

Final Report (2 of 2) for:
Agreement: WQC-2015-CwCoHH-00129

Project Name: Water Quality Testing & Improvement at Two Cowlitz County Lakes

Recipient: Cowlitz County Health & Human Services

Total Cost of Project: \$143,028

Grant Amount: \$107,271

Project Start Date: 1/1/2015

Project End Date: 6/30/2018

Subproject: Silver Lake



Authorized Signatory / Date

Project Manager / Date

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2.0 Executive Summary

2.1 Project Description

Silver Lake is one of two lakes included in *Water Quality Testing and Improvement at Two Cowlitz County Lakes*. This program, which also addresses Horseshoe Lake in Washington State, was funded in part by a Washington State Department of Ecology (Ecology) grant awarded to Cowlitz County Health Department (CCHD). The long-term goal is to improve the water quality of two major lakes in Cowlitz County for the public's health and recreational benefit by minimizing the health risks posed by toxic algae growth events and controlling non-native noxious weeds that limit the recreational potential of each lake. The project's short-term goals include the creation of a databank of lake constituents, which is now available through Ecology's EIM database and on the County's website ([Cowlitz County EHU Water Quality Grants](#)) for the use of stakeholders and interested citizens to assist in making long-term mitigation, restoration, and education decisions.

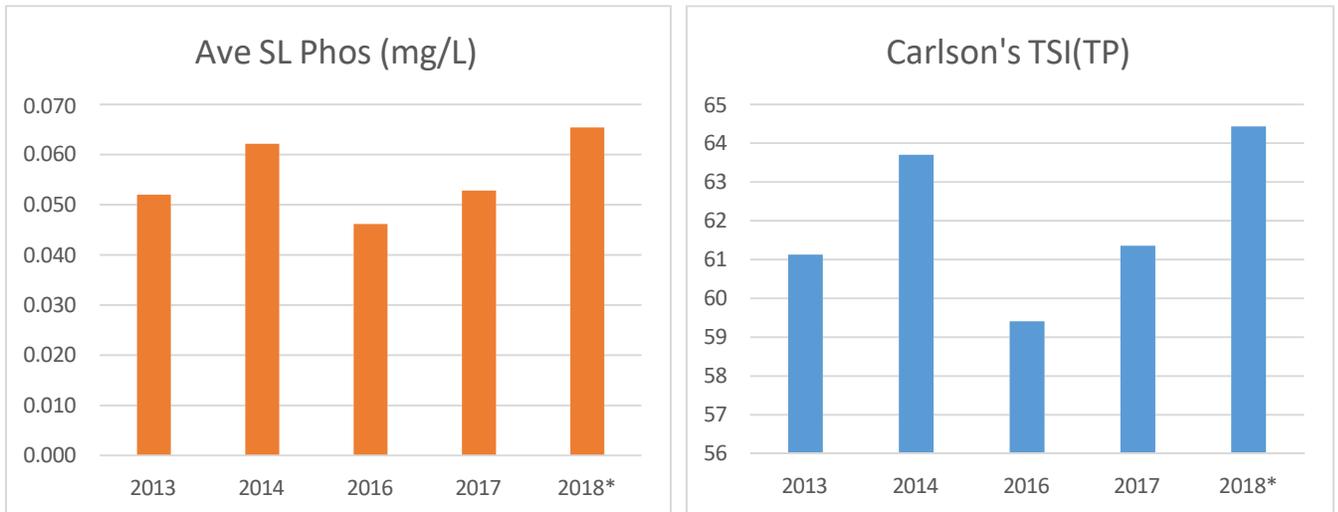
This report pertains specifically to the portion of the project that addresses Silver Lake (SL), a eutrophic 1650 acre warm water reservoir near Toutle, Washington. Silver Lake has a history of milfoil infestation dating back to the mid 1970s, shortly after the water level control structure was installed. This problem got worse and was accompanied with algae blooms through the 1980s. In 1990, Moore noted in the Silver Lake Restoration Project Phase I report that "without intervention, the lake will probably become essentially a large marsh, without any openwater areas, within the next decade." Moore recommended a stocking rate of 40 grass carp per acre, or 66,000 fish. However, 83,000 fish was stocked in 1992, or 126% of Moore's recommendation. The Cowlitz Conservation District completed the Silver Lake Watershed Management Plan (SLWMP) in 1994. KCM noted in 1998 that grass carp had eaten essentially all of the submersed plants in the lake, but that this did not result in large increases in nutrient concentrations, and that the larger nutrient concentrations of 1997 correlated with an increase in precipitation and runoff loading into the lake.

For the next ten years, citizens enjoyed improved lake access, but grew increasingly concerned about algal blooms. Public health cautionary postings occurred six times between 2009 and 2013. The Silver Lake Watershed Advisory Council (SLWAC) was formed in 2010 by the Cowlitz County Commissioners. The vision of this seven member council is to assist the commissioners with making Silver Lake clean and safe for the use of recreational fishing, boating, water skiing, swimming, aesthetics, waterfowl utilization, wildlife, and wetland habitat. SLWAC began water quality testing in 2012, and submitted a grant application in 2014 to conduct some "pilot" remediation projects in conjunction with water quality testing. Ecology awarded a modified grant without the pilot projects, and this project, *Water Quality Testing and Improvement at Two Cowlitz County Lakes*, began in April of 2015.

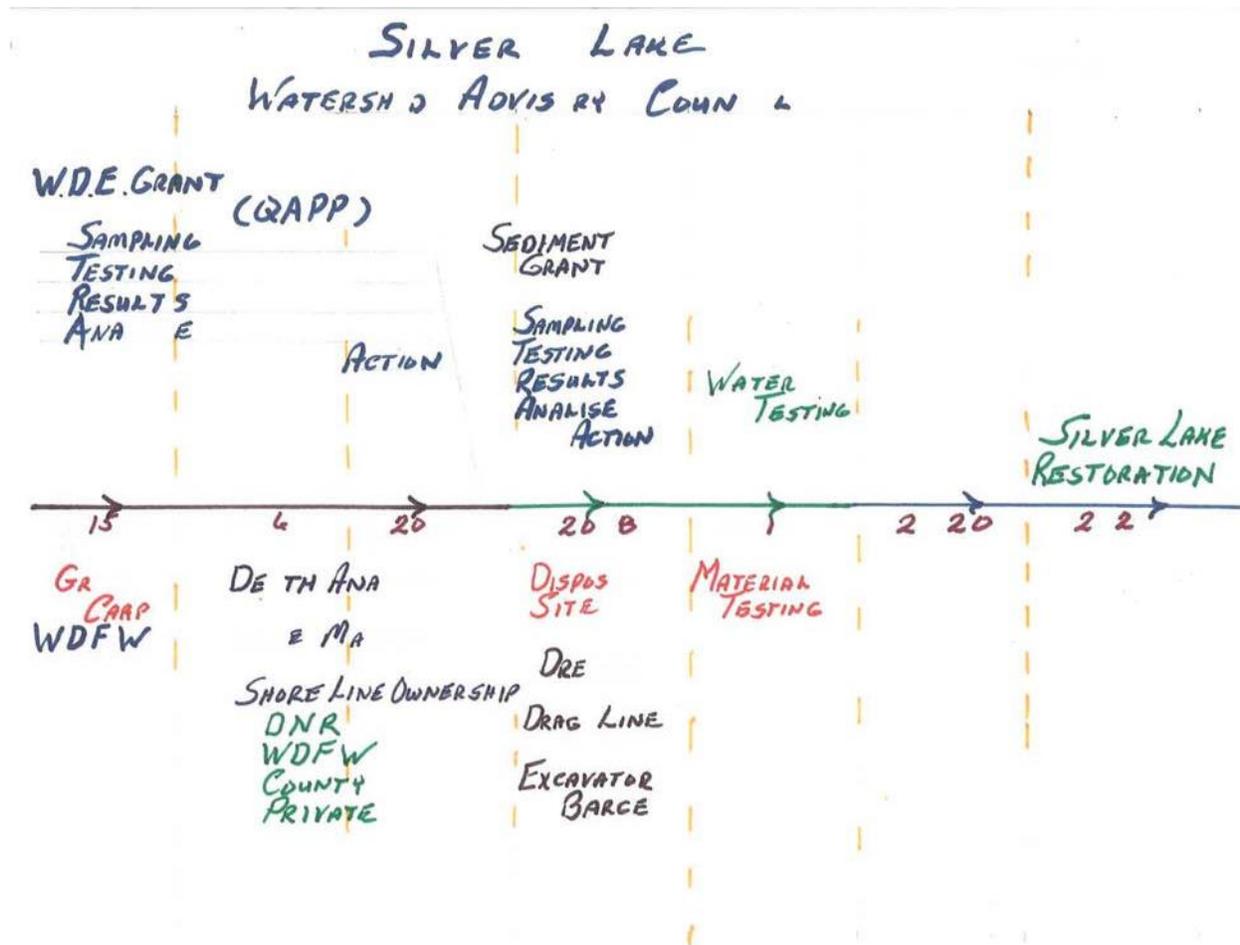
Project results of water quality testing show that the lake is eutrophic with an average Carlson's trophic state calculation (TSI) from chlorophyll a concentration of sixty-three, or TSI(CHL) = 63

Summer algal blooms occur regularly. A reduction of eutrophic state would be desirable for the lake uses of swimming and aesthetics.

For longer trend analysis, the previous results of total phosphorus during 2013 and 2014, can be compared to the total phosphorus results in this study, as show below. These results can be converted to TSI(TP). The graph of this data doesn't show a consistent pattern of increase or decrease, but rather a consistent range of TSI(TP) from 59 to 64 over the last five years. In the last three years, a steady pattern of increase is observed.



This project also fortified the partnership between CCHD and SLWAC, who have together engaged interested stakeholders and the public, have planned remediation actions, and have applied for and obtained the opportunity to conduct another grant funded project. During the duration of this project, SLWAC has been successful in lobbying Washington Department of Fish and Wildlife (WDFW) to allow for the catch and keep of the surviving grass carp. They have also obtained permission from WDFW to draw down the lake level in September of 2018. CCHD has regularly attended SLWAC meetings, and has encouraged the planning of long-term remediation actions. The timeline below is an example of such SLWAC and CCHD collaboration, intended to help integrate a dredging remediation project into general lake planning:



Pre-dredge sediment testing is included in the Ecology approved grant, which also includes water quality testing of the lake and creeks, making the watershed management plan more accessible and current, and providing a quarterly educational newsletter to shoreline landowners.

