# Executive Summary

The Columbia Lake Stewardship Society (CLSS) began monitoring the water quality of Columbia Lake on April 20, 2014 and has continued, while the lake is ice-free, through to October 9, 2017. In 2017 the first water quality monitoring event on Columbia Lake was on April 5, 2017 and the last monitoring event was on October 9, 2017. Monitoring included approximately bi-weekly monitoring of selected water quality indicator parameters and approximately monthly sampling of water for chemical analyses.

CLSS' water quality monitoring program is administered, implemented and interpreted entirely by volunteers. Further, the water quality program for 2017 involved many volunteers that had participated in several previous years and some volunteers new to the program. The 2017 monitoring program was enhanced by assistance received from a summer student made available to the program by a grant received from the Canada Summer Jobs program.

Funding for the program was provided by:

- Columbia Valley Local Conservation Fund,
- Regional District of East Kootenay,
- Columere Marina,
- Fairmont Hot Springs Resort Ltd. including the Riverside Golf course and the Fairmont Hot Springs Airport,
- Village of Canal Flats,
- Columbia Ridge Community Association,
- Timber Springs Community Association,
- Columere Park Community Association, and
- Spirits Reach Community Association.

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

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

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

The findings from the program are:

1. The dynamics of the lake suggested by the oxygen profile measured in 2016 indicate that lake is performing in a manner that sustains the ecological health of the lake.

2. Seasonal changes from year to year are consistently repeated and the water quality parameters measured fall within a narrow range of values.

3. Turbidity measurement on the north end of the lake and south end of the lake suggest that these areas are more sensitive to surface disturbances and inflows of groundwater and surface water than elsewhere on the lake. We are concerned about turbidity because the material that causes the turbidity (sediments and organic debris) can limit the suitability of the lake water for drinking water and aquatic habitat.

4. Typically, conductivity values measured in the south end of the lake are greater than those measured elsewhere. Because conductivity is a measure of the soluble salt content of the water this finding suggests that the lake water at this end of the lake receives more dissolved material than elsewhere on the lake. Although there are a few streams that drain into the lake and a small intermittent stream near S3 that is believed to have introduced dissolved salt to the lake for a short period in 2016 we suspect that groundwater inflow to the lake may be the source of the increased conductivity.

5. Compared to other lakes monitored by BCMOE, Columbia Lake water has greater concentrations of dissolved chloride. Because the major contributor of chloride will be wastewater or surface runoff affected by road salt or dust control, monitoring of chloride concentrations needs to be continued. The concentrations measured are well less than the concentration that makes the lake water unsafe for other uses (usually 230 m/L is the limit for chloride in drinking water). This finding of greater concentrations of chloride has been measured by BCMOE on each of the six occasions it has monitored the lake.

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# WATER QUALITY MONITORING PROGRAM SUMMARY

## 1. Introduction

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

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

In response to concerns about future development along the lake and the consequent impact on the quality of the lake's water, the Columbia Lake Management Strategy was written by Urban Systems in 1997. One of the recommendations in that strategy was monitoring of the lake.

The Columbia Lake Stewardship Society (CLSS) began monitoring the lake's water quality on April 20, 2014 and has continued the monitoring program while the lake is ice- free through to October 2017. During 2017, water quality monitoring of Columbia Lake began on April 5, 2017 and ended on October 9, 2017. Monitoring included approximately bi-weekly monitoring of selected water quality indicator parameters and approximately monthly sampling of water for chemical analysis. We understand the British Columbia Ministry of the Environment is considering revising this management strategy, although the timing of a revision has not been decided.

This summary of water quality monitoring program:

- describes the water quality monitoring program;
- summarizes the water quality monitoring results; and
- compares the water quality of Columbia Lake to nearby lakes.

# 2.0 Monitoring Program

Sections 2.1 through 2.6 describe the water quality program conducted by CLSS on Columbia Lake.

## 2.1 Acknowledgements

CLSS's water quality program is administered, implemented and interpreted entirely by volunteers. In 2017, the following volunteers contributed to the water quality monitoring program:

- Tracy Flynn – overall program administration and management, on-the-lake training of new volunteers and monitoring in March, September and October;
- Mark Ariss – monitoring in July;
- Gina Forte - participation in on the lake training and monitoring in September
- Ed Gillmor – monitoring in April and May;
- Gary Gray – monitoring in July and August;
- Dave and Donna Rae – assistance with on-the-lake training:
- Barb and Kevin Stromquist – monitoring in June and July; and
- Nancy Wilson and Tom Dance – on the lake training in June, data compilation and graphing, data interpretation and reporting.

For the 2017 monitoring program, CLSS received a grant from the Canada Summer Jobs program to retain a summer student to assist with the water quality and water quantity program and with some of the education opportunities the society is engaged with. That summer student, Siobhan Demulder, participated on the program in June of 2017 and continued work until she returned to school on August 23, 2017.

The program receives funding from the following agencies:

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

Advice on the conduct of the program was also provided by Wendy Booth of RDEK, Suzanne Bayley of the Columbia Wetlands Society Partnership (CWSP); and Rick Nordin and Dave Schindler of the BC

Lake Stewardship Society.

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

## 2.2 Historical Information

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

- Station S4 was moved 2.4 km north: and
- Station S3 was moved 1.7 km southward.

This new location for S4 placed the site in shallow water, which is difficult to access by motor boats for sampling and might cause disturbance of lake sediments that alter the turbidity measurements.

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

| Station location | Northing | Easting |
|---|---|---|
| N1 | N50.28769 | W115.87126 |
| S1 | N50.25329 | W115.86256 |
| S3 | N50.20107 | W115.84820 |
| S4 | N50.17533 | W115.83442 |

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

## Figure 1 – Monitoring Locations


On January 15, 2016, at location S1, a special investigation of the oxygen distribution in the lake was made by Tracy Flynn and Dave Hubbard. This special investigation was not repeated in 2017 but is brought forward here as a reminder of those factors potentially influencing the lake's water quality.

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

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

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

These data suggest two features about the probable dynamics of the lake and the photosynthetic processes in the lake. First, because water's maximum density occurs at $4^{o}$C, as the cold surface water, melted from the ice, begins to warm up in the spring it will fall to the bottom of the lake. This "falling water" brings greater concentrations of dissolved oxygen into the deeper water to support the growth of aquatic plants and to 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 3.8.

Second, during the winter, input of oxygen due to wave action and inflow of surface water is minimal and therefore the oxygen concentration at shallow depth must be almost entirely due to photosynthetic processes (mostly micro-organisms and phytoplankton). As the water warms up, photosynthetic activity will increase and is the likely cause of the increases in turbidity observed in the early spring. The principal source of light to support photosynthesis is diffusion through the ice. This evidence that photosynthetic process continue over the winter months indicates the lake is healthy. In years of heavy snowfall, when the lake surface is snow covered and less sunlight diffuses through the ice, the dissolved oxygen content of the surface water might become depleted and may lead to a less healthy water body in the spring.

## 2.3 Purpose

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

- To act as a citizen-based water stewardship group for Columbia Lake;

- To implement activities which monitor and help maintain the ecological health of Columbia Lake; and
- To communicate and network with others, as required to achieve these two prior activities.

## 2.4 Water Quality Objectives

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

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

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

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

Because no WQO's have been set for Columbia Lake, the water quality information collected is compared to the values established within the Lake Windermere management plan. These objectives are:

| Parameter | Objectives (revised for Lake Windermere in 2010) |
|---|---|
| Turbidity | <1 NTU (Average) during clear flow periods<br>< 5 NTU (Maximum) during clear flow periods<br>5 NTUS (measured as the 95$^{th}$ percentile of measurement) during turbid flow periods |
| Phosphorous | 0.010 mg/L (maximum) |
| Temperature | <20$^{o}$C in June (average)<br>< 25$^{o}$C in July (average)<br><23$^{o}$C in August (average) |
| PH | no recommended objective |

| | |
|---|---|
| Dissolved oxygen | > 5 mg/L instantaneous minimum<br>>8 mg/L 30-day mean |
| Conductance | no recommended objective |

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

A methodology for CLSS to establish WQO's may be expected as the revised water management program for Columbia Lake is developed. The timing of that revision is not known to CLSS.

## 2.5 Monitoring Parameters

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

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

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

As much as lake conditions allowed, water temperature, and conductance were measured at both "shallow" and "deep" depths. Shallow refers to measurements in the upper 0.5 metres of the lake (an arms' reach below the water surface for practical purposes) while deep refers to measurements made about 0.5 metres from the lake bottom as measured using the Secchi disk. The deep and shallow measurements began in 2016 but were not routinely collected in 2017. The 2016 information showed that the lake had no noticeable differences in parameters between the deep and shallow depth and should have been repeated but was not due to rough water conditions at the time of sampling. The 2018 monitoring program will endeavour to collect this information and, if possible, confirm the 2016 findings.

## 2.6 Stations and Monitoring Events

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

The 2017 monitoring program began on April 5, 2017, a couple of weeks after the ice left the lake's surface. The last set of water quality monitoring information was collected on October 9, 2017. During the twelve monitoring events conducted on the lake, seven sets of water quality samples were submitted for chemical analysis. Twenty-three water quality analyses (total phosphorous and dissolved phosphorous) were made on the collected samples. Caro Analytical of Kelowna provided the analytical services.

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

# 3.0 Water Quality Monitoring Results

The water quality monitoring results obtained in 2017 are summarized by:

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

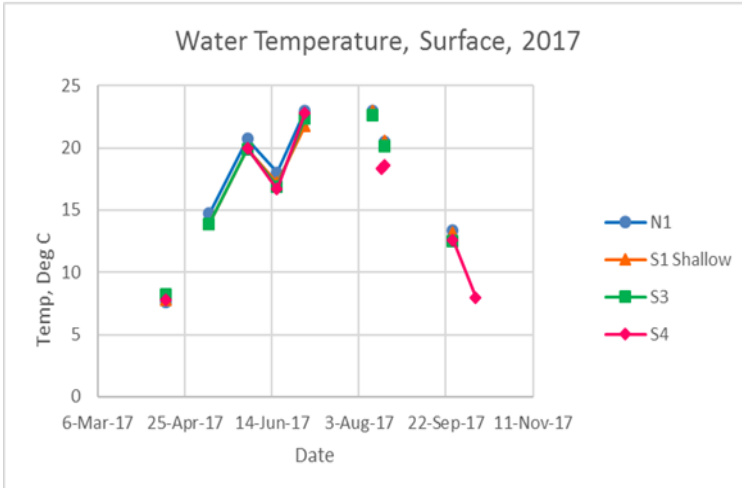
## 3.1 Temperature

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

Figure 2 plots the temperature measured during each monitoring event during 2017 at surface and bottom depths. The minimum temperature measurements in 2017 of approximately $5^{0}$ to $7^{0}$ C were measured during the early April and early October monitoring events while the maximum temperatures (greater than $20^{0}$C) were measured between late June and late August. There are no noticeable differences (greater than $2^{o}$C) in temperature during any monitoring event with position on the lake. Figures 2a and 2b compare the shallow and bottom temperatures and illustrate that there is no noticeable difference in water temperature with depth at all monitoring locations.

## Figure 2: Water Temperature 2017

### 2a




### 2b

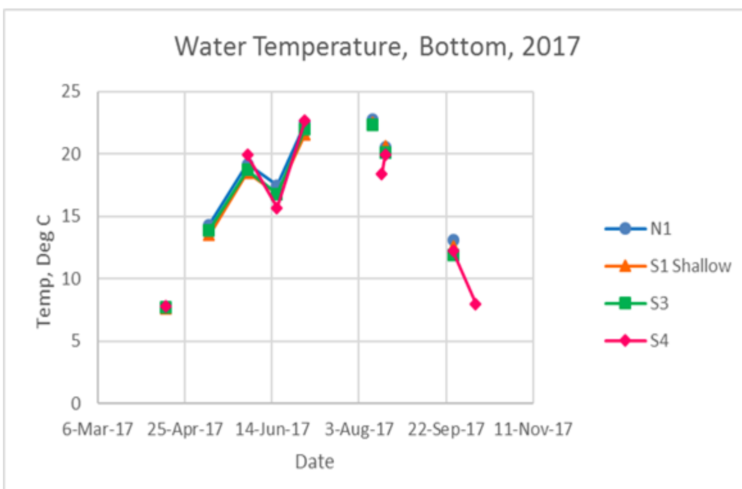



Figure 3 compares the temperature measurements along the lake from 2014 to 2017. Temperatures measured during several of the summer monitoring events in all four years exceed the water quality objectives (23°C) that have been established for Lake Windermere for the month of August but are less than the maximum water temperature (25°C) established for the month of July. In 2014, 2015 and 2017, the peak temperatures were measured during the July monitoring events. In contrast, during the 2016 monitoring events the peak temperature was measured in August. For that year, the later measurement of the peak temperature is attributed to a cooler spring and early summer air temperatures.

