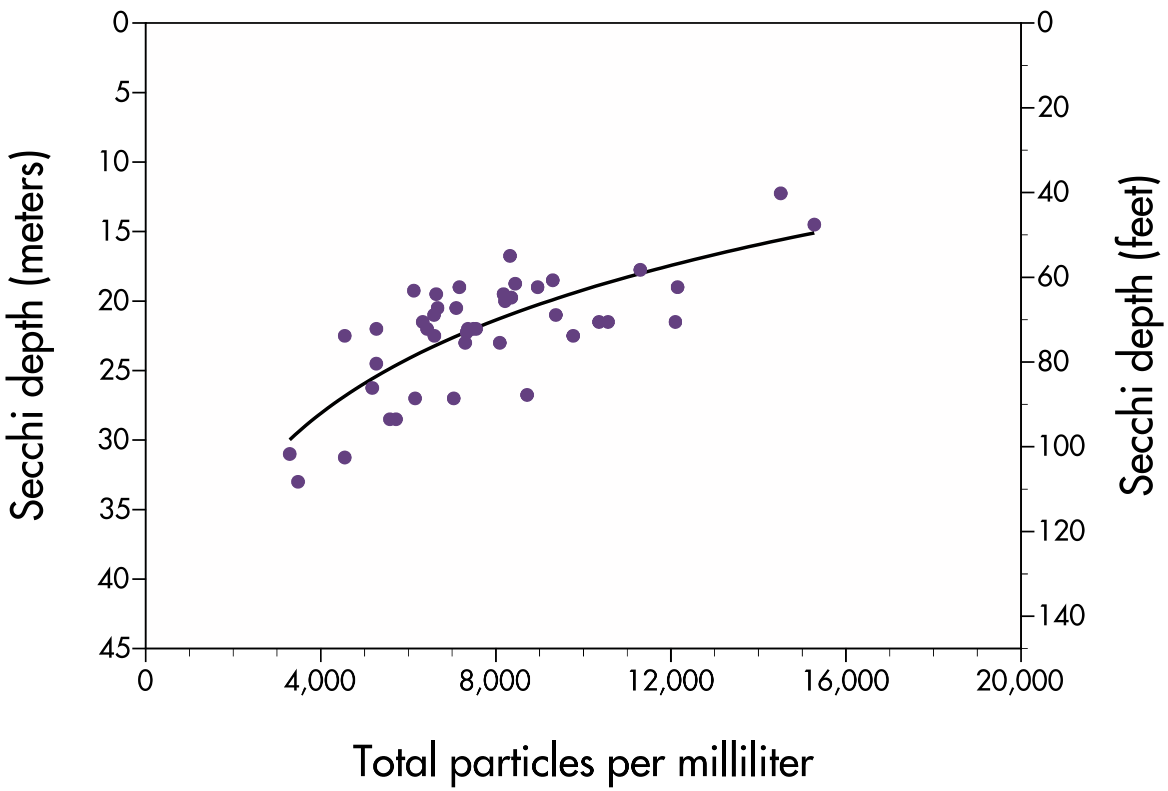
Summer clarity in Lake Tahoe in 2008 and 2010 were the lowest values ever recorded (50.4 feet and 51.9 feet respectively). Unlike the winter clarity pattern, where there is a long-term trend of declining and then improving clarity, the summer trend is dominated by a consistent long-term decline (dashed line) but with a noticeable 10-15 year cyclic pattern. This is clearly visible in 1968-1983, 1984-1997 and 2000-2010. For about the last decade there has been a near-continuous decline in summer clarity. The reasons behind this periodicity are being investigated, however, there is some evidence pointing towards a possible cause of the most recent decline.



