TETRA TECH

TECHNICAL MEMO

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Subject:	2021 Annual Summary Technical Memo

1.0 Introduction

The purpose of the Long Lake Integrated/Adaptive Lake Management Program is to achieve water quality and aquatic habitat goals established during the 2006 – 2010 lake management efforts. The current Long Lake management program is being implemented through the Kitsap County's Long Lake Management District (LLMD) from 2018 through 2022. Targeted management of the lake is to approach an ecologically sustainable and balanced ecosystem with aesthetic appeal that supports water contact recreation, sport fishery, downstream water quality needs, and salmon migration. The lake management program has partially limited internal phosphorus loading to reduce excessive phytoplankton production, has partially limited excessive growth of rooted aquatic plants, and has targeted the elimination, where possible, of non-native plants such as Eurasian watermilfoil, Curly-leaf pondweed, fragrant waterlily (fragrant white lily) and Brazilian elodea. The integrated management program for Long Lake includes six basic elements: project management, integrated/adaptive planning, monitoring, implementation, reporting, and public education. This technical memo provides an annual assessment of in-lake activities and monitoring data collected in 2021, as well as recommended activities for 2022.

Figure 1. Map of Long Lake and surrounding area

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Long Lake is a shallow, lowland lake located approximately four miles south of Port Orchard in southern Kitsap County in Western Washington State (T2 3N-R2E) (**Figure 1**). Long Lake lies at an elevation of 118 feet (ft.) (36 meters [m]) above sea level. The 339-acre (137 hectare) lake has a historical volume of 2,200 acre-feet (2.69 X 10^6 cubic meters [m^3]), average depth of 6.5 ft. (2 m), and center depth of 12 ft. (4 m) (Bortleson et. al., 1976). Nearly 75% of the lake is less than 10 ft. (3 m) in depth, providing a large littoral area. The drainage area is approximately 9.4 square miles (24.3 square kilometers [km^2]), encompassing an increasingly urbanized watershed. Salmonberry Creek is the major inlet, entering on the western shore. The single outlet, Curley Creek, drains the lake at the northeastern end, eventually flowing into the Puget Sound. Several unnamed streams enter at the southern end of the lake. Long Lake exhibits a rather high flushing rate varying from 3.6 to 8.0 yr^{-1} (Jacoby et. al., 1982).

2.0 2020 In-Lake Activities

2.1 Algae Control

No specific phosphorus management activities were conducted in 2021. There were no sustained cyanobacteria (blue-green algae) warnings issued by Kitsap Public Health District for Long Lake in 2021. Citizens reported several surface blooms during the summer, but the blooms were a mix of algae and not exclusively or dominated by cyanobacteria.

In 2019, a low-dose alum treatment was conducted to remove phosphorus from the water column and to inactivate the release of phosphorus from the lake sediments to reduce algal production. Despite the lower dose (5 mg Al/L compared to the 2007 dose of 17.5 mg Al/L), there was a significant increase in water clarity following the 2019 treatment due to the reduction in algal production, and Long Lake did not experience a toxic bloom, which had occurred each year for the previous four years. The 2019 treatment was anticipated to reduce HAB (Harmful Algal Blooms) event occurrences and intensity for 2 to 5 years, depending upon phosphorus cycling and loading as well as climatic impacts. To ensure prevention of HABs in the future, alum treatment will need to be repeated within 3 to 5 years (2022-2024).

2.2 Lake Monitoring

Citizen volunteers and Tetra Tech staff conducted in-situ monitoring on a monthly basis (April through October) in 2021. All monitoring in 2021 included measurements of DO, conductivity, temperature, and pH at three sites in Long Lake (**Figure 2**). At the lake sites, these parameters were measured at 0.5-meter intervals within the water column. Citizens or staff recorded secchi disk depth, or transparency, at each station, and made notes on the weather and water conditions at the time of sampling.

At the mid-lake site, citizen volunteers or Tetra Tech staff also collected water samples at depths of 0.5 and 2.5 meters for laboratory analysis. These lake water samples were analyzed to determine total phosphorus (TP) concentrations and concentrations of soluble reactive phosphorus (SRP) and chlorophyll (chl). During each monitoring event, citizen volunteers or staff also collected a grab sample from Salmonberry Creek. The creek water sample was analyzed for TP. All samples were either delivered or packed with ice and sent to IEH Analytical Laboratory on the same day they were collected.

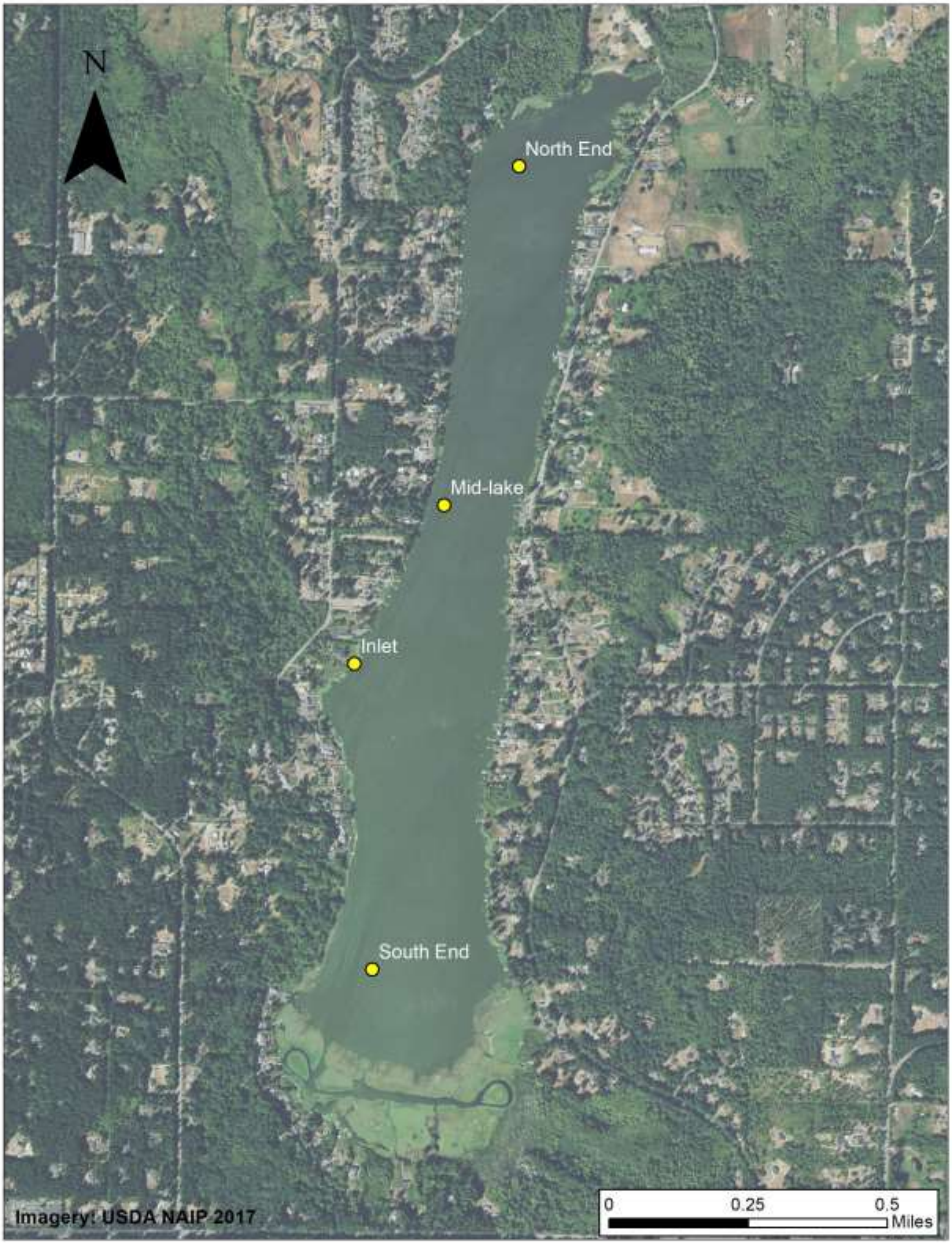

Figure 2. Map showing sampling locations

2.3 Aquatic Plant Management

2.3.1 Aquatic Plant Background

Brazilian elodea *(Egeria densa*) has existed in the lake for over 40 years. It was not observed in the south end of the lake in the mid-1960s where endemic pond weeds were more abundant. The exotic elodea allegedly was introduced around 1970. During the 20-year study by University of Washington (UW), this plant composed at least 2/3 of the total plant mass (dry weight) and much of that time over ¾ of the biomass (Welch, 1996). In 1985, its abundance dropped to only 10% of total mass and summer TP and chl averaged 66 and 36 µg/L, respectively due to increased internal phosphorus loading. Harvesting in the 1990s had no effect on the dominance of Brazilian elodea. Eurasian watermilfoil (*Myriophyllum spicatum*) was not present during the 20-year UW study, but it was observed during the 1996 IAVMP study (Water Environmental Services, 1996) so it is a more recent invader. Curly-leaf pondweed (*Potamogeton crispus*) is also a more recent invader and was first observed in 2006. Native pondweed species were also targeted for control in 2020 due to increasing coverage and density since 2008.

Aquatic plant management during 2006-2010 resulted in a more diverse plant community within Long Lake. The density of native macrophytes species in heavy boat use areas declined while the diversity (number of species) increased over that time period. Eurasian watermilfoil had nearly disappeared but the Brazilian elodea population in the open lake and south end had remained stable (Tetra Tech, 2010). The non-native fragrant white lily (*Nymphaea odorata*), however, became established and had started to replace some of the native yellow lily (*Nuphar polysepala*) in the South Lake emergent plant beds.

Aquatic plant management activities restarted in 2018 with the updated Long Lake Integrated/Adaptive Lake Management Program. The initial 2018 aquatic plant survey of Long Lake indicated that Brazilian elodea was the dominant submersed plant and was observed throughout the lake in addition to small, relatively isolated groupings of the invasive Eurasian watermilfoil and Curly-leaf pondweed. Lilies were abundant in the nearshore areas near each end of the lake with the invasive fragrant white lily (*Nymphaea odorata*) as the dominate species that was targeted in 2019 and 2020 treatments. The native yellow pond lily, *Nuphar polysepala*, covered less than 30% of the emergent plant beds. From 2008-2018 the native pondweed *P. praelongus* had increased its coverage and density to warrant control.

