

Preliminary Lake Evaluation (PLE) for Willow Lake

Ownership and management: U.S. Forest Service, Lassen National Forest, Almanor Ranger District.

Location: Plumas County (40°24'14.27" N 121°21'40.03" W)

Contact: Craig Hemping, Supervisory Fisheries Biologist, (530-258-5169), craig.hemping@usda.gov

PREFACE

Prior to 2019, there were no reports of massive cyanobacteria blooms at Willow Lake. The sample analysis report (CVRWQCB July 2019), confirmed the presence of a cyanobacterial harmful algal bloom for the first time, and it was producing saxitoxin. The surprise, given the bloom-free history of the lake, was the magnitude of the bloom and that it covered the entire lake surface with a thick pea soup layer of algae (Figure 1). Due to the lakes small size, remote location and the lack of a compelling reason, no monitoring has been conducted to document water quality or limnological characteristics. There are no data giving basic descriptive measurements of the lake and no known water quality data are available. The information gained through an interview process with the Fisheries Biologist is provided in the attached PLE spreadsheet along with additional information (in red) gathered during supplemental online searches using Google Earth, USGS, CEDC and other sites.

Given the delicate and special nature of this fen lake, the surrounding wetlands and the protections given it within the U.S. Forest Service, it is unlikely that mitigation actions can be taken. However, it is of great interest to understand what caused this lake to switch from one ecological extreme to another in such a short period. There should be general interest in what happened here given that It is only one of many such lakes perched at higher altitudes of California's mountains. The other big question is whether or not the problems will continue into the future.



Figure 1. Willow Lake CyanoHAB bloom, July 22, 2019 (Craig Hemping)

BACKGROUND

Willow Lake is a botanically special place. It is located about 16 km (10 miles) Southeast of Lassen Peak in Plumas County, California, at an altitude of 1663 m (5457 ft). Willow Lake is surrounded by forest covered mountains rising up into Lassen Volcanic National Park. The lake shores are covered by extensive floating mats of sphagnum moss 0.6 m (2 feet) or thicker. These floating sphagnum mats have no mineral soil and are a kind of wet Meadow often called a fen. Normally a fen is an open peatland system that generally receives some drainage from surrounding mineral soils and are often covered by grasses, sedges, or reeds (Mitsch and Gosselink 2000). They support a variety of unusual plants, some typical of arctic and sub-arctic climates, rare in California. *Scheuchzeria palustris*, once thought to have been eliminated from California by the creation of Lake Almanor, was rediscovered at Willow Lake in 1988. Two species of carnivorous plants English sundew (*Drosera anglica*) and round Leaf sundew (*Drosera rotundifolia*), grow here and also hybridize with each other. A variety of other fen species thrive here as well). Thick sphagnum meadows extend over saturated soils as well, covering an area over three times the surface area of the open water on the upstream side of the lake.

Because of the unusual assemblage of plants that occur here, Willow Lake was designated a Botanical special interest area in the Lassen National Forest's Land and Resources Management Plan in 1993. Forests surrounding Willow Lake include red fir, white fir, Sugar Pine, Jeffrey Pine and Lodgepole Pine. A small primitive Campground is located in the forest adjacent to the lake, for visitors wishing to linger in the area, and a hiking trail leads northwest about a mile from Willow Lake to Terminal Geyser, a geothermal feature within Lassen Volcanic National Park. Most of this background information came from the U.S. Forest Service, Lassen National Forest, Almanor Ranger District:
https://www.fs.fed.us/wildflowers/regions/Pacific_Southwest/WillowLake/index.shtml .

HARMFUL ALGAL BLOOM HISTORY

This history was extracted directly from the harmful algal bloom report ID 2027 - Willow Lake (Plumas County) Lassen National Forest.

The U.S. Forest Service, Almanor Ranger District, received a call from a member of the public (week of July 8, 2019) concerned about the color of the water in Willow Lake. US Forest Service staff visited the lake on July 15 and noticed the color of the water appeared like green pea soup. A sample was collected for jar testing (i.e., to see if cyanobacteria [was] present and floating at the surface). The jar test was positive, so the staff reached out to the Water Boards for assistance in analysis.

