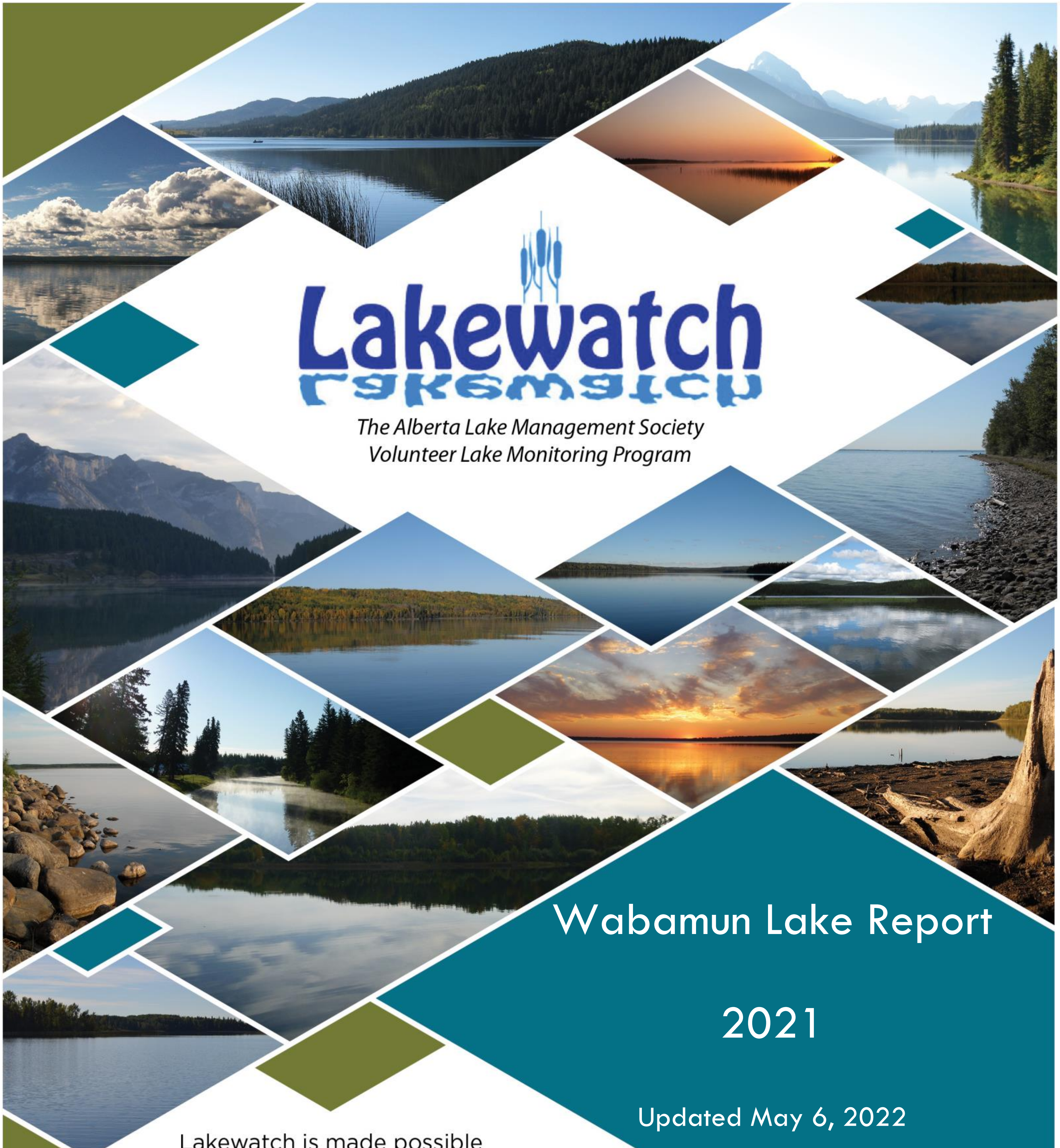

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Wabamun Lake Report

2021

Updated May 6, 2022

Lakewatch is made possible with support from:

Alberta · LICA Environmental Stewards · Pigeon Lake Watershed Association · MD 61 Wainwright · Alberta ecotrust · Discover Hardisty More Than You Imagine · Municipal District Bonnyville No. 87

ALBERTA LAKE MANAGEMENT SOCIETY'S LAKEWATCH PROGRAM

LakeWatch has several important objectives, one of which is to collect and interpret water quality data from Alberta's Lakes. Equally important is educating lake users about aquatic environments, encouraging public involvement in lake management, and facilitating cooperation and partnerships between government, industry, the scientific community and lake users. LakeWatch reports are designed to summarize basic lake data in understandable terms for the widest audience, and are not meant to be a complete synopsis of information about specific lakes. Additional information is available for many lakes that have been included in LakeWatch, and readers requiring more information are encouraged to seek those sources.

ALMS would like to thank all who express interest in Alberta's aquatic environments, and particularly those who have participated in the LakeWatch program. These leaders in stewardship give us hope that our water resources will not be the limiting factor in the health of our environment.

If you require data from this report, please contact ALMS for the raw data files.

ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks to Sue Styles, Neil Flemming, and Stan Franklin for their commitment to collecting data at Wabamun Lake. We would also like to thank Keri Malanchuk and Brittany Onysyk, who were summer technicians in 2021. Executive Director Bradley Peter and Program Manager Caleb Sinn were instrumental in planning and organizing the field program. This report was prepared by Caleb Sinn and Bradley Peter.

BEFORE READING THIS REPORT, CHECK OUT A BRIEF INTRODUCTION TO LIMNOLOGY AT ALMS.CA/REPORTS

WABAMUN LAKE

Wabamun Lake Watershed. Base data provided by the Government of Alberta under the Alberta Open Data License (2020).

Wabamun Lake is a well-known, large lake situated 60km west of Edmonton in the North Saskatchewan watershed. The lake's watershed is approximately 351 km^2, and the lake itself has a surface area of 79 km^2, a mean depth of 5.1 m, with the deepest area being approximately 11 m deep.[1] *Wabamun* is Cree for "mirror," and has been the historical name of the lake, but was also called White Whale Lake for most of the 1800s, due to the size of large Whitefish harvested from the lake at that time.[2] The Paul Band reserve is situated on the Eastern edge of the lake, and many other communities line Wabamun's shore. Of them, the Village of Wabamun was established in 1912, and the summer villages of Lakeview and Kapasiwin were some of the first summer villages to be established in Alberta. Other communities across the lake include Fallis, Seba Beach, Betula Beach, and Point Allison, to name just a few. Wabamun Lake Provincial Park is located on the northeast part of the lake, and protects much of the shoreline of Moonlight Bay.

There is much industrial activity in the watershed. TransAlta currently operates two coal-fired power plants and one coal mine that impact the Wabamun watershed. The Sundance plant is located near the southeast shore within the watershed, and is the largest coal-fired electrical generation plant in Western Canada.[3] While the Keephills plant is located outside of the Wabamun watershed, both Keephills' and Sundance's cooling pond drain into the lake after treatment by the Wabamun Water Treatment Plant.[4] SunHills Mining, a subsidiary of TransAlta, also operates the Highvale Mine located on the south shore of the lake, and stretches southeast to the North Saskatchewan River. TransAlta also operated the Wabamun Power Plant and Whitewood Mine on the northeast shore from 1962 - 2010.[5]

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[1] Aquality Environmental Consulting (2013). Wabamun Lake State of the Watershed Report. Wabamun Watershed Management Council.
[2] Mitchell, P. and E. Prepas (1990). Atlas of Alberta Lakes, University of Alberta Press.
[3] TransAlta Corporation (2018). Retrieved from https://www.transalta.com/facilities/plants-operation/sundance/
[4] Associated Environmental (2018). Water Quality Status and Trends in Wabamun Lake.
[5] TransAlta Corporation (2018). Retrieved from https://www.transalta.com/facilities/mines-operation/whitewood-mine/

A railway runs along the north shore of the lake, and even crosses over the lake at the mouth of Moonlight Bay. On August 3, 2005, a Canadian National (CN) train travelling west towards Vancouver, BC derailed and spilled approximately 400,000 L of Bunker C oil and 88,000 L of toxic pole treating oil, with unknown quantities of each being released into the lake.[6] Subsequently, oil was spread across the northern, eastern and southern shores of the lake, severely impacting aquatic and riparian habitat for numerous aquatic species, and waterfowl. Cleanup efforts commenced immediately, and a report released by the Alberta Government in 2007 states that bulrush growth was not impacted by the toxic components of the spilt oil, but rather suffered from the treatments used to clean up the oil.[7] Toxic compounds were still detectable in sediments in 2007, although they were below environmental guideline limits.

Aerial photo of Wabamun Lake (Alberta Atlas of Lakes: http://albertalakes.ualberta.ca/).

