Lake Windermere
Community-Based Water Quality Monitoring Program

2018 Final Report

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Executive Summary

The Lake Windermere Ambassadors (LWA) currently direct a community-based water monitoring and citizen science education program within the Lake Windermere watershed. 2018 marked the twelfth year of lake monitoring since the Lake Windermere Project began collecting water quality data in 2006.

In 2018, the LWA collected physical and chemical water quality parameters at three sample sites on Lake Windermere. Once weekly during the summer from late May to mid-September, the lake sampling regime included: water temperature, turbidity/clarity, pH, conductivity, depth, and dissolved oxygen. Once monthly from April to August, we collected samples for Total and Total Dissolved Phosphorous. The LWA also collected *E. coli* data at public swim beaches in partnership with the Interior Health Authority, and monitored tributary flows and water quality at the outlet of Windermere Creek and Abel Creek. Lastly, we conducted an aquatic plant survey as well as a fall waterbird survey on Lake Windermere with the help and expertise of Goldeneye Ecological Services.

Findings from 2018 show that Lake Windermere continues to flow in good quality to support aquatic life and recreation. Parameters that deviated from Ministry of Environment thresholds included turbidity and Total Phosphorous, however these likely arose due to natural conditions and are not of immediate concern (see below). The three public swim beaches (Windermere, James Chabot, and Kinsmen) were in swimmable quality during all sample collection dates in 2018. The annual aquatic plant survey found no invasive species in Lake Windermere for the ninth year of sampling, and the lake continues to show healthy abundance and biodiversity of aquatic vegetation. A newly developed waterbird survey protocol and investigative report highlights the importance of the South end of Lake Windermere for waterbird survival and biodiversity, and recommends improved education regarding recreational protections for the Southern part of Lake Windermere. We await confirmation regarding the presence of invasive mussel larvae (veligers) which were sampled for by the East Kootenay Invasive Species Council in 2018, but to date there have been no reports of invasive mussels in the lake.

Comparing current results to past years indicates that 2018 was a relatively average year in terms of pH, conductivity, turbidity, and dissolved oxygen in Lake Windermere. While no water temperature readings exceeded the Ministry of Environment threshold on sampling days and times, temperature exceedances were noted at public swim beaches in the late afternoon on hot days in August. Average summer water temperature and average summer lake depth are showing trends of increasing and decreasing with time, respectively. Water conservation measures will become more critical with time to help ensure Lake Windermere continues to flow in good health. Fortunately, phosphorous samples have not indicated a significant increase in Total Phosphorous since 2015, and actually indicate lower sample results than in past years.

Our major funders for this project and its final report include the Columbia Valley Local Conservation Fund, the District of Invermere, the Regional District of East Kootenay and the Columbia Basin Trust's Environment Large Grants program. Additional funding support for our 2018 programs came from the Columbia Valley Community Foundation, the Real Estate Foundation of BC, Canada Summer Jobs, and Columbia Basin Trust's Community Initiatives and Affected Areas program.

Questions about this report?

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1. Introduction

Lake Windermere is one of two headwaters lakes located at the source of the Columbia River in southeast British Columbia, Canada. The "lake" is actually a long widening of the river, with an average depth of only 3—4 m (10—13 ft).

Lake Windermere has historically supported several species of fish, and is used by hundreds of species of resident and migratory birds (McPherson and Hlushak 2008). Birds, fish, and wildlife all depend on the lake and its outflows to the Columbia Wetlands, which are one of the longest intact wetlands in North America and a wetland of international importance (Ramsar 2004).

Humans also depend on Lake Windermere for its social, cultural, environmental, and economic values. Not only is it a drinking water source, but the lake is heavily used for recreation, including swimming, fishing, paddling, tow-sports, motorized boating, skating, and skiing.

1.1 - Climate

Lake Windermere sits within the Southern Rocky Mountain Trench in the Interior Douglas-fir (IDF) biogeoclimatic zone (Braumandl and Curran 2002). The region is temperate and experiences all four seasons, characterized by relatively mild, cold winters and dry, hot summers.

Average annual precipitation is in the range of 300-400 mm (Urban Systems 2012; District of Invermere 2017), and most rainfall typically occurs between May and June. Spring freshet (also known as the peak melt and runoff period) usually occurs between late May and early July.

The warmest days of the year are historically recorded in July and August. 2017 and 2018 have been notable as being hot summer years, with significant forest fire activity and minimal summer precipitation.

1.2 - Watershed characteristics

Lake Windermere sits at approximately 800masl, and is bordered to the east and west by two distinct mountain ranges. The lake flows from south to north as part of the main channel of the Columbia River, which exits Columbia Lake approximately 20km upstream. Lake Windermere flushes on average every 47 days, which contributes to its relatively good water quality (McKean and Nordin 1985).

The main tributary entering Lake Windermere is Windermere Creek, a fourth-order mountain stream that drains an area of approximately 90 km^2 (Northwest Hydraulic Consultants 2013). Some of the major developments within the Lake Windermere watershed include an active gypsum mine, railroad, roads and highway, agricultural and grazing activities, golf courses, ski hills, urban and residential development, and historical forest harvesting (McPherson *et al.* 2018).

1.3 - Community-Based Monitoring

Concerns about increased development and changes to Lake Windermere in the early 2000's prompted the creation of a community-based water quality monitoring program and watershed stewardship education initiative, in the form of the Lake Windermere Ambassadors.

The Lake Windermere Ambassadors (LWA) are a community-led, charitable society formed in 2010 with the mandate of protecting Lake Windermere in perpetuity. The LWA have overseen a community-based water monitoring program on Lake Windermere since their inception, using the assistance of volunteers to build upon a substantial baseline of data collected by Wildsight's Lake Windermere Project.

From 2006 to 2009, the Lake Windermere Project assessed water quality for wildlife and human recreational uses. In 2010, the BC Ministry of Environment used those four years of data and determined an updated list of Water Quality Objectives for Lake Windermere. These Objectives are a benchmark against which the LWA can compare present conditions, to evaluate if the lake water quality continues to be suitable for recreational and ecological needs.

By continuing to test lake water quality on a weekly basis every summer, the LWA now have twelve years of water quality data for Lake Windermere. This data allows the LWA to detect seasonal and annual changes to water quality, and to communicate information about Lake Windermere that will help inform sustainable watershed planning and restoration initiatives in the Upper Columbia watershed.

1.4 - Sample sites

Water quality is sampled at three locations on Lake Windermere, which were historically monitored by the BC Ministry of Environment and the Lake Windermere Project. These locations include the North (Timber Ridge), Middle (Windermere) and South (Rushmere/Lakeshore Resort) sample sites (Figure 1).

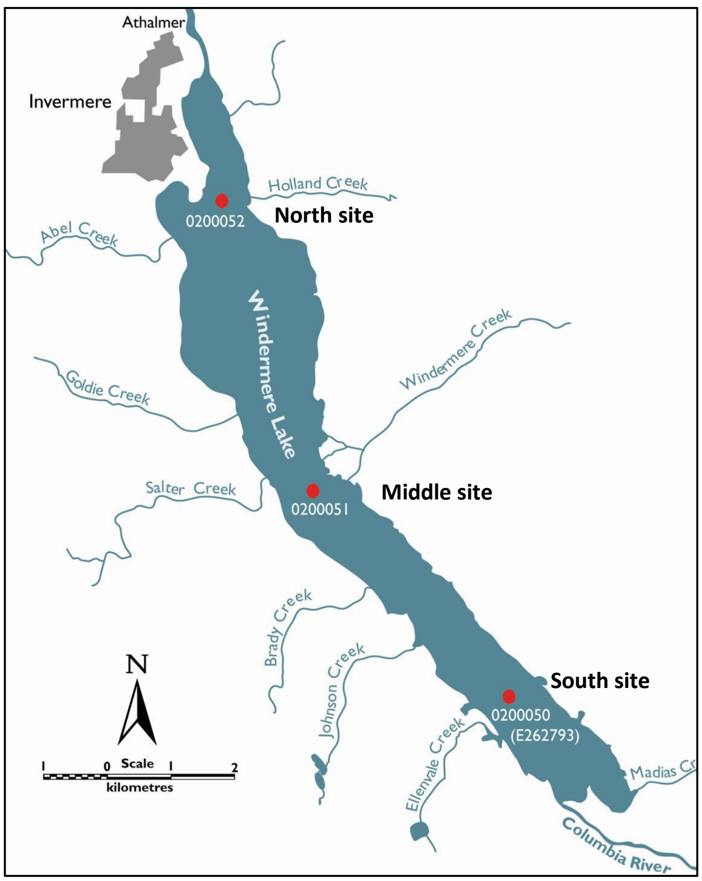


Figure 1: Lake Windermere Sampling Sites (North (0200052), Middle (0200051), and South (0200050)). (Image Source: Neufeld 2010)

For a review of Sampling Methodology and Data Analysis, please refer to Appendix A.

2. Lake Windermere Water Quality Results

2.1 - Temperature

Lake Windermere's water temperature is naturally elevated because of its shallow depth. Unlike many other lakes, Lake Windermere does not stratify into different layers of temperature and density, and tends to be well-mixed throughout (McKean and Nordin 1985).

To adjust for the naturally warmer temperatures in Lake Windermere, the average monthly water temperature objectives are 20°C, 25°C and 23°C in June, July and August respectively (Neufeld 2010).

