DRAFT
BLACK LAKE
ALUM TREATMENT PLAN

Prepared for
Black Lake Special District

Prepared by
Herrera Environmental Consultants, Inc.

Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will copy correctly when duplexed.

BLACK LAKE
ALUM TREATMENT PLAN

Prepared for
Black Lake Special District
120 State Avenue Northeast, No. 303
Olympia, Washington 98501

Prepared by
Herrera Environmental Consultants, Inc.
2200 Sixth Avenue, Suite 1100
Seattle, Washington 98121
Telephone: 206-441-9080

January 22, 2016 DRAFT

CONTENTS

Executive Summary iii

1. Introduction 1

2. Project Background 3

   2.1. Lake Watershed 3
   2.2. Lake Water Quality 5
      2.2.1. Trophic State Parameters 7
      2.2.2. Cyanotoxins 8
      2.2.3. Fisheries 8
      2.2.4. Recreational and Beneficial Uses 8
   2.3. Sediment Phosphorus 10

3. Alum Dose 13

   3.1. Original Dose 13
   3.2. Revised Dose 13
   3.3. Comparison to Other Lakes 18

4. Alum Treatment 21

   4.1. Chemical Materials 21
   4.2. Preparation 21
   4.3. Equipment Staging and Chemical Storage 22
   4.4. Chemical Application 22
   4.5. Permit Requirements 24
      4.5.1. Permit Restrictions 25
      4.5.2. Ecology Notification 26
      4.5.3. Public Notification and Sign Posting 26

5. Treatment Oversight and Monitoring 29

   5.1. Treatment Oversight 29
   5.2. Water Quality Objectives 29
   5.3. Water Quality Monitoring 30
      5.3.1. Jar Test 30
      5.3.2. Treatment Monitoring 31
      5.3.3. Post-Treatment Monitoring 32
   5.4. Reporting 33

6. References 35

APPENDICES

Appendix A Water Quality Monitoring Plan

TABLES

Table 2 1. Black Lake Physical Features. 3
Table 2-2. Carlson's Trophic State Indices and Criteria Compared to Black Lake. 7
Table 3-1. Black Lake Sediment Phosphorus Data for Alum Dose Calculation. 16
Table 3-2. Black Lake Alum Treatment Dose and Cost Estimate for Spring 2016 Sediment Phosphorus Inactivation. 17
Table 3-3. Comparison of Alum Treatment Doses in Washington. 18
Table 6-1. Alum Treatment Objectives for Summer Trophic Status in Black Lake. 29

FIGURES

Figure 2-1. Black Lake Location Maps. 4
Figure 2-2. Black Lake Monitoring Locations. 6
Figure 2-3. Trophic State Indices, Black Lake 1992–2014. 9
Figure 2-4. Sediment Phosphorus Concentrations in Black Lake, March 2015. 11
Figure 4-1. Black Lake Alum Treatment and Sign Locations. 23

EXECUTIVE SUMMARY

Black Lake, located in Olympia, Washington, has high nutrient levels that result in cyanobacteria (blue-green algae) blooms. These blooms have occurred in most years since routine lake monitoring began in 1992. Water quality data collected by Thurston County since 1992 shows that Black Lake is eutrophic (high nutrients and algae) due to high phosphorus concentrations. Lake sediments are a primary source of the phosphorus during summer when it is released from iron as anoxic (no oxygen) conditions develop in the bottom waters. The excess phosphorus fuels excess cyanobacteria that float to the surface to form scums and often produce various cyanotoxins (chemicals which are toxic to humans, mammals, and waterfowl).

The Black Lake Special District is committed to improving water quality in Black Lake and funded preparation of the Black Lake Phosphorus and Algae Control Plan (Herrera 2015a) to identify the measures needed to reduce phosphorus inputs to Black Lake, and control the production of cyanobacteria and toxic algal blooms by accomplishing the following objectives:

- Develop a water and phosphorus budget to estimate the amount and sources of phosphorus in the lake
- Analyze the lake bottom sediments to determine the amount of alum (aluminum sulfate used with the buffer sodium aluminate) or Phoslock® (lanthanum treated clay) that would be needed to inactivate sediment phosphorus
- Evaluate alum and Phoslock® treatment methods to control phosphorus sources on a short-term and long-term basis
- Develop a conceptual plan to control phosphorus (and therefore cyanobacteria) using alum

A water budget and phosphorus budget were developed for three study years (2010–2012) using an existing watershed model and lake water quality data. The water budget indicates that the primary sources of water flowing into Black Lake on an annual basis are surface inflows (77 percent) and shallow groundwater (14 percent).

The phosphorus budget focused on the summer monitoring period (May through October) when lake data were available for calculating net internal loading from mass balance equations. On average, 60 percent of the total phosphorus loading during the summer months came from net internal loading, 35 percent came from surface inflows, and 5 percent came from shallow groundwater inflow. Because internal loading is a significant source of phosphorus in Black Lake during the summer algae bloom period, a whole lake alum dose was identified as the most appropriate method to inactivate mobile sediment phosphorus. Phoslock® was excluded from consideration due to high cost and poor longevity.

Three alternative alum treatment scenarios were considered that differ in the timing of the treatment due to uncertainties in funding, permitting, and contractor availability. The Spring

2016 Full Treatment Scenario was selected as the preferred scenario because it was the least cost and allowed more time for proper planning, permitting, and funding.

The purpose of this Black Lake Alum Treatment Plan is to refine the alum dose and cost estimate, provide additional details about the treatment procedures and timing, and present an alum treatment oversight and monitoring plan that meets permit requirements.

The alum dose initially calculated in the previous study was revised in consideration of recent developments in alum treatment technology and other factors. The alum dose was revised based on the following factors:

- The biogenic phosphorus concentration was reduced from 163 to 95 mg/kg to include only the active fraction as an inactivation target because it is most susceptible to mineralization by sediment microbes and release to the water.
- The ratio of aluminum added to aluminum phosphorus formed was reduced from 20 to 10 because active biogenic phosphorus (95 mg/kg) was targeted for inactivation in addition to the immediately reactive mobile phosphorus (30 mg/kg).
- The treatment area was expanded from below a depth of 15 feet (412 acres) to below a depth of 5 feet (509 acres) to include inactivation of shallow sediments that may release phosphorus when oxygen is present in the overlying waters, but absent in the sediments due to microbial activity.

The revised aluminum dose is 1.9 mg Al/L on a volumetric basis and 12.9 g Al/m2 on an areal basis. This dose is approximately 40 percent of the original dose of 4.8 mg Al/L on a volumetric basis and 39 g Al/m2 on an areal basis (Herrera 2015a). Comparison of this dose to results of other alum treated lakes in Washington suggests that the Black Lake alum treatment will last at least 5 years, and may last up to 10 years depending on lake conditions and watershed inputs.

A total of 53,560 gallons of alum and 26,780 gallons of sodium aluminate (buffer) will be applied to Black Lake by an experienced contractor. These amounts are based on the amount of aluminum present in liquid alum (0.22 kg/gallon) and sodium aluminate (0.55 kg/gallon), and a ratio of 2 parts alum to 1 part sodium aluminate (by volume) to prevent a change in the pH of lake waters. Based on a truck capacity of 4,500 gallons, a total of 12 trucks will be required for the alum and 6 trucks for the sodium aluminate. It is expected to take approximately 3 to 4 days to apply these materials.

The treatment will occur between April 11 and April 29, 2016, when the lake waters have sufficiently warmed, and to minimize potential interference with recreational use of the lake and public boat launch. The treatment will be staged at the Washington Department of Wildlife public boat launch. This launch has recently been improved, and has sufficient space for truck access, two chemical storage tanks, and public use during the treatment.

The contractor will apply the alum and sodium aluminate evenly over the treatment area by injecting the two chemicals simultaneously below the water surface from a boom distribution system on a boat or barge. Herrera will provide an engineer to oversee the treatment and will monitor water quality to ensure proper application and prevention of impacts to fish from changes in the pH of lake waters.

The alum treatment will be conducted in accordance with Ecology's Aquatic Plant and Algae Management General Permit. This permit includes treatment restrictions, monitoring requirements, and public notification requirements. There are no recreational use restrictions for alum treatments. A detailed water quality monitoring plan is included in this treatment plan that describes procedures for short-term and long-term effects monitoring in addition to the permit-required monitoring of pH during the treatment.

1. INTRODUCTION

Black Lake, located in Olympia, Washington, has high nutrient levels that result in cyanobacteria (blue-green algae) blooms. These blooms have occurred in most years since routine lake monitoring began in 1992. Water quality data collected by Thurston County since 1992 shows that Black Lake is eutrophic (high nutrients and algae) due to high phosphorus concentrations. Lake sediments are a primary source of the phosphorus during summer when it is released from iron as anoxic (no oxygen) conditions develop in the bottom waters. The excess phosphorus fuels excess cyanobacteria that float to the surface to form scums and often produce various cyanotoxins (chemicals which are toxic humans, mammals, and waterfowl).

The Black Lake Special District is committed to improving water quality in Black Lake and funded preparation of the Black Lake Phosphorus and Algae Control Plan (Herrera 2015a). That plan identified measures needed to reduce phosphorus inputs to Black Lake and control the production of cyanobacteria and toxic algal blooms, and accomplished the following objectives:

- Developed a water and phosphorus budget to estimate the amount and sources of phosphorus in the lake
- Analyzed the lake sediments to determine the amount of alum (aluminum sulfate used with the buffer sodium aluminate) or Phoslock® (lanthanum treated clay) that would be needed to inactivate sediment phosphorus
- Evaluated alum and Phoslock® treatment methods to control phosphorus sources on both a short-term and long-term basis
- Developed a conceptual plan to control phosphorus (and therefore cyanobacteria) using alum

Water and phosphorus budgets were developed for three study years (2010–2012) using an existing watershed model and lake water quality data. The water budget showed that the primary sources of water flowing into Black Lake on an annual basis are surface inflows (77 percent) and shallow groundwater (14 percent).

The phosphorus budget focused on the summer monitoring period (May through October) when lake data were available for calculating net internal loading from mass balance equations. On average, 60 percent of the total phosphorus loading during the summer months came from net internal loading, 35 percent came from surface inflows, and 5 percent came from shallow groundwater inflow. Because internal loading is a significant source of phosphorus in Black Lake during the summer algae bloom period, a whole lake alum dose was identified as the most appropriate method to inactivate mobile sediment phosphorus. Phoslock® was excluded from consideration due to high cost and poor longevity.

Three alternative alum treatment scenarios were considered; the main differences between the alternatives were related to the timing and dose of the treatment due to uncertainties in funding, permitting, and contractor availability (see Herrera 2015a). The Spring 2016 Full Treatment Scenario was selected as the preferred scenario because it was the least costly and allowed more time for proper planning, permitting, and funding.

The purpose of this plan is to refine the alum dose and cost estimate, provide additional details about the treatment procedures and timing, and present an alum treatment oversight and water quality monitoring plan that meets permit requirements.

2. PROJECT BACKGROUND

Background information about the Black Lake watershed and lake water quality are presented in the Black Lake Phosphorus and Algae Control Plan (Herrera 2015a), and briefly summarized below for informational purposes.

2.1. Lake Watershed

Black Lake is located in Thurston County, Washington, directly west of Tumwater and 4 miles southwest of Olympia (Figure 2-1). The current outlet of Black Lake is located at the northern end of the lake and flows into Percival Creek, which flows into Capital Lake, located at the mouth of the Deschutes River, and into Budd Inlet in southern Puget Sound. Black Lake is located in the western part of the Deschutes River Water Resources Inventory Area (WRIA) 13). Historically, Black Lake was in the Upper Chehalis River watershed (WRIA 23) because it drained south to the Black River, a tributary to the Chehalis River, as described below.

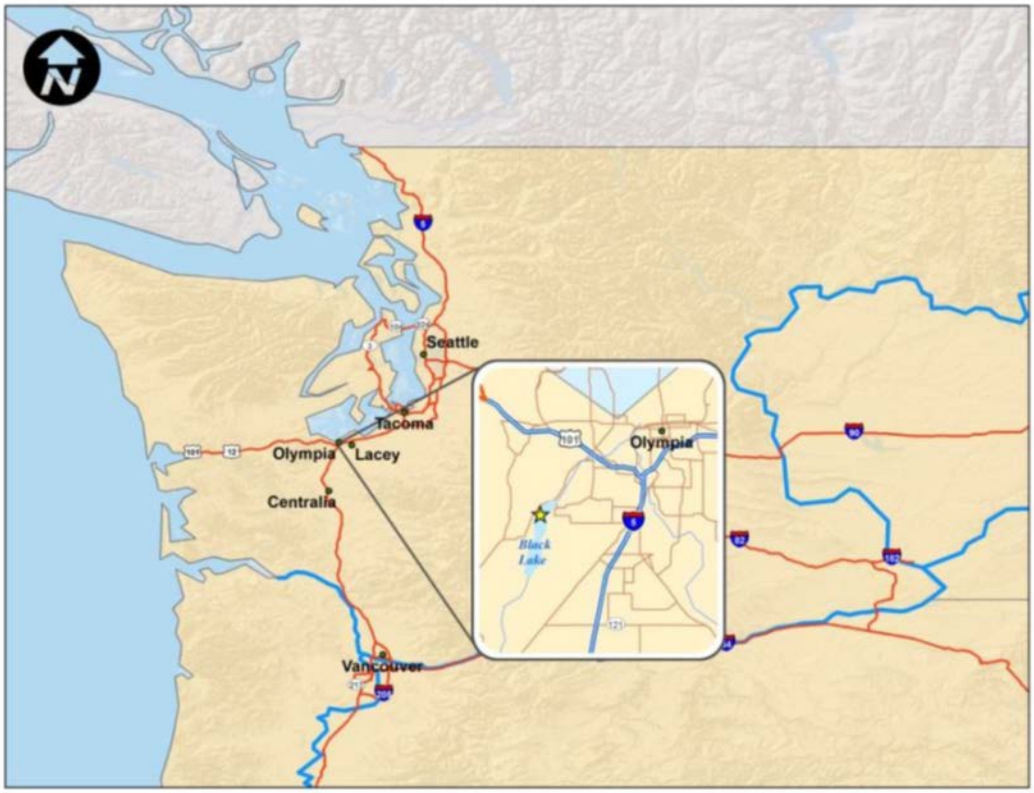
Black Lake is one of the largest lakes in Thurston County (Thurston County 2012). Black Lake is 2.4 miles long, and has a surface area of approximately 570 acres and a volume of approximately 11,000 acre-feet (Table 2-1). The maximum depth is 30 feet with a mean depth of 19 feet. The lake has approximately 6 miles of shoreline and is located at an altitude of approximately 130 feet mean sea level. Average annual precipitation in Olympia is 49.95 inches with 48 percent occurring in 3 winter months from November through January and only 24 percent occurring during the summer monitoring period from May through October.

Table 2 1. Black Lake Physical Features.

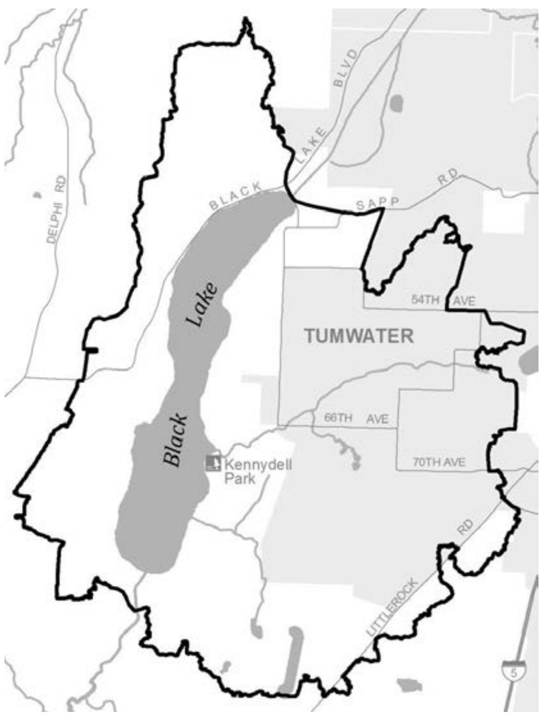
Watershed Area	10.1 square miles (2,616 hectares)[a]
Lake Area	544 to 580 acres (220 to 235 hectares)[b]
Watershed to Lake Area Ratio	11.2 to 11.9 [b]
Lake Length	2.4 miles (9.6 kilometers)[a]
Shoreline Length	6 miles (3.9 kilometers)[a]
Volume	10,408 to 11,259 acre-feet (12.8 to 13.9 million cubic meters)[b]
Maximum Depth	30.1 to 31.6 feet (9.2 to 9.3 meters)[b]
Mean Depth	19.1 to 19.4 feet (5.8 to 5.9 meters)[b]

[a] Source: Thurston County 2012.

[b] Range for lake surface elevations of 127.5 to 129.0 feet NAVD 1988, representing the typical monthly minimum in the summer to the typical monthly maximum in the winter.



Source: Tetra Tech 2012



Source: Thurston County 2012

Figure 2-1. Black Lake Location Maps.

