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LAKE BRITTON HARMFUL ALGAL BLOOM ASSESSMENT

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CALIFORNIA ENVIRONMENTAL PROTECTION AGENCY

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INTRODUCTION

In recent years, toxin-producing cyanobacterial harmful algal blooms (HABs) have increased globally in geographic range, frequency, duration, and severity (Carmichael 2008, Hudnell and Dortch 2008, Paerl and Huisman 2009, O'Neil et al., 2012, Paerl and Paul 2012, Paerl and Otten 2013, Quiblier et al., 2013, Hudon et al., 2014, Wood et al., 2014). These increases have been attributed to a wide variety of factors such as increased nutrient pollution including eutrophication, increased temperature, salinity, water residence time, water column stratification and climate change (Paerl 1988, Paerl and Fulton 2006, Carmichael 2008, Paerl and Huisman 2009, Paerl et al., 2011, O'Neil et al., 2012, Paerl and Paul 2012, Paerl and Otten 2013).

The State of California, like other states across the United States, has observed increasing numbers of waterbodies affected by HABs. This report presents an assessment of blooms identified at Lake Britton, a small reservoir in Shasta County. Lake Britton has recurring blooms of cyanobacteria that effect beneficial uses in the lake and Pit River. HABs have impacted contact recreation by creating undesirable water conditions with concentrated cyanobacterial mats and scum. HABs have also raised concern regarding fish consumption and health risks to dogs and wildlife.

The purpose of this assessment is to describe the ongoing HAB events in Lake Britton, identify potential causes, or environmental drivers most likely to attribute to HABs, and determine next steps for future mitigation of blooms.

SETTING

Lake Britton is a 140,000-acre-foot reservoir located approximately 60 miles northeast of Redding, in Shasta County. Lake Britton was formed in 1925 by the Pit River Number Three Dam impoundment about a mile down canyon from Burney Falls. The lake is characterized by a basin meadow hydrology that has been transformed by streambed alterations and influx of irrigation canals. The shoreline is primarily owned by Pacific Gas and Electric (PG&E); 21 of the 22 miles. One mile of shoreline lies within the McArthur-Burney Falls State Park which includes 182-acre parcel leased from PG&E. (FERC, 2004).

WATERSHEDS AND LANDUSE

The Pit River begins in the northeastern portion of California and drains into the Sacramento River at the confluence of Shasta Lake. The Pit River Watershed (Figure 1) originates near Alturas, California and flows southwest through the Warner Mountains toward Shasta Lake. This watershed, the Upper Pit River, experiences large inflows of cold water from Fall River, Hat Creek and Burney Creek making it a renowned location for wild trout. The Lower Pit River Watershed begins at Lake Britton and continues downstream to Shasta Lake. This section of the watershed contains a series of PG&E reservoirs, Pit 4, 5, 6, and 7, that are operated for hydropower generation.

Landforms in the surrounding watersheds include the Cascade Range, Modoc Plateau, Klamath Mountains and Basin-Ranges physiographic provinces. Lake Britton is in a border zone between the Cascade Range and Modoc Plateau provinces. Primary land uses include forest and agriculture. Farming practices include both crop production and grazing land.

Pit River, Hat Creek, Burney Creek, Clark Creek, and Cayton Creek provide the most flow and influence on Lake Britton's water quality. These five tributaries were assessed for flow, water quality, land uses, overall conditions, potential nutrient sources, and history of HAB occurrences.

