Lake Windermere
2017 Water Quality Monitoring Results

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February 2018

Executive Summary

The Lake Windermere Ambassadors (LWA) direct a community-based water monitoring and citizen science education program within the Lake Windermere watershed. 2017 marked the eleventh year of lake monitoring since the Lake Windermere Project began collecting water quality data in 2006. This database offers a substantial baseline against which to compare current water quality results.

In 2017, the LWA collected physical and chemical water quality parameters at three sample sites on Lake Windermere. Once weekly during the summer from mid-June to mid-September, the lake sampling regime included: temperature, turbidity/clarity, pH, conductivity, depth, dissolved oxygen, and Total and Dissolved Phosphorous. The LWA also collected *E. coli* data at public swim beaches with the support of the Interior Health Authority, and monitored tributary flows and water quality at the outlet of Windermere Creek with the support of the Columbia Basin Water Quality Monitoring Project (CBWQ). Finally, we conducted an aquatic plant and invasive veliger survey with the help and expertise of the East Kootenay Invasive Species Council and Goldeneye Ecological Services.

Findings from 2017 show that Lake Windermere continues to flow in good quality to support aquatic life and recreation. Parameters that deviated from Ministry of Environment recommendations included turbidity and dissolved oxygen, however these deviations were self-correcting and likely arose due to natural conditions. The three public swim beaches (Windermere, James Chabot, and Kinsmen) were in swimmable quality during all sample collection dates in 2017. Windermere Creek maintained temperatures favourable for fish health but showed relatively high levels of Aluminum and Iron on one sample date in early June of 2017, the reason for which cannot be concluded by this author. The annual aquatic plant survey found no invasive species in Lake Windermere for the eighth year of sampling, and presence of the unknown algae found near the weir at the lake outlet in 2015 could not be detected again. No invasive mussels were detected through veliger sampling in 2017.

Comparing trends from 2011-2017 indicate that 2017 was a relatively average year in terms of conductivity, turbidity, and dissolved oxygen. Water temperature was a bit higher than in past years for June, July, and August, but remained just below the MOE guidelines for protection of aquatic life. Lake depth showed a dramatic decline compared to previous years. Mid-summer phosphorous sampling from 2011 to 2017 indicates average Total Phosphorous values are trending downwards with time (June - September period only). However, ice-off/spring values for average Total Phosphorous had been trending strongly upwards until 2016 (April-May period only). The peak in Total Phosphorous values at ice-off occurred in 2015. No ice-off sampling occurred in 2017, so we cannot conclude if this trend was continuing. Further monitoring of phosphorous and other nutrients is recommended, especially during the critical ice-off period in 2018.

Our major funders for this project and final report include the Columbia Valley Local Conservation Fund, the District of Invermere, the Regional District of East Kootenay, and the Columbia Basin Trust via the Columbia Basin Water Quality Monitoring Project (CBWQ).

<u>Questions about this report?</u>

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1. Introduction

1.1 - Location, climate, and significance

Lake Windermere is one of two headwaters lakes located at the source of the Columbia River in southeast British Columbia, Canada. The lake itself is actually a widening of the Columbia River, and as a result is very shallow with an average depth of ~3-4m. Lake Windermere has capacity to support several species of fish and is used by several dozens of species of resident and migratory birds (McPherson and Hlushak, 2008). Birds, fish, and wildlife 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).

The Columbia Valley sits within the Southern Rocky Mountain Trench in the Interior Douglas-fir (IDF) biogeoclimatic zone (Braumandl and Curran, 2002). The region experiences all four seasons, characterized by relatively mild, cold winters and dry, hot summers. Most rainfall typically occurs in May-June, and this can result in rain-on-snow events in the upper mountainous regions. Spring freshet (runoff period) typically occurs between late May and early July. The warmest days are historically recorded in July-August. 2017 was notable as being a hot summer year, with an aggressive forest fire season and very little precipitation.

Lake Windermere flushes on average every 47 days, which contributes to its good water quality (McKean and Nordin, 1985). People living around and visiting Lake Windermere depend on this pristine water for recreation (whether swimming, fishing, paddling, or tow-sports), supporting a healthy ecosystem and wildlife populations, and as a drinking water source for select communities around the lake. The main factors affecting water quality in the lake are human uses and development in the watershed, from road building and housing development to stream modifications and shoreline erosion, which have been increasing over the years as the valley population grows in size.

1.2 - Community-based water quality monitoring

The Lake Windermere Ambassadors (LWA) are a community-run, charitable non-profit 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 2010, building upon a substantial baseline of data collected by Wildsight's Lake Windermere Project from 2006-2010. This water quality monitoring program is the heart of the LWA's activities, which also includes stewardship education, public outreach, and advocacy for localized water governance.

From 2006 to 2009, the Lake Windermere Project worked to assess the quality of Lake Windermere's waters for wildlife and human recreational uses. In 2010, the BC Ministry of Environment took those four years of data, as well as historic data, and determined updated 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 is suitable for recreation as well as for fish and wildlife. By continuing to test lake water quality on a weekly basis every summer, the LWA now have eleven years of water quality data for Lake Windermere. This has allowed for detection of changes in water quality over time, and helps to inform sustainable watershed planning and restoration initiatives in the Upper Columbia watershed.

1.3 - Methods

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

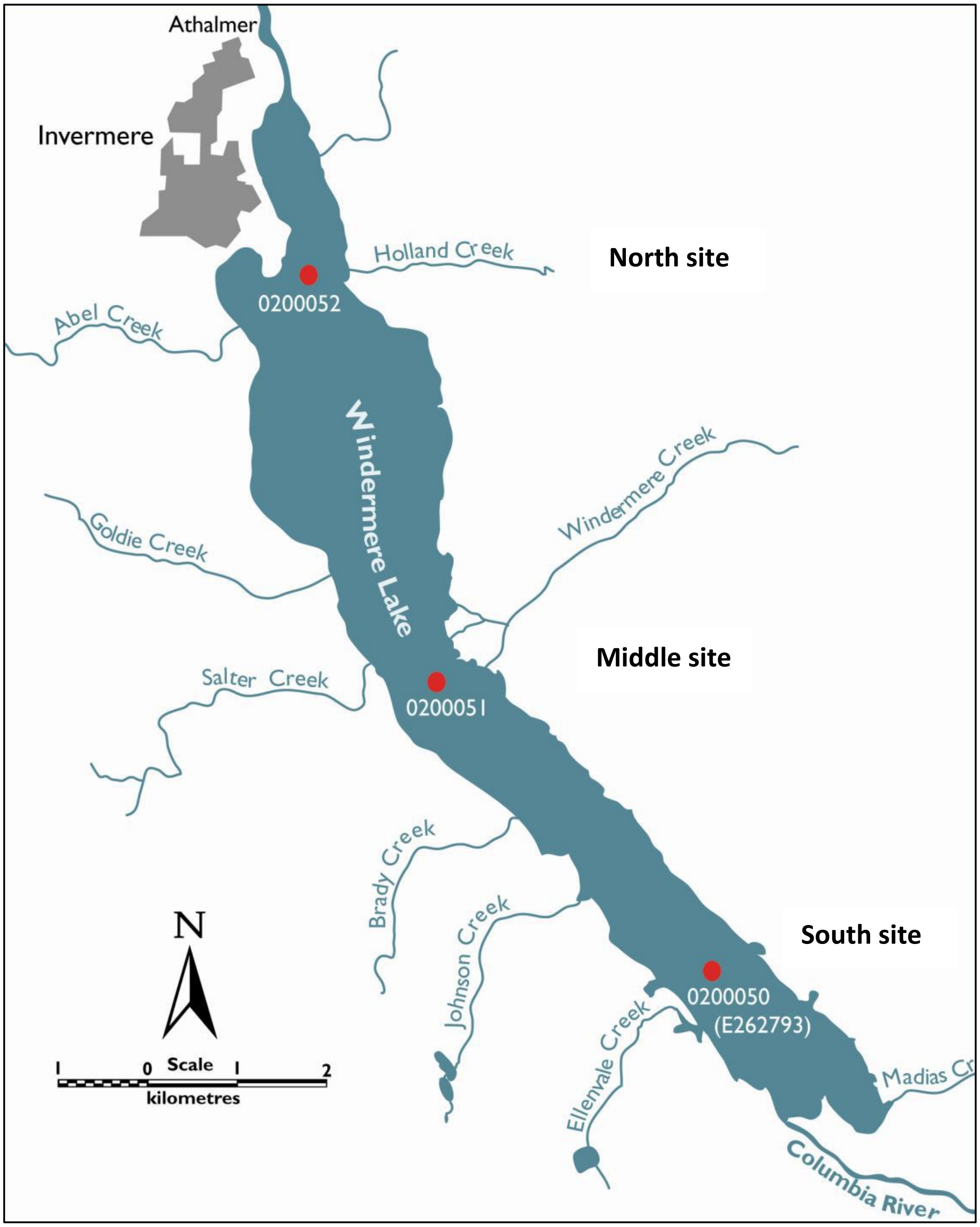


Figure 1: Lake Windermere Sampling Sites: North (0200052), Middle (0200051), and South (0200050). (Image Source: Neufeld, 2010)

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

Water sampling took place weekly, within a four-hour timeframe on Tuesday mornings, from June - September 2017. Sample sites were first located by boat using a handheld 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 using a Hach Model OX-2P (0.2-20mg/L) Test Kit. Turbidity was read using the Hach 2100Q Portable Turbidimeter. Air temperature was taken using a standard analog thermometer.

When monthly phosphorous samples were collected, a cooler containing sample bottles with additive 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.

The rest of this report documents the Lake Windermere Ambassadors' 2017 Lake Windermere water quality sampling results, including chemical and physical lake water quality parameters, swim beach water quality, tributary flows, and aquatic invasive species inventory.

2. Lake Windermere Water Quality Results

2.1 - Temperature

Overview

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

Lake Windermere's water temperature is naturally elevated relative to other freshwater lakes (Neufeld, 2010), likely because of its shallow depth. Unlike deep lakes, Lake Windermere does not stratify into different layers of temperature and density within the water column (McKean and Nordin, 1985).

The warm, clear water makes Lake Windermere a desirable lake for human recreation. However, average summer water temperatures have historically exceeded the BC Ministry of Environment (MOE)'s Temperature Guidelines for the protection of freshwater aquatic life (Neufeld, 2010). For example, many of the freshwater fish species observed in this lake have optimum temperature ranges below 18°C for rearing, spawning, and incubation (Ministry of Environment, 2017a), whereas historical monthly water temperatures in Lake Windermere have been recorded up to 25°C (Neufeld, 2010).

