Final Report 1 of 2 for:
Agreement: WQC-2015-CwCoHH-00129

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

Recipient: Cowlitz County Health and Human Services

Total Cost of Project: $143,028

Grant Amount: $107,271

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Subproject: Horseshoe Lake

Picture of Horseshoe Lake taken by Noel Johnson.

Authorized Signatory / Date

Project Manager / Date

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2.0 Project Description

2.1 Introduction

Horseshoe Lake is located in Woodland Washington, and is managed by the City of Woodland. The lake was formed in 1940 when a meander of the North Fork of the Lewis River was cut off during construction of Highway 99 (now Interstate 5). The Department of Highways, now the Department of Transportation, assumes responsibility for "preventing stagnation." Horseshoe Lake is located in both Cowlitz and Clark counties. The popular swimming beach is in Cowlitz County. The Horseshoe Lake Management Committee (HSLMC) was formed by the City of Woodland to identify problems and issues, research possible solutions, identify possible funding sources, and make recommendations to the Woodland City Council. The committee's top priority is to ensure that the lake remains in a healthy and safe state thereby providing optimal recreational opportunities for the public as well as enhanced wildlife habitat. The top five goals of HSLMC for 2018 include the completion of an Integrated Aquatic Vegetation Management Plan (IAVMP), milfoil management and monitoring, pump replacement, grant funding, and the continuation of water quality testing.

The lake's outflow, located at the end of the south arm, occurs via a concrete outlet structure. A gate valve at the bottom of the outlet structure is used to lower the lake water level. Water may also enter the outlet structure by flowing over the metal grated top if the water level exceeds 14.6 feet mean sea level, per Welch et al (1992). Once in the structure, water flows out through a 36 inch diameter pipe to the Lewis River. Another valve located in the outflow line, east of I5, can shut off flow from the overflow structure and acts as a back up valve to the gate valve. Additionally, a flap valve (tide gate) is located at the river outfall to prevent backflow under flooding conditions.

In the 1960s due to complaints of stagnation, the Department of Transportation installed a pump from the river to the lake, and 320,000 cubic yards of material was dredged. The pump was last upgraded in 1981, and currently delivers approximately 3,000 gpm. It is scheduled to be replaced in the summer of 2019 with a system that will deliver approximately 6,000 gpm. The water quality of Horseshoe Lake is strongly influenced by the rate of inflow from the Lewis River and by the river's water quality. The movement of water is generally helpful to the water quality of Horseshoe Lake. However, sometimes this water can be considered an advantageous dilution of Horseshoe Lake, and at other times it may be considered a source of "contamination."
Welch et al (1992) states that the lake did not permanently stratify, and that the lake remained mixed due to the large quantity of river water entering the lake that was more dense than the lake water, helping to prevent stagnation and oxygen depletion.

2.2 General Project Description

Horseshoe Lake is one of two lakes included in *Water Quality Testing and Improvement at Two Cowlitz County Lakes*. This project, which also addresses Silver 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 the two 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 Horseshoe Lake (HSL). Horseshoe Lake has a history of algae blooms, and at the start of this project, was impaired by dense milfoil. At that time, some water quality monitoring was being conducted by City of Woodland Public Works, but did not go through a planning process or have formal SOPs. Through this project, a Quality Assurance Project Plan (QAPP) was developed, and SOPs were written and adhered to. Sampling sites were reduced from five to four. Chlorophyll *a* and Nitrate-Nitrite were added to the sampling plan, while total phosphorus was retained as a sampling constituent from the Public Works sampling. A portable water quality mulitparameter instrument was purchased by the project and captured in-situ measurements of water temperature, pH, dissolved oxygen and turbidity.

Education, collaboration and planning on this project occurred between CCHD and HSLMC. At the start of the project, CCHD educated HSLMC on the importance of the development of an Integrated Aquatic Vegetation Management Plan (IAVMP), and provided some resources for its development. HSLMC started work on it. Ecology conducted a lake survey in August 2016 and noted that water was green from algae growth, and that Eurasion milfoil dominated the plant community. Due to the information that HSLMC was accumulating from their work on the IAVMP, they shifted their focus away from a sterile grass carp method of milfoil eradication and considered other options. CCHD facilitated the attainment of applicable information from Ecology and the Cowlitz County Noxious Weed Program, while Washington Department of Fish and Wildlife continued to be directly informative to HSLMC. In September of 2018, funded by the City of Woodland, HSLMC implemented successful Eurasion milfoil eradication via a selective herbicide. With those funds spent, and the grant project now complete, HSLMC is struggling to find funding for continued water quality sampling, the recommended planting of native aquatic vegetation, and the completion of the IAVMP. HSLMC wishes to continue water quality improvements in order to protect the desired uses of recreational wading, swimming, fishing, kayaking, motor boating, and bird watching. Algae blooms are not currently a problem, but the results of this study support the HSLMC's belief the return of summer algae blooms is imminent.

2.3 Project Accomplishments

In January of 2016 the Quality Assurance Project Plan – Horseshoe Lake (QAPP) was approved by Ecology. Training of volunteers took place with approved SOPs. The project's design included sampling at four designated locations, as shown below by red stars in Figure 1. These sites were identified with buoys and accessed by boat. Sampling occurred monthly from October to May, and twice a month from June to September. A Sechhi disk was used at these locations to determine visibility. Water temperature, pH, dissolved oxygen and turbidity were measured in-situ using a digital sampling handheld multiparameter meter that was funded by this project. An Ecology-accredited lab determined total phosphorus, nitrate-nitrite, chlorophyll *a*, and E. coli. All 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.

Supporting daily data, provided by City of Woodland Public Works, includes high air temperatures, rainfall, and valve status of outlet gate. Weekly supporting data includes lake level, temperature at 1 foot from surface, and visibility with Secchi disk. Occasionally, pump status (GPM or Off) and other comments are also noted.

Trophic State Index (TSI) was determined separately, per Carlson's formulas, using chlorophyll *a*, total phosphorus, and Secchi depth. All three methods of TSI calculation indicate Horseshoe Lake is in the upper mesotrophic state, and on the verge of entering the eutrophic state. The most accurate method, using chlorophyll *a*, resulted in a calculation of TSI(CHL) = 48. Sampling for E. coli during the summer demonstrated that the swim beach met EPA's primary recreation standards.