2.2. Lake Water Quality

Thurston County Environmental Health has been consistently monitoring water quality of Black Lake since 1992. Lake monitoring is conducted on a monthly basis during the summer months (May through October) at one site in the deepest point of the lake. This site is located in the south basin adjacent to the Washington Department of Fish and Wildlife (WDFW) public boat launch near Kenneydell County Park (Figure 2-2). Water temperature, dissolved oxygen, pH, and conductivity are measured in profiles at 1-meter depth intervals. Secchi depth is measured with a Secchi disk and water color is recorded. Total phosphorus and total nitrogen are measured in surface water samples collected at a depth of 0.5 meters and bottom water samples are collected approximately 1 meter from the lake bottom. Chlorophyll *a* and phaeophytin *a* (an indicator of degraded chlorophyll) are measured in composite water samples typically from depths of 1, 2, and 3 meters, representing the epilimnion or surface layer of the lake. Selected relevant data are described below.

Black Lake thermally stratifies into an epilimnion (warmer surface layer) and hypolimnion (cooler bottom layer) starting in May. These layers are separated by a thermocline that typically lies at about 15 feet (4.6 meters) from May through July. At this thermocline depth, the hypolimnion covers 83 percent of the lake bottom (see Figure 2-2). The typical seasonal pattern is that the thermocline weakens and deepens in September as air temperatures cool, and the lake completely mixes by the end of October (see Herrera 2015a).

Due to microbial respiration and lack of mixing with the air, dissolved oxygen concentrations are lower below the thermocline. The typical pattern is that the water above the sediments, become anoxic (no oxygen) starting in June and lasting through September and that this anoxic condition spreads throughout the hypolimnion in July and August. Dissolved oxygen concentrations in the epilimnion are typically between 8 and 11 milligrams per liter (mg/L) during the summer months. The low dissolved oxygen concentrations in the hypolimnion (less than 2 mg/L), combined with the high temperatures in the epilimnion, impact habitat for cold water salmonids (trout) in Black Lake where the preferred habitat (i.e., cool water and adequate oxygen) is limited to a small region near the thermocline.

The pH in Black Lake during summer months is typically between 7 (neutral) and 8 in the epilimnion, and at approximately 7 in the hypolimnion. In other eutrophic lakes, algae blooms can drive the pH higher (over 9), which results in increased release of phosphorus from the sediments.

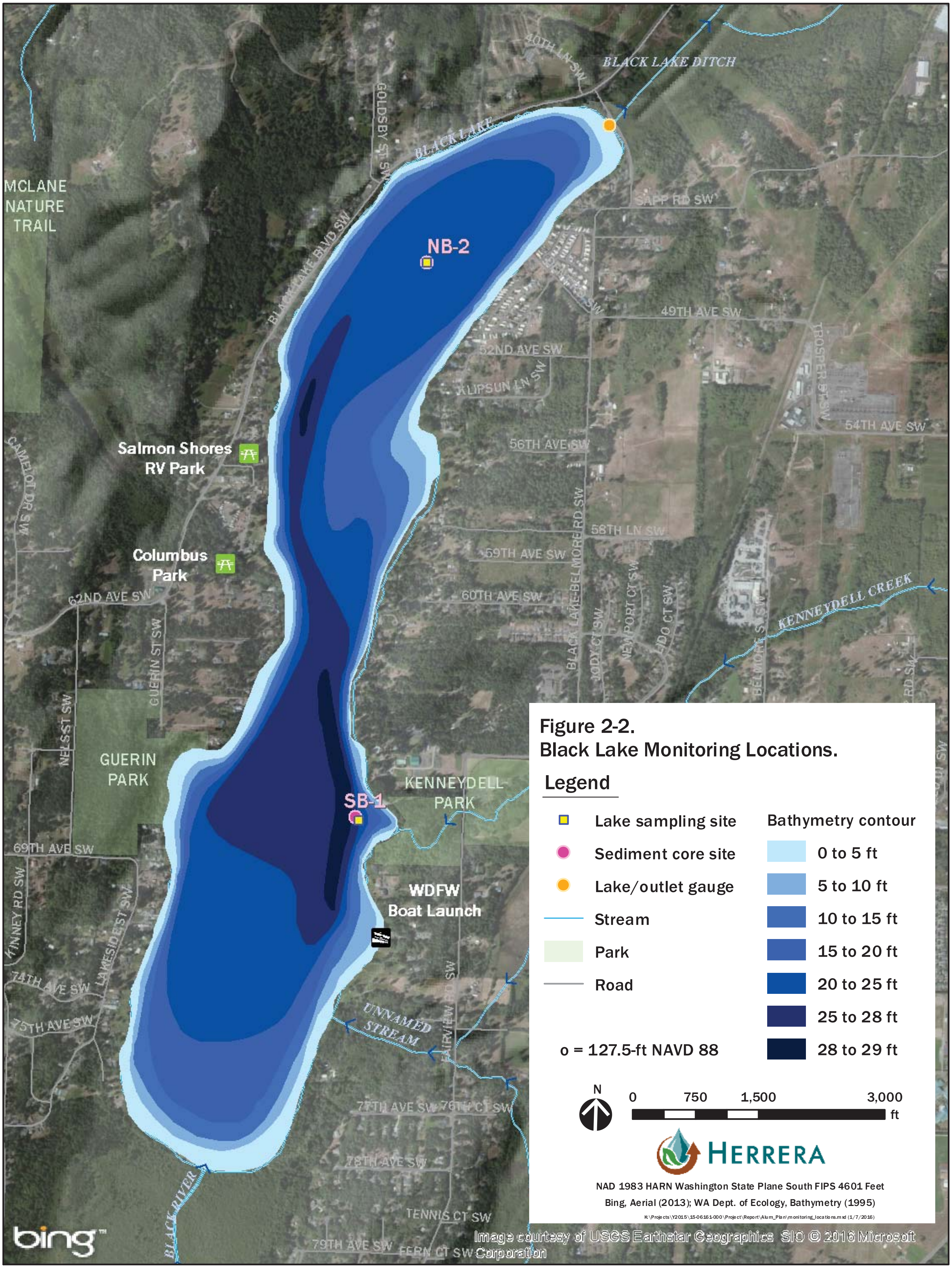


Figure 2-2.
Black Lake Monitoring Locations.

2.2.1. Trophic State Parameters

Lakes are classified into one of four trophic states based on increasing amounts of nutrients and algae: oligotrophic (low nutrients and productivity), mesotrophic (intermediate nutrients and productivity), eutrophic (high nutrients and productivity), and hypereutrophic (very high nutrients and productivity). Carlson's trophic state index is commonly used to determine the trophic state based on summer (May through October) average values of Secchi depth, chlorophyll a, and total phosphorus in the epilimnion (surface layer) of a lake. The trophic state indices and criteria used in the evaluation are compared to ranges observed in Black Lake in Table 2-2.

Table 2-2. Carlson's Trophic State Indices and Criteria Compared to Black Lake.

Trophic Class	Trophic State Index	Secchi Depth (meters)[a]	Chlorophyll *a* (µg/L)[a]	Total Phosphorus (µg/L)[a]
Oligotrophic	< 40	> 4	< 2.6	< 12
Mesotrophic	40 to 50	2 to 4	2.6 to 7.2	12 to 24
Eutrophic	50 to 60	0.5 to 1	7.2 to 20.1	24 to 48
Hypereutrophic	> 70	< 0.5	> 56	> 96
Black Lake (1992–2014)	45 to 65	1.3 to 2.8	9.7 to 35	21 to 53

[a] Summer mean value for epilimnion (Cook et al. 2005).

The summer mean Secchi Depth ranged from 1.3 to 2.8 meters and the overall range was 0.6 to 3.9 meters. The mean Secchi depth results indicate that Black Lake lies between eutrophic and mesotrophic conditions (Table 2-2). There is no apparent long-term trend in Secchi depth (see Herrera 2015a).

The summer mean chlorophyll *a* ranged from 9.7 to 35 µg/L and the overall range among all sample values was 0.5 to 129 µg/L. Thus, mean chlorophyll results are indicative of eutrophic conditions (7.2 to 20.1 µg/L) in Black Lake. There is no apparent long-term trend in chlorophyll concentrations in the epilimnion of Black lake. Chlorophyll *a* and Secchi depth exhibit a moderately strong relationship (R^2 = 0.61). This relationship and the relative lack of turbid water inputs to Black Lake suggests that phytoplankton (suspended algae) are the primary factor affecting water transparency in Black Lake.

In the surface water samples, summer means of total phosphorus ranged from 21 to 53 µg/L, while the overall range among samples was 1 to 110 µg/L. Thus, mean total phosphorus concentrations in the surface waters of Black Lake results are typically indicative of eutrophic conditions (24 to 48 µg/L), with concentrations that often exceed the threshold for undesirable algae growth (30 µg/L). In the bottom water samples, summer means ranged from 44 to 304 µg/L, and the overall range among samples was 11 to 624 µg/L. Total phosphorus varied much more in the bottom than the surface, and surface water values are not strongly correlated to bottom water values. There is no apparent long-term trend in phosphorus concentrations in either the surface or bottom waters of Black Lake.

Total phosphorus concentrations in surface water samples (collected at 0.5 meters) are correlated to chlorophyll *a* concentrations in epilimnion samples (collected at 1, 3, and 5 meters) in Figure 2-8. Chlorophyll *a* increases linearly with total phosphorus in a moderately weak relationship (R^2 = 0.23). Thus, total phosphorus is not a very reliable predictor of chlorophyll *a* in Black Lake. This is possibly due to the different sampling depths and variable phosphorus content of different phytoplankton, which can vary by species and growth stage.

The trophic state index (TSI) for each of the three indicator parameters is presented in Figure 2-3. The Secchi and total phosphorus TSI values were typically eutrophic and sometimes mesotrophic. All chlorophyll TSI values were within the eutrophic range within the 23-year period of record. No long-term trends are apparent with either TSI parameter. The consistently higher chlorophyll TSI than the other two indices suggests that phosphorus produces more algae (i.e., that more of the phosphorus is in a bioavailable form) and that algae have less impact on water transparency (i.e., larger particle size) in Black Lake than lakes used to develop the TSI. In combination, these results indicate that the lake is well within the eutrophic range for nutrients and productivity.

2.2.2. Cyanotoxins

Cyanotoxin concentrations in Black Lake algae scum samples indicate that only microcystin concentrations have exceeded state guidelines. Black Lake microcystin concentrations exceeded the recreational guideline of 6 µg/L in all years except 2014. Aphanizomenon and Anabaena appear to be the primary microcystin producers in Black Lake, based on their higher frequency of detection in the scum samples.

2.2.3. Fisheries

Black Lake supports a variety of fish species, making it a popular location for sport fishing (Table 2-4). During the fall and spring, Black Lake is stocked with rainbow trout and supports naturally reproducing coastal cutthroat trout (WDFW 2015). The lake provides diverse habitat for fish, including submersed logs, overhanging and shoreline vegetation and manmade structures such as pilings, docks, and floats.

2.2.4. Recreational and Beneficial Uses

Black Lake supports a variety of beneficial and recreational uses. Protected beneficial uses include swimming, boating, and wildlife habitat (WAC 173-201A). Common recreational uses include waterskiing, jet skiing, and fishing which occur across the waterbody. Public access to Black Lake consists of a Washington Department of Fish and Wildlife (WDFW) public boat launch, Kenneydell County Park (owned by Thurston County), one church camp, two private resorts, and three small private community accesses points. No known drinking/domestic water or irrigation withdrawals or stock watering sites are known to occur around Black Lake (Thurston County 2012).

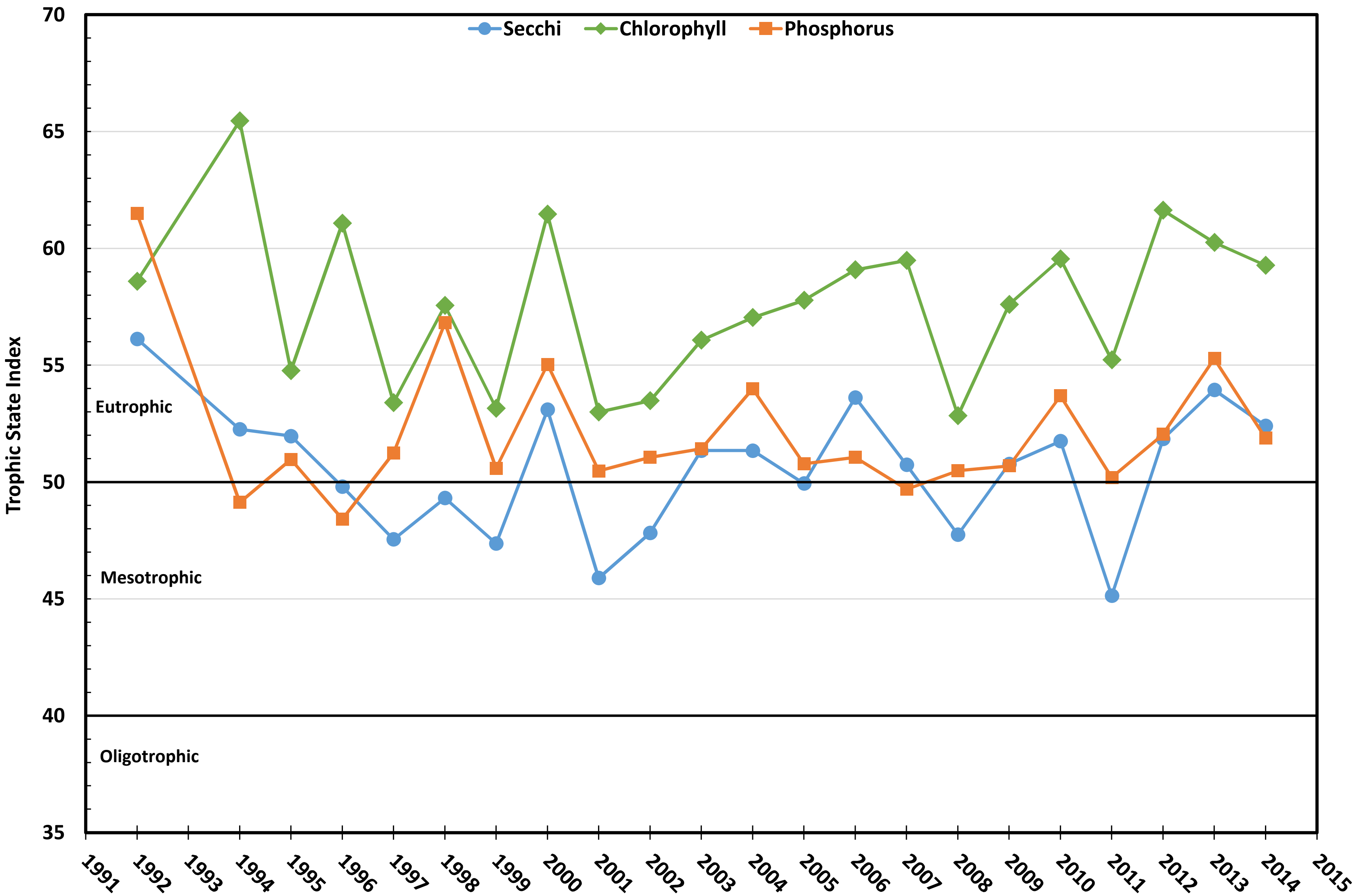


Figure 2-3. Trophic State Indices, Black Lake 1992-2014.

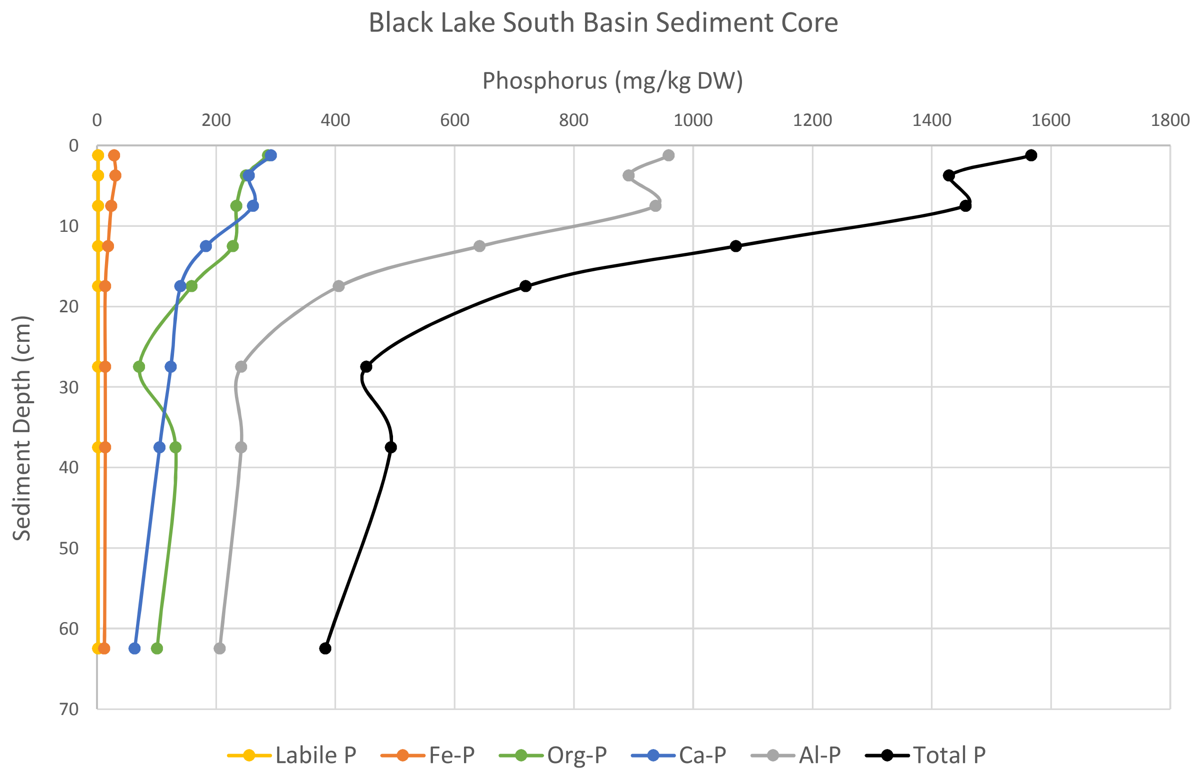
2.3. Sediment Phosphorus

Sediment core analysis of Black Lake was performed to evaluate its potential for contributing to internal phosphorus loading, and then to calculate the dose of alum for sediment phosphorus inactivation. Duplicate sediment cores were collected on March 17, 2015, from each of two locations located in the north basin (station NB-2) and south basin (station SB-1) of the lake (see Figure 2-2), for a total of four sediment cores. The sediment cores were collected in an area with a water depth greater than 4.6 meters (15 feet), to ensure they represented the region that would be considered hypolimnion in the summer. This region represents approximately 83 percent of the lake surface area. The water depth was 23 feet at station NB-1 and 29 feet at station SB-1.

