Summary of the 2018 Water Quality Monitoring Program for Columbia Lake

Columbia Lake Stewardship Society

February 6, 2019

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 September 2, 2018. In 2018 the first water quality monitoring event on Columbia Lake was on April 22, 2018 and the last monitoring event was on September 2, 2018. Monitoring included approximately bi-weekly monitoring of selected water quality indicator parameters and approximately monthly sampling of water for chemical analyses.

CLSS' water quality monitoring program is administered, implemented and interpreted entirely by volunteers and a summer student. Further, the water quality program for 2018 involved many volunteers that had participated in several previous years and some volunteers new to the program. The 2018 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,
- Regional District of East Kootenay,
- Columere Marina,
- Fairmont Hot Springs Resort Ltd. including the Riverside Golf course and the Fairmont Hot Springs Airport,
- Village of Canal Flats,
- Columbia Ridge Community Association,
- Timber Springs Community Association,
- Columere Park Community Association, and
- Spirits Reach Community Association.

The contributions by the volunteers and funding agencies are acknowledged gratefully.

CLSS' water quality monitoring program involves collecting three types of information:

- Observations about cloud cover, water surface disturbance (waves), and air temperature;
- Measurements of:
  - the depth of water at each sampling locations,
  - the depth of clear water using the Secchi disk,
  - water temperature,
  - turbidity,
  - conductance,
  - pH, and
  - dissolved oxygen; and
- Chemical analyses of water samples for total and dissolved phosphorous.

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

- Overall the lake's water quality has not changed within the five years of monitoring and remains suitable for a variety of intended uses (recreational, potable water and aquatic habitat).

- It is important that water quality objectives specific to Columbia Lake are established. Water quality objectives for Columbia Lake should be included in any revision of the 1997 lake management plan.

- Using the monitoring results for the indicator parameters on the lake from the past 5 years, CLSS has established a water quality baseline. The baseline uses calculated Control Limits that can help to determine whether the lake's water quality has noticeably changed in the future. The establishment of the water quality baseline means that the we will only monitor in early June, mid-July and early August to confirm the water quality is still within the baseline conditions. This change will reduce the monitoring program by more than one half its previous level of effort.

- Although a water quality baseline has been established, there are still data gaps caused by lack of sampling in the early spring and late fall. Therefore, the baseline for the water quality indicator parameters needs additional information for mid-May, and mid-September. We will gather samples at these times using small craft. Since safety is our first concern, it may take multiple years to attain enough samples due to potentially difficult weather conditions. Also, bi-weekly monitoring will be conducted at the south end of the lake (S4) in the summer months by small craft because this location could not be safely accessed by motor boats and needs additional information to define an adequate baseline at S4.

- Turbidity measurements at the north and south ends of the lake exceeded the guidelines established by the Lake Windermere Objectives on several occasions. The greater concentrations of turbidity in these areas may be due to a greater intensity of recreational use. However, the concentrations are not steadily increasing and are therefore considered to be only a temporary occurrence. We are concerned about turbidity because the material that causes the turbidity (sediments and organic debris) can limit the suitability of the lake water for drinking water and aquatic habitat.

- Low concentrations (below detectable limits) of dissolved oxygen were measured in the late part of the 2018 season at the north end of the lake.

- The turbidity and conductivity concentrations along the lake decline from the south end to the north end of the lake. This trend is consistent with groundwater discharge along the south shoreline of the lake sourced from the Kootenay River as described by Gillmor (2018). These findings suggest that dilution of the lake water is occurring. Whether dilution is occurring due to direct rainfall on the lake surface, or due to the inflow of surface water from the several small steams along the lake shore or due to the discharge of groundwater to the lake has not been confirmed. To improve our understanding of why this dilution is occurring and to better understand the water distribution of the lake, CLSS intends to re-direct some of the resources previously used to conduct the lake sampling program to monitor small streams along the lake and to conduct a more thorough assessment of water quality in the south end of the lake

- Compared to other lakes monitored by BCMOE, Columbia Lake water has greater concentrations of dissolved chloride. There are no natural sources of chloride within soil and rock types surrounding the lake.

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WATER QUALITY MONITORING PROGRAM SUMMARY

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 British Columbia Ministry of the Environment (BCMOE) is considering revising this management strategy, although the timing of a revision has not been decided or otherwise been made known to us.

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 October 2018. During 2018, water quality monitoring of Columbia Lake began on April 22, 7 and ended on September 2 Monitoring included approximately bi-weekly monitoring of selected water quality indicator parameters and approximately monthly sampling of water for selective chemical analysis.

In addition, during the summer months of 2018 a bi-weekly survey of the distribution of turbidity and conductivity concentrations along the lake was conducted.

BCMOE also monitors the quality of the Columbia Lake water. 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 2018.

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 entirely by volunteers. In 2018, the following volunteers contributed to the water quality monitoring program:

- Tracy Flynn – overall program administration and management, on-the-lake training of new volunteers and monitoring in March, September and October;
- 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 May 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
- Nancy Wilson and Tom Dance – on the lake training in June, data compilation and graphing, data interpretation and reporting.

For the 2018 monitoring program, CLSS received a grant from the Canada Summer Jobs program 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, Salema Dewar-Ghazal participated on the program in June of 2018 and continued work until she returned to school in August of 2018.

The program receives funding from the following agencies:

- Columbia Valley Local Conservation Fund,
- Regional District of East Kootenay (RDEK),
- Columere Marina,
- Fairmont Hot Springs Resort (including Riverside Golf Course and the Fairmont Hot Springs Airport,
- Village of Canal Flats,
- Columbia Ridge Community Association,
- Timber Springs Community Association,
- Columere Park Community Association, and

- Spirits Reach Community Association.

Advice on the conduct of the program was also provided by Wendy Booth of 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, which is difficult to access by motor boats for sampling and might cause disturbance of lake sediments that alter the turbidity measurements.

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	N50.25329	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

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 or 2018 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 created by this investigation.

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

	Trial One		Trial Two	
Lake Depth (m below base ice)	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^{o} C, as the cold surface water, melted from the ice (at 0^{0}C), 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 no WQO's have 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. The timing of that revision is not known to CLSS.

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:
  - the depth of water at each sampling locations,
  - the depth of clear water using the Secchi disk,
  - water temperature,
  - turbidity,
  - conductance,
  - pH and
  - 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 and 2018. The 2016 information showed that the lake had no noticeable differences in parameters between the deep and shallow depth and should have been repeated but was not due to rough water conditions at the time of sampling.

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 2018 monitoring program began on April 22, 2018. The last set of water quality monitoring information was collected on September 2, 2108. During the nine monitoring events conducted on the lake, five sets of water quality samples were submitted for chemical analysis (total phosphorous and dissolved phosphorous) Caro Analytical of Kelowna provided the analytical services.

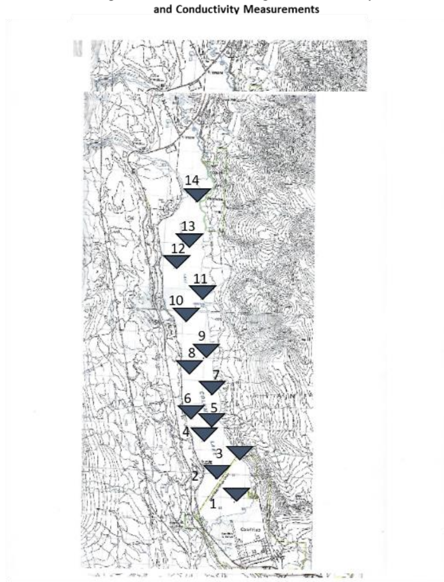
The spreadsheet in Appendix B provides the observations, measurements and chemical analysis collected during the five years of the monitoring program.

Also, during the summer months of 2018, CLSS conducted a special monitoring program to assess the distribution of turbidity and conductivity long the lake. This special monitoring program was conducted because prior monitoring results suggested that the southernmost monitoring location – location S4, frequently yielded greater concentrations of conductivity and turbidity than the other three monitoring locations. However, the greater concentrations of turbidity and conductivity were measured at only the S4 location and we wished to have a greater number of monitoring locations to confirm this observation.

It was understood that these greater concentrations might be due to the contribution of different water (surface streams or groundwater inflow) draining to the lake and were not a consequence of evaporation because the water temperature along the lake did not vary for south to north by more than a degree or two.

For this program volunteers, Lucas Fuertes, Cesar Fuertes and Gina Fryer monitored the concentration of turbidity and conductivity at fourteen locations along the lake (Figure 2) every two weeks between June 30 and August 30, 2018. The results of this monitoring program are tabulated in Appendix D and 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 metres 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. 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.

Other information compiled by 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)

3.0 Water Quality Monitoring Results

The water quality monitoring results obtained in 8 are summarized in Section 3.1 and 3.2. 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 2018 to those obtained from 2014, 2015 2016 and 2017;
- 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 turbidity and conductivity along the lake.

3.1 Annual Monitoring Program

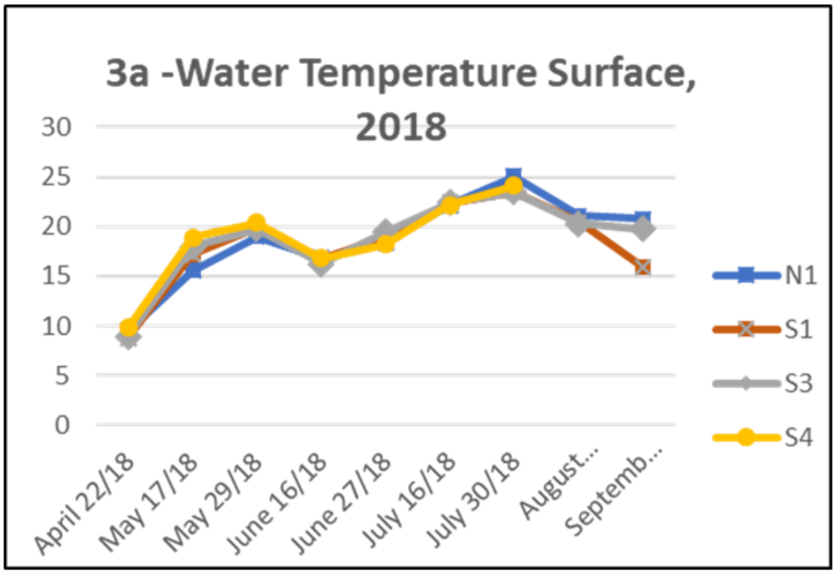
The 2018 annual monitoring program is the fifth year CLSS has monitored the water quality of Columbia Lake. The information obtained from the prior four years has shown a consistent pattern in the location and timing of the greater and lesser values measured for the parameters from month to month. Therefore, in addition to identifying, comparing and describing the information, a statistical evaluation of the parameters has been undertaken. That evaluation consists of a month to month calculation of the average (mean) and variability (standard deviation) for the water quality monitoring measurements made during the past five years. Expected maximum and expected minimum concentrations were calculated for each month as mean +/- 3 times the standard deviation. These calculations are consistent with those made by regulatory agencies in many jurisdictions in Canada and the United States when evaluating water quality information. Values that exceed either the expected maximum or minimum 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 y 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 3 plots the temperature measured during each monitoring event during 2018 at surface and bottom depths. The minimum temperature measurements in 2017 of approximately 7^0 to 10^0 C were measured during the late April monitoring event while the maximum temperatures (greater than 20^0C) were measured between late July and the middle of 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 compare the shallow and bottom temperatures and illustrate that there is no noticeable difference in water temperature with depth at all monitoring locations.

Figure 3 – Water Temperature, 2018



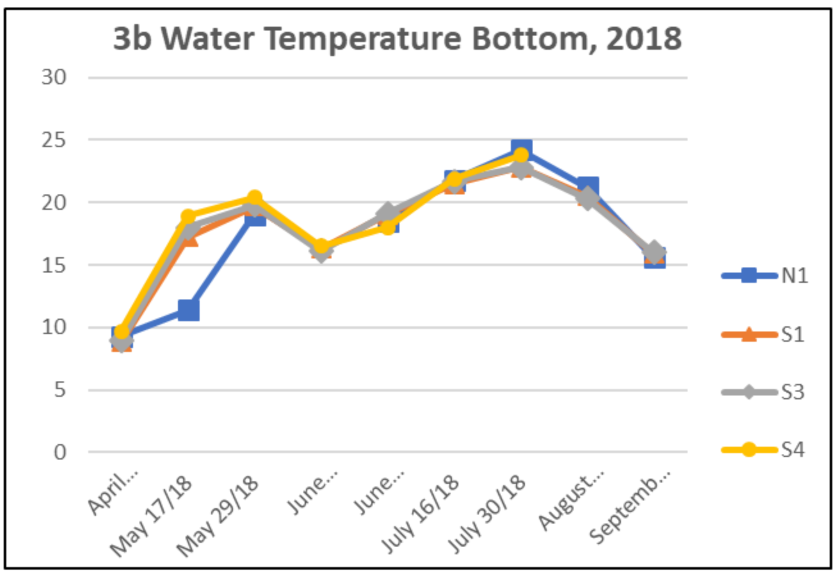


Figure 4 compares the temperature measurements along the lake from 2014 to 2018. Temperatures measured during several of the summer monitoring events in all five years exceed the water quality objectives (23°C) that have been established for Lake Windermere for the month of August but are less than the maximum water temperature (25°C) established for the month of July. In 2014, 2015, 2017 and 2018 the peak temperatures were measured during the late July monitoring events. In contrast, during the 2016 monitoring events the peak temperature was measured in August. For that year, the later measurement of the peak temperature is attributed to a cooler spring and early summer air temperatures.