2.2 Project Accomplishments

In August of 2015 the Quality Assurance Project Plan – Silver Lake (QAPP) was approved by Ecology, and training of the SOPs were reviewed with volunteers. The project’s design included sampling at five designated locations, as shown with red pins in Figure 1. Two locations represent the lake and the other three are intended to represent water from the two inlets and the outlet. These sites were accessed by boat. Sampling frequency was monthly from October – May, and twice a month during June - September. A Secchi disc was used at these locations to determine Secchi visibility. Water temperature, pH, dissolved oxygen and turbidity was measured in-situ using a digital sampling handheld multiparameter meter funded by this project. An accredited lab determined total phosphorus, chlorophyll *a*, and E. coli. Samples were collected per Ecology approved protocols as outlined in the QAPP. The mean, variance, and standard deviation of the results was calculated. The results were graphed, and trends and patterns were identified, where possible.

The project also included supporting data. The Silver Lake Flood Control District has provided lake level data, and maps of the drainage areas.

Trophic State Index (TSI) was determined separately, per Carlson’s formulas, using chlorophyll *a* (the most representative indicator), total phosphorus, and Secchi depth. All three methods indicate that SL is in the eutrophic state. The most accurate method, using chlorophyll *a*, resulted in a calculation of TSI(CHL) of 63. Sampling for *E.coli* during the summer demonstrated that the swim areas met EPA primary recreation standards.

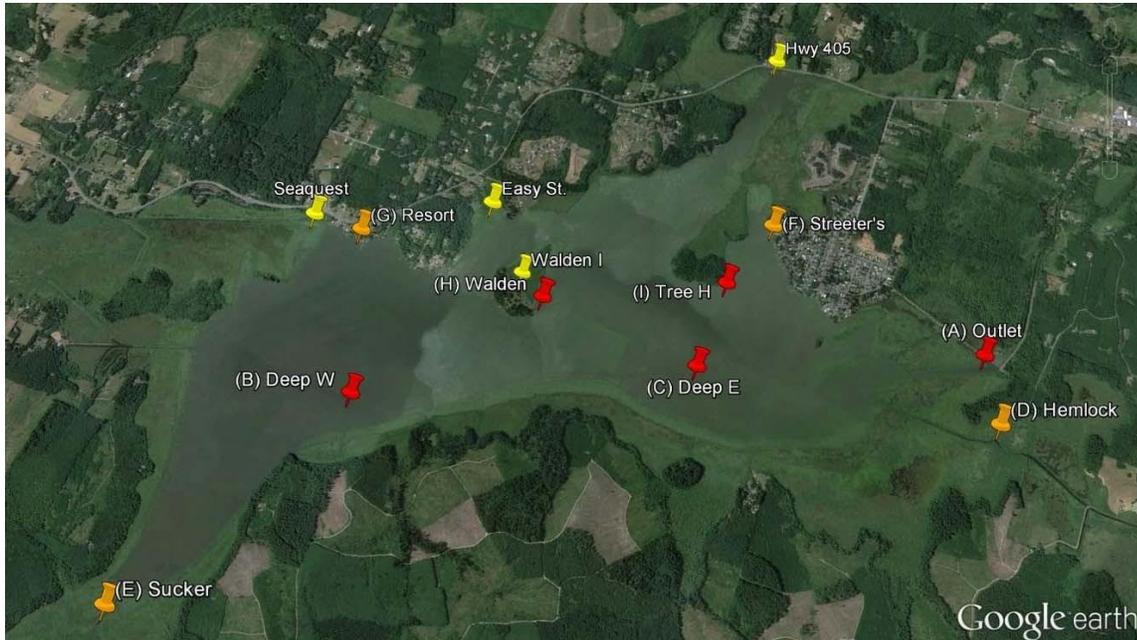


Figure 1 – Silver Lake sample sites for this project shown with red pins. Yellow pins represent sites used by SLWAC prior to study. Orange pins represent sites used both prior and in this project.

2.3 Water Quality Improvements

Long-term project objectives include water quality improvement for the public’s health and recreational benefit. The application for this project included some test projects, but they were not approved for inclusion by Ecology. Therefore, this project did not include remediation action that would lead to current water quality improvements. However, this project did fortify the partnership between CCHD and SLWAC, and both agencies continue to strategize on remediation action.

In 2016 and 2017 the lake dropped about twelve inches naturally. In the fall of 2015, the lake dropped by more than seventeen inches. SLWAC noted that following this greater drop in lake level, phosphorus levels were lower. SLWAC is hoping that there is a correlation, and that a drop of three feet will result in a reduction of phosphorus. Throughout the duration of the project, SLWAC has been planning on such a “flush of the lake.” Lack of explicit approval from

Washington Department of Fish and Wildlife (WDFW) delayed this plan for several years, but it has now been obtained. A community meeting was held in June 2018, where it was estimated that 80-90% of attendees approved of the proposed action. On September 10th, 2018 the lake will be lowered three feet from the top of the weir (the stabilization point). Due to natural summer lake level reduction, the actual adjustment need to attain this level will be less than three feet. The lake will then fill back up with rain water and normal Hemlock and Sucker Creek inflow during the fall of 2018. Phosphorus levels will be closely monitored during the refill process, and monitored on a monthly basis throughout 2019, during which time it is hoped that a reduction of phosphorus, and a subsequent reduction of algal blooms, is observed.

SLWAC has also been advocating the removal of carp throughout the duration of this project. The 83,000 grass carp installation of 1992 is now considered to be an overstocking. Grass carp are still present in the lake, 26 years after the installation, as seen in Figure 2. The continued lack of aquatic vegetation is thought to have negative effects on the water quality of Silver Lake. An effective solution for reducing or eliminating the grass carp has not been found, but WDFW are changing their regulations on July 1, 2018 to allow for fishermen to catch and retain grass carp.



Figure 2 – Grass carp caught in SL during Washington Bow Fishing Association event February 2015

2.4 The Next Step for Continued Success

The stakeholders have arranged for water quality testing to continue through 2018. This will be especially important in order to evaluate the effects of lowering the lake level. CCHD has been awarded agreement WQC-2018-CwCoHH-00092 that will facilitate continued water quality testing in the lake, and new water quality testing of the inlet streams. It will also allow for testing of lake bottom sediment, both for phosphorus levels and for tests required by US Army Corps of Engineers prior to dredging. Additionally, the Silver Lake Watershed Management Plan will be placed into electronic format and updated with current events and developments. Lastly, public engagement will be increased with quarterly newsletters going out to landowners with properties adjacent to the lake and creeks, and with CCHD participation at public events.

Agreement WQC-2018-CwCoHH-00092 will accomplish some of the required groundwork necessary to implement a dredging project, as recommended by Moore (1990). Dredging is a potential remediation project favored by SLWAC, although sources of funding have not been identified. The Silver Lake Watershed Management Plan also recommends stream shading, bank and road erosion control, fenced aquatic nurseries, and the management of riparian zones. These will be reconsidered through the activities of Agreement WQC-2018-CwCoHH-00092.

SLWAC is also considering the value and possibility of increasing the influence of Hemlock Creek. They have observed that currents tend to cause the inflow of Hemlock Creek water to enter the lake and then proceed to Outlet Creek. Further testing of Hemlock Creek is necessary before such action is taken.

2.5 Lessons Learned

- 1) Chlorophyll *a* accreditation process is different than that for the other analytes. Although there is not an outside approved proficiency testing provider for chlorophyll *a*, Ecology requires labs to provide evidence of in house proficiency testing in order to attain accreditation.
- 2) Chlorophyll *a* sampling is of limited value during the winter months, and can be eliminated from October – May, as one way to reduce the cost of a water quality monitoring program. Chlorophyll *a* is a valuable analyte when taken once or twice a month during the months of June – September because these values are most representative of algal mass and used to calculate the most accurate trophic state index, or TSI(CHL).
- 3) The normal Secchi disk arrangement could be improved upon by substituting the rope, which is influenced by horizontal wave movement, with a telescoping pole, as shown in Figure 3. This was done by Bill Dunlop, the volunteer captain and Horseshoe Lake Management Committee member on Horseshoe Lake, with no disadvantages noted, other than the added cost of the pole and labor of securing the disk. SL is a large waterbody that experiences significant winds and currents, and would benefit from this type of Secchi disk set up.
- 4) Use the deepest sampling sites when in a relatively shallow lake. When the Secchi disk is read from the bottom, the information is of reduced value.
- 5) Take the phosphorus field duplicates from the same subsurface grab capture.
- 6) When doing additional quality assurance on turbidity by submitting concurrent lab samples, place the probe into the capture jar and take a probe turbidity reading of that particular sample, and then pour that water into the lab container.
- 7) The collection of weekly rainfall and water temperature by SLWAC members was unsuccessful due to temporary relocation of one member and extensive out of country travel by another. Strategizing on a new plan is necessary in the future.



Figure 3 – Secchi disk installed on telescoping pole by Bill Dunlop, HSLMC

3.0 Overview Description of Project

3.1 General Project Description

This project provided data helpful in the evaluation of Silver Lake, and in planning long-term actions. The immediate goal of this project was to provide the data and site-specific results necessary to plan, execute, and evaluate continuous improvement actions. One measurement of success included the completion of 31 out of 32 sampling events. Another key goal of this project was accomplished by the launching of a public website containing the QAPP, SOP and a link to all data collected. The long-term project goal is to improve the water quality of Silver Lake for the public's health and recreational benefit, minimizing the health risks posed by toxic algae growth events, and to control non-native noxious weeds that limit the recreational use of the lake.

The Silver Lake QAPP was written and approved by Ecology, and a water quality probe was purchased. This study then generated a reliable databank that includes 209 data points for total phosphorus and Secchi depth, 181 data points for chlorophyll *a*, 124 data points for *e. coli*, 28 data points for fecal coliform, and 27 for turbidity. These data points supported trend analysis regarding each constituent, as well as a calculation of the trophic state index included later in this report. A water quality probe provided four additional water quality parameters, generating 128 data points for each. All data was collected following the approved QAPP.

The project also encouraged local discussion and improved the understanding of individuals' effect on lake water quality. The project's data was cataloged and was made available to the public via the county's public website, and submitted to Ecology through the Environmental Information Management (EIM) database. Community understanding and discussion was facilitated via annual informational presentations and annual inter-agency meetings. SLWAC members also interacted regularly with CCHD staff during their monthly meetings to gain further understanding and clarity.