In 2018, several native narrow-leaf pondweed species *Potamogeton zosteriformis, P. pectinatus* and *P. filiformis* (flat stem pondweed, sago pondweed and slender-leaved pondweed) were observed throughout the lake with a relatively small percent cover. However, in 2019 an increase in pondweed production was observed due to several factors including clearer water, abundant solar energy, and nutrients within the shallow sediments. Sudden production of *P. zosteriformis* was observed within the mid-depth littoral areas especially on the east side of the lake and expanding on the west side. In addition to the expanding *P. zosteriformis* coverage, previously rare *P. pectinatus* and *P. filiformis* (sago pondweed and slender-leaved pondweed) were observed in 2019 to have displaced *P. praelongus* and taken up dominance on the east and west shorelines to a depth of 3 m, inhibiting boat passage. By the end of June 2019 these species densely covered over 24 acres along the east and west shorelines, and although four of the five species of *Potamogeton* are native, three of the four native species were observed to have grown to extreme densities that exceed a balanced habitat and have the potential to adversely impact water quality. The 2019 plant survey also indicated that the non-native invasive fragrant white lily (*Nymphaea odorata*) was a dominant species and had expanded its nearshore littoral coverage significantly on the west side of the lake and in the northeast littoral areas.

Surveys of aquatic plant growth were conducted in May and August of 2020. The May survey was conducted prior to aquatic plant treatment, and the August survey was conducted after treatment and at the end of the summer growing season. In May, a continued increase in area and density of aquatic plants was observed. At the south end of the lake, large swaths of lilies, especially white lily, have continued to expand in coverage and the formation of several small islands was observed. Brazilian elodea and native pondweed species were observed throughout the littoral area, especially in the southern portion of the lake, and a high density of *P. praelongus* was observed along the east bank and northwest corner of the lake. Proposed treatment areas for 2020 were identified in 2019 and confirmed in May 2020 to target littoral areas along the east and west shores of the lake.

A late-summer survey in August 2020 indicated that the treatments were successful in limiting pondweed growth in targeted areas, but in other areas there was continued expansion of aquatic plant growth over the summer. In the treatment areas along the west bank, no noticeable patches of pondweed species were observed in August, but the presence of the white lily had continued to expand in coverage and density since the 2018 survey. Both north and south of the treatment area on the west bank, thick patches of *P. praelongus* and other pondweed species were observed in August 2020. In the littoral area along the east bank of Long lake, some thick patches of *P. praelongus* were observed even in the treatment areas, but coverage was lower than in 2019. North of the treated area on the east bank, expanded coverage of white lily and pondweed species was observed.

The excessive growth of white lilies in Long Lake has resulted in floating masses of aquatic plant material, especially at the southern end of the lake. In 2020 one of these masses became a free-floating island. The floating island, made by root mass of mainly invasive aquatic plants, posed a significant hazard to lakefront property and directly impacted aquatic habitat both physically and chemically. In addition to the dangers of such floating plant masses, which are likely to continue to occur, removal of the floating mass was difficult and costly. In order, to prevent similar hazards in the future, aggressive treatment targeting the invasive white lilies in the southern portion of the lake is highly recommended.

2.3.2 2021 Aquatic Plant Survey

An aquatic plant survey was conducted by citizen volunteers on May 22, 2021. Tetra Tech conducted aquatic plant surveys in June and September 2021. A map of the surveyed aquatic plants in Long Lake during 2021 is shown in **Figure 3**.

During the May survey, citizens indicated that the ski course and waterways in the south end of the lake appeared to have been cleared by lake residents with only sporadic small areas of various plants in those areas between the lilies. However, they noted that in the southeast corner of the lake the lilies had not been maintained and the waterways that were previously created were beginning to fill back in as the lilies continued to expand. The citizens also noted in their survey that *P. praelongus* was abundant and was observed within the majority of the littoral area with only an occasional spot where it was not present. Specific areas that the citizens indicated to have heavy growth of *P. praelongus* included along the west shoreline and in the northern end of the lake. The citizens also indicated heavy growth of Brazilian elodea outside of the large swath of lilies in the southwest portion of the lake. This heavy growth has also been observed to be increasing by Tetra Tech and specifically noted in the spring of 2019 and every year since. Tetra Tech has observed that lake depth along the northern edge and further to the north of the large swath of lilies has been getting shallower, enabling the increase in Brazilian elodea biomass density. This is an indication that the southern lily community is contributing to the reduction of lake water volume by direct organic over-production and is enhancing production of other plants like *P. praelongus* and Brazilian elodea.

In 2021, aquatic plants in Long Lake continued to increase in diversity with more native species, which is good for overall lake habitat and ecology. However, there was also an increase in overall aquatic plant biomass which appears to be accelerating the eutrophication process. The emergent vegetation in the littoral areas of the lake is growing in density, biomass, and diversity, indicating that the lake is aging or becoming more productive over time, as well as becoming shallower. It appears that lake depth is decreasing in most locations due to sedimentation from largely organic material from rooted aquatic plant vegetation. This is accelerating the overall production within the lake and contributing to the eutrophication process and lake aging. Tetra Tech observed in the spring of 2021 that aquatic plant growth had accelerated relative to the normal seasonal patterns and was approximately 6 to 12 weeks ahead of the normal seasonal growth. This was due to the increase in solar availability as well as unusually high water temperatures in the spring and early summer of 2021.

Even with the increase in overall plant biomass and diversity, three of the four non-native, invasive aquatic plant species have been reduced in both density and coverage. Eurasian watermilfoil was not observed in the spring nor fall 2021 plant surveys. Curlyleaf pondweed (*P. crispus*) has been reduced in density but still was observed in scattered patches within the shallow shoreline littoral area. Brazilian elodea is still the dominant submersed plant, but its coverage density has been greatly reduced in the east and west shoreline littoral areas and replaced with native plants. Brazilian elodea, however, has expanded in density from its lowest growth stasis in 2010, but still, in 2021 is less in overall coverage and density than in 2006.

Fragrant Waterlily or white lily (*Nymphaea odorata*) has significantly expanded in density and coverage resulting in accelerated lake aging (eutrophication) and sediment accumulation to the point of creating wetland islands in the southern area, as was observed in 2020. This area, in time, will evolve to wetland from littoral area and from there to dry land due to the sediment build-up and excessive plant growth. The fragrant waterlily, a non-native plant, will greatly accelerate eutrophication of the lake and reduce the lake's open water area significantly if management actions are not taken to control this plant. Unfortunately, due to the expansion and excess growth of the lilies, the lake will require significant management actions in the southern end and littoral shoreline habitat to reduce the aging process and maintain the lake's ecological status and human beneficial uses.