Figure 4 – Water Temperature, Year to Year Comparison, Sites S4 and S4

4 a- site S4 **4b – site S3**

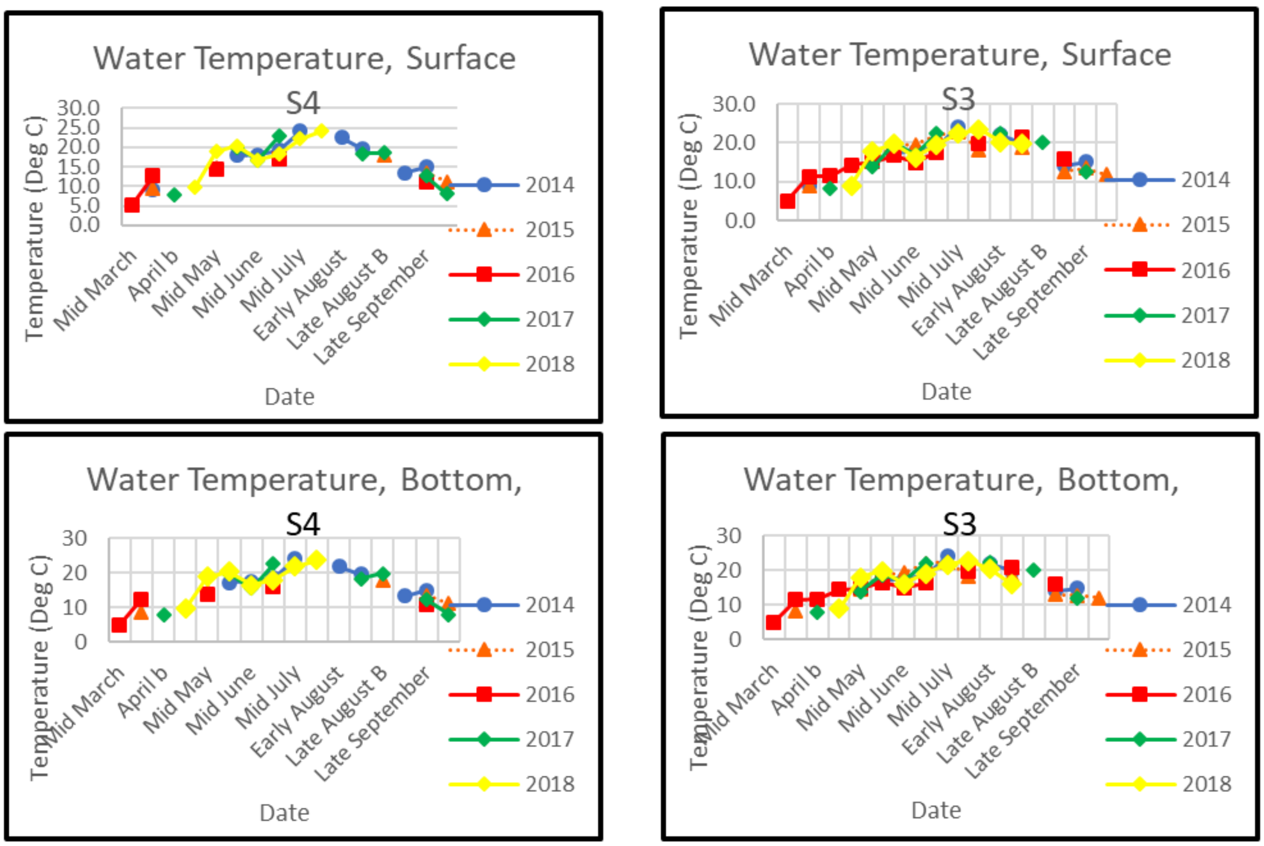
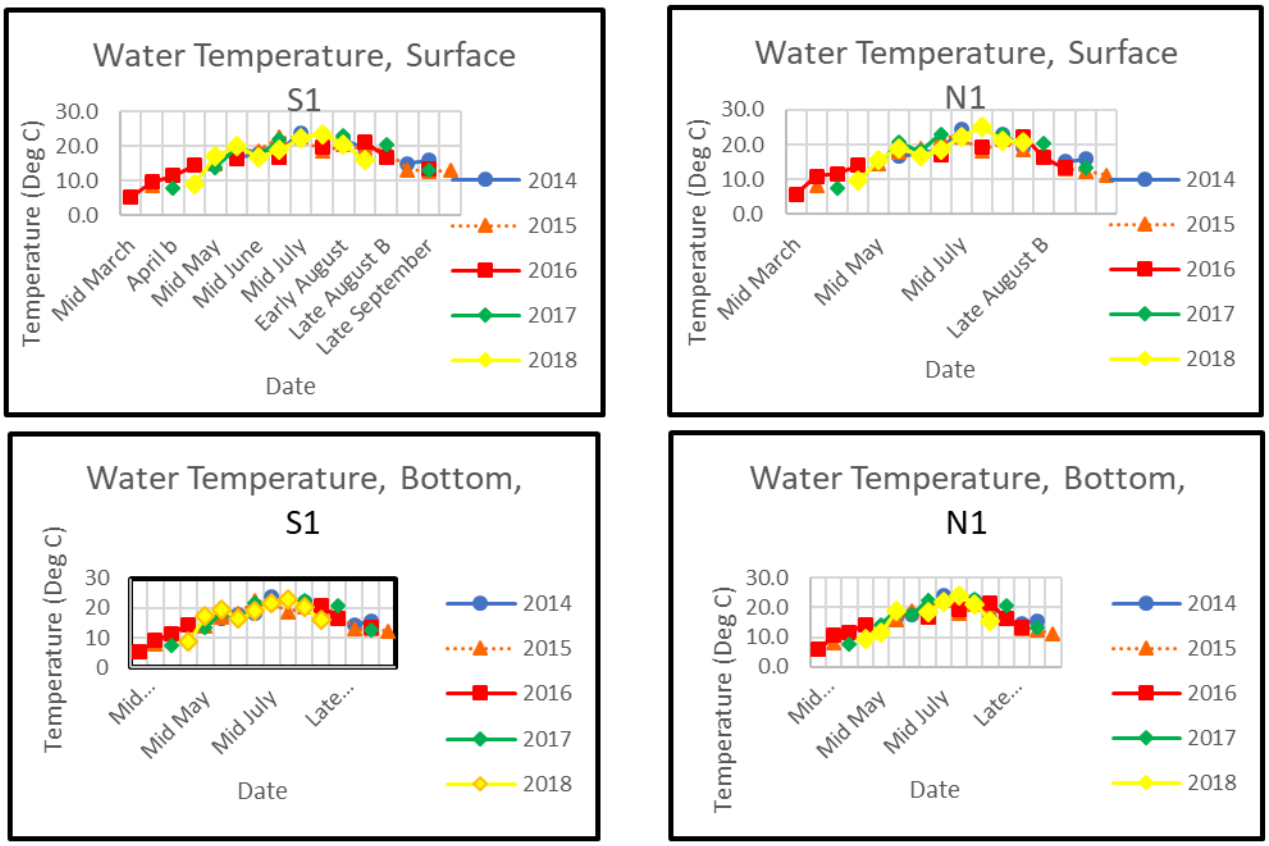


Figure 4 cont'd – Water Temperature, Year to Year Comparison, Sites S1 and N1

4c – site S1 4d – site N1



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 2018 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.

The available lake measurements (Appendix B) suggest that for the most part, the 2018 measurements of

Secchi disk depths are comparable to those of other years. The only measurements where the Secchi disk was less than the bottom depth occurring 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. Exceptions are the Secchi disk measurements made in late May and June of 2017 at S1. During these monitoring events, the Secchi disk depths and the lake bottom depths differed by more than 1.5 metres and the Columbia Lake water would be considered less clear than at other times of the year. This time of the year is also when the greatest recreational activity occurs on the lake and stronger wave action due to winds disturb bottom sediments.

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 is influenced mostly by the growth of phytoplankton and the amount of suspended sediments contained in the lake water. Suspended sediments are introduced by surface water draining into the lake 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. The turbidity may be influenced by some chemical reactions that create insoluble precipitates (carbonates mostly) but is not as great a contributor as suspended mineral sediments and organic debris and requires a much greater concentration of dissolved salt (conductance) than measured on the lake.

Turbidity measurements made during the 2018 monitoring events are plotted on Figure 5. This plot illustrates that the greatest turbidity measurements occurred in mid-May in the north end of the lake (N1). This area is close to where Dutch Creek drains into Columbia Lake. Some of the turbidity may be due to suspended sediments in the water. But this sampling location is also close to the marina at Columere Park and the beach/swimming area. A portion of the turbidity may be due to suspended sediments introduced by the disturbance of bottom sediments associated with these recreational activities.

In June and July, the greatest turbidity concentrations are measured in the south end of the lake (S4). A portion of the turbidity in this area of the lake may be attributed to suspended sediments introduced by surface drainage from the marshy area that borders this end of the lake. This southern end of the lake is understood to be associated with groundwater seepage to the lake believed to be sourced by seepage from the Kootenay River. Although groundwater does not carry suspended particulates nor decayed organic material, areas of groundwater discharge on the lake bottom can lift fine-grained bottom sediments into the lake water. Anecdotal evidence by our volunteer monitors during the early summer of 2017 and 2018 has identified zones of groundwater upwelling on the bed of the lake along the marshland bordering the south end of the lake that are readily distinguished as "mud volcanoes". These features may result in the turbidity increase measured at this end of the lake. The relative contribution of groundwater inflow versus surface water drainage at this end of the lake was further evaluated by Mr. Ed Gillmor during the summer of 2018. A copy of his report describing the potential quantity of groundwater entering the lake along this southern shoreline is provided on CLSS's website. Other anecdotal evidence provided to CLSS during the summers of 2017 and 2018, suggests that this end of the lake was also the area where falling ash from forest fires to the south of Canal Flats was most noticeable on the lake surface.

This ash-fall may also result in a turbidity increase.

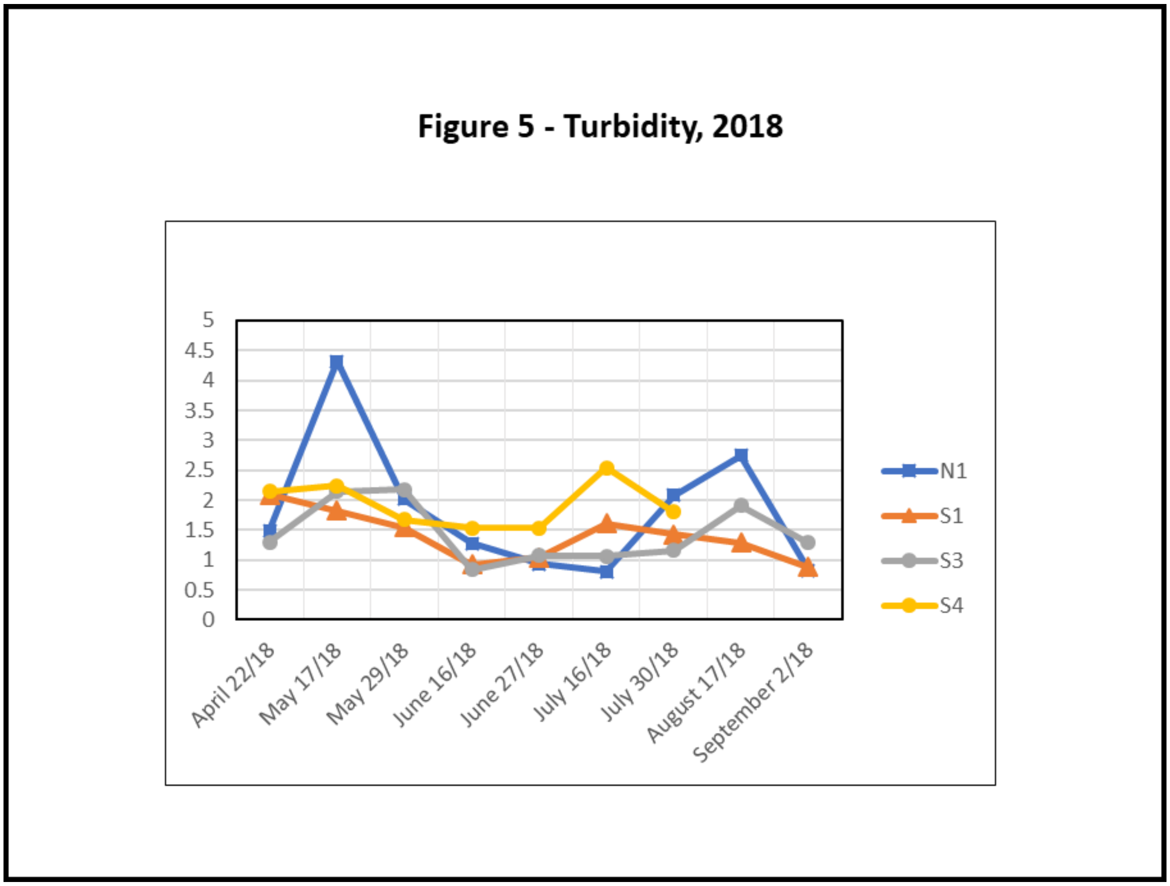
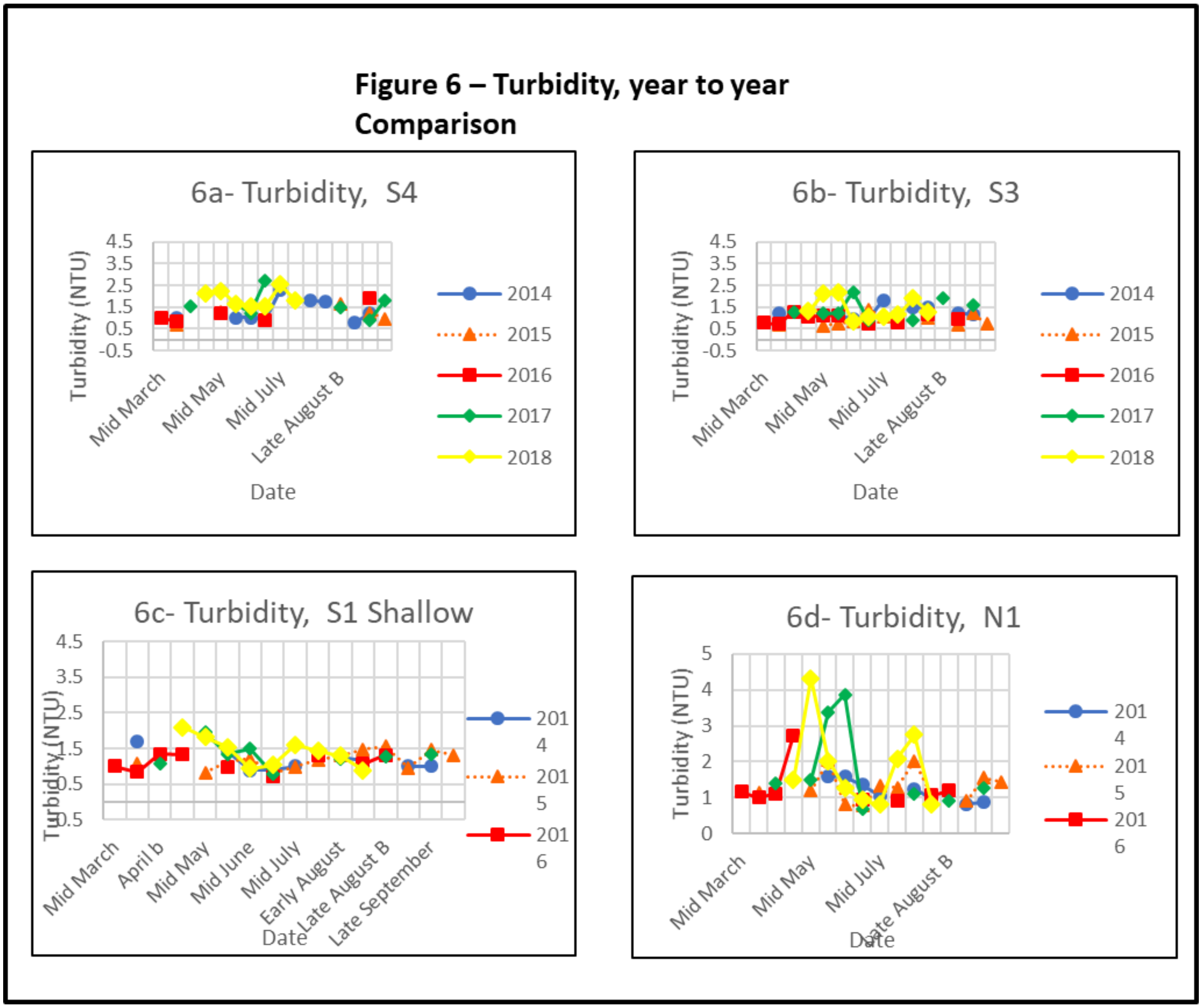


Figure 6 compares the year over year turbidity measurements at each monitoring location on the lake.