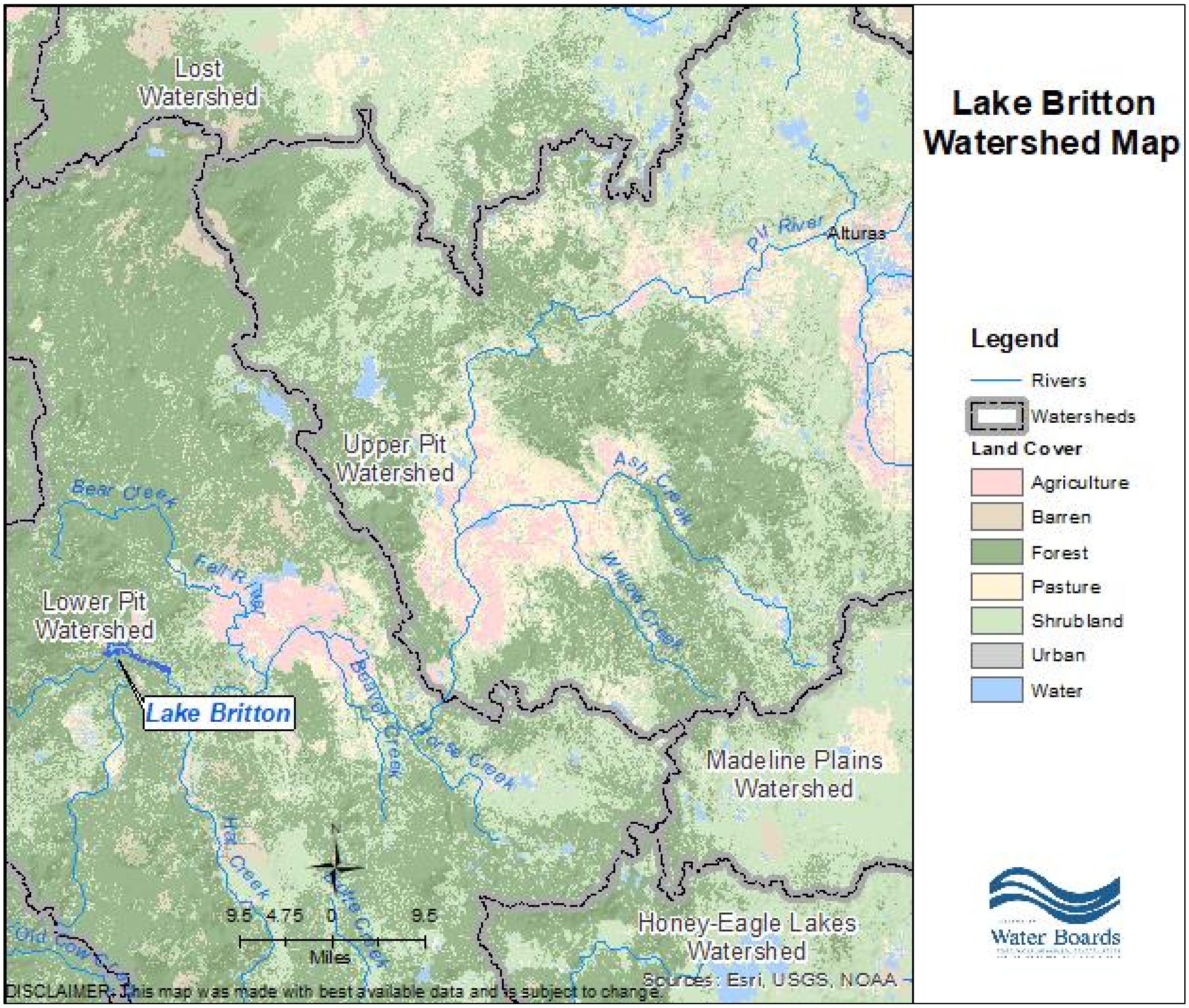


Figure 1: Pit River Watershed Map

DESIGNATED BENEFICIAL USES AND EXISTING WATER QUALITY IMPAIRMENTS

The Central Valley Regional Water Quality Control Board's (Central Valley Water Board) Basin Plan identifies beneficial uses for waterbodies within its region. Table 1 below lists the beneficial uses of the Pit River and Lake Britton. The Basin Plan is also used as guidance for the Clean Water Act section 303d list of Impaired Waters, as it governs what beneficial uses are affected by water pollutants within a waterbody.