To adjust for the naturally warmer temperatures in Lake Windermere, the MOE set the maximum allowable average monthly water temperatures at 20°C, 25°C and 23°C in June, July and August respectively (Neufeld, 2010). These guidelines are based on the MOE recommendation that lake water temperatures should remain within ± 1 °C of natural conditions.

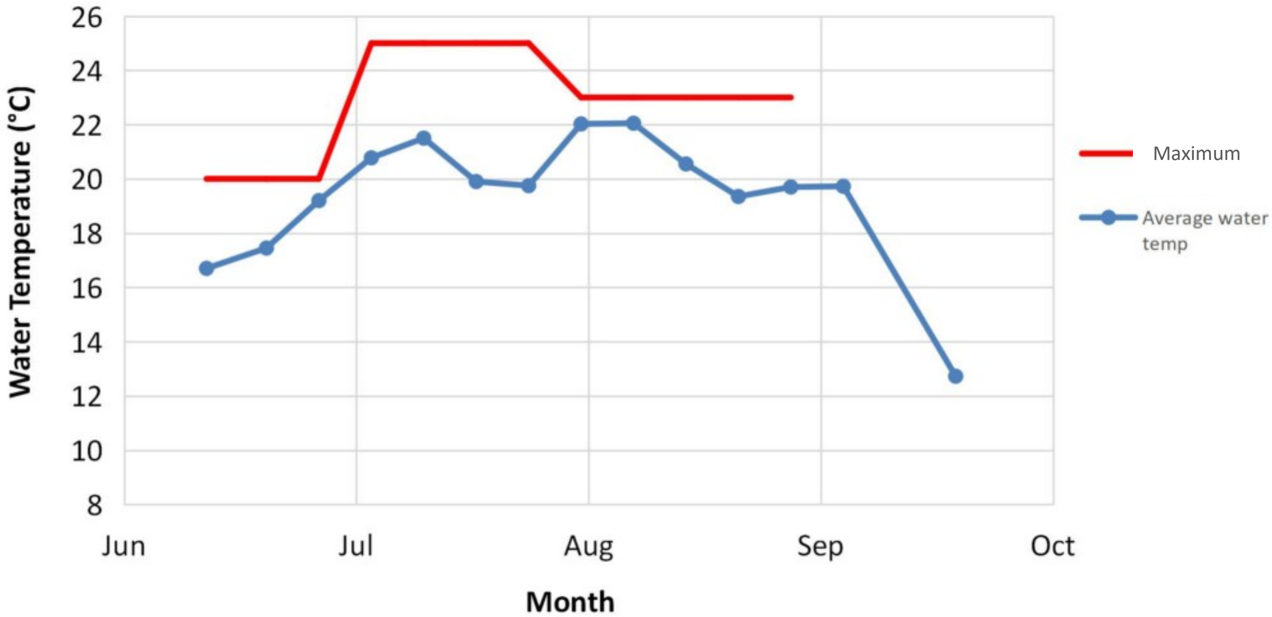
Results

During the 2017 summer season, all three water monitoring stations on Lake Windermere had average monthly temperatures consistently below the maximum threshold recommended by MOE (Figure 2a).

The highest temperature measured in 2017 was 22.6°C, recorded on August 8th at the Middle sample station (Figure 2b). For comparison, the highest temperature measured in 2016 was 21.8°C, on August 16th at the same sample site. In 2015, this value was 22.8°C, recorded both on July 7th and July 14th at the Middle station and the North station, respectively.

These values are all within the recommended maximums suggested by MOE. But it is important to note that since samples are only collected on a weekly basis, water temperatures could have exceeded these maximum values at times when samples were not being collected.

(a)



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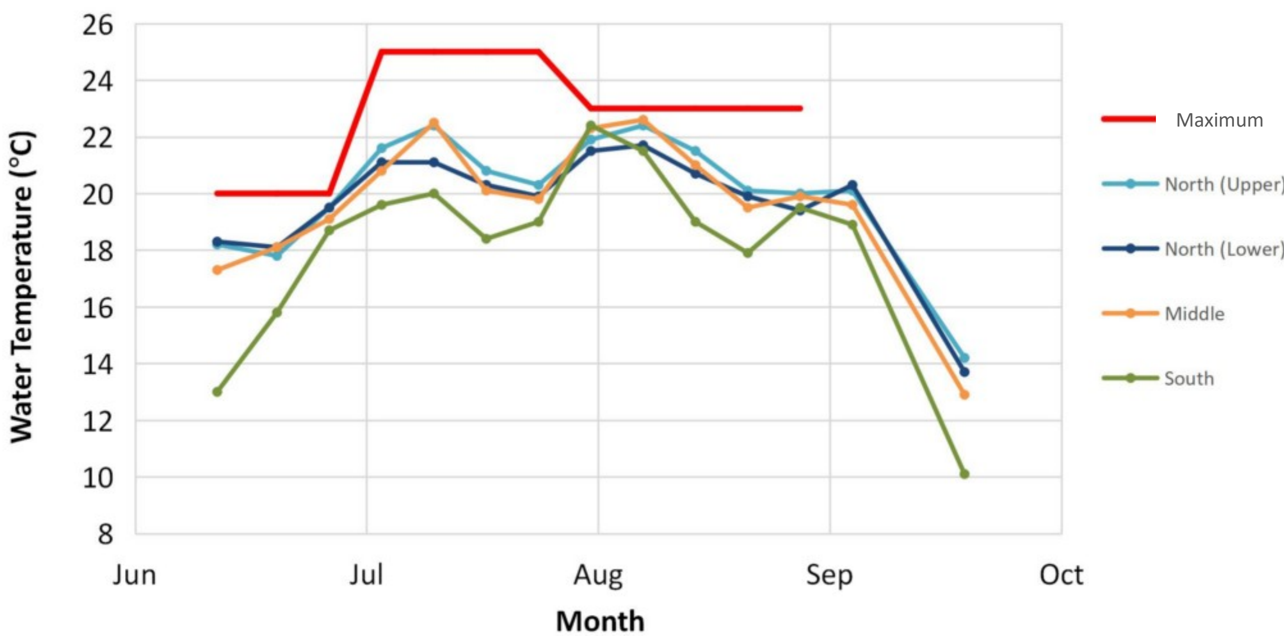


Figure 2: (a) Average water temperature for Lake Windermere, measured weekly from 12 June to 20 September, 2017. (b) Water temperature results separated by sample site. *Note:* Lines are for interpretation only, and do not represent continuous measurements.

2.2 - Dissolved Oxygen

Overview

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

Oxygen is transferred to water from the atmosphere and is also produced by submerged aquatic plants during photosynthesis. It is removed from the water by respiration in aquatic plants and animals, chemical reactions, and organic decomposition. For example, a large amount of decomposing plant material within a lake can decrease DO concentrations in the water, because oxygen is consumed during the decomposition process (Neufeld, 2010).

The capacity for water to hold dissolved oxygen is inversely related to water temperature. In simpler terms, warmer water holds less oxygen, and cooler water holds more oxygen (Ministry of Environment, 2017a).

The BC Ministry of Environment (MOE) recommends that DO should never drop below an instantaneous minimum of 5 mg/L, in order to reduce stress for aquatic life, and the MOE guideline for an average of five samples taken over a 30-day period is 8 mg/L (Neufeld, 2010; Truelson, 1997). It is also recommended that DO not exceed a maximum of 15 mg/L, in order to prevent negative effects of toxicity (Neufeld, 2010).

Results

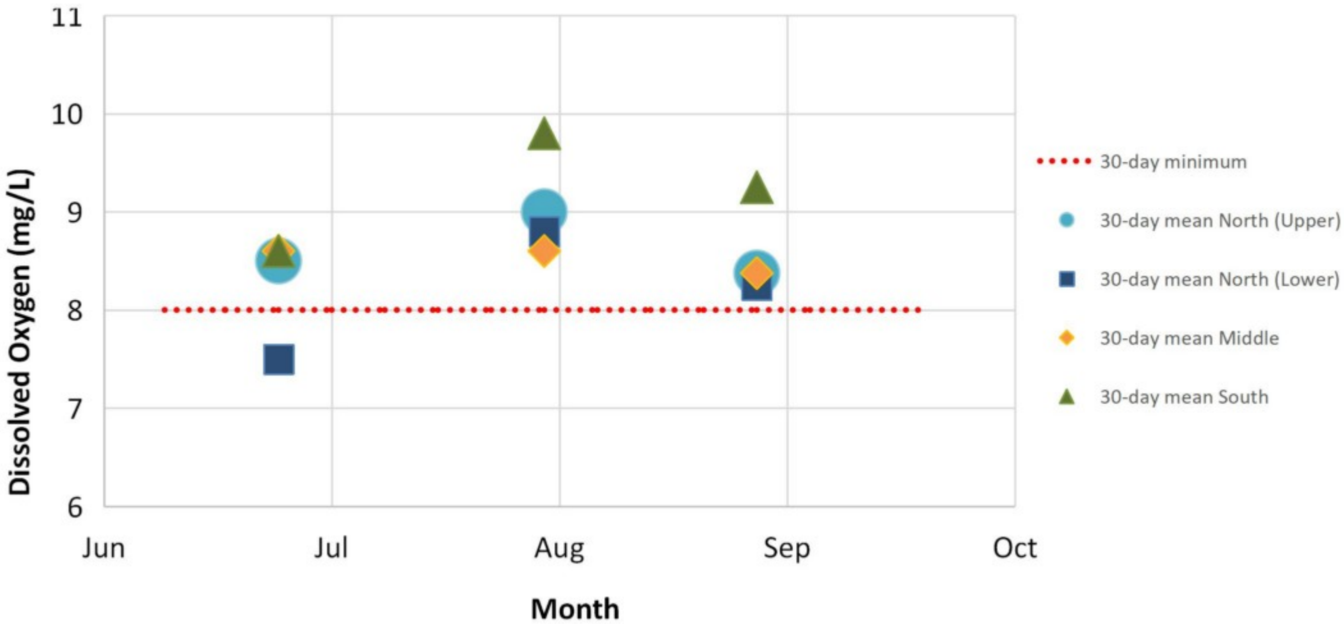
During the 2017 summer season, dissolved oxygen (DO) values in Lake Windermere never dropped below the 5 mg/L minimum threshold recommended by MOE (Figure 3a). Instantaneous values ranged between a low of 6 mg/L and a high of 11 mg/L (Figure 3b).