The four graphs Figures 6 a, b, c, and d demonstrate that the turbidity of the lake water falls within a narrow range of 0.7 to 2 NTU's. The exception is location N1 where in both 2017 and 2018 turbidity concentrations where in the of 3 to 4.5 NTU range. Overall the plots suggest that the turbidity of the lake water has not noticeably changed since the monitoring program began in 2014. The plots on Figure 6 suggest that both S4 and N1 yield the greatest value for the turbidity while S3 and S1 yield lower values. Both S4 and N1 are areas where surface water drainage to the lake is noticeable (the marshland to the south of S4 contains several small creeks and Dutch Creek is close to N1). However, a portion of the turbidity measured at N1 may be attributed to the accumulation of suspended sediments (mostly organic debris and fine-grained particulate material) that drifts to this end of the lake due to wave action and the drainage of the lake into the Columbia River. This N1 location also exhibits the largest range in values for turbidity during the monitoring season (ranges from less than 1.5 NTU's to greater than 3.5 NTU's. The N1 location is the closest location to the marina located at Columere Park.

Turbidity values greater than the value of 2 NTU's set by the Lake Windermere objectives were measured in the late May monitoring events at all monitoring locations 2018

Table 2 provides the expected maximum and minimum concentrations for turbidity to be measured in the lake water during future monitoring events. These "expected values are based upon the average turbidity and the range in turbidity values measured at each sampling location by month over the five years of the monitoring programs. These estimates are not very reliable for those months with very few previous monitoring results and will need to become more reliable as additional monitoring data is collected. The calculated values suggest that based upon the range in turbidity values collected over the past five years, turbidity values will exceed the objectives set to Lake Windermere.

Table 2 - Expected Maximum and Minimum Turbidity Concentration by Location and Month

	Location on the Lake											
	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	3	0.3	2	1.7	0.6	1	-	--
mid May	3	1.9	0.7	2	3.8	0	3	1.9	0.1	2	1.3	1.1
end of May	4	5.1	0	4	1.8	0.6	5	2.9	0	2	2.8	0
mid June	4	6.8	0	4	2.1	0	4	3.2	0	3	1.5	0.6
end of June	4	2	0	3	1	0.6	5	1.8	0.2	2	5.7	0
mid July	3	1.8	0.6	3	1.6	0.6	2	3.1	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	0	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	1.8	0.5	3	2	0.6	4	2.7	0.4
October	1	--	--	3	2.7	0	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

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

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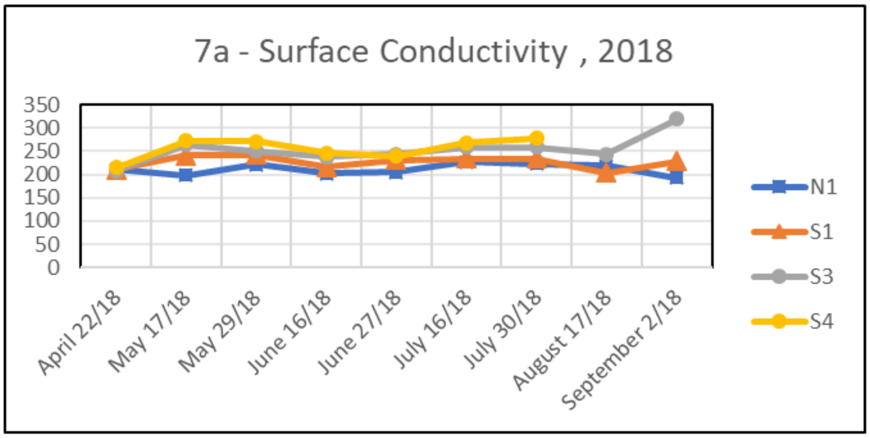
3.1.4 Conductivity

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 2018. The maximum values for conductivity are measured in the south end of the lake at S3 and S4. Because there are no major streams entering the lake over this area, it might be concluded that the higher conductivity is due to an increased salt content due to lake evaporation or due to the relative increase in contribution by groundwater discharge to the lake. Because this end of the lake is also associated with greater turbidity values the increase in conductance may also be a consequence of a greater amount of organic debris (ash or plant material) in the lake water. During 2018, the maximum conductivity value was measured during the summer months when the lake is warmest but also when lake water evaporation is the greatest.

Figure 7 – Conductivity, 2018



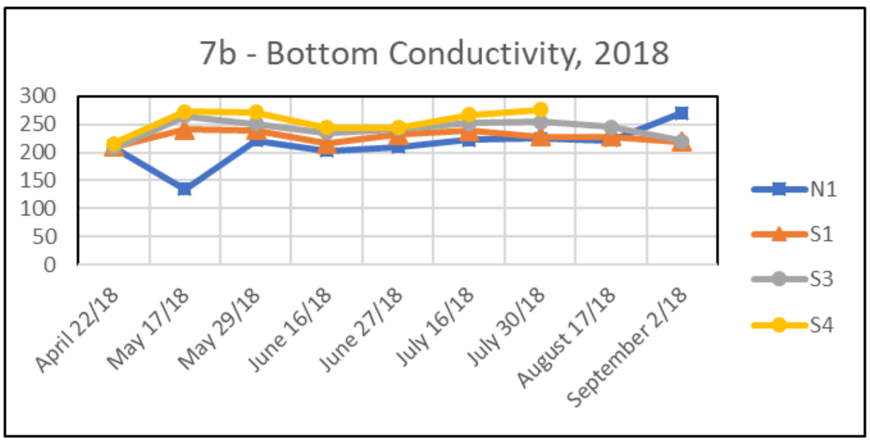


Figure 8 compares the conductivity measurements over the five years of the monitoring program at each monitoring location on the lake. The plots all show a similar trend to increases in conductivity values over the spring and summer months with declines in late summer and early autumn. The two southern most monitoring locations S4 and S3 (Figures 8a and 8b respectively) yield greater conductivity values than either S1 or N1 (Figures 7c and d respectively). This finding suggests that because neither location is close to a surface water drain to the lake (except for the small intermittent creek near S3) that these greater values are due to the contribution of dissolved salts from groundwater discharge to the lake.

In 2016 at S3 (Figure 8b), the conductivity continued to rise during the late summer and into the autumn. This rise in conductivity values did not occur in 2014 or 2015 nor was it measured during the monitoring events of 2017 or 2018. It may be considered that a one-time event (e.g. a spring discharge or surface water discharge is the most likely source) of highly conductive water occurred during 2016.

Water quality objectives for this parameter have not been established so the significance of the values measured to the lake water quality cannot be assessed.

Figure 8 – Conductivity, year to year comparison

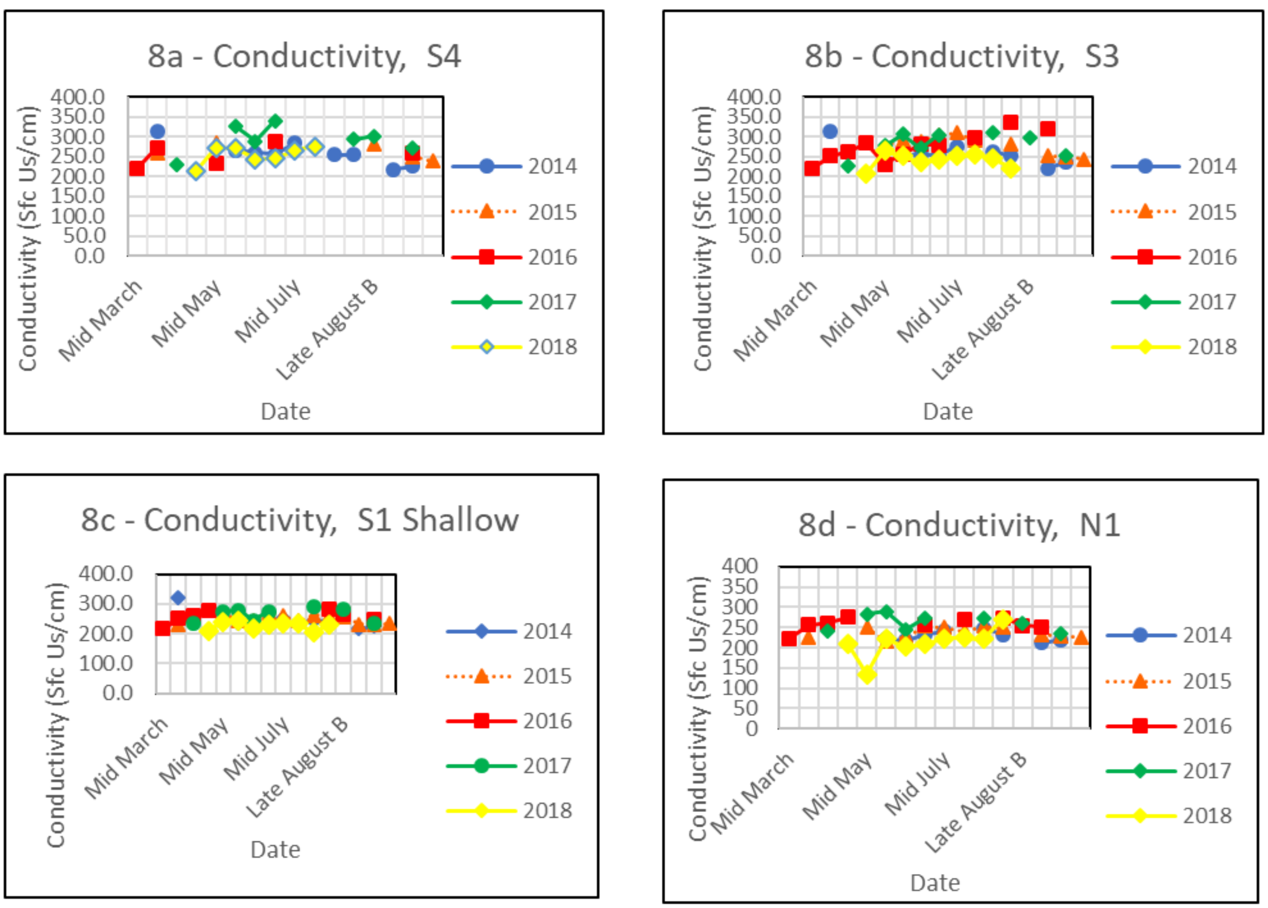


Table 3 contains the expected maximum and minimum concentration for conductivity calculated from the average concentration measured at each of the four locations along the lake. Most of the late spring to end of summer monitoring events yield values based upon five sets of information but information from early May and the middle of September is lacking make these expected concentrations less accurate and will require additional information to improve their reliability.

Table 3 - Expected Maximum and Minimum Conductivity Concentrations by Location and Month

	Location on the Lake											
	N1			S1			S3			S4		
month	Number of sampling events	expected maximum concentration	expected minimum concnetration	Number of sampling events	expected maximum concentration	expected minimum concnetration	Number of sampling events	expected maximum concentration	expected minimum concnetration	Number of sampling events	expected maximum concentration	expected minimum concnetration
March	1	--	--	1	--	--	1	--	--	1	--	--
mid April	4	295	196	4	376	157	4	362	175	3	382	173
end of April	1	--	--	2	285	264	2	407	85	1	--	--
mid May	3	337	196	2	278	276	4	342	190	1	--	--
end of May	4	365	121	4	373	167	5	371	185	2	376	141
mid June	4	271	189	4	275	221	5	335	202	2	420	172
end of June	5	303	204	4	333	181	5	363	193	3	474	121
mid July	4	265	226	4	269	247	3	375	215	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	343	201
end of August	5	306	159	4	288	199	4	382	158	3	345	212
mid September	1	--	--	2	257	190	1	--	--	1	--	--
end of September	4	272	194	2	263.2	203	3	275	216	1	--	--
October	1	--	--	2	300	157	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

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 2018. Excluding the pH value measured in September at N1 the lowest pH values were measured in April and May and increased throughout the year to provide a more alkaline pH by the time the monitoring period ended for 2018. At location N1 the pH declined in September.

Figure 9 – PH, 2018

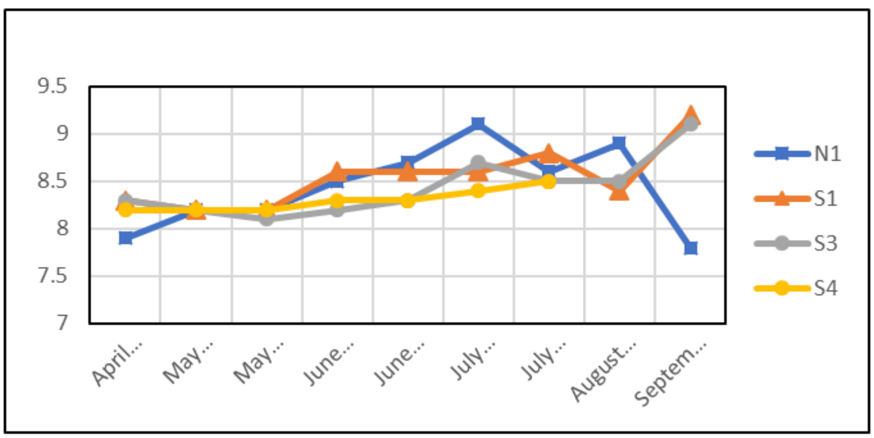
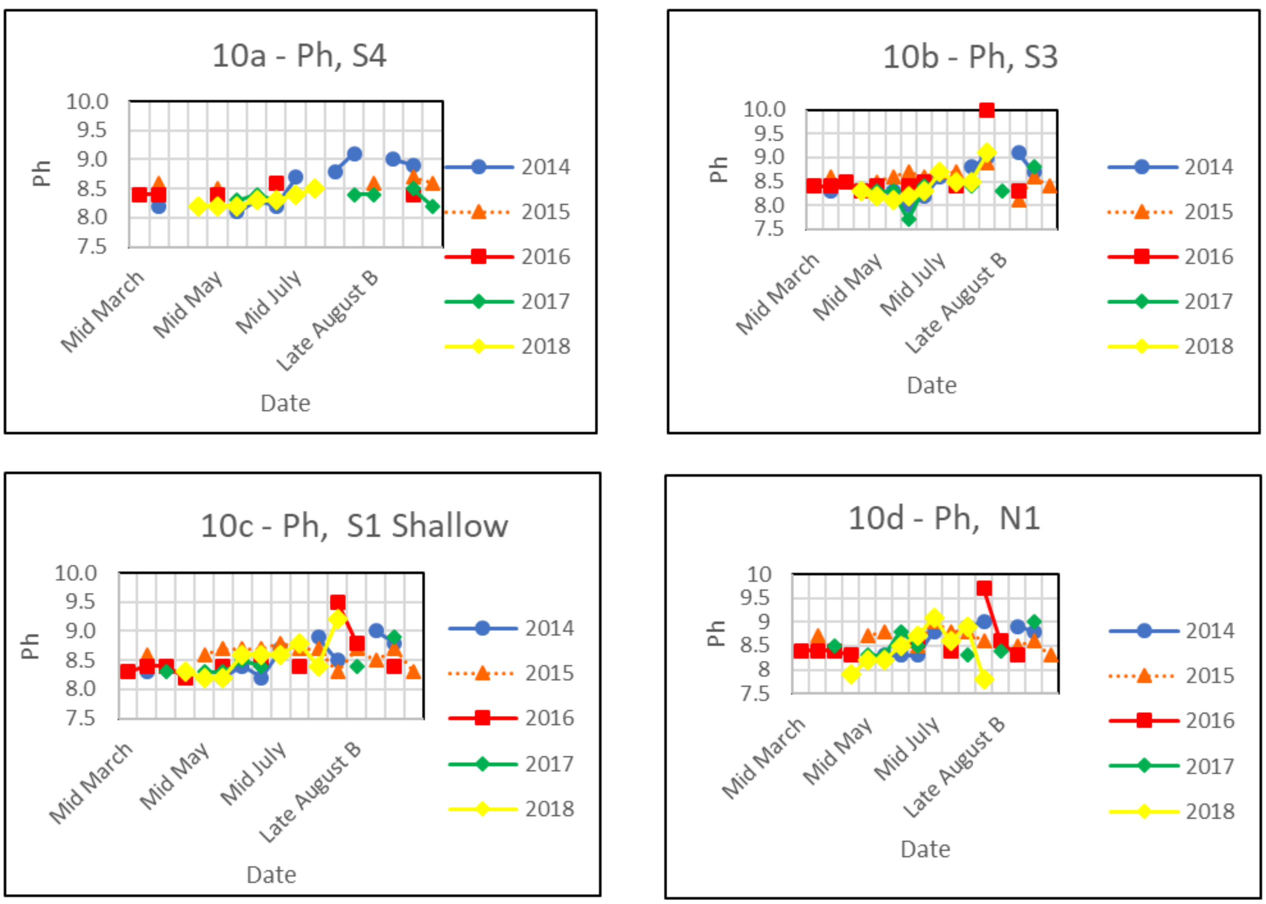