The relatively shallow lake attracts many avid anglers to catch walleye, lake whitefish, and burbot. See current sportfishing regulations for more information.[8] Sailing is a popular activity due to the strong winds and northwest orientation of the lake. The lake also attracts many boaters and visitors, due to its relatively good water quality and the scenic aspen parkland that surrounds the lake. Since the lake is one of the most extensively monitored lakes in the province, long-term trend analyses performed by the Alberta Government, [9] Associated Environmental and ALMS all confirm that phytoplankton and nutrient levels within the lake are stable at moderate levels (mesotrophic), and even slightly decreasing. Cyanobacteria blooms are relatively rare, however in 2019 Alberta Health Services issued a cyanobacteria bloom beach advisory at Wabamun for the first time. Alberta Health Services' cyanobacteria monitoring program is ever-evolving, and has been in existence only since 2010.[10] Total dissolved solids (TDS) have been increasing in the lake since the lake was first sampled in 1980, likely due to climate impacts and possibly the return of treated water to the lake from the power plant activities within the watershed.[11, 12]

The Wabamun Watershed Management Council (WWMC) is an active group that has collectively worked with Alberta Environment and Parks, the North Saskatchewan Watershed Alliance, various consultants, and municipalities on watershed studies, plans, and on-the-ground projects that aim to protect the lake and inform Wabamun Watershed residents. In addition, 2019 was the first year that ALMS collaborated with the WWMC to sample Wabamun as part of its LakeWatch program. A draft watershed management plan was released in 2020 and is available on their website.

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[6] QM Environmental (2020). Retrieved from http://www.qmenv.com/Projects/Wabamun-Lake-Oil-Spill
[7] Thormann, M. N. and S. E. Bayley (2008). Impacts of the CN Rail Oil Spill on Softstem Bulrush-Dominated Lacustrine Marshes in Wabamun Lake. Alberta Environment and Parks.
[8] https://albertaregulations.ca/fishingregs/pp2.html. Accessed May 2022.
[9] Casey, R. (2011). Water Quality Conditions and Long-Term Trends in Alberta Lakes. Alberta Environment and Parks.
[10] Health Protection Branch, Alberta Health (2014). Alberta Cyanobacteria Beach Monitoring, 2010 – 2013. Alberta Health.
[11] Associated Environmental (2018). Water Quality Status and Trends in Wabamun Lake.
[12] Casey, R. (2003). Wabamun Lake Water Quality, 1982 – 2001. Alberta Environment and Parks.

WATER CHEMISTRY

ALMS measures a suite of water chemistry parameters. Phosphorus, nitrogen, and chlorophyll-a are important because they are indicators of eutrophication, or excess nutrients, which can lead to harmful algal/cyanobacteria blooms. One direct measure of harmful cyanobacteria blooms are Microcystins, a common group of toxins produced by cyanobacteria. See Table 2 for a complete list of parameters.

The average total phosphorus (TP) concentration for Wabamun Lake was 26 µg/L (Table 2), falling into the mesotrophic, or moderately productive trophic classification. This value is in the mid to low-range of historical averages. TP was lowest at the end of the season at 20 µg/L during the September 9th sampling event, and was highest early in the season at 35 µg/L, during the June 8th sampling event (Figure 1).

Average chlorophyll-*a* concentration in 2021 was 12 µg/L (Table 2), falling into the eutrophic, or highly productive trophic classification. Chlorophyll-*a* was lowest during the June 4th sampling event at 5.9 µg/L, and increased later in the season to a peak of 16.9 µg/L on September 9th (Figure 1).

The average TKN concentration was 1.0 mg/L (Table 2) and varied from 0.77 mg/L to 1.20 mg/L, having the highest level during the July 8th sampling event (Figure 1).

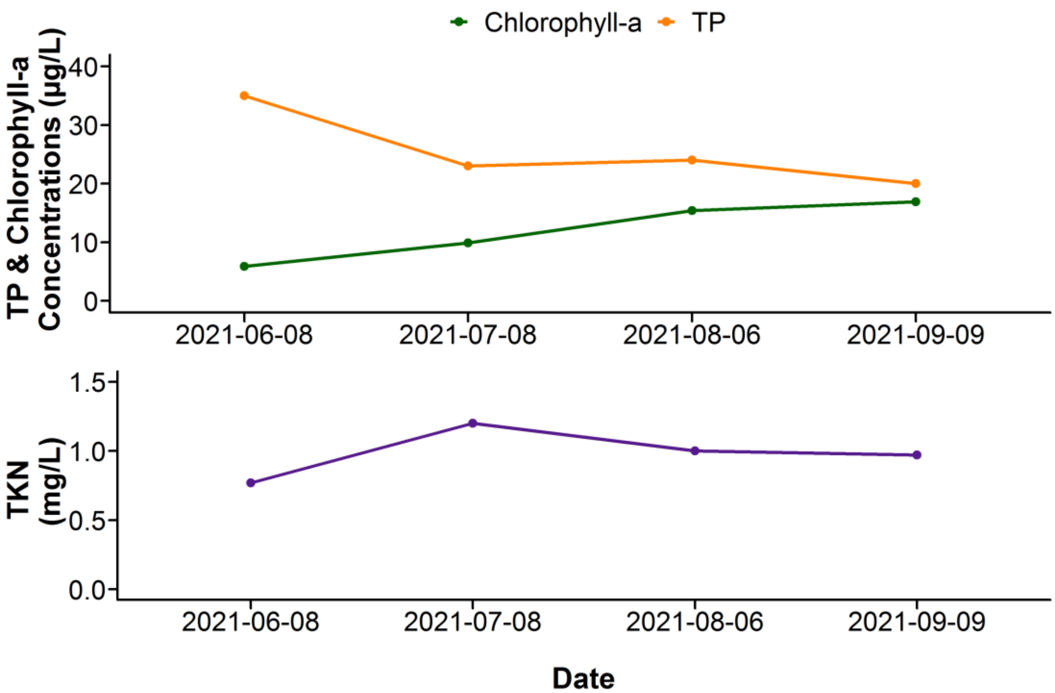


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Wabamun Lake.

Average pH was measured as 8.62 in 2021, buffered by moderate alkalinity (212 mg/L $CaCO_3$) and bicarbonate (238 mg/L HCO_3). Aside from bicarbonate, the dominant ions were sulphate and sodium, which contributed to a moderate conductivity of 630 µS/cm (Table 2). Wabamun Lake is in the moderate range of ion levels compared to other LakeWatch lakes sampled in 2021 (Figure 2, bottom).

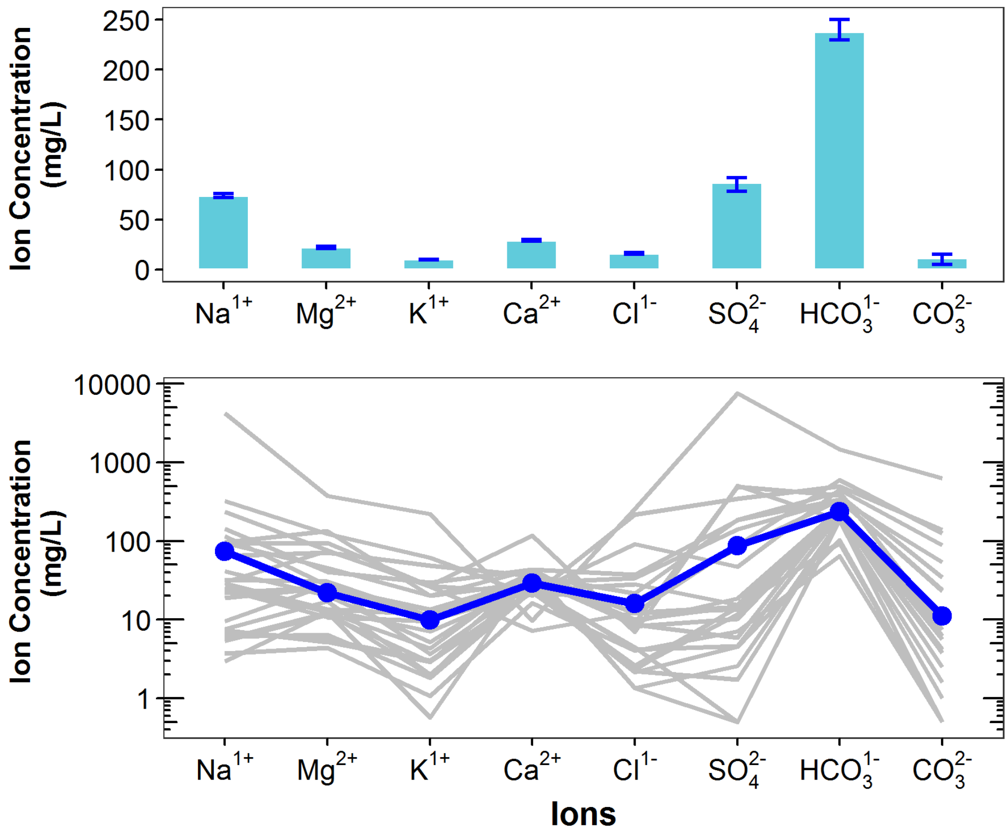


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Wabamun Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Wabamun Lake (blue line) compared to 25 lake basins (gray lines) sampled through the LakeWatch program in 2021 (note $\log_{10}$ scale on y-axis of bottom figure).