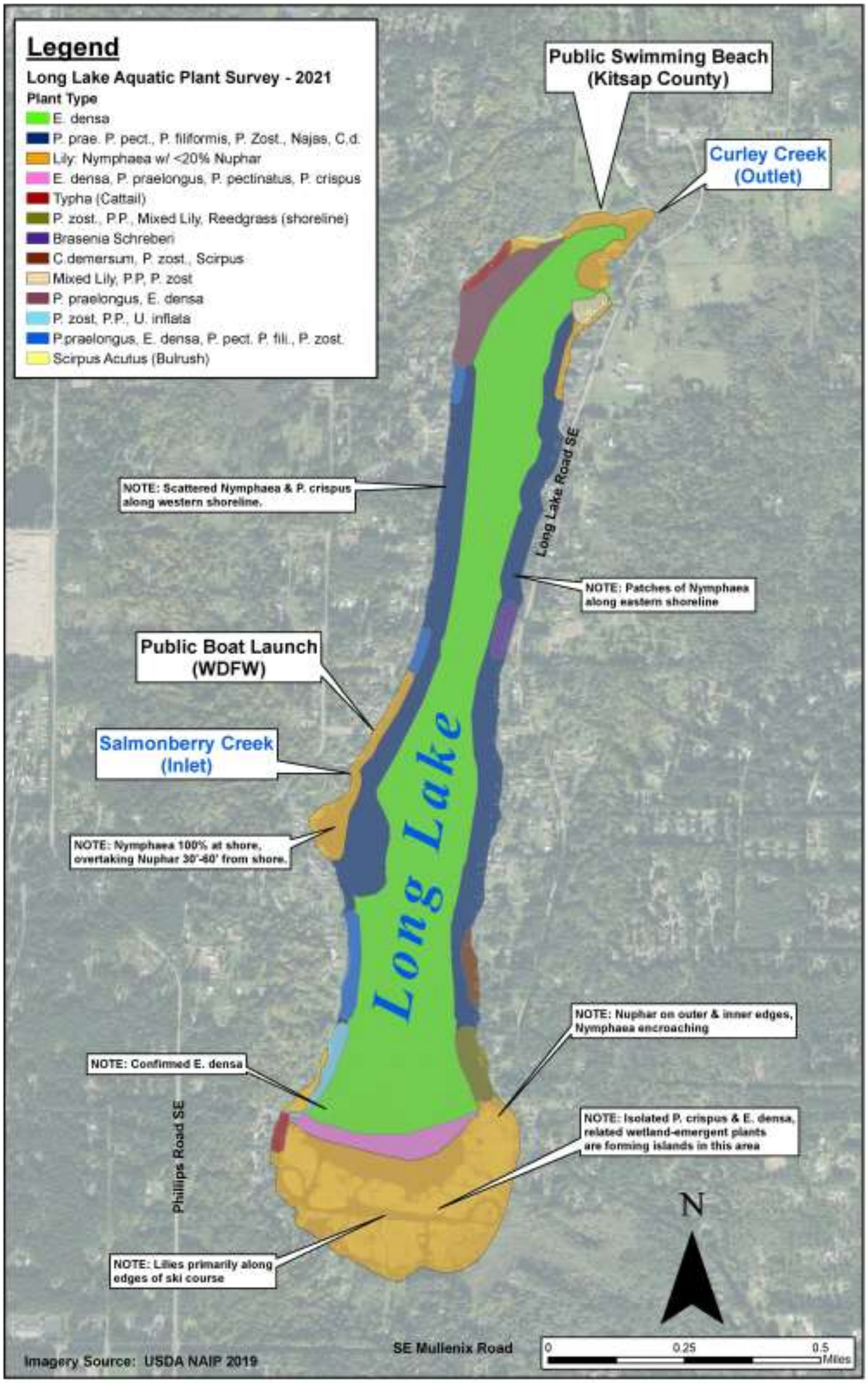

Figure 3. Aquatic Plant Distribution – 2021 Aquatic Plant Survey

2.3.3 Aquatic Plant Treatment

The goal of aquatic plant treatment at Long Lake is to target noxious invasive non-native weeds that are already present and were documented in the 2010 report and confirmed during plant surveys from 2018-2021, including the white lily, Brazilian elodea, Eurasian watermilfoil, and Curly-leaf pondweed. Native species *Potamogeton praelongus, P. zosteriformis, P. pectinatus* and *P. filiformis* (white-stemed pondweed, flat stem pondweed, sago pondweed and slender-leaved pondweed) that have grown to extreme densities exceeding a balanced habitat may be targeted as well for density reduction, but not eradication as is the case for non-native species. The excess density of these plants and the dominance of non-native species within the plant community adversely impacts aquatic habitat, fisheries, and direct recreation. It also decreases water quality, leading to the release of phosphorus, which in turn leads to cyanobacteria toxic blooms. Following the pattern of rotating treatment sites used for aquatic plant treatment in 2006-2010, small areas of the littoral zone are anticipated to be treated each year in Long Lake. As in past studies, the expected result is a dramatic decrease in the density of non-native species, a dramatic increase in the presence of native species, and a reduction in the overall density of nuisance species (including non-natives), leading to an improvement in aquatic habitat. Controlling both cyanobacteria blooms and invasive plant species in 2006-2010 improved aquatic habitat, increased plant community diversity, reduced release of phosphorus that stimulated excess phytoplankton production, and improved conditions for recreational use.

Aquatic plant management activities restarted in 2018 with fall shallow littoral zone treatments targeting invasive, non-native white lily, Brazilian elodea, Eurasian watermilfoil, and pondweed, *P. praelongus*. In April 2019, initial carryover effectiveness of the 2018 treatment was evaluated prior to the alum treatment, and early-season sprouting of the non-native white lily indicated a limited carryover in species reduction. Based on the July 2019 survey, carryover reduction of the white lily was roughly 30%, while treatment of *P. praelongus* was more effective, with a carryover reduction of 60-70%.

Aquatic herbicides were applied in May, June and July of 2020. The treatments originally planned for 2019 were delayed until spring 2020 in order to address the change in plant community and density observed in 2019 and to avoid untimely release of phosphorus that could have fueled a HAB event in the late summer of 2019. In the spring of 2020, targeted treatment areas included the extensive native pondweed coverage in the littoral areas along the east and west banks. In total, 16.6 acres of the littoral zone were treated with the aquatic herbicide fluridone, targeting Eurasian watermilfoil, Brazilian elodea, and pondweeds. High density areas of native pondweed were targeted for treatment with the knowledge that over time bringing these species back into a balanced littoral habitat may be easier than controlling non-native species, such as the white lily.

Based on the fall 2020 and spring 2021 plant surveys and continued observations of expanding coverage of the white lilies (fragrant waterlily), the treatment areas for 2021 were identified along the western shoreline and in the southern end of the lake (**Figure 4**). In early August 2021 the aquatic herbicides endothall and diquat were applied to 10.3 acres each targeting dense growths of *P. praelongus* and Brazilian elodea. This was followed up in mid and late August with two applications of fluridone pellets to the same 10.3 acres also targeting pondweeds and Brazilian elodea. The dense and expanding areas of fragrant waterlily was targeted with an application of Imazamox and an adjuvant to 13 acres in late September and to a smaller area (4 acres) in early October. Note that Imazamox will also control invasive, Brazilian elodea, Eurasian watermilfoil, and pondweed (*P. praelongus*) that are within the targeted fragrant waterlily area**.**

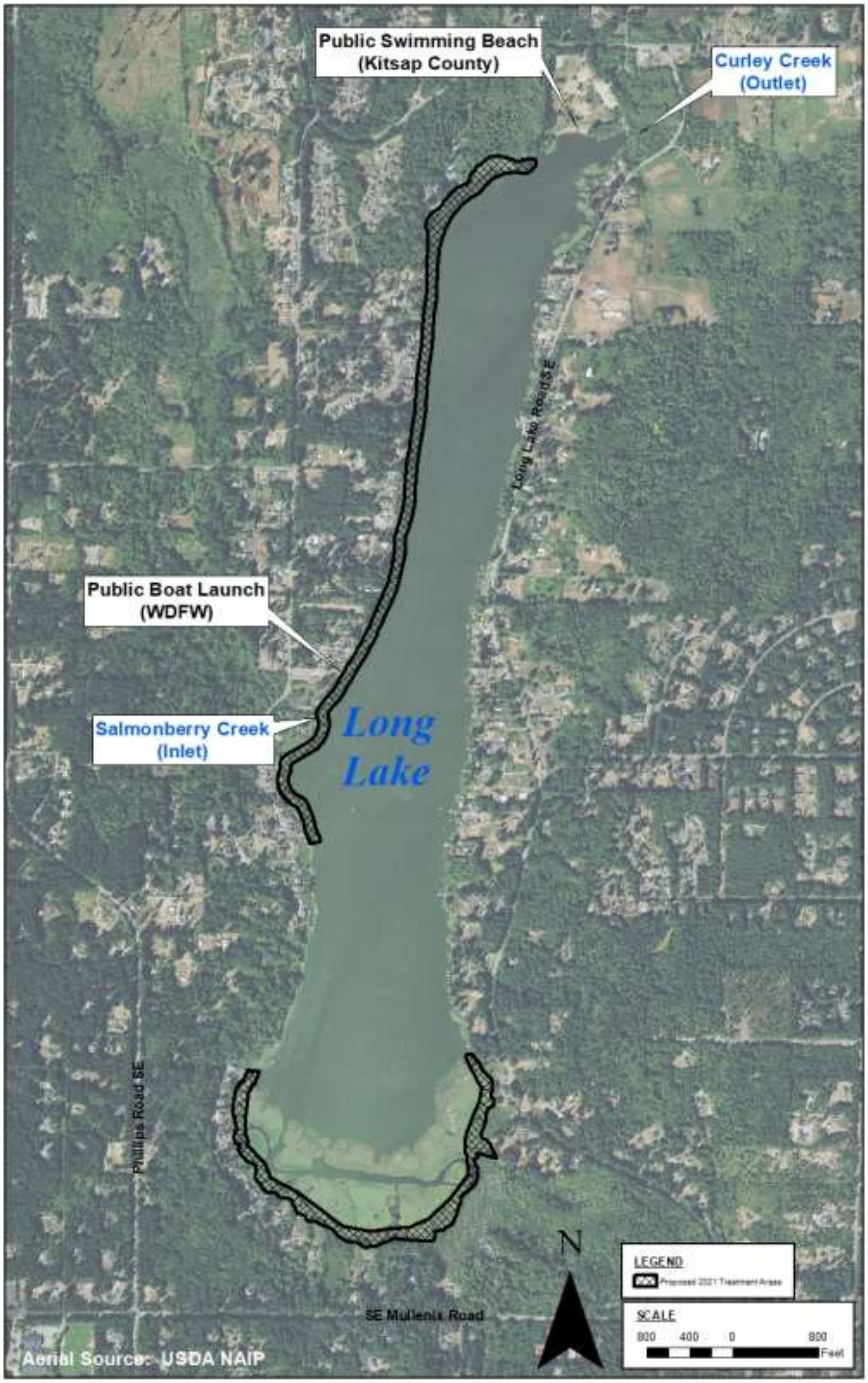
Public Swimming Beach
(Kitsap County)
Curley Creek
(Outlet)
Long Lake Road SE
Public Boat Launch
(WDFW)
Salmonberry Creek
(Inlet)
Long
Lake
Phillips Road SE
SE Mullenix Road
N
LEGEND
Proposed 2021 Treatment Areas
SCALE
800 400 0 800
Feet
Aerial Source: USDA NAIP

Figure 4 All herbicide applications were covered under an Aquatic Plant and Algae Management General Permit issued by the Washington Department of Ecology to Kitsap County on September 12th, 2018 (permit number WAG994398). The herbicide was applied by a licensed applicator, Kyle Langan of AquaTechnex.