## Figure 3: Water Temperature, Year to Year Comparison

## 3.2 Secchi Disk Measurements

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

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

During the 2017 monitoring events, the lake's surface was frequently too turbulent to allow accurate measurements to be made. A plot of this information has not been provided.

The available lake measurements (Appendix B) suggest that for the most part, the 2017 measurements of Secchi disk depths is comparable to that of other years. The only measurements where the Secchi disk was less than the bottom depth occurring at S1, the deepest sampling location on the lake. At this location, the Secchi disk depth and lake bottom measurements generally differed by less than one metre. Exceptions are the Secchi disk measurements made in late May and June of 2017 at S1. During these monitoring events, the Secchi disk depths and the lake bottom depths differed by more than 1.5 metres and the Columbia Lake water would be considered less clear than at other times of the year. This time of the year is also when the greatest recreational activity occurs on the lake and stronger wave action due to winds disturb bottom sediments.

## 3.3 Turbidity

Turbidity measurements are another means of measuring the clarity (or in contrast the cloudiness or murkiness) of the water but, unlike the Secchi disk, these measurements are made in terms of NTU's (Nephelometric Turbidity Units) - a quantifiable measure of turbidity. The turbidity of the lake water is influenced mostly by the growth of phytoplankton and the amount of suspended sediments contained in the lake water. Suspended sediments are introduced by surface water draining into the lake and disturbance of bottom sediments by wave action and recreational activities. Organic matter that decays in the water as it warms up is also a significant contributor to the lake's murkiness. The turbidity may be influenced by some chemical reactions that create insoluble precipitates (carbonates mostly) but is not as great a contributor as suspended mineral sediments and organic debris and requires a much greater concentration of dissolved salt (conductance) than measured on the lake.

Turbidity measurements made during the 2017 monitoring events are plotted on Figure 4. This plot illustrates that the greatest turbidity measurements occurred in mid-June in the north end of the lake (N1). This area is close to where Dutch Creek drains into Columbia Lake. Some of the turbidity may be due to suspended sediments in the water. But this sampling location is also close to the marina at Columere Park and the beach/swimming area. A portion of the turbidity may be due to suspended sediments introduced by the disturbance of bottom sediments associated with these recreational activities.

Later in the year (August through October) the greatest values for the turbidity are measured in the south end of the lake (S3 and S4). A portion of the turbidity in this area of the lake may be attributed to suspended sediments introduced by surface drainage from the marshy area that borders this end of the lake. Also, this southern end of the lake it is understood to be associated with groundwater seepage to the lake believed to be sourced by seepage from the Kootenay River. Although groundwater does not carry suspended particulates nor decayed organic material, areas of groundwater discharge on the lake bottom might lift fine-grained bottom sediments into the lake water. Anecdotal evidence by our volunteer monitors during the late summer of 2017 has identified zones of groundwater upwelling on the bed of the lake along the marshland bordering the south end of the lake that are readily distinguished as “mud volcanoes”. These features may result in the turbidity increase measured at this end of the lake. The relative contribution of groundwater inflow versus surface water drainage at this end of the lake needs to be further evaluated. Other anecdotal evidence suggests that this end of the lake was also the area where falling ash from forest fires to the south of Canal Flats was most noticeable on the lake surface. This ash-fall may also result in a turbidity increase.

**Figure 4: Turbidity 2017**

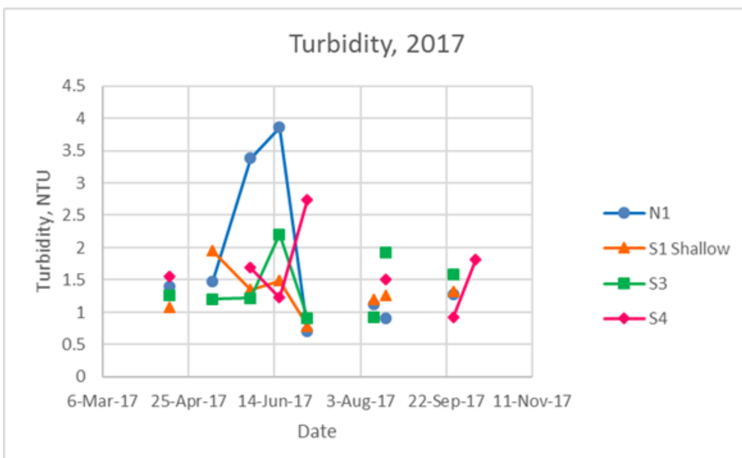
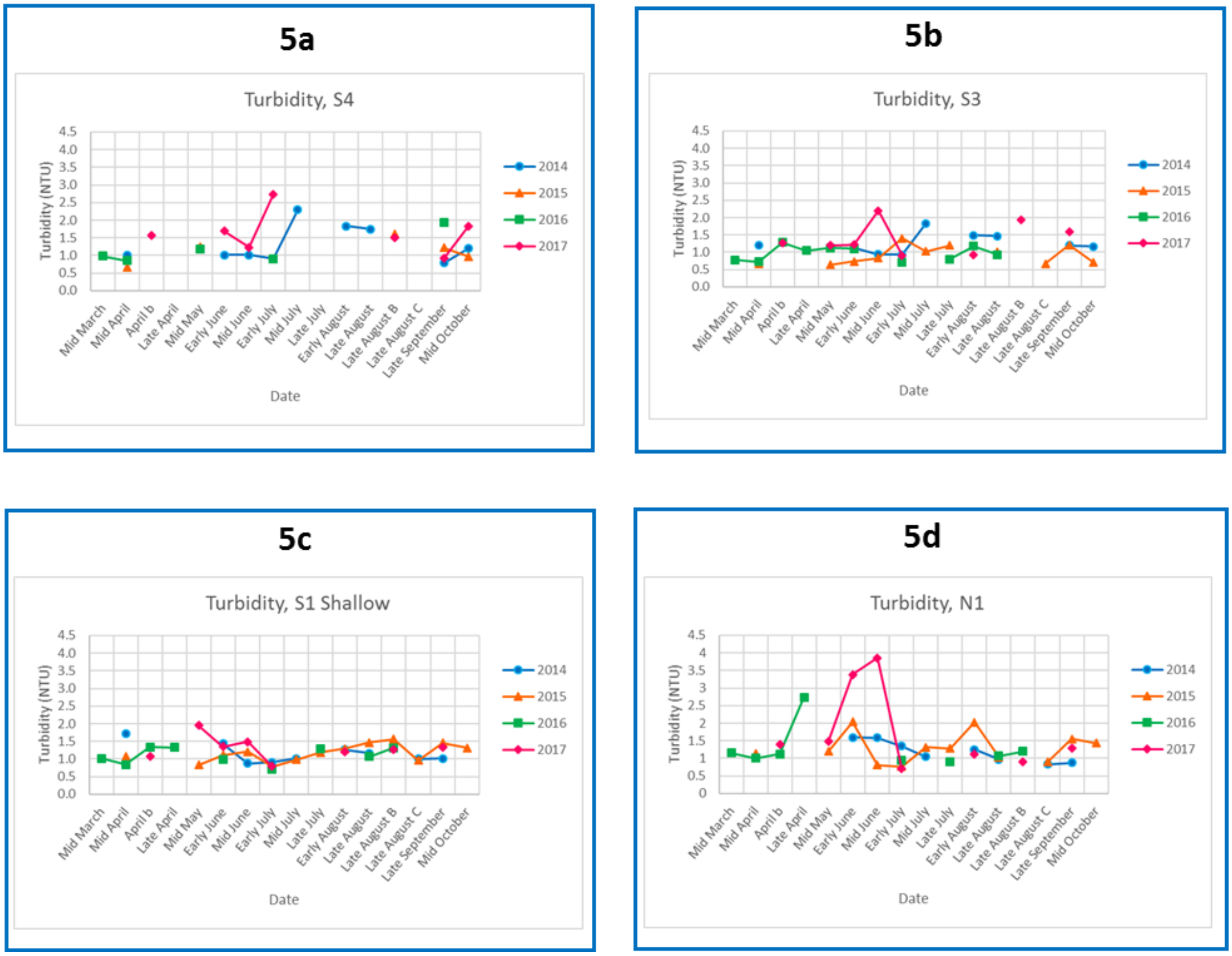



Figure 5 compares the year over year turbidity measurements at each monitoring location on the lake. The four graphs Figures 6 a, b, c, and d demonstrate that the turbidity of the lake water falls within a narrow range of 0.7 to 2 NTU’s. Overall the plots suggest that the turbidity of the lake water has not noticeably changed since the monitoring program began in 2014. The plots on Figure 6 suggest that both S4 and N1 yield the greatest value for the turbidity while S3 and S1 yield lower values. Both S4 and N1 are areas where surface water drainage to the lake is noticeable (the marshland to the south of S4 contains several small creeks and Dutch Creek is close to N1). However, a portion of the turbidity measured at N1 may be attributed to the accumulation of suspended sediments (mostly organic debris and fine grained particulate material) that drifts to this end of the lake due to wave action and the drainage of the lake into the Columbia River. This N1 location also exhibits the largest range in values for turbidity during the monitoring season (ranges from less than 1.5 NTU’s to greater than 3.5 NTU’s. The N1 location is the closest location to the marina located at Columere Park.

**Figure 5: Turbidity, Year to Year Comparison**




Turbidity values greater than the value of 2 NTU's set by the Lake Windermere objectives were measured in the late June monitoring events at the N1 location during 2017.

## 3.4 Conductivity

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

Figure 6 plots the values measured for the conductivity during 2017. The maximum values for conductivity are measured in the south end of the lake at S3 and S4. Because there are no major streams entering the lake over this area, it might be concluded that the higher conductivity is due to an increased salt content due to lake evaporation or due to the relative increase in contribution by groundwater discharge to the lake. Because this end of the lake is also associated with greater turbidity values the increase in conductance may also be a consequence of a greater amount of organic debris (ash or plant material) in the lake water. During 2017, the maximum conductivity value was measured during the summer months when the lake is warmest but also when lake water evaporation is the greatest. The conductivity's probe automatic correction for temperature needs to be confirmed during the 2018 monitoring events.