Figure 1 – Horseshoe Lake sample sites for this project (red stars)

2.4 Water Quality & Lake Health Improvement

Water quality of Horseshoe Lake did not improve as a direct result of this monitoring project. However, this project provided support to some significant projects that did affect lake health and will affect water quality. One of HSLMC's top priorities include a pump replacement, which is expected to provide both an increase in volume of flow and an increase in flow occurring during lower water level times. This project is out of HSLMC's jurisdiction, but they have actively lobbied for the improvement. Welch et al (1992) noted that pump enlargement will dilute lake total phosphorus, and has other benefits in maintaining high lake level to prevent groundwater influx and increased lake mixing to prevent stratification. A new pump is scheduled to be installed in the summer of 2019.
In pursuit of lake health and usability, the control of non-native noxious aquatic vegetation was attained during the course of this project. When the project first began, HSLMC installed another 160 sterile (triploid) grass carp in September 2015, reaching a total transplant number of 510 or just over 50% of the stocking rate that WDFW recommended for them to be effective at reducing / eliminating the milfoil. HSLMC then became more aware of the disadvantages of this control measure. They were unable to determine how many of the fish from previous installations had survived, and they were wary that SLWAC still has live grass carp twenty-four years present after installation and continues to suffer from lack of rooted aquatic vegetation. WDFW reminded them that Silver Lake was overstocked, but HSLMC decided to engage in more research and planning before purchasing additional grass carp.

This project provided a platform of collaboration that facilitated communication amongst several key stakeholders. CCHD facilitated discussions regarding the milfoil infestation between HSLMC and Cowlitz County Weed Control Board, and between HSLMC and Ecology. In addition, HSLMC members consulted with several manager of other lakes that had experienced milfoil infestations. A small dredging project was a considered option, and CCHD obtained Ecology's viewpoint on this from an aquatic vegetation management perspective. Ultimately, HSLMC obtained approval and funding from the City of Woodland in 2017 to obtain bids for the application of a selective herbicide. Application of 2,4-D occurred in September 2017. HSLMC is pleased with the reported elimination of all milfoil as of summer of 2018.

Before and after pictures of the lake bottom are shown in figures 2 and 3 below. Herbicide application occurred during September of Year 2. Concentrations of total phosphorus were lower in October of Year 2 compared to October of Year 1, but higher during the winter months that followed. It is possible that the increased decay of macropoytes in the winter of Year 2 leached phosphorus into the lake water, contributing to winter lake water concentrations higher than in Year 1. And similarly, it is likely that chlorophyll *a* concentrations were much lower in the winter of Year 2 due to the decaying and reduced milfoil.

Figure 2 - Eurasion water-milfoil in Horseshoe Lake on August 17, 2015 – photo by CCHD

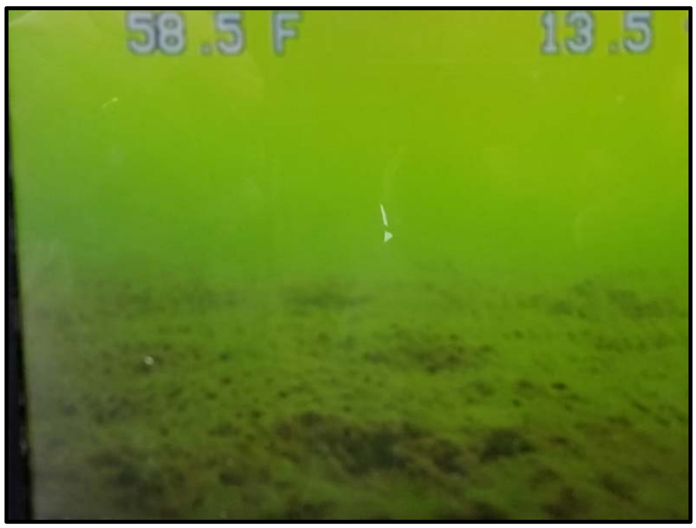

Figure 3 - HSL lake bottom devoid of milfoil May 2018 – photo by Bill Dunlop

2.5 The Next Step for Continued Success

Horseshoe Lake is undergoing the natural process of eutrophication, drastically accelerated by cultural activities such as road construction, agricultural, residential development, and wastewater treatment discharges. The resulting excess of nutrients, mainly phosphorus, can cause potentially toxic cyanobacteria blooms. It is important for HSLMC to control nutrient inputs through education, and to continue to monitor phosphorus levels. Lake management strategies and future educational efforts should be formalized with a lake management plan.

The lake's ecosystem has been affected by the elimination of milfoil. Lake water quality is influenced by submerged macrophyte density. The recent reduction of rooted plants may increase wave action and may cause the destabilization of sediments. Also the available phosphorus will not be used by the weeds. Both of these factors could cause an increase in algae.

The re-emergence of algal blooms would certainly be an unwanted consequence of milfoil elimination. Native vegetation may need to be installed to stabilize the lake bottom to prevent an increase in turbidity, depending on how quickly or if native vegetation grows back on its own. The development of an Integrated Aquatic Vegetation Management Plan for Horseshoe Lake is needed in order to help prevent degraded water quality. Stakeholders including HSLMC, the City of Woodland, and CCHD are currently seeking resources to accomplish this.

CCHD recommends year round monthly sampling for total phosphorus, and summer sampling for chlorophyll *a* from June – September. Secchi disk reading should accompany every sampling, in addition to water temperature, pH, dissolved oxygen, and turbidity. E. coli testing at the Swim Beach site during the summer months is also recommended for public health purposes. Continued testing should follow the QAPP if applicable. If other testing methods are utilized, then an applicable QAPP and SOP should be developed. Currently the CCHD and HSLMC volunteer Bill Dunlap are continuing monthly sampling per the plan described above, and the City of Woodland is providing funds for the lab fees. The results of this study will be utilized as an important baseline for constituents before and during milfoil removal, and before pump replacement.