The iron to phosphorus (Fe:P) ratio was high (17 to 57) except for the 5 to 10 cm samples from the north basin (13) and south basin (9). The Fe:P ratio should exceed 10 if it is to regulate phosphorus release and should exceed 15 to prevent phosphorus release from oxidized sediments (Sondergaard et al. 2003). Overall, the Fe:P ratios suggest that phosphorus release would be expected to be low from sediments in the epilimnion (i.e., at water depths less than 15 feet) in Black Lake.

The sediment phosphorus data are presented in Figure 2-4. Results are similar between the two cores; the exception is that aluminum bound phosphorus in the south basin core was 10 to 55 percent higher than the north basin core, which resulted in higher concentrations of total phosphorus in the south basin core. Phosphorus concentrations generally decreased with depth in the sediment cores until reaching relatively stable background concentrations. Stable background concentrations were reached at the 25 to 30 cm interval for aluminum bound phosphorus and at the 15 to 20 cm interval for calcium bound phosphorus, organic phosphorus, and iron bound phosphorus.

Iron bound phosphorus concentrations were very low (24 to 39 mg/kg above 10 cm and 11 to 19 mg/kg below 10 cm) and labile (loosely bound) phosphorus was not detected (less than 2 mg/kg) in any samples. The sum of iron bound and labile phosphorus represents mobile phosphorus that is released from anoxic sediments. Organic phosphorus concentrations were much higher, ranging from 71 to 290 mg/kg. The samples were not analyzed for biogenic phosphorus, which is the fraction of organic phosphorus that is potentially mineralized to labile phosphorus by microbial activity. Biogenic phosphorus was estimated at 163 mg/kg by subtracting the organic phosphorus concentration in the deep sediment samples (non-labile background at 100 mg/kg) from the average organic phosphorus concentration in the shallow sediments (263 mg/kg) (Pilgrim et al. 2007).



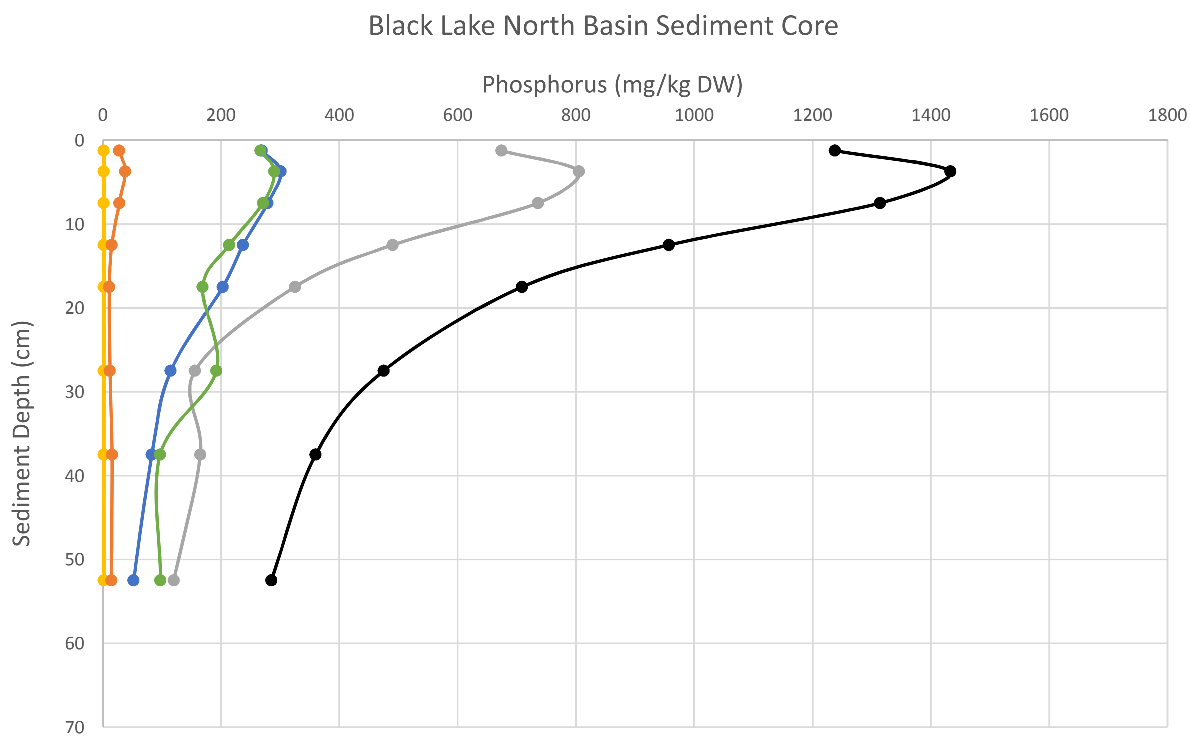


Figure 2-4. Sediment Phosphorus Concentrations in Black Lake, March 2015.

3. ALUM DOSE

3.1. Original Dose

For the Black Lake Phosphorus and Algae Control Plan (Herrera 2015a), the alum dose was calculated as the amount of aluminum required to inactivate sediment phosphorus, and an included a small amount to strip water column phosphorus expected during the treatment (April average). Based on the sediment core results, the dose was designed to bind active phosphorus in the top 10 cm of sediments, which is the phosphorus considered most likely to be released into the water column. Similar to what has been used in other lake treatments, a ratio of 20 parts aluminum to 1 part aluminum bound phosphorus formed was selected in order to effectively bind the active phosphorus.

Active phosphorus in the sediment was calculated using the sum of the labile phosphorus, iron-bound phosphorus, and biogenic phosphorus. Biogenic phosphorus was estimated as the difference between organic phosphorus in the surface (top 10 cm) and subsurface (below 15 cm) sediments to represent the fraction of organic phosphorus that is potentially mineralized by microbial activity. For Black Lake, the average active phosphorus concentration was calculated to be 193 mg P/kg dry weight (DW). A total solids content of 10 percent and a wet bulk density of 1.02 g wet weight/cm^3 was used to determine the average areal amount of active phosphorus in the lake at 1.96 g P/m^2. A maximum hypolimnion area of 1.67 million m^2 was used based on a minimum thermocline depth of 15 feet and corresponding lake area of 412 acres.

Based on these assumptions, the aluminum dose to inactivate hypolimnetic sediments was calculated to be 65,201 kg Al. An additional 359 kg Al was included to account for the phosphorus present in the water column that would also need to be inactivated. (An aluminum to phosphorus binding ratio of 1 was used for the water column to account for the amount of aluminum added that could bind with phosphorus in the water column instead of the sediments.) The sum of these two doses is 65,560 kg Al. Based on the amount of aluminum present in liquid alum (0.22 kg/gallon) and sodium aluminate (0.56 kg/gallon), and a ratio of 2 parts alum to 1 part sodium aluminate (by volume), a total of 131,119 gallons of alum and 65,560 gallons of sodium aluminate was calculated to achieve the recommended dose.

3.2. Revised Dose

The alum dose initially calculated in the previous study (and summarized above) was revised in consideration of recent developments in alum treatment technology and other factors. The following describes each of the components of the alum dose calculation and provides rationale as to why it was or was not modified:

- **No change in the inactivation depth of 10 cm.** The initial evaluation of the appropriate inactivation depth determined that 10 cm is appropriate for long-term inactivation because mobile phosphorus concentrations substantially decreased below

10 cm in both of the sediment cores. Thus, phosphorus release is expected to be significant where mobile phosphorus in enriched in the upper 10 cm (Pilgrim et al. 2007). In addition, evaluation of alum treated lakes in Washington showed that the aluminum bound phosphorus formed by the treatment was limited to the upper 10 cm of sediment in most lakes (Rydin and Welch 2000).

- **No change in the mobile phosphorus concentration.** The average mobile phosphorus concentration initially used for calculating the aluminum dose was not changed because it was correctly calculated as the depth-weighted average of iron bound and labile phosphorus in the two cores. In addition, the similar concentrations observed in the cores suggest that mobile phosphorus concentrations are relatively uniform throughout the lake area, and that the aluminum dose does not need to vary with depth or location. An average mobile phosphorus concentration of 30 mg/kg in the upper 10 cm of sediment was used to calculate the aluminum dose based on the sum of the average iron phosphorus concentration (29 mg/kg) and labile phosphorus concentration (1 mg/kg, or one-half the detection limit of 2 mg/kg for undetected values in all core samples) (Table 3-1).
- **Reduce biogenic phosphorus concentrations to include only the active fraction.** Initially, the average biogenic phosphorus concentration was estimated to be 163 mg/kg as the difference in average organic phosphorus concentrations in the surface and subsurface sediment samples (see above). For this revision, biogenic phosphorus concentrations were estimated to be 75 percent of the organic phosphorus concentration measured in every core sample. This proportion is based on proportions recently observed on a consistent basis throughout sediment cores collected from Green Lake (64 percent average and 47 to 77 percent range at all stations; Herrera 2015b) and Lake Ketchum (81 percent average and 74 to 86 percent range at the mid-lake station; Snohomish County 2012), and while also recognizing that organic matter production in Black Lake is greater than Green Lake and less than Lake Ketchum. In addition, depth-weighted average subsurface (15 to 40 cm) concentrations of biogenic phosphorus were subtracted from the average surface (0 to 10 cm) concentrations to estimate the active fraction of biogenic phosphorus that will potentially mineralize into mobile phosphorus due to microbial degradation (Pilgrim et al. 2007). An average active biogenic phosphorus concentration of 95 mg/kg in the upper 10 cm of sediment was used to calculate the revised aluminum dose based on the difference in the average biogenic phosphorus concentration of 197 mg/kg and the average organic phosphorus concentration of 263 mg/kg (Table 3-1). The resulting sum of mobile and active biogenic phosphorus targeted for sediment inactivation is 124 mg/kg dry weight.
- **No change in the solids content and bulk density of the targeted sediments.** A total solids content of 10 percent (0.10 g dry weight/g wet weight) was initially measured as the depth-weighted average in the top 10 cm of both cores, and was appropriately used was used to convert the dry weight to wet weight of targeted phosphorus. A wet bulk density of 1.02 g/cm^3 was initially measured in one core sample, and was appropriately used to calculate the mass of targeted phosphorus per unit area of sediment in the top 10 cm. The resulting areal amount of mobile and active biogenic phosphorus is 1.27 g/m^2.
- **Reduce the ratio of aluminum added to aluminum phosphorus formed.** The ratio of aluminum added to aluminum phosphorus formed was reduced from 20 in the original

calculation (Herrera 2015a) to 10 to account for the addition of active biogenic phosphorus in the targeted amount of sediment phosphorus. A high ratio of 20 has been successfully used in Washington lakes because the targeted amount of sediment phosphorus was based only on the mobile phosphorus concentration. A lower ratio of 8.8 parts aluminum to aluminum phosphorus formed has recently been recommended by European limnologists when active biogenic phosphorus is included in the targeted amount of sediment phosphorus to be inactivated. For this revision, a slightly higher ratio of 10 parts aluminum to targeted sediment phosphorus was used to calculate the amount of aluminum added for the alum treatment and provide an additional safety factor for effectiveness longevity.

- **Expand the treatment area to include the littoral (shallow) sediments between depths of 5 and 15 feet.** The treatment area was increased to include the entire lake bottom below a depth of 5 feet. In the initial estimate only the area located below a depth of 15 feet was included. Originally, the area of sediment above a depth of 15 feet was not included because those waters do not become anoxic and there is sufficient iron to prevent release of mobile phosphorus under those conditions. However, it has been shown in other eutrophic lakes that phosphorus is released from shallow sediments even when the overlying waters do not become anoxic because oxygen is reduced and phosphorus is mineralized by microbial activity (Cooke et al. 2005). The treatment area was expanded from 412 to 509 acres, representing 72 and 89 percent, respectively, of the 570-acre lake. Applying the expanded treatment area to the areal amount of targeted phosphorus (1.27 g/m^2) to the ratio of aluminum added to aluminum phosphorus formed (10) resulted in a total aluminum amount of 26,155 kg to inactivate the targeted sediment phosphorus (Table 3-2).

- **No change in the amount of aluminum added to inactivate water column phosphorus.** The total aluminum amount required to inactivate sediment phosphorus was increased to account for the binding of aluminum to phosphorus present in the water column during the treatment. The initial water column dose was appropriately based on average total phosphorus concentrations observed in the epilimnion and hypolimnion in May (first month of summer monitoring) of 2010–2014, and the average volume of those layers measured in April of 2010–2012. A ratio of 1 part aluminum to aluminum phosphorus formed was appropriately applied to total phosphorus in the water column because total phosphorus includes all forms of phosphorus and additional aluminum is not required to react with additional sources, as for the targeted sediment phosphorus. The additional amount of aluminum required to inactivate water column phosphorus is 359 kg, which amounts to only 1.3 percent of the total aluminum dose of 26,514 kg (sum of 26,155 kg for sediment phosphorus inactivation and 359 kg for water phosphorus inactivation) (Table 3-2).

Table 3-1. Black Lake Sediment Phosphorus Data for Alum Dose Calculation.

Core Location	Depth Interval (cm)	Labile P (mg/kg)	Iron P (mg/kg)	Mobile P (mg/kg)[a]	Organic P (mg/kg)	Depth Interval (cm)	Mobile P (mg/kg)[a]	Organic P (mg/kg)	Biogenic P (mg/kg)	Active Biogenic P (mg/kg)[b]	Mobile + Active Biogenic P (mg/kg)
South Basin at 29 feet depth	0–2.5	1.0	29.0	30.0	287						
	2.5–5	1.0	31.2	32.2	250						
	5–10	1.0	24.0	25.0	234	0–10	28.1	251	188	98	126
	10–15	1.0	18.7	19.7	228						
	15–20	1.0	14.0	15.0	159						
	25–30	1.0	13.8	14.8	71.0						
	35–40	1.0	14.1	15.1	132	15–40	15.0	121	91	0.0	15.0
	60–65	1.0	12.6	13.6	101						
North Basin at 23 feet depth	0–2.5	1.0	27.9	28.9	267						
	2.5–5	1.0	37.8	38.8	290						
	5–10	1.0	28.0	29.0	271	0–10	31.4	275	206	92	123
	10–15	1.0	15.4	16.4	214						
	15–20	1.0	11.2	12.2	169						
	25–30	1.0	12.3	13.3	192						
	35–40	1.0	15.6	16.6	97.1	15-40	14.0	153	115	0.0	14.0
	50–55	1.0	14.8	15.8	97.7						
Lake Average						0–10	29.7	263	197	95	124

[a] Mobile P = Labile P + Iron P

[b] Biogenic P = 75 % of Organic P based on Green Lake (64%) and Lake Ketchum (81%).

[c] Active Biogenic P = Biogenic P - Biogenic P from deep sediments (15–40 cm)

Table 3-2. Black Lake Alum Treatment Dose and Cost Estimate for Spring 2016 Sediment Phosphorus Inactivation.

