Summary of the 2019 Water Quality Monitoring Program for Columbia Lake

Columbia Lake Stewardship Society
February 9, 2020

Executive Summary

The Columbia Lake Stewardship Society (CLSS) began monitoring the water quality of Columbia Lake on April 20, 2014 and has continued, while the lake is ice-free, through to October 10, 2019.   In 2019 the first water quality monitoring event on Columbia Lake was in late May and the last monitoring event was in early October. Monitoring included:

- approximately bi-weekly monitoring of selected water quality indicator parameters and approximately monthly sampling of water for chemical analyses;

- a survey of chloride, turbidity and conductivity concentrations along the lake; and

- measurement of the water quality of Dutch Creek, Hardie Creek, Marion Creek and the small creek the drains from Canal Flats

CLSS' water quality monitoring program is administered, implemented and interpreted largely by volunteers. Further, the water quality program for 2019 involved many volunteers that had participated in several previous years and some volunteers new to the program. The 2019 monitoring program was enhanced by assistance received from a summer student made available to the program by a grant received from the Canada Summer Jobs program.

Funding for the program was provided by:

- Columbia Valley Local Conservation Fund,
- Columbia Basin Trust,
- Columbia Valley Conservation Trust,
- British Columbia Hydro, and
- Fresh Water Conservation Program
- Regional District of East Kootenay,
- Columere Marina,
- Fairmont Hot Springs Resort Ltd. including the Riverside Golf course and the Fairmont Hot Springs Airport,
- Columbia Ridge Community Association, and
- Columere Park Community Association.
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The contributions by the volunteers and funding agencies are acknowledged gratefully.

The key findings and subsequent continuous improvement suggestions from the 2018 water quality monitoring program ar*e:*

- Overall lake water quality is acceptable for the current uses of the lake (recreational, potable water and aquatic habitat).   However, the 2019 results differ from those of the prior five years.

- The concentrations for turbidity measured in 2019 exceed the maximum expected value recorded between 2014 and 2018. The measured concentration over the summer months are among the greatest recorded. The greatest turbidity changes from prior years are noticed in the south end of the lake where water is the shallowest.

- The greatest values for conductivity are in the south end of the lake where prior work by CLSS, as reported in 2018, suggests a substantial volume of groundwater may drain to the lake from beneath Canal Flats

- In 2019 we noticed that the lowest values for the pH of the lake water was measured in August. In prior years the lowest values for the pH of the lake water were measured in April and May. This change in pattern of pH values should be monitored carefully.

- Although the dissolved oxygen concentrations measured are suitable to support aquatic life the timing of the maximum dissolved oxygen concentration differed in 2019 from that of other years. Between 2014 and 2018, the greatest concentrations of dissolved oxygen occurred in the spring. In 2019 the greatest dissolved oxygen concentrations were measured in late August. In addition to the noticeable change in when the maximum dissolved oxygen concentration was measured on the lake, the concentrations for dissolved oxygen are among the lowest recorded on the lake and are less than the 30 day average for dissolved oxygen of 8 mg/L set within the Lake Windermere water quality objectives.

- The survey at fourteen monitoring locations along the lake repeated from the 2018 survey shows that pH values increase from the north to south and conductivity and chloride both increase from north to south (i.e. the highest pH and greatest concentration of conductivity and chloride are in the south end of the lake). This increase from north to south is not uniform along the lake and therefore is not due to direct rainfall on the lake surface. The greater concentration of chloride in south end of lake is understood to be a consequence of the water quality of those waters draining to the lake both surface and groundwater.

- The stream sampling monitoring program demonstrates that the small creek draining from the marshy area to the north of Canal Flats and likely other waters (groundwater and surface water) draining from this area contains chloride that comes from a man-made source. Associated with the chloride found in the creek water of the creek draining from this area flats are concentrations of nitrate that are ten times that measured in the other streams CLSS monitored.

- Compared to other lakes in the region, Columbia Lake water has a higher concentration of chloride. Although the chloride concentrations are well less than the concentrations that may be considered to make the water unacceptable for potable water or recreational uses, the only source of chloride are man-made. Consequently, these concentrations are directly to use of the surrounding land.

For the 2020 monitoring program CLSS intends to:

- Plot control limits showing the maximum and minimum expected concentrations from month to month.

- Confirm the greater concentrations of conductivity and chloride in the south end of the lake needs by expanding the program to other months of the year.

- The suspected disturbance of lake bottom sediments by recreational activity and the decline in oxygen over the summer months suggests that during the summer months more intense measurement of dissolved oxygen should be made when the concentration of dissolved oxygen is measured to be less than the 30 day minimum of 8 mg/L.

- The differences in the concentration of water indicator parameters observed among the four creeks sampled in 2019 will be confirmed by sampling of these water courses in early spring, mid-summer and late summer.

- The regular bimonthly monitoring program and the semi-monthly program of water quality sample collection will be continued. We will add iron and manganese, chloride and nitrate to the chemical analytical program.

- Although we have attributed several of the observations made in 2019 to increases in growth of phytoplankton, increase wave action and resuspension of bottom sediments, we have no means of determining the likely greatest contributor to the findings observed.

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WATER QUALITY MONITORING PROGRAM SUMMARY For 2019

1. Introduction

Columbia Lake, located in the East Kootenay region of British Columbia between the villages of Fairmont Hot Springs and Canal Flats, is the headwater of the Columbia River drainage system. Because Columbia Lake is a headwater lake, the quality of water draining from the lake potentially influences the water quality received downstream.

Columbia Lake is part of the Columbia Wetlands system. These wetlands extend from the south end of Columbia Lake near the village of Canal Flats to the village of Donald on the north side of the TransCanada highway near Golden BC. Columbia Lake drains into the Columbia River at the north end of the lake. This river drains into Late Windermere and from Lake Windermere continues into the Columbia Wetlands north of the town of Invermere. North of Donald and just beyond the Mica Dam, the Columbia River turns south and drains through the Arrow Lakes system to exit Canada south of Nelson BC.

In response to concerns about future development along the lake and the consequent potential for impact on the quality of the lake's water, the Columbia Lake Management Strategy was written by Urban Systems in 1997. One of the recommendations in that strategy was monitoring of the lake. We understand the Regional District of East Kootenay (RDEK) has scheduled the commencement of a revision of the lake management strategy for completion some time in 2020.

The Columbia Lake Stewardship Society (CLSS) began monitoring the lake's water quality on April 20, 2014 and has continued the monitoring program while the lake is ice- free through to September 2019. In 2019, water quality monitoring of Columbia Lake began on May 29 and ended on August 22. Monitoring included approximately bi-weekly monitoring of selected water quality indicator parameters and the collection of three water quality sample in each of June, July and August.

Previously, during the summer months of 2018 a bi-weekly survey of the distribution of turbidity and conductivity concentrations along the lake had been conducted. On July 23, 2019, CLSS conducted another similar survey to confirm the findings of the 2018 surveys with the addition of chloride to the analyses.

BCMOE also monitors the quality of the Columbia Lake water although CLSS understands the program is administered and undertaken by Living Lakes Canada. BCMOE's monitoring program involves measuring a broader range of chemical parameters than that undertaken by CLSS. BCMOE monitors the lake water each year in the early spring (late April to early May) and late summer (late August to early September). The BCMOE program began in April 2015 in conjunction with monitoring of other nearby lakes (Lake Windermere, White Swan Lake, Premiere Lake and Moyie Lake) and has continued until August 2019.

In October of 2019, CLSS monitored the water quality of Dutch Creek, Hardie Creek, and Marion Creek along the lake's west side and the creek draining to the lake from Canal Flats at the south end of Columbia Lake.

Water quality monitoring of these creeks was **undertaken to begin to evaluate the** influence of these streams on the water quality of the riparian areas where the streams drain to the lake.

This summary of water quality monitoring program:

- describes the water quality monitoring program;
- summarizes the water quality monitoring results;
- compares the water quality of Columbia Lake to nearby lakes as monitored and reported by BCMOE; and
- provides suggestions to improve the monitoring program.

2.0 Monitoring Program

Sections 2.1 through 2.6 describe the water quality program conducted by CLSS on Columbia Lake. Section 2.7 briefly summarizes the report entitled "Groundwater Contribution to Columbia lake", dated November 2018, and authored by Mr. Ed Gillmor, a Board Member of CLSS. Mr. Gillmor is a professional geologist specializing in hydrogeology and is a property owner in Columere Park.

2.1 Acknowledgements

CLSS's water quality program is administered, implemented and interpreted largely by volunteers. In 2019, the following volunteers contributed to the water quality monitoring program:

- Tracy Flynn — overall program administration and management;
- Gina Forte, Lucas and Cesar Fuertes - participation in on the lake training and measurement of the distribution of Specific Conductance and Turbidity along the lake in the summer of 2018;
- Ed Gillmor — monitoring in the summer months, the July 23 and preparation of the potential groundwater contribution to Columbia Lake ;
- Gary Gray — monitoring in August;
- Dave and Donna Rae — assistance with on-the-lake training:
- Barb and Kevin Stromquist — monitoring in June and July and stream monitoring;
- Tom Dance and Nancy Wilson — on the lake training in June, data compilation and graphing, data interpretation and reporting.

For the 2019 monitoring program, CLSS received a grant from the Canada Summer Jobs program and from the Columbia Valley Conservation Foundation (CVCL) to retain a summer student to assist with the water quality and water quantity program and with some of the education opportunities the society is engaged with. That summer student, Ellen Storey participated on the program in May through August of 2019.

The program receives funding from the following agencies:

- Columbia Valley Local Conservation Fund,
- Columbia Basin Trust,
- Columbia Valley Conservation Trust,
- British Columbia Hydro, and
- Fresh Water Conservation Program
- Regional District of East Kootenay,
- Columere Marina,
- Fairmont Hot Springs Resort Ltd. including the Riverside Golf course and the Fairmont Hot Springs Airport,
- Columbia Ridge Community Association, and
- Columere Park Community Association.

Advice on the program was also provided by Regional District of East Kootenay (RDEK), Suzanne Bayley of the Columbia Wetlands Society Partnership (CWSP); and Rick Nordin and Dave Schindler of the BC Lake Stewardship Society.

The participation of these volunteers, individuals and agencies is acknowledged gratefully.

2.2 Historical Information

The water quality monitoring program of Columbia Lake initiated by the CLSS in 2014, was in response to recommendations contained in the Columbia Lake Management Strategy (Urban Systems, 1997) indicating that a water quality and water level monitoring program should be established. In 2014, the water quality confirmed that the lake's condition was consistent with the nearly pristine conditions used to form the strategy. Four stations for monitoring lake quality conditions were established by this initial program. In 2015, two changes to the water quality monitoring program were made to better align the program with the management strategy. These changes were the location of two stations:

- Station S4 was moved 2.4 km north: and

- Station S3 was moved 1.7 km southward.

This new location for S4 placed the site in shallow water.

The current station locations are shown on Figure 1 and summarized from north to south along the lake as:

Station location	Northing	Easting
N1	N50.28769	W115.87126
S1	N50.253929	W115.86256
S3	N50.20107	W115.84820
S4	N50.17533	W115.83442

Additional changes to the program were made in 2016 following advice provided to CLSS volunteers at the Lake Keepers workshop sponsored by the BC Lake Stewardship Society and held in conjunction with the May 2016 Wings over the Rockies event. At that workshop, it was learned that dissolved phosphorous might be a more useful indicator of the ecological health of the lake and of contributions to the lake from surface water inflow. Consequently, beginning with the May 2016 event, nitrate was removed from the chemical analysis and dissolved phosphorous was added. In addition, it was suggested that a more useful indicator of lake ecological health was the contrast between deep and shallow water quality. To make this determination, at the deepest sampling location (location S1) two water quality samples, one shallow (about 0.5 m below the water surface) and one deep (about 0.5 m above the bottom of the lake), were collected each month. To collect the deep sample required use of a Van Doren sampler provided to CLSS by Dr. Suzanne Bayley.

In 2018, the demise of the van Doren sampler required CLSS to use a bailer system with one-way valves to collect the deep- water sample. This bailer was built by Mr. Gillmor.

Figure 1 – Monitoring Locations

Fairmont Hot Springs
Riverside
WSC
Dutch Creek
Timber Springs
N1
S1
Hardie Creek
Marion Creek
S3
S4
Creek draining from Canal Flats
Canal Flats
Image © 2015 DigitalGlobe
Image © 2015 Province of British Columbia
Canal Flats
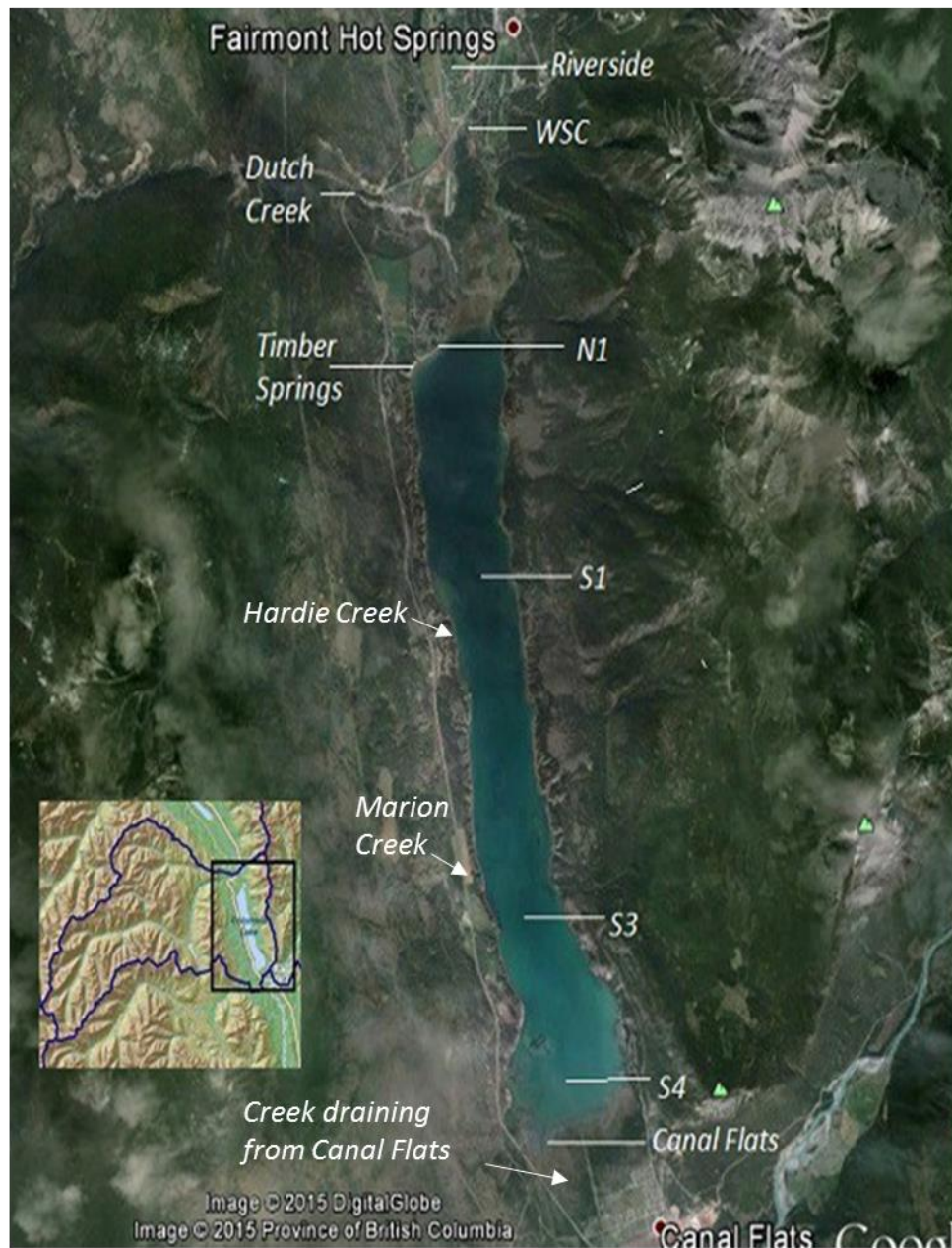
On January 15, 2016, at location S1, a special investigation of the oxygen distribution in the lake was made by Tracy Flynn and Dave Hubbard. This special investigation was not repeated in 2017, 2018 or 2019 but is brought forward here as a reminder of those factors potentially influencing the lake's water quality.

For this investigation, a hole was cut through the ice and the water temperature and dissolved oxygen concentrations with depth below the lake surface measured using handheld instruments. Table 1 provides the dissolved oxygen depth profile measured during that investigation.

Table 1: Water Temperature and Dissolved Oxygen Concentrations: S1, January 15, 2016

Lake Depth (m below base ice)	Trial One		Trial Two	
	Temperature (deg C)	Dissolved oxygen (mg/l)	Temperature (deg C)	Dissolved oxygen (mg/l)
0	1.2	15.1	--	--
0.5	1.7	15.1	1.2	14.2
1	2.5	14.4	2.5	13.9
1.5	3.3	13.9	2.7	13.9
2	3.4	13.7	3.3	13
2.5	4.1	13.1	4	12
3	4.3	9.6	4.2	9.5
3.5	4.5	7	4.5	6.9
4	4.7	8.3	4.6	8.1
4.5	4.9	5.4	4.9	5.7
5	4.9	0.7	4.9	0.8

These data suggest two features about the probable dynamics of the lake and the photosynthetic processes in the lake. First, because water's maximum density occurs at 4° C, as the cold surface water, melted from the ice (at 0^0C), begins to warm up in the spring, it will sink through the water column and rest at the bottom of the lake. This "falling water" brings greater concentrations of dissolved oxygen from the lake's surface into the deeper water to supporting growth of aquatic plants and improving fish habitat.   As the shallow and denser water falls within the lake, it displaces the deeper less dense water on the bottom of the lake. The displaced water rises to the surface. This rising water brings with it suspended inorganic and organic particulates and increases the phosphate concentrations in the shallow water as observed in the water quality results described more fully in Section 3.1.8.

Second, during the winter, input of oxygen due to wave action and inflow of surface water is minimal and therefore the oxygen concentration at shallow depth must be almost entirely due to photosynthetic processes (mostly micro-organisms and phytoplankton). As the water warms up, photosynthetic activity will

increase and is the likely cause of the increases in turbidity observed in the early spring. The principal source of light to support photosynthesis is diffusion through the ice. This evidence that photosynthetic process continue over the winter months indicates the lake is healthy. In years of heavy snowfall, when the lake surface is snow covered and less sunlight diffuses through the ice, the dissolved oxygen content of the surface water might become depleted and may lead to a less healthy water body in the spring.

2.3 Purpose

The purpose of the water quality monitoring program undertaken by the CLSS is to provide baseline water quality information against which the impacts of current and future activities on the lake and in the surrounding lands that drain into the lake can be identified. This purpose helps to satisfy the main missions for establishing the CLSS:

- To act as a citizen-based water stewardship group for Columbia Lake;
- To implement activities which monitor and help maintain the ecological health of Columbia Lake; and
- To communicate and network with others, as required to achieve these two activities.

2.4 Water Quality Objectives

To identify potentially harmful changes in water quality, collected quantitative water quality information is compared to water quality standards as established by regulatory bodies.

The Province of British Columbia provides water quality guidance in two forms: one form is to use a set of numerical guidelines or criteria (Water Quality Guidelines – WQG's) and the other is to apply a set of water quality objectives (WQO's). BC has established a variety of guidelines (WQGs) or criteria useful for judging the quality of water used for drinking water, for agricultural use, for aquatic life and for recreational purposes. These guidelines are for broad application on a province wide basis and do not consider local land uses or ambient lake conditions and thus may be over or under protective of a lake's conditions and development pressure.

The other form of water quality guidance used to assist in management and to ensure the sustainability of water resources is the use of water quality objectives (WQO's). Water quality objectives are an extension of WQG's. WQO's may be established by:

- Direct adoption of WQG's for each monitoring parameter;
- Establishing the upper limit of background concentration for each monitoring parameter; or
- Deriving a site specific WQO based upon data collected at the site.

Because WQO's have not been set for Columbia Lake, the water quality information collected is compared to the values established within the Lake Windermere management plan. These objectives are:

Parameter	Objectives (revised for Lake Windermere in 2010)
Turbidity	<1 NTU (Average) during clear flow periods < 5 NTU (Maximum) during clear flow periods 5 NTUS (measured as the 95th percentile of measurement) during turbid flow periods
Phosphorous	0.010 mg/L (maximum)
Temperature	<20°C in June (average) < 25°C in July (average) <23°C in August (average)
PH	no recommended objective
Dissolved oxygen	> 5 mg/L instantaneous minimum >8 mg/L 30-day mean
Conductance	no recommended objective

The WQO's for Lake Windermere are set with a different water quality monitoring program than that applied by CLSS to Columbia Lake. The Lake Windermere objectives suggest that some form of continuous monitoring is in place to establish measured instantaneous or mean values and thus are not strictly suitable for application to Columbia Lake.

A methodology for CLSS to establish WQO's may be expected as the revised water management program for Columbia Lake is developed.

2.5 Monitoring Parameters

The water quality monitoring program conducted by CLSS collects three types of information:

- Observations about cloud cover, water surface disturbance (waves), and air temperature;

- Measurements of:

- o the depth of water at each sampling locations,
- o the depth of clear water using the Secchi disk,
- o water temperature,
- o turbidity,
- o conductance,
- o pH and
- o dissolved oxygen; and
- Chemical analyses of water samples for total and dissolved phosphorous.

Appendix A provides information on the contribution of each of the measured parameters to our understanding of the water quality of Columbia Lake. Dissolved oxygen was measured using a hand-held meter previously calibrated for dissolved oxygen concentrations. Acquisition of the dissolved oxygen meter was a recommendation made in the 2016 water quality report. Purchase of the equipment was made possible by the grants provided to CLSS by the funding agencies and a monetary contribution by two of our volunteers.

As much as lake conditions allowed, water temperature, and conductance were measured at both "shallow" and "deep" depths. Shallow refers to measurements in the upper 0.5 metres of the lake (an arms' reach below the water surface for practical purposes) while deep refers to measurements made about 0.5 metres from the lake bottom as measured using the Secchi disk. The deep and shallow measurements began in 2016 but were not routinely collected in 2017, 2018 nor 2019. This information showed that the lake had no noticeable differences in parameters between the deep and shallow depth.

2.6 Stations and Monitoring Events

Water quality monitoring was undertaken at each of the four stations identified in Section 2.1 as weather conditions allowed.

The 2019 monitoring program began May 29, 2019. Seven monitoring events were conducted on the lake and three sets of water quality samples were submitted for chemical analysis (total phosphorous and dissolved phosphorous). Caro Analytical of Kelowna provided the analytical services. The spreadsheet in Appendix B provides the observations, measurements and chemical analysis collected during the six years of the monitoring program.