2.6 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 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) Selecting the deepest site in an area is important in order for Secchi disk measurements to retain their value. A deeper site in the southern area of the lake should be considered, to replace the South site where the Secchi disk was read from the lake bottom several times.
4) The sampling results of the inlet site would be more meaningful if it could be moved out of the lake.
5) The normal Secchi disk arrangement was improved by substituting the rope (which is influenced by horizontal wave movement), with a telescoping pole. No disadvantages were noted, other than the added cost of the pole and the labor of securing the disk.
6) Phosphorus field duplicates should be taken from the same aliquat jar capture to qualify as a better duplicate, which will give the QA results more value. Unfortunately this isn’t possible for chlorophyll *a*, due to the large quantity of sample water necessary.
7) When performing quality assurance on turbidity, place the probe into the capture jar and take a probe reading. Then pour that water into the lab container.
8) Public presentations are a good way to educate committee members, but it is challenging to get the public to attend such events. Better advertising of these events may help, and / or the information disseminated in a different manner.

3.0 Project Details

3.1 General Project Details

This study generated a databank that includes 128 data points for total phosphorus, 128 data points for chlorophyll *a*, and 124 data points for Secchi depth. These data points support trend analysis regarding each constituent as well calculations of the trophic state index. In addition, 100 data points of total nitrate-nitrite were established. A water quality probe generated 124 data points for the in-situ measurements of water temperature, pH, DO, and turbidity. The County project lead and at least one HSLMC volunteer were present at each sampling event. Training was provided to the volunteers, and data was collected following the Ecology approved QAPP.

The project facilitated local discussion and understanding of individuals' effect on lake water quality. The project's data was compiled and made available to the public via the County's website, and submitted to Ecology through the Environmental Information Management (EIM) database. Community understanding and discussion was facilitated via a presentation at a public Cowlitz County Board of Health meeting, and at annual presentations held at the public HSLMC meetings. HSLMC members also interacted regularly with CCHD staff during their monthly meetings to gain further understanding and clarity.

3.2 Project Schedule Year 1

Horseshoe Lake - Year 1 Schedule & Sample Plan March 2016 – February 2017						
Event	Target Date	Intended Week	Total Phosphorus	Chlorophyll a	Nitrate-Nitrite	Turbidity
1	7 Mar '16	Mar wk 1	4	4	4	4
2	4 Apr '16	Apr wk 1	4	4	4	
3	9 May '16	May wk 1	4 + Q@3 = 5	4 + Q@3 = 5	4 + Q@3 = 5	
4	13 Jun '16	June wk 2	4	4	4	
5	27 Jun '16	June wk 4	4	4	4	
6	11 Jul '16	July wk 2	4	4	4	
7	26 Jul '16	July wk 4	4	4	4	
8	8 Aug '16	Aug wk 2	4 + Q@2 = 5	4 + Q@2 = 5	4 + Q@2 = 5	4
9	22 Aug '16	Aug wk 4	4	4	-	
10	12 Sep '16	Sep wk 2	4 + B = 5	4 + B = 5	-	
11	26 Sep '16	Sep wk 4	4	4	_	
12	10 Oct '16	Oct wk 2	4 + Q@2 = 5	4 + Q@2 = 5	4 + Q@2 = 5	
13	21 Nov '16	Nov	4	4	4	
14	19 Dec '16	Dec	4	4	4 + B = 5	4
15	23 Jan '17	Jan	4	4	4	
16	27 Feb '17	Feb	4 + Q@3 = 5	4 + Q@3 = 5	4 + Q@3 = 5	
Totals/Year			69	69	57	12
Q = Quarterly Field Replicate B = Annual Field Blank						

3.3 Project Schedule Year 2

Horseshoe Lake Year 2 Schedule & Sample Plan March 2017 – February 2018						
Event	Target Date	Intended Week	Total Phosphorus	Chlorophyll a	Nitrate-Nitrite	Turbidity
17	21 Mar '17	Mar	4	4	4	4
18	19 Apr '17	Apr	4	4	4	
19	22 May'17	May	4 + Q@2 = 5	4 + Q@2 = 5	4 + Q@2 = 5	
20	12 Jun '17	June wk 2	4	4	4	
21	26 Jun '17	June wk 4	4	4	4	
22	10 Jul '17	July wk 2	4	4	4	
23	24 Jul '17	July wk 4	4	4	4	
24	7 Aug '17	Aug wk 2	4 + Q@3 = 5	4 + Q@3 = 5	4 + Q@3 = 5	4
25	28 Aug '17	Aug wk 4	4	4	-	
26 field sheet lost	12 Sep '17	Sep wk 2	4 + B = 5	4 + B = 5	4 + B = 5	
27 late	6 Oct '17	Sep wk 4	4	4	_	
28	17 Oct '17	Oct wk 2	4 + Q@3 = 5	4 + Q@3 = 5	4 + Q@3 = 5	
29	16 Nov '17	Nov	4	4	4	4
30 no probe	19 Dec '17	Dec	4	4	4 + B = 5	
31	30 Jan '18	Jan	4	4	4	
32	13 Feb '18	Feb	4 + Q@3 = 5	4 + Q@3 = 5	4 + Q@3 = 5	
Totals/Year			69	69	62	12
Q = Quarterly Field Replicate						
B = Annual Field Blank						
Sample Site 1 = Inlet						
Sample Site 2 = Swim Beach						
Sample Site 3 = Midpoint						
Sample Site 4 = South						

4.0 Tasks Accomplished

- Collaborated with HSLMC 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 and chlorophyll *a* sampling for lab analysis at four locations monthly from October-May and twice a month from June-September. 128 data points were established for each analyte over the two year study.
- Conducted total nitrate-nitrite sampling for lab analysis at four locations monthly. 100 data points were established for this constituent over the two-year study (four more than original objective).
- Determined Secchi disk depth at four locations twice each month during the summer months of June – September and once a month from October - May. 124 data points were established for Secchi depth (four less than original objective but equal to goal of completing 31 or 32 events).
- Determined probe measurements at water depth of three feet for water temperature, pH, dissolved oxygen and turbidity at four locations monthly from October-May and twice a month from June-September. 124 data points were established for each of these measurements.
- Conducted pubic presentation to CCHD Board of Health in July of 2016. Many county staff members and approximately fifteen members of the public attended.
- Conducted public presentations in December 2016, April 2017 and September 2017 at HSLMC meeting. HSLMC members, City of Woodland personnel, City of Woodland Coucilman, and only a couple members of the public attended.
- Input water quality monitoring data into Ecology's EIM system annually.
- Provided public access to all data on County website.
- Submitted quarterly progress reports and billings to Ecology.
- Conducted Technical Audit within 90 days of project commencement and submitted report to Ecology.
- Conducted 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 was planned and described in the QAPP. Field duplicates were taken quarterly. Field blanks were taken annually, and all came back with non-detect values. All 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 #8, 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.