Metals

Metals will naturally be present in aquatic environments due to in-lake processes or the erosion of rocks, or introduced to the environment from human activities such as urban, agricultural, or industrial developments. Many metals have a unique guideline as they may become toxic at higher concentrations. Where current metal data are not available, historical concentrations for 27 metals have been provided (Table 3).

Metals were not measured at Wabamun Lake in 2021, but Table 3 displays historical metal concentrations.

WATER CLARITY AND EUPHOTIC DEPTH

Water clarity is influenced by suspended materials, both living and dead, as well as dissolved colored compounds in the water column. During the melting of snow and ice in spring, lake water can become turbid (cloudy) from silt transported into the lake. Lake water usually clears in late spring, but then becomes more turbid with increased algal growth as the summer progresses. The easiest and most widely used measure of lake water clarity is the Secchi depth. Two times the Secchi depth equals the euphotic depth – the depth to which there is enough light for photosynthesis.

The average euphotic depth of Wabamun Lake in 2021 was 5.40 m, corresponding to an average Secchi depth of 2.70 m (Table 2). The euphotic depth was deepest during the June 8th sampling event at 7.20 m, then decreased through the season to a low of 4.20 m on August 4th, followed by a slight increase again during the September 22nd sampling event, to 5.00 m (Figure 3).

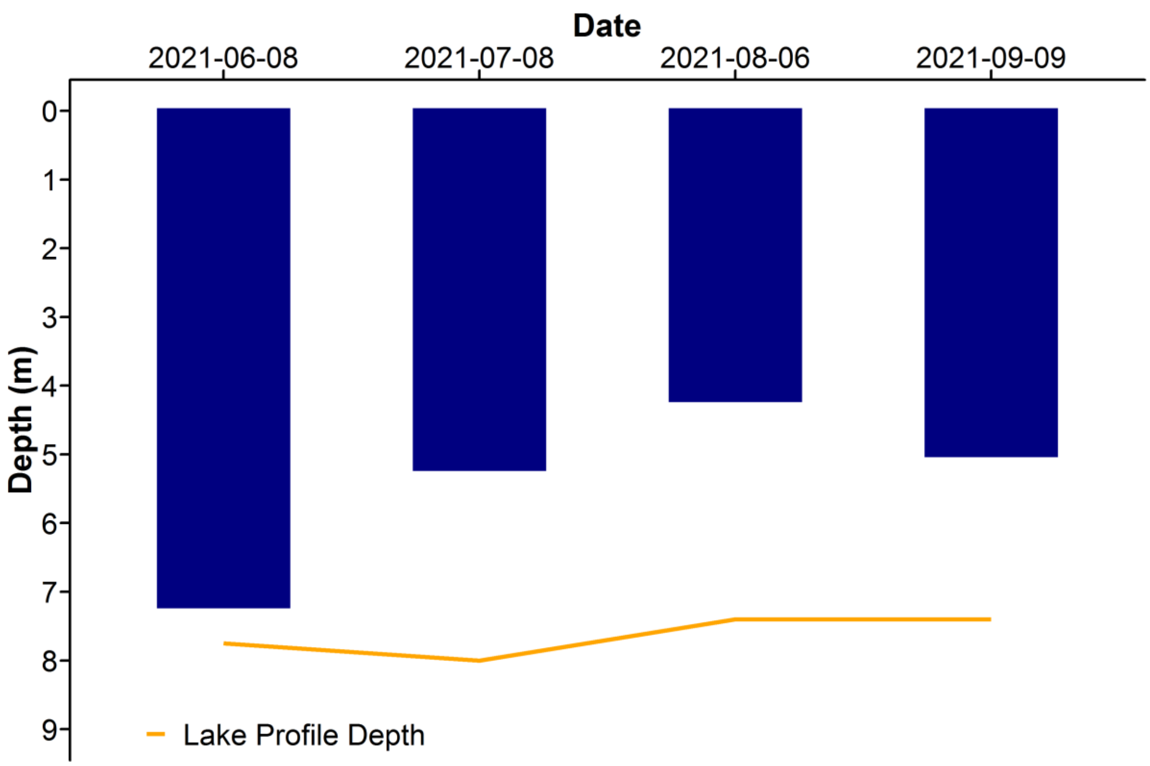


Figure 3. Euphotic depth values measured four times over the course of the summer at Wabamun Lake in 2021.

WATER TEMPERATURE AND DISSOLVED OXYGEN

Water temperature and dissolved oxygen (DO) profiles in the water column can provide information on water quality and fish habitat. The depth of the thermocline is important in determining the depth to which dissolved oxygen from the surface can be mixed. Please refer to the end of this report for descriptions of technical terms.

Surface temperatures of Wabamun Lake varied throughout the summer, with the July 8th sampling date having the warmest temperatures at 22.8°C (Figure 4a). The lake was weakly stratified during the June 8th sampling event, and was consistent in temperature and relatively well mixed during all other sampling events. The lake was much warmer during the July and August sampling dates, relative to the June and September sample dates.

Wabamun Lake was well oxygenated in the surface waters on all sampling dates, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 4b). All dates displayed a decrease in dissolved oxygen with depth, but the depth to which this occurred varied throughout the season. During the July 8th sampling event, levels decreased below 6.5 mg/L at 4.5 m depth, while levels decreased below 6.5 mg/L at 6.5 – 7 m depth during every other sampling event. The likely reason for the relatively shallow decrease in oxygen during the July 8th sampling event could be that sampling occurred during a relatively warm, calm period (Figure 6), which would reduce whole-lake mixing, leading to oxygen depletion below the mixed layer.

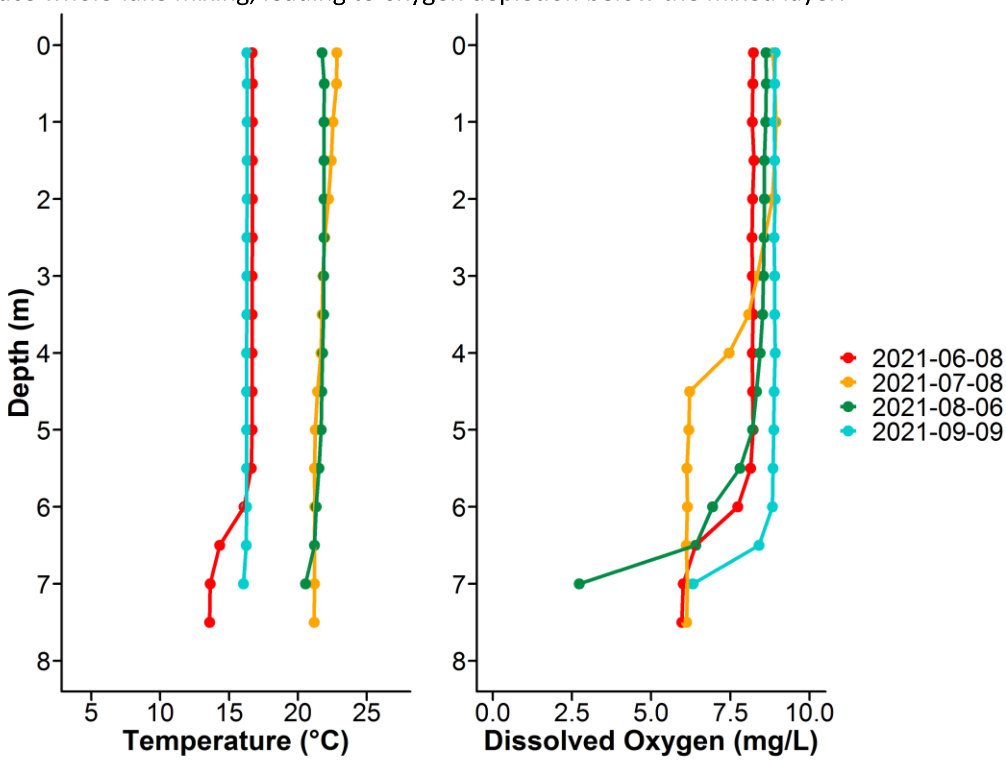


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Wabamun Lake measured four times over the course of the summer of 2021.

MICROCYSTIN

Microcystins are toxins produced by cyanobacteria (blue-green algae) which, when ingested, can cause severe liver damage. Microcystins are produced by many species of cyanobacteria which are common to Alberta's Lakes, and are thought to be one of the most common cyanobacteria toxins. In Alberta, recreational guidelines for microcystin are set at 10 μg/L. Blue-green algae advisories are managed by Alberta Health Services. Recreating in algal blooms, even if microcystin concentrations are not above guidelines, is not recommended.

Microcystin levels in Wabamun Lake fell below the recreational guideline of 10 μg/L during every sampling event in 2021 (Table 1), and the seasonal average was below historical averages (Table 2). In addition, microcystin levels from June 8th and July 8th were below the laboratory detection limit of 0.10 μg/L. A value of 0.05 μg/L is assigned to these dates in order to calculate an average. Even though low levels of microcystin were detected, caution should always be observed when recreating around cyanobacteria.