The instantaneous DO at the lower North, Middle, and South sample sites dropped below the recommended 30-day average of 8 mg/L for the weeks of June 12th - July 25th, and once again on September 20th (Figure 3b). However, when viewed cumulatively over the 30-day period, only the lower North sample site fell below the recommended mean value between early June and early July (Figure 3a).

The South sample site had higher 30-day average DO values than the other sites. This may be due to the proximity to the Columbia wetlands, which have an abundance of aquatic plant life that are photosynthesizing and contributing oxygen to the water. It may also be due to the slightly cooler temperatures of water flowing out of the wetlands, since cooler water holds more oxygen.

It is important to acknowledge the Winkler titration method used for collecting DO results can come with significant human error if completed or interpreted incorrectly in the field. We were able to compare field titration results with readings from a YSI Pro20 Dissolved Oxygen meter *in situ*, and found the titration results to be within +/- 2mg/L of the calibrated meter. This is a significant variation, suggesting the LWA should invest in a DO meter to independently verify the titration readings performed by citizen scientists and ensure a higher level of accuracy in future.

(a)



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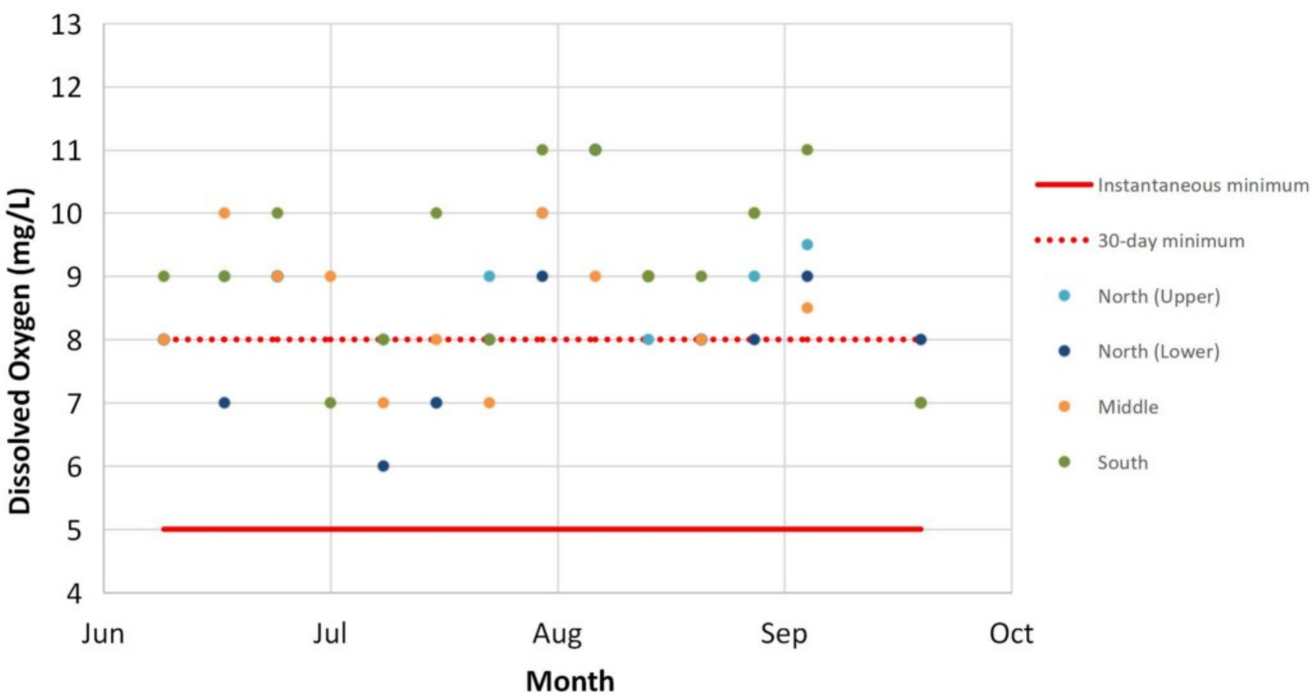
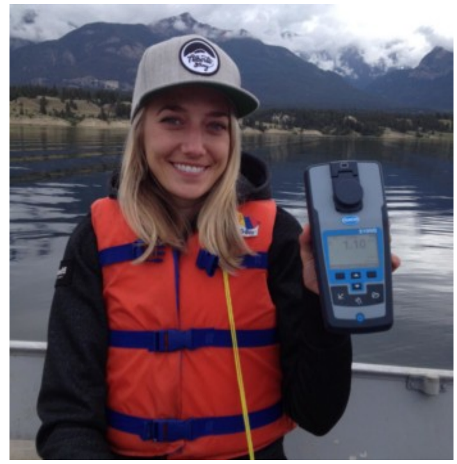


Figure 3: (a) 30-day mean values for dissolved oxygen, calculated for the fourteen weeks between 12 June and 20 September, 2017. (b) Weekly dissolved oxygen data for Lake Windermere, measured from 12 June to 20 September, 2017 (missing data from North sample site on 4 July).

2.3 - Turbidity

Overview



Turbidity is a measure of the light scattered by particles suspended in water, and indicates the clarity of the water. When waters are highly turbid — for instance, when they are filled with lots of suspended sediment (as tends to happen during spring runoff) — light does not penetrate as easily to reach aquatic plants, which reduces photosynthesis. Fish can become stressed due to reduced ability to navigate, clogging of gills, and other physiological stressors (Ministry of Environment, 2017a).

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 "freshet" (the spring runoff period), or after heavy rainfalls.

The turbidity Objectives for Lake Windermere are set to protect recreational water quality and aquatic life (Neufeld, 2010). During freshet (May 1 – August 15), in what is known as the "turbid flow period", the 95^{th} percentile of turbidity measurements taken in 5 days over a 30-day period should not exceed 5 NTU (turbidity units). During the "clear flow period" (August 16 – April 30), the maximum turbidity at any time should be less than or equal to 5 NTU. Additionally, the Objective for "clear flow" is that the average of 5 samples over 30 days should not exceed 1 NTU (Neufeld, 2010).

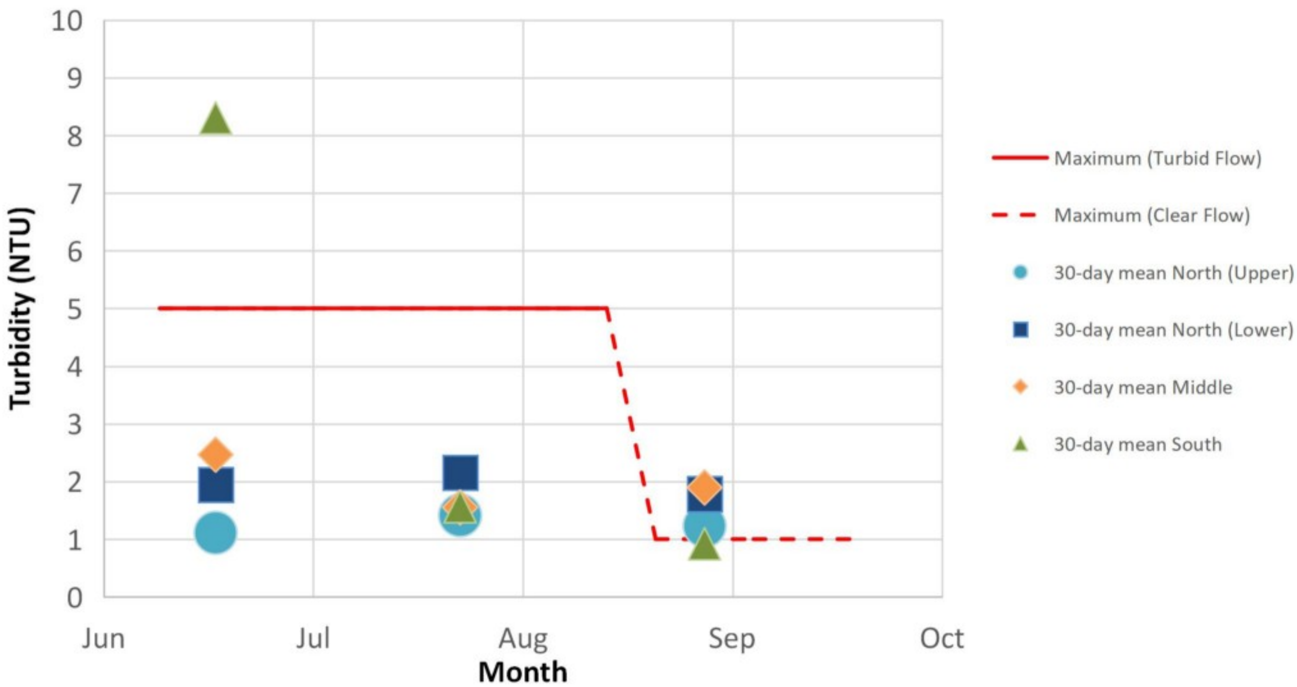
Results

Overall, turbidity was slightly higher at certain times of year in 2017 as compared to 2016, but well below the peaks seen in 2012 and 2013 when Windermere Creek experienced heavy flooding. The mean 30-day turbidity values for 2017 exceeded the MOE Recommendations at two times during the sampling period: once at the South site for the 30-day period between June 12^{th} - July 11^{th}, and once at the Middle and Upper/Lower North sites for the 30-day period between August 22^{nd} - September 20^{th} (Figure 4a).

The high turbidity events at the South site on June 12^{th} and 19^{th} (Figure 4b) correspond to a high turbidity event recorded in early- to mid-June at the north end of Columbia Lake, near where Dutch Creek enters the Columbia River (CLSS, 2018). This event occurred during spring freshet, which suggests large amounts of sediment may have been transported by the Columbia River south of Lake Windermere and through the wetlands at the south end of the lake. Wetlands usually help to attenuate high turbidity events by slowing flows and allowing sediment to settle out; however, the sediment loads coming in through the wetlands in June may have been too high for this to occur. The result is that the South sample site exceeded maximum turbidity values on June 12^{th} and on June 19^{th}, with readings of 24.4 and 7.5 NTU, respectively (Figure 4b). This type of turbidity response is not uncommon for many river systems during freshet, because of the high volumes of meltwater runoff which can erode lower-order stream channels and carry large amounts of sediment downstream. These findings suggest Dutch Creek outflows may potentially be a relevant source of sediment for Lake Windermere, especially in the southern part of the lake.

