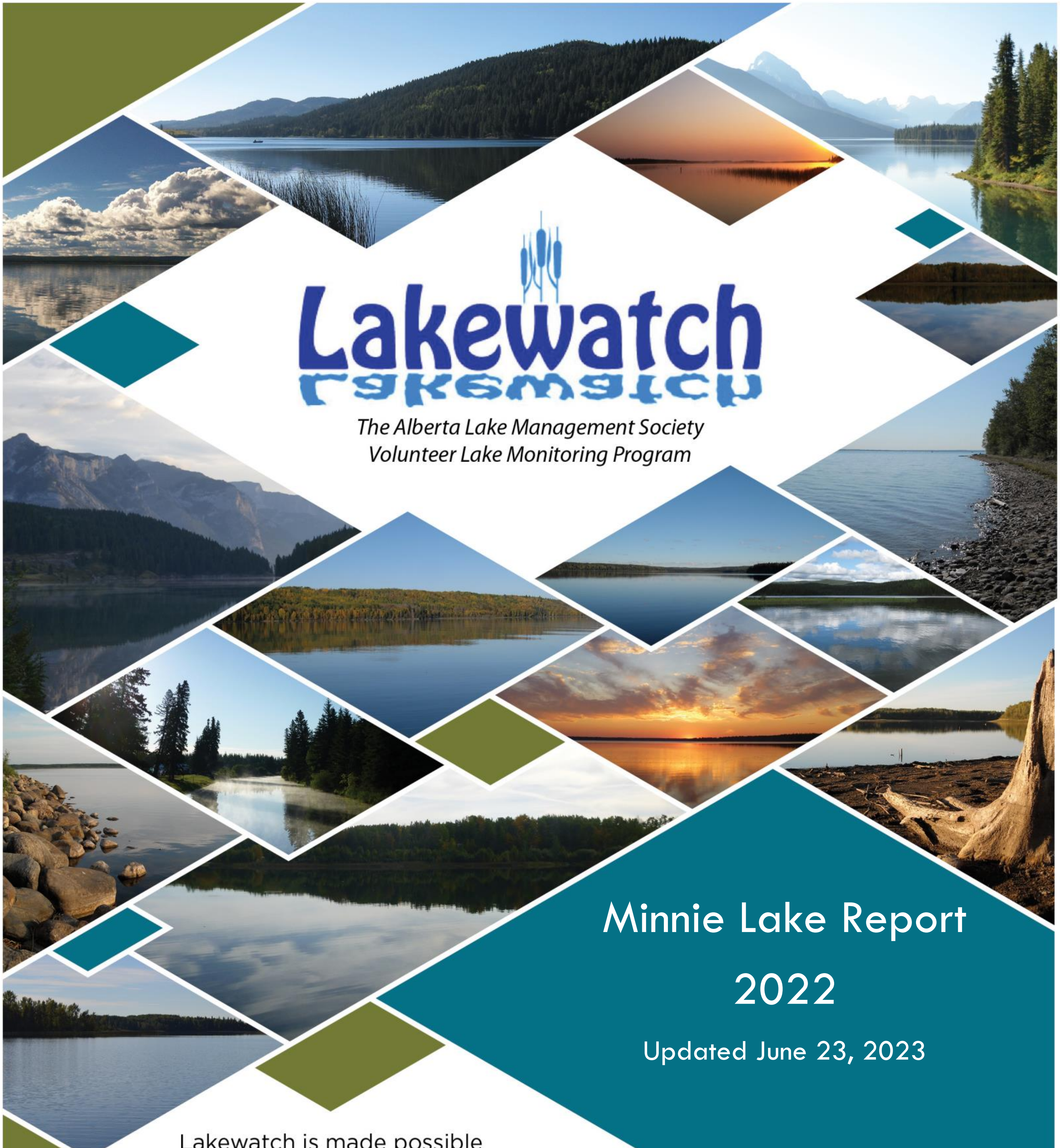

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Minnie Lake Report 2022

Updated June 23, 2023

Lakewatch is made possible with support from:

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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 Garry & Nadine Kissel for their commitment to collecting data at Minnie Lake. We would also like to thank Kurstyn Perrin and Dominic Wong, who were summer technicians in 2022. 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.

MINNIE LAKE

Minnie Lake is a small lake located west of Bonnyville and northeast of Glendon, within the Beaver River Watershed. The lake is 2 km long and 0.6 km wide, with a surface area of 0.84 km^2. Mean depth is 8.3 m and maximum depth is about 23 m, though water levels have decreased since these values were calculated.

Minnie Lake. Photo by Laura Redmond, 2017.

The shoreline of the lake hosts two municipal campsites, private cabins and recreational properties, agricultural land, and boreal forest. Minnie Lake is spring-fed by the Beverly channel aquifer and surface runoff from precipitation.

In 2006-2007 the lake experienced a winterkill, which decimated stocks of northern pike and yellow perch that previously supported a recreational fishery. Fish populations have not recovered to date.

The watershed area for Minnie Lake is 4.43 km^2 and the lake area is 0.67 km^2. The lake to watershed ratio of Minnie Lake is 1:7. A map of the Minnie Lake watershed area can be found at http://alms.ca/wp-content/uploads/2016/12/Minnie.pdf

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

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 Minnie Lake was 12 µg/L (Table 2), falling into the mesotrophic, moderately productive trophic classification. This value falls on the lower end of all previously observed historical averages going back to 1985 (Table 2). TP ranged from a minimum of 6.3 µg/L on August 10th, to a maximum of 17 µg/L on July 6th (Figure 1).

The average chlorophyll-*a* concentration in 2022 was 4.5 µg/L (Table 2), falling into the mesotrophic, or moderately productive trophic classification. Chlorophyll-*a* was highest during the October 6th sampling event at 7.4 µg/L, and lowest at 2.8 µg/L on August 10th.

The average TKN concentration was 1.3 mg/L (Table 2). TKN levels were relatively higher during the October 6th sampling event, relative to the consistent levels observed earlier in the summer (Figure 1).