Item	Value	Basis
Sediment Phosphorus		
Mobile P (mg P/kg DW)	30	Depth weighted average of both cores from 0-10 cm for iron-P + 1 for labile-P (<2)
Organic P (mg P/kg DW)	263	Depth weighted average of both cores from 0-10 cm
Active Biogenic P (mg P/kg DW)	95	Biogenic = 75% of Organic P, Active = surface 0-10 cm minus deep 15-40 cm
Mobile+Active P (mg P/kg DW)	124	Sum of mobile and active biogenic P
Total Solids (g DW/g WW)	0.10	Depth weighted average of both cores from 0-10 cm
Wet Bulk Density (g WW/cm^3)	1.02	Maximum for 0-10 equal to sample NB-25-30 lab result
Inactivation Depth (cm)	10	Based on mobile+active P profile and observed in alum-treated Washington lakes
Mobile+Active P areal amount (g P/m^2)	1.27	Mobile-P x total solids x density x depth x 10^{-3} kg DW/g DW x 10^{-3} g P/mg P x 10^4 cm^2/m^2
Al-P binding ratio	10	Excess Al to inactivate migrated and mineralized sediment P (recent research in Europe)
Treatment area (m^2)	2,059,923	Lake area > 5 feet depth = 509 acres x 4047 m^2/acre
Treatment dose (kg Al)	**26,155**	Mobile-P x Al-P ratio x area x 10^{-3} kg/g
Water Phosphorus		April Application
Epilimnion TP (ug/L = mg/m^3)	16	May 2010-2014 mean
Epilimnion Volume (m^3)	9,820,000	April whole lake - hypo volume at 15 ft (13.70-3.88 x 10^6 m^3)
Hypolimnion TP (ug/L = mg/m^3)	52	May 2010-2014 mean
Hypolimnion Volume (m^3)	3,880,000	Hypolimnion volume (3.88x10^6 m^3)
Total water phosphorus amount (kg)	359	(Epi TPxVol + Hypo TPxVol) x 10^{-6} kg/mg
AL-P binding ratio	1	No excess Al needed for TP in water
Water dose (kg Al)	**359**	
Aluminum Dose		
Total Al dose (kg Al)	**26,514**	Sum of sediment and water Al dose
Al volumetric dose (mg Al/L)	1.9	Total dose/lake volume in kg/m^3 x10^3L/m^3
Al areal dose (g Al/m^2)	12.9	Total dose/treatment area in kg/m^2 x 10^3g/kg
Material Amounts		
Al sediment+water dose (kg Al)	26,514	Sum of sediment and water Al dose
Al in Alum (kg Al)	11,784	2:1 liguid = 0.44:0.55 weight ratio; Alum at 4.4% soluble Al and SG of 1.337 g/mL
Al in Sodium aluminate (kg Al)	14,730	2:1 liguid = 0.44:0.55 weight ratio; Aluminate at 32% and SG of 1.40 g/mL
Alum volume (gal)	**53,563**	0.22 kg Al/gal; round to 53,560 = 12 trucks at 4,500 gal/truck
Sodium aluminate volume (gal)	**26,781**	0.55 kg Al/gal; round to 26,780 = 6 trucks at 4,500 gal/truck

The revised aluminum dose is 1.9 mg Al/L on a volumetric basis and 12.9 g Al/m^2 on an areal basis (Table 3-2). This dose is approximately 40 percent of the original dose of 4.8 mg Al/L on a volumetric basis and 39 g Al/m^2 on an areal basis (Herrera 2015a).

Based on the amount of aluminum present in liquid alum (0.22 kg/gallon) and sodium aluminate (0.55 kg/gallon), and a ratio of 2 parts alum to 1 part sodium aluminate (by volume), a total of 53,560 gallons of alum and 26,780 gallons of sodium aluminate will be applied to Black Lake. Based on a truck capacity of 4,500 gallons, a total of 12 trucks will be required for the alum and 6 trucks for the sodium aluminate. It is expected to take 3 to 4 days to apply these materials.

3.3. Comparison to Other Lakes

The revised aluminum dose for Black Lake (12.9 g Al/m^2) is lower than doses applied to other lakes treated since 2004 when the sediment phosphorus method was first used in Washington State (Table 3.3). Recently treated lakes with higher areal doses include Green Lake in King County (94 g Al/m^2 in 2004 and 32 g Al/m^2 planned for 2016), Long Lake in Kitsap County (41 g Al/m^2) in 2006 and 2007, Long Lake in Thurston County (55 g Al/m^2 in 2008), and Lake Ketchum in Snohomish County (66 g Al/m^2 in each of 2014 and 2015). These lakes received higher doses because they had higher mobile phosphorus concentrations, or the doses were based on deeper inactivation depths or higher ratios of aluminum to aluminum phosphorus formed. The revised areal dose for Black Lake exceeds amounts applied to other lakes in western Washington from 1980 to 1995 (6 to 12 g Al/m^2) when the alum dose was calculated using an entirely different method based on jar tests of alum effects on lake pH.

Table 3-3. Comparison of Alum Treatment Doses in Washington.

Lake (County)	Treatment Date	Volumetric Dose (mg Al/L)	Areal Dose (g Al/m^2)	Longevity (years)[a]	Reference
Black Lake (Thurston)	2016 (planned)	1.9	12.9	unknown	–
Lake Ketchum (Snohomish)	May 2014 March 2015	19 19	66.5 66.5	NA unknown	G. Williams (pers. comm.)
Long Lake (Thurston)	September 1983 2008 (planned)	7.7 15.2	27.8 54.9	5 unknown	Welch/Cooke 1999 Tetra Tech 2006
Long Lake (Kitsap)	September 1980 September 1991 August 2006 April 2007	5.5 5.5 2.5 17.5	10.7 10.7 4.6 36.2	> 11 > 11 NA > 5	Rydin and Welch 2000 Rydin and Welch 2000 Tetra Tech 2010 Tetra Tech 2010
Green Lake (King)	October 1991 April 2004 2016 (planned)	8.6 24 8.2	34 94 32	3 > 10 unknown	Herrera 2003 Herrera 2004 Herrera 2015b
Phantom Lake (King)	September 1990	4.2	9.5	unknown	Rydin and Welch 2000
Lake Ballinger (King)	June 1990	5.0	6.5	unknown	Rydin and Welch 2000
Lake Campbell (Skagit)	October 1985	10.9	12.2	> 8	Rydin and Welch 2000
Lake Erie (Skagit)	September 1985	10.9	5.7	> 8	Rydin and Welch 2000
Medical Lake (Spokane)	Aug.-Sept. 1977	12.2	83.5	unknown	Rydin and Welch 2000

[a] Cooke et al. 2005 except Herrera 2015b for Green Lake.

Cooke (et al. 2005) assessed the longevity of several alum treatments in western Washington and those treatments lasting at least 5 years were considered to be successful. Each of the successful treatments applied less aluminum than the planned dose for Black Lake. These successful treatments were for lakes located in relatively undeveloped watersheds like Black Lake, and included Long Lake in Kitsap County in 1980 and 1991, and Lake Campbell and Lake Erie in 1985 (see Table 7-1). This comparison suggests that the Black Lake alum treatment will last at least 5 years. The treatment may prevent toxic cyanobacteria blooms for up to 10 years if the added aluminum continues to react with mineralized biogenic phosphorus and inputs of watershed phosphorus, as was recently discovered to have occurred following the 2004 alum treatment of Green Lake (Herrera 2015b).

4. ALUM TREATMENT

Chemical materials and the application procedures have been designed as described below for the revised dose to achieve maximum effectiveness with protection of fish and other aquatic organisms. Technical specifications have been prepared separately based on this final design for advertisement and procurement of an experienced contractor to perform the alum treatment. The technical specifications include additional details on the materials and application procedures to ensure proper handling, dosing, floc formation, and distribution of the materials in the lake.

The technical specifications also include requirements for public notification and equipment calibration and maintenance that are specified in the Aquatic Plant and Algae Management Permit (Permit) issued the Washington Department of Ecology (Ecology 2015). The Permit also requires water quality monitoring and reporting that is described in Section 5 below. The Permit is currently a draft that is expected to be finalized before the treatment begins, without any substantial changes to alum applications.

4.1. Chemical Materials

The Contractor will apply liquid aluminum sulfate (alum) and liquid sodium aluminate (buffer) simultaneously at a volumetric ratio of 2:1 (alum: sodium aluminate) for phosphorus control in Blake Lake. A ratio of 2:1 will provide 0.44 kg Al from 2 gallons of liquid alum and 0.55 kg Al from 1 gallon of liquid sodium aluminate, given a concentration of 4.2 percent of total water-soluble aluminum in the alum, and of 32 percent of available soluble sodium aluminate in the buffer. The application ratio of alum and sodium aluminate will need to be modified and quantities of sodium aluminate revised if concentrations differ and depending on results of jar tests conducted immediately prior to treatment (see Section 5).

The alum and sodium aluminate will be drinking water treatment grade as specified by the National Sanitation Foundation (NSF), and will contain no substances in quantities capable of producing deleterious or injurious effects on public health or water quality.

4.2. Preparation

The Contractor will protect structures, utilities, pavements, and other facilities from damage caused by settlement, lateral movement, undermining, washout, or other hazards created by the transport and delivery of chemicals, chemical storage tanks, and chemical spills. During and at the completion of the application of liquid alum and sodium aluminate, the Contractor will conduct all operations in such a way as to:

- Comply with any and all permit conditions for this project.
- Prevent damage to the lake, equipment, and surrounding properties.
- Prevent damage to the aquatic environment from hydraulic fluid leaks by using a biodegradable hydraulic fluid in all equipment.

- Prevent damage to the lake by ensuring that no aquatic invasive species are introduced into the lake. This shall include decontaminating all equipment and gear that will come into contact with lake water prior to bringing such equipment to the staging area.
- Maintain orderly appearance at the staging area an on the treatment vessel while the treatment is occurring.
- Prevent damage to the aquatic environment if temporary on-shore storage tanks are used at the staging area.
- Prevent damage to all utilities and below ground infrastructure at the staging area.

4.3. Equipment Staging and Chemical Storage

The use of temporary, on-shore storage tanks for staging the chemicals is recommended, but not required, to ensure that the application of alum and sodium aluminate is successfully completed in the required applications time frame of 3 working days. On-shore storage tanks are not required if the rate of application can keep pace with delivery of chemicals. On-shore and on-board chemical storage tanks and associated spill containment equipment that meet local state and federal regulations, including those specified by the Washington State Department of Fish and Wildlife (WDFW) for use of the WDFW boat launch for the staging area see Section 4.5).

If on-shore storage tanks are used, separate tanks shall be provided for each chemical. All on-shore storage tanks shall be fabricated out of HDPE or other suitable material (i.e., stainless steel) that is tolerant of temperature in excess of 200 degrees Fahrenheit.

4.4. Chemical Application

The alum and sodium aluminate application shall occur between April 11 and April 29, 2016. Although there are no use restrictions during the treatment, this schedule was selected to perform the treatment to minimize potential interference with periods of high recreational use that are anticipated to occur during spring break for local schools before the period and the Black Lake Fishing Derby after the treatment. The application will be completed within 4 consecutive weekdays, with 2 additional days for mobilization and another additional 2 days for demobilization.

The area of the lake within the 5-foot depth contour (509 acres or 206 hectares) will be treated at 12.9 mg Al/m^2 (Figure 4-1). Application of the alum and sodium aluminate will take place after the lake water temperature has risen to over 5.5°C (42° F) throughout the first 4 meters of the water column, which will occur by April 11, 2016. Application will take place only when the wind speed is less than or equal to 15 mph at the lake surface, as required by the permit.

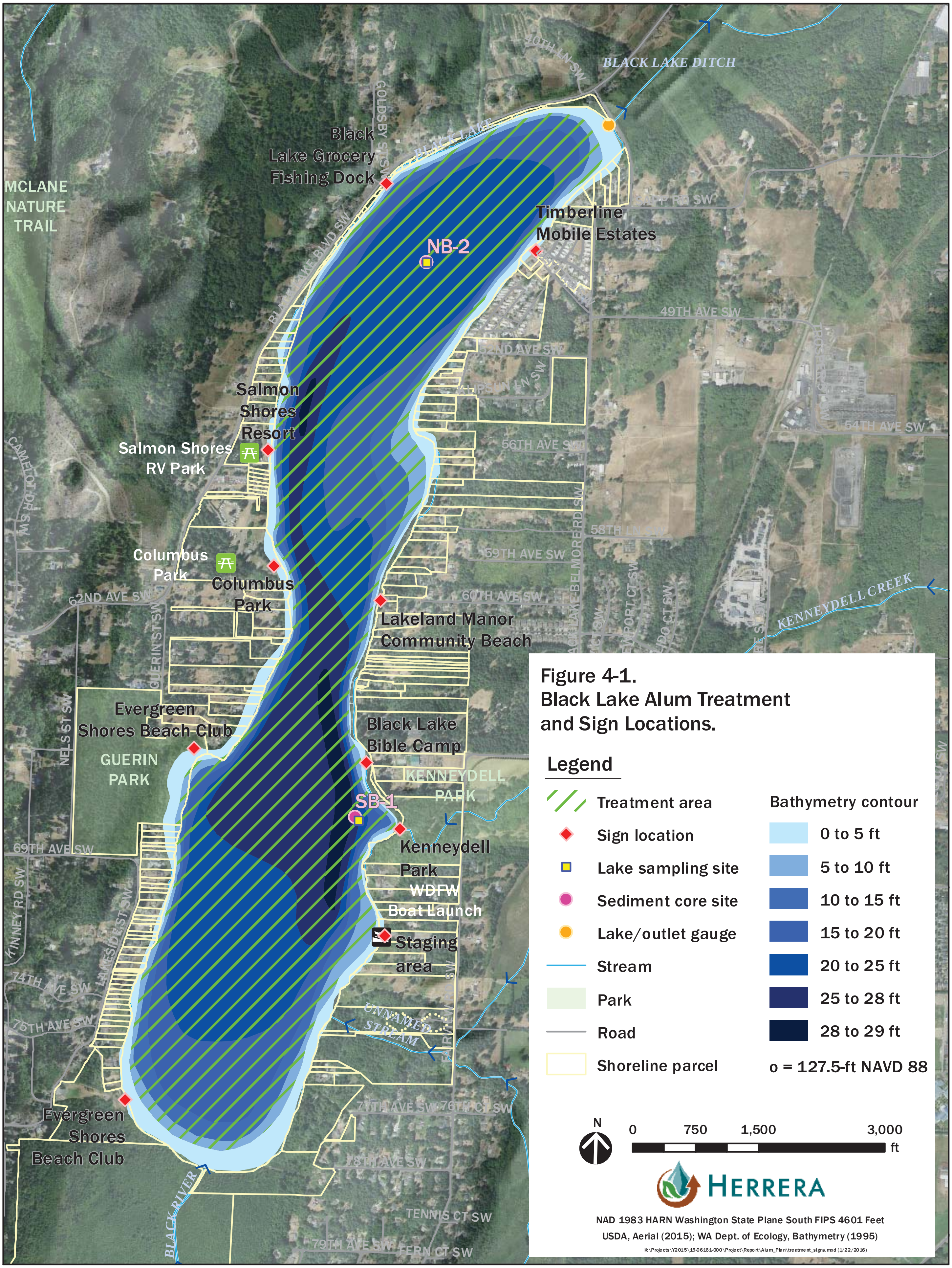


Figure 4-1.
Black Lake Alum Treatment and Sign Locations.

A mixture of liquid aluminum sulfate (alum) and liquid sodium aluminate (buffer) will be injected below the lake surface from a moving vessel (barge or boat). The alum and sodium aluminate should not come in contact with one another outside of the water. The treatment vessel position in the lake will be controlled by a global positioning system (GPS) to continuously adjust the application rate of liquid alum and sodium aluminate mixture (2 gallons alum to 1 gallon sodium aluminate, assuming 32 percent soluble sodium aluminate concentration) based on boat speed. This will ensure complete and uniform chemical coverage during application.

The treatment vessel will have sonar equipment to record water depth, but this equipment does not need to be integrated with the GPS system because the treatment rate will not vary with water depth.

The treatment vessel will contain chemical storage tanks with secondary containment, and applicator equipment for even chemical distribution. The system of chemical distribution will have a minimum application rate of 20,000 gallons per day of combined alum and sodium aluminate. The chemicals will be delivered to the lake water from a boom system at an approximate depth of 1 to 2 inches below the water surface from a minimum of 12 pairs, up to a maximum of 24 pairs, of alum and sodium aluminate injection tubes (nozzles or small hoses) spaced 8 to 12 inches between pairs and with the alum and sodium aluminate injection tubes within each pair spaced 2 to 4 inches apart. The injection tubes will be alternating so that the closest tubes in each direction are always tubes of the other chemical. The treatment will not begin until the boom system is approved on-site by the Resident Engineer (see Section 5).

In accordance with the Ecology permit, the lake pH, and if needed, alkalinity will be monitored in surface water samples by the District representative (Herrera) as described in Section 5. Work will be suspended if the pH of lake water is consistently less than 6.0 (± 0.05) or greater than 8.7 (± 0.05) in the collected water samples. The threshold for re-starting treatment will be a pH between 6.2 and 8.4 (± 0.05) and an alkalinity of at least 12 mg/L (± 0.5 mg/L). Prior to beginning the lake alum treatment (0.5 to 48 hours before), the District representative will also conduct a jar test at the lake in a bucket or barrel using alum and sodium aluminate at 1.9 mg Al/L to verify that treated water is above pH 6.0 after addition and mixing (0.25 to 0.5 hours after being dosed).

4.5. Permit Requirements

The alum treatment will be conducted in accordance with Ecology's Aquatic Plant and Algae Management General Permit (Ecology 2015). This permit is currently being revised and the draft permit does not include any revisions to restrictions for alum treatments. A notice of intent (permit application) was submitted to Ecology on behalf of the District on November 20, 2015. The 30-day public comment period began on December 2, 2015, which coincides with the second notice was published in the newspaper. The notice was published in The Daily Olympian on November 25 and December 2, 2015. Ecology anticipates authorization of the treatment by January 31, 2016.