RECENT RESEARCH UPDATES: CLARITY

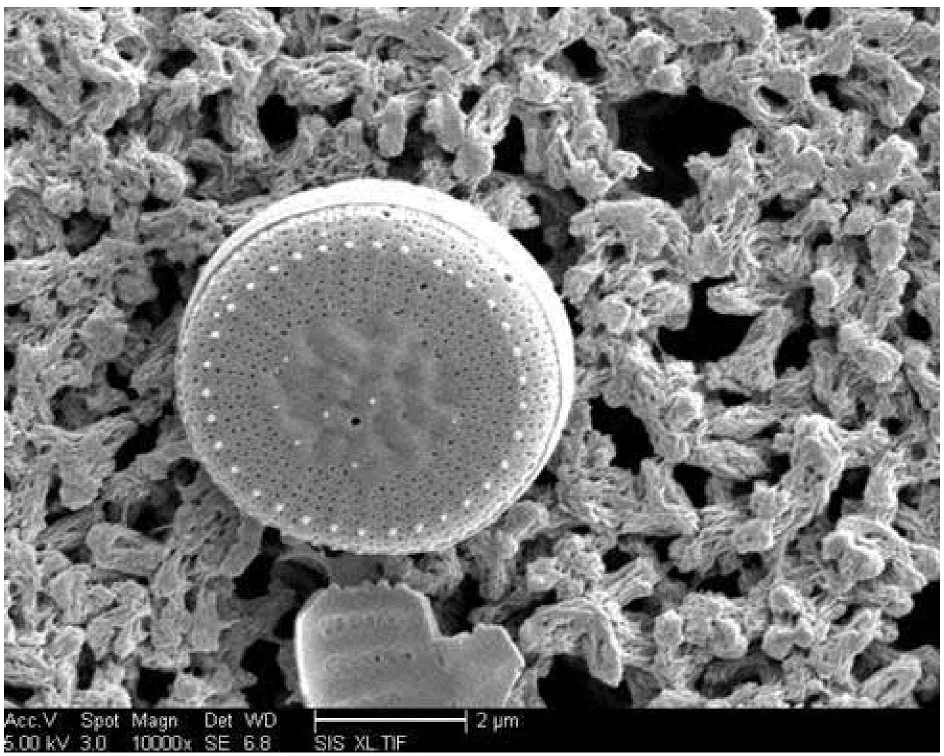
Summer clarity, continued

As our research has shown, increasing concentrations of fine particles is one of the principal factors affecting Lake Tahoe's clarity. While light scattering by fine inorganic particles introduced by urban stormwater is a major concern, the production of algal cells, and especially diatoms that both scatter and absorb light, is also important. The presence of excess nutrients is a factor that will influence their abundance.



Summer clarity, continued

Approximately one third of all the particles close to the surface in summer 2010 were in fact algal cells, dominated by the small, centric diatom *Cyclotella gordonensis* (see image below). Cells ranged from 4-10 µm in diameter, within the maximum scattering range for visible light. The peak abundance was in the upper 16 feet of the water column but the population extended down to greater depths. The abundance of *C. gordonensis* was remarkable, with cell counts of over 6,000 cells per milliliter (mL). In a sample from the 16 foot depth, *C. gordonensis* accounted for 99 percent of the algae present. The dominance of this diatom species during July 2010 was not unique nor without precedence. In July 2009 a similar event occurred, but the algae were concentrated deeper in the water column and therefore did not affect the Secchi depth readings as much.

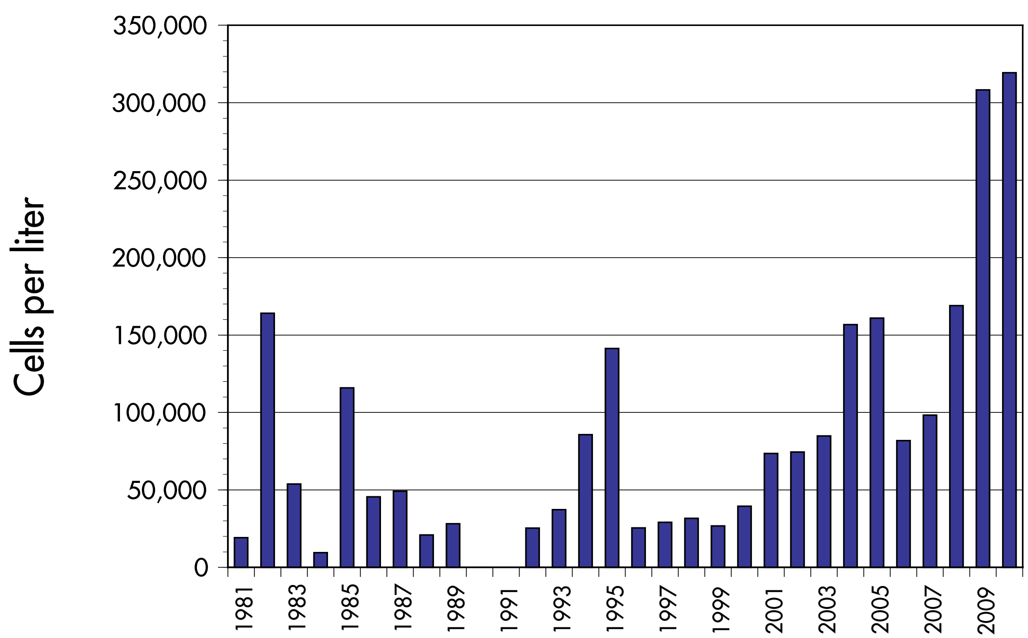


Cyclotella gordonensis dominated particles sampled in summer 2010

Summer clarity, continued

It is reasonable to ask why there is this recent increase in small diatoms. In a recent paper, (Winder, M., Reuter, J. E. and Schladow, S. G. 2009. "*Lake warming favors small-sized planktonic diatom species*". Proc. Royal Society B. 276, 427-435.), it was argued that climate change was warming and stabilizing the upper waters in Lake Tahoe (see Page 8.8). The greater the density difference between shallow and deep water, the greater is the resistance to mixing. This physical phenomenon in turn imparts a competitive advantage to the smallest algal species, such as the diatom *Cyclotella*, that sink slowly and therefore can stay suspended in the light for a long period of time.