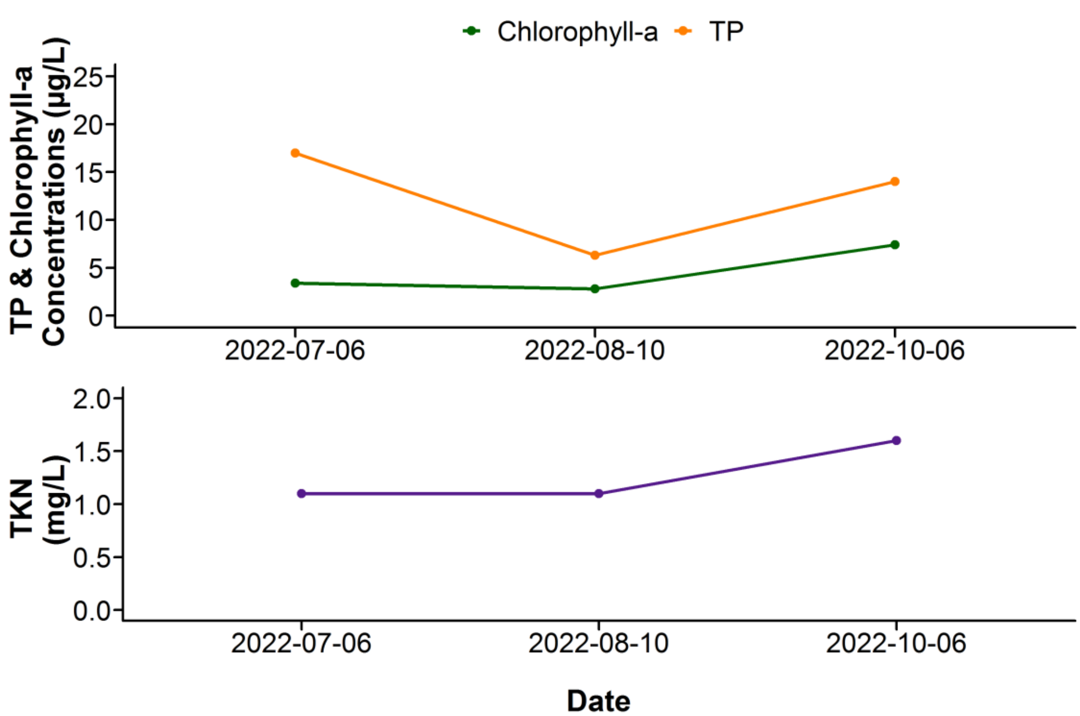


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Minnie Lake.

Average pH was measured as 8.60 in 2022, buffered by high alkalinity (350 mg/L $CaCO_3$) and bicarbonate (390 mg/L HCO_3). Sulphate was most abundant ion, followed be bicarbonate, then by magnesium and sodium with all other ions quite a bit lower in abundance. The major ions together contributed to a high conductivity of 1467 µS/cm (Figure 2, top; Table 2). Minnie Lake is in the high range of ion levels, compared to other LakeWatch lakes sampled in 2022. (Figure 2, bottom).

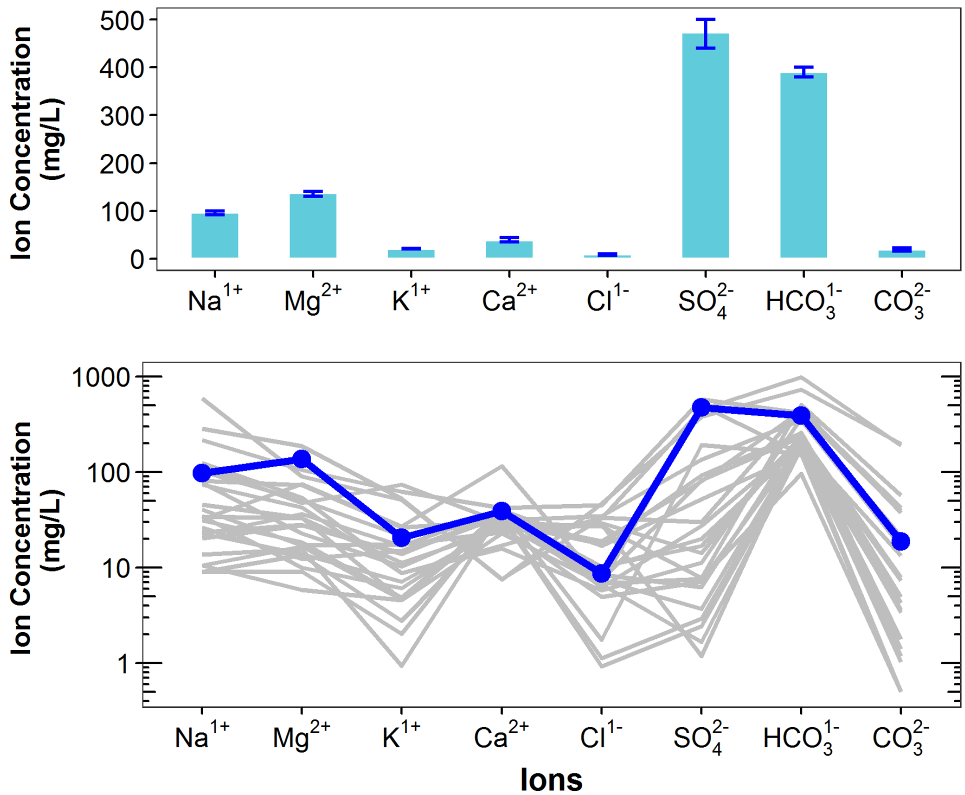


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Minnie Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Minnie Lake (blue line) compared to 26 lake basins (gray lines) sampled through the LakeWatch program in 2022 (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 measured at Minnie Lake in 2022, and Arsenic was the only metal to exceed the CCME chronic guideline for the protection of aquatic life (Table 3).

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 Minnie Lake in 2022 was 5.30 m, corresponding to an average Secchi depth of 2.65 m (Table 2). Euphotic depth varied over the season, ranging from as deep as 5.50 m on July 6th and August 10th, to 4.90 m on October 10th (Figure 3).