Table 1: Lake Britton and Pit River Beneficial Uses and Potential HAB Impacts

Beneficial Use	**Potential HAB Impacts to Beneficial Use**
Municipal and domestic water supply	Toxin consumption, undesirable flavors and odors, treatment costs.
Irrigation supply	Cyanotoxins can be taken up by crops when irrigated with contaminated water.
Stock watering	Toxin consumption by livestock.
Power generation	Potential loss of power generation flexibility if changes in flow are necessary to control HABs.
Contact recreation	Toxin pathway for humans and pets. Reduced recreation use. Potential toxin exposure through consumption of fish.
Freshwater habitat (Warm and Cold)	Alteration of ecosystem. Potential fish kills from toxicity and low oxygen.
Fish spawning	Potential impacts from toxicity and low oxygen.
Wildlife habitat	Toxin consumption by wildlife. Ecosystem and food web changes.

Current water quality impairments at Lake Britton and the Pit River include excess nutrients, high temperature, organic enrichment, and low dissolved oxygen. Nutrients and high temperatures are 2 significant environmental drivers of HABs.

In addition to the pollutants listed above, Lake Britton is impaired by methylmercury, as documented in elevated fish tissue levels. The mercury comes from natural hot springs and air deposition from burning fossil fuels, primarily coal. Sulfate reducing bacteria generate the methyl form of mercury, which can bioaccumulate in the food chain. This process is linked to decay of organic matter, including accumulated HAB biomass, in benthic sediment.

LAKE BRITTON HABS

HISTORY

PG&E, Water Board records, and public reports show a history of HABs in Lake Britton. Cyanobacteria blooms have been reported since 2002 and have been reported yearly since 2011. While blooms are found in all types of water years, they have been more pronounced drought years. Public reports show that localized cyanobacteria populations can reach 'near' HAB concentrations during average to wet years.

CYANOBACTERIA SPECIES AND TOXINS

Generally, cyanobacteria in Lake Britton, seen below in Figures 2-4, is prevalent in the hot summer months. Blooms typically develop in late June/early July and disperse by October. Blooms are most pronounced in the drought years and have an impact to recreational beneficial uses at Lake Britton. HAB species, toxins, and features at the lake are summarized below in Table 2.

There was data on cyanotoxin risk that was reviewed by Water Board staff. Surface water samples were collected by PG&E in 2016 and 2017 at 5 sites in Lake Britton, 3 sites in the Upper Pit River, and 11 sites in lower Pit River (only collected in 2016). The samples were analyzed for DNA based Quantitative Polymerase Chain Reaction or qPCR. This molecular technique detects toxigenic genes and determines the risk or potential for cyanotoxins to be present. The presence of toxin producing genes does not mean cyanotoxins are present; cyanotoxins may or may not be present. As such, qPCR is used as a screening tool to determine if toxin analysis is needed (if no genes are detected then no toxins will be present).

The Lake Britton samples collected in July, August, September and October 2016 and 2017 had no qPCR detections of cyanotoxin genes for microcystins, cylindrospermopsin or anatoxin except one sample collected on August 11, 2017 that had 1.5 anatoxin genes/mL. This indicates a potential risk of anatoxin presence, but no toxin analysis was conducted. Samples collected in July, August, and September in the Upper Pit River had results ranging from no genes detected to 0.5 anatoxin genes/mL and no genes were detected in samples for microcystins or cylindrospermopsin. The anatoxin gene detection was only in the July sample. The Pit River samples collected in 2016 ranged from no detections to 0.5 anatoxin genes/mL and microcystin and cylindrospermopsin genes were not detected but only analyzed at 1 site. Overall, these results indicate anatoxin was potentially present at multiple sites in 2016 and 2017.

