TAHOE: OF THE LAKE 2016

PHYSICAL PROPERTIES



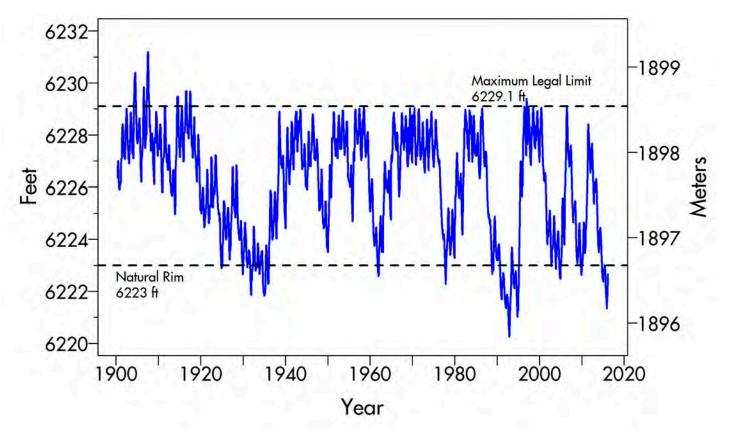
PHYSICAL PROPERTIES

Lake surface level

Daily since 1900

Lake surface level vary throughout the year. Lake level rises due to high stream inflow, groundwater inflow and precipitation directly onto the lake surface. It falls due to evaporation, in-basin water withdrawals, groundwater outflows, and outflow via the Truckee River at Tahoe City. Overall, lake level fell by about 9 inches during 2015. The highest lake level was 6223.01 feet on June 10, and the lowest was 6221.33 feet on December 9. The natural rim of the lake is at an elevation of 6223 feet. Lake Tahoe was below its rim for almost the entire year, except for one day on December 9, 2015.

When the lake is below its rim, outflow via the Truckee River ceases. Several episodes of lake level falling below the natural rim are evident in the last 114 years. The frequency of such episodes appear to be increasing.



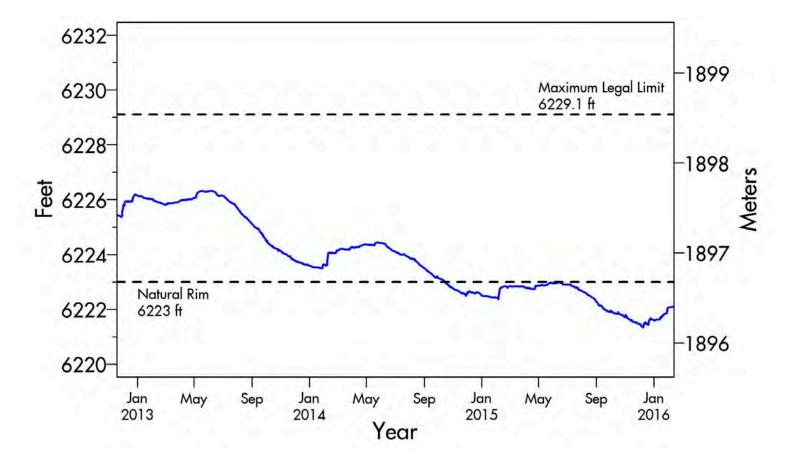
PHYSICAL PROPERTIES

Lake surface level, continued

Daily since 2013

Displayed below is the lake surface data from 2013-2015 extracted from the same data on page 8.1. This more time restricted presentation of recent lake level data

allows us to see the annual patterns of rising and falling lake level in greater detail. Data clearly show the lake level falling below the natural rim in October 2014 and its final level of 1.39 feet below the rim at the end of 2015. The effects of the drought on overall lake water level is evident.