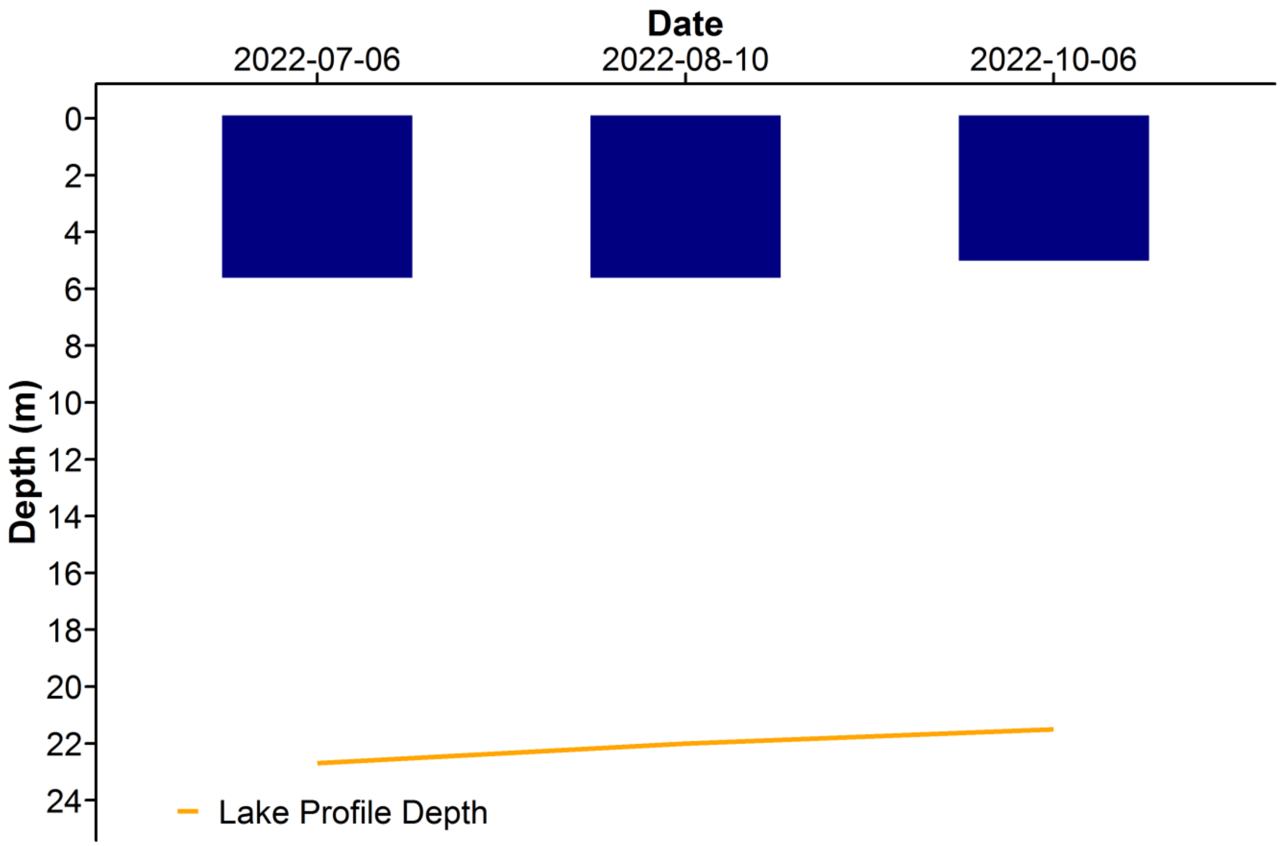


Figure 3. Euphotic depth values measured four times over the course of the summer at Minnie Lake in 2022.

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 Minnie Lake varied throughout the summer, with the August 10th sampling date having the warmest temperatures at 20.7°C (Figure 4a). The lake was strongly stratified during each sampling trip and was especially strong during the July and August sampling events. During each sampling event, the bottom layer of water (hypolimnion) approached 4°C.

Minnie 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). During the July and August sampling events, an appreciable increase in dissolved oxygen occurred at the thermocline, or mixing depth, at 7 m on both dates. This is likely due to accumulation of algae or cyanobacteria which are adapted to growing in high abundance at the thermocline, which photosynthesizing and produce a high amount of oxygen at the thermocline depth.

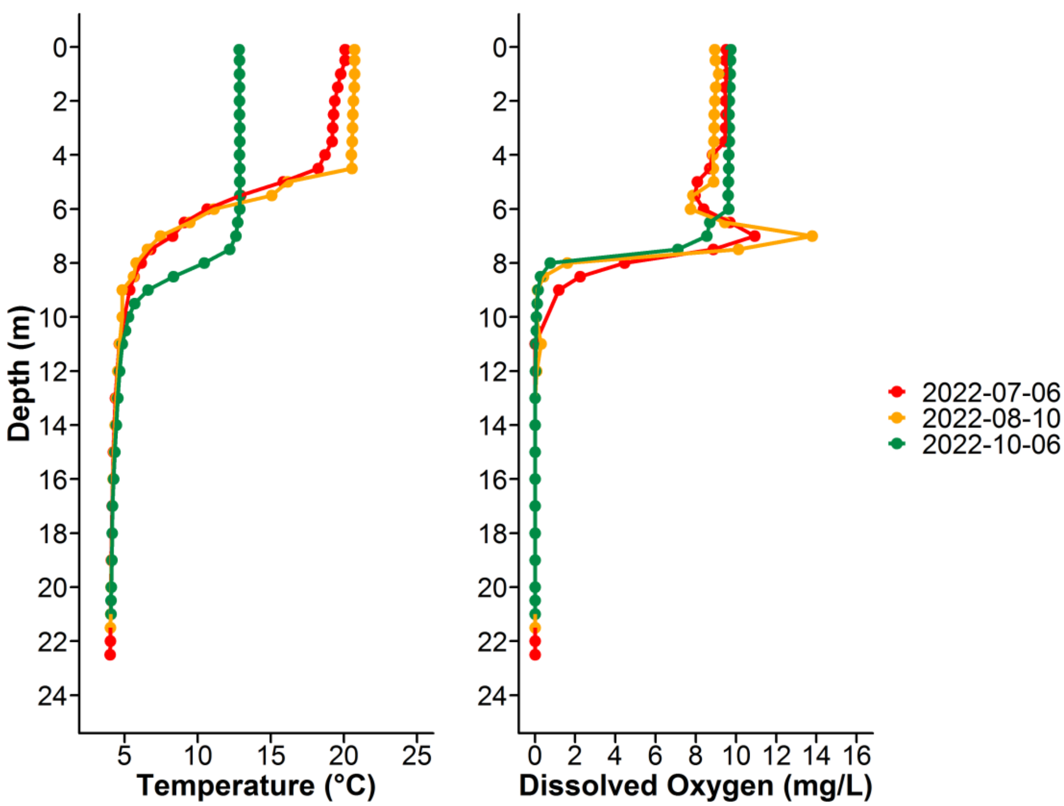


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Minnie Lake measured four times over the course of the summer of 2022.

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 Minnie Lake fell below the recreational guideline of 10 μg/L during every sampling event in 2022. In addition, microcystin levels from the July 6th sampling event were below the laboratory detection limit of 0.10 μg/L. A value of 0.05 μg/L is assigned when a value is below detection, in order to calculate an average. Despite low levels of microcystin detected during the three sampling events, caution should be observed in areas of the lake where significant cyanobacteria accumulation occurs.

Table 1. Microcystin concentrations measured four times at Minnie Lake in 2022.

Date	Microcystin Concentration (μg/L)
6-Jul-22	<0.1
10-Aug-22	0.29
6-Oct-22	1.59
Average	0.64

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 for aquatic invasive species involved sampling with a 63 μm plankton net at three sample sites. This monitoring is designed to detect juvenile Dreissenid mussel veligers and spiny water flea. In 2022, no mussels or spiny water flea were detected at Minnie 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.

A watermilfoil specimen was collected from Minnie Lake on July 6th and was 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 Minnie Lake in 2022 were slightly below the historical average. Recent levels indicate the lake has increasing after a prolonged period of dropping water levels (Figure 5). Despite the recent increase, the lake is still nearly 2.5 m lower than the historical high recorded at the beginning of the historical in 1981.

