Summary of the 2020 Water Quality Monitoring Program for Columbia Lake

Columbia Lake Stewardship Society

January 12, 2021

Executive Summary

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

- approximately bi-weekly monitoring of selected water quality indicator parameters and approximately monthly sampling of water for chemical analyses;
- a survey of chloride, turbidity and conductivity concentrations along the lake; and
- measurement of the water quality of Dutch Creek, Hardie Creek, Marion Creek and the small creek that drains from Canal Flats.

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

Funding for the program was provided by:

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

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

The monitoring program carried out over the past seven years on Columbia Lake has shown that the lake water is suitable for drinking water, preservation of aquatic life and recreational purposes. In 2020 the trend in concentrations of turbidity that in previous years increased over the summer months was different. In 2020 turbidity concentrations declined over the summer months

Columbia Lake contains different concentrations of chloride than the other four neighbouring lakes monitored each year by the British Columbia Ministry of the Environment (BCMOE). Different concentrations of chloride are of concern because there are no natural soils or rocks that can contribute chloride to surface water or groundwater draining into the lake.

CLSS intends to proceed in 2021 with a similar monitoring program to that undertaken in 2020. The program will include:

1. The “Regular” program of bi-weekly measurements of temperature, lake depth, Sechi depths, turbidity, specific conductance, pH and dissolved oxygen at the four locations (N1, S1, S3 and S4);
2. Chemical analyses during the regular program in late May and mid-July for total and dissolved oxygen, nitrate, iron and manganese, alkalinity, hardness and chloride;
3. Monitoring the distribution of temperature, turbidity, specific conductance and chloride on two occasions during the summer months (mid-July and mid-August);
4. Monthly monitoring of the four creeks (Dutch Creek, Hardie Creek, Marion Creek and the creek draining from Canal Flats) for temperature turbidity, specific conductance, pH and dissolved oxygen;
5. Twice annual (spring and fall) analyses of the creek waters for nitrate, total and dissolved phosphorous, iron and manganese, alkalinity, hardness and chloride.

Summary of the 2020 Water Quality Monitoring Program for Columbia Lake

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WATER QUALITY MONITORING PROGRAM SUMMARY For 2020

1. Introduction

Columbia Lake, located in the East Kootenay region of British Columbia between the community of Fairmont Hot Springs and the Village of 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 community of Donald on the north side of the Trans-Canada Highway, 28 kilometres northwest of Golden, BC. Columbia Lake drains into the Columbia River at the north end of the lake. The river then 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 Trail, 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. That strategy included a recommendation to monitor the lake. The Regional District of East Kootenay (RDEK) and the Village of Canal Flats are in the process of reviewing the lake management strategy as they develop an updated Columbia Lake Management Plan now scheduled for completion in 2021.

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 every year through to September 2020. Water quality monitoring of Columbia Lake began on May 28, 2020 and ended September 5, 2020.

This summary of the 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 2.3 describe:

- the purpose of the program and contributions of volunteers to the program during 2020;
- the historical development of the monitoring program; and
- the monitoring program conducted during 2020.

2.1 Purpose and Acknowledgements

The purpose of the water quality monitoring program conducted by 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 activity helps to satisfy the CLSS mission statement:

- 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 goals.

The CLSS water quality program is, for the most part, administered, implemented and interpreted by volunteers. In 2020, the following volunteers contributed to the water quality monitoring program:

- Layla Chouchene - assistance with stream sampling
- Amira Elwakeel
- Yusuf Elwakeel - assistance with stream sampling
- Tracy Flynn - monitoring on the lake in early May
- Gina Fryer and Cesar Fuertes - participation in lake monitoring events
- Ed Gillmor - monitoring in late May
- Garry Gray - monitoring in August
- Dianne Jeffrey - monitoring assistance in July and August
- Dave and Donna Rae - assistance with on-the-lake training
- Prithvi Shankara - assistance with stream sampling
- Pat Silver - overall program administration and accounting
- Barb and Kevin Stromquist - monitoring in June and July
- Tom Symington - assistance with report preparation
- Katie Watt - on the lake monitoring in May and August and
- Tom Dance and Nancy Wilson -on the lake monitoring, and compilation, graphing, nterpretation and reporting of the monitoring results.

For the 2020 monitoring program, CLSS received a grant from the Canada Summer Jobs program to hire a summer student to assist with the water quality and water quantity monitoring programs and with some of the educational opportunities the society offers. Our summer student Amira Ellwakeel participated in the program from May through September of 2020. She has subsequently worked on graphing and tabulating results for this report while attending her final year of studies in engineering at the University of Calgary. In the autumn of 2020, CLSS also retained the services of Ms. Georgia Peck who has assisted us with the monitoring program data and educational offerings.

The program receives funding from the following agencies:

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

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

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

2.2 Development of the Monitoring Program

CLSS monitors both the water quality of Columbia Lake and the quantity of surface water entering and leaving the lake. Water quantity is reported separately.

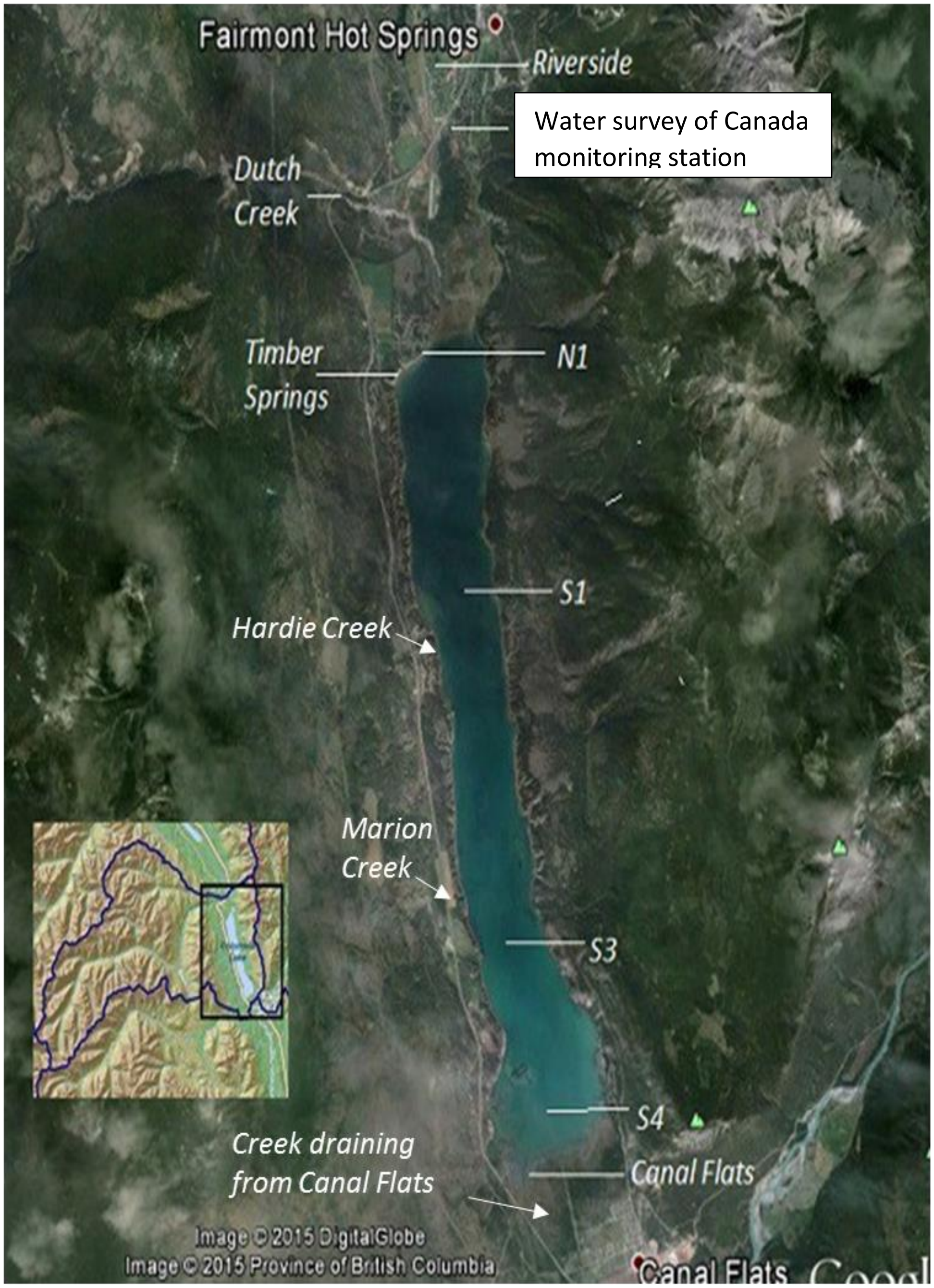
Initially, the water quality monitoring program of Columbia Lake was developed to respond to recommendations contained in the Columbia Lake Management Strategy (Urban Systems, 1997) that indicated a water quality and water level monitoring program should be implemented. In 2014, four water quality monitoring stations were established on the lake. However, since 2014, the program has undergone several changes as more is learned about the lake. Chronologically, these changes are summarized as follows:

2014

Four stations for monitoring lake quality conditions were established by this initial program. These stations are referred to throughout this report as N1, S1, S3 and S4. The station locations are shown on Figure 1 and summarized from north to south along the lake as:

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

Figure 1 – Monitoring Locations



Water quality monitoring in 2014 confirmed that the lake's condition was consistent with the nearly pristine conditions used as the basis of this management strategy.

2015

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.

2016

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 has not been repeated in the ensuing years (2017 – 2020) but is brought forward here as a reminder of those factors potentially influencing the lake's water quality.

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

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

	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, produced 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 support growth of aquatic plants and improve 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 3.1.7.

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 continues 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.

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.

These findings and advice prompted CLSS to begin the annual monitoring program as soon as possible each spring to confirm the dissolved oxygen and total and dissolved phosphorous concentrations. The timing of this early monitoring event is largely controlled by the availability of boats provided by our volunteers.

2017

No changes to the monitoring program were made.

2018

During the summer of 2018, a CLSS board member (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 through this valley to the south of the Village of Canal Flats. Residents of Canal Flats have described to CLSS members that water can be observed and heard to flow within some of the water wells used to provide potable water to the village.

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 available on the CLSS website.

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

This assessment of groundwater inflow at the south end of the lake and considering that there are no other significant streams flowing into the lake except for Dutch Creek at the north end prompted CLSS to consider whether lake water changed from south to north. Over the summer months of 2018, a survey of conductivity and turbidity concentrations was undertaken by CLSS volunteers Gina Fryer and Lucas and Caesar Fuertes. Every two weeks during the summer of 2018, these volunteers measured conductivity and turbidity concentrations at fourteen locations along the lake (Figure 2). The results of this monitoring program are tabulated in Appendix D.

As CLSS reported in 2018, the results from this survey showed that the conductivity and turbidity concentrations decreased from the south end to the north end of the lake. The results confirmed that the water in the south end of the lake is influenced by the contribution of surface or ground water draining into the lake from Canal Flats.

2019

To confirm the differences in water quality along the lake found in 2018, the survey was repeated in 2019 with Chloride added to the analyses of water quality at the fourteen locations. That survey was undertaken on July 23, 2019.

Further, visual inspections of the outlets of small streams draining into the lake along the west side, showed that the shorelines had a different appearance that was associated with rust and black stained rocks. CLSS decided to initiate an evaluation of the water quality of streams draining into the lake. Over the summer of 2019, Dutch Creek, Hardie Creek Marion Creek and the small stream draining from Canal Flats to the lake were monitored on four occasions. Testing was undertaken for specific conductance, temperature, turbidity, pH and chloride (on one occasion).

The stream sampling results showed noticeable differences in the quality of surface water between the four creeks.

2.3 The Monitoring Program Undertaken During 2020

In 2020, the monitoring program on Columbia Lake undertaken by CLSS involved:

- the “regular” monitoring program comprising approximately bi-weekly measurements of three types of information at the four locations (N1, S1, S3 and S4) along the lake shown on Figure 1:
    - 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,
        - specific conductance,

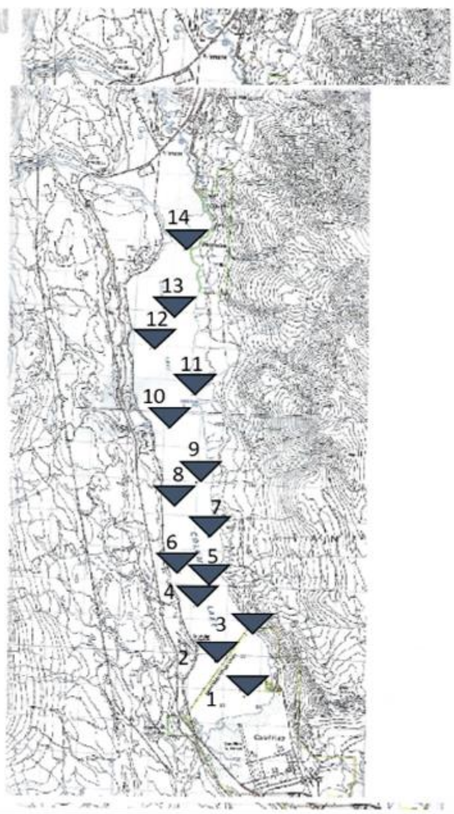
- pH,
- dissolved oxygen, and
- Two sets (May 28 and July 18) of chemical analyses on water samples from the lake for total and dissolved phosphorous as well as, Fe, Mn, hardness, alkalinity, and chloride added to the program for 2020 to help evaluate causes for turbidity increases during the summer months (growth of aquatic vegetation or disturbed bottom sediments;

- Collection of two sets (July 18 and August 18) of south to north measurements of turbidity, conductance, pH and chloride at the 14 locations along the lake shown on Figure 2; and
- Four measurements of temperature, specific conductance, turbidity, dissolved oxygen and pH on
  - Dutch Creek on the northwest side of the bridge over highway 93;
  - Hardie Creek at the outfall to the lake on the Spirits Reach property;
  - Marion Creek at the outfall to the lake within the provincial picnic area; and
  - A small creek draining north from Canal Flats on the pathway (Figure 1).

Appendix A provides information on how each of the measured parameters contributes 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 specific conductance were measured at both “shallow” and “deep” depths. Shallow refers to measurements in the upper 0.5 metres of the lake (an arm’s reach below the water surface for practical purposes) while deep refers to measurements made about 0.5 metres from the lake bottom as measured using the Secchi disk. The deep and shallow measurements began in 2016 but were not routinely collected in 2017, 2018, 2019 and 2020. This information revealed that the lake had no noticeable differences in parameters between the deep and shallow depths.

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



Not to scale

In 2020, the regular monitoring program began on May 5 and ended on September 5. Measurements were made as weather permitted on six occasions at approximately biweekly intervals with water samples collected for chemical analyses on May 28 and July 18. Caro Analytical of Kelowna provided the analytical services. The spreadsheet in Appendix B provides the observations, measurements and chemical analysis collected during all seven years of the monitoring program. The results are described in section 3.1.

The south to north lake profiles along the lake for turbidity, specific conductance and chloride were undertaken on July 18 and August 18. These results are described in Section 3.2.

Monitoring of Dutch Creek, Hardie Creek, Marion Creek and the stream flowing from Canal Flats occurred on June 14, July 23, August 27 and September 19. The monitoring results are described in section 3.3.

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 – WQGs) and the other is to apply a set of water quality objectives (WQOs). 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 pressures.

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 (WQOs). Water quality objectives are an extension of WQGs. WQOs may be established by:

- Direct adoption of WQGs 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 WQOs have not been set for Columbia Lake, the water quality information collected is compared to the values established within the Lake Windermere management plan. These objectives are:

Parameter	Objectives (revised for Lake Windermere in 2010)
Turbidity	<1 NTU (Average) during clear flow periods < 5 NTU (Maximum) during clear flow periods 5 NTUS (measured as the 95th percentile of measurement) during turbid flow periods
Phosphorous	0.010 mg/L (maximum)
Temperature	<20^{o}C in June (average) < 25^{o}C in July (average) <23^{o}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 WQOs 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 method for CLSS to establish WQOs may be provided with the revised water management program for Columbia Lake.

3.0 Water Quality Monitoring Results

Respectively, Sections 3.1, 3.2 and 3.3 summarize:

- The monitoring results obtained at the four monitoring locations (N1, S1, S3 and S4) along the lake;
- The distribution of turbidity, specific conductance and chloride concentrations from south to north along the lake over the summer months; and
- The monitoring results obtained for Dutch Creek, Hardie Creek, Marion Creek and the creek draining from Canal Flats to the lake.