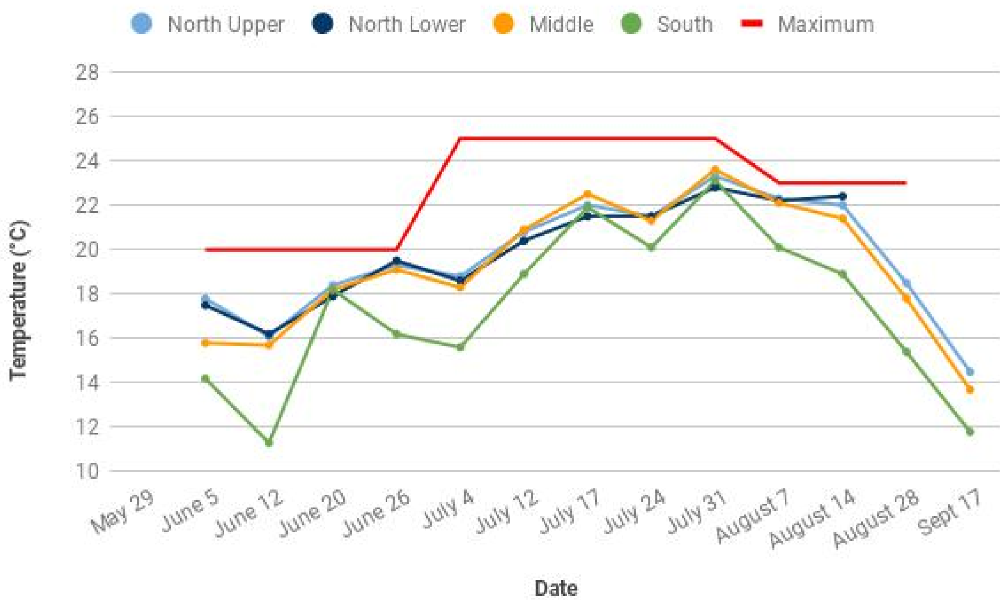


Figure 2: Water temperature results for Lake Windermere, measured weekly from June 5 to Sept 17, 2018. (Note: Lines are for interpretation only, and do not represent continuous measurements.)

The maximum recorded water temperature was 23.6 degrees, on July 31st at 10:30 am at the Middle sample site (Figure 2). The minimum recorded water temperature was 11.3 degrees, on June 12th at 10:15 am at the South sample site. The mean water temperature across all sites was 19.1 degrees (Table 1).

Table 1: Water temperature results for Lake Windermere, measured weekly from June 5 to Sept 17, 2018.

Temperature (°C) (June 5 - Sept 17, 2018)				
	North Upper	North Lower	Middle	South
Maximum	23.3	22.8	23.6	23.1
Median	19.3	20.4	19.1	18.2
Minimum	14.5	16.2	13.7	11.3
Mean	19.6	20.0	19.3	17.4
St Dev	2.62	2.24	3.01	3.65

2.2 - Dissolved Oxygen

Dissolved oxygen, or "DO", is another name for free oxygen gas that is dissolved in water. DO is required for almost all species of aquatic life to survive, but too much or too little can harm aquatic life and negatively impact water quality (Ministry of Environment 2017a).

The capacity for water to hold oxygen is inversely related to temperature. This means that cool water holds more oxygen, while warm water holds less oxygen (Ministry of Environment 2017a).

As DO levels in water drop below 5 mg/L, aquatic life is put under stress. DO levels that remain below 1-2 mg/L for a few hours can result in large fish die-offs. As a result, the DO objectives for Lake Windermere are a minimum of 5 mg/L at all times, and a minimum of 8 mg/L for an average of 5 samples over a 30-day period (Neufeld 2010).

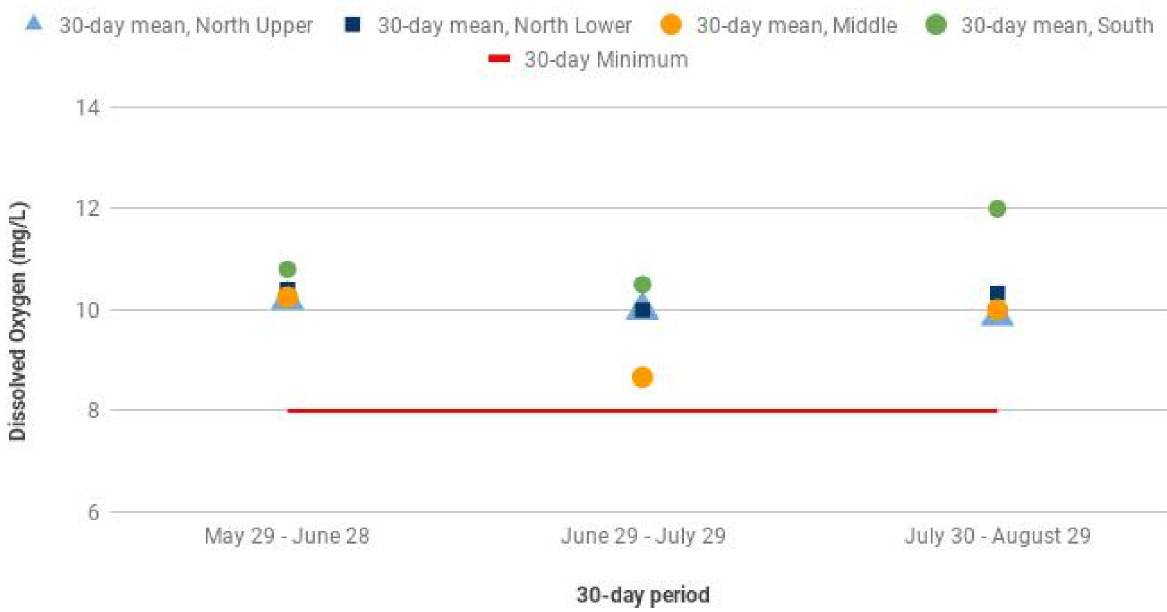


Figure 3: 30-day mean values of dissolved oxygen for Lake Windermere, calculated for the thirteen weeks between May 29 and Sept 17, 2018.

The maximum recorded DO concentration was 12 mg/L, on four different dates in June, July, and August between 9:00—11:00 am at the South sample site (Figure 3). The minimum recorded DO concentration was 8 mg/L, on three different dates in May and July between 9:00—11:00 am at the Middle sample site. The mean DO concentration across all sites was 10.2 mg/L (Table 2).

Table 2: Dissolved oxygen results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018.

Dissolved Oxygen (mg/L) (May 29 - Sept 17, 2018)				
	North Upper	North Lower	Middle	South
Maximum	11	11	11	12
Median	10	10	9	11
Minimum	8	9	8	10
Mean	10.0	10.3	9.4	11.0
St Dev	0.97	0.65	1.21	0.94

2.3 - Turbidity

Turbidity is a measure of the light that is scattered by particles suspended in water, and indicates the clarity of the water.

Since aquatic life in Lake Windermere has adapted to seasonal flushes of sediment into the lake, the acceptable amount of turbidity depends on the time of year. During the spring "turbid flow period" (May 1 – Aug. 15), the 95th percentile of 5 samples taken over 30 days should not exceed 5 NTU. During the late summer/fall/winter "clear flow period" (Aug. 16 – Apr. 30), the max. turbidity at any time should be less than or equal to 5 NTU, while the average of 5 samples over 30 days should be less than 1 NTU (Neufeld 2010).

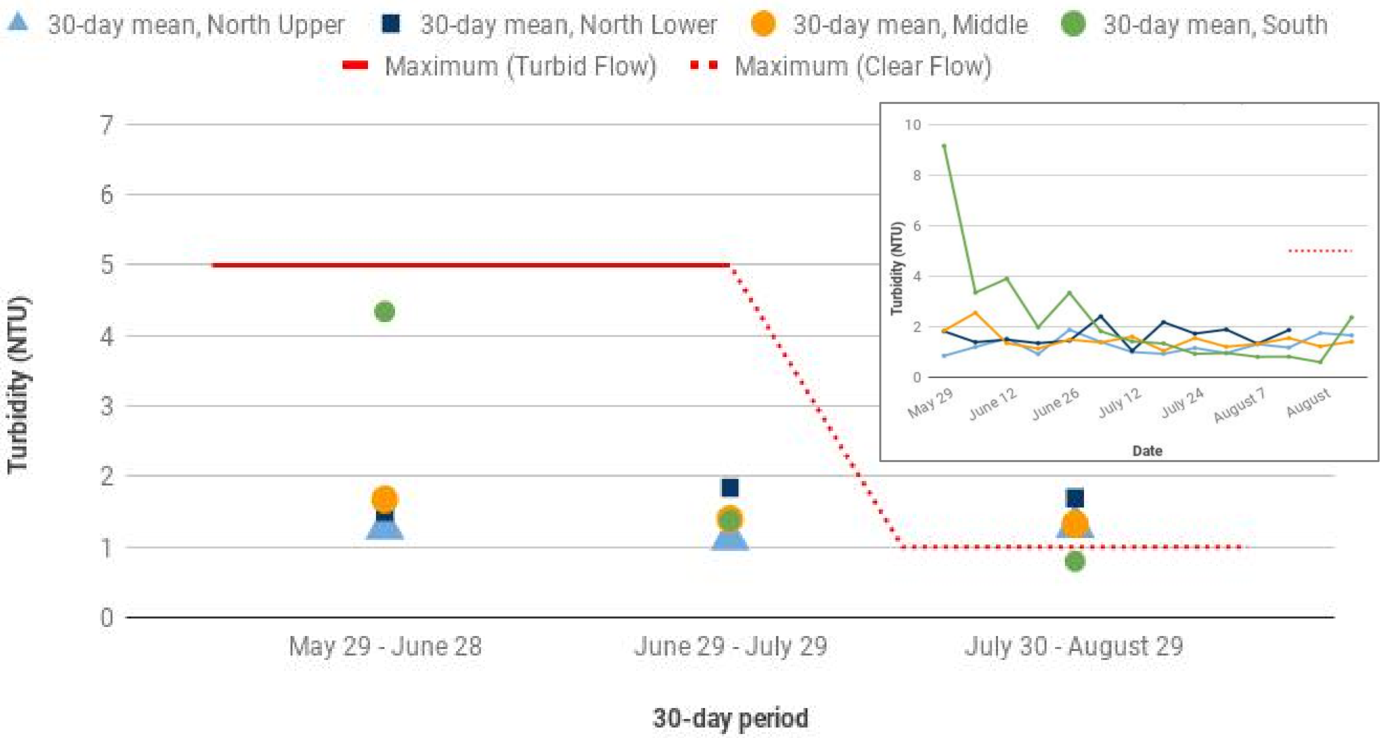


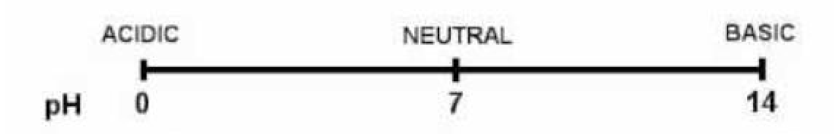
Figure 4: 30-day mean values of turbidity for Lake Windermere, calculated for the thirteen weeks between May 29 and Sept 17, 2018; (Inset: Turbidity values recorded weekly between May 29 - Sept 17, 2018).