3.2 Project Schedule Year 1

Year 1 Sample and Test Schedule September 2015 – September 2016						
Event	Date	Total Phosphorus	Chlorophyll <i>a</i>	<i>E. coli</i> (+ fecal coliform indicated by ^)	Fecal colifom	Turbidity
1	Spt 21, 2015	(5) a, b, c, d, e	(5) a, b, c, d, e	(4) f, g, h, i		3
2	Oct 5, 2015	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
3	Nov 9, 2015	(6) a, b, c, d, e	(5) a, b, c, d, e	(3) d, e		
4	Dec 7, 2105	(5) a, b, c, d, e	(6) a, b, c, d, e	(2) d, e		
5	Jan 11, 2016	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
6	Feb 1, 2016	(6) a, b, c, d, e	(5) a, b, c, d, e	(3) d, e		3
7	Mar 7, 2016	(5) a, b, c, d, e	(6) a, b, c, d, e	(2) d, e		
8	Apr 4, 2016	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
9	May 9, 2016	(7) a, b, c, d, e + B	(6) a, b, c, d, e	(3) d, e		3
10	Jun 13, 2016	(5) a, b, c, d, e	(6) a, b, c, d, e + B	(6) d, e, f, g, h, i		
11	Jun 27, 2016	(5) a, b, c, d, e	(5) a, b, c, d, e	(5) f, g, h, i + B		
12	Jul 11, 2016	(5) a, b, c, d, e	(5) a, b, c, d, e	(6) d, e, f, g, h, i		
13	Jul 25, 2016 boat broke	(4) a, b, c, d no e	(4) a, b, c, d no e	(2) f, I no g or h,	(2) f, I no g or h,	
14	Aug 11	(6) a, b, c, d, e	(6) a, b, c, d, e	(7) d, e, f, g, h, i	(6) d, e, f, g, h, i	3
15	Aug 22	(5) a, b, c, d, e	(5) a, b, c, d, e	(4) f, g, h, i	(2) f, g	
16	Sept 12 No access to sucker e	(4) a, b, c, d,	(4) a, b, c, d,	(5) d, , f, g, h, i	(5) d, , f, g, h, i	
	Totals Yr 1 (valid data only)	84	56	46	15	12
B = take “blank” sample at this location with distilled water						
X = take duplicate sample here						
Red lettering = samples rejected by Ecology for QA issues (chlor a = lab accreditation, e. coli = indirect pour)						

3.3 Project Schedule Year 2

Year 2 Sample and Test Schedule September 2016 – September 2017						
Event	Date	Total Phosphorus (target = 84)	Chlorophyll A (84)	<i>E. coli</i> (56)	Fecal coliform (10)	Turbidity - 12
17	Spt 26, 2016	(5) a, b, c, d, e	(5) a, b, c, d, e	(4) f, g, h, i	(4) f, g, h, i	
18	Oct 24, 2016	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
19	Nov 21 2016	(6) a, b, c, d, e	(5) a, b, c, d, e	(3) d, e		
20	Dec 19, 2016	(5) a, b, c, d, e	(6) a, b, c, d, e	(2) d, e		3
21	Jan 30 , 2017	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
22	Feb 27 , 2017	(6) a, b, c, d, e	(5) a, b, c, d, e	(3) d, e		
23	Mar 20, 2017	(5) a, b, c, d, e	(6) a, b, c, d, e	(2) d, e		3
24	Apr 17 , 2017	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
25	May22 , 2017	(7) a, b, c, d, e + B	(6) a, b, c, d, e	(3) d, e		
26	Jun 12, 2017	(5) a, b, c, d, e	(6) a, b, c, d, e + B	(6) d, e, f, g, h, i		3
27	Jun 26, 2017	(5) a, b, c, d, e	(5) a, b, c, d, e	(5) f, g, h, i + B		
28	Jul 10, 2017	(5) a, b, c, d, e	(5) a, b, c, d, e	(6) d, e, f, g, h, i		
29	Jul 24, 2017	(5) a, b, c, d, e	(5) a, b, c, d, e	(4) f, i, g, h		3
30	Aug 7, 2017	(6) a, b, c, d, e	(6) a, b, c, d, e	(7) d, e, f, g, h, i	(6) d, e, f, g, h, i	
31	Aug 28,2017	(5) a, b, c, d, e	(5) a, b, c, d, e	(4) f, g, h, i		
32	Sept 11, 2017	(5) a, b, c, d, e	(5) a, b, c, d, e	(6) d, , f, g, h, i, e		
	Totals Yr 2	84	84	61	10	12
<p>B = take “blank” sample at this location with distilled water</p> <p>X = take duplicate sample here</p>						

3.4 Project Schedule Year 3

Year 3 Sample and Test Schedule September 2017 – May 2018						
Event	Date	Total Phosphorus	Chlorophyll <i>a</i>	E. coli	Fecal Coliform	Lab Turbidity
33	SPT 25, 2018	(5) a, b, c, d, e	(5) a, b, c, d, e	(4) f, g, h, i		
34	OCT 16, 2018	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		3
35	NOV 17, 2018	(6) a, b, c, d, e	(6) a, b, c, d, e	(3) d, e		
36	DEC 14, 2018	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e	3	
37	JAN 31, 2018	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
38	FEB 12, 2018	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
	MAR – no event					
39	APR 23, 2018	(5) a, b, c, d, e	(5) a, b, c, d, e	(2) d, e		
40	MAY 25, 2018	(5) a, b, c, d, e	(5) a, b, c, d, e			
Total Yr 3		41	41	17	3	3
Total Yr 2		84	84	61	10	12
Total Yr 1		84	56	46	15	12
Project Total		209	181	124	28	27

4.0 Tasks Accomplished

- Collaborated with SLWAC technical advisors in project planning and implementation.
- Developed and wrote a lake-specific QAPP for Ecology approval.
- Compared previously used sampling methods with Ecology-approved Standard Operating Procedures (SOP), and provided training and training documents.
- Provided oversight and audits of volunteers during field testing. CCHD presided over every sampling event.
- Conducted total phosphorus, chlorophyll *a* sampling for lab analysis at 5 locations monthly from October-May and twice a month from June-September. 209 data points were established for total phosphorus and 181 chlorophyll *a* data points were established.

- Sampled for E. coli monthly at the deep lake sample sites, and sampled for E. coli at the swim areas monthly from June-September, for a total of 124 data points.
- Determined Secchi disk depth at five locations twice each month during the summer months of June – September, and once a month from October - May. 209 data points were established for Secchi depth.
- Determined probe measurements at 3' water depth: water temperature, pH, dissolved oxygen and turbidity at five locations twice each month during the summer months of June – September and once a month from October - May. 200 data points were established for each of these measurements.
- Conducted public presentations to CCHD Board of Health in July of 2016 and in July of 2018. These were broadcast via KLTN and stored in their publically accessible archives, which are available for streaming on demand.
- Conducted annual educational meetings on the project and on lake stewardship.
- Presented at / participated in annual inter-agency meetings to better collaborate with other agencies during November of 2016 and 2017.
- Input water quality monitoring data into Ecology's EIM system annually.
- Compiled and published all data on County website.
- Submitted quarterly progress reports and billings to Ecology.
- Conducted Technical Audit and submitted report to Ecology.
- Conduct numerical and trending analysis of the study's data.
- Submitted a report to Ecology Project Manager summarizing data results and data analysis.

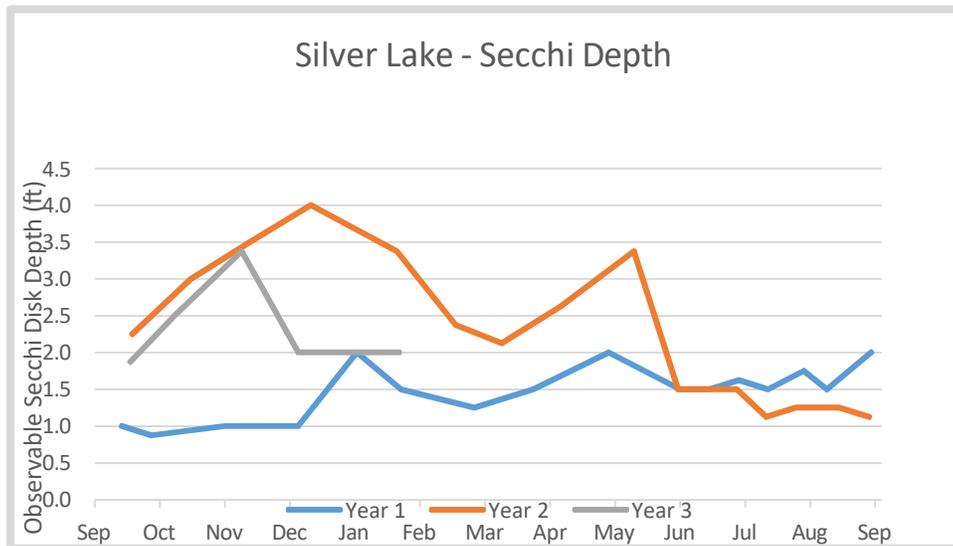
5.0 Quality Assurance Measures

All quality control went as planned in the QAPP. Field duplicates were taken quarterly. Field blanks were taken annually, and all came back below the non-detect values. Probe measurements were taken in duplicate, and the average of two readings was recorded as the final result.

Ecology requested that quality assurance measures include quarterly turbidity measurements as determined by the lab to compare with probe turbidity readings. However, these quality assurance tests were not taken from the same aliquot and the project lead considers their comparison to be of diminished value. As listed in Lessons Learned #6, and perhaps intended by Ecology originally, one would need to capture the sample first and take a probe reading of the water while in the jar of the subsurface sampler, and then pour the same water into the (very small) turbidity lab bottle. The capture jar of the subsurface sampling pole is just wide enough to accommodate this procedure in the future. The monthly calibration of the probe's turbidity is a better assessment of quality assurance for this project. Maximum deviation of turbidity was +/- 5% of the standard throughout the course of the project.