Table 1. Microcystin concentrations measured four times at Wabamun Lake in 2021.

Date	**Microcystin Concentration (μg/L)**
8-Jun-21	<0.1
8-Jul-21	<0.1
6-Aug-21	0.11
9-Sep-21	0.10
Average	0.08

INVASIVE SPECIES MONITORING

Dreissenid mussels pose a significant concern for Alberta because they impair the function of water conveyance infrastructure and adversely impact the aquatic environment. These invasive mussels can change lake conditions which can then lead to toxic cyanobacteria blooms, decrease the amount of nutrients needed for fish and other native species, and cause millions of dollars in annual costs for repair and maintenance of water-operated infrastructure and facilities. Spiny water flea pose a concern for Alberta because they alter the abundance and diversity of native zooplankton, as they are aggressive zooplankton predators. Through over-predation, they will impact higher trophic levels such as fish. They also disrupt fishing equipment by attaching in large numbers to fishing lines.

Monitoring involved sampling with a 63 μm plankton net at three sample sites to look for juvenile mussel veligers and spiny water flea in each lake sampled. In 2021, no mussels or spiny water flea were detected at Wabamun Lake.

Eurasian watermilfoil is a non-native aquatic plant that poses a threat to aquatic habitats in Alberta because it grows in dense mats preventing light penetration through the water column, reduces oxygen levels when the dense mats decompose, and outcompetes native aquatic plants. Eurasian watermilfoil can look similar to the native Northern watermilfoil, thus genetic analysis is ideal for suspect watermilfoil species identification.

Watermilfoil specimens were collected from Wabamun Lake on June 8th and July 26th, and both specimens were confirmed to be the native Northern Watermilfoil.

WATER LEVELS

There are many factors influencing water quantity. Some of these factors include the size of the lake's drainage basin, precipitation, evaporation, water consumption, ground water influences, and the efficiency of the outlet channel structure at removing water from the lake. Requests for water quantity monitoring should go through Alberta Environment and Parks Monitoring and Science division

Water levels at Wabamun Lake in 2021 were slightly above the historical average (Figure 5), although decreased throughout length of the season (Figure 5).

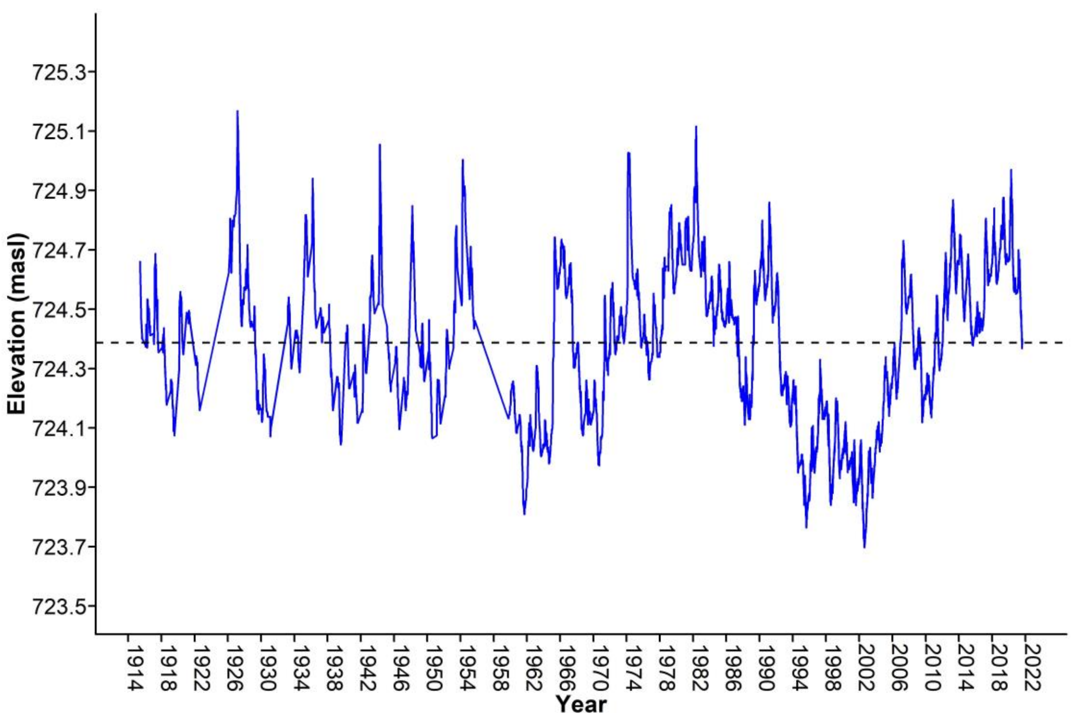


Figure 5. Water levels measured at Wabamun Lake in metres above sea level (masl) from 1914-2021. Data retrieved from Alberta Environment and Parks and Environment Canada. Black dashed line represents historical yearly average water level.

WEATHER & LAKE STRATIFICATION

Air temperature will directly impact lake temperatures, and result in different temperature layers (stratification) throughout the lake, depending on its depth. Wind will also impact the degree to which a lake mixes, and how it will stratify. The amount of precipitation that falls within a lake's watershed will have important implications, depending on the context of the watershed and the amount of precipitation that has fallen. Solar radiation represents the amount of energy that reaches the earth's surface, and has implications for lake temperature & productivity.

Wabamun Lake experienced a warmer, drier, slightly more windy summer with slightly less solar radiation compared to normal (Figure 6). A few warm spells prior to the July 8th and August 6th sampling events likely resulted in relatively high whole-lake temperatures. Slightly reduced surface oxygen levels during the June 8th and August 6th sampling events could be due to decreased photosynthesis as a result of reduced solar radiation during those sampling events.

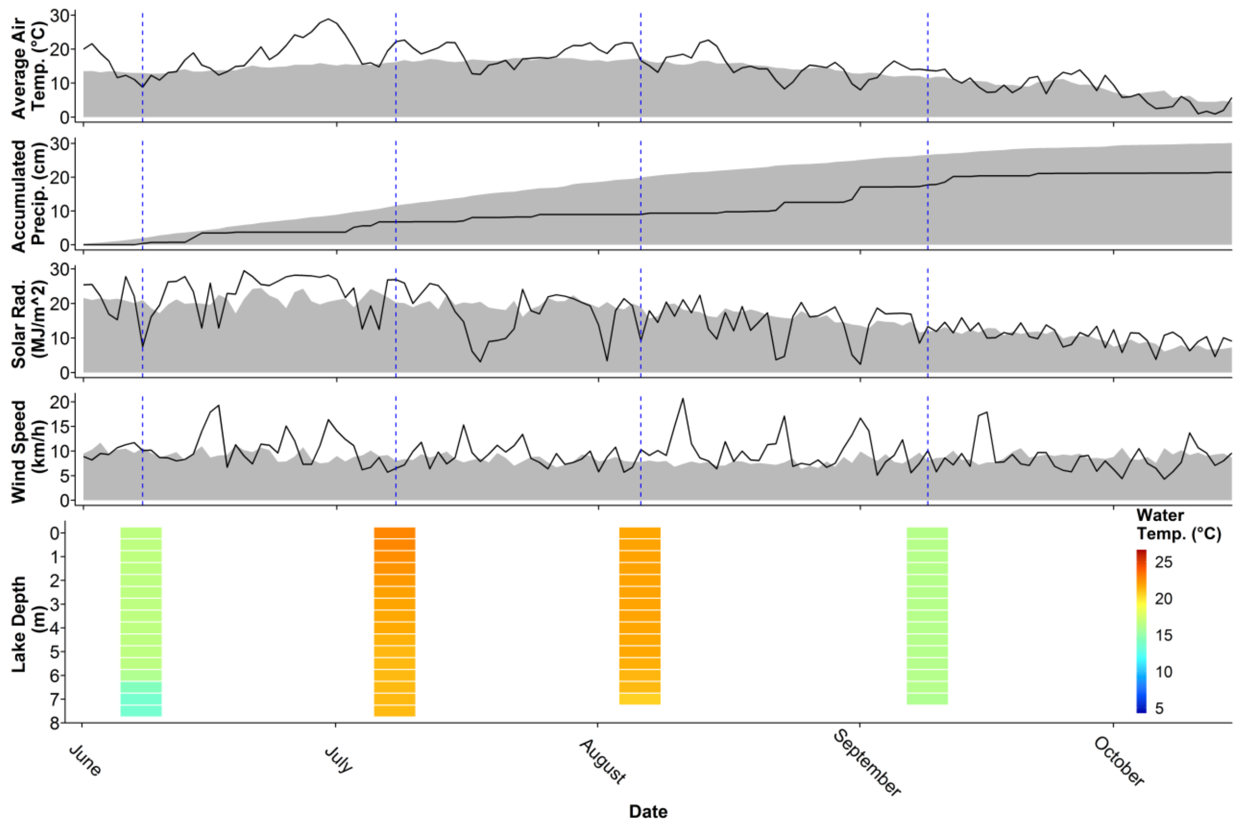


Figure 6. Average air temperature (°C), accumulated precipitation (cm), and wind speed (km/h) measured from Hoselaw AGCM, as well as solar radiation (MJ/m^2) measured from Dupre AGCM, with Wabamun Lake temperature profiles (°C) at the bottom. Black lines indicate 2021 levels, gray indicates long-term normals, and blue lines indicate sampling dates for Wabamun Lake over the summer. Further information about the weather data provided is available in the LakeWatch 2021 Methods report. Weather data provided by Agriculture, Forestry and Rural Economic Development, Alberta Climate Information Service (ACIS) https://acis.alberta.ca (retrieved April 2022).