The maximum recorded turbidity value was 9.15 NTU, on May 29th at 9:30 am at the South sample site, while the 30-day average for May 29 - June 28 was 4.34 NTU (Figure 4). The minimum recorded turbidity value was 0.60 NTU, on August 28th at 10:15 am at the South sample site (Figure 4, inset). The mean turbidity across all sites was 1.69 NTU (Table 3).

Table 3: Turbidity results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018.

Turbidity (NTU) (May 29 - Sept 17, 2018)				
	North Upper	North Lower	Middle	South
Maximum	1.88	2.41	2.55	9.15
Median	1.19	1.61	1.40	1.62
Minimum	0.85	1.05	1.05	0.60
Mean	1.27	1.66	1.48	2.34
St Dev	0.33	0.39	0.37	2.23

2.4 - pH



pH is a measure of the free hydrogen ion concentration (H^+) of a solution. pH is reported on a scale from 0 to 14. Solutions with a pH between 0-7 represent an acidic environment, while solutions with a pH between 7-14 represent a basic environment.

The pH of natural lakes is rarely neutral because there are dissolved salts and carbonates, aquatic plants, and minerals from the surrounding soils that will all affect water's pH.

There is no objective set for pH in Lake Windermere, however the majority of aquatic organisms prefer a habitat where pH stays within 6.5 - 9.0 (Neufeld 2010; McKean and Nagpal 1991).

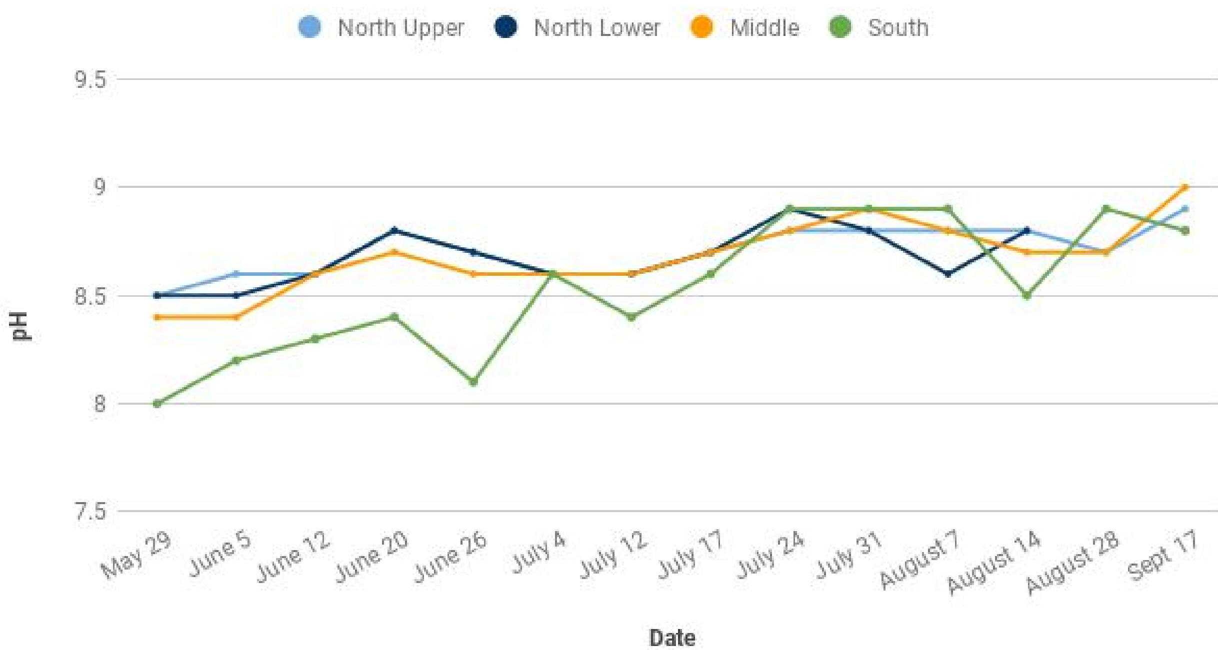


Figure 5: pH results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018. (Note: Lines are for interpretation only, and do not represent continuous measurements.)

The maximum recorded pH was 9.0, on September 17th at 12:15 pm at the Middle sample site (Figure 5). The minimum recorded pH was 8.0, on May 29th at 9:30 am at the South sample site. The mean pH across all sites was 8.65 (Table 4).

Table 4: pH results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018.

pH (May 29 - Sept 17, 2018)				
	North Upper	North Lower	Middle	South
Maximum	8.9	8.9	9.0	8.9
Median	8.7	8.65	8.7	8.55
Minimum	8.5	8.5	8.4	8.0
Mean	8.71	8.68	8.68	8.54
St Dev	0.11	0.13	0.17	0.32

2.5 - Specific Conductivity

Conductivity measures the ability of water to conduct an electrical current. It is affected by the presence and movement of ions in the water.

Because conductivity is so strongly affected by temperature, water meters often measure the s*pecific conductivity,* which is a conductivity value that has been corrected to a standard temperature.

Specific conductivity values have remained fairly consistent over time in Lake Windermere (on average between 200-300 µS/cm), so there is no set objective. It is, however, still important to monitor and observe if changes in conductivity are occurring which might negatively impact aquatic health.

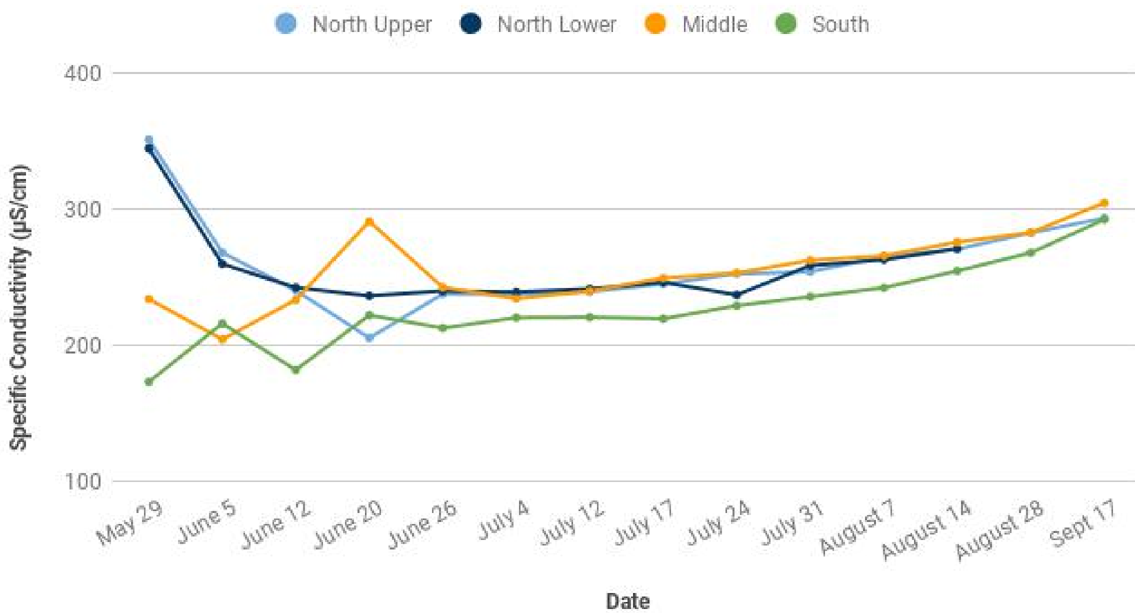


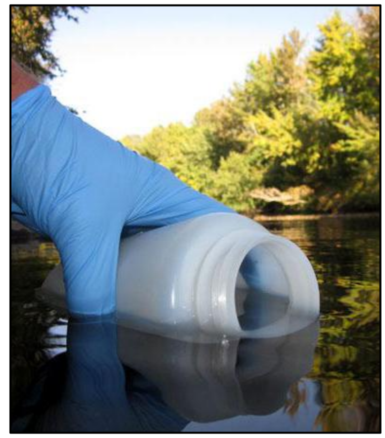
Figure 6: Specific conductivity results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018. (Note: Lines are for interpretation only, and do not represent continuous measurements.)

The maximum recorded specific conductivity was 351.2 µS/cm, on May 29th at 11:00 am at the North sample site (Figure 6). The minimum recorded specific conductivity was 173.5 µS/cm, on May 29th at 9:30 am at the South sample site. The mean specific conductivity across all sites was 250.2 µS/cm (Table 5).

Table 5: Specific conductivity results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018.

Specific Conductivity (µS/cm) (May 29 - Sept 17, 2018)				
	North Upper	North Lower	Middle	South
Maximum	351.2	344.7	304.8	292.6
Median	253.5	244.6	251.6	221.6
Minimum	205.7	236.6	204.7	173.5
Mean	260.4	256.8	255.5	228.0
St Dev	34.2	29.98	26.9	30.9

2.6 - Phosphorus



Phosphorus (P) is a nutrient which is essential for life. P exists in two main forms in water: Dissolved P and Particulate P.

A portion of Dissolved P is readily available to algae and aquatic plants for growth and photosynthesis (US EPA 2012), whereas Particulate P is attached to particles in the water and is not immediately available to aquatic plants or animals. "Total P" is the sum of both Dissolved P and Particulate P.

The Total P objective for Lake Windermere is to stay below a maximum of 10 µg/L (0.01 mg/L) in order to protect drinking water sources and aquatic life (Neufeld 2010).