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6.0 Results – Secchi Depth

Water Quality Goal = 5.9 ft to 7.9 ft
Summer 1 Results = 5.7 ft +/- 1.5 ft
Conclusion = Secchi Depth may be within goal, and is improved from summer 1991 results of 3.9 ft.

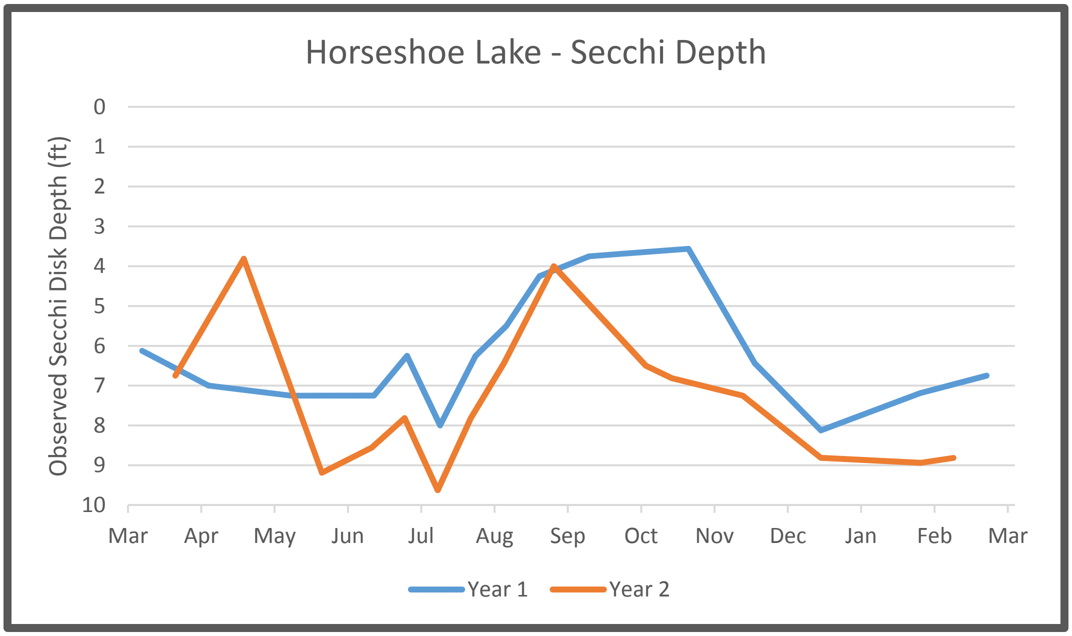
Secchi visibility is a measure of lake water clarity determined by lowering a 20 cm black and white disk into the water until it is no longer visible. Secchi visibility is inversely proportional to the amount of algae in the lake. As algae concentration increases, Secchi visibility decreases. It is one of the oldest, simplest, and most budget friendly measurements used to characterize a water body. It is not, however, the most precise; the QAPP lists the precision of this measurement at 0.5 m or a little over 1.5 ft, and accuracy as N/A since the quality of Secchi depth is user-dependent and varies from person to person as a function of vision. However, the project lead has reasons to be confident in the consistency of the Secchi disk measurements taken during this project since the same person took the measurements throughout the two year study on the shady side of the boat between 10am and 4pm, and horizontal movement was eliminated with the use of a pole instead of a rope. See pictures below:

Secchi disk adhered to base and telescoping pole

Results through the two year study averaged 6.7 ft with a variance of 3.9 ft and a standard deviation (SD) of 2.0. Year 1 averaged 6.1 ft while Year 2 measured improved visibility at 7.4 ft. The disk was occasionally read from the bottom of the lake, which will make TSI(SD) calculations less accurate and perhaps artificially higher to some degree. This occurred at the South site on five different occasions (Events, 9, 27, 28, 29 and 30). Notably only event 9 was used in TSI(SD) calculations since it was the only summer event of the five. These results are similar to what were reported after alum treatment in 1999. The two-year seasonal trend for Secchi depth is an observed decrease of visibility during the fall, perhaps related to fall die off and decomposition of plants. In 1998 Entranco identified lower water quality at the end of summer was caused by the introduction of phosphorus by the Lewis River. An increase of visibility occurred during the summer and at the end of both calendar years.

Welch et al (1992) established water quality goal of 5.9 to 7.9 ft based on the summer mean of Secchi visibility. Entranco Secchi depth results were 5.6 ft in the summer of 1997 and 6.6 ft in the summer of 1998. The summer data is only fully available for year 1 with the summer mean of 5.6 with a variance of 3.6 and standard deviation of 1.9. The results of Year 2 for June – August only are 7.4 ft with a variance of 5.0 and a SD of 2.2.

As noted above the precision for Secchi measurements is 1.5 ft and must be considered when comparing one study from another. With this in mind, it appears that Secchi visibility is within the water quality goal range established by Welch et al (1992) and similar to measurments taken in 1998 by Entranco.



7.0 Results – Lab Analytes

7.1 Nitrate-Nitrite

Nitrate-nitrite was sampled during twenty-five events over the two year course of study. Results measured greater than non-detect amounts only in December of 2016 and January of 2017. They were highest at the Inlet sampling location; 0.101 mg/L in December and 0.085 in January. The Swim Beach was second highest with 0.094 mg/L in December and 0.082 in January. Results for Midpoint and South were at the minimal detection level of 0.05 mg/L during both of those months. While these are detectable results, they are not significant. Washington State action limit for drinking water, which is held at a higher standard, is 10.0mg/L for nitrate and 1.0mg/L for nitrite. A state standard for water bodies that do not provide a source a drinking water would presumably be even higher.