Figure 2: Photo of HABs near Burney Falls State Park beach at Lake Britton, 2017

Figure 3:Photo of HAB in Lake Britton at the State Park Boat Ramp, 2016

Figure 4: Photo of HABs near Burney Falls State Park beach at Lake Britton, 2015

Table 2: Lake Britton Cyanobacteria Bloom Features

Cyanobacteria	Bloom at Lake Britton
Genera	***Aphanizomenon****; Dolichospermum; Gloeotrichia*
Color	Green and yellow green when alive in water. Blue green and paint like scum when dead and accumulated near shore.
Duration	Variable on the order of weeks to months, from June to October.
Odor	Report of strong odor associated with blooms in 1990s under different lake level management
Toxins	Potential cyanotoxins are anatoxin, cylindrospermopsin, microcystins
Impacts	Beneficial use impairments. One unconfirmed dog death.
Water year	Blooms typically more pronounced and more extensive during drought years. Blooms typically less pronounced or not present during wet years.

ENVIRONMENTAL DRIVERS OF CYANOBACTERIA BLOOMS

Cyanobacteria blooms can occur naturally, but most are caused by excess nutrient loading from municipal, industrial and agricultural sources into local watersheds. Other factors that can influence the growth of HABs include hydromodification of natural systems as well as the physical, chemical, biological, and environmental factors of each waterbody.

Berg and Sutula 2015 completed a global literature review on the factors that influence the growth of cyanobacteria and identified five principal drivers that are important determinants of blooms.

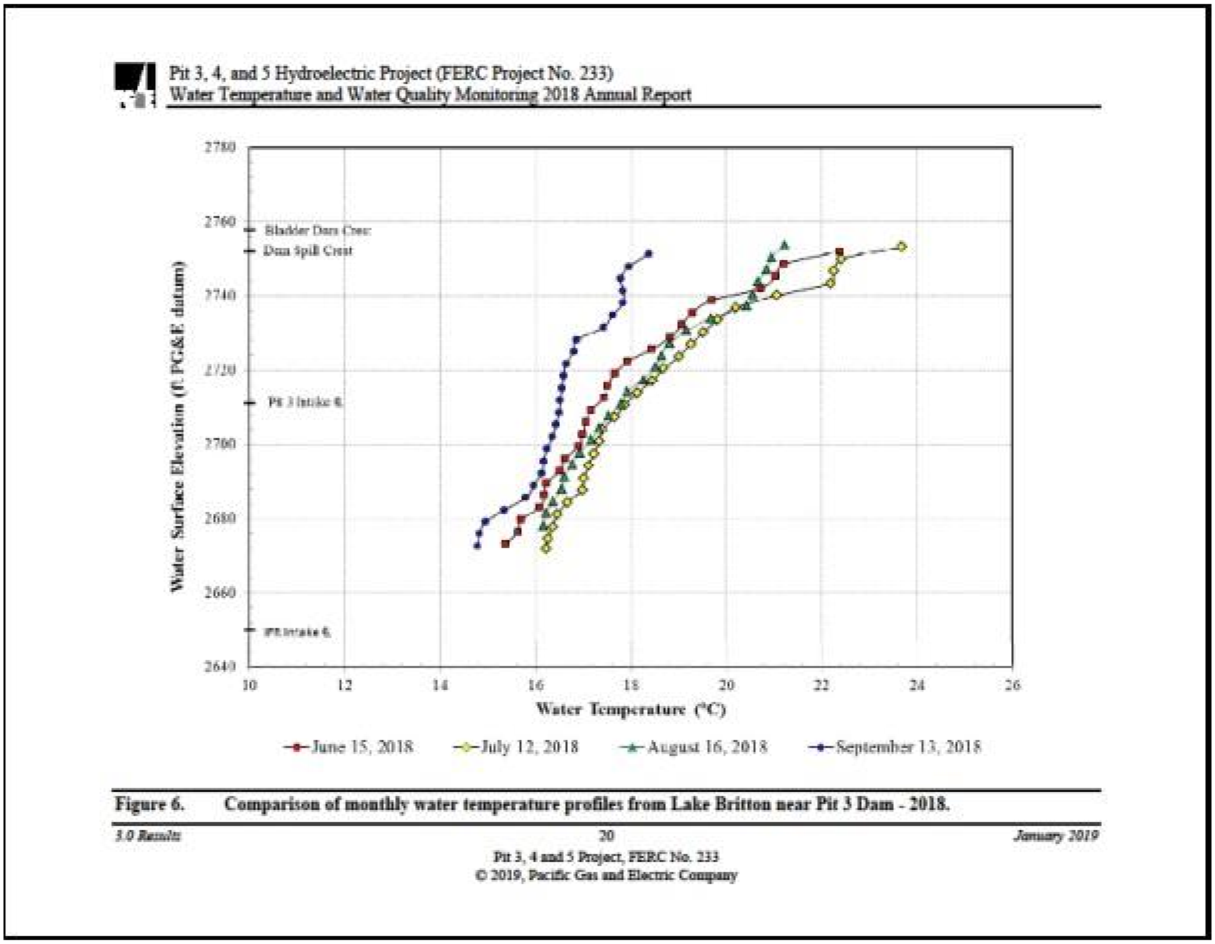
- Water temperatures above 19°C
- Nutrient enrichment (nitrogen and phosphorus) in non-limiting amounts
- Long residence times and a stable, stratified water column
- High irradiance and water clarity
- Salinity tolerance