HISTORICAL DATA

Wabamun Lake has been extensively monitored by Alberta Environment, and has composite lake sampling data that dates back to 1980. Over the years, Wabamun Lake has been sampled many different ways, likely to answer specific questions. For instance, there are four different codes in the Alberta Environment database denoting different spatial samplings of the lake.

There is composite lake data for the East Basin, West Basin and Moonlight Bay, and there is data for the Main basin, which represents composite data from the entire lake. As this report aims to report data on Wabamun Lake as a whole, the data tables were assembled to represent the most complete, whole lake data. For years where both the East and West basins were sampled at the same time, the values were averaged to capture a more accurate picture of the whole lake. Main Basin data is reported as is, and years where only the East Basin was sampled are also reported as is (this is only the case for 1982, 2014 and 2016). Generally, sampling occurred once a month from May till October, however some years had more or less frequent sampling events. This sort of variability in sampling frequency is typical of water quality data, as well as environmental data more generally. Otherwise, Wabamun Lake has a remarkably complete dataset with monthly, multi-basin sampling occurring in 37 years of the past 41 years.

Table 2a. Average Secchi depth and water chemistry values for Wabamun Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
TP (µg/L)	/	34	30	30	33	18	33	37	35	34	35	34	34
TDP (µg/L)	/	11	10	10	14	6	10	11	13	12	13	13	12
Chlorophyll-*a* (µg/L)	10.4	13	11.6	10.4	11.8	10.6	10.3	12.5	12	11.2	17.2	11.1	13.4
Secchi depth (m)	2.15	1.88	/	2.30	1.87	2.46	2.58	2.74	2.86	2.72	2.64	2.13	1.93
TKN (mg/L)	1.2	1.1	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1	0.9	0.9
NO_2-N and NO_3-N (µg/L)	4	6	1	5	6	3	2	7	2	2	3	1	1
NH_3-N (µg/L)	26	62	27	17	22	9	17	19	15	30	16	14	9
DOC (mg/L)	12	13	11	11	11	14	11	11	12	13	12	11	12
Ca (mg/L)	25	24	23	24	23	25	26	26	25	24	25	24	25
Mg (mg/L)	13	13	12	12	12	13	13	13	15	14	15	15	15
Na (mg/L)	41	41	43	45	47	46	47	47	51	49	49	46	51
K (mg/L)	8	8	7	7	8	8	8	8	8	8	8	8	8
SO_4^{2-} (mg/L)	25	30	28	28	26	25	27	30	28	27	29	28	31
Cl^- (mg/L)	2	3	3	3	3	3	4	4	4	5	4	4	5
CO_3 (mg/L)	/	/	/	7	11	5	9	10	11	5	10	11	10
HCO_3 (mg/L)	/	/	/	217	216	223	219	223	225	228	223	222	238
pH	8.23	8.09	8.60	8.52	8.67	8.56	8.67	8.57	8.67	8.43	8.61	8.62	8.70
Conductivity (µS/cm)	408	403	406	412	413	421	421	430	439	428	432	434	447
Hardness (mg/L)	120	113	/	108	108	115	117	119	124	118	123	123	122
TDS (mg/L)	224	231	241	233	237	235	241	247	252	245	249	245	256
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	182	184	187	190	195	192	195	198	203	197	199	200	203
Basin Sampled	E, W	E, W	E	M	M	M	M	M	M	M	M	M	M

Table 2b. Average Secchi depth and water chemistry values for Wabamun Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**
TP (µg/L)	35	39	36	34	36	36	27	28	32	28	31	33	30
TDP (µg/L)	14	12	12	11	11	11	9	9	10	9	9	11	9
Chlorophyll-*a* (µg/L)	11.6	12.8	11.3	11.2	14.1	13.3	7.6	7.4	10.9	7.9	10.4	11.2	11.8
Secchi depth (m)	2.09	1.90	2.05	2.06	2.28	2.00	2.25	2.12	1.85	2.30	2.18	2.43	2.39
TKN (mg/L)	1	1	1	0.8	0.8	0.9	0.9	0.8	0.8	0.8	0.8	0.9	0.9
NO_2-N and NO_3-N (µg/L)	4	2	3	4	5	4	2	3	6	2	3	4	3
NH_3-N (µg/L)	13	8	10	37	16	15	8	12	11	12	26	35	29
DOC (mg/L)	12	13	12	13	12	/	13	12	13	13	12	13	12
Ca (mg/L)	22	23	23	24	24	22	24	23	21	21	22	23	23
Mg (mg/L)	15	15	16	15	16	15	16	16	16	16	18	18	18
Na (mg/L)	52	54	56	57	57	58	59	63	64	65	66	67	67
K (mg/L)	8	9	9	9	9	9	10	10	9	9	10	10	9
SO_4^{2-} (mg/L)	28	27	30	33	31	31	39	42	43	51	56	61	69
Cl^- (mg/L)	5	5	6	6	9	6	7	7	8	9	8	9	10
CO_3 (mg/L)	11	10	10	8	10	12	9	4	7	8	10	7	9
HCO_3 (mg/L)	235	241	238	237	238	235	249	253	246	255	240	252	244
pH	8.71	8.66	8.62	8.47	8.51	8.51	8.44	8.36	8.50	8.52	8.60	8.55	8.58
Conductivity (µS/cm)	444	452	459	466	470	479	483	499	492	516	522	528	546
Hardness (mg/L)	116	120	123	124	124	120	127	125	118	120	127	131	134
TDS (mg/L)	253	257	268	270	274	271	288	292	291	308	310	321	327
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	0.14
Total Alkalinity (mg/L $CaCO_3$)	203	206	212	207	213	212	218	214	213	222	213	219	215
Basin Sampled	M	M	M	M	M	M	E, W	E, W	E, W	E, W	E, W	E, W	E, W

Table 2c. Average Secchi depth and water chemistry values for Wabamun Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	**2006**	**2007**	**2008**	**2010**	**2011**	**2012**	**2013**	**2014**	**2016**	**2019**	**2020**	**2021**
TP (µg/L)	21	28	22	34	40	33	36	416	26	27	44	26
TDP (µg/L)	5	8	7	13	9	14	14	22	6	7	6	7
Chlorophyll-*a* (µg/L)	10.8	13.9	10.3	7.9	11.5	11	8.8	9.1	9.2	11.1	11.7	12
Secchi depth (m)	2.70	2.41	2.27	1.93	1.47	2.00	1.80	2.39	2.82	2.70	2.42	2.70
TKN (mg/L)	1	0.9	0.9	1.1	1.1	1	1	0.8	0.9	0.9	1	1
NO_2-N and NO_3-N (µg/L)	4	4	3	7	2	3	2	26	4	2	2	3
NH_3-N (µg/L)	48	41	57	12	12	17	11	26	25	15	24	15
DOC (mg/L)	12	11	10	12	/	11	/	10	11	10	10	10
Ca (mg/L)	25	26	26	/	/	/	/	/	26	28	29	29
Mg (mg/L)	19	19	20	/	/	/	/	/	22	22	22	22
Na (mg/L)	69	67	70	77	73	72	73	79	76	75	74	74
K (mg/L)	10	9	9	10	10	10	9	10	10	10	10	10
SO_4^{2-} (mg/L)	74	75	76	86	80	85	83	84	90	88	87	86
Cl^- (mg/L)	10	10	12	13	13	13	12	14	15	16	16	16
CO_3 (mg/L)	9	6	10	8	9	7	10	8	7	7	7	11
HCO_3 (mg/L)	240	241	238	243	233	245	239	242	252	255	230	238
pH	8.59	8.50	8.57	8.62	8.65	8.50	8.36	8.43	8.54	8.59	8.54	8.62
Conductivity (µS/cm)	562	561	577	592	583	602	608	610	623	612	598	630
Hardness (mg/L)	140	142	144	141	140	146	153	149	157	158	162	162
TDS (mg/L)	334	332	343	356	343	353	353	370	372	370	360	365
Microcystin (µg/L)	/	/	/	0.10	0.17	0.20	0.10	0.13	0.19	0.12	0.24	0.08
Total Alkalinity (mg/L $CaCO_3$)	212	208	211	213	207	212	213	212	217	220	198	212
Basin Sampled	E, W	E, W	E, W	M	M	M	M	E	E	M	M	M

Table 3. Concentrations of metals measured in Wabamun Lake. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Note that metal sample collection method changed in 2016 from composite to single surface grab at the profile location.