Forest Service staff revisited the lake on July 22 and collected two surface water grab samples. Air temperature of about 20 °C and water temperature of about 22°C at time of collection above the floating algal mat. The reported Lab results identified two genera of cyanobacteria - *Aphanizomenon* sp. and *Dolichospermum* sp. The saxitoxin gene was detected in both samples, and toxin analysis detected low concentrations of saxitoxin in each sample (0.22 ug/L and 0.19 ug/L). As far as is known, these data are the sum total of all water quality data on record for the lake.

At the recommendation of the Water Board a Caution advisory was placed at Willow Lake until the bloom fully subsided. This recommendation was based on several considerations (1) this waterbody is heavily recreated per email communication with Forest Service, which may be visited by people with dogs; (2) saxitoxin is a known potent neurotoxin, small children and pets tend to be more sensitive due to their water play and behavior (3) very little information on blooms in this water body is known (i.e., duration and extent of bloom and types of toxins and concentrations observed, and (4) toxin concentrations can potentially increase once the cells begin to die, thereby increasing the currently known toxin concentrations.

No previous information on cyanobacteria blooms has been reported for Willow Lake (Craig Hemping, Forest Service). Anecdotally, a local resident noted that no blooms like this had been observed in 25 years of visits to the lake and another lake user noted an increased algal presence in the last few years.

WILLOW LAKE WATERSHED AND HYDROLOGY

As far as is known, hydrological data describing flows into and out of Willow Lake are not available. Given that data of that type is critical to evaluating what may have happened in Willow Lake in 2019, a cursory look at weather patterns and knowledge basic to the workings of fens was used to speculate on potential causes of the changes in productivity.

Willow Lake lies at the head of the of the Feather River watershed just 16 km (10 miles) south east of Mt. Lassen. Willow Creek flows into the North Fork of the Feather River about 10 km (6 miles) above Lake Almanor. Its own watershed ranges in elevation from 2258 m (7409 ft) at Mount Sifford to the lake surface at 1663 m (5457 ft), a drop of some 570 m (1866 ft)(Figure 2). The watershed area is about 11.4 km², (2842 acres) roughly 76 times the area of the lake surface (Table 1). There are two short streams above the lake, one stream flows easterly from Little Willow Lake about 2.4 km (1.5 miles) to

Willow Lake and the other flows southerly from Terminal Geyser and joins Willow Creek about 0.5 km (0.3 miles) above Willow Lake (Figure 2). It is not known by us if Terminal Geyser is active or not. There is another active hydrothermal pool, Boiling Springs Lake, further upstream that appears to be linked to Terminal Geyser. Water may flow or seep from Little Willow Lake most of the time, possibly as ground water feeding springs closer to Willow Lake (not confirmed).

We are speculating that in addition to direct runoff, much of the flow from snow melt may normally pass through soils to arrive at the lake as springs, as is typical for fen lakes. Spring water could extend the period of flows to the lake throughout the summer. The Fisheries Biologist indicated that water flows from Willow Lake all year long. Rapid snow melt, from an intense rain event or unusually high temperatures could interfere with that process and produce enough surface flow to rapidly flush Willow Lake multiple times in a short period. If snow melt occurs too early, flows to the lake could be significantly reduced for the remainder of the year. In 2019, there was enough water, as snow, in the watershed to flush the lake dozens of times if it melted rapidly. This is a possible mechanism to explain the observed change in the nature of the lake in 2019. High flow rates and rapid flushing could have several possible consequences: 1) radically change the water quality and chemistry of the lake, 2) overcome the ability of the sphagnum beds to perform their cation exchange function 3), scour sediments out of the lake or, 4) carry nutrient rich sediments into the lake off the watershed or combinations of the above.