6.0 Results – Secchi Depth

Secchi depth of the lake, including sites Deep West and Deep East, was measured by the same person during all events on the shady side of the boat between 9am and 12pm. Results through the duration of the project averaged 2.0 ft with a variance of 0.1 and a standard deviation (SD) of 0.1. Year 1 averaged 1.5 feet while year 2 saw slight improvement with visibility at 2.5 ft, variance of 0.1 and SD of 0.2. The Year 3 measurements thus far, including eight events over nine months, are better than Year 1 and not as good as Year 2 with an average of 2.1 ft, with a variance of 0.0 and SD = 0.1.



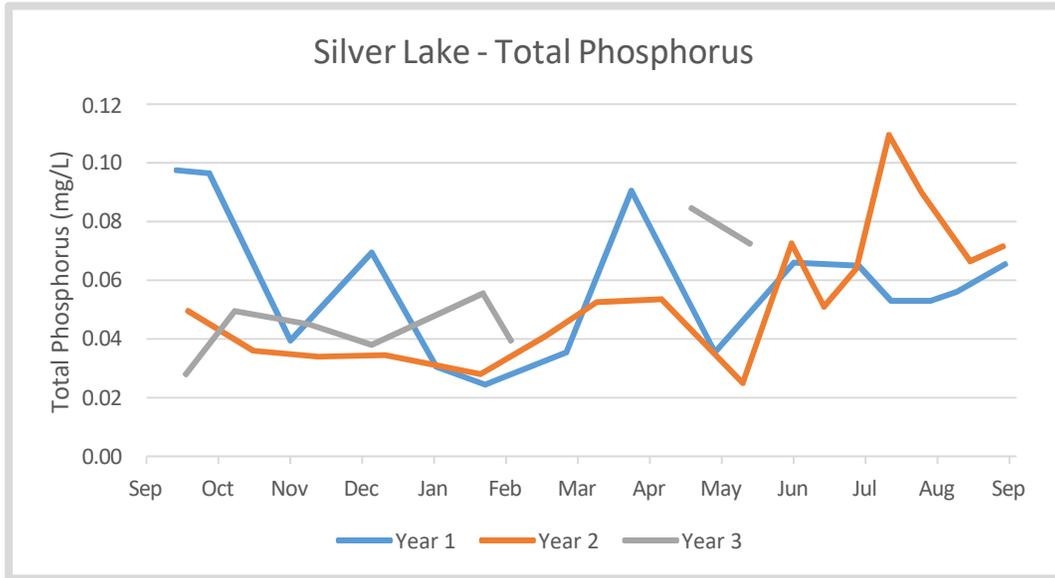
Although Sucker Creek sample site had higher visibility than the lake itself, the Hemlock Creek sample site consistently had more visibility than Sucker Creek, with two year averages of Hemlock Creek 3.8 ft and of Sucker Creek at 2.6 ft.

7.0 Results – Lab Analytes

7.1 Total Phosphorus

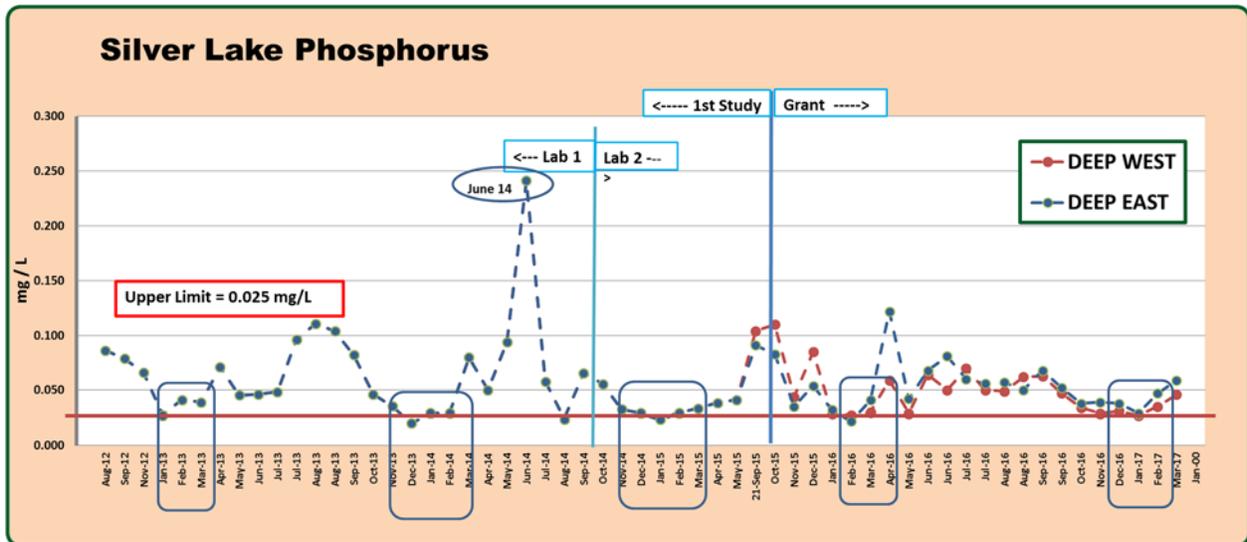
The average total phosphorus levels in Silver Lake are double that of the state action level and the EPA criteria. Washington Administrative Code 173-201A-230 indicates that lake specific studies may be initiated for values over 20 $\mu\text{g/L}$, or 0.020 mg/L in Puget Lowlands Ecoregion. The EPA (1987) water criteria for total phosphorus is 25 $\mu\text{g/L}$, or 0.025 mg/L.

The average total phosphorus over the course of the study was 0.053 mg/L with a variance of 0.000 and SD of 0.008. Year 1 average was 0.056 mg/L with variance of 0.000 and SD of 0.011. Year 2 was slightly lower with an average of 0.049 mg/L with a variance of 0.000 and SD 0.007. Year 3 so far averages 0.054 with variance of 0.000 and SD of 0.006. Seasonal trends include total phosphorus concentrations increasing during the summer and into the fall months.



Hemlock Creek and Sucker Creek had slightly less total phosphorus through the 40 events at 0.043 mg/L and 0.049 mg/L. Outlet Creek averaged 0.045 mg/L. SLWAC is currently discussing the merit of finding a way for Hemlock Creek to have more influence on the lake to combat the current which causes it to flow directly towards Outlet Creek. At 0.043 $\mu\text{g/L}$, Hemlock phosphorus concentrations are still quite high. However, SLWAC theorizes that the concentrations will be less when we test out of the lake and further up the creek.

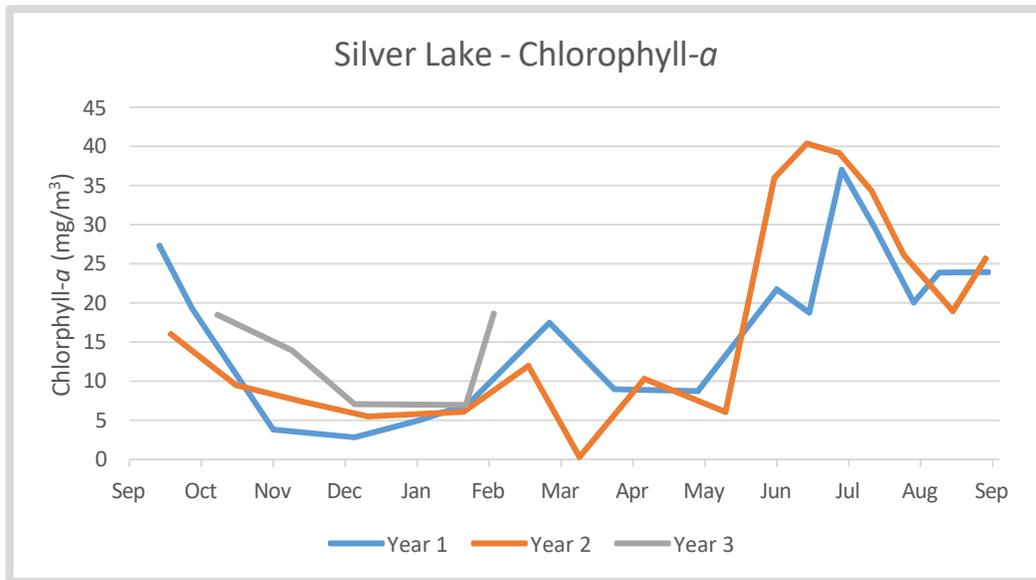
Previous SLWAC results can be compared keeping some important differences in mind. SLWAC testing did not include any sites near Deep West or Deep East, so the results of all nine sample sites are combined for an average. A different lab was used, and slightly different protocols were used.



7.2 Chlorophyll a

Average chlorophyll *a* concentration throughout the course of the project were 14.8 mg/m³ with a variance of 20.9 and SD of 2.9. The annual averages show a pattern of modest increase; Year 1 averaged 14.3 mg/m³ with a variance of 26.9 and SD of 3.4 while Year 2 averages 14.8 with a variance of 13.6 and SD of 2.3, and Year 3 to far averages 15.6 with a variance of 24.1 and SD of 3.3.

Oftentimes, chlorophyll *a* is only sampled for and considered during the summer months. Chlorophyll *a* peaked during the summer months of both years. If we isolate the data to the two summers including months June – September, then the average is 26.9 mg/m³ with a variance of 66.1 and SD of 8.1. Following the trend of increase, the second summer was higher at 29.9 mg/m³ with variance of 76.4 and SD of 8.7, versus the first summer with an average of 23.9 mg/m³ with a variance of 44.8 and a SD of 6.7.



7.3 E. coli

E.coli was test in the inlet creeks on a monthly basis. These areas are not common sites of primary recreation. Sucker Creek average about twice as high at 44.3 MPN/100mL versus 21.3 MPN/100mL at Hemlock creek. However, if you remove the one spike that Sucker Creek had of 488 MPN/100mL in January of 2017, then the average is closer at 29.1 MPN/100mL. When the swim sites were tested during the summer months, they all come back well below EPA’s Primary Recreation standard.

8.0 Results - Sonde

In-situ data was collected using Ysi ProDSS sonde, calibrated and used according to manufacturer’s instructions (<https://www.ysi.com/ProDSS>). Calibration occurred at least every 30 days, and drift was noted in a calibration log. All data was taken at 3 ft from surface, and the final result is the average of two field duplicate readings.