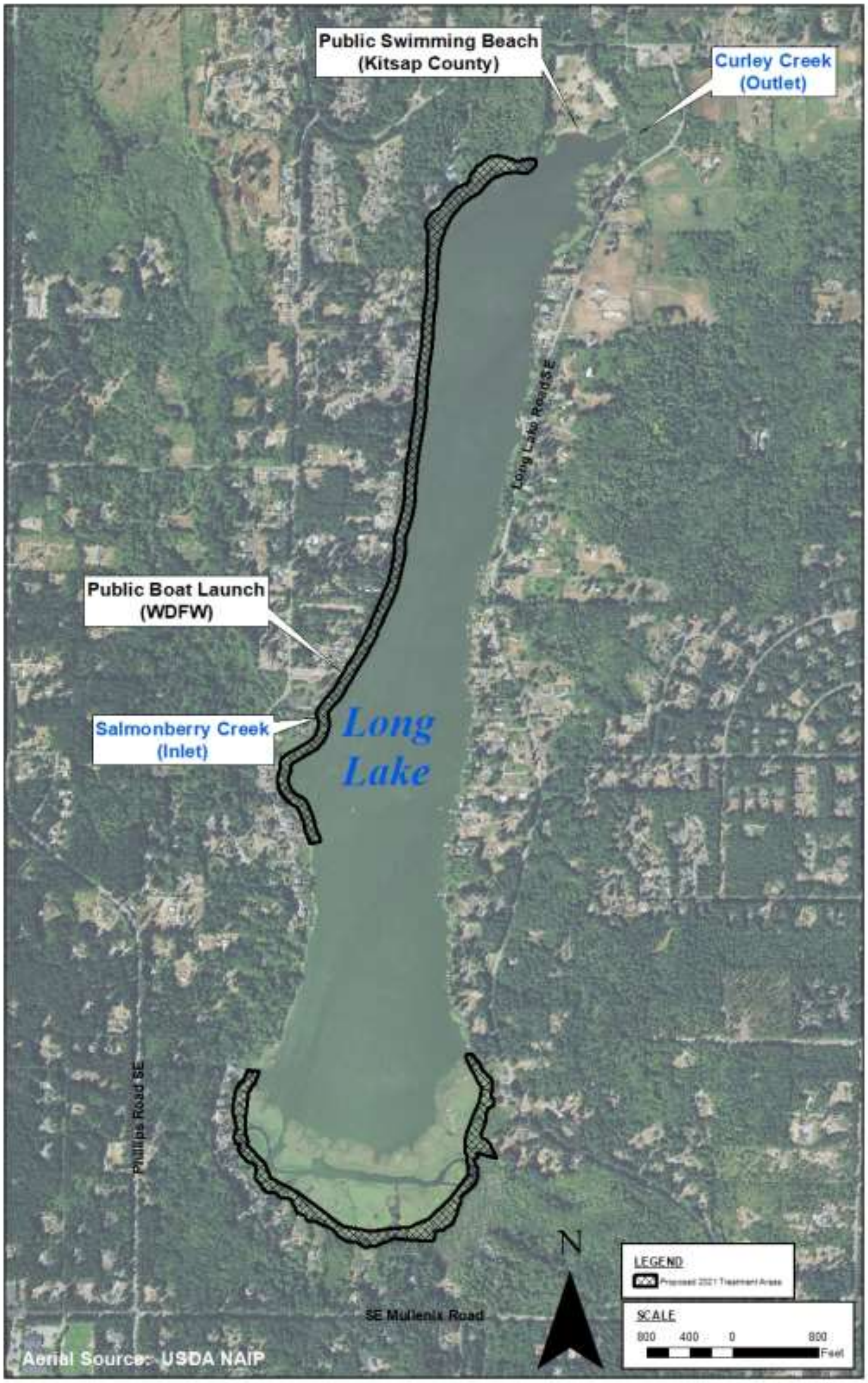

Figure 4: Areas treated in 2021 aquatic plant treatment

3.0 Monitoring Results

3.1.1 Water Level

A data logger that records water level in Long Lake was installed in June 2018 on a homeowner's private dock and has been maintained through 2021. The logger records lake level continuously at hourly intervals. Logger data from January 2021 through December 2021 (**Figure 5)** shows that there is some correlation with precipitation records, indicating that the level in Long Lake is, at times, responsive to local rainfall, as well as dependent on recharge from groundwater or upstream storage. A large precipitation event in the middle of January 2021 appears to have caused an increase in lake level of almost 2 ft (**Figure 5**). An increase in lake level, but smaller in magnitude, was also observed in the middle of June following a large precipitation event that occurred on June 13th, 2021 (**Figure 5**).

Efforts to install a data logger in Salmonberry Creek, the main inlet to Long Lake, were unsuccessful. Kitsap County does not maintain a gage on the creek, and loggers that were previously installed on Salmonberry Creek have been subject to vandalization and theft. In 2019 and again in 2021, citizens along the creek were contacted for potential access to a protected location near the mouth of Salmonberry Creek. However, access to private property for installation and maintenance was not granted and other options will need to be explored in the future.

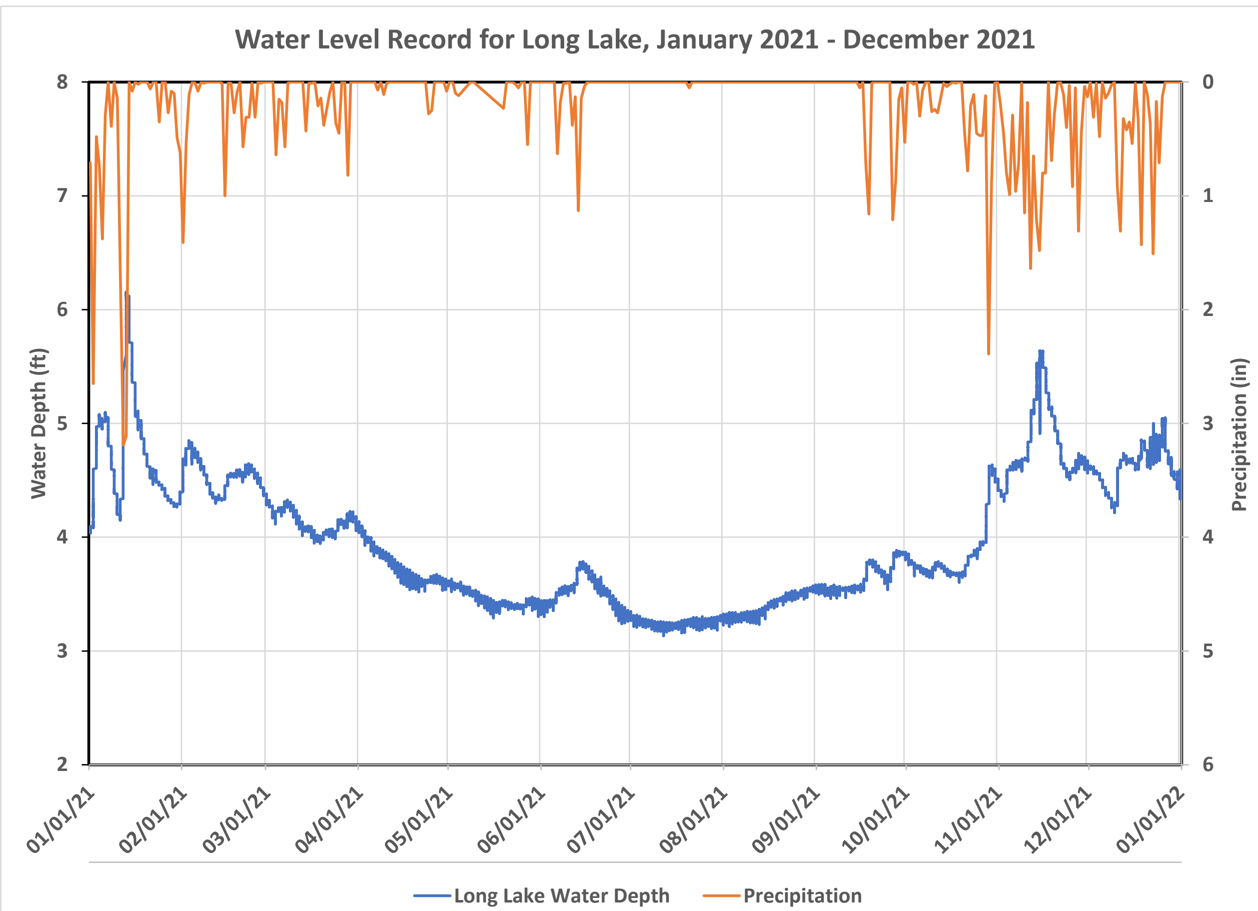

Figure 5: Water level and precipitation records, 2021.

3.1.2 Total and Soluble Phosphorus

Concentrations of TP at the mid-lake station averaged 38 µg/L at 0.5 and 2.5 m depth and ranged from 16 to 51 µg/L during 2021 (**Table 1, Figure 6**). Maximum recorded TP (51 µg/L) was observed in September at 2.5 m, and higher concentrations of TP generally corresponded with higher chl concentrations in the lake.

Surface concentrations of TP observed in 2021 were slightly lower than those observed in 2020 (average of 37.3 µg/L and range of 25 – 62 µg/L) and similar to surface concentrations in 2018 and 2019 that ranged from 18-34 µg/L. There is a consistent trend of lower TP concentrations observed in the spring and fall. In 2018, 2019, and 2021 the mid-lake TP concentrations were generally higher near the lake bottom however in 2020 higher surface concentrations of TP were observed during both July and September.

The concentration of TP at the inflow, Salmonberry Creek, averaged 29.7 µg/L in 2021, lower than in 2020 which had an average TP concentration of 45 µg/L. The highest TP concentrations in Salmonberry Creek occurred in spring and early summer and was higher than at the mid-lake station in early July. TP concentrations in Salmonberry Creek were lower than concentration at the mid-lake station in August, September, and October. In 2021, Salmonberry Creek had about average concentrations of TP when compared to recent years (average around 30 µg/L).

Soluble Reactive Phosphorus (SRP) concentrations were low for all observations, with an average concentration of 2.3 µg/L (**Table 1**). Low concentrations of SRP in the summer months are consistent with higher chl concentrations, indicating phytoplankton activity in the water column that results in low concentrations of SRP while TP concentrations are high. Soluble reactive phosphorus concentrations in 2021 were generally consistent with low concentrations observed in recent years.