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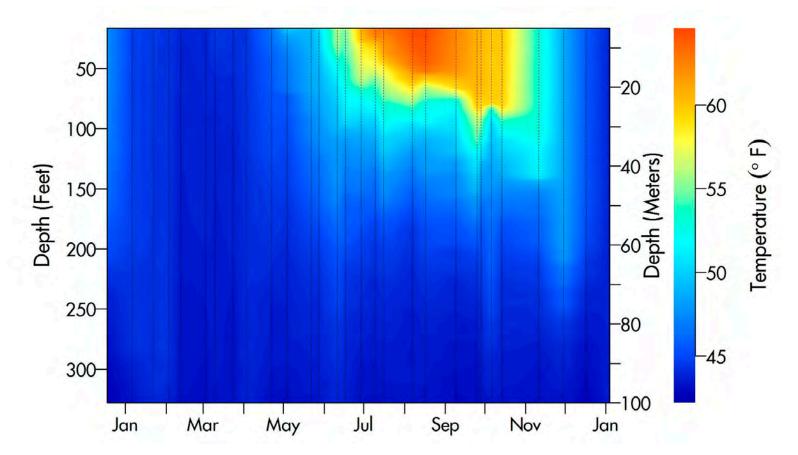
Water temperature profile

In 2015

Water temperature profiles are measured in the lake using a Seabird CTD (conductivity, temperature, depth) profiler at the times indicated by the dashed vertical lines. The temperature is accurate to within 0.005 °F. Here the

temperature in the upper 330 feet (100 m) is displayed as a color contour plot. In 2015, the lake temperature followed a typical seasonal pattern. In February-March, the lake surface was at its coldest, while it was at its warmest at the end of

August. The deepening of the warm water zone toward the end of the year is the result of winter mixing, a process that is important in bringing oxygen to the deeper parts of the lake.



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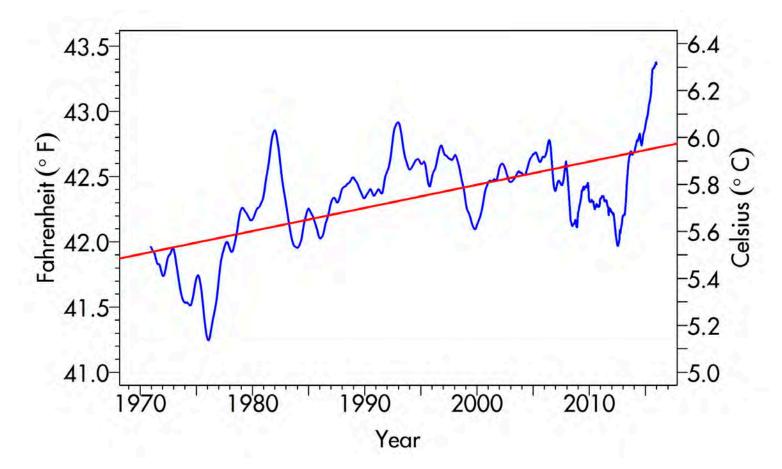
Average water temperature

Since 1970

The trend in the volume-averaged temperature of Lake Tahoe has increased by approximately 0.8 °F since 1970. The annual rate of warming is 0.018 °F/year (0.01 °C/year). The monthly temperature

profile data from the top to the bottom of the lake has been smoothed and seasonal influences removed to best show the long-term trend. Up until the late 1990s the warming rate was high,

but a high number of deep mixing years between 1997 and 2011 caused the lake temperature to cool. Since that time, warming has accelerated to its highest recorded rate.



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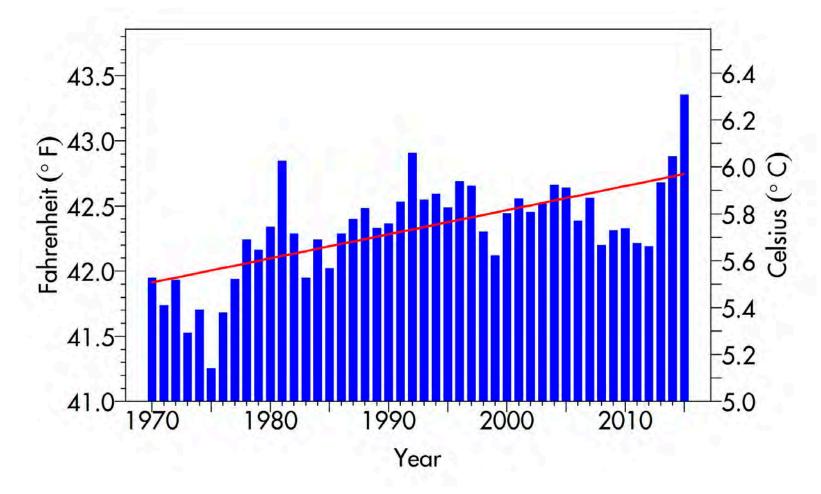
Annual average water temperature