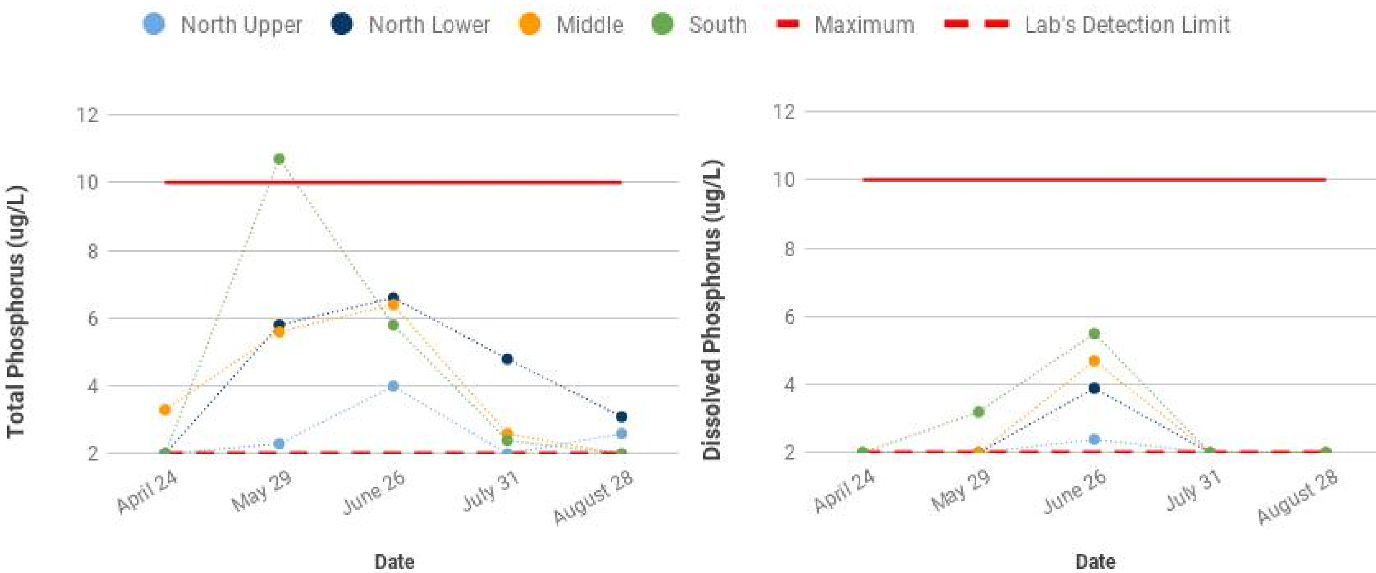


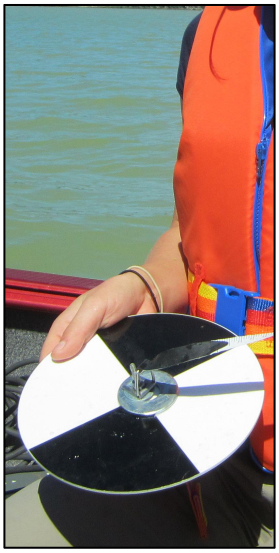
Figure 7: Total P and Total Dissolved P results from Lake Windermere, measured monthly from April 24 to August 28, 2018. The "Detection limit" is the limit at which the extraction procedure can detect phosphorous in water; values below this line were considered "undetectable". These values were assumed equal to 2.

The maximum recorded Total P concentration was 10.7 µg/L, on May 29th at 9:50 am at the South sample site, while the maximum Total Dissolved P was 5.5 µg/L, on June 26th at 11:15 am at the South sample site (Figure 7). The minimum recorded Total P and Total Dissolved P concentrations were 2.0 µg/L, or below the lab's detection limit, on a number of dates across all sites (Figure 7). The mean Total P concentration across all sites was 3.9 µg/L (Table 6).

Table 6: Total P and Total Dissolved P results for Lake Windermere, measured monthly from April 24 to August 28, 2018.

Total Phosphorous (µg/L) (April 24 - August 28, 2018)				
	North Upper	North Lower	Middle	South
Maximum	4.0	6.6	6.4	10.7
Median	2.3	4.8	3.3	2.4
Minimum	2.0	2.0	2.0	2.0
Mean	2.6	4.5	4.0	4.6
St Dev	0.8	1.9	1.9	3.8

Total Dissolved Phosphorous (µg/L) (April 24 - August 28, 2018)				
	North Upper	North Lower	Middle	South
Maximum	4.0	6.6	6.4	10.7
Median	2.3	4.8	3.3	2.4
Minimum	2.0	2.0	2.0	2.0
Mean	2.6	4.5	4.0	4.6
St Dev	0.8	1.9	1.9	3.8



2.7 - Secchi Depth

A Secchi disc is a black-and-white metal disk that gives a reading of water transparency. The disk is lowered over the side of the boat, and the depth at which the black and white pattern can no longer be seen clearly through the water is recorded as the “Secchi depth”.

Secchi depth generally follows the inverse pattern of turbidity. When turbidity is high (lots of suspended particles in the water), the Secchi depth is low because it is difficult to see deep into the water. When turbidity is low (few suspended particles in the water), the Secchi depth is high because it is easy to see deep into the water.

There is no objective set for Secchi depth in Lake Windermere (Neufeld 2010). But following the objectives for turbidity, we should expect the Secchi depth to be lower in the spring and higher in the summer.

Figure 8: Secchi depth results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018. “X” marks measurements where Secchi depth = Total Depth. (Note: Lines are for interpretation only, and do not represent continuous measurements.)

The maximum recorded Secchi depth was 5.3 m, on May 29th at 11:00 am at the North sample site (Figure 8). The minimum recorded Secchi depth was 1.1 m, on May 29th at 9:30 am at the South sample site. The mean Secchi depth across all sites was 3.2 m (Table 7).

Table 7: Secchi Depth results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018.

Secchi Depth (m) (May 29 - Sept 17, 2018)			
	North	Middle	South
Maximum	5.30	4.00	2.90
Median	4.08	3.40	2.38
Minimum	2.75	2.30	1.10
Mean	4.03	3.25	2.32
St Dev	0.86	0.49	0.46

2.8 - Total Depth

Total depth is a measure of how deep the lake water is. We measure this by dropping a weighted metre tape to the bottom of the lake, and recording where the water rises to on the tape.

There is no objective for lake depth in Lake Windermere, but levels below 2m generally cause concern for motorized boaters and increase water's susceptibility to warming.

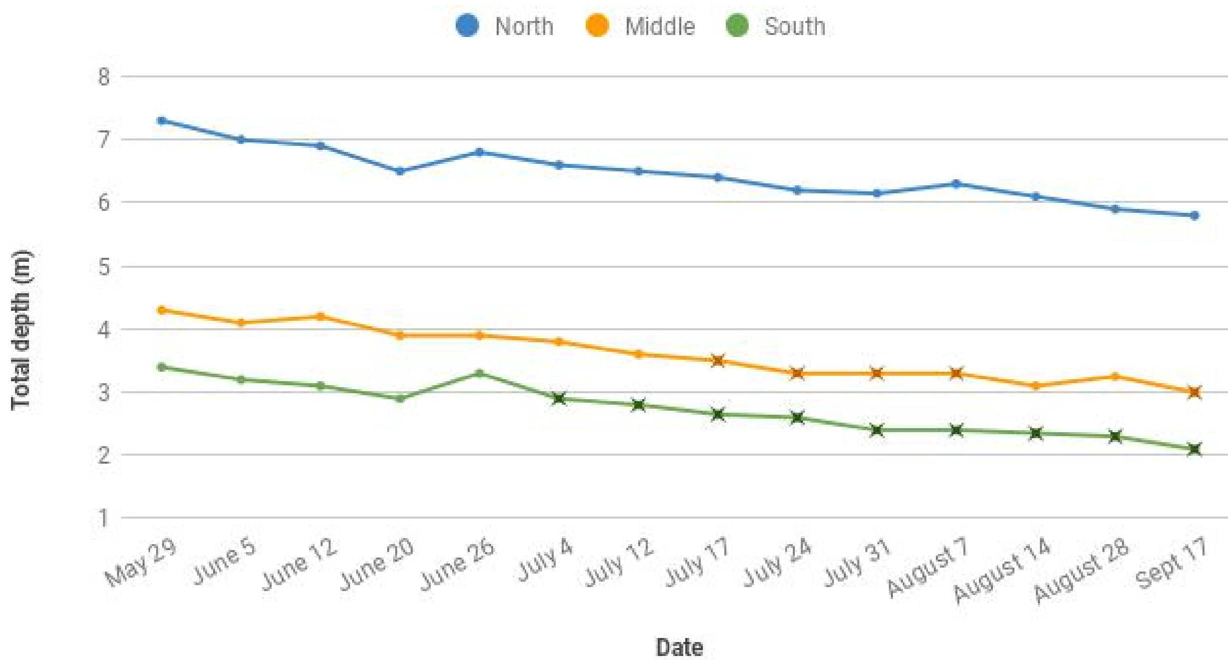


Figure 9: Total lake depth results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018. "X" marks measurements where Secchi depth = Total Depth. (Note: Lines are for interpretation only, and do not represent continuous measurements.)

The maximum recorded depth was 7.3 m, on May 29th at 11:00 am at the North sample site (Figure 8). The minimum recorded depth was 2.1 m, on September 17th at 9:45 am at the South sample site. The mean depth across all sites was 4.3 m (Table 8).

Table 8: Total lake depth results for Lake Windermere, measured weekly from May 29 to Sept 17, 2018.