The higher turbidity values on September 20^{th} might have been due to the high wind events and rain showers in the seven days leading up to sampling, which could have caused sediment runoff into tributary streams and heavy mixing of the lake water to occur because of wave action. While this time of year is normally known as the "clear flow period", large storm events can still cause high turbidity events to occur.

(a)



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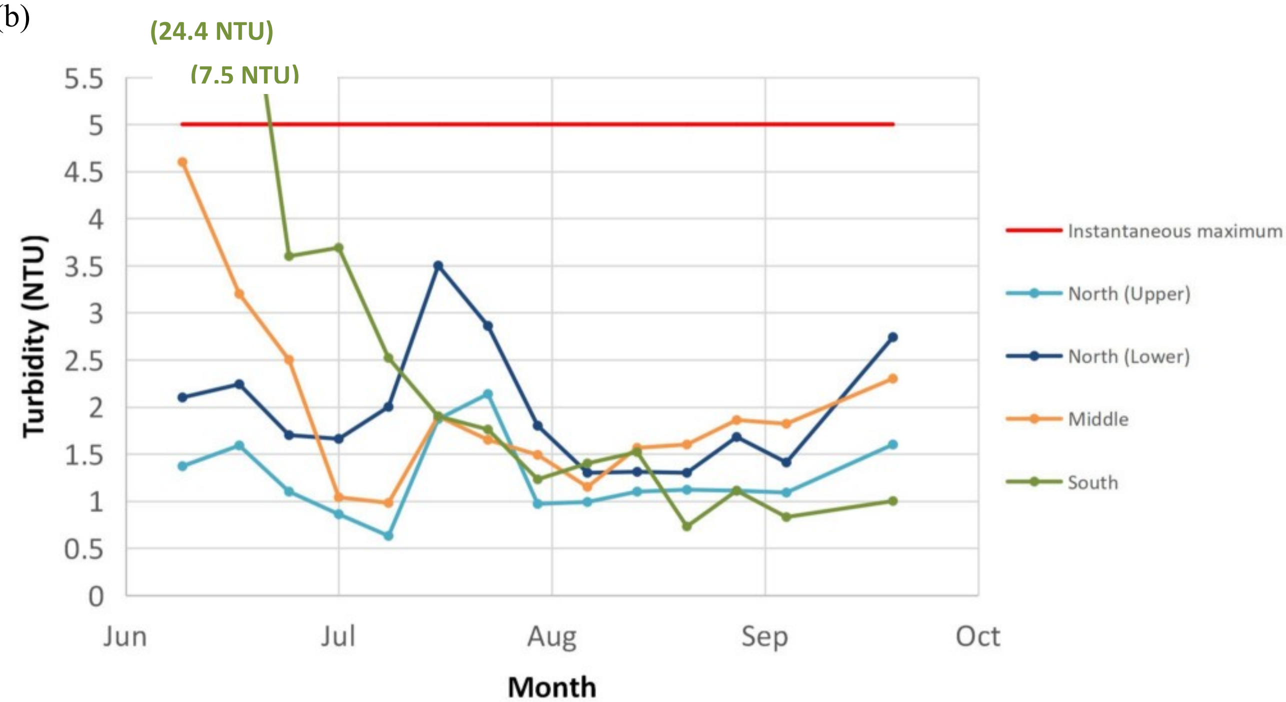
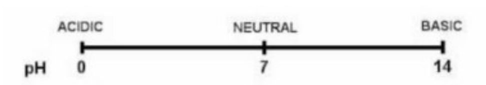


Figure 4: (a) 30-day mean values of turbidity for Lake Windermere, measured weekly from 12 June to 20 September, 2017. (b) Turbidity results separated by sample site. Early June saw very high turbidity measurements of 24.4 and 7.5 NTU at the South sample site (outside bounds of graph). *Note:* Lines are for interpretation only, and do not represent continuous measurements.

2.4 - pH

Overview

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 or alkaline environment.



pH is reported in logarithmic units, meaning a change in one unit of pH represents a ten-fold change in the actual pH of the solution. For instance, water with a pH of 4.5 is ten times more acidic than water with a pH of 5.5, while water with a pH of 3.5 is one hundred times more acidic than water with a pH of 5.5.

The pH of natural lakes is rarely neutral, because of the presence of dissolved salts and carbonates, aquatic plants, and the mineral composition of the surrounding soils. pH can fluctuate daily as well as seasonally: for example, during photosynthesis and respiration by submerged plants or phytoplankton in the water, or due to other chemical and hydrological processes that add or remove acids from the water.

Many aquatic species are sensitive to sudden changes in pH, however most species have adapted to deal with the natural pH fluctuations of a lake that are spread over time. If the pH of a lake changes dramatically within a short time frame, it could be an indicator of a pollution event or some other form of disturbance.

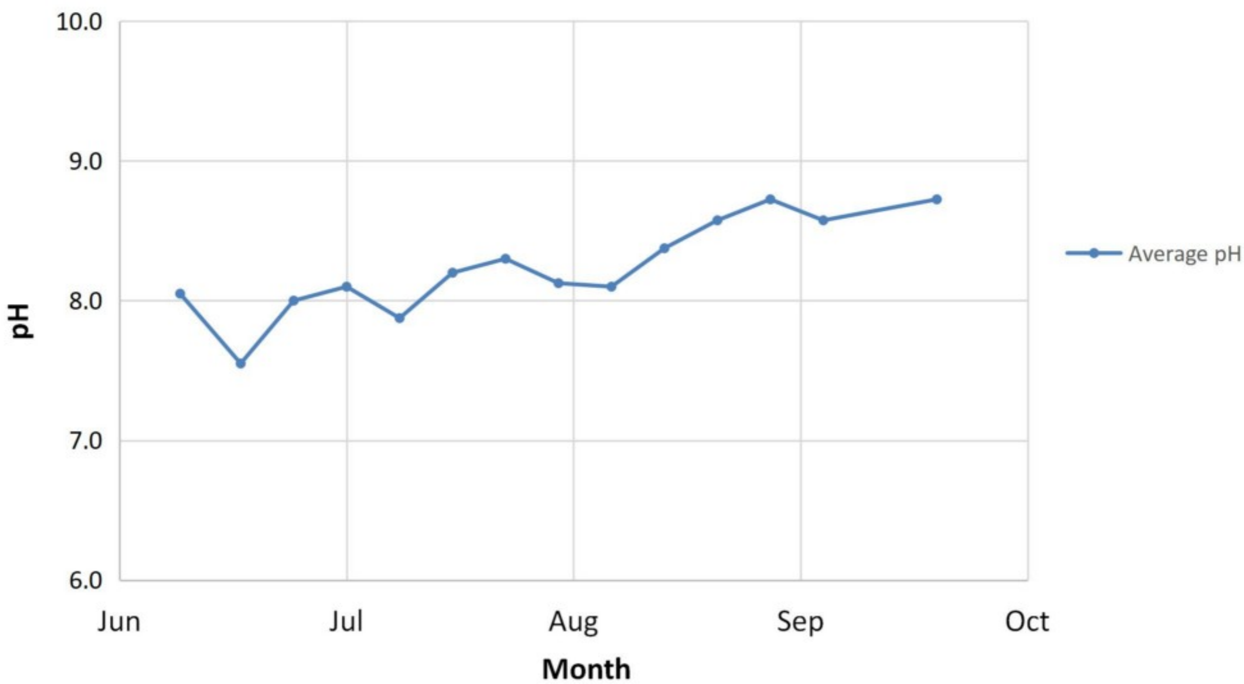
The water in Lake Windermere consistently trends towards slightly alkaline (pH values around 8.5), which is characteristic of lakes fed by water flowing over limestone bedrock materials present in the Canadian Rockies (BC Ministry of Health, 2007; Rollins, 2004). There is no MOE Objective set for pH 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).

Results

The lake pH measured in 2017 was relatively similar to last year's values, ranging between 7.4 and 8.9. There was a slight trend of increasing pH towards the later half of the summer (Figure 5a). This might be explained by the drop in turbidity around mid-August - with less turbidity, there are fewer particles available to scatter sunlight that enters the water, and with greater amounts of light reaching submerged aquatic plants then sunlight would not be a limiting factor to photosynthesis or plant growth. This could have increased the bulk photosynthetic rate within the lake, removing more CO_2 from the water and causing the pH to rise over time.

There was a dramatic change in pH at the North (upper) sample site between June 12th and 20th (Figure 5b). We hypothesize that these erratic results may have been due to a calibration error. The bulb on the pH probe was replaced on July 31st 2017. We see that the weekly results smooth out after this point in time, which suggests the nearly ten-year old probe may have been giving erratic readings. No lab tests had been done on the old bulb for accuracy, and it is suspected that the pH probe was being incorrectly calibrated in the past. Therefore, the results prior to July 31st should be interpreted with caution. The other water quality results do not raise any flags on these corresponding sample dates.