Figure 10 plots the year over year measurements of pH at each of the monitoring locations on the lake. Visually the plots of pH versus the monitoring date for each of the five years suggest that a general increase in pH is observed between April and September. A trend analysis has not been undertaken to confirm this visual observation numerically. This trend for increases in pH during the year is most evident in the 2014 data. The information available also illustrates several outlying values for pH that have not been adjusted as erroneous measurements.

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 less than 6.5 and greater the 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.

Table 4 summarizes the expected pH value on the lake based upon the range in pH values collected over the past five years. This estimate suggests that most of the lake will stay within the range of values considered acceptable by the Canadian Council of Ministers of the Environment. However, the reliability of the early season and late season pH values needs to be improved with the collection of additional monitoring information. Reliability is a concern for those locations where only one or two monitoring events was included in the calculated for the expected concentrations.

Table 4 - Expected Maximum and Minimum pH Value by Location and Month

Location on the Lake

month	N1 Number of sampling events	N1 expected maximum value	N1 expected minimum value	S1 Number of sampling events	S1 expected maximum value	S1 expected minimum value	S3 Number of sampling events	S3 expected maximum value	S3 expected minimum value	S4 Number of sampling events	S4 expected maximum value	S4 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	8.5	8	2	8.3	8.3	1	--	--
mid May	2	9.43	7.65	1	--	--	3	8.7	8.1	2	8.7	8.2
end of May	4	9.33	7.6	4	9	7.8	4	8.9	7.7	2	8.6	7.8
mid June	4	9.32	77.81	4	8.9	8.1	5	9.3	7.1	3	8.9	8
end of June	5	11.2	6.45	3	9.2	7.7	5	8.9	7.9	2	8.5	8
mid July	3	9.32	8.48	3	8.9	8.6	2	8.9	8.4	1	--	--
end of July	4	9.49	7.9	5	9.3	7.9	4	8.9	8.1	1	--	--
mid August	5	10.71	6.88	5	10.1	7.2	5	10.9	6.9	2	9.4	7.8
end of August	5	9.8	7.19	3	9.7	7.8	4	10.1	7.1	3	9.8	7.6
mid September	1	--	--	2	9.5	8.2	1	--	--	1	--	--
end of September	4	9.57	7.78	2	9.1	8.6	3	9	8.4	3	9.5	7.6
October	1	--	--	2	9	7.9	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

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 2018 at the four monitoring locations along the lake. This graph illustrates that except for location N1, the dissolved oxygen concentrations were always greater than 6 mg/L and should support aquatic invertebrates. The maximum dissolved oxygen concentration of about 13 mg/L was measured at S4 in middle of June when the lake water was still relatively cool. The concentrations of dissolved oxygen in the lake increase from early April when the ice has first melted and is understood to be a consequence of both the contribution due to rainfall and snow melt to the lake and a by-product of photosynthetic processes that occur beneath the ice over the winter months. The dissolved oxygen concentrations decline after mid-June as the lake water becomes warmer. At N1, however a noticeable decline in dissolved oxygen concentrations were measured in late August and early September.

Figure 11 – Dissolved Oxygen, 2018

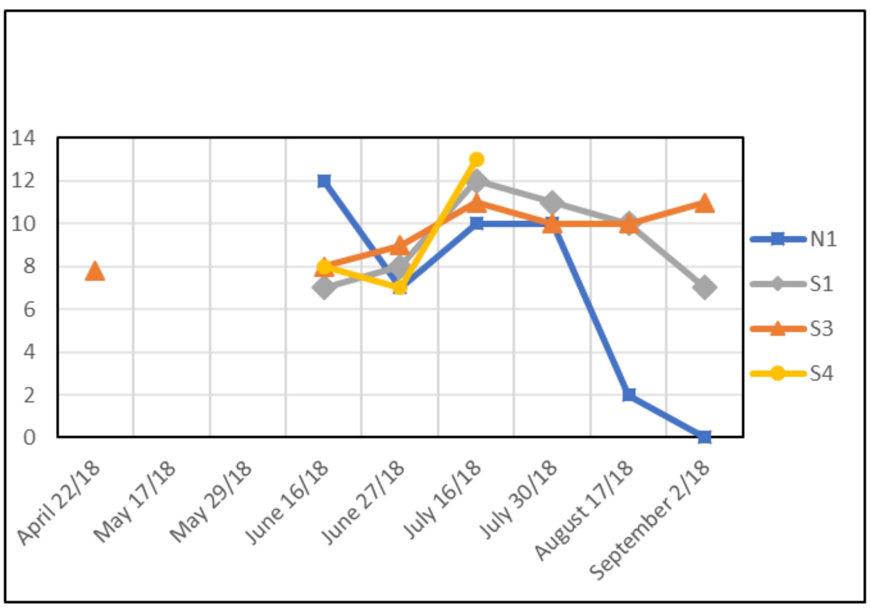
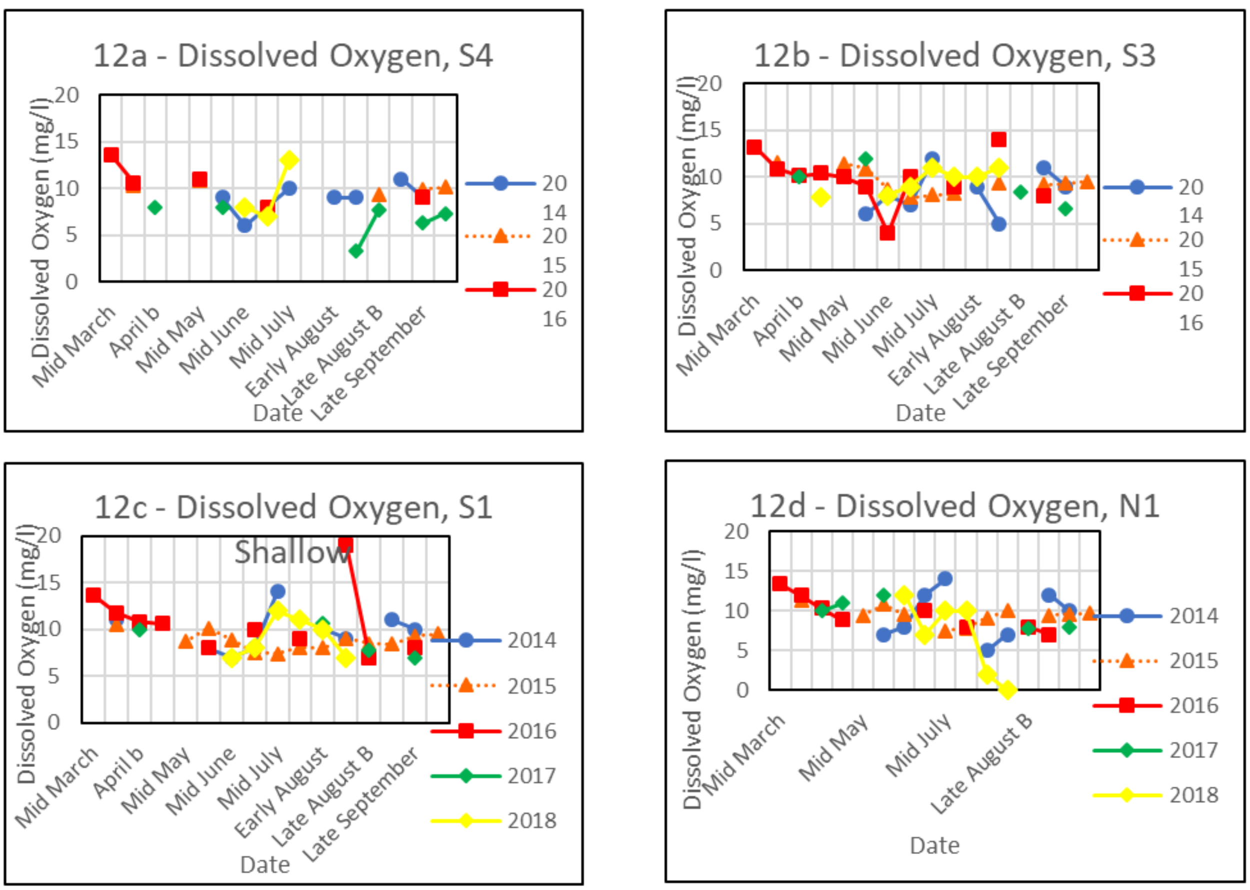


Figure 12 compares the year over year dissolved oxygen concentrations at each monitoring location on the lake. These graphs all show a similar pattern in the dissolved oxygen concentration: greater concentration in the spring as the lake water is cold, declining concentrations through the summer as the lake warms up and then a slight rise in early September to October as the lake water cools with the decline in air temperature during the autumn. These graphs also suggest that exception for N1, there is no difference in oxygen concentration with the location on the lake.

Figure 12 – Dissolved Oxygen, Year to Year Comparison



The water quality management objectives for Lake Windermere suggest that the minimum concentration for dissolved oxygen in the lake water should be 5 mg/L. Although the plots on Figure 13 suggest that from time to time the lake water contains less than 5mg/L, this condition is not sustained over an extended period. However, at N1 there may be insufficient dissolved oxygen to support over wintering of aquatic life. Early season monitoring of N1 will help to determine whether the dissolved oxygen concentrations increase due to photosynthetic processes over the winter months.

Table 5 presents the expected maximum and minimum dissolved oxygen predicted for the lake from the prior year's monitoring results. These predictions however are less reliable because the spread of the information yielded some negative values which have been corrected hear to be 0. Also, the dissolved oxygen measurements were made with both field titrations and direct measurement and thus cannot be reliably compared.

Table5 - Expected Maximum and Minimum Dissolved Oxygen Concentration by Location and Month

	Location on the Lake											
	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	13.5	8.2	1	-	-	4	12.9	8.4	2	11.1	9.8
end of April	1	-	-	4	12.7	9.4	2	14.6	3.6	1	-	-
mid May	1	-	-	1	-	-	1	-	-	2	11.2	10.7
end of May	3	17.7	2.1	4	12.3	5.1	4	17.4	1.6	2	10.6	6.4
mid June	3	11.9	5.56	3	13.2	4.1	4	13.6	0.7	2	11.2	2.8
end of June	1	-	-	2	8.8	6.7	4	12.4	4.5	1	-	-
mid July	1	-	-	3	-	-	2	18.3	1.8	1	-	-
end of July	4	11.9	1.9	5	13.3	6.2	4	12	6.7	1	-	-
mid August	3	11.1	5.8	3	-	-	5	16.9	3.4	1	-	-
end of August	5	10	8	3	10.9	4.8	4	15.9	0.7	3	11.3	6
mid September	1	-	-	2	13.8	6.5	1	-	-	1	-	-
end of September	4	12.9	4.4	2	14.9	2.1	3	12.7	3.9	4	12.5	5.5
October	1	-	-	1	-	-	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

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

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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 present in concentrations too large to be assimilated into organisms can lead to oxygen consumption and eutrophication of lake waters. Nitrate is also an important component of runoff from agricultural lands and waste water 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 2018.

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 analysis conducted to date does 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 in the lake water in 2018. During the mid-summer monitoring event of 2018, the maximum concentration for phosphorous occurred at monitoring station N1 in the northern part of the lake. At all locations on the lake, phosphorous concentrations increase during the late spring and early summer events of 2018. We understand this to be due to the increased in photosynthetic processes as the lake water warms. The total phosphorous concentrations decline into the autumn monitoring events. During most of these autumn monitoring events, the maximum total phosphorous concentrations were measured in the southern end of the lake (monitoring stations S3 and S4). Because these stations are closest to the marshy area at the south end of the lake and where the lake is shallow, we suspect that the greater total phosphorous concentrations in this area of the lake are due to the proximity to the marsh and an increase in the suspended organic material in the water. We note that this end of the lake also had greater concentrations of turbidity than the other locations on the lake during 2018.