3.1 Annual Monitoring Program

The 2020 annual monitoring program is the seventh year CLSS has monitored the water quality of Columbia Lake using the indicator parameters of temperature, turbidity, specific conductance, pH and dissolved oxygen. To illustrate the differences in the concentrations of these parameters from month to month, CLSS compiled the information collected between 2014 and 2020 into a statistical summary for each of the four monitoring locations along the lake. That compilation involved a month by month calculation of mean, the standard deviation and the expected maximum and minimum concentrations. The expected maximum and minimum concentrations were calculated as the mean plus and minus three times the standard deviation and are labelled as upper and lower control limits on graphs of the indicator parameters. Those statistical calculations are provided in Appendix E

Concentrations that exceed either the expected maximum or minimum values identify water quality information that is beyond the normal or expected range and may suggest further assessment of the lake's water quality should be considered. These exceedances are mentioned in the text of this report

Sections 3.1.1 to 3.1.7 describe the variation in concentration for temperature, Sechi disk depth measurements, turbidity, specific conductance, pH, dissolved oxygen and total and dissolved phosphorous. In 2020, CLSS added nitrate, iron and manganese, hardness, alkalinity and chloride to the water quality analyses. Section 3.18 summarizes those results.

3.1.1 Temperature

Lake temperature is an important ecological condition because, at higher temperatures, the quantity of dissolved oxygen available for fish and aquatic invertebrates declines and creates a potential environmental stressor. (We understand from conversations at the BC Lake Keepers workshop held at the Columbia Ridge Community Centre in May of 2016 that temperatures greater than 20^0C can so dramatically stress fish that fish kills may occur). Further, higher water temperatures increase the rate of 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. Figures 3a and 3b plot the temperatures measured during 2020 at the surface and bottom depths.

Figure 3 – Lake Water Temperature

Figure 3A - Water Temperature at Surface, 2020

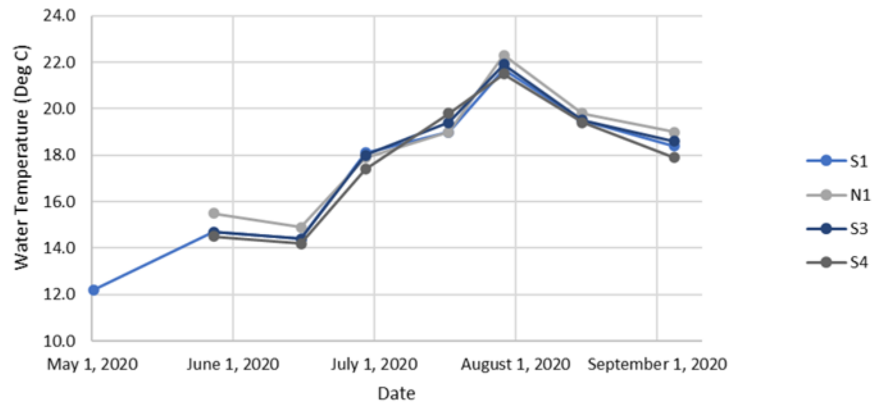
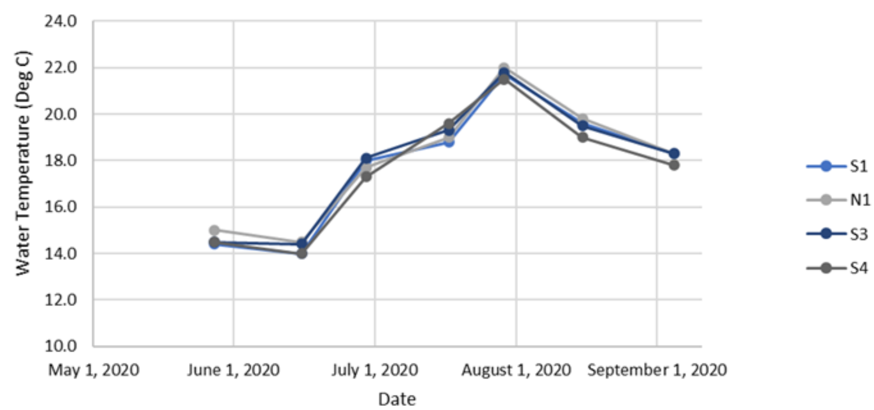


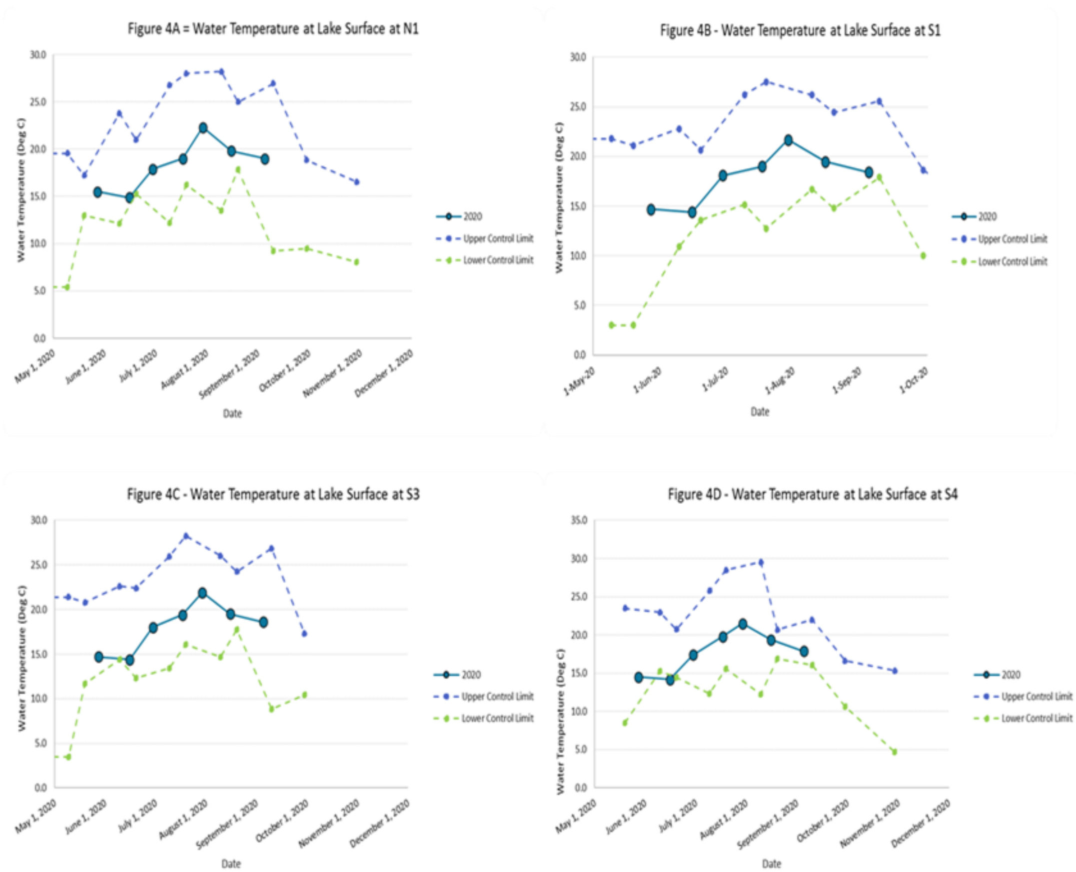
Figure 3B - Water Temperature at Bottom, 2020



The minimum temperature measurements in 2020 of approximately 12^0 C were measured during the first monitoring event in early May. The maximum temperatures (greater than 20^0 C) were measured between the middle of 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 illustrate that there is no noticeable difference in water temperature with depth at all monitoring locations.

Figure 4 compares the temperature measurements along the lake in 2020 to the upper and lower temperatures measured between 2014 and 2019. During 2020 temperatures lower than this expected range were measured in June. This observation is consistent with the general observation that overall, the spring of 2020 was cooler than other years.

Figure 4 – Lake Surface Temperature – Year to Year Comparison



3.1.2 Secchi Disk Measurements

Secchi disk measurements are used to qualitatively determine the clarity of the water. Water clarity is an important consideration for lake water quality since it improves the aesthetic appeal of the lake to recreational users and increases the chance of successful predation by 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 2020 monitoring events, the lake's surface was frequently too turbulent to allow accurate measurements to be made. A plot of this information has not been provided.

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

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 NTUs (Nephelometric Turbidity Units) - a quantifiable measure of turbidity. The turbidity of the lake water in the open water zone is influenced mostly by the growth of phytoplankton and the amount of suspended sediments contained in the lake water. In the open water zone, the main cause of turbidity increase is the growth of phytoplankton. Closer to the shoreline however, suspended sediments are introduced by surface water draining into the lake, shoreline erosion by wave action and disturbance of bottom sediments by wave action and recreational activities. Organic matter that decays in the water as it warms up is also a significant contributor to the lake's murkiness and consumes oxygen as the organic material decays. Decaying organic water consumes oxygen that potentially limits the oxygen available to support aquatic life. The measured turbidity may also be influenced by some chemical reactions that create insoluble precipitates (carbonates mostly) but due to the low mineral content of the Columbia Lake water they are not as great a contributor to the turbidity as the suspended mineral sediments and organic debris.

Turbidity measurements made during the 2020 monitoring events are plotted on Figure 5. The plot demonstrates that the greatest concentrations of turbidity were measured during the late spring at N1 and S1 at the north end of the lake and the middle of the lake respectively. At all locations, the turbidity measurements declined throughout the summer months. In the early summer months at S4 in the southern end of the lake, the turbidity measurements differ from those of the other three locations. This difference is understood to be a result of the increase in phytoplankton growth in the shallow water as the lake temperature increases.

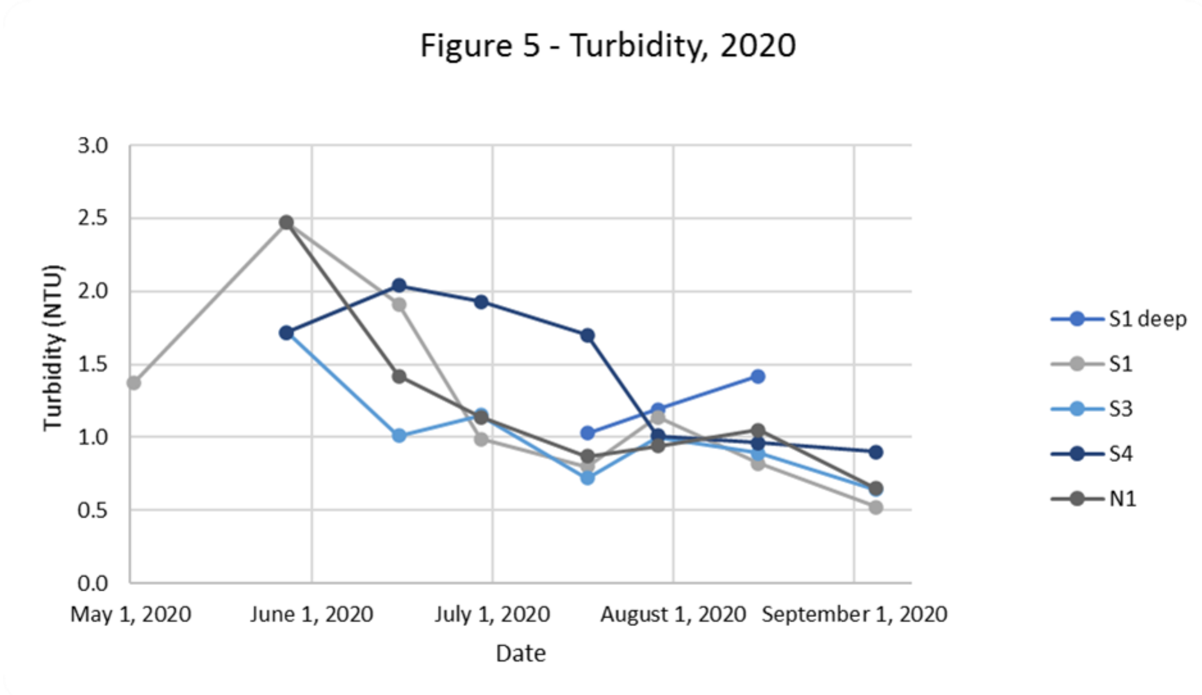
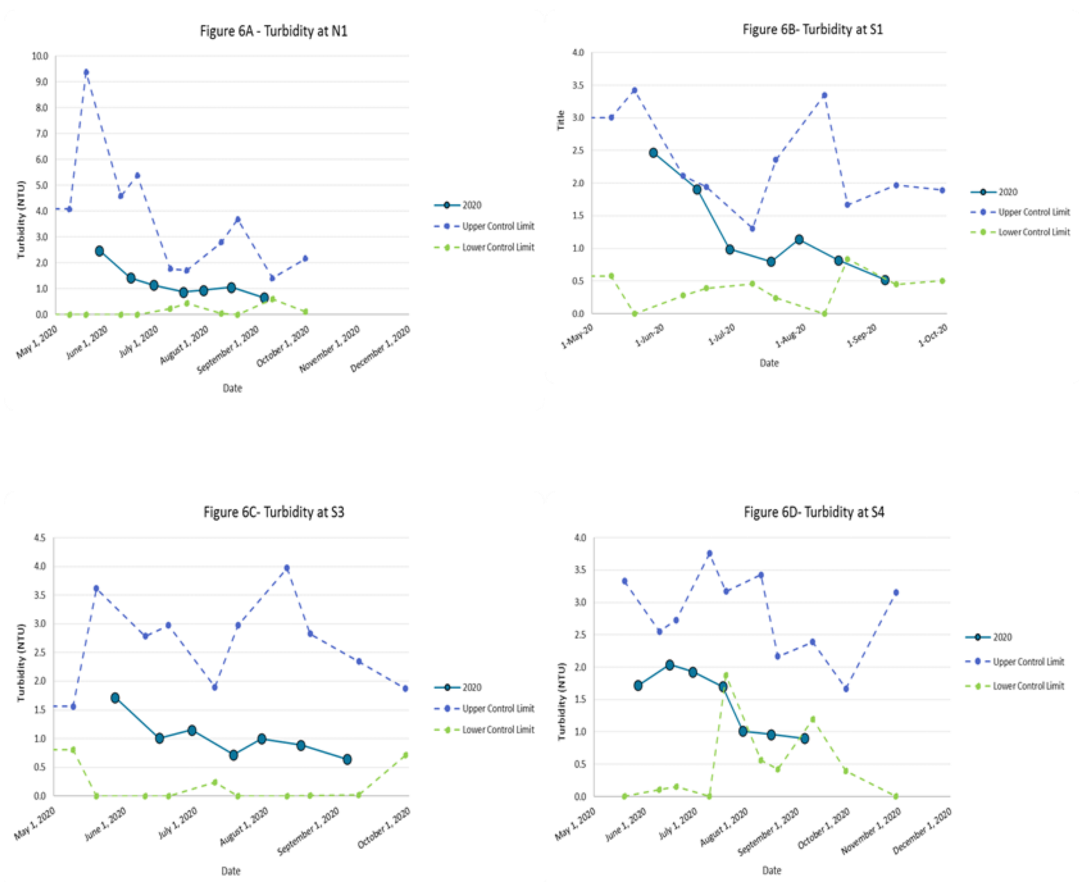


Figure 6 compares the year over year turbidity measurements at each monitoring location on the lake. The four graphs (Figures 6 a, b, c, and d) show that the trend in turbidity measured over the summer months differs from that measured in previous years. For example, during the summer months in most years the turbidity concentrations increased over the middle of the summer whereas in 2020 the turbidity concentrations declined over the same time period.

Trends in turbidity concentrations need to be monitored to determine if 2020 was an anamous year or represents a new trend over that of the prior 6 years.

Figure 6 – Turbidity – Year to Year Comparison



3.1.4 Specific Conductance

Specific 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 that are carried into the lake by groundwater inflows and surface water drainage. A portion of the specific conductance of the lake water is also due to soluble organic matters that create weak acids as they dissolve (like vinegars) but usually this contribution is considered minor. Specific conductance is 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.