Table 1. TP and SRP concentrations in Long Lake and Salmonberry Creek in 2021

Date	Station	Depth (m)	TP (µg/L)	SRP (µg/L)
4/28/2021	Mid-Lake	0.5	40	4.0
		2.5	29	3.0
	Salmonberry Creek	--	30	--
5/21/2021	Mid-Lake	0.5	16	3.0
		2.5	41	3.0
	Salmonberry Creek	--	30	--
7/1/2021	Mid-Lake	0.5	32	3.0
		2.5	40	2.0
	Salmonberry Creek	--	44	--
7/26/2021	Mid-Lake	0.5	40	2.0
		2.5	40	2.0
	Salmonberry Creek	--	No sample	--
8/20/2021	Mid-Lake	0.5	37	< 1.0
		2.5	43	< 1.0
	Salmonberry Creek	--	25	--
9/14/2021	Mid-Lake	0.5	48	2.0
		2.5	51	2.0
	Salmonberry Creek	--	26	--
10/12/2021	Mid-Lake	0.5	40	2.0
		2.5	32	2.0
	Salmonberry Creek	--	23	--

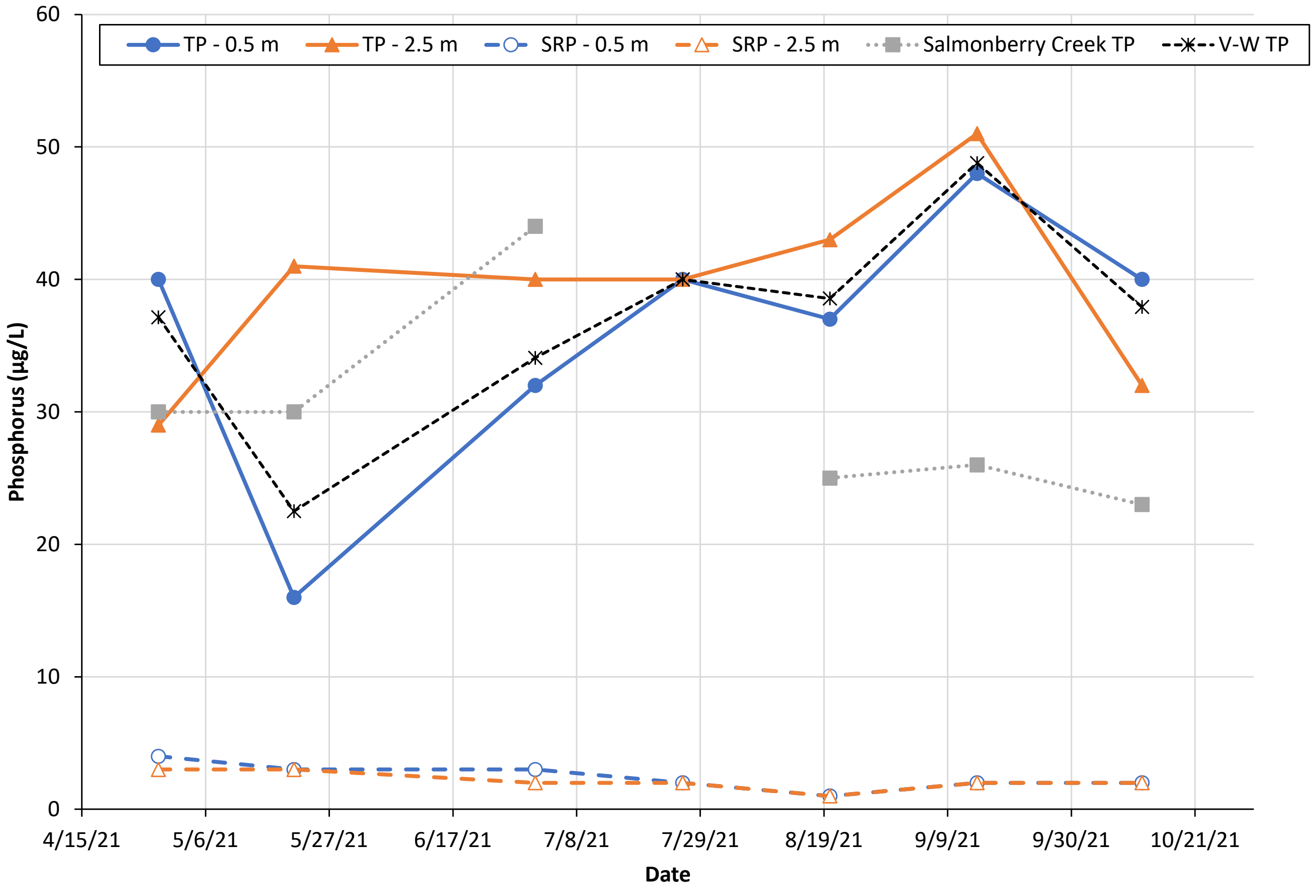

Figure 6. Phosphorus concentrations in Long Lake and Salmonberry Creek in 2021.

3.1.3 Chlorophyll-*a*

Surface concentrations of chl at the mid-lake station averaged 23.5 µg/L and ranged from 4.5 to 42 µg/L during 2021 observations (**Table 2, Figure 7**). At a depth of 2.5 m, the average mid-lake chl concentration was 21.9 µg/L, slightly lower than at the surface. Maximum recorded chl (42 and 43 µg/L) was observed in August and September, and higher concentrations of chl generally corresponded with higher TP concentrations in the lake. Average chl concentrations observed in 2021 were somewhat higher than observations in 2020 when surface concentrations averaged around 19 µg/L. Average chl concentrations in 2020 and 2021 were higher than those in 2018 and 2019, when surface concentrations averaged only around 12 µg/L.

There were no observed algae blooms in 2019 following the alum treatment however several blooms were observed in 2020. There were no large blooms or scum accumulations reported in 2021 and no samples for cyanotoxins were collected in 2021. However, both the TP and chl concentrations have returned to eutrophic levels in the lake. Like the rooted aquatic plants, the phytoplankton production in the lake has returned to high levels of organic production, which could lead to HAB events in the future; unless management actions are taken inactivate the phosphorus in the lake water and sediment to reduce the generation of phytoplankton and specifically cyanobacteria. The target for long-term beneficial use preservation of the lake is to reduce the average TP concentration to 18 µg/L, which will result in average chl concentrations of 6 to 8 µg/L. At those concentrations the lake will not have significant HAB events.

Table 2. Chlorophyll concentrations in Long Lake in 2021

Date	Station	Depth (m)	CHL-a (µg/L)
4/28/2021	Mid-Lake	0.5	25
		2.5	8.3
5/21/2021	Mid-Lake	0.5	4.5
		2.5	7.1
7/1/2021	Mid-Lake	0.5	26
		2.5	19
7/26/2021	Mid-Lake	0.5	12
		2.5	12
8/20/2021	Mid-Lake	0.5	42
		2.5	43
9/14/2021	Mid-Lake	0.5	40
		2.5	42
10/12/2021	Mid-Lake	0.5	15
		2.5	No sample

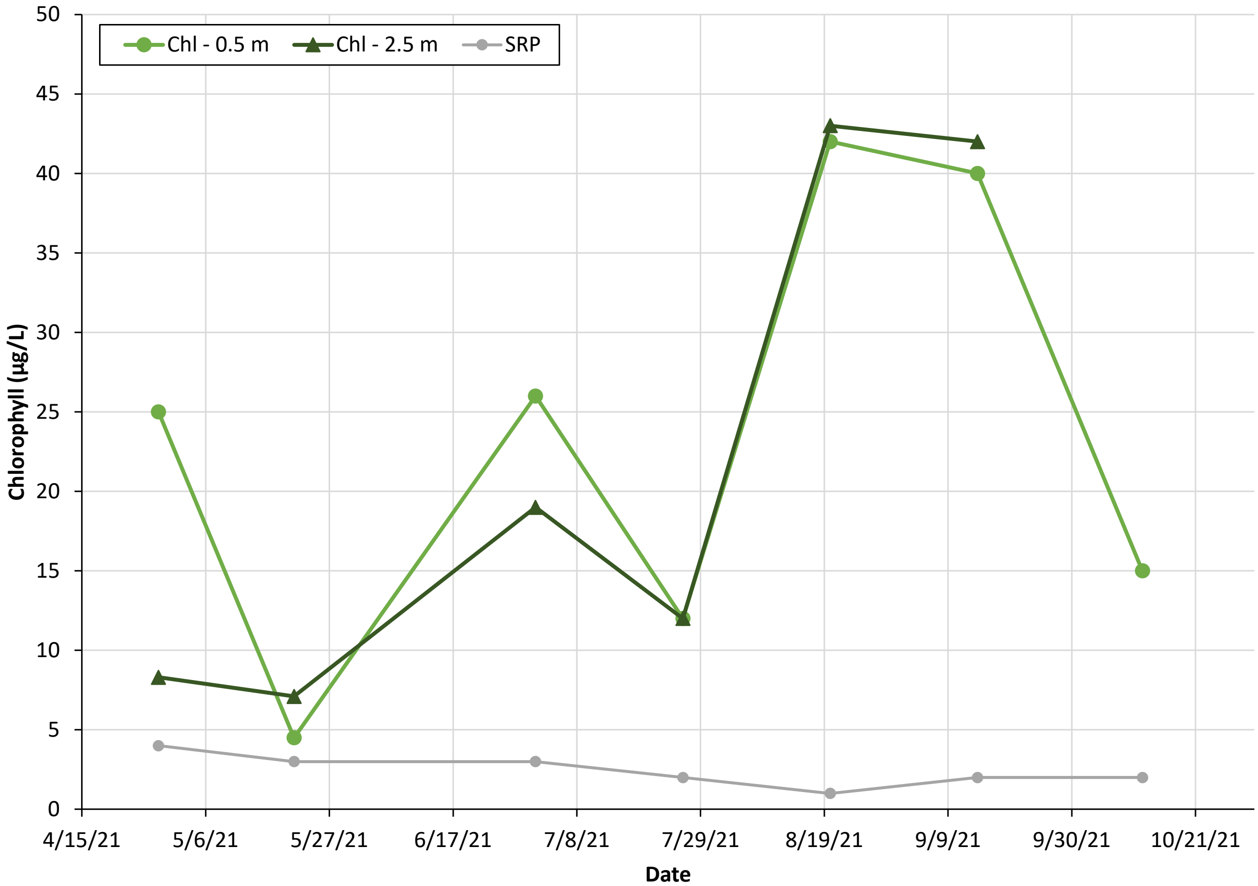

Figure 7. Chlorophyll and SRP concentrations in Long Lake in 2021.

3.1.4 Water Clarity

Water clarity, or transparency, as measured with a secchi disk, ranged from 0.8 to 1.8 m at the mid-lake and north lake stations, and 0.8 to 1.7 m at the south station (**Figure 8**). In the summer, water clarity was generally consistent across all stations, although there were no measurements collected in August. Spring and fall measurements of water clarity varied slightly between dates and sites. The minimum secchi disk depth (0.8 m) was observed at all lake stations in September and maximum secchi disk depths were observed in May at all stations. The higher level of water clarity in May corresponds with lower observed chl concentrations. Water clarity was significantly lower in 2020 and 2021 when compared to the high clarity in 2019 due to the low-dose alum treatment and corresponding reduction in algal production. In 2021, water clarity was similar but slightly lower than in 2020, which had an average water clarity of 1.4 m. Water clarity in both 2020 and 2021 was lower than in 2018, which had clarity over 2 meters in June before dropping to around 1.6 meters in July and less than 1 meter throughout August. In 2021, as in other years, lower clarity was an indication of increased algae production.