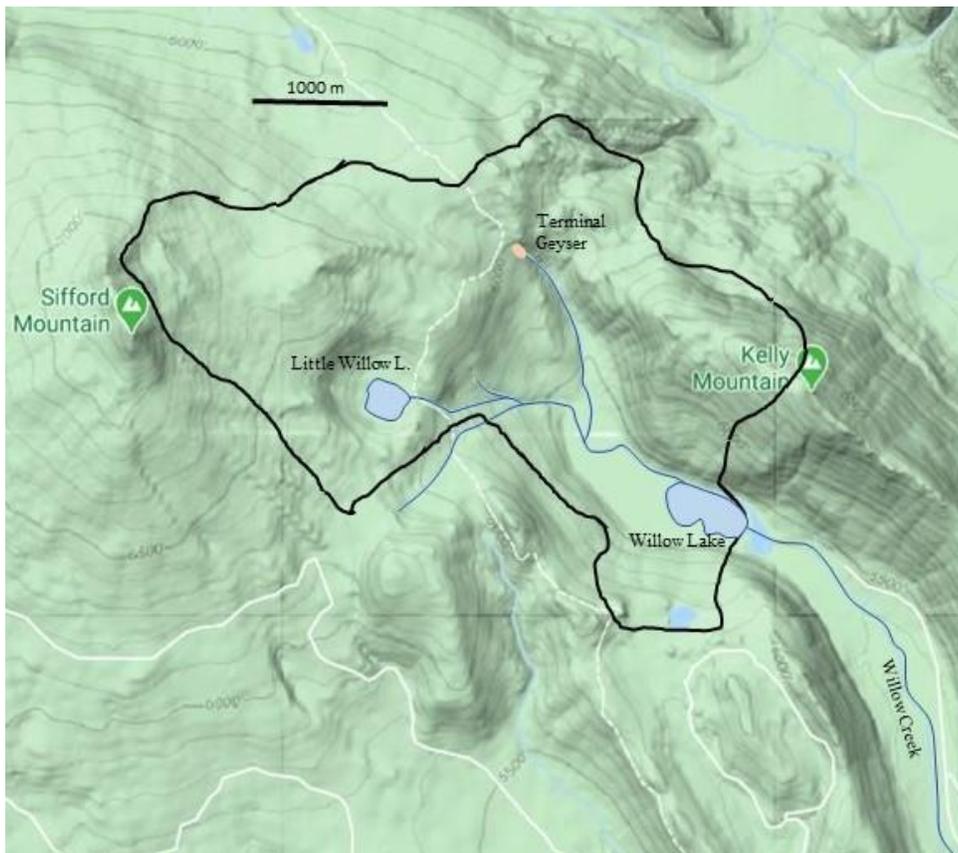


Figure 2. Willow Lake watershed

WILLOW LAKE MORPHOLOGY

Willow Lake is natural with no dam and no flow control structures or valves (Table 1). On all available historical Google earth images, Willow Lake appears as a consistently small oval-shaped lake with extensive bog/wetland like areas around much of its periphery, especially upstream and downstream (Figure 3). In addition, there are areas where floating sphagnum mats in excess of 0.6 m (2 ft) thick extend out over the surface of the lake. These mats more or less hide the true shape of the lake basin. Satellite imagery going back to 1993 show very little change in the shape and size of the open water and the extent of the wetland areas. The wetland area upstream of the lake is about 3.4 times the size of the open lake area. Willow Lake has a maximum length of 661 m (2169 ft) and a maximum width of 284 m (931 ft), with a shoreline of 1.8 km (1.2 mi). It sits at an elevation of about 1663 m (5457 ft). Based solely upon examination of contour maps of the valley, the lake appears to be quite shallow, perhaps less than 2 m (6 ft) deep. For calculation purposes we assumed the mean depth is half the estimated maximum depth, or 1 m (3 ft) deep. The surface area of 0.15 km² (37 acres) was based on the open water area up to the edge of the floating sphagnum mats. The estimated volume of 150,000 m³ was calculated by multiplying surface area by mean depth. With a watershed area of 11.4 km² (2842 acres), it is about 76 times the area of the lake surface. Given the frequent large snow packs, it should not be surprising if an intense rainstorm or unusually warm weather could rapidly melt snow and basically flood and flush the lake with, perhaps, radical changes to the water chemistry.



Figure 3. Willow Lake satellite image taken on 7/2/2017. The sphagnum wetland upstream to the left of the lake is about 3.4x the surface area of the lake

Table 1. Willow Lake Morphology*

Feature	Value	Comments
Natural lake	No dam	Spills directly to Willow Creek. No flow controls.
Shape	Oval	Extensive sphagnum peat mats floating out over the water hide the actual shape and size of the basin.
Lake elevation	1663 m (5457 ft)	
Maximum depth	2 m (6 ft)	Best guess, based on USGS contour map.
Mean depth	1 m (3 ft)	Assumed mean depth is ½ max depth
Maximum length	661 m (2169 ft)	Measured using Google Earth
Maximum width	284 m (931 ft)	Measured using Google Earth
Shoreline	1.8 km (1.2 mi)	Measured using Google Earth
Surface area	0.15 km ² (37 acres)	
Estimated volume	150,000 m ³ (122 a-f)	Assumes mean depth = 1 m, then 150,000 m ² x 1m = estimated volume.
Watershed area	11.4 km ² (2842 acres)	About 76x the area of the lake surface
Sphagnum wetland area NW of lake	0.51 km ² (126 acres)	About 3.4x the surface area of the lake

*No known measurements were available. All values were estimated from Google Earth and Google Maps imagery, and USGS contour maps.