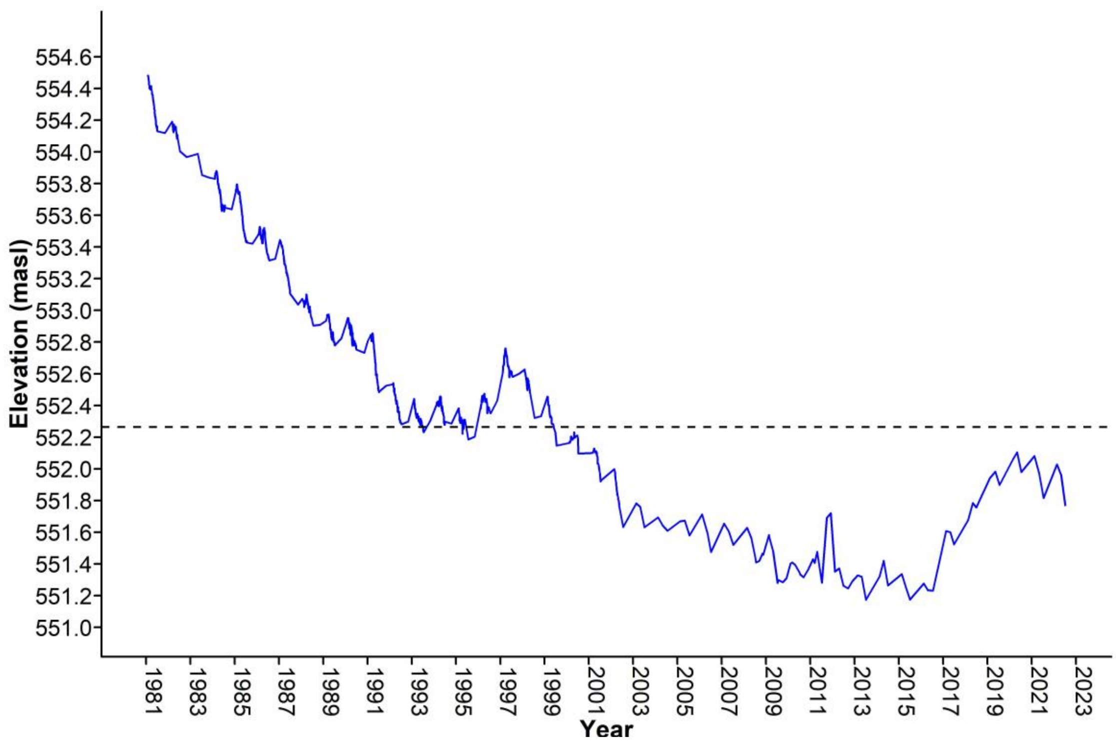


Figure 5. Water levels measured at Minnie Lake in metres above sea level (masl) from 1981-2022. Data retrieved from Alberta Environment and Parks and/or Environment and Climate Change Canada. Black dashed line represents historical yearly average water level.

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.

Minnie Lake experienced a warmer, drier, and slightly windier summer with more solar radiation than normal (Figure 6). Despite a calmer and slightly warmer spell leading up to the October 6th sampling event, the thermocline was much deeper than earlier in the summer.

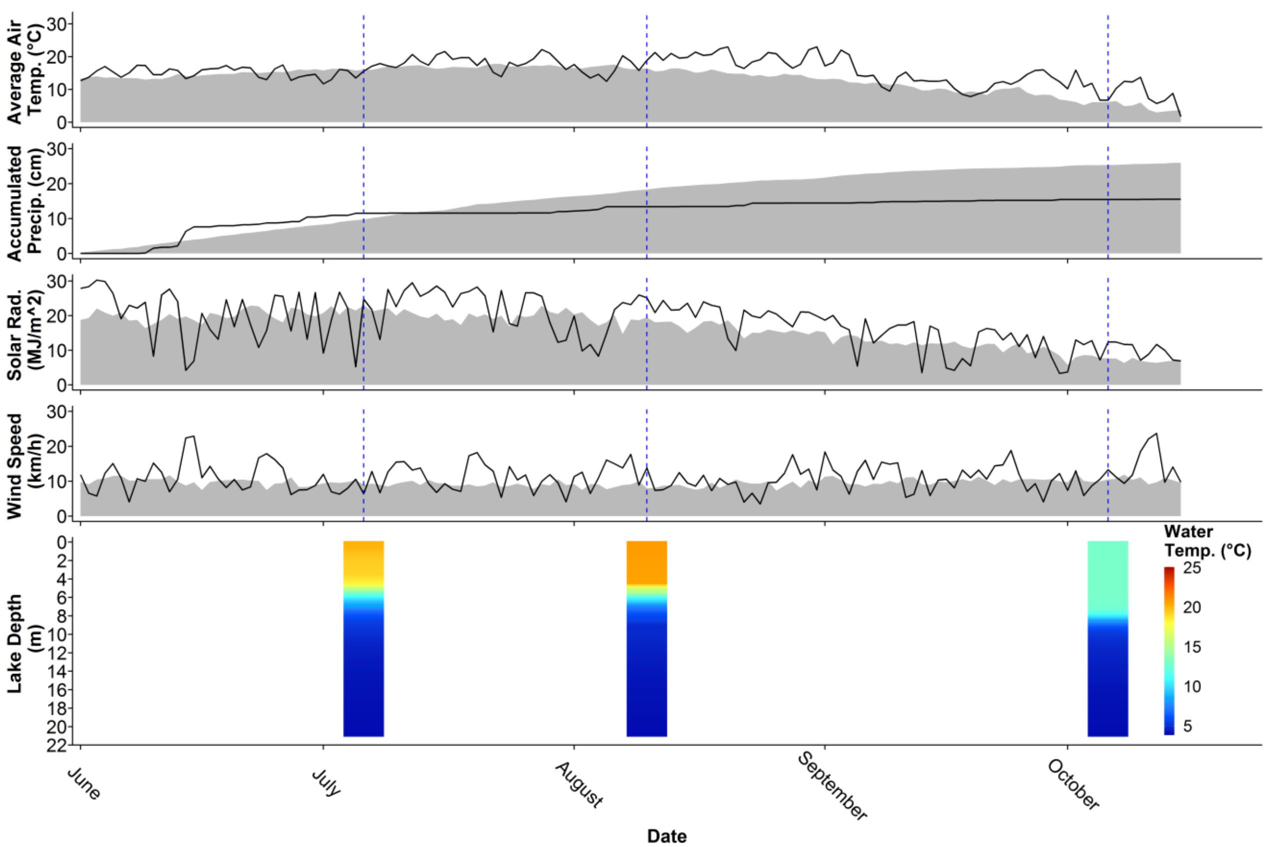


Figure 6. Average air temperature (°C) accumulated precipitation (cm), and wind speed (km/h) measured from 'Hoselaw AGCM' weather station, as well as solar radiation (MJ/m^2) measured from 'Dupre AGCM,' as well as Minnie Lake temperature profiles, interpolated (°C). Black lines indicate 2022 levels, gray indicates long-term normals, and blue lines indicate sampling dates for Minnie Lake over the summer. Further information about the weather data provided is available in the LakeWatch 2022 Methods report. Weather data provided by Agriculture, Forestry and Rural Economic Development, Alberta Climate Information Service (ACIS) https://acis.alberta.ca (retrieved March 2023).