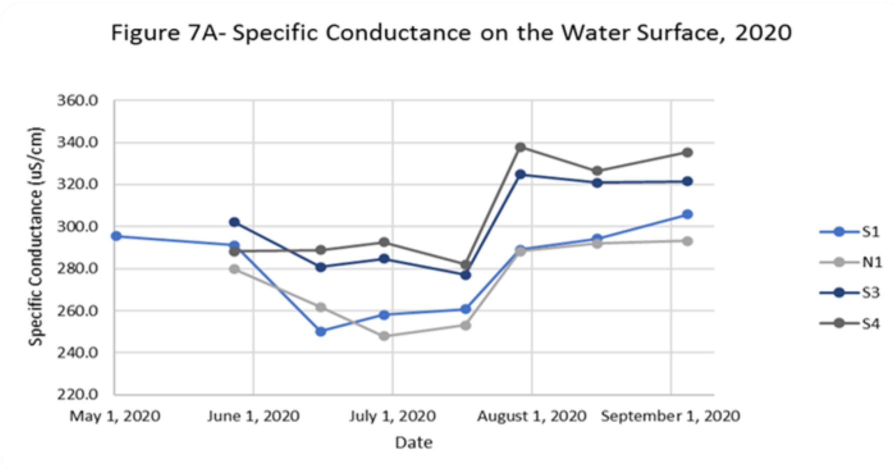
Figure 7 plots the values measured for the conductivity during 2020. Figures 7a and 7b show there is no appreciable difference in specific conductance concentrations between the surface and bottom of the lake. Figures 7a and b also show that the greatest concentration for specific conductance are in the south end of the lake at S3 and S4.

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

The plots on Figure 7 illustrate that the specific conductance increases during the summer months. This increase is understood to be created by evaporation from the lake surface that increases the salt content of the water. This trend is similar to that observed in other years (Figure 8).

There has been no water quality objective established for Lake Windermere and thus the significance of the specific conductance measurements on Columbia Lake cannot be stated.

Figure 7 – Specific Conductance



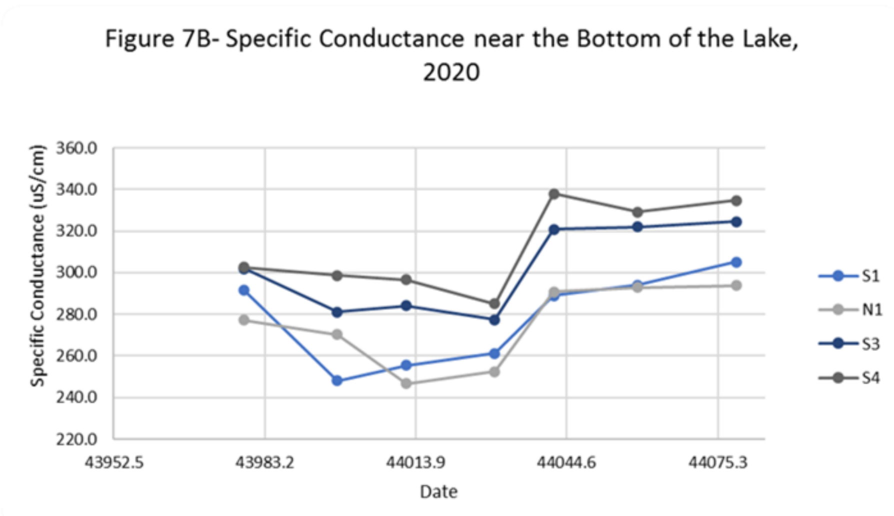
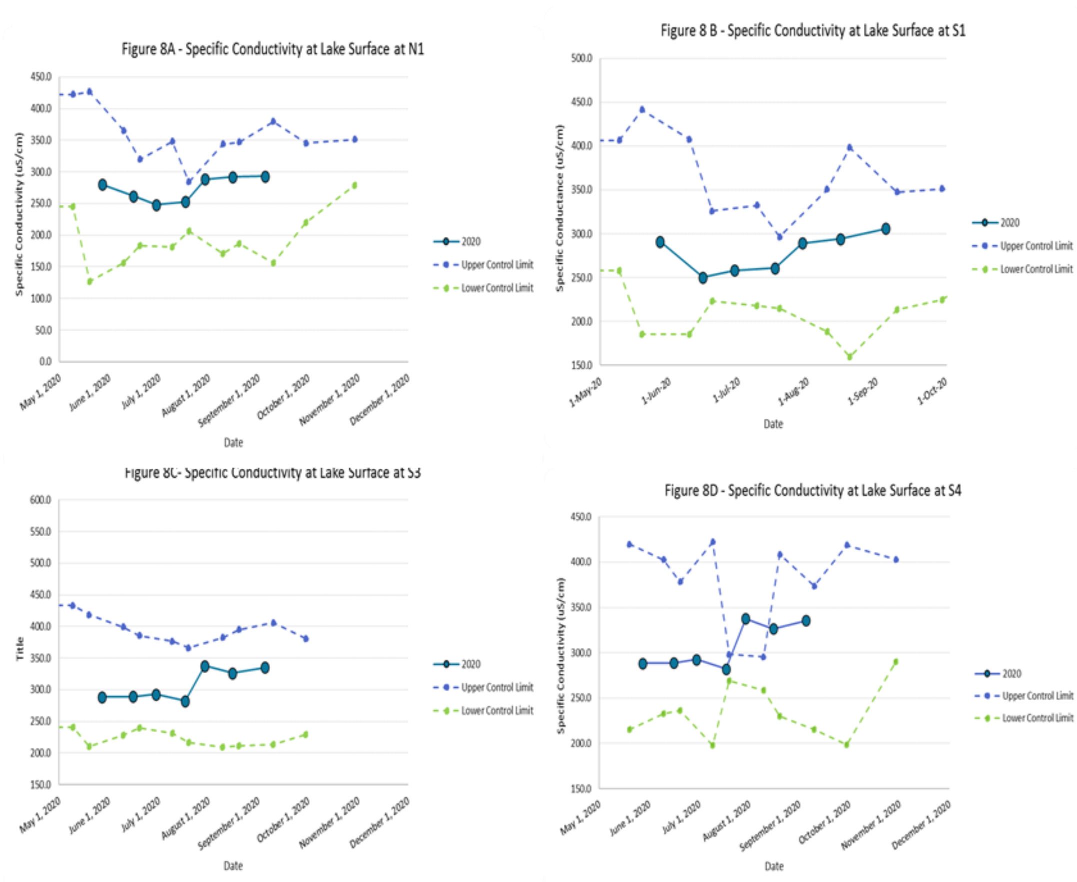


Figure 8 – Specific Conductance – Year to Year Comparison



3.1.5 Potential of hydrogen (pH)

Potential of hydrogen (pH) is a measure of the acidity (pH values less than 7) or alkalinity (pH values greater than 7) of 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 (pH 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 2020. Generally, the pH values fall within a narrow range from 7.4 to 9 pH units. An exception to this observation was measured in July of 2020 at N1 in the north end of the lake when a pH value of greater than 9 pH units was measured. These values are within the range of pH for most water quality objectives (drinking water for people and wildlife, aquatic life/habitat protection and recreational uses).

During 2020, pH values declined from close to 9 pH units to approximately 8 pH units in early August at all monitoring locations.

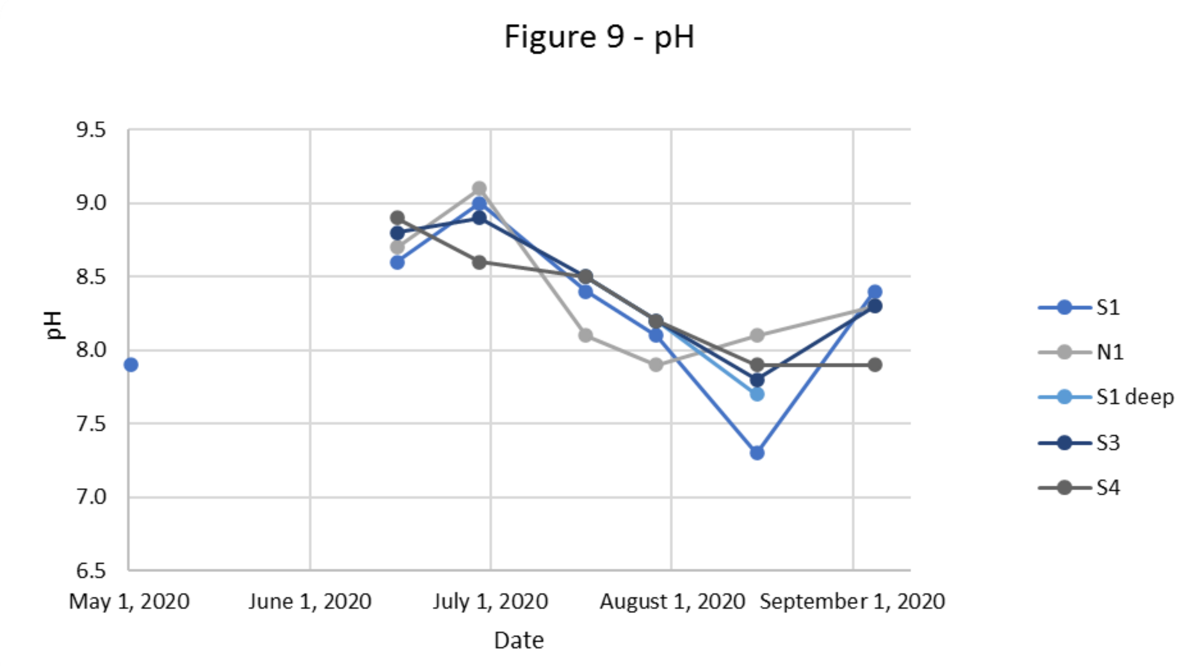
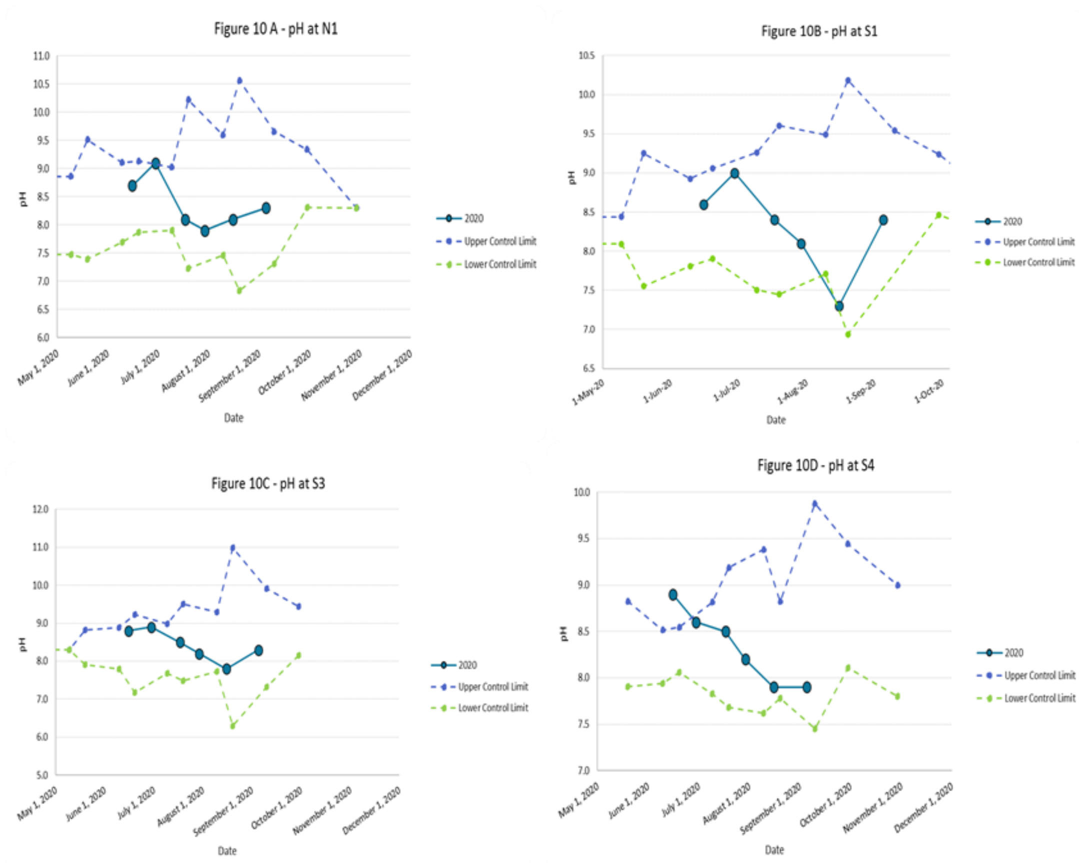


Figure 10 plots the year over year measurements of pH at each of the monitoring locations on the lake. Visually, the plots of pH versus the monitoring date for each of the prior years suggest that a general increase in pH is observed between April and September. A trend analysis has not been undertaken to confirm this visual observation numerically. This trend for increases in pH toward the end of summer was not observed by the 2020 measurements. Instead, during 2020, we see a decline in pH between May and August.

This trend to declining pH values needs to be monitored carefully because ultimately acidic conditions (pH values less than 8) are not suitable as aquatic habitats.

Figure 10 – pH Year to Year Comparison



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

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

3.1.6 Dissolved Oxygen

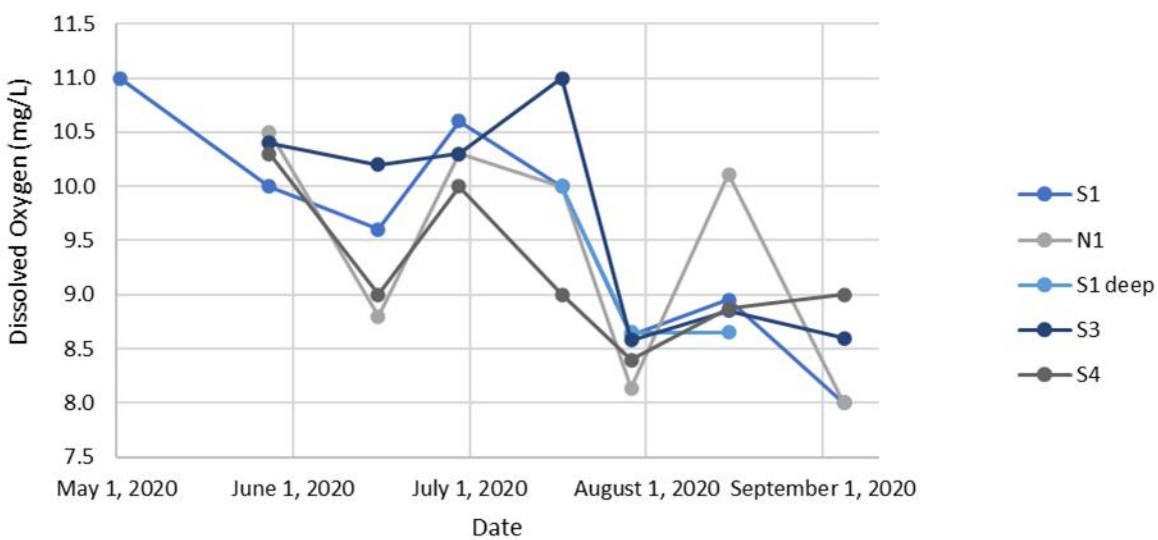
Water containing dissolved oxygen and carbon dioxide and which receives sunlight is essential for photosynthetic processes in the lake to occur and allows aquatic and amphibious flora and fauna to thrive. Both carbon dioxide and oxygen are produced by photosynthesis. The only mechanical source of dissolved 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^o C and 14 mg/L at water temperatures of 1^o C).

Figure 11 plots the dissolved oxygen concentrations measured in 2020 at the four monitoring locations along the lake. This graph illustrates that the dissolved oxygen concentrations were always greater than 8 mg/L and less than 11 mg/L. These measured concentrations are greater than the instantaneous concentration for dissolved oxygen set for Lake Windermere of greater than 5 mg/L.