Figure 13 – Total Phosphorous, 2018

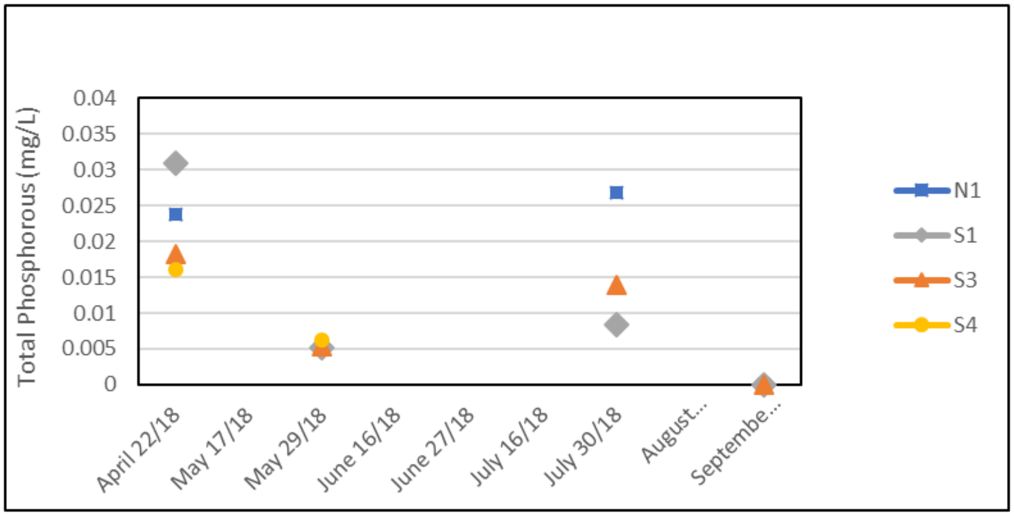


Table 6 summarizes the maximum and minimum concentrations for total and dissolved phosphorous concentrations calculated from from the range of information collected over the past five years. Collection of phosphorous concentrations was not done as frequently nor by month as frequently as the other parameters and consequently only the range measured at each location has been calculated.

Table 6 - Expected Maximum and Minimum 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 monitoring events	19	6	20	11	21	4	14	4
expected maximum concentation (mg/L)	0.032	0.012	0.027	0.011	0.026	0.023	1.71	0.02
expected minimum concentration (mg?L)	<0.002	<0.002	<0.002	<0.0002	<0.002	<0.002	<0.002	<0.002

Figure 14 plots the ratio of dissolved phosphorous to total phosphorous measured at each monitoring location. The plot illustrates that during the early part of the year the concentration of dissolved phosphorous was less than the amount of total phosphorous. In the later part of the year the ratio increased to about 1, meaning that nearly all the measured phosphorous concentration was dissolved in the water. This concentration of dissolved phosphorous suggests that at this time of year the primary source of phosphate needed by aquatic organisms to thrive has been reached and abundant plant growth may be observed.

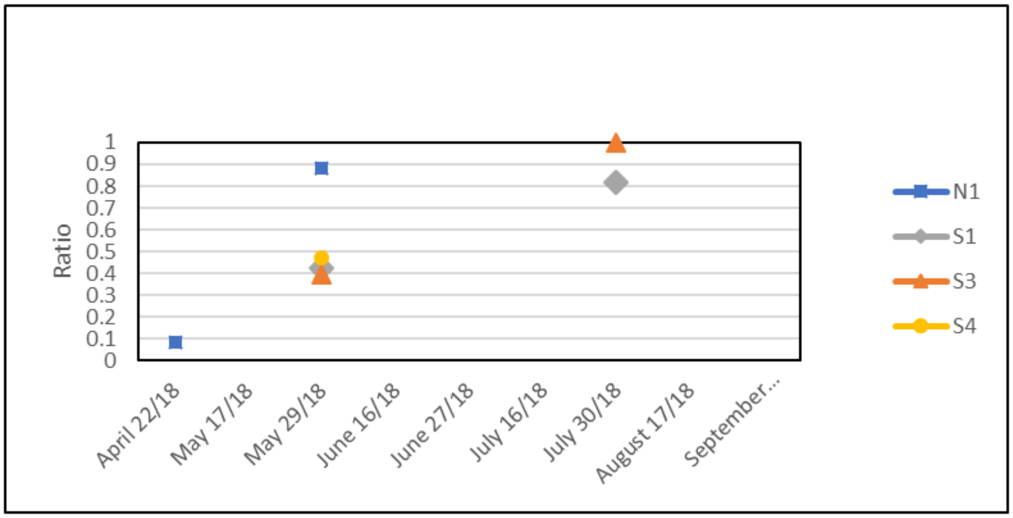
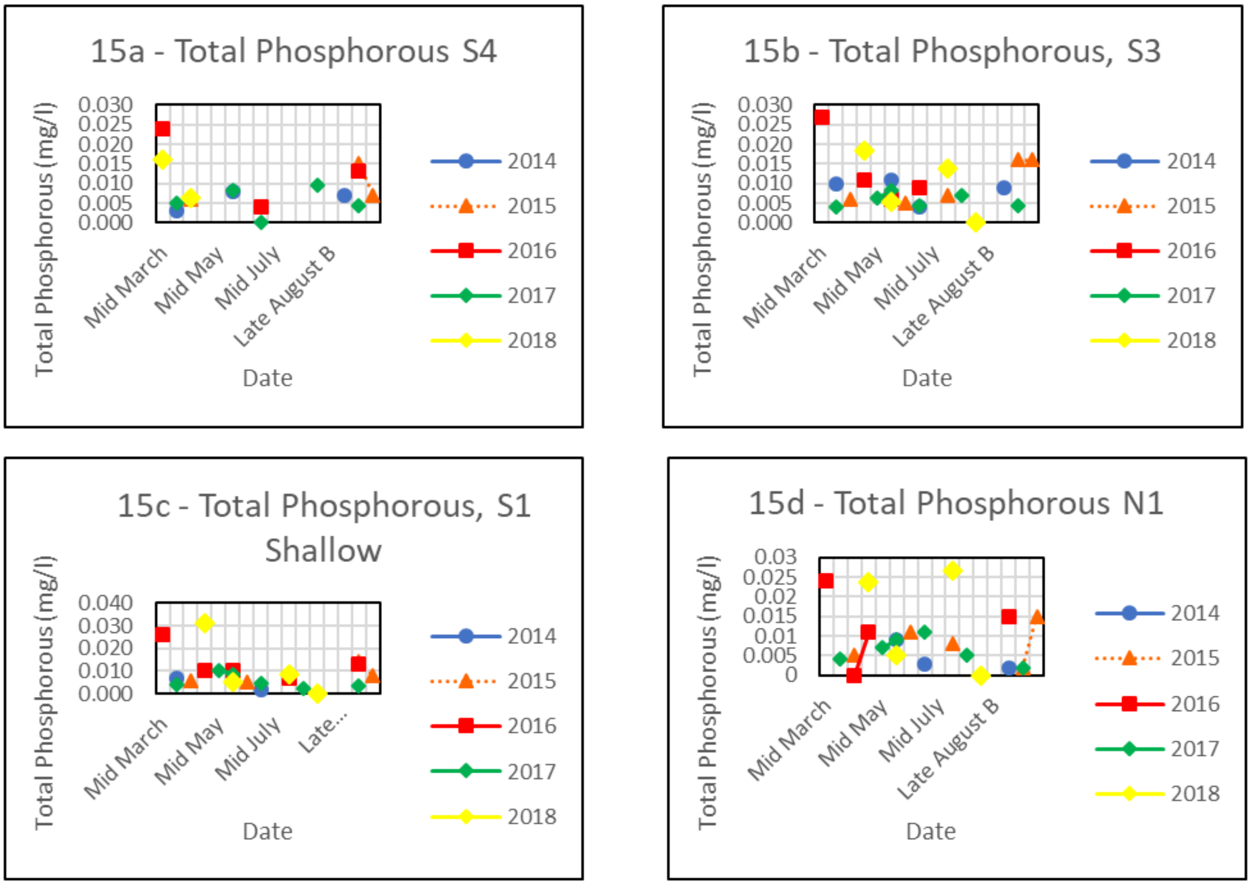


Figure 14- Ratio of Dissolved to Total Phosphorous, 2018

Figure 15 compares the year to year differences in total phosphorous concentrations with location on the lake. These graphs illustrate that during 2015 and 2016 and except for some measurements when samples were not collected and, at all monitoring locations the peak total phosphorous concentration occurred in the later portion of the year. This increase is believed to be due to an increase in particulate organic material in the later portions of the year. In contrast during 2014, 2017 and 218 the total phosphorous concentrations declined during the later portion of the years. Missing information prevents any speculation on the cause of these year to year changes.

Figure 15 – Total Phosphorous, Year to Year Comparison



The occurrence of the peak total phosphorous concentration in the lake water is important because it helps to define when the lake is most biologically active and thus is healthiest, more robust and able to adapt to changes in recreational use or climate changes more effectively.

During the monitoring program in 2016, the peak total phosphorous concentration was measured just after the ice came off the lake; a monitoring event that occurred much earlier in 2016 (mid -March) than in the other years. (The first monitoring events of 2017 and 2018 took place some weeks after the lake was ice free.) We understand that particulate organic matter will be caught in the lake ice as it freezes. Further, as the lake's ice cover thaws, this particulate material becomes suspended in the water column and therefore is the cause of the greater total phosphorous concentration measured on March 20, 2016. As described in Section 2.2, the concentration of dissolved oxygen just below the ice suggests an active phytoplankton community over the winter months, (dissolved oxygen is a by-product of photosynthetic reactions) and that this particulate organic material contributes to the greater total phosphorous concentration measured in 2016.

Within Lake Windermere's management plan, an objective for phosphorous (understood to be total phosphorous) was set as 0.01 mg/L. During 2018 this concentration was exceeded at all four monitoring locations during monitoring events in early May and in the late July monitoring event at N1. Exceedances of the water quality objective might be a rationale to conclude that activity on the lake has caused a concern for the lake's water quality. However, the concentrations measured in early March of 2016 when the lake was just ice-free do not support this conclusion. Because phosphorous is generally in short supply in freshwater systems and is such an essential element for a healthy aquatic system, we need to confirm the early in the year total phosphorous concentration and establish a water quality objective for phosphorous unique to Columbia Lake.

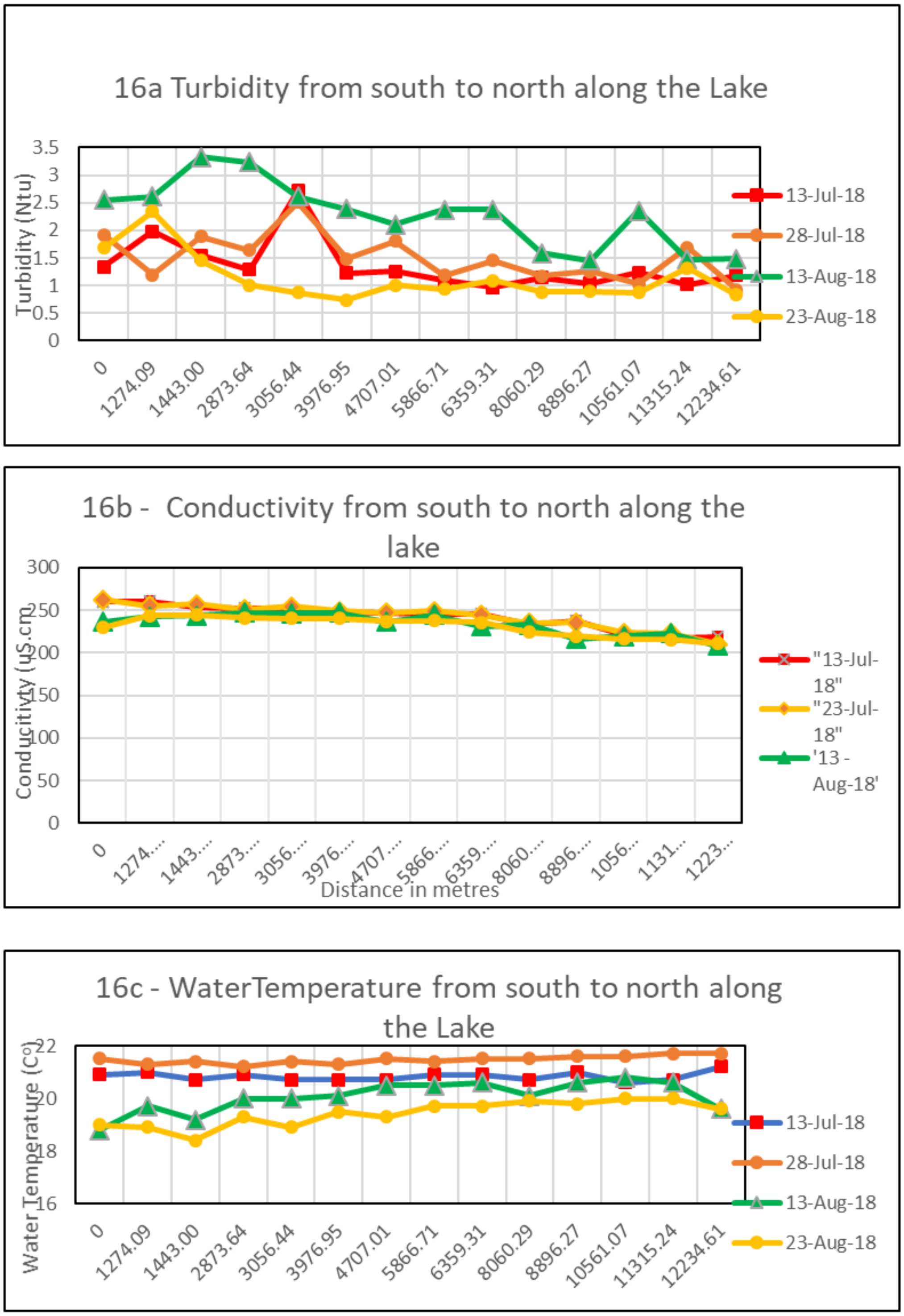
3.2 Distribution of Turbidity and Conductivity

To assess the distribution of turbidity and conductivity concentrations from south to north along the lake, a special survey was conducted on July 13, July 28, August 13 and August 22, 2019 at the fourteen locations plotted on Figure 2. During each survey date each of the fourteen locations was located using GPS with each subsequent monitoring location found to within 20 metres of the original location.

Turbidity is a measure of the "cloudiness" of the lake water created by suspended materials such as organic debris and sediment. Conductivity is a measure of the dissolved solids the lake water and is created by contact of the lake water with the suspended material or brought into the lake by surface water inflow or groundwater discharge. Both turbidity and conductivity are routinely used as indicators of changes in water quality.

The information collected during the survey temperature, turbidity and conductivity are tabulated in Appendix D. Turbidity, and conductivity concentrations and the lake water temperature for the four monitoring dates are plotted on may Figures 16a, 16b, and 16c respectively.

Figure 16 – Distribution of Turbidity and Conductivity



The plotted information shows similar trends: the concentration of both turbidity and conductivity are greatest in the south end of the lake and lowest at the north end of the lake. Turbidity shows a greater variability along the lake (from left to right on the plots) than does conductivity. The variability may be due to differences in the intensity of recreational activity along the lake. The greater concentration at the south end of the lake is consistent with Gillmor's finding of the potential contribution by groundwater to the lake along the southern shoreline.

Along the lake the decline in conductivity is relatively constant (as shown by the information plotted for conductivity on Figure 16a and b during the early part of the summer. This decline in concentration is consistent with a steady state of dilution by rainfall falling directly on the lake's surface or by the inflow of streams. However, the decline may not be due to enhanced evaporation from the lake's surface in this shallow southern area because it occurs consistently from north to south.