**Figure 6: Conductivity 2017**

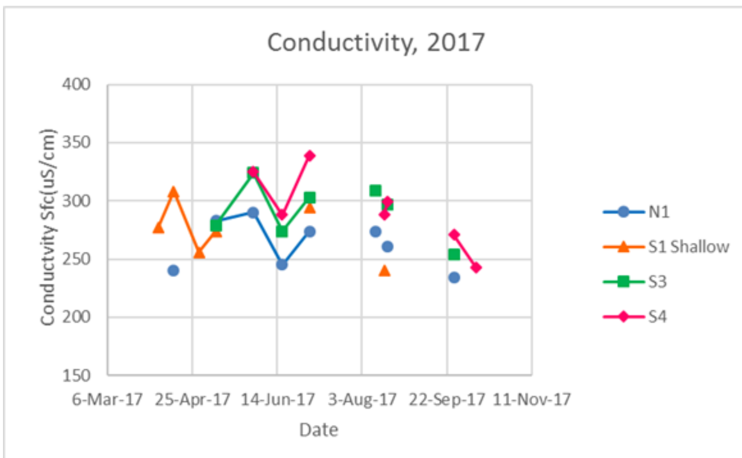
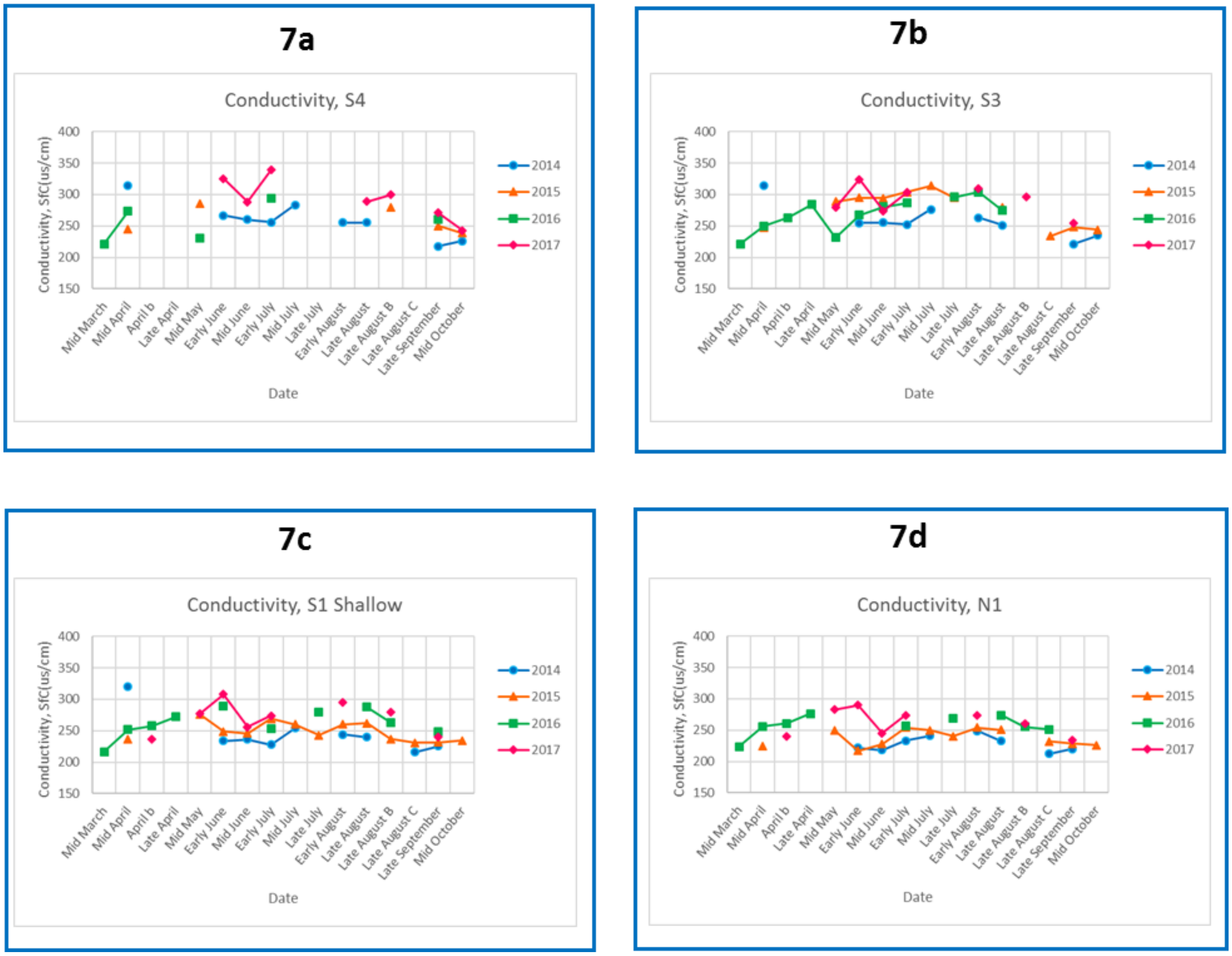



Figure 7 compares the conductivity measurements over the four years of the monitoring program at each monitoring location on the lake. The plots all show a similar trend to increases in conductivity values over the spring and summer months with declines in late summer and early autumn. The two southern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

In 2016 at S3 (Figure 7b), the conductivity continued to rise during the late summer and into the autumn. This rise in conductivity values did not occur in 2014 or 2015 nor was it measured during the monitoring events of 2017. It may be considered that a one-time event (e.g. a spring discharge or surface water discharge is the most likely source) of highly conductive water occurred during 2016.

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

**Figure 7: Conductivity, Year to Year Comparison**




## 3.5 PH

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

Figure 8 plots the pH values measured at each monitoring location during 2017. Excluding the pH value measured in mid-June at S3 (as a possible erroneous report), the pH of the lake water ranged between 8.3 and 9 pH units. The lowest pH values were measured in the early portion of the monitoring program and the highest during the later portion. Both monitoring locations S1 and N1 show a trend of increasing pH over the monitoring program. By the date of the last monitoring event, the pH values had not declined to the value measured at the start of the monitoring program. Monitoring data from early in 2018 will determine whether the upward trend of lake water's pH continues.

**Figure 8: PH, 2017**

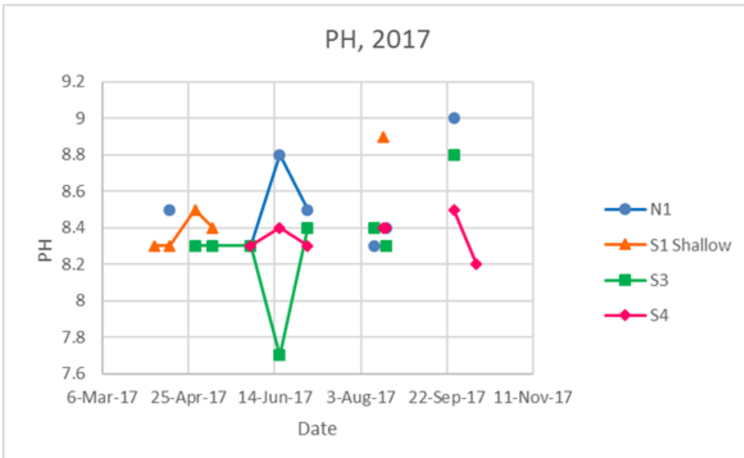
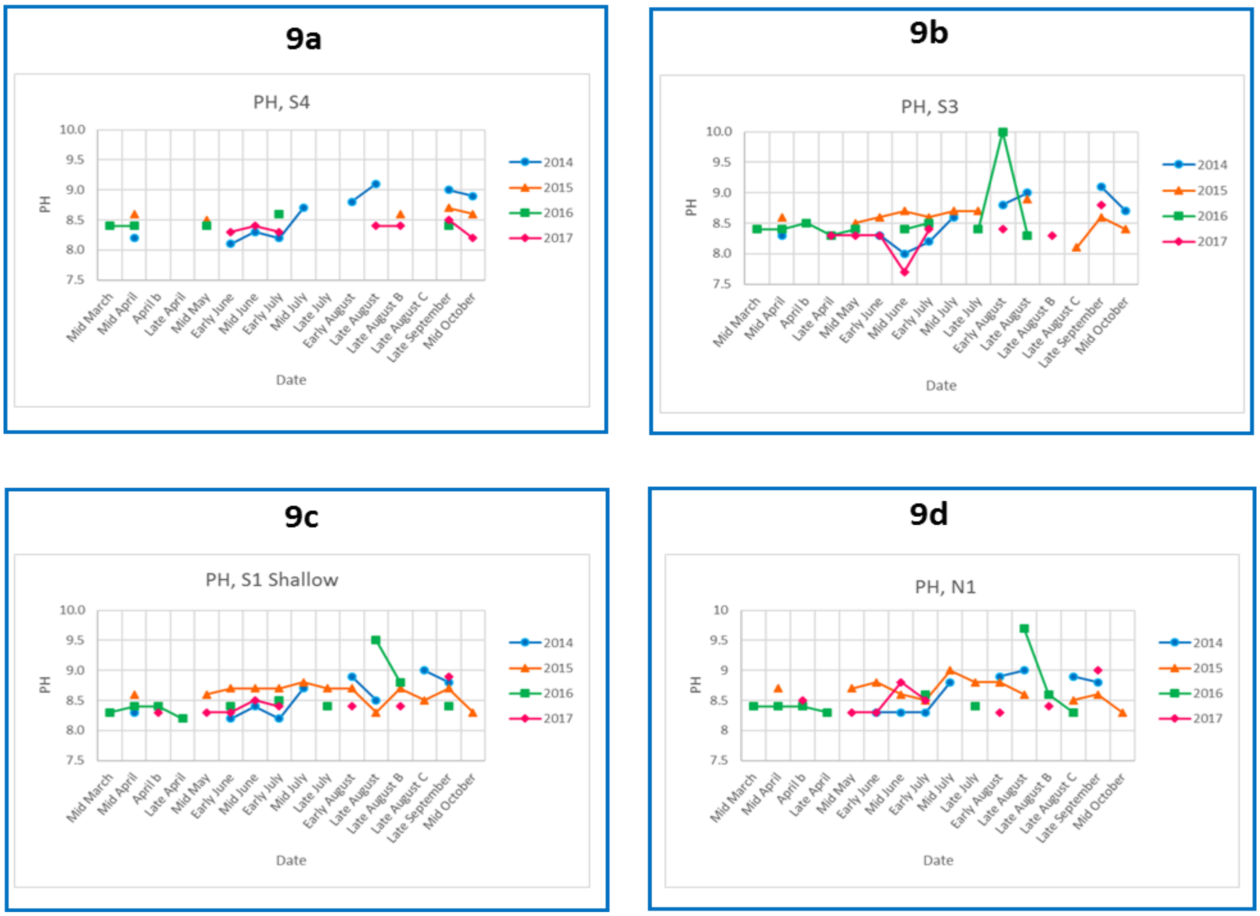



Figure 9 plots the year over year measurements of pH at each of the monitoring locations on the lake. Visually the plots of pH versus the monitoring date for 2014 suggest that a general increase in pH is observed between April and September of that year. A trend analysis has not been undertaken to confirm this visual observation numerically. However, this trend for increases in pH during the year is not as evident in either 2015 nor in 2016. The information available also illustrates several outlying values for pH that have not been adjusted as erroneous measurements.

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

**Figure 9: PH, Year to Year Comparison**




## 3.6 Dissolved Oxygen

Water containing dissolved oxygen and carbon di-oxide and which receives sunlight is essential for photosynthetic processes in the lake to occur and allows aquatic and amphibious flora and fauna to thrive. Both carbon dioxide and oxygen are produced by photosynthesis. The only mechanical source of dissolved oxygen is precipitation falling directly on the lake or introduced as snow melt. Lake surface disturbances that create turbulence and waves produced by winds also introduce oxygen to the lake. Some dissolved oxygen is provided to the lake by the inflow of surface drainage but groundwater inflow will not contribute any noticeable amounts of dissolved oxygen.

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

Figure 10 plots the dissolved oxygen concentrations measured in 2017 at the four monitoring locations along the lake. This graph illustrates that the dissolved oxygen concentrations were always greater than 6 mg/L and should be sufficient to support aquatic invertebrates. The maximum dissolved oxygen concentration of about 12 mg/L was measured at S3 in early June when the lake water was still relatively cool. The concentrations of dissolved oxygen in the lake increase from early April when the ice has first melted and is understood to be a consequence of both the contribution due to rainfall and snow melt to the lake and a by-product of photosynthetic processes that occur beneath the ice over the winter months. The dissolved oxygen concentrations decline after mid-June as the lake water becomes warmer.