During the annual monitoring program in 2018, a special survey of conductivity and turbidity concentrations had been undertaken by CLSS volunteers, Gina Fryer and Lucas and Caesar Fuertes. Every two weeks during the summer of 2018, these volunteers measured conductivity and turbidity concentrations at fourteen locations along the lake (Figure 2). The results of this monitoring program are tabulated in Appendix D.

As CLSS reported in 2018, the results from this survey showed that the conductivity and turbidity concentrations decreased from the south end to the north end of the lake. In 2018 CLSS suspected that these greater concentrations in the south end of the lake might be due to the contribution of different waters (surface streams or groundwater inflow) draining to the lake

On July 23, 2019, this survey was repeated both to confirm the 2018 results and to include the measurement of chloride concentrations at each of the fourteen sites. These results are provided in Table 2 and are described more fully in Section 3.2.

Figure 2 – Location of Monitoring Points For Turbidity and Conductivity Measurements

Not to scale
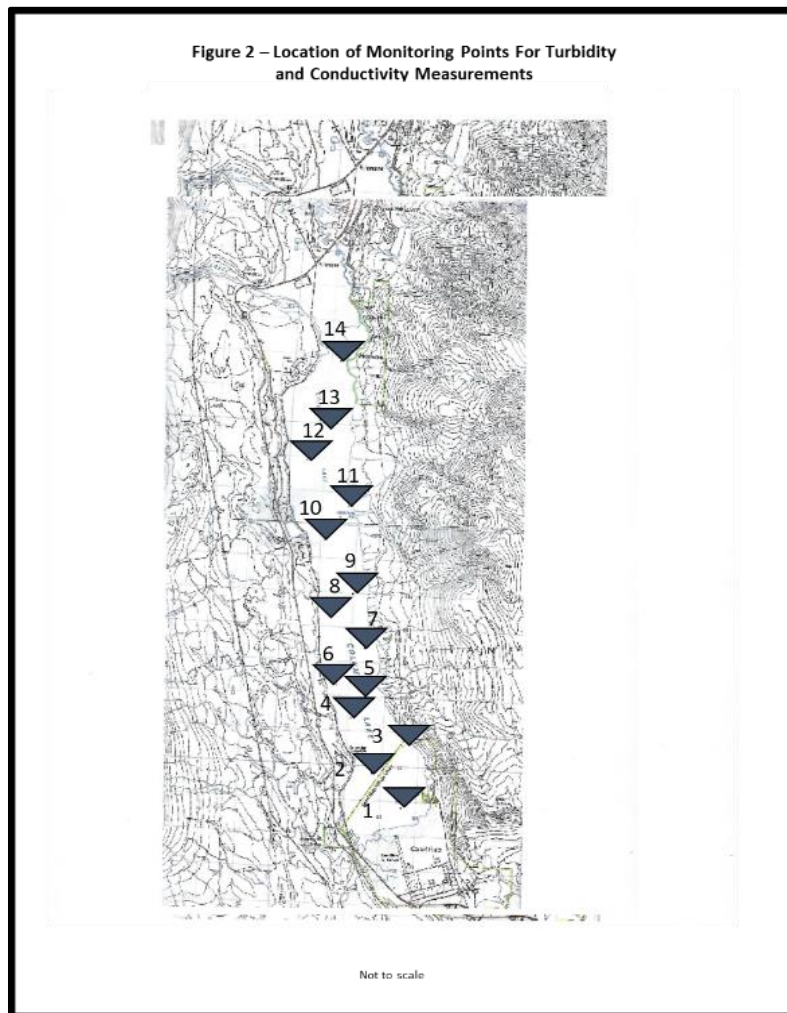
2.7 Groundwater Contribution to Columbia Lake

In the summer of 2018, a board member of CLSS, Mr. Ed Gillmor, compiled information on the groundwater conditions in the vicinity of the south end of Columbia Lake near the village of Canal Flats.

Canal Flats sits on a deposit of granular materials (predominantly sand and gravel) that infills the valley across the south end of Columbia Lake. The valley is confined between the Rocky Mountains to the east and the Purcell Mountains to the west. The Kootenay River flows across this valley to the south of the village and Columbia Lake and shoreline wetlands along the north side.   Residents of Canal Flats had often described to members of CLSS that water within some of the water wells used to provide potable water to the village water can be observed and heard to flow.

Mr. Gillmor's compilation of the available information is provided in a report entitled "An estimate of Groundwater's Contribution to Columbia Lake". That report is contained on CLSS's website.

This report documents that there is a difference in water level between the Kootenay River and Columbia Lake of some 7 m with Columbia Lake at a lower elevation than the river. The river and the lake are approximately 1500 meters apart. Further, this difference is relatively constant throughout the year. This finding indicates that a persistent hydraulic gradient exists from the river to the lake and that the lake is being supplied by water seeping from the Kootenay River.

Considering the nature of the granular material observed between the lake and the river, Gillmor estimates an amount of some 35 million m3/year of groundwater may discharge to Columbia Lake from the sediments that underlie Canal Flats.   Other information compiled by Mr. Gillmor indicates that BCMOE has designated the granular materials beneath Canal Flats as a vulnerable aquifer (aquifer number 816). An aquifer is considered vulnerable where, in its natural geologic setting, the aquifer is not confined by overlying geologic materials that are finer grained (such as clay or silt).

Further work on the groundwater contribution to Columbia Lake from the Canal Flats area and the Kootenay River was not undertaken by CLSS in 2019. However, the granular deposit beneath Canal Flats varies in composition from place to place across the valley. Observations of sand volcanoes (two to four centimeters across) and upwellings of silt and sand on the base of the lake by recreational kayakers and boaters along the south shoreline of Columbia Lake, demonstrate that the groundwater contribution to Columbia Lake from the Kootenay River also varies across the valley.

 CLSS also understands that further hydrologic and hydrogeologic assessments would be provided by the Canal Flats study of flood water protection (commissioned in the spring of 2019) and a groundwater supply study to be undertaken for a proposed bottling plant.

2.8 Stream Sampling Program

As part of the annual monitoring program for 2019, CLSS volunteers measured the quantity of flow and the quality of surface water draining to the lake from Dutch Creek and three smaller streams along the

west side of Columbia Lake. This sampling program was undertaken on October 9, 2019. The need to begin sampling the streams arose from assessments of the conductivity and turbidity concentration measured along the lake in 2018 and a repeat survey of the conductivity and turbidity concentrations as well as pH and chloride concentrations measured on July 23, 2019.

Water quality samples were collected at the locations show on Figure 2. These locations are:

> Dutch Creek on the northwest side of the bridge over highway 93;

> Hardie Creek at the outfall to the lake on the Spirits Reach property;

> Marion Creek at the outfall to the lake within the provincial picnic area; and

> A small creek draining north from Canal Flats on the pathway bridge.

Water quality measurements included pH, dissolved oxygen, temperature and turbidity with hand-held equipment. Water samples were collected for analysis of chloride, hardness, calcium and magnesium, iron, manganese, alkalinity nitrate and phosphorous concentrations.

The measurements of flow have been incorporated to the water quantity portion of CLSS's annual report. The results of the water quality sampling program are provided in Section 3.3.

3.0 Water Quality Monitoring Results

The water quality monitoring results obtained in 2019 are summarized in Sections 3.1, 3.2 and 3.3 . Section 3.1 , summarizes the results of the annual monitoring program by:

- Identifying differences in the measured parameters along the lake from south to north;
- Comparing the results obtained in 2019 to those obtained from 2014, 2015, 2016, 2017 and 2018;
- Describing noticeable trends in concentrations along the lake (from south to north); and
- Comparing the results to the objectives established for Lake Windermere.

Section 3.2 summarizes the results of the special monitoring program for pH, chloride, turbidity and conductivity along the lake. Section 3.3 summarizes the stream sampling program.

3.1 Annual Monitoring Program

The 2019 annual monitoring program is the sixth year CLSS has monitored the water quality of Columbia Lake.   Sections 3.1.1 to 3.1.8 describe the variation in concentration for each of the indicator parameters

measured on the lake – temperature, Sechi disk depths, turbidity, conductivity, pH, dissolved oxygen and nitrate and total and dissolved phosphorous.

To appreciate the range in the baseline condition on the lake and the differences in water quality conditions that might be expected from month to month, for the 2018 annual report, CLSS compiled the information collected between 2014 and 2018 into a statistical summary for each of the four monitoring locations along the lake. That summary included month by month calculation of mean, the standard deviation and the expected maximum and minimum concentrations for each of the water quality parameters CLSS monitors on the lake. Those statistics are provided here in Appendix E.

Concentrations that exceed either the expected maximum or minimum values identify water quality information that is beyond the normal or expected range and may suggest further assessment should be considered.

3.1.1 Temperature

Lake temperature is an important ecological condition because, at high temperatures the quantity of dissolved oxygen available for fish and aquatic invertebrates declines and creates a potential environmental stressor. (We understand from conversations at the BC Lake Keepers workshop held at the Columbia Ridge Community Centre in May of 2016 that temperatures greater than 20^0C can so dramatically stress fish that fish kills may occur). Further, higher water temperatures increase the degradation of organic matter and creates potentially cloudy, murky or odorous water. The degradation process also consumes dissolved oxygen from the lake water further increasing the stress on fish and aquatic invertebrates.

Figure 3a and 3b plot the temperature measured during each of the 2019 monitoring events at surface and bottom depths respectively.

Figure 3 – Water Temperature

Figure 3A - Water Temperature Surface, 2019

Figure 3B - Water Temperature Bottom, 2019
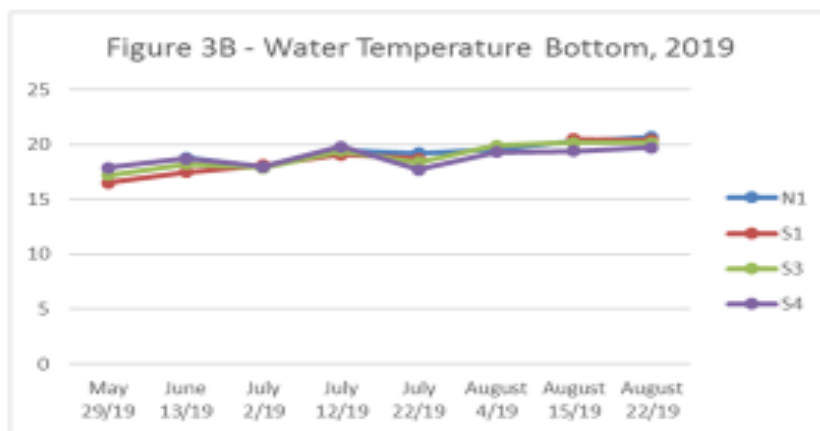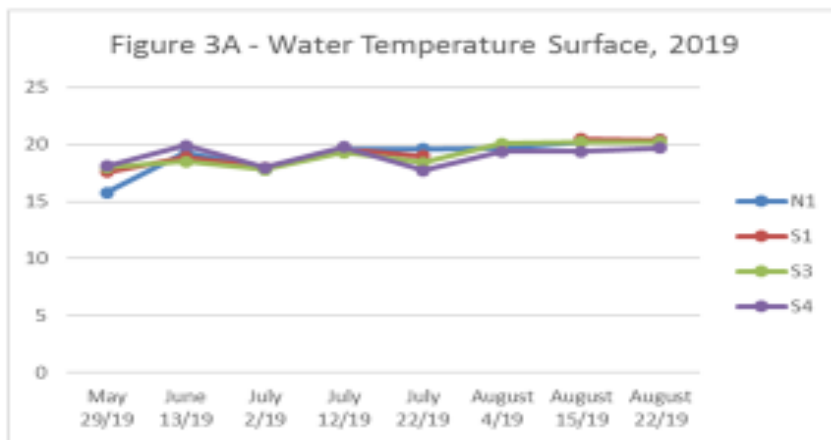
The minimum temperature measurements in 2019 of approximately 16^0 to 18^0 C were measured during the first monitoring event in late May. The maximum temperatures (greater than 20^0C) were measured between the middle and late August. There are no noticeable differences (greater than 2^oC) in temperature during any monitoring event with the position on the lake. Figures 3a and 3b illustrate that there is no noticeable difference in water temperature with depth at all monitoring locations.

Figure 4 compares the temperature measurements along the lake from 2014 to 2019. For 2019 the lake surface water temperatures are less than those of the water quality objective (23^oC) established for Lake Windermere for the month of August. The late August temperatures at all monitoring locations are the highest temperatures recorded for the lake in 2019.

The lake temperatures measured in 2014 are the maximum temperatures measured for the lake waters during the summer months. Lake temperatures measured in 2019 are within the range of temperatures measured over the previous five years.

Figure 4 Temperature – Year to Year comparison

3.1.2 Secchi Disk Measurements

Secchi disk measurements are used to qualitatively determine the clarity of the water. Water clarity is an important consideration for lake water quality since it improves the aesthetic appeal of the lake to recreational users and success by predators (birds, terrestrial animals and fish). Clear water also promotes photosynthetic processes needed to maintain the ecological health of the lake.

The measurement involves dropping a marked disk into the lake water and determining when the symbols on the disk are not visible at the lake's surface. Monitoring the difference between the Secchi depth and lake depth is used to determine changes in the water's clarity.

During the 2019 monitoring events, the lake's surface was frequently too turbulent to allow accurate measurements to be made. A plot of this information has not been provided.

As reported in 2018 and confirmed in 2019 (Appendix B) the only measurements where the Secchi disk was less than the bottom depth occurred at S1, the deepest sampling location on the lake. At this location, the Secchi disk depth and lake bottom measurements generally differed by less than one metre. The Secchi disk measurements made in late May and June of 2017 at S1 differed by more than 1.5 metre.

3.1.3 Turbidity

Turbidity measurements are another means of measuring the clarity (or in contrast the cloudiness or murkiness) of the water but, unlike the Secchi disk, these measurements are made in terms of NTU's (Nephelometric Turbidity Units) - a quantifiable measure of turbidity. The turbidity of the lake water in the open water zone is influenced mostly by the growth of phytoplankton and the amount of suspended sediments contained in the lake water.   In the open water zone, the main cause of turbidity increases is the growth of phytoplankton. Closer to the shoreline however, suspended sediments are introduced by surface water draining into the lake, shoreline erosion by wave action and disturbance of bottom sediments by wave action and recreational activities. Organic matter that decays in the water as it warms up is also a significant contributor to the lake's murkiness and consumes oxygen as the organic material decays which limit the oxygen available to support aquatic life. The turbidity may be influenced by some chemical reactions that create insoluble precipitates (carbonates mostly) but is not as great a contributor to the turbidity as the suspended mineral sediments and organic debris.

Turbidity measurements made during the 2019 monitoring events are plotted on Figure 5. The plot demonstrates that the greatest concentrations of turbidity were measured during the mid-summer months at locations S3 and S4 in the southern end of Columbia Lake and at S1 located approximately in the middle of the lake.   At the S3 and S4 locations there are two small streams (Marion Creek and the creek from Canal Flats) that drain into the lake but the inflow from these creeks is not considered large enough that their drainage would influence the entire lake.

Near S4 there is little opportunity for resuspension of bottom sediment by recreational activity because the lake is shallow. At this location the growth of phytoplankton and increased wave action is suspected of being the major contributors to the greater turbidity concentrations. Both S3 and S1 are in deeper waters.   The turbidity concentrations at these locations may be mostly attributed to growth of phytoplankton. However,

for much of the monitoring period the lake water was too turbulent to allow Secchi disk measurements to be made and consequently some of the turbidity at these locations must be at attributed to wave action eroding the shoreline and resuspension of bottom sediments. The information collected by CLSS to date does not help to determine the greatest contributor to the increase turbidity over the summer months.

Figure 5 - Turbidity, 2019
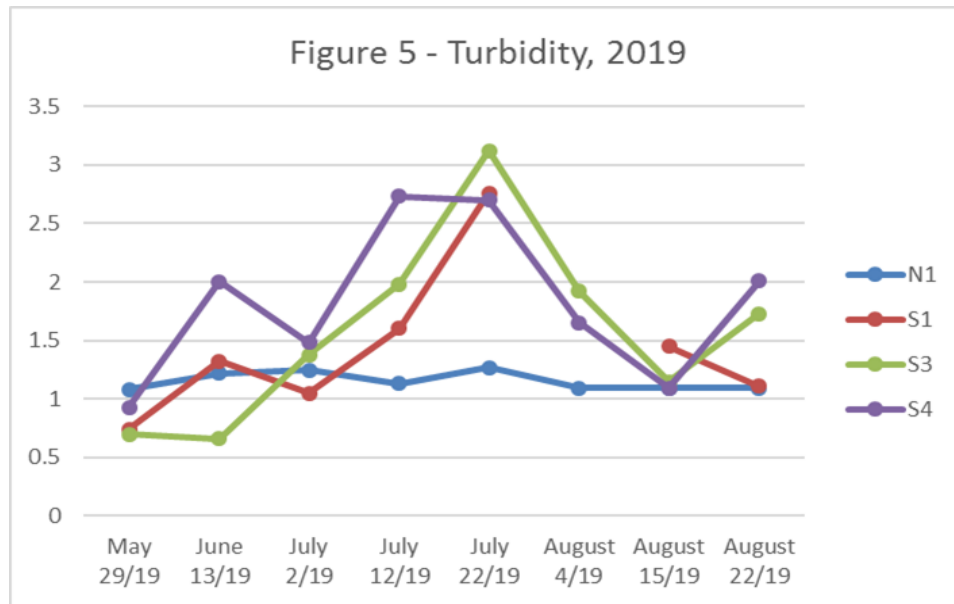
This understanding is reinforced by the measurements of conductivity (Section 3.1.4) that do not demonstrate a comparable increase during the summer months in the south end of the lake. The turbidity concentrations measured exceed the average quality guideline for turbidity established for Lake Windermere as part of the management plan for that lake.

Figure 6 compares the year over year turbidity measurements at each monitoring location on the lake. The four graphs (Figures 6 a, b, c, and d) demonstrate that the turbidity of the lake water generally occur within a narrow range of 0.7 to 2 NTU's. During 2019 exceptions to this general observation occurred during the mid- July and early August events at the southern and middle areas on the lake (S4, S3 and S1 locations). The concentrations measured during these events exceed the maximum expected concentrations (Table E1) for these locations. The cause of the turbidity increase is believed to be due to the resuspension of bottom sediments.

Trends in turbidity concentrations need to be monitored to determine if the increase continues.

Figure 6 – Turbidity – Year to Year Comparison

6A - Turbidity, S4

6B - Turbidity, S3

6C - Turbidity, S1 Shallow

6D- Turbidity, N1
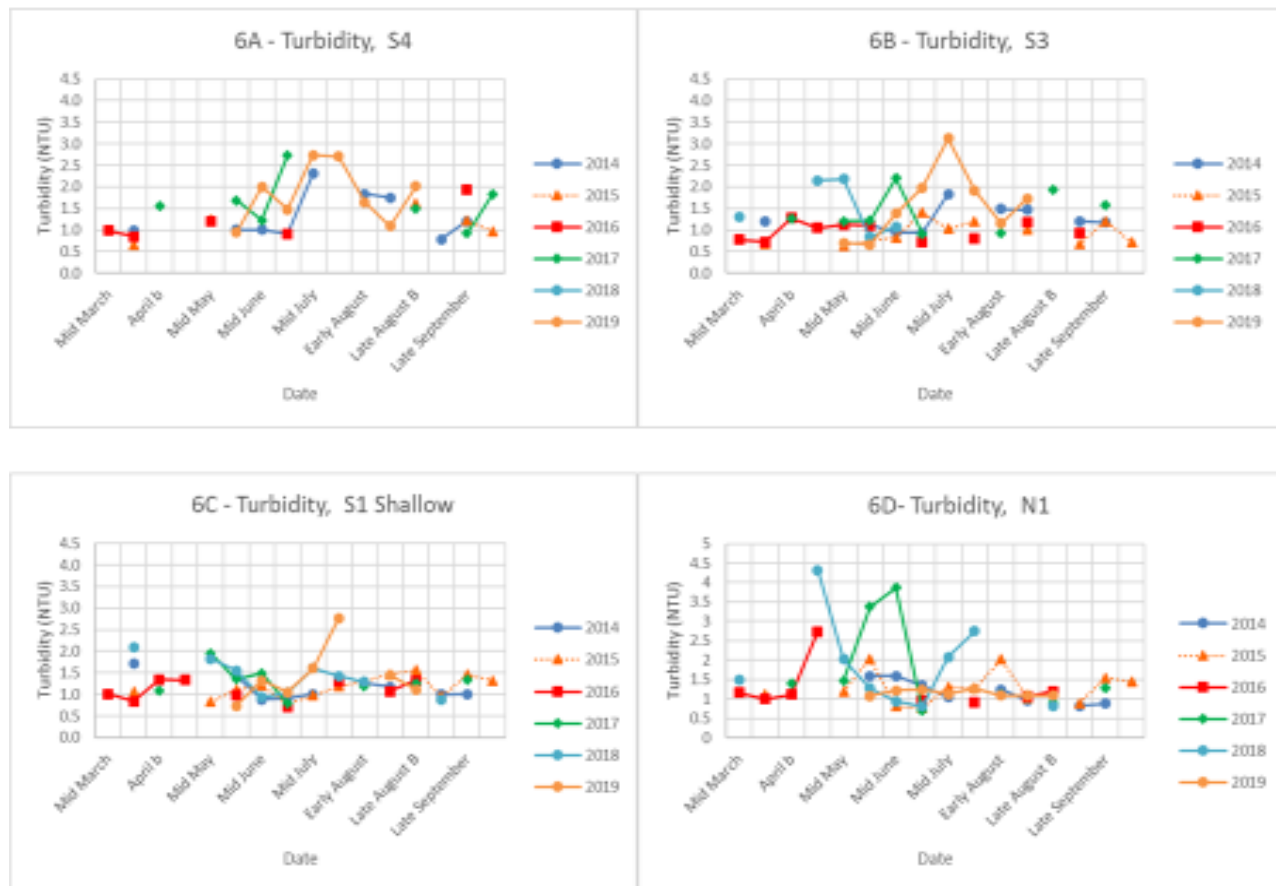
3.1.4 Conductivity

Conductivity or conductance is a measure of the electrical conductivity of the lake water; a measure of the dissolved salt the lake water contains. These dissolved salts consist of both mineral salts dissolved from particulate sediments in the lake water or carried into the lake by groundwater inflows and surface water drainage. A portion of the conductivity of the lake water is also due to soluble organic matters that create weak acids as they dissolve (like vinegars) but usually this contribution of organic acids to the conductance is considered a minor contributor. Conductivity is also a temperature dependent measurement with higher values measured in warmer water. Most probes correct automatically for the temperature such that the values reported here should not be influenced by temperature changes from month to month.

