Windermere Lake, BC:
State of the Lake Report
2010-2019

Prepared
by

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September 2020

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Acknowledgements

The authors would like to thank Les Swain of TriStar Environmental Consulting for reviewing the report and providing valuable comment. Our appreciation also goes to Dawn Roumieu, Project Coordinator with the BC Lake Stewardship Society for assistance throughout the project. In addition, Annika Niemeyer greatly assisted with data tables and graphs.

A special thank you to our project funders:

Executive Summary

Lake Windermere Ambassadors (LWA) www.lakeambassadors.ca have undertaken a 10-year review of water quality monitoring and related activities of their organization on Lake Windermere in the East Kootenay region of British Columbia. LWA staff engaged the BC Lake Stewardship Society (BCLSS) www.bclss.org to undertake this review with the assistance of LWA staff.

The review had the following major objectives:

- Assess compliance with the established Water Quality Objectives (WQOs) for the period 2010-2019
- Examine indications of potential trends in water quality
- Conduct more in-depth analysis where WQOs are exceeded or trends are evident, as applicable
- Synthesize applicable findings of each of the LWA Annual Reports in a concise manner for water quality parameters. Summarize E. coli 10-year compliance with WQOs (bathing beaches)
- Review all relevant information on the lake and its watershed including any relevant anecdotal information e.g., septic concerns on east shore, NPS concerns, relevant First Nations information and Traditional Environmental Knowledge (TEK), including predictions on the potential impacts of climate change, as applicable
- Review the lake water quality monitoring program and recommend improvements where applicable
- Recommend priority areas for LWA to focus on to protect Lake Windermere in the future

The report recognized that the Columbia Valley is a traditional hunting and fishing ground used seasonally as part of the traditional territory of the Ktunaxa [pronounced too-nah-hah] and Shuswap/Secwepemc [pronounced suh-wep-muh] first nations. It was noted that the Shuswap Indian Band and Akisqnuk First Nation are involved at many levels in management of the Columbia basin including the two headwater lakes. Collaboration and support of the Lake Windermere Ambassadors continues in a variety of ways, including the provision of TEK, community restoration projects, and representation on the Board of Directors.

The review found that LWA has had, and continues to have, exemplary programs to monitor and protect Windermere Lake water quality and other lake attributes. LWA has trained over 100 volunteer citizen scientists over the years. LWA activities over the 10 year period of 2010 to 2019 are presented in the report.

The water quality monitoring program was reviewed. In addition to recommending an enhanced Quality Control/Quality Assurance program, 14 recommendations were made to improve and enhance the water quality program.

Water quality data was reviewed for the 10 year period for the following parameters: E.coli, Dissolved Oxygen, Phosphorus, Secchi Transparency, and Turbidity. Based on available data, water quality in Windermere Lake was found to be relatively stable with no evidence of a deteriorating trend. The monitoring program was reviewed in light of climate change predictions and it was concluded that monitoring by LWA should continue for a minimum of three additional years and that the Ministry of Environment and Climate Change Strategy (ENV) should be requested to review the established Water Quality Objectives (WQOs) for Windermere Lake following this period.

Land uses in the watershed were reviewed through a land use map generated by ENV, Google Earth, and tributary surveys by LWA staff. It was found that there is potential for land uses to contribute Non-point Source pollution (NPS).

The overall report conclusions and recommendations were as follows:

1. Windermere Lake is oligotrophic as indicated by the Secchi readings from 2010-2019 and the recent Total Phosphorus levels. There is no indication of a declining trend.
2. Further monitoring is required to adequately check attainment with WQOs and to obtain more information about the relationship between Total Phosphorus, Total Dissolved Phosphorus, and Ortho-Phosphorus levels in the lake.
3. Climate change predictions for the Upper Columbia Basin highlight the need for long term trend monitoring as is being conducted by the BC Ministry of Environment and Climate Change Strategy (ENV) and supplemented by LWA's programs.
4. It is 10 years since the Water Quality Objectives (WQOs) have been reviewed by ENV. It is recommended that a request be made in 2020 to ENV for a review of the WQOs to be completed following an additional three years of monitoring. ENV should be approached for funding for completion of the WQO monitoring parameters that have not been able to be addressed by LWA.
5. In 2019, the annual report by LWA on the results of the Community Based Water Quality Monitoring Program was peer reviewed. It is essential that the annual reports receive peer review by a professional qualified in the area of water quality monitoring and assessment. It is recommended that this funding requirement be included in monitoring program budgets.
6. LWA should continue its exemplary programs to protect Windermere Lake as described in Section 2.0 of the report.
7. As discussed in Section 5.1 and Section 6.4 of the report, a non-point source pollution assessment should be conducted over the entire watershed. Priority should be given to Windermere Cr. due to its high fisheries value and potential watershed issues as indicated by watershed surveys and water quality data.
8. Following a non-point source pollution assessment, a Watershed Management Plan should be considered to compliment the Lake Management Plan.

Following the foregoing recommendations will improve management of the lake and watershed and help ensure continued protection of Windermere Lake going forward.

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1.0 Introduction

Lake Windermere Ambassadors (LWA) www.lakeambassadors.ca have undertaken a 10-year review of water quality monitoring and related activities of their organization on Lake Windermere in the East Kootenay region of British Columbia. The review was done in two phases. Phase 1 was a preliminary analysis of data and other pertinent lake information in order to present a plan for the development of a state of the lake report in Phase 2.

LWA staff engaged the BC Lake Stewardship Society (BCLSS) www.bclss.org to undertake this review with the assistance of LWA staff.

1.1 Windermere Lake First Nations People

The Columbia Valley is a traditional hunting and fishing ground used seasonally as part of the traditional territory of the Ktunaxa [pronounced too-nah-hah] and Shuswap/Secwepemc [pronounced suh-wep-muh] first nations. The Ktunaxa band to the south of Windermere, known as the Akisqnuk First Nation, and the Shuswap band to the north of Athalmer, known as the Shuswap Indian Band, lived in this area for thousands of years and used the land and river as sources of food, hygiene, medicine, spirituality, and materials for shelter and clothing.

Lake Windermere was formerly called “Lower Columbia Lake”, and before European settlers came to the area, the Akisqnuk First Nation knew of the Columbia River as the “Chickadee River”. Lake Windermere area was known as “?akisq’nuk” whereas Columbia Lake area was known as “Yaqa·n Nukiy”. This area has a rich cultural history that is often not considered or gets forgotten by outside visitors and even people who have lived here for decades. It is important to the Ambassadors that we acknowledge the traditional ties our local First Nations once had, and still have, to this area.

Shuswap Indian Band and Akisqnuk First Nation are involved at many levels in management of the Columbia basin including the two headwater lakes. Collaboration and support of the Lake Windermere Ambassadors continues in a variety of ways, including the provision of Traditional Ecological Knowledge (TEK), community restoration projects, Board of Director representation, and more.

1.2 Phase One Report

Phase 1 resulted in the development of an annotated Table of Contents for the Phase 2 report which was reviewed by LWA and this served as an outline for this report. Compliance with established Water Quality Objectives (WQOs) was determined with graphs and tables in Phase 1.

The following recommendations resulted from the Phase 1 review:

- Conduct three more years of monitoring WQOs. While the Citizen Based Monitoring (CBM) aspect of the Lake Windermere Program is exemplary, WQOs cannot be adequately checked for exceedances without following the Ministry of Environment and Climate Change Strategy (ENV) monitoring protocols more strictly (timing of spring sampling, five weekly samples in a 30-day period). LWA has implemented this more strictly in 2020.

- A field QA/QC program should be implemented, and a protocol developed as to what to do if readings or lab reports are exceedances of WQOs or suspect results are obtained. LWA staff has implemented a field QA/QC program in 2020 in consultation with BCLSS (Section 4.1 and Appendix A).
- Land use mapping of tributary watersheds should be conducted to assist with prioritization of tributaries for non-point source (NPS) pollution assessment. This has been done by ENV for lakes that are part of the BC Lake Stewardship and Monitoring Program partnership between BCLSS and ENV. BCLSS requested and obtained this mapping for use in Phase 2.

1.3 Phase Two Objectives

Phase 2 was to conduct a 10 year anniversary review with the following objectives:

- Assess compliance with the established Water Quality Objectives (WQOs) for the period 2010-2019
- Examine indications of potential trends in water quality
- Conduct more in-depth analysis where WQOs are exceeded or trends are evident, as applicable
- Synthesize applicable findings of each of the LWA Annual Reports in a concise manner for water quality parameters. Summarize E. coli 10 year compliance with WQOs (bathing beaches)
- Review all relevant information on the lake and its watershed including any relevant anecdotal information e.g., septic concerns on east shore, NPS concerns, relevant FN information and TEK, including predictions on the potential impacts of climate change, as applicable
- Review the lake water quality monitoring program
- Recommend priority areas for LWA to focus on to protect Lake Windermere in the future

2.0 Major Accomplishments of Lake Windermere Ambassador's Programs

Lake Windermere Ambassadors www.lakeambassadors.ca have an excellent lake stewardship program for Windermere Lake. The following table shows a brief summary of LWA's accomplishments from 2010-2019.

Table 1 Lake Windermere Ambassadors Accomplishments 2010-2019

2010-2011	**2011-2012**	**2012-2013**
11 lake sampling events 13 beach sampling events 12 volunteers trained First aquatic vegetation survey Vegetation mapping 1 stream keeper workshop hosted Kinsmen Beach restoration started Green Boating Guides distributed New website created 1 shoreline cleanup	Purchased new sampling equipment 13 volunteers trained Continued lake monitoring Monthly sampling Windermere Creek Collected macroinvertebrate samples Delivered interpretive tours Concluded Kinsmen Beach planting 2 shoreline cleanups done	Continued lake and beach monitoring - collected stormwater samples at DOI stormwater outlet Detected heavy metal concentrations in excess & conveyed to decision makers Led to student stormwater action projects 15 volunteers trained Kinsmen Beach finished and used as an example for a restoration project on Premier Lake Stewardship tours of site and interpretive signage installed
2013-2014	**2014-2015**	**2015-2016**
Continued lake and beach monitoring - changing trends in phosphorus levels and chlorophyll 'a' Recommend ongoing water quality monitoring rather than periodic assessments conducted on a needs basis to detect changes over time 16 volunteers trained Hosted water conservation events Maintain Kinsmen restoration site Aquatic invasive plant survey Supported development and implementation of Columbia Lake Stewardship Society's water quality monitoring program	Continued lake and beach monitoring - high phosphorus values at ice-off and late summer 14 volunteers trained Aquatic plant survey Veliger sampling Aquatic invasives signage Public events and education Classroom on the Creek Research and inventories of water level monitoring by RDEK, Corix Utilities and DOI	Continued lake and beach monitoring - elevated ice-off Manganese led to discussions with Corix High P led to golf course outreach and brochures 16 volunteers trained Aquatic plant survey Veliger sampling MOE sampling audit Lake keepers workshop Invasive mussel education Boat launch outreach Public events and education 2 shoreline cleanups

Table 1 Lake Windermere Ambassadors Accomplishments 2010-2019 continued.

2016-2017	**2017-2018**	**2018-2019**
Continued lake and beach monitoring 21 volunteers trained Aquatic plant survey Veliger sampling Nuisance Nutrients workshop Responsible boating pamphlets and public map Green Shores for Homes program Summer students exchanges with CLSS Lake tours Mooring buoy education and outreach Installed temp logger in Windermere 2 shoreline cleanups	Continued lake and beach monitoring - high water temps led to education and outreach re: shoreline health / riparian planting Installed flow logger in Windermere Info about responsible boating and decreasing turbidity Alert FLNRORD and DFO to dry Holland creek 24 volunteers trained Aquatic plant survey Veliger sampling Green Shores for Homes workshop Lake and wetland tours Getting water quality data online 2 shoreline cleanups	Continued lake, creek, and beach monitoring Installed flow logger on Abel Creek 25 volunteers trained Aquatic plant survey Veliger sampling Continue to update water quality data online 3 shoreline cleanups Continued winter outreach and education in partnership with TCNSC Connect with School Groups for Clean Ups and Great Waters Challenge Hosted community information and connection sessions Attend community outreach events Connected with other organizations that share similar missions to collaborate (ex. CBWN, CLSS, Canadian Freshwater Alliance) Provided 10 free kids summer camps on topics related to Lake Health

Further information on the activities and accomplishments of the LWA can be found on the web site www.lakeambassadors.ca.

3.0 Background to the Monitoring Program

The current Lake Windermere monitoring program commenced in 2010 to monitor compliance with Water Quality Objectives (WQOs) set for the lake by the Ministry of Environment. Water Quality Objectives are site specific levels of water quality parameters (i.e., specific to a particular water body). WQOs are based on water quality guidelines and local water quality conditions and are designed to protect the most sensitive designated water use at that location (Neufeld et.al. 2010).

Sampling locations are illustrated on Figure 1. Lake Windermere Ambassadors (LWA) has conducted this monitoring with the assistance of a large number of citizen scientists they have trained. In addition, LWA has conducted monitoring on tributary streams: Windermere and Abel Creeks. From this perspective, the LWA program is exemplary.

3.1 Water Quality Assessment and Objectives for Windermere Lake

The 2010 report by Neufeld et al. was a revision of WQOs first set in 1985 by the Ministry of Environment based on water monitoring data and other watershed information. Neufeld et al. (2010) found that there had not been any substantial change in the water quality of Windermere Lake compared to historical data, and that the lake's rapid turnover of water (water residence time of 47 days), allows the lake to effectively assimilate nutrients. The report did find that elevated concentrations of microbiological indicators were noted at Althamer and Windermere Cr. public beaches (Figure 1). It was concluded that while the overall lake water quality did not show much variation, non-point (diffuse) sources of pollution from heavy recreational use or septic systems along the east shore may be evident in near-shore areas (Neufeld et.al, 2010).

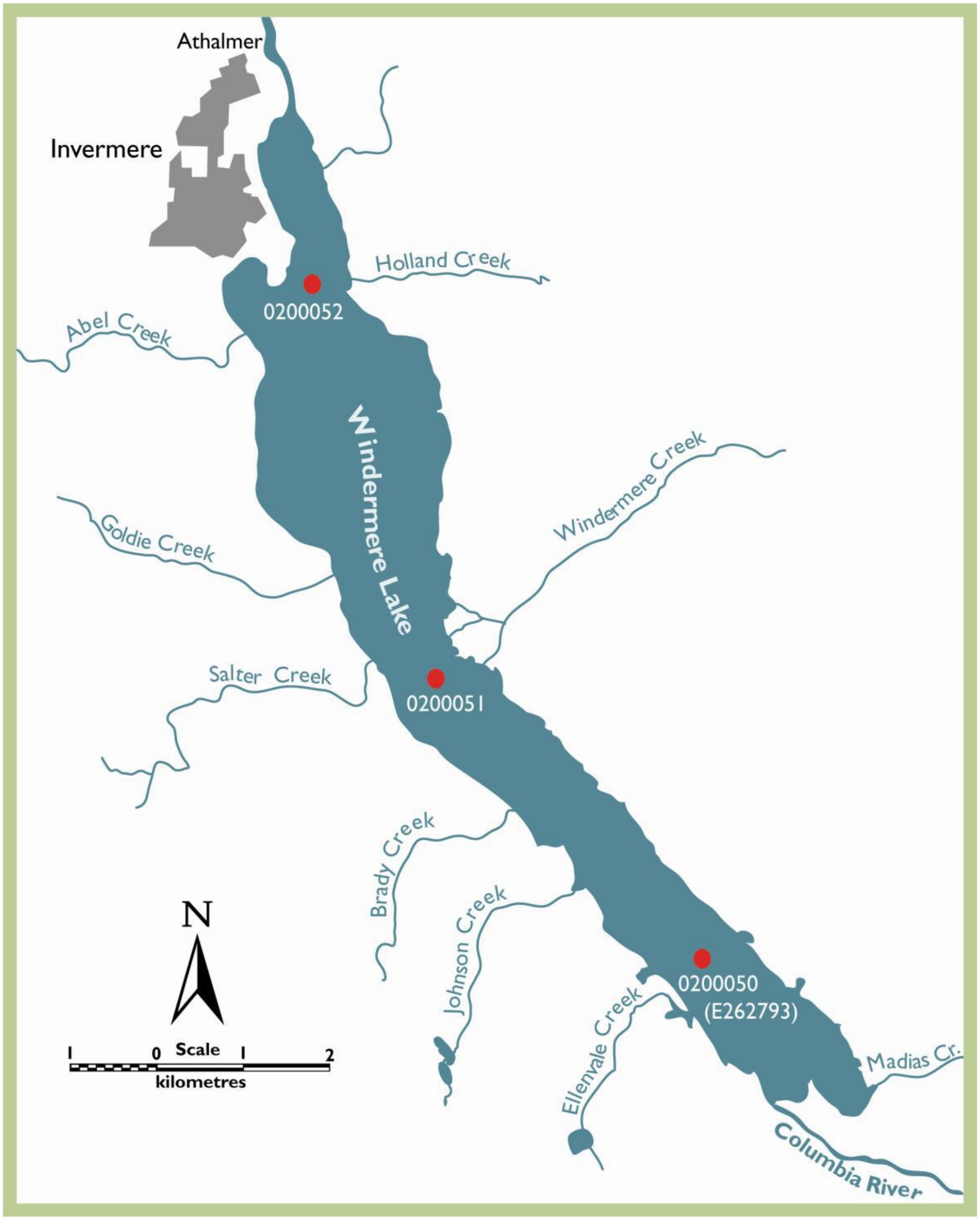

Figure 1: Windermere Lake sampling sites (from Neufeld et. al, 2010)

The 2010 Water Quality Assessment (Neufeld et al., 2010) was a review of hydrology, climate, water uses (including fisheries), and potential influences on water quality from various land uses. This assessment combined with a review of monitoring data resulted in a revised set of WQOs for Windermere Lake as follows in Table 2.