(a)



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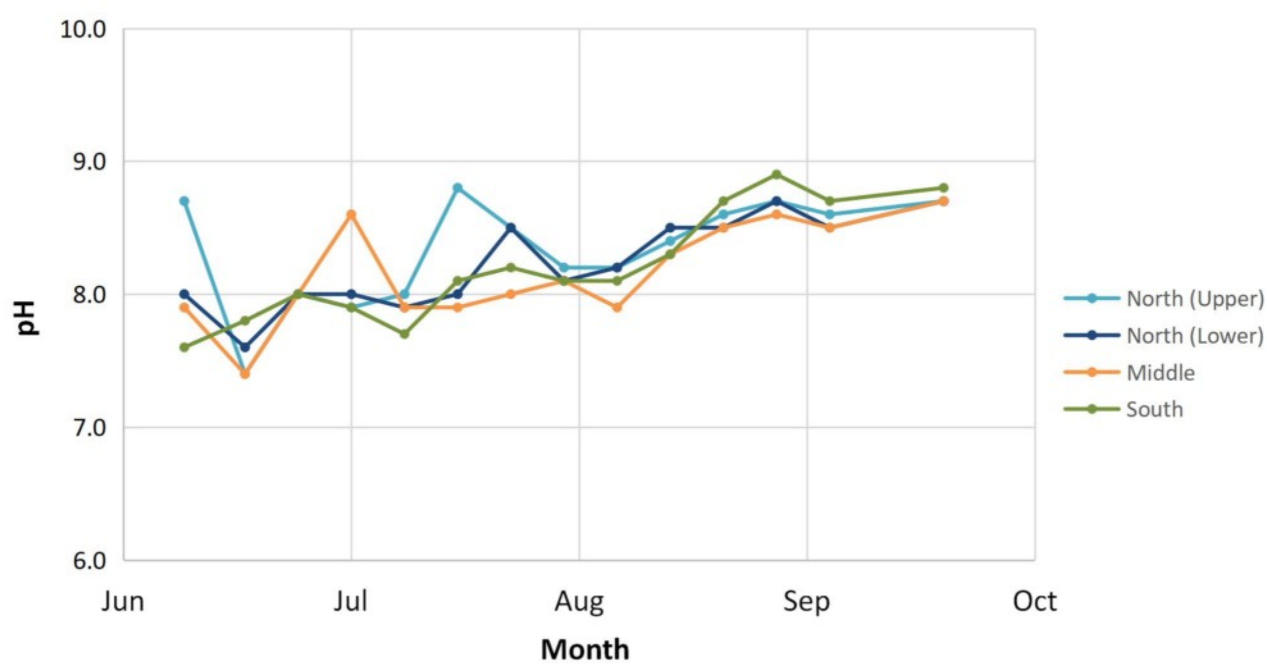


Figure 5: (a) Average pH for Lake Windermere as measured weekly between June 12th and September 20th, 2017. (b) Weekly pH values separated by sample site. *Note:* Lines are for interpretation only, and do not represent continuous measurements.

2.5 - Specific Conductivity

Overview

Specific conductivity measures the ability of water to conduct an electrical current. It is affected by the presence and mobility of ions in the water. Conductive ions include dissolved salts and inorganic compounds, like chlorides, sulfides, and carbonates. For this reason, a measure of conductivity in water can sometimes be used as an indicator of water pollution.

The conductivity of water is affected by temperature. In general, the warmer the water, the faster the mobility of the ions, and so the higher the conductivity (Behar, 1997). Conductivity of water is also affected by the bedrock geology of the surrounding area, with more weathering-prone bedrock (such as limestones or clays) giving rise to higher conductivity values than more stable bedrock (such as granite).

Conductivity can provide insights about pollutants such as sewage (because the addition of chloride, phosphate, and nitrate rapidly increases conductivity), road salts (high in chloride salts), or an oil spill (oil's organic nature and higher resistance to conducting electricity will reduce the conductivity).

Since conductivity values have remained fairly consistent over time in Lake Windermere (on average between 200-300 µS/cm), the Ministry of Environment has not set specific attainment objectives. It is, however, still important to monitor and observe if changes in conductivity are occurring which might negatively impact aquatic health. Freshwater streams can support diverse aquatic life with a conductivity range of 150 - 300 µS/cm (Behar, 1997; Weaver and Northrup, 2016). Therefore, readings above or below these values should be treated with caution and possibly investigated further.

Results

Conductivity in Lake Windermere varied between ~180 - 275 µS/cm in 2017 (Figure 6a). Conductivity was lowest at the South sample site, which is near the outlet of the southern wetlands (Figure 6b). This may be due to the influence of temperature, since water at the South end was also reported as cooler during this time period.

The Middle sample site, which is located just off of Windermere creek, had the highest values for conductivity. This location is very close to the outflow from the tributary and often sees suspended and dissolved sediments carried downstream to be deposited in the lake. We do expect to see high values of conductivity in this area, especially during the warmer months due to the influence of temperature on conductance.

2017 was rather average in terms of overall conductivity when compared to data from the past six years. The years of 2011 and 2012 both had higher conductivity (~240-280 µS/cm), while 2014-2016 had lower conductivity (~180-230 µS/cm) (Lake Windermere Ambassadors' data archive).

(a)

(b)

Figure 6: (a) Average specific conductance for Lake Windermere, as measured weekly between June 27th and September 20th, 2017 (data not recorded on June 12th and 20th). (b) Weekly specific conductance values separated by sample site. *Note:* Lines are for interpretation only, and do not represent continuous measurements.

2.6 - Phosphorus

Overview

Phosphorus (P) is a nutrient which is essential for life. P is used by plants and aquatic animals for processes involved in photosynthesis and metabolism. When present in low quantities, this nutrient can limit the growth of aquatic life. When present in high quantities, it can lead to excessive algae growth and overproduction of bacteria, which can severely compromise other forms of aquatic life and human health.

P exists in two main forms in water: dissolved and particulate. Dissolved P is readily available to algae and aquatic plants for growth and photosynthesis (US EPA, 2012). Particulate P is attached to particles in the water, and is not always available to aquatic plants or animals. "Total P" is a combined measurement of both the dissolved and particulate forms, and is often the parameter that is monitored during water quality objective studies.

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

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. As recently as 2015, however, the LWA was finding that water samples just after ice-off were significantly exceeding the MOE recommendations for total phosphorous concentrations in Lake Windermere. The Ministry of Environment (MOE) recommends Total Phosphorus in Lake Windermere not exceed a concentration of 10 µg/L (0.01 mg/L) in order to protect drinking water sources and aquatic life.

Results

In 2017, the LWA was not able to capture phosphorous results during the critical ice-off period (~May-April) due to a staff transition. Results captured on June 20th (Figure 7a) indicate that Total P levels *may* have exceeded the MOE objective earlier in the season, assuming the lake would have followed a similar trend as in past years which is a spike in early spring P followed by a gradual decrease in P throughout the summer as the lake flushes out. We did observe a decrease in Total and Dissolved P to below detectable limits at most sample sites in mid-summer 2017 (Figure 7b), which is typical of results collected since 2007.

The highest recorded value of Total P by the LWA was 67 µg/L, on August 20th 2013 at the Middle sample site. This was more than 6x the recommended limit, and prompted the LWA to increase monitoring for phosphorous. Since that date, twelve samples have exceeded for Total P and six have exceeded for Dissolved P. A graph of average Total P values from 2011-2017 is shown in Figure 7c.

The higher Total and Dissolved P values observed in late September 2017 (Figure 7a/7b) may have been caused by the release of nutrients from decomposing plants. This is the typical time of year when plants are rapidly decomposing, and this decomposition releases nutrients back into the water.

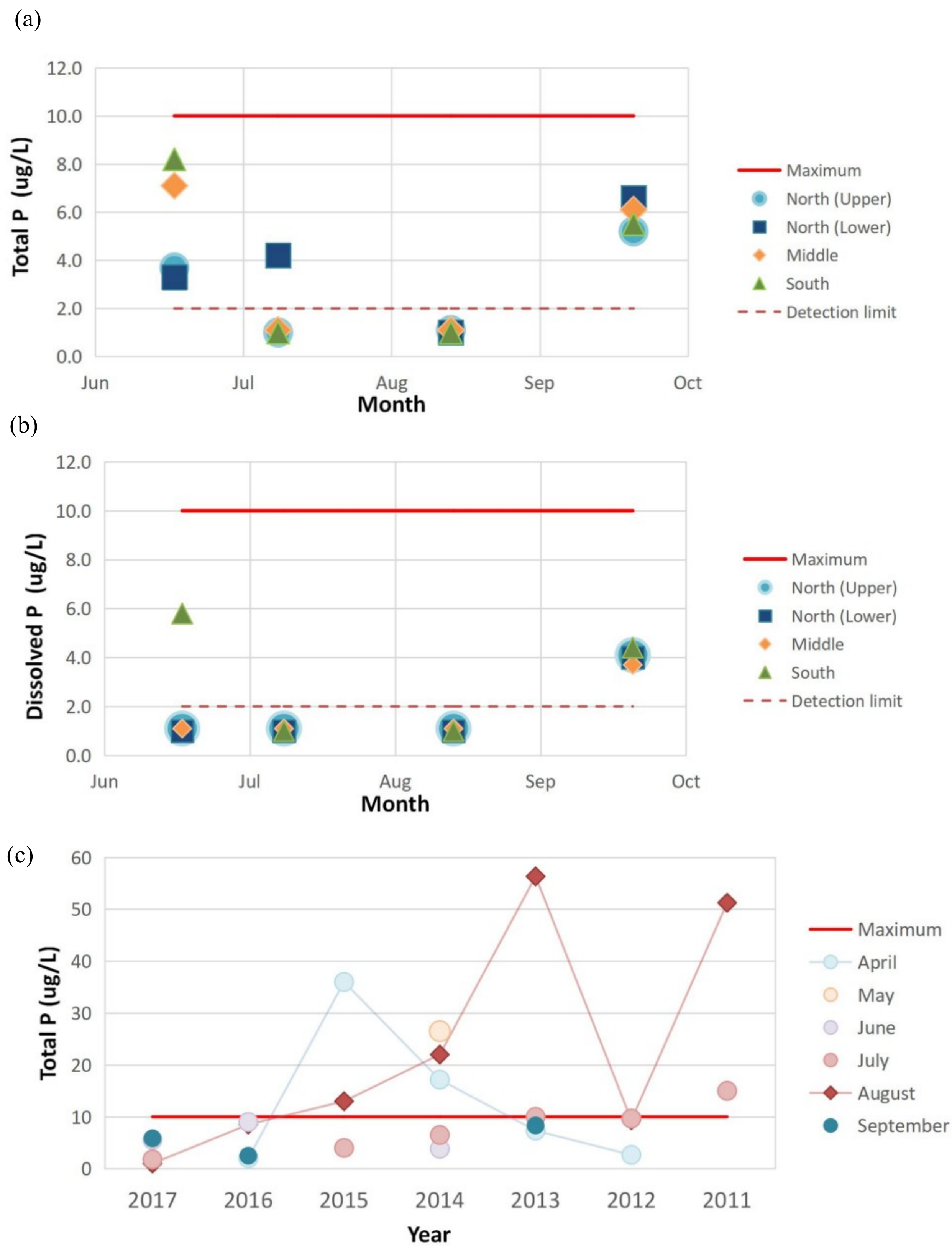


Figure 7: (a) Monthly Total Phosphorus, collected from Lake Windermere between June 20th and September 21st . (b) Monthly Dissolved Phosphorous, collected from Lake Windermere between June 20th and September 21st . The "Detection limit" is the limit at which the extraction procedure can detect phosphorous in water; values below this line were considered "undetectable". (c) Average Total Phosphorous data, 2011-2017; ice-off/April trend represented by light-blue line, while mid-summer/August trend represented by dark red line.