RECENT METEOROLOGICAL HISTORY

Weather patterns in this region have been extreme and variable in recent years producing conditions that may have contributed to the drastic changes in productivity in Willow Lake. During the winter of 2017 heavy rains and snow melt in the Feather River watershed contributed to high flows that ultimately caused considerable damage to the Oroville Dam spillways and threatened the town of Oroville to the point of mandated evacuations.

[A] study published in June 2018 in the Journal of Geophysical Research Letters investigated temperature impacts on snowpack and runoff-driven flood risk in the Sierra Nevada during the extremely wet year of 2016–2017. The team of researchers (led by D. Swain) from the University of California Los Angeles determined that warming that year increased the Sierra Nevada's early-season snowpack runoff by 30 percent. In the Feather River Watershed, historical warming increased runoff by over one third during the period of heaviest precipitation in February 2017 (reported by Pam Wright at

<https://weather.com/science/environment/news/2018-06-28-oroville-dam-failure-global-warming-connection>).

A 30 percent change could result in saturation of soils and excessive surface water flows having consequences to hydraulic turnover in a small lake such as Willow Lake. The following year, 2018, was a drought year, producing significantly low amounts of water. A repeat of 2017 occurred in 2019, producing an exceptionally large volume of water in April.

Snow water content data from CEDC was used here to document these events in terms of how they might have affected Willow Lake and perhaps contributed to the excessive, and toxic cyanobacteria HAB growth documented in 2019. It should be noted that for two weeks the Paradise fire in November of 2018 produced huge amounts of smoke, some of which may have drifted northward 76 km (46 miles) to be deposited in the lake directly or onto the local watershed to be washed into the lake later. Smoke particles can contain nutrients of concern among other things.

Snow water content (CEDC) from Warner Creek (WRN), a nearby monitoring station, was used to evaluate hydrologic conditions surrounding Willow Lake. WRN is at a similar elevation and about 1.3 km (0.8 mi) SE of Willow Lake. Snow fall and snow water content are the only data available at that station. Snow water content, by month, is presented for 2016 through 2020 in Figure 4. Readings are taken on the first day of each month, so the value represents the quantity of snow-water present at the end of the preceding month. In years 2016, 17 and 19, most of the snow melted during April (Figure 5), which, in 2017, is contrary to the report cited above when Oroville failed due to flooding in February. This may have been due to local variations in weather patterns in the small Willow Lake watershed which is 100 km (62 air miles) from Lake Oroville. The years 2017 and 2019 were exceptionally wet while 2018 and projections for 2020 indicate severe drought years.