Understanding these drivers, or the underlying causes that compound to create a suitable habitat for HABS, are necessary to develop trends and a possible mitigation strategy for blooms at Lake Britton. Although environmental drivers have not been fully determined for Lake Britton, the drivers mostly likely attributed to HABs are water temperature, water quality and excessive nutrients. Droughts, potentially due to climate change, also appear to increase the likelihood of HABs in Lake Britton.

WATER TEMPERATURE

Water temperature is an important environmental factor that controls phytoplankton growth (Paerl and Huisman 2008, Berg and Sutula 2015). Phytoplankton (e.g., chlorophytes, dinoflagellates, diatoms, and cyanobacteria) have specific growth rates based on optimum growth temperatures. Cyanobacteria grow slower at colder water but as the temperature increases cyanobacteria can outgrow diatoms and dominate a waterbody when water temperatures are >25°C (Paerl 2014). As water temperatures continue to increase globally above 20°C due to climate change, the difference in these optimum growth temperatures for the different species of phytoplankton will become increasingly important in determining the overall aquatic phytoplankton community composition in Central Valley waterbodies.

Lake Britton is seasonally stratified by water density with warmer, less dense water near the surface and cool higher density water below in the summer. During the winter, the surface layer cools, wind velocity increases and inflow rises reducing lake stratification. Flow management through the reservoir can influence the lake stratification by drawing water from different levels in the lake. PG&E water column monitoring, lake stratification, and changes produced by water releases all have potential impacts on HABs. Figure 5 compares four water temperature profiles throughout the summer in 2018 (PG&E, 2019). Sampling between June and August all show water temperatures above 20°C.



Pit 3, 4, and 5 Hydroelectric Project (FERC Project No. 233)
Water Temperature and Water Quality Monitoring 2018 Annual Report

Figure 6. **Comparison of monthly water temperature profiles from Lake Britton near Pit 3 Dam - 2018.**

3.0 Results 20 *January 2019*

Pit 3, 4 and 5 Project, FERC No. 233
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Figure 5: PG&E figure of Lake Britton water temperature at depth, showing warm surface water and cool deep water

NUTRIENT ENRICHMENT

Nutrient over-enrichment by urban, agricultural, and industrial activities has contributed to the growth of HABs in our waterbodies. Nutrients such as nitrogen and phosphorus are key environmental drivers that influence the proportion of cyanobacteria in the phytoplankton community, the cyanobacterial biovolume, cyanotoxin production, and the impact that cyanobacteria may have on ecosystem function and water quality (Paerl et al. 2011). Cyanobacteria production and cyanotoxin concentrations are dependent on nutrient levels (Wang et al. 2002); however, nutrient uptake rates and the utilization of organic and inorganic nutrient forms of nitrogen and phosphorus vary considerably by cyanobacteria species.