Total Depth (m) (May 29 - Sept 17, 2018)			
	North	Middle	South
Maximum	7.30	4.30	3.40
Median	6.45	3.55	2.73
Minimum	5.80	3.00	2.10
Mean	6.46	3.61	2.74
St Dev	0.43	0.42	0.41

2.9 - Long-term averages

Average Summer Lake Temperature (2010 - 2018)

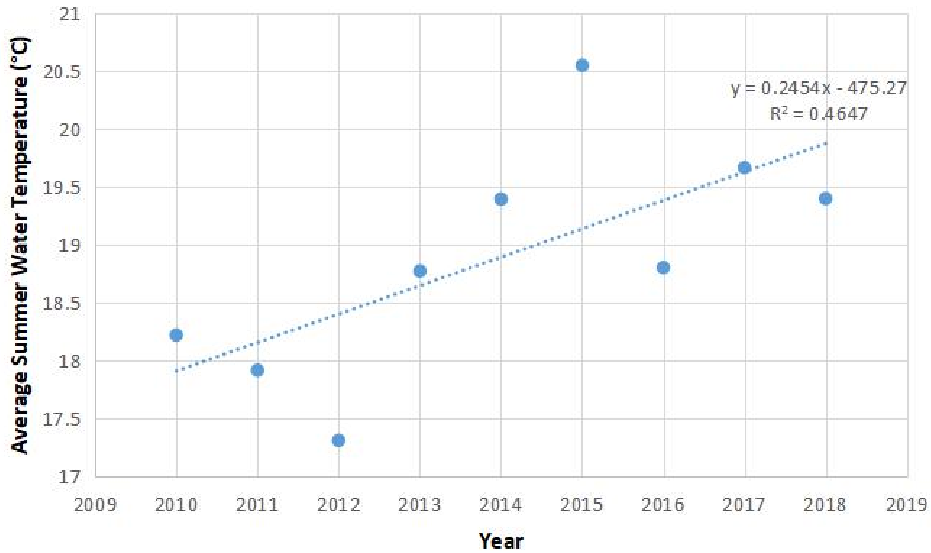


Figure 10: Long-term summer water temperature trend for Lake Windermere, averaged across all sites from 2010 - 2018.

The maximum average summer (June - August) lake temperature occurred in 2015 at 20.5°C, whereas the minimum average summer season lake temperature occurred in 2012, at 17.3°C (Figure 10). A positive linear regression produces a slope of 0.24 and an R^2 value of 0.46, indicating that the model explains a some of the variability of the data around its mean, with an approximately 0.25°C increase in average summer water temperature per year.

Average Summer Turbidity (2006 - 2018)

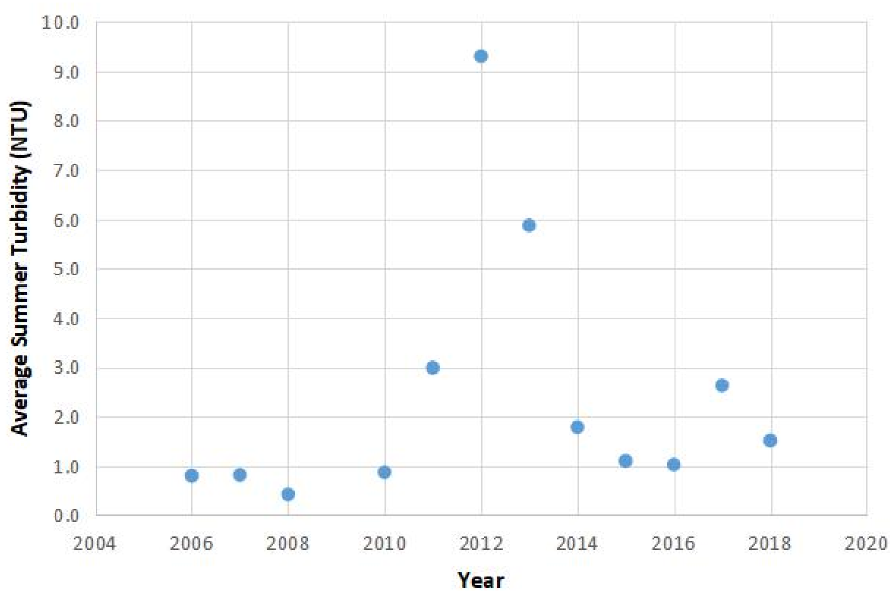


Figure 11: Long-term summer turbidity trend for Lake Windermere, averaged across all sites from 2006 - 2018.

The maximum average summer season (June - August) lake turbidity occurred in 2012, at 9.3 NTU, whereas the minimum average summer season lake turbidity occurred in 2008, at 0.4 NTU (Figure 11). There is no clear linear trend for average summer turbidity values.

Average Total Phosphorous (2006 - 2018)

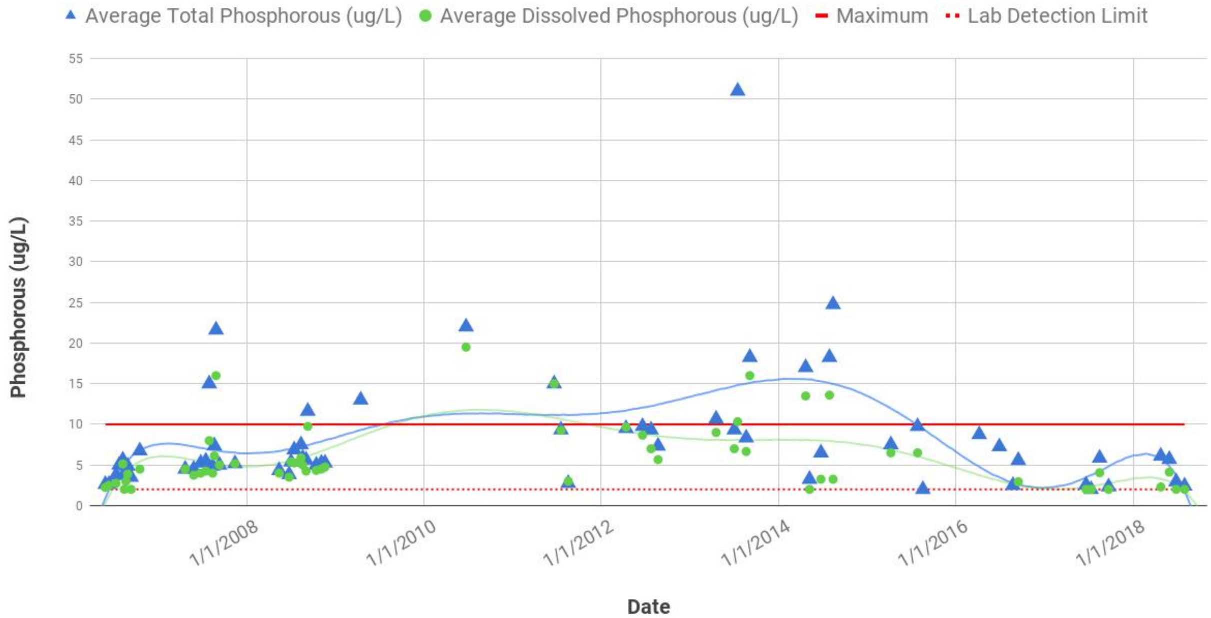
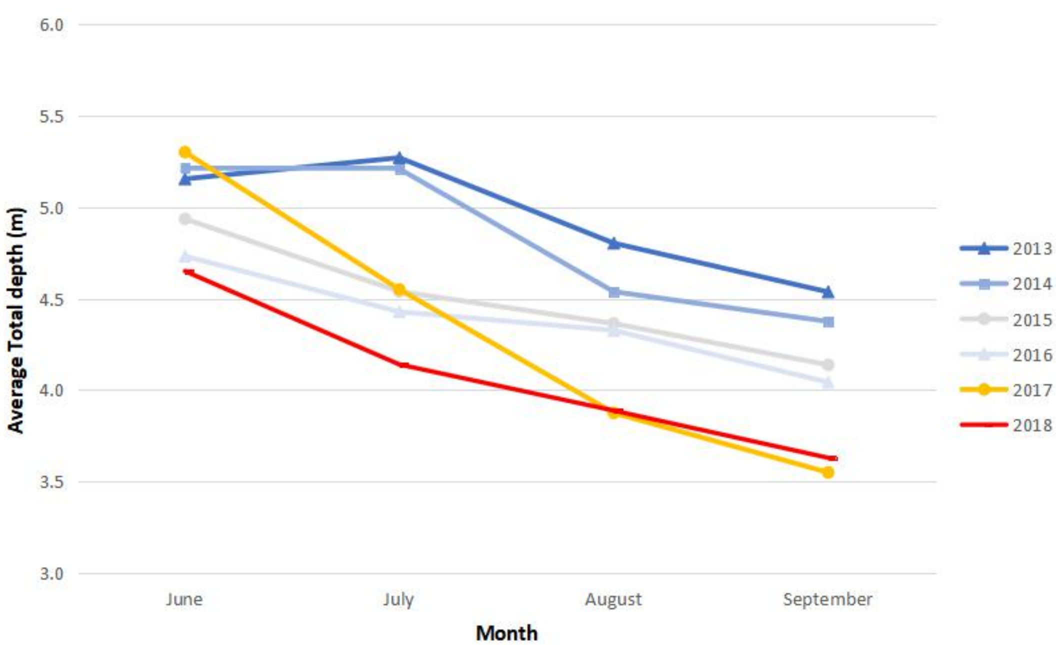


Figure 12: Long-term Total and Total Dissolved P trend for Lake Windermere, averaged across all site from 2006 - 2018.

The maximum average Total P sample was 51 µg/L, on August 20th, 2013, whereas the maximum average Total Dissolved P sample was 19.5 µg/L, on June 23rd, 2010 (Figure 12). These values are approximately 5x and 2x the recommended Total P value for Lake Windermere, respectively.

Average Lake Depth (2013 - 2018)



Average rate of change (m/month) June - September, 2013 to 2018	
2013	0.18
2014	0.20
2015	0.20
2016	0.18
2017	0.43
2018	0.26

Figure 13: Long-term lake depth trend for Lake Windermere, for summer months from 2013 - 2018.

The average monthly summer water level of Lake Windermere has roughly declined each year since 2013 (Figure 13). The average rate of change (from June—September) has increased slightly since 2013, with the highest rate of lake level decline at approximately 0.43 metres per month in the summer of 2017 (Figure 13).

3. Lake Windermere Water Quality Discussion

The main factors posing risks to water quality in Lake Windermere are human disturbances and climate change. From recreation and housing development to stream modifications and shoreline erosion, human impacts to the lake and watershed have increased over time as the population of the Columbia Valley has increased. Additionally, climate change is having stronger impacts on seasonal weather patterns, such as longer, hotter summers and shorter, warmer winters (Carver 2017). Either individually or when combined, these impacts have the potential to negatively affect the ecological health of Lake Windermere.

Key water quality results and their relationship to the impacts of human development and climate change are discussed below.

3.1 - Water Temperature

Water temperature plays a critical role in the growth, survival, and reproduction of aquatic life. Temperature also influences many other water properties, such as conductivity, density, oxygen solubility, and the rates of chemical and biological reactions (Alberta Regional Aquatics Monitoring Program 2008).