Since 1970

The volume-averaged temperature of the lake for each year since 1970 is shown. In 2015 the volume-averaged temperature increased by $0.48 \,^{\circ}\text{F}$ ($0.26 \,^{\circ}\text{C}$) over the

previous year. In the last 4 years the lake has warmed at an alarming rate of over 0.3 °F/year, 15 times faster than the long-term warming rate. Increases in temperature

generally correspond to those years in which deep mixing did not occur. In 2015, deep mixing was the shallowest ever recorded.



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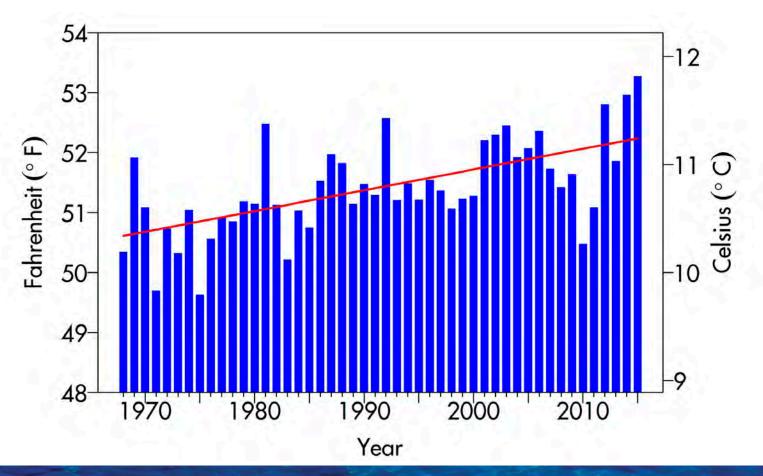
Surface water temperature

Yearly since 1968

Surface water temperatures have been recorded monthly at the mid-lake and index stations since 1968 from the R/V John LeConte and the R/V Bob Richards. Despite year-to-year variability,

the annual average surface water temperatures show an increasing trend. The average temperature in 1968 was 50.3 °F (10.2 °C). For 2015, the average surface water temperature was 53.3 °F (11.8 °C),

making it the warmest year ever recorded. The overall rate of warming of the lake surface is 0.035 °F (0.019 °C) per year.



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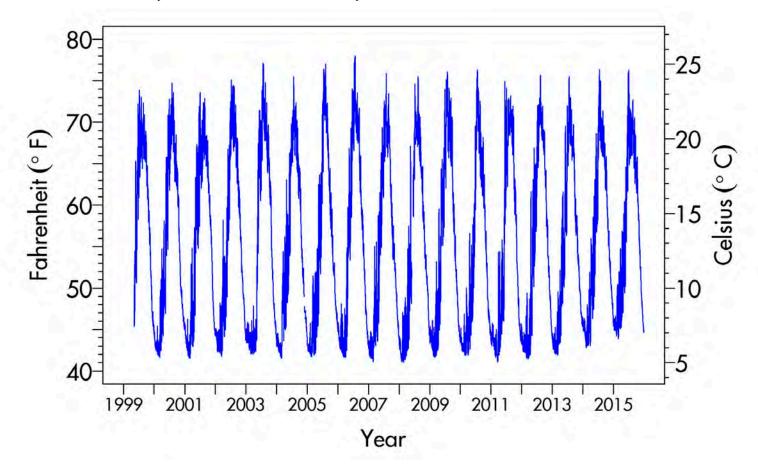
Maximum daily surface water temperature

Surface temperature measured since 1999 every 2 minutes

The maximum daily summer surface water temperature in 2015 was similar to the previous year, and for the winter-time maximum, it was the warmest surface water temperature observed since 1999.

The highest maximum daily surface water temperature (summer) was 76.26 °F, which was recorded on July 2, 2015. The lowest maximum daily surface water temperature (winter) was 43.90 °F, which

was recorded on March 1, 2015. These data are collected in real-time by NASA-JPL and UC Davis from 4 buoys located over the deepest parts of the lake.