4.5.1. Permit Restrictions

Permit restrictions for alum treatments (see Table 4 in Ecology 2015) include:

- Timing restrictions:
  - None for fish or other priority species.
  - Early spring or fall treatment if aquatic plant biomass interferes with inactivation of sediment phosphorus.
- Lake use restrictions or advisories:
  - None.
- Treatment restrictions:
  - Application must cease when wind speed is greater than 15 miles per hour.
  - Powdered alum must be mixed with water to form a slurry before applying to the water surface.
  - The pH of lake water during treatment must remain between 6.0 and 8.5 based on lake average.
  - Only aluminum compounds suitable for water treatment may be used.
  - Buffering materials must be available for use.
- Monitoring requirements:
  - Minimum monitoring is one surface water pH measurement in the morning prior to any alum addition and one surface water pH measurement 1 hour after alum addition has stopped for that day.
  - Monitoring for pH must continue for the duration of the treatment and for 24 hours following treatment completion.
  - Monitoring locations must be representative of water body-wide conditions.
- Other restrictions:
  - A jar test must be completed prior to whole lake treatments only if a buffer other than sodium aluminate is used or a ratio of liquid alum to liquid sodium aluminate differs from 2:1 by volume.
  - An on-site storage facility is required for any treatment requiring 9,000 gallons of alum or more, or the project proponent must have a plan to store any unused alum or buffering products.

The general permit allows for short- and long-term exceedance of Washington State Surface Water Quality Standards (WAC 173-201A) provided that the Permittee complies with any short-term modifications of water quality criteria authorized in writing by Ecology. Water quality degradation is allowed if the degradation does not significantly interfere with or become injurious to existing or designated water uses or cause long-term harm to the environment (WAC 173-201A-410).

4.5.2. Ecology Notification

The District representative (Herrera) will email pre- and post-treatment information to Ecology as required by the permit. The District representative (Herrera) and will coordinate and schedule inspections by Ecology, and will immediately call Ecology if the following conditions occur during or after the treatment:

- Any person(s) exhibiting or indicating any toxic and/or allergic response as a result of the treatment
- Any fish or fauna exhibiting stress or dying inside or outside of the treatment area
- Any spill of chemicals covered under this permit that occurs into the water or onto land with a potential for entry into waters of the state.

4.5.3. Public Notification and Sign Posting

The District will notify residents, businesses, and shoreline recreational facilities at least 10 days in advance and at most 42 days before the first day of treatment in accordance with permit requirements, and will proved Ecology and the Washington Department of Natural Resources a copy of the notice.

The Contractor will provide and install all required shoreline and public access notification signs per the posting requirements of the Ecology permit. General signage requirements will include the following:

- Use the template provided in the permit.
- Post signs no more than 48 hours prior to treatment.
- Post signs so that they are secure from the normal effects of weather and water currents, but cause minimal damage to property.
- Make best efforts to ensure that the signs remain in place and are legible until removed.
- Remove all signs between 2 and 10 days after the treatment ends.

Posting shoreline public access areas with 2- by 3-foot signs will include:

- The Contractor will post 2- by 3-foot signs at all public access areas that include a total of 10 locations shown in Figure 4-1.
- The Contractor will post the signs to face both the water and the shore and site them on the shore side of the pathway where they are visible to pathway users and do not obstruct pathway use.
- Signs must be a minimum size of 2- by 3-foot and constructed of durable weather-resistant material.

- The Contractor will attach an 8.5- by 11-inch weather resistant map of the lake to each sign designating the following:
    - o "Treatment area includes the entire lake area below a depth of 5 feet for both chemicals" (located within the lake area)
    - o Mark and label the "Start and Stop Address: WDFW Boat Launch, Latitude 46.9830314, Longitude -122.9731335
    - o Mark and label the "Reader's Location"
- Signs must include the word "CAUTION" in bold black type at least 2 inches high, and use a font at least 0.5 inches high for all other words.

Posting privately-owned and publicly-owned shoreline properties (excluding public access areas) with 8.5- by 11-inch signs will include:

- The Contractor will post 8.5- by 11-inch signs at every waterfront residence or business.
- The Contractor will post the signs to face both the water and the shore and site them on the shore side of the pathway where they are visible to pathway users and do not obstruct pathway use.
- Signs must be a minimum size of 8.5- by 11-inch and protected from constructed of durable weather-resistant material.

5. Treatment Oversight and Monitoring

5.1. Treatment Oversight

Herrera will assist the Black Lake Special District with the selection of an experienced contractor to perform the alum treatment. The alum treatment will be observed by a qualified Resident Engineer from Herrera during each day of treatment to record material quantities, observe application procedures, and modify application procedures if needed. Construction inspection forms with a summary of observations and monitoring results should be prepared on a daily basis. These forms will be presented in a treatment monitoring report (see Section 5.2) with additional documentation provided by the contractor. The Resident Engineer will obtain and review water quality data provided by a qualified Water Quality Monitor from Herrera on a regular basis. The treatment application will be terminated or modified as necessary to meet the technical specifications and water quality requirements specified in Section 5.

5.2. Water Quality Objectives

The Black Lake water quality data and phosphorus budget clearly show that internal phosphorus loading from lake sediments is the primary source of phosphorus used by cyanobacteria, and that control of internal phosphorus loading is needed to reduce the amount of phosphorus available to cyanobacteria in the lake during the summer growing season (Herrera 2015a). Net internal phosphorus loading to the lake varied greatly among the 3 study years, but consistently represented 60 percent (± 2 percent) of the total phosphorus loadings to the lake during the summer months (May through October).

Treatment goals and water quality objectives must be established to evaluate treatment effectiveness. The overall treatment goal for Black Lake is to prevent cyanobacteria blooms and lake closures for at least 5 years. Although it is not possible to reliably estimate the amount of phosphorus reduction needed to meet this goal, it is reasonable to establish treatment objectives based on lake trophic status. A reasonable objective for Black Lake is to decrease the trophic state from eutrophic to mesotrophic. Specific objectives for each trophic state parameter are compared to the recent lake status in Table 6-1.

Table 6-1. Alum Treatment Objectives for Summer Trophic Status in Black Lake.

		Five-Year Status (2010–2014)	
Parameter	Treatment Objective	Mean	Range
Trophic Class	Mesotrophic	Eutrophic	Meso-Eutrophic
Trophic State Index	< 50	54	50 to 56
Secchi Depth (meters)	> 2	1.9	1.5 to 2.8
Chlorophyll *a* (µg/L)	< 7.2	18.9	12.4 to 23.7
Total Phosphorus (µg/L)	< 24	29.0	24.3 to 34.6

To meet the treatment goal, the alum treatment is designed to significantly reduce internal phosphorus loading for at least 5 years. Successful treatments reduced internal loading by approximately 70 percent for at least 5 years (Cooke et al. 2005). Based on the phosphorus budget estimate of internal loading accounting for 60 percent total summer phosphorus input, a 70 percent reduction of internal loading in Black Lake would result in a 40 percent reduction in the total summer phosphorus input (70 percent reduction of 60 percent of the input). An equivalent reduction in summer mean phosphorus concentrations over the past 5 years, ranging from 24 to 35 µg/L (see Table 7-2), equates to post-treatment summer mean phosphorus concentrations ranging from 14 to 21 µg/L. This range is well below the treatment objective for total phosphorus at less than 24 µg/L (eutrophic threshold). A change in trophic status from eutrophic to mesotrophic is likely to reduce the amount and frequency of cyanobacteria blooms.

The chlorophyll objective will be more difficult to meet than the phosphorus objective because of the high chlorophyll to phosphorus ratio in Black Lake. Based on the phosphorus-chlorophyll relationship observed in Black Lake (see Figure 2-8), the 5-year summer mean chlorophyll *a* concentrations are predicted to be reduced from 12 to 24 µg/L to 11 to 14 µg/L. Thus, the predicted phosphorus reduction would not be sufficient to meet the treatment objective for chlorophyll *a* at less than 7.2 µg/L. While the treatment objectives are reasonable, predictions for meeting the objectives are not reliable given the weak relationships among tropic state parameters, potential changes in those relationships due to changes in the algal composition, and the unknown relationships between summer mean values and peak values observed during cyanobacteria blooms.

5.3. Water Quality Monitoring

Water quality monitoring will consist of jar tests, treatment monitoring, and post-treatment monitoring. A detailed water quality monitoring plan is presented in Appendix A.

5.3.1. Jar Test

Jar tests will be conducted on the first day of alum treatment. This testing will be performed for pH using the alum treatment chemicals, dose, and application method provided by the treatment contractor using water and water quality conditions present at the time of application. This large-scale jar test will be performed at the alum treatment staging area located at the WDFW boat launch on the east shore of Black Lake (see Figure 2-2).

A testing vessel (e.g., 5-gallon plastic bucket) will be filled with lake water and treated with aluminum sulfate and sodium aluminate directly taken from the supply trucks or storage tanks. As described in the monitoring plan, the jar test will be conducted using three ratios (1.9:1, 2.0:1, and 2.1:1) of alum and sodium aluminate to ensure correct buffering under current treatment conditions. A control bucket with only lake water will also be tested.

The pH of the collected lake water will be tested immediately before treatment and after 2 minutes, 15 minutes, 30 minutes, and 1 hour after dosing. Monitoring results will be recorded and immediately reported to the Resident Engineer.

5.3.2. Treatment Monitoring

For planning purposes, it is assumed that the treatment monitoring will be conducted over a 19-day period from April 11 through April 29, which will include the application of alum during up to 4 consecutive days.

Treatment monitoring will include the following three elements:

- Monitoring before and after the alum addition to evaluate short-term impacts of the treatment on various water quality parameters at established monitoring stations.
- Twice-daily monitoring (in the morning before treatment begins and in the afternoon or evening when treatment ends) to verify that pH criteria (between 6.0 and 8.7) and alkalinity criteria (greater than 12 mg/L) are met at established monitoring stations.
- Random monitoring of pH during the alum application at treatment sites will be conducted at least once every 2 hours at specific treatment locations and allowing for 1 hour of alum settling.

Short-term impact monitoring will consist of measuring field parameters, and collecting water samples from 1 meter below the water surface and 1 meter above the lake bottom at the south and north basin monitoring stations (see Figure 2-2). A total of four water samples will be collected from the lake on three occasions: 1) the day before the first day of treatment, 2) two days following the last day of treatment, and 3) two weeks following the last day of treatment. The collected samples will be analyzed for the following parameters:

- Secchi depth (field measurement)
- Temperature (field measurement at 1-meter intervals)
- Dissolved oxygen (field measurement at 1-meter intervals)
- pH (field measurement at 1-meter intervals)
- Conductivity (field measurement at 1-meter intervals)
- Total alkalinity
- Dissolved aluminum
- Total recoverable aluminum
- Sulfate
- Soluble reactive phosphorus
- Total phosphorus
- Chlorophyll *a*

Twice-daily monitoring will consist of measuring field parameters at the south and north basin stations (see Figure 2-2) in the morning before treatment begins, and in the afternoon or evening when treatment ends. The field parameters include Secchi depth and vertical profiles of temperature, dissolved oxygen, pH, and conductivity at 1-meter intervals. In addition, total alkalinity will be tested in the field on water samples collected from 1 meter below the water surface and 1 meter above the lake bottom at each station. If the pH is consistently less than 6.0 at a monitoring station, then the samples collected from that station will be analyzed for dissolved and total aluminum.

Random daily monitoring will consist of measuring pH at the treatment site during the alum application at a frequency of at least once every 2 hours. The pH will be measured at 1-meter intervals at the location where alum was applied approximately 1 hour before the time of sample collection. The 1 hour delay in sampling will allow for settling of the alum floc and stabilization of water quality conditions. If the pH is consistently less than 6.0 at a treatment site, then samples will be collected from 1 meter below the water surface and 1 meter above the lake bottom, and analyzed in the field for total alkalinity.

The alum treatment will be suspended if the pH is consistently less than 6.0 (± 0.05) or greater than 8.7 (± 0.05) in samples collected at the treatment sites or at the twice-daily monitoring stations. Additional monitoring will be conducted as necessary to determine when the lake pH and alkalinity have adequately recovered. Treatment may resume if the pH is between 6.2 and 8.4 (± 0.05) and the alkalinity is greater than 12 mg/L (± 0.5 mg/L) at all monitoring locations.

Observations of the alum treatment activities, floc formation, and potential fish and wildlife impacts will be made during random daily monitoring. All data and observations will be recorded and reported in the treatment monitoring report (Section 5.4).

In the event of a spill or treatment monitoring data that do not comply with the permit conditions, Ecology's Southwest Regional Office will be notified immediately. Pretreatment and post-treatment notification will be submitted to Ecology on a weekly basis as required by the permit. In addition, observations of fish or wildlife impacts will be immediately reported to Ecology and the Region 6 (Coastal) office of the Washington Department of Fish and Wildlife.

5.3.3. Post-Treatment Monitoring

It is anticipated that long-term water quality monitoring will be conducted for at least 5 years after the alum treatment has been completed. The objective of post-treatment monitoring will be to evaluate whether the alum treatment objectives for Black Lake are being met. Post-treatment monitoring will be conducted by Thurston County Environmental Health according to methods used historically to assess lake conditions and public health. Lake monitoring will occur once each month from May through October. Water samples will be collected near the lake surface and bottom at the south basin station for analysis of the following:

- Secchi depth (field measurement)
- Temperature, dissolved oxygen, pH, and conductivity profiles (field measurement)
- Total phosphorus and total nitrogen (laboratory analysis)
- Chlorophyll *a* (laboratory analysis)

If a cyanobacteria bloom is observed in Black Lake, Thurston County will collect scum samples from the lake for analysis of cyanotoxins and identification of phytoplankton species present in samples.

5.4. Reporting

Herrera will prepare a treatment report summarizing all observations and data collected for treatment oversight and water quality monitoring. Water quality monitoring results will include jar tests and treatment monitoring in spring 2016, and the first year of post-treatment monitoring in summer 2016. Field and laboratory results will be tabulated in spreadsheets that include associated data qualifiers for estimated values, rejected values, and values exceeding established thresholds, objectives, or water quality criteria. Data quality assurance reports should be prepared that summarize the following information:

- Changes in the monitoring plan
- Significant quality assurance problems and corrective actions
- Data quality assessment in terms of precision, accuracy, representativeness, completeness, comparability, and detection limits
- Discussion of whether the quality assurance objectives were met, and the resulting impact on decision-making
- Limitations on use of the measurement data.

The monitoring report will describe the treatment oversight and monitoring methods, present data tables, and discuss the monitoring results. Treatment monitoring results will be compared to the permit requirements and the short-term water quality impact of the alum treatment will be discussed. Post-treatment monitoring values will be evaluated by comparison with historical data and treatment objectives. Thurston County will report water quality conditions beyond the first year of post-treatment monitoring.

6. REFERENCES

Cooke, G.D., E.B. Welch, S.A. Peterson, and S.A. Nichols. 2005. Restoration and Management of Lakes and Reservoirs. 3rd ed. Taylor and Francis Group, Boca Raton, Florida.

Herrera. 2003. Green Lake Alum Treatment Study. Prepared for City of Seattle Parks and Recreation, Seattle, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington.

Herrera. 2004. Treatment Monitoring Report, Green Lake 2004 Alum Treatment. Prepared for the City of Seattle Parks and Recreation, Seattle, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. September 30, 2004.

Herrera. 2015a. Black Lake Phosphorus and Algae Control Plan. Prepared for Black Lake Special District, Olympia, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. June 16, 2015.

Herrera. 2015b. Phosphorus Management Plan, Green Lake Alum Treatment 2016. Prepared for the City of Seattle Parks and Recreation, Seattle, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. December 22, 2015.

Ecology. 2015. Water Quality, Aquatic Plant and Algae Management General Permit. Washington Department of Ecology, Olympia, Washington. Website address: <http://www.ecy.wa.gov/programs/wq/pesticides/final_pesticide_permits/aquatic_plants/permitdocs/Reissue2016/APAM2016DraftPermit.pdf>.

Pilgrim, K.M., B.J. Huser, P.L Bresonik. 2007. A Method for Comparative Evaluation of Whole-Lake and Inflow Alum Treatment. Water Research 41:1215–1224.

Rydin, E. and E.B. Welch. 2000. Amount of Phosphorus Inactivated by Alum Treatments in Washington Lakes. Linmol. Oceanogr. 45(1):226–230.

Sondergaard, M., J. P. Jensen, and E. Jeppesen. 2003. Role of Sediment and Internal Loading of Phosphorus in Shallow Lakes. Hydrobiologia 506–509:135-145.

Snohomish County. 2012. Lake Ketchum Algae Control Plan Technical Appendix. Snohomish County Surface Water Management Division, Everett, Washington. June 2016.

Tetra Tech. 2006. Long Lake, Thurston County Integrated Phosphorus Management Plan. Prepared for Long Lake management District, Thurston County Water and Waste Management, Olympia, Washington, by Tetra Tech, Inc., Seattle, Washington. December 2006.

Tetra Tech. 2010. Final Report on Long Lake Water Quality, 2006–2010. Prepared for Kitsap County and Citizens for Improving Long Lake, Kitsap County, Washington, by Tetra Tech, Inc., Seattle, Washington. December 2010.

Tetra Tech. 2012. Black Lake Integrated Aquatic Vegetation Management Plan. Prepared for Thurston County Department of Resource Stewardship by Tetra Tech, Inc., Seattle, Washington. August 2012. Website address: <http://saveblacklake.org/system/assets/general/Black%20Lake%20IAVMP_28AUG12_DRAFT%20with%20Appendices.pdf>.