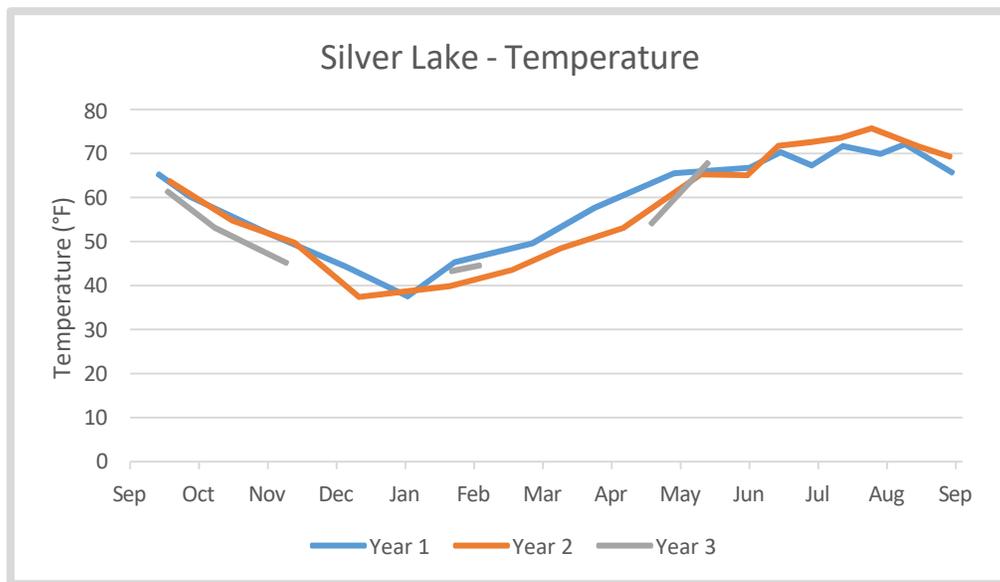
During December of 2017, the probe was out for repair resulting in no data for that month.



Figure 4 – YSI ProDSS Sonde with calibration solutions

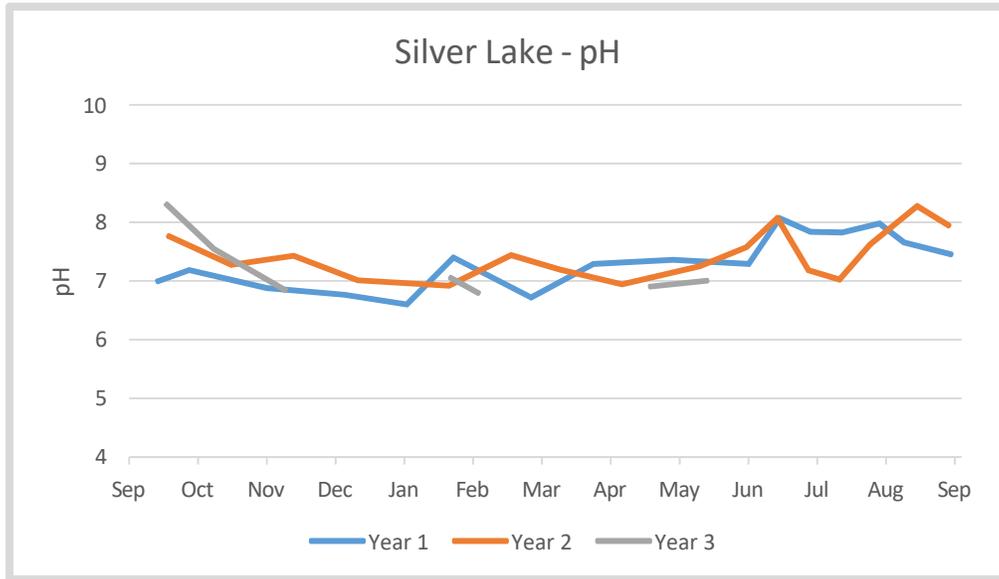
8.1 Temperature

The average temperature for the duration of the project at the Deep West and Deep East was 55.0°F, with a variance of 0.2 and SD of 0.3. Year 1 average temperature was just slightly warmer 57.7 ° F with a variance of 0.1 and SD of 0.2. Year 2 average temperature was 56.2°F with a variance of 0.2 and SD of 0.3. The difference is significant only in a higher temperature cannot be attributed to the higher chlorophyll *a* concentrations observed in year 2.



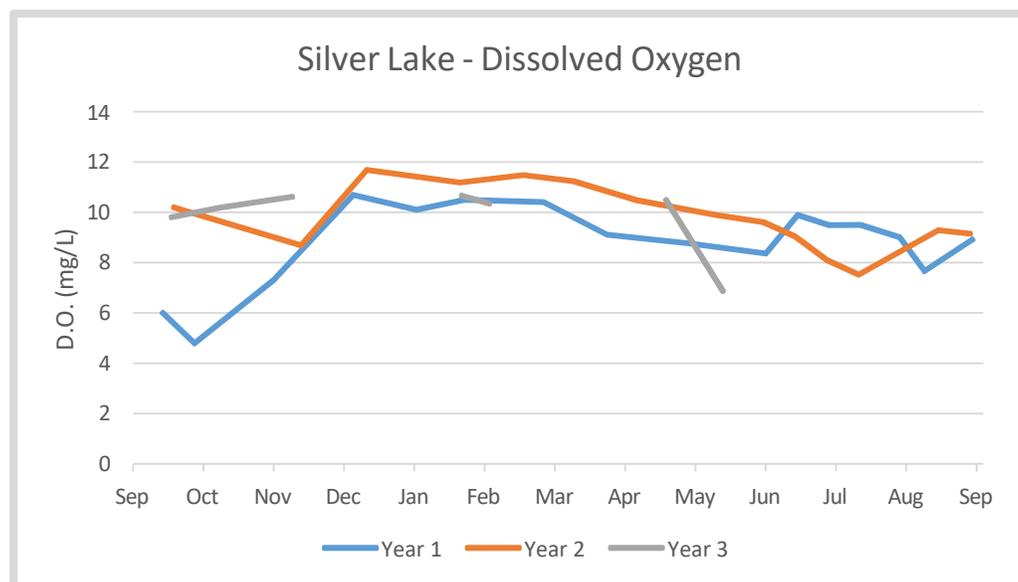
8.2 pH

The average pH throughout the project at Deep West and Deep East was 7.24 with a variance of 0.07 and SD of 0.21. The pH during Year 1 was 7.25 with a variance of 0.07 and SD of 0.19. The pH during Year 2 was 7.37 with a variance of 0.05 and SD of 0.14.

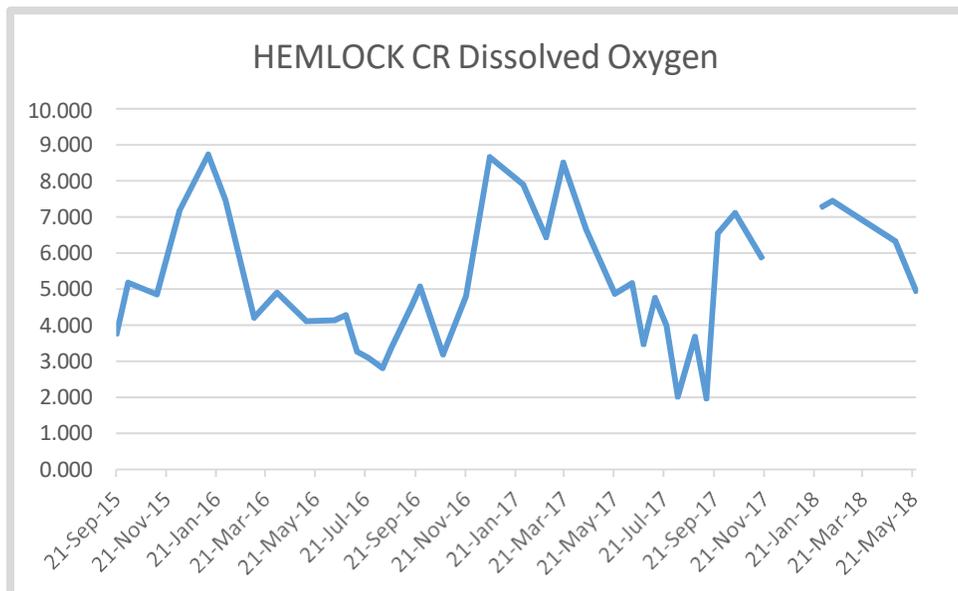
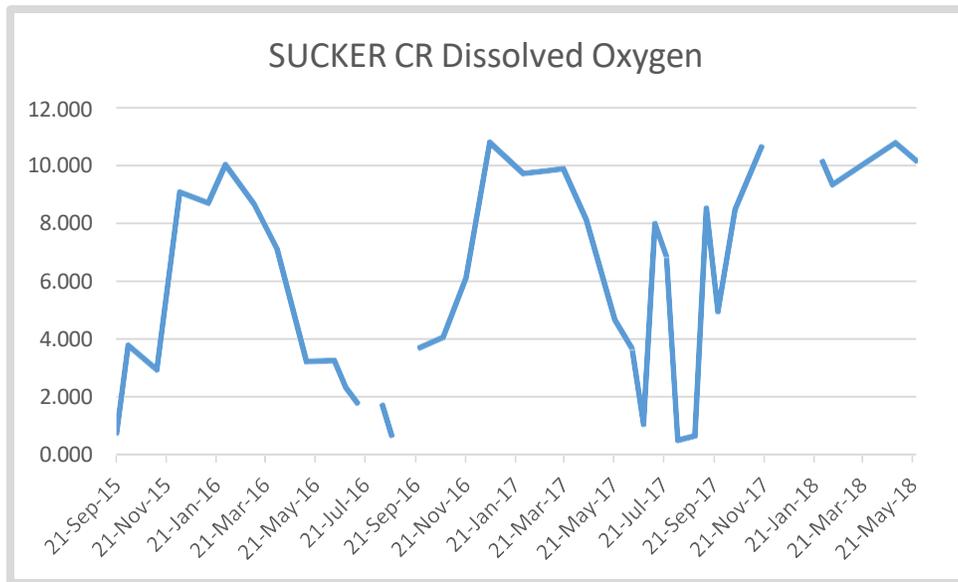


8.3 Dissolved Oxygen

The average DO measured through the project at Deep West and Deep East was 9.7 mg/L with variance of 0.1 and SD of 0.3. Year 1 was lower than than year 2 at 8.9mg/L vs 10.0 mg/L.