7.2 Total Phosphorus

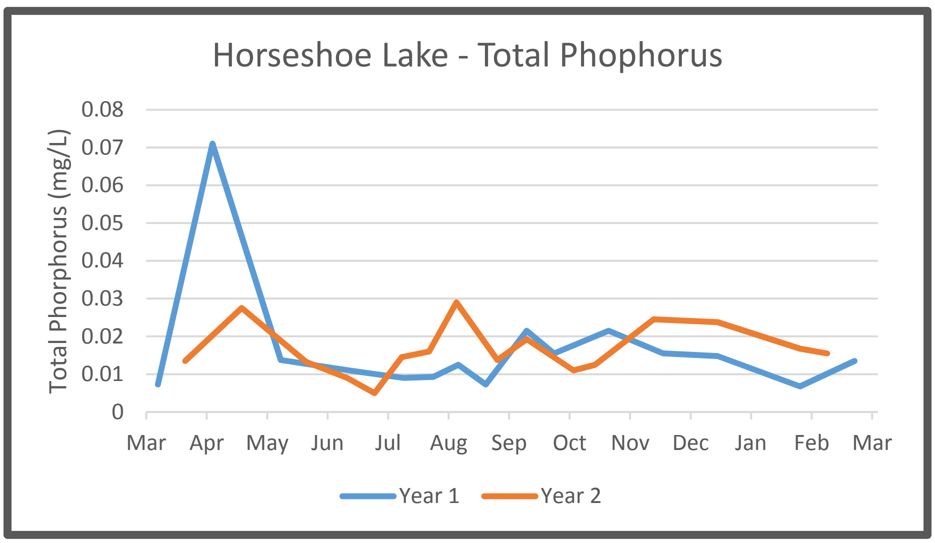
Water Quality Goal = 13.0 to 18.0 µg/L
Summer 1 Results = 13.9 µg/L
Summer 2 Results = 16.6 µg/L
Conclusion = total phosphorus is within goal range and lower than 1991 summer mean results of 30 µg/L

Welch et al (1992) established summer mean total phosphorus water quality goal of 13.0 to 18.0 µg/L. Both summer 1 and summer 2 results fall within this range at 13.9 and 16.6 µ/L respectively. Phophorus is considered the limiting nutrient of Horseshoe Lake, and limiting sources and concentration of phosphorus continues to be important in retaining the desired uses of Horseshoe Lake.

The average total phosphorus over the course of the two year study was 0.0164 mg/L (16.4 µg/L) with a variance of 0.0002 and SD of 0.0151. Year 1 average was 0.0163 mg/L (16.3µg/L) with variance of 0.0004 and SD of 0.0192. Year 2 was similar with 0.0165 mg/L (16.5 µg/L) with a variance of 0.0002 and SD 0.0094. Per the QAPP, non detects were recorded at half of the detection limit, or 0.005 mg/L.

The average total phosphorus levels in HSL are currently lower than both 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 µg/L, or 0.020 mg/L in Puget Lowlands Ecoregion. EPA (1987) water criteria for total phosphorus is 25 µg/L, or 0.025 mg/L. Although the averages for Year 1 and Year 2 are similar, the graph shows the variations involved in obtaining those averages. When comparing the Year 1 to Year 2, it can be observed that after an initial dip, total phosphorus concentration remained higher through the winter of Year 2 following the herbicide treatment in September, possibly due to the lack of vegetation available for phosphorus uptake.

The two-year seasonal trends that can be identified include a decrease of total phosphorus in the summer (likely being utilized by greater plant density), and an increase in the fall to level off through the winter. Spikes occurred during the spring.



The average TP results during this study were much lower than the 1991 results of 30µg/L, and are within Welch’s water quality goals. The average summer concentrations of total phosphorus between 1991 and 2016 are largely unknown. The City of Woodland Public Works Department started occasionally testing for total phosphorus in 2013. The mean summer average of total phosphorus calculated from Public Works data in 2013 is 9.4µg/L, while the mean summer average in 2014 is 24 µg/L. These results are both under and over the water quality goal range of 13.0 to 18.0 µg/L.

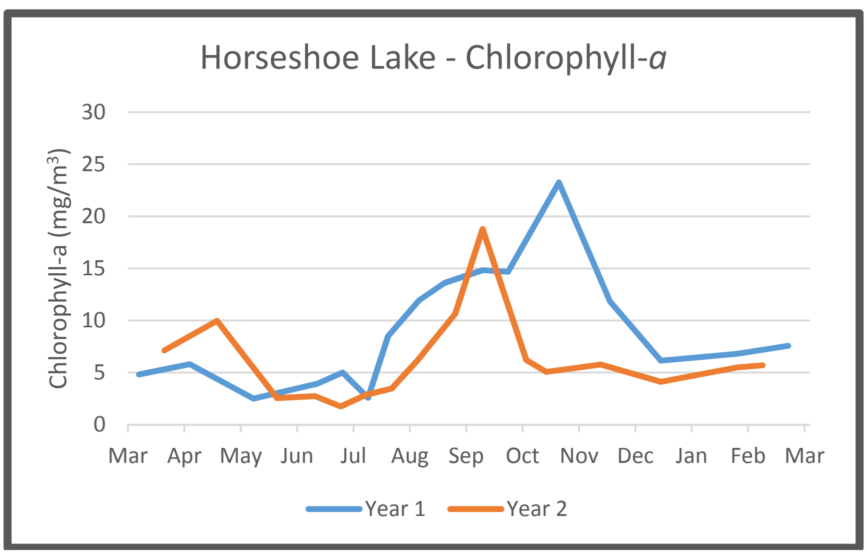
7.3 Chlorophyll *a*

Water Quality Goal = 5.4 to 8.3 µg/L
Summer 1 Results = 9.4 µg/L
Summer 2 Results = 6.6 µg/L
Conclusion = total phosphorus was higher than goal range range in 2016, was within goal range in 2017.