2.7 - Secchi Depth

Overview

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 Secchi disk can no longer be seen through the water is recorded as the "Secchi depth".

Secchi depth, like turbidity, is a measure of the suspended particles in the water. These suspended particles can be a combination of zooplankton, phytoplankton, algae, pollutants, or sediment (clay and silt).

Clear water lets a beam of light penetrate more deeply into the lake than murky water. Sunlight is needed for aquatic plants to photosynthesize, and for phytoplankton to grow and reproduce (Ministry of Environment, 2017a).

Secchi data collected year after year can provide information about trends in water clarity. Secchi depth generally follows the inverse pattern of turbidity — that is, when turbidity is high (lots of suspended matter in the water), the Secchi depth is low because it is difficult to see very deep into the water. And when turbidity is low, the Secchi depth is high because visibility extends 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 during freshet, and higher in the summer as the lake flushes out over time.

Results

The average Secchi depth in 2017 across all sample sites was 3.2 m +/- 0.5 m (Figure 8a). Secchi depth was highest during the weeks of July 4th - July 11th at the North sample site, which corresponded with a low turbidity at this site during this time (Figure 8b).

Secchi depth tends to appear lower in the South sample site, simply because this site is much shallower than the North site. We can compare Secchi depth to Total depth to get a more accurate picture of how clear the water column is; if the Secchi depth is the same as total depth, that means we were able to see all the way to the bottom of the lake. This is most common at the South sample site near the end of summer, when the water level gets lower and it is easier to see the bottom of the lake.

Secchi depth was equal to Total depth on 6 occasions at the Middle site, and on 7 occasions at the South site; these all occurred after July 11th.

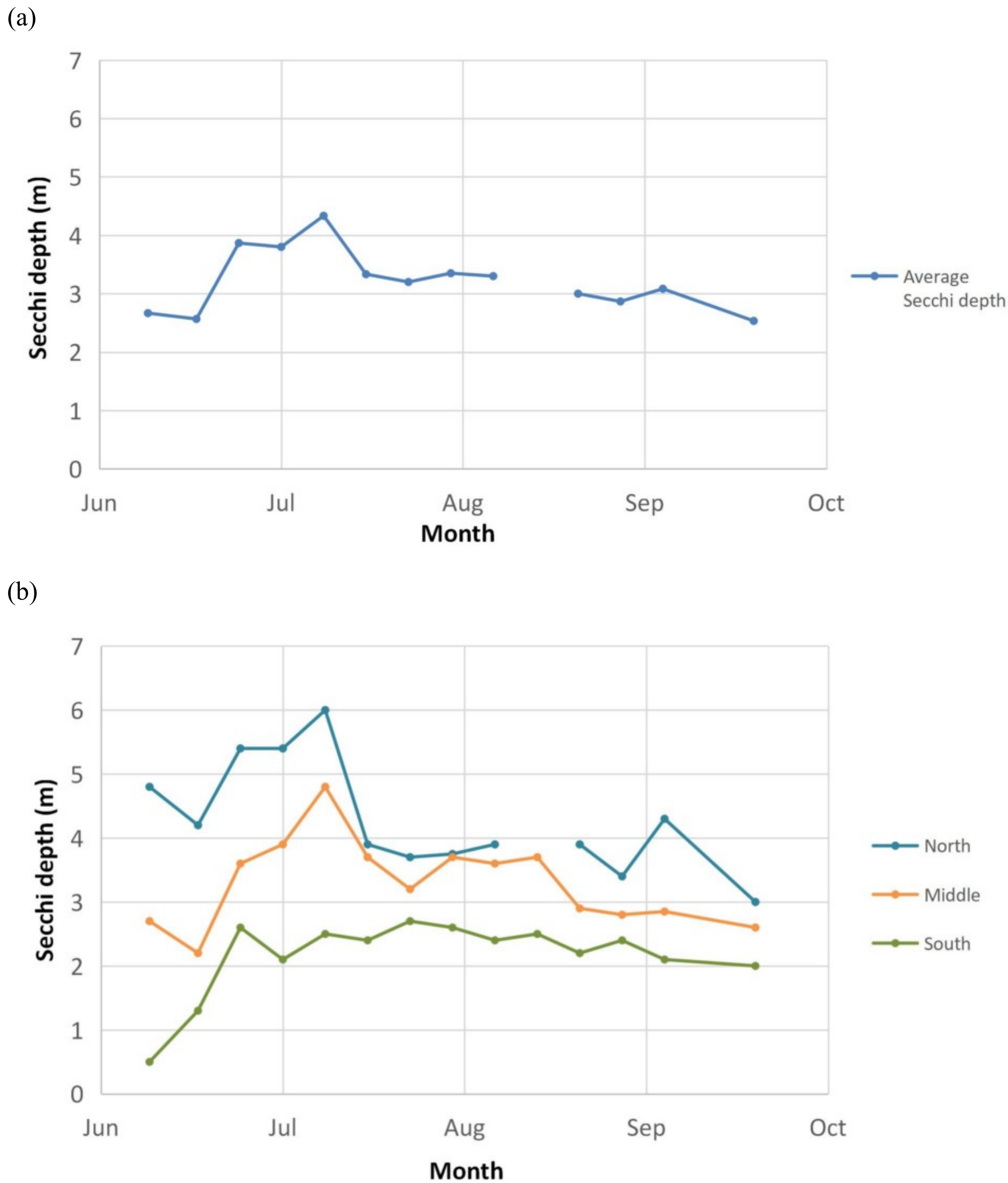


Figure 8: (a) Average Secchi depth (in metres) measured weekly for the sampling period June 12th - September 20th. (b) Secchi depth at each sample site. The North site was not sampled on August 15th due to windy conditions which made it difficult to get an accurate depth reading. ***Note:*** Lines are for interpretation only, and do not represent continuous measurements.

2.8 - Total Depth

Overview

Lake Windermere is really a wide portion of the main Columbia River channel, meaning it is different from other typical lakes you might find in southern BC. The main difference is that it is very shallow - on average, between 3-4m depth in mid-summer. It also flushes much more quickly than an average lake and has a better capacity to carry sediments and nutrients downstream because of this faster flow.

We do report the average water depth for all three sample sites in the lake, but this is not very representative of Lake Windermere as a whole. This is because the South end, where water flows in from the Columbia Wetlands, tends to be much shallower than the other two sites. And the North sample site is measured at the deepest point in the lake, which is located just off of Fort Point in Invermere where the lake is on average between 6-7m in depth.

In deep lakes, water at depth tends to be cooler and more dense. When water is separated into lighter and denser layers like this, it is called “stratification”. Lake Windermere doesn’t tend to stratify, so we usually don’t see a very large difference between the North (Upper) and North (Lower) water quality samples.

Depth can be an important consideration for aquatic life as well as for recreational boaters and drinking water users. Shallow water poses more risks because boaters can more easily get caught on sediment bars or clog their motors with aquatic vegetation growing on the bottom of the lake. Shallower water also warms up more quickly, which can pose issues for drinking water quality and for the survival of aquatic life. There is no objective set for lake depth in Lake Windermere, but levels below 2m generally cause concern for boaters.

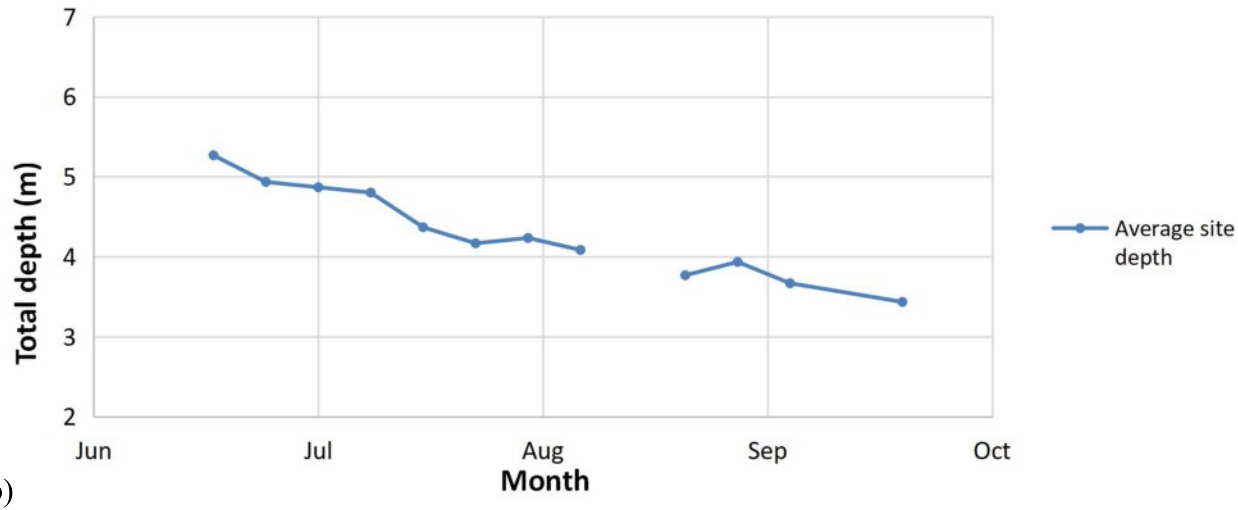
Results

Lake depth in 2017 followed the expected trend of being higher in spring during freshet, and gradually declining through the late summer due to less input from snowmelt runoff/precipitation and increased evaporation effects (Figure 9a).