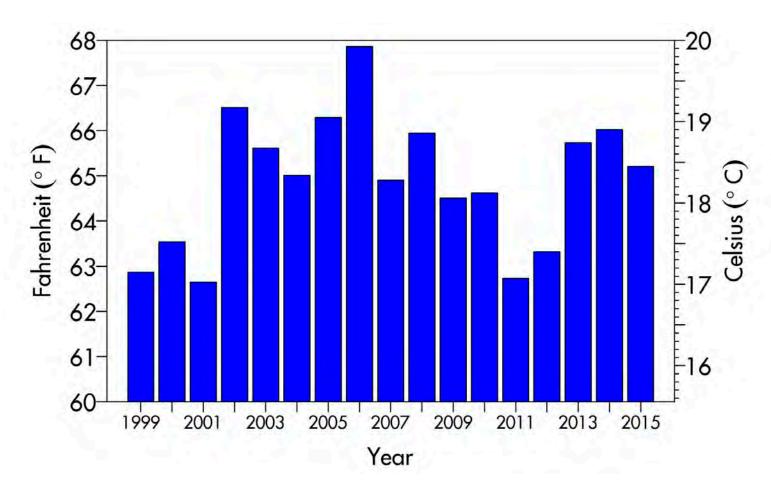
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July average surface water temperature

Measured since 1999 every 2 minutes

Since 1999, surface water temperature has been recorded every two minutes from four NASA/UC Davis buoys. Shown here are 17 years of average surface water temperatures in the month of July when water temperatures are typically warmest. In 2015, July surface water temperature averaged 65.2 °F. The warmest July

temperatures were 67.9 °F in 2006. The average July surface water temperature for the 16 year period is 64.9 °F.



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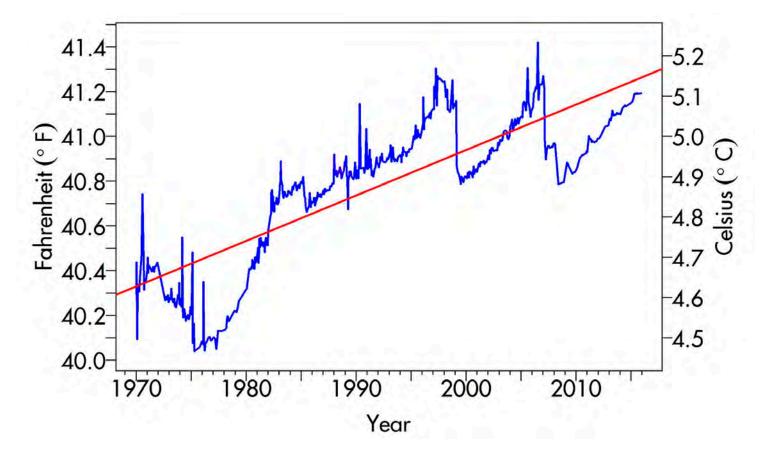
Deep water temperature

Since 1970

The water temperature at a depth of 1,320 feet (400 m) is indicative of conditions in the deeper waters (hypolimnion) of Lake Tahoe. Since 1970 the deep water temperature has increased by approximately 1 $^{\circ}$ F (0.6 $^{\circ}$ C), at an annual

rate of $0.020\,^{\circ}\text{F}$ ($0.011\,^{\circ}\text{C}$), a rate of warming that is half that of the surface water. This increase has not been steady but is punctuated by occasional drops in temperature. These coincide with times when the lake completely mixes to the

bottom, an event which allows a huge amount of heat to escape from the lake. The short spikes of temperature increase are temporary effects caused by the motions of internal waves (or seiches).