The increase in the annual average numbers of *Cyclotella* from 1982 to 2010 in the upper 100 m of Lake Tahoe are plotted below. While high values occur in several years through the record, there is a clear upward trend from about 2000, coinciding with the start of the most recent period of decline in summer clarity.



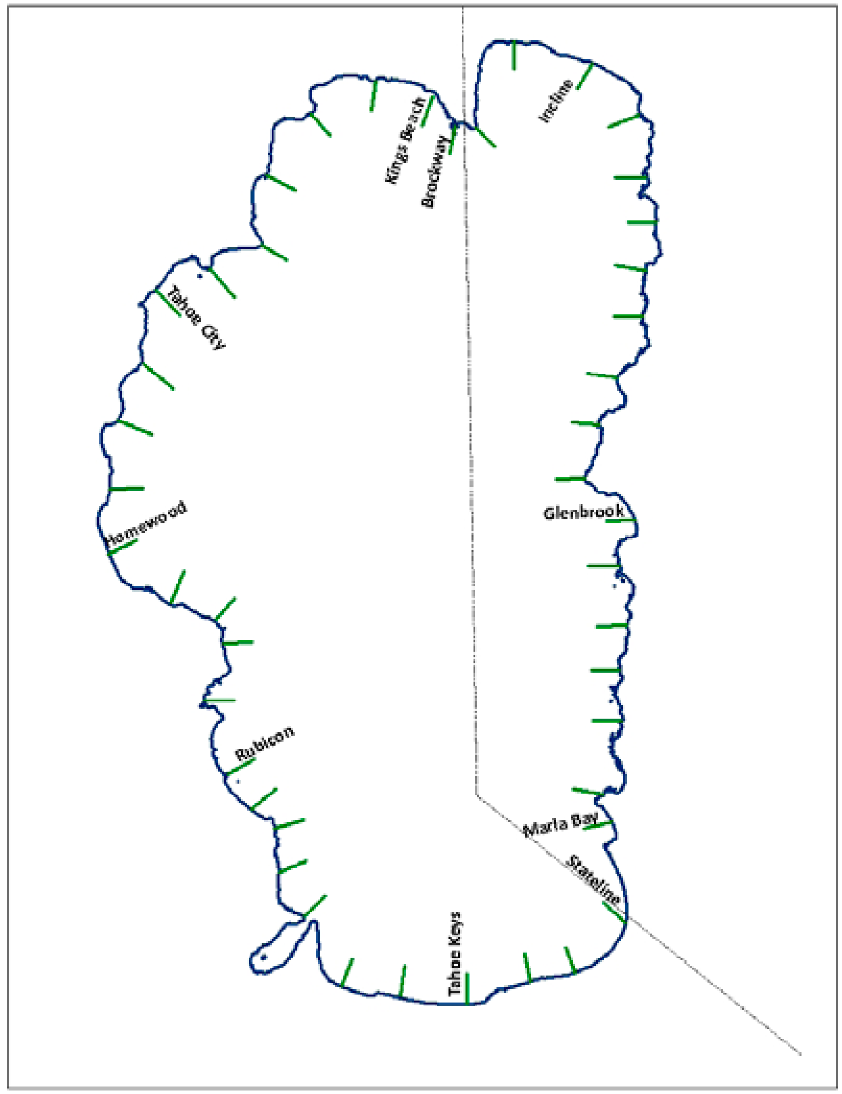
RECENT RESEARCH UPDATES: CLARITY

Spatial variations in clarity

TERC and NASA recently completed a study (funded through the Southern Nevada Public Lands Management Act) to demonstrate the use of Remote Sensing for measuring water quality at Lake Tahoe. The advantages of remote sensing are that it allows collection of data on every cloud-free day, and it measures everywhere on the lake. These data were used to create estimates of water clarity close to the shoreline over a yearly cycle.

The lines around the edge of the map show the locations of 45 "virtual" monitoring points around the shoreline where clarity was calculated using remotely sensed data. To quantify the annual cycle of the distribution and changes of nearshore water quality, the combined average monthly Secchi Depth measured by the MODIS satellite at 0.5 miles and 1.0 miles from the shoreline were computed for the period 2002 – 2010.

To see the full report visit http://terc.ucdavis.edu/publications/publications.html.