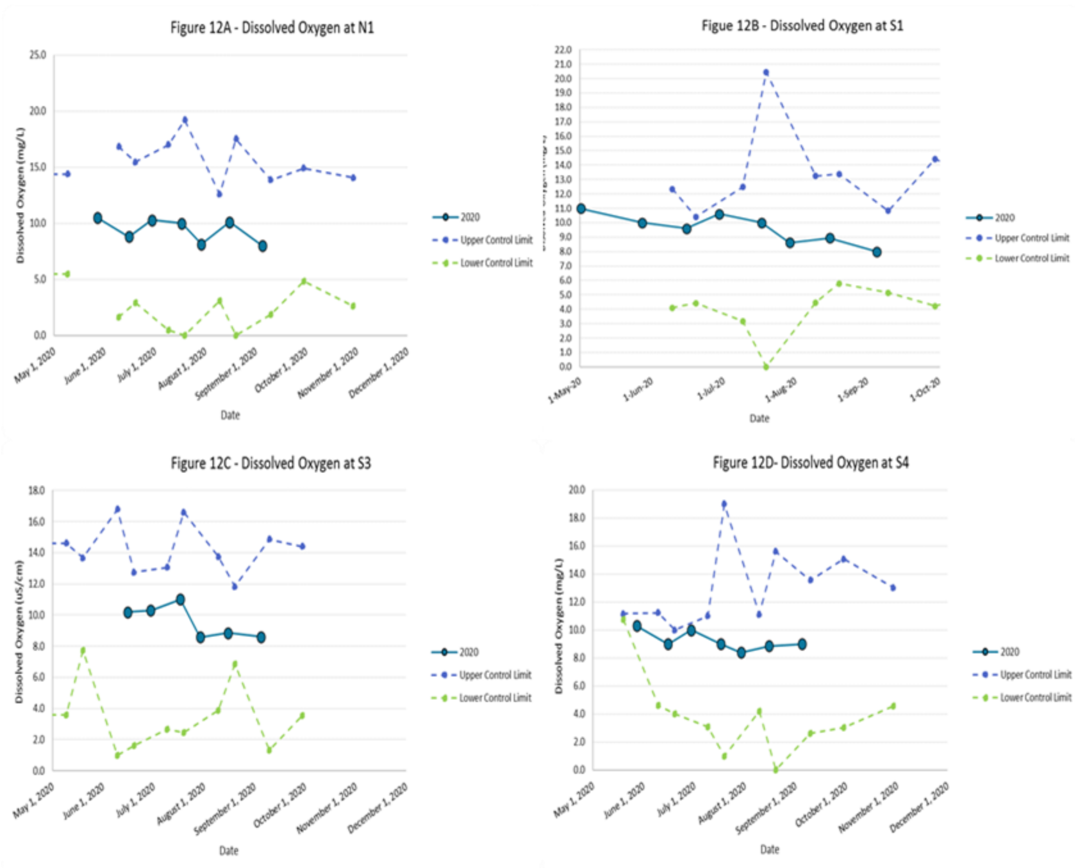
Figure 11 - Dissolved Oxygen, 2020



During the summer months the maximum dissolved oxygen concentration of about 11 mg/L was measured at location S3 in the middle of July. However, in general the dissolved oxygen concentrations declined over the summer months, a finding consistent with the observation of prior years and the increased temperatures over the same months.

Figure 12 compares the year over year measurements of dissolved oxygen. As the graphs on Figures 12 a, b, c, and d suggest, the concentrations of dissolved oxygen measured in 2020 are within the expected ranges measured over the previous six years.

Figure 12 – Dissolved Oxygen – Year to Year Comparison



3.1.7 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 feedstock of larger fish and aquatic/amphibious vertebrates. Therfore, 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 that contain dissolved mineral salts and organic materials into the lake. Some phosphorous may also be introduced by wastewater discharge and drainage of organic wastes 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 (derived from decayed organics animal and vegetable) forms. 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 South East Alberta Water Alliance (2014).

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

Only two measurements of dissolved phosphorous concentrations were made during 2019, both at location S1. These measurements were:

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

For comparison purposes, the two measurements (May 28 and July 18) of total and dissolved phosphorous were made on the lake water in 2020

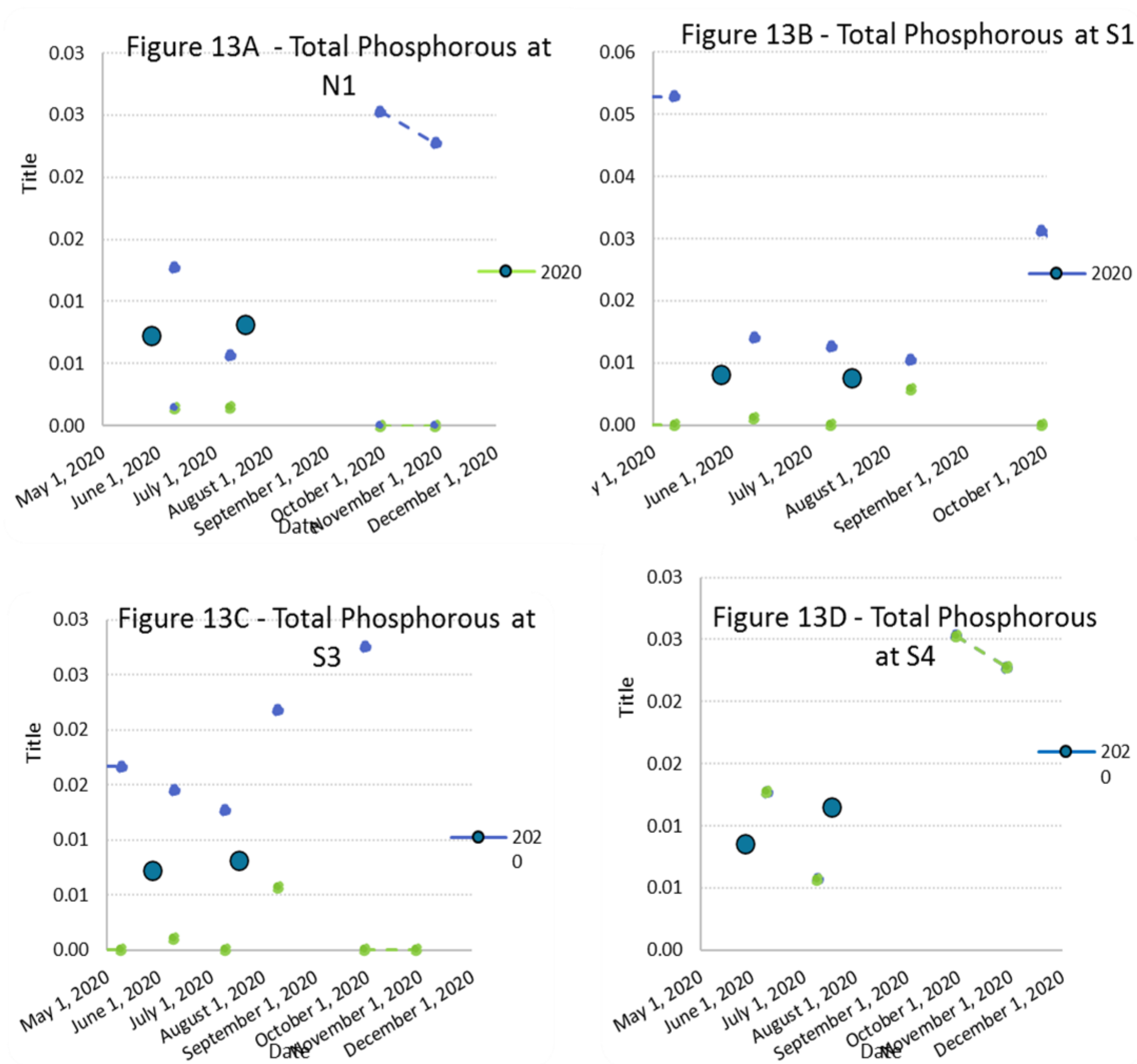
	May 28, 2020		July 18, 2020	
	Total P	Dissolved P	Total P	Dissolved P
N1	0.0073	0.0039	0.0082	0.0056
S1 – shallow	0.0082	0.0054	0.0077	0.0065
S1-deep	0.0099	0.0044	0.0106	0.0066
S3	0.0072	0.0042	0.0084	0.0064
S4	0.0086	0.0040	0.0115	0.0099

These results demonstrate that the lake water contains approximately similar concentrations to those measured in 2019 and is generally the same from place to place on the lake. However, on two occasions the lake water contained total phosphorous concentrations that are greater than the water quality objective set for Lake Windermere for total phosphorous of 0.01 mg/L. These exceedances are highlighted in yellow in the preceding table.

The ratio of dissolved to total phosphorous based upon these measurements is between 40 and 50 percent. In prior years, this ratio was as much as 100 percent.

Figure 13 compares the phosphorous concentrations measured over the six years of the monitoring program. This plot illustrates that the concentrations of total phosphorous in 2020 are within the range of concentrations measured in prior years.

Figure 13 – Total Phosphorous – Year to Year Comparison



3.1.8 Additional analyses in 2020

In 2020, during the monthly monitoring program, CLSS began to collect and analyze water samples for nitrate, iron and manganese, alkalinity, hardness, and chloride.

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

Nitrate concentrations were measured at the onset of the program on April 20, 2014 and continued to be measured until May of 2016. All nitrate concentrations were less than the analytical detection limit. Nitrate concentrations were not measured in 2017, 2018 or 2019. However, we note that detectable concentrations of nitrate were measured during the stream sampling program conducted in the early autumn of 2019 (Section 3.3). These measurements suggested that nitrate should be reintroduced to the annual sampling program.

Iron and manganese, alkalinity and hardness were added to the chemical analysis to aid in determining whether increases in turbidity noted in the lake water over the summer months in 2019 were due to increases in phytoplankton growth or the disturbance of bottom sediments. Bottom sediments were understood to be disturbed due to increased shoreline erosion, sediments from streams draining into the lake, wave action or recreational activity.

Chloride was added to the chemical analysis because it was noted in the results of BCMOE's sampling program that Columbia Lakes contained greater concentrations of chloride than other neighbouring lakes. Furthermore, analysis of water quality in the small creek draining into the lake from Canal Flats showed that it contained chloride concentrations much greater than that measured in the other streams sampled in 2019. CLSS wanted to learn whether chloride concentrations would increase in the lake.

The results of the two sets of water quality analyses (May 28, and July 18) are tabulated in Table 2.

Table 2 - Comparison of Concentrations for Nitrate, Iron, Manganese, Alkalinity, Hardness and Chloride from South to North							
			south				north
	monitoring location		S4	S3	S1- shallow	S1 - deep	N1
May 28, 2020							
	nitrate	mg/L	<0.01	<0.01	<0.01	<0.01	<0.01
	iron	mg/L	<0.01	<0.01	<0.01	0.011	0.032
	managanese	mg/L	0.00472	0.00395	0.00831	0.00872	0.0112
	alkalinity (as $CaCO_3$)	mg/L	173	175	164	166	169
	hardness (as $CaCO_3$)	mg/L	177	170	162	167	160
	chloride	mg/L	5.7	5.63	5.23	5.32	4.84
July 18, 2020							
	nitrate	mg/L	<0.01	<0.01	0.064	<0.01	<0.01
	iron	mg/L	0.015	<0.01	<0.01	0.014	0.01
	managanese	mg/L	0.0038	0.0078	0.0108	0.0149	0.0142
	alkalinity (as $CaCO_3$)	mg/L	150	145	138	138	135
	hardness (as $CaCO_3$)	mg/L	173	169	157	153	146
	chloride	mg/L	5.04	4.74	4.14	4.32	3.67

These results illustrate that:

- Nitrate concentrations were less than the analytical detection limit except for the shallow sample collected on July 18 at S1;
- Iron and manganese concentrations were greatest in the north end of the lake at S1 and N1; and
- Alkalinity, hardness and chloride concentrations decrease from the south end to the north end of the lake.

3.2 Distribution of Temperature, and Concentrations of Turbidity, Specific Conductance and Chloride from South to North

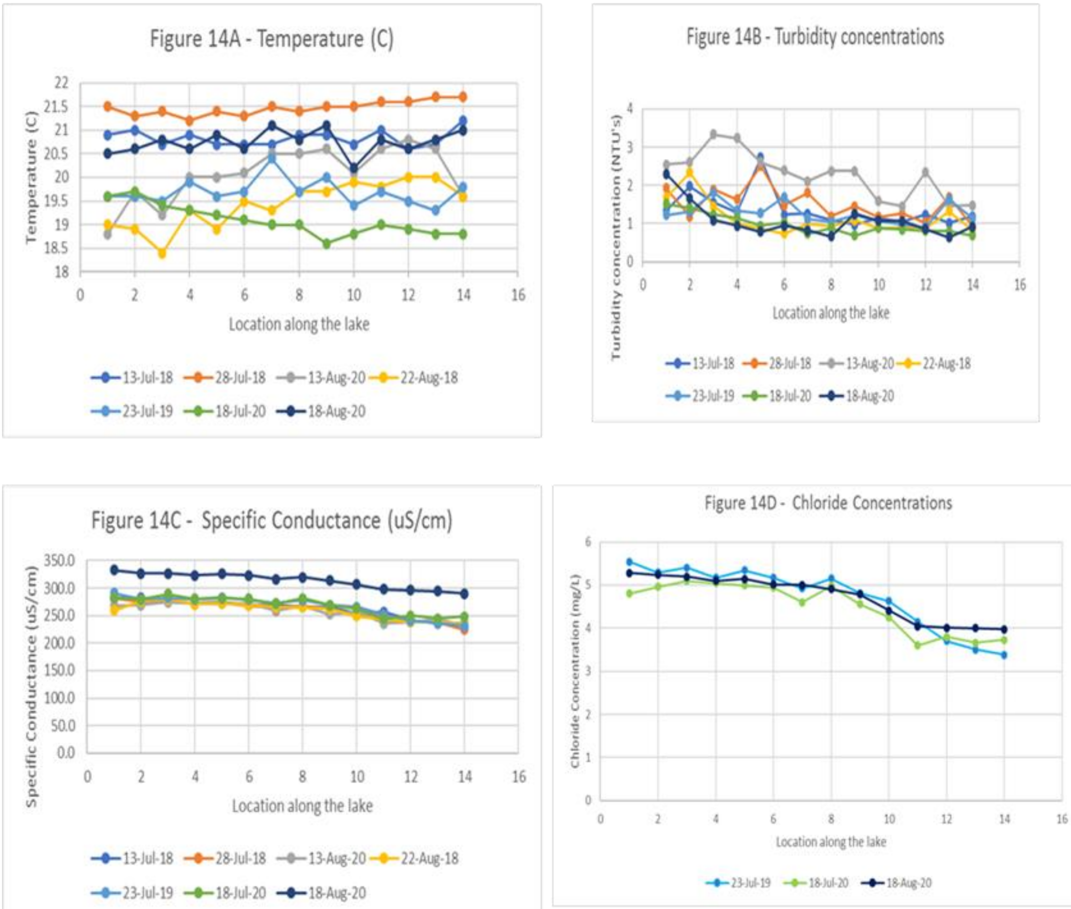
Temperature and concentrations of turbidity, specific conductance and chloride were measured at fourteen locations along the lake on three occasions over the summer of 2020. These measurements are tabulated in Table 3 along with similar measurements made in 2018 and 2019. The graphs of these parameters are plotted on Figure 14.

These measurements demonstrate that temperature is relatively constant along the lake on any given measurement date. However, concentrations of turbidity, specific conductance and chloride all decrease from the south end of the lake to the north end of the lake.