Figure 7 plots the values measured for the conductivity during 2019.   Figures 7a and 7b show there is no difference in conductivity concentrations between the surface and bottom of the lake.   Figure 7a and b also show that the greatest concentration for conductivity are in the south end of the lake at S3 and S4.

Apart from the small creek draining from the vicinity of Canal Flats (Section 3.3), there are no other streams entering the lake in this area of the lake. A contribution to the greater concentration of conductivity in this area of the lake may be associated with drainage from this stream . However, as reported in 2018 by CLSS volunteers, this section of the lake is also understood to be associated with groundwater inflow from beneath Canal Flats. Small sand volcanoes were observed from kayaks at several locations across this end of the lake and along the small creek that drains to the lake by CLSS volunteers that suggest groundwater inflow is occurring across the south end of the lake.   Therefore, groundwater discharge to the lake at this south end may also be a cause of the greater conductivity concentrations.

Figure 7 – Conductivity, 2019

Figure 7A - Surface Conductivity , 2019

Figure 7B - Bottom Conductivity, 2019
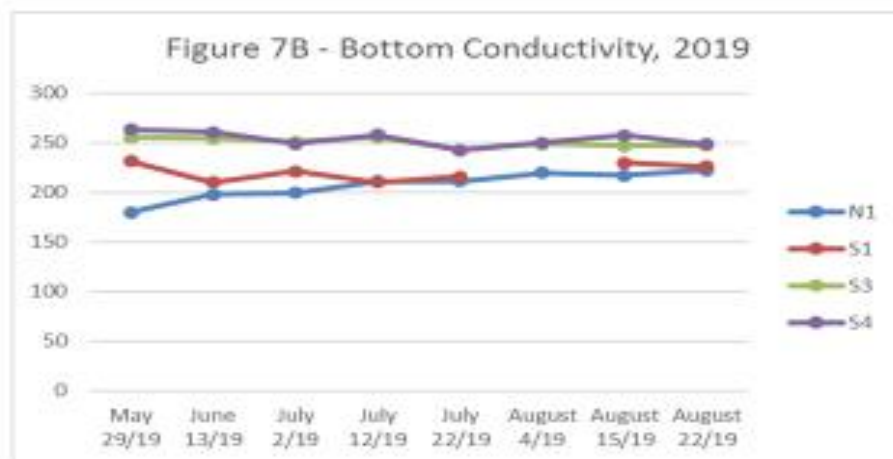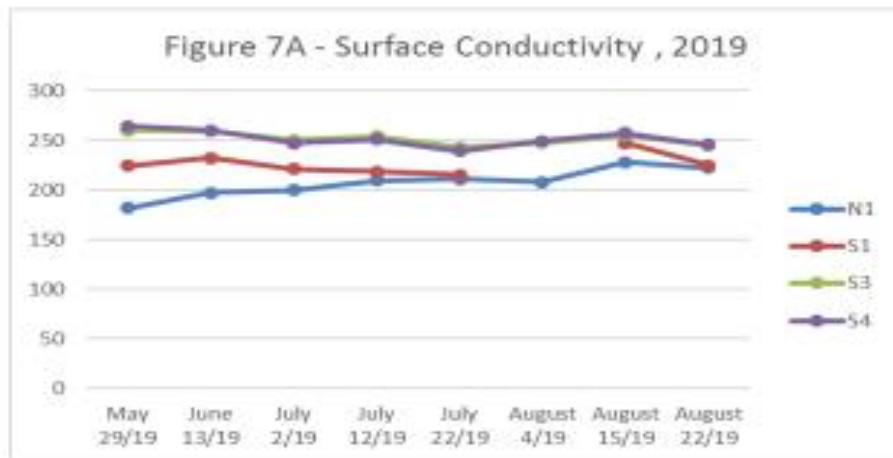
The year over year comparison of conductivity concentrations provided on Figures 8A, B, C and D show that the conductivity concentrations along the lake are lower than those measured in other years. All conductivity concentrations measured are within the range established between 2014 and 2018.

There has been no water quality objective established for Lake Windermere and thus the significance of the conductivity concentrations measured on Columbia Lake cannot be stated.

Figure 8 – Conductivity – Year to Year Comparison
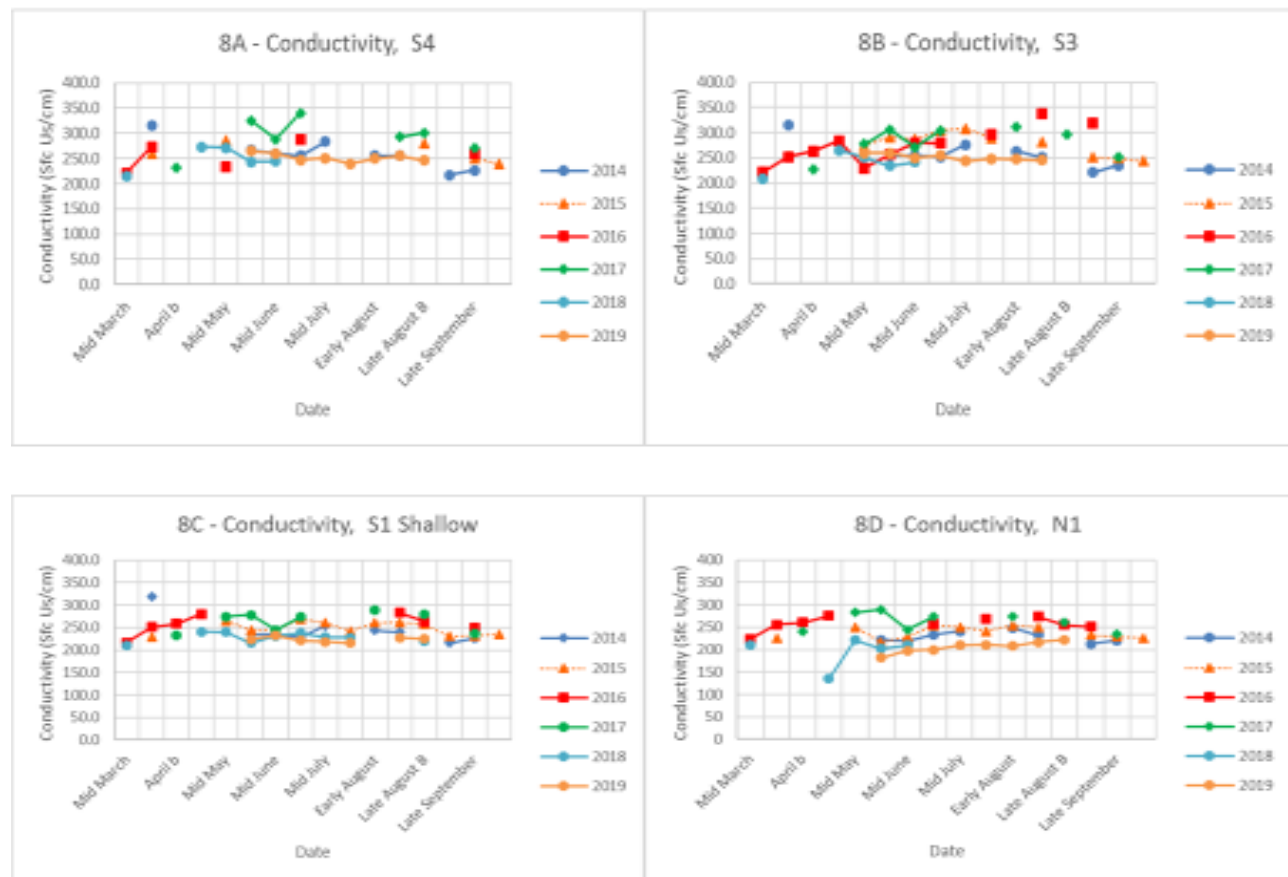
3.1.5 PH

PH is a measure of the acidity (pH values less than 7) or alkalinity (PH values greater than 7) of the lake water. In water that is too acidic (pH less than 6.5) it is difficult for aquatic organisms to incorporate carbonates into their developing skeletons and water that is too alkaline (greater than 8.5) affects the bio-availability of phosphorous and carbonate to aquatic plants also needed for skeletal growth.   Water suitable for people to drink has a pH between 6.5 and 8.5 pH units.

Figure 9 plots the pH values measured at each monitoring location during 2019. Generally, the pH values fall within a narrow range from 7.9 to 8.4 pH, an exception in August of 2019 was noted at S4 in the south end of the lake where the pH value increased to about 8.6. These values are within the range of pH for most water quality objectives (drinking water for people and wildlife, aquatic life/habitat protection and recreational uses).

Excluding the pH value measured in August at S4 the lowest pH values were measured in July of 2019. In prior years (April and May of 2018) the minimum pH values were measured in the spring and increased throughout the year.

Figure 9 - pH, 2019
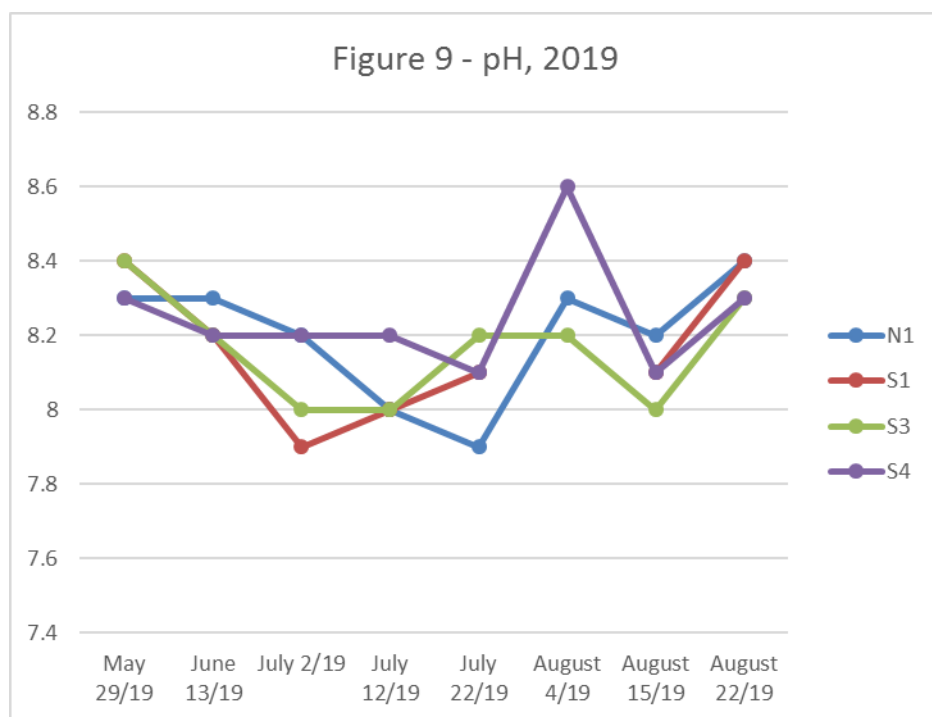
Figure 10 plots the year over year measurements of pH at each of the monitoring locations on the lake. Visually the plots of pH versus the monitoring date for each of the prior year's suggests that a general increase in pH is observed between April and September. A trend analysis has not been undertaken to confirm this visual observation numerically.   This trend for increases in pH during the year is not noticed in the 2019 measurements. Instead we see decline in pH between May and July and a rise in pH from July until September at all four monitoring locations .   This trend in pH coincides with a summer season that did not have the marked effects of nearby forest fires and whether the rise in pH is due ash fall from these prior years cannot be determined.   Also, from Figure 10 we note that the 2019 pH measurements are the lowest measured values at all four monitoring sites. This trend to declining pH values needs to be monitored carefully because ultimately acidic conditions are not suitable as aquatic habitats.

Figure 10 – pH – Year to Year Comparison
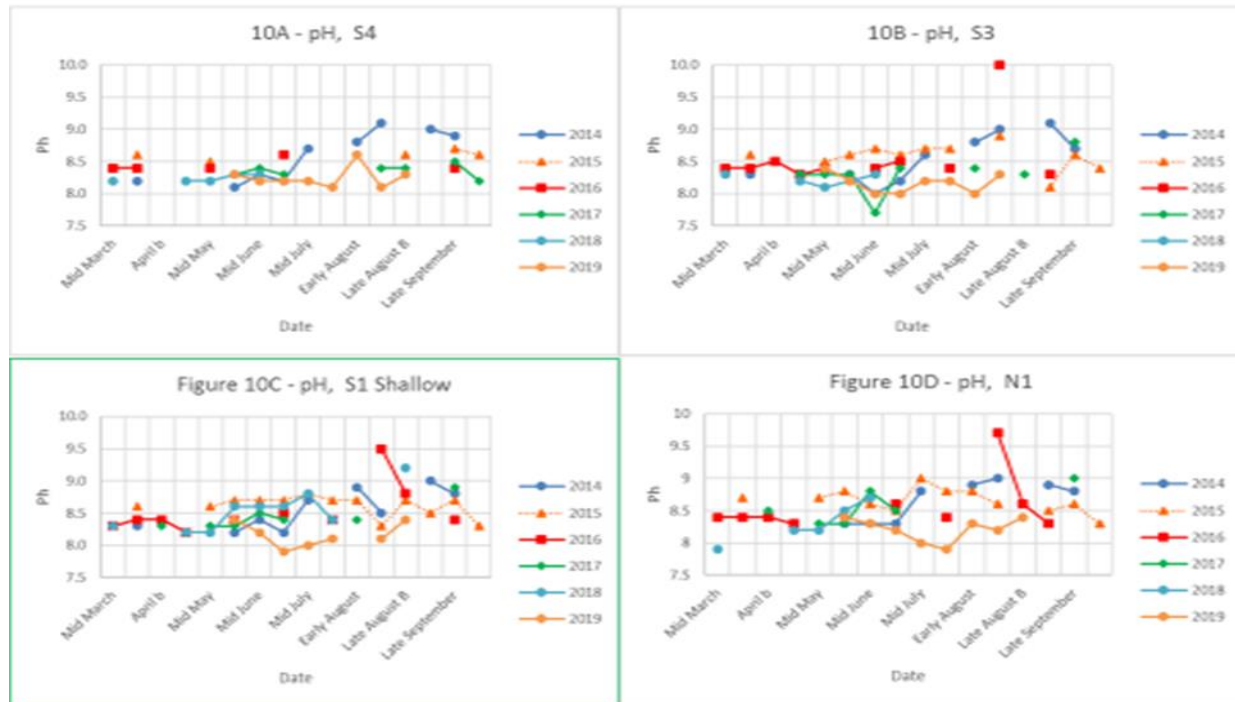
There are no objectives for pH established within the Lake Windermere management plan. However, the Canadian Council of Ministers of the Environment (CCME) suggest that pH values greater than 6.5 and less than 8.5 are necessary for the protection of drinking water and an upper pH value of 9 for the protection of aquatic life. The plotted data on Figure 10 illustrates that on no occasion does the lake water become more acidic than 6.5 and occasionally the lake water exceeds a pH value of 9.

The measured pH values are within the expected range in pH measured over the prior five years of the monitoring program.

3.1.6 Dissolved Oxygen

Water containing dissolved oxygen and carbon di-oxide and which receives sunlight is essential for photosynthetic processes in the lake to occur and allows aquatic and amphibious flora and fauna to thrive.

Both carbon dioxide and oxygen are produced by photosynthesis. The only mechanical source of dissolved oxygen is precipitation falling directly on the lake or introduced as snow melt. Lake surface disturbances that create turbulence and waves produced by winds also introduce oxygen to the lake. Some dissolved oxygen is provided to the lake by the inflow of surface drainage but groundwater inflow will not contribute any noticeable amounts of dissolved oxygen.

The saturation level of oxygen in water is between 8 and 14 mg/L depending upon the temperature. Oxygen is more readily soluble in cooler water than in warmer waters (i.e. 8 mg/L at water temperatures of 25° C and 14 mg/L at water temperatures of 1° C).

Figure 11 plots the dissolved oxygen concentrations measured in 2019 at the four monitoring locations along the lake. This graph illustrates that, except for locations S1, S3 and S4 in early July, the dissolved oxygen concentrations were always greater than 6 mg/L and less than 8 mg/L and should support aquatic invertebrates because these measured concentrations are greater than the instantaneous concentration for dissolved oxygen set for Lake Windermere of greater than 5 mg/L.

Figure 11 - Dissolved Oxygen, 2019
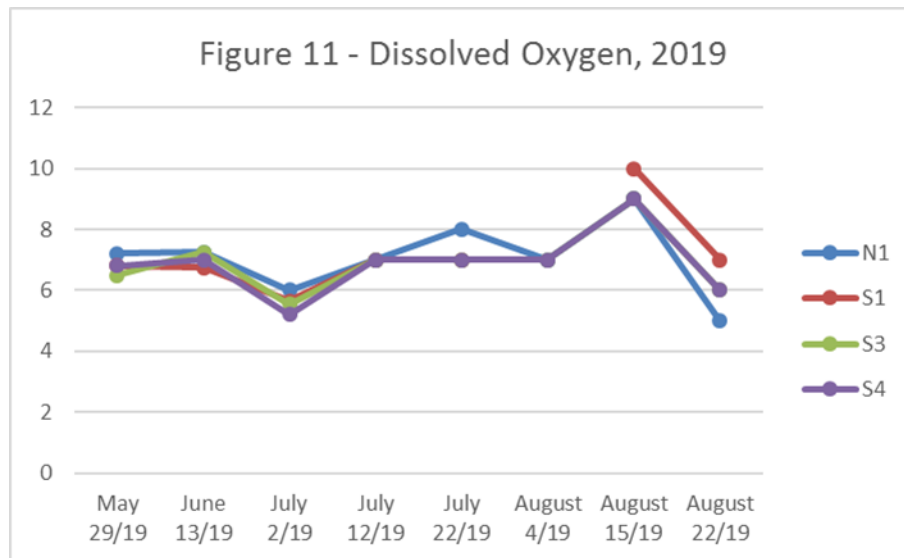
The maximum dissolved oxygen concentration of about 10 mg/L was measured at location S1 in the middle of August and is associated with an increase in the dissolved oxygen concentration measured at the other locations. The increase in the dissolved oxygen at this time of year can be either due to direct rainfall or due to photosynthetic activity. Although we have not provided any records of rainfall on the lake surface during the summer months and a local weather station is not close enough to be reliable, we are concerned that the increase is due to an increase in phytoplankton. This concern is strengthened by the increase in turbidity during the summer months as described in Section 3.1.2 and plotted on Figure 5.

In prior years the maximum dissolved oxygen was measured in early spring when photosynthetic reactions on the lake would be at their maximum. During those years, the concentrations of dissolved oxygen in the lake increased from early April when the ice has first melted and was understood to be a consequence of the contributions from direct rainfall and snow melt additions to the lake and a by-product of photosynthetic

processes that occur beneath the ice over the winter months. The dissolved oxygen concentrations declined after mid-June as the lake water becomes warmer. During 2019 the dissolved oxygen concentrations increased after mid-June and is associated with the increase in turbidity concentrations (Figure 5).

Figure 12 compares the year over year measurements of dissolved oxygen. As the graphs Figures 12 a, b, c and d suggest, the concentrations of dissolved oxygen made in 2019, are the lowest recorded over the prior five years.   We note that the water quality objective for Lake Windermere also suggests that the 30 day mean average for dissolved oxygen should be greater than 8 mg/L.   As the plots of Figure 12 suggest, Columbia Lake did not satisfy this objective for most of the summer.   However, we also note that for much of the summer monitoring events our dissolved oxygen meter was not working and we had to use a test kit method to measure the oxygen concentration. This measurement method may be prone to judgement errors and consequently confirmation of the declining oxygen concentrations over the summer months is required in 2020 before raising a concern of the decline in water quality.

In future events, when measurements of dissolved oxygen are less than 8 mg/L , CLSS will,   with the support of our volunteers, increase the frequency of monitoring events to determine whether dissolved oxygen concentrations of less than 8 mg/L are sustained for longer than 30 days. We will purchase a new dissolved oxygen meter for use in 2020.

Figure 12 – Dissolved Oxygen – Year to Year Comparison
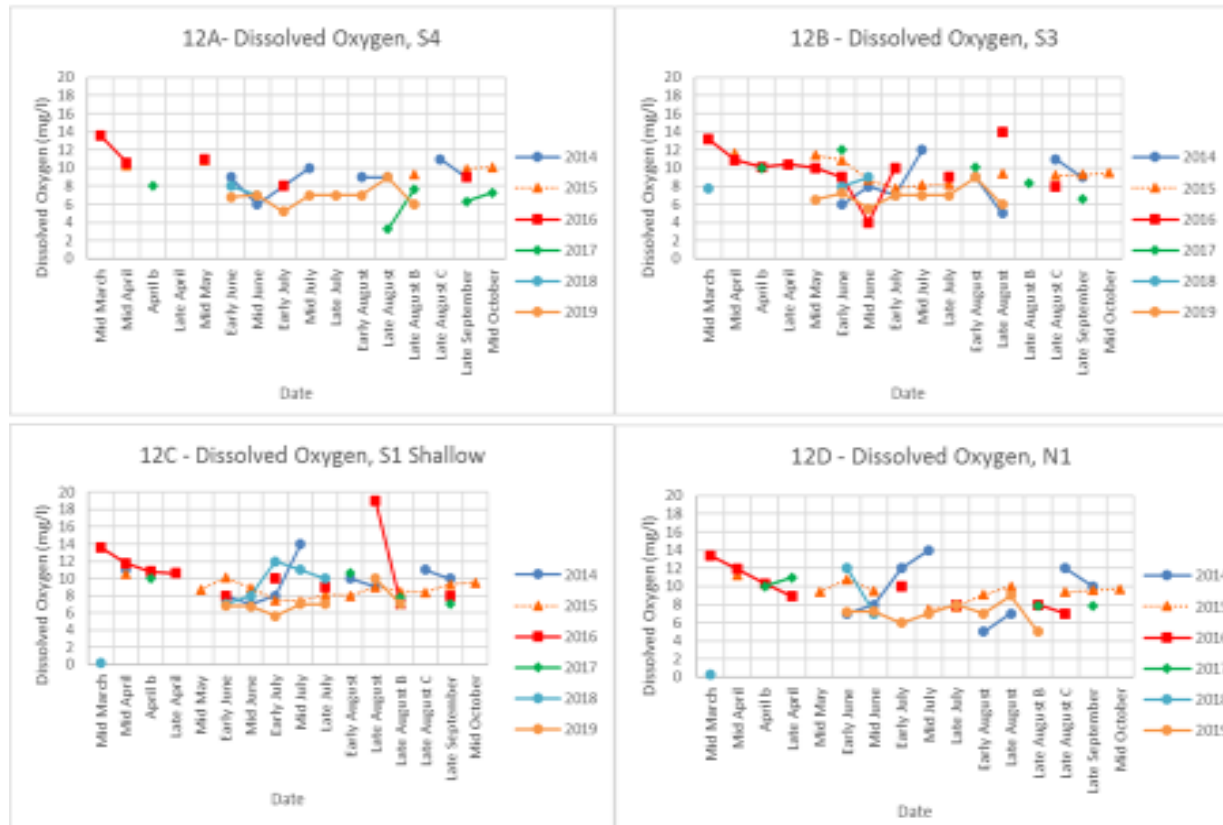
3.1.7 Nitrate

Nitrate is a nutrient necessary for aquatic organisms to thrive and is introduced naturally to the lake as dissolved nitrate in rainfall and snowmelt. But if nitrate concentrations become too large to be assimilated into organisms can lead to oxygen consumption and eutrophication of lake waters. Nitrate is also frequently a component of runoff from agricultural lands and wastewater systems into lakes and is a reliable means of detecting contribution to the lake from these potential sources.