**Figure 10: Dissolved Oxygen, 2017**

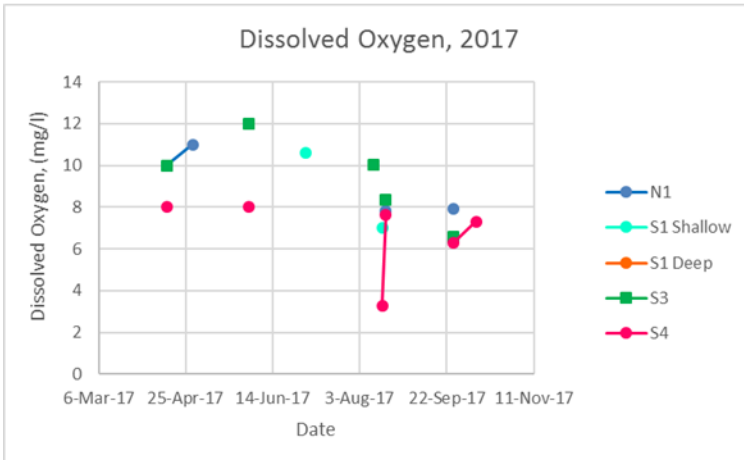
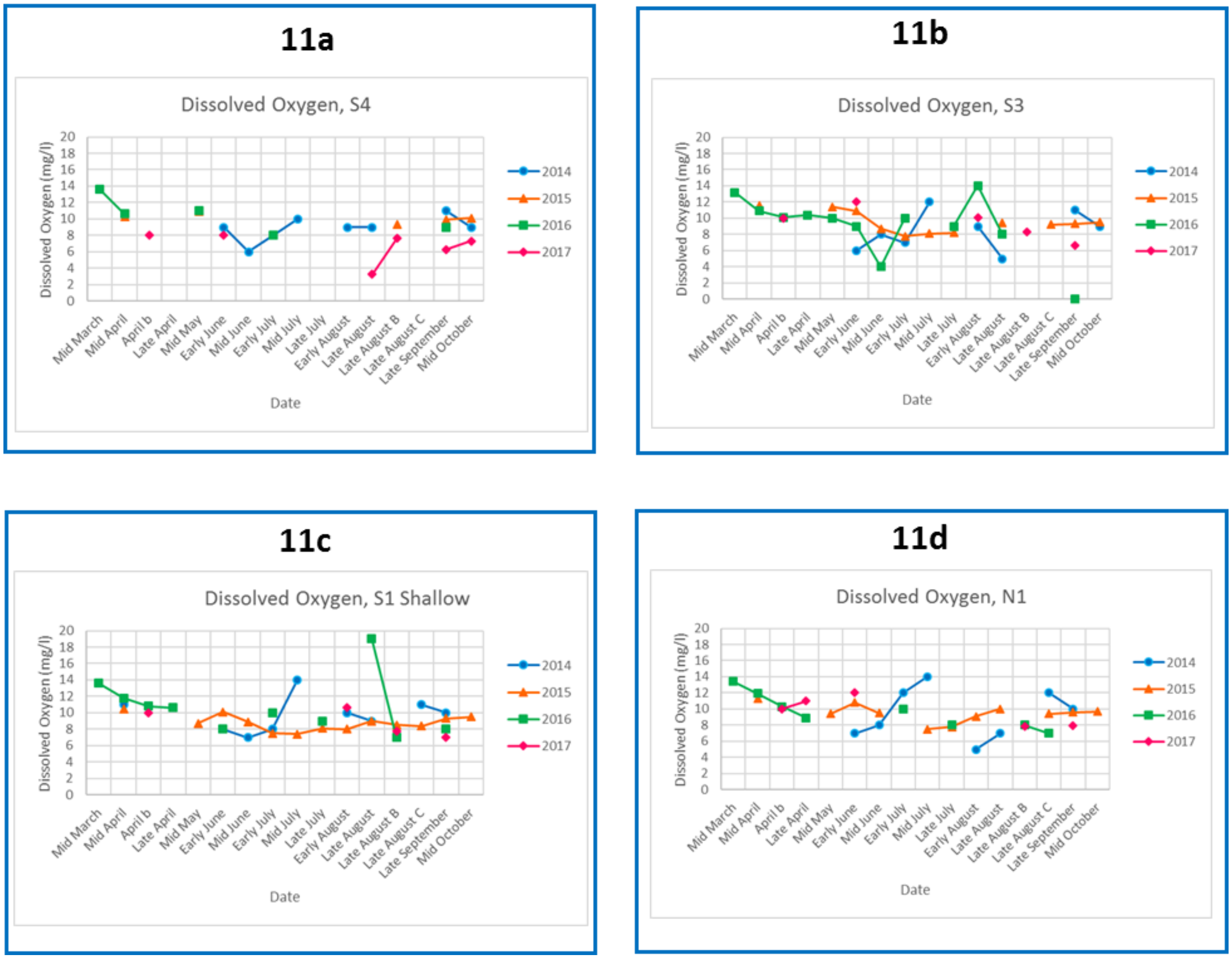



Figure 11 compares the year over year dissolved oxygen concentrations at each monitoring location on the lake. These graphs all show a similar pattern in the dissolved oxygen concentration: greater concentration in the spring as the lake water is cold, declining concentrations through the summer as the lake warms up and then a slight rise in early September to October as the lake water cools with the decline in air temperature during the autumn. These graphs also suggest that there is no difference in oxygen concentration with the location on the lake.

The water quality management for Lake Windermere suggest that the minimum concentration for dissolved oxygen in the lake water should be 5 mg/L. Although the plots on Figure 12 suggest that from time to time the lake water contains less than 5mg/L, this condition is not sustained over an extended period.

**Figure 11: Dissolved Oxygen, Year to Year Comparison**




## 3.7 Nitrate

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

Nitrate concentrations were measured at the onset of the program on April 20, 2014 and continued to be measured until May of 2016. All nitrate concentrations were less than the analytical detection limit.

Nitrate concentrations were not measured in 2017.

## 3.8 Total and dissolved phosphorous

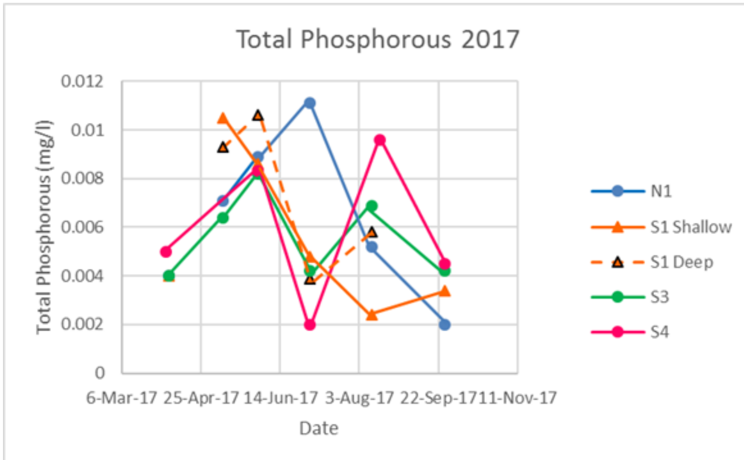
Phosphorous is a nutrient essential for plant growth. Aquatic plants and particularly microscopic plants are the principal feed stock of phytoplankton which are consumed by small fish and invertebrates and in turn eventually become the feed stock of larger fish and aquatic/ amphibious vertebrates. Thus,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

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

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

Figure 12 plots the total phosphorous concentrations measured in the lake water in 2017. During the mid-summer monitoring event of 2017, the maximum concentration for phosphorous occurred at monitoring station N1 in the northern part of the lake. In early 2017. At all locations on the lake, phosphorous concentrations increase during the late spring and early summer events of 2017. We understand this to be due to the increased in photosynthetic processes as the lake water warms. The total phosphorous concentrations decline into the autumn monitoring events. During most of these autumn monitoring events, the maximum total phosphorous concentrations were measured in the southern end of the lake (monitoring stations S3 and S4). Because these stations are closest to the marshy area at the south end of the lake and where the lake is shallow, we suspect that the greater total phosphorous concentrations in this area of the lake are due to the proximity to the marsh and an increase in the suspended organic material in the water. We note that this end of the lake also had greater concentrations of turbidity than the other locations on the lake during 2017, a finding that supports this speculation.

## Figure 12: Total Phosphorous, 2017




The graph on Figure 13, the plot of the ratio of dissolved phosphorous to total phosphorous concentrations, illustrates that for the much of the year most of the phosphorous in the lake water had a greater proportion of dissolved phosphorous than total phosphorous (ratios greater than 0.5). On a couple of occasions (S1 shallow in early June and August and at N1 in September) the phosphorous concentration was almost entirely dissolved phosphorous (ratio of about 1). Because dissolved phosphorous is the preferred feedstock for plant growth this finding suggests that plant growth might have been exceptional during this time periods.

## Figure 13:
## Ratio of Dissolved Phosphorous to Total Phosphorous, 2017

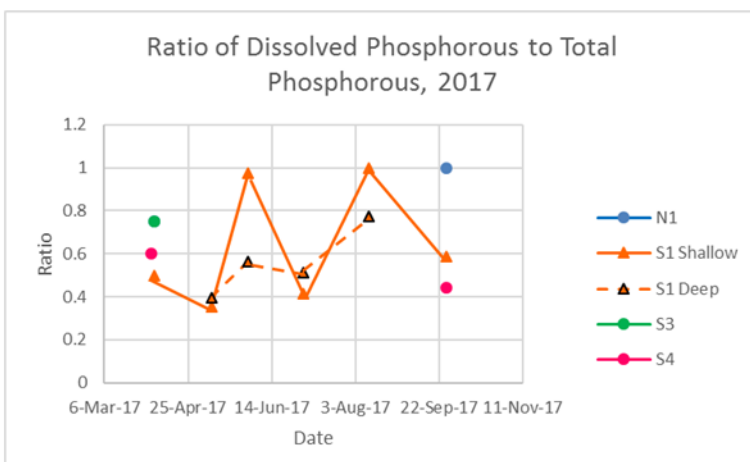



Figure 14 compares the year to year differences in total phosphorous concentrations with location on the lake. These graphs illustrate that during 2015 and 2016 and except for f some measurements when samples were not collected and, at all monitoring locations the peak total phosphorous concentration occurred in the later portion of the year. This increase is believed to be due to an increase in particulate organic material in the later portions of the year. In contrast during 2014 and 2017 the total phosphorous concentrations declined during the later portion of the years. Missing information prevents any speculation on the cause of these year to year changes. In 2018 we will endeavor to collect a more complete set of information.

**Figure 14: Total Phosphorous, Year to Year Comparison**


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

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

Within Lake Windermere's management plan, an objective for phosphorous (understood to be total phosphorous) was set as 0.01 mg/L. During 2017 this concentration was exceeded on three monitoring events (early August at S4, early May at S1 and early June at N1). The total phosphorous concentration was also greater than 0.01 mg/L during 2016 at all monitoring locations in the early March and during the spring events at S1 and again during the later monitoring events of 2015 at monitoring location N1. Exceedances of the water quality objective might be a rationale to conclude that activity on the lake has caused a concern for the lake's water quality. However, the concentrations measured in early March of 2016 when the lake was just ice-free do not support this conclusion. Because phosphorous is generally in short supply in freshwater systems and is such an essential element for a healthy aquatic system, we need to confirm the early in the year total phosphorous concentration within the 2018 monitoring program and establish a water quality objective for phosphorous unique to Columbia Lake.

# 4.0 Comparison to Nearby Lakes

Appendix C contains water quality information tabulated for Columbia Lake, Lake Windermere, and Moyie Lake using information provided to CLSS by BCMOE. The tabulation has been prepared by CLSS and not by BCMOE, therefore any transcription errors are the fault of CLSS.

These data provide a more extensive list of water quality parameters than monitored in CLSS' annual program. Although some consideration must be applied to allow for the differences in geologic setting between the three lakes, this information provides another useful measure of the quality of the water in Columbia Lake.

Table 2 compares the minimum and maximum concentrations for selected water quality parameters for the three lakes. When reviewing these data, it is important to appreciate that Moyie Lake is much deeper than either Lake Windermere or Columbia Lake. The data in Table 2 is selected for comparable depths of Lake Moyie to that of Lake Windermere and Columbia Lake. Moyie Lake's depth (greater than 30 metres) suggests it may be prone to seasonal stratification and consequently dissolved salts and metals may be distributed differently than in either Lake Windermere or Columbia Lake.

Water quality information missing from these analyses and that is important to understanding the drinking water and water quality changes are bicarbonate or alkalinity. Alkalinity or bicarbonate concentration effect the ability of treatment systems to treat waters to drinking water standards and influences the impact of metals (e.g. aluminum on aquatic invertebrates – fish).