Average chlorophyll *a* concentrations throughout the course of the two year study were 7.57 mg/m3 with a variance of 33.64 and SD of 5.80. Year 1 averaged 8.98 mg/m3 with a variance of 41.21 and SD of 6.42 while Year 2 averages less at 6.15 with a variance of 22.53 and SD of 4.75. The seasonal two-year trends include that the lowest levels are in the summer, and the highest levels are in the fall. It can be noted that chlorophyll *a* concentrations dropped quickly following the herbicide treatment in September of Year 2. They remained much lower through the fall compared to fall levels of Year 1, and then leveled off to similar levels in January.

Oftentimes, chlorophyll *a* is only sampled for and considered during the summer months. If we isolate our summer data to months June – September, then the average is 8.09 mg/m3 with a variance of 43.93 and SD of 6.63. Summer only during Year 1 averaged 9.38 with a variance of 41.43 and SD of 6.44, while summer of Year 2 was lower with an average of 6.63, variance 44.23, SD 6.65.

When Entranco conducted summer testing in 1998 prior to alum treatment, average results of chlorophyll *a* was 15 µg/L (Entranco Inc and Gibbs & Olson Inc 1999), which is equal to 15mg/m3. After alum treatment, results decreased to 8.5 µg/L, which is equal to 8.5 mg/m3. Thus it would appear that chlorophyll a results are averaging similarly to what they were in 1999, post alum treatment. This doesn't mean, however, that they have been averaging similarly for the entire interim. The current HSLMC president noted that blooms were occurring every summer to some degree, up until "4 or 5 years ago."



8.0 Results - Sonde

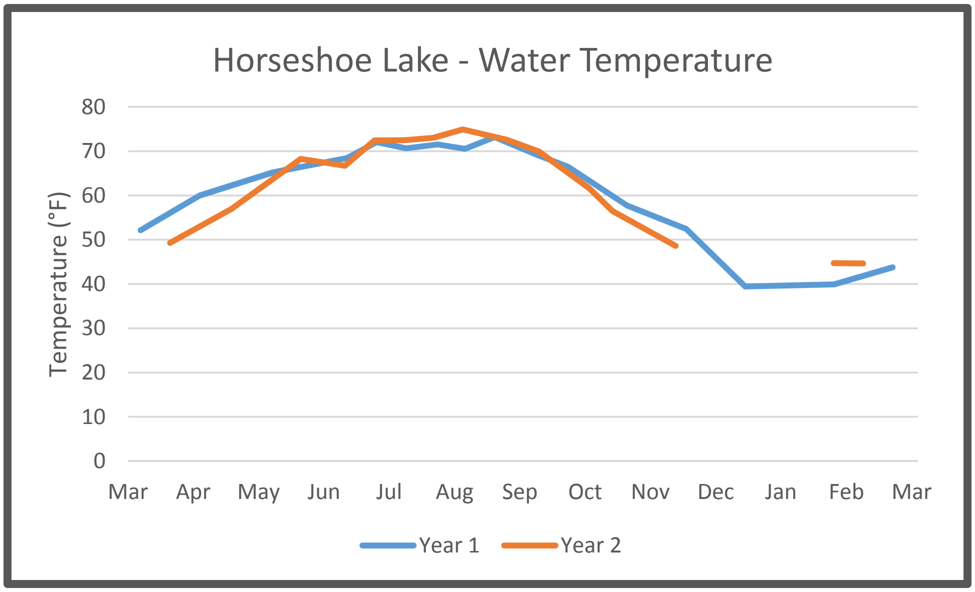
In-situ data was collected using Ysi ProDSS digital sampling system, calibrated and used according to manufacturer's instructions (https://www.ysi.com/ProDSS). Calibration occurred at least every 30 days, and drift was noted in a calibration log. All data was taken at three feet from the water surface,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

During October of 2016 the probe readings were not retained at the South site for an unknown reason. This omission in data was handled by using an average of the other three sites. During December of 2017 and into January 2018, the probe was out for repair resulting in no data for that month of December.

Figure 5 – YSI ProDSS Sonde with calibration solutions

8.1 Temperature

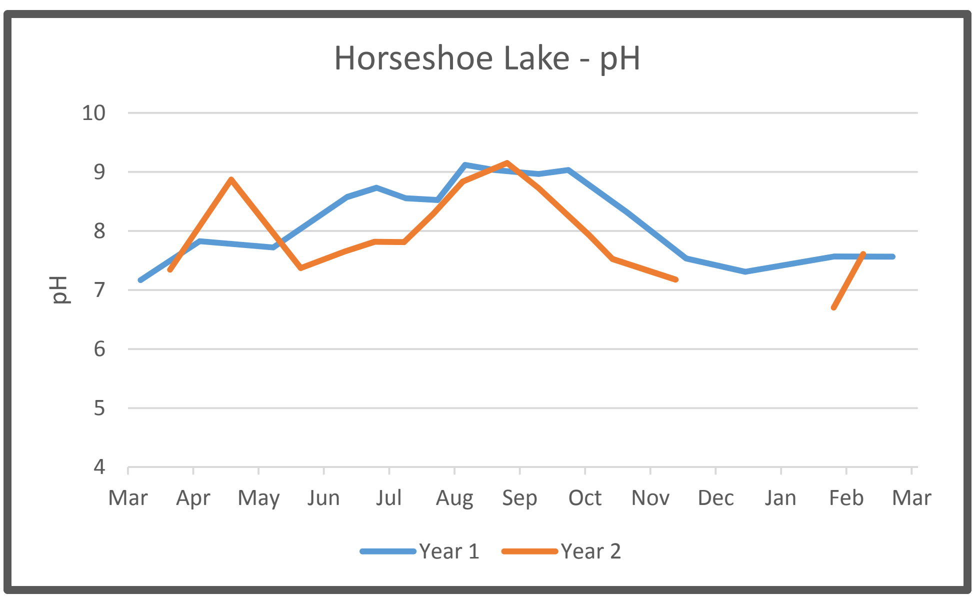
Temperatures were similar from sample site to sample site, with just a small increase in temperature at the Southern site, due to more shallow water depths. The average temperature for the duration of the project was 58.5° when corrected for multiple summer samplings, with a average daily variance of 0.7 and SD of 0.7. The temperature tends to be lowest at the end of the calendar year, which may be a factor in Sechhi depth increasing at this time.