The effects of evaporation from the lake's surface are noticeable for August 13 and 22, 2018 On these plots the concentration of both turbidity and conductivity increase from the southernmost monitoring location to the more northern monitoring locations before declining across the areas where the lake is deepest (approximately 5000 m from the south end of the lake) and across the areas where larger stream flows to the lake are observed. The timing of this evaporation effect is consistent with the records of temperature that illustrate the greatest lake surface temperatures and thus the greatest potential evaporation from the lake's surface occurs in late July.

The decline in the concentrations of turbidity and conductivity in the northern part of the lake is unlikely to be due to the inflow from Dutch Creek. At this time of year (late July through August) measurements of the inflow from Dutch Creek demonstrate are at a seasonal low and is exceeded by drainage from the lake by the Columbia River. This August period is when the lake is at its lowest level of the year. Clearly the lake is losing water and not gaining enough water to dilute the turbidity and conductivity concentrations. Further it is unrealistic to expect that the Dutch Creek inflow is sufficient to cause a decline in concentration that extends along the entire ten-kilometer length of the lake. However Dutch Creek inflow is understood to support the rise in lake levels over the autumn, winter and spring.

We infer from the findings of this survey that the contribution from sources other than direct rainfall and inflow from Dutch Creek must cause the decline in concentrations of turbidity and conductivity. Those sources include the inflow from small streams along the lake and groundwater discharge to the lake. The chemical quality of these sources has not been evaluated as part of the baseline water quality information collected to date.

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 provided to CLSS by BCMOE. 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 and 2018. BCMOE also provided CLSS with bi-annual monitoring results from Premier Lake and White Swan Lake for 2018 only: 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 2 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 noticeable different (a factor of two or more) from the concentrations measured in 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. Yellow represents values that are within the range of concentrations measured on Columbia Lake. 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. 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 in both Lake Windermere and Moyie Lake are less than those measured in Columbia Lake during the late summer monitoring events. Lower dissolved oxygen levels represent a potential threat to aquatic life and are likely due to higher water temperatures.

Turbidity in both Lake Windermere and Moyie Lake is 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 minimize the disturbance of shallow sediments due to recreational activities. Consequently, it may be considered that the turbidity values reflect the shallowness of Columbia Lake and from season to season may vary.

Dissolved sulphate, barium, strontium and zinc are measured in the waters of Lake Windermere, Columbia Lake 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. area. 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. Columbia Lake is upstream of Lake Windermere. Therefore, 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.

Chloride bearing minerals are not found close to the ground surface throughout most of western Canada. Exceptions may be outcrops of marine sedimentary rocks that occur from place to place on the Canadian Prairies. However, none of those outcroppings exist near Columbia Lake. Therefore, it is unusual to find exceptional concentrations of chloride in natural water systems. 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. As measured in 2017 the chloride concentration in the water of Columbia Lake (4mg/L) has decreased over that measured in 2015 and 2016 (6mg/L), this trend did not continue in the 2018 monitoring results. Additional monitoring of chloride concentration by BCMOE will aid in determining future trends in chloride concentrations.

Of the metals, iron, lead, manganese, and lithium concentrations measured in both Columbia Lake and Lake Windermere yield noticeably greater concentrations than the other three 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).

Table 7 - Water Quality Comparision with Nearby Lakes

Parameter	RDL[*]	Units	Lake Windermere[1] shallow spring	Lake Windermere[1] shallow late summer	White Swan Lake[2] spring	White Swan Lake[2] late summer	Premiere Lake[2] spring	Premiere Lake[2] late summer	Moyle Lake[1] south spring	Moyle Lake[1] south late summer	Columbia Lake[1] shallow spring	Columbia Lake[1] shallow late summer
Field measurements												
Conductivity	-	uS/cm	389.3-404.2	256-268.9	249.6		338.5		48.3-58.2	49.6-52.2	301.3-339.3	290.9-293
Dissolved Oxygen	-	mg/L	9.18-11.6	7.44-7.99	10.71		10.11		10.54-12.05	7.61-8.43	9.37-10.72	8.23-9.18
Turbidity		NTU	0.57-1.04	0.67-0.75	0.23		0.27		0.64-1.63		0.74-0.93	
Anions												
Dissolved Sulphate (SO4)	0.5	mg/L	70.8-71.1	28.4-32.3	3.8	19.5	25.4	25.8	1.65-2.36	1.74-2.01	27.1-29.7	22.4-25.3
Dissolved Chloride (Cl)	0.5	mg/L	2.9-3.15	1.45-1.68	2.83	2.5	<0.5	<0.5	1.21-1.5	0.99-1.14	5.01-6.44	4.38-5.92
Calculated parameters												
Hardness	0.5	mg/L	201-224	148-153	145	138	179	176	22.7-27.2	20.3-23.1	169-193	150-153
Nutrients												
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L	0.122-1.83	0.139-0.228	0.07	0.1	0.219	0.227	0.089-0.185	0.094-0.121	0.164-0.23	0.226-0.255
Total metals by ICPMS												
Aluminium (Al)	0.5	ug/L	1.29-4.33	1.56-4.09	2.37		3		28.3-59.8		4.02-13.5	
Barium (Ba)	0.02	ug/L	66.8-86.1	66.8-67.2	94.0		94.7		6.57-8.66		71-85.7	
Iron (Fe)	1	ug/L	17-43.7	8.7-11.6	2.70		<1.0		36.6-61.3		14.5-18.8	
Lead (Pb)	0.005	ug/L	0.0192-0.0589	0.025-0.036	0.0085		<0.005		1.17-1.96		0.0384-0.0485	
Lithium (Li)	0.5	ug/L	3.43-3.62	1.91-2.13	1.250		2.7		<0.5		2.85-3.4	
Manganese (Mn)	0.05	ug/L	5.1-29	26-29	1.320		1.6		2.98-4.91		6.25-12.6	
Strontium	0.05	ug/L	292-373	138-143	108		164		15.3-17.9		195-217	
Zinc (Zn)	0.1	ug/L	0.21-3.02	1.09-1.42	0.63		0.460		7.95-13.8		0.47-1.31	

Notes
1 concenrations or measured values the same as Columbia Lake
2 conentrations or measured values are less than Columbia Lake
3 Concentrations or meaured values greater than Columbia Lake

5.0 Summary of Findings

The key findings from the 2018 water quality monitoring program by CLSS are:

1. Overall the lake's water quality has not changed within the five years of monitoring and remains suitable for a variety of intended uses (recreational, potable water and aquatic habitat).

2. Using the past five years of monitoring results for the indicator parameters on the lake, CLSS has established a water quality baseline. The baseline uses calculated Control Limits (expressed as maximum and minimum concentrations or measured values) that can help to determine whether the lake's water quality has noticeably changed in the future. Although a water quality baseline has been established, additional monthly monitoring is required at all locations on the lake for the middle of May, the middle of July and the middle of September because these dates were only monitored on one or two occasions over the past five years. Also, additional monitoring results are required for the south end of the lake (S4) because in the summer months this location could not be safely accessed by motor boats and needs additional information to define an adequate baseline at S4.

3. Turbidity measurements at the north and south ends of the lake exceeded the guidelines established by the Lake Windermere Objectives on several occasions. The greater concentrations of turbidity in these areas may be due to a greater intensity of recreational use. However, the concentrations are not steadily increasing and are therefore considered to be only a temporary occurrence. We are concerned about turbidity because the material that causes the turbidity (sediments and organic debris) can limit the suitability of the lake water for drinking water and aquatic habitat.

4. Low concentrations (below detectable limits) of dissolved oxygen were measured in the late part of the 2018 season at the north end of the lake. The levels measured will not support aquatic life in these areas. It should be expected that dissolved oxygen concentrations will increase over the winter months and as more aquatic activity increases in the later fall (when the water is cooler) and early spring.

5. A special survey of the turbidity and conductivity concentrations along the lake was conducted over the summer months. The survey demonstrates that the concentrations decline from the south end to the north end of the lake. This finding is consistent with groundwater discharge along the south shoreline of the lake and sourced from the Kootenay River as described by Gillmor (2018). The chemical quality of this groundwater contribution to the lake is not known.
Along the lake the decline in concentration to the north suggests that other sources of water contribute to the dilution of the lake water. Whether this source is direct rainfall, surface water inflow or groundwater discharge is not known.

6. Compared to other nearby lakes as tested by BCMOE, Columbia Lake water contains greater concentrations of chloride. There are no natural sources of chloride within soil and rock types surrounding the lake.

6.0 Continuous Improvements

1. Water Quality Objectives

It is important that water quality objectives specific to Columbia Lake are established. We understand that BCMOE is considering revising the lake management plan for Columbia Lake as prepared in 1997. The timing of that revision/update is not known to CLSS. Water quality objectives for Columbia Lake should be included in the revision.

2. Monitoring Frequency

The regular monitoring program applied in prior years consisted of as many as fourteen monitoring events beginning from the ice-free period (end of March until the middle of October). With the establishment of Water Quality Control Limits, it will be possible to reduce the frequency of sampling during the late spring and summer. We will monitor in early June, mid-July and early August to confirm the water quality is still within the baseline conditions. This change will reduce the monitoring program by more than one half its previous level of effort.

3. Data Gaps

Although we attempted to gather samples from the beginning to the end of the ice-free period, most of the volunteers do not get their boats into the water until the May long weekend and removed their boats by the end of September. Therefore, the baseline for the water quality indicator parameters needs additional information for mid-May, and mid-September. We will gather samples at these times using small craft. Since safety is our first concern, it may take multiple years to attain enough samples due to potentially difficult weather conditions.
Also, bi-weekly monitoring will be conducted at the south end of the lake (S4) in the summer months by small craft because this location could not be safely accessed by motor boats and needs additional information to define an adequate baseline at S4.

4. Groundwater and Surface Water Contributions to the Lake

Several of the findings described in Section 5 suggest that from south to north along the lake dilution of the lake water is occurring. Whether dilution is occurring due to direct rainfall on the lake surface, or due to the inflow of surface water from the several small steams along the lake shore or due to the discharge of groundwater to the lake has not been confirmed.
To improve our understanding of the baseline conditions on the lake and our objective to ensure that the lakes water quality is protected, CLSS intends to re-direct some of the resources previously used to conduct the lake sampling program to monitor small streams along the lake and to conduct a more thorough assessment of water quality in the south end of the lake.
This work will involve:

- monthly measurements of water flow rates and indicator parameters at the three to four small streams along the lake from the first of May to the end of September; and
- analysis for the indicator parameters and sulphate and chloride concentrations at four to five locations across the south end of the lake.

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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

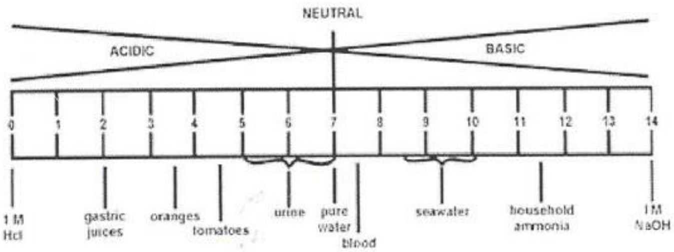
Turbidity is a measure of water clarity or more simply, how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. These materials are typically in the size 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, Premiere Lake and White Swan Lake

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

Parameter	RDL*	Units	Location on the lake	Columbia lake midlake north							
				Surface (1 m)							
			Date sampled	15-Apr-15	26-Aug-15	7-Apr-16	24-Aug-16	25-Apr-17	29-Aug-17	16-May-18	4-Sep-18
Chlorophyll a	0.5	mg/L		0.91	1.46	1.33	1.39	1.85	0.856	1.03	1.14
Chlorophyll a rep	0.5	mg/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	
Dissolved Oxygen	-	mg/L		10.72	8.27	10.75	8.23	10.49	9.18	9.37	
Secchi (H20 clarity)	-	m		4.5	3.6	4.5	3.6	3.18	4.4	3.9	
pH	-	pH		8.27			8.4			8.36	
Temperature	-	^0C		7.8	18.6	9.86	18.9	10.1	20.3	19.2	
Turbidity		NTU				0.74		0.93			
Anions											
Silica	0.5	mg/L		4.91	7.69	5.97	7.13	4.76	7.83	6.18	6.99
Orthophosphate (p)	0.001	mg/L		0.0012	<0.001	0.0015	<0.001	<0.001	<0.001	0.0016	0.0016
Dissolved Sulphate (SO4)	0.5	mg/L		27.6	22.4	29.7	25.3	29	23.1	27.1	22.9
Dissolved Chloride (Cl)	0.5	mg/L		6.1	5.47	6.44	5.92	5.88	4.78	5.01	4.38
Calculated parameters											
Hardness	0.5	mg/L		169	151	193	150	182	151		153
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
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
Dissolved Phosphorous (P)	0.002	mg/L		0.0058	0.003	0.002	0.002	0.002	0.0021	0.002	0.0029
Nitrate plus nitrite (n)	0.002	mg/L		<0.002	0.002	0.0032	0.0032	0.0032	<0.0032	<0.0032	<0.003
Total Nitrogen (N)	0.02	mg/L		0.23	0.227	0.169	0.226	0.187	0.312	0.164	0.255
Total Phosphorous (P)	0.002	mg/L		0.0183	0.0043	0.0031	0.0039	0.004	0.0058	0.002	0.0064
Total metals by ICPMS											
Aluminium (Al)	0.5	ug/L		6.18		4.23		4.02		13.500	
Antimony (Sb)	0.02	ug/L		0.073		0.065		0.071		0.085	
Arsenic (As)	0.02	ug/L		0.644		0.0663		0.696		0.767	
Barium (Ba)	0.02	ug/L		74.3		76.5		85.7		71.0	
Beryllium (Be)	0.01	ug/L		<0.01		<0.01		<0.01		<0.02	
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005		<0.005		<0.001	
Boron (B)	10	ug/L		<10		<10		<10		5.500	
Cadmium (Cd)	0.005	ug/L		<0.005		<0.005		<0.005		<0.0050	
Chromium (Cr)	0.1	ug/L		<0.01		<0.1		<0.1		<0.0050	
Cobalt (Co)	0.005	ug/L		0.027		0.0293		0.0373		0.029	
Copper (Cu)	0.05	ug/L		0.259		0.135		0.182		0.423	
Iron (Fe)	1	ug/L		18.8		14.5		13.7		16.400	
Lead (Pb)	0.005	ug/L		0.0481		0.0384		0.0485		0.041	
Lithium (Li)	0.5	ug/L		3.07		3.37		3.4		2.850	
Manganese (Mn)	0.05	ug/L		6.25		9.21		10.3		12.600	
Molybdenum (Mo)	0.05	ug/L		0.514		0.532		0.54		0.614	
Nickel (Ni)	0.02	ug/L		0.138		0.069		0.05		0.126	
Selenium (Se)	0.04	ug/L		<0.04		0.041		<0.04		0.059	
Silver (Ag)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005	
Strontium (Sr)	0.05	ug/L		217		215		202		195.000	
Thallium (Tl)	0.002	ug/L		<0.002		<0.002		0.0025		0.002	
Tin (Sn)	0.2	ug/L		<0.2		<0.01		<0.01		<0.01	
Uranium (U)	0.002	ug/L		1		0.933		1.02		1.060	
Vanadium (V)	0.2	ug/L		<0.2		<0.2		<0.2		0.087	
Zinc (Zn)	0.1	ug/L		0.47		0.55		0.509		1.310	
Calcium (Ca)	0.05	mg/L		34.2	26.2	38.8	26.9	37.9	28.6	40.4	25.3
Magnesium (Mg)	0.05	mg/L		20.4	20.7	23.3	20.1	21.3	19.4	19.8	21.8
Potassium (K)	0.05	mg/L				0.84		0.8		0.834	
Sodium (Na)	0.05	mg/L				6.79		6.71		5.58	