Secchi disk transparency represents light availability in the water column, which translates into potential photosynthesis by algae and rooted aquatic plants. For example, the potential photosynthetic depth (photic zone) is approximately 3 times the measured transparency depth. Hence, rooted plants and periphyton (attached algae) are in direct competition for light and nutrients with the phytoplankton which is good when overall nutrient levels are lower.

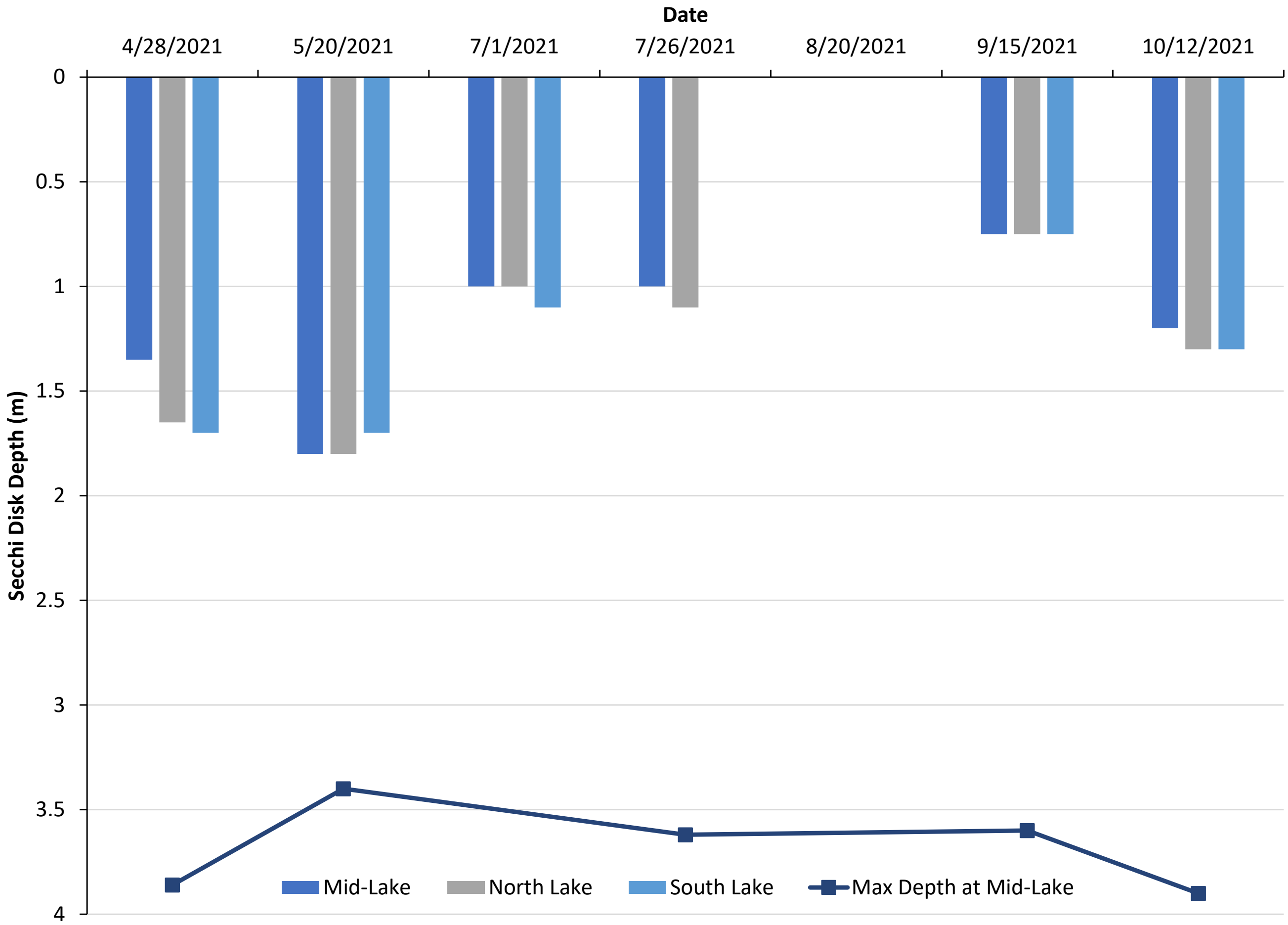

Figure 8. Secchi disk depth (water transparency) in Long Lake during 2021

3.1.5 Water Temperature, Dissolved Oxygen, Conductivity, and pH

Profiles of water temperature, dissolved oxygen (DO), conductivity, and pH were measured at 0.5-meter intervals at each station in 2021. At the north and south stations, profiles to the lake bottom ranged from 2 to 2.5 meters deep. At the mid-lake station, profiles extended 3 to 3.5 meters deep. The profiles are generally representative of 2021 conditions on Long Lake, showing seasonal and depth-related trends. Field measurements of water temperature, DO, conductivity and pH were not recorded during the August 20, 2021 sampling event.

Water Temperature

Water temperature profiles are shown in **Figure 9**. Temperatures ranged from 12.9°C to 25.8°C at all stations. The highest temperatures were observed in July while the lowest temperatures were observed in October. The average temperature in 2021 was 19.1°C. For most observations in 2021, temperature did not vary significantly throughout the water column, as Long Lake is a shallow lake that mixes frequently throughout the year. Weak stratification was observed in the summer months (**Figure 9**), which is consistent with prior observations of mid-late summer stratification. Stratification was stronger at the shallower stations at the north and south ends. At the mid-lake station there was slightly stronger stratification near the surface at the beginning of July which corresponded to much warmer air temperatures than normal during that time. Water temperatures in 2021 were similar at all 3 stations, with average values differing by at most 0.8°C. The largest variation in water temperature between stations was during July and September.

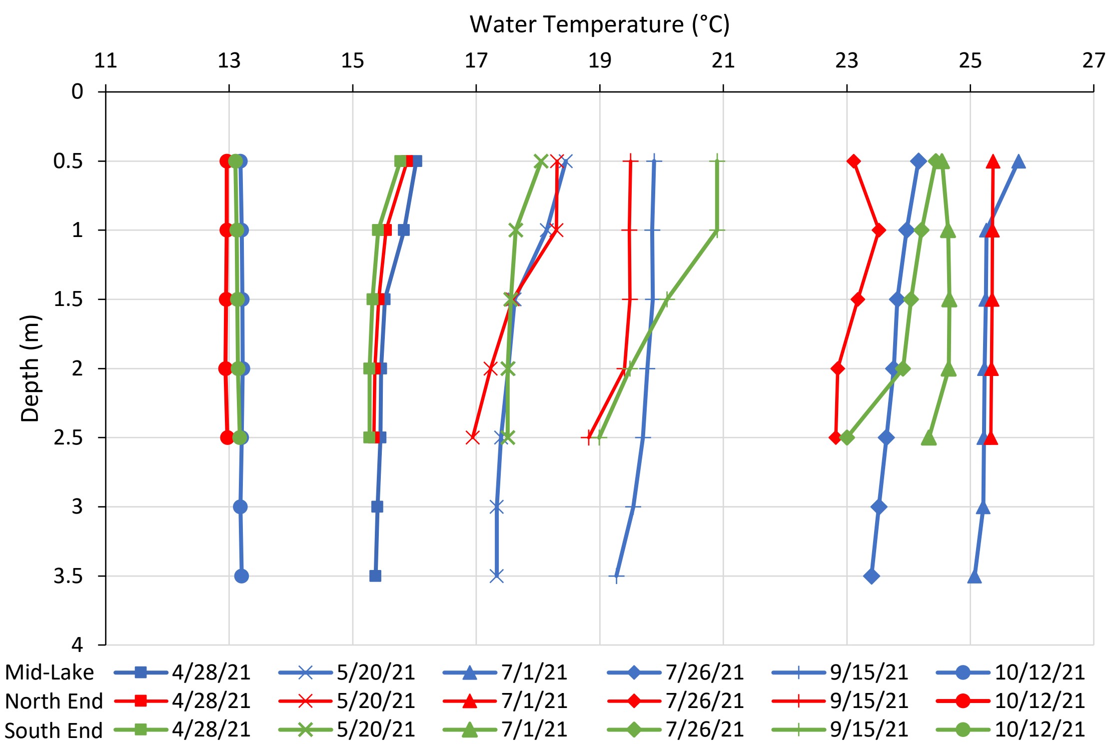

Figure 9. Water temperatures in Long Lake, 2021

Dissolved Oxygen

Dissolved oxygen (DO) concentrations ranged from 0.02 to 10.8 mg/L across all stations (**Figure 10**). Minimum DO occurred near the bottom at all stations and was lowest at the north and south lake stations during the summer months, when the water column was weakly stratified. At the bottom of each profile, DO concentrations can be especially low due to potential interactions with bottom sediment. This is due to the organic degradation that consumes DO. This low DO concentration combined with the low sediment pH enables the release of phosphorus from the bottom sediments that fertilizes phytoplankton. The maximum DO concentrations recorded in 2021 occurred in May and September. In May at the south lake station DO was highest at the bottom and at the north lake station DO was highest in the middle of the water column around 1.5 m. In September, DO was highest near the surface, where there was greater photosynthetic activity and high chl concentrations.