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

Parameter	1978	1979	1985	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
TP (µg/L)	/	/	21	40	4	39	52	45	32	34	24	19	29
TDP (µg/L)	/	/	11	24	23	27	26	22	21	24	11	8	10
Chlorophyll-*a* (µg/L)	/	/	6.0	5.3	4.0	3.4	5.2	6.4	3.0	4.1	4.8	7.0	9.4
Secchi depth (m)	/	/	/	4.50	2.20	4.70	3.90	3.80	3.30	3.70	2.60	1.90	1.90
TKN (mg/L)	/	/	1.2	1.5	1.5	1.6	1.8	1.7	1.6	1.5	1.5	1.5	1.5
NO_2-N and NO_3-N (µg/L)	/	/	6	21	8	12	14	11	3	38	3	3	2
NH_3-N (µg/L)	/	/	50	6	36	99	35	42	24	50	31	25	22
DOC (mg/L)	/	/	13	18	20	20	19	19	22	18	18	19	18
Ca^{2+} (mg/L)	29	30	19	27	26	22	26	24	23	23	26	23	29
Mg^{2+} (mg/L)	90	87	91	120	121	123	131	121	144	124	144	142	136
Na^{+} (mg/L)	62	61	68	94	97	97	96	96	99	103	96	97	93
K^{+} (mg/L)	12	9	13	23	19	19	19	20	21	20	20	20	20
SO_4^{2-} (mg/L)	223	211	197	399	421	409	400	451	391	433	440	428	420
Cl^{-} (mg/L)	3	3	4	7	7	8	7	8	7	8	8	8	8
CO_3^{2-} (mg/L)	/	/	21	26	31	23	29	28	45	38	37	38	32
HCO_3^{-} (mg/L)	340	398	368	408	390	412	393	398	359	425	376	360	354
pH	8.90	8.60	8.60-8.90	8.63	8.80	8.65	8.77	8.73	8.88	8.78	8.82	8.86	8.84
Conductivity (µS/cm)	922	981	992	1340	1323	1370	1350	1368	1418	1360	1400	1400	1320
Hardness (mg/L)	442	435	422	562	564	562	605	558	649	567	660	634	630
TDS (mg/L)	614	611	595	897	914	903	902	943	906	948	962	932	912
Microcystin (µg/L)	/	/	/	0.13	0.11	0.08	0.11	0.14	0.09	0.08	0.07	0.11	0.12
Total Alkalinity (mg/L $CaCO_3$)	324	316	338	378	372	376	371	373	369	352	370	356	344

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

Parameter	2018	2019	2021	2022
TP (µg/L)	28	41	25	12
TDP (µg/L)	9	11	9	5
Chlorophyll-*a* (µg/L)	8.1	19.4	7.8	4.5
Secchi depth (m)	2.30	1.58	1.81	2.65
TKN (mg/L)	1.5	1.6	1.6	1.3
NO_2-N and NO_3-N (µg/L)	4	2	6	3
NH_3-N (µg/L)	39	15	22	12
DOC (mg/L)	19	20	18	17
Ca (mg/L)	34	36	44	39
Mg (mg/L)	130	130	135	137
Na (mg/L)	94	93	96	96
K (mg/L)	20	19	20	20
SO_4^{2-} (mg/L)	423	467	490	473
Cl^- (mg/L)	8	9	9	9
CO_3 (mg/L)	27	46	34	19
HCO_3 (mg/L)	368	347	380	390
pH	8.72	8.85	8.74	8.6
Conductivity (µS/cm)	1375	1400	1500	1467
Hardness (mg/L)	628	640	672	660
TDS (mg/L)	918	973	1000	983
Microcystin (µg/L)	0.27	0.75	0.08	0.64
Total Alkalinity (mg/L $CaCO_3$)	348	360	370	350

Table 3. Concentrations of metals measured in Minnie 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)	2008	2009	2010	2011	2013	2014	2021	2022	Guidelines
Aluminum µg/L	13.7	13	14.26	14.84	22.55	17.4	9.4	6	100[a]
Antimony µg/L	0.382	0.375	0.392	0.3725	0.3685	0.349	0.296	0.289	/
Arsenic µg/L	9.15	9.33	9.56	9.07	9.83	9.875	7.58	6.82	5
Barium µg/L	20.6	18.7	18.5	18.25	12.65	12.35	23	15.3	/
Beryllium µg/L	<0.003	<0.003	0.005	0.0015	0.0057	0.004	0.0015	0.0015	100[c,d]
Bismuth µg/L	0.0073	0.0057	0.00385	0.0005	0.00795	0.0005	0.0015	0.0015	/
Boron µg/L	162	205.5	159.5	204.5	186.5	185	179	198	1500
Cadmium µg/L	0.0124	0.0187	0.01725	0.01385	0.0036	0.00186	0.005	0.005	0.37[b]
Chromium µg/L	0.494	0.394	0.169	0.2575	0.3065	0.292	0.05	0.05	/
Cobalt µg/L	0.111	0.092	0.0972	0.07485	0.09775	0.0687	0.087	0.048	50,1000[c,d]
Copper µg/L	0.332	2.09	0.6815	1.0825	1.3	0.9025	0.33	0.19	4[b]
Iron µg/L	10.9	43.6	16.1	8.9	29.3	16.85	15.1	4.7	300
Lead µg/L	0.0274	0.0544	0.0851	0.03275	0.0617	0.01115	0.017	0.011	7[b]
Lithium µg/L	74.1	101.5	84.05	106.5	93.95	92.95	98.4	91.1	2500[d]
Manganese µg/L	8.61	6.36	5.905	15.75	4.515	6.78	14.1	5.51	210[e]
Molybdenum µg/L	0.799	0.727	0.746	0.735	0.6685	0.5695	0.361	0.307	73
Nickel µg/L	0.271	0.665	0.3805	0.15125	0.5225	0.3475	0.45	0.37	150[b]
Selenium µg/L	0.2	0.292	0.232	0.228	0.089	0.123	0.4	0.1	1
Silver µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.001	0.0005	0.25
Strontium µg/L	74	69.7	55	73.25	49.7	58.7	141	97.6	/
Thallium µg/L	0.0026	0.0029	0.00555	0.000275	0.0015	0.00085	0.001	0.001	0.8
Thorium µg/L	0.0628	0.00215	0.01825	0.01015	0.0321	0.01137	0.004	0.003	/
Tin µg/L	0.0308	<0.03	0.015	0.015	0.015	0.00825	0.03	0.03	/
Titanium µg/L	0.667	0.691	1.0995	0.686	1.1145	0.685	0.3	0.15	/
Uranium µg/L	2.3	2.08	2.16	2.14	2.1	2.165	2.04	1.76	15
Vanadium µg/L	1.31	1.22	1.165	1.06	1.035	1.04	0.531	0.384	100[c,d]
Zinc µg/L	1.58	1.34	1.165	1.48	1.465	1.58	1.8	0.8	30[f]

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5
[b] Based on 2022 avg. water hardness (as $CaCO_3$) 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 2022 avg. water hardness (as $CaCO_3$) and avg. pH
[f] Based on 2022 avg. water hardness (as $CaCO_3$), avg. pH, and avg. DOC with CCME equation
A forward slash (/) indicates an absence of data or guideline

LONG TERM TRENDS

Trend analysis was conducted on the parameters total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth to look for changes over time in Minnie Lake. In sum, significant increasing trends were observed in chlorophyll-*a* and TDS, and significant decreasing trends were detected for TP and Secchi depth. Secchi depth can be subjective and is sensitive to variation in weather; therefore, trend analysis must be interpreted with caution. Data is presented below as both line and box-and-whisker plots. Detailed methods are available in the *ALMS Guide to Trend Analysis on Alberta Lakes.*

Table 4. Summary table of trend analysis on Minnie Lake data from 2008 to 2022.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	2008-2022	Decreasing
Chlorophyll-*a*	2008-2022	Increasing
Total Dissolved Solids	2008-2022	Increasing
Secchi Depth	2008-2022	Decreasing