Table 2 Water Quality Objectives for Windermere Lake (from Neufeld et. al, 2010)

Parameter	Site	Objective
Turbidity[1]	0200051, 0200052, E262793	≤ 5 NTU (maximum)
		≤ 1 NTU (average)
	0200051, 0200052, E262793	5 NTU (95^{th} percentile)
Temperature[2]	0200051, 0200052, E262793	20 °C June (average)
		25 °C July (average)
		23 °C August (average)
E. coli[3]	Bathing Beaches; Drinking Water Intakes	≤77 CFU/100 mL (geo. mean)
		≤10 CFU/100 mL (90^{th} percentile)
Phosphorus[4]	0200051, 0200052, E262793	10 µg/L (maximum)
TOC[5]	Near Drinking Water Intakes	4 mg/L (maximum)
DO	0200051, 0200052, E262793	≥5 mg/L (instantaneous minimum)
		≥8 mg/L (average)

1. During the clear-flow period (August 16 through April 30) maximum turbidity at any time should be ≤5 NTU and mean turbidity (based on a minimum of five weekly samples collected within a 30-day period) during the clear-flow (non-freshet) period should be ≤ 1 NTU. During the turbid-flow period (May 1through Aug 15), the 95^{th} percentile turbidity should not exceed 5 NTU (based on a minimum of five weekly samples collected in a 30-day period).
2. For the protection of aquatic life, the average water temperature (measured in the top and bottom of the water column) should not exceed 20 °C, 25 °C, and 23 °C, in June, July, and August, respectively.
3. To protect primary-contact recreation, the geometric mean for *E. coli* should be ≤ 77 CFU/100 mL. To protect drinking water sources, the 90^{th} percentile *E. coli* count should be ≤ 10 CFU/100 mL near drinking water intakes. These statistics are to be calculated from at least five weekly samples collected within a 30- day period.
4. Monitoring to check for attainment of the objective should take place as soon as possible after ice-off to determine if any internal P loading is occurring over winter.
5. To protect drinking water quality total organic carbon (near water intakes) should not exceed a maximum of 4 mg/L at any time.

3.2 Water Quality Objectives Monitoring Program

Table 3 shows the recommended monitoring program to check attainment of the WQOs.

Table 3 Windermere Lake Monitoring Program (from Neufeld et. al, 2010)

Parameter	Site	Depth	Frequency and Timing
Turbidity, temperature, conductivity, pH, DO	0200051, 0200052, E262793		Five times (weekly) in 30 days during the turbid-flow period (May 1 – August 15). Five times (weekly) in 30 days during the clear-flow period (August 16 – April 30).
E. coli	Bathing beaches (Athalmer, Invermere and Windermere beaches minimum)		Weekly June 15 – August 31
	Water intakes		Weekly June 15 – August 31
Total and dissolved phosphorus	0200051, 0200052, E262793	Surface and 1 m above the bottom	Monthly (June – August)
TOC	Near water intakes		Monthly (June – August)
Dissolved sulphate	0200051	Surface and 1 m above the bottom	Monthly (June – August)
Total nitrogen, nitrite, nitrate, chloride	0200051, 0200052, E262793	Surface and 1 m above the bottom	Monthly (June – August)

4.0 Monitoring Program 2010-2019

The Phase 1 review found that the monitoring program did not strictly follow the program specified by Neufeld et.al. (2010). For example, there were often not five weekly samples in 30 days during the turbid and clear flow periods as per Table 3. The five weekly sampling regime has a sound scientific basis[1] in research conducted by the Ministry of Environment (ENV)[2]. This research determined by statistical analysis of different sampling schedules and frequencies, that the five weekly program was cost effective and little was gained by additional sampling.

In addition, phosphorus samples were not taken immediately after ice-out which was designed to answer a question raised in the Water Quality Assessment by Neufeld et al. (2010). This was whether winter conditions under ice were such that phosphorus is being released from the sediments under winter ice conditions. Samples should be taken at surface and 1 m above the bottom immediately after ice-out in the spring.

Neufeld et.al. (2010) also recommended monitoring for Total Organic Carbon, Dissolved Sulphate, Total Nitrogen, Nitrate, Nitrite, and Chloride. A review of the LWA data base by LWA staff has determined that these parameters have not been measured on Windermere Lake.

With regard to Quality Assurance/Quality Control (QA/QC), the Phase 1 review found that while the lab analyzing the samples was conducting QA/QC, there was little or no field QA/QC conducted from 2010-2019. Field QA/QC programs are fundamental and essential for all water quality monitoring programs (Zirnhelt et al., 2018). The Phase 1 review recommended this and LWA implemented a QA program in 2020 outlined in the following section.

4.1 Quality Assurance/Quality Control

In 2020, the Lake Windermere Ambassadors has collected physical and chemical water quality and quantity parameters at three sample sites on Lake Windermere and one sample site on Abel and Windermere Creeks. The frequency is once weekly during the summer, from late May to September.

The lake sampling regime included water temperature, turbidity/clarity, pH, conductivity, depth, and dissolved oxygen. The creek sampling regime included water temperature, turbidity, pH, conductivity, dissolved oxygen, flow and velocity. Once monthly from May to September additional lab samples were collected at all sampling sites to test for Total Dissolved Phosphorus, Total Phosphorus, and pH. To ensure quality control, all sampling equipment was inspected and cleaned twice per week, following each field trip and calibrated on the day of each sampling event (monthly). All calibration readings were recorded in a calibration log.

All sampling sites were recorded and marked using an etrex 20 Garmin GPS system to ensure sample site consistency and all lake sampling data were collected while anchored at individual sites to avoid drifting from sites. All employees, volunteers and related personnel were trained in water sampling techniques and are following *Water Quality Assessment and Objectives for Windermere Lake* (Neufeld et al., 2010).

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[1] The lead author has knowledge of the research conducted to support this sampling schedule

[2] Now the Ministry of Environment and Climate Change Strategy, abbreviated as ENV for this report

For consistency, one person (Program Coordinator) was responsible for filling out monthly Chain of Custody forms (COC) to CARO Analytical Services. Laboratory samples were packed in secure coolers with multiple ice packs during transportation, to keep samples below 8°C as per lab requirements and a single analytical lab, CARO Analytical Services, was used for consistency.

In collaboration with Water Rangers and Living Lakes Canada, a water quality test kit, loaned in 2020 has been utilized to verify field readings. These test kits have been created for communities, schools and passionate individuals who want to learn about the health of local lakes, rivers, or other waterbodies. Parameters that have been compared between sampling equipment includes pH, dissolved oxygen, Secchi depth, specific conductivity, water temperature, and air temperature (accuracies for the components of this kit can be found in Appendix A).

Field QA samples collected for the Lake Windermere Water Quality Monitoring Program included duplicates, equipment blanks, and split samples. Field duplicate samples were taken by the same team, at the same time and location and used to analyze sampling and equipment precision. Equipment blanks were taken using deionized water, which prior to use was known to be free of contaminants and was processed with identical in-field techniques as the actual water sample. This was used to determine if field equipment introduced contaminants into samples.

Finally, split samples were taken with one single grab sample and divided, each representing the original sample. Split samples were often used to compare results between two different samplers. While sampling on lakes and creeks, monthly duplicate samples were taken to compare the precision of pH readings. In addition to this, equipment blanks were sent with 50% of monthly lab samples at random times throughout the season. Furthermore, random duplicate samples to assess the precision of turbidity, conductivity, and dissolved oxygen were taken. The majority of weekly sampling trips included at least one form of QA on one individual parameter. The guidance was that a minimum of 10% of samples were QA/QC.

Complete details of the QA/QC program can be found in Appendix A.

4.2 Monitoring Results 2010-2019

Water quality monitoring results from 2010-2019 are presented in Tables 4 to 10 and Figures 2 to 9 for all three monitoring locations illustrated in Figure 1: Windermere Lake North (off Timber Ridge), off Windermere Cr., and Windermere Lake South. Parameters include E. coli, Dissolved Oxygen, Phosphorus, Secchi Transparency, Temperature, and Turbidity. A discussion of these results is found in Sections 4.3.1 to 4.3.6. Conductivity and pH are also monitored by LWA; however, WQOs were not set for these parameters. Results for these parameters are summarized in the LWA Annual Water Quality Reports and can be found on the LWA web site (www.lakeambassadors.ca/).

Table 4: E. coli 2011-2019

Year	Geometric Mean (coli/100 mL)			Highest Single Sample (coli/100 mL)
2011	James Chabot Beach: **8.0**	Kinsmen Beach: **5.0**	Windermere Beach: **4.0**	2550 (James Chabot Beach)
2012	James Chabot Beach: **69.0**	Kinsmen Beach: **22.0**	Windermere Beach: **5.0**	5150 (James Chabot Beach)
2013	James Chabot Beach: **9.0**	Kinsmen Beach: **3.3**	Windermere Beach: **3.1**	727 (Kinsmen Beach)
2014	James Chabot Beach: **7.3**	Kinsmen Beach: **7.1**	Windermere Beach: **1.8**	135 (Kinsmen Beach)
2015	James Chabot Beach: **8.0**	Kinsmen Beach: **11.0**	Windermere Beach: **1.0**	35 (Kinsmen Beach)
2016	James Chabot Beach: **6.3**	Kinsmen Beach: **9.9**	Windermere Beach: **6.1**	86 (James Chabot Beach)
2017	James Chabot Beach: **9.7**	Kinsmen Beach: **7.4**	Windermere Beach: **<5**	40 (Kinsmen Beach)
2018	James Chabot Beach: **14.7**	Kinsmen Beach: **8.5**	Windermere Beach: **5.0**	55 (James Chabot Beach)
2019	James Chabot Beach: **15.5**	Kinsmen Beach: **27.2**	Windermere Beach: **8.7**	65 (Kinsmen Beach)

Table 5: Lake Windermere Dissolved Oxygen (mg/L) 2010-2019 for all sampling locations.

Percentage of exceedance was not calculated because measured values throughout the years are within the Water Quality Objectives.

		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Off Timber Ridge (200052) [a]	Maximum	21.5	10.0	10.0	10.5	10.5	9.8	10.0	10.0	12.0	11.8
	Minimum	14.2	6.5	5.0	7.5	8.5	7.0	7.5	6.5	8.0	7.0
	Average	17.0	8.0	8.2	8.8	9.7	8.6	8.7	8.5	10.3	10.0
	Std. Deviation	2.24	0.82	1.21	0.87	0.71	0.83	0.89	0.89	0.92	1.03
	# Samples	11	11	12	13	13	10	13	13	19	22
Off Windermere Creek (200051)	Maximum	13.0	10.0	10.0	11.0	11.0	10.0	11.0	10.0	12.0	11.0
	Minimum	6.0	7.0	7.0	7.0	8.0	8.0	8.0	7.0	8.0	8.0
	Average	9.2	8.6	8.7	8.7	9.7	9.0	9.1	8.5	9.7	10.1
	Std. Deviation	1.94	0.86	0.85	1.09	0.92	0.74	1.04	1.04	1.39	0.96
	# Samples	10	11	12	13	12	10	12	14	7	8
South Station (E262793)	Maximum	10.0	12.0	10.0	11.0	12.0	10.0	12.0	12.0	12.0	13.0
	Minimum	8.0	7.0	8.0	7.0	8.0	8.0	10.0	7.0	10.0	9.0
	Average	9.0	8.7	8.8	9.0	9.8	9.1	10.4	9.3	10.6	10.7
	Std. Deviation	0.89	1.40	0.72	1.21	1.10	0.86	0.76	1.44	0.80	1.24
	# Samples	7	11	11	11	13	11	12	14	5	8
WQO[b]	Minimum	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5
	30-day average	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8

[a]Values calculated by taking the mean of measurements from upper (30 cm below surface) and lower (1 m above bottom) depth samples.

[b]The WQO for the protection of aquatic life is set to a minimum of ≥ 5 mg/L and an average of ≥ 8 mg/L based on a 30-day average.

Table 6: Variation of Lake Windermere Dissolved Oxygen (mg/L) concentrations on a monthly basis from 2010-2019 for all sampling locations through spring, summer, and fall.

Percentage of exceedance was not calculated because measured values throughout the years are within the Water Quality Objectives.

		Apr	May	Jun	Jul	Aug	Sept	Oct
[a]Off Timber Ridge (200051)	Maximum	8.5	15.3	18.0	19.2	21.5	17.3	14.2
	Minimum	9.0	9.5	8.0	5.0	7.0	7.0	14.2
	Average	9.0	11.6	10.1	9.3	9.6	10.0	14.2
	Std. Dev.	0.0	2.6	2.2	2.2	2.8	2.6	0.0
	# Samples	2	8	66	78	76	44	2
Off Windermere Creek (200052)	Maximum		13.0	12.0	11.0	11.0	10.0	
	Minimum		8.0	8.0	7.0	7.0	6.0	
	Average		10.3	9.7	8.9	8.9	8.7	
	Std. Dev.		2.1	1.0	1.2	1.1	1.0	
	# Samples		3	26	31	35	15	
South Station (E262793)	Maximum	10.0	10.0	12.0	12.0	13.0	12.0	
	Minimum	10.0	9.0	7.0	7.0	7.0	7.0	
	Average	10.0	9.5	9.6	9.1	9.7	9.5	
	Std. Dev.	0.0	0.5	1.3	1.2	1.3	1.4	
	# Samples	1	2	23	28	32	15	
[b]WQO	Minimum	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5	≥ 5
	30-day average	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8	≥ 8

[a]Values calculated by taking the mean of measurements from upper (30cm) and lower (4 -5m) depth samples.

[b]The WQO for the protection of aquatic life is set to a minimum of ≥ 5 mg/L and an average of ≥ 8 mg/L based on a 30-day average.

Off Timber Ridge (200052)

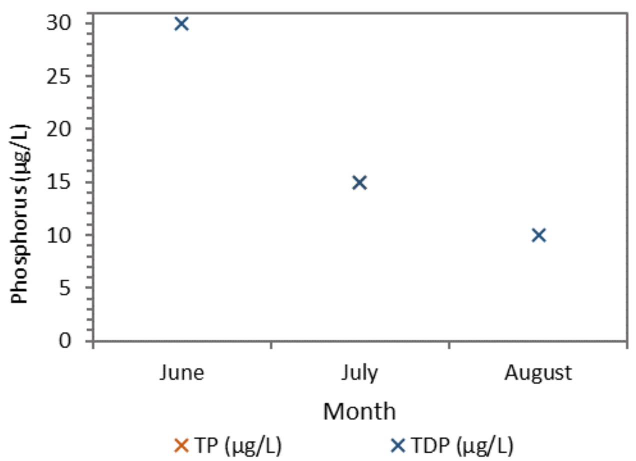

Figure 2a: Lake Windermere Off Timber Ridge Total and Total Dissolved Phosphorus (µg/L) – 2011. TP and TDP levels in July are identical and overlapping in the graph. TP levels in June and August 30 µg/L and 97.5 µg/L respectively.