RDL reportabel detection limit

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

Parameter	RDL*	Units	Location on the lake	Columbia lake midlake north							
				Bottom (3M)							
			Date sampled	15-Apr-15	26-Aug-15	7-Apr-16	24-Aug-16	4-Apr-17	29-Aug-17	16-May-18	4-Sep-18
Chlorophyll a	0.5	mg/L		-	-	-	-	-			
Chlorophyll a rep	0.5	mg/L		-	-	-	-	-			
Field measurements											
Conductivity	-	uS/cm		-	-	-	-	301.2			
Dissolved Oxygen	-	mg/L		-	-	-	-	-			
Secchi (H20 clarity)	-	m		-	-	-	-	-			
pH	-	pH		-	-	-	-	-			
Temperature	-	^{0}C		-	-	-	-	-			
Turbidity		NTU						0.95			
Anions											
Silica	0.5	mg/L		4.97	8.09	5.66	7.37	4.71	7.42	4.79	7.46
Orthophosphate (p)	0.001	mg/L		<0.001	0.006	0.0012	<0.001	<0.001	<0.001	0.0013	0.0013
Dissolved Sulphate (SO4)	0.5	mg/L		27.6	23	29.7	25	29	23.2	25.5	22.9
Dissolved Chloride (Cl)	0.5	mg/L		6.1	5.6	6.43	5.89	5.89	4.78	4.62	4.39
Calculated parameters											
Hardness	0.5	mg/L		167	151	183	149	175	148	161	148
Misc. Organics											
Total Organic Cargon	0.5	mg/L		2.15	2.77	2.27	3.35	2.12	2.65	2.28	2.67
Nutrients											
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.225	0.223	0.193	0.237	0.178	0.224	0.157	0.239
Dissolved Phosphorous (P)	0.002	mg/L		0.0165	0.0065	<0.002	<0.002	<0.002	<0.002	0.0037	0.0031
Nitrate plus nitrite (n)	0.002	mg/L		<0.002	<0.0032	<0.0032	<0.0032	<0.0032	<0.0032	<0.003	<0.003
Total Nitrogen (N)	0.02	mg/L		0.225	0.223	0.193	0.237	0.178	0.224	0.157	0.239
Total Phosphorous (P)	0.002	mg/L		0.0175	0.0061	0.0038	0.0036	0.0066	0.0033	0.0049	0.0077
Total metals by ICPMS											
Aluminium (Al)	0.5	ug/L		7.08				3.13			
Antimony (Sb)	0.02	ug/L		0.068				0.072			
Arsenic (As)	0.02	ug/L		0.705				0.654			
Barium (Ba)	0.02	ug/L		75.2				81.5			
Beryllium (Be)	0.01	ug/L		<0.01				<0.01			
Bismuth (Bi)	0.005	ug/L		<0.005				<0.005			
Boron (B)	10	ug/L		<10				6.1			
Cadmium (Cd)	0.005	ug/L		<0.005				<0.005			
Chromium (Cr)	0.1	ug/L		<0.01				<0.01			
Cobalt (Co)	0.005	ug/L		0.0311				0.0407			
Copper (Cu)	0.05	ug/L		0.164				0.161			
Iron (Fe)	1	ug/L		18.4				14.4			
Lead (Pb)	0.005	ug/L		0.0514				0.0472			
Lithium (Li)	0.5	ug/L		3.23				3.32			
Manganese (Mn)	0.05	ug/L		6.66				9.87			
Molybdenum (Mo)	0.05	ug/L		0.519				0.583			
Nickel (Ni)	0.02	ug/L		0.104				<0.05			
Selenium (Se)	0.04	ug/L		<0.04				<0.04			
Silver (Ag)	0.005	ug/L		<0.005				<0.005			
Strontium (Sr)	0.05	ug/L		214				198			
Thallium (Tl)	0.002	ug/L		<0.002				0.0029			
Tin (Sn)	0.2	ug/L		<0.02				<0.01			
Uranium (U)	0.002	ug/L		1				1.03			
Vanadium (V)	0.2	ug/L		<0.2				<0.2			
Zinc (Zn)	0.1	ug/L		1.06				2.8			
Calcium (Ca)	0.05	mg/L		33.8	26.2	37.9	26.7	36.8	28.4	32.2	25.0
Magnesium (Mg)	0.05	mg/L		20.1	20.7	21.5	19.9	20.2	18.7	19.5	21.8
Potassium (K)	0.05	mg/L						0.781			
Sodium (Na)	0.05	mg/L						6.51			

*RDL Reportable Detection Limit

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

Parameter	RDL*	Units	Location on the lake	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
Chlorophyll a	0.5	mg/L		0.85	1.83	1.1	1.64	1.14	2.23	1.66	2.07
Chlorophyll a rep	0.5	mg/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	
Dissolved Oxygen	-	mg/L		10.85	7.79	11.6	7.44	10.47	7.99	9.18	
Secchi (H20 clarity)	-	m		5	4.65	5.3	5.3	2.72	4	3.7	
pH	-	pH		-					8.23	7.88	
Temperature	-	^{0}C		8.4	19.3	9.75	19.8	11.6	20	17.7	
Turbidity		NTU				0.57	0.67	1.04	0.75		
Anions											
Silica	0.5	mg/L		4.49	5.84	5.5	5.8	3.84	6.42	3.71	6.4
Orthophosphate (p)	0.001	mg/L		0.0011	0.001	<0.001	<0.001	<0.001	<0.001	0.0015	<0.001
Dissolved Sulphate (SO4)	0.5	mg/L		70.8	28.4	71.7	30.5	71.6	31	71.1	32.3
Dissolved Chloride (Cl)	0.5	mg/L		2.9	1.68	3.15	1.45	2.91	1.57	3.04	1.44
Calculated parameters											
Hardness	0.5	mg/L		201	148	224	149	203	148		153
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
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
Dissolved Phosphorous (P)	0.002	mg/L		0.0033	0.0031	<0.002	<0.002	<0.002	0.0021	0.0038	0.0029
Nitrate plus nitrite (n)	0.002	mg/L		<0.002	<0.0032	<0.0032	<0.0032	<0.0032	<0.0032	<0.003	<0.003
Total Nitrogen (N)	0.02	mg/L		0.183	0.193	0.122	0.139	0.183	0.198	0.16	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
Total metals by ICPMS											
Aluminium (Al)	0.5	ug/L		4.33		1.29	1.56	4.17	3.02	4.09	
Antimony (Sb)	0.02	ug/L		0.049		0.05	0.063	0.061	0.073	0.07	
Arsenic (As)	0.02	ug/L		0.672		0.585	1.06	0.634	1.19	0.80	
Barium (Ba)	0.02	ug/L		77.9		83.9	66.8	83.7	67.2	86.10	
Beryllium (Be)	0.01	ug/L		<0.01		<0.01	<0.01	<0.01	<0.01	<0.002	
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005	<0.005	<0.005	<0.005	<0.001	
Boron (B)	10/1	ug/L		<10		9.2	5.9	8.2	5.7	8.00	
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	<0.05	
Cobalt (Co)	0.005	ug/L		0.015		0.0165	0.0161	0.0344	0.0232	0.0274	
Copper (Cu)	0.05	ug/L		0.172		0.123	0.188	0.147	0.179	0.4030	
Iron (Fe)	1	ug/L		43.7		28.9	8.7	24.6	11.6	17.00	
Lead (Pb)	0.005	ug/L		0.0311		0.0192	0.025	0.0589	0.0346	0.0339	
Lithium (Li)	0.5	ug/L		3.62		3.8	1.91	3.43	2.13	3.63	
Manganese (Mn)	0.05	ug/L		5.1		12.9	29	25.3	26	23.30	
Molybdenum (Mo)	0.05	ug/L		0.581		0.515	0.564	0.598	0.574	0.72	
Nickel (Ni)	0.02	ug/L		0.093		0.058	0.083	0.05	0.139	0.19	
Selenium (Se)	0.04	ug/L		<0.04		0.044	0.044	<0.04	0.047	0.08	
Silver (Ag)	0.005	ug/L		<0.005		<0.005	<0.005	<0.005	<0.005	<0.005	
Strontium (Sr)	0.05	ug/L		373		340	138	297	143	292	
Thallium (Tl)	0.002	ug/L		<0.002		<0.002	<0.002	0.0041	0.0027	0.0013	
Tin (Sn)	0.2/0.01	ug/L		<0.2		<0.01	<0.01	<0.01	<0.01	<0.01	
Uranium (U)	0.002	ug/L		1.18		1.1	0.726	1.24	0.843	1.47	
Vanadium (V)	0.2	ug/L		<0.2		<0.2	<0.2	<0.2	<0.2	0.06	
Zinc (Zn)	0.1	ug/L		0.21		0.26	1.42	3.02	1.09	1.37	
Calcium (Ca)	0.05	mg/L		42.9	33.2	47.7	34.7	45.9	33.9	48.9	
Magnesium (Mg)	0.05	mg/L		22.8	15.9	25.6	15.1	21.5	15.9	24.5	
Potassium (K)	0.05	mg/L				0.964	0.71	0.833	0.709	1.000	
Sodium (Na)	0.05	mg/L				4.81	2.17	4.06	2.37	4.42	

RDL Reportable Detection Limit

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

Parameter	RDL*	Units	Location on the lake	Lake Windermere off Timber Ridge							
				Deep (3metres)							
			Date sampled	15-Apr-15	26-Aug-15	7-Apr-16	24-Aug-16	25-Apr-17	29-Aug-17	16-May-18	4-Sep-18
Chlorophyll a	0.5	mg/L		-	-	-	-	-	-	-	
Chlorophyll a rep	0.5	mg/L		-	-	-	-	-			
Field measurements											
Conductivity	-	uS/cm		-	-	-	-	-	-	-	-
Dissolved Oxygen	-	mg/L		-	-	-	-	-	-	-	-
Secchi (H20 clarity)	-	m		-	-	-	-	-	-	-	-
pH	-	pH		-	-	-	-	-	-	-	-
Temperature	-	^0C		-	-	-	-	-	-	-	-
Turbidity		NTU		-	-	-	0.71	1.39	-	-	-
Anions											
Silica	0.5	mg/L		4.51	6.06	5.18	5.6	3.97	6.91	3.37	6.37
Orthophosphate (p)	0.001	mg/L		<0.001	<0.001	<0.001	<0.001	<0.001	0.001	0.0014	0.0012
Dissolved Sulphate (SO4)	0.5	mg/L		71.6	28.3	71.6	30.5	71.7	30.6	74.3	32.3
Dissolved Chloride (Cl)	0.5	mg/L		2.7	1.68	3.13	1.46	2.9	1.55	3.08	1.44
Calculated parameters											
Hardness	0.5	mg/L		197	141	220	164	206	150	223	157
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
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
Dissolved Phosphorous (P)	0.002	mg/L			0.0029	<0.002	<0.002	<0.002	<0.002	0.0032	0.0025
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
Total Nitrogen (N)	0.02	mg/L		0.16	0.212	0.123	0.174	0.933	0.192	0.152	0.206
Total Phosphorous (P)	0.002	mg/L		0.185	0.0062	0.003	0.0031	0.0053	0.0035	0.0057	0.0075
Total metals by ICPMS											
Aluminium (Al)	0.5	ug/L		3.77			1.44	3.55			
Antimony (Sb)	0.02	ug/L		0.054			0.069	0.059			
Arsenic (As)	0.02	ug/L		0.646			1.23	0.689			
Barium (Ba)	0.02	ug/L		78.5			72.8	80.2			
Beryllium (Be)	0.01	ug/L		<0.01			<0.01	<0.01			
Bismuth (Bi)	0.005	ug/L		<0.005			<0.005	<0.005			
Boron (B)	10/1	ug/L		<10			5.6	8.2			
Cadmium (Cd)	0.005	ug/L		<0.005			<0.005	<0.005			
Chromium (Cr)	0.1	ug/L		<0.1			<0.1	<0.1			
Cobalt (Co)	0.005	ug/L		0.014			0.0167	0.0375			
Copper (Cu)	0.05	ug/L		0.158			0.148	0.165			
Iron (Fe)	1	ug/L		43.9			10.4	27.1			
Lead (Pb)	0.005	ug/L		0.0237			0.0138	0.0742			
Lithium (Li)	0.5	ug/L		3.69			1.9	3.36			
Manganese (Mn)	0.05	ug/L		5.17			43.5	30.3			
Molybdenum (Mo)	0.05	ug/L		0.603			0.495	0.563			
Nickel (Ni)	0.02	ug/L		0.093			0.104	0.068			
Selenium (Se)	0.04	ug/L		<0.04			<0.04	0.052			
Silver (Ag)	0.005	ug/L		<0.005			<0.005	<0.005			
Strontium (Sr)	0.05	ug/L		353			139	281			
Thallium (Tl)	0.002	ug/L		<0.002			0.002	0.0044			
Tin (Sn)	0.2/0.01	ug/L		<0.2			<0.01	<0.01			
Uranium (U)	0.002	ug/L		1.19			0.711	1.27			
Vanadium (V)	0.2	ug/L		<0.2			<0.2	<0.2			
Zinc (Zn)	0.1	ug/L		0.22			0.43	3.32			
Calcium (Ca)	0.05	mg/L		43	31.8	48.9	37.1	46.6	33.9	48.9	33.5
Magnesium (Mg)	0.05	mg/L		21.7	14.9	23.7	17.3	21.7	15.9	24.5	17.7
Potassium (K)	0.05	mg/L					0.841	0.884			
Sodium (Na)	0.05	mg/L					2.48	4.23			