Definitions:

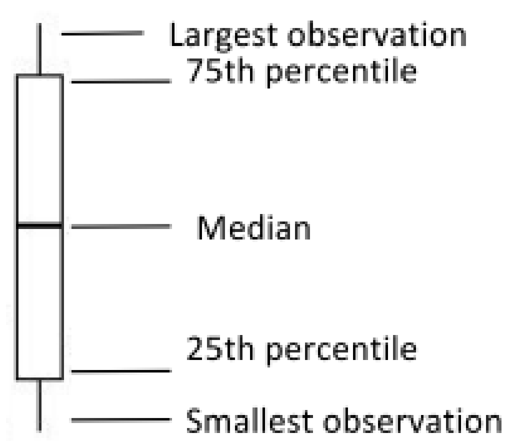
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

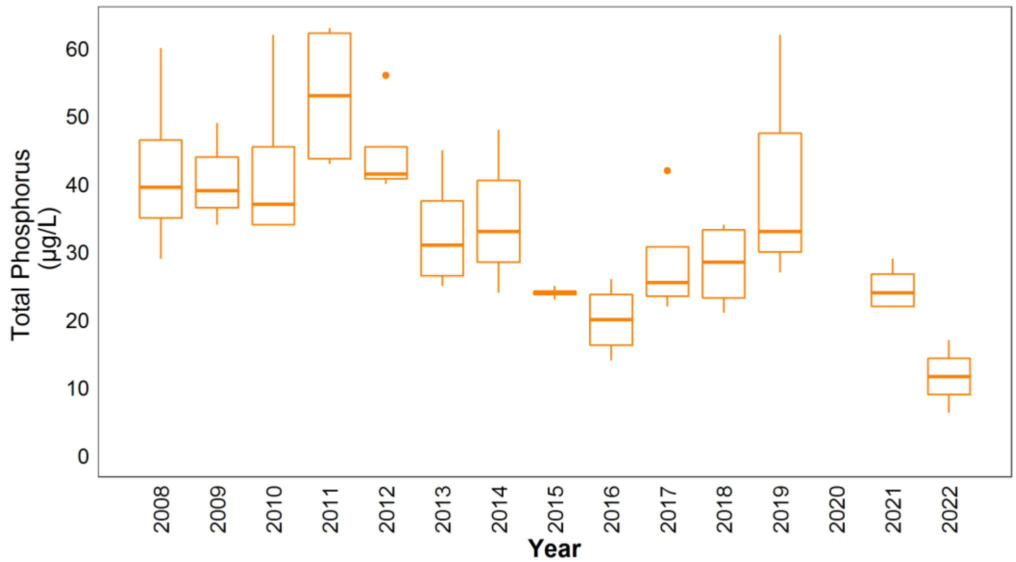
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

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 of TP over time showed that it has significantly decreased in Minnie Lake since 2008 (Tau = -0.50, p = <0.001).



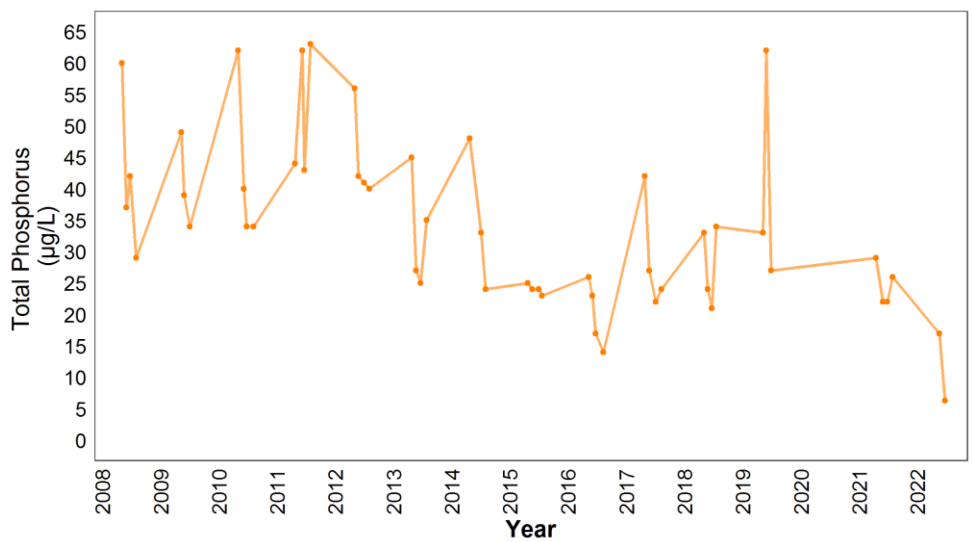
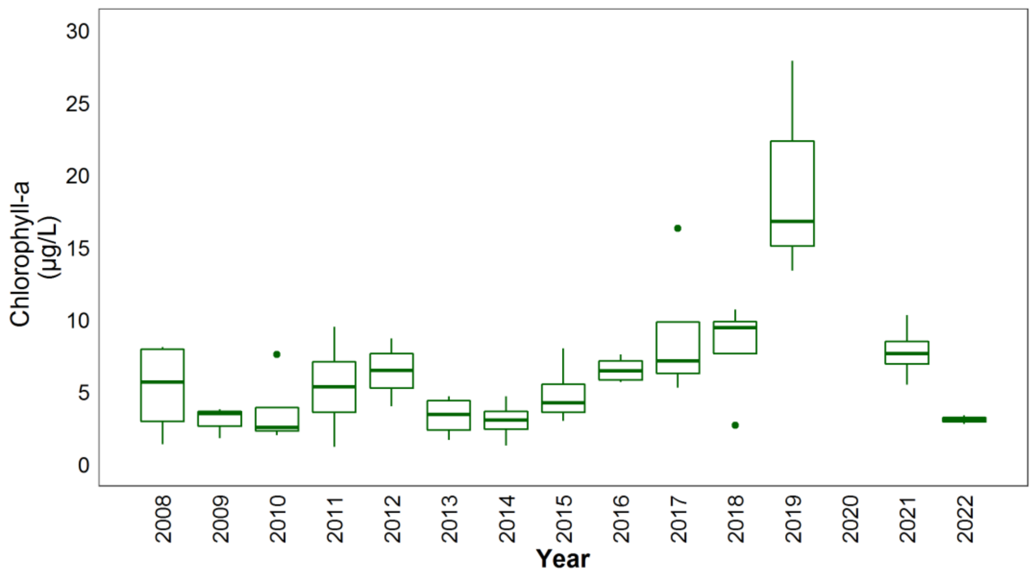


Figure 7. Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 2008 and 2022 (n = 51). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Trend analysis of chlorophyll-*a* over time showed that it has significantly increased in Minnie Lake since 2008 (Tau = 0.33, p = 0.003).