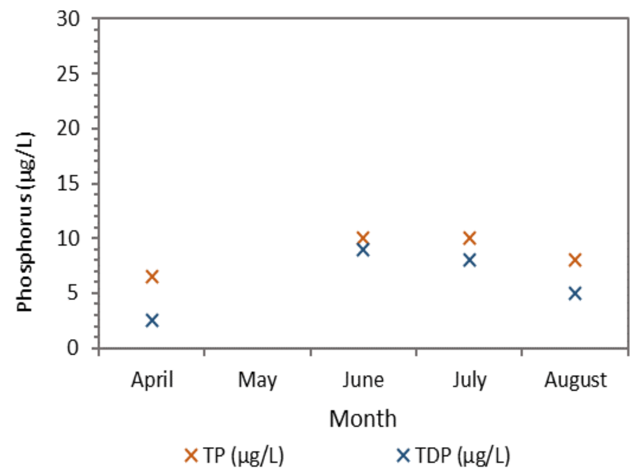

Figure 2b: Lake Windermere Off Timber Ridge Total and Total Dissolved Phosphorus (µg/L) – 2012.

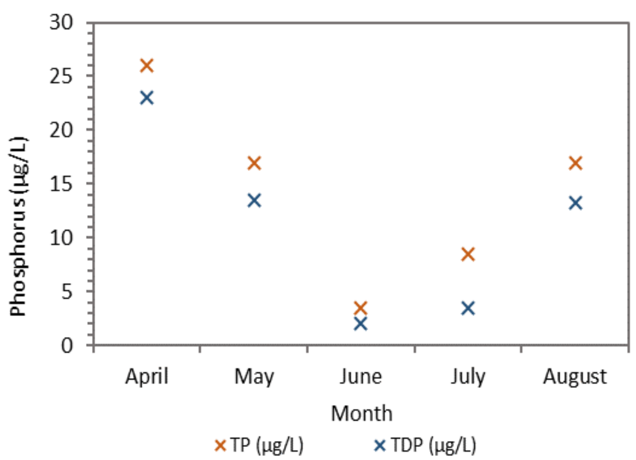

Figure 2c: Lake Windermere Off Timber Ridge Total and Total Dissolved Phosphorus (µg/L) – 2014.

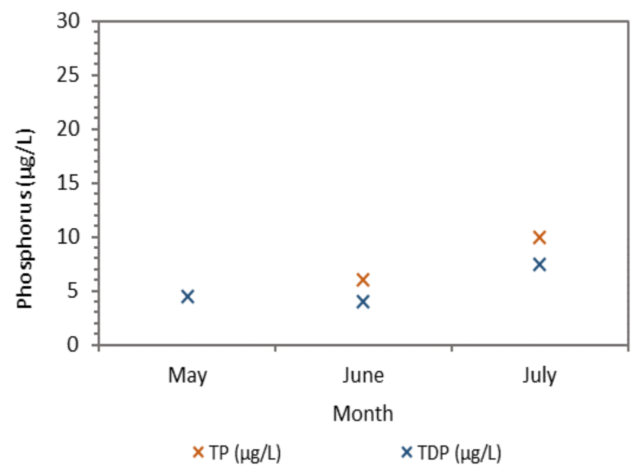

Figure 2d: Lake Windermere Off Timber Ridge Total and Total Dissolved Phosphorus (µg/L) – 2015. TP level in May 36 µg/L.

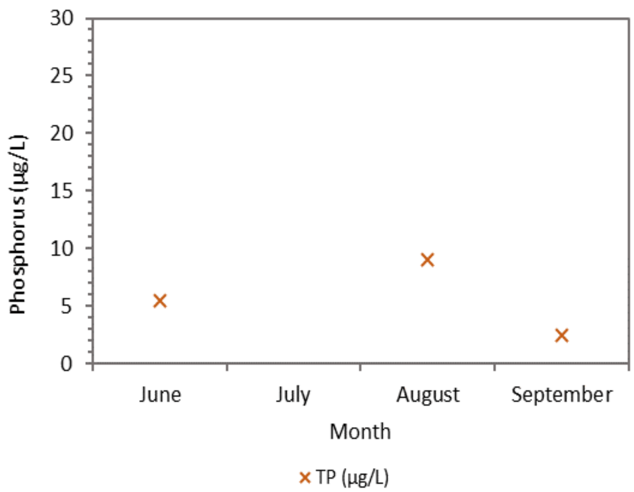

Figure 2e: Lake Windermere Off Timber Ridge Total Phosphorus (µg/L) – 2016.

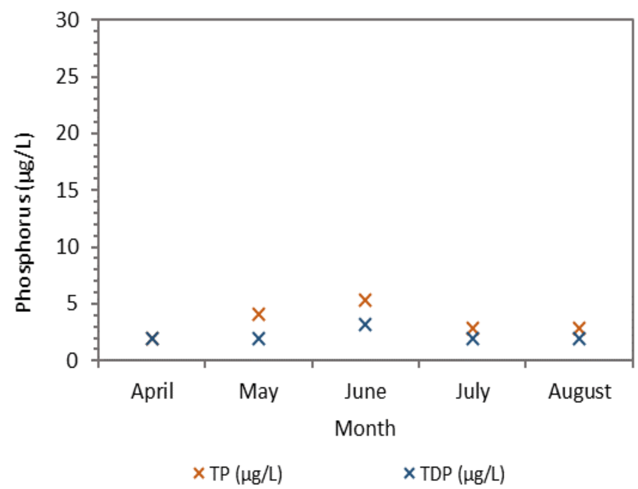

Figure 2f: Lake Windermere Off Timber Ridge Total and Total Dissolved Phosphorus (µg/L) – 2018. TP and TDP levels in April are identical and overlapping in the graph.

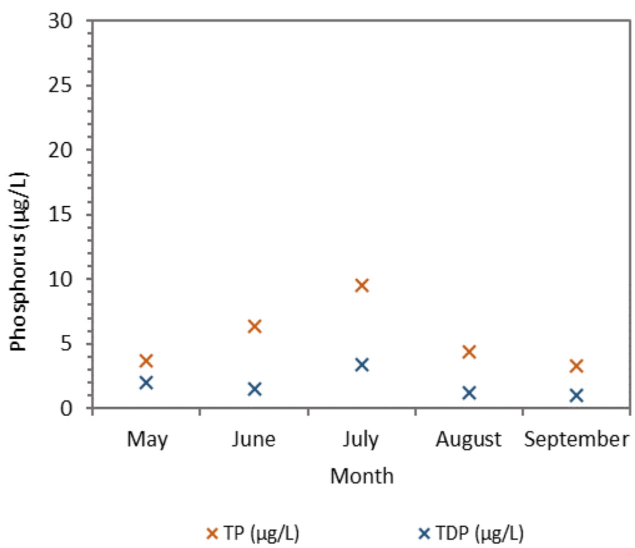

Figure 2g: Lake Windermere Off Timber Ridge Total and Total Dissolved Phosphorus (µg/L) – 2019

Figure 2 a-g: Lake Windermere off Timber Ridge, Total and Total Dissolved Phosphorus (µg/L) 2011-2019.

There are no data for 2017 and only one sample for 2013, which was taken in September. TP level in 2011 49.17 µg/L

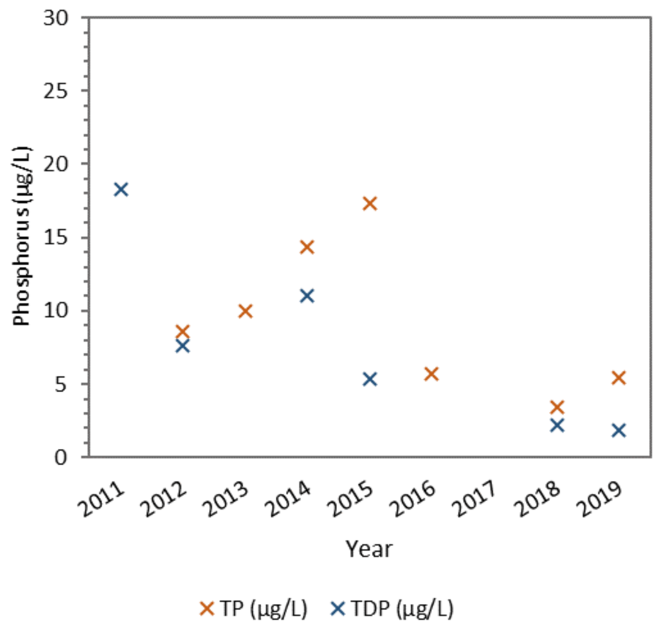

Figure 3: Lake Windermere off Timber Ridge, Mean Total and Total Dissolved Phosphorus (µg/L) 2011-2019.

There are no data for 2017 and only one sample for 2013, which was taken in September. TP level in 2011 49.17 µg/L.

Off Windermere Creek (200051)

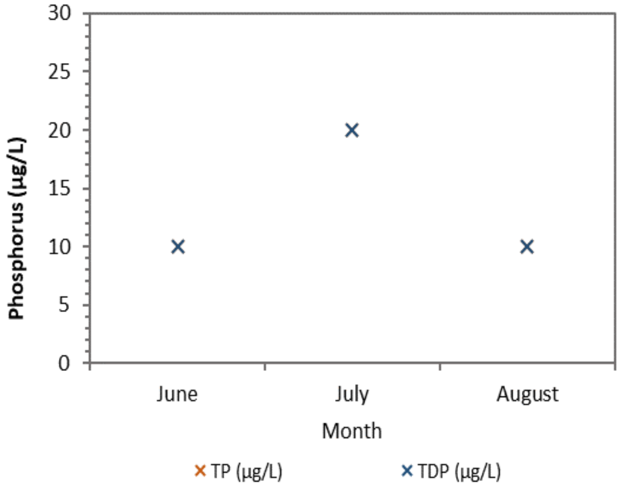

Figure 4a: Lake Windermere Off Windermere Creek Total and Total Dissolved Phosphorus (µg/L) – 2011. TP and TDP levels are identical and overlapping in the graph.

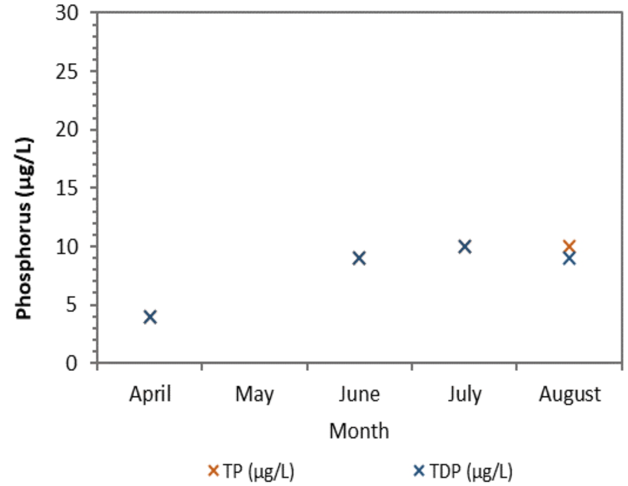

Figure 4b: Lake Windermere Off Windermere Creek Total and Total Dissolved Phosphorus (µg/L) – 2012. TP and TDP levels in April, June and July are identical and overlapping in the graph.

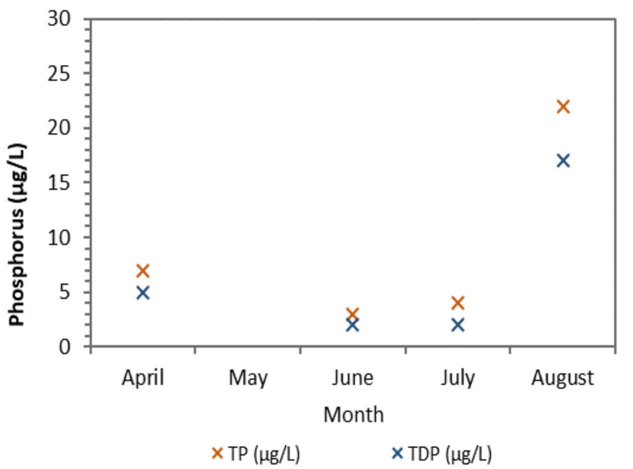

Figure 4c: Lake Windermere Off Windermere Creek Total and Total Dissolved Phosphorus (µg/L) - 2014

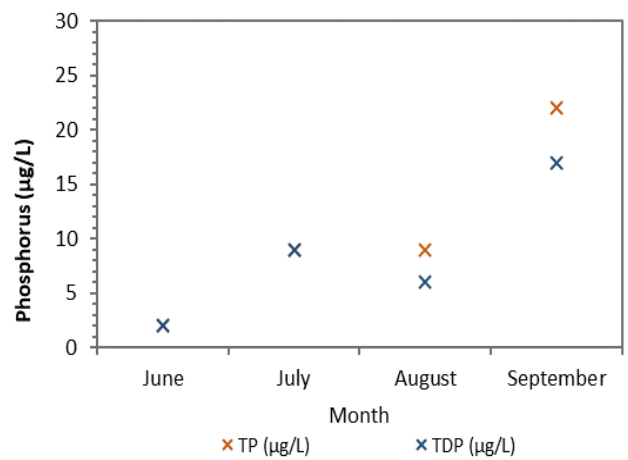

Figure 4d: Lake Windermere Off Windermere Creek Total and Total Dissolved Phosphorus (µg/L) – 2015. TP and TDP levels in June and July are identical and overlapping in the graph.

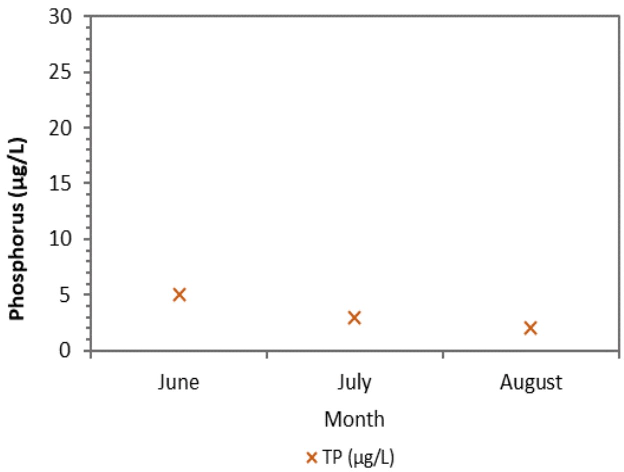

Figure 4e: Lake Windermere Off Windermere Creek Total Phosphorus (µg/L) – 2016.

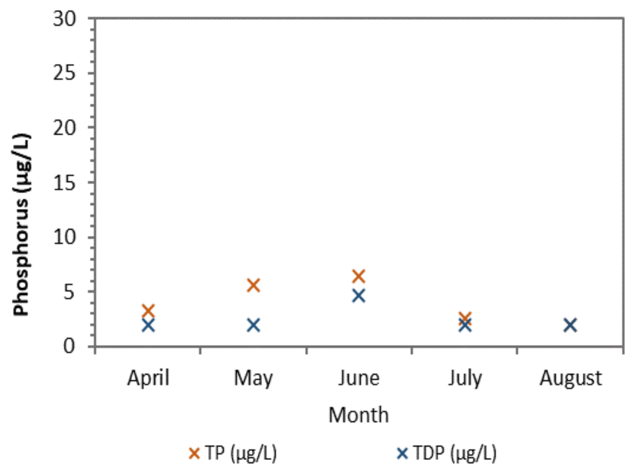

Figure 4f: Lake Windermere Off Windermere Creek Total and Total Dissolved Phosphorus (µg/L) – 2018. TP and TDP levels in August are identical and overlapping in the graph.

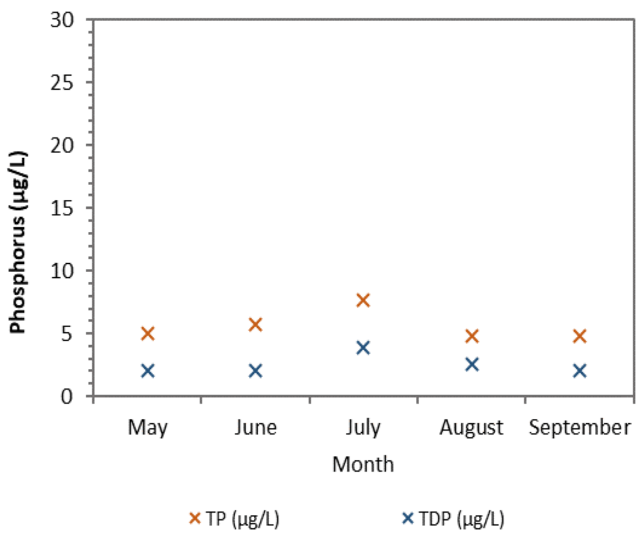

Figure 4g: Lake Windermere Off Windermere Creek Total and Total Dissolved Phosphorus (µg/L) – 2019

Figure 4 a-g: Lake Windermere off Windermere Creek, Total and Total Dissolved Phosphorus (µg/L) 2011-2019.

There are no data for 2017 and only one sample for 2013, which was taken in September.