Table 3 - Temperature, Turbidity, Specific Conductance and Choride concentrations along Columbia Lake

	Date						
	2018				2019	2020	
Location	13-Jul-18	28-Jul-18	13-Aug-20	22-Aug-18	23-Jul-19	18-Jul-20	18-Aug-20
A) Temperature							
1	20.9	21.5	18.8	19	19.6	19.6	20.5
2	21	21.3	19.7	18.9	19.6	19.7	20.6
3	20.7	21.4	19.2	18.4	19.5	19.4	20.8
4	20.9	21.2	20	19.3	19.9	19.3	20.6
5	20.7	21.4	20	18.9	19.6	19.2	20.9
6	20.7	21.3	20.1	19.5	19.7	19.1	20.6
7	20.7	21.5	20.5	19.3	20.4	19	21.1
8	20.9	21.4	20.5	19.7	19.7	19	20.8
9	20.9	21.5	20.6	19.7	20	18.6	21.1
10	20.7	21.5	20.1	19.9	19.4	18.8	20.2
11	21	21.6	20.6	19.8	19.7	19	20.8
12	20.6	21.6	20.8	20	19.5	18.9	20.6
13	20.7	21.7	20.6	20	19.3	18.8	20.8
14	21.2	21.7	19.6	19.6	19.8	18.8	21
B) Turbidity concentrations (NTU's)							
1	1.34	1.92	2.55	1.68	1.22	1.51	2.3
2	1.98	1.19	2.61	2.34	1.31	1.42	1.66
3	1.55	1.89	3.33	1.45	1.82	1.24	1.09
4	1.29	1.64	3.23	1.01	1.34	1.15	0.94
5	2.72	2.51	2.61	0.87	1.27	0.94	0.79
6	1.23	1.48	2.39	0.74	1.69	1.03	0.94
7	1.26	1.81	2.11	1.01	1.12	0.74	0.82
8	1.09	1.18	2.37	0.93	1.04	0.88	0.66
9	0.97	1.45	2.38	1.09	1.22	0.69	1.26
10	1.14	1.17	1.59	0.88	1.08	0.88	1.08
11	1.04	1.26	1.45	0.89	0.97	0.85	1.06
12	1.24	1.03	2.35	0.87	0.91	0.81	0.86
13	1.02	1.69	1.47	1.32	1.64	0.8	0.64
14	1.18	0.92	1.48	0.83	1.14	0.69	0.92
C) Specific Conductance (uS/cm)							
1	281.8	281.3	268.2	259.3	290.3	282.1	332.7
2	281.8	274.4	269.3	275.6	279.4	279.0	326.8
3	275.4	275.8	274.1	279.8	282.3	288.9	326.5
4	273.5	270.3	272.7	270.6	279.2	280.5	322.8
5	274.2	273.0	272.0	272.2	283.2	281.1	325.3
6	269.9	267.9	272.5	268.5	278.8	280.4	323.2
7	268.6	264.5	258.6	265.6	272.0	271.4	316.1
8	266.7	267.4	266.9	264.6	278.0	281.0	319.5
9	266.5	262.0	252.3	262.2	269.1	269.1	313.5
10	253.4	251.5	257.2	248.7	265.0	263.2	306.2
11	256.9	251.7	236.1	243.5	251.6	243.8	298.1
12	241.4	239.3	238.6	238.7	241.4	249.9	296.0
13	236.6	237.6	243.1	238.3	235.5	244.6	294.1
14	235.7	224.4	232.4	234.8	230.3	247.7	290.1
D) Chloride Concentrations (mg/L							
1					5.54	4.8	5.28
2					5.29	4.96	5.24
3					5.4	5.10	5.19
4					5.17	5.05	5.1
5					5.34	4.99	5.14
6					5.17	4.94	5.01
7					4.92	4.6	5
8					5.15	4.98	4.91
9					4.81	4.56	4.78
10					4.63	4.25	4.41
11					4.15	3.6	4.04
12					3.7	3.8	4.01
13					3.5	3.66	4
14					3.38	3.73	3.97

Figure 14 – Distribution of Temperature, Turbidity, Specific Conductance and Chloride from South to North



The results of this survey should be confirmed by a repeat of the work in 2021.

3.3 Stream sampling program

The stream sampling sites were as follows:

> Dutch Creek – a high rate of turbulent flow, the creek bed was composed largely of boulders that were not stained with iron oxides, and the water was clear. There was no organic growth along the stream sides.
>
> Hardie Creek - steady and turbulent water flow - the creek bed had gravel-sized material with iron and manganese oxide staining (red to black colored coating) on the gravel particles - the water sampled was clear , no organic material along the stream sides;

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

Canal Flats Creek - steady water flow (no turbulence) - the creek bed was covered in fine-grained grey clay to silt type materials that were easily disturbed and became muddy quickly,mthe water sampled was clear and the stream banks were covered by marshy grasses.

In 2020 the four streams were monitored on June 15, July 23, August 27 and September 18. The water quality measurements and analyses made during the stream sampling program are in Table 4 and are plotted on Figure 15.

Figure 15- - Stream Water Comparison

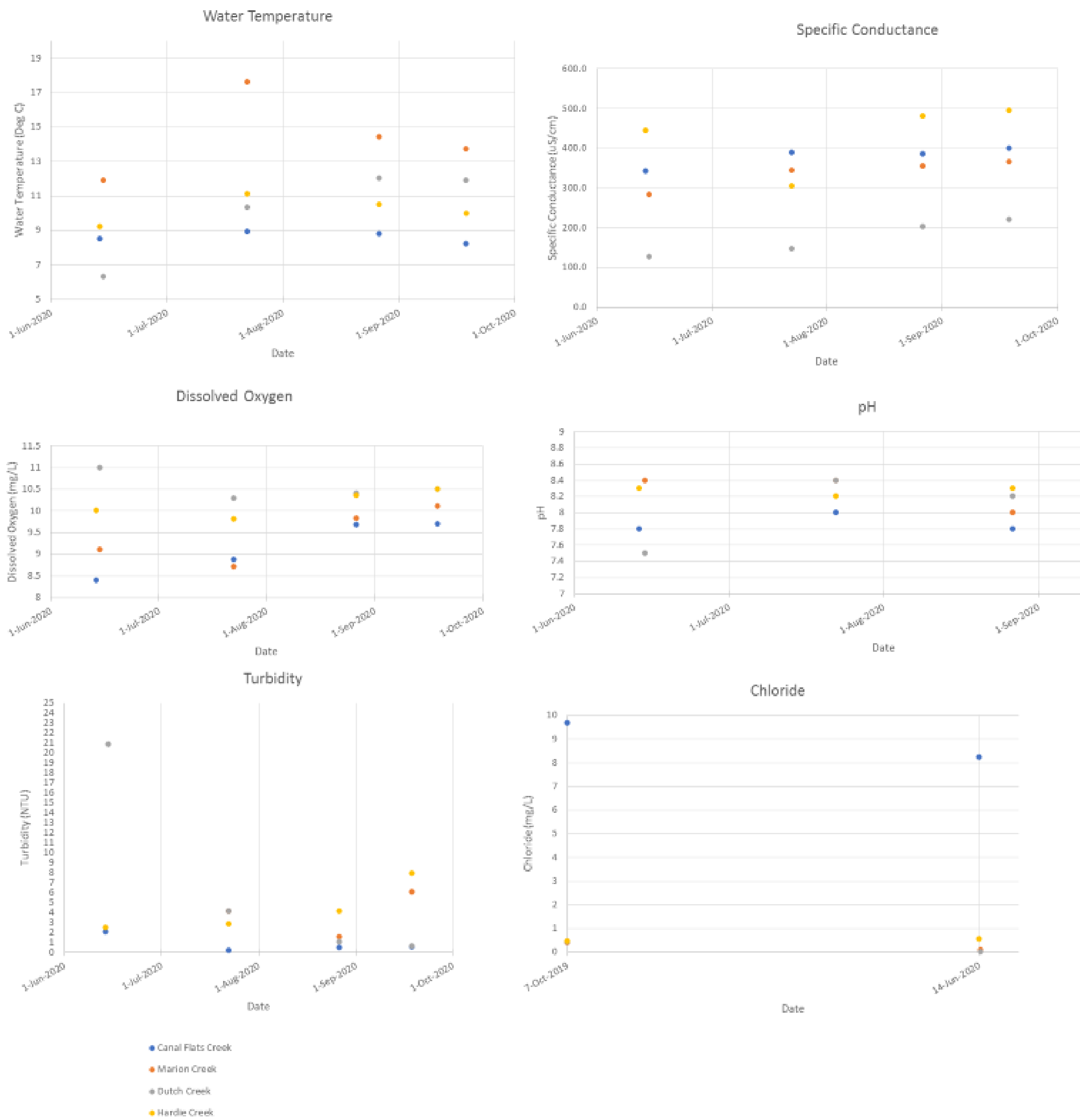


Table 4 - Comparison of Stream Quality Measurements

	Date	Time	Water Temp (°C)	Specific Cond. (uS/cm)	Dissolved Oxygen (mg/L)	pH	Turbidity (NTU)	Chloride (mg/L)
A) Dutch Creek	7-Oct-2019							0.43
	15-Jun-2020		6.3	126.2	11.0	7.5	20.8	0
	23-Jul-2020		10.3	147.2	10.3	8.4	4.1	
	27-Aug-2020	1:45:00 PM	12.0	201.5	10.4	8.2	1.0	
	19-Sep-2020	2:45:00 PM	11.9	221.0	10.5	8.4	0.6	
B) Hardie Creek	7-Oct-2019							0.45
	14-Jun-2020		9.2	444.0	10	8.3	2.47	0.56
	23-Jul-2020		11.1	303.8	9.81	8.2	2.85	
	27-Aug-2020	1:00:00 PM	10.5	481.3	10.36	8.3	4.09	
	19-Sep-2020	11:41:00 AM	10	494	10.5	7.9	7.9	
C) Marion Creek	7-Oct-2019							0.4
	15-Jun-2020		11.9	283.0	9.1	8.4		0.11
	23-Jul-2020		17.6	344.1	8.7	8.4	4.09	
	27-Aug-2020	11:15:00 AM	14.4	354.6	9.82	8	1.56	
	19-Sep-2020	2:20:00 PM	13.7	366	10.1	8.3	6.03	
D) creek flowing from Canal Flats	7-Oct-2019							9.68
	14-Jun-2020		8.5	341.0	8.4	7.8	2.01	8.22
	23-Jul-2020		8.9	388.6	8.88	8	0.17	
	27-Aug-2020	12:05:00 PM	8.8	385.3	9.68	7.8	0.47	
	19-Sep-2020	1:40:00 PM	8.2	400.3	9.7	7.4	0.53	

pH

The pH values ranged from 7.40 to 8.40. These results show that the lowest pH value was measured in Canal Flats at the south end of the lake. The lower pH at this location may be attributed to acidity generated by the decay of organic materials because the stream bank was well vegetated and the overall surrounding area marshy.

Dissolved oxygen

The dissolved oxygen measured ranged from 8.4 to 11.0 mg/L. The lowest dissolved concentration measured was at Marion Creek and the greatest in Dutch Creek.

Turbidity

Turbidity concentrations ranged from 0.17 to 6.03 NTUs. The greatest turbidity concentration was measured in Marion Creek.

Chloride

The concentrations of chloride measured in the four surface water samples in 2020 ranged from 0.11 mg/L to 8.22 mg/L. The greatest concentration was measured in the creek flowing from Canal Flats. The other three steams yielded chloride concentrations ranging from less than the analytical detection limit (Dutch Creek) to 0.56 (Hardie Creek).

4.0 Comparison to Nearby Lakes

Appendix C contains water quality information tabulated for Columbia Lake, Lake Windermere, Moyie Lake, Premier Lake and Whiteswan Lake using information obtained by CLSS from BCMOE's database. The information provided consists of biannual water quality results for Columbia Lake, Lake Windermere and Moyie Lake collected by BCMOE from 2015, 2016, 2017, 2018 and 2019 (Tables C-1, C-2, and C-3). CLSS also obtained biannual monitoring results from Premier Lake and Whiteswan Lake for 2018 and 2019 (Table C-4 and C-5). (We understand that 2018 was the first year that water quality monitoring was conducted on these two lakes.) In 2020 BCMOE collected and analyzed water quality samples form the five lakes in August only.

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

These data provide a more extensive list of water quality parameters than those monitored in the CLSS 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 5 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 Premier Lake or Whiteswan Lake because depths of these lakes are not known to us.

Table 5 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.

Table 5 - Comparison of Lake Concentrations

Parameter	Units	Columbia Lake Shallow (1 metre)		Columbia Lake Deep (4 metres) *		Lake Windermere (shallow 1 m)		Lake Windermere (Bottom 4 metres)*		Whiteswan Lake		Premier Lake		Moyie Lake north		Moyie Lake south	
		min	max	min	max	min	max	min	max	min	max	min	max	min	max	min	max
Chlorophyll a	ug/L	0.856	1.96			0.282	2.23			0.425	1.36	0.448	2.63	0.397	2.62	0.498 2	2.02
Field measurements																	
Conductivity	uS/cm	290.9	345.3	301.2	301.2	239.4	404.2			249.6	289.9	338.5	350.9	47.2	62.3	47	58.2
Dissolved Oxygen	mg/L	8.23	10.8			7.44	11.6			8.97	10.71	8.57	10.43	8.41	12.04	7.61	12.05
Secchi (H20 clarity)	m	3.18	4.5			2.72	5.3			9.2	9.2	14.2	14.2	3	9.05	3.05	6.4
pH	pH	8.14	8.4			7.88	8.7			7.33	8.95	8.15	9.66	6.26	9.33	6.6	8.4
Temperature	0C	7.8	20.7			8.1	20.7			6.07	17.8	7.4	20.8	3.7	19.9	4.4	20
Turbidity	NTU	0.49	0.93	0.55	0.95	0.3	1.04	0.51	1.39	0.19	0.25	0.2	0.36	0.25	11.7	0.29	1.63
Anions																	
Silica	mg/L	4.76	7.83	3.33	8.09	2.65	6.42	2.28	6.91	0.823	3.9	0.87	3.04	3.24	8.81	3.45	8.72
Orthophosphate (p)	mg/L	0.0012	0.0016	0.0012	0.006	0.001	0.0015	<0.001	0.0014			0.0012	0.0012	0.0017	0.0017	0.0018	0.0026
Dissolved Sulphate (SO4	mg/L	22.4	29.7	22.9	29.7	25	71.7	25	74.3	3.8	22.4	24.1	26	1.82	2.36	1.65	2.36
Dissolved Chloride (Cl)	mg/L	4.36	6.44	4.39	6.43	1.11	3.15	1.11	3.13	2.14	3	<0.5	<0.5	0.84	1.22	0.94	1.5
Calculated parameters																	
Hardness	mg/L	150	193	148	183	115	224	120	223	138	145	176	195.2	19.2	28.4	19.6	27.2
Misc. Organics																	
Total Organic Cargon	mg/L	1.03	3.27	1.79	3.35	1.51	2.36	1.22	2.29	1.45	1.94	2.19	2.56	2.33	3.44	2.44	3.4
Nutrients																	
Total Kjeldahl Nitrogen	mg/L	0.164	0.308	0.157	0.239	0.122	0.228	0.123	0.933	0.07	0.105	0.199	0.227	0.061	0.119	0.089	0.185
Dissolved Phosphorous	mg/L	0.002	0.0058	0.0031	0.0165	0.0021	0.0048	<0.002	0.0046	0.002	0.0035	0.003	0.0054	0.0021	0.0032	0.0022	0.042
Nitrate plus nitrite (n)	mg/L	0.002	0.0032			0.003	0.0195	0.0032	0.019	0.0052	0.0052			0.001	0.0728	0.0261	0.0445
Total Nitrogen (N)	mg/L	0.164	0.312	0.157	0.239	0.122	0.228	0.123	0.933	0.075	0.105	0.199	0.227	0.094	0.178	0.094	0.228
Total Phosphorous (P)	mg/L	0.002	0.0183	0.002	0.0175	0.0022	0.0067	0.003	0.185	0.0025	0.0037	0.0032	0.0065	0.0023	0.0052	0.0021	0.0086
Total metals by ICPMS																	
Aluminium (Al)	ug/L	1.52	13.5	3.13	7.08	1.29	4.49	1.44	4.67	1.16	3.33	1.28	3	17.4	34.8	18	59.8
Antimony (Sb)	ug/L	0.06	0.085	0.068	0.123	0.049	0.073	0.054	0.069	0.081	0.107	0.062	0.072	0.021	0.037	0.034	0.071
Arsenic (As)	ug/L	0.0663	1.26	0.629	1.18	0.535	1.19	0.564	1.23	0.246	0.278	0.373	0.414	0.202	0.24	0.217	0.306
Barium (Ba)	ug/L	68.2	85.7	67.7	81.5	56.7	86.1	56.1	83.6	92.3	102	81.4	94.7	4.91	7.85	5.8	8.66
Boron (B)	ug/L	5.5	7.2	5.6	7.2	5.7	9.2	5.6	8.2								
Cadmium (Cd)	ug/L															0.0299	0.0591
Chromium (Cr)	ug/L					0.14	0.14										
Cobalt (Co)	ug/L	0.015	0.0373	0.0224	0.0407	0.015	0.0344	0.014	0.0375	0.0094	0.0122	0.0137	0.022	0.0204	0.0365	0.0206	0.0563
Copper (Cu)	ug/L	0.131	0.423	0.161	0.352	0.123	0.403	0.148	0.24	0.097	0.568	0.079	0.97	0.359	0.646	0.598	2.36
Iron (Fe)	ug/L	2.2	18.8	10.9	18.4	8.7	43.7	10.3	43.9	1.3	4.6	1.5	3.5	14.1	41.5	21.3	61.3
Lead (Pb)	ug/L	0.008	0.0485	0.0263	0.0514	0.01	0.123	0.0138	0.0742	0.0076	0.024	0.00516	0.0469	0.0284	0.0688	1.17	3.68
Lithium (Li)	ug/L	2.52	3.4	2.89	3.32	1.58	3.8	1.7	3.69	1.09	1.25	2.7	2.94				
Manganese (Mn)	ug/L	4.2	12.6	2.11	9.87	5.1	29	5.17	43.5	0.427	2.26	1.12	2.42	2.04	3.61	2.45	4.91
Molybdenum (Mo)	ug/L	0.514	0.614	0.519	0.583	0.515	0.717	0.495	0.604	0.653	0.723	1.09	1.19	0.073	0.113	0.078	0.097
Nickel (Ni)	ug/L	0.05	0.138	0.074	0.142	0.05	0.192	0.068	0.112	0.061	0.091	0.102	0.102	0.099	0.153	0.134	0.196
Selenium (Se)	ug/L	0.041	0.059	0	0	0.044	0.082	0.051	0.055	0.063	0.079	0.077	0.192			0.042	0.042
Strontium (Sr)	ug/L	182	217	167	214	115	373	125	353	105	108	164	192	14.9	18.8	15.3	17.9
Thallium (Tl)	ug/L	0.0015	0.0025	0.0029	0.0029	0.0013	0.0057	<0.002	0.0047	<0.002	0.0074			0.003	0.0064	0.0021	0.007
Tin (Sn)	ug/L															0.011	0.011
Uranium (U)	ug/L	0.685	1.06	0.713	1.03	0.648	1.47	0.638	1.27	0.43	0.517	1.41	1.56	0.061	0.119	0.064	0.102
Vanadium (V)	ug/L	0.087	0.087	0	0	0.057	0.057										
Zinc (Zn)	ug/L	0.47	1.31	0.93	2.8	0.21	3.02	0.22	3.32	0.17	1.82	0.2	2.17	0.32	2.01	3.45	13.8
Calcium (Ca)	mg/L	25.3	40.4	25	37.9	23	48.9	24	48.9	37.1	39.4	28.7	28.9	2.67	8.33	5.69	7.97
Magnesium (Mg)	mg/L	18.5	23.3	18.7	21.8	14	25.6	14.5	24.5	11.2	12.2	26.1	26.2	1.36	3.44	1.4	1.87
Potassium (K)	mg/L	0.703	0.84	0.673	0.781	0.418	1	0.418	0.884	0.291	0.322	0.62	0.675	0.423	0.634	0.439	0.618
Sodium (Na)	mg/L	4.89	6.79	5.27	6.51	2.01	4.81	2.09	4.5	2.05	2.57	2.95	3.19	1.36	1.91	1.49	1.92