Conductance, dissolved sulphate, barium, strontium and uranium are measured in the waters of Lake Windermere and Columbia Lake at concentrations much greater than those measured on Moyie Lake. We understand that the wall board plant near Mount Swansea on the east side of Lake Windermere uses

**Table 2 - Comparison of selected water quality parameters to other lakes**

| Water quality parameter[4] | | Moyie Lake[2] | | | | Lake Windermere[2] | | | | Columbia Lake[2] | | | | | Comments[1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | upper[3] | | lower[3] | | Surface | | Deep | | Surface | | Deep | | CLSS[5] | |
| | units | minimum | maxiumum | minimum | maximum | minimum | maximum | minimum | maximum | minimum | maximum | minimum | maximum | | |
| Chlorophyll a | ug/L | 0.397 | 0.262 | 1.03 | 2.02 | 0.85 | 2.23 | | | 0.856 | 1.85 | | | | Columbia Lake, Lake Windermere and the lower portion of Lake Moyie yield higher concentrations of chloropyll than the upper portion of Moyie Lake. |
| Conductivity | uS/cm | 47.2 | 57.7 | 48.3 | 56.5 | 256 | 404.2 | | | 290.9 | 339.3 | - | 301.2 | Same range as measured by MOE | Columbia Lake, and Lake Windermere contain noticeably greater (5 to 8 times) concentrations for specific conductance than Moyie Lake. There are noticeable differences between the spring and autumn with the autumn concentrations (Table C-3) in Moyie Lake less than autumn concentrations in Lake Windermere (Table C 2) and Columbia Lake (Table C-1). |
| dissolved oxygen | mg/L | 8.6 | 12.04 | 7.61 | 12.05 | 7.79 | 11.6 | | | 8.23 | 10.72 | | | | The greatest concentations are always in the spring when the water is colder. |
| Secchi disk (depth) | metres | 3 | 9.05 | 3.1 | 6.4 | 2.72 | 5.3 | | | 3.18 | 4.5 | | | | |
| dissolved sulphate | mg/L | 1.84 | 2.36 | 1.65 | 2.25 | 30.5 | 71.7 | 30.5 | 71.7 | 22.4 | 29.7 | 23 | 29.7 | | Columbia Lake and Lake Windermere yield similar trends to that of Conductance with noticeably greater concentrations than those measured in Lake Moyie. Greater conctrations alos occur in the spring than in the autumn. The concentrations in Columbia Lake are 3 to 4 times lower than those of Lake Windermere in the spring monitroign events |
| dissolved chloride | mg/L | 0.88 | 1.22 | 0.99 | 1.5 | 1.45 | 2.91 | 1.46 | 2.9 | 4.78 | 6.1 | 4.78 | 6.43 | | Over the historic range in meassurment Columbia Lake yields concentrations 3 to 4 times greater than those of Lake Windermere and Lake Moyie. Concentrations have declined in Columbia Lake in the 2017 measurements while the concentrations in the other two lakes remain the same. |
| total kjeldahl nitrogen[6] | mg/L | 0.061 | 0.114 | 0.09 | 0.185 | 0.122 | 0.198 | 0.933 | 0.212 | 0.169 | 0.227 | 0.178 | 0.237 | | approximately the same in all lakes |
| nitrate | mg/L | 0.032 | 0.0728 | <0.0032 | 0.0445 | <0.0032 | <0.0032 | <0.0032 | <0.0032 | <0.0032 | 0.0032 | <0.0032 | <0.0032 | | no detectable nitrate concentrations in Columbia Lake or Lake Windermere |
| orthophosphate[7] | mg/L | <0.001 | 0.0017 | <0.001 | 0.0018 | <0.001 | 0.011 | <0.001 | 0.001 | <0.001' | 0.0012 | <0.001 | 0.006 | | |
| dissolved phosphorous | mg/L | <0.002 | 0.0032 | <0.002 | 0.0022 | <0.002 | 0.0033 | <0.002 | <0.002 | 0.002 | 0.0058 | <0.002 | 0.0165 | | about the same concentration in all three lakes. In 2017 dissolved phosphorous concentrations were less than the analytical detection limit in Columbia Lake. |
| total phosphorous | mg/L | <0.002 | 0.0039 | <0.002 | 0.0086 | 0.0022 | 0.0056 | 0.003 | 0.0062 | 0.0183 | 0.0058 | 0.0033 | 0.0175 | | Columbia Lake yields greater concentratoins for total phosphorous in the autumn. The other two lakes yield the greatest concentration in the spring. |
| total organic carbon | mg/L | 2.49 | 3.1 | 2.44 | 3 | 1.55 | 2.36 | 1.47 | 2.29 | 1.03 | 2.71 | 2.12 | 3.35 | | |
| Aluminum | ug/L | 26.5 | 32.4 | 28.3 | 44.9 | 1.29 | 4.17 | 1.44 | 3.77 | 4.02 | 6.18 | 3.13 | 7.08 | | |
| antimony | ug/L | 0.021 | 0.024 | 0.034 | 0.038 | 0.049 | 0.073 | 0.054 | 0.069 | 0.065 | 0.073 | 0.068 | 0.072 | | Metal concentrations were for the most part only measured once per year and thus changes seasonal concentrations can not be determined. Aluminum, Copper, and Iron concentrations in Moyie Lake are much greater than those measured in Columbia Lake and Lake Windermere. Columbia Lake provides greater concentrations for Al than Lake Windermere. Antimoony, Arsenic, Barium, Lithium, Manganese, Molybendum, Stontium and Uranium concentrations are all greater than those measured in Moyie Lake |
| Arsenic | ug/L | 0.202 | 0.213 | 0.217 | 0.221 | 0.585 | 1.19 | 0.646 | 1.23 | 0.663 | 0.696 | 0.654 | 0.705 | | |
| Barium | ug/L | 6.15 | 6.42 | 6.57 | 6.96 | 66.8 | 83.7 | 72.8 | 80.2 | 74.3 | 85.7 | 75.2 | 81.5 | | |
| Cobalt | ug/L | 0.0267 | 0.365 | 0.0292 | 0.0419 | 0.015 | 0.0344 | 0.014 | 0.0375 | 0.027 | 0.0373 | 0.0311 | 0.0407 | | |
| Copper | ug/L | 0.491 | 3.59 | 0.71 | 2.36 | 0.123 | 0.188 | 0.148 | 0.165 | 0.135 | 0.259 | 0.161 | 0.164 | | |
| Iron | ug/L | 28 | 37.9 | 36.6 | 57.1 | 8.7 | 43.7 | 10.4 | 43.9 | 13.7 | 18.8 | 14.4 | 18.4 | | |
| Lead | ug/L | 0.0489 | 0.0688 | 1.17 | 1.96 | 0.0192 | 0.0589 | 0.138 | 0.0742 | 0.0384 | 0.0485 | 0.0472 | 0.0514 | | |
| Lithium | ug/L | <0.5 | <0.5 | <0.5 | <0.5 | 1.91 | 3.8 | 1.9 | 3.69 | 3.07 | 3.4 | 3.23 | 3.32 | | |
| Manganese | ug/L | 2.31 | 3.09 | 2.98 | 4.68 | 5.1 | 29 | 5.17 | 43.5 | 6.25 | 10.3 | 6.66 | 9.87 | | |
| Molybdenum | ug/L | 0.085 | 0.105 | 0.078 | 0.089 | 0.515 | 0.598 | 0.495 | 0.603 | 0.514 | 0.54 | 0.519 | 0.583 | | |
| Nickel | ug/L | 0.136 | 0.153 | 0.162 | 0.184 | 0.05 | 0.139 | 0.068 | 0.104 | 0.05 | 0.138 | <0.05 | 0.104 | | |
| Strontium | ug/L | 16.1 | 18.8 | 15.3 | 17.9 | 138 | 373 | 139 | 353 | 202 | 217 | 198 | 214 | | |
| Uranium | ug/L | 0.0841 | 0.0969 | 0.0763 | 0.0806 | 0.726 | 1.24 | 0.711 | 1.27 | 0.933 | 1.02 | 1 | 1.03 | | |
| Zinc | ug/L | 0.32 | 2.01 | 7.95 | 13.8 | 0.21 | 3.02 | 0.22 | 3.32 | 0.47 | 5.09 | 1.06 | 2.8 | | |

Notes

1 Yellow highlights identify parameters that exceed those measured in other lakes either in part or entirely within the range of parameters measured

2 Information tabulated here is the range in concentration measured during the 2015, 2016 and 2017 monitoring programs on these lakes by BCMOE

3 upper and lower refer to the geographic location on the lake and not the depth. All samples reported here are for the samples from shallow depth (<10m)

4 Information summarized here was provided by BCMOE. A more comprehensive summary of these data is tabulated by lake in Appendix C.

5 CLSS data refers to the information collected by the CLSS volunteers between 2014 and 2017.

6 kjeldahl nitrogen is a measure of the organic nitrogen (including ammonia) and is often used as a parameter for monitoring waste water treatment plants

7 Orthophosphate is created by natural processes but major man-made influences sources include lawn fertilizers, partially treated and untreated sewage and run off from agricultural area

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 that are sulphurous. Columbia Lake is upstream of Lake Windermere and before these natural sources of sulphate are cited as the source of dissolved sulphate, barium, strontium and uranium, a review of the geologic setting of Columbia Lake should be undertaken. In many fresh water bodies, sulphate concentrations increases from season to season due to evaporation of surface water. Trends in sulphate concentrations from season to season need to be monitored to confirm that evaporation is not a possible reason for increased concentrations.

Of interest is that there are no concentrations greater than the analytical detection limit reported for selenium in any of the lakes. Selenium is an element also associated with sulphide/sulphate bearing minerals and coal. But selenium is an element that is of greater concern for protection of freshwater aquatic life than are barium, strontium or uranium. Therefore, to protect freshwater aquatic life it may be necessary to monitor the change in sulphate concentrations and, where substantial concentration increases occur, to begin monitoring concentrations of selenium.

Dissolved chloride in Columbia Lake does not come from a natural source (although it is a common constituent of some types of marine sedimentary rocks, none of these types of rocks (marine shales and sandstones) are believed to be present on the mountains surrounding Columbia Lake). The most common source of chloride in fresh waters are wastewater disposal and drainage of road salts along highways where salt is used to control dust or to gain traction on icy roads. The chloride concentration in Columbia Lake is much greater than in Lake Windermere or Moyie Lake. Although the concentrations measured will not influence the use of the lake water, the difference in concentration between the three lakes is notable. As measured in 2017 the chloride concentration in the water of Columbia Lake (4mg/L) has decreased over that measured in 2015 and 2016 (6mg/L). Additional monitoring of chloride concentration by BCMOE will aid in determining if this trend continues.

Both Lake Windermere and Columbia Lake yield greater concentrations for total phosphorous immediately after the ice disappears from the lake in the spring. This phenomenon may be due to the photosynthetic processes occurring in the shallow water over the winter months. In Lake Windermere's case, the total phosphorous exceeded the WQO's objectives in the spring. This finding is consistent with the information collected by CLSS.

For many of the metals, Columbia Lake and Lake Windermere provide greater concentrations than those measured at comparable depths in Moyie Lake. This finding is currently attributed to the differences in geologic setting but trends in the concentrations need to be monitored. If the metals come from a mineral source, the concentrations should remain constant over time – allowing for a small variation due to natural conditions.

# 5.0 Continuous Improvements

The following suggestions/recommendations of changes to the water quality program are provided in keeping with the overall purpose of the CLSS.

1. Water Quality Objectives (WQO's)

We understand BCMOE is considering an update to the water quality management plan for Columbia Lake. The timing of that update is unknown but when it is provided the information presented here should be re-evaluated relative to new WQO's presented in that update.

2. Control limits and Monitoring Frequency

Control limits should be set following the 2018 sampling season when sufficient water quality data (five data sets) is available to set statistical measures (mean and standard deviation). These calculated values will establish a baseline to monitor any changes in the quality of the lake's water and that those changes are not due to natural variability in the measured parameters. This will allow the water quality monitoring program to be reduced and ongoing monitoring conducted only for those months when the greatest variation in concentrations (i.e. the greatest standard deviation) has been measured historically.

3. Parameter measurements.

The dissolved oxygen profile in the lake should be repeated as funds become available for the 2018 program. Dissolved oxygen profiling should be undertaken when the lake first becomes ice covered (allowing for safe travel on the ice) and late in the winter. This information will help to determine if fish can over winter in the lake.