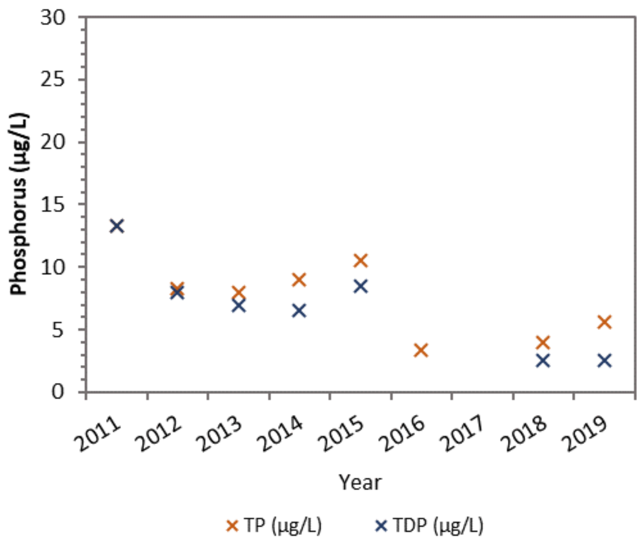

Figure 5: Lake Windermere off Windermere Creek, Mean Total and Total Dissolved Phosphorus (µg/L) 2011-2019.

There are no data for 2017 and only one sample for 2013, which was taken in September.

South Station (E262793)

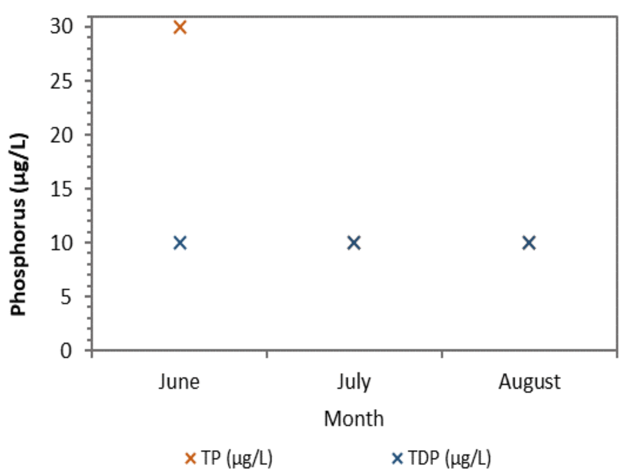

Figure 6a: Lake Windermere South Station Total and Total Dissolved Phosphorus (µg/L) – 2011. TP and TDP levels in July and August are identical and overlapping in the graph.

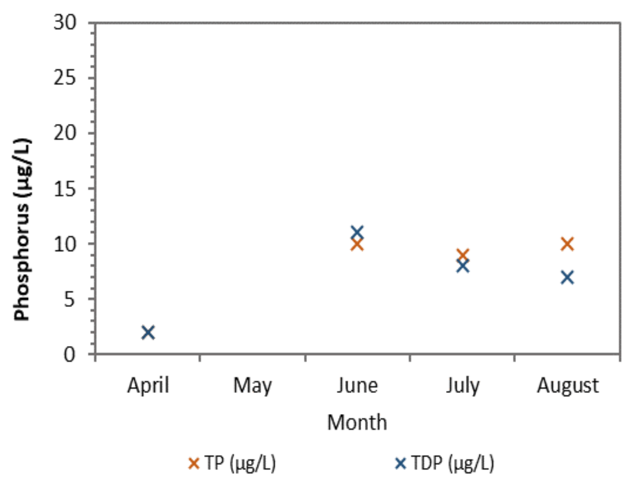

Figure 6b: Lake Windermere South Station Total and Total Dissolved Phosphorus (µg/L) – 2012. TP and TDP levels in April are identical and overlapping in the graph.

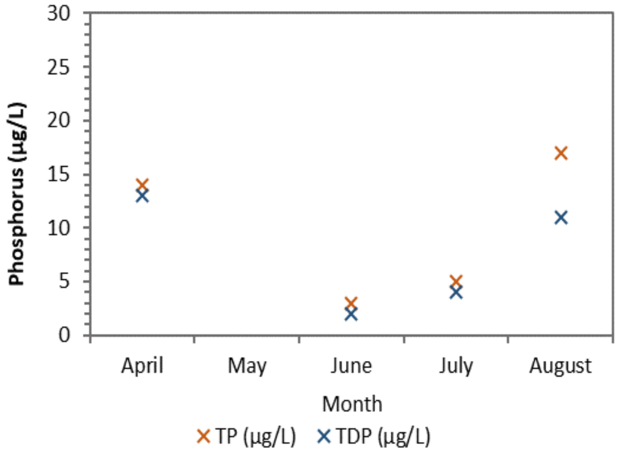

Figure 6c: Lake Windermere South Station Total and Total Dissolved Phosphorus (µg/L) - 2014

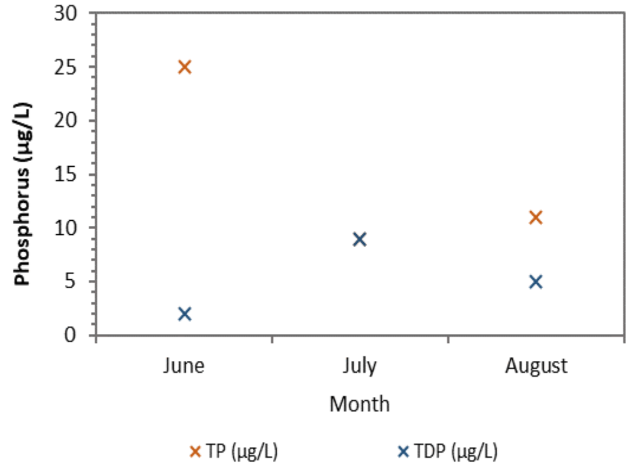

Figure 6d: Lake Windermere South Station Total and Total Dissolved Phosphorus (µg/L) – 2015. TP and TDP levels in July are identical and overlapping in the graph.

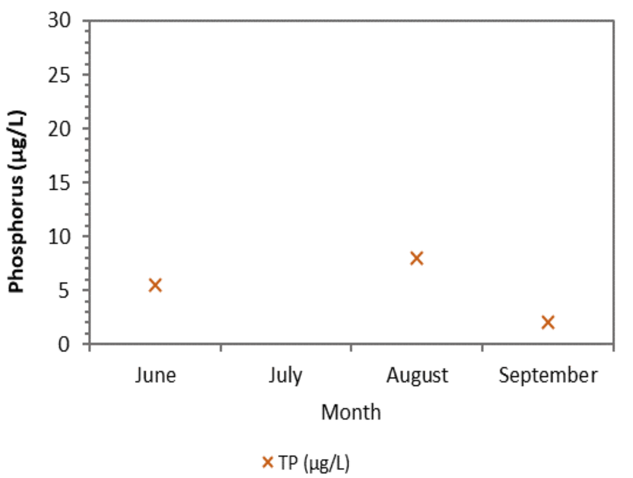

Figure 6e: Lake Windermere South Station Total Phosphorus (µg/L) – 2016.

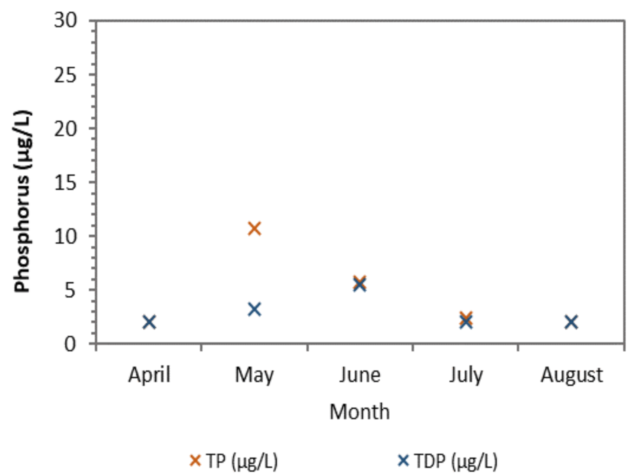

Figure 6f: Lake Windermere South Station Total and Total Dissolved Phosphorus (µg/L) – 2018. TP and TDP levels in April and August are identical and overlapping in the graph.

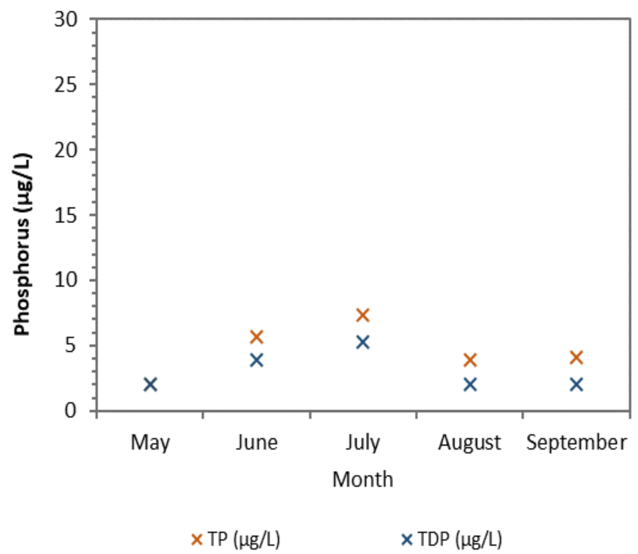

Figure 6g: Lake Windermere South Station Total and Total Dissolved Phosphorus (µg/L) – 2019. TP and TDP levels in May are identical and overlapping in the graph.

Figure 6 a-g: Lake Windermere South Station, Total and Total Dissolved Phosphorus (µg/L) 2011-2019.

There are no data for 2017 and only one sample for 2013, which was taken in September.

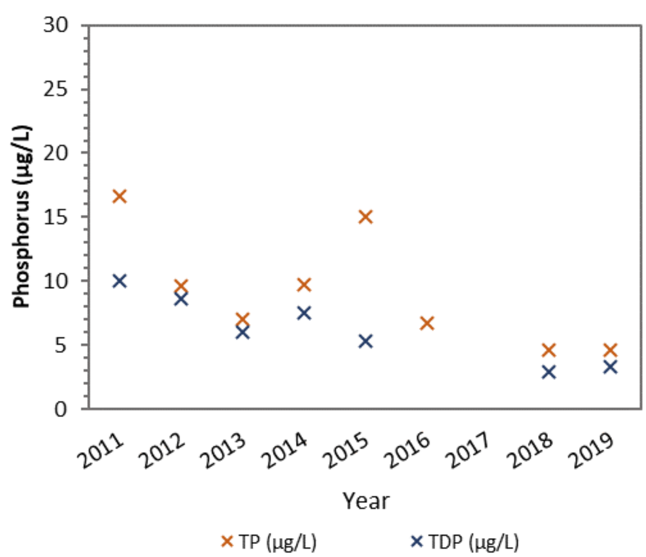

Figure 7: Lake Windermere South Station, Mean Total and Total Dissolved Phosphorus (µg/L) 2011-2019.

There are no data for 2017 and only one sample for 2013, which was taken in September.

Table 7: Lake Windermere, Total Phosphorus (µg/L) 2011-2019 in April or May.

Percentage of Exceedance calculated according to Water Quality Objectives (Neufeld et.al. 2010). Red highlighting indicates an exceedance from WQOs.

		Off Timber Ridge (200052)		Off Windermere Creek (200051)	South Station (E262793)
		TP [a]		TP [a]	TP [a]
		Top (µg/L)	Bottom (µg/L)		
2011	April	n/a	n/a	n/a	n/a
2012	April	3	10	4	2
2013	April	n/a	n/a	n/a	n/a
2014	April	9	43	7	14
2015	May	36	36	n/a	n/a
2016	April	n/a	n/a	n/a	n/a
2017	April	n/a	n/a	n/a	n/a
2018	April	2	2	3.3	2
2019	May	3.5	3.8	5	2
	# Samples	5	5	4	4
	WQO (µg/L) [b]	≤10	≤10	≤10	≤10
	Exceedance (%) [c]	20%	40%	0%	25%

[a] Detection limits were 10 µg/L for 2011 and 2 µg/L for the years thereafter. In order to be able to include all available samples into statistical analysis, measurements with <10 µg/L and <2 µg/L were set to 10 µg/L and 2 µg/L respectively. Although true values might be much below detection limits, this is a conservative approach.

[b] The objective set for Windermere Lake is a maximum of 10 µg/L Total Phosphorus, based on top (30 cm below surface) and bottom (1 m above bottom) samples taken in spring.

[c] Percentage of exceedance was calculated by determining the number of times the set WQO was exceeded during the period 2011 – 2019. Only April and May samples were included into the calculation, since monitoring should be conducted as soon as possible after ice-off in order to capture Phosphorus loading during winter. The small amount of April and May samples illustrates a weakness in the monitoring program.

[d] Due to the small sampling size, validity and significance of Phosphorus levels through 2011 – 2019 cannot be guaranteed. Sampling in April or May was only conducted in 2012, 2014, 2018 and 2019.

Table 8: Windermere Lake North Mean, Standard Deviation, Maximum, and Minimum Secchi Depth (m) 2006 - 2019.

Years with Secchi Depth measurements on lake bottom have been excluded.

Year	Mean (m)	Std. Dev. (m)	Max (m)	Min (m)	# Samples
2006	4.46	0.90	5.5	3.0	8
2007	4.17	0.63	5.2	3.1	11
2011	4.04	0.54	4.8	3.2	10
2012	3.00	1.10	4.3	1.3	12
2013	4.36	1.00	5.8	2.4	13
2016	5.31	0.58	6.1	4.2	11
2017	4.19	0.94	6.0	2.7	13
2018	4.03	0.82	5.3	2.8	14
2019	5.29	0.67	6.2	3.5	15

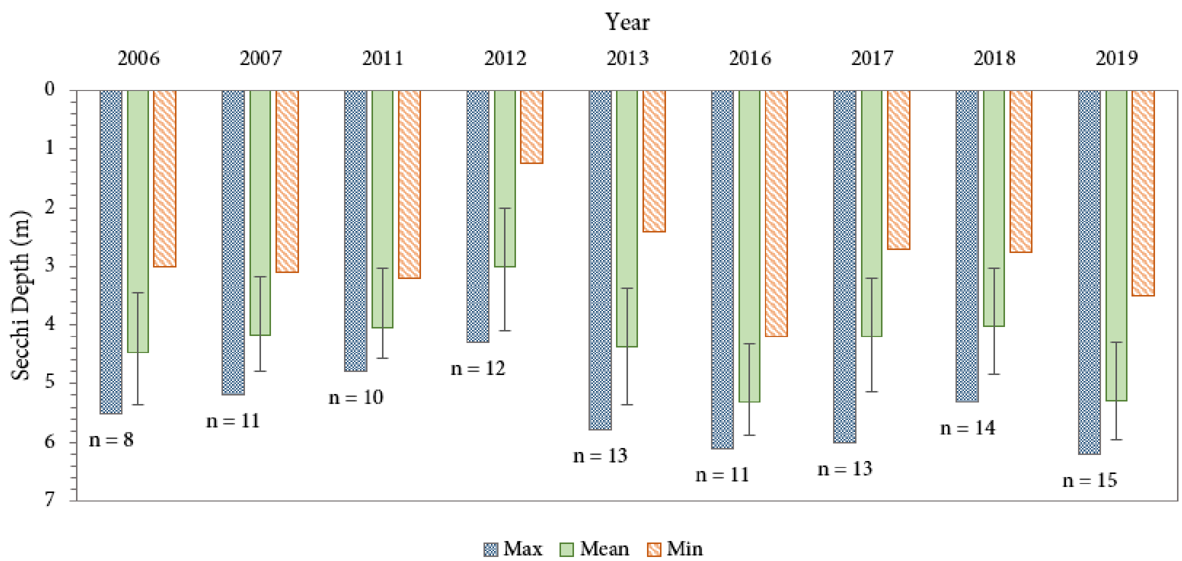

Figure 8: Windermere Lake North Mean, Maximum, and Minimum Secchi Depth (m) 2006-2019.

Years with Secchi Depth measurements on lake bottom have been excluded from statistical analysis. n = number of samples. Margin of error shown as Standard Deviation (I) in Mean Secchi Depth bars.