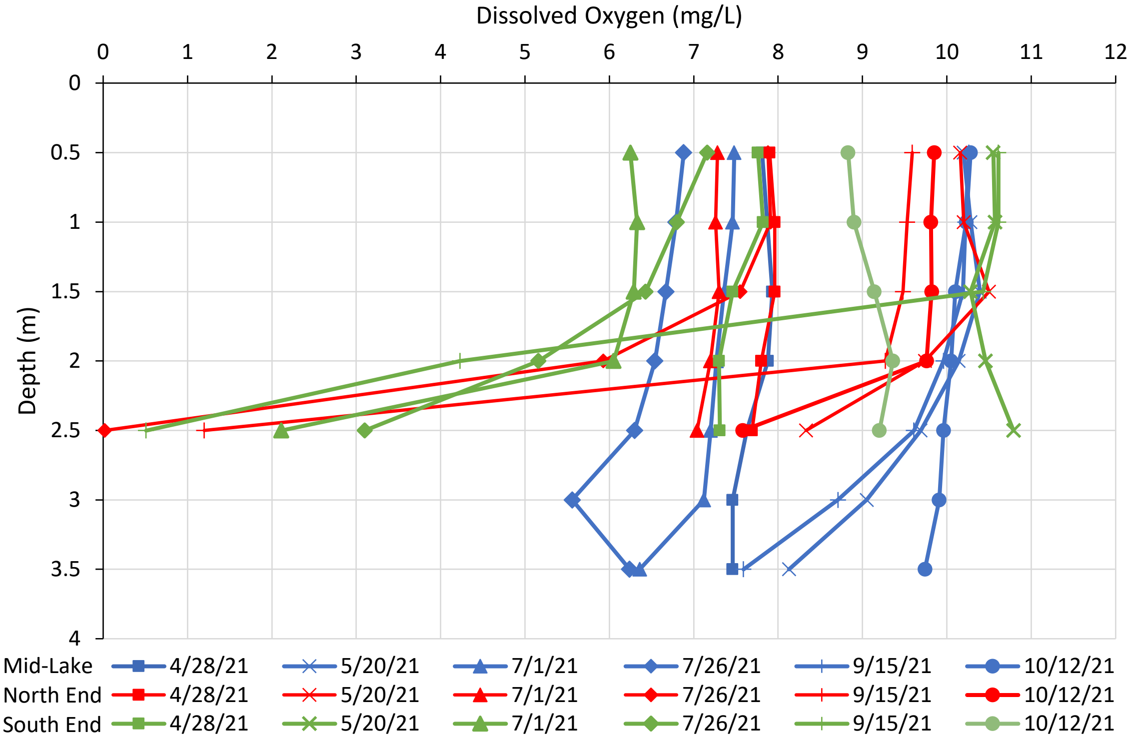

Figure 10. Dissolved oxygen in Long Lake, 2021

pH

pH varied throughout the water column and ranged from 4.6 to 8.7 at all stations for 2021 monitoring dates (**Figure 11**). The low and high pH values measured in October could be the result of equipment malfunction although instrument calibration records indicate that the sonde was calibrated correctly. Observed pH in 2021 was slightly lower than in 2021 when pH ranged from 6.6-8.9. The highest pH values, outside of October, were observed in April and July.

Water column pH typically followed a pattern of higher values near the surface due to photosynthetic activity, and lower values measured near the bottom due to respiration with light limited photosynthesis. The pH was most likely influenced by photosynthesis both from phytoplankton in the water column as well as aquatic plants.

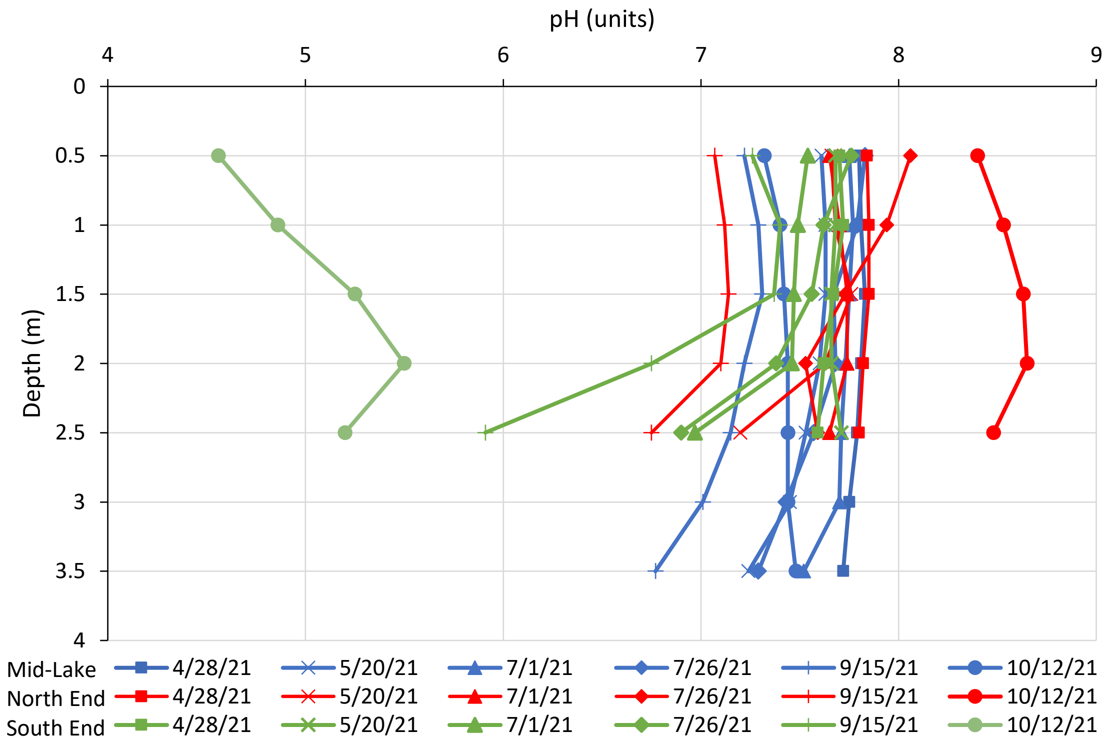

Figure 11. pH in Long Lake, 2021

Conductivity

Conductivity varied over the course of the monitoring period (**Figure 12**). Conductivity ranged from maximums around 137 µS/cm in October to a minimum of just under 100 µS/cm in April. Conductivity was generally uniform throughout the water column, varying only at the bottom of the profile, especially at the north end station, likely due to interaction with lake-bottom sediments. This interaction most likely caused the spikes at the bottom of the profiles in May and September. Variation in conductivity is directly correlated with phosphorus cycling at the lake bottom and in the water column. Seasonal variation in conductivity, DO, and pH is based on the processes of photosynthesis taking place in the water column and respiration near the lake bottom. In the late summer, an increase in conductivity is observed due to vertical mixing and plant senescence.

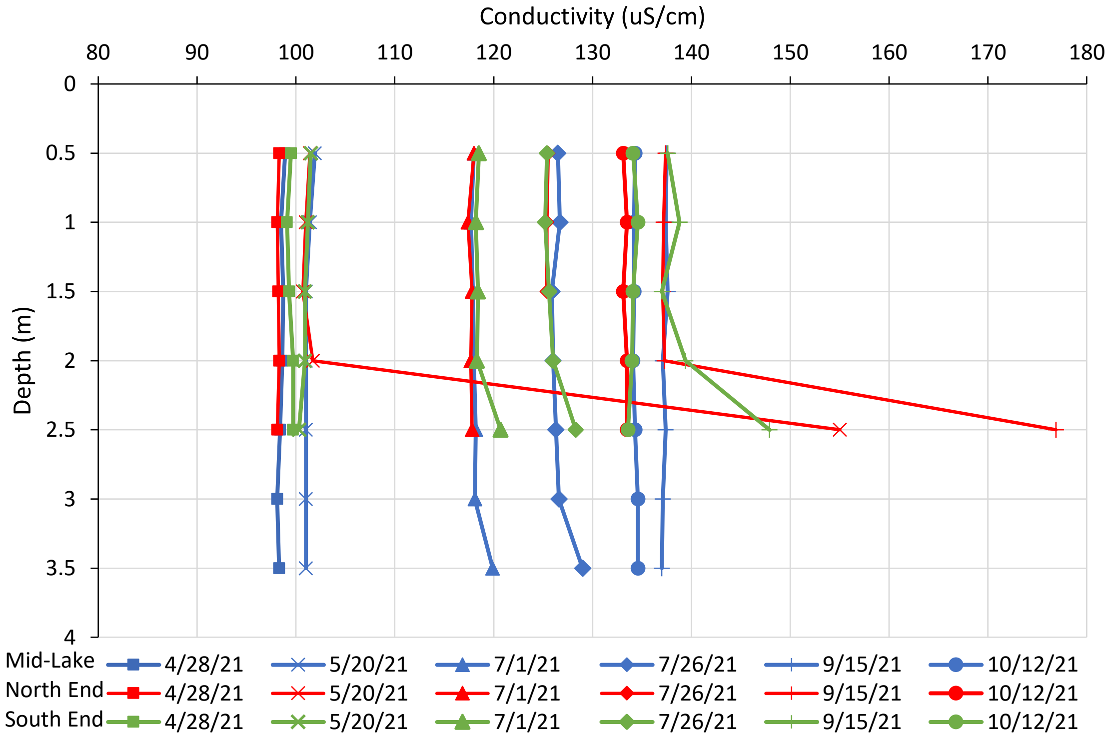

Figure 12. Conductivity in Long Lake, 2021

4.0 Water Quality Summary Discussion

This was an interesting year for lake water quality in Long Lake. The continued expansion of aquatic plants was prominent in 2021, creating health and safety concerns for lake residents and users as well as imbalanced ecosystem conditions. Algal growth, forming algal scums, was not as abundant in 2021 as it has been in previous years. This may have been in part due to the weather conditions allowing prolific growth of rooted plants which are in direct competition with phytoplankton. In-situ monitoring was conducted monthly from April through October, with water samples collected for laboratory analysis by mostly citizen volunteers with occasional assistance by Tetra Tech staff. Below is a summary of noteworthy findings from the 2021 monitoring season.