As the monitoring program is reduced following the 2018 monitoring program, sulphate, chloride and selenium concentrations should be added to complement the information collected by BCMOE. This additional monitoring should take place in mid-June when the spring drainage of snowmelt to the lake is complete as a means of assessing the contribution of drainage water versus lake evaporation to these concentrations.

4. Benthic invertebrates

In 2017 some training was provided to our volunteers on the collection of invertebrate samples from the lake water as measure of the lake's ecological conditions. With the baseline sampling of the lake's water quality being established, CLSS should consider monitoring the invertebrate population at various locations on the lake. These aquatic organisms are the main feedstock of fish and other amphibious fauna which in turn support wildlife and waterfowl that live in and around the lake.

5. Groundwater

Several of the findings described here on the water quality of the lake suggest an influence from groundwater inflow to the lake. Also, the findings of CLSS on the water quantity monitoring program suggest that during some periods of the year the drainage of Dutch Creek provides significant quantities of water to Columba Lake. The relative contribution of these two sources of water to the lake needs to be evaluated so that ways and means of protecting lake water levels can be effectively developed.

## 6.0 Summary of Findings

There are five main findings from the 2017 water quality monitoring program.

1. The dynamics of the lake suggested by the oxygen profile measured in 2016 indicate that lake is performing in a manner that sustains the ecological health of the lake.

2. Seasonal changes from year to year are consistently repeated and the water quality parameters measured fall within a narrow range of values.

3. Turbidity measurement on the north end of the lake and south end of the lake suggest that these areas are more sensitive to surface disturbances and inflows of groundwater and surface water than elsewhere on the lake. We are concerned about turbidity because the material that causes the turbidity (sediments and organic debris) can limit the suitability of the lake water for drinking water and aquatic habitat.

4. Typically, conductivity values measured in the south end of the lake are greater than those measured elsewhere. Because conductivity is a measure of the soluble salt content of the water this finding suggests that the lake water at this end of the lake receives more dissolved material than elsewhere on the lake. Although there are a few streams that drain into the lake and a small intermittent stream near S3 that is believed to have introduced dissolved salt to the lake for a short period in 2016 we suspect that groundwater inflow to the lake may be the source of the increased conductivity.

5. Compared to other lakes monitored by BCMOE, Columbia Lake water has greater concentrations of dissolved chloride. Because the major contributor of chloride will be wastewater or surface runoff affected by road salt or dust control, monitoring of chloride concentrations needs to be continued. The concentrations measured are well less than the concentration that makes the lake water unsafe for other uses (usually 230 m/L is the limit for chloride in drinking water). This finding of greater concentrations of chloride has been measured by BCMOE on each of the six occasions it has monitored the lake.

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# Appendix A

# Monitoring parameters and their application to understanding water quality changes

What are the Parameters we Measure and Why are they Important

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

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

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

Water Temperature

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

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

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

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

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

Phosphorus and Nitrogen

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

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

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

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

Turbidity

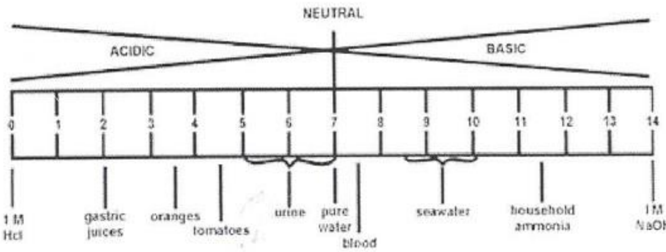
Turbidity is a measure of water clarity or more simply, how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. These materials are typically in the size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

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

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

pH

pH is a term used to indicate the alkalinity or acidity of a substance as ranked on a scale from 1.0 to 14.0. Acidity increases as the pH gets lower. The following figure presents the pH of some common liquids.




pH affects many chemical and biological processes in the water. For example, different organisms flourish within different ranges of pH. The largest variety of aquatic animals prefers a range of 6.5-8.0. pH outside this range reduces the diversity in the stream because it stresses the physiological systems of most organisms and can reduce reproduction. Low pH can also allow toxic elements and compounds to become mobile and "available" for uptake by aquatic plants and animals. This can produce conditions that are toxic to aquatic life, particularly to sensitive species like rainbow trout. Changes in acidity can be caused by atmospheric deposition (acid rain), surrounding rock, and certain wastewater discharges.

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

Conductivity

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

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

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

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

# Appendix B
# Spreadsheet of Collected Water Quality Information

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

# Appendix C

# Water Quality Information for Columbia Lake, Lake Windermere and Moyie Lake

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

| Parameter | RDL* | Units | Location on the lake | Columbia lake midlake north | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Surface (1 m) | | | | | |
| | | | Date sampled | 15-Apr-15 | 26-Aug-15 | 7-Apr-16 | 24-Aug-16 | 25-Apr-17 | 29-Aug-17 |
| Chlorophyll a | 0.5 | mg/L | | 0.91 | 1.46 | 1.33 | 1.39 | 1.85 | 0.856 |
| Chlorophyll a rep | 0.5 | mg/L | | 1.28 | 0.828 | 1.45 | 1.97 | 1.84 | 0.922 |
| **Field measurements** | | | | | | | | | |
| Conductivity | - | uS/cm | | 339.3 | 290.9 | 345.3 | 293 | 301.3 | |
| Dissolved Oxygen | - | mg/L | | 10.72 | 8.27 | 10.75 | 8.23 | 10.49 | 9.18 |
| Secchi (H20 clarity) | - | m | | 4.5 | 3.6 | 4.5 | 3.6 | 3.18 | 4.4 |
| pH | - | pH | | 8.27 | | | 8.4 | | |
| Temperature | - | $^0C$ | | 7.8 | 18.6 | 9.86 | 18.9 | 10.1 | 20.3 |
| Turbidity | | NTU | | | | 0.74 | | 0.93 | |
| **Anions** | | | | | | | | | |
| Silica | 0.5 | mg/L | | 4.91 | 7.69 | 5.97 | 7.13 | 4.76 | 7.83 |
| Orthophosphate (p) | 0.001 | mg/L | | 0.0012 | <0.001 | 0.0015 | <0.001 | <0.001 | <0.001 |
| Dissolved Sulphate (SO4) | 0.5 | mg/L | | 27.6 | 22.4 | 29.7 | 25.3 | 29 | 23.1 |
| Dissolved Chloride (Cl) | 0.5 | mg/L | | 6.1 | 5.47 | 6.44 | 5.92 | 5.88 | 4.78 |
| **Calculated parameters** | | | | | | | | | |
| Hardness | 0.5 | mg/L | | 169 | 151 | 193 | 150 | 182 | 151 |
| **Misc. Organics** | | | | | | | | | |
| Total Organic Cargon | 0.5 | mg/L | | 1.03 | 2.51 | 1.95 | 3.27 | 2.23 | 2.71 |
| **Nutrients** | | | | | | | | | |
| Total Kjeldahl Nitrogen (Calc) | 0.02 | mg/L | | 0.23 | 0.227 | 0.169 | 0.226 | 0.187 | 0.224 |
| Dissolved Phosphorous (P) | 0.002 | mg/L | | 0.0058 | 0.003 | 0.002 | 0.002 | 0.002 | 0.0021 |
| Nitrate plus nitrite (n) | 0.002 | mg/L | | <0.002 | 0.002 | 0.0032 | 0.0032 | 0.0032 | <0.0032 |
| Total Nitrogen (N) | 0.02 | mg/L | | 0.23 | 0.227 | 0.169 | 0.226 | 0.187 | 0.312 |
| Total Phosphorous (P) | 0.002 | mg/L | | 0.0183 | 0.0043 | 0.0031 | 0.0039 | 0.004 | 0.0058 |
| **Total metals by ICPMS** | | | | | | | | | |
| Aluminium (Al) | 0.5 | ug/L | | 6.18 | | 4.23 | | 4.02 | |
| Antimony (Sb) | 0.02 | ug/L | | 0.073 | | 0.065 | | 0.071 | |
| Arsenic (As) | 0.02 | ug/L | | 0.644 | | 0.0663 | | 0.696 | |
| Barium (Ba) | 0.02 | ug/L | | 74.3 | | 76.5 | | 85.7 | |
| Beryllium (Be) | 0.01 | ug/L | | <0.01 | | <0.01 | | <0.01 | |
| Bismuth (Bi) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Boron (B) | 10 | ug/L | | <10 | | <10 | | <10 | |
| Cadmium (Cd) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Chromium (Cr) | 0.1 | ug/L | | <0.01 | | <0.1 | | <0.1 | |
| Cobalt (Co) | 0.005 | ug/L | | 0.027 | | 0.0293 | | 0.0373 | |
| Copper (Cu) | 0.05 | ug/L | | 0.259 | | 0.135 | | 0.182 | |
| Iron (Fe) | 1 | ug/L | | 18.8 | | 14.5 | | 13.7 | |
| Lead (Pb) | 0.005 | ug/L | | 0.0481 | | 0.0384 | | 0.0485 | |
| Lithium (Li) | 0.5 | ug/L | | 3.07 | | 3.37 | | 3.4 | |
| Manganese (Mn) | 0.05 | ug/L | | 6.25 | | 9.21 | | 10.3 | |
| Molybdenum (Mo) | 0.05 | ug/L | | 0.514 | | 0.532 | | 0.54 | |
| Nickel (Ni) | 0.02 | ug/L | | 0.138 | | 0.069 | | 0.05 | |
| Selenium (Se) | 0.04 | ug/L | | <0.04 | | 0.041 | | <0.04 | |
| Silver (Ag) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Strontium (Sr) | 0.05 | ug/L | | 217 | | 215 | | 202 | |
| Thallium (Tl) | 0.002 | ug/L | | <0.002 | | <0.002 | | 0.0025 | |
| Tin (Sn) | 0.2 | ug/L | | <0.2 | | <0.01 | | <0.01 | |
| Uranium (U) | 0.002 | ug/L | | 1 | | 0.933 | | 1.02 | |
| Vanadium (V) | 0.2 | ug/L | | <0.2 | | <0.2 | | <0.2 | |
| Zinc (Zn) | 0.1 | ug/L | | 0.47 | | 0.55 | | 5.09 | |
| Calcium (Ca) | 0.05 | mg/L | | 34.2 | 26.2 | 38.8 | 26.9 | 37.9 | 28.6 |
| Magnesium (Mg) | 0.05 | mg/L | | 20.4 | 20.7 | 23.3 | 20.1 | 21.3 | 19.4 |
| Potassium (K) | 0.05 | mg/L | | | | 0.84 | | 0.8 | |
| Sodium (Na) | 0.05 | mg/L | | | | 6.79 | | 6.71 | |