RECENT RESEARCH UPDATES: CLARITY

Spatial variations in clarity, continued

The monthly graphs highlight the variation of Secchi depth around the lake, the improvement in clarity as you move from near the shore (0.5 miles) to away from shore (1.0 miles), and the annual cycle of variation in the water clarity.

Generally for all times of year and for all locations, there is an improvement in clarity as one moves away from shore. This is most evident outside of winter, as for example in the periods April through September. The greater site-to-site variability displayed in the near shore (0.5 miles from shore) record is a reflection of the contribution from local sources such as streams and urban runoff.

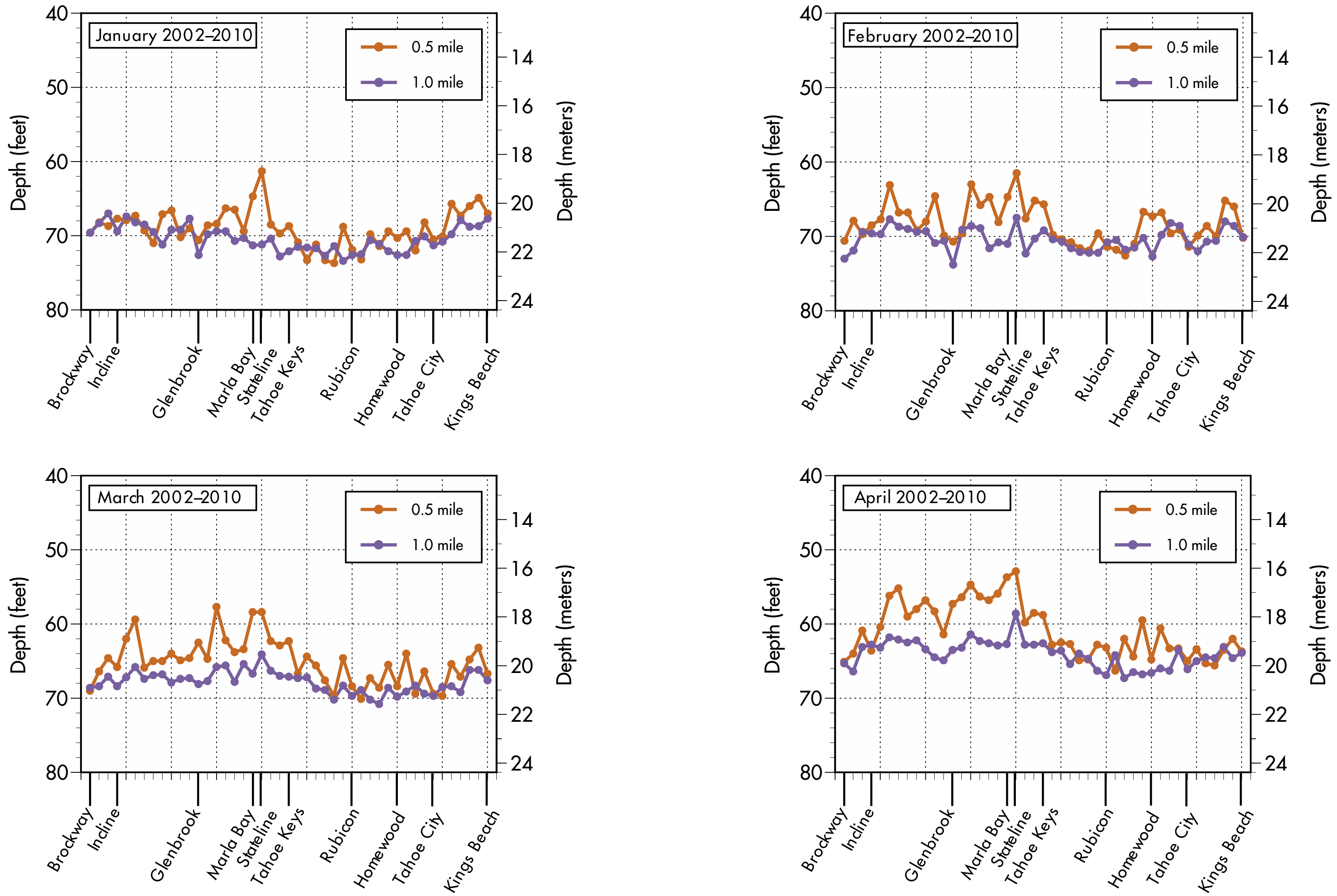
Winter clarity, December through March, is typically the highest. At this time of year the clarity is most uniform around the lake, with typical values being in the range of 65 to 70 feet (20 to 22 m).