Potential nutrient sources to Lake Britton include surface and groundwater inflow, recycled nutrients within the lake basin, modifications to the basin meadow hydrology and wetlands, and atmospheric. Livestock, irrigated pasture, dirt roads, and decay of wetland vegetation all play a role in increasing the nutrient load within the watershed.

Waterboard staff analyzed sampling data, gaging stations, and flow estimates and determined that most of the nitrogen and phosphorus inputs to Lake Britton come from the Pit River, Hat Creek, and Burney Creek.

DROUGHT AND CLIMATE CHANGE

Drought conditions fueled by climate change are being assessed as possible drivers of HABS, as they increase the water temperature and susceptibility of nutrients described above. The California Office of Environmental Health Hazard Assessment described climate change affects in our region as rising air and water temperatures, longer droughts, increased evapotranspiration, more energetic hydrologic cycle, and more large fires. These acts compound to create an ideal habitat for HABs through, in part, increased surface water temperatures, increased nutrient loads, accelerated wetland oxidation, accelerated erosion during big storm events, deeper thermocline from warmer surface water, more vigorous lake nutrient cycling from warmer water, and reduced tributary flow from higher evapotranspiration in watershed.

Based on data seen within the Pit River area, affects from climate change are possibly altering the watershed. PG&E monitoring data shows outflow from the upper Pit River and upper Feather River watersheds have been on a declining trend due to prolonged droughts. Droughts reduce flow-through or flushing flows, increasing residence time, heating and nutrient accumulation in the reservoir. Droughts also may increase depth of thermocline, exposing deeper, nutrient rich areas of the lake to higher temperature.

WATER QUALITY SAMPLING

To assess the water quality and potential drivers of HABs in Lake Britton, Waterboard staff conducted water quality sampling over multiple years at the main tributaries entering Lake Britton (Figure 6). Between 2017 and 2019, there were four sampling events that took place both at low water and high water (Table 3). Staff also reviewed temperature data and flow estimates collected by PG&E to compare the temperature stratification.