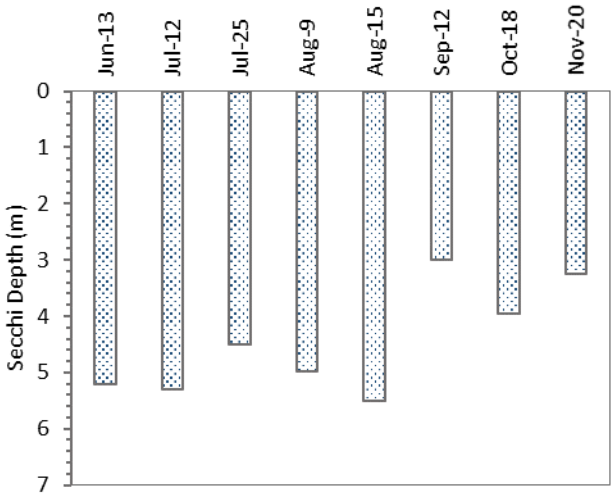

Figure 9a: Windermere Lake North Summer Secchi Depth – 2006

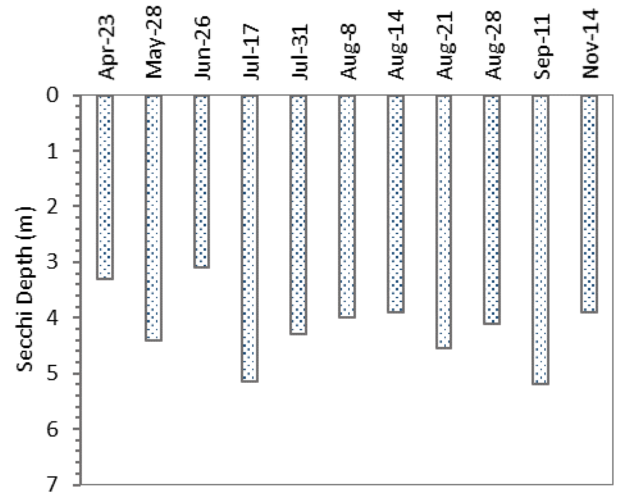

Figure 9b: Windermere Lake North Summer Secchi Depth – 2007

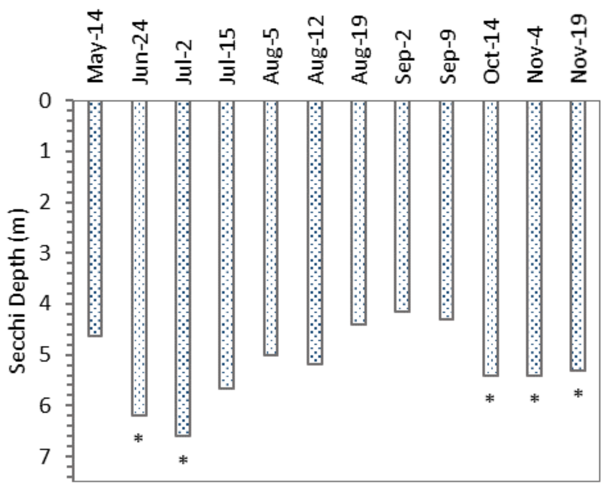

Figure 9c: Windermere Lake North Summer Secchi Depth – 2008.
* indicates disk on lake bottom.

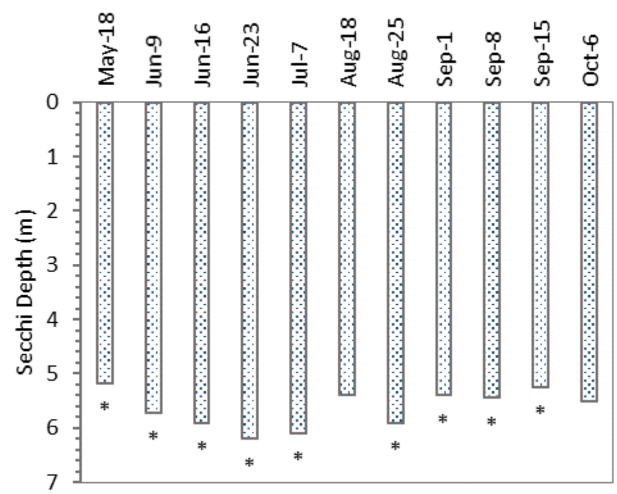

Figure 9d: Windermere Lake North Summer Secchi Depth – 2010.
* indicates disk on lake bottom.

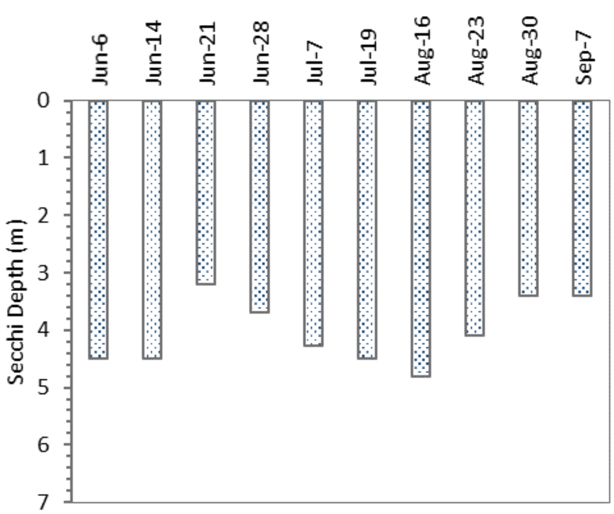

Figure 9e: Windermere Lake North Summer Secchi Depth – 2011

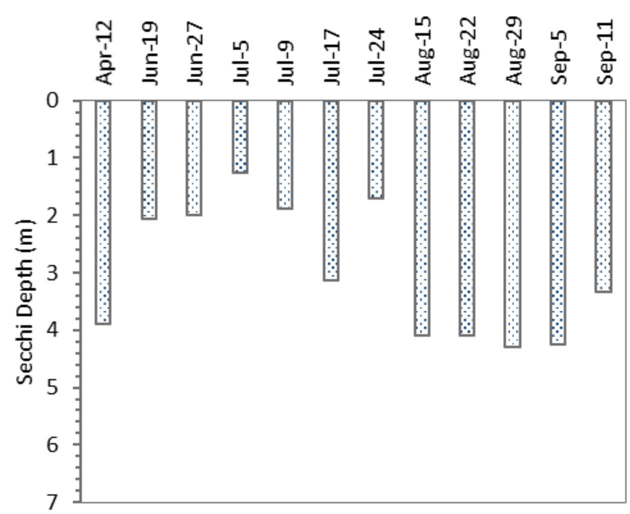

Figure 9f: Windermere Lake North Summer Secchi Depth – 2012

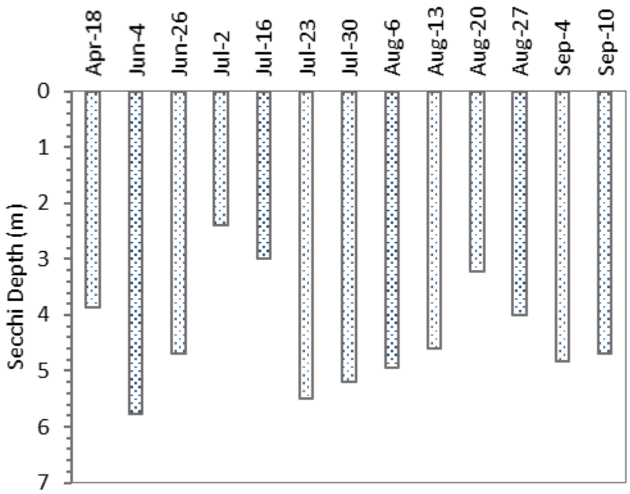

Figure 9g: Windermere Lake North Summer Secchi Depth – 2013

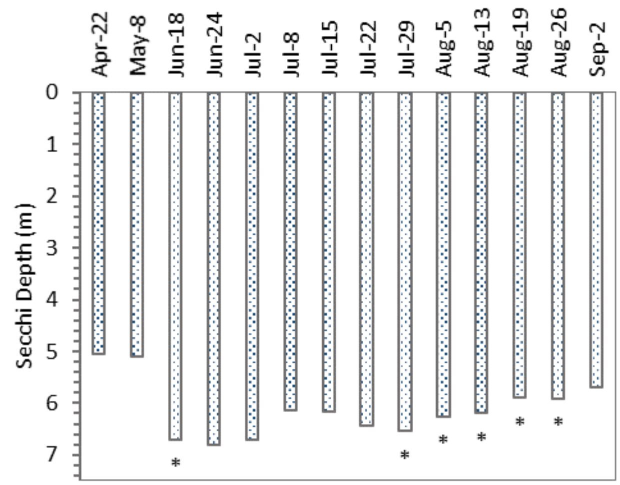

Figure 9h: Windermere Lake North Summer Secchi Depth – 2014.
* indicates disk on lake bottom.

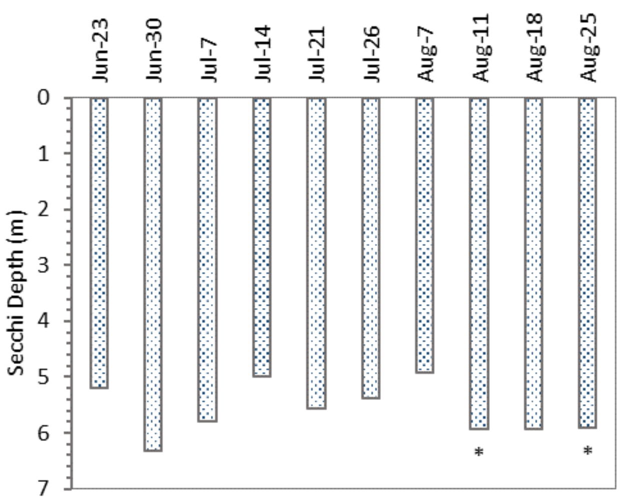

Figure 9i: Windermere Lake North Summer Secchi Depth – 2015.
* indicates disk on lake bottom.

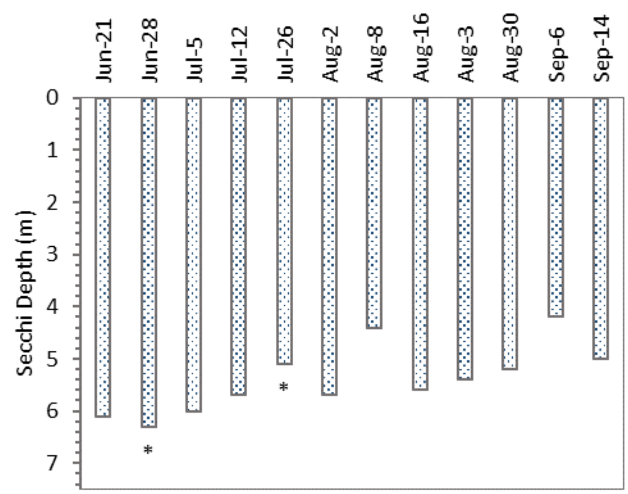

Figure 9j: Windermere Lake North Summer Secchi Depth – 2016.
* indicates disk on lake bottom.

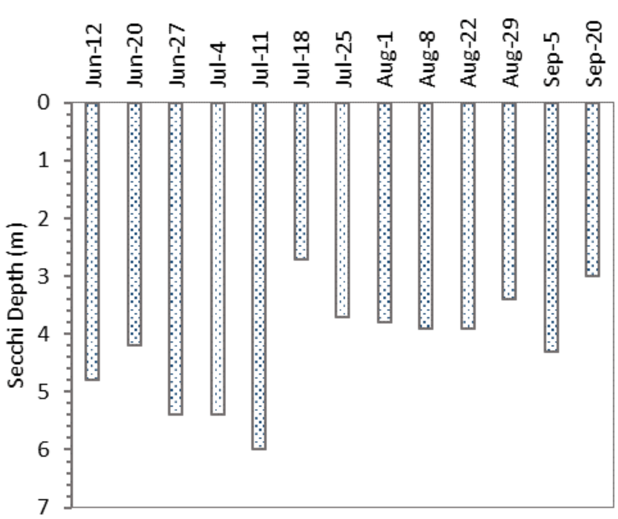

Figure 9k: Windermere Lake North Summer Secchi Depth – 2017

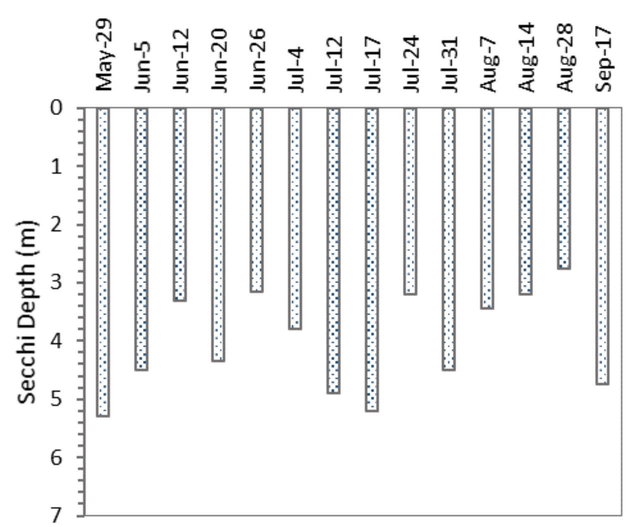

Figure 9l: Windermere Lake North Summer Secchi Depth – 2018

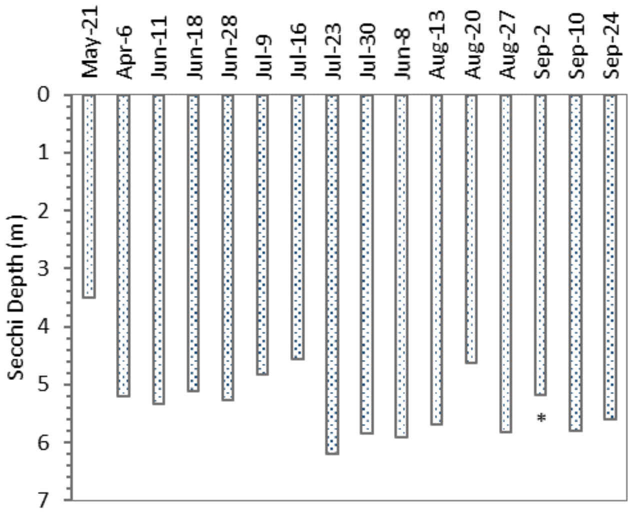

Figure 9m: Windermere Lake North Summer Secchi Depth – 2019.
* indicates disk on lake bottom.

Figure 9 a-m: Windermere Lake North, Summer Secchi Depth 2006-2019.

Table 9: Windermere Lake, Temperature (°C) 2010-2019 for all sampling locations.

Percentage of exceedance calculated according to Water Quality Objectives Report (Neufeld et al., 2010)

Location	Month	Av.	Max.	Min.	95th Percentile	Std. Dev.	# Samples	WQO[a]	Percentage Exceedance
		°C	°C	°C	°C	°C		°C	
Off Timber Ridge	June	17.5	22.5	14.0	20.1	1.9	56	20	0 %
	July	20.5	23.3	15.5	22.8	1.6	74	25	0 %
	August	20.7	22.4	18.5	22.1	1.1	72	23	0 %
Off Windermere Creek	June	17.3	22.5	13.0	20.3	2.1	29	20	0 %
	July	20.4	23.6	15.0	22.5	1.7	38	25	0 %
	August	19.9	22.6	2.9	22.1	3.1	37	23	0 %
South Station	June	15.8	21.9	11.3	20.3	2.7	28	20	0 %
	July	18.6	23.1	10.5	21.9	2.6	37	25	0 %
	August	19.0	22.4	13.2	21.5	2.0	37	23	0 %

[a] WQO for the protection of aquatic life measured in the top (30 cm below surface) and bottom (1 m above bottom) of the water column) should not exceed an average water temperature of 20 °C, 25 °C, and 23 °C, for June, July, and August, respectively. There is no WQO for drinking water supplies since the objective of 15°C will unlikely be met during summer months.

Table 10: Windermere Lake, Turbidity (NTU) 2010-2019 Individual Years.

Percentage of Exceedance calculated according to Water Quality Objectives (Neufeld et.al. 2010). TF = Turbid Flow Period, CF = Clear Flow Period. Red highlighting indicates exceedance from set WQOs. * indicates an insufficient sample size.