The most startling revelation in the data is the spatial variation in nearshore clarity as we move around the shoreline. The eastern side of the lake, particularly from Stateline Point in the north to the eastern end of South Lake Tahoe, consistently shows the lowest Secchi depth values (lowest transparency). Looking, for example, at the plots for May and June, the region from just south of Glenbrook to Stateline has nearshore Secchi depths in the range of 45 feet to 53 feet (14 to 16 m) compared to values of 60 feet to 63 feet (18 to 19 m) around Rubicon in California.

The causes of these spatial differences are currently being studied, but it appears to be closely linked to the patterns of water movements around the lake. What happens in the waters of Lake Tahoe is a direct reflection of activities in both states. If a concrete example of why Lake Tahoe needs to be managed jointly by the two states is needed, then this is one.

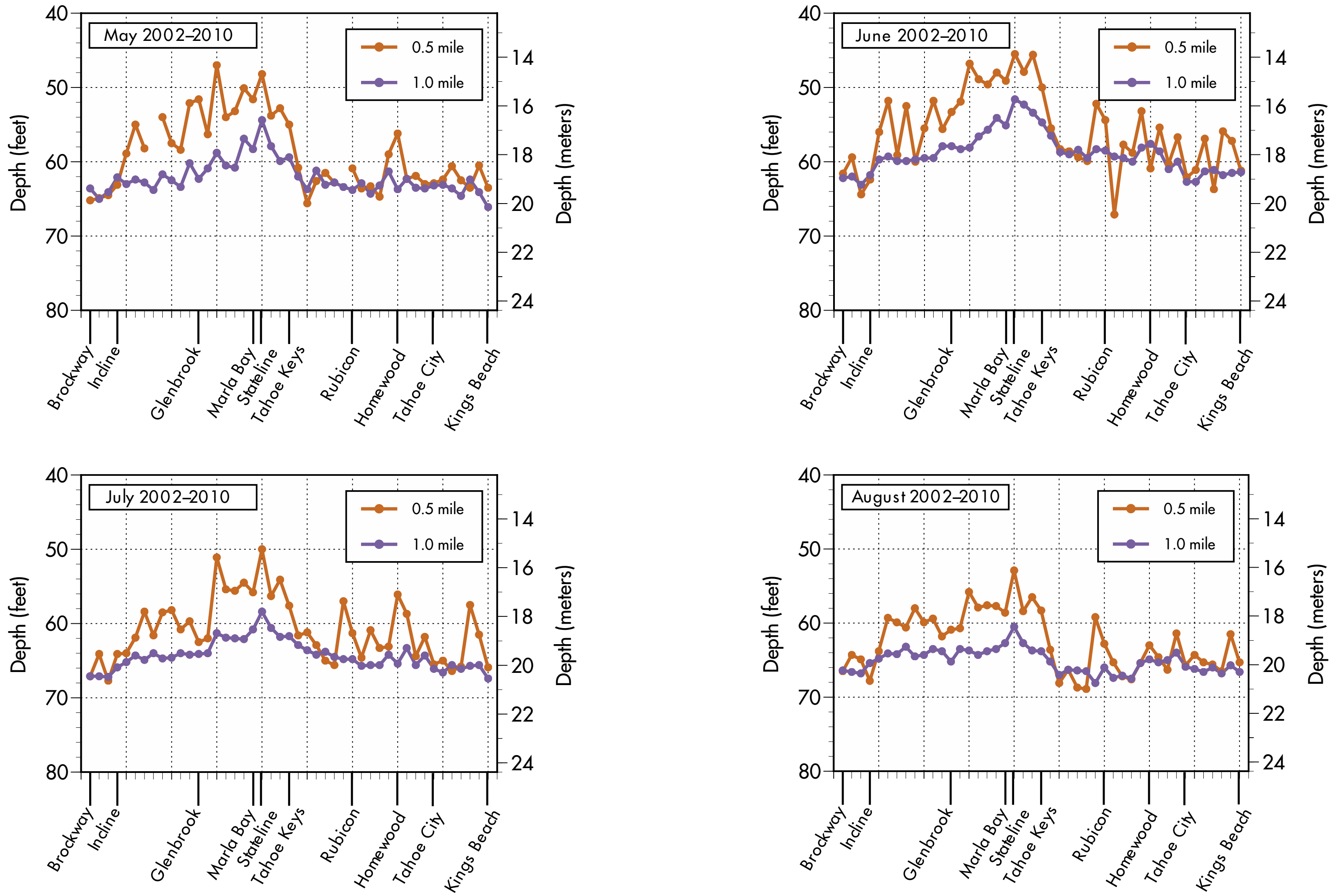
RECENT RESEARCH UPDATES: CLARITY

Spatial variations in clarity: January - April



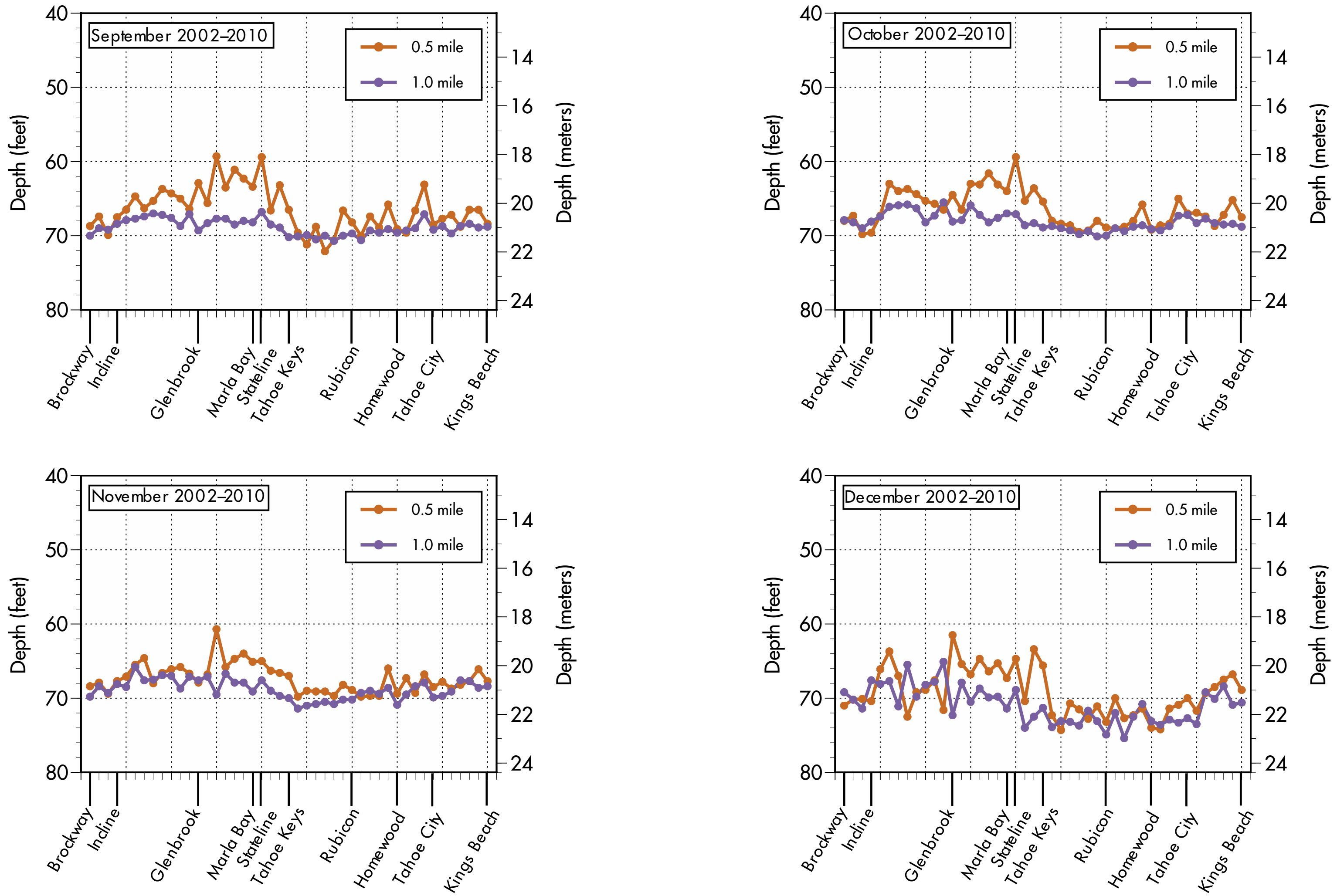
RECENT RESEARCH UPDATES: CLARITY

Spatial variations in clarity: May - August



RECENT RESEARCH UPDATES: CLARITY

Spatial variations in clarity: September - December



Clarity summary

- The annual average Secchi depth in Lake Tahoe declined in 2010 by 3.7 feet from last year's value. Such a large interannual rate of change is not unusual, although the low clarity is unusual.
- Underlying the trend in the annual average Secchi depth is both a general improvement in winter clarity and a continued decline in summer clarity. The annual average is a combination of both these factors.
- The improvement in winter clarity may be due to recent efforts to reduce urban stormwater flows to the lake, however, comprehensive data on urban stormwater loads to the lake are needed to substantiate this.
- The decline in summer clarity may be related to the impacts of climate change, in stabilizing the water column. This is producing conditions that strongly favor small diatom-algae cells very close to the surface. These strongly scatter light producing lower Secchi disk values.
- While some of the conclusions presented herein are still working-hypotheses, they highlight the importance of controlling both inorganic particles and nutrients to Lake Tahoe.
- Remote sensing of the nearshore indicates that clarity on the eastern shore is significantly lower than the west shore for most of the year.
- Long-term monitoring data is essential to be able to both track progress toward improved clarity and to understand the changing conditions.