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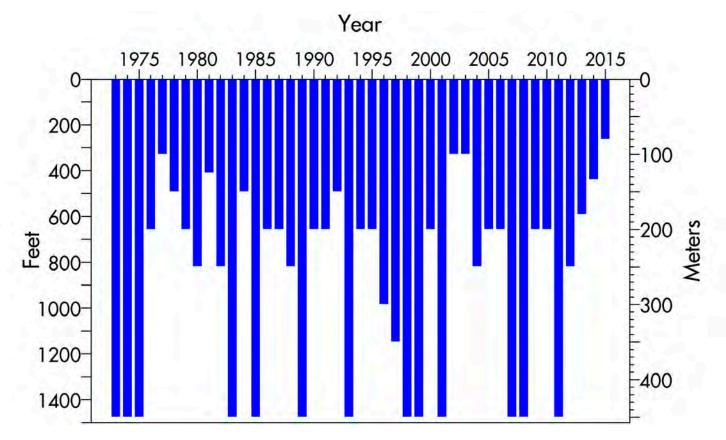
Depth of mixing

Yearly since 1973

Lake Tahoe mixes each winter as surface waters cool and sink downward. In a lake as deep as Tahoe, the wind energy and intense cooling of winter helps to determine how deep the lake mixes. Mixing depth has profound impacts on lake ecology and water quality. Deep mixing brings nutrients to the surface,

where they promote algal growth. It also moves oxygen to deep waters, promoting aquatic life throughout the water column. The deepest mixing typically occurs between February and March. In 2015, Lake Tahoe mixed to a depth of only 262 feet (80 m). This lack of deep mixing most likely contributed to the warm

surface and bottom temperature, the continuing buildup of nitrate in the lake, and the generally lower clarity. Beginning in 2013, the determination of the depth of mixing has been based on high-resolution temperature profiles rather than nitrate concentration sampled at discrete depths.



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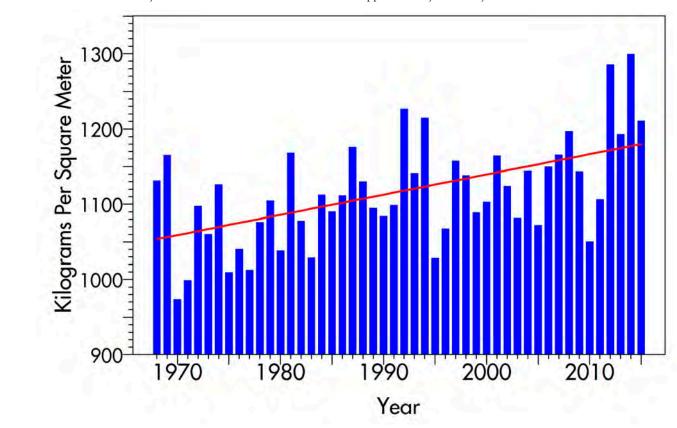
Lake stability

Since 1968

When the lake has a vertical distribution of temperature, it has a corresponding density distribution, with warm and lighter water at the surface, and colder, denser water at depth. The stability index is a measure of the energy required to fully mix the water column when its

density is stratified. The average stability index for the upper 330 feet (100 m) of Lake Tahoe is plotted for the period of May through October each year. The values are derived from temperature profiles taken at the Index Station at approximately 10-20 day intervals. There

has been an overall increase in lake stability by over 10% in the last 45 years. In 2015, the stability of the lake fell, but it was still above the long-term rate of increasing stability.



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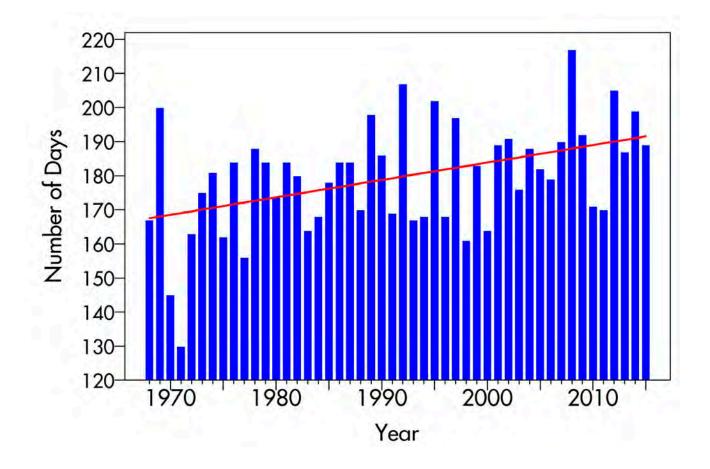
Stratified season length

Since 1968

The stability index, a measure of the energy required to fully mix the lake, can be evaluated for every day of the year. We define the stratification season as the length of time when the stratification

index exceeds a value of 600 kilograms per square meter. Since 1968 the length of the stratification season has increased, albeit with considerable year-to-year variation. Overall, the stratification

season has lengthened by approximately three weeks. In 2015, the length of the stratified season was 189 days.