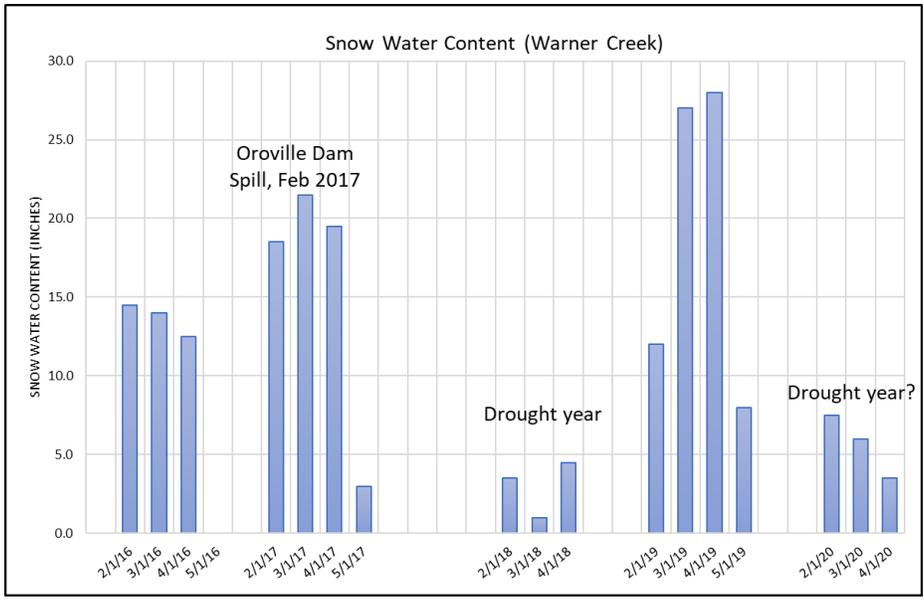


Figure 4. Snow Water Content at the Warner Creek (WRN) monitoring station at a similar elevation and about 1.3 km (0.8 mi) SE of Willow Lake (source CDEC). The readings were reported on the first day of each month.

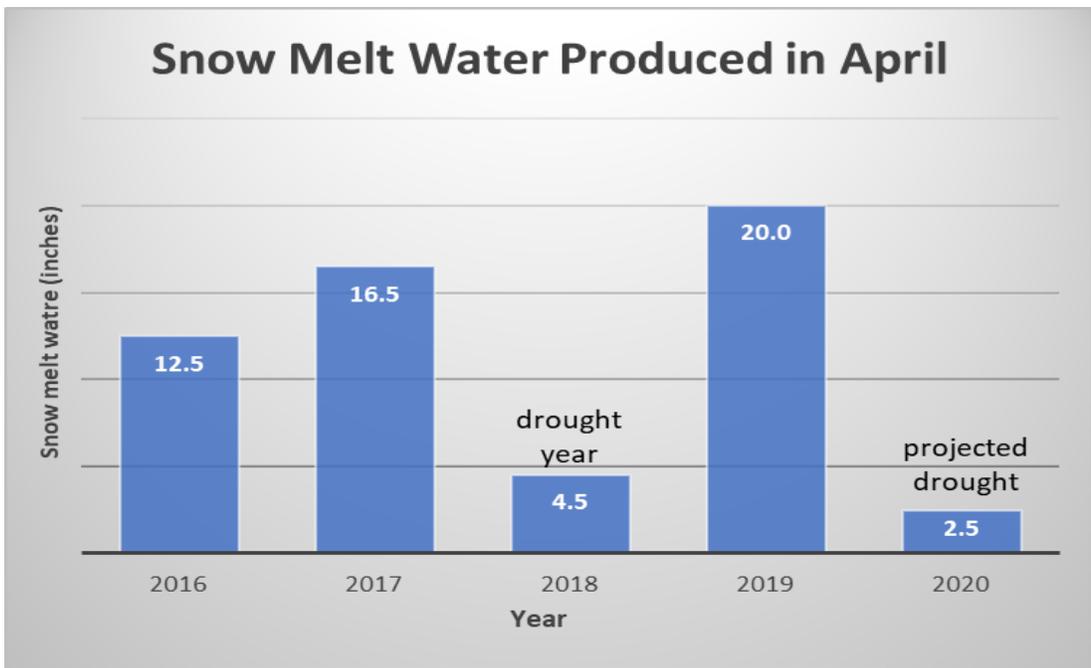


Figure 5. Snow melt water produced during the month of April from 2016 through 2020 based on Warner Creek station (WRN) data (CDEC). Values were calculated by subtracting snow water content on May first of each month from snow water content on April first of each year (Figure 4).

Assuming saturated soils, there was enough snow melted during April 2016, 2017 and 2019 to flush Willow Lake 24, 32 and 39 times, respectively, or 0.8, 1.1 and 1.3 times each day of the month if the melting was uniformly distributed during the month, (Figure 6). The water quality consequences of this much water passing through this system are worthy of further study. The buffering capacity of sphagnum beds is considerable, but normally they are fed by lower drainage rates as seepage and springs through the soils. Overland sheet flow was possible during 2016 and most likely in 2017 and 2019 sometime in April.