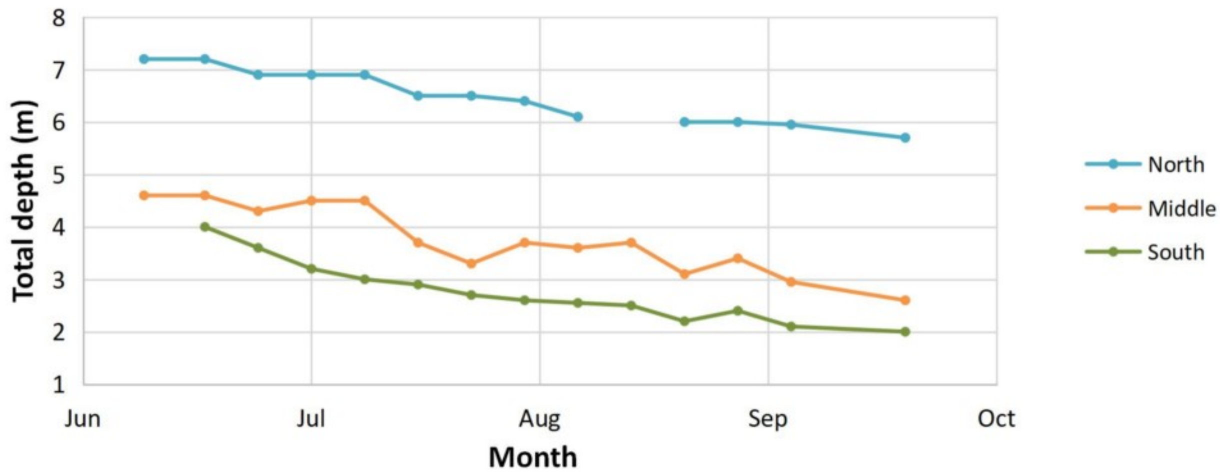
Fluctuations in lake depth at the Middle station were most likely due to the difficulty of getting accurate depth readings at this location (Figure 9b). The Middle sample site is often windy, wavy, turbid, and contains dense aquatic vegetation - all of which makes getting a physical depth reading more difficult, and therefore less accurate. This location is also just downstream (north) of where Windermere Creek empties into Lake Windermere, resulting in more current activity which can disrupt the depth measurement.

The deepest value (measured at the North sample site) in 2017 was ~7.2m, while in 2016 this was ~6.5m and in 2015 was ~6.7m. The highest recorded value at this site since monitoring began in 2006 has been ~7.3m, recorded in July 2012 and June 2013. Yearly trends show that 2017 had a more dramatic change in water level compared to previous years, ending up just slightly deeper than the very low average in 2011 (Figure 9c). This graph shows lake *averages* by month, so keep in mind that actual data readings would have been higher at the North site and lower at the South site, when looking at this graph.

(a)



(b)



(c)

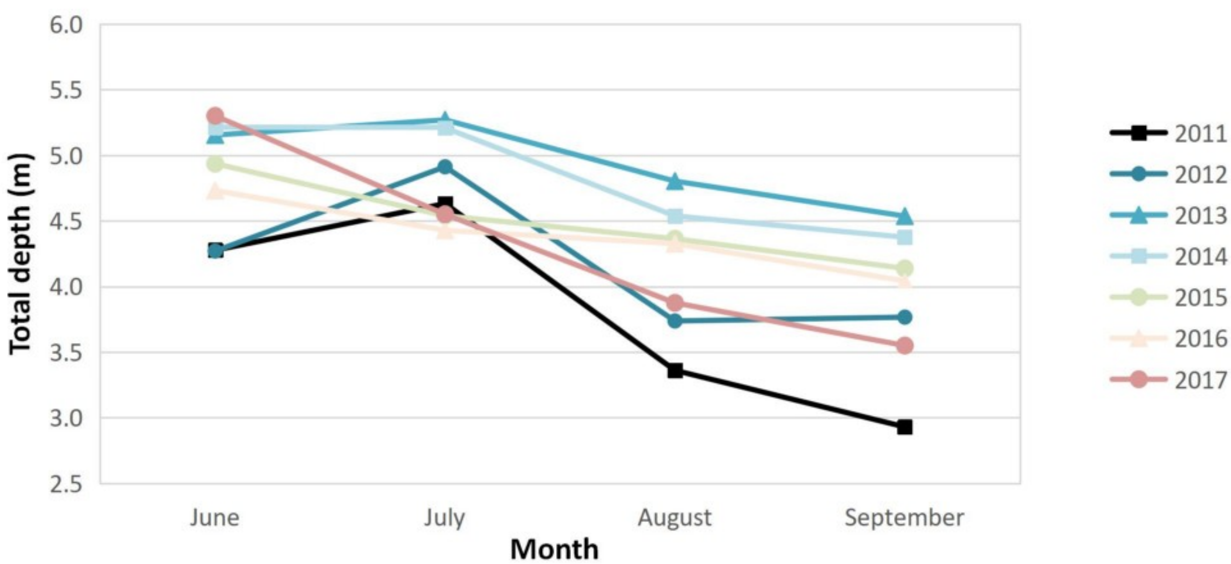


Figure 9: (a) Average lake depth (in metres) measured weekly for the sampling period June 12th - September 20th. (b) Lake depth at each sample site. The South site was not sampled on June 12th and the North site was not sampled on August 15th due to windy conditions which made it difficult to get an accurate depth reading. (c) Average lake depth, 2011-2017. *Note:* Lines are for interpretation only, and do not represent continuous measurements.

2.9 - Summer Historical Averages (2006-2017)

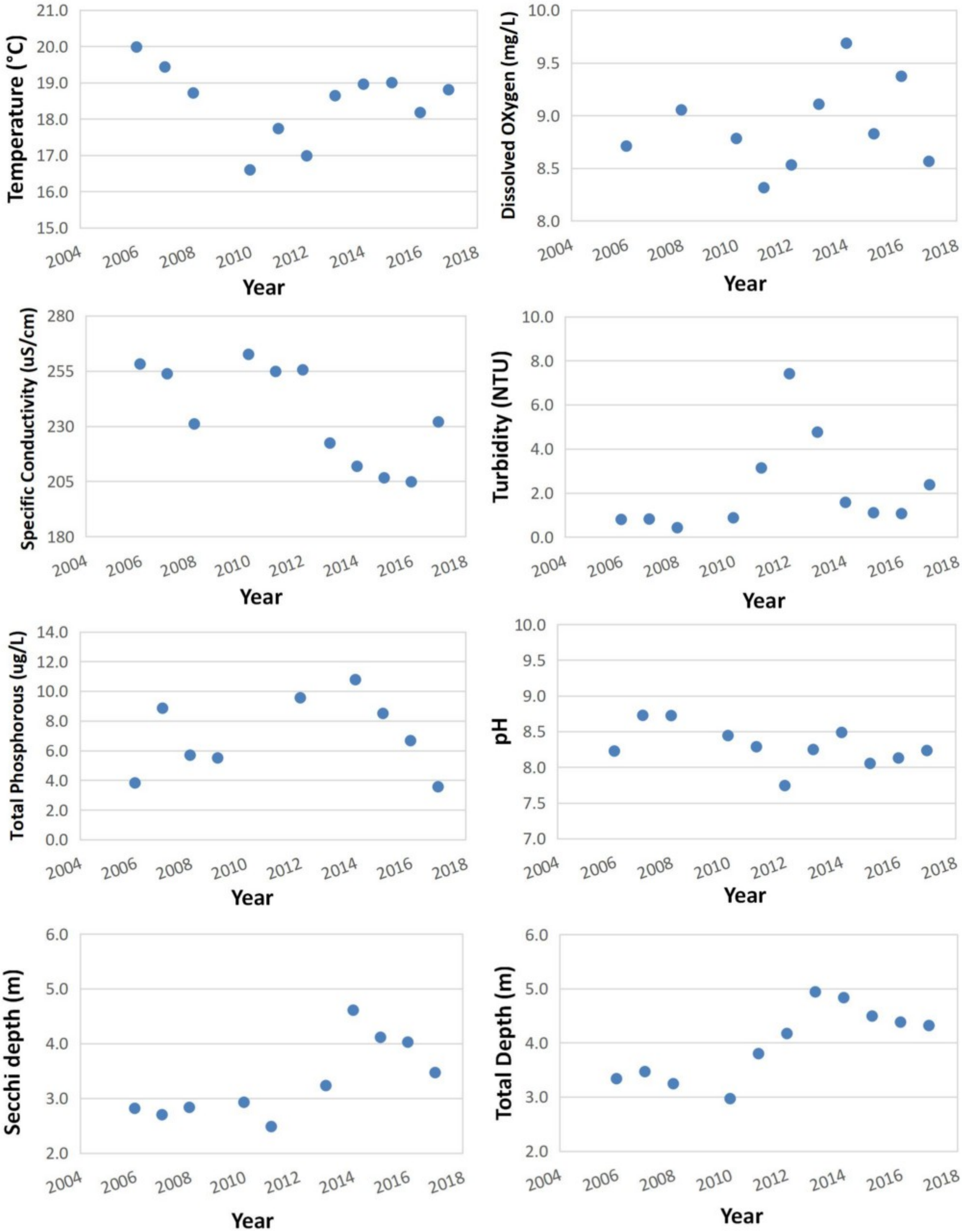


Figure 10: Historic water quality averages for the months of June - September, 2006-2017.

3. Aquatic Plant Survey and Veliger Sampling

3.1 - 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 filtering out nutrients that might otherwise be used for 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.

Zebra and quagga mussel species have already caused significant environmental, social, and economic damage throughout North America due to their rapid spread and devastation of entire lake ecosystems (Darvill, 2017). Until recently, invasive mussels were mostly confined to Eastern Canada and the Southern United States; however, in 2016, invasive mussels were detected in two reservoirs in Montana (Ministry of Environment, 2017b) and in 2013 were found introduced in Lake Winnipeg, Manitoba (Lake Winnipeg Foundation, n.d.). This proximity to BC has increased the risk that an infected boat can pass through the border into BC waters, and Lake Windermere's proximity to two main borders of the province as well as its high recreational use further increase this risk of introduction.

Invasive species out-compete most other native species if allowed to establish. This often results in a loss of biodiversity and native species, which can have a cascading effect on water quality and fish & wildlife populations. The introduction and spread of invasive aquatic plants or mussels 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 while Pat Wray (East Kootenay Invasive Plant Council) led the veliger sampling in 2017.

3.2 - 2017 Sample Results

The 2017 survey marked the eighth 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 species (either plants or mussel larvae) were found during either the offshore or shoreline plant surveys and the veliger testing.

There appeared to be "a higher amount of Chara species (muskgrass) detected in 2017, when compared to other years of sampling effort in 2015/2016" (Darvill, 2017). This is a native species of filamentous algae which can reproduce vegetatively via fragmentation, meaning that fragmenting and chopping of the vegetation by boat propellers may be causing an increase in spread of this plant species along the lake bottom. More investigation is needed in order to conclude if this is the case. The full 2017 AIS Inventory Report, published by Rachel Darvill, can be found on the LWA website under "Documents".