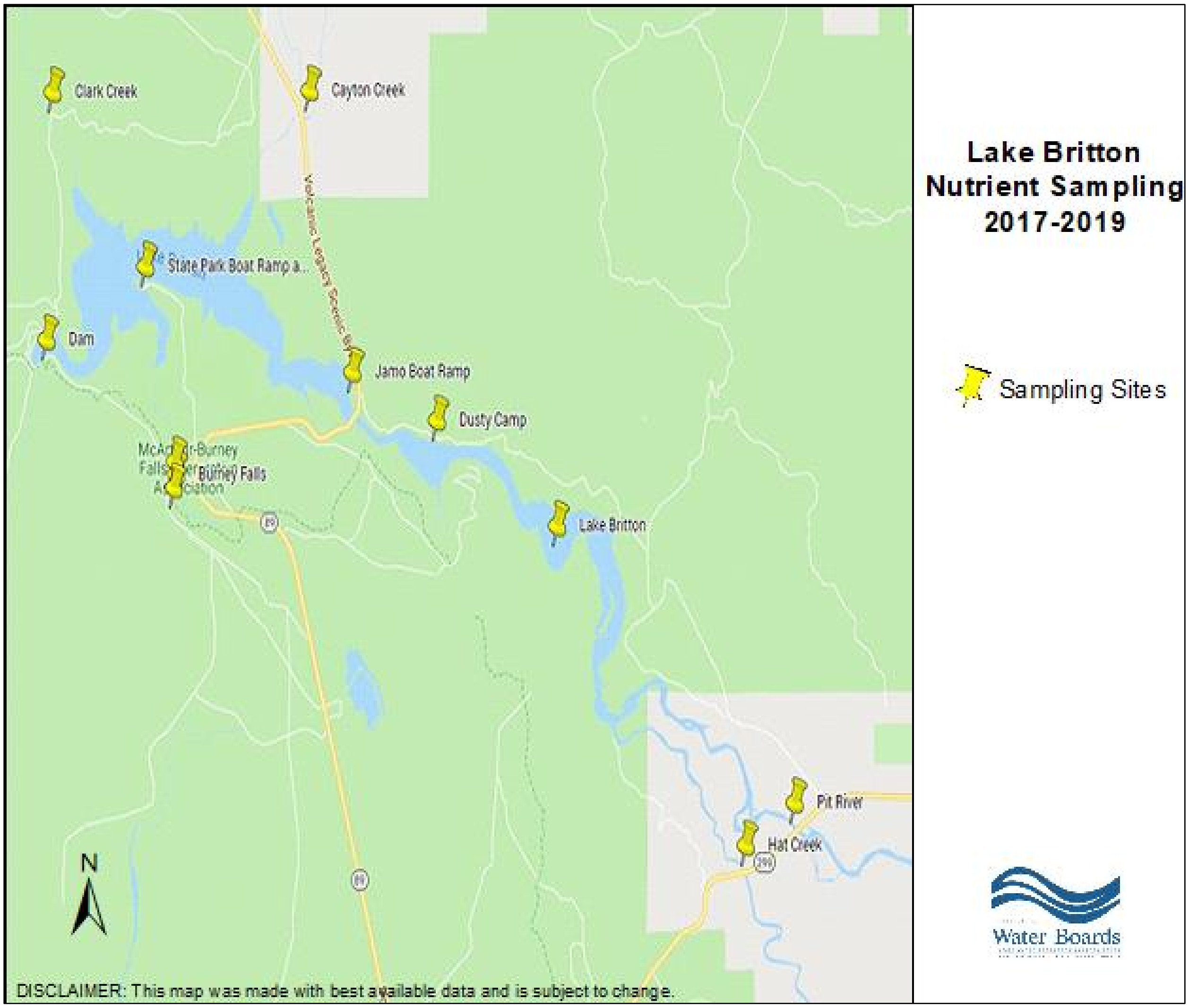

Figure 6: Map of sampling locations around Lake Britton

Table 3: Range of values from nutrient samples collected by Water Board staff from August 2017 to May 2019

Sample Location/ Nutrient Constituent (mg/L)	Lake Britton - State Park Boat Ramp	Burney Creek	Hat Creek	Pit River	Cayton Creek	Clark Creek
Nitrogen (total)	0.241-1.120	0.182-0.461	0.135-0.298	0.258-0.950	ND-0.527	ND-0.190
Phosphorous (total)	0.063-0.110	0.028-0.090	0.054-0.092	0.050-0.184	0.030-0.090	ND-0.078
Chloride	1.610-2.310	0.530-1.350	1.110-1.120	3.260-5.820	0.700-1.280	0.290-0.420
Sulfate	2.180-2.370	0.640-1.560	1.790-1.800	2.880-7.730	0.360-4.080	ND-0.290
Calcium	9.400-11.20	6.400-8.800	9.700-10.00	11.60-14.20	4.700-11.40	6.100-6.900
Magnesium	5.500-6.900	3.600-5.100	6.900-7.100	7.100-8.100	3.100-7.600	3.500-3.900
Manganese (ug/L)	17.80-14.20	5.170-31.50	2.140-7.600	17.40-36.10	33.50-35.10	1.480-38.00
Potassium	2.200-2.500	1.300-1.900	2.400-2.600	2.500-4.000	1.900-2.300	ND-0.600
Sodium	6.000-10.80	4.500-3.500	7.600-8.200	16.10-12.90	2.000-4.000	2.100-2.400
Iron (ug/L)	173.0-1280.0	253.0-2090.0	32.00-560.00	362.0-3390.0	278.0-2490.0	47.00-2610.00
Copper (ug/L)	2.270-0.660	0.500-2.780	0.320-1.060	0.770-4.230	1.520-2.770	ND-2.570
Zinc (ug/L)	ND-10.70	ND-10.80	ND-3.500	0.700-9.300	ND-4.400	ND-7.400

FINDINGS

The nutrient loads show that the Pit River, Hat Creek and Burney Creek delivered most of the nitrogen and phosphorus entering Lake Britton. The load calculations were developed as a product of the average nutrient concentration in grab samples and the average estimated discharge value of the corresponding tributary delivered from tributaries.