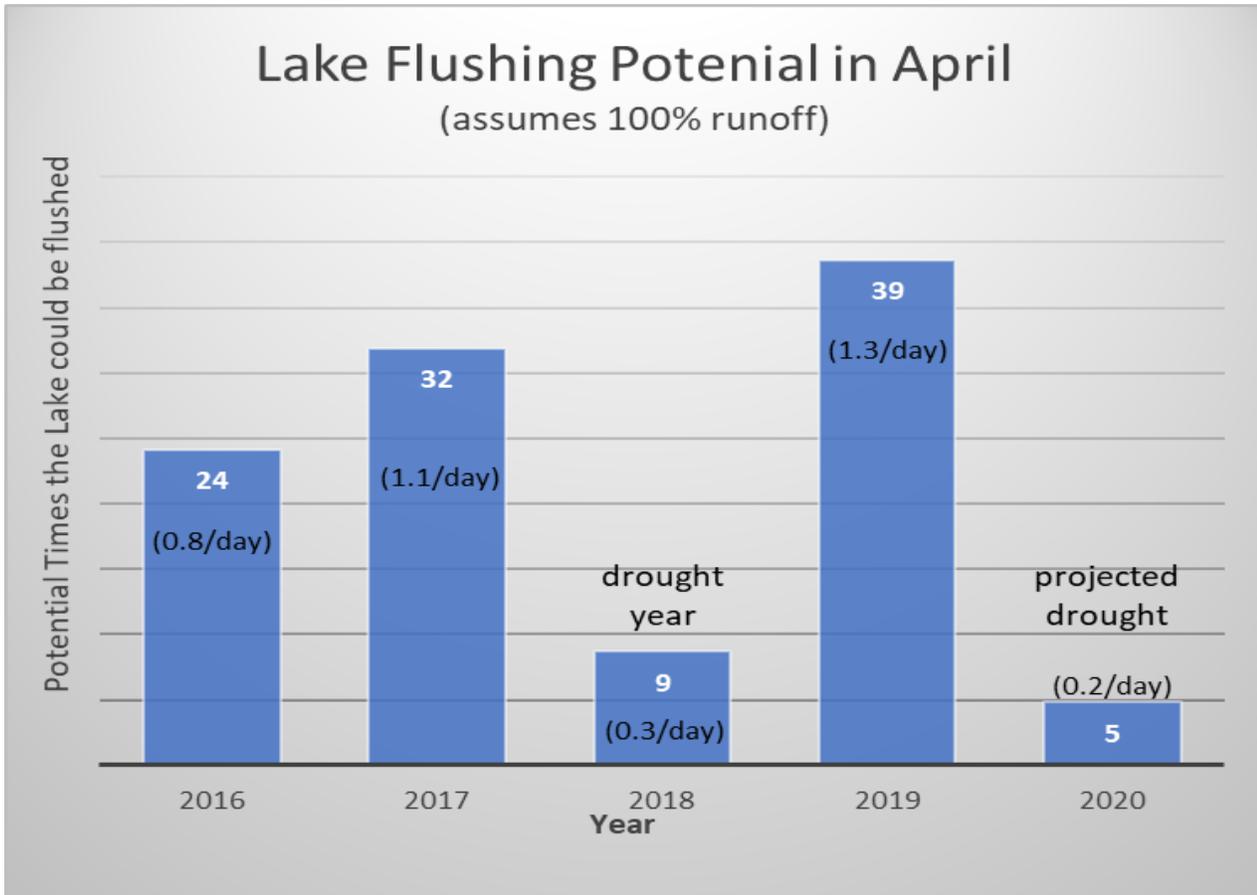


Figure 6. Potential number of times Willow Lake could have been flushed during April of each year assuming saturated soils and 100% runoff of melt water.

DISCUSSION

Willow Lake experienced a severe water quality change during 2019, from a sphagnum fen lake to a eutrophic CyanoHAB producing lake. Conditions leading up to this change are unknown as there have been no monitoring or water quality studies at this site. The only data available are from two samples taken for microscopic evaluation and toxin analysis in July 2019. Otherwise, casual observations by locals and visitors constitute the entirety of our knowledge.

There are no pH measurements to confirm, but it is highly likely that the lake switched from low pH (sphagnum modulated) to high pH (algae modulated) during the bloom. At some point, nutrients in

large amounts were made available for such cyanobacteria blooms to develop. A sphagnum bog/fen lake has a tightly complexed chemistry unlike most highly productive lakes, or at least in an entirely different form than is found in eutrophic lakes. Something drastic occurred to increase availability of nutrients to produce such a high biomass and “eutrophic” assemblage of algae.