8.2 pH

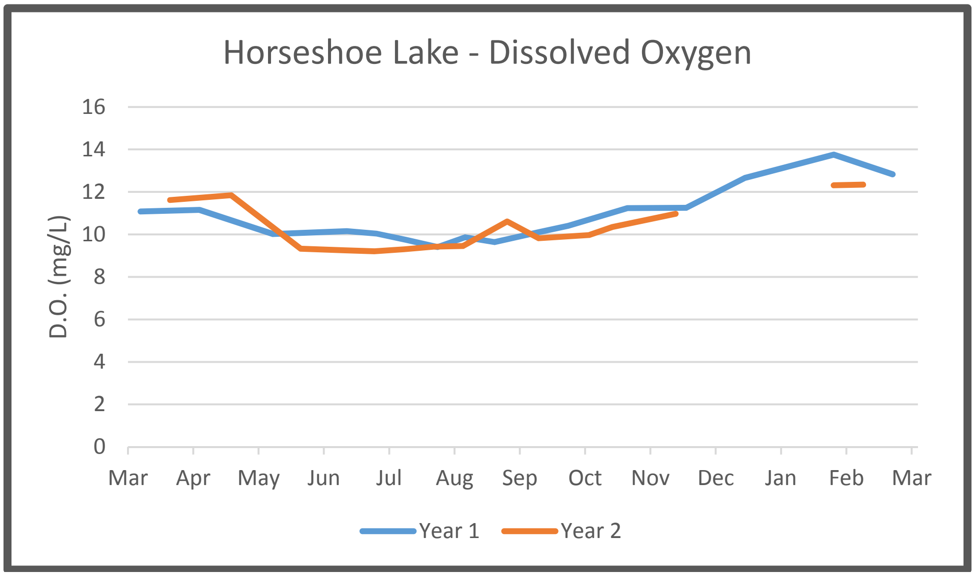
The average pH throughout the 2 year study was 8.07 with a variance of 0.51 and SD of 0.71. The pH during Year 1 was 8.22 with a variance of 0.48 and SD of 0.69. The pH during Year 2 was 7.92 was a variance of 0.5 and SD of 0.71. Seasonally, pH climbs through the summer, peaks, and then declines through the winter.

Somers (1988-1989) observed that pH was an average of 8.3. Results were 7.3 when the pump was off, but was 8.8 when the pump was on. Somers noted that there was some evidence that the lake was becoming more basic, which could allow a new species of algae to gain foothold. Ten years later the Entranco study (1997-1998) obtained an average pH of 7.7.



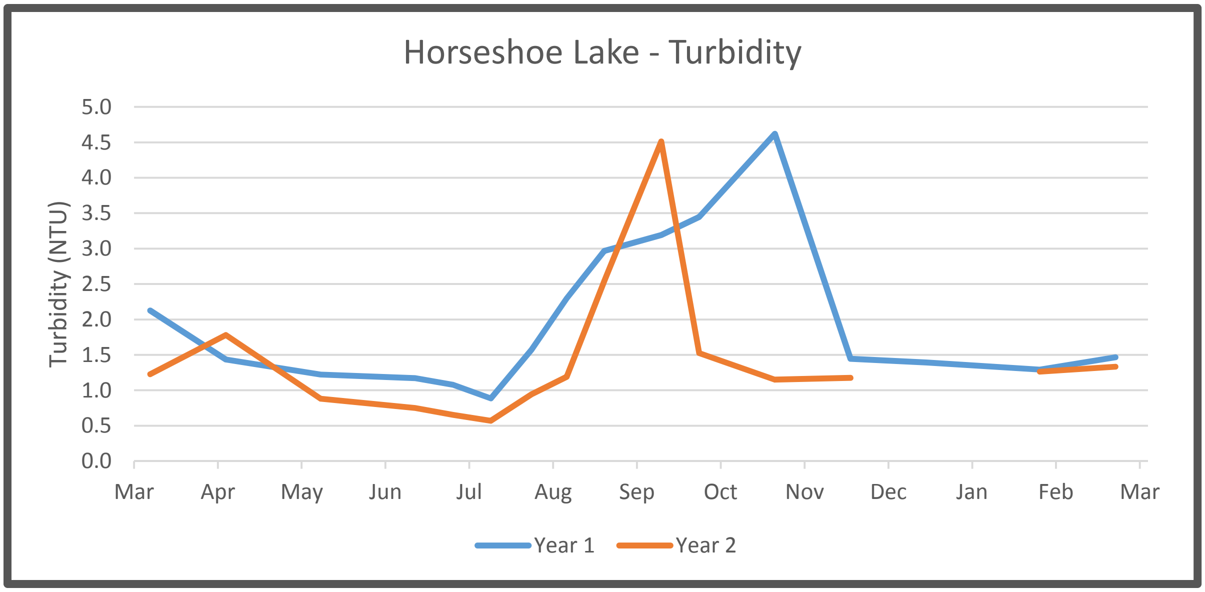
8.3 Dissolved Oxygen

The average DO measured through the course of the two year study was 10.62 mg/L with variance of 1.54 and SD of 1.24. Year 1 was slightly higher than year 2 at 10.83 vs 10.38 mg/L. Dissolved oxygen is lowest when the temperatures are highest, and vice versa. In the Welch (1992) study, average DO from April 1991 – March 1992 was 10.4. In the Entranco study, the average was DO from June 1997 to September 1998 was 10.0.



8.4 Turbidity

The average turbidity for the 2 year study was 1.71 NTU with a variance of 1.41 and a SD of 1.19. The average turbidity in Year 1 was 1.98 (variance 1.26 and SD 1.12) while the average in Year 2 was 1.43 (variance 1.43 and SD 1.20). The higher measured turbidity in Year 1 is expected considering that the Secchi visibility was lower in year 1. Seasonally, turbidity sharply increases during the summer and then falls off in the fall or winter.



9.0 Supporting Data

Supporting data was furnished by City of Woodland Public Works. Daily records include river level, day high temperature, 24 hour rainfall, and pump valve status. Weekly records include lake level, lake temperature, and visibility in feet. Visibility is by a homemade Secchi disk, and water temperature is at 1 foot from water surface.