These relative load estimates for the tributaries do not included other sources of Lake Britton nutrients such as groundwater, lake shore, air borne, and nutrient cycling.

The PG&E temperature depth profile, seen above in Figure 5, could also influence HABs in Lake Britton. The lake is stratified in the summer with warm water accumulating in the upper five meters and cool water at depth. This warm layer is produced by warm inflow and air temperatures. The warm layer gets larger during June through September when blooms are most pronounced. This layer provides favorable habitat for cyanobacteria and warm temperatures may also stimulate nutrient cycling in the lake. The low dissolved oxygen layer may also have an impact on phosphorus cycling in the lake. Current flow management is raising water temperatures at middle and lower depths in Lake Britton. Higher water temperatures could stimulate increased nutrient from lake sediment and stimulate activity in benthic life stages of cyanobacteria.

Findings made by the assessment and stakeholder monitoring of Lake Britton conclude that HABs are an ongoing problem and have been observed for many years. Three main HAB genera identified, *Aphanizomenon, Dolichospermum, and Gloeotrichia*, can all produce toxins, such as anatoxin-a and microcystin, all have potential to fix atmospheric nitrogen. HABs appear to be more pronounced during droughts and warm, low flow years. HABs negatively impact contact recreation in Lake Britton by reducing quality of contact recreation and raising concern regarding potential toxin exposure. More data monitoring and analysis is needed to determine the primary environmental drivers of HABs in Lake Britton.

DATA GAPS

Sampling at Lake Britton is the first step to understanding the role and reasons HABs are continually forming. There are many data gaps that need to be addressed to gain a full understanding of the pollution issue. The following data gaps pertain to potential environmental drivers of HABs (Table 4)

Table 4: Lake Britton Nutrient Sources, Influencing Factors and Data Gaps

Source	Pollution	Data Gap
Erosion	Phosphorous loads	Little documentation available on nutrient loads from shoreline erosion, natural sources, dirt roads, and grazing.
Wastewater	Nitrate loads	Unknown leaks and insufficient maintenance can lead to nutrient leaching.
Agriculture	Fertilizer runoff	Limited surface water and sediment sampling and analysis
Climate Change	Nutrient loads	Pollutant via fire, fossil fuels, and wetland oxidation.

MANAGEMENT AND MITIGATION OF HABS

HABs are a significant and growing threat to beneficial uses of Lake Britton. This assessment has described the watershed conditions that could be driving HABs in lake Britton. Mitigation of Lake Britton HABs is needed to protect and enhance beneficial uses at the lake. If HAB mitigation is prioritized, next steps should include the factors described below.

- Obtain additional stakeholder input on HABs history, drivers, and mitigation options. Stakeholder input is needed to fill in gaps in the assessment, guide next steps, and develop options for HAB mitigation.
- Investigate natural nutrient sources, loading and mitigation options. Additional information is needed regarding the influence of naturally occurring nutrients to inform development of a mitigation strategy.
- Assess loading of permitted discharges: wastewater, septic, irrigated agriculture, dirt roads, etc. Existing regulatory programs could provide water quality data on nutrient sources to inform mitigation strategy.
- Investigate nutrient cycling in Lake Britton. Assessment of how much existing nutrients in Lake Britton cycle between bottom sediment and the water column is needed to inform development of a mitigation strategy.

CONCLUSION

Cyanobacteria blooms have been identified at Lake Britton since the early 2000s. While blooms are prevalent in dry water years, they have been present in all types of water years since 2011. Multiple entities, including the Waterboards, have conducted water quality sampling to document HABs.

While potential environmental driers have been described in this report, more data gathering, water quality monitoring, and analysis is required to determine the primary drivers of HABs in Lake Britton.

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