Nitrate concentrations were measured at the onset of the program on April 20, 2014 and continued to be measured until May of 2016. All nitrate concentrations were less than the analytical detection limit. Nitrate concentrations were not measured in 2017, 2018 nor 2019. However, we note that detectable concentrations of nitrate were measured during the stream sampling program conducted in the early autumn of 2019 (Section 3.3). These measurements suggest that nitrate is being introduced to Columbia Lake and should be re-introduced to the annual sampling program.

3.1.8 Total and Dissolved Phosphorous

Phosphorous is a nutrient essential for plant growth.   Aquatic plants and particularly microscopic plants are the principal feed stock of phytoplankton which are consumed by small fish and invertebrates and in turn eventually become the feed stock of larger fish and aquatic/ amphibious vertebrates. Thus, healthy lake water must contain phosphorous. However, it is a nutrient that is usually in short supply in freshwater systems. Phosphorous is provided naturally by drainage of water courses to the lake that contain dissolved mineral salts and by the decay and release from decaying organic material. Some phosphorous may also be introduced by wastewater discharge and drainage from agricultural lands. However, too much phosphorous will cause algal blooms, deterioration of oxygen concentrations and stagnation of the lake water, an ecological condition not favorable to a healthy lake.

Phosphorous occurs in both inorganic (derived from the dissolution of minerals in sediments) and organic forms (derived from decayed organics animal and vegetable). The measure Total Phosphorous includes both particulate and dissolved phosphorous. Dissolved inorganic phosphorous is the form required for plant growth while animals (including phytoplankton) can use both inorganic and organic forms. This information has been obtained from SEAWA, the southeast Alberta Water Alliance and dated, 2014.

The analyses conducted to date do not distinguish between inorganic and organic phosphorous and perhaps this distinction needs to be implemented in future years as more data on the proportions of total and dissolved phosphorous are available.

Figure 13 plots the total phosphorous concentrations measured on the water samples from the lake in 2019. Two measurements of total phosphorous were made at the four sampling locations on the lake: one on May 29 and the other on July 22. The plot on Figure 13 suggests that the concentration of total phosphorous increased over the summer; this observation is comparable to the trend in prior years.   The greatest concentrations of total phosphorous was measured at locations N1 and S1 in July . Similar to a study of Manitoba Lakes in the 1990's (Nedohin and Elefsiniotis, 1997 "The Effects of Motor Boats on Water Quality in Shallow Lakes" as published in *Toxicological and Environmental Chemistry* Vol. 61 pp 127 – 133) CLSS assumes the increased in total phosphate may be due to a resuspension of bottom sediments.

Figure 13 - Total Phosphorous, 2019
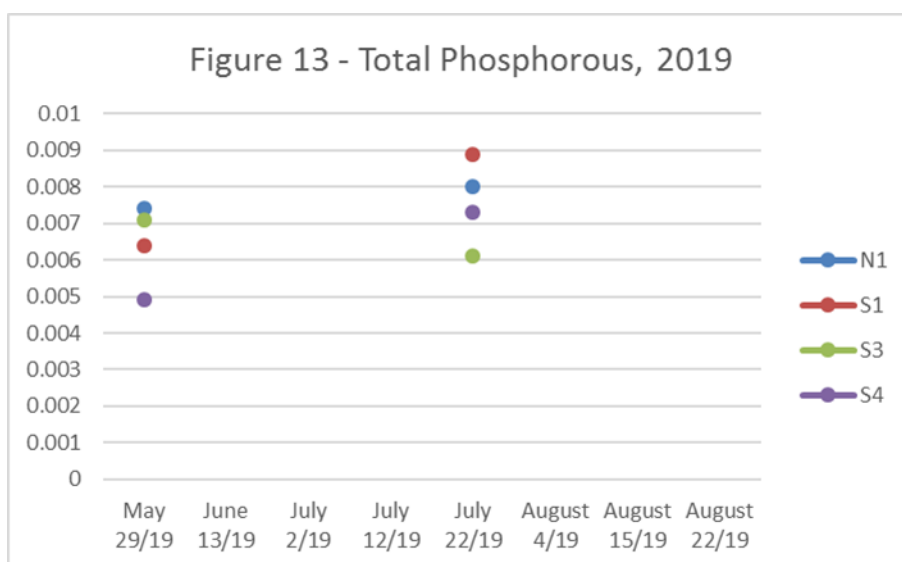
Only two measurements of dissolved phosphorous concentrations were made during 2019, both at location S1. These measurements were:

|	Total phosphorous	Dissolved phosphorous
May 29, 2019	0.0064 mg/L	0.0022 mg/L
July 22, 2019	0.0089 mg/L	0.0037 mg/L

The ratio of dissolved to total phosphorous based upon these measurements is between 33 and 40 percent. In prior years this ratio was as much as 100 percent. Because much of the total phosphorous is in the solid form, this lower ratio may reflect a higher suspended sediment in the water and is consistent with the increase in the turbidity of the lake water measured over the summer months.

Figure 14 compares the phosphorous concentrations measured over the six years of the monitoring program. This plot illustrates that the concentrations of total phosphorous in 2019 are within the range of concentrations measured in prior years. In 2018 we observed that total phosphorous concentrations exceeded the water quality objective set for Lake Windermere of 0.01 mg/L in early May at all four monitoring locations and at N1 during the late July monitoring event. This observation was not noticed in 2019. In 2019 the total phosphorous concentrations were less than the maximum expected concentration measured over the five prior years (Table E-5).

Figure 14 – Total Phosphorous – Year to Year Comparison

14A - Total Phosphorous S4

14B - Total Phosphorous, S3

14C - Total Phosphorous, S1 Shallow

14D - Total Phosphorous N1
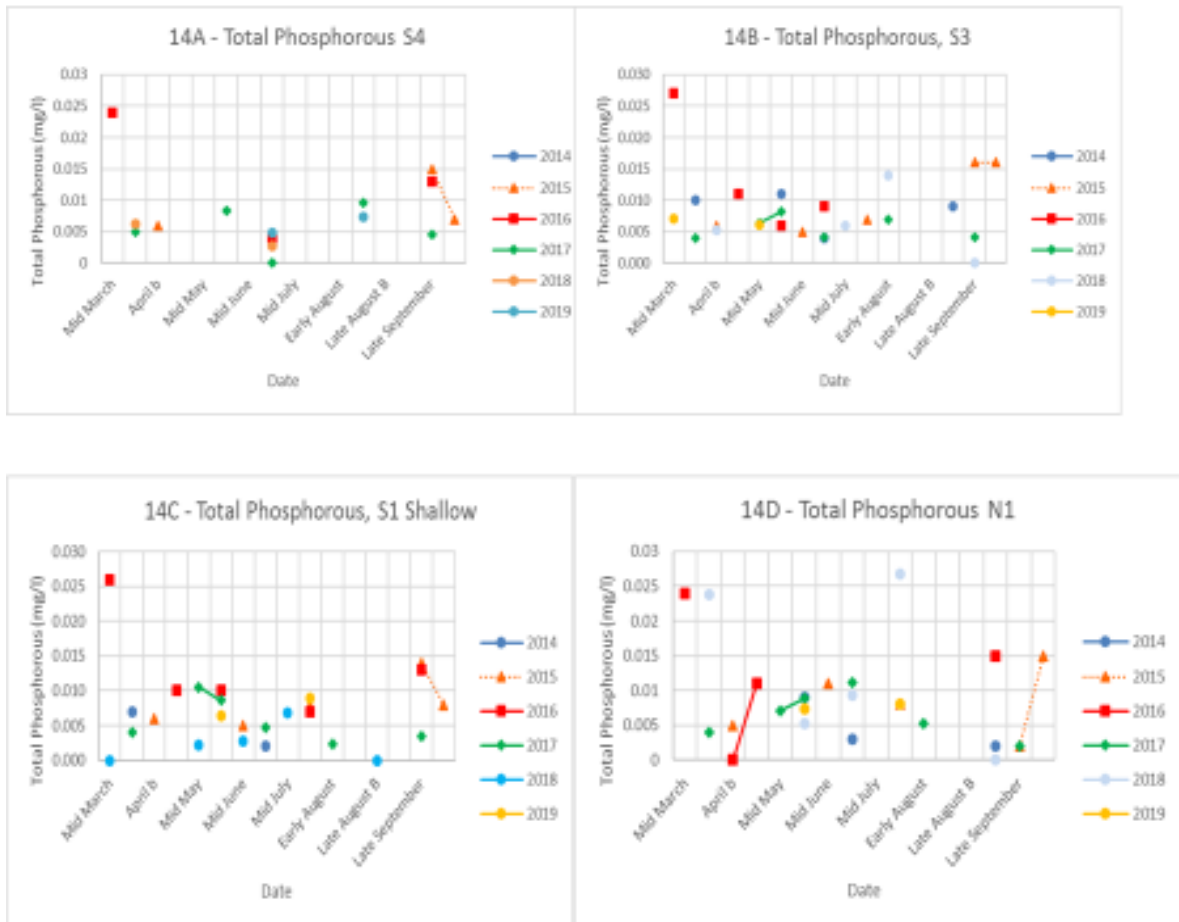
3.2 Distribution of Chloride, Conductivity and Turbidity Concentrations

The concentrations of pH, chloride, conductivity and turbidity at each of the fourteen monitoring locations are tabulated in Table 2. The distribution of chloride is plotted on Figure 15.

Table 2: Chloride Distribution Survey along Columbia Lake								
Date:	July 23rd 2019							
Location	Time	pH	Conductivity Surface	Conductivity Bottom	Turbidity	Water Temp surface	Water Temp bottom	Chloride (mg/L)
14	10:00	7.7	207.4	205.4	1.14	19.8	19.4	3.38
13	10:28	7.8	209.9	208.4	1.64	19.3	19.1	3.5
12	10:37	7.9	216	212.1	0.91	19.5	19.1	3.7
11	10:59	8	226.1	223.3	0.97	19.7	19.4	4.15
10	11:15	7.9	236.7	232.8	1.08	19.4	19.1	4.63
9	11:24	7.9	243.4	240.4	1.22	20	19.4	4.81
8	11:37	8	249.9	247.3	1.04	19.7	19.2	5.15
7	11:47	8	248.1	240.3	1.12	20.4	19.9	4.92
6	11:59	8.1	250.6	245.7	1.69	19.7	19.2	5.17
5	12:05	8.1	254	247	1.27	19.6	19.1	5.34
4	12:11	8.2	252	245.81	1.34	19.9	19.2	5.17
3	12:21	8.2	252.6	248.6	1.82	19.5	19.1	5.4
2	12:29	8.3	250.6	249.1	1.31	19.6	19.7	5.29
1	12:38	8.3	260.4	253.6	1.22	19.6	19.2	5.54

The tabulated results show that from north to south along the lake (stations 14 to 1) the pH of the lake water rises from about 7.7 to 8.3. Also, from north to south along the lake both the concentration of chloride and conductivity increases. Turbidity concentrations remain unchanged along the lake. This finding suggests that a source of chloride exists to the south end of the lake and is consistent with CLSS finding of 2018 that groundwater inflow to the south end of the lake is potentially a major source of water to the lake.

As the chloride concentrations plotted on Figure 15 illustrate, the concentration of chloride decreases from the south end of the lake (Station 1 of 5.54 mg/L chloride) to about 4.98 mg/L chloride (the average of stations 8 and 9). This decrease   of 0.56mg/L (approximately 10% of the concentration) occurs over a distance of approximately 5 kilometers.   From stations 8 and 9 to stations 12 and 13 the chloride concentration further decreases to an average of 3.6 mg/L; a decrease of about 1.3mg/L or approximately 33 percent of the concentration measured at stations 8 and 9. This concentration decrease also occurs over about 5 kilometers

Chloride is not taken up by any biological processes therefore the decrease in chloride concentrations along the lake is not due to differing levels of aquatic activity. Likewise, the concentration decrease observed and particularly, the differing rate of decrease along the lake is not due to direct precipitation along the lake.   If the decrease in concentration was due solely to direct precipitation, we would expect the rate of decrease in chloride concentrations to be uniform along the lake.   Further the decrease in chloride concentrations from south to north occurred over a time of year when the lake temperature was nearly the greatest of the season (Section 3.1.1 on temperature). During this season we would expect evaporation from the lake's surface to be highest – a process that would serve to uniformly increase the concentration in the lake and not to decrease the concentration.

The different rate in the decrease of Chloride concentrations along the lake from south to north suggests that other sources of water to the lake must exist.   The importance of the quantity of water small streams drain to the lake and of groundwater discharge from the granular materials along the lake has not been evaluated. However, as the chloride concentration information suggest, these contributors of water to the lake must be assessed to appreciate how the quality of Columbia Lake water can be best protected.

The results of this survey should be confirmed by a repeat of the work in 2020 and it would be prudent to determine if these findings are dependent on the season of the year by conducting similar sampling programs in early May and in late September or August of 2020.

Figure 15
Chloride Measurements along Columbia Lake, July 23, 2019

Legend

Monitoring locations

4.18 chloride concentration in mg/L

3.3 Stream sampling program

The stream sampling sites appeared as follows:

Dutch Creek – high rate of turbulent flow and the creek bed was largely boulders with no evidence of staining or dis-colorization and the water visibly cloudy when sampled – no organic growth along the stream sides ;

Hardie Creek – water flowing steadily and turbulent - the creek bed had gravel sized material with iron and manganese oxide staining (red to black colored coating) on the gravel particles – the water sampled was clear – nor organic material along the stream sides;

Marion Creek – water flowing steadily and turbulent - the creek bed contained gravel sized material that had some staining by iron and manganese oxides the water sampled was clear – some fibrous organic material was observed along the stream bed; and

Canal Flats Creek – water was flowing steadily but not turbulent – the creek bed was covered in fine grained grey clay to silt type materials that were easily disturbed and became muddy quickly – the water sampled was clear and the stream banks were covered by marshy grasses.

Only parameters that indicate or suggest that water quality of waters draining to the lake may differ from place to place have been analyzed on the water samples and are not necessarily useful as indicators of the water quality relative to human health, aesthetic quality or aquatic life's enjoyment of the lake. The water quality measurements and analyses made during the stream sampling program are in Table 3 and are summarized as follows:

Table 3 - Stream Sampling Results 2019							
Columbia Lake Stewardship Society							
Sampling Date:	7-Oct-19						
				Dutch Creek	Hardie Creek	Marion Creek	Canal Flats Creek
	parameter	units	MRL				
Field measurments							
	pH			8.67		8.40	7.60
	Conductivity	uS/m					
	Dissolved Oxygen	mg/L		8.0		3.0	10.0
	Temperature	°C		7		7	7
	Turbidity	nTu		0.97		2.16	1.02
Chemica analytsit	Chloride	mg/L	0.1	0.43	0.45	0.4	9.68
	Hardness, Total (as CaCO3)	mg/L	0.5	108	282	190	187
	Calcium, total	mg/L	0.2	21.6	49.7	34.2	49.9
	Magnesium, total	mg/L	0.01	13	38.3	25.3	15.2
	Iron, total	mg/L	0.01	<0.010	0.064	0.014	<0.010
	Manganese, total	mg/L	0.0002	0.00143	0.00431	0.00139	0.0154
	Alkalinity, Total (as CaCO3)	mg/L	1	128	295	205	157
	Alkalinity, Phenolphthalein (as CaCO3)	mg/L	1	<1.0	8.6	<1.0	<1.0
	Alkalinity, Carbonate (as CaCO3)	mg/L	1	<1.0	17.1	<1.0	<1.0
	Alkalinity, Hydroxide (as CaCO3)	mg/L	1	<1.0	<1.0	<1.0	<1.0
	Nitrate (as N)	mg/L	0.01	0.021	0.011	<0.010	0.24
	Phosphorus, Total (as P)	mg/L	0.002	0.0031	0.0128	0.0074	0.0086
	Note:						
	MRL - minimum reported value (analytical detection limit)						

pH

The pH values ranged from 7.60 to 8.67. These results show that the lowest pH value was measured in Canal Flats at the south end of the lake. The lower pH at this location may be attributed to acidity generated by the decay of organic materials because the stream bank was well vegetated and the overall surrounding area marshy.

Dissolved oxygen

The dissolved oxygen measured ranged from 3 mg/L to 10 mg/L. The lowest concentration measured was at Marion Creek and despite the turbulent flow at this location. Turbulent flow typically gives rise to more dissolved oxygen in streams.   We suspect that the lower value at this location is due to the consumption of organic material but the total organic carbon concentration of these stream waters has not been measured. The higher turbidity of the water at this location supports this observation.

Turbidity

Turbidity concentrations ranged from 0.97 to 2.16 NTU's and the highest concentration was measured in Marion Creek. Marion creek also yielded the lowest value for dissolved oxygen so we have assumed that the higher turbidity at Marion Creek is associated with organic sediments carried by the water.

Chloride

The concentrations of chloride measured in the four surface water samples ranged from 0.40 mg/L to 9.68 mg/L. The greatest concentration was measured in the creek flowing from Canal Flats. The other three steams yielded chloride concentration of about 0.4 mg/L to 0.45mg/L and represents the chloride concentration due to natural erosion and drainage from the soils and rock surrounding Columbia Lake. The chloride concentration in the water from the creek draining from Canal Flats is an unusual exception. Chloride does not originate from any of the natural salts in soils and rocks that occur near the ground surface and this exception over the natural levels must come from a man-made source.

We associate this greater concentration of chloride in this creek with the greater concentrations of chloride measured in the Columbia Lake waters in the south end of the lake.

Iron and Manganese

Iron and manganese range from less than the analytical detection limit to 0.064 mg/L to 0.00431 and 0.0154 respectively. The greatest iron concentration is measured at Hardie Creek and is associated with iron oxide and manganese oxides that stain the cobbles of the stream bed.   Recent ground disturbances near Hardie Creek may contribute to this greater concentration. However, there are no recent ground disturbances near Marion Creek and that creek is also associated with a detectable concentration of iron. The greatest concentration of manganese was measured in the creek that drains from Canal Flats. At the location of the Canal Flats creek's the measured concentration of manganese is more than a factor of 3 times that measured elsewhere.

Alkalinity

The concentration for alkalinity (a measure of the bicarbonate content of a water) range from 128 to 295 mg/L as CaCO3. The greatest concentration was measured at Hardie Creek and is believed to be also associated with the similar physical disturbance described for hardness.

 Nitrate

The concentration of nitrate measured in the four streams ranged from <0.01 to 0.24 mg/L. The greatest concentration was measured at Canal Flats and is understood to be the result of leaching of decayed material from the surrounding marshy area.   At this location the nitrate concentration is ten times that measured in the other streams.

Phosphorous

The concentration of total phosphorous measured in the four streams ranged from 0.0031 to 0.0128 mg/L. The greatest concentration was measured at Hardie Creek. The creek draining from Canal Flats yielded the second greatest concentration.   Marshy ground surrounding the Canal Flats creek and the associated decay of organic material may have caused phosphorous to be present in the creek water similar to the nitrate concentration, a similar case cannot be made for the situation at Hardie Creek because the nitrate

concentration was much lower than that measured in the Canal Flats creek, the source of the greater phosphorous in Hardie Creek may, in part, be attributed to the local ground disturbance.

4.0 Comparison to Nearby Lakes

Appendix C contains water quality information tabulated for Columbia Lake, Lake Windermere, Moyie Lake, Premiere Lake and White Swan Lake using information obtained by CLSS from BCMOE's database. The information provided consists of bi-annual water quality results for Columbia Lake, Lake Windermere and Moyie Lake collected by BCMOE from 2015, 2016, 2017, 2018 and 2019. CLSS also obtained bi-annual monitoring results from Premier Lake and White Swan Lake for 2018 and 2019: we understand that 2018 was the first year that water quality monitoring was conducted on these two lakes.

The tables in Appendix C were prepared by CLSS and not by BCMOE, therefore any transcription errors are the fault of CLSS.

These data provide a more extensive list of water quality parameters than monitored in CLSS's annual program. Although an allowance for the differences in geologic setting between the five lakes must be made, this information provides a comparative measure of the water quality of Columbia Lake to the nearby lakes. When reviewing these data, it is important to appreciate that Moyie Lake is much deeper than either Lake Windermere or Columbia Lake. The data in Table 2 is selected for comparable depths of Lake Moyie to that of Lake Windermere and Columbia Lake. Moyie Lake's depth (greater than 30 metres) suggests it may be prone to seasonal stratification and consequently dissolved salts and metals may be distributed differently than in either Lake Windermere or Columbia Lake. We cannot make a similar comment about Premiere Lake or White Swan Lake because depths of these lakes are not known to us.

Table 4 reduces the more extensive list of water quality parameters measured by BCMOE to only those parameters that in one or more lakes differ from the measurements made on the water samples collected from Columbia Lake. Only the concentrations of conductivity, dissolved oxygen, turbidity, dissolved SO4, dissolved chloride, hardness, total Kjeldahl nitrogen, aluminum, barium, iron, lead, lithium, manganese, strontium and zinc are noticeably different (a factor of two or more) from the concentrations measured in Columbia lake.