*RDL Reportable Detection Limit

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

Parameter	RDL*	Units	Location on the lake	Moyie Lake, Lower/South							
				Shallow (1 to 10 metres)							
			Date sampled	14-Apr-15	28-Sep-15	6-Apr-16	23-Sep-16	19-Apr-17	23-Aug-17	2-May-19	7-Sep-18
Chlorophyll a	0.5	mg/L		1.51	1.35	2.02	1.19	1.23	1.03	0.52	1.22
Chlorophyll a rep	0.5	mg/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	-
Dissolved Oxygen	-	mg/L		12.05	7.61	10.93		10.54	8.43	10.98	-
Secchi (H20 clarity)	-	m		3.1	6.2	6.1		4.6	6.4	3.05	-
pH	-	pH			7.5				7.47	8.4	-
Temperature	-	^0C		5.2	18.7	5.27		4.4	20	6.2	-
Turbidity		NTU				0.64		0.78		1.63	-
Anions											
Silica	0.5	mg/L		7.89	8.12	8.72	7.53	8.32	7.15	8.6	6.99
Orthophosphate (p)	0.001	mg/L		0.0026	0.0018	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dissolved Sulphate (SO4)	0.5	mg/L		1.65	2.01	2.25	1.77	2.04	1.83	2.36	1.74
Dissolved Chloride (Cl)	0.5	mg/L		1.5	1.07	1.34	0.99	1.28	1.14	1.21	1.04
Calculated parameters											
Hardness	0.5	mg/L		22.7	23.1	26.3	21.2	27.2	22.1	24.4	20.3
Misc. Organics											
Total Organic Cargon	0.5	mg/L		2.52	2.66	2.44	2.85	2.8	3	3.4	2.96
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
Dissolved Phosphorous (P)	0.002	mg/L		0.0056	<0.002	<0.002	<0.002	0.0022	<0.002	-	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
Total Nitrogen (N)	0.02	mg/L		0.122	0.094	0.115	0.161	0.228	0.1	0.144	0.121
Total Phosphorous (P)	0.002	mg/L		0.0086	0.0021	0.0069	<0.002	<0.002	0.0025	0.0045	0.0024
Total metals by ICPMS											
Aluminium (Al)	0.5	ug/L		39.8		28.3		44.9		59.8	
Antimony (Sb)	0.02	ug/L		0.037		0.038		0.034		0.042	
Arsenic (As)	0.02	ug/L		0.219		0.221		0.217		0.221	
Barium (Ba)	0.02	ug/L		6.57		6.96		6.81		8.66	
Beryllium (Be)	0.01	ug/L		<0.01		<0.01		<0.01		<0.01	
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005	
Boron (B)	10	ug/L		<10		<10		<10		<5	
Cadmium (Cd)	0.005	ug/L		0.0318		0.0464		0.0591		0.0591	
Chromium (Cr)	0.1	ug/L		<0.1		<0.1		<0.1		<0.1	
Cobalt (Co)	0.005	ug/L		0.0364		0.0292		0.0419		0.0563	
Copper (Cu)	0.05	ug/L		0.71		0.598		2.36		0.986	
Iron (Fe)	1	ug/L		50.2		36.6		57.1		61.3	
Lead (Pb)	0.005	ug/L		1.17		1.96		1.73		1.62	
Lithium (Li)	0.5	ug/L		<0.5		<0.5		<0.5		<0.5	
Manganese (Mn)	0.05	ug/L		2.98		3.69		4.68		4.91	
Molybdenum (Mo)	0.05	ug/L		0.081		0.089		0.078		0.086	
Nickel (Ni)	0.02	ug/L		0.162		0.184		0.173		0.196	
Selenium (Se)	0.04	ug/L		<0.04		<0.04		<0.04		<0.04	
Silver (Ag)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005	
Strontium (Sr)	0.05	ug/L		17.7		17.9		15.3		17.5	
Thallium (Tl)	0.002	ug/L		<0.002		0.0022		0.0039		0.0070	
Tin (Sn)	0.2/0.01	ug/L		<0.2		<0.01		<0.01		0.0110	
Uranium (U)	0.002	ug/L		0.0806		0.0763		0.0787		0.1020	
Vanadium (V)	0.2	ug/L		<0.2		<0.2		<0.2		<0.2	
Zinc (Zn)	0.1	ug/L		9.31		7.95		13.8		10	
Calcium (Ca)	0.05	mg/L		6.32	6.59	7.45	6.03	7.97	6.34	6.71	5.69
Magnesium (Mg)	0.05	mg/L		1.68	1.62	1.87	1.48	1.77	1.54	1.81	1.49
Potassium (K)	0.05	mg/L				0.575		0.618		0.598	
Sodium (Na)	0.05	mg/L				1.89		1.92		1.92	

*RDL Reportable Detection Limit

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

Parameter	RDL*	Units	Location on the lake / Date sampled	Moyie Lake Upper/North Shallow 1 to 10 meter) 14-Apr-15	24-Sep-15	6-Apr-16	23-Sep-16	19-Apr-17	23-Aug-17	2-May-18	7-Sep-18
Chlorophyll a	0.5	mg/L		1.86	2.62	1.79	1.08	0.397	0.884	1.44	0.997
Chlorophyll a rep	0.5	mg/L		1.46	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	-
Dissolved Oxygen	-	mg/L		12.04	9.08	10.99	8.6	11.11	8.46	10.85	-
Secchi (H20 clarity)	-	m		3	8.6	7.6	9.05	4.5	5.85	4.9	-
pH	-	pH			7.8		8	7.3	7.56	9.33	-
Temperature	-	°C		4.3	19.9	4.8	18.9	3.7	19.4	6.8	-
Turbidity		NTU				0.5		0.69		11.7	-
Anions											
Silica	0.5	mg/L		8.1	7.91	8.72	8.26	8.52	8.81	8.58	7.2
Orthophosphate (p)	0.001	mg/L		<0.001	0.0017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Dissolved Sulphate (SO4)	0.5	mg/L		1.84	2.01	2.36	2.1	2.22	2.26	2.35	1.83
Dissolved Chloride (Cl)	0.5	mg/L		1	0.91	1.17	1.02	1.22	0.88	1.19	0.89
Calculated parameters											
Hardness	0.5	mg/L		23	22.5	25.9	23.9	28.4	22.9	27.4	20.5
Misc. Organics											
Total Organic Cargon	0.5	mg/L		2.55	2.33	2.49	2.68	2.59	3.1	2.97	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
Dissolved Phosphorous (P)	0.002	mg/L		0.003	0.0021	<0.002	<0.002	0.0032	0.0025	0.0028	0.0032
Nitrate plus nitrite (n)	0.002	mg/L		0.0462	0.032	0.0454	0.0536	0.0632	0.0728	0.0495	0.0063
Total Nitrogen (N)	0.02	mg/L		0.149	0.094	0.124	0.114	0.178	0.098	0.155	0.125
Total Phosphorous (P)	0.002	mg/L		0.0033	<0.002	<0.002	<0.002	0.0039	0.0023	0.0052	<0.002
Total metals by ICPMS											
Aluminium (Al)	0.5	ug/L		32.3		26.5		32.4		34.80	
Antimony (Sb)	0.02	ug/L		0.024		0.021		0.022		0.03	
Arsenic (As)	0.02	ug/L		0.213		0.202		0.211		0.21	
Barium (Ba)	0.02	ug/L		6.21		6.15		6.42		7.85	
Beryllium (Be)	0.01	ug/L		<0.010		<0.01		<0.01		<0.01	
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005	
Boron (B)	10	ug/L		<10		<10		<10		<0.0050	
Cadmium (Cd)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005	
Chromium (Cr)	0.1	ug/L		<0.1		<0.1		<0.1		<0.1	
Cobalt (Co)	0.005	ug/L		0.0333		0.0267		0.0365		0.0348	
Copper (Cu)	0.05	ug/L		0.646		0.491		0.359		0.574	
Iron (Fe)	1	ug/L		37.9		28		36.4		41.50	
Lead (Pb)	0.005	ug/L		0.0489		0.0356		0.0688		0.0623	
Lithium (Li)	0.5	ug/L		<0.5		<0.5		<0.5		<0.5	
Manganese (Mn)	0.05	ug/L		2.31		2.39		3.09		3.14	
Molybdenum (Mo)	0.05	ug/L		0.094		0.105		0.085		0.113	
Nickel (Ni)	0.02	ug/L		0.144		0.136		0.153		0.152	
Selenium (Se)	0.04	ug/L		<0.040		<0.04		<0.04		<0.04	
Silver (Ag)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005	
Strontium	0.05	ug/L		17.9		18.8		16.1		18.60	
Thallium (Tl)	0.002	ug/L		<0.002		0.003		0.0038		0.0064	
Tin (Sn)	0.2/0.01	ug/L		<0.2		<0.01		<0.01		<0.01	
Uranium (U)	0.002	ug/L		0.0902		0.0841		0.0969		0.1190	
Vanadium (V)	0.2	ug/L		<0.2		<0.2		<0.2		<0.2	
Zinc (Zn)	0.1	ug/L		0.46		0.32		2.01		1.69	
Calcium (Ca)	0.05	mg/L		6.38	6.43	7.21	6.79	8.33	7.36	7.21	2.67
Magnesium (Mg)	0.05	mg/L		1.71	1.57	1.92	1.68	1.85	1.83	1.89	3.44
Potassium (K)	0.05	mg/L				0.589		0.604		0.634	
Sodium (Na)	0.05	mg/L				1.71		1.67		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

Parameter	RDL*	Units	Location on the lake	Premiere Lake Shallow 1 to 10 meter)	
			Date sampled	3-May-18	6-Sep-18
Chlorophyll a	0.5	mg/L		0.864	0.448
Chlorophyll a rep	0.5	mg/L			
Field measurements					
Conductivity	-	uS/cm		338.5	
Dissolved Oxygen	-	mg/L		10.11	
Secchi (H20 clarity)	-	m		14.2	
pH	-	pH		9.66	
Temperature	-	^{0}C		10.6	
Turbidity		NTU		0.27	
Anions					
Silica	0.5	mg/L		3.04	1.93
Orthophosphate (p)	0.001	mg/L		0.0012	<0.001
Dissolved Sulphate (SO4)	0.5	mg/L		25.4	25.8
Dissolved Chloride (Cl)	0.5	mg/L		<0.5	<0.5
Calculated parameters					
Hardness	0.5	mg/L		179	176
Misc. Organics					
Total Organic Cargon	0.5	mg/L		2.19	2.56
Nutrients					
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.219	0.227
Dissolved Phosphorous (P)	0.002	mg/L		0.003	0.0054
Nitrate plus nitrite (n)	0.002	mg/L		<0.003	<0.003
Total Nitrogen (N)	0.02	mg/L		0.219	0.227
Total Phosphorous (P)	0.002	mg/L		0.0057	0.0032
Total metals by ICPMS					
Aluminium (Al)	0.5	ug/L		3	
Antimony (Sb)	0.02	ug/L		0.062	
Arsenic (As)	0.02	ug/L		0.375	
Barium (Ba)	0.02	ug/L		94.7	
Beryllium (Be)	0.01	ug/L		<0.1	
Bismuth (Bi)	0.005	ug/L		<0.005	
Boron (B)	10	ug/L		<5	
Cadmium (Cd)	0.005	ug/L		0.244	
Chromium (Cr)	0.1	ug/L		<0.1	
Cobalt (Co)	0.005	ug/L		0.0137	
Copper (Cu)	0.05	ug/L		0.97	
Iron (Fe)	1	ug/L		<1.0	
Lead (Pb)	0.005	ug/L		<0.005	
Lithium (Li)	0.5	ug/L		2.7	
Manganese (Mn)	0.05	ug/L		1.6	
Molybdenum (Mo)	0.05	ug/L		1.16	
Nickel (Ni)	0.05	ug/L		<0.05	
Selenium (Se)	0.04	ug/L		0.192	
Silver (Ag)	0.005	ug/L		<0.005	
Strontium	0.05	ug/L		164	
Thallium (Tl)	0.002	ug/L		<0.002	
Tin (Sn)	0.2/0.01	ug/L		<0.01	
Uranium (U)	0.002	ug/L		1.560	
Vanadium (V)	0.2	ug/L		<0.2	
Zinc (Zn)	0.1	ug/L		0.460	
Calcium (Ca)	0.05	mg/L		28.7	
Magnesium (Mg)	0.05	mg/L		26.200	
Potassium (K)	0.05	mg/L		0.675	
Sodium (Na)	0.05	mg/L		3.19	

*RDL Reportable Detection Limit

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

Parameter	RDL*	Units	Location on the lake	Whiteswan Lake Shallow 1 to 10 meter)	
			Date sampled	8-May-18	5-Sep-18
Chlorophyll a	0.5	mg/L		0.543	0.547
Chlorophyll a rep	0.5	mg/L			
Field measurements					
Conductivity	-	uS/cm		249.6	
Dissolved Oxygen	-	mg/L		10.71	
Secchi (H20 clarity)	-	m		9.2	
pH	-	pH		8.95	
Temperature	-	^{0}C		9.3	
Turbidity		NTU		0.23	
Anions					
Silica	0.5	mg/L		3.9	
Orthophosphate (p)	0.001	mg/L		<0.001	<0.001
Dissolved Sulphate (SO4)	0.5	mg/L		3.8	19.5
Dissolved Chloride (Cl)	0.5	mg/L		2.83	2.5
Calculated parameters					
Hardness	0.5	mg/L		145	138
Misc. Organics					
Total Organic Cargon	0.5	mg/L		1.56	1.45
Nutrients					
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.07	0.1
Dissolved Phosphorous (P)	0.002	mg/L		0.002	0.0035
Nitrate plus nitrite (n)	0.002	mg/L		0.0052	<0.003
Total Nitrogen (N)	0.02	mg/L		0.075	0.1
Total Phosphorous (P)	0.002	mg/L		0.0025	<0.002
Total metals by ICPMS					
Aluminium (Al)	0.5	ug/L		2.37	
Antimony (Sb)	0.02	ug/L		0.107	
Arsenic (As)	0.02	ug/L		0.265	
Barium (Ba)	0.02	ug/L		94.0	
Beryllium (Be)	0.01	ug/L		<0.010	
Bismuth (Bi)	0.005	ug/L		<0.0050	
Boron (B)	10	ug/L		<5.0	
Cadmium (Cd)	0.005	ug/L		<0.0050	
Chromium (Cr)	0.1	ug/L		<0.10	
Cobalt (Co)	0.005	ug/L		0.0122	
Copper (Cu)	0.05	ug/L		0.2020	
Iron (Fe)	1	ug/L		2.70	
Lead (Pb)	0.005	ug/L		0.0085	
Lithium (Li)	0.5	ug/L		1.250	
Manganese (Mn)	0.05	ug/L		1.320	
Molybdenum (Mo)	0.05	ug/L		0.723	
Nickel (Ni)	0.02	ug/L		0.091	
Selenium (Se)	0.04	ug/L		0.079	
Silver (Ag)	0.005	ug/L		<0.0050	
Strontium	0.05	ug/L		108	
Thallium (Tl)	0.002	ug/L		0.0025	
Tin (Sn)	0.2/0.01	ug/L		<0.010	
Uranium (U)	0.002	ug/L		0.517	
Vanadium (V)	0.2	ug/L		<0.20	
Zinc (Zn)	0.1	ug/L		0.63	
Calcium (Ca)	0.05	mg/L		37.5	
Magnesium (Mg)	0.05	mg/L		11.4	
Potassium (K)	0.05	mg/L		0.322	
Sodium (Na)	0.05	mg/L		2.27	
	*RDL		Reportable Detection Limit		

Appendix D
Summer Survey of the Distribution of Turbidity and Conductivity Along Columbia Lake

Location (UTM NAD27)			Location#	Date	Turbidity (NTU)	perature (Ce	Conductivity (us/cm
easting	northing	distance					
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