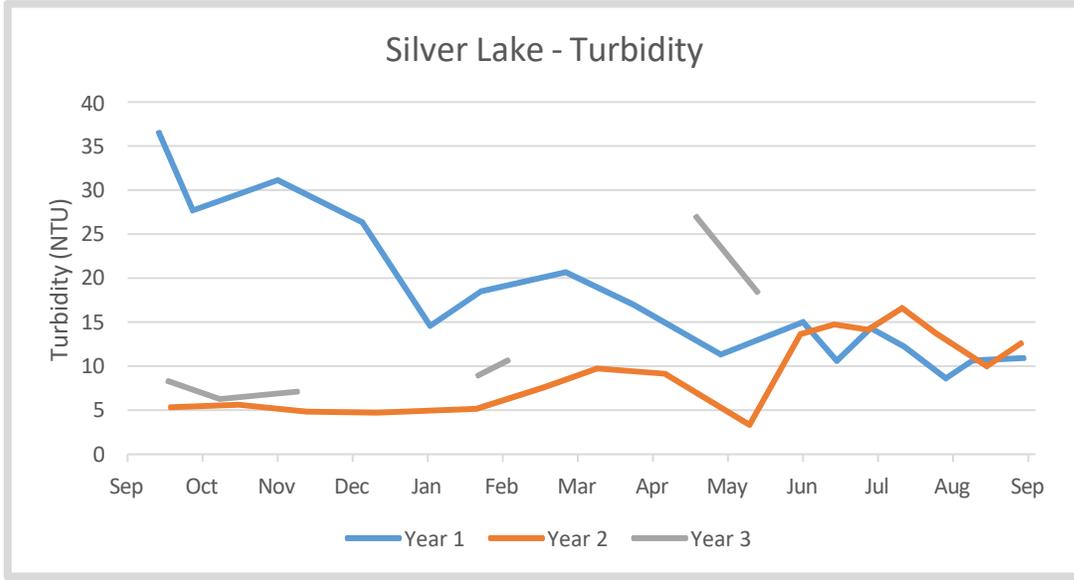


Fish do best in waters with 5 mg/L of DO or more. They struggle in waters between 2 and 5 mg/L, and they can die in waters that are below 2 mg/L. The actual die off level is dependent on the fish species. While average levels in the lake were adequate, the creeks sample sites have low concentrations of dissolved oxygen in the summer, with the Sucker Creek site measuring the lowest.



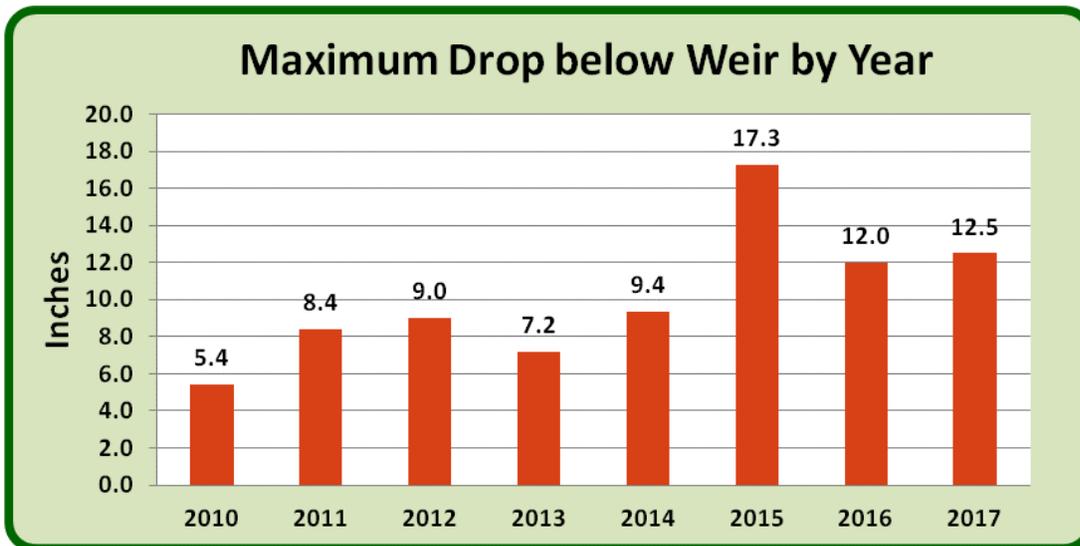
8.4 Turbidity

The average turbidity for the project was 13.2 NTU with a variance of 3.5 and a SD of 1.3. The average turbidity in Year 1 was higher at 18.2 NTU (variance 4.1 and SD 1.5) while the average in Year 2 was lower at 8.4 NTU (variance 2.3 and SD 1.1). The higher measured turbidity in Year 1 is correlated with the lower Secchi visibility of Year 1.