Table 4 - Comparison of Lake Concentrations

Parameter	Units	Columbia Lake Shallow (1 metre) min	max	Columbia Lake Deep (4 metres) min	max	Lake Windermere (shallow 1 m) min	max	Lake Windermere (Bottom 4 metres) min	max	White Swan Lake min	max	Premiere Lake min	max	Moyie Lake north min	max	Moyie Lake south min	max
Chlorophyll a	ug/L	0.856	1.96			0.85	2.23			0.491	1.36	0.448	2.63	0.397	2.62	0.52	2.02
Field measurements																	
Conductivity	uS/cm	290.9	345.3	301.2	301.2	239.4	404.2			249.6	289.9	338.5	350.9	47.2	62.3	48.3	58.2
Dissolved Oxygen	mg/L	8.23	10.8			7.44	11.6			8.97	10.71	9.08	10.43	8.46	12.04	7.61	12.05
Secchi (H2O clarity)	m	3.18	4.5			2.72	5.3			9.2	9.2	14.2	14.2	3	9.05	3.05	6.4
pH	pH	8.14	8.4			7.88	8.7			7.33	8.95	8.15	9.66	6.26	9.33	6.6	8.4
Temperature	OC	7.8	20.7			8.1	20.7	0.51	1.39	6.07	17.8	7.4	20.8	3.7	19.9	4.4	20
Turbidity	NTU	0.55	0.93	0.55	0.95	0.47	1.04			0.21	0.25	0.25	0.36	0.27	11.7	0.29	1.63
Anions																	
Silica	mg/L	4.76	7.83	3.33	8.09	2.65	6.42	2.28	6.91	1.03	3.9	0.87	3.04	3.8	8.81	3.6	8.72
Orthophosphate (p)	mg/L	0.0012	0.0016	0.0012	0.006	<0.001	0.0015	<0.001	0.0014	0.0012	0.0012	0.0012	0.0012	0.0017	0.0017	0.0018	0.0026
Dissolved Sulphate (SO4)	mg/L	22.4	29.7	22.9	29.7	25	71.7	25	74.3	3.8	22.4	24.1	26	1.83	2.36	1.65	2.36
Dissolved Chloride (Cl)	mg/L	4.38	6.44	4.39	6.43	1.11	3.15	1.11	3.13	2.44	3			0.88	1.22	0.99	1.5
Calculated parameters																	
Hardness	mg/L	150	193	148	183	115	224	120	223	138	145	176	195.2	20.5	28.4	20.3	27.2
Misc. Organics																	
Total Organic Cargon	mg/L	1.03	3.27	1.79	3.35	1.51	2.36	1.22	2.29	1.45	1.94	2.19	2.56	2.33	3.44	2.44	3.4
Nutrients																	
Total Kjeldahl Nitrogen	mg/L	0.164	0.256	0.157	0.239	0.122	0.228	0.123	0.933	0.07	0.105	0.208	0.227	0.061	0.119	0.089	0.185
Dissolved Phosphorous	mg/L	0.002	0.0058	0.0031	0.0165	0.0021	0.0048	<0.002	0.0046	0.002	0.0035	0.003	0.0054	0.0021	0.0032	0.0022	0.042
Nitrate plus nitrite (n)	mg/L	0.002	0.0032			0.003	0.0195	0.0032	0.019	0.0052	0.0052			0.032	0.0728	0.0261	0.0445
Total Nitrogen (N)	mg/L	0.164	0.312	0.157	0.239	0.122	0.228	0.123	0.933	0.075	0.105	0.208	0.227	0.094	0.178	0.094	0.228
Total Phosphorous (P)	mg/L	0.002	0.0183	0.002	0.0175	0.0022	0.0067	0.003	0.185	0.0025	0.0037	0.0032	0.0065	0.0023	0.0052	0.0021	0.0086
Total metals by ICPMS																	
Aluminium (Al)	ug/L	1.52	13.5	3.13	7.08	1.29	4.49	1.44	4.67	1.16	3.33	1.28	3	17.4	34.8	18	59.8
Antimony (Sb)	ug/L	0.06	0.085	0.068	0.123	0.049	0.073	0.054	0.069	0.081	0.107	0.062	0.072	0.021	0.037	0.034	0.071
Arsenic (As)	ug/L	0.0663	1.26	0.629	1.18	0.535	1.19	0.564	1.23	0.246	0.278	0.373	0.414	0.202	0.24	0.217	0.306
Barium (Ba)	ug/L	68.2	85.7	67.7	81.5	56.7	86.1	56.1	83.6	92.3	102	84.4	94.7	6.15	7.85	5.8	8.66
Boron (B)	ug/L	5.5	7.2	5.6	7.2	5.7	9.2	5.6	8.2								
Cadmium (Cd)	ug/L					0.14	0.14									0.0299	0.0591
Chromium (Cr)	ug/L																
Cobalt (Co)	ug/L	0.015	0.0373	0.0224	0.0407	0.015	0.0344	0.014	0.0375	0.0094	0.0122	0.0137	0.022	0.0204	0.0365	0.0206	0.0563
Copper (Cu)	ug/L	0.135	0.423	0.161	0.352	0.123	0.403	0.148	0.24	0.097	0.568	0.079	0.97	0.359	0.646	0.598	2.36
Iron (Fe)	ug/L	2.2	18.8	10.9	18.4	8.7	43.7	10.3	43.9	1.3	4.6	1.5	3.5	14.1	41.5	21.3	61.3
Lead (Pb)	ug/L	0.008	0.0485	0.0263	0.0514	0.0192	0.123	0.0138	0.0742	0.0076	0.024	0.00516	0.0469	0.0284	0.0688	1.17	3.68
Lithium (Li)	ug/L	2.85	3.4	2.89	3.32	1.58	3.8	1.7	3.69	1.14	1.25	2.7	2.94	2.04	3.61	2.8	4.91
Manganese (Mn)	ug/L	4.2	12.6	2.11	9.87	5.1	29	5.17	43.5	0.427	2.26	1.42	2.42	0.085	0.113	0.078	0.097
Molybdenum (Mo)	ug/L	0.514	0.614	0.519	0.583	0.515	0.717	0.495	0.604	0.7	0.723	1.09	1.19	0.099	0.153	0.146	0.196
Nickel (Ni)	ug/L	0.05	0.138	0.074	0.142	0.05	0.192	0.068	0.112	0.066	0.091	0.102	0.102			0.042	0.042
Selenium (Se)	ug/L	0.041	0.059	0	0	0.044	0.082	0.051	0.055	0.063	0.079	0.077	0.192			0.042	0.042
Strontium (Sr)	ug/L	183	217	167	214	115	373	125	353	105	108	164	192	16.1	18.8	15.3	17.9
Thallium (Tl)	ug/L	0.0015	0.0025	0.0029	0.0029	0.0013	0.0057	<0.002	0.0047	<0.002	0.0074			0.003	0.0064	0.0021	0.007
Tin (Sn)	ug/L			0	0											0.011	0.011
Uranium (U)	ug/L	0.752	1.06	0.713	1.03	0.648	1.47	0.638	1.27	0.43	0.517	1.41	1.56	0.077	0.119	0.0733	0.102
Vanadium (V)	ug/L	0.087	0.087	0	0	<0.2	0.057	0.22	3.32	0.17	1.82	0.2	2.17			0.102	0.102
Zinc (Zn)	ug/L	0.47	1.31	0.93	2.8	0.21	3.02							0.32	2.01	3.83	13.8
Calcium (Ca)	mg/L	25.3	40.4	25	37.9	23	48.9	24	48.9	37.1	39.4	28.7	28.9	2.67	8.33	5.69	7.97
Magnesium (Mg)	mg/L	18.9	23.3	18.7	21.8	14	25.6	14.5	24.5	11.2	12.2	26.1	26.2	1.57	3.44	1.48	1.87
Potassium (K)	mg/L	0.703	0.84	0.673	0.781	0.418	1	0.418	0.884	0.291	0.322	0.62	0.675	0.496	0.634	0.489	0.618
Sodium (Na)	mg/L	5.47	6.79	5.27	6.51	2.01	4.81	2.09	4.5	2.13	2.57	2.95	3.19	1.56	1.91	1.72	1.92

Concentration range is less than Columbia Lake

Concentration range is greater than Columbia Lake

For this comparison, the range of concentration measured by BCMOE have been summarized as a range in values (or single values) and compared to the concentrations measured by BCMOE as a colour. Orange identifies concentrations that are noticeably greater than those measured in Columbia Lake while green identifies concentration that are noticeable less than those measured in Columbia Lake. Those parameters that are less than those measured in Columbia Lake should not be inferred to suggest that Columbia Lake has water quality issues but merely to identify parameters that should be monitored more extensively for spatial differences within the lake and for increasing trends that may suggest the beginning of a water quality concern.

Comparing the concentration of conductivity between the five lakes we note that Moyie Lake concentrations are considerably less than those in Columbia Lake and the other nearby lakes. This finding is likely a consequence of Moyie Lake being much deeper than Columbia Lake and should not be considered a potential future water quality issue.

Dissolved oxygen concentrations amongst the lakes are all within a similar range.

Turbidity concentrations in both Lake Windermere and Moyie Lake are comparable to those measured in Columbia Lake although both Premiere Lake and White Swan Lake contain much lower turbidity values. Anecdotal evidence suggest that the steep shorelines of Premiere Lake and White Swan lake inhibit the growth of aquatic plants and minimizes shoreline erosion and the resuspension of bottom sediment. Consequently, it may be considered that the turbidity values reflect the shallowness of Columbia Lake and from season to season may vary.

Dissolved silica concentrations in both Columbia Lake and Moyie lake are similar and greater than those measured in either Lake Windermere, White Swan Lake and Premiere Lake.

Dissolved sulphate concentrations in both Columbia Lake and Lake Windermere are greater than those measured in White Swan Lake, Premiere Lake and Moyie Lake and is likely a consequence of the local rock formations.

Dissolved chloride concentrations in Columbia Lake is noticeably greater than those measured in any of the nearby lakes, although the chloride concentrations in Lake Windermere and White Swan Lake are only slightly less than those measured in Columbia Lake. Because readily soluble naturally occurring chloride salts are not believed to be present in the sedimentary materials and bedrock formations that surround any of these lakes, the presence of chloride suggests man-made source.

The most common source of chloride in fresh waters are wastewater disposal and drainage of road salts along highways where salt is used to control dust or to gain traction on icy roads. The chloride concentration in Columbia Lake is noticeable greater than in Lake Windermere, Premiere Lake, White Swan Lake and Moyie Lake. Although the concentrations measured will not influence the use of the lake water, the difference in concentration between the five lakes is notable.

Dissolved barium, calcium, magnesium, and strontium are measured in the waters of Columbia Lake, Lake Windermere, Premiere Lake and White Swan Lake at concentrations much greater than those measured on Moyie Lake. We understand that these compounds and elements occur naturally in the vicinity of these four lakes. The wall board plant near Mount Swansea on the east side of Lake Windermere uses

sulphide/sulphate bearing rocks to make the wall board. There are also several mineral hot springs along Columbia Valley including the mineral hot springs at Fairmont Resorts that are sulfurous. Molybdenum and uranium concentration in Columbia Lake, Lake Windermere, Premiere Lake and White Swan Lake, are also greater than those measured in Moyie Lake and may be likewise attributed to the difference in geologic setting. Before these natural sources of sulphate are cited as natural sources of the dissolved sulphate, barium, strontium and zinc, a review of the geologic setting of Columbia Lake, Premiere Lake and White Swan Lake should be undertaken.

Of the metals, iron, lead, manganese, and lithium concentrations measured in both Columbia Lake and Lake Windermere yield noticeably greater concentrations than in White Swan or Premiere lakes. This finding is attributed to difference in the geologic settings but trends in the concentrations need to be monitored. If the metals come from a natural occurring mineral source, the concentration should remain constant over time (allowing for a small variation due to changes in natural climatic events (including forest fires).

5.0 Summary of Findings

Overall lake water quality is acceptable for any of the current uses of the lake (recreational, potable water and aquatic habitat).   However, the 2019 results differ from those of the prior five years and suggest that activity on the lake, uses of the surrounding lands and development pressures are having noticeable influence on the indicator parameters used by CLSS to monitor the lake's condition.

The key findings from the 2019 water quality monitoring program on Columbia Lake are:

1 The concentrations for turbidity measured in 2019 exceed the maximum expected value recorded between 2014 and 2018. The measured concentration over the summer months are among the greatest recorded. The greater concentrations should not be attributed to the inflow of surface water from streams but because of the time of year when the greatest concentration was recorded, are attributed to an increase in phytoplankton growth and resuspension of bottom sediments. The greatest turbidity changes from prior years are noticed in the south end of the lake where water is the shallowest.

In contrast the conductivity of the lake water has not changed over prior years.   if both conductivity and turbidity had increased then the increases in these concentrations might have been attributed to changes in the drainage of surface water and groundwater to the lake. This is not the case and the main cause of turbidity changes is attributed to the growth of phytoplankton and disturbance of the bottom sediments.

The greatest values for conductivity are in the south end of the lake where prior work by CLSS as reported in 2018 suggests a substantial volume of groundwater may drain to the lake from beneath Canal Flats

2. In 2019 we noticed that the lowest values for the pH of the lake water was measured in August. In prior years the lowest values for the pH of the lake water was measured in April and May. Changes in the trend of the pH values is a concern because it potential affects the dynamics of the lake and may influence aquatic

and terrestrial wildlife's use of the shoreline areas. This change in pattern of pH values should be monitored carefully.

3. Although the dissolved oxygen concentrations measured are suitable to support aquatic life the timing of the maximum dissolved oxygen concentration differed in 2019 from that of other years. Between 2014 and 2018, the greatest concentrations of dissolved oxygen occurred in the spring.   In those years we attributed this greater concentration to be a consequence of colder water and photosynthetic activity occurring beneath the ice over the winter months.   In 2019 the greatest oxygen measurements were made in the late summer. If the dissolved oxygen is due to photosynthetic activity then, even during the warmer months, the late in the year rise in dissolved oxygen despite the increase in temperature of the water may imply that there is an increase in photosynthetic processes.

In addition to the noticeable change in when the maximum dissolved oxygen concentration was measured on the lake, the concentrations for dissolved oxygen are among the lowest recorded on the lake and are less than the 30 day average for dissolved oxygen of 8 mg/L set within the Lake Windermere water quality objectives.

4. The survey at fourteen monitoring locations along the lake repeated from the 2018 survey shows that pH values increase from the north to south and conductivity and chloride both increase from north to south i.e. the highest pH and greatest concentration of conductivity and chloride are in the south end of the lake.

This increase in conductivity and chloride concentrations from north to south is not uniform along the lake and therefore is not due to direct rainfall on the lake surface. The increase is also contrary to the trend we would expect to occur from evaporation (evaporation would tend to demonstrate an increase in concentration from south to north – the direction of drainage to the Columbia River). Therefore, the higher concentration of chloride in south end of lake is understood to be a consequence of the water quality of those waters draining to the lake both surface and groundwater. The decline in chloride concentrations northward along the lake is due to the contribution of small streams of differing water quality or due to the inflow of groundwater.

5.   The stream sampling monitoring program demonstrates that the small creek draining from the marshy area to the north of Canal Flats and likely other waters (groundwater and surface water) draining from this area contains a chloride concentration of 9 mg/L. Associated with the chloride found in the creek water of the creek draining from this area are concentrations of nitrate that are ten times that measured in the other streams CLSS monitored.

Leaching and drainage from the marsh north of Canal Flats allows products of organic decay (nitrate) to drain to Columbia Lake. Although this leaching process is natural and may be well accommodated by biological processes within Columbia Lake, any change in water distribution or surface water drainage to the south of the lake within Canal Flats or the marshy north of Canal Flats may cause undesirable effects to the water quality of Columbia Lake.

We understand that the rock and soil that surrounds Columbia Lake does not contain naturally readily soluble chloride salts and therefore the chloride in the lake and stream draining into it must come from a man-made source.

6. The water quality of Hardie Creek is associated with several indicator compounds that demonstrate ground surface disturbances potentially influences the quality of water entering the lake. It is not known how long these differences in water quality may last because none of the creek water quality (to the best of CLSS's knowledge) was measured pre-construction disturbance. Any work around the lake shore that requires a ground disturbance needs to keep these findings in mind and put in place measures that ensure the quality of the surface water draining to the lake is preserved.

7. Compared to other lakes in the region, Columbia Lake water has a higher concentration of chloride. Although the chloride concentrations are well less than the concentrations that may be considered to make the water unacceptable for potable water or recreational uses, the only source of chloride are man-made and consequently are directly attributed to use of the surrounding land.   It is not known whether this man made source of chloride is under control or otherwise limited in the ability to provide chloride to groundwater and surface water draining into Columbia Lake.

6.0 Continuous improvements

CLSS intends to implement the following improvements for the 2020 monitoring program.

1. The plots of measured concentrations will be revised to be presented with control limits showing the maximum and minimum expected concentrations from month to month as control charts.

2. The occurrence of greater concentrations of conductivity and chloride in the south end of the lake needs to be confirmed during the 2020 annual monitoring program and expanded to other months of the year say early May and late August as a minimum. This will involve repeat visits to the fourteen locations first monitored in 2018 biweekly over the summer months and re-visited in 2019 in July. This work will involve measurements of turbidity, conductivity, pH and dissolved oxygen and collection of water samples for chloride, iron and manganese, nitrate and total phosphorous.

3. The suspected growth of phytoplankton, resuspension of bottom sediments and or increased shoreline erosion and the apparent decline in oxygen over the summer months suggests that during the summer months more intense measurement of dissolved oxygen should be made when the concentration of dissolved oxygen is measured to be less than the 30 day minimum of 8 mg/L – the Lake Windermere water quality objective or a revised water quality objective established by a management plan developed specifically for Columbia Lake.

4. The differences in the concentration of water indicator parameters observed among the four creeks sampled in 2019 will be confirmed by sampling of these water courses in early spring, mid-summer and late summer.   During these monitoring events water samples should test for turbidity, conductivity, pH, dissolved oxygen and samples will be submitted for analysis of the chloride, iron and manganese, total nitrate, total phosphorous and dissolved phosphorous concentrations. Iron, manganese and total phosphorous are all indicators of resuspension of bottom sediments whether by wave action or recreational activity.

5. The regular bimonthly monitoring program and the semi-monthly program of water quality sample collection will be continued with the modifications as and when suggested by item 3. However, because of the suspected disturbance of bottom sediments, water samples to measure concentrations of iron and manganese should be added as potential indicators of metal increases to the lake water. Many aquatic organisms and potable water supplies have limits on metal concentration that are considered safe. Chloride concentrations should be added to the monthly analysis of water samples because man made sources of chloride have caused the water quality of Columbia Lake to differ from that of surrounding lakes. Nitrate will also be added because the local streams are shown to contain detectable concentrations for nitrate.

6. Although we have attributed several of the observations made in 2019 to increases in phytoplankton, growth, increased wave action and resuspension of bottom sediments none of the information collected by CLSS helps to better define the cause with more certainty. The information collected by CLSS to date does not help to determine the greatest contributor to these increases.

Appendix A

Monitoring parameters and their application to understanding water quality changes

What are the Parameters we Measure and Why are they Important

Ed. Note: The following is a brief description of the parameters that we measure and a comment on their importance. The description is intended to help us understand their relevance in the biological world. It is far from complete and indeed is not even original – most of the material is copied verbatim from two references:

http://water.epa.gov/type/rsl/monitoring/vms50.cfm

http://www.env.gov.bc.ca/wat/wq/wq_guidelines.html

Water Temperature

The rates of biological and chemical processes depend on temperature. Aquatic organisms from microbes to fish are dependent on certain temperature ranges for their optimal health. Optimal temperatures for fish depend on the species: some survive best in colder water, whereas others prefer warmer water. Benthic macroinvertebrates *(Ed. note -includes the immature stages of many flies, beetles, dragonflies, aquatic worms, snails, leeches, etc.)* are also sensitive to temperature and will move in the stream to find their optimal temperature. If temperatures are outside this optimal range for a prolonged period of time, organisms are stressed and can die.

For fish, there are two kinds of limiting temperatures the maximum temperature for short exposures and a weekly average temperature that varies according to the time of year and the life cycle stage of the fish species. Reproductive stages (spawning and embryo development) are the most sensitive stages. The following Table provides optimum temperature criteria for some local species.

Species	Incubation	Rearing	Spawning
Brown Trout	1.0-10.0	6.0-17.6	7.2-12.8
Cutthroat Trout	9.0-12.0	7.0-16.0	9.0-12.0
Rainbow Trout	10.0-12.0	16.0-18.0	10.0-15.5
Mountain Whitefish	less than 6.0	9.0-12.0	less than 6.0
Burbot	4.0-7.0	15.6-18.3	0.6-1.7

Temperature affects the oxygen content of the water (oxygen levels become lower as temperature increases); the rate of photosynthesis by aquatic plants; the metabolic rates of aquatic organisms; and the sensitivity of organisms to toxic wastes, parasites, and diseases.

Causes of temperature change include weather, removal of shading stream bank vegetation, impoundments (a body of water confined by a barrier, such as a dam), urban storm water, and groundwater inflows.

Phosphorus and Nitrogen

Both phosphorus and nitrogen are essential nutrients for the plants and animals that make up the aquatic food web. They are natural parts of aquatic ecosystems.

There are many sources of phosphorus, both natural and human. These include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from animal manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations.

Nitrogen and phosphorus support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water. But when too much nitrogen and phosphorus enter the environment - usually from a wide range of human activities - the water can become polluted. Nutrient pollution has impacted many rivers and lakes resulting in serious environmental and human health issues, and impacting the economy.

Too much nitrogen and phosphorus in the water causes algae to grow faster than ecosystems can handle. Significant increases in algae harm water quality, food resources and habitats, and decrease the oxygen that fish and other aquatic life need to survive. Large growths of algae are called algal blooms and they can severely reduce or eliminate oxygen in the water, leading to illnesses in fish and the death of large numbers of fish. Some algal blooms are harmful to humans because they produce elevated toxins and bacterial growth that can make people sick if they come into contact with polluted water, consume tainted fish or shellfish, or drink contaminated water.

Turbidity

Turbidity is a measure of water clarity or more simply, how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. These materials are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand). Turbidity can affect the color of the water.

Higher turbidity increases water temperatures because suspended particles absorb more heat. This, in turn, reduces the concentration of dissolved oxygen (DO) because warm water holds less DO than cold. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of DO. Suspended materials can clog fish gills, reducing resistance to disease in fish, lowering growth rates, and affecting egg and larval development. As the particles settle, they can blanket the stream bottom, especially in slower waters, and smother fish eggs and benthic macroinvertebrates. Sources of turbidity include: Soil erosion, Waste discharge, Urban runoff, and Eroding stream banks.

Turbidity can be useful as an indicator of the effects of runoff from construction, agricultural practices, logging activity, discharges, and other sources. Turbidity often increases sharply during a rainfall, especially in developed watersheds, which typically have relatively high proportions of impervious surfaces. The flow of storm water runoff from impervious surfaces rapidly increases stream velocity, which increases the erosion rates of stream banks and channels. Turbidity can also rise sharply during dry weather if earth-disturbing activities are occurring in or near a stream without erosion control practices in place.

pH

pH is a term used to indicate the alkalinity or acidity of a substance as ranked on a scale from 1.0 to 14.0. Acidity increases as the pH gets lower. The following figure presents the pH of some common liquids.
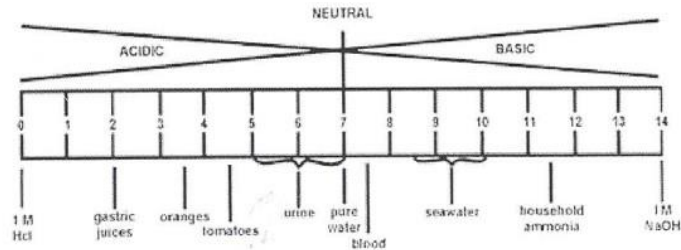
pH affects many chemical and biological processes in the water. For example, different organisms flourish within different ranges of pH. The largest variety of aquatic animals prefers a range of 6.5-8.0. pH outside this range reduces the diversity in the stream because it stresses the physiological systems of most organisms and can reduce reproduction. Low pH can also allow toxic elements and compounds to become mobile and "available" for uptake by aquatic plants and animals. This can produce conditions that are toxic to aquatic life, particularly to sensitive species like rainbow trout. Changes in acidity can be caused by atmospheric deposition (acid rain), surrounding rock, and certain wastewater discharges.