The trajectory of the Secchi depth curve into the future is uncertain. The investment to date in water quality control projects cannot be underestimated. Reduction in nutrients and fine sediment load is clearly in the best interest of lake clarity. There is every reason to believe that if it were not for the decades of watershed management, development policy and water quality restoration projects, the Lake's transparency would be worse than it is today.

RECENT RESEARCH UPDATES: TROPHIC STATUS

Lake Tahoe's trophic status

The term trophic status defines lake condition based on biological productivity - where a lake lies along a continuum between extremely pristine to choked with excessive plant growth.

Three general categories of trophic status are commonly used: oligotrophic, mesotrophic and eutrophic. Lake Tahoe is classified as oligotrophic, implying clear water, containing few nutrients with little algae and rooted-plant life, rich in dissolved oxygen, and supporting a healthy diversity of fish and other aquatic animals. Oligotrophic lakes are typically deep with rocky or sandy shorelines, with limited land disturbance or urbanization in its drainage basin. Ultra-oligotrophic status is reserved for those lakes that are nearly pristine.

Eutrophic lakes are usually shallow, biologically productive with murky green water, high levels of nutrients and algal growth, oxygen-free conditions in deep water during the summer, and occasional fish-kills due to a lack of oxygen. The bottom sediment in eutrophic lakes is typically rich in thick, organic ooze and at times there can be odor problems and algal blooms that cover the surface and can release toxic compounds into the water.

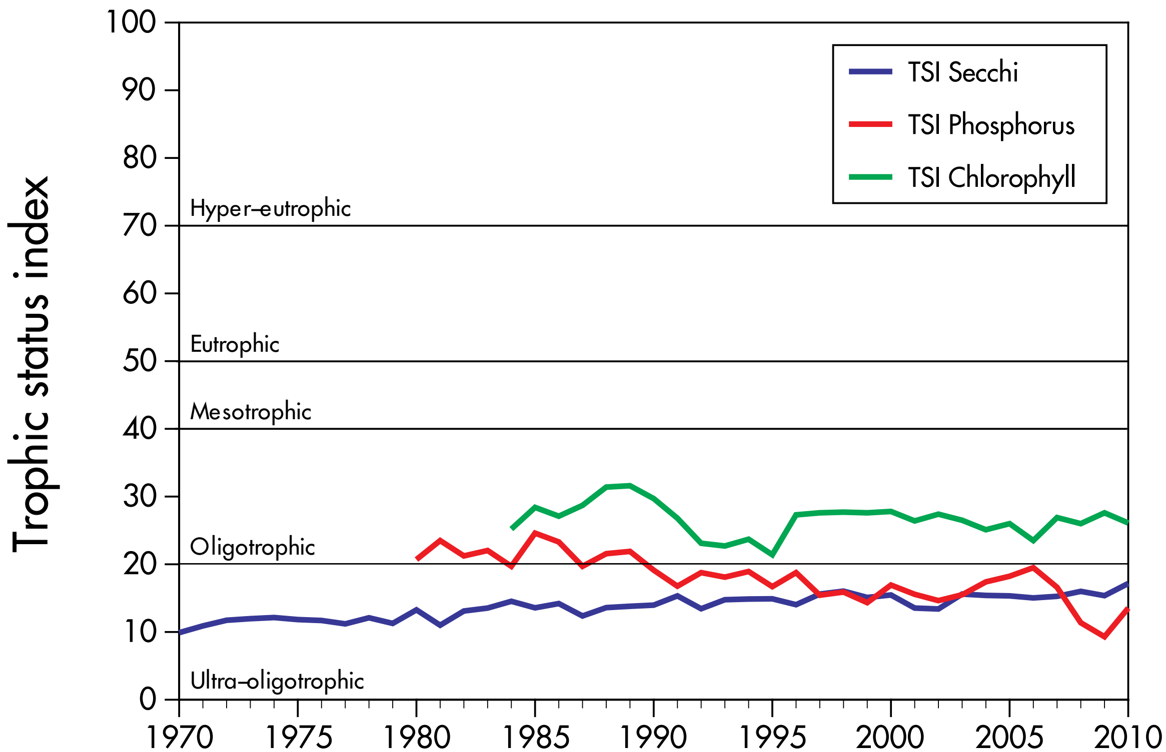
Mesotrophic lakes lie in between oligotrophic and eutrophic lakes and are characterized by moderate levels of nutrients and algae. During the summer, the deep water can lose its oxygen thereby limiting cold-water fish. Mesotrophic lakes are usually good lakes for fishing.