Thurston County. 2012. Thurston County Water Resources Monitoring Report, 2009–2010 Water Year, 2010–2011 Water Year, Budd/Deschutes Watershed, WRIA 13. Thurston County Public Health and Social Services Department, Environmental Health Division and Thurston County Resource Stewardship Department, Water Resources Division, Olympia, Washington. August 2012. <http://www.co.thurston.wa.us/health/ehrp/pdf/AR10-11/AR09-10--AR10-11_Budd.pdf>.

Welch, E. B., and D. G. Cooke. 1999. Effectiveness and Longevity of Phosphorus Inactivation with Alum. Lake Res. Man. 15:5–27

APPENDIX A

Water Quality Monitoring Plan

WATER QUALITY MONITORING PLAN

BLACK LAKE ALUM TREATMENT

Prepared for
Black Lake Special District

Prepared by
Herrera Environmental Consultants, Inc.

HERRERA

Note:
Some pages in this document have been purposely skipped or blank pages inserted so that this document will copy correctly when duplexed.

WATER QUALITY MONITORING PLAN

BLACK LAKE ALUM TREATMENT

Prepared for
Black Lake Special District
120 State Avenue Northeast, No. 303
Olympia, Washington 98501

Prepared by
Herrera Environmental Consultants, Inc.
2200 Sixth Avenue, Suite 1100
Seattle, Washington 98121
Telephone: 206-441-9080

January 22, 2016

CONTENTS

1. Introduction 1

2. Project Description 3

2.1. Permit Restrictions and Relevant Criteria 3
2.2. Project Goals and Objectives 5

3. Project Organization and Responsibilities 7

3.1. Organization and Key Personnel 7
3.2. Schedule 8

4. Data Quality Objectives 9

4.1. Precision 9
4.2. Bias 11
4.3. Representativeness 11
4.4. Completeness 11
4.5. Comparability 11

5. Water Quality Monitoring Design 13

5.1. Lake Monitoring Locations 14
5.2. Jar Test 14
5.3. Treatment Monitoring 16
5.4. Post-Treatment Monitoring 17

6. Sample Collection Procedures 19

6.1. Equipment Decontamination 19
6.2. Field Notes 19
6.3. Sample Containers, Preservation, and Holding Times 20
6.4. Sample Identification and Labeling 20
6.5. Sample Handling 20

7. Analytical Procedures 21

8. Quality Control 23

8.1.1. Method Blanks 23
8.1.2. Control Standards 23
8.1.3. Matrix Spikes 23
8.1.4. Laboratory Duplicates 24

9. Data Management Procedures 25

9.1. Data Management 25
9.2. Documentation and Records 25
9.2.1. Field Operation Records 25

9.2.2. Laboratory Records 25
9.2.3. Data Handling Records 25
9.2.4. Revisions to the WQMP 26

10. Audits and Reports 27

10.1. Audits and Response Actions 27
10.2. Deficiencies, Nonconformance, and Corrective Action 27
10.3. Reporting 28
10.3.1. Data Quality Assurance Report 28
10.3.2. Treatment Report 28

11. Data Verification and Validation 31

11.1. Completeness 31
11.2. Methodology 31
11.3. Holding Times 32
11.4. Method Blanks 32
11.5. Reporting Limits 32
11.6. Duplicates 32
11.7. Matrix Spikes 32
11.8. Control Standards 32
11.9. Sample Representativeness 33

12. Data Quality (Usability) Assessment 35

13. References 37

TABLES

Table 1. Measurement Quality Objectives for Water Quality Data 10

Table 2. Water Quality Monitoring Design for the Black Lake Alum Treatment 13

Table 3. Jar Test Ratios and Amounts. 14

Table 4. Quality Control Requirements and Frequency for Water Quality Sample Analyses 23

Table 5. Quality Assurance Audit Schedule and Response Actions. 27

Table 6. Data Qualifier Definitions and Usage Criteria. 33

FIGURES

Figure 1. Black Lake Monitoring Stations 15

1. INTRODUCTION

Black Lake, located in Olympia, Washington, has high nutrient levels that result in cyanobacteria (blue-green algae) blooms. These blooms have occurred in most years since routine lake monitoring began in 1992. Water quality data collected by Thurston County since 1992 shows that Black Lake is eutrophic (high nutrients and algae) due to high phosphorus concentrations. Lake sediments are a primary source of the phosphorus during summer when it is released from iron as anoxic (no oxygen) conditions develop in the bottom waters. The excess phosphorus fuels excess cyanobacteria that float to the surface to form scums and often produce various cyanotoxins (chemicals which are toxic to humans, mammals, and waterfowl).

The Black Lake Special District is committed to improving water quality in Black Lake and funded preparation of the Black Lake Phosphorus and Algae Control Plan (Herrera 2015) to identify the measures needed to reduce phosphorus inputs to Black Lake. A water budget and phosphorus budget were developed for three study years (2010–2012) using an existing watershed model and lake water quality data. The water budget indicates that the primary sources of water flowing into Black Lake are surface inflows (77 percent) and shallow groundwater (14 percent) on an annual basis.

The phosphorus budget focused on the summer monitoring period (May through October) when lake data were available for calculating net internal loading from mass balance equations. On average, 60 percent of the total phosphorus loading during the summer months came from net internal loading, 35 percent came from surface inflows, and 5 percent came from shallow groundwater inflow. Because internal loading is a significant source of phosphorus in Black Lake during the summer algae bloom period, a whole lake alum dose was identified as the most appropriate method to inactivate mobile sediment phosphorus.

Three alternative alum treatment scenarios were considered that differ in the timing and dose of the treatment due to uncertainties in funding, permitting, and contractor availability. The Spring 2016 Full Treatment Scenario was selected as the preferred scenario because it was the least cost and allowed more time for proper planning, permitting, and funding.

This water quality monitoring plan has been written in support of the Black Lake Alum Treatment Plan (Treatment Plan), which is concurrently being prepared to refine the alum dose and cost estimate, and provide additional details about the treatment procedures and timing. Additional background information is provided in the Treatment Plan. This monitoring plan was prepared in accordance with Guidelines and Specifications for Preparing Quality Assurance Project Plans (Ecology 2004), and includes monitoring elements specified in Ecology's Aquatic Plant and Algae Management General Permit (Ecology 2015). This monitoring plan includes the following sections:

- Project description
- Project organization and responsibilities

- Data quality objectives
- Water quality monitoring design
- Sample collection procedures
- Analytical procedures
- Quality control
- Data management procedures
- Audits and reports
- Data verification and validation
- Data assessment (usability) assessment.

2. PROJECT DESCRIPTION

The alum application will occur on 3 to 4 consecutive days between April 11 and April 29, 2016. Liquid alum will be applied concurrently with liquid sodium aluminate as a buffer at a ratio of 2:1 by volume to ensure that the water pH does not decrease below 6.0. Sodium aluminate has been shown to be an effective buffer at this ratio, but the ratio may be adjusted depending on the chemical concentrations and results of on-site jar tests (to be implemented according to this monitoring plan). Treatment monitoring will be completed 2 weeks after the last day of alum application. Post-treatment monitoring will be conducted as part of routine lake monitoring by Thurston County.

The recommended total aluminum dose is 1.9 mg Al/L on a volumetric basis and 12.9 g Al/m2 on an areal basis. This will require approximately 53,560 gallons of liquid alum and 26,780 gallons of liquid sodium aluminate over 509 acres (i.e., area within the 5-foot depth contour). The materials will be delivered in tanker trucks to a parking lot and pumped to holding tanks staged near the Washington Department of Fish and Wildlife (WDFW) boat launch, located on the southeast shore of Black Lake.

Each material will be injected into the lake surface waters from a boat or barge at a specified rate to ensure an even application at the recommended dose. The recommended dose is anticipated to meet water quality goals for at least 5 years, based on comparison to successful treatments for lakes located in relatively undeveloped watersheds like Black Lake (Herrera 2015).

2.1. Permit Restrictions and Relevant Criteria

The alum treatment will be conducted in accordance with Ecology's Aquatic Plant and Algae Management General Permit (Ecology 2015). This permit is currently being revised and the draft permit does not include any revisions to restrictions for alum treatments. Permit restrictions for alum treatments (see Table 4 in Ecology 2015) include:

- Timing restrictions:
  - None for fish or other priority species.
  - Early spring or fall treatment if aquatic plant biomass interferes with inactivation of sediment phosphorus.
- Lake use restrictions or advisories:
  - None.
- Treatment restrictions:
  - Application must cease when wind speed is greater than 15 miles per hour.
  - Powdered alum must be mixed with water to form a slurry before applying to the water surface.

  - The pH of lake water during treatment must remain between 6.0 and 8.5 based on lake average.
  - Only aluminum compounds suitable for water treatment may be used.
  - Buffering materials must be available for use.

- Monitoring requirements:
  - Minimum monitoring is one surface water pH measurement in the morning prior to any alum addition and one surface water pH measurement 1 hour after alum addition has stopped for that day.
  - Monitoring for pH must continue for the duration of the treatment and for 24 hours following treatment completion.
  - Monitoring locations must be representative of water body-wide conditions.

- Other restrictions:
  - A jar test must be completed prior to whole lake treatments only if a buffer other than sodium aluminate is used or a ratio of liquid alum to liquid sodium aluminate differs from 2:1 by volume.
  - An on-site storage facility is required for any treatment requiring 9,000 gallons of alum or more, or the project proponent must have a plan to store any unused alum or buffering products.

The general permit allows for short- and long-term exceedance of Washington State Surface Water Quality Standards (WAC 173-201A) provided that the Permittee complies with any short-term modifications of water quality criteria authorized by Ecology in writing. Water quality degradation is allowed if the degradation does not significantly interfere with or become injurious to existing or designated water uses, or cause long-term harm to the environment (WAC-173-201A-410).

As for all undesignated lakes in Washington, Black Lake is to be protected for the designated uses of: core summer salmonid habitat and extraordinary primary contract recreation. The following parameters with associated surface water quality criteria will be monitored to evaluate short-term water quality impacts:

- Water temperature – The 7-day average of the daily maximum temperatures (7-DADMax) shall not exceed 16 °C, and human actions considered cumulatively shall not increase the 7-DADMax temperature more than 0.3°C if the natural temperature exceeds 16°C.

- Dissolved oxygen: The 1-day minimum dissolved oxygen concentration shall exceed 9.5 mg/L, and human actions considered cumulatively shall not decrease the dissolved oxygen concentration more than 0.2 mg/L

- pH: The pH shall be within the range of 6.5 to 8.5, with a human-caused variation within this range of less than 0.2 units

In addition, the National Recommended Water Quality Criteria for the protection of freshwater aquatic life (EPA 2015a) include the following criteria for total aluminum:

- Criteria maximum concentration (acute criterion) of 0.750 mg/L

- Criteria continuous concentration (chronic criterion) of 0.087 mg/L.

2.2. Project Goals and Objectives

Water quality monitoring will be conducted at Black Lake to protect aquatic biota during the 2016 alum treatment, and to evaluate the short-term and long-term effects of the treatment. The goals of water quality monitoring under this plan are to:

- Conduct a jar test before the alum treatment and measure pH in Black Lake during the alum treatment to ensure that pH levels exceed 6.0 for protection of aquatic biota from aluminum toxicity
- Collect water quality data before, during, and after the treatment to evaluate the short-term water quality effects of the alum treatment in the lake to ensure that pH criteria (between 6.0 and 8.7) and alkalinity criteria (greater than 12 mg/L) are met for protection of aquatic biota from aluminum toxicity
- Collect post-treatment water quality data to evaluate the long–term effectiveness of the alum treatment in relation to water quality goals that have been established for Black Lake

Treatment monitoring will be performed to determine if the following short-term water quality objectives are met:

- Average lake pH shall be between 6.0 and 8.7
- Average lake alkalinity in the lake shall be greater than 12 mg/L

Post-treatment monitoring will be performed to determine if the following long-term water quality objectives are met for at least 5 years (2016 through 2021):

- Summer average total phosphorus concentration shall be less than 24 µg/L
- Summer average chlorophyll α concentration shall be less than 7.2 µg/L
- Summer average Secchi depth (clarity) shall be at least 2.0 meters (6.6 feet)
- The lake will not be closed to recreational uses due to toxic cyanobacteria

3. PROJECT ORGANIZATION AND RESPONSIBILITIES

This section describes how the project is organized, key personnel, and the project schedule.

3.1. Organization and Key Personnel

BLSD is responsible for oversight of the Treatment Plan and the alum treatment project. Herrera Environmental Consultants (Herrera) is responsible for engineering oversight of the alum treatment, implementing this water quality monitoring plan, including pretreatment jar testing and treatment monitoring activities. IEH Analytical Laboratories is responsible for conducting the laboratory analysis for the treatment monitoring samples, and is certified by Ecology for all of the identified analytical procedures. Thurston County is responsible for long-term monitoring as part of routine summer lake monitoring. Specific responsibilities of key personnel are identified below:

Black Lake Special District
120 State Avenue NE, No. 303
Olympia, Washington 98501
(360) 867-8814
info@blacklakespecialdistrict.org

Lake Stintzi, BLSD Project Manager

Herrera Environmental Consultants
2200 Sixth Avenue, Suite 1100
Seattle, WA 98121
(206) 441-9080

Rob Zisette, Herrera Project Manager, rzisette@herrerainc.com
Christina Avolio, P.E., Senior Engineer, cavolio@herrerainc.com
Anneliese Sytsma, Resident Engineer, asytsma@herrerainc.com
Alex Svendsen, Water Quality Monitoring Lead, asvendsen@herrerainc.com
Gina Catarra, Data Quality Assurance Officer, gcatarra@herrerainc.com

Thurston County
Environmental Health, Water Quality
412 Lilly Road NE
Olympia, WA 98506-5132
(360) 867-2643
venninj@co.thurston.wa.us

Jane Mountjoy-Venning, Surface Water Monitoring

IEH Analytical Laboratories
3927 Aurora Avenue North
Seattle, WA 98103
(206) 632-2715
damieng@iehinc.com

Damien Gadomski, Ph.D, Laboratory Project Manager

3.2. Schedule

Water quality monitoring activities for the 2016 Black Lake alum treatment project will primarily occur in April and May 2016 for short-term impact analysis, and continue during summer months for a period of at least 5 years for long-term impact analysis. Herrera will complete the jar test and treatment monitoring tasks. Post-treatment monitoring will be completed by Thurston County as part of their routine summer lake monitoring. The following monitoring activities will occur according to the schedule indicated:

- Jar Test: April 2016 (day prior to alum application).
- Treatment Monitoring: April through May 2016
  - Short-term Impact: Day before the first day of treatment, 2 days following last day of treatment, and 2 weeks following the last day of treatment.
  - Twice Daily: Morning and afternoon from first to last day of treatment.
  - Hourly: During alum application.
- Post-treatment Monitoring: Once a month from May through October for at least 5 years (2016 through 2021).

4. Data Quality Objectives

The goal of this monitoring plan is to ensure that the data collected for this study are scientifically accurate, useful for the intended analysis, and legally defensible. To achieve this goal, the collected data will be evaluated relative to the following indicators of quality assurance:

- **Precision**: A measure of the variability in the results of replicate measurements due to random error
- **Bias**: The systematic or persistent distortion of a measurement process that causes errors in one direction (for example the measured mean is different from the true value)
- **Representativeness**: The degree to which the data accurately describe the conditions being evaluated based on the selected sampling locations, sampling frequency and duration, and sampling methods
- **Completeness**: The amount of data obtained from the measurement system
- **Comparability**: The ability to compare data from the current study to data from other similar studies, regulatory requirements, and historical data

Measurement quality objectives (MQOs) are performance or acceptance criteria that have been established for each of these quality assurance indicators. These MQOs are described below and summarized in Table 1. Note that the term "reporting limit" in this document refers to the practical quantification limit established by the laboratory, not the method detection limit.

4.1. Precision

Precision will be assessed by laboratory duplicates. These will be assessed using relative percent difference (*RPD*) as calculated using the following equation:

$$RPD = \left(\frac{\left| C_1 - C_2 \right|}{C_1 + C_2} \right) \times 200\%$$

Where: RPD = Relative percent difference

C_1 and C_2 = Concentration values

If either the sample or duplicate sample is at or below the reporting limit the MQO cannot be calculated. *RPD* values exceeding those identified in Table 1 will trigger an assessment as to whether there are any problems with laboratory methodology, which might warrant remediation.

Table 1. Measurement Quality Objectives for Water Quality Data.

Parameter	Analytical Method	Method Number	Maximum Holding Time	Reporting Limit Target and Unit	Method Blank	Control Standard Recovery	Matrix Spike Recovery	Laboratory Duplicate RPD
Laboratory Analysis								
Total alkalinity	Titrimetric, pH 4.5	EPA 310.1	14 days	1.0 mg/L $CaCO_3$	≤ RL	80–120%	NA	≤ 20%
Dissolved aluminum	ICP-MS	EPA 200.8	6 months[b]	0.003 mg/L	≤ RL	85–115%	80–120%	≤ 20%
Total aluminum	ICP	EPA 200.7	6 months	0.100 mg/L	≤ RL	90–110%	75–125%	≤ 20%
Sulfate	Turbidimetric	EPA 375.4	28 days	1.00 mg/L	≤ RL	80–120%	75–125%	≤ 20%
Soluble reactive phos.	Auto. ascorbic acid	EPA 365.1	48 hours[b]	0.001 mg/L	≤ RL	80–120%	75–125%	≤ 20%
Total phosphorus	Auto. ascorbic acid	EPA 365.1	28 days	0.002 mg/L	≤ RL	80–120%	75–125%	≤ 20%
Chlorophyll *a*	Spectrophotometric	SM 10200 H	28 days	0.1 µg/L	≤ RL	NA	NA	≤ 20%
Field Analysis								
Total alkalinity	Titrimetric, pH 4.5	EPA 310.1	1 day	1.0 mg/L $CaCO_3$	NA	NA	NA	NA
Secchi depth	20-cm disc	NALMS 1995	*in situ*	0.1 m	NA	NA	NA	NA
Temperature	Electrode	Field meter	*in situ*	± 0.2 °C	NA	NA	NA	NA
Dissolved oxygen	Electrode	Field meter	*in situ*	± 0.2 mg/L	NA	NA	NA	NA
pH	Electrometric	Field meter	*in situ*	± 0.2 std. units	NA	NA	NA	NA
Conductivity	Platinum electrode	Field meter	*in situ*	± 0.005 mS/cm	NA	NA	NA	NA

[a] Method numbers from APHA (1998) and EPA (1983).