The pH scale is logarithmic. A pH of 7.0 indicates a neutral condition. Distilled water has pH of 7.0. Below 7.0, the water is acidic. When the pH is above 7.0, the water is alkaline, or basic. Since the scale is logarithmic, a drop in the pH by 1.0 unit is equivalent to a 10-fold increase in acidity. So, a water sample with a pH of 5.0 is 10 times as acidic as one with a pH of 6.0, and pH 4.0 is 100 times as acidic as pH 6.0.

Conductivity

Conductivity is a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge). Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore have a low conductivity when in water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius (25 C).

Conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through.

Discharges to streams can change the conductivity depending on their make-up. A failing sewage system would raise the conductivity because of the presence of chloride, phosphate, and nitrate; an oil spill would lower the conductivity.

Conductivity is measured in micromhos per centimeter (μmhos/cm). Distilled water has conductivity in the range of 0.5 to 3 μmhos/cm. The conductivity of rivers in the United States generally ranges from 50 to 1500 μmhos/cm. Studies of inland fresh waters indicate that streams supporting good mixed fisheries have a range between 150 and 500 μhos/cm. Conductivity outside this range could indicate that the water is not suitable for certain species of fish or macroinvertebrates. Industrial waters can range as high as 10,000 μmhos/cm.

Appendix B
Spreadsheet of Collected Water Quality Information

We have provided an electronic version of the spreadsheet instead of reproducing a paper copy here. Several interested parties have asked for the data and we expected the electronic data would be more useful. The spreadsheet accompanies the pdf version of the report.

Appendix C

Water Quality Information for Columbia Lake, Lake Windermere, Moyie Lake, Premiere Lake and White Swan Lake

Table C-1a - Water Quality results for Columbia Lake Surface Samples

Parameter	RDL*	Units	Columbia lake midlake north Surface (1m) 15-Apr-15	26-Aug-15	7-Apr-16	24-Aug-16	25-Apr-17	29-Aug-17	16-May-18	4-Sep-18	19-Apr-19	21-Aug-19	Concentration Range minimum	maximum
Chlorophyll a	0.5	ug/L	0.91	1.46	1.33	1.39	1.85	0.856	1.03	1.14	1.96	1.51	0.856	1.96
Chlorophyll a rep	0.5	ug/L	1.28	0.828	1.45	1.97	1.84	0.922						
Field measurements														
Conductivity	-	uS/cm	339.3	290.9	345.3	293	301.3		320.3		320.3	291	290.9	345.3
Dissolved Oxygen	-	mg/L	10.72	8.27	10.75	8.23	10.49	9.18	9.37		10.8	8.65	8.23	10.8
Secchi (H20 clarity)	-	m	4.5	3.6	4.5	3.6	3.18	4.4	3.9				3.18	4.5
pH	-	pH	8.27			8.4			8.36		8.14	8.17		
Temperature	-	°C	7.8	18.6	9.86	18.9	10.1	20.3	19.2		8.9	20.7	7.8	20.7
Turbidity	-	NTU		0.74	0.93						0.55	0.72	0.55	0.93
Anions														
Silica	0.5	mg/L	4.91	7.69	5.97	7.13	4.76	7.83	6.18	6.99	5.12	7.11	4.76	7.83
Orthophosphate (p)	0.001	mg/L	0.0012	<0.001	0.0015	<0.001	<0.001	<0.001	0.0016	0.0016	<0.001	<0.001	0.0012	0.0016
Dissolved Sulphate (SO4)	0.5	mg/L	27.6	22.4	29.7	25.3	29	23.1	27.1	22.9	26.7	25.1	22.4	29.7
Dissolved Chloride (Cl)	0.5	mg/L	6.1	5.47	6.44	5.92	5.88	4.78	5.01	4.38	5.09	4.58	4.38	6.44
Calculated parameters														
Hardness	0.5	mg/L	169	151	193	150	182	151		153	165	156	150	193
Misc. Organics														
Total Organic Cargon	0.5	mg/L	1.03	2.51	1.95	3.27	2.23	2.71	2.42	2.65	2.05	2.62	1.03	3.27
Nutrients														
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L	0.23	0.227	0.169	0.226	0.187	0.224	0.164	0.255	0.188	0.256	0.164	0.256
Dissolved Phosphorous (P)	0.002	mg/L	0.0058	0.003	0.002	0.002	0.002	0.0021	0.002	0.0029	0.0025	0.0023	0.002	0.0058
Nitrate plus nitrite (n)	0.002	mg/L	<0.002	0.002	0.0032	0.0032	0.0032	<0.0032	<0.0032	<0.003	<0.003	<0.003	0.002	0.0032
Total Nitrogen (N)	0.02	mg/L	0.23	0.227	0.169	0.226	0.187	0.312	0.164	0.255	0.188	0.256	0.164	0.312
Total Phosphorous (P)	0.002	mg/L	0.0183	0.0043	0.0031	0.0039	0.004	0.0058	0.002	0.0064	0.0046	0.0023	0.002	0.0183
Total metals by ICPMS														
Aluminium (Al)	0.5	ug/L	6.18		4.23		4.02		13.500		2.08	1.52	1.52	13.5
Antimony (Sb)	0.02	ug/L	0.073		0.065		0.071		0.085		0.06	0.077	0.060	0.085
Arsenic (As)	0.02	ug/L	0.644		0.0663		0.696		0.767		0.621	1.26	0.0663	1.260
Barium (Ba)	0.02	ug/L	74.3		76.5		85.7		71.0		74.8	68.2	68.2	85.7
Beryllium (Be)	0.01	ug/L	<0.01		<0.01		<0.01		<0.01		<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L	<0.005		<0.005		<0.005		<0.005		<0.005	<0.005		
Boron (B)	10	ug/L	<10		<10		<10		5.500		5.9	7.2	5.5	7.2
Cadmium (Cd)	0.005	ug/L	<0.005		<0.005		<0.005		<0.0050		<0.005	<0.005		
Chromium (Cr)	0.1	ug/L	<0.01		<0.1		<0.1		<0.1		<0.1	<0.1		
Cobalt (Co)	0.005	ug/L	0.027		0.0293		0.0373		0.029		0.024	0.015	0.015	0.0373
Copper (Cu)	0.05	ug/L	0.259		0.135		0.182		0.423		0.224	0.22	0.135	0.423
Iron (Fe)	1	ug/L	18.8		14.5		13.7		16.400		14.9	2.2	2.2	18.8
Lead (Pb)	0.005	ug/L	0.0481		0.0384		0.0485		0.041		<0.005	0.008	0.008	0.0485
Lithium (Li)	0.5	ug/L	3.07		3.37		3.4		2.850		3.19	2.94	2.85	3.4
Manganese (Mn)	0.05	ug/L	6.25		9.21		10.3		12.600		7.02	4.2	4.2	12.6
Molybdenum (Mo)	0.05	ug/L	0.514		0.532		0.54		0.614		0.539	0.59	0.514	0.614
Nickel (Ni)	0.02	ug/L	0.138		0.069		0.05		0.126		0.13	0.06	0.05	0.138
Selenium (Se)	0.04	ug/L	<0.04		0.041		<0.04		0.059		<0.04	0.046	0.041	0.059
Silver (Ag)	0.005	ug/L	<0.005		<0.005		<0.005		<0.005	<0.005	<0.005	<0.005		
Strontium (Sr)	0.05	ug/L	217		215		202		195.000		183	188	183	217
Thallium (Tl)	0.002	ug/L	<0.002		<0.002		0.0025		0.002				0.0015	0.0025
Tin (Sn)	0.2	ug/L	<0.2		<0.01		<0.01		<0.01		<0.01	<0.05		
Uranium (U)	0.002	ug/L	1		0.933		1.02		1.060		0.926	0.752	0.752	1.06
Vanadium (V)	0.2	ug/L	<0.2		<0.2		<0.2		0.087		<0.2	<0.2	0.087	0.087
Zinc (Zn)	0.1	ug/L	0.47		0.55		0.509		1.310		0.84	0.5	0.47	1.31
Calcium (Ca)	0.05	mg/L	34.2	26.2	38.8	26.9	37.9	28.6	40.4		25.3	28.5	25.3	40.4
Magnesium (Mg)	0.05	mg/L	20.4	20.7	23.3	20.1	21.3	19.4	19.8		18.9	20.5	18.9	23.3
Potassium (K)	0.05	mg/L	0.84		0.84		0.8		0.834		0.795	0.703	0.703	0.840
Sodium (Na)	0.05	mg/L	6.79		6.71		6.71		5.58		6.05	5.47	5.47	6.79

RDL reportable detection limit

*reportable detection limit

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Table C-1b - Water Quality results for Columbia Lake Bottom Samples

Location on the lake: Columbia lake midlake north — Bottom (3M)

Parameter	RDL*	Units	15-Apr-15	26-Aug-15	7-Apr-16	24-Aug-16	4-Apr-17	29-Aug-17	16-May-18	4-Sep-18	19-Apr-19	21-Sep-19	Conc. Range min	Conc. Range max
Chlorophyll a	0.5	ug/L	-	-	-	-	-	-	-	-	-	-		
Chlorophyll a rep	0.5	ug/L	-	-	-	-	-	-	-	-	-	-		
Field measurements														
Conductivity	-	uS/cm					3012						3012	3012
Dissolved Oxygen	-	mg/L	-	-	-	-	-	-	-	-	-	-		
Secchi (H2O clarity)	-	m	-	-	-	-	-	-	-	-	-	-		
pH	-	pH	-	-	-	-	-	-	-	-	-	-		
Temperature	-	°C	-	-	-	-	-	-	-	-	-	-		
Turbidity	-	NTU	-	-	-	-	-	-	-	-	0.55	0.89	0.55	0.95
Anions														
Silica	0.5	mg/L	4.97	8.09	5.66	7.37	4.71	7.42	4.79	7.46	5.12	3.35	3.33	8.09
Orthophosphate (P)	0.001	mg/L	<0.001	0.006	0.0012	<0.001	<0.001	<0.001	0.0013	0.0031	<0.001	<0.001	<.001	0.006
Dissolved Sulphate (SO4)	0.5	mg/L	27.6	23	29.7	25	23.2	29	25.5	22.9	26.6	24.9	22.9	29.7
Dissolved Chloride (Cl)	0.5	mg/L	6.1	5.6	6.43	5.89	4.78	5.89	4.62	4.39	5.08	4.54	4.39	6.43
Calculated parameters														
Hardness	0.5	mg/L	157	151	185	149	148	148	161	148	159	150	148	185
Misc. Organics														
Total Organic Carbon	0.5	mg/L	2.15	2.77	2.27	3.35	2.12	2.65	2.28	2.67	1.79	2.55	1.79	3.35
Nutrients														
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L	0.225	0.223	0.195	0.237	0.178	0.224	0.157	0.239	0.19	0.228	0.157	0.239
Dissolved Phosphorous (P)	0.002	mg/L	0.0065	0.0065	<0.002	<0.002	<0.002	<0.002	0.0037	0.0031	0.0071	<0.002	0.0031	0.0065
Nitrate plus nitrite (n)	0.002	mg/L	<0.002	<0.0032	<0.00032	<0.00032	<0.00032	<0.0032	<0.003	<0.008	<0.0032	<0.002		
Total Nitrogen (N)	0.02	mg/L	0.225	0.223	0.195	0.237	0.178	0.224	0.157	0.239	0.19	0.228	0.157	0.239
Total Phosphorous (P)	0.002	mg/L	0.0075	0.0061	0.0038	0.0036	0.0066	0.0033	0.0049	0.0077	0.002	0.002	0.002	0.0075
Total metals by ICPMS														
Aluminium (Al)	0.5	ug/L	7.08				3.13				3.94	6.47	3.13	7.08
Antimony (Sb)	0.02	ug/L	0.068				0.072				0.123	0.069	0.066	0.123
Arsenic (As)	0.02	ug/L	0.705				0.654				0.629	1.18	0.629	1.18
Barium (Ba)	0.02	ug/L	75.2				81.5				76	67.7	67.7	81.5
Beryllium (Be)	0.01	ug/L	<0.01				<0.01				<0.01	<0.01	<0.01	<0.01
Bismuth (Bi)	0.005	ug/L	<0.005				<0.005				<0.005	<0.005	<0.005	<0.005
Boron (B)	10	ug/L	<10				6.1				5.6	7.2	5.6	7.2
Cadmium (Cd)	0.005	ug/L	<0.005				<0.005				<0.005	<0.005	<0.005	<0.005
Chromium (Cr)	0.1	ug/L	<0.1				<0.1				<0.1	<0.1	<0.1	<0.1
Cobalt (Co)	0.005	ug/L	0.0311				0.0407				0.0224	0.0242	0.0224	0.0407
Copper (Cu)	0.05	ug/L	0.164				0.161				0.352	0.262	0.161	0.352
Iron (Fe)	1	ug/L	18.4				14.4				17.3	10.9	10.9	18.4
Lead (Pb)	0.005	ug/L	0.0514				0.0472				0.0496	0.0263	0.0263	0.0514
Lithium (Li)	0.5	ug/L	3.23				3.32				3	2.89	2.89	3.32
Manganese (Mn)	0.05	ug/L	6.66				9.87				7.45	2.11	2.11	9.87
Molybdenum (Mo)	0.05	ug/L	0.519				0.583				0.52	0.573	0.519	0.583
Nickel (Ni)	0.02	ug/L	0.104				<0.05				0.142	0.074	0.074	0.142
Selenium (Se)	0.04	ug/L	<0.04				<0.05				<0.04	<0.04	<0.04	<0.05
Silver (Ag)	0.005	ug/L	<0.005				<0.005				<0.005	<0.005	<0.005	<0.005
Strontium (Sr)	0.05	ug/L	214				198				157	182	157	214
Thallium (Tl)	0.002	ug/L	<0.002				0.0029				<0.01	--	0.0029	0.0029
Tin (Sn)	0.2	ug/L	<0.02				<0.01				<0.01	<0.05	0	0
Uranium (U)	0.002	ug/L	1				1.05				0.905	0.713	0.713	1.05
Vanadium (V)	0.2	ug/L	<0.2				<0.2				<0.2	<0.2	<0.2	<0.2
Zinc (Zn)	0.1	ug/L	1.06				2.8				0.99	0.93	0.93	2.8
Calcium (Ca)	0.05	mg/L	33.8	37.9	26.2	26.7	36.8	28.4	32.2	25.0	32.8	27.6	25	37.9
Magnesium (Mg)	0.05	mg/L	20.1	21.5	20.7	19.9	20.2	18.7	19.5	21.8	18.8	19.8	18.7	21.8
Potassium (K)	0.05	mg/L					0.781				0.738	0.673	0.673	0.781
Sodium (Na)	0.05	mg/L					6.51				5.55	5.27	5.27	6.51

*RDL   Reportable Detection Limit

Table C-2a - Water Quality results for Lake Windermere Shallow Samples

Parameter	RDL*	Units	Location on the lake										Concentration Range	
			Lake Windermere off Timber Ridge Shallow (1 metre)											
		Date sampled	15-Apr-15	26-Sep-15	7-Apr-16	24-Sep-16	25-Apr-17	29-Aug-17	16-May-18	4-Sep-18	19-Apr-19	20-Aug-19	minimum	maximum
Chlorophyll a	0.5	uG/L	0.85	1.83	1.1	1.64	1.14	2.23	1.66	2.07	1.12	1.53	0.85	2.23
Chlorophyll a rep	0.5	uG/L	0.82	1.08	1.27		2.02	2.14						
Field measurements														
Conductivity	-	uS/cm	389.3	268.9	404.2	256	350.4		401		403.1	239.4	239.4	404.2
Dissolved Oxygen	-	mg/L	10.85	7.79	11.6	7.44	10.47	7.99	9.18		11.1	8.59	7.44	11.6
Secchi (H2O clarity)	-	m	5	4.65	5.3	5.3	2.72	4	3.7		--	--	2.72	5.3
pH	-	pH	-	-	-	-	8.23		7.88	8.02	8.1	8.7	7.88	8.7
Temperature	-	°C	8.4	19.3	9.75	19.8	11.6	20	17.7		8.1	20.7	8.1	20.7
Turbidity	-	NTU			0.57	0.67	1.04	0.75			0.65	0.47	0.47	1.04
Anions														
Silica	0.5	mg/L	4.49	5.84	5.5	5.8	3.84	6.42	3.71	6.4	4.34	2.65	2.65	6.42
Orthophosphate (p)	0.001	mg/L	0.0011	0.001	<0.001	<0.001	<0.001	<0.001	0.0015	<0.001	<0.001	<0.001	0.001	0.0015
Dissolved Sulphate (SO4)	0.5	mg/L	70.8	28.4	71.7	30.5	71.6	31	71.1	32.3	65.8	25	25	71.7
Dissolved Chloride (Cl)	0.5	mg/L	2.9	1.68	3.15	1.45	2.91	1.57	3.04	1.44	2.91	1.11	1.11	3.15
Calculated parameters														
Hardness	0.5	mg/L	201	148	224	149	203	148		153	197	115	115	224
Misc. Organics														
Total Organic Cargon	0.5	mg/L	<0.5	1.86	1.63	1.96	1.55	2.36	2.03	1.87	1.51	1.96	1.51	2.36
Nutrients														
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L	0.183	0.193	0.122	0.139	0.183	0.198	0.16	0.228	0.17	0.157	0.122	0.228
Dissolved Phosphorous (P)	0.002	mg/L	0.0033	0.0031	<0.002	<0.002	<0.002	0.0021	0.0038	0.0029	0.0021	0.0048	0.0021	0.0048
Nitrate plus nitrite (n)	0.002	mg/L	<0.002	<0.0032	<0.0032	<0.002	<0.0032	0.0021	<0.003	<0.003	0.0195	<0.0034	0.003	0.0195
Total Nitrogen (N)	0.02	mg/L	0.183	0.193	0.122	0.139	0.183	0.198	0.16	0.228	0.19	0.157	0.122	0.228
Total Phosphorous (P)	0.002	mg/L	0.0056	0.0042	0.0033	0.0035	0.0042	0.0022	0.0046	0.0067	0.0049	0.0066	0.0022	0.0067
Total metals by ICPMS														
Aluminium (Al)	0.5	ug/L	4.33		1.29	1.56	4.17	3.02	4.09	4.49	4.49	4.17	1.29	4.49
Antimony (Sb)	0.02	ug/L	0.049		0.05	0.063	0.061	0.073	0.07	0.071	0.07	0.062	0.049	0.073
Arsenic (As)	0.02	ug/L	0.672		0.585	1.06	0.634	1.19	0.80	0.535	0.535	0.929	0.535	1.19
Barium (Ba)	0.02	ug/L	77.9		83.9	66.8	83.7	67.2	86.10	81.1	81.1	56.7	56.7	86.1
Beryllium (Be)	0.01	ug/L	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L	<0.005		<0.005	<0.005	<0.005	<0.005	<0.001	<0.005	<0.005	<0.005		
Boron (B)	10/1	ug/L	<10		9.2	5.9	8.2	5.7	8.00	7.8	7.8		5.7	9.2
Cadmium (Cd)	0.005	ug/L	<0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		
Chromium (Cr)	0.1	ug/L	<0.1		<0.1	<0.1	<0.1	<0.1	<0.05	<0.1	0.14	<0.1	0.14	
Cobalt (Co)	0.005	ug/L	0.015		0.0165	0.0161	0.0344	0.0232	0.0274	0.0179	0.028	0.0259	0.015	0.0344
Copper (Cu)	0.05	ug/L	0.172		0.123	0.188	0.147	0.179	0.4030	0.147	0.287	0.264	0.123	0.403
Iron (Fe)	1	ug/L	43.7		28.9	8.7	24.6	11.6	17.00	34.8	34.8	11.1	8.7	43.7
Lead (Pb)	0.005	ug/L	0.0311		0.0192	0.025	0.0589	0.0346	0.0339	0.13	0.123	0.038	0.0192	0.123
Lithium (Li)	0.5	ug/L	3.62		3.8	1.91	3.43	2.13	3.63	3.73	3.73	1.58	1.58	3.8
Manganese (Mn)	0.05	ug/L	5.1		12.9	29	25.3	26	23.30	9.73	9.73	12.3	5.1	29
Molybdenum (Mo)	0.05	ug/L	0.581		0.515	0.564	0.598	0.574	0.72	0.578	0.578	0.549	0.515	0.717
Nickel (Ni)	0.02	ug/L	0.093		0.058	0.083	0.05	0.139	0.19	0.13	0.13	0.138	0.05	0.192
Selenium (Se)	0.04	ug/L	<0.04		0.044	0.044	<0.04	0.047	0.08	0.055	0.055	0.049	0.044	0.082
Silver (Ag)	0.005	ug/L	<0.005		<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005		
Strontium (Sr)	0.05	ug/L	373		340	138	297	143	292	281	281	115	115	373
Thallium (Tl)	0.002	ug/L	<0.002		<0.002	<0.002	0.0041	0.0027	0.0013	0.0057	0.0057	<0.002	0.0013	0.0057
Tin (Sn)	0.2/0.01	ug/L	<0.2		<0.2	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05		
Uranium (U)	0.002	ug/L	1.18		1.1	1.24	0.843	1.47	1.23	0.648	0.648		0.648	1.47
Vanadium (V)	0.2	ug/L	<0.2		<0.2	<0.2	<0.2	0.06	<0.2	<0.2	<0.2	<0.2	<0.2	0.057
Zinc (Zn)	0.1	ug/L	0.21		0.26	1.42	3.02	1.09	1.37	1.6	1.6	1.85	0.21	3.02
Calcium (Ca)	0.05	mg/L	42.9	33.2	47.7	34.7	45.9	33.9	48.9	45.9	46	23	23	48.9
Magnesium (Mg)	0.05	mg/L	22.8	15.9	25.6	15.1	21.5	15.9	24.5	20	20	14	14	25.6
Potassium (K)	0.05	mg/L	0.964		0.71	0.833	0.709	1.000	0.888	0.888	0.418		0.418	1
Sodium (Na)	0.05	mg/L	4.81		2.17	4.06	2.37	4.42	4.59	2.01	2.01		2.01	4.81