Warm waters make Lake Windermere a desirable lake for human recreation, but summer water temperatures have historically exceeded the BC Ministry of Environment (MOE)'s Temperature Guidelines for the protection of freshwater aquatic life (Neufeld 2010). Historical monthly water temperatures in Lake Windermere have been recorded up to 25°C, the maximum threshold for the protection of aquatic life (Neufeld 2010).

Lake results

In the 2018 sampling season, none of the LWA's water samples were recorded above the 25°C threshold (Figure 2). However, data was collected only once per week, and always collected in the morning before 12:30pm. As we know, the hottest part of the day occurs in the late afternoon. Therefore, we can't assume that our sampling results accurately captured the hottest lake temperatures of the summer.

LWA staff recorded water temperatures of up to 28°C in the knee-deep swimming waters at James Chabot Provincial Park Beach, around 5:00pm on August 5th, 2018 when the air temperature was approximately 31°C. This clearly shows that lake temperatures *have* exceeded that 25°C threshold, although not necessarily in the same sampling locations or at the same times that the LWA performs routine sampling.

For comparison, the maximum recorded water temperature during routine lake sampling excursions was 23.6°C in 2018, 22.6°C in 2017, 21.8°C in 2016, and 22.8°C in 2015 (Rodgers 2017). All of these values were recorded at the Middle sample site, just west of Windermere Beach.

Figure 10 shows the annual average summer (June - August) water temperatures across all sample sites for the past eight years. Prior to 2010, water temperature data was collected with a different instrument therefore data prior to this year is excluded from analysis. A linear trendline produced a positive trend in the data (R^2 = 0.46) with a slope of approximately 0.25 degrees per year, indicating that average lake water temperatures appear to have been slightly increasing on an annual basis since 2010. However, a one-way ANOVA determined the difference between annual means was not statistically significant at a significance interval of 0.05 (p-value = 0.739).

Ecological Impacts

Many of the fish species observed in Lake Windermere, especially trout and salmon, have optimal water temperature ranges below 18°C for rearing, spawning, and incubation (Ministry of Environment 2017a). A major reason for this is because of temperature's influence on dissolved oxygen (DO) availability. When lake temperatures get too warm, it results in stress and even mortality of fish, because they are unable to get enough oxygen.

However, certain fish species in Lake Windermere - such as the introduced Largemouth Bass (*Micropterus salmoides*) - have optimal temperature ranges that surpass those of native salmonid species. The temperature tolerance for LM Bass is in the range of 18—34°C (Nevada Division of Environmental Protection 2016), meaning they could potentially out-compete cold-water fish species when lake temperatures warm.

Temperature can also impact the reproduction, metabolism, and survival of plants, insects, microbes, and parasites living in the lake. For example, Impoinvil *et al.* (2007) found that the optimum water temperature for mosquito egg hatching ranges from 24 to 30°C, suggesting that mosquito larvae may hatch more quickly and successfully in warmer lake water. Additionally, *Escherichia coli (*E. coli) bacteria are known to grow best between 10 to 45°C, but have an optimal growth temperature of 37°C (Health Canada n.d.). This suggests that the closer lake waters get to 37°C, the more successfully *E. coli* will be able to survive and reproduce. Finally, freshwater aquatic plant species such as those found in Lake Windermere tend to grow best in clear, shallow waters with warm water temperatures, and the quantity of plant biomass (leaves, shoots, stems) tends to increase with increasing water temperatures to at least 28°C (Barko *et al.* 1982).

In addition to its effects on aquatic organisms, higher water temperatures can increase the solubility and toxicity of certain heavy metals like zinc, lead, and cadmium, as well as compounds like ammonia (Fondriest 2017). Warmer water temperatures also influence the tolerance limit of aquatic organisms to these compounds — mortality rates for zinc are significantly higher at temperatures above 25°C than at temperatures below 20°C (Fondriest 2017).

So in summary, although Lake Windermere is naturally warmer than many other freshwater lakes, water temperatures that rise above 25°C may be harmful to the natural ecology of the lake. Unfortunately, the hot and dry summer periods over the past two years have shown that lake temperatures are already getting close to crossing that threshold, even early in the morning before the heat of the day.

Recommendations

A solution to be able to more accurately monitor lake water temperature at the hottest time of day is to install continuous water temperature loggers in the lake for 2019. The loggers will have to be located in sheltered areas, so as not to be disturbed by motorized boat traffic. Water depth must be deep enough to allow for mixing and avoid significant solar radiation influences. These loggers can be deployed once in the spring and collected once in the fall, allowing temperature trends to be recorded and then analyzed for the entire summer period. This would give a much more comprehensive understanding of just how warm the lake water gets, which could help inform fisheries management and invasive species management in the future.

Maintaining riparian areas with shrubs and trees can help protect streambanks from erosion and shade tributary streams and shorelines. In doing so, vegetation helps keep water temperatures cool. Additionally, conserving water at home, in your yard, and in agricultural practices can help ensure enough stream and groundwater is available to help keep lake temperatures cool.

3.2 - Turbidity

Turbidity is caused by suspended particles in water, which are most often a combination of zooplankton, phytoplankton, algae, pollutants, and/or sediment (clay and silt).

Since aquatic life in Lake Windermere has adapted to seasonal flushes of sediment into the lake, the acceptable amount of turbidity depends on the time of year. The most turbid waters typically occur during the spring or after heavy rains.

When waters are very turbid — for instance, when the lake is filled with lots of suspended sediment after a heavy rainfall carries soil down through tributary creeks and off of shoreline properties — light does not pass through the water as easily to reach aquatic plants. When there is low light for plants, photosynthesis slows down and less oxygen is produced. Therefore, highly turbid water can stress fish and other aquatic organisms because it decreases the amount of oxygen in the water. High turbidity can also stress fish and aquatic insects because it impedes their ability to navigate and it can clog their gills (Ministry of Environment 2017a).

Turbidity can also influence the temperature of water — turbid water absorbs more of the sun's energy and can warm the water more quickly (Fondriest 2017). This also reduces the amount of oxygen the water can hold.

Lake results
In the late spring of 2018, the South site experienced the highest turbidity (9.15 NTU) whereas the Middle and North sites experienced relatively low turbidity in the range of 0.8—2.5 NTU (Figure 4). Conversely, in the late summer of 2018, the South site experienced the lowest turbidity (0.60 NTU) whereas the Middle and North sites experienced slightly higher turbidity in the range of 1—2 NTU (Figure 4).

In late spring of 2018 (May 29 - June 28), the 30-day mean turbidity values did not exceed the maximum threshold of 5 NTU at any of the sample sites, although the South site was the closest at 4.34 NTU (Figure 4). For comparison, between mid-June and early July of 2017, the South site exceeded the 30-day average threshold with a turbidity of approximately 8 NTU (Rodgers 2017).

The average summer lake turbidity increased dramatically from 2011—2013 (Figure 11). In early August of 2011, Windermere Creek (Lake Windermere's main tributary, near the Middle sample site) flooded and caused a state of emergency to be declared by the Regional District of East Kootenay (NHC 2013). In mid-July of 2012 and again in 2013, Fairmont Creek (upstream of Lake Windermere) experienced a significant debris flow triggered by high water levels (Columbia Valley Pioneer 2017). These are the most likely explanations for this spike in average summer lake turbidity from 2011—2013.

Ecological Impacts
In the spring, turbid waters spill out of Dutch Creek into the main Columbia River channel, flowing north away from Columbia Lake towards Lake Windermere (Rodgers 2017). Within the river channel, water flows relatively quickly and has a better ability to transport suspended sediments. It is typical to see a surge in turbidity at the South end of Lake Windermere in the spring, which is most likely due to this sediment transport from Dutch Creek (Rodgers 2017).

When water enters Lake Windermere, it slows down, spreads out, and loses some of the velocity that was carried through the narrower river channel flowing into the lake at its south end. This loss of velocity means the water can no longer transport as much suspended sediment, and sediment settles out to the bottom of the lake. This contributes to clearer waters at the Middle and North end of the lake, however it may be a cause for nutrient enrichment and lake level decline at the South end of the lake, because this extra sediment accumulates on the lake bottom at this site.

River and lake sediments contain nutrients and pollutants that are "adsorbed" (attached) to the sediment particles. "Adsorbed" nutrients are not immediately available for plants or algae to take up, however they can be released back into the water column — especially when there is a lack of dissolved oxygen at the sediment-water interface (Government of Alberta 2018). As we have learned, warm water temperatures and high turbidity levels both contribute to reducing the amount of dissolved oxygen available in the water.

If we imagine a future scenario where water temperatures are very warm, the lake is experiencing high turbidity, and aquatic plants are removed from the lake through dredging to improve recreational boating, this could decrease the amount of dissolved oxygen in the water and potentially increase the amount of nutrients and pollutants that are released from lake-bottom sediments. This could potentially spur an increase in water pollution and nutrient enrichment, leading to increased aquatic plant and algae growth and disruption of the lake's ecological health.

Recommendations

Turbidity monitoring should continue, although earlier spring season sampling could be attempted in order to capture the true maximum during freshet (e.g. April-May). Further investigations into possible correlations between spring nutrient concentrations from Dutch Creek and Fairmont Creek outflows and the water quality in Lake Windermere could be conducted. If budget allows, nutrient and heavy metal analysis of lake-bottom sediment from each of the three sample sites could be conducted to help determine if there is risk of major pollutant release under low oxygen conditions.

Maintaining riparian areas with shrubs and trees can help protect streambanks from erosion, which can help stabilize soils, reduce the amount of nutrients and sediment entering the lake, and reduce overall turbidity. Development and construction projects, especially directly upland from Lake Windermere, must manage their soil and debris runoff during rainy periods, and avoid incorporating large paved areas without adequate stormwater management, as this can cause rapid slope erosion due to the volume of runoff that runs downslope.

Upstream activities along Dutch, Fairmont, and Windermere creeks must also recognize their impact on the watershed, and residents must work to maintain adequate riparian buffers with healthy vegetation that can help trap urban runoff and take up nutrients that might otherwise enter the stream. The LWA could work to improve responsible riparian area conservation in the upstream areas for Lake Windermere, namely the communities of Dutch Creek and Fairmont Hot Springs.