[b] Samples must be filtered within 48 hours.

NA = not applicable, RL = reporting limit, RPD = relative percent difference.

4.2. Bias

Bias will be assessed based on analyses of method blanks, matrix spikes, and laboratory control samples (LCS). The values for method blanks will not exceed the reporting limit. The acceptable percent recoveries for matrix spikes and LCS are identified for each parameter in Table 1. Percent recovery will be calculated using the following equation:

$$\%R = \frac{(S - U)}{C_{sa}} \times 100\%$$

Where:	%R	=	Percent recovery
	S	=	Measured concentration in spike sample
	U	=	Measured concentration in unspiked sample
	C_{sa}	=	Actual concentration of spike added

If the analyte is not detected in the unspiked sample, then a value of zero will be used in the equation.

Percent recovery for LCS will be calculated using the following equation:

$$\%R = \frac{M}{T} \times 100\%$$

Where:	%R	=	Percent recovery
	M	=	Measured value
	T	=	True value

4.3. Representativeness

Sample representativeness will be ensured by employing consistent and standard sampling procedures.

4.4. Completeness

Completeness will be assessed based on the percentage of specified samples (listed in this QAPP) collected. The completeness goal shall be 90 percent. Completeness for acceptable data is defined as the percentage of acceptable data out of the total amount of data generated. Acceptable data is either data that passes all QC criteria, or data that may not pass all QC criteria but has appropriate corrective actions taken.

4.5. Comparability

Standard sampling procedures, analytical methods, units of measurement, and reporting limits will be applied in this study to meet the goal of data comparability. The results will be tabulated in standard spreadsheets to facilitate analysis and comparison with water quality threshold limits (e.g., permit restrictions and water quality criteria), where appropriate.

5. WATER QUALITY MONITORING DESIGN

Water quality monitoring will include the following three components: jar test, treatment monitoring, and post-treatment monitoring. A jar test using the specified dose will be conducted on site immediately prior to the first day of alum treatment to verify that the lake pH will exceed 6.0 during the treatment. Treatment monitoring will include various elements to evaluate short-term effects of the treatment. Post-treatment monitoring will be conducted during subsequent summers over a period of at least 5 years to evaluate the long-term effects of alum treatment. The following sections describe the sampling locations and the design of each monitoring component. The overall monitoring design is summarized in Table 2.

Table 2. Water Quality Monitoring Design for the Black Lake Alum Treatment.

Monitoring Component	Sampling Locations[a]	Analytical Parameters	Sampling Frequency
Pretreatment Jar Test	WDFW boat launch	Alkalinity, pH	Three or more tests as needed
Treatment Monitoring			
Short-term impact	North Basin station, South Basin station (surface, bottom)	Alkalinity, dissolved Al, total Al, sulfate, TP, SRP, chlorophyll a, Secchi depth, temperature/DO/pH/conductivity profile	Day before treatment, and 2 days and 2 weeks after treatment
Twice daily	North Basin station, South Basin station (surface, bottom)	Alkalinity (field), dissolved and total Al (if pH is less than 6.0), Secchi depth, temperature/DO/pH/conductivity profile	Morning before and evening after each day of treatment
Random daily	Treatment sites (surface, bottom)	pH profile and alkalinity (if pH is less than 6.0)	At least every 2 hours during treatment
Post-Treatment Monitoring	South Basin station (surface, bottom)	Secchi depth, TP, TN, chlorophyll a, temperature/DO/pH/conductivity profile	Monthly from May through October for at least 5 years

Al = aluminum

TP = total phosphorus

SRP = soluble reactive phosphorus

DO = dissolved oxygen

[a] Treatment sampling stations include North Basin and South Basin at 1 meter below water surface and 1 meter above lake bottom. The post-treatment sampling station is the South Basin at 0.5 meter below water surface and 1 meter above the lake bottom; a composite sample will be collected from 1, 2, and 3 meters below the water surface for chlorophyll α analysis.

[b] Dissolved and total aluminum will be analyzed only if the pH is less than 6.0.

5.1. Lake Monitoring Locations

Water quality monitoring will be conducted at two stations on Black Lake that have been used for previous monitoring projects to allow for comparison to historical data. The monitoring stations include (Figure 1):

- North Basin (NB-2) station: Located in the center of the northern basin in Black Lake, at a depth of approximately 23 feet.
- South Basin (SB-1) station: Located at the deepest (approximately 29 feet) point of the southern basin in Black Lake, along the southeast shore.

In addition, the pretreatment jar test will be conducted at the treatment staging area, which is located at the WDFW boat launch.

5.2. Jar Test

Jar tests will be conducted on the first day of alum treatment. This testing will be performed for pH using the alum treatment chemicals, dose, and application method described in the Treatment Plan using water and water quality conditions present at the time of application. This large-scale jar test will be performed at the alum treatment staging area located near the WDFW boat launch (see Figure 1).

A testing vessel (e.g., 5-gallon plastic bucket) will be filled with lake water and treated with aluminum sulfate and sodium aluminate directly taken from the supply trucks or storage tanks. As shown in Table 3, the jar test will be conducted using three ratios (1.9:1, 2.0:1, and 2.1:1) of alum and sodium aluminate to ensure correct buffering under current treatment conditions. A 1,000 microliter pipet will be used to inject the materials into 16 liters of lake water to achieve the 1.9 mg Al/L dose. The material amounts in Table 3 are based on a concentration of 4.2 percent of soluble aluminum for the alum and 32 percent of soluble $NaAlO_2$ for the sodium aluminate, and will be adjusted as necessary if different material concentrations are obtained. A control bucket with only lake water will also be tested.

Table 3. Jar Test Ratios and Amounts.

Sample ID	Test Ratio[a]	Water (L)	Aluminum Sulfate (mL)	Sodium Aluminate (mL)
Test 1	2.1:1	16	0.242	0.115
Test 2	2.0:1	16	0.230	0.115
Test 3	1.9:1	16	0.219	0.115
Control	NA	16	0.00	0.00

[a] Ratio of liquid aluminum sulfate (at 4.2 percent aluminum) to sodium aluminate (at 32 percent sodium aluminate).

L = liters.

The pH of the collected lake water will be tested immediately before treatment and after 2 minutes, 15 minutes, 30 minutes, and 1 hour after dosing. Monitoring results will be recorded and immediately reported to the Herrera Resident Engineer.

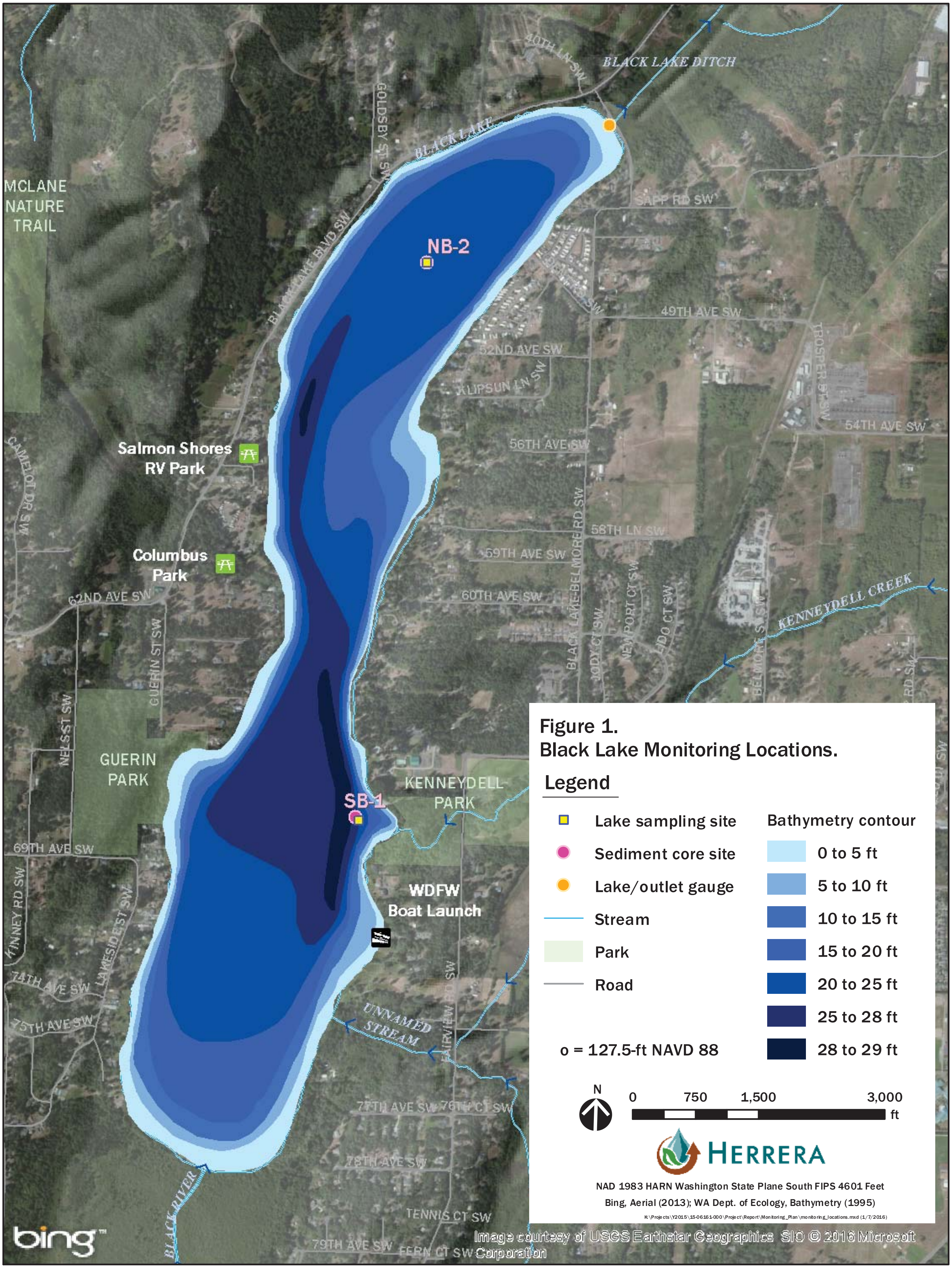


Figure 1.
Black Lake Monitoring Locations.

5.3. Treatment Monitoring

Treatment monitoring will be conducted by Herrera over a 3-week period, which will include the application of alum during approximately 4 days. Water quality monitoring for the treatment component is anticipated to occur in April 2016.

Treatment monitoring will include the following three elements:

- Monitoring before and after the alum addition to evaluate short-term impacts of the treatment on various water quality parameters at established monitoring stations.
- Twice-daily monitoring (in the morning before treatment begins and in the afternoon or evening when treatment ends) to verify that pH criteria (between 6.0 and 8.7) and alkalinity criteria (greater than 12 mg/L) are met at established monitoring stations.
- Random monitoring of pH and alkalinity during the alum application at treatment sites will be conducted at least once every 2 hours at specific treatment locations and allowing for 1 hour of alum settling.

Short-term impact monitoring will consist of measuring field parameters and collecting water samples from 1 meter below the water surface and 1 meter above the lake bottom at each of the following two stations: North Basin and South Basin stations. A total of four water samples will be collected from the lake on three occasions: 1) the day before the first day of treatment, 2) two days following the last day of treatment, and 3) two weeks following the last day of treatment. The collected samples will be analyzed for the following parameters:

- Secchi depth (field measurement)
- Temperature (field measurement at 1-meter intervals)
- Dissolved oxygen (field measurement at 1-meter intervals)
- pH (field measurement at 1-meter intervals)
- Conductivity (field measurement at 1-meter intervals)
- Total alkalinity
- Dissolved aluminum
- Total recoverable aluminum
- Sulfate
- Soluble reactive phosphorus
- Total phosphorus
- Chlorophyll *a*.

Twice-daily monitoring will consist of measuring field parameters at the North Basin and South Basin stations in the morning before treatment begins, and in the afternoon or evening when treatment ends. The field parameters include Secchi depth and vertical profiles of temperature, dissolved oxygen, pH, and conductivity at 1-meter intervals. In addition, total alkalinity will be tested in the field on water samples collected from 1 meter below the water surface and 1 meter above the lake bottom at each of the three stations. If the pH is consistently less than 6.0 at a monitoring station, then the samples collected from that station will be analyzed for dissolved and total aluminum.

Random daily monitoring will consist of measuring pH at the treatment site during the alum application at a frequency of at least once every 2 hours. The pH will be measured at 1-meter intervals at the location where alum was applied approximately 1 hour before the time of sample collection. The 1 hour delay in sampling will allow for settling of the alum floc and stabilization of water quality conditions. If the pH is consistently less than 6.0 at a treatment site, then samples will be collected from 1 meter below the water surface and 1 meter above the lake bottom, and analyzed in the field for total alkalinity.

The alum treatment will be suspended if the pH is consistently less than 6.0 (± 0.05) or greater than 8.7 (± 0.05) in samples collected at the treatment sites or at the twice-daily monitoring stations. Additional monitoring will be conducted as necessary to determine when the lake pH and alkalinity have adequately recovered. Treatment may resume if the pH is greater than 6.2 and 8.4 (± 0.05) and the alkalinity is greater than 12 mg/L (± 0.5 mg/L) at all monitoring locations.

Observations of the alum treatment activities, floc formation, and potential fish and wildlife impacts will be made during random daily monitoring.

In the event that treatment monitoring data do not comply with the permit terms and conditions, Ecology's Northwest Regional Office will be notified immediately. In addition, observations of fish or wildlife impacts will be immediately reported to the Region 6 (Coastal) office of Washington Department of Fish and Wildlife (WDFW).

5.4. Post-Treatment Monitoring

It is anticipated that long-term water quality monitoring will be conducted by Thurston County Environmental Health for at least a 5-year period after the alum treatment has been completed. The objective of post-treatment monitoring will be to evaluate whether the total phosphorus goal (summer mean value less than 24 µg/L), chlorophyll α goal (summer mean value less than 7.2 µg/L), and Secchi depth goal (summer mean value greater than 2.0 meters) for Black Lake are being met.

Monitoring will occur once each month from May through October, beginning in May 2016. Post-treatment monitoring will consist of measuring field parameters and collecting water samples from 0.5 meter below the water surface and 1 meter above the lake bottom from the South Basin station. The samples will be analyzed for the following parameters:

- Secchi depth (field measurement)
- Temperature (field measurement at 1-meter intervals)
- Dissolved oxygen (field measurement at 1-meter intervals)
- pH (field measurement at 1-meter intervals)
- Conductivity (field measurement at 1-meter intervals)
- Total phosphorus
- Total nitrogen

Chlorophyll α will be measured in composite water samples typically collected from depths of 1, 2, and 3 meters, representing the epilimnion or surface layer of the lake.

In addition, if a cyanobacteria bloom is observed in Black Lake, Thurston County will collect scum samples from the lake for analysis of cyanotoxins and identification of phytoplankton species present in samples.

6. SAMPLE COLLECTION PROCEDURES

Measurements for field parameters will be made prior to the collection of water samples during treatment and post-treatment monitoring. Water temperature, dissolved oxygen, pH, and conductivity will be measured in situ by lowering the probe of a portable, multi-parameter water quality meter from a boat to record values at 1-meter intervals from the water surface to the lake bottom. The water quality meter will be calibrated according to the manufacturer's directions and following standard measurement procedures (APHA 1998).

Secchi depth will be measured by using a Secchi disk measuring 20 centimeters in diameter according to standard measurement procedures (NALMS 1995). The Secchi disk will be lowered from the sunny side of the boat to the depth where the disk disappears from view and raised to the depth where the disk reappears. Secchi depth is the average depth of the disk disappearance and reappearance. An underwater viewer (viewscope) will not be used during the measurement.

Water samples will be collected by deploying a clean Van Dorn sampler or similar sampling device from a boat. The sampler will be opened, lowered to the desired depth, and then closed by releasing the messenger.

For treatment monitoring, water samples will be collected from 1 meter below the lake surface and 1 meter above the lake bottom at treatment sites and two monitoring stations. Sample bottles will be filled directly from the Van Dorn sampler.

For post-treatment monitoring, water samples will be collected from 0.5 meter below the lake surface and 1 meter above the lake bottom at the South Basin station on each sampling event. Sample bottles will be filled directly from the Van Dorn sampler.

The following quality control procedures will be used in the field to ensure that data quality objectives are met.