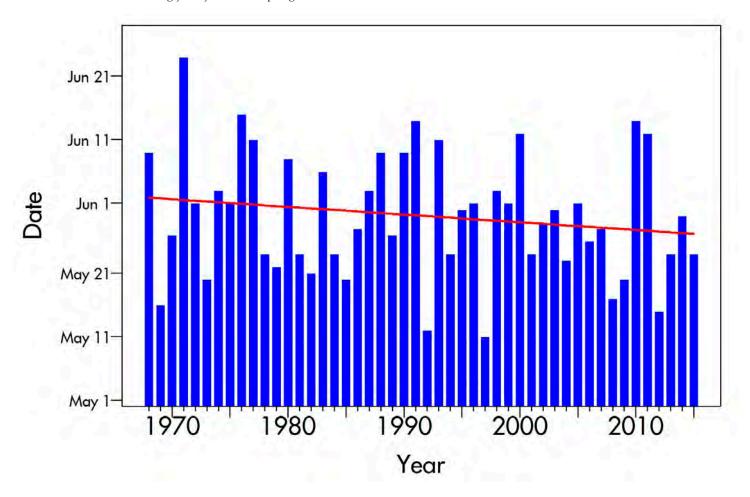
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Beginning of the stratification season

Since 1968

The length of time that Lake Tahoe is stratified has been lengthening since 1968. One reason for this is the increasingly early arrival of spring as

evidenced by the earlier commencement of stratification. Stratification occurs approximately three days earlier than it did in 1968. The commencement of the stratification season is typically in late May or early June. In 2015 stratification began on Day 144 (May 24).



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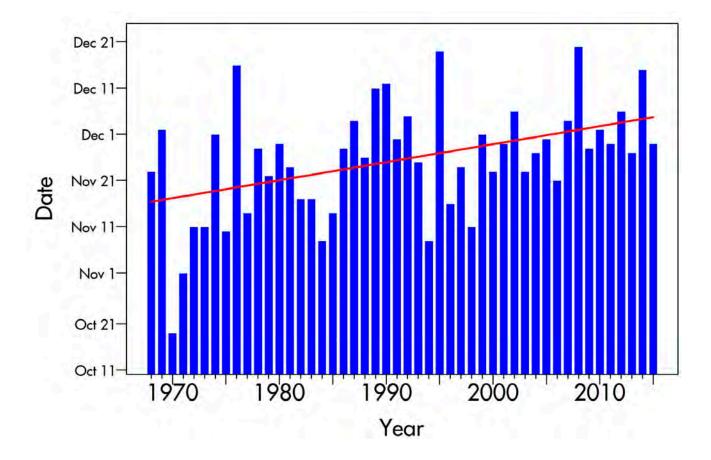
End of stratification season

Since 1968

The length of time that Lake Tahoe is stratified has lengthened since 1968 by approximately three weeks. The end of stratification appears to have been extended by approximately 18 days on

average. In other words, the fall season for the lake has been considerably extended. In the late 1960's stratification ended in mid-November. Now it often ends in December. In 2015, stratification

ended on Day 333 (November 29) This has important implications for lake mixing and water quality, such as the buildup of nitrate at the bottom of the lake.

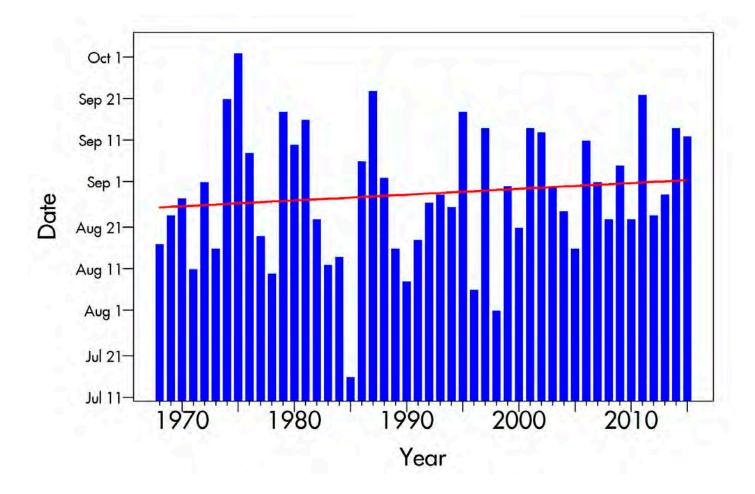


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Peak of stratification season