RDL* Reportable Detection Limit

Table C-2b - Water Quality results for Lake Windermere Deep Samples

Parameter	RDL*	Units	Lake Windermere off Timber Ridge Deep (3metres)										Concentration Range	
			15-Apr-15	26-Aug-15	7-Apr-16	24-Aug-16	25-Apr-17	29-Aug-17	16-May-18	4-Sep-18	19-Apr-19	20-Aug-19	minimum	maximum
Chlorophyll a	0.5	ug/L	-	-	-	-	-	-	-	-	-	-	0	0
Chlorophyll a rep	0.5	ug/L	-	-	-	-	-	-	-	-	-	-		
Field measurements														
Conductivity	-	uS/cm	-	-	-	-	-	-	-	-	-	-	0	0
Dissolved Oxygen	-	mg/L	-	-	-	-	-	-	-	-	-	-	0	0
Secchi (H2O clarity)	-	m	-	-	-	-	-	-	-	-	-	-	0	0
pH	-	pH	-	-	-	-	-	-	-	-	-	-	0	0
Temperature	-	°C	-	-	-	-	-	-	-	-	-	-	0	0
Turbidity	-	NTU	-	-	-	0.71	1.39	-	-	-	0.67	0.51	0.51	1.39
Anions														
Silica	0.5	mg/L	4.51	6.06	5.18	5.6	3.97	6.91	3.37	6.37	2.28	2.68	2.28	6.91
Orthophosphate (p)	0.001	mg/L	<0.001	<0.001	<0.002	<0.001	<0.001	0.001	0.0014	0.0012	<0.001	<0.001	<0.001	0.0014
Dissolved Sulphate (SO4)	0.5	mg/L	71.6	28.3	71.6	30.5	71.7	30.6	74.3	32.3	66	25	25	74.3
Dissolved Chloride (Cl)	0.5	mg/L	2.7	1.68	3.13	1.46	2.9	1.55	3.08	1.44	2.9	1.11	1.11	3.13
Calculated parameters														
Hardness	0.5	mg/L	197	141	220	164	206	150	223	157	199	120	120	223
Misc. Organics														
Total Organic Cargon	0.5	mg/L	1.49	2.1	1.47	2.29	1.81	2.15	1.78	2.23	1.22	1.74	1.22	2.29
Nutrients														
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L	0.16	0.212	0.123	0.174	0.933	0.192	0.152	0.206	0.169	0.163	0.123	0.933
Dissolved Phosphorous (P)	0.002	mg/L	0.054	0.0029	<0.002	<0.002	<0.002	<0.002	0.0032	0.0025	<0.002	0.0046	<0.002	0.0046
Nitrate plus nitrite (n)	0.002/0.003	mg/L	<0.002	<0.0032	<0.0032	<0.0032	<0.0032	<0.0032	<0.003	<0.003	0.019	0.0032	0.0032	0.019
Total Nitrogen (N)	0.02	mg/L	0.16	0.212	0.123	0.174	0.933	0.192	0.152	0.206	0.188	0.163	0.123	0.933
Total Phosphorous (P)	0.002	mg/L	0.185	0.0062	0.003	0.0031	0.0053	0.0035	0.0057	0.0075	0.0046	0.0063	0.003	0.185
Total metals by ICPMS														
Aluminium (Al)	0.5	ug/L	3.77			1.44	3.55				4.11	4.67	1.44	4.67
Antimony (Sb)	0.02	ug/L	0.054			0.069	0.059				0.057	0.069	0.054	0.069
Arsenic (As)	0.02	ug/L	0.646			1.23	0.689				0.564	0.926	0.564	1.230
Barium (Ba)	0.02	ug/L	78.5			72.8	80.2				83.6	56.1	56.1	83.6
Beryllium (Be)	0.01	ug/L	<0.01			<0.01	<0.01				<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L	<0.005			<0.005	<0.005				<0.005	<0.005		
Boron (B)	10/1	ug/L	<10			5.6	8.2				7.9	8.2	5.6	8.2
Cadmium (Cd)	0.005	ug/L	<0.005			<0.005	<0.005				<0.005	<0.005		
Chromium (Cr)	0.1	ug/L	<0.1			<0.1	<0.1				<0.1	<0.01		
Cobalt (Co)	0.005	ug/L	0.014			0.0167	0.0375				0.0219	0.0309	0.014	0.0375
Copper (Cu)	0.05	ug/L	0.158			0.148	0.165				0.188	0.24	0.148	0.24
Iron (Fe)	1	ug/L	43.9			10.4	27.1				34.6	10.3	10.3	43.9
Lead (Pb)	0.005	ug/L	0.0237			0.0138	0.0742				0.0686	0.027	0.0138	0.0742
Lithium (Li)	0.5	ug/L	3.69			1.9	3.36				3.62	1.7	1.7	3.69
Manganese (Mn)	0.05	ug/L	5.17			43.5	30.3				10.1	12.4	5.17	43.5
Molybdenum (Mo)	0.05	ug/L	0.603			0.495	0.563				0.552	0.604	0.495	0.604
Nickel (Ni)	0.02	ug/L	0.093			0.104	0.068				0.092	0.112	0.068	0.112
Selenium (Se)	0.04	ug/L	<0.04			<0.04	0.052				0.051	0.055	0.051	0.055
Silver (Ag)	0.005	ug/L	<0.005			<0.005	<0.005				<0.005	<0.005		
Strontium (Sr)	0.05	ug/L	353			139	281				252	125	125	353
Thallium (Tl)	0.002	ug/L	<0.002			0.002	0.0044				0.0047	<0.002	0.002	0.0047
Tin (Sn)	0.2/0.01	ug/L	<0.2			<0.01	<0.01				<0.001	<0.05	<0.001	<0.05
Uranium (U)	0.002	ug/L	1.19			0.711	1.27				1.2	0.638	0.638	1.27
Vanadium (V)	0.2	ug/L	<0.2			<0.2	<0.2				<0.1	<0.002	0	0
Zinc (Zn)	0.1	ug/L	0.22			0.43	3.32				0.56	1.16	0.22	3.32
Calcium (Ca)	0.05	mg/L	43	31.8	48.9	37.1	46.6	33.9	48.9	33.5	44.5	24	24	48.9
Magnesium (Mg)	0.05	mg/L	21.7	14.9	23.7	17.3	21.7	15.9	24.5	17.7	23.4	14.5	14.5	24.5
Potassium (K)	0.05	mg/L	0.841			0.841	0.884				0.848	0.418	0.418	0.884
Sodium (Na)	0.05	mg/L	2.48			2.48	4.23				4.5	2.09	2.09	4.5

*RDL — Reportable Detection Limit

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Table C-3a - Water Quality results for South Moyie Lake Shallow Samples

Parameter	RDL*	Units	Moyie Lake, Lower/South Shallow (1 to 10 metres) 14-Apr-15	28-Sep-15	6-Apr-16	23-Sep-16	19-Apr-17	23-Aug-17	2-May-18	7-Sep-18	20-Apr-19	22-Aug-19	Concentration Range minimum	maximum
Chlorophyll a	0.5	ug/L	1.51	1.35	2.02	1.19	1.23	1.03	0.52	1.22	1.16	0.985	0.52	2.02
Chlorophyll a rep	0.5	ug/L	2.25	1.54	2.05	1.11	1.14	0.94	-	-	-	-		
Field measurements														
Conductivity	-	uS/cm	53.4	52.2	56.5		48.3	49.6	58.2	-	58.1	55.6	48.3	58.2
Dissolved Oxygen	-	mg/L	12.05	7.61	10.93		10.54	8.43	10.98	-	11.14	8.32	7.61	12.05
Secchi (H2Oclarity)	-	m	3.1	6.2	6.1		4.6	6.4	3.05	-	-	-	3.05	6.4
pH	-	pH											6.6	8.4
Temperature	-	°C	5.2	18.7	5.27		4.4	20	6.2	-	4.4	19.9	4.4	20
Turbidity	-	NTU			0.64		0.78		1.68	-	0.38	0.29	0.29	1.68
Anions														
Silica	0.5	mg/L	7.89	8.12	8.72	7.53	8.32	7.15	8.6	6.99	3.79	3.6	3.6	8.72
Orthophosphate (p)	0.001	mg/L	0.0026	0.0018	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0018	0.0026
Dissolved Sulphate (SO4)	0.5	mg/L	1.65	2.01	2.25	1.77	2.04	1.83	2.36	1.74	1.84	2.16	1.65	2.36
Dissolved Chloride (Cl)	0.5	mg/L	1.5	1.07	1.34	0.99	1.28	1.14	1.21	1.04	1.26	1.19	0.99	1.5
Calculated parameters														
Hardness	0.5	mg/L	22.7	23.1	26.3	21.2	27.2	22.1	24.4	20.3	23.1	23.1	20.3	27.2
Misc. Organics														
Total Organic Carbon	0.5	mg/L	2.52	2.66	2.44	2.85	2.8	3	3.4	2.96	2.72	2.5	2.44	3.4
Nutrients														
Total Kjeldahl Nitrogen (calc)	0.02	mg/L	0.09	0.094	0.089	0.162	0.185	0.1	0.108	0.121	0.093	0.116	0.089	0.185
Dissolved Phosphorous (P)	0.002	mg/L	0.0056	<0.002	<0.002	<0.002	0.0022	<0.002	-	0.042	<0.002	<0.002	0.0022	0.042
Nitrate plus nitrite (n)	0.002	mg/L	0.0322	<0.0032	0.0261	<0.0032	0.0445	<0.0032	0.0365	<0.003	<0.003	<0.003	0.0261	0.0445
Total Nitrogen (N)	0.02	mg/L	0.122	0.094	0.115	0.161	0.228	0.1	0.144	0.121	0.127	0.118	0.094	0.228
Total Phosphorous (P)	0.002	mg/L	0.0086	0.0021	0.0069	<0.002	<0.002	0.0025	0.0045	0.0024	0.0045	0.0023	0.0021	0.0086
Total metals by ICPMS														
Aluminium (Al)	0.5	ug/L	39.8		28.3		44.9		59.8		18	18.7	18	59.8
Antimony (Sb)	0.02	ug/L	0.037		0.038		0.034		0.042		0.071	0.054	0.034	0.071
Arsenic (As)	0.02	ug/L	0.219		0.221		0.217		0.221		0.233	0.306	0.217	0.306
Barium (Ba)	0.02	ug/L	6.57		6.96		6.81		8.66		5.8	6.52	5.8	8.66
Beryllium (Be)	0.01	ug/L	<0.01		<0.01		<0.01		<0.01		<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L	<0.005		<0.005		<0.005		<0.005		<0.005	<0.005		
Boron (B)	10	ug/L	<10		<10		<10		<5		<5	<5		
Cadmium (Cd)	0.005	ug/L	0.0318		0.0464		0.0591		0.0591		0.0427	0.0299	0.0299	0.0591
Chromium (Cr)	0.1	ug/L	<0.1		<0.1		<0.1		<0.1		<0.1	<0.1		
Cobalt (Co)	0.005	ug/L	0.0364		0.0292		0.0419		0.0563		0.0256	0.0206	0.0206	0.0563
Copper (Cu)	0.05	ug/L	0.71		0.598		2.36		0.986		0.62	0.612	0.598	2.36
Iron (Fe)	1	ug/L	50.2		36.6		57.1		61.3		27.3	21.3	21.3	61.3
Lead (Pb)	0.005	ug/L	1.17		1.96		1.73		1.62		2.56	3.68	1.17	3.68
Lithium (Li)	0.5	ug/L	<0.5		<0.5		<0.5		<0.5		<0.5	<0.5		
Manganese (Mn)	0.05	ug/L	2.98		3.69		4.68		4.91		4.63	2.8	2.8	4.91
Molybdenum (Mo)	0.05	ug/L	0.081		0.089		0.078		0.086		0.091	0.097	0.078	0.097
Nickel (Ni)	0.02	ug/L	0.162		0.184		0.173		0.196		0.146	0.159	0.146	0.196
Selenium (Se)	0.04	ug/L	<0.04		<0.04		<0.04		<0.04		<0.04	0.042	0.042	0.042
Silver (Ag)	0.005	ug/L	<0.005		<0.005		<0.005		<0.005		<0.005	<0.005		
Strontium (Sr)	0.05	ug/L	17.7		17.9		15.3		17.5		16.9	16.1	15.3	17.9
Thallium (Tl)	0.002	ug/L	<0.002		0.0022		0.0039		0.0070		0.0025	0.0021	0.0021	0.007
Tin (Sn)	0.2/0.01	ug/L	<0.2		<0.01		<0.01		0.0110		<0.01	<0.05	0.011	0.011
Uranium (U)	0.002	ug/L	0.0806		0.0763		0.0787		0.1020		0.0797	0.0733	0.0733	0.102
Vanadium (V)	0.2	ug/L	<0.2		<0.2		<0.2		<0.2		<0.2	<0.2		
Zinc (Zn)	0.1	ug/L	9.31		7.95		13.8		10		6.52	3.83	3.83	13.8
Calcium (Ca)	0.05	mg/L	6.32	6.59	7.45	6.03	7.97	6.34	6.71	5.69	6.54	6.58	5.69	7.97
Magnesium (Mg)	0.05	mg/L	1.68	1.62	1.87	1.48	1.77	1.54	1.81	1.49	1.65	1.64	1.48	1.87
Potassium (K)	0.05	mg/L			0.575		0.618		0.598		0.536	0.489	0.489	0.618
Sodium (Na)	0.05	mg/L			1.89		1.92		1.92		1.73	1.72	1.72	1.92

*RDL   Reportable Detection Limit

Table C-3b - Water Quality results for north Moyie Lake Shallow samples

Columns grouped under: **Moyie Lake Upper/North — Shallow 1 to 10 meter** (Location on the lake / Date sampled)

Parameter	RDL*	Units	14-Apr-15	24-Sep-15	6-Apr-16	23-Sep-16	19-Apr-17	23-Aug-17	2-May-18	7-Sep-18	20-Apr-19	22-Aug-19	Conc. Range min	Conc. Range max
Chlorophyll a	0.5	ug/L	1.86	2.62	1.79	1.08	0.397	0.884	1.44	0.997	1.52	1.55	0.397	2.62
Chlorophyll a rep	0.5	ug/L	1.45	2.6	1.92	-	1.05	0.92	-	-	-	-		
Field measurements														
Conductivity	-	uS/cm	55	52.3	57.7	47.2	51.6	49.8	62.3	-	61.4	55.8	47.2	62.3
Dissolved Oxygen	-	mg/L	12.04	9.08	10.99	8.6	11.11	8.46	10.85	-	11.18	8.47	8.45	12.04
Secchi (H2O clarity)	-	m	3	8.6	7.6	9.05	4.5	5.85	4.9	-	-	-	3	9.05
pH	-	pH	7.8	7.8	8	8	7.3	7.55	9.33	-	8.99	6.26	6.26	9.33
Temperature	-	°C	4.3	19.9	4.8	18.9	3.7	19.4	6.8	3.7	3.7	18.9	3.7	19.9
Turbidity	-	NTU								11.7			0.27	11.7
Anions														
Silica	0.5	mg/L	8.1	7.91	8.72	8.26	8.52	8.81	8.58	7.2	7.85	3.8	3.8	8.81
Orthophosphate (p)	0.001	mg/L	<0.001	0.0017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0017	0.0017
Dissolved Sulphate (SO4)	0.5	mg/L	1.84	2.01	2.36	2.1	2.22	2.26	2.35	1.83	1.96	2.26	1.83	2.36
Dissolved Chloride (Cl)	0.5	mg/L	1	0.91	1.17	1.02	1.22	0.88	1.19	0.89	1.09	1.05	0.88	1.22
Calculated parameters														
Hardness	0.5	mg/L	23	22.5	25.9	23.9	28.4	22.9	27.4	20.5	23.6	23	20.5	28.4
Misc. Organics														
Total Organic Carbon	0.5	mg/L	2.55	2.33	2.49	2.68	2.59	3.1	2.97	3.44	2.56	2.69	2.33	3.44
Nutrients														
Total Kjeldahl Nitrogen (calc)	0.02	mg/L	0.103	0.094	0.078	0.061	0.114	0.098	0.106	0.119	0.086	0.101	0.061	0.119
Dissolved Phosphorous (P)	0.002	mg/L	0.003	0.0021	<0.002	<0.002	0.0032	0.0025	0.0028	0.0032	<0.002	<0.002	0.0021	0.0032
Nitrate plus nitrite (n)	0.002	mg/L	0.0462	0.032	0.0454	0.0536	0.0632	0.0728	0.0485	0.063	0.056	<0.003	0.032	0.0728
Total Nitrogen (N)	0.02	mg/L	0.149	0.094	0.124	0.114	0.178	0.098	0.155	0.125	0.142	0.104	0.094	0.178
Total Phosphorous (P)	0.002	mg/L	0.0033	<0.002	<0.002	<0.002	0.0039	0.0023	0.0052	<0.002	0.0039	0.0046	0.0023	0.0052
Total metals by ICP MS														
Aluminium (Al)	0.5	ug/L	32.3		26.5		32.4		34.80		17.4	18.7	17.4	34.8
Antimony (Sb)	0.02	ug/L	0.024		0.021		0.022		0.03		0.037	0.026	0.021	0.037
Arsenic (As)	0.02	ug/L	0.213		0.202		0.211		0.21		0.24	0.219	0.202	0.24
Barium (Ba)	0.02	ug/L	6.21		6.15		6.42		7.85		6.69	6.25	6.15	7.85
Beryllium (Be)	0.01	ug/L	<0.010		<0.01		<0.01		<0.01		<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L	<0.005		<0.005		<0.005		<0.0050		<0.005	<0.005		
Boron (B)	10	ug/L	<10		<10		<10		<10		<10	<10		
Cadmium (Cd)	0.005	ug/L	<0.005		<0.005		<0.005		<0.005		<0.005	<0.005		
Chromium (Cr)	0.1	ug/L	<0.1		<0.1		<0.1		<0.1		<0.1	<0.1		
Cobalt (Co)	0.005	ug/L	0.0333		0.0267		0.0365		0.0348		0.024	0.0204	0.0204	0.0365
Copper (Cu)	0.05	ug/L	0.646		0.491		0.359		0.574		0.467	0.519	0.359	0.646
Iron (Fe)	1	ug/L	37.9		28		36.4		41.50		19.7	14.1	14.1	41.5
Lead (Pb)	0.005	ug/L	0.0489		0.0356		0.0688		0.0623		0.0546	0.0284	0.0284	0.0688
Lithium (Li)	0.5	ug/L	<0.5		<0.5		<0.5		<0.5		<0.5	<0.5		
Manganese (Mn)	0.05	ug/L	2.31		2.39		3.09		3.14		3.61	2.04	2.04	3.61
Molybdenum (Mo)	0.05	ug/L	0.094		0.105		0.085		0.113		0.106	0.092	0.085	0.113
Nickel (Ni)	0.02	ug/L	0.144		0.136		0.153		0.152		0.099	0.152	0.099	0.153
Selenium (Se)	0.04	ug/L	<0.040		<0.04		<0.04		<0.04		<0.04	<0.04		
Silver (Ag)	0.005	ug/L	<0.005		<0.005		<0.005		<0.005		<0.005	<0.005		
Strontium	0.05	ug/L	17.9		18.8		16.1		18.60		18	16.4	16.1	18.8
Thallium (Tl)	0.002	ug/L	<0.002		0.003		0.0038		0.0064		0.0048	<0.002	0.003	0.0064
Tin (Sn)	0.2/0.01	ug/L	<0.2		<0.01		<0.01		<0.01		<0.01	<0.05		
Uranium (U)	0.002	ug/L	0.0902		0.0841		0.0969		0.1190		0.101	0.077	0.077	0.119
Vanadium (V)	0.2	ug/L	<0.2		<0.2		<0.2		<0.2		<0.2	<0.2		
Zinc (Zn)	0.1	ug/L	0.46		0.32		2.01		1.69		0.51	1.02	0.32	2.01
Calcium (Ca)	0.05	mg/L	6.38	6.43	7.21	6.79	8.33	7.36	7.21	2.67	6.88	6.58	2.67	8.33
Magnesium (Mg)	0.05	mg/L	1.71	1.57	1.92	1.68	1.85	1.83	1.89	3.44	1.67	1.64	1.57	3.44
Potassium (K)	0.05	mg/L	0.589		0.604		0.634		0.594		0.496		0.496	0.634
Sodium (Na)	0.05	mg/L	1.71		1.67		1.57		1.91		1.65	1.56	1.56	1.91

Note: After the sampling event in the spring of 2015, all samples collected from the upper Moyie Lake were composite samples collected over the entire depth interval from surface to the bottom of the lake (30 to 40 metres).