- Water level in Long Lake does appear to respond to precipitation.
  - At times there is an apparent correlation between logger data and rainfall, especially with larger storm events.
- The effects of the 2019 alum treatment were not significantly persistent in 2021 most likely due to the low dose imposed upon the treatment due to budget limitations.
  - Water clarity in 2021 returned to pre-treatment levels and summer average transparency was below 1.0 m.
  - Summer average chl concentrations were much higher in 2021 than in 2018-2020.
  - However, Long Lake did not experience a toxic bloom in 2021 as it did in 2020. Toxic algae blooms have been reoccurring each year for the last six years except for in 2019 (the year alum was applied) and 2021.
- Aquatic plant treatments in 2021 targeted approximately 17 acres of the littoral zone areas along the west, northwest and south shorelines. These areas were treated with the aquatic herbicides endothall, diquat, and fluridone, targeting Brazilian elodea, and pondweeds. Applications of Imazamox were completed in the fall of 2021 targeting fragrant waterlily in the southern end of the lake. Aquatic plant surveys in the fall of 2021 indicated that the treatments were successful in limiting pondweed growth in targeted areas, specifically the west and northwest shorelines. However, the emergent and submersed plants in the southern and northern end of the lake continued to increase in density and area. Fragrant waterlily (*Nymphaea odorata*) has continued expansion in these areas in both coverage and density.
- Floating islands made by root mass of mainly invasive aquatic plants (lilies) have formed at the southern end of the lake, and in 2020 one of these masses became a free-floating island that was a hazard to lake residents and property and directly impacted aquatic habitat. In 2021, these floating islands did not occur in as large of magnitude or were as impactful to residents and property as in 2020. However, this will continue to be an ongoing problem in the future as the southern end of the lake continues to evolve towards becoming an extended wetland versus lake littoral area, unless direct management actions are taken to eliminate or significantly reduce the white lily (*Nymphaea odorata*) and reduce the coverage and expansion of native yellow lilies. The excessive growth of plants in the southern end of the lake are causing portions of the lake to fill in and rapidly transform from an emergent plant littoral area to a terrestrial wetland environment.
- Compared to observations from 2006-2010 and 2018-2020, averages of temperature, pH, DO, and conductivity in 2021 are consistent with the historical data.
- There was further decline in water quality in 2021 compared to 2020 and to historical averages.
  - A historical record of water quality indicators and alum treatments in Long Lake is shown in **Figure 13**.

- Compared to data from 2007-2010 and 2018-2019, average concentrations of TP and chl were much higher and transparency was lower in 2021. Average chl and transparency in 2021 was even lower than in 2020. Note that in 2018 a wet winter with increased flushing resulted in lower concentrations of TP and chl and higher transparency, while the 2019 improvements are due to the low-dose alum treatment.
- The lake will need on-going phosphorus inactivation to reduce algal production and prevent HAB events, and aggressive management of emergent plants (white lilies) to maintain the beneficial uses of the lake for citizens and aquatic life.

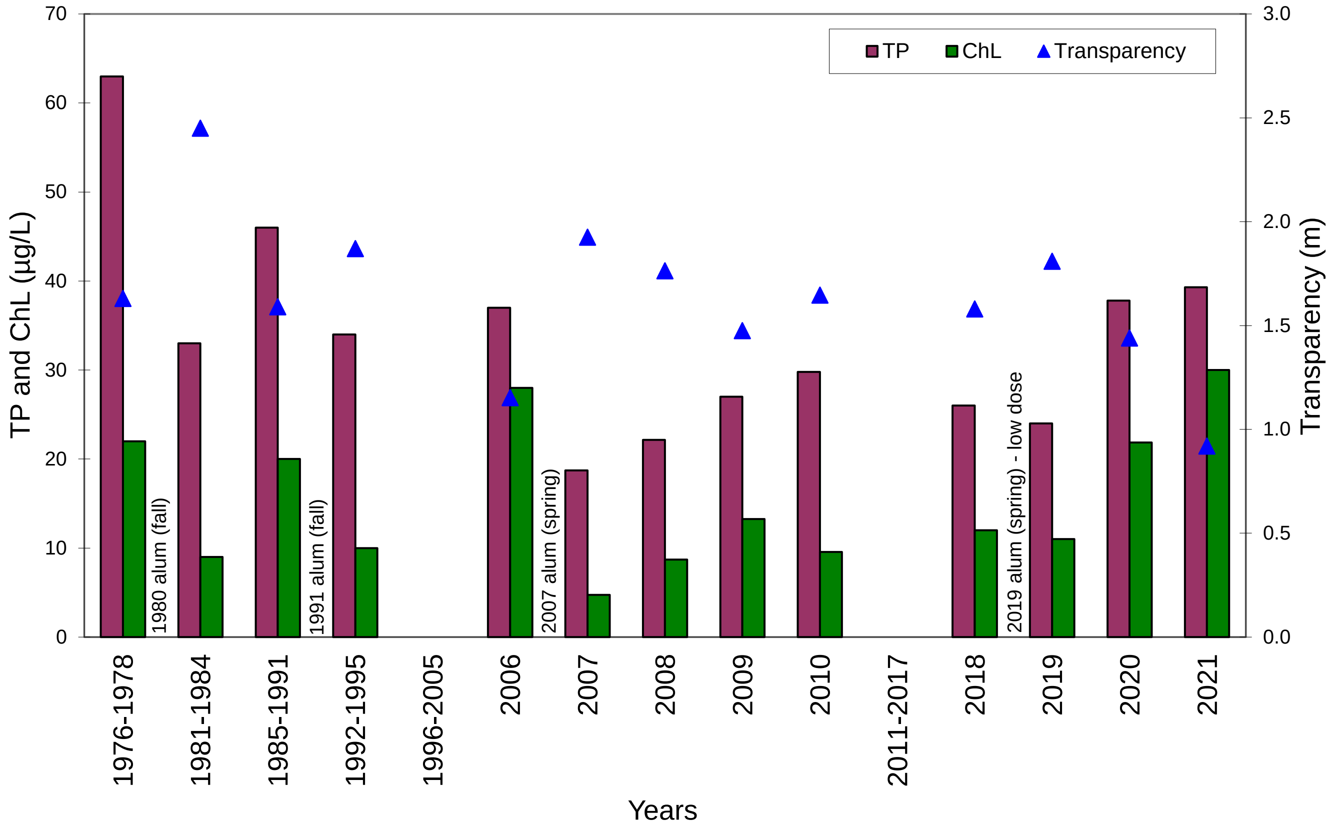

Figure 13. Historical water quality averages

5.0 Recommendations for Future Work

Based on the overall positive results of the aquatic plant adaptive management plan developed in 2006 to maintain a sustainable aquatic habitat that also helps to limit HAB events, a portion of the lake's littoral area (5 to 25%) should continue to be managed on a rotational 4-year adaptive program to ensure the re-establishment of native plant communities for aquatic ecosystem recovery, while maximizing the direct beneficial uses of the lake.

However, the increase in lily expansion and coverage, in both the north end and, specifically, the south end of the lake has reached a point where direct and aggressive management actions are needed to address the sustainability of the lake. The growth and expansion of fragrant (white) waterlily (*Nymphaea odorata*) has accelerated the filling in of the littoral area in the southern end of the lake. This portion of the lake is rapidly transforming from an emergent plant littoral area to a terrestrial wetland environment

Aquatic plant treatments were successfully implemented in 2020 following postponement of the 2019 treatments in order to address the change in plant community and density observed following the 2019 alum treatment. Note, there was a fall treatment targeting white lilies in 2018. Treatments in 2021 consisted of applications of endothall, diquat, and slow-release fluridone targeting the dense submersed plant community along the northwest and west shorelines. There were also multiple treatments of imazamox, targeting the white lilies in the southern portion of the lake in the fall of 2021. The result of the 2021 treatments was a significant reduction in aquatic submersed plant production that should carry over to 2022 as well, allowing other areas and plants to be targeted in 2022. Treatments in 2022 should occur such that they do not directly enhance the cycling of phosphorus to cause a spike in phosphorus availability leading to an algal bloom. The use of a slow herbicide release, as was done in 2021 with fluridone, would not result in an immediate die-off and decay of existing plants, but a reduction in plant production and targeted plant biomass over time. In 2022, the east shoreline of the lake should be treated with slow-release fluridone with a pre-treatment of a contact herbicide to stress the plants prior to the systemic fluridone application. The northeast and southern lily beds should be treated with Imazamox.

While there was a successful decrease in submersed plant production in 2021 in the northwest and west shorelines, the southern end of the lake continues to dramatically evolve from a mixed emergent/submergent plant littoral community to a plant community that is dominated by emergent plants like white lilies that have transformed the area into a developing wetland, essentially filling in the lake. There are currently several portions in the southern end of the lake where terrestrial wetland plants are forming islands. To enhance the adaptive aquatic plant management program of Long Lake, Kitsap County has obtained a grant to update the integrated aquatic vegetation management plan (IAVMP). Treatment strategies in the updated IAVMP will be expanded to include specific alternatives for restoring the southern end of the lake. These could potentially include shallow sediment removal and/or bottom barrier planning and installation, the latter involving burlap barrier purchase and training of citizens on how to install barriers near their shorelines. Shallow sediment removal and bottom barrier installation would result in increased lake habitat diversity and open water for recreation. It would also over time reduce the amount of herbicide treatment required to manage the littoral lake area, as well as reduce the potential for nutrient recycling leading to HAB events. After completion of an updated IAVMP, implementation of the plan will require additional funding through future grants or other sources.

The most recent phosphorus inactivation and water column stripping alum treatment was implemented in late April of 2019. This helped limit the potential for an algal bloom and improve overall lake water quality. However, due to cost increases in materials to perform this action the dose was 3.5 times less than the successful 2007 alum treatment. To continue to limit HAB events, additional alum treatments to limit phosphorus will be needed in the near future. Additional funding through future grants and a renewed LLMD will be required to implement future phosphorus inactivation treatments that would include exploring treatment on periodic low dose strategies as well as potential high dose options in a cost-effective way to maintain the beneficial uses of the lake.

6.0 Revisions to the Adaptive Plan

Currently, the data has started to indicate that revisions to the adaptive plan may be necessary within the next couple of years. The data continues to indicate the strong need for enhancements to the management program through grant funding and future LLMD funding, which will be required to maintain the beneficial uses of the lake and protect downstream aquatic resources. Unfortunately, the cost of providing an effective phosphorus inactivation program has increased significantly, beyond the estimates and costs determined in 2016, and now requires a more aggressive funding program. However, even with the increase in phosphorus inactivation management strategies, the current costs are still 300 to 500 times less than that of other restoration alternatives such as dredging. Although dredging as a management alternative can be costly, a small partial shoreline sediment removal may have to be evaluated for portions of the southern end of the lake to achieve the lake's management goals. Aggressive bottom barrier installation would also need to be considered as a management strategy to help control the excessive expansion of emergent aquatic plants. The development of an updated IAVMP will provide further details and the recommended management strategy for aquatic plants which can be used to revise the lake's adaptive management plan.

Long Lake is a resource that is in need of immediate and long-term management to preserve its beneficial use for aquatic habitat, fishery, water quality, and aesthetics and recreation: plus, community property values.

7.0 References

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