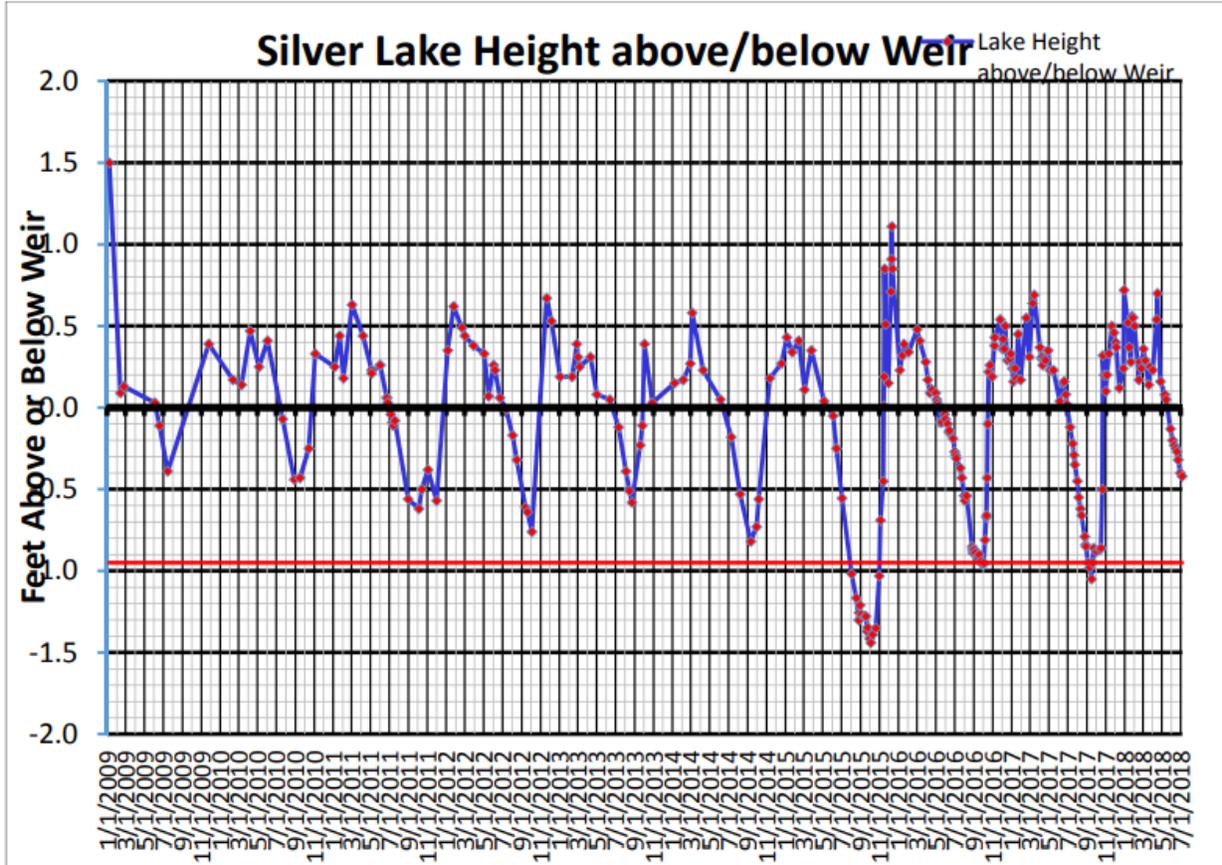


9.0 Supporting Data

9.1 Lake Level

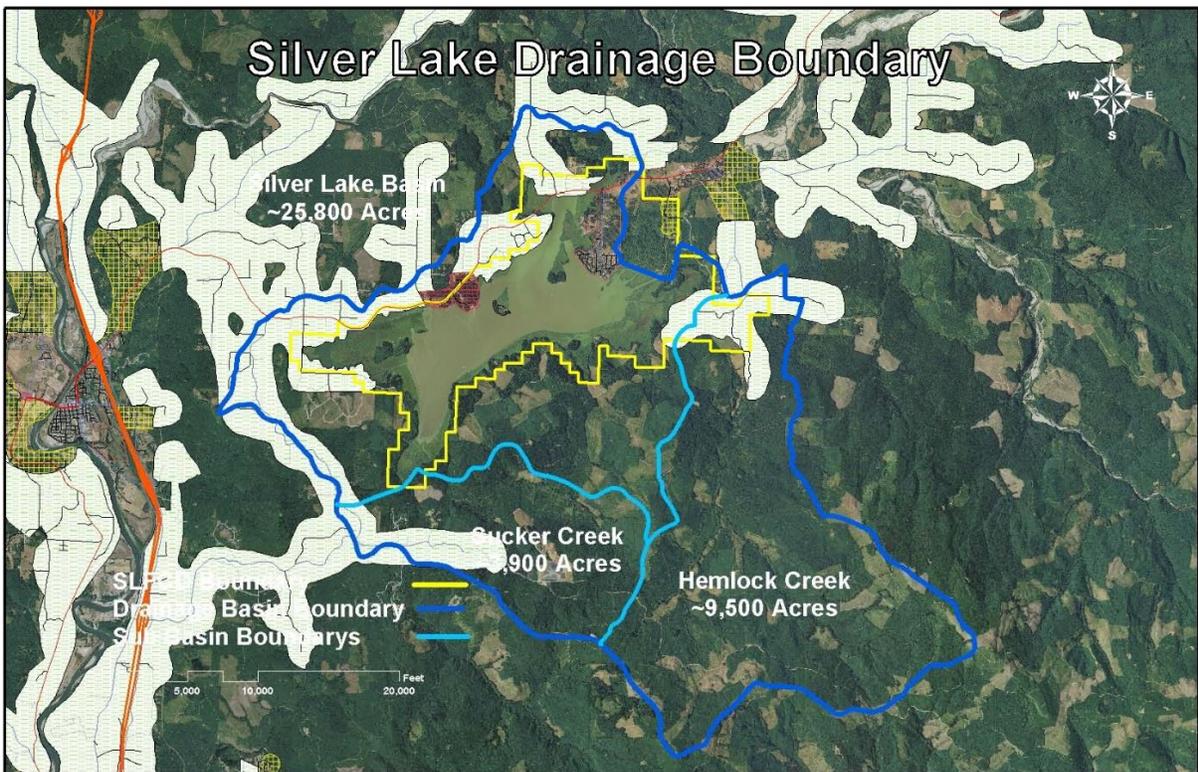
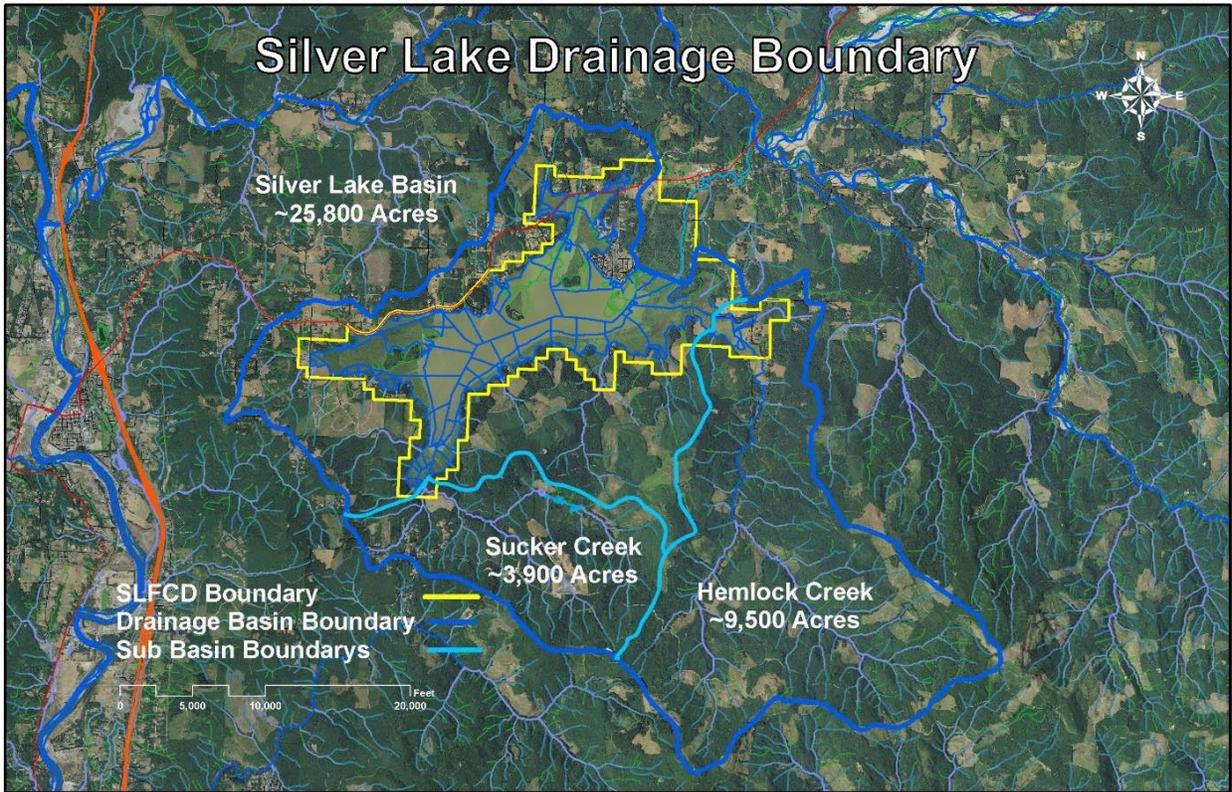


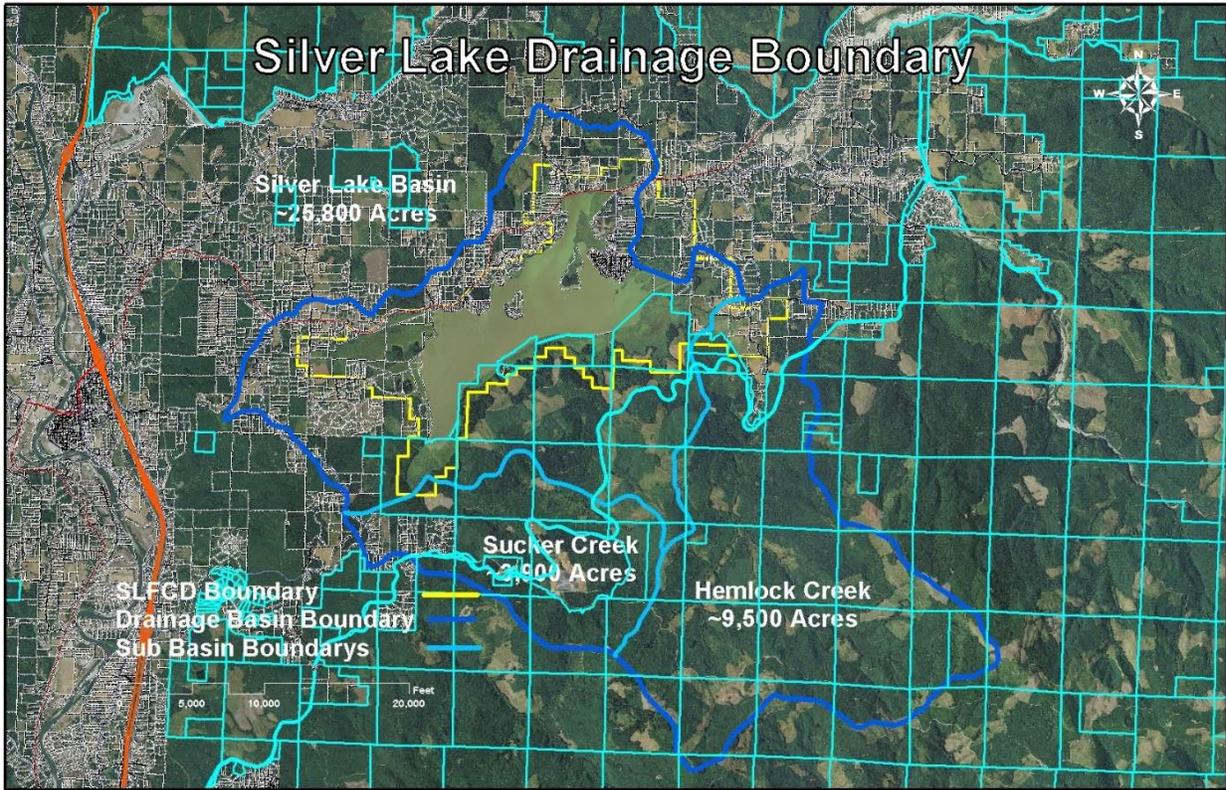
The above chart is used by SLWAC to promote the flushing project scheduled for September of 2018. The lake dropped more than usual in 2015, and this was followed by a drop in the concentration of lake phosphorus. The lake level chart below is provided by Silver Lake Flood Control District.



9.2 Silver Lake Drainage Boundary

The drainage basin charts below are provided by Silver Lake Flood Control District.





10.0 Trophic State Index

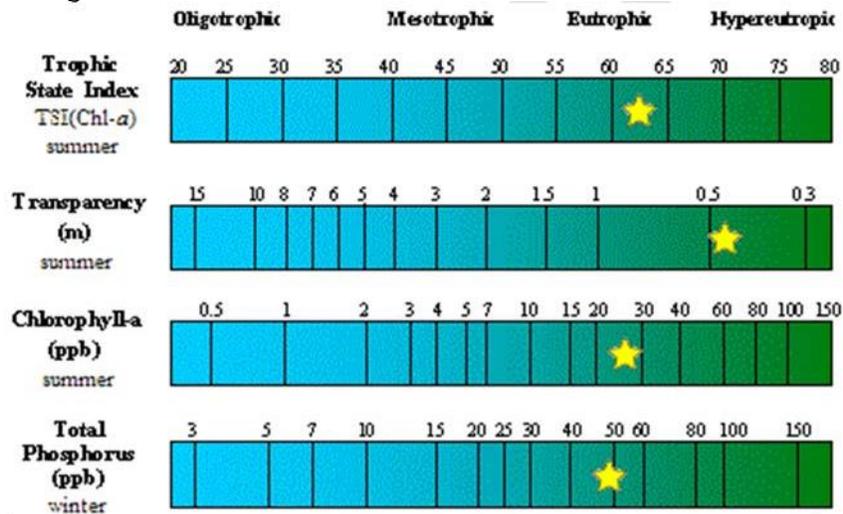
In 1977 Robert Carlson wrote “A trophic state index for lakes” in which he used the algal biomass to classify a water body’s trophic status. Chlorophyll *a*, total phosphorus, and Secchi depth can all be used to independently calculate what is now known as the Carlson’s Index. Carlson cautioned that the three calculations should never be combined and averaged, because the calculation from chlorophyll *a*, or TSI(CHL) is the most accurate. Increased total phosphorus and smaller Secchi depth measurements tend to correlate with higher chlorophyll *a*, and Carlson provides separate formulas for each. Calculations of trophic state index using Secchi depth is the least accurate, but it is the most affordable, accessible, and expedient. In the case of SL, Secchi disk was occasionally read from the bottom of the lake, which reduced the value of the measurement as well as the accuracy of the trophic state index calculated from the measurement.

In *A Coordinator’s Guide to Volunteer Lake Monitoring Methods* (1996) Carlson and J. Simpson related trophic state index to the general trophic classifications including oligotrophy, mesotrophy, eutrophy and hypereutrophy, as charted below:

TSI	Chl	P	SD	Trophic Class
< 30—40	0—2.6	0—12	> 8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—56	24—96	2—0.5	Eutrophic
70—100+	56—155+	96—384+	0.5— < 0.25	Hypereutrophic

Figure 5 – Carlson’s TSI and corresponding Chl, P, SD and Trophic Class

Below is a visualization of the TSI(CHL) result of SL, presented with the results of the additional correlating constituents:



Silver Lake is in the eutrophic classification with a TSI(CHL) of 63 over the course of the project. TSI(TP) is calculated at 60, and TSI(SD) is calculated at 71. This level of eutrophication interferes with some of its current uses, including swimming, jet skiing, water skiing, and aesthetics. Boating is supported sufficiently, while recreational fishing, duck hunting, and bird watching are well supported. However, the summer algal blooms are publically perceived as a problem for all uses, and can potentially pose a health threat to humans and pets.