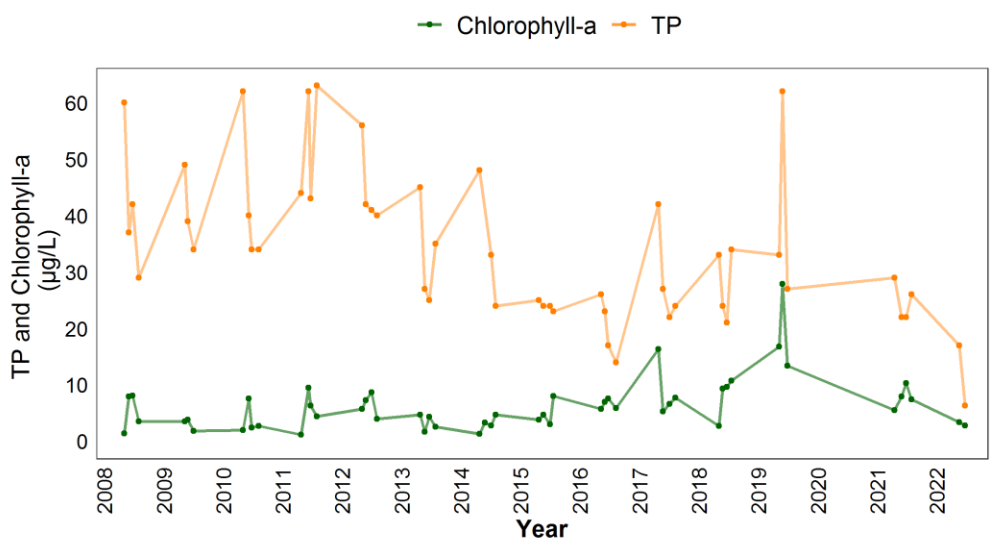
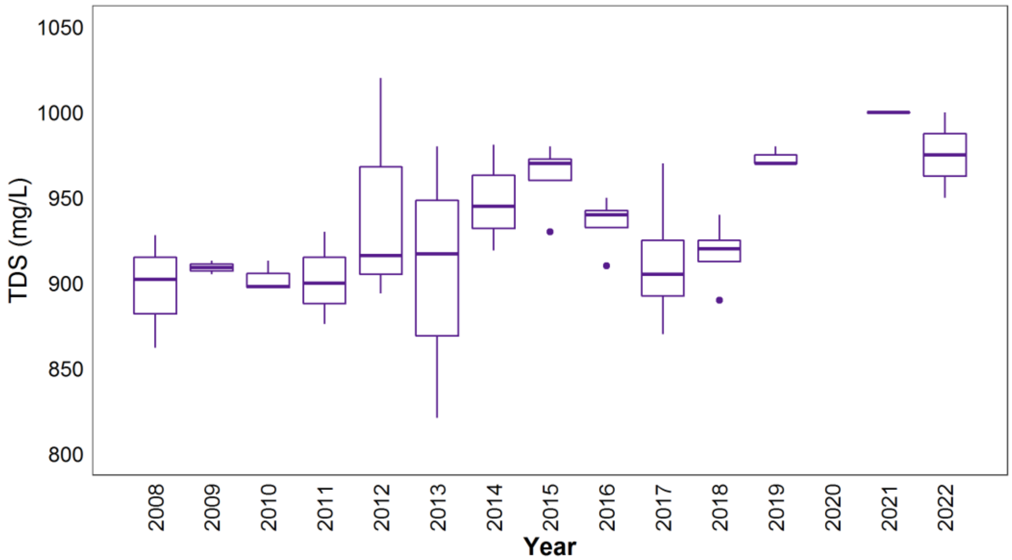


Figure 8. Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 2008 and 2022 (n = 52). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 2008 and 2022 (Tau = 0.33, p = 0.002) in Minnie Lake (Figure 9).



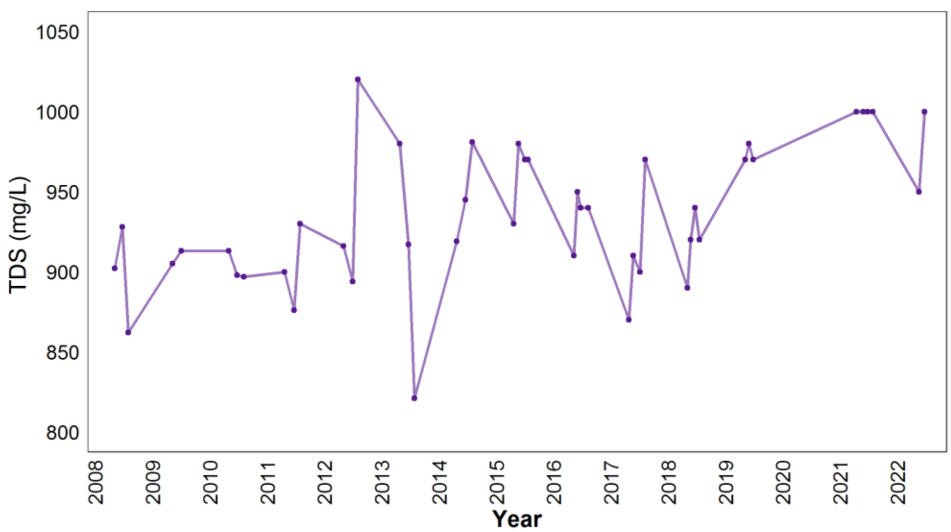


Figure 9. Monthly TDS values measured between June and September over the long term sampling dates between 2008 and 2022 (n = 45). The value closest to the 15^{th} day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Due to the significant increasing trend of TDS in Minnie Lake, exploring the specific major ions which may be driving this trend is important to determine. Trend analysis of major ions at Minnie Lake indicates that sulphate is the key parameter that drove the historical increase in TDS (Figure 10). Chloride and potassium also display significantly increasing trends over time, and while calcium does not have enough data to perform trend analysis, the figure indicate it has also increased in recent years. Interestingly, alkalinity (bicarbonate, carbonate) displays a significant decreasing trend, at appreciably high rate at -1.88 mg/L per year.