Metals (Total Recoverable)	2013	2020	Guidelines
Aluminum μg/L	30.6	15.1	100[a]
Antimony μg/L	0.178	0.145	/
Arsenic μg/L	2.77	3.2	5
Barium μg/L	131	128	/
Beryllium μg/L	0.0074	0.003	100[c,d]
Bismuth μg/L	<0.001	<0.003	/
Boron μg/L	921	791	1500
Cadmium μg/L	0.0106	<0.01	0.24[b]
Chromium μg/L	0.493	<0.1	/
Cobalt μg/L	0.0283	0.016	50,1000[c,d]
Copper μg/L	0.642	0.46	3.59[b]
Iron μg/L	18.96	13	300
Lead μg/L	0.0624	0.045	5.93[b]
Lithium μg/L	39.7	38	2500[d]
Manganese μg/L	37.6	24	180[e]
Molybdenum μg/L	4.63	5.14	73
Nickel μg/L	0.182	0.42	138.6[b]
Selenium μg/L	0.148	0.3	1
Silver μg/L	0.0185	<0.001	0.25
Strontium μg/L	402	367	/
Thallium μg/L	0.0008	<0.002	0.8
Thorium μg/L	0.0055	0.012	/
Tin μg/L	0.0423	<0.06	/
Titanium μg/L	1.20	0.48	/
Uranium μg/L	0.456	0.419	15
Vanadium μg/L	0.827	0.873	100[c,d]
Zinc μg/L	1.07	1.7	30[f]

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

[b] Based on 2020 avg. water hardness (as CaCO3) with CCME equation

[c] Based on CCME Guidelines for Agricultural use (Livestock).

[d] Based on CCME Guidelines for Agricultural Use (Irrigation).

[e] Based on CCME Manganese variable calculation (https://ccme.ca/en/chemical/129#_aql_fresh_concentration), using 2020 avg. water hardness (as CaCO3) and avg. pH

[f] Based on 2020 avg. water hardness (as CaCO3), avg. pH, and avg. DOC with CCME equation

[g] Did not exceed guideline due to effect of relatively lower pH value in 2014 on Manganese variable calculation.

A forward slash (/) indicates an absence of data or guidelines

LONG TERM DATA

Wabamun Lake has a fairly unique water quality dataset, as explained above in the Historical Data section, and thus has been analyzed slightly differently than other lakes with long term data. For other lakes' long term trend analyses, any historical data used excludes data from May and October sampling trips. However, for Wabamun Lake, as it was part of the provincial long term lake monitoring program, samplings occurred in May and October for the majority of years, and over a long time span. Therefore, the October and May data were included to improve the analysis' capture of seasonal variability at Wabamun Lake.. In addition, data was excluded from the trend analysis from any year where only one of the East or West basins were sampled. For years where both the East and West basins were sampled at the same time each month, the data was averaged between each basin and included in the trend analysis. These steps were taken to best capture the trends for Wabamun Lake as a whole.

Trend analysis was conducted on the parameters total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth to look for changes from 1980 or 1981 to 2021 in Wabamun Lake. In summary, significant decreasing trends were observed in TP and in chlorophyll-*a,* significant increasing trends were observed in TDS, and no change was observed in Secchi depth. Data is presented below as both a line graph (all data points) or a box-and-whisker plot. Detailed methods are available in the *ALMS Guide to Trend Analysis on Alberta Lakes.*

Table 4. Summary table of trend analysis on Wabamun Lake data from 1980 or 1981 to 2021.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	1981-2021	Decreasing
Chlorophyll-*a*	1980-2021	Decreasing
Total Dissolved Solids	1980-2021	Increasing
Secchi Depth	1980-2021	No change

Definitions:

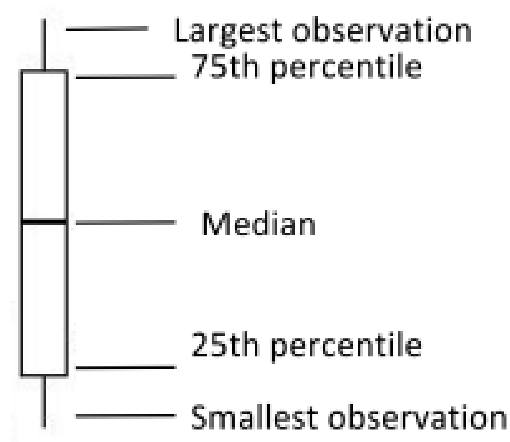
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

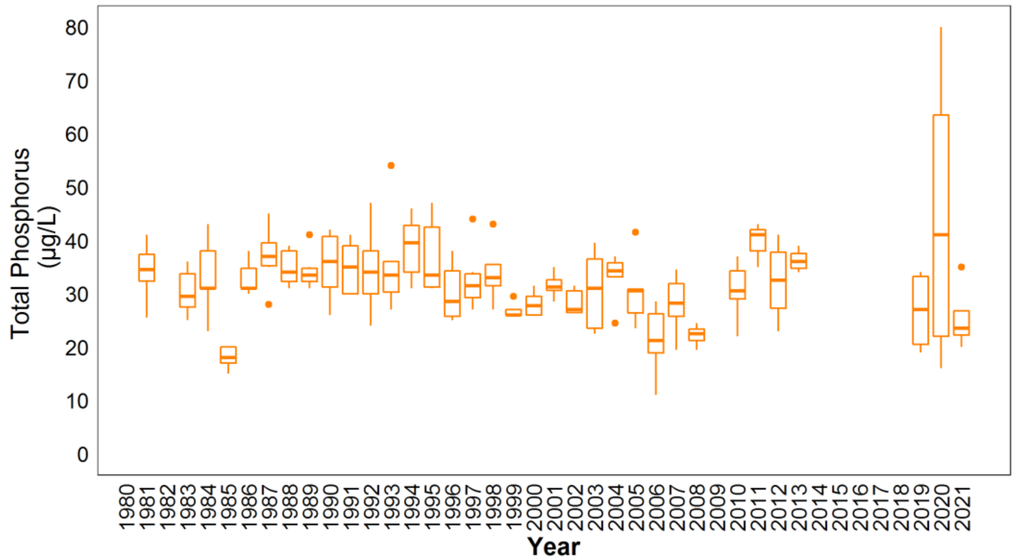
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

Box and Whisker Plot: a box-and-whisker plot, or boxplot, is a way of displaying all of our annual data. The median splits the data in half. The 75th percentile is the upper quartile of the data, and the 25th percentile is the lower quartile of the data. The top and bottom points are the largest and smallest observations.



Total Phosphorus (TP)

Trend analysis indicates there has been a significant decreasing trend of TP in Wabamun Lake since 1981 (Tau = -0.18, p = <0.001; Table 5).



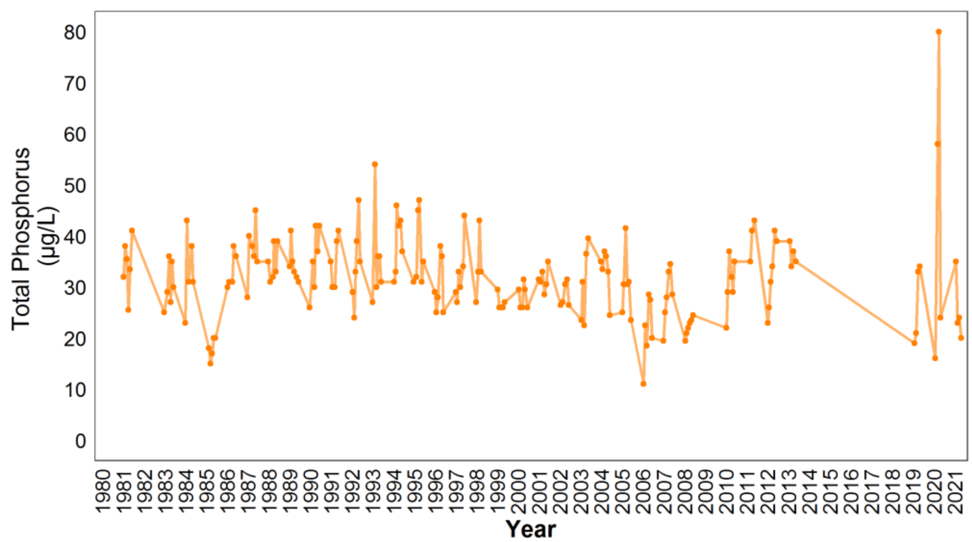


Figure 6. Monthly total phosphorus (TP) concentrations measured between May and October on sampling dates between 1981 and 2021 (n = 185). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Chlorophyll-*a* concentrations have been significantly decreasing in Wabamun Lake since 1980 (Tau = 0.14, p = 0.038; Table 5). TP and chlorophyll-*a* were significantly correlated (r = -0.14, p = 0.008).