6.1. Equipment Decontamination

The Van Dorn water sampler and any other sampling equipment will be decontaminated before each day of use. The equipment will be scrubbed with a brush and phosphate-free detergent (e.g., Liquinox®), and thoroughly rinsed with potable water followed by deionized water. Cleaned sampling equipment will be protected from contamination and will be rinsed with lake water prior to the collection of each sample.

6.2. Field Notes

At each water quality monitoring station, the following information will be recorded in a waterproof bound field notebook:

- Sample identification (ID)
- Sampling date
- Name of sampler

- Time of sample collection, measurement, or observation
- Station location
- Weather conditions
- Calibration results for field instruments
- Field measurements
- Number and type of samples collected
- Unusual conditions (e.g., oily sheen, odor, color, fish kill)
- Modifications of or unusual sampling procedures.

6.3. Sample Containers, Preservation, and Holding Times

Pre-cleaned sample containers will be obtained from the analytical laboratory for the required analyses. Spare sample containers will be carried by the sampling team in case of breakage or possible contamination. Sample containers, preservation techniques, and holding times will follow the analytical method requirements and US EPA guidelines (EPA 2015b).

6.4. Sample Identification and Labeling

Short-term and twice-daily samples will be identified by its station number (NB-2 or SB-1), depth (S for surface or B for bottom), and the date and time of collection in military format. For example, a sample collected from 1 meter depth at station NB-2 on April 16 at 8:00 am would be identified as sample NB-2-S-041616-0800. Random daily samples collected from treatment sites will be identified as the daily number of the treatment sample (T1, T2, etc.), and the date and time of collection in military format.

Prior to filling, sample containers will be labeled with the following information using indelible ink:

- Sample ID
- Date of collection (month/day/year)
- Time of collection (military format)
- Project ID (Black Lake)
- Company/sampler initials.

Labels on glass containers will be secured with clear adhesive tape.

6.5. Sample Handling

To minimize contamination, laboratory containers without preservative will be rinsed twice with sample water before filling. Samples will be stored at 4° C in a cooler and transported to the laboratory within 12 hours of collection. A chain-of-custody record will accompany the samples that clearly identifies the analytical parameters and methods.

7. ANALYTICAL PROCEDURES

Analytical methods are presented in Table 1 for field and laboratory parameters. Also included in Table 1 are the target reporting limits, units of measurement, and maximum sample holding times.

Field measurements of Secchi depth will be conducted using a 20-centimeter Secchi disk according to standard measurement procedures (NALMS 1995) (see Section 6). Field measurements of temperature, dissolved oxygen, pH, and conductivity will be conducted using a portable meter operated according to the manufacturer's directions and following standard measurement procedures (APHA 1998).

Laboratory analytical procedures will follow US EPA approved methods (APHA 1998; EPA 1983, 2015b). These methods provide detection limits that are below the state and federal regulatory criteria or guidelines, and will enable direct comparison of analytical results with these criteria.

The laboratory identified for this project (IEH Analytical Laboratories) is certified by Ecology for each of the analytical parameters, and participates in audits and inter-laboratory studies by Ecology and EPA. These performance and system audits have verified the adequacy of the laboratory standard operating procedures, which include preventative maintenance and data reduction procedures.

The laboratory will report the analytical results within 30 days of receipt of the samples. If necessary, the laboratory will provide draft results within hours of receipt of the samples. Sample and quality control data will be reported in a standard format. The reports will also include a case narrative summarizing any problems encountered in the analyses.

8. QUALITY CONTROL

Quality control procedures are identified below for laboratory activities. The overall objective of these procedures is to ensure that data collected for this project are of a known and acceptable quality. Quality control procedures that will be implemented in the laboratory are described in the following subsections. The frequency and type of quality control samples to be analyzed by the laboratory are summarized in Table 4.

Table 4. Quality Control Requirements and Frequency for Water Quality Sample Analyses.

Parameter	Laboratory Method Blanks	Laboratory Control Standard	Matrix Spike	Lab Duplicates
Total alkalinity	1/batch[a]	1/batch[a]	NA	1/batch[a]
Dissolved aluminum	1/batch[a]	1/batch[a]	1/batch[a]	1/batch[a]
Total recoverable aluminum	1/batch[a]	1/batch[a]	1/batch[a]	1/batch[a]
Sulfate	1/batch[a]	1/batch[a]	1/batch[a]	1/batch[a]
Soluble reactive phosphorus	1/batch[a]	1/batch[a]	1/batch[a]	1/batch[a]
Total phosphorus	1/batch[a]	1/batch[a]	1/batch[a]	1/batch[a]
Chlorophyll *a*	1/batch[a]	NA	NA	1/batch[a]

NA = not applicable.

[a] Laboratory quality assurance samples will be analyzed with each batch of samples submitted to the laboratory for analysis. A laboratory batch will consist of no more than 20 samples.

8.1.1. *Method Blanks*

Method blanks consisting of deionized and micro-filtered pure water will be analyzed with every laboratory sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. Blank values will be presented in each laboratory report.

8.1.2. *Control Standards*

Control standards for each parameter will be analyzed by the laboratory with every sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. Control standard values and percent recovery will be presented in each laboratory report.

8.1.3. *Matrix Spikes*

For applicable parameters, matrix spikes will be analyzed by the laboratory with every sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. Matrix spike values and percent recovery will be presented in each laboratory report.

8.1.4. Laboratory Duplicates

Laboratory duplicate samples will be analyzed by the laboratory with every sample batch. A laboratory sample batch will consist of no more than 20 samples and may include samples from other projects. Laboratory duplicate values and percent recovery will be presented in each laboratory report.

9. DATA MANAGEMENT PROCEDURES

This section discusses data management, which addresses the path of data from recording in the field or laboratory to final use and archiving. The data management and documentation strategy provides for consistency when collecting, assessing, and documenting environmental data and electronic storage of all documents and records on servers that are regularly backed up.

9.1. Data Management

The laboratory will report the analytical results within 30 days of receipt of the samples. The laboratory will provide sample and quality control data in standardized reports that are suitable for evaluating the project data. These reports will include all data including raw quality assurance results, and all quality control results associated with the data. The reports will also include a case narrative summarizing any problems encountered in the analyses, corrective actions taken, changes to the referenced method, and an explanation of data qualifiers. Laboratory analytical and quality assurance sample results will be delivered from the laboratory in both electronic and hardcopy form.

Both the laboratory and Herrera will retain project related data for 5 years after completion of the project.

9.2. Documentation and Records

Four types of documentation will be managed: 1) field operation records, 2) laboratory records, 3) data handling records, and 4) QAPP revision documentation.

9.2.1. Field Operation Records

Field operation records may include data sheets and field notes, and photographs taken of the described activities (when taken).

9.2.2. Laboratory Records

Laboratory records will include a data package (lab report in Excel® format). Hardcopy laboratory reports will not be issued by the project laboratory.

9.2.3. Data Handling Records

All documents associated with a sampling event will be stored electronically. Paper copies will not be archived. Each sampling event will be documented with the following records:

- Chain-of-Custody (COC)
- Field Reports (field notes)
- Data Package

All documents will be provided in portable document format (PDF) with the exception of the lab reports, which will be in Excel® format.

9.2.4. Revisions to the WQMP

In the event that significant changes to this WQMP are required prior to the completion of the study, a revised version of the document (with changes tracked) shall be prepared and submitted to the BLSD Project Manager for review. The approved version of the WQMP shall remain in effect until the revised version has been approved. Justifications, summaries, and details of expedited changes to the WQMP will be documented in the monitoring report.

10. AUDITS AND REPORTS

The following section describes the procedures used to ensure that this WQMP is implemented correctly and that the data generated is of sufficient quality to meet the project objectives, and that corrective actions, if necessary, are implemented in a timely manner. The procedures include audits and response actions; deficiencies, nonconformances, and corrective actions; and reports to management.

10.1. Audits and Response Actions

Audits will be conducted for field, laboratory, and data management activities, following the schedule outlined below in Table 5.

Table 5. Quality Assurance Audit Schedule and Response Actions.

Assessment Activity	Approximate Schedule	Responsible Party	Scope	Response Requirements
Field Measurement Audit	Within 7 days of completion of sampling event	Data QA Officer	Review of field notes and data	Annotate field notes and notify field staff within 1 day
Laboratory Measurement Audit	Within 2 days of receiving laboratory data reports	Data QA Officer	Review analytical and quality control procedures employed at laboratory	Laboratory to respond in writing within 3 days to address corrective actions
Data Entry Audit	Within 7 days of data entry	WQ Monitoring Lead	Review all data entry values	Correct errors and repeat audit until no error found

10.2. Deficiencies, Nonconformance, and Corrective Action

The Herrera Project Manager is responsible for implementing and tracking corrective action procedures as a result of audit findings by the Data QA Officer. Records of audit findings and corrective actions are maintained by the Data QA Officer in the project file. Documentation of quality assurance issues will be made by the Data QA Officer in the project file and in quality assurance worksheets, if applicable.

Upon completion of an audit, the results will be reviewed to determine if a deficiency has occurred, and whether the deficiency is classified as a nonconformance. Deficiencies are defined as unauthorized deviations from procedures documented in the WQMP. Nonconformances are deficiencies which affect data quality and render the data unacceptable or indeterminate. Deficiencies related to field and laboratory measurement systems include but are not limited to instrument malfunctions and quality control sample failures.

The Herrera Project Manager, in consultation with the Data Quality Assurance Officer (and other affected individuals/organizations), will determine if the deficiency constitutes a nonconformance. If it is determined a nonconformance does exist, the Herrera Project Manager, in consultation with the QA Officer, will determine the disposition of the nonconforming data or activity and necessary corrective action(s). Corrective actions may include the qualification of the data as estimates (J) or rejected (R). If the data is qualified as rejected (R), additional corrective actions may include collection of additional samples or reanalysis of the existing samples as authorized by the BLSD Project Manager.

10.3. Reporting

10.3.1. Data Quality Assurance Report

The Herrera Data Quality Assurance Officer (see Project Organization and Schedule section) will provide an independent review of the laboratory QC data from each sampling event using the MQOs that have been identified in this WQMP. A data quality assurance report will be prepared that summarize the following information:

- Changes in the monitoring plan
- Significant quality assurance problems and corrective actions
- Data quality assessment in terms of precision, accuracy, representativeness, completeness, comparability, and detection limits
- Discussion of whether the quality assurance objectives were met, and the resulting impact on decision-making
- Limitations on use of the measurement data.

10.3.2. Treatment Report

Herrera will prepare a treatment report presenting and summarizing all observations and data collected for treatment oversight and water quality monitoring. Water quality monitoring results will include jar tests and treatment monitoring in spring 2016. All post-treatment water quality monitoring will be conducted by Thurston County as part of routine summer lake monitoring, and those results will not be evaluated or reported by Herrera. Field and laboratory results will be tabulated in spreadsheets that include associated data qualifiers for estimated values, rejected values, and values exceeding established thresholds, objectives, or water quality criteria. A data quality assurance memorandum will be prepared that summarize the following information:

- Changes in the monitoring plan
- Significant quality assurance problems and corrective actions
- Data quality assessment in terms of precision, accuracy, representativeness, completeness, comparability, and detection limits
- Discussion of whether the quality assurance objectives were met, and the resulting impact on decision-making
- Limitations on use of the measurement data.

The treatment report will describe the engineering oversight and water quality monitoring methods, and present the data and findings. Treatment oversight results will be presented and summarized, and any deviations from the technical specifications will be identified. Water quality monitoring results will be compared to the permit requirements, and the short-term water quality impact of the alum treatment will be discussed.

11. DATA VERIFICATION AND VALIDATION

Data will be reviewed and audited within 14 business days of receiving the results from the laboratory (see *Audits and Reports* section). This review will be performed to ensure that all data are consistent, correct and complete, and that all required quality control information has been provided. Specific quality control elements for the data (see Table 1) will also be examined to determine if the MQOs for the project have been met. Values associated with minor quality control problems will be considered estimates and assigned *J* qualifiers. Values associated with major quality control problems will be rejected and qualified *R*. Estimated values may be used for evaluation purposes, while rejected values will not be used. The following sections describe in detail the data validation procedures for these quality control elements:

- Completeness
- Methodology
- Holding times
- Method blanks
- Reporting limits
- Duplicates
- Matrix spikes
- Control standards
- Sample representativeness

11.1. Completeness

Completeness will be assessed by comparing valid sample data with this WQMP and the chain-of-custody records. Completeness will be calculated by dividing the number of valid values by the total number of values. If fewer than 95 percent of the samples submitted to the laboratory are judged to be valid, then more samples will be collected until at least 95 percent are judged to be valid.

11.2. Methodology

Methodologies for analytical procedures will follow US EPA approved methods (APHA 1998 US EPA 1983) specified in Table 1. Field procedures will follow the methodologies described in this WQMP. Any deviations from these methodologies will be documented in the treatment report.

11.3. Holding Times

Holding times for each analytical parameter in this study are summarized in Table 1. Holding time compliance will be assessed by comparing sample collection dates and times analytical dates and times.

Data from samples that exceed the specified maximum holding times by less than 2 times the holding time will be considered estimates (*J*). Data from samples that exceed the maximum holding times by more than 2 times holding time will be rejected values (*R*).

11.4. Method Blanks

Method blank values will be compared to the MQOs that have been identified for this project (see Table 1). If an analyte is detected in a method blank at or below the reporting limit, no action will be taken. If blank concentrations are greater than the reporting limit, the associated method blank data will be labeled with a *U* (in essence increasing the reporting limit for the affected samples), and associated project samples within 5 times the reporting limit will be flagged with a *J*.

11.5. Reporting Limits

Reporting limits will be presented in each laboratory report. If the proposed reporting limits are not met by the laboratory, the laboratory will be requested to reanalyze the samples or revise the method, if time permits. Proposed reporting limits for this project are summarized in Table 1.

11.6. Duplicates

Duplicate results exceeding the MQOs for this project (see Table 1) will be noted, and associated values may be flagged as estimates (*J*). If the objectives are severely exceeded (such as more than twice the objective), then associated values may be rejected (*R*).

11.7. Matrix Spikes

Matrix spike results exceeding the MQOs for this project (see Table 1) will be noted, and associated values may be flagged as estimates (*J*). However, if the percent recovery exceeds the MQOs and a value is less than the reporting limit, the result will not be flagged as an estimate. Non-detected values will be rejected (*R*) if the percent recovery is less than 10 percent.

11.8. Control Standards

Control standard results exceeding the MQOs for this project (see Table 1) will be noted, and associated values will be flagged as estimates (*J*). If the objectives are severely exceeded (such as more than twice the objective), then associated values may be rejected (*R*).

11.9. Sample Representativeness

The data collected for this study will be labeled with unique quality assurance flags for both laboratory and field data quality issues. Table 6 presents the flagging scheme that will be used in the reports produced for this project.

Table 6. Data Qualifier Definitions and Usage Criteria.

Data Qualifier	Definition	Criteria for Use
J	Value is an estimate based on analytical results.	MQOs for field duplicates, laboratory duplicates, matrix spikes, laboratory control samples, holding times, or blanks have not been met.
R	Value is rejected based on analytical results.	Major quality control problems with the analytical results.
U	Value is below the reporting limit.	Based on laboratory method reporting limit.
UJ	Value is below the reporting limit and is an estimate based on analytical results.	Based on laboratory method reporting limit; MQOs for analytical results have not been met.

12. DATA QUALITY (USABILITY) ASSESSMENT

Data quality assessment for this project will include applying the data quality objectives and sampling design, preparing summary tables, and drawing conclusions from the data. Conclusions from this monitoring project will be drawn based on comparisons with water quality standards and historical values.

13. REFERENCES

APHA. 1998. Standard Methods for the Examination of Water and Wastewater, 20th edition. American Public Health Association, Washington, DC.

Ecology. 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Publication No. 04-03-030. Washington Department of Ecology, Environmental Assessment Program, Manchester, Washington. July 2004.

Ecology. 2015. Water Quality, Aquatic Plant and Algae Management General Permit. Washington Department of Ecology, Olympia, Washington. Website address: <http://www.ecy.wa.gov/programs/wq/pesticides/final_pesticide_permits/aquatic_plants/aquatic_plant_permit_index.html>.

EPA. 1983. Methods for Chemical Analysis of Water and Wastes. EPA-600/4-79-020. US Environmental Protection Agency, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

EPA. 2015a. National Recommended Water Quality Criteria, Aquatic Life Criteria Table. US Environmental Protection Agency, Washington, DC. Data obtained November 9, 2015, from EPA website: <http://water.epa.gov/scitech/swguidance/standards/criteria/current/index.cfm>.

EPA. 2015b. Federal Register 40 CFR Part 136 – Guidelines for Establishing Test Procedures for the Analysis of Pollutants. US Environmental Protection Agency, Water Programs, Washington, D.C. Accessed on November 10, 2015 from US Government Publishing Office website: <http://www.ecfr.gov/cgi-bin/text-idx?SID=e409ed089dfb378924589b2b47d84a5a&mc=true&node=pt40.23.136&rgn=div5>.

Herrera. 2015. Black Lake Phosphorus and Algae Control Plan. Prepared for the Black Lake Special District, Olympia, Washington, by Herrera Environmental Consultants, Inc., Seattle, Washington. January 21, 2015.

NALMS. 1995. The Secchi Disk and the Volunteer Monitor. Lakeline, April 1995. North American Management Society, Madison, Wisconsin.