Concentration range is less than Columbia Lake

Concentration range is greater than Columbia Lake

* not updated with 2020 findings

Only the concentrations of conductivity, dissolved oxygen, turbidity, dissolved SO4, dissolved chloride, hardness, total Kjeldahl nitrogen, aluminum, barium, iron, lead, lithium, manganese, strontium and zinc are noticeably different (a factor of two or more) from the concentrations measured in Columbia Lake.

For this comparison, two colours are used to compare the range of concentrations measured by BCMOE in the other four lakes to the concentrations measured in Columbia Lake:

- Orange identifies concentrations that are noticeably greater than those measured in Columbia Lake; and
- Green identifies concentrations that are noticeably less than those measured in Columbia Lake.

Those parameters that are less than those measured in Columbia Lake should not be inferred to suggest that Columbia Lake has water quality issues but merely to identify parameters that should be monitored more extensively for spatial differences within the lake and for increasing trends that may suggest the beginning of a water quality concern.

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

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

Turbidity concentrations in both Lake Windermere and Moyie Lake are comparable to those measured in Columbia Lake although both Premier Lake and Whiteswan Lake contain much lower turbidity values. Anecdotal evidence suggest that the steep shorelines of Premier Lake and White Swan lake inhibit the growth of aquatic plants and minimizes shoreline erosion and the resuspension of bottom sediment. Consequently, it may be considered that the turbidity values reflect the shallowness of Columbia Lake and will differ from season to season depending upon the distrubance of the lake’s surface due to wind, surface drainage into the lake or recreational activity.

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

Dissolved chloride concentrations in Columbia Lake are noticeably greater than those measured in any of the nearby lakes, although the chloride concentrations in Lake Windermere and White Swan Lake are only slightly less than those measured in Columbia Lake. Because readily soluble naturally occurring chloride salts are not believed to be present in the sedimentary materials and bedrock formations that surround any of these lakes, the presence of chloride suggests a man-made source. The most common sources 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 noticeably greater than in Lake Windermere, Premier Lake, Whiteswan Lake and Moyie Lake. Although the concentrations measured will not influence the use of the lake water, the difference in concentrations between the five lakes is notable.

Dissolved sulphate concentrations in both Columbia Lake and Lake Windermere are greater than those measured in Whiteswan Lake, Premier Lake and Moyie Lake and are likely a consequence of the local rock formations. Also associated with sulphate bearing rock formations are the greater dissolved barium, calcium, magnesium, and strontium concentrations measured in the waters of Columbia Lake, Lake Windermere, Premier Lake and Whiteswan Lake than those measured on Moyie Lake. We understand that these compounds and elements occur naturally in geologic formations in the vicinity of these four lakes. The gypsum mine 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 Resort that are sulfurous. Barium, calcium, magnesium and strontium are elements commonly found with sulphate bearing minerals. 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, Premier Lake and White Swan Lake should be undertaken.

Molybdenum and uranium concentrations in Columbia Lake, Lake Windermere, Premier Lake and Whiteswan Lake are also greater than those measured in Moyie Lake and may be likewise attributed to the difference in geologic setting.

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

5.0 Suggested Monitoring Program for 2021

The monitoring program undertaken over the past seven years on Columbia Lake has shown that there are noticeable differences in concentrations for the indicator parameters between the north and south ends of the lake. In particular, CLSS has observed that:

- Over the summer months the turbidity concentration decreases and are similar in concentration from the south end to north end of the lake. A similar trend to declining values is observed in the pH values measured and in the dissolved oxygen concentrations;
- In contrast, the specific conductance concentrations increase over the summer months and are greater in the southern end of the lake;
- Total and dissolved phosphorous concentrations from time to time exceed those established as water quality objectives for Columbia Lake;
- Further we note that some trends in concentration over the years from 2014 to 2019 were not observed in 2020. Turbidity concentrations, for example, were observed to increase over the summer months in the earlier years, but not in 2020. Whether this is due to a shorter sampling period or a change in water quality cannot be determined. However, trends for the concentrations of other parameters are similar to those in other years;

- Profiles of concentrations for turbidity, specific conductance and chloride along the lake at 14 monitoring locations illustrate the concentrations decline from south to north. Whether this trend is due to the inflow of different surface or groundwater sources from one end of the lake to the other cannot be determined;
- The concentrations of the elements and compounds differ between the four streams. Most noticeable are the differences in concentration of chloride with the creek draining from Canal Flats containing the greatest concentration of chloride. This difference may in part explain why the lake water to the south also yields greater concentrations of specific conductance and chloride.

Columbia Lake also contains different concentrations of chloride than the other four neighbouring lakes monitored each year by BCMOE. Although chloride is not the only element or compound that has a concentration different than that found in the other lakes, it is of concern because there are no natural soils or rocks that can contribute chloride to surface water or groundwater draining into the lake.

Therefore, CLSS intends to proceed in 2021 with a similar program to that undertaken in 2020. The program will include:

- The “Regular” program of bi-weekly measurements of temperature, lake depth, Sechi depths, turbidity, specific conductance, pH and dissolved oxygen at the four locations (N1, S1, S3 and S4);
- Chemical analyses during the regular program in late May and mid-July for total and dissolved oxygen, nitrate, iron and manganese, alkalinity, hardness and chloride;
- Monitoring the distribution of temperature, turbidity, specific conductance and chloride on two occasions during the summer months (mid-July and mid-August);
- Monthly monitoring of the four creeks, Dutch Creek, Hardie Creek, Marion Creek and the creek draining from Canal Flats for temperature, turbidity, specific conductance, pH and dissolved oxygen;
- Twice per year (spring and fall) analyses of the creek waters for nitrate, total and dissolved phosphorous, iron and manganese, alkalinity, hardness and chloride;

Appendix A

Monitoring parameters and their application to understanding water quality changes

Note – these pages have been reproduced from another source

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

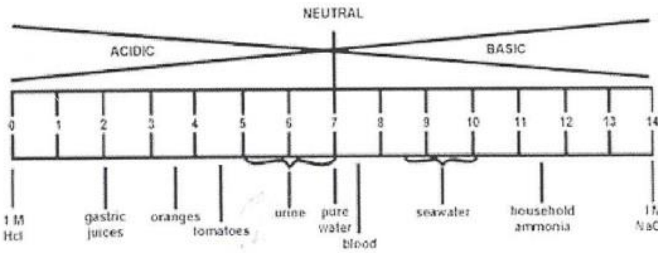
Turbidity is a measure of water clarity or more simply, how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. These materials are typically in the size 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. The spreadsheet is available on our web site http://columbialakess.com/

Several interested parties have asked for the data and we expected the electronic data would be more useful.

Appendix C

Water Quality Information for Columbia Lake, Lake Windermere, Moyie Lake, Premier Lake and Whiteswan Lake

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

January 13, 2021

Parameter	RDL*	Units	Location on the lake	Columbia lake midlake north, Surface (1 m)											Concentration Range	
			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	19-Apr-19	21-Aug-19	17-Aug-20	minimum	maximum
Chlorophyll a	0.5	ug/L		0.91	1.46	1.33	1.39	1.85	0.856	1.03	1.14	1.96	1.51	0.65	0.65	1.96
Chlorophyll a rep	0.5	ug/L		1.28	0.828	1.45	1.97	1.84	0.922							
Field measurements																
Conductivity	-	uS/cm		339.3	290.9	345.3	293	301.3		320.3		320.3	291	305	290.9	345.3
Dissolved Oxygen	-	mg/L		10.72	8.27	10.75	8.23	10.49	9.18	9.37		10.8	8.65	8.64	8.23	10.8
Secchi (H20 clarity)	-	m		4.5	3.6	4.5	3.6	3.18	4.4	3.9					3.18	4.5
pH	-	pH		8.27			8.4			8.36		8.14	8.17	8.17	8.14	8.4
Temperature	-	^0C		7.8	18.6	9.86	18.9	10.1	20.3	19.2		8.9	20.7	21	7.8	21
Turbidity		NTU				0.74		0.93				0.55	0.72	0.49	0.49	0.93
Anions																
Silica	0.5	mg/L		4.91	7.69	5.97	7.13	4.76	7.83	6.18	6.99	5.12	7.11	5.65	4.76	7.83
Orthophosphate (p)	0.001	mg/L		0.0012	<0.001	0.0015	<0.001	<0.001	<0.001	0.0016	0.0016	<0.001	<0.001	0.001	0.001	0.0016
Dissolved Sulphate (SO4)	0.5	mg/L		27.6	22.4	29.7	25.3	29	23.1	27.1	22.9	26.7	25.1	24.1	22.4	29.7
Dissolved Chloride (Cl)	0.5	mg/L		6.1	5.47	6.44	5.92	5.88	4.78	5.01	4.38	5.09	4.58	4.36	4.36	6.44
Calculated parameters																
Hardness	0.5	mg/L		169	151	193	150	182	151		153	165	156	149	149	193
Misc. Organics																
Total Organic Cargon	0.5	mg/L		1.03	2.51	1.95	3.27	2.23	2.71	2.42	2.65	2.05	2.62	2.29	1.03	3.27
Nutrients																
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.23	0.227	0.169	0.226	0.187	0.224	0.164	0.255	0.188	0.256	0.308	0.164	0.308
Dissolved Phosphorous (P)	0.002	mg/L		0.0058	0.003	0.002	0.002	0.002	0.0021	0.002	0.0029	0.0025	0.0023	0.0026	0.002	0.0058
Nitrate plus nitrite (n)	0.002	mg/L		<0.002	0.002	0.0032	0.0032	0.0032	<0.0032	<0.0032	<0.003	<0.003	<0.003	0.0032	0.002	0.0032
Total Nitrogen (N)	0.02	mg/L		0.23	0.227	0.169	0.226	0.187	0.312	0.164	0.255	0.188	0.256	0.303	0.164	0.312
Total Phosphorous (P)	0.002	mg/L		0.0183	0.0043	0.0031	0.0039	0.004	0.0058	0.002	0.0064	0.0046	0.0023	0.0056	0.002	0.0183
Total metals by ICPMS																
Aluminium (Al)	0.5	ug/L		6.18		4.23		4.02		13.500		2.08	1.52	3.69	1.52	13.5
Antimony (Sb)	0.02	ug/L		0.073		0.065		0.071		0.085		0.06	0.077	0.072	0.06	0.085
Arsenic (As)	0.02	ug/L		0.644		0.0663		0.696		0.767		0.621	1.26	1.1	0.0663	1.26
Barium (Ba)	0.02	ug/L		74.3		76.5		85.7		71.0		74.8	68.2	70.8	68.2	85.7
Beryllium (Be)	0.01	ug/L		<0.01		<0.01		<0.01		<0.02		<0.01	<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005		<0.005		<0.001		<0.005	<0.005	<0.005		
Boron (B)	10	ug/L		<10		<10		<10		5.500		5.9	7.2	6.2	5.5	7.2
Cadmium (Cd)	0.005	ug/L		<0.005		<0.005		<0.005		<0.0050		<0.005	<0.005	<0.005		
Chromium (Cr)	0.1	ug/L		<0.01		<0.1		<0.1		<0.0050		<0.1	<0.1	<0.1		
Cobalt (Co)	0.005	ug/L		0.027		0.0293		0.0373		0.029		0.024	0.015	<0.001	0.015	0.0373
Copper (Cu)	0.05	ug/L		0.259		0.135		0.182		0.423		0.224	0.22	0.131	0.131	0.423
Iron (Fe)	1	ug/L		18.8		14.5		13.7		16.400		14.9	2.2	12	2.2	18.8
Lead (Pb)	0.005	ug/L		0.0481		0.0384		0.0485		0.041		<0.005	0.008	0.0156	0.008	0.0485
Lithium (Li)	0.5	ug/L		3.07		3.37		3.4		2.850		3.19	2.94	2.52	2.52	3.4
Manganese (Mn)	0.05	ug/L		6.25		9.21		10.3		12.600		7.02	4.2	15.3	4.2	15.3
Molybdenum (Mo)	0.05	ug/L		0.514		0.532		0.54		0.614		0.539	0.59	0.492	0.492	0.614
Nickel (Ni)	0.02	ug/L		0.138		0.069		0.05		0.126		0.13	0.06	0.061	0.05	0.138
Selenium (Se)	0.04	ug/L		<0.04		0.041		<0.04		0.059		<0.04	0.046	<0.04	0.041	0.059
Silver (Ag)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005	<0.005	<0.005	<0.005	<0.005	0	0
Strontium (Sr)	0.05	ug/L		217		215		202		195.000		183	183	182	182	217
Thallium (Tl)	0.002	ug/L		<0.002		<0.002		0.0025		0.002		--	--		0.0015	0.0025
Tin (Sn)	0.2	ug/L		<0.2		<0.01		<0.01		<0.01		<0.01	<0.05	<0.002		
Uranium (U)	0.002	ug/L		1		0.933		1.02		1.060		0.926	0.752	0.685	0.685	1.06
Vanadium (V)	0.2	ug/L		<0.2		<0.2		<0.2		0.087		<0.2	<0.2	<0.2	0.087	0.087
Zinc (Zn)	0.1	ug/L		0.47		0.55		0.509		1.310		0.84	0.5	1.08	0.47	1.31
Calcium (Ca)	0.05	mg/L		34.2	26.2	38.8	26.9	37.9	28.6	40.4	25.3	34.9	28.5	29	25.3	40.4
Magnesium (Mg)	0.05	mg/L		20.4	20.7	23.3	20.1	21.3	19.4	19.8	21.8	18.9	20.5	18.5	18.5	23.3
Potassium (K)	0.05	mg/L				0.84		0.8		0.834		0.795	0.703	0.74	0.703	0.84
Sodium (Na)	0.05	mg/L				6.79		6.71		5.58		6.05	5.47	4.89	4.89	6.79