Site	Period		WQO[c]	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Exceedance[a]
Off Timber Ridge[b] (200052)	CF	Minimum	n/a	0.84	1.73	1.35	1.02	0.99	0.94	1.27	1.21	1.66	0.59	n/a
		Maximum	≤ 5	1.93	4.46	2.66	4.52	1.35	1.16	1.64	2.17	1.75	0.99	0%
		Average	≤ 1	1.31	3.05	2.12	2.21	1.16	1.03	1.43	1.51	1.71	0.78	90%
		Std. Dev.	n/a	0.42	0.91	0.47	1.20	0.13	0.09	0.12	0.39	0.05	0.13	n/a
		# Samples[d]	5	12	10	10	10	8	6	10	8	2*	10	
	TF	# Samples[d]	5	4*	12	16	18	20	16	14	20	23	22	
		95th Percentile	5	0.89	2.56	9.07	9.58	1.08	1.29	1.09	2.60	1.60	1.71	20%
Off Windermere Creek (200051)	CF	Minimum	n/a	0.78	1.36	2.43	0.60	0.71	0.54	0.84	1.60	1.22	0.62	n/a
		Maximum	≤ 5	1.23	6.36	3.66	2.03	1.24	0.99	1.04	2.30	1.41	0.91	10%
		Average	≤ 1	0.96	3.21	2.84	1.39	0.95	0.80	0.92	1.90	1.32	0.75	50%
		Std. Dev.	n/a	0.16	1.76	0.48	0.52	0.22	0.19	0.07	0.25	0.09	0.10	n/a
		# Samples[d]	5	5	5	4*	4*	3*	3*	5	4*	2*	5	
	TF	# Samples[d]	5	3*	6	8	9	9	8	7	10	12	11	
		95th Percentile	5	0.90	8.24	36.08	16.52	2.25	1.08	0.79	2.94	2.47	1.87	30%
South Station (E262793)	CF	Minimum	n/a	0.66	0.96	0.92	0.55	0.88	0.74	0.83	0.73	0.60	0.66	n/a
		Maximum	≤ 5	0.94	3.52	3.91	3.11	4.11	1.66	1.16	1.11	2.37	1.08	0%
		Average	≤ 1	0.79	1.62	1.66	1.56	1.84	1.09	1.02	0.92	1.49	0.83	70%
		Std. Dev.	n/a	0.11	0.96	1.13	1.01	1.32	0.40	0.14	0.15	0.89	0.16	n/a
		# Samples[d]	5	4*	5	5	4	4	3*	5	4	2*	5	
	TF	# Samples[d]	5	3*	7	8	8	9	8	7	10	12	11	
		95th Percentile	5	3.36	12.05	44.23	42.86	9.25	2.03	1.91	16.71	6.26	5.36	70%

See next page for footnotes to Table 10

[a] Exceedance was determined by calculating the percentage of times the WQOs were exceeded over the years from 2010 to 2019

[b] Values calculated by taking the mean of a top (30 cm below surface) and bottom (1 m above bottom) sample.

[c] Mean turbidity (based on a minimum of five weekly samples collected within a 30-day period) during the clear-flow period should be ≤ 1 NTU. Maximum turbidity at any time during the clear-flow period should be ≤ 5 NTU. The 95th percentile turbidity during the turbid-flow period (May 1 through Aug 15) should not exceed 5 NTU (based on a minimum of five weekly samples collected in a 30-day period).

[d] For several years, the required minimum of five weekly samples collected within a 30-day period is not provided. This applies to the following years for the clear-flow period: 2012, 2013, 2014, 2015, 2017, 2018 for Off Windermere Creek (200051), 2018 for Off Timber Ridge (200052) and 2010, 2015 and 2018 for South Station (E262793), and to the year 2010 for the turbid-flow period at all sampling locations. Insufficient sampling sizes are indicated with an asterisk (*).

4.3 Discussion

The following discussion of the water quality parameters focuses on compliance with Water Quality Objectives (WQOs). For detailed descriptions of the environmental significance of each of these parameters, the reader is referred to the annual water quality reports by Lake Windermere Ambassadors www.lakeambassadors.ca, in particular the most recent (2019) report.

4.3.1 E. coli

Since 2011, Escherichia coli (E. coli) data has been collected by the Lake Windermere Ambassadors in partnership with the Interior Health Authority (IHA), at multiple public swimming beaches every Monday, from May until September, with the exception of statutory holidays.

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, 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.

Samples are 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, checks compliance with the established Water Quality Objectives for Windermere Lake, and is therefore safe for contact 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) includes:

Geometric Mean Concentration (minimum of five samples taken over 30 days): ≤200 E. coli/100mL
Single Sample Maximum Concentration: ≤400 E. coli/100mL

The BC Ministry of Environment Water Quality Objective for Lake Windermere bathing beaches (Neufeld et al. 2010) is:

Geometric Mean Concentration: <77 CFU/100 mL

An overview of E. coli results from 2011-2019 was presented in Table 4. The swim beach water of Lake Windermere exhibits a relatively high quality, as it has remained below the Health Canada recommendations since 2013, and the BC Ministry of Environment Water Quality Objective for Lake Windermere (Neufeld et al. 2010) since sampling began in 2011.

The first three sampling seasons exhibited one or multiple occurrences, where a single sample exceeded 400 colonies of E. coli/100 mL. 2012 exhibited the highest historical reading with a sample of 5150 colonies of E. coli/100 mL on the West side of James Chabot Provincial Park Beach. Field notes indicated a large quantity of bird fecal matter was present throughout the beach. As of 2014, the geometric mean of results has not exceeded 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 year of 2015 exhibited the lowest recorded single sample of 35 E. coli/100 mL, which has been followed by a minimal annual incline with 2019 reaching a high of 65 E. coli/100 mL.

Noticeable trends over the years display an apparent increase of E. coli towards the end of the summer season. 56% of sampling seasons share the highest single sample during the month of August. As of 2012, no high-record samples have been recorded in the months of May or June. Another discernible trend shows 56% of highest single samples having been recorded on Kinsmen Beach. This particular beach is thought to have the greatest number of beach users and swimmers, throughout the sampling seasons and sees the largest number of visitors per day.

While a slight, yet steady increase in E. coli colonies has been displayed since 2015, the overall general swim beach water quality on Lake Windermere, as it pertains to E. coli presence, has improved since the beginning of data collection in 2011. E. coli continues to remain below the Health Canada recommendations and the BC Ministry of Environment Water Quality Objectives for Lake Windermere (Neufeld et al. 2010).

4.3.2 Dissolved Oxygen

Dissolved Oxygen (DO) is another name for the 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). The capacity for water to hold dissolved oxygen is inversely related to water temperature, meaning, that warmer water holds less oxygen, and cooler water holds more oxygen (Ministry of Environment, 2017a).

The Ministry of Environment recommends that DO should never drop below an instantaneous minimum of 5 mg/L, and the guideline for an average of five samples taken over a 30-day period is 8 mg/L (Neufeld et al., 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 et al., 2010).

Dissolved oxygen did not exceed the Water Quality Objective (WQO) during the entire 2010-2019 period as illustrated in Tables 5 and 6. The WQOs are the same as the water quality guideline for the protection of aquatic life, therefore, the lake exhibits good oxygen levels for fish and other aquatic species.

4.3.3 Phosphorus

Phosphorus (P) is a nutrient 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 (Nordin, 1985).

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 phosphorus can be limiting to the growth of aquatic life. The Ministry of Environment Water Quality Objective for Total Phosphorus in Lake Windermere is that TP not exceed a concentration of 10 µg/L in order to protect drinking water sources and aquatic life (Neufeld et al., 2010).

Over the period 2010-2019, TP exceedances of the WQO ranged from 0% (i.e. no exceedances) at the Off Windermere Cr. sampling site to 40% at the Off Timber Ridge site (Table 7). Following the recommendations of Neufeld et.al. (2010), monitoring to check for attainment of the TP objective should take place as soon as possible after ice-off to determine if any internal phosphorus is occurring over winter. As can be seen in Table 7, there was very limited sampling done at this time of year over the period 2010-2019, making interpretation of this parameter difficult. This has been a weakness in the monitoring program.[3]

Exceedances of the WQO for phosphorus are evident in Table 7 in 2014 and 2015. While the WQO is for Total Phosphorus (TP), Total Dissolved Phosphorus (TDP) is reviewed as a check on potential TP anomalies. The TDP analysis is the same as the TP except the water is filtered through a 0.45-micron filter. Sometimes TP can be elevated but this is not reflected in the TDP and this is an indication that the elevated TP may be the result of sediment or particulate in the sample.

In 2014, TP exceeded the WQO of 10 µg/L in the bottom sample at the Off Timber Ridge site, and at the South Station. Close examination of the Off Timber Ridge data reveals that the top water does not exceed the WQO at 9 µg/L and only the bottom water is elevated. The TDP supports the TP result with 5 µg/L at the top and 41 µg/L at the bottom. It is not known why the TDP is elevated in the bottom water. If the cause was release of phosphorus from sediments under winter conditions, dissolved orthophosphate would be a helpful supplemental analysis in the spring. Dissolved orthophosphate is the form of phosphorus released from sediments under ice conditions and should be added to the spring sampling.

It is possible that bottom sediments were disturbed during sampling causing an elevation in the sample and since there was no Quality Assurance/Quality Control (QA/QC) program in effect, contamination cannot be ruled out. Care should be taken during sampling to ensure bottom sediments are not disturbed and that the sampling device is kept one metre above the bottom.

The exceedance at the South Site was not large at 14 µg/L given the forgoing considerations about QA/QC and bottom sediment.

As discussed above, also evident from Table 7 is that sampling was missed in the spring after ice off making it difficult to assess compliance with the WQO over the periods 2010-2019. There are many

[3] This has been addressed by LWA in 2020, and in addition ice-off records are now being kept.

years without data and in recent years (2018 and 2019) there were no exceedances. Further monitoring i.e., another 3 years should be done to adequately assess TP compliance with WQOs.

Figures 2 a-g show the relationship between TP and TDP by month for each year at the North (Off Timber Ridge) sampling site. Figure 3 shows average summer TP and TDP levels. For the majority of years with complete data, TDP generally makes up a large portion of the TP. This is also true for the Off Windermere Creek. sampling site (Figures 4 a-g and Figure 5), and the South sampling site (Figures 6 a-g and Figure 7). Future monitoring should include TDP to improve the understanding of the relationship between TP and TDP.

TP levels in 2018 and 2019 are consistent with Windermere Lake being in the oligotrophic category

4.3.4 Secchi Transparency

Secchi transparency measures the depth of light penetration into the water and the depth to which photosynthesis will occur is approximately two times the Secchi depth. It is affected by sediments from erosion and the density of algae present in the water. There is no Water Quality Objective set for this parameter for Windermere Lake.

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 over the long term can provide information about trends in water clarity. Secchi generally follows an inverse pattern to turbidity i.e., when turbidity is high, Secchi depth is low because it is difficult to see deep into the water. Although there is no Water Quality Objective set for Secchi Depth, is a valuable tool widely used in lake assessment. Following the WQO for turbidity, it is expected that Secchi Depth will be lower in the spring during freshet, and higher in the summer when the inflowing Columbia River is less turbid. During this period, algae growth is likely to be the primary determinant of clarity.

Seasonal patterns and long-term trends with Secchi can be valuable for assessment of lake conditions and as an indication as to whether water quality may be changing through time. Only the North site is valuable as it is deep enough that the disk is usually not on the bottom. In both Table 8 and Figure 8 Secchi depth measurements that were on the lake bottom have been excluded from the calculation of the basic statistics of minimum, mean and maximum readings, as well as standard deviation.

Secchi data for each year is presented in Figure 9a to m. Asterisks indicate readings where the disk was on the bottom of the lake and could still be seen. These are not valid readings because the reader has no way of knowing how deep the disk would have been visible if it were not on the bottom.

Table 8 shows that the mean summer reading varied from 3.00m to 5.31m over the period 2006 to 2019[4]. Readings prior to August likely reflect sediment loading from the Columbia River as the turbid

[4] Secchi was assessed over a longer time frame than other parameters because it was not part of the assessment for the development of the Water Quality Objectives which reviewed the other parameters up to 2010

flow period is generally from May 1 to August 15 as discussed in Neufeld et. al. (2010). Later summer and early fall readings likely reflect algae growth as this is the clear flow period.

It is evident from this data that there is not a large variation in the clarity of the water over the time frame of 2006-2019. For example, while the lowest mean reading is 1.3 m, excluding this value shows a variation of 2.4 to 4.2 m in minimum readings. Maximum Secchi readings varied from 4.3 to 6.1 m. It is noteworthy that the very low readings occurred in 2012 and 2013 and this coincided with unusually high turbidity as reported in the annual water quality reports by Lake Windermere Ambassadors. This will be discussed further in S 4.3.6 on Turbidity.

Furthermore, the Secchi data has not been validated for each participant with side-by-side readings therefore it is unclear whether or not the low reading is anomalous. There is a large potential for error if these readings are not done in a standard way under standard conditions. The Quality Assurance Program should include Secchi by conducting and documenting side-by-side readings.

Further visualization of Secchi data can be seen in Figure 8 where there is no evidence of either an increasing or decreasing trend in water clarity, rather variation from year to year is evident. This is likely due to environmental variability as a result of year to year climatic variability affecting flow and weather patterns. If anything, there is a slight increase in clarity from 2013 to 2019. Average Secchi readings from 2011-2019 have always have been greater than 4m, placing Windermere Lake in the oligotrophic range. Oligotrophic lakes are typically clear lakes with low nutrients (Nordin, 1985).

4.3.5 Temperature

Water temperature is critically important to lake health as it has direct impacts on water chemistry (e.g., Dissolved Oxygen, Conductivity, water density) and influences the rate of chemical and biological reactions. This affects the ability for aquatic life to grow, survive, and reproduce in an environment (*Lake Windermere Community Based Water Quality Monitoring Program Annual Reports 2011-2019).*

Due to the shallow depth of Lake Windermere, it has a naturally elevated temperature relative to other freshwater lakes (Neufeld et al., 2010). Warm and clear water makes Lake Windermere a desirable lake for human recreation. However, average summer water temperatures have historically exceeded the BC Ministry of Environment's (MOE) Temperature Guidelines for the protection of freshwater aquatic life (Neufeld et al., 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 et al., 2010). These guidelines are based on the MOE recommendation that lake water temperatures should remain within ± 1°C of natural conditions.

Table 9 shows that there were no exceedances of the WQO for temperature from 2010-2019. Given climate change predictions (Section 6.3) continued monitoring of water temperature is important according to the schedule outlined in the WQO document.

4.3.6 Turbidity

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, such as when they have high suspended sediment, 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). Algae growth is well documented to increase turbidity as well. Good field notes as to what may be causing low clarity or high turbidity are essential for later data interpretation.

The turbidity objectives for Lake Windermere are set to protect recreational water quality and aquatic life (Neufeld et al, 2010). During freshet (May 1 to August 15), in what is known as the turbid flow period, the 95th 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 to 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 et al, 2010).

Turbidity results for the period 2010-2019 are reported in Table 10. Table 10 shows that in the clear flow period, in all years except 2019, the WQO of an average turbidity of $\leq$ 1 NTU was exceeded at all sites, with a rate of exceedance of 90% at the Off Timber Ridge site, 50% Off Windermere Cr., and 70% at the South site. The maximum turbidity of $\leq$ 5 NTU was only exceeded in one year (2011) at 6.36 NTU.

The turbid flow period had exceedances of the 5 NTU 95thperecentile 70% of the years at the South site, 30% at the Off Windermere site, and was never exceeded at the Off Timber Ridge site. This is evidence of turbid flow from the Columbia R. Influencing the inlet end (South site), with less influence toward the outlet end (Off Timber Ridge), no doubt due to settling. LWA water quality reports www.lakeambassadors.ca have noted this effect as well as some influence from Windermere Cr. closer to the centre of the lake. This cannot be corroborated by Secchi readings because the South and central (Off Windermere) sites are not deep enough to obtain good Secchi readings.

The Off Timber Ridge site has the most consistent data and usually an adequate number of samples (Table 10). For several years, the required minimum of five weekly samples collected within a 30-day period are not available at the other sites. This applies to the following years for the clear-flow period: 2012, 2013, 2014, 2015, 2017, and 2018 for Off Windermere Creek (200051), 2018 for Off Timber Ridge (200052) and 2010, 2015 and 2018 for South Station (E262793), and to the year 2010 for the turbid-flow period at all sampling locations.

It is noteworthy that at the Off Timber Ridge site in 2019 there were no exceedances of average turbidity at any of the sites and that 2019 was a relatively clear year as indicated by Secchi depth readings. The annual water quality reports by LWA often note excessive rain events (2013, 2018) and landslides (Windermere Cr. in 2011, 2012). Results cannot be verified without a QA/QC program in effect.