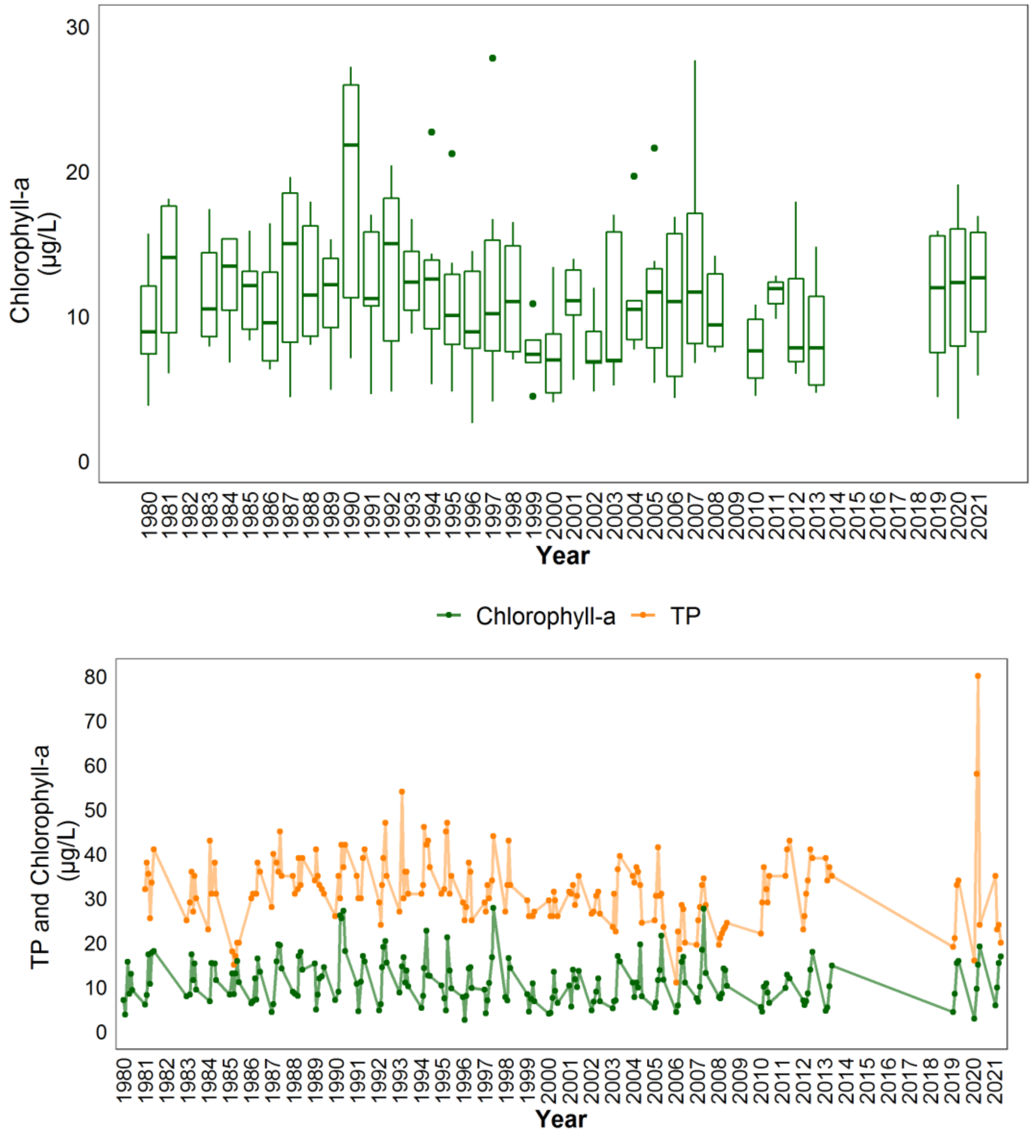


Figure 7. Monthly chlorophyll-*a* concentrations measured between May and October on sampling dates between 1980 and 2021 (n = 190). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 1980 and 2021 (Tau = 0.92, p = <0.001) in Wabamun Lake. The magnitude of change is relatively high (slope = 4.11 mg/L per year), with levels of TDS having increased by nearly 150 mg/L since 1980 (Figure 8). Previous trend analysis performed by Alberta Environment and Parks indicates these changes are likely related to the lake receiving treated North Saskatchewan River water.[13] The increasing trend has appeared to slow in recent years, which could be related to the reduction of the volume of treated water entering the lake in starting in 2007.[14]

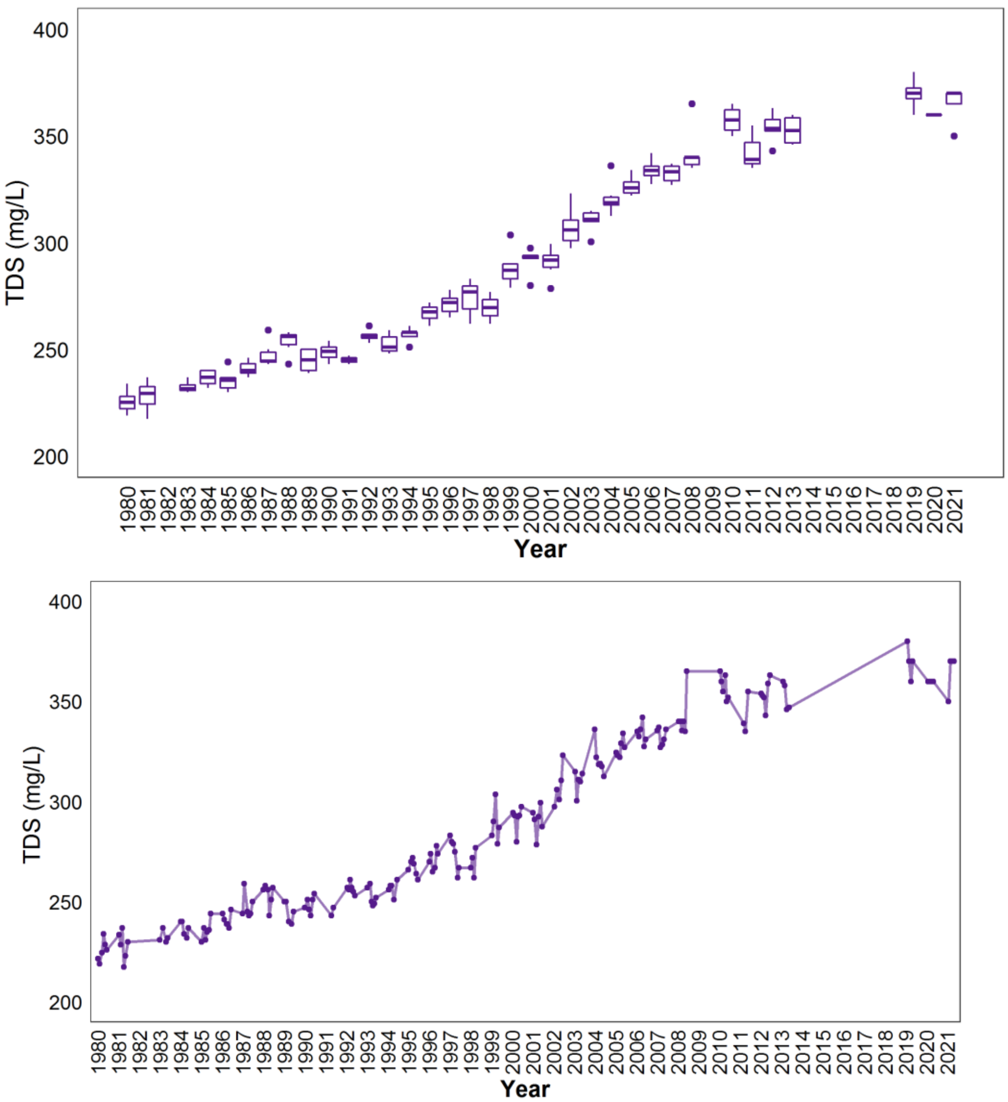


Figure 8. Monthly TDS values measured between May and September on sampling dates between 1980 and 2021 (n = 185). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

[13] Casey, R. (2011). Water Quality Conditions and Long-Term Trends in Alberta Lakes. Alberta Environment and Parks.

Due to the significant increasing trend of TDS in Wabamun Lake, exploring the specific major ions which may be driving this trend is important to determine. Trend analysis of major ions at Wabamun Lake indicates that sulphate, sodium, and alkalinity (bicarbonate, carbonate) are likely the key parameters that drove the historical increase in TDS (Figure 9). Most parameters which displayed significant increasing trends (sodium, potassium, sulphate, alkalinity) followed the trajectory of TDS over time and showed an initial level increase, followed by stabilization. Only chloride and magnesium differ as they have appeared to continue to increase in recent years.