RDL reportable detection limit

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

January 13, 2021

			Location on the lake	Lake Windermere off Timber Ridge											Concentration Range	
Parameter	RDL*	Units		Shallow (1 metre)											minimum	maximum
			Date sampled	15-Apr-15	26-Sep-15	7-Apr-16	24-Sep-16	25-Apr-17	29-Aug-17	16-May-18	4-Sep-18	19-Apr-19	20-Aug-19	17-Aug-20		
Chlorophyll a	0.5	uG/L		0.85	1.83	1.1	1.64	1.14	2.23	1.66	2.07	1.12	1.53	0.281	0.281	2.23
Chlorophyll a rep	0.5	uG/L		0.82	1.08	1.27		2.02	2.14							
Field measurements																
Conductivity	-	uS/cm		389.3	268.9	404.2	256	350.4		401		403.1	239.4	266	239.4	404.2
Dissolved Oxygen	-	mg/L		10.85	7.79	11.6	7.44	10.47	7.99	9.18		11.1	8.59	8.41	7.44	11.6
Secchi (H20 clarity)	-	m		5	4.65	5.3	5.3	2.72	4	3.7		--	--	--	2.72	5.3
pH	-	pH		-					8.23	7.88		8.02	8.7	8.45	7.88	8.7
Temperature	-	^0C		8.4	19.3	9.75	19.8	11.6	20	17.7		8.1	20.7	21	8.1	21
Turbidity		NTU				0.57	0.67	1.04	0.75			0.65	0.47	0.3	0.3	1.04
Anions																
Silica	0.5	mg/L		4.49	5.84	5.5	5.8	3.84	6.42	3.71	6.4	4.34	2.65	2.56	2.56	6.42
Orthophosphate (p)	0.001	mg/L		0.0011	0.001	<0.001	<0.001	<0.001	<0.001	0.0015	<0.001	<0.001	<0.001	<0.001	0.001	0.0015
Dissolved Sulphate (SO4)	0.5	mg/L		70.8	28.4	71.7	30.5	71.6	31	71.1	32.3	65.8	25	27.8	25	71.7
Dissolved Chloride (Cl)	0.5	mg/L		2.9	1.68	3.15	1.45	2.91	1.57	3.04	1.44	2.91	1.11	1.36	1.11	3.15
Calculated parameters																
Hardness	0.5	mg/L		201	148	224	149	203	148		153	197	115	132	115	224
Misc. Organics																
Total Organic Cargon	0.5	mg/L		<0.5	1.86	1.63	1.96	1.55	2.36	2.03	1.87	1.51	1.96	1.5	1.5	2.36
Nutrients																
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.183	0.193	0.122	0.139	0.183	0.198	0.16	0.228	0.17	0.157	0.169	0.122	0.228
Dissolved Phosphorous (P)	0.002	mg/L		0.0033	0.0031	<0.002	<0.002	<0.002	0.0021	0.0038	0.0029	0.0021	0.0048	0.0041	0.0021	0.0048
Nitrate plus nitrite (n)	0.002	mg/L		<0.002	<0.0032	<0.0032	<0.0032	<0.0032	<0.0032	<0.003	<0.003	0.0195	<0.0034	0.0032	0.0032	0.0195
Total Nitrogen (N)	0.02	mg/L		0.183	0.193	0.122	0.139	0.183	0.198	0.16	0.228	0.19	0.157	0.169	0.122	0.228
Total Phosphorous (P)	0.002	mg/L		0.0056	0.0042	0.0033	0.0035	0.0042	0.0022	0.0046	0.0067	0.0049	0.0066	0.0039	0.0022	0.0067
Total metals by ICPMS																
Aluminium (Al)	0.5	ug/L		4.33		1.29	1.56	4.17	3.02	4.09		4.49	4.17	2.23	1.29	4.49
Antimony (Sb)	0.02	ug/L		0.049		0.05	0.063	0.061	0.073	0.07		0.071	0.062	0.062	0.049	0.073
Arsenic (As)	0.02	ug/L		0.672		0.585	1.06	0.634	1.19	0.80		0.535	0.929	1.06	0.535	1.19
Barium (Ba)	0.02	ug/L		77.9		83.9	66.8	83.7	67.2	86.10		81.1	56.7	63.9	56.7	86.1
Beryllium (Be)	0.01	ug/L		<0.01		<0.01	<0.01	<0.01	<0.01	<0.002		<0.01	<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005	<0.005	<0.005	<0.005	<0.001		<0.005	<0.005	<0.005		
Boron (B)	10/1	ug/L		<10		9.2	5.9	8.2	5.7	8.00		7.8	<0.005	<0.005	5.7	9.2
Cadmium (Cd)	0.005	ug/L		<0.005		<0.005	<0.005	<0.005	<0.005	<0.005		<0.005	<0.005	<0.005	0	0
Chromium (Cr)	0.1	ug/L		<0.1		<0.1	<0.1	<0.1	<0.1	<0.05		0.14	<0.1	<0.1	0.14	0.14
Cobalt (Co)	0.005	ug/L		0.015		0.0165	0.0161	0.0344	0.0232	0.0274		0.028	0.0259	<0.005	0.015	0.0344
Copper (Cu)	0.05	ug/L		0.172		0.123	0.188	0.147	0.179	0.4030		0.287	0.264	0.152	0.123	0.403
Iron (Fe)	1	ug/L		43.7		28.9	8.7	24.6	11.6	17.00		34.8	11.1	10.9	8.7	43.7
Lead (Pb)	0.005	ug/L		0.0311		0.0192	0.025	0.0589	0.0346	0.0339		0.123	0.038	0.01	0.01	0.123
Lithium (Li)	0.5	ug/L		3.62		3.8	1.91	3.43	2.13	3.63		3.73	1.58	1.7	1.58	3.8
Manganese (Mn)	0.05	ug/L		5.1		12.9	29	25.3	26	23.30		9.73	12.3	7.6	5.1	29
Molybdenum (Mo)	0.05	ug/L		0.581		0.515	0.564	0.598	0.574	0.72		0.578	0.549	0.572	0.515	0.717
Nickel (Ni)	0.02	ug/L		0.093		0.058	0.083	0.05	0.139	0.19		0.13	0.138	0.083	0.05	0.192
Selenium (Se)	0.04	ug/L		<0.04		0.044	0.044	<0.04	0.047	0.08		0.055	0.049	<0.04	0.044	0.082
Silver (Ag)	0.005	ug/L		<0.005		<0.005	<0.005	<0.005	<0.005	<0.005		<0.005	<0.005	<0.005	0	0
Strontium (Sr)	0.05	ug/L		373		340	138	297	143	292		281	115	151	115	373
Thallium (Tl)	0.002	ug/L		<0.002		<0.002	<0.002	0.0041	0.0027	0.0013		0.0057	<0.002	--	0.0013	0.0057
Tin (Sn)	0.2/0.01	ug/L		<0.2		<0.01	<0.01	<0.01	<0.01	<0.01		<0.01	<0.05	<0.002	0	0
Uranium (U)	0.002	ug/L		1.18		1.1	0.726	1.24	0.843	1.47		1.23	0.648	0.647	0.647	1.47
Vanadium (V)	0.2	ug/L		<0.2		<0.2	<0.2	<0.2	<0.2	0.06		<0.2	<0.2	<0.2	0.057	0.057
Zinc (Zn)	0.1	ug/L		0.21		0.26	1.42	3.02	1.09	1.37		1.6	1.85	1.84	0.21	3.02
Calcium (Ca)	0.05	mg/L		42.9	33.2	47.7	34.7	45.9	33.9	48.9		46	23	28.8	23	48.9
Magnesium (Mg)	0.05	mg/L		22.8	15.9	25.6	15.1	21.5	15.9	24.5		20	14	14.7	14	25.6
Potassium (K)	0.05	mg/L				0.964	0.71	0.833	0.709	1.000		0.888	0.418	0.551	0.418	1
Sodium (Na)	0.05	mg/L				4.81	2.17	4.06	2.37	4.42		4.59	2.01	2.06	2.01	4.81

RDL Reportable Detection Limit

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

January 13, 2021

Parameter	RDL*	Units	Location on the lake / Date sampled	Moyie Lake, Lower/South Shallow (1 to 10 metres)											Concentration Range	
			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	20-Apr-19	22-Aug-19	19-Aug-20	minimum	maximum
Chlorophyll a	0.5	ug/L		1.51	1.35	2.02	1.19	1.23	1.03	0.52	1.22	1.16	0.985	0.498	0.498	2.02
Chlorophyll a rep	0.5	ug/L		2.25	1.54	2.05	1.11	1.14	0.94			-	-			
Field measurements																
Conductivity	-	uS/cm		53.4	52.2	56.5		48.3	49.6	58.2	-	58.1	55.6	47.2	47.2	58.2
Dissolved Oxygen	-	mg/L		12.05	7.61	10.93		10.54	8.43	10.98	-	11.14	8.32	8.28	7.61	12.05
Secchi (H20 clarity)	-	m		3.1	6.2	6.1		4.6	6.4	3.05	-	-	-	--	3.05	6.4
pH	-	pH			7.5				7.47	8.4	-	8.17	6.6	7.93	6.6	8.4
Temperature	-	^{o}C		5.2	18.7	5.27		4.4	20	6.2	-	4.4	19.9	20.5	4.4	20.5
Turbidity		NTU				0.64		0.78		1.63	-	0.38	0.29	0.2	0.2	1.63
Anions																
Silica	0.5	mg/L		7.89	8.12	8.72	7.53	8.32	7.15	8.6	6.99	3.79	3.6	3.45	3.45	8.72
Orthophosphate (p)	0.001	mg/L		0.0026	0.0018	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0018	0.0026
Dissolved Sulphate (SO4)	0.5	mg/L		1.65	2.01	2.25	1.77	2.04	1.83	2.36	1.74	1.84	2.16	1.79	1.65	2.36
Dissolved Chloride (Cl)	0.5	mg/L		1.5	1.07	1.34	0.99	1.28	1.14	1.21	1.04	1.26	1.19	0.94	0.94	1.5
Calculated parameters																
Hardness	0.5	mg/L		22.7	23.1	26.3	21.2	27.2	22.1	24.4	20.3	23.1	23.1	19.6	19.6	27.2
Misc. Organics																
Total Organic Cargon	0.5	mg/L		2.52	2.66	2.44	2.85	2.8	3	3.4	2.96	2.72	2.5	3.12	2.44	3.4
Nutrients																
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.09	0.094	0.089	0.162	0.185	0.1	0.108	0.121	0.093	0.116	0.107	0.089	0.185
Dissolved Phosphorous (P)	0.002	mg/L		0.0056	<0.002	<0.002	<0.002	0.0022	<0.002	-	0.042	<0.002	<0.002	<0.002	0.0022	0.042
Nitrate plus nitrite (n)	0.002	mg/L		0.0322	<0.0032	0.0261	<0.0032	0.0445	<0.0032	0.0365	<0.003	0.0346	<0.003	<0.0032	0.0261	0.0445
Total Nitrogen (N)	0.02	mg/L		0.122	0.094	0.115	0.161	0.228	0.1	0.144	0.121	0.127	0.118	0.107	0.094	0.228
Total Phosphorous (P)	0.002	mg/L		0.0086	0.0021	0.0069	<0.002	<0.002	0.0025	0.0045	0.0024	0.0045	0.0023	<0.002	0.0021	0.0086
Total metals by ICPMS																
Aluminium (Al)	0.5	ug/L		39.8		28.3		44.9		59.8		18	18.7	21.1	18	59.8
Antimony (Sb)	0.02	ug/L		0.037		0.038		0.034		0.042		0.071	0.054	0.043	0.034	0.071
Arsenic (As)	0.02	ug/L		0.219		0.221		0.217		0.221		0.233	0.306	0.242	0.217	0.306
Barium (Ba)	0.02	ug/L		6.57		6.96		6.81		8.66		5.8	6.52	5.92	5.8	8.66
Beryllium (Be)	0.01	ug/L		<0.01		<0.01		<0.01		<0.01		<0.01	<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005		<0.005	<0.005	<0.005		
Boron (B)	10	ug/L		<10		<10		<10		<5		<5	<5	<5		
Cadmium (Cd)	0.005	ug/L		0.0318		0.0464		0.0591		0.0591		0.0427	0.0299	<0.003	0.0299	0.0591
Chromium (Cr)	0.1	ug/L		<0.1		<0.1		<0.1		<0.1		<0.1	<0.1	<0.1		
Cobalt (Co)	0.005	ug/L		0.0364		0.0292		0.0419		0.0563		0.0256	0.0206	<0.02	0.0206	0.0563
Copper (Cu)	0.05	ug/L		0.71		0.598		2.36		0.986		0.62	0.612	0.808	0.598	2.36
Iron (Fe)	1	ug/L		50.2		36.6		57.1		61.3		27.3	21.3	25.9	21.3	61.3
Lead (Pb)	0.005	ug/L		1.17		1.96		1.73		1.62		2.56	3.68	3.27	1.17	3.68
Lithium (Li)	0.5	ug/L		<0.5		<0.5		<0.5		<0.5		<0.5	<0.5	<0.5		
Manganese (Mn)	0.05	ug/L		2.98		3.69		4.68		4.91		4.63	2.8	2.45	2.45	4.91
Molybdenum (Mo)	0.05	ug/L		0.081		0.089		0.078		0.086		0.091	0.097	0.084	0.078	0.097
Nickel (Ni)	0.02	ug/L		0.162		0.184		0.173		0.196		0.146	0.159	0.134	0.134	0.196
Selenium (Se)	0.04	ug/L		<0.04		<0.04		<0.04		<0.04		<0.04	0.042	<0.04	0.042	0.042
Silver (Ag)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005		<0.005	<0.005	<0.005		
Strontium (Sr)	0.05	ug/L		17.7		17.9		15.3		17.5		16.9	16.1	15.6	15.3	17.9
Thallium (Tl)	0.002	ug/L		<0.002		0.0022		0.0039		0.0070		0.0025	0.0021	<0.002	0.0021	0.007
Tin (Sn)	0.2/0.01	ug/L		<0.2		<0.01		<0.01		0.0110		<0.01	<0.05	<0.05	0.011	0.011
Uranium (U)	0.002	ug/L		0.0806		0.0763		0.0787		0.1020		0.0797	0.0733	0.069	0.069	0.102
Vanadium (V)	0.2	ug/L		<0.2		<0.2		<0.2		<0.2		<0.2	<0.2	<0.2		
Zinc (Zn)	0.1	ug/L		9.31		7.95		13.8		10		6.52	3.83	3.45	3.45	13.8
Calcium (Ca)	0.05	mg/L		6.32	6.59	7.45	6.03	7.97	6.34	6.71	5.69	6.54	6.58	5.55	5.55	7.97
Magnesium (Mg)	0.05	mg/L		1.68	1.62	1.87	1.48	1.77	1.54	1.81	1.49	1.65	1.64	1.4	1.4	1.87
Potassium (K)	0.05	mg/L				0.575		0.618		0.598		0.536	0.489	0.439	0.439	0.618
Sodium (Na)	0.05	mg/L				1.89		1.92		1.92		1.73	1.72	1.49	1.49	1.92