4.4 BC Long Term Lake Trends Program

The Long-Term Lake Trends program provides a strategic and coordinated approach to monitoring water quality in lakes across B.C. Following is a description of the BC Long Term Lake Trends Program taken from the ENV website https://www2.gov.bc.ca/gov/content/environment/research-monitoring-reporting/monitoring/lake-monitoring

Lakes are complex ecosystems that are sensitive to a wide range of stressors that operate at provincial, regional, and local scales. Lakes are sentinels of environmental change, and long-term monitoring of water quality trends in B.C. lakes allows for inter-annual variation to be distinguished from directional *change. Understanding these trends can provide insights into the causes of change, and support effective watershed management.*

Program Goals

- *To determine current water quality status and long-term trends of the physical, chemical, and biological properties of B.C. lakes.*
- *To assess lake water quality data in relation to ecosystem change, including watershed stressors and climate change.*
- *To evaluate lake water quality to Water Quality Guidelines and Objectives for key parameters and determine lake trophic status.*
- *To provide accessible, accurate and timely water quality data for B.C. lakes to inform decision makers within government, industry, research institutions, and the public.*
- *To develop partnerships with stewardship groups and other programs such as B.C. Lake Stewardship Society, to provide a strategic and co-ordinated approach to provincial lake sampling.*

It is important to note that Windermere Lake is part of this Ministry of Environment and Climate Change Strategy (ENV) long term program. Trends in lake quality can only be determined by consistent long-term monitoring and this is the only way to discern inter-annual variation from other factors such as land use impacts or climate change. LWA's programs can provide important supplemental information to the provincial program e.g., long term trends in clarity through frequent Secchi depth measurements. The Long-Term Trends program samples the lakes twice per year.

4.5 Conclusions and Recommendations regarding the Monitoring Program

1. The LWA program of training citizen scientists is exemplary and serves as an excellent example of what can be accomplished with volunteer, citizen-based monitoring programs.
2. Compliance with Water Quality Objectives *per se* cannot be adequately checked without carrying out the full program at the frequency outlined in the WQO document (Neufeld et.al. 2010; Tables 2 and 3 of this report). Three years of compliance monitoring needs to be conducted, following the recommendations in the 2010 WQO report.
3. The overall general swimming beach water quality on Lake Windermere, as it pertains to E. coli presence continues to remain below the Health Canada recommendations and the BC Ministry of Environment Water Quality Objectives for Lake Windermere (Neufeld et al. 2010).
4. Dissolved oxygen levels are in compliance with established Water Quality Objectives and guidelines for the protection of aquatic life.
5. Total Phosphorus (TP) should be monitored within 2 weeks of ice-out as per the WQO report. An additional 3 years of monitoring of compliance with WQOs is recommended to address gaps in data as evident in Table 7. Monitoring for TP should continue throughout the summer as per monitoring recommendations of the Technical Assessment for the review of WQOs (Neufeld et.al.,2010).
6. Total Dissolved Phosphorus (TDP) should continue to be monitored to improve the understanding of the relationship between TP and TDP. This could be supplemented by a late winter sampling under ice conditions at surface and 1 m above the bottom. Dissolved orthophosphate is the form of phosphorus released from sediments under ice conditions and

should be added to the early spring sampling to better answer the question about this raised in the 2010 WQO Technical Assessment.

7. There is no evidence of changing water clarity (Secchi transparency) from 2006-2019.
8. Each citizen scientist or staff person doing Secchi readings should have a side-by-side reading done initially and at least once more during the season. This component of the quality assurance program should be documented each year to assist with data validation for all parameters. Long term Secchi is a valuable lake assessment tool if done properly and consistently.
9. Total Organic Carbon, Dissolved Sulphate, Total Nitrogen, Nitrate, Nitrite, and Chloride should be monitored as per Table 3.
10. Verification of field turbidity readings should be part of the QA/QC program.
11. LWA should approach the local ENV office and request assistance with auditing of field instruments by comparing the instruments of the two organizations.
12. LWA should approach the Headquarters of the Ministry of Environment and Climate Change Strategy (ENV) for help with lab funds associated with additional parameters, given LWA's active involvement with, and funding of monitoring compliance with Water Quality Objectives established by the Ministry.
13. It is important to monitor trends in Windermere Lake's water quality. Long term trends in Windermere Lake are being monitored by The Ministry of Environment and Climate Change Strategy. LWA's citizen-based program provides valuable supplemental data to this program as well as monitors compliance with established Water Quality Objectives.
14. It is recommended that LWA continue the practice of peer review of annual reports and build in funding for this purpose. This will result in a high degree of credibility going forward for the LWA water quality program.

5.0 Water Quality and Land Use in the Windermere Lake Watershed

5.1 Non-point Source Pollution

The United States Environmental Protection Agency (EPA) defines point source pollution as any contaminant that enters the environment from an easily identified and confined place e.g. a pipe from a wastewater treatment plant. Non-point source (NPS) pollution is the opposite of point-source pollution, with pollutants released in a wide area. NPS pollution is caused by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries away natural and human-made pollutants from a variety of diffuse sources, finally depositing them into lakes, rivers, wetlands, coastal waters and ground waters https://www.epa.gov/nps/basic-information-about-non-point-source-nps-pollution.

The Technical Assessment for the WQO revision in 2010 indicated NPS pollution may be a problem in certain areas of the Windermere Lake watershed (Neufeld et.al., 2010). The 2010 Technical Assessment also cited a 2004 report by Dobson Engineering Ltd. that noted dead mountain pine beetle stands will have similar impacts to hydrological processes as clear cuts, with increased peak flows and water yield, accelerated soil erosion, landslides, channel destabilization, and nutrient losses.

Little is known about sources of NPS in the watershed, and what impact these may be having on either tributary or lake water quality and habitat. NPS pollution is very difficult to assess simply due to the diffuse nature of the sources i.e., much different to assess than a discharge directly from a pipe from a treatment plant to a watercourse.

Neufeld et.al. (2010) also noted that Windermere Cr. had had the greatest degree of logging. The degree of logging, observations by LWA staff (Section 5.3), and that Windermere Cr. has the most significant fisheries value of the tributaries (Neufeld et.al., 2010) makes this stream a priority for non-point source assessment.

5.2 Land Uses

The land uses occurring in the Windermere Lake watershed are indicated in the following Figure 10 and Table 11 prepared by the Ministry of Forests, Lands, Natural Resource Operations and Rural Development.

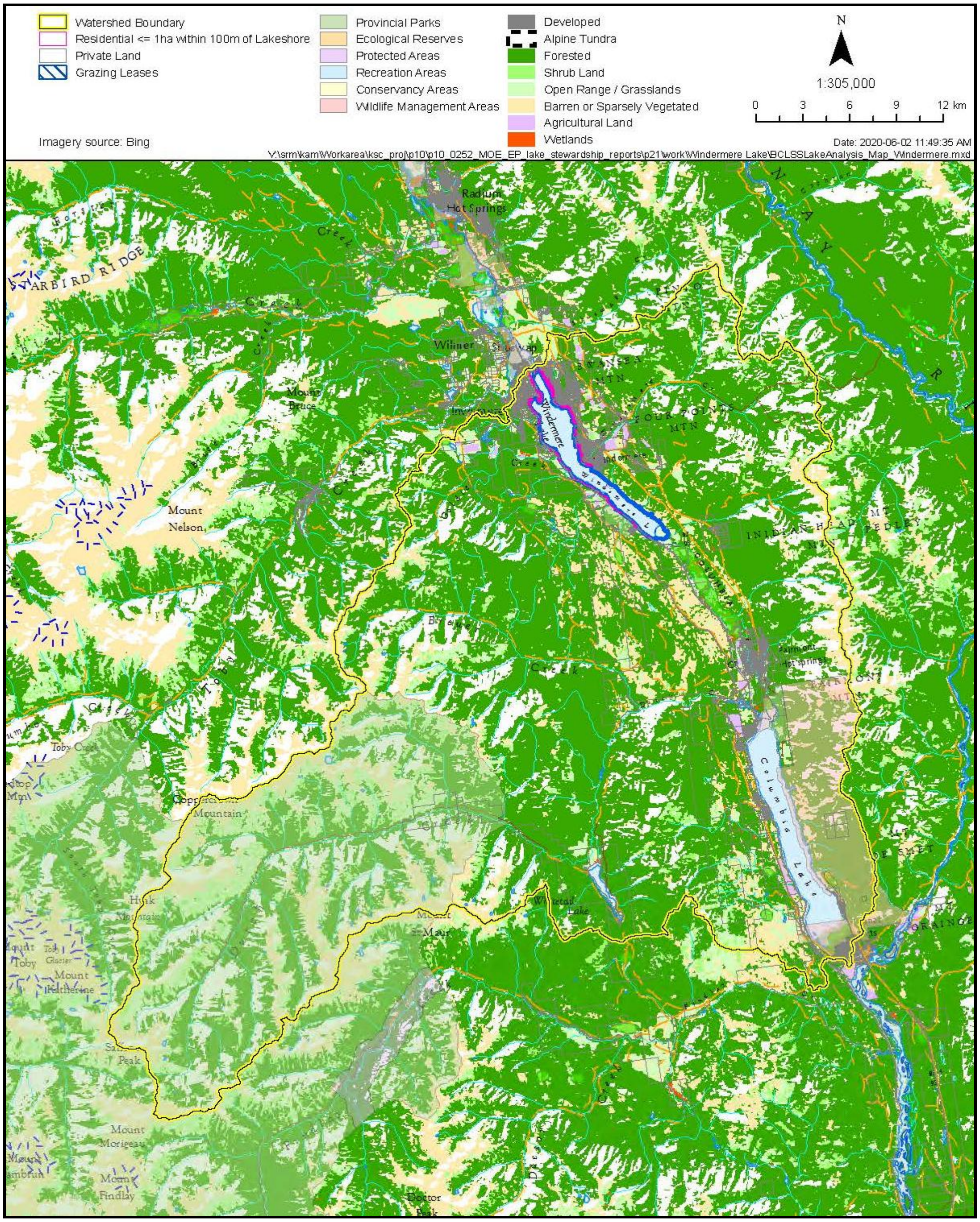

Figure 10: Land Use Map of Lake Windermere Watershed

Table 11: Land Use in the Windermere Lake Watershed by Area (ha).

	Area (ha)				
Land Class	**Total**	**Parks**	**Grazing Leases**	**Private Land**	**Lakeshore Residential**
Agricultural Land	1164.42	-	-	1149.07	-
Barren/Sparsely Vegetated	26365.67	12846.39	-	8239.02	9.56
Developed	2334.68	26.70	-	1834.03	67.84
FC Openings	13775.88	3043.70	-	1925.20	-
Forested	99436.38	26578.68	-	32495.17	22.41
Open Range/Grasslands	14830.56	8497.71	-	3172.50	1.64
Shrub Land	6283.10	4252.49	-	605.62	0.06
Unknown	25511.12	14527.53	-	513.26	0.07
Water	4885.08	198.37	-	332.60	7.41
Wetlands	369.82	4.02	-	246.39	-
Total	194956.71	69975.60	-	50512.86	109.00

As can be seen in Table 11, forestry is the dominant land use. Open range, agriculture, and lakeshore residential are evident, albeit much smaller than forest land. The map and table provide insight into dominant land uses in the watershed which could potentially impact water quality and combined with a survey of land uses can assist with a determination as to whether further assessment is warranted.

5.3 Tributary Survey

Lake Windermere Ambassadors staff conducted a survey of land use practices along the main tributary streams to provide information to assist with an assessment of Non-point source pollution. As described in S.5.1, nonpoint-source pollution is the release of pollutants from various sources including land use practices over a wide area. This is further discussed in Section 6.4.

The Lake Windermere watershed is made up of approximately 194,956.hectares of land. This land sees a variety of uses, some of which would be considered non-point source areas of focus. Non-point source pollution is categorized as the general results of urban, residential and agricultural runoff, wetland areas, forestry practices, boating and marinas, infrastructure, weather events, drainage or seepage and environmental alteration. The impacts of non-point source pollution can range from minimal to astronomical and for Lake Windermere, a water body that has seen a large variety of land use and an accelerated increase in development; the need for a non-point source assessment is evident.

As of 2020, the water itself, takes up 2.5% of the Lake Windermere watershed. 51% of the surrounding land is forested, over 13% is barren or sparsely vegetated, and a combined 17.2% is made up of forest cover openings (clearcuts), shrub land and/or open range grasslands. 1.2% of the watershed is developed, 0.6% is agricultural land, and 0.2% consists of wetlands (Section 5.1). In order to assess the need for a for a non-point source assessment, observations were taken and interpreted through a variety of approaches.

A preliminary survey of potential non-point sources began through the use of Google Earth Pro.

Areas of focus were highlighted and described to identify the potential non-point source concerns, however, all areas of focus are potential sources of non-point source pollution and all will require further investigation. Certain areas that stood out during the preliminary survey were residential properties and developments, agricultural land, which may include greenhouses, nurseries, ranches and hobby farms. Recreational practices, including golf courses and resorts were highlighted; highways, bridges and other urban developments have potential cause for concern as well as marinas, boating practices and gas docks. Urban structures like septic and sewer systems, storm drains and ponds were highlighted as well.

All of these potential areas of focus have associated concerns that could potentially lead to non-point source pollution. These concerns include the proximity to Lake Windermere and surrounding tributaries, the use of fertilizer, herbicides and pesticides, bacteria and nutrient runoff from pet and livestock waste, oil, grease and toxic chemicals from recreational practices and urban runoff, heavy metals from motor vehicles and finally, sediment transport.

Following the identification of potential sources and associated concerns, the distance between sources to adjacent sub-basins and Lake Windermere itself were measured. Once the proximity of sources was recorded, internet research was performed to identify relevant pieces of information related to the historical and present-day practices of potential non-point sources. This could include the number of surrounding golf courses and their watering schedules, the amount of greenhouse space utilized by commercial farms, or the proximity of hobby farms to the nearest sub-basin. Following virtual research, a driving and walking tour on or near multiple sub-basins and surrounding areas took place to identify additional potential non-point sources, their proximity to the creek and the physical terrain with which they remain on. This will be discussed further in Section 6.4.

6.0 Long Term Management Concerns for Windermere Lake

Long term management concerns need to be viewed in the context of whether the lake water quality has changed and whether it is expected to change in the future.

6.1 Historical Water Quality

The results of a sediment core below are taken from BCLSS (2008).

The Windermere Lake monitoring program was initiated well after local land development and possible impacts to the lake began. While this program can accurately document current lake water quality, it cannot reveal historical baseline conditions or long-term water quality trends. Here lies the value in coring lake sediments. Past changes in water quality can be inferred by studying the annual deposition of algal cells (in this case diatoms) on the lake bottom. Diatoms are a type of algae commonly found in lake environments. Their glass-like shell (known as a frustule) is composed of silicon. This frustule leaves a permanent record of diatom history in lake bottoms.

The deepest point (north site) in Windermere Lake was cored on July 23, 1998 by Ministry of Environment, Lands and Parks staff. The 35 cm core was separated into 5 mm sections and analyzed by Dr. Brian Cumming of Queen’s University. His report is available upon request.

Historical changes in relative diatom abundance were measured directly by microscopy. Knowing the age of various core sections and the phosphorus preferences of the specific diatom in each section, historical changes in lake phosphorus concentrations, chlorophyll-a, and water clarity can be estimated.

The Windermere Lake sediments were dominated by benthic (those living on the surface of the sediments) diatom species with some epiphytic forms (those living on aquatic plants). The benthic component in Windermere Lake is much larger compared to the phytoplankton component due to light penetration to the bottom throughout the entire lake.

Cumming infers historical water quality utilizing a database comprised of over 200 B.C. lakes that are generally deeper, with minor benthic components (McDonald, 2000). Therefore, reconstruction of the diatom community from sediment coring is a less useful tool for determining historic water quality in Windermere Lake than in deeper lakes.

The sediment core indicates that Windermere Lake has undergone a change in species composition over the last several hundred years. Algae commonly associated with clean water and low nutrient levels were displaced by forms that may cause taste and odour problems in water supplies.

Cumming (1999) reported minor changes in the diatom community structure starting around 1950 as evidenced by the loss of a few diatom species and the appearance of others. However, the species identified are not well represented in the B.C. lakes database used to infer changes in phosphorus. Therefore, predictions of change in the total phosphorus in Windermere Lake are considered preliminary.

A comparison of pre-settlement sediment loading rates with current rates can indicate the impact of human development in an area. The sediment core analysis suggests sedimentation rates increased around 1920, peaking in the late 1940’s, then returned to historic levels from 1960 to present. Land development in the Windermere Lake watershed increased between 1920 and 1960 but has greatly accelerated since 1970. Since the increased sedimentation rate does not coincide with the population increase around Windermere Lake, Cumming (1999) suggested land disturbances associate with logging and cattle ranching may have caused the increased sedimentation rate.

In conclusion, although the evidence is not strong, the core suggests subtle changes in the water quality, benthic community composition and sedimentation of Windermere Lake beginning around 1950 which coincides with the time of accelerated settlement in the area.

6.2 Water Quality in 2020

Water quality in Windermere Lake remains relatively good and stable as evidenced by apparent general compliance with established Water Quality Objectives.