CCHD examined the 24 hr and 48 hr rainfall and did not find a direct correlation to lake phosphorus levels. Oftentimes when phosphorus was at 0.02 mg/L or higher, there had been significant rain within a 48 hour period, but sometimes such a reading had no associated rainfall.

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 HSL, 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 tropic 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 6 – Carlson's TSI and corresponding Chl, P, SD and Trophic Class

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

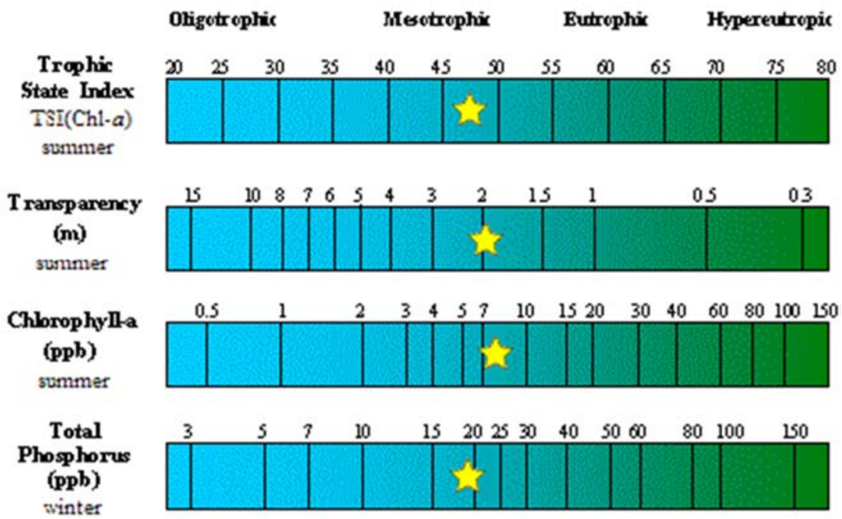


Figure 7 color spectrum of trophic state (www.lakeaccess.org), with project results shown with yellow stars.

HSL is in the upper mesotrophic classification with a TSI(CHL) of 47.5. Whether this is good or bad is dependent on desired uses and fish species. Current uses include wading, swimming, kayaking, fishing and bird watching. HLS has resident eagles and osprey, and functions as a temporary home to migratory ducks and geese. Wading and swimming are better supporting with mesotrophic biological conditions, while birds are better supported with eutrophic conditions.

11.0 Evaluation

This study has determined that the major constituents of phosphorus, chlorophyll a, and Secchi visibility are within the goal ranges established in 1992 by Welch et. al. The trophic state index calculations place Horseshoe Lake in the upper mesotrophic part of the spectrum, which allows the lake's current desired uses. Algal blooms were not present within the duration of the study.

The QAPP identified the goal of completing thirty-one out of the thirty-two scheduled sampling events, and this was accomplished. This success results in a high quality databank that is helpful in planning, executing, and evaluating improvement actions. One example of the significance of this success is demonstrated with the recent application of herbicide that appears to have eliminated the milfoil. The stakeholders are continuing to measure the major lake constituents, and will be able to compare them with the measurements taken before herbicide application. This will provide information on water quality changes, if any, caused by milfoil removal.

A strong partnership now exists between CCHD and HSLMC, which will help to ensure the continued collection of high quality data, will aid in planning further improvement projects, and will assist with engaging more members of the community. Methods other than public meetings should be considered for community outreach. The public website now provides another method with which to educate and engage the public. It contains the QAPP, the SOP, a link to all data collected, as well as information on helping lakes via responsible stewardship. Also, the lakeside neighborhood seems suitable for a "merit badge" program such as the LakeWise program in Snohommish County, or the Lake Smart program in Maine, in which lakeside property owners earn an attractive sign proving their participation in a lake care program.

The calculation of the trophic state index is new for the HSLMC, and is sustainable. Summer chlorophyll concentrations result in the most accurate index, and total phosphorus results in the second most accurate index. Secchi depth can be used for its calculation if the other two are not available. The trophic state index, if continued, will be a relatively easy way for HSLMC members to know if their lake is entering a eutrophic state. 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.

The long-term project goal is to improve the water quality of Horseshoe 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. There were no algal events during the course of this study, and phosphorus levels are within goal range. However, the removal of the milfoil that occurred during the study may result in increased phosphorus concentrations. A formalized lake management plan that includes the control and reduction of phosphorus input is recommended.

12.0 Follow up

Currently Horseshoe Lake is in the upper mesotrophic state, on the verge of eutrophic classification. This supports both the swimmers who find the water to be adequately clear, and the wildlife population and fisherman that appreciate the abundant fish that are supported nicely from the near eutrophic biological state of the lake. Continued water quality monitoring is essential to determine if / when the lake is entering a eutrophic state, which would be perceived as reduction of lake health to those who use it for primary recreation and visual aesthetics. Water quality monitoring will also help to determine the effects that the herbicide treatment and elimination of milfoil had on lake health. Thus far, results show that during the winter after the herbicide treatment, phosphorus concentrations increased compared to the year prior, while chlorophyll *a* concentrations decreased. Now the lakebed is relatively bare and devoid of rooted plants, especially on the south end. This too affects the water quality. It could potentially lead to increased algal blooms, which could lead to yet another remediation action (such as the alum treatment of 1997).

HSLMC has typically received funding from the City of Woodland, but the amount varies year by year, and has been inadequate to support both a comprehensive testing program and remediation activities. The CCHD and the City of Woodland are funding current water quality testing activities. However, without an additional funding stream, these activates are only scheduled through 2018.

CCHD is currently looking for other ways to partner with the HSLMC to continue to improve the water quality of Horseshoe Lake. One proposal is to assist the HSLMC with developing the IAVMP. Cowlitz County continues to state its commitment to HSL with the following 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

The top five goals of HSLMC for 2018 include the completion of an Integrated Aquatic Vegetation Management Plan (IAVMP), milfoil management and monitoring, pump replacement, grant funding, and the continuation of water quality testing. CCHD recommends that continued water quality testing includes the calculation of Carlson’s trophic state index, and that the IAVMP, once written, is expanded into a formal lake management plan.