*RDL Reportable Detection Limit

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

January 13, 2021

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	20-Apr-19	22-Aug-19	19-Aug-20	Concentration Range minimum	maximum
Chlorophyll a	0.5	ug/L		1.86	2.62	1.79	1.08	0.397	0.884	1.44	0.997	1.52	1.55	0.622	0.397	2.62
Chlorophyll a rep	0.5	ug/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	-	61.4	55.8	48.4	47.2	62.3
Dissolved Oxygen	-	mg/L		12.04	9.08	10.99	8.6	11.11	8.46	10.85	-	11.18	8.47	8.42	8.42	12.04
Secchi (H20 clarity)	-	m		3	8.6	7.6	9.05	4.5	5.85	4.9	-	-			3	9.05
pH	-	pH			7.8		8	7.3	7.56	9.33	-	8.99	6.26	7.99	6.26	9.33
Temperature	-	°C		4.3	19.9	4.8	18.9	3.7	19.4	6.8	-	3.7	18.9	19.8	3.7	19.9
Turbidity		NTU				0.5		0.69		11.7	-	0.27	0.3	0.25	0.25	11.7
Anions																
Silica	0.5	mg/L		8.1	7.91	8.72	8.26	8.52	8.81	8.58	7.2	7.85	3.8	3.24	3.24	8.81
Orthophosphate (p)	0.001	mg/L		<0.001	0.0017	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	0.0017	0.0017
Dissolved Sulphate (SO4)	0.5	mg/L		1.84	2.01	2.36	2.1	2.22	2.26	2.35	1.83	1.96	2.26	1.82	1.82	2.36
Dissolved Chloride (Cl)	0.5	mg/L		1	0.91	1.17	1.02	1.22	0.88	1.19	0.89	1.09	1.05	0.81	0.81	1.22
Calculated parameters																
Hardness	0.5	mg/L		23	22.5	25.9	23.9	28.4	22.9	27.4	20.5	23.6	23	19.2	19.2	28.4
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	2.56	2.69	2.93	2.33	3.44
Nutrients																
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.103	0.094	0.078	0.061	0.114	0.098	0.106	0.119	0.086	0.101	0.118	0.061	0.119
Dissolved Phosphorous (P)	0.002	mg/L		0.003	0.0021	<0.002	<0.002	0.0032	0.0025	0.0028	0.0032	<0.002	<0.002	<0.002	0.0021	0.0032
Nitrate plus nitrite (n)	0.002	mg/L		0.0462	0.032	0.0454	0.0536	0.0632	0.0728	0.0495	0.063	0.056	<0.003	0.001	0.001	0.0728
Total Nitrogen (N)	0.02	mg/L		0.149	0.094	0.124	0.114	0.178	0.098	0.155	0.125	0.142	0.104	0.118	0.094	0.178
Total Phosphorous (P)	0.002	mg/L		0.0033	<0.002	<0.002	<0.002	0.0039	0.0023	0.0052	<0.002	0.0039	0.0046	0.0027	0.0023	0.0052
Total metals by ICPMS																
Aluminium (Al)	0.5	ug/L		32.3		26.5		32.4		34.80		17.4	18.7	26.2	17.4	34.8
Antimony (Sb)	0.02	ug/L		0.024		0.021		0.022		0.03		0.037	0.026	0.024	0.021	0.037
Arsenic (As)	0.02	ug/L		0.213		0.202		0.211		0.21		0.24	0.219	0.198	0.198	0.24
Barium (Ba)	0.02	ug/L		6.21		6.15		6.42		7.85		6.69	6.25	4.91	4.91	7.85
Beryllium (Be)	0.01	ug/L		<0.010		<0.01		<0.01		<0.01		<0.01	<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005		<0.005	<0.005	<0.005		
Boron (B)	10	ug/L		<10		<10		<10		<0.0050		<0.005	<0.005	<0.005		
Cadmium (Cd)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005		<0.005	<0.005	<0.005		
Chromium (Cr)	0.1	ug/L		<0.1		<0.1		<0.1		<0.1		<0.1	<0.1	<0.1		
Cobalt (Co)	0.005	ug/L		0.0333		0.0267		0.0365		0.0348		0.024	0.0204	<0.002	0.0204	0.0365
Copper (Cu)	0.05	ug/L		0.646		0.491		0.359		0.574		0.467	0.519	0.507	0.359	0.646
Iron (Fe)	1	ug/L		37.9		28		36.4		41.50		19.7	14.1	17.6	14.1	41.5
Lead (Pb)	0.005	ug/L		0.0489		0.0356		0.0688		0.0623		0.0346	0.0284	<0.003	0.0284	0.0688
Lithium (Li)	0.5	ug/L		<0.5		<0.5		<0.5		<0.5		<0.5	<0.5	<0.5	0	0
Manganese (Mn)	0.05	ug/L		2.31		2.39		3.09		3.14		3.61	2.04	1.66	1.66	3.61
Molybdenum (Mo)	0.05	ug/L		0.094		0.105		0.085		0.113		0.106	0.092	0.073	0.073	0.113
Nickel (Ni)	0.02	ug/L		0.144		0.136		0.153		0.152		0.099	0.152	0.125	0.099	0.153
Selenium (Se)	0.04	ug/L		<0.040		<0.04		<0.04		<0.04		<0.04	<0.04	<0.04	0	0
Silver (Ag)	0.005	ug/L		<0.005		<0.005		<0.005		<0.005		<0.005	<0.005	<0.005	0	0
Strontium	0.05	ug/L		17.9		18.8		16.1		18.60		18	16.4	14.9	14.9	18.8
Thallium (Tl)	0.002	ug/L		<0.002		0.003		0.0038		0.0064		0.0048	<0.002	<0.002	0.003	0.0064
Tin (Sn)	0.2/0.01	ug/L		<0.2		<0.01		<0.01		<0.01		<0.01	<0.05	<0.05	0	0
Uranium (U)	0.002	ug/L		0.0902		0.0841		0.0969		0.1190		0.101	0.077	0.067	0.067	0.119
Vanadium (V)	0.2	ug/L		<0.2		<0.2		<0.2		<0.2		<0.2	<0.2	<0.2	0	0
Zinc (Zn)	0.1	ug/L		0.46		0.32		2.01		1.69		0.51	1.02	1.44	0.32	2.01
Calcium (Ca)	0.05	mg/L		6.38	6.43	7.21	6.79	8.33	7.36	7.21	2.67	6.88	6.58	5.45	2.67	8.33
Magnesium (Mg)	0.05	mg/L		1.71	1.57	1.92	1.68	1.85	1.83	1.89	3.44	1.67	1.64	1.36	1.36	3.44
Potassium (K)	0.05	mg/L				0.589		0.604		0.634		0.594	0.496	0.423	0.423	0.634
Sodium (Na)	0.05	mg/L				1.71		1.67		1.91		1.65	1.56	1.36	1.36	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 Premier Lake Deepest Point Shallow samples

January 17, 2021

Parameter	RDL*	Units	Location on the lake	Premier Lake					Concentration Range	
				Shallow 1 to 10 meter)					minimum	maximum
			Date sampled	3-May-18	6-Sep-18	1-May-19	23-Aug-19	24-Aug-20		
Chlorophyll a	0.5	ug/L		0.864	0.448	2.63	0.748	0.594	0.448	2.63
Chlorophyll a rep	0.5	ug/L				-	-			
Field measurements										
Conductivity	-	uS/cm		338.5		350.9	340	342	338.5	350.9
Dissolved Oxygen	-	mg/L		10.11		10.43	9.08	8.52	8.52	10.43
Secchi (H20 clarity)	-	m		14.2		-	-		14.2	14.2
pH	-	pH		9.66		8.35	8.15	9.09	8.15	9.66
Temperature	-	^{0}C		10.6		7.4	20.8	20.3	7.4	20.8
Turbidity		NTU		0.27		0.36	0.25	0.2	0.2	0.36
Anions										
Silica	0.5	mg/L		3.04	1.93	1.31	0.87	0.899	0.87	3.04
Orthophosphate (p)	0.001	mg/L		0.0012	<0.001	<0.001	<0.001	<0.001	0.0012	0.0012
Dissolved Sulphate (SO4)	0.5	mg/L		25.4	25.8	26	24.1	25.7	24.1	26
Dissolved Chloride (Cl)	0.5	mg/L		<0.5	<0.5	<0.5	<0.5	<0.5		
Calculated parameters										
Hardness	0.5	mg/L		179	176	179.6	195.2	189	176	195.2
Misc. Organics										
Total Organic Cargon	0.5	mg/L		2.19	2.56	2.45	2.4	2.51	2.19	2.56
Nutrients										
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.219	0.227	0.208	0.224	0.199	0.199	0.227
Dissolved Phosphorous (P)	0.002	mg/L		0.003	0.0054	0.0032	<0.002	0.0032	0.003	0.0054
Nitrate plus nitrite (n)	0.002	mg/L		<0.003	<0.003	<0.003	<0.003	<0.003		
Total Nitrogen (N)	0.02	mg/L		0.219	0.227	0.208	0.224	0.199	0.199	0.227
Total Phosphorous (P)	0.002	mg/L		0.0057	0.0032	0.0065	0.0033	0.0045	0.0032	0.0065
Total metals by ICPMS										
Aluminium (Al)	0.5	ug/L		3		1.28	2.2	1.91	1.28	3
Antimony (Sb)	0.02	ug/L		0.062		0.064	0.072	0.07	0.062	0.072
Arsenic (As)	0.02	ug/L		0.375		0.373	0.414	0.38	0.373	0.414
Barium (Ba)	0.02	ug/L		94.7		84.4	86.6	81.40	81.4	94.7
Beryllium (Be)	0.01	ug/L		<0.1		<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		<5		<5	<5	<5		
Cadmium (Cd)	0.005	ug/L		0.244		<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		0.0137		0.0148	0.022	0.0165	0.0137	0.022
Copper (Cu)	0.05	ug/L		0.97		0.079	0.144	0.12	0.079	0.97
Iron (Fe)	1	ug/L		<1.0		1.5	3.5	1.50	1.5	3.5
Lead (Pb)	0.005	ug/L		<0.005		0.00516	0.0469	0.0214	0.00516	0.0469
Lithium (Li)	0.5	ug/L		2.7		2.73	2.94	2.87	2.7	2.94
Manganese (Mn)	0.05	ug/L		1.6		2.42	1.42	1.12	1.12	2.42
Molybdenum (Mo)	0.05	ug/L		1.16		1.09	1.19	1.130	1.09	1.19
Nickel (Ni)	0.05	ug/L		<0.05		<0.05	0.102	<0.05	0.102	0.102
Selenium (Se)	0.04	ug/L		0.192		0.084	0.077	0.11	0.077	0.192
Silver (Ag)	0.005	ug/L		<0.005		<0.005	<0.005	<0.005		
Strontium	0.05	ug/L		164		184	192	182.00	164	192
Thallium (Tl)	0.002	ug/L		<0.002		<0.002	<0.002	<0.002		
Tin (Sn)	0.2/0.01	ug/L		<0.01		<0.01	<0.05	<0.05		
Uranium (U)	0.002	ug/L		1.560		1.54	1.41	1.4600	1.41	1.56
Vanadium (V)	0.2	ug/L		<0.2		<0.2	<0.2	<0.2		
Zinc (Zn)	0.1	ug/L		0.460		0.2	2.17	0.68	0.2	2.17
Calcium (Ca)	0.05	mg/L		28.7		28.9		29.1	28.7	29.1
Magnesium (Mg)	0.05	mg/L		26.200		26.1		28.4	26.1	28.4
Potassium (K)	0.05	mg/L		0.675		0.643	0.62	0.624	0.62	0.675
Sodium (Na)	0.05	mg/L		3.19		2.95		3.65	2.95	3.65

*RDL Reportable Detection Limit

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

January 13, 2021

Parameter	RDL*	Units	Location on the lake / Date sampled	8-May-18	5-Sep-18	1-May-19	21-Aug-19	18-Aug-20	Concentration Range minimum	Concentration Range maximum
			Location on the lake	Whiteswan Lake Shallow 1 to 10 meter)						
			Date sampled	8-May-18	5-Sep-18	1-May-19	21-Aug-19	18-Aug-20		
Chlorophyll a	0.5	ug/L		0.543	0.547	1.36	0.491	0.425	0.425	1.36
Chlorophyll a rep	0.5	ug/L				-				
Field measurements										
Conductivity	-	uS/cm		249.6		289.9	273.2	264	249.6	289.9
Dissolved Oxygen	-	mg/L		10.71		10.66	8.97	9.08	8.97	10.71
Secchi (H20 clarity)	-	m		9.2		-	-		9.2	9.2
pH	-	pH		8.95		8.27	7.33	8.72	7.33	8.95
Temperature	-	^{0}C		9.3		6.07	17.8	18.3	6.07	18.3
Turbidity		NTU		0.23		0.21	0.25	0.19	0.19	0.25
Anions										
Silica	0.5	mg/L		3.9		1.55	1.03	0.823	0.823	3.9
Orthophosphate (p)	0.001	mg/L		<0.001	<0.001	<0.001	<0.001	<0.001		
Dissolved Sulphate (SO4)	0.5	mg/L		3.8	19.5	22.4	19.2	17	3.8	22.4
Dissolved Chloride (Cl)	0.5	mg/L		2.83	2.5	3	2.44	2.14	2.14	3
Calculated parameters										
Hardness	0.5	mg/L		145	138	145	143	143	138	145
Misc. Organics										
Total Organic Cargon	0.5	mg/L		1.56	1.45	1.45	1.94	1.58	1.45	1.94
Nutrients										
Total Kjeldahl Nitrogen (Calc)	0.02	mg/L		0.07	0.1	0.105	0.105	0.093	0.07	0.105
Dissolved Phosphorous (P)	0.002	mg/L		0.002	0.0035	0.002	<0.002	<0.002	0.002	0.0035
Nitrate plus nitrite (n)	0.002	mg/L		0.0052	<0.003	<0.003	<0.003	<0.003	0.0052	0.0052
Total Nitrogen (N)	0.02	mg/L		0.075	0.1	0.105	0.105	0.093	0.075	0.105
Total Phosphorous (P)	0.002	mg/L		0.0025	<0.002	0.0037	<0.002	0.0025	0.0025	0.0037
Total metals by ICPMS										
Aluminium (Al)	0.5	ug/L		2.37		1.16	3.33	2.68	1.16	3.33
Antimony (Sb)	0.02	ug/L		0.107		0.081	0.087	0.082	0.081	0.107
Arsenic (As)	0.02	ug/L		0.265		0.246	0.278	0.257	0.246	0.278
Barium (Ba)	0.02	ug/L		94.0		92.3	102	97.4	92.3	102
Beryllium (Be)	0.01	ug/L		<0.010		<0.01	<0.01	<0.01		
Bismuth (Bi)	0.005	ug/L		<0.0050		<0.005	<0.005	<0.005		
Boron (B)	10	ug/L		<5.0		<5	<5	<5	0	0
Cadmium (Cd)	0.005	ug/L		<0.0050		<0.005	<0.005	<0.005		
Chromium (Cr)	0.1	ug/L		<0.10		<0.1	<0.1	<0.1		
Cobalt (Co)	0.005	ug/L		0.0122		0.0115	0.0094	<0.001	0.0094	0.0122
Copper (Cu)	0.05	ug/L		0.2020		0.097	0.568	1.38	0.097	1.38
Iron (Fe)	1	ug/L		2.70		4.6	1.3	2	1.3	4.6
Lead (Pb)	0.005	ug/L		0.0085		0.0076	0.024	<0.005	0.0076	0.024
Lithium (Li)	0.5	ug/L		1.250		1.14	1.16	1.09	1.09	1.25
Manganese (Mn)	0.05	ug/L		1.320		2.26	0.427	0.888	0.427	2.26
Molybdenum (Mo)	0.05	ug/L		0.723		0.7	0.704	0.654	0.654	0.723
Nickel (Ni)	0.02	ug/L		0.091		0.076	0.066	0.061	0.061	0.091
Selenium (Se)	0.04	ug/L		0.079		0.066	0.063	0.077	0.063	0.079
Silver (Ag)	0.005	ug/L		<0.0050		<0.005	<0.005	<0.005		
Strontium	0.05	ug/L		108		105	107	106	105	108
Thallium (Tl)	0.002	ug/L		0.0025		0.0074	<0.002	<0.002	<0.002	0.0074
Tin (Sn)	0.2/0.01	ug/L		<0.010		<0.01	<0.05	0.082		
Uranium (U)	0.002	ug/L		0.517		0.503	0.43	0.435	0.43	0.517
Vanadium (V)	0.2	ug/L		<0.20		<0.2	<0.2	<0.2	0	0
Zinc (Zn)	0.1	ug/L		0.63		0.17	1.82	0.78	0.17	1.82
Calcium (Ca)	0.05	mg/L		37.5		39.4	37.1	37.1	37.1	39.4
Magnesium (Mg)	0.05	mg/L		11.4		11.2	12.2	12.1	11.2	12.2
Potassium (K)	0.05	mg/L		0.322		0.291	0.297	0.324	0.291	0.324
Sodium (Na)	0.05	mg/L		2.27		2.57	2.13	2.05	2.05	2.57

*RDL Reportable Detection Limit

Appendix D

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

Location (UTM NAD27)			Location#	Date	Turbidity (NTU	perature (Cel	onductivity (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

Appendix E – Statistics for 2014 to 2019

This spreadsheet is saved on the CLSS webpage http://columbialakess.com/