While the historical water quality from the sediment core analysis (Section 6.1) indicated subtle changes associated with human development of the watershed, two things are noteworthy. The first is that the core sample was taken over 20 years ago in 1998 and would therefore not reflect potential changes over the past two decades, a period of much development on the lake and watershed, and a time period for which there is water quality data. The second is that the core *did* indicate some changes during earlier time periods.

The Water Quality Assessment Technical Report by Neufeld et.al. (2010) reviewed water quality monitoring data to 2010 and concluded that there had not been any substantial change in water quality as compared to historical data (back to 1985, not to be confused with sediment core data). The large flow through of water from the Columbia River is the primary reason cited for Windermere's ability to assimilate nutrients, thus making the lake less sensitive to change than other lakes with less flushing.

The Water Quality Assessment Technical Report by Neufeld et.al. (2010) noted that while water quality results from the three main stations did not display much variation, it is possible that non-point source pollution may be more evident in near shore areas.

Windermere Lake is oligotrophic as indicated by the Secchi readings from 2010-2019 and the recent total phosphorus levels. There is no indication of a declining trend in water quality.

6.3 Climate Change

As a consequence of land use and human-induced climate change, water resources and aquatic ecosystems like Lake Windermere could potentially change quickly and continue to change as populations grow and land-use intensifies. Human activity like agriculture, industry, residential developments, town sites, infrastructure and recreation among many others, are directly influencing the condition of Lake Windermere and the resources it provides to the surrounding community and environment. These impacts to watersheds can portray themselves through alterations in water quality, distribution of water and the timing of hydrological events. This highlights the need for careful and consistent water quality and quantity monitoring.

According to *Water Monitoring and Climate Change in the Upper Columbia Basin: Summary of Current Status and Opportunities* (Columbia Basin Trust, 2017), seasonal temperatures recorded from the 1900s to present day are climbing steadily. Within the Columbia Basin, the Columbia-Kootenay Headwaters region exhibits some of the lowest winter temperatures and in 1910, the mean average temperatures of winter in the Columbia-Kootenay Headwaters region stood at -10 ^{o}C. As of today, the mean average rests just below -6 ^{o}C. The projected mean average in 2041-2070 is predicted to be around -5 ^{o}C. This is a 5 ^{o}C difference in less than 200 years. Similar to winter, summer temperatures averaged at 13 ^{o}C in 1910 and are now 16 ^{o}C. As of 2041-2070, the average summer temperature is predicted to increase to just below 18 ^{o}C, again, exhibiting a projected 5 ^{o}C increase in average temperature.

An increase in air temperature in this area may result in less precipitation, potentially causing drought and arid conditions, as well as a likely increase in water temperature, which could result in a decrease in dissolved oxygen. This can negatively impact fish, invertebrate and plant populations that depend on the oxygen in their environment.

Regions like the Columbia-Kootenay Headwaters, surrounding Lake Windermere, experience warm, moist summers and cool, dry winters with moderate snowpack at higher elevations. The summer season experiences the highest temperature levels, where winter experiences the highest precipitation levels, closely followed by summer and fall. The headwaters region experiences the most continental climate, showing the largest variation between coldest and warmest seasons (CBT, 2017). Historical data and Global Climate Models utilized by Climate BC state that the average winter precipitation in the Columbia-Kootenay Headwaters region back in 1910, was approximately 180mm. As of today, that average is 200 mm and is predicted to climb to 210 mm as of 2041-2070. Summer precipitation varies greatly from the winter trend. 1910 exhibited an average summer precipitation of 150 mm, dropping

down to 120 mm as of 1930 and going back up to approximately 175 mm in 1980. As of today, summer precipitation rests at roughly 150 mm and is projected to continue declining overtime.
While each hydrological region predicts different outcomes based on climate change, most future climate predictions project increases in annual precipitation and due to increases in annual temperatures, future patterns will likely witness increases in rates of evaporation, decreases in annual snowpack and an onset of earlier spring melts. The river-related consequences of such could result in earlier and heavier peak flow rates and a reduction in low flow rates. The implications of climate change on Lake Windermere are inevitable as the global population grows and land-use continues to intensify.

The need for consistent water quality and quantity monitoring programs throughout the world has never been more important than they are today. However, with the assistance of historical data, present day technology and consistent funding, hydrological patterns and behaviour can be anticipated and planned for in a way that protects the resources and processes, which surrounding environments and communities depend on. The BC Lake Long Term Trends Program should continue on Windermere Lake, supplemented by the LWA water quality program.

6.4 Non-point Source Pollution

Section 5.2 described the survey of potential NPS pollution carried out in 2020 by LWA staff. It is important to note that such a survey only determines possible non-point sources and cannot ascertain impact to water quality from any of these sources. The survey combined with the land use map in Section 5.1 serve to illustrate that there is potential for NPS pollution this should therefore be assessed. This will require an assessment by a professional experienced in NPS assessment.

7.0 Conclusions and Recommendations

Detailed conclusions and recommendations regarding the water quality monitoring program were outlined in Section 4.5. This section contains the overall report conclusions and recommendations.

1. Windermere Lake is oligotrophic as indicated by the Secchi readings from 2010-2019 and the recent Total Phosphorus levels. There is no indication of a declining trend; however further monitoring should be done.
2. Further monitoring is required to adequately check attainment with WQOs and to obtain more information about the relationship between TP, TDP, and Ortho-Phosphorus levels in the lake.
3. Climate change predictions for the Upper Columbia Basin highlight the need for long term trend monitoring as is being conducted by the BC Ministry of Environment and Climate Change Strategy (ENV) and supplemented by LWA's programs.
4. It is 10 years since the Water Quality Objectives (WQOs) have been reviewed by ENV. It is recommended that a request be made in 2020 to ENV for a review of the WQOs to be completed following an additional three years of monitoring. ENV should be approached for funding for completion of the WQO monitoring parameters that have not been able to be addressed by LWA.
5. In 2019, the annual report by LWA on the results of the Community Based Water Quality Monitoring Program was peer reviewed. It is essential that the annual reports receive peer review by a professional qualified in the area of water quality monitoring and assessment. It is recommended that this funding requirement be included in monitoring program budgets.
6. LWA should continue its exemplary programs to protect Windermere Lake as described in Section 2.0.
7. As discussed in Section 5.1 and Section 6.4, a non-point source pollution assessment should be conducted over the entire watershed, with priority being given to Windermere Cr. due to its high fisheries value and potential watershed issues as indicated by watershed surveys and water quality data.
8. Following a non-point source pollution assessment, a Watershed Management Plan should be considered to compliment the Lake Management Plan.

Following the foregoing recommendations will improve management of the lake and watershed and help ensure continued protection of Windermere Lake going forward.

8.0 References

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Appendix A – Quality Assurance Quality Control Program

Table A-1 Sampling Locations

Sampling Locations	Site Description
Windermere Creek	N 50.46162” W 115.98558”
Abel Creek	N 50.48690” W 116.03405”
Windermere Lake South Station	N 50° 29’ 37.08” W 116° 00’ 59.04”
Windermere Lake Mid Station/Windermere	N 50° 27’ 37.08” W 115° 59’ 53.88”
Windermere Lake North Station/Timber Ridge- Upper (0.3m below surface)	N 50° 25’ 00.5” W 115° 56’ 34.2”
Windermere Lake North Station/Timber Ridge- Lower (1m above lake bottom)	N 50° 25’ 00.5” W 115° 56’ 34.2”

Table A-2: Description and results of QA analysis on Lake Windermere, Windermere Creek and Abel Creek

Date	Control Type	Complete?	Parameter	Notes	Field Results	Lab results
05/26/2020	Duplicate	Yes	pH (Lake and Creeks)	Lab sample collected at same time and place as field sample. All samples collected 30cm below the surface apart from Timber Ridge (Lower), which was collected using a Van Dorn bottle, 1m above the lake bottom	Timber Ridge (Upper): **8.5** Timber Ridge (Lower): **8.5** Windermere Mid Station: **8.5** South Station: **8.4** Windermere Creek: **8.1** Abel Creek: **8.4**	Timber Ridge (Upper): **7.85** Timber Ridge (Lower): **7.84** Windermere Mid Station: **7.8** South Station: **7.78** Windermere Creek: **7.71** Abel Creek: **7.83**
	Equipment Blank	Yes	pH	Deionized water processed with the same pH equipment as the field sample	pH: **6.7**	pH: **4.76** *lab results are 100x more acidic than the field sample. The cause of this has not been determined.
06/16/2020	Split Sample	Yes	Secchi depth (Lake)	Two secchi readings performed by two separate people in the same place, one after the other	Timber Ridge: **3.4 m** Mid Station: **2.0 m** South Station: **1.1 m**	Timber Ridge: **3.4 m** Mid Station: **1.9 m** South Station: **1.0 m**
06/23/2020	Duplicate	Yes	Turbidity (Creeks)	Two samples taken by one sampler with two different vials, at the same time and depth and measured in the same turbidimeter	Windermere Creek: **375.3** Abel Creek: **5.9**	Windermere Creek: **380.3** Abel Creek: **6.0**
	Duplicate	Yes	pH (Lake and Creeks)	Lab sample collected at same time and place as field sample. All samples collected 30cm below the surface apart from Timber Ridge (Lower), which was collected using a Van Dorn bottle, 1m above the lake bottom	Timber Ridge (Upper): **8.1** Timber Ridge (Lower): **7.7** Windermere Mid Station: **7.5** South Station: **7.2** Windermere Creek: **7.7** Abel Creek: **8.1**	Timber Ridge (Upper): **8.11** Timber Ridge (Lower): **8.16** Windermere Mid Station: **8.13** South Station: **8.06** Windermere Creek: **8.21** Abel Creek: **8.37**
	Equipment Blank	Yes	pH	Deionized water processed with the same pH equipment as the field sample	pH: **6.8**	pH: **5.85** *lab results are 10x more acidic than the field sample. The cause of this has not been determined.
06/30/2020	Duplicate	Yes	Turbidity (Lake)	Two samples taken by one sampler with two different vials, at the same time and depth and measured in the same turbidimeter	Timber Ridge (upper): **1.3** Timber Ridge (lower): **3.6** Mid Station: **1.7** South Station: **7.9**	Timber Ridge (upper): **1.2** Timber Ridge (lower): **3.0** Mid Station: **1.5** South Station: **7.0**
07/15/2020	Duplicate	Yes	Specific Conductivity (creeks)	Two samples taken at the same time and depth, and measured for in the same graduated cylinder with the same YSI meter	Windermere creek: **766** Abel creek: **358.2**	Windermere creek: **751** Abel creek: **358.4**
07/21/2020	Duplicate	Yes	Specific Conductivity (lakes)	Two samples taken at the same time and depth, and measured for in the same graduated cylinder with the same YSI meter	Timber Ridge (upper): **229.2** Timber Ridge (lower): **231.1** Mid Station: **241.6** South Station: **207.3**	Timber Ridge (upper): **229.8** Timber Ridge (lower): **231.1** Mid Station: **242.4** South Station: **204.8**
06/30/2020	Duplicate	Yes	Turbidity (Lake)	Two samples taken by one sampler with two different vials, at the same time and depth and measured in the same turbidimeter	Timber Ridge (upper): **1.3** Timber Ridge (lower): **3.6** Mid Station: **1.7** South Station: **7.9**	Timber Ridge (upper): **1.2** Timber Ridge (lower): **3.0** Mid Station: **1.5** South Station: **7.0**
07/15/2020	Duplicate	Yes	Specific Conductivity (creeks)	Two samples taken at the same time and depth, and measured for in the same graduated cylinder with the same YSI meter	Windermere creek: 766 Abel creek: 358.2	Windermere creek: 751 Abel creek: 358.4
07/21/2020	Duplicate	Yes	Specific Conductivity (lakes)	Two samples taken at the same time and depth, and measured for in the same graduated cylinder with the same YSI meter	Timber Ridge (upper): 229.2 Timber Ridge (lower): 231.1 Mid Station: 241.6 South Station: 207.3	Timber Ridge (upper): 229.8 Timber Ridge (lower): 231.1 Mid Station: 242.4 South Station: 204.8

Table A-3: Water Rangers Pilot Project Equipment Accuracy Comparison

Water Rangers Equipment	Lake Windermere Ambassadors Equipment
Taylor Test Strips for spas: - Measures pH, alkalinity, chlorine/bromine, hardness - The accuracy for color-matching tests and test strips is ½ the distance between two color standards. The accuracy for drop tests is ± one drop (10%)	**pH Testr 10** - The pH Testr 10 has resolution and accuracy +/- 0.1 pH
Conductivity/Temperature meter (8362 AZ Digital Conductivity and TDS Pen): - TDS accuracy: ±1% F.S ±1 digit - Temperature accuracy: ±0.5℃ **CHEMets Dissolved Oxygen (K-7512):** - CHEMets and ULR CHEMets kits: ± 1 color standard increment; Vacu-vials kit: ± 10% error at 0.750 ppm, ± 20% error at 0.250 ppm, and ±30% error at 0.100 ppm.	**YSI Pro Solo** - Measures temperature, dissolved oxygen, specific conductivity - **Temperature:** ±0.2°C; - **Dissolved Oxygen:** 0 to 200%: ±1% of reading or 1% saturation, whichever is greater; 200 to 500%: ±8% of reading; 0 to 20 mg/L: ±0.1 mg/L or 1% of reading, whichever is greater; 20 to 50 mg/L: ±8% of reading - **Conductivity:** 0 to 100 mS/cm ±0.5% of reading or .001 mS/cm, whichever is greater; 100 to 200 mS/cm ±1.0% of reading;
	HACH 2100Q Portable Turbidimeter - The Hach 2100Q is accurate to within 2% plus <0.02 NTU of stray light.

Table A-4: Comparison of data readings using Lake Windermere equipment versus Water Rangers testkit equipment

Location	Date/Time	Parameter	Results (Lake Windermere)	Results (Water Rangers)
Timber Ridge- North (upper)	June 30th, 2020 at 9:30am MDT	Air Temperature (degrees C)	13	15
		Water Temperature (degrees C)	18.9	18.2
		Specific Conductivity (µS /cm)	238	234.5
		Dissolved Oxygen (mg/L)	9.39	8
		pH ([H+])	8.1	7.5
		Total Depth (m)	7.2	6.9
		Secchi Depth (m)	5.1	5.4
		Total Chlorine (mg/L)	N/A*	0**
		Alkalinity (mg/L)	N/A*	120**
		Total Hardness (mg/L)	N/A*	100**
Timber Ridge- North (upper)	July 28th, 2020 at 10:04am MDT	Air Temperature (degrees C)	22	24
		Water Temperature (degrees C)	21.3	20.8
		Specific Conductivity (µS /cm)	239.9	237.0
		Dissolved Oxygen (mg/L)	8.87	10.0
		pH ([H+])	7.7	7.5
		Total Depth (m)	6.5	6.5
		Secchi Depth (m)	6.5	6.2
		Total Chlorine (mg/L)	N/A*	0
		Alkalinity (mg/L)	N/A*	100
		Total Hardness (mg/L)	N/A*	100

*N/A readings are not included in weekly sampling for Lake Windermere
**pH, chlorine, alkalinity and total hardness sampled with the same Test strips

Table A-5: Sampling Equipment Calibration Log- HACH 2100G Portable turbidimeter

Turbidimeter				
Date Calibrated	**Next calibration due**	**Reading (0-10 NTU)**	**Reading (0-100 NTU)**	**Reading (0-1000 NTU)**
April 21, 2020	May 21, 2020	Not recorded	Not recorded	Not recorded
May 21 2020	June 17, 2020	5.84	54.3	564
June 17, 2020	July 22, 2020	5.79	54.3	564
July 22, 2020	August 19, 2020	5.77	53.9	563

Table A-6: Sampling Equipment Calibration Log- YSI Pro Solo

YSI		
Date Calibrated	**Next calibration due**	**Notes**
April 21, 2020	May 21, 2020	Specific Conductivity: 1413 Micro siemens Dissolved Oxygen: 89.9%
May 21 2020	June 17, 2020	Specific Conductivity: 1413 Micro siemens Dissolved Oxygen: 89.9%
June 17, 2020	July 22, 2020	Specific Conductivity: 1413 Micro siemens Dissolved Oxygen: 89.9%
July 22, 2020	August 19, 2020	Specific Conductivity: 1413 Micro siemens Dissolved Oxygen: 89.9%

Table A-7: Sampling Equipment Calibration Log- pH Testr 10

pH Pen			
Date Calibrated	**10.01 Buffer Reading**	**7.00 Buffer Reading**	**Next calibration due**
April 21, 2020	Not recorded	Not recorded	May 21, 2020
May 21 2020	10.50	7.00	June 17, 2020
June 17, 2020	10.60	7.00	July 22, 2020
July 22, 2020	10.40	7.00	August 19, 2020