RDL – reportable detection limit

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

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

RDL – reportable detection limit

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

| Parameter | RDL* | Units | Location on the lake | Lake Windermere off Timber Ridge | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Shallow (1 metre) | | | | | |
| | | | Date sampled | 15-Apr-15 | 26-Sep-15 | 7-Apr-16 | 24-Sep-16 | 25-Apr-17 | 29-Aug-17 |
| Chlorophyll a | 0.5 | mg/L | | 0.85 | 1.83 | 1.1 | 1.64 | 1.14 | 2.23 |
| Chlorophyll a rep | 0.5 | mg/L | | 0.82 | 1.08 | 1.27 | | 2.02 | 2.14 |
| **Field measurements** | | | | | | | | | |
| Conductivity | - | uS/cm | | 389.3 | 268.9 | 404.2 | 256 | 350.4 | |
| Dissolved Oxygen | - | mg/L | | 10.85 | 7.79 | 11.6 | 7.44 | 10.47 | 7.99 |
| Secchi (H20 clarity) | - | m | | 5 | 4.65 | 5.3 | 5.3 | 2.72 | 4 |
| pH | - | pH | | - | | | | | 8.23 |
| Temperature | - | $^0C$ | | 8.4 | 19.3 | 9.75 | 19.8 | 11.6 | 20 |
| Turbidity | | NTU | | | | 0.57 | 0.67 | 1.04 | 0.75 |
| **Anions** | | | | | | | | | |
| Silica | 0.5 | mg/L | | 4.49 | 5.84 | 5.5 | 5.8 | 3.84 | 6.42 |
| Orthophosphate (p) | 0.001 | mg/L | | 0.0011 | 0.001 | <0.001 | <0.001 | <0.001 | <0.001 |
| Dissolved Sulphate (SO4) | 0.5 | mg/L | | 70.8 | 28.4 | 71.7 | 30.5 | 71.6 | 31 |
| Dissolved Chloride (Cl) | 0.5 | mg/L | | 2.9 | 1.68 | 3.15 | 1.45 | 2.91 | 1.57 |
| **Calculated parameters** | | | | | | | | | |
| Hardness | 0.5 | mg/L | | 201 | 148 | 224 | 149 | 203 | 148 |
| **Misc. Organics** | | | | | | | | | |
| Total Organic Cargon | 0.5 | mg/L | | <0.5 | 1.86 | 1.63 | 1.96 | 1.55 | 2.36 |
| **Nutrients** | | | | | | | | | |
| Total Kjeldahl Nitrogen (Calc) | 0.02 | mg/L | | 0.183 | 0.193 | 0.122 | 0.139 | 0.183 | 0.198 |
| Dissolved Phosphorous (P) | 0.002 | mg/L | | 0.0033 | 0.0031 | <0.002 | <0.002 | <0.002 | 0.0021 |
| Nitrate plus nitrite (n) | 0.002 | mg/L | | <0.002 | <0.0032 | <0.0032 | <0.0032 | <0.0032 | <0.0032 |
| Total Nitrogen (N) | 0.02 | mg/L | | 0.183 | 0.193 | 0.122 | 0.139 | 0.183 | 0.198 |
| Total Phosphorous (P) | 0.002 | mg/L | | 0.0056 | 0.0042 | 0.0033 | 0.0035 | 0.0042 | 0.0022 |
| **Total metals by ICPMS** | | | | | | | | | |
| Aluminium (Al) | 0.5 | ug/L | | 4.33 | | 1.29 | 1.56 | 4.17 | 3.02 |
| Antimony (Sb) | 0.02 | ug/L | | 0.049 | | 0.05 | 0.063 | 0.061 | 0.073 |
| Arsenic (As) | 0.02 | ug/L | | 0.672 | | 0.585 | 1.06 | 0.634 | 1.19 |
| Barium (Ba) | 0.02 | ug/L | | 77.9 | | 83.9 | 66.8 | 83.7 | 67.2 |
| Beryllium (Be) | 0.01 | ug/L | | <0.01 | | <0.01 | <0.01 | <0.01 | <0.01 |
| Bismuth (Bi) | 0.005 | ug/L | | <0.005 | | <0.005 | <0.005 | <0.005 | <0.005 |
| Boron (B) | 10/1 | ug/L | | <10 | | 9.2 | 5.9 | 8.2 | 5.7 |
| Cadmium (Cd) | 0.005 | ug/L | | <0.005 | | <0.005 | <0.005 | <0.005 | <0.005 |
| Chromium (Cr) | 0.1 | ug/L | | <0.1 | | <0.1 | <0.1 | <0.1 | <0.1 |
| Cobalt (Co) | 0.005 | ug/L | | 0.015 | | 0.0165 | 0.0161 | 0.0344 | 0.0232 |
| Copper (Cu) | 0.05 | ug/L | | 0.172 | | 0.123 | 0.188 | 0.147 | 0.179 |
| Iron (Fe) | 1 | ug/L | | 43.7 | | 28.9 | 8.7 | 24.6 | 11.6 |
| Lead (Pb) | 0.005 | ug/L | | 0.0311 | | 0.0192 | 0.025 | 0.0589 | 0.0346 |
| Lithium (Li) | 0.5 | ug/L | | 3.62 | | 3.8 | 1.91 | 3.43 | 2.13 |
| Manganese (Mn) | 0.05 | ug/L | | 5.1 | | 12.9 | 29 | 25.3 | 26 |
| Molybdenum (Mo) | 0.05 | ug/L | | 0.581 | | 0.515 | 0.564 | 0.598 | 0.574 |
| Nickel (Ni) | 0.02 | ug/L | | 0.093 | | 0.058 | 0.083 | 0.05 | 0.139 |
| Selenium (Se) | 0.04 | ug/L | | <0.04 | | 0.044 | 0.044 | <0.04 | 0.047 |
| Silver (Ag) | 0.005 | ug/L | | <0.005 | | <0.005 | <0.005 | <0.005 | <0.005 |
| Strontium (Sr) | 0.05 | ug/L | | 373 | | 340 | 138 | 297 | 143 |
| Thallium (Tl) | 0.002 | ug/L | | <0.002 | | <0.002 | <0.002 | 0.0041 | 0.0027 |
| Tin (Sn) | 0.2/0.01 | ug/L | | <0.2 | | <0.01 | <0.01 | <0.01 | <0.01 |
| Uranium (U) | 0.002 | ug/L | | 1.18 | | 1.1 | 0.726 | 1.24 | 0.843 |
| Vanadium (V) | 0.2 | ug/L | | <0.2 | | <0.2 | <0.2 | <0.2 | <0.2 |
| Zinc (Zn) | 0.1 | ug/L | | 0.21 | | 0.26 | 1.42 | 3.02 | 1.09 |
| Calcium (Ca) | 0.05 | mg/L | | 42.9 | 33.2 | 47.7 | 34.7 | 45.9 | 33.9 |
| Magnesium (Mg) | 0.05 | mg/L | | 22.8 | 15.9 | 25.6 | 15.1 | 21.5 | 15.9 |
| Potassium (K) | 0.05 | mg/L | | | | 0.964 | 0.71 | 0.833 | 0.709 |
| Sodium (Na) | 0.05 | mg/L | | | | 4.81 | 2.17 | 4.06 | 2.37 |

RDL – reportable detection limit

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

| Parameter | RDL* | Units | Location on the lake | Lake Windermere off Timber Ridge | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Deep (3metres) | | | | | |
| | | | Date sampled | 15-Apr-15 | 26-Aug-15 | 7-Apr-16 | 24-Aug-16 | 25-Apr-17 | 29-Aug-17 |
| Chlorophyll a | 0.5 | mg/L | | - | - | - | - | - | |
| Chlorophyll a rep | 0.5 | mg/L | | - | - | - | - | - | |
| **Field measurements** | | | | | | | | | |
| Conductivity | - | uS/cm | | - | - | - | - | - | |
| Dissolved Oxygen | - | mg/L | | - | - | - | - | - | |
| Secchi (H20 clarity) | - | m | | - | - | - | - | - | |
| pH | - | pH | | - | - | - | - | - | |
| Temperature | - | $^0C$ | | - | - | - | - | - | |
| Turbidity | | NTU | | - | - | - | 0.71 | 1.39 | |
| **Anions** | | | | | | | | | |
| Silica | 0.5 | mg/L | | 4.51 | 6.06 | 5.18 | 5.6 | 3.97 | 6.91 |
| Orthophosphate (p) | 0.001 | mg/L | | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 | 0.001 |
| Dissolved Sulphate (SO4) | 0.5 | mg/L | | 71.6 | 28.3 | 71.6 | 30.5 | 71.7 | 30.6 |
| Dissolved Chloride (Cl) | 0.5 | mg/L | | 2.7 | 1.68 | 3.13 | 1.46 | 2.9 | 1.55 |
| **Calculated parameters** | | | | | | | | | |
| Hardness | 0.5 | mg/L | | 197 | 141 | 220 | 164 | 206 | 150 |
| **Misc. Organics** | | | | | | | | | |
| Total Organic Cargon | 0.5 | mg/L | | 1.49 | 2.1 | 1.47 | 2.29 | 1.81 | 2.15 |
| **Nutrients** | | | | | | | | | |
| Total Kjeldahl Nitrogen (Calc) | 0.02 | mg/L | | 0.16 | 0.212 | 0.123 | 0.174 | 0.933 | 0.192 |
| Dissolved Phosphorous (P) | 0.002 | mg/L | | | 0.0029 | <0.002 | <0.002 | <0.002 | <0.002 |
| Nitrate plus nitrite (n) | 0.002/0.003 | mg/L | | <0.002 | <0.0032 | <0.0032 | <0.0032 | <0.0032 | <0.0032 |
| Total Nitrogen (N) | 0.02 | mg/L | | 0.16 | 0.212 | 0.123 | 0.174 | 0.933 | 0.192 |
| Total Phosphorous (P) | 0.002 | mg/L | | 0.185 | 0.0062 | 0.003 | 0.0031 | 0.0053 | 0.0035 |
| **Total metals by ICPMS** | | | | | | | | | |
| Aluminium (Al) | 0.5 | ug/L | | 3.77 | | | 1.44 | 3.55 | |
| Antimony (Sb) | 0.02 | ug/L | | 0.054 | | | 0.069 | 0.059 | |
| Arsenic (As) | 0.02 | ug/L | | 0.646 | | | 1.23 | 0.689 | |
| Barium (Ba) | 0.02 | ug/L | | 78.5 | | | 72.8 | 80.2 | |
| Beryllium (Be) | 0.01 | ug/L | | <0.01 | | | <0.01 | <0.01 | |
| Bismuth (Bi) | 0.005 | ug/L | | <0.005 | | | <0.005 | <0.005 | |
| Boron (B) | 10/1 | ug/L | | <10 | | | 5.6 | 8.2 | |
| Cadmium (Cd) | 0.005 | ug/L | | <0.005 | | | <0.005 | <0.005 | |
| Chromium (Cr) | 0.1 | ug/L | | <0.1 | | | <0.1 | <0.1 | |
| Cobalt (Co) | 0.005 | ug/L | | 0.014 | | | 0.0167 | 0.0375 | |
| Copper (Cu) | 0.05 | ug/L | | 0.158 | | | 0.148 | 0.165 | |
| Iron (Fe) | 1 | ug/L | | 43.9 | | | 10.4 | 27.1 | |
| Lead (Pb) | 0.005 | ug/L | | 0.0237 | | | 0.0138 | 0.0742 | |
| Lithium (Li) | 0.5 | ug/L | | 3.69 | | | 1.9 | 3.36 | |
| Manganese (Mn) | 0.05 | ug/L | | 5.17 | | | 43.5 | 30.3 | |
| Molybdenum (Mo) | 0.05 | ug/L | | 0.603 | | | 0.495 | 0.563 | |
| Nickel (Ni) | 0.02 | ug/L | | 0.093 | | | 0.104 | 0.068 | |
| Selenium (Se) | 0.04 | ug/L | | <0.04 | | | <0.04 | 0.052 | |
| Silver (Ag) | 0.005 | ug/L | | <0.005 | | | <0.005 | <0.005 | |
| Strontium (Sr) | 0.05 | ug/L | | 353 | | | 139 | 281 | |
| Thallium (Tl) | 0.002 | ug/L | | <0.002 | | | 0.002 | 0.0044 | |
| Tin (Sn) | 0.2/0.01 | ug/L | | <0.2 | | | <0.01 | <0.01 | |
| Uranium (U) | 0.002 | ug/L | | 1.19 | | | 0.711 | 1.27 | |
| Vanadium (V) | 0.2 | ug/L | | <0.2 | | | <0.2 | <0.2 | |
| Zinc (Zn) | 0.1 | ug/L | | 0.22 | | | 0.43 | 3.32 | |
| Calcium (Ca) | 0.05 | mg/L | | 43 | 31.8 | 48.9 | 37.1 | 46.6 | 33.9 |
| Magnesium (Mg) | 0.05 | mg/L | | 21.7 | 14.9 | 23.7 | 17.3 | 21.7 | 15.9 |
| Potassium (K) | 0.05 | mg/L | | | | | 0.841 | 0.884 | |
| Sodium (Na) | 0.05 | mg/L | | | | | 2.48 | 4.23 | |