4. Swim Beach Water Quality

4.1 - Background

Escherichia 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, it is important to know that this value represents a total count of all colonies, and does not necessarily contain any 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 Lake Windermere Ambassadors have an ongoing agreement with the Interior Health Authority to collect public beach water samples which are then analyzed by the IHA laboratory for *E. coli* bacteria, in compliance with Health Canada Guidelines. This assesses whether swim beach water quality meets recognized health standards.

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):
- Geometric mean concentration (minimum of five samples taken over 30 days): ≤200 *E. coli*/100mL
- Single-sample maximum concentration: ≤400 *E. coli*/100mL

4.2 - 2017 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. For Lake Windermere, the highest geometric mean values over a 30-day period were as follows:

James Chabot = 9.7 *E. coli*/100 mL
Kinsmen Beach = 7.4 *E. coli*/100 mL
Windermere = <5 *E. coli*/100 mL

The highest single sample in 2017 was 40 *E. coli* /100mL, recorded on August 21st at the East side of Kinsmen Beach. This is a popular dog swimming area, which might explain the slightly higher bacterial concentration at this location. For comparison, in 2016, the highest single sample was 86 *E. coli* /100mL, recorded on August 8th at the East side of James Chabot beach. This beach area sees frequent visitation by geese and other waterfowl, which can add droppings to the water and increase the *E. coli* content. In 2010, values reached as high as 1150 *E. coli* /100mL at James Chabot beach in mid-August. When values exceed the Health Canada recommendations, a notice is put out to deter people from swimming at that location because, although the number of colonies does not equate the number of toxic strains of *E. coli*, the higher number of colonies increases the risk that a toxic strain may be present.

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

5. Tributary inflow (Windermere Creek)

5.1 - Background

Besides the main Columbia River channel, Windermere Creek is the major source of inflow into Lake Windermere. This tributary stream drains an area of approximately 90 km^2, and provides important fish spawning habitat (NHC, 2013).

In 2007, the Columbia Basin Water Quality Monitoring Project (CBWQ) was initiated. This project oversees scientific data collection in streams of the East and West Kootenay, through field work that is undertaken by local volunteers and non-profit organizations. Up until 2016, Wildsight Regional was the lead organization responsible for data collection on Windermere Creek (though the LWA would assist with field data collection). In 2017, the Lake Windermere Ambassadors formally took over the monitoring of Windermere Creek for the remainder of the CBWQ project, which comes to an end in early 2018.

The CBWQ project is funded by the Columbia Basin Trust. This funding allows partner groups to collect data about water chemistry, velocity and stream flow, and water temperature. The data is then analyzed and summarized into year-end and 5-year reports by professional contractors. These reports and data are readily accessible on the CBWQ website, found at http://cbwq.ca/reports/

5.2 - 2017 Sample Results

Temperature monitoring was initiated on July 18th 2017 using a HOBO Onset U22 Water Temperature logger, which collects temperature data to an accuracy of ±0.2^oC once per day at midnight. Windermere Creek has been found to maintain an average temperature around 10^oC in the summer months (Figure 10). In 2017, the highest recorded temperature was 13.3^oC on July 29th, while the lowest was 5.0^oC on October 4th.. These temperatures are within BC MOE ranges to support trout health (<15°C).

Water chemistry follows similar protocols and uses the same equipment as the lake water quality monitoring, with data collected for dissolved oxygen, specific conductivity, pH, turbidity, and temperature. Additional funding was supplied through the CBWQ project to monitor for heavy metals and nutrients.

Flow/velocity measurements are crude, and taken using a meter stick to obtain surface velocity based upon the principle of conversion of kinetic to potential energy. This overestimates average channel flow, but underestimates actual surface flow due to friction. While not exact, if measured carefully and repeated the same way each time, this measurement can give us a general idea as to how flow volumes change seasonally within a given area of stream.

In-depth water chemistry data and flow/velocity analyses have not been completed, but a brief summary of raw results is compiled here for interest (Tables 1, 2 and 3).

The most notable results for water chemistry are the Total Aluminum (Al) and Total Iron (Fe) concentrations, which both exceeded the given Canadian Water Quality Guidelines (CCME) for the samples taken on June 13th 2017 (Table 3). Dissolved sulphate remained well below the Health Canada aesthetic objective of 500mg/L on both sample occasions; this parameter is of interest because sulphates occur naturally in gypsum ($CaSO_4 \cdot 2H_2O$), and there is a gypsum mine located ~ 5km upstream of the sample location. The reason for the higher Iron and Aluminum concentrations is not currently known, but more insight on this may come in the final 5-year report for Windermere Creek that will be released later in 2018.

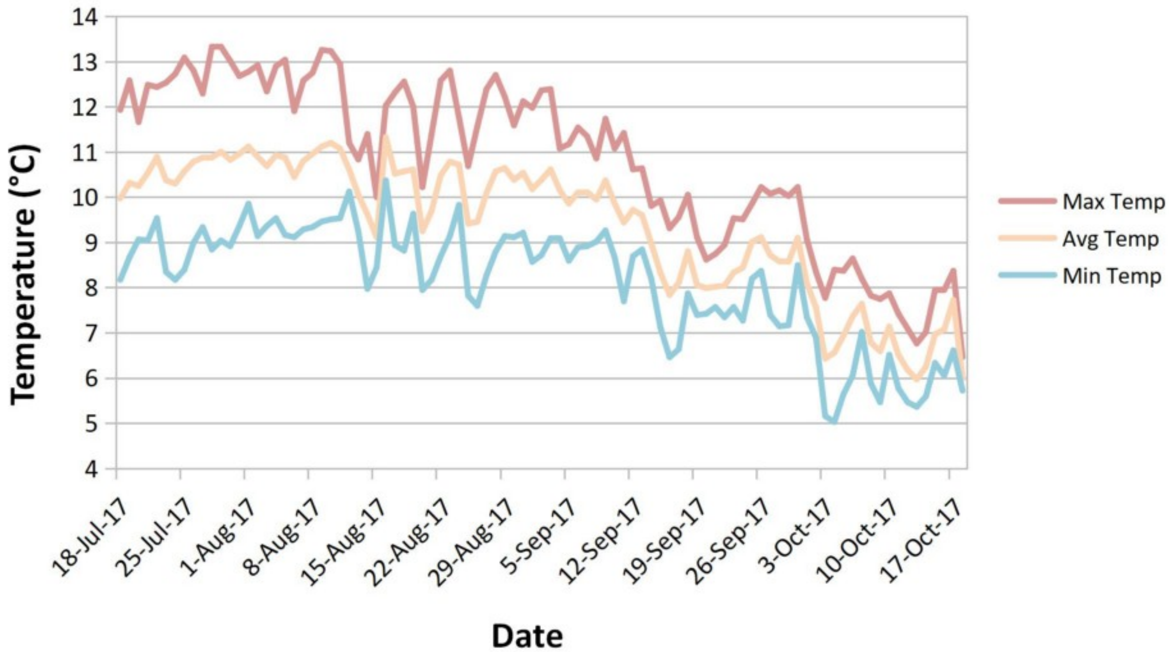


Figure 11: Daily average, maximum and minimum water temperatures recorded in Windermere Creek from July 18th to October 17th 2017.

Table 1: Monthly flow and velocity in Windermere Creek, June 13 - Oct 18, 2017.

Date	Velocity (m/s)	Flow (m^3/s)
2017-06-13	1.42	2.03
2017-07-18	0.96	1.11
2017-08-16	0.90	0.94
2017-09-26	0.80	0.71
2017-10-18	0.75	0.60

Table 2: Monthly water chemistry in Windermere Creek, June 13 - Oct 18, 2017.

Date	Water Temperature (°C)	Air Temperature (°C)	Dissolved Oxygen	Specific Conductivity	Turbidity	pH
2017-06-13	10.5	20	10	897	33.0	8.2
2017-07-18	11.3	21	11	785	4.8	8.2
2017-08-16	10.0	16	8	835	2.32	8.5
2017-09-26	9.6	16	11	877	1.28	8.7
2017-10-18	6.3	8	9	908	2.34	8.7

Table 3: Metals and nutrients in Windermere Creek, June 13 - Oct 18, 2017.

Date	pH	Total Aluminum (ug/L)	Total Iron (ug/L)	Total Hardness ($CaCO_3$)	Total Phosphorous (mg/L)	Total Nitrogen (mg/L)	Nitrate (mg/L)	Nitrite (mg/L)	Total Suspended Solids (mg/L)	Dissolved Sulphate (mg/L)
2017-06-13	8.2	161	335	389	0.0307	0.237	0.113	<0.005	42.0	187
2017-07-18	8.2				<0.0050	0.110	0.109	<0.005	6.8	
2017-08-16	8.5				<0.0050	0.166	0.104	<0.005	<4.0	
2017-09-26	8.7	8	25	496	<0.0050	0.214	0.115	<0.005	<4.0	297 (*)
2017-10-18	8.7				<0.0050	0.186	0.133	<0.005	<4.0	

(*) = Detection limits raised due to dilution to bring analyte within the calibrated range.

6. Acknowledgements

The 2017 Lake Windermere community-based water quality monitoring project was made possible thanks to generous funding support from the Columbia Valley Local Conservation Fund, Regional District of East Kootenay, and the District of Invermere.

In-kind support was provided directly by the District of Invermere through use and delivery of the tin boat and fuel. Additional in-kind support was provided by community volunteers Gavin Jacobs and Danny Osborne through use of their personal boats, and by the Interior Health Authority for swim beach samples.

Big thanks goes out to all of our citizen scientists! This year's community volunteers included:

- Tracy Flynn
- Kelly Carlson
- Ray Pierre
- Emma Norquay
- Danny Osborne
- Kaori Maruyama
- The Friedenburg family
- Chevy Demulder
- Peter Hale
- The McGrath family
- Araleigh Cranch
- Paul Christy
- Gavin Jacobs

A final thank you goes out to the following people for providing assistance with our community-based water quality monitoring program for 2017:

- Katie Watt (2016 & 2017 Watershed Stewardship Assistant)
- Rachel Darvill (Goldeneye Ecological Services)
- Pat Wray (East Kootenay Invasive Species Council)
- Jody Fisher & Jessica Penno (BC Ministry of Environment)

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