Since 1968

The day of the year when lake stratification reaches its maximum value has been plotted. There is considerable year-to-year variation, but over time there has been only a slight delay in when the peak occurs. In 2015 the peak occurred on September 12, over a week later than the long-term trend would have indicated.



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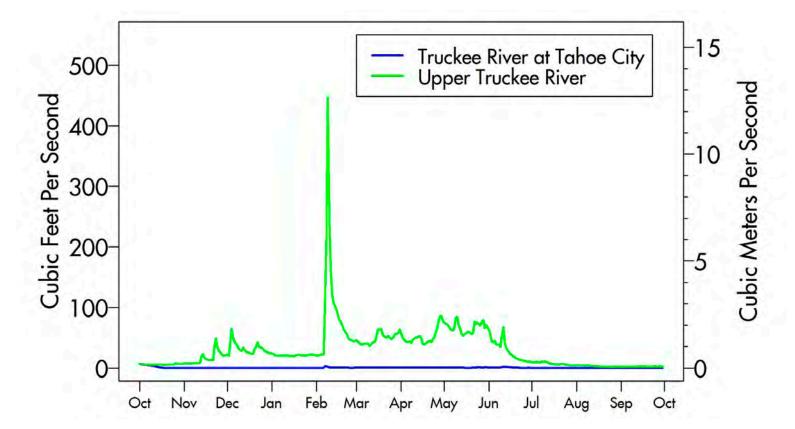
Mean daily streamflow of Upper Truckee River vs. Truckee River

Water Year 2015

The largest stream flowing into Lake Tahoe is the Upper Truckee River. The small peaks in the hydrograph generally represent rain events or short warm periods in winter or spring. The extended seasonal increase (March-May) represents the snowmelt. The peak snowmelt flow

was approximately 446 cfs, compared to the long-term average of 300 cfs.

The Truckee River is the only outflow from Lake Tahoe. It is a regulated flow, with release quantity controlled by the Federal Water Master. Typical maximum summer discharge is approximately 300 cfs in mid-June. In 2015 the lake level was below the lake's rim for almost the entire year, so outflow was essentially zero. Streamflow data are collected by the U.S. Geological Survey under the Lake Tahoe Interagency Monitoring Program (LTIMP).



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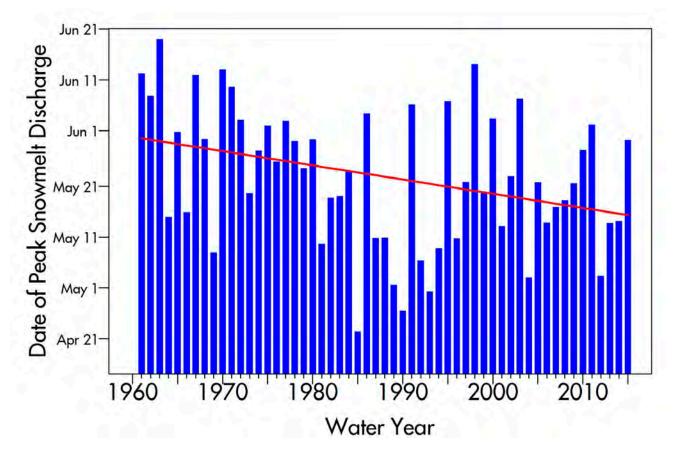
Shift in snowmelt timing

Yearly since 1961

Although the date on which peak snowmelt occurs varies from year to year, since 1961 it has shifted earlier an average of more than 2 weeks (15 days). This shift is statistically significant and is one effect of climate change at Lake

Tahoe. Peak snowmelt is defined as the date when daily stream flows reach their yearly maximum. Daily stream flows increase throughout spring as the snow melts because of rising air temperatures, increasing solar radiation, and longer

hours of daylight. The data here are based on the average discharge from the Upper Truckee River, Trout Creek, Blackwood Creek, Ward Creek, and Third Creek. In 2015 the timing of the snowmelt peak fell above the long-term trend line.