RDL – reportable detection limit

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

| Parameter | RDL$^{*}$ | Units | Location on the lake | Moyie Lake, Lower Shallow (1 metre) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Date sampled | 14-Apr-15 | 28-Sep-15 | 6-Apr-16 | 23-Sep-16 | 19-Apr-17 | 23-Aug-17 |
| Chlorophyll a | 0.5 | mg/L | | 1.51 | 1.35 | 2.02 | 1.19 | 1.23 | 1.03 |
| Chlorophyll a rep | 0.5 | mg/L | | 2.25 | 1.54 | 2.05 | 1.11 | 1.14 | 0.94 |
| **Field measurements** | | | | | | | | | |
| Conductivity | - | uS/cm | | 53.4 | 52.2 | 56.5 | | 48.3 | 49.6 |
| Dissolved Oxygen | - | mg/L | | 12.05 | 7.61 | 10.93 | | 10.54 | 8.43 |
| Secchi (H20 clarity) | - | m | | 3.1 | 6.2 | 6.1 | | 4.6 | 6.4 |
| pH | - | pH | | | 7.5 | | | | 7.47 |
| Temperature | - | $^{0}$C | | 5.2 | 18.7 | 5.27 | | 4.4 | 20 |
| Turbidity | | NTU | | | | 0.64 | | 0.78 | |
| **Anions** | | | | | | | | | |
| Silica | 0.5 | mg/L | | 7.89 | 8.12 | 8.72 | 7.53 | 8.32 | 7.15 |
| Orthophosphate (p) | 0.001 | mg/L | | 0.0026 | 0.0018 | <0.001 | <0.001 | <0.001 | <0.001 |
| Dissolved Sulphate (SO4) | 0.5 | mg/L | | 1.65 | 2.01 | 2.25 | 1.77 | 2.04 | 1.83 |
| Dissolved Chloride (Cl) | 0.5 | mg/L | | 1.5 | 1.07 | 1.34 | 0.99 | 1.28 | 1.14 |
| **Calculated parameters** | | | | | | | | | |
| Hardness | 0.5 | mg/L | | 22.7 | 23.1 | 26.3 | 21.2 | 27.2 | 22.1 |
| **Misc. Organics** | | | | | | | | | |
| Total Organic Cargon | 0.5 | mg/L | | 2.52 | 2.66 | 2.44 | 2.85 | 2.8 | 3 |
| **Nutrients** | | | | | | | | | |
| Total Kjeldahl Nitrogen (Calc) | 0.02 | mg/L | | 0.09 | 0.094 | 0.089 | 0.162 | 0.185 | 0.1 |
| Dissolved Phosphorous (P) | 0.002 | mg/L | | 0.0056 | <0.002 | <0.002 | <0.002 | 0.0022 | <0.002 |
| Nitrate plus nitrite (n) | 0.002 | mg/L | | 0.0322 | <0.0032 | 0.0261 | <0.0032 | 0.0445 | <0.0032 |
| Total Nitrogen (N) | 0.02 | mg/L | | 0.122 | 0.094 | 0.115 | 0.161 | 0.228 | 0.1 |
| Total Phosphorous (P) | 0.002 | mg/L | | 0.0086 | 0.0021 | 0.0069 | <0.002 | <0.002 | 0.0025 |
| **Total metals by ICPMS** | | | | | | | | | |
| Aluminium (Al) | 0.5 | ug/L | | 39.8 | | 28.3 | | 44.9 | |
| Antimony (Sb) | 0.02 | ug/L | | 0.037 | | 0.038 | | 0.034 | |
| Arsenic (As) | 0.02 | ug/L | | 0.219 | | 0.221 | | 0.217 | |
| Barium (Ba) | 0.02 | ug/L | | 6.57 | | 6.96 | | 6.81 | |
| Beryllium (Be) | 0.01 | ug/L | | <0.01 | | <0.01 | | <0.01 | |
| Bismuth (Bi) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Boron (B) | 10 | ug/L | | <10 | | <10 | | <10 | |
| Cadmium (Cd) | 0.005 | ug/L | | 0.0318 | | 0.0464 | | 0.0591 | |
| Chromium (Cr) | 0.1 | ug/L | | <0.1 | | <0.1 | | <0.1 | |
| Cobalt (Co) | 0.005 | ug/L | | 0.0364 | | 0.0292 | | 0.0419 | |
| Copper (Cu) | 0.05 | ug/L | | 0.71 | | 0.598 | | 2.36 | |
| Iron (Fe) | 1 | ug/L | | 50.2 | | 36.6 | | 57.1 | |
| Lead (Pb) | 0.005 | ug/L | | 1.17 | | 1.96 | | 1.73 | |
| Lithium (Li) | 0.5 | ug/L | | <0.5 | | <0.5 | | <0.5 | |
| Manganese (Mn) | 0.05 | ug/L | | 2.98 | | 3.69 | | 4.68 | |
| Molybdenum (Mo) | 0.05 | ug/L | | 0.081 | | 0.089 | | 0.078 | |
| Nickel (Ni) | 0.02 | ug/L | | 0.162 | | 0.184 | | 0.173 | |
| Selenium (Se) | 0.04 | ug/L | | <0.04 | | <0.04 | | <0.04 | |
| Silver (Ag) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Strontium (Sr) | 0.05 | ug/L | | 17.7 | | 17.9 | | 15.3 | |
| Thallium (Tl) | 0.002 | ug/L | | <0.002 | | 0.0022 | | 0.0039 | |
| Tin (Sn) | 0.2/0.01 | ug/L | | <0.2 | | <0.01 | | <0.01 | |
| Uranium (U) | 0.002 | ug/L | | 0.0806 | | 0.0763 | | 0.0787 | |
| Vanadium (V) | 0.2 | ug/L | | <0.2 | | <0.2 | | <0.2 | |
| Zinc (Zn) | 0.1 | ug/L | | 9.31 | | 7.95 | | 13.8 | |
| Calcium (Ca) | 0.05 | mg/L | | 6.32 | 6.59 | 7.45 | 6.03 | 7.97 | 6.34 |
| Magnesium (Mg) | 0.05 | mg/L | | 1.68 | 1.62 | 1.87 | 1.48 | 1.77 | 1.54 |
| Potassium (K) | 0.05 | mg/L | | | | 0.575 | | 0.618 | |
| Sodium (Na) | 0.05 | mg/L | | | | 1.89 | | 1.92 | |

RDL – reportable detection limit

**Table 3b - Water Quality results for upper Moyie Lake Shallow samples**

| Parameter | RDL* | Units | Location on the lake | Moyie Lake, Upper Surface (1m) | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Date sampled | 14-Apr-15 | 24-Sep-15 | 6-Apr-16 | 23-Sep-16 | 19-Apr-17 | 23-Aug-17 |
| Chlorophyll a | 0.5 | mg/L | | 1.86 | 2.62 | 1.79 | 1.08 | 0.397 | 0.884 |
| Chlorophyll a rep | 0.5 | mg/L | | 1.46 | 2.6 | 1.92 | - | 1.05 | 0.92 |
| **Field measurements** | | | | | | | | | |
| Conductivity | - | uS/cm | | 55 | 52.3 | 57.7 | 47.2 | 51.6 | 49.8 |
| Dissolved Oxygen | - | mg/L | | 12.04 | 9.08 | 10.99 | 8.6 | 11.11 | 8.46 |
| Secchi (H20 clarity) | - | m | | 3 | 8.6 | 7.6 | 9.05 | 4.5 | 5.85 |
| pH | - | pH | | | 7.8 | | 8 | 7.3 | 7.56 |
| Temperature | - | $^{0}$C | | 4.3 | 19.9 | 4.8 | 18.9 | 3.7 | 19.4 |
| Turbidity | | NTU | | | | 0.5 | | 0.69 | |
| **Anions** | | | | | | | | | |
| Silica | 0.5 | mg/L | | 8.1 | 7.91 | 8.72 | 8.26 | 8.52 | 8.81 |
| Orthophosphate (p) | 0.001 | mg/L | | <0.001 | 0.0017 | <0.001 | <0.001 | <0.001 | <0.001 |
| Dissolved Sulphate (SO4) | 0.5 | mg/L | | 1.84 | 2.01 | 2.36 | 2.1 | 2.22 | 2.26 |
| Dissolved Chloride (Cl) | 0.5 | mg/L | | 1 | 0.91 | 1.17 | 1.02 | 1.22 | 0.88 |
| **Calculated parameters** | | | | | | | | | |
| Hardness | 0.5 | mg/L | | 23 | 22.5 | 25.9 | 23.9 | 28.4 | 22.9 |
| **Misc. Organics** | | | | | | | | | |
| Total Organic Cargon | 0.5 | mg/L | | 2.55 | 2.33 | 2.49 | 2.68 | 2.59 | 3.1 |
| **Nutrients** | | | | | | | | | |
| Total Kjeldahl Nitrogen (Calc) | 0.02 | mg/L | | 0.103 | 0.094 | 0.078 | 0.061 | 0.114 | 0.098 |
| Dissolved Phosphorous (P) | 0.002 | mg/L | | 0.003 | 0.0021 | <0.002 | <0.002 | 0.0032 | 0.0025 |
| Nitrate plus nitrite (n) | 0.002 | mg/L | | 0.0462 | 0.032 | 0.0454 | 0.0536 | 0.0632 | 0.0728 |
| Total Nitrogen (N) | 0.02 | mg/L | | 0.149 | 0.094 | 0.124 | 0.114 | 0.178 | 0.098 |
| Total Phosphorous (P) | 0.002 | mg/L | | 0.0033 | <0.002 | <0.002 | <0.002 | 0.0039 | 0.0023 |
| **Total metals by ICPMS** | | | | | | | | | |
| Aluminium (Al) | 0.5 | ug/L | | 32.3 | | 26.5 | | 32.4 | |
| Antimony (Sb) | 0.02 | ug/L | | 0.024 | | 0.021 | | 0.022 | |
| Arsenic (As) | 0.02 | ug/L | | 0.213 | | 0.202 | | 0.211 | |
| Barium (Ba) | 0.02 | ug/L | | 6.21 | | 6.15 | | 6.42 | |
| Beryllium (Be) | 0.01 | ug/L | | <0.010 | | <0.01 | | <0.01 | |
| Bismuth (Bi) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Boron (B) | 10 | ug/L | | <10 | | <10 | | <10 | |
| Cadmium (Cd) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Chromium (Cr) | 0.1 | ug/L | | <0.1 | | <0.1 | | <0.1 | |
| Cobalt (Co) | 0.005 | ug/L | | 0.0333 | | 0.0267 | | 0.0365 | |
| Copper (Cu) | 0.05 | ug/L | | 0.646 | | 0.491 | | 3.59 | |
| Iron (Fe) | 1 | ug/L | | 37.9 | | 28 | | 36.4 | |
| Lead (Pb) | 0.005 | ug/L | | 0.0489 | | 0.0356 | | 0.0688 | |
| Lithium (Li) | 0.5 | ug/L | | <0.5 | | <0.5 | | <0.5 | |
| Manganese (Mn) | 0.05 | ug/L | | 2.31 | | 2.39 | | 3.09 | |
| Molybdenum (Mo) | 0.05 | ug/L | | 0.094 | | 0.105 | | 0.085 | |
| Nickel (Ni) | 0.02 | ug/L | | 0.144 | | 0.136 | | 0.153 | |
| Selenium (Se) | 0.04 | ug/L | | <0.040 | | <0.04 | | <0.04 | |
| Silver (Ag) | 0.005 | ug/L | | <0.005 | | <0.005 | | <0.005 | |
| Strontium | 0.05 | ug/L | | 17.9 | | 18.8 | | 16.1 | |
| Thallium (Tl) | 0.002 | ug/L | | <0.002 | | 0.003 | | 0.0038 | |
| Tin (Sn) | 0.2/0.01 | ug/L | | <0.2 | | <0.01 | | <0.01 | |
| Uranium (U) | 0.002 | ug/L | | 0.0902 | | 0.0841 | | 0.0969 | |
| Vanadium (V) | 0.2 | ug/L | | <0.2 | | <0.2 | | <0.2 | |
| Zinc (Zn) | 0.1 | ug/L | | 0.46 | | 0.32 | | 2.01 | |
| Calcium (Ca) | 0.05 | mg/L | | 6.38 | 6.43 | 7.21 | 6.79 | 8.33 | 7.36 |
| Magnesium (Mg) | 0.05 | mg/L | | 1.71 | 1.57 | 1.92 | 1.68 | 1.85 | 1.83 |
| Potassium (K) | 0.05 | mg/L | | | | 0.589 | | 0.604 | |
| Sodium (Na) | 0.05 | mg/L | | | | 1.71 | | 1.67 | |

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