* RDL Reportable Detection Limit

Table C-4 - Water Quality results for Premiere Lake Deepest Point Shallow samples

Location on the lake: **Premiere Lake — Shallow 1 to 10 meter**

Parameter	RDL*	Units	3-May-18	6-Sep-18	1-May-19	23-Aug-19	Conc. Range minimum	Conc. Range maximum
Chlorophyll a	0.5	ug/L	0.864	0.448	2.63	0.748	0.448	2.63
Chlorophyll a rep	0.5	ug/L			-	-		
Field measurements								
Conductivity	-	uS/cm	338.5	350.9	340		338.5	350.9
Dissolved Oxygen	-	mg/L	10.11	10.43	9.08		9.08	10.43
Secchi (H2O clarity)	-	m	14.2	-	-		14.2	14.2
pH	-	pH	9.66	8.35	8.15		8.15	9.66
Temperature	-	°C	10.6	7.4	20.8		7.4	20.8
Turbidity	-	NTU	0.27	0.36	0.25		0.25	0.36
Anions								
Silica	0.5	mg/L	3.04	1.93	1.31	0.87	0.87	3.04
Orthophosphate (p)	0.001	mg/L	0.0012	<0.001	<0.001	<0.001	0.0012	0.0012
Dissolved Sulphate (SO4)	0.5	mg/L	25.4	25.8	26	24.1	24.1	26
Dissolved Chloride (Cl)	0.5	mg/L	<0.5	<0.5	<0.5	<0.5		
Calculated parameters								
Hardness	0.5	mg/L	179	176	179.6	195.2	176	195.2
Misc. Organics								
Total Organic Cargon	0.5	mg/L	2.19	2.56	2.45	2.4	2.19	2.56
Nutrients								
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L	0.219	0.227	0.208	0.224	0.208	0.227
Dissolved Phosphorous (P)	0.002	mg/L	0.003	0.0054	0.0032	<0.002	0.003	0.0054
Nitrate plus nitrite (n)	0.002	mg/L	<0.003	<0.003	<0.003	<0.003		
Total Nitrogen (N)	0.02	mg/L	0.219	0.227	0.208	0.224	0.208	0.227
Total Phosphorous (P)	0.002	mg/L	0.0057	0.0032	0.0065	0.0033	0.0032	0.0065
Total metals by ICPMS								
Aluminium (Al)	0.5	ug/L	3		1.28	2.2	1.28	3
Antimony (Sb)	0.02	ug/L	0.062		0.064	0.072	0.062	0.072
Arsenic (As)	0.02	ug/L	0.375		0.373	0.414	0.373	0.414
Barium (Ba)	0.02	ug/L	94.7		84.4	86.6	84.4	94.7
Beryllium (Be)	0.01	ug/L	<0.1		<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L	<0.005		<0.005	<0.005		
Boron (B)	10	ug/L	<5		<5	<5		
Cadmium (Cd)	0.005	ug/L	0.244		<0.005	<0.005		
Chromium (Cr)	0.1	ug/L	<0.1		<0.1	<0.1		
Cobalt (Co)	0.005	ug/L	0.0137		0.0148	0.022	0.0137	0.022
Copper (Cu)	0.05	ug/L	0.97		0.079	0.144	0.079	0.97
Iron (Fe)	1	ug/L	<1.0		1.5	3.5	1.5	3.5
Lead (Pb)	0.005	ug/L	<0.005		0.00516	0.0469	0.00516	0.0469
Lithium (Li)	0.5	ug/L	2.7		2.73	2.94	2.7	2.94
Manganese (Mn)	0.05	ug/L	1.6		2.42	1.42	1.42	2.42
Molybdenum (Mo)	0.05	ug/L	1.16		1.09	1.19	1.09	1.19
Nickel (Ni)	0.05	ug/L	<0.05		<0.05	0.102	0.102	0.102
Selenium (Se)	0.04	ug/L	0.192		0.084	0.077	0.077	0.192
Silver (Ag)	0.005	ug/L	<0.005		<0.005	<0.005		
Strontium	0.05	ug/L	164		184	192	164	192
Thallium (Tl)	0.002	ug/L	<0.002		<0.002	<0.002		
Tin (Sn)	0.2/0.01	ug/L	<0.01		<0.01	<0.05		
Uranium (U)	0.002	ug/L	1.560		1.54	1.41	1.41	1.56
Vanadium (V)	0.2	ug/L	<0.2		<0.2	<0.2		
Zinc (Zn)	0.1	ug/L	0.460		0.2	2.17	0.2	2.17
Calcium (Ca)	0.05	mg/L	28.7	28.9			28.7	28.9
Magnesium (Mg)	0.05	mg/L	26.200	26.1			26.1	26.2
Potassium (K)	0.05	mg/L	0.675	0.643		0.62	0.62	0.675
Sodium (Na)	0.05	mg/L	3.19	2.95			2.95	3.19

*RDL   Reportable Detection Limit

Table C-5 - Water Quality results for Whiteswan Lake Shallow samples

Parameter	RDL*	Units	Whiteswan Lake — Shallow 1 to 10 meter (Location on the lake)				Concentration Range	
			Date sampled				minimum	maximum
			8-May-18	5-Sep-18	1-May-19	21-Aug-19		
Chlorophyll a	0.5	ug/L	0.543	0.547	1.36	0.491	0.491	1.36
Chlorophyll a rep	0.5	ug/L			-	-		
Field measurements								
Conductivity	-	uS/cm	249.6	289.9	273.2		249.6	289.9
Dissolved Oxygen	-	mg/L	10.71	10.66	8.97		8.97	10.71
Secchi (H20 clarity)	-	m	9.2	-	-		9.2	9.2
pH	-	pH	8.95	-	8.27	7.33	7.33	8.95
Temperature	-	°C	9.3	6.07	17.8		6.07	17.8
Turbidity		NTU	0.23	0.21	0.21	0.25	0.21	0.25
Anions								
silica	0.5	mg/L	3.9	1.55	1.03		1.03	3.9
Orthophosphate (p)	0.001	mg/L	<0.001	<0.001	<0.001	<0.001		
Dissolved Sulphate (SO4)	0.5	mg/L	3.8	22.4	19.5	19.2	3.8	22.4
Dissolved Chloride (Cl)	0.5	mg/L	2.83	3	2.5	2.44	2.44	3
Calculated parameters								
Hardness	0.5	mg/L	145	145	138	143	138	145
Misc. Organics								
Total Organic Carbon	0.5	mg/L	1.56	1.45	1.45	1.94	1.45	1.94
Nutrients								
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L	0.07	0.105	0.1		0.07	0.105
Dissolved Phosphorous (P)	0.002	mg/L	0.002	0.002	0.0035		0.002	0.0035
Nitrate plus nitrite (n)	0.002	mg/L	0.0052	<0.003	<0.003		0.0052	0.0052
Total Nitrogen (N)	0.02	mg/L	0.075	0.105	0.1		0.075	0.105
Total Phosphorous (P)	0.002	mg/L	0.0025	0.0037	<0.002		0.0025	0.0037
Total metals by ICP MS								
Aluminium (Al)	0.5	ug/L	2.37	1.16	3.33		1.16	3.33
Antimony (Sb)	0.02	ug/L	0.107	0.081	0.087		0.081	0.107
Arsenic (As)	0.02	ug/L	0.265	0.246	0.278		0.246	0.278
Barium (Ba)	0.02	ug/L	94.0	92.3	102		92.3	102
Beryllium (Be)	0.01	ug/L	<0.010	<0.01	<0.01			
Bismuth (Bi)	0.005	ug/L	<0.0050	<0.005	<0.005			
Boron (B)	10	ug/L	<5.0	<5	<5		0	0
Cadmium (Cd)	0.005	ug/L	<0.0050	<0.005	<0.005			
Chromium (Cr)	0.1	ug/L	<0.10	<0.1	<0.1			
Cobalt (Co)	0.005	ug/L	0.0122	0.0115	0.0094		0.0094	0.0122
Copper (Cu)	0.05	ug/L	0.2020	0.097	0.568		0.097	0.568
Iron (Fe)	1	ug/L	2.70	4.6	1.3		1.3	4.6
Lead (Pb)	0.005	ug/L	0.0085	0.0076	0.024		0.0076	0.024
Lithium (Li)	0.5	ug/L	1.250	1.14	1.16		1.14	1.25
Manganese (Mn)	0.05	ug/L	1.320	2.26	0.427		0.427	2.26
Molybdenum (Mo)	0.05	ug/L	0.723	0.7	0.704		0.7	0.723
Nickel (Ni)	0.02	ug/L	0.091	0.076	0.066		0.066	0.091
Selenium (Se)	0.04	ug/L	0.079	0.066	0.063		0.063	0.079
Silver (Ag)	0.005	ug/L	<0.0050	<0.005	<0.005			
Strontium	0.005	ug/L	108	105	107		105	108
Thallium (Tl)	0.002	ug/L	0.0025	0.0074	<0.002		<0.002	0.0074
Tin (Sn)	0.2/0.01	ug/L	<0.010	<0.01	<0.05			
Uranium (U)	0.002	ug/L	0.517	0.503	0.43		0.43	0.517
Vanadium (V)	0.2	ug/L	<0.20	<0.2	<0.2		0	0
Zinc (Zn)	0.1	ug/L	0.68	0.17	1.82		0.17	1.82
Calcium (Ca)	0.05	mg/L	37.5	39.4	37.1		37.1	39.4
Magnesium (Mg)	0.05	mg/L	11.4	11.2	12.2		11.2	12.2
Potassium (K)	0.05	mg/L	0.322	0.291	0.297		0.291	0.322
Sodium (Na)	0.05	mg/L	2.27	2.57	2.13		2.13	2.57

*RDL = Reportable Detection Limit

Appendix D

2018 Summer Survey of the Distribution of Turbidity and Conductivity Concentrations Along Columbia Lake

Location (UTM NAD27)		distance	Location#	Date	Turbidity (NTU)	Temperature (Cel)	Conductivity (us/cm
easting	northing						
583559	5558877	0	1	Friday, July 13, 2018	1.34	20.9	259.7
582686	5559805	1274.09	2	Friday, July 13, 2018	1.98	21	260.3
583561	5560320	1443.00	3	Friday, July 13, 2018	1.55	20.7	252.8
582135	5561373	2873.64	4	Friday, July 13, 2018	1.29	20.9	252.1
582656	5561797	3056.44	5	Friday, July 13, 2018	2.72	20.7	251.7
581654	5562368	3976.95	6	Friday, July 13, 2018	1.23	20.7	247.7
582361	5563429	4707.01	7	Friday, July 13, 2018	1.26	20.7	246.5
581428	5564343	5866.71	8	Friday, July 13, 2018	1.09	20.9	245.8
581999	5565042	6359.31	9	Friday, July 13, 2018	0.97	20.9	245.6
581125	5566561	8060.29	10	Friday, July 13, 2018	1.14	20.7	232.6
581596	5567554	8896.27	11	Friday, July 13, 2018	1.04	21	237.3
580440	5568967	10561.07	12	Friday, July 13, 2018	1.24	20.6	221.1
581074	5569916	11315.24	13	Friday, July 13, 2018	1.02	20.7	217.2
581267	5570895	12234.61	14	Friday, July 13, 2018	1.18	21.2	218.6
11 U 583559E 5558877N	11 U 583559E 5558877N	0	1	Saturday, July 28, 2018	1.92	21.5	262.5
11 U 582686E 5559805N	11 U 582686E 5559805N	1274.09	2	Saturday, July 28, 2018	1.19	21.3	255
11 U 583561E 5560320N	11 U 583561E 5560320N	1443.00	3	Saturday, July 28, 2018	1.89	21.4	256.8
11 U 582135E 5561373N	11 U 582135E 5561373N	2873.64	4	Saturday, July 28, 2018	1.64	21.2	250.7
11 U 582656E 5561797N	11 U 582656E 5561797N	3056.44	5	Saturday, July 28, 2018	2.51	21.4	254.2
11 U 581654E 5562368N	11 U 581654E 5562368N	3976.95	6	Saturday, July 28, 2018	1.48	21.3	249
11 U 582361E 5563429N	11 U 582361E 5563429N	4707.01	7	Saturday, July 28, 2018	1.81	21.5	246.8
11 U 581428E 5564343N	11 U 581428E 5564343N	5866.71	8	Saturday, July 28, 2018	1.18	21.4	249
11 U 581999E 5565042N	11 U 581999E 5565042N	6359.31	9	Saturday, July 28, 2018	1.45	21.5	244.5
11 U 581125E 5566561N	11 U 581125E 5566561N	8060.29	10	Saturday, July 28, 2018	1.17	21.5	234.7
11 U 581596E 5567554N	11 U 581596E 5567554N	8896.27	11	Saturday, July 28, 2018	1.26	21.6	235.4
11 U 580440E 5568967N	11 U 580440E 5568967N	10561.07	12	Saturday, July 28, 2018	1.03	21.6	223.8
11 U 581074E 5569916N	11 U 581074E 5569916N	11315.24	13	Saturday, July 28, 2018	1.69	21.7	222.6
11 U 581267E 5570895N	11 U 581267E 5570895N	12234.61	14	Saturday, July 28, 2018	0.92	21.7	210.3
11 U 583559E 5558877N	11 U 583559E 5558877N		1	Monday, August 13, 2018	2.55	18.8	236.4
11 U 582686E 5559805N	11 U 582686E 5559805N		2	Monday, August 13, 2018	2.61	19.7	242
11 U 583561E 5560320N	11 U 583561E 5560320N		3	Monday, August 13, 2018	3.33	19.2	243.7
11 U 582135E 5561373N	11 U 582135E 5561373N		4	Monday, August 13, 2018	3.23	20	246.7
11 U 582656E 5561797N	11 U 582656E 5561797N		5	Monday, August 13, 2018	2.61	20	246
11 U 581654E 5562368N	11 U 581654E 5562368N		6	Monday, August 13, 2018	2.39	20.1	247
11 U 582361E 5563429N	11 U 582361E 5563429N		7	Monday, August 13, 2018	2.11	20.5	236.4
11 U 581428E 5564343N	11 U 581428E 5564343N		8	Monday, August 13, 2018	2.37	20.5	244
11 U 581999E 5565042N	11 U 581999E 5565042N		9	Monday, August 13, 2018	2.38	20.6	231.1
11 U 581125E 5566561N	11 U 581125E 5566561N		10	Monday, August 13, 2018	1.59	20.1	233.1
11 U 581596E 5567554N	11 U 581596E 5567554N		11	Monday, August 13, 2018	1.45	20.6	216.3
11 U 580440E 5568967N	11 U 580440E 5568967N		12	Monday, August 13, 2018	2.35	20.8	219.5
11 U 581074E 5569916N	11 U 581074E 5569916N		13	Monday, August 13, 2018	1.47	20.6	222.7
11 U 581267E 5570895N	11 U 581267E 5570895N		14	Monday, August 13, 2018	1.48	19.6	208.4
11 U 583559E 5558877N	11 U 583559E 5558877N		1	Wednesday, August 22, 2018	1.68	19	229.6
11 U 582686E 5559805N	11 U 582686E 5559805N		2	Wednesday, August 22, 2018	2.34	18.9	243.5
11 U 583561E 5560320N	11 U 583561E 5560320N		3	Wednesday, August 22, 2018	1.45	18.4	244.5
11 U 582135E 5561373N	11 U 582135E 5561373N		4	Wednesday, August 22, 2018	1.01	19.3	241.1
11 U 582656E 5561797N	11 U 582656E 5561797N		5	Wednesday, August 22, 2018	0.87	18.9	240.5
11 U 581654E 5562368N	11 U 581654E 5562368N		6	Wednesday, August 22, 2018	0.74	19.5	240.3
11 U 582361E 5563429N	11 U 582361E 5563429N		7	Wednesday, August 22, 2018	1.01	19.3	236.7
11 U 581428E 5564343N	11 U 581428E 5564343N		8	Wednesday, August 22, 2018	0.93	19.7	237.8
11 U 581999E 5565042N	11 U 581999E 5565042N		9	Wednesday, August 22, 2018	1.09	19.7	235.7
11 U 581125E 5566561N	11 U 581125E 5566561N		10	Wednesday, August 22, 2018	0.88	19.9	224.5
11 U 581596E 5567554N	11 U 581596E 5567554N		11	Wednesday, August 22, 2018	0.89	19.8	219.3
11 U 580440E 5568967N	11 U 580440E 5568967N		12	Wednesday, August 22, 2018	0.87	20	215.9
11 U 581074E 5569916N	11 U 581074E 5569916N		13	Wednesday, August 22, 2018	1.32	20	215.5
11 U 581267E 5570895N	11 U 581267E 5570895N		14	Wednesday, August 22, 2018	0.83	19.6	210.6

Appendix E

Statistical Summary of Monitoring Results for 2014 to 2018

Table E-1 - Expected Maximum and Minimum Turbidity Concentration by Location and Month

	N1			S1			S3			S4		
month	Number of sampling events	expected maximum concentration	expected minimum concentration	Number of sampling events	expected maximum concentration	expected minimum concentration	Number of sampling events	expected maximum concentration	expected minimum concentration	Number of sampling events	expected maximum concentration	expected minimum concentration
March	1	--	--	1	--	--	1	--	--	1	--	--
mid April	4	1.7	0.7	4	2.4	0.1	5	1.9	0.1	3	1.3	0.3
end of April	1	--	--	2	2.1	1.3	2	1.3	1.1	1	--	--
mid May	2	1.5	1.2	2	2	0.8	3	1.9	0.1	2	3.3	--
end of May	4	3.2	0.8	4	1.8	0.6	5	2.9	--	3	2.6	0.3
mid June	4	4.9	--	4	2.1	--	4	3.2	--	3	1.5	0.6
end of June	4	2	--	3	1	0.6	5	1.8	0.2	2	2.7	0.9
mid July	3	1.8	0.5	3	1.6	0.6	2	1.8	1.0	1	--	--
end of July	4	1.8	0.5	5	1.6	1	4	1.6	0.4	1	--	--
mid August	5	2.8	--	5	1.9	0.8	5	2.8	0.3	1	--	--
end of August	5	1.4	0.6	3	1.7	0.5	4	2.2	0.9	3	2	1.2
mid September	1	--	--	2	2.2	0.3	1	--	--	1	--	--
end of September	4	2.2	0.2	2	1.5	1	3	2	0.6	4	2.7	0.4
October	1	--	--	2	1.3	1	1	--	--	1	--	--

Location on the Lake

NOTE: -- Indicates there have not been enough sampling events to calculated expected maximum and minimum concentrations

maximum concentration is estimated as the mean concentration plus 3 time the standard deviation

mmum concentration is estimated as the mean concentration minus 3 time the standard deviation

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where only 2 sample measurements have been taken the maxiumum expected value is stated as the maximum value measured and the minimum expected value is recorded as the minimum value measured

Table E-2 - Expected Maximum and Minimum Conductivity Concentrations by Location and Month

Location on the Lake

month			N1				S1				S3				S4		
			Number of sampling events	expected maximum concentration	expected minimum concentration		Number of sampling events	expected maximum concentration	expected minimum concentration		Number of sampling events	expected maximum concentration	expected minimum concentration		Number of sampling events	expected maximum concentration	expected minimum concentration
March			1	--	--		1	--	--		1	--	--		1	--	--
mid April			4	295	193		4	376	157		4	362	175		3	382	173
end of April			1	--	--		2	277	210		2	284	208		1	--	--
mid May			3	337	196		3	277	241		4	342	190		3	349	176
end of May			4	365	121		4	373	167		5	371	185		3	385	190
mid June			4	271	189		4	275	221		5	335	202		3	335	226
end of June			5	303	204		4	333	183		5	363	193		3	474	121
mid July			4	265	226		4	269	247		3	314	258		1	--	--
end of July			4	297	209		5	338	180		4	354	226		1	--	--
mid August			5	295	236		5	356	152		5	351	204		2	289	255
end of August			5	306	159		4	288	194		4	382	158		3	345	212
mid September			1	--	--		2	232	216		1	--	--		1	--	--
end of September			4	272	194		2	240	226		3	275	216		4	288	202
October			1	--	--		2	249	234		1	--	--		1	--	--

NOTE: -- Indicates there have not been enough sampling events to calculated expected maximum and minimum concentrations

maximum concentration is estimated as the mean concentration plus 3 time the standard deviation

mmum concentration is estimated as the mean concentration minus 3 time the standard deviation

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where only 2 sample measurements have been taken the maxiumum expected value is stated as the maximum value measured and the minimum expected value is recorded as the minimum value measured

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Table E-3 - Expected Maximum and Minimum pH Value by Location and Month

Location on the Lake

month		N1				S1				S3				S4		
		Number of sampling events	expected maximum value	expected minimum value		Number of sampling events	expected maximum value	expected minimum value		Number of sampling events	expected maximum value	expected minimum value		Number of sampling events	expected maximum value	expected minimum value
March		1	--	--		1	--	--		1	--	--		1	--	--
mid April		4	8.9	8.1		4	8.8	8		4	8.8	8.1		2	9	7.8
end of April		1	--	--		2	8.3	8.2		2	8.3	8.3		1	--	--
mid May		2	8.7	8.3		2	8.6	8.2		3	8.7	8.1		3	8.8	7.9
end of May		4	9.3	7.6		4	9	7.8		4	8.9	7.7		3	8.5	7.9
mid June		4	9.3	7.8		4	8.9	8.1		5	9.3	7.1		3	8.9	8
end of June		5	11.2	6.5		3	9.2	7.7		5	8.9	7.9		2	8	7
mid July		3	9.3	8.5		3	8.9	8.6		2	8.7	8.4		1	--	--
end of July		4	9.5	7.9		5	9.3	7.9		4	8.9	8.1		1	--	--
mid August		5	10.7	6.9		5	10.1	7.2		5	10.9	6.9		2	8.8	8.4
end of August		5	9.8	7.2		3	9.7	7.8		4	10.1	7.1		3	9.8	7.6
mid September		1	--	--		2	9	8.7		1	--	--		1	--	--
end of September		4	9.6	7.8		2	8.9	8.8		3	9	8.4		3	9.5	7.6
October		1	--	--		2	8.4	8.3		1	--	--		1	--	--

NOTE: -- Indicates there have not been enough sampling events to calculated expected maximum and minimum concentrations

maximum concentration is estimated as the mean concentration plus 3 time the standard deviation

minimum concentration is estimated as the mean concentration minus 3 time the standard deviation

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where only 2 sample measurements have been taken the maxiumum expected value is stated as the maximum value measured and the minimum expected value is recorded as the minimum value measured

	Table E-4 - Expected Maximum and Minimum Dissolved Oxygen Concentration by Location and Month													

Table E-4 - Expected Maximum and Minimum Dissolved Oxygen Concentration by Location and Month

Location on the Lake

month	N1				S1				S3				S4		
	Number of sampling events	expected maximum concentration	expected minimum concentration		Number of sampling events	expected maximum concentration	expected minimum concentration		Number of sampling events	expected maximum concentration	expected minimum concentration		Number of sampling events	expected maximum concentration	expected minimum concentration
March	1	--	--		1	--	--		1	--	--		1	--	--
mid April	4	13.5	8.2		4	12.7	9.4		4	12.9	8.4		2	10.6	10.3
end of April	1	--	--		1	--	--		2	10.4	7.8		1	--	--
mid May	2	9.4	4.3		1	--	--		1	--	--		2	11.2	10.7
end of May	3	17.7	2.1		4	12.3	5.1		2	12	9		2	9	8
mid June	3	11.9	5.6		3	13.2	4.1		4	13.6	0.7		2	11.2	2.8
end of June	3	12	7		2	8	7.5		4	12.4	4.5		1	--	--
mid July	1	14	7.5		3	14	7.4		2	12	8.1		2	8	7
end of July	4	12	7.8		3	13.3	6.2		4	12	6.7		1	--	--
mid August	3	11.1	5.8		5	19	7.7		5	16.9	3.4		1	9	3.3
end of August	5	10	7		3	10.9	4.8		4	15.9	0.7		2	11.3	6
mid September	1	--	--		2	11	9.3		1	--	--		1	--	--
end of September	4	12.9	4.4		2	10	7		3	12.7	3.9		4	12.1	5.5
October	1	--	--		2	9.8	8		1	--	--		1	--	--

NOTE: -- Indicates there have not been enough sampling events to calculated expected maximum and minimum concentrations

maximum concentration is estimated as the mean concentration plus 3 time the standard deviation

mmum concentration is estimated as the mean concentration minus 3 time the standard deviation

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where only 2 sample measurements have been taken the maxiumum expected value is stated as the maximum value measured and the minimum expected value is recorded as the minimum value measured

Table E-5 - Expected Maximum and Minimum Concentrations for Total and Dissolved Phosphorous														
			N1			S1			S3			S4		
			Total phosphorous	Dissolved phosphorous		Total phosphorous	Dissolved phosphorous		Total phosphorous	Dissolved phosphorous		Total phosphorous	Dissolved phosphorous	
	number of monitori		19	6		20	11		21	4		14	4	
	expected maximum		0.032	0.012		0.027	0.011		0.026	0.023		1.71	0.02	
	expected minimum		<0.002	<0.002		<0.002	<0.0002		<0.002	<0.002		<0.002	<0.002	