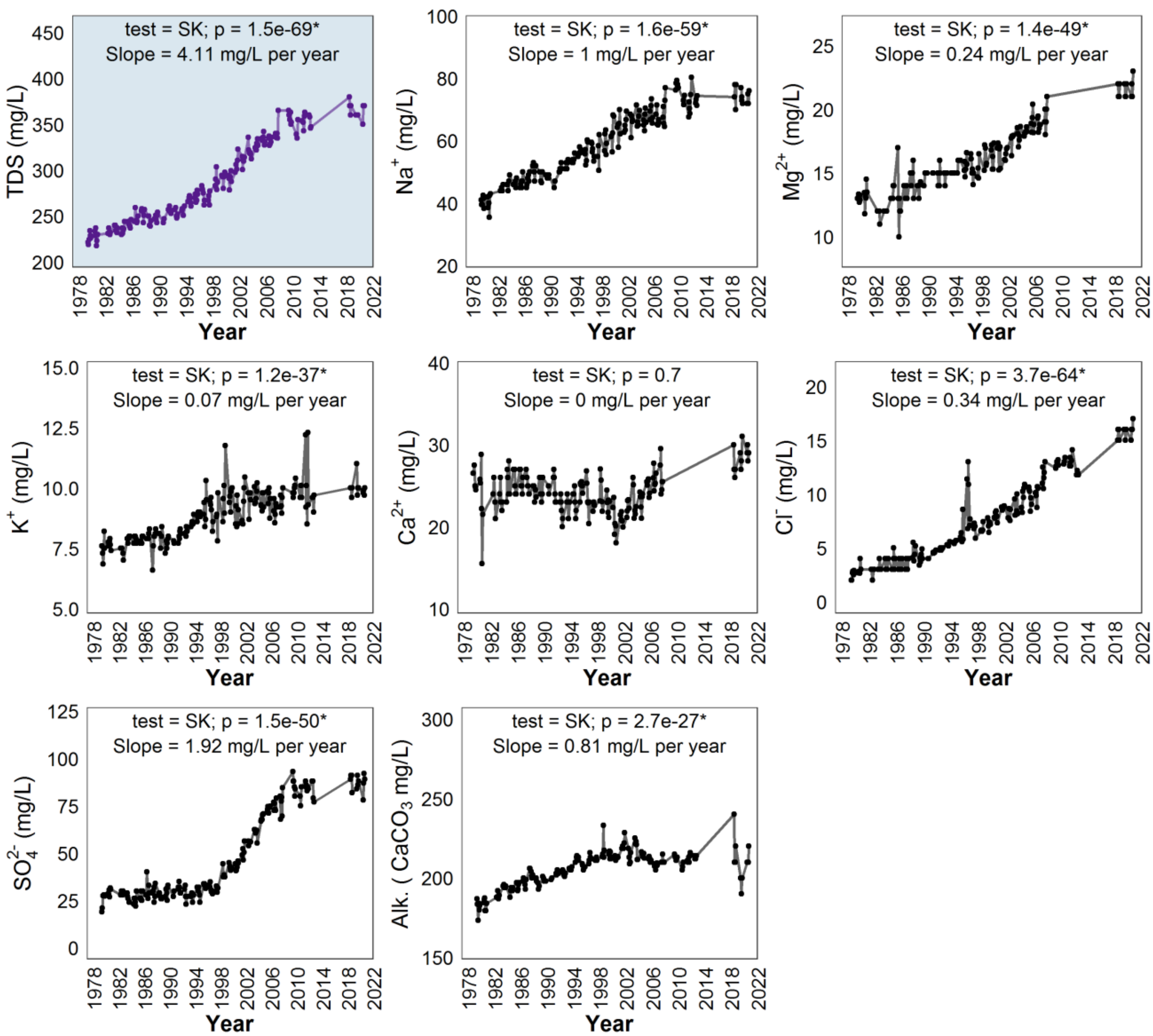
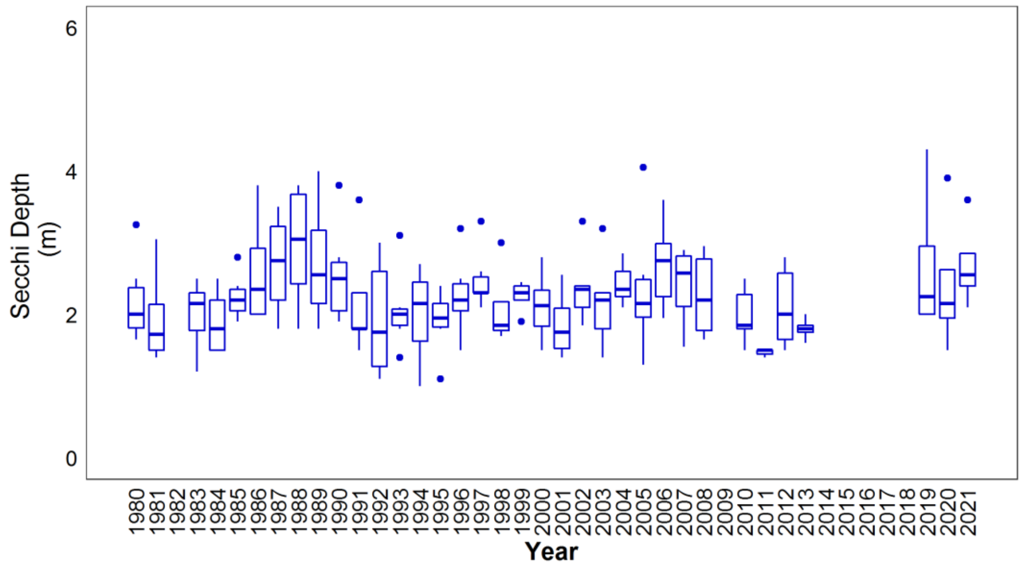


Figure 9. Concentrations of TDS (top left, blue panel), major ions (sodium = Na^+, magnesium = Mg^{2+}, potassium = K^+, calcium = Ca^{2+}, chloride = Cl^-, sulphate = SO_4^{2-}), and total alkalinity (Alk., as mg/L $CaCO_3$) measured monthly between May and October on sampling dates between 1980 and 2021. Also represented is the monotonic trend results for each parameter; test used (MK = Mann Kendall, SK = Seasonal Kendall), significance of test (p; assessed as significance when $p < 0.05$, marked with '*' if significant), and the slope of the trend. Test selection follows method outline in the *ALMS Guide to Trend Analysis on Alberta Lakes.* Note that some ions had insufficient data (*I.D.*) therefore trends were not calculated. The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Trend analysis of Secchi depth over time indicates it has not significantly changed in Wabamun Lake since 1980 (Tau = 0.06, p = 0.17; Table 5).



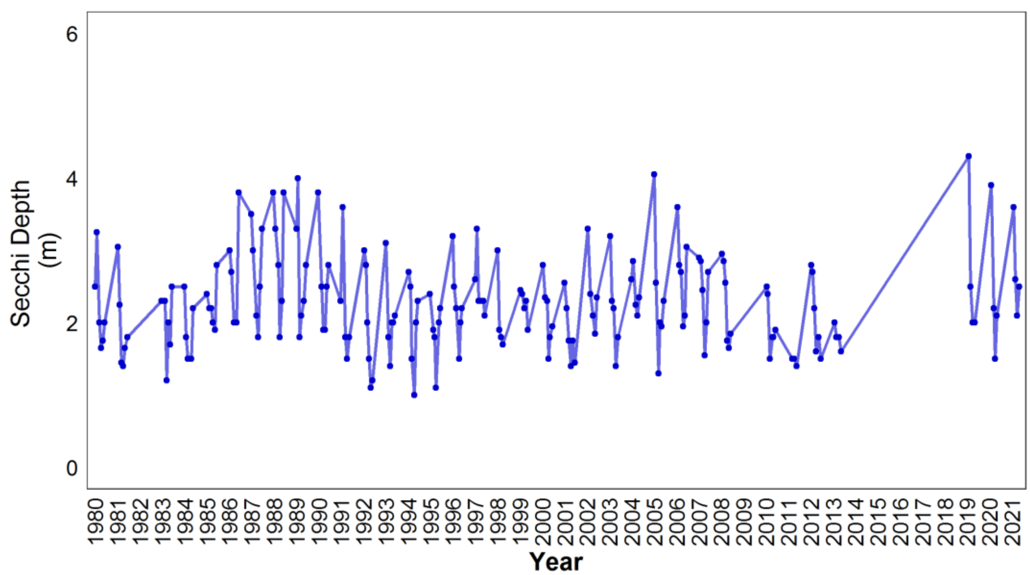


Figure 9. Monthly Secchi depth values measured between May and October on sampling dates between 1980 and 2021 (n = 191). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 5. Results of trend tests using total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from May and October, for sampled years from 1980 or 1981 to 2021 on Wabamun Lake data.

Definition	Unit	Total Phosphorus (TP)	Chlorophyll-a	Total Dissolved Solids (TDS)	Secchi Depth
Statistical Method	-	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall
The strength and direction (+ or -) of the trend between -1 and 1	Tau	-0.18	-0.14	0.92	0.06
The extent of the trend	Slope (units per year)	-0.19	-0.06	4.11	2.94×10^{-3}
The statistic used to find significance of the trend	Z	-3.30	-2.64	17.63	1.36
Number of samples included	n	185	190	185	191
The significance of the trend	*p*	9.68×10^{-4}*	8.34×10^{-3}*	1.47×10^{-69}*	0.17

*$p < 0.05$ is significant within 95%