Oligotrophic Lake Tahoe

Eutrophic Lake Erie

Trophic status, continued

To make the determination of lake trophic status more objective, Dr. Robert Carlson (Kent State University) developed a multi-parameter numeric trophic status index (TSI). TSI values range from 0 to greater than 100, with each 10 units representing either a doubling or halving of a particular parameter. Trophic status indexes for Lake Tahoe from 1970 to the present, based on Secchi depth, phosphorus and chlorophyll are shown, along with the demarcation between different trophic states. During this time Lake Tahoe's trophic status has decreased on the basis of clarity (Secchi depth), while it has actually improved for phosphorus, and stayed similar based on chlorophyll concentration.



Asian clams

In spring 2008 UC Davis researchers discovered extensive beds of an invasive bivalve, the Asian clam (*Corbicula fluminea*), in the nearshore of Lake Tahoe along the southeastern edge of Lake Tahoe. Clam densities reach over 6,000 per square meter and are among the highest anywhere in the world. In Lake Tahoe Asian clams can affect plankton levels and food webs, outcompete native species, and cause attached algae to form nuisance blooms.

Researcher Marion Wittmann measures Asian clam shells from Lake Tahoe. In Lake Tahoe the Asian clams grow to be as large as 28 millimeters, but in other warmer systems can be as large as 55 mm. They are found in Lake Tahoe at water depths of 5 to 100 feet (2 to 30 meters), and within the sediments buried in up to 7 inches below the surface.

Lake Tahoe underwater landscape without non-native Asian clam invasion

Lake Tahoe underwater landscape following non-native Asian clam invasion. Dead clam shells rise to the surface of the sediment and clam densities below the surface can reach over 6,000 clams per square meter. Green filamentous algae (*Zygnema* and *Cladophora*) blooms above the clam beds.

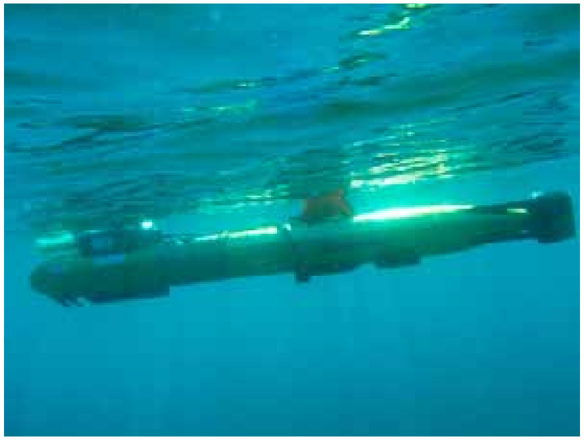
RECENT RESEARCH UPDATES: AQUATIC INVASIVE SPECIES

Asian clams: 2009 small-scale experiment

In 2009 a small-scale experiment to manage Asian clams showed that laying rubber bottom barriers on the lake sediment resulted in a dramatic reduction in clam density within a month after its installation. This is a new method that was developed in Lake Tahoe by UC Davis and University of Nevada Reno scientists in close collaboration with resource managers including the Tahoe Regional Planning Agency, the Tahoe Resource Conservation District and the US Fish and Wildlife Service and others.

10-foot by 10-foot rubber bottom barriers were tested as a strategy for managing Asian clam populations

Researchers sampled Asian clam densities before and after rubber bottom barrier experiment



Autonomous Underwater Vehicle (AUV) is used to map clam beds around Lake Tahoe

RECENT RESEARCH UPDATES: AQUATIC INVASIVE SPECIES

Asian clams: 2010 large-scale experiment

In the summer of 2010, two sets of half-acre barriers were installed to test whether large-scale application of this experimental method is a feasible option. The bottom barriers were installed in Marla Bay, NV, and Lakeside, CA, and consisted of 20 rolls of 10 foot wide and 100 foot long high density polyethylene.

The installation and removal of large areas of bottom barriers was found to be practical using SCUBA and specially engineered equipment operated from a working barge. Asian clams populations in treated areas were reduced by 98%, while native bottom dwelling invertebrates were reduced by 96%. The time it takes for Asian clams to recolonize the treated areas is currently being studied; this knowledge will determine the true treatment costs and influence long-term management strategy decisions. This new technique was transferred to lake managers at Lake George, NY, where bottom barriers were deployed to treat a large Asian clam infestation in 2011. This is yet another example of where science at Lake Tahoe is having an impact nationally and globally.

Release mechanism on barge helps researchers to lower barriers into water

UC Davis scientists roll out bottom barriers on the lake bottom

The large (one-half acre) bottom barrier deployed in Marla Bay is visible from the air