A cursory look at snow/melt patterns has shown dramatic swings between drought and wet years in the watershed. Perhaps these swings provide at least part of the explanation for the observed changes. Under “normal” flow conditions, the well-known buffering capacity of sphagnum bogs/fens should modulate the quality of water reaching the lake. During extreme flood events, such as those resulting from elevated rainfall or rapid snow melt, the buffering capacity could be overwhelmed resulting in a significant change in water quality in the lake, at least temporarily. There is a projection for a severe drought year in 2020 without any indication as to how the lake will respond, i.e., recovery from last year’s condition or worsening conditions with even more severe blooms.

Is it possible that Willow Lake is the ‘canary in the coal mine’ for this type of lake in the Sierra Nevada? A monitoring plan and study designed to improve knowledge of the functioning of this system could be quite useful in understanding the processes occurring there that might be applicable to many other similar lakes in the Sierra Nevada. Mitigating for the drastic changes in Willow Lake will probably be difficult if not impossible given the regulatory environment and the difficulty of working in this system without doing additional damage.

MONITORING PLAN

A few samples will do little to understand the water quality dynamics of this lake. A comprehensive research study of the lake is the most appropriate approach to take to gain knowledge of the mechanism by which the lake switched from one form to another in a relatively short period. Lacking that however, a basic monitoring program would be a start and provide the information needed to develop a comprehensive study. Two huge knowledge gaps are in the hydrologic details and the nutrient dynamics. Details of flows into the lake by creeks, seepage, spring flows and sheet flow are very difficult to obtain, but necessary. Total outflows of the lake may be easier to measure at Willow Creek below the lake if a weir can be set up. Basic monitoring should include an electronic profile for pH, oxygen, conductivity, temperature, chl a over the deepest point in the lake and at the most convenient location in Willow Creek below the lake. At a minimum, nutrients should include Total P, Ortho-P, NO₂-NO₃, ammonia, Kjeldahl-N, Fe. Samples should be collected for TDS, hardness, DOC and TOC. The monitoring should be conducted at 2-week intervals throughout the accessible season. Regular analyses should be conducted of the phytoplankton community structure with detailed monitoring for cyanoHABs when a bloom is in progress.

A more comprehensive research project would include: (1) continuation and expansion of the monitoring described above with modifications based on the results, (2) a detailed workup of the watershed, (3) measurements of the lake morphology that were estimated here as a table top exercise, (4) evaluation of the wetland/sphagnum community, (5) sediment nutrient dynamics and (6) detailed documentation of weather patterns. The initial monitoring would identify additional effort required to understand this system. Individual(s) with specialized knowledge of sphagnum-based systems and meteorology should be included in the work.

Another approach would be to fund an RFP seeking to develop and implement a comprehensive study.

SUMMARY

1. This report is the first case-study being used to test the Preliminary Lake Evaluation concept.
2. Prior to 2019, Willow Lake (a sphagnum fen) was not known to produce cyanobacteria blooms.
3. Samples analyzed in July 2019, confirmed saxitoxin production within an extensive lake-wide pea soup surface mat.
4. The total lack of water quality data limited the ability to evaluate root causes for the bloom and explain the drastic change in trophic status.
5. An interview process with the Fisheries Biologist provided limited background information that was supplemented via online searches using Google Earth, USGS, CEDC and meteorological sites (see PLE spreadsheet).
6. Given the delicate and special nature of this fen lake, the surrounding wetlands, limited funds and the protections given it within the U.S. Forest Service, it is unlikely that mitigation actions can be taken.
7. However, it is of great interest to understand what caused this lake to switch from one ecological extreme to another in such a short period. There should be general interest in what happened here given that it is only one of many such lakes perched in the higher elevations of California's mountains.
8. No specific mitigation recommendations can be made at this time due to the complete lack of pertinent data. However, the great cyanobacteria biomass produced in 2019 required high concentrations of nutrients, the source of which must be understood if mitigation is to be considered.
9. By July 2020, Willow Lake was once again in full bloom.

Attachment:

PLE spreadsheet (populated from notes during the interview and with information gathered through online searches)

REFERENCES

Mitsch, W. J. and J. G. Gosselink. 2000. Wetlands. 3rd Ed. John Wiley & sons, Inc. New York. 920 p.