Finally, responsible boating practices can go a long way towards helping keep the lake's turbidity low. Motorists should avoid using motorized boats in shallow areas that might stir up and disturb lake-bottom sediments. Improved signage could be placed at very shallow areas (e.g. Windermere Creek outlet, near Middle sample site) to warn boaters, as not only does boating in shallow water damage the ecosystem, it can damage expensive watercraft as well.

3.3 - Phosphorous

Phosphorous (P) is used by humans, plants and animals for photosynthesis and metabolism. As such, it is an essential nutrient required for all life to survive.

P exists in two main forms in water: Dissolved P and Particulate P. A portion of Dissolved P is readily available to algae and aquatic plants for growth and photosynthesis (also called "orthophosphorous") (US EPA 2012), whereas Particulate P is attached to particles in the water and is not immediately available to aquatic plants or animals. "Total P" is the sum of both Dissolved P and Particulate P.

Historic sampling results indicate that Lake Windermere is "oligotrophic". This means that low nutrient levels and clear waters have been the norm in this lake, and phosphorous is often limiting to the growth of aquatic life.

Lake results

In 2018, phosphorous was sampled monthly. The Total Phosphorous (Total P) value exceeded Ministry of Environment recommendations on May 29th with 10.7 µg/L at the South sample site (Figure 7). This may be correlated with the higher turbidity at this site on the same date (Figure 4), especially considering the Total Dissolved P value was low - which suggests that the sample may have contained mostly Particulate P fraction (Figure 7).

The highest recorded value of Total P by the LWA was 67 µg/L, on August 20th 2013 at the Middle sample site. This value was more than 6x the recommended limit, and prompted the LWA to increase monitoring for phosphorous in the lake. Since that date, few extremely high values have been detected, but elevated levels at 2—3 x the recommended limit were recorded in 2014 and 2015. In general, the Total and Dissolved P results from 2016—2018 have been lower than in previous years (Figure 12).

Although water quality samples have not shown elevated levels of average Total or Total Dissolved P in Lake Windermere since 2015 (Figure 12), there is a potential for phosphorous and other nutrient levels to increase if Lake Windermere experiences high turbidity, high temperatures, and low dissolved oxygen conditions that would facilitate introduction of nutrient sources and prompt the release of adsorbed particles from lake-bottom sediments.

Ecological impacts

When present in low quantities, phosphorous can limit the growth of aquatic life. When present in high quantities, phosphorous can cause excessive growth of algae and bacteria, which can severely compromise other forms of aquatic life and human health.

Two major human-caused inputs of phosphorous to waterways in North America include agricultural runoff and wastewater. Within the Lake Windermere watershed, possible sources of phosphorous inputs to the tributaries and the lake include agricultural runoff, golf course and lawn & garden fertilizer runoff, municipal stormwater runoff containing detergents and other phosphate-bearing chemicals, or leaky shoreline septic systems. Natural sources include nutrient cycling that releases P when plants and animals die and decompose, and soil mineral and sediment transport.

Phosphorous can change from one form to another (called cycling) in response to a variety of environmental conditions. It is this cycling that determines what fraction of Total P is available for plants and algae to take up into their tissues.

A portion of Particulate P is contained in organic matter, such as algae, plant and animal tissues, waste solids, or other organic matter. Microbial decomposition of organic compounds can convert organic Particulate P to Dissolved P.

Another portion of Particulate P is contained in inorganic materials, such as soil mineral particles. These can also be converted to Dissolved P, both in the water column and during chemical and physical changes in bottom sediment (such as low dissolved oxygen concentrations, as described above in section 3.2). This inorganic form of Dissolved P is the most readily available form for plants and algae to take up into their tissues. Only the most tightly bound forms of Particulate P, such as aluminum-bound phosphorus, are not generally available for algal growth.

Luckily, Lake Windermere's relatively rapid flushing helps contribute to its low phosphorous concentrations. However, that doesn't mean that phosphorous inputs can't pose a problem in the coming years, especially with the cumulative impacts of growing development, urbanization, climate change, and risk of invasive species establishment.

Recommendations
Continue monitoring for phosphorous on a monthly basis from April to September, and continue nutrient education and invasive species stewardship outreach within the watershed. As mentioned above, if budget allows, nutrient analysis of lake-bottom sediment from each of the three sample sites could be conducted to help determine if there is a risk of major nutrient release under low oxygen conditions. Improved dissolved oxygen data collection will be pursued in 2019 with a new Dissolved Oxygen meter.

People can help reduce nutrient-rich runoff from leaving their lawns and gardens by ensuring they never fertilize right before a rain event, avoid tilling or disturbing soil right before a rainstorm, and leave all riparian areas around their property with ample vegetated buffers of shrubs and trees to help trap sediment runoff and take up nutrients through their root systems.

Additional ways to reduce P inputs to the watershed include replacing old septic tanks that may be leaky, avoid using old detergents and phosphate-containing chemicals, and only allowing clean rainwater to go down stormwater drains since this water is not treated before it re-enters the environment. Finally, if you notice evidence of an algae bloom or algae growth in Lake Windermere or any of its tributaries, please notify the LWA.

3.4 - Lake depth

Lake Windermere is very shallow, on average only 3—4m depth in mid-summer. The North site is the deepest point in the lake, and reaches a maximum of approximately 6—7m in depth each spring. The South end of the lake, where water flows in from the Columbia Wetlands, tends to be much shallower than the Middle and North sites. As we have learned above, this might be due to sediment deposition at the South end.

Lake results
Lake depth in 2018 followed the expected trend of being higher in spring and gradually declining through the late summer due to less input from snowmelt/precipitation and increased evaporation to the atmosphere (Figure 9).
The deepest value (measured at the North sample site) in 2018 was 7.3m (Table 8) on May 29th, which is the greatest depth recorded at this site since monitoring began in 2006. Only two other

occurrences of this depth have been recorded, which happened in July 2012 and June 2013 - the same years as the flooding in Fairmont creek. For comparison, the deepest measurement at this site in 2017 was 7.2m, in 2016 was 6.5m, and in 2015 was 6.7m.

Yearly trends show that 2017 had a more dramatic change in June- September water levels as compared to previous years (Figure 13). Figure 13 illustrates how Lake Windermere's average depth (June - September) has been steadily decreasing since 2013. A one-way ANOVA determined the difference between annual means was not statistically significant at significance interval of 0.05 (p-value = 0.132), but monitoring should continue in case this trend grows stronger over time.

We exclude data prior to 2013 because a significant shift happened at the middle site which has skewed the data. The sampling location was changed for an unknown reason between fall 2012 and spring 2013, and depth measurements at the Middle site went from an average of 0.5 - 1.5 m to an average of 3 - 4 m between the end of the 2012 season and the beginning of the 2013 season. Since we can only compare depth data between years that used the same sample site, we have reported out on only the 2013-2018 data.

Ecological Impacts

Depth can be an important consideration for aquatic life, as well as for recreational boaters and drinking water users. While seasonal changes to lake levels may not have as much of an impact at the North end of Lake Windermere, they can have major effects to the ecology and recreational capacity at the South end of the lake, where water depths often get as low as 1—2 m (3.5—6.5 ft) with thickets of aquatic vegetation growing right below the water's surface.

Shallow water poses more risks for recreation, because motorized boaters can more easily get caught on sediment bars or clog their motors with aquatic vegetation. Not all boaters are aware of Lake Windermere's shallow depth, and may venture into areas of only 1—2m depth by accident. Boat propellers disrupt and stir up the lake bottom sediment in shallow water, increasing turbidity and making conditions worse for fish and aquatic insects.

Shallower water also warms up more quickly, which can pose issues for drinking water quality and the survival of aquatic life as mentioned above. Bacteria, parasites, and algae blooms can all flourish under warmer water temperatures caused by shallow water.
Finally, shallow water also promotes more submerged aquatic plant growth because there is better light penetration beneath the water surface. When light is not a limiting factor to plant growth and metabolism, we often see increases in the amount of plant biomass produced.

Lake depth will become more of a concern in future years as we experience hotter summers with less precipitation, as our hydrologic regime shifts to an earlier spring peak and lower later-summer flows (Carver 2017), and as the population and water consumption demand for the Columbia Valley increases with time.

Recommendations

The LWA should continue to work on quantifying lake water volumes and rates of lake level change with time. Improved education and outreach regarding home, garden, and agricultural water conservation practices will be essential for helping to maintain adequate lake levels in the future. The LWA should also stay current with any future hydrologic studies for the Upper Columbia Basin, in order to learn how findings could be applied to help preserve lake levels for Lake Windermere.

4. Aquatic Plant Survey

4.1 - Background

Being relatively clear and shallow throughout the summer, Lake Windermere allows for good light penetration which helps promote aquatic plant growth beneath the surface.

Aquatic plants improve water quality by producing oxygen, filtering out nutrients that might otherwise be taken up by algae blooms, and by trapping sediments that would otherwise be disturbed by motorized boat and wave action. Without rooted aquatic plants to help hold sediment in place, increased turbidity can result which degrades water quality (Rideau Valley Conservation Authority, 2016). Excess plant growth, however, can impede motorized boating and provide shaded habitat for predatory fish species such as largemouth bass.

Invasive species out-compete most other native species if allowed to establish. This often results in a loss of biodiversity, which can have a cascading effect on water quality and fish & wildlife populations. The introduction and spread of invasive aquatic plants would not only be devastating to the economy, ecology and biodiversity of Lake Windermere, but to the entire Columbia Valley.

The Lake Windermere Ambassadors initiated an Aquatic Invasive Species (AIS) Inventory Project in 2009, which has seen an annual plant and veliger (mussel larvae) sampling occur on the lake in all years except 2013. Rachel Darvill (Goldeneye Ecological Services) was the lead biologist for aquatic plant sampling with the LWA in 2018, while the East Kootenay Invasive Species Council conducted independent veliger sampling during their own surveys.

4.2 - 2018 Sample Results

The 2018 survey marked the ninth year of invasive species sampling and included eleven lake-bottom (offshore) sampling locations and six shoreline sampling locations, all at high-risk areas for invasive introduction around the lake.