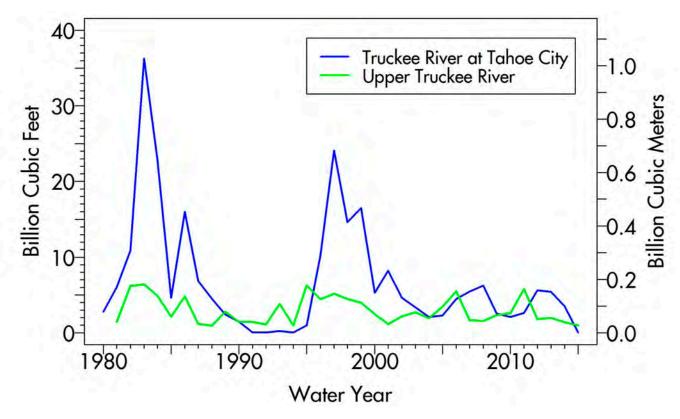
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Annual discharge volume for upper Truckee River and Truckee River

Flow into Lake Tahoe (e.g. Upper Truckee River) and discharge out of Lake Tahoe (Truckee River at Tahoe City) have shown considerable variation since 1980. The large peaks in discharge from the lake correspond to years when precipitation (and therefore total inflow) was the greatest, e.g. 1982-1983, 1986, 1995-1999. Similarly, the drought-like

conditions in the early 1990s and the low precipitation years in the beginning of the 2000s culminating in the current drought year also stand out. Since many of the pollutants of concern for Lake Tahoe's clarity enter along with surface flow, year-to-year changes in clarity are influenced by precipitation and runoff. The average annual Upper Truckee inflow

since 1981 is 2.94 billion cubic feet, while the average annual outflow through the Truckee River is 6.92 billion cubic feet. In 2015 discharges into and out of the lake were well below the long-term averages. The Upper Truckee River inflow volume was 0.96 billion cubic feet. The Truckee River discharge was zero.



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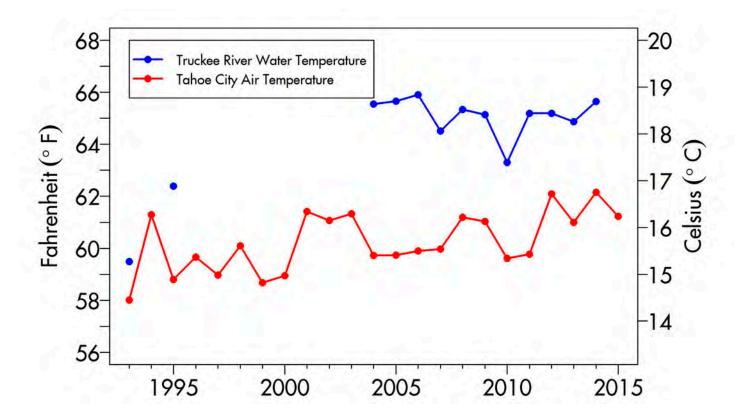
Truckee River July-September water temperatures

Since 1993

Water temperature of the Truckee River as it departs Lake Tahoe in the summer months (July-September) is measured by the U.S. Geological Survey. Data gaps prevent a complete pattern, but the measurements suggest that a 4-5 °F (2.2-

2.8 °C) rise in the average temperature may have occurred since 1993. Average air temperatures from Tahoe City for the same period also suggest a temperature rise but at a lower rate. Elevated river temperatures can also negatively impact

fish spawning and fish rearing. In 2015 there was no flow released to the Truckee River from Lake Tahoe, so an average water temperature could not be calculated.



PHYSICAL PROPERTIES

Truckee River summer discharge and lake elevation

Since 1993

Flow rate of the Truckee River as it departs Lake Tahoe in the summer months (July-September) and lake level for the same period is measured by the U.S. Geological Survey. Here

the relationship between these two variables is evident, with mean daily river discharge typically showing a one- to two-year lag from the lake elevation. Gage height is measured relative to a datum of 6,220 feet. Release of water from Lake Tahoe is controlled by the Federal Water Master.