11.0 Evaluation

The QAPP identified the goal of completing thirty-one out of the thirty-two scheduled sampling events, and this goal was exceeded. Some data was initially rejected due to quality assurance issues, but the desired quantity of data was supplied by eight extra sampling events. The QAPP was followed, and a high quality databank was established that is helpful in planning, executing, and evaluating improvement actions. During the project duration, SLWAC has elected to plan and soon implement the remediation action of lowering the lake. The established databank will be utilized as a baseline to assess the effects of such action. If lowering the lake has a significant

effect on one or more of the measured lake constituents, the stakeholders will be able to note this and use the information to help direct their actions in the future.

The calculation of the trophic state index is new for the SLWAC, and it can foreseeably be done in the future. The trophic state index, if continued, will help monitor the rate of eutrophication, and will be a relatively easy way for SLWAC members to know if and to what degree any remediation action has in halting and or reversing eutrophication. The index may also help with lake management conversations relating the biological state of the lake to the desired and encouraged uses of the lake.

A strong partnership now exists between CCHD and SLWAC, which will help to ensure the future collection of high quality data, will aid in planning further improvement projects, and will assist with engaging more members of the community. SLWAC hopes to get more agencies involved, and will continue to hold the inter-agency annual meetings to work towards this goal. This project's educational meetings were not well attended, but we will increase publicity of them and find additional educational methods. Another key goal of this project was the launching of the website page that contains the QAPP, SOP, a link to all data collected, as well as information on helping lakes via responsible stewardship. This webpage provides a foundation with which to continue educating and engaging the public, and new information will be added to this in the future.

The long-term project goal is to improve the water quality of Silver Lake for the public's health and recreational benefit, minimizing the health risks posed by toxic algae growth events, and to control non-native noxious weeds that limit the recreational use of the lake (Horseshoe Lake). The data generated from this report re-enforced the need for remediation actions. As intended, the data generated from this project is being used to determine effectiveness of a remediation action that begins September 2018.

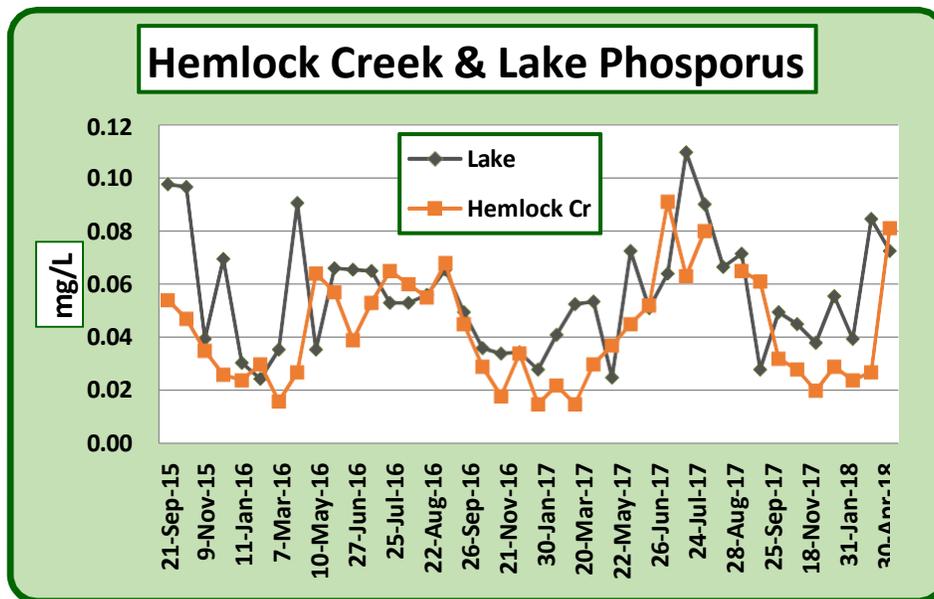
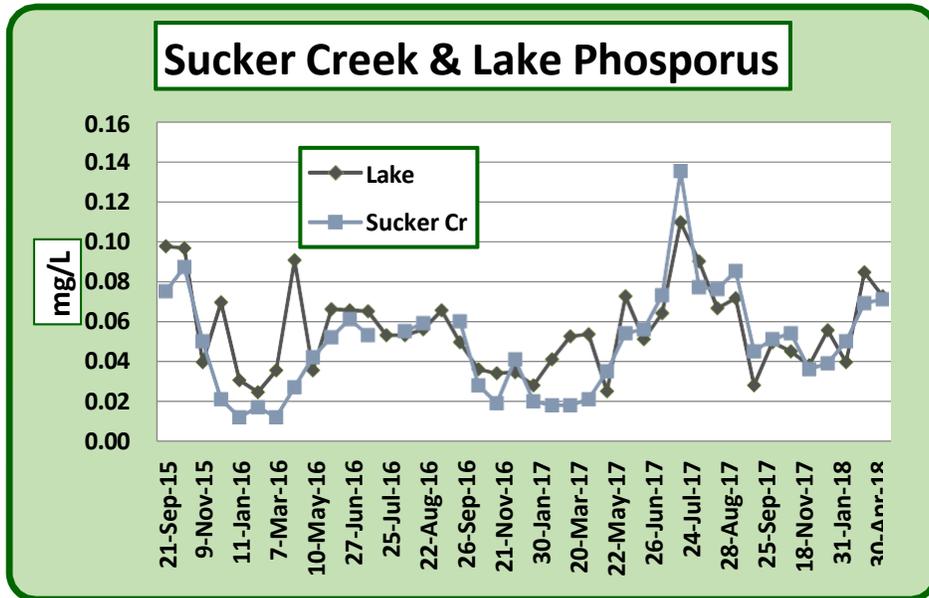
12.0 Follow Up

The stakeholders have arranged for water quality testing to continue through 2018. This will be especially important in order to evaluate the effects of lowering the lake level. If a pattern of improved lake constituents is demonstrated, SLWAC will consider lowering the lake regularly, and will investigate and implement ways to reduce or eliminate any negative effect this may have on fish. SLWAC is also now taking tests outside of the lake and up the creeks further to help evaluate the influence of the inflow creeks.

If implemented, Ecology Agreement WQC-2018-CwCoHH-00092 will accomplish some of the required groundwork necessary to implement a dredging project, as recommended by Moore (1990). Dredging is a potential remediation project favored by SLWAC, although sources of funding have not been identified. The Silver Lake Watershed Management Plan (SLWMP) also recommends stream shading, bank and road erosion control, fenced aquatic nurseries, and the management of riparian zones. These activities will be reconsidered through the activities of the Agreement, as the SLWMP will be placed into electronic format and updated with the current of

recommended actions and new developments. Public engagement will be increased with quarterly newsletters going out to landowners of properties adjacent to the lake and creeks, and with CCHD participation at public events.

SLWAC is also considering the value and possibility of increasing the influence of Hemlock Creek, since current results show that Hemlock Creek has less phosphorus than Sucker Creek and the lake (see graphs below). They have observed that currents cause the inflow of Hemlock Creek water to enter the lake and then proceed to Outlet Creek.



Cowlitz County continues to demonstrate commitment to both Horseshoe Lake and Silver Lake with inclusion in the Cowlitz County Strategic Plan:

Degraded Water Quality in Silver & Horseshoe Lakes Threatens Public Health & Safety

Silver Lake and Horseshoe Lake are two premier recreation and tourism sites with increasing water quality problems that pose a threat to public health and safety. Since 2009 Cowlitz County Health & Human Services (CCHHS) has posted warning signs six times around Silver Lake for high levels of cyanobacteria, commonly known as Blue-green algae. Three times since 2013, CCHHS has posted warning signs for E. coli levels that have exceeded safe recreation limits. The presence of E. coli is used as an indicator for the possible presence of harmful microbes, such as cryptosporidium, giardia, shigella, and norovirus. Exposure to these types of pathogens can be especially dangerous to vulnerable populations including the elderly, children, and people with existing medical conditions. In 2012 Silver Lake was listed as an impaired waterway by the Washington State Department of Ecology (section 303 (d)). Tissue samples of both carp and largemouth bass were found to have exceeded the National Toxics Rule criteria. Silver Lake is also listed for the presence of Brazilian elodea, an invasive aquatic plant that interferes with swimming, boating, fishing and water skiing, and provides poor habitat for fish. Horseshoe Lake is also experiencing similar water quality issues. The impaired water quality of Silver Lake and Horseshoe Lake negatively impacts the recreation potential of the area resulting in less tourism and hampering economic growth for this rural area.

Long-Term Goals

- To increase the water quality of Silver Lake and Horseshoe Lake
- To reduce the exposure of the public to waterborne disease
- To reduce the public's exposure to contaminated fish
- Increase tourism and economic growth

Strategies/ Actions

- Continue regular water testing at Silver Lake and Horseshoe Lake until a more robust monitoring program can be implemented
- Apply for Washington Department of Ecology grants to enable long term monitoring of water quality at both lakes
- Implement and maintain a volunteer based water quality monitoring programs at Silver Lake and Horseshoe Lake
- Enhance public participation in Silver Lake Watershed Advisory Council (SLWAC) and Horseshoe Lake Management Committee
- Hire a Cowlitz County Lakes water quality program coordinator
- Engage the public through educational workshops on water quality monitoring program progress
- Engage SLWAC and Horseshoe Lake Management Committee to gain feedback on sampling program and determine if goals are being met
- Engage the public on best management practices to improve water quality
- Use the data generated from the water quality monitoring project to investigate long-term strategies to improve water quality
- Develop comprehensive water quality improvement plan for Silver Lake and Horseshoe Lake
- Increase the timberland acreage in public ownership eligible for the Community Forest Trust in an amount acceptable to private owners
- Investigate the benefit of creating a lakes district in Cowlitz County to create a permanent funding mechanism to conduct water quality testing
- Develop and implement a comprehensive management plan for Silver Lake and Horseshoe Lake

As Moore notes in the conclusion section of his 1990 report, “The sponsors, residents, and users of Silver Lake and the Silver Lake watershed should also realize that the restoration and maintenance of good water quality in Silver Lake will only derive from a long term commitment to protect and manage activities in the watershed.” Twenty-eight years later the Silver Lake stakeholders continue to work determinedly towards a solution to protect the healthy and safe use of the lake.