No invasive plant species were found during the offshore or shoreline plant surveys (Darvill 2018a). As with previous years of inventory effort, Lake Windermere appears to have good diversity and abundance of native aquatic plant species, which is a critical component of a healthy aquatic ecosystem.

Due to Lake Windermere's high environmental, economic and societal significance it is recommended that aquatic invasive plant species inventories continue on an annual basis. This would allow for a rapid management response to follow if any aquatic invasive plant species were detected. The high level of recreational use that Lake Windermere receives puts it at a high level of risk for introducing new AIS into the lake as well as the ecologically significant Columbia Wetlands ecosystem. The LWA should continue education and outreach about the importance of native aquatic plant species and how to prevent establishment of invasive aquatic plant species.

The full 2018 AIP Inventory Report can be found on the LWA website under "Documents".

5. Waterbird Survey

5.1 - Background

Although the Columba Wetlands Waterbird Survey (CWWS) has been ongoing since 2015, this was the first year that a dedicated waterbird survey was planned for Lake Windermere.

Lake Windermere does not receive much attention or recognition for the significant bird habitat it provides for large migrant flocks and breeding birds (Darvill 2018b). Previous bird surveys have documented Lake Windermere as important bird habitat, even when compared to the rest of the Columbia Wetlands ecosystem. The lake is especially important for large flocks of migratory birds, such as American coots (*Fulica americana*), as well as four species of grebe - three of which are considered at-risk species (Darvill 2018b).

A review of the CWWS results and the online public eBird database produced a list of 165 bird species, including aquatic and terrestrial species, that have been observed using Lake Windermere at all times of year. The LWA and Goldeneye Ecological Services undertook a boat survey in September 2018 to help supplement the information collected from the eBird database and the CWWS results.

5.2 - 2018 Sample Results

Of the 165 species reported through eBird for Lake Windermere, 17 of these are considered to be species-at-risk. Results indicate that there are specific at-risk bird species that utilize the habitat found at Lake Windermere with a greater frequency, such as western grebe, horned grebe, and great blue heron, when compared to other at-risk bird species (Darvill 2018b).

The south end of Lake Windermere has been demonstrated through historical and current bird surveys as important habitat during migration for large mixed flocks of American coot and other waterfowl (e.g. American wigeon, Canada geese, mallard) (Darvill 2018b). It appears that the South end of Lake Windermere could be the most important habitat for these specific bird species during migration, as it supports the highest concentrations of migrating waterbirds compared to the entire continuous Columbia Wetlands ecosystem.

Current risks to the presence and survival of at-risk and other waterbird species on Lake Windermere include shoreline development, destruction of emergent vegetation in front of docks or lakefront properties, shoreline and bank erosion, and decreasing water levels (Darvill 2018b). Human activity or disturbance at potential breeding sites is also known to have negative impacts on breeding colonies, with high incidence of nest abandonment (Darvill 2018b).

It is strongly recommended that management strategies be designed that can work to accommodate both human-use values and bird conservation for Lake Windermere. Specific recommendations to achieve this balance of conservation and human uses include:

- undertaking additional breeding season and fall migratory bird studies for Lake Windermere,
- factoring waterbird and wetland conservation into land-use decisions for Lake Windermere,
- improving signage about motorized boating regulations in the Columbia Wetlands WMA, and
- improving public education about the use of eBird and the importance of conserving habitat values of Lake Windermere for migratory and at-risk bird species.

6. Swim Beach Water Quality

6.1 - Background

Escherichia coli (E. coli) is a type of fecal coliform bacteria found in the intestines of most healthy animals. *E. coli* in water can be an indicator of sewage or animal waste contamination, or it may come naturally from the soil. Most strains of *E. coli* are harmless, though some can produce toxins that cause illness in people.

The count of *E. coli* colonies per 100mL of water is a common way to measure how much bacteria is present in the water; however, this value represents a total count of all colonies, and does not necessarily contain strains that are capable of producing toxins that affect humans. A higher *E. coli* count simply increases the probability that the water may contain a toxin-producing strain.

The LWA collect public beach water samples which are then analyzed by the Interior Health Authority for *E. coli* bacteria, in compliance with Health Canada Guidelines. This assesses whether swim beach water quality meets recognized health standards for recreation.
Samples are collected at three public beaches around the lake: James Chabot Provincial Park (Athalmer), Kinsmen Beach (Invermere), and Windermere Beach (Windermere).

The Health Canada Guidelines for recreational water used for "primary contact" activities (e.g., swimming) is: Geometric mean concentration (minimum of five samples taken over 30 days): ≤200 *E. coli*/100mL; Single-sample maximum concentration: ≤400 *E. coli*/100mL

6.2 - 2018 Sample Results

The geometric mean did not exceed the Health Canada recommended limit of 200 colonies of *E. coli*/100 mL for any of the public beaches tested, nor did any single sample exceed 400 colonies of *E. coli*/100 mL. The highest geometric mean values over a 30-day period were as follows:

James Chabot Beach =	14.7	*E. coli*/100 mL
Kinsmen Beach =	8.5	*E. coli*/100 mL
Windermere Beach =	5.0	*E. coli*/100 mL

The highest single sample in 2018 was 55 *E. coli* /100mL, recorded on September 10th at James Chabot Beach. This beach often sees geese and waterfowl populations congregate in the spring and fall, which can add droppings to the water and increase the *E. coli* content.

For comparison, in 2017 the highest single sample was 40 E. coli/100mL on August 21st at Kinsmen beach, and in 2016 the highest single sample was 86 *E. coli* /100mL on August 8th at James Chabot beach. In 2010, values reached as high as 1150 *E. coli* /100mL at James Chabot beach in mid-August (almost 3x the recommended limit).

When bacteriology results exceed the Health Canada recommendations, a notice is put out to deter people from swimming at a high-risk location.

Results of swim beach sampling are updated throughout the summer season and can be found by searching for Kinsmen, James Chabot or Windermere beaches at
https://www.interiorhealth.ca/YourEnvironment/DrinkingWater/Pages/WaterSamples.aspx

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Appendix A

Sampling methodology

Water Quality
Lake Windermere is sampled following the BC Ministry of Environment Water Quality Assessment and Objectives for Lake Windermere (Neufeld *et al.* 2010). Water quality laboratory analysis was completed by CARO (Kelowna, BC). The following water quality data were collected at all three sample sites:

a. Weekly (May - September) - in situ (field measured) data including depth, Secchi depth, water temperature, specific conductivity, pH, dissolved oxygen (DO), and turbidity.

b. Monthly (April - August) - Total Phosphorous and Total Dissolved Phosphorous.

The North site was sampled at two depths (Upper and Lower) since this is the deepest part of the lake. The Upper water sample was collected at arms' reach approximately 30cm below the surface, while the Lower water sample was collected 1m above the lake bottom using a vertical VanDorn sampler. The Middle and South sites were sampled at arms' reach 30cm below the surface only.

Water sampling took place within a four-hour timeframe on Tuesday mornings, from May to September 2018. Volunteer citizen scientists were joined by at least one trained LWA staff member for all lake excursions and assisted with field data collection.

Lake sample sites were first located by boat using a hand-held Garmin eTrex20 GPS and pre-programmed coordinates that align with the sample sites in Figure 1. Once at a sample site, depth and Secchi depth measurements were taken using a weighted Secchi disk and metre line. Water temperature and conductivity were read using a YSI Pro30 conductivity meter. pH was read using a Eutech Waterproof pHTestr 10. Dissolved Oxygen was collected using the Winkler titration method with a Hach Model OX-2P (0.2-20mg/L) Test Kit. Turbidity was read using a Hach 2100Q Portable Turbidimeter calibrated to 10 NTU.

When monthly phosphorous samples were collected, a cooler containing sample bottles was brought on board the boat. Water samples were collected into bottles which were then kept on ice while being shipped via Greyhound to CARO laboratories in Kelowna for analysis.

Aquatic Plants
Please see Darvill (2018a).

Waterbirds
Please see Darvill (2018b).

Swim Beaches
Bacteriology samples were collected on Mondays between June and early September (excluding long weekend holidays) before 1:00pm from three public beaches (Windermere (1 site), James Chabot (2 sites), and Kinsmen (2 sites)). Sample bottles were filled using a triple-rinsed beaker dipped inverted below the water's surface then turned upright within the middle of the water column. Filled bottles were immediately kept on ice until delivery to the Invermere Health Unit located at 110 10 St, Invermere, BC with a copy of each associated requisition form. From there, custody of samples was transferred to the IHA and samples were sent to their labs for analysis.

Data analysis and QA/QC

Raw data were first subjected to a quality control evaluation, to assess the accuracy and validity of the laboratory and field methods. Field sampling protocols followed those outlined above.

Water Quality
For in situ data collection, water quality instruments were calibrated once monthly as per manufacturer's specifications and expired or out-dated solutions were discarded and replaced.

All data was reviewed by the LWA for consistency and anomalies before being analyzed. Data was analyzed by plotting parameters over time in Excel, for the current sampling year and past sampling years whenever possible. Geometric means of samples were taken where indicated, and included all samples taken within a 30-day period between start and end of sampling. For average summer (June - August) water temperature and lake depth, a one-way Analysis of Variance (ANOVA) test was performed to determine if the difference between annual means was statistically significant at a significance interval of 0.05. The null hypothesis, H_0, assumed that there were no inequalities between the means, whereas H_1 assumed there was at least one inequality.

CARO laboratory's analysis for Total and Total Dissolved Phosphorous was completed using Persulfate Digestion / Automated Colorimetry (Ascorbic Acid) referencing the Guidelines for Canadian Drinking Water Quality (Health Canada Feb 2017). CARO assessed accuracy through use of laboratory control samples, trip blanks, and duplicate samples.

Aquatic Plants
Please see Darvill (2018a).

Waterbirds
Please see Darvill (2018b).

Swim Beaches
Sample results were obtained from the Interior Health Authority (IHA) and analyzed for geometric mean as well as individual sample result over time. Please contact the IHA if you have specific questions about their QA/QC protocol for lab samples.
https://www.interiorhealth.ca/FindUs/_layouts/FindUs/info.aspx?type=Location&loc=Invermere%20Health%20Centre&svc=&ploc=