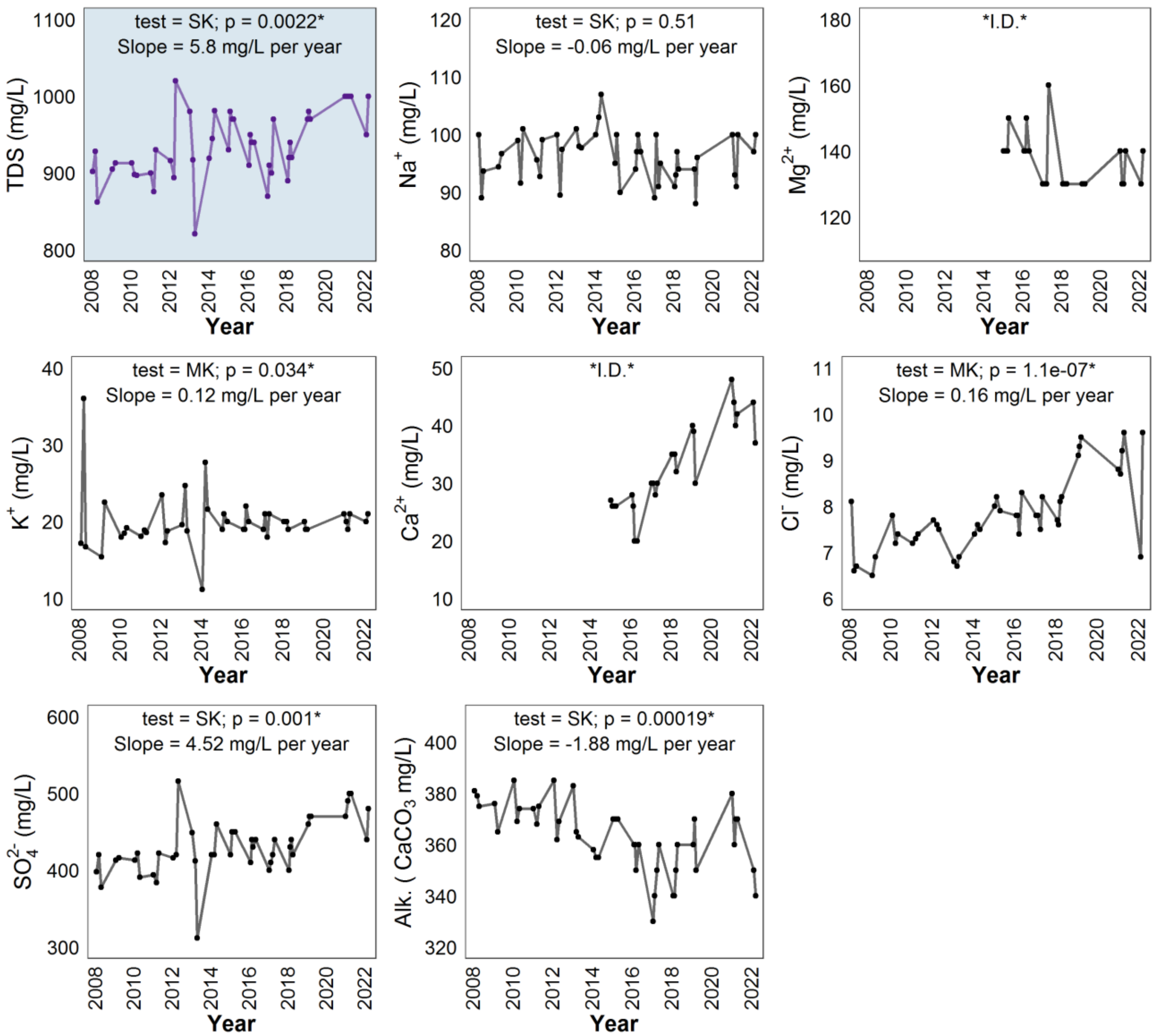
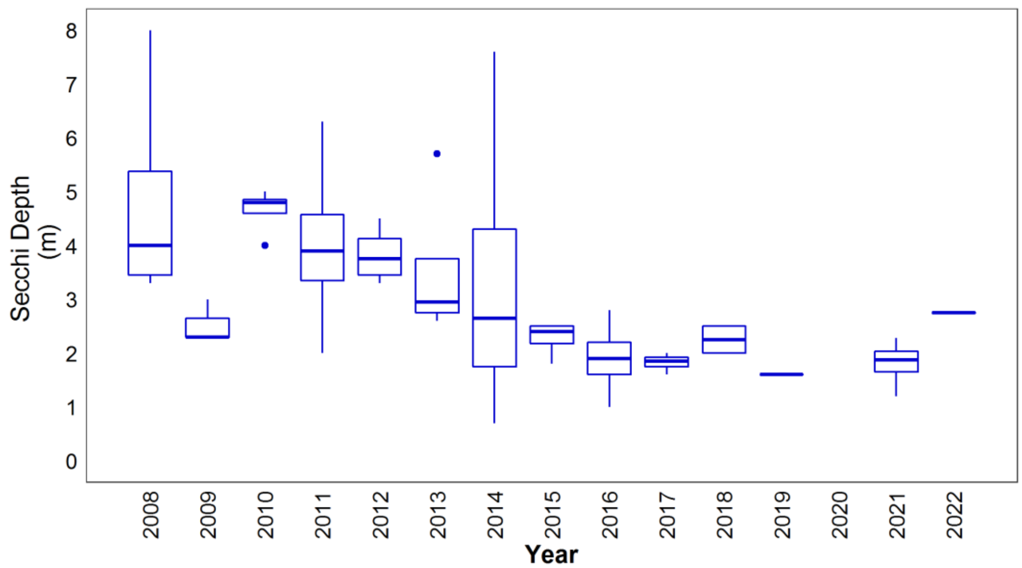


Figure 10. Concentrations of TDS (top left, blue panel), major ions (sodium = Na^+, magnesium = Mg^{2+}, potassium = K^+, calcium = Ca^{2+}, chloride = Cl^-, sulphate = SO_4^{2-}), and total alkalinity (Alk., as mg/L $CaCO_3$) measured monthly between June and September on sampling dates between 2008 and 2022. 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 showed that it has significantly decreased (the lake has become less clear) in Minnie Lake since 2008 (Tau = -0.51, *p* = <0.001).



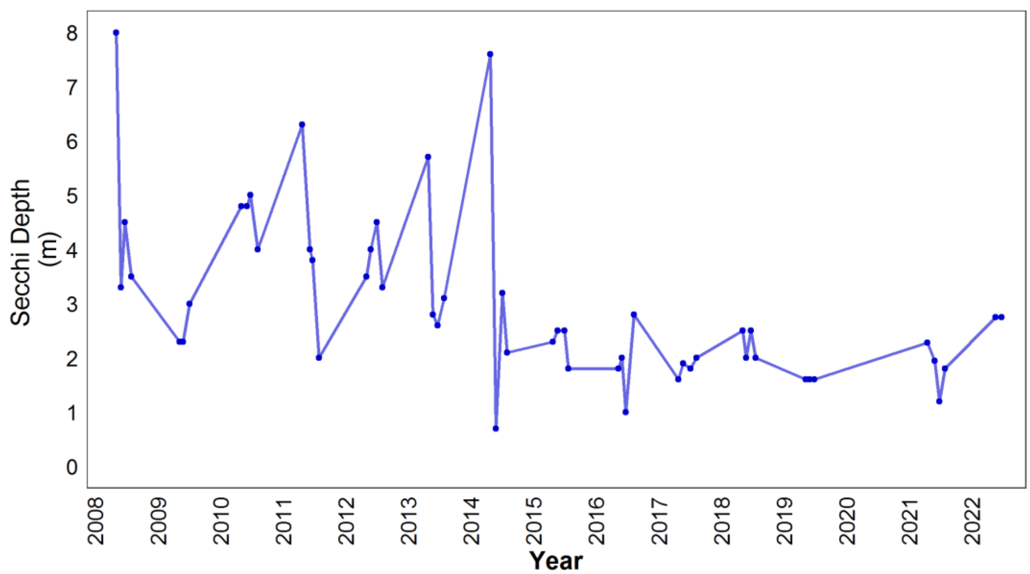


Figure 11. Monthly Secchi depth values measured between June and September on sampling dates between 2008 and 2022 (n = 52). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 5. Results of trend tests using total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from June to September, for sampled years from 2008-2022 on Minnie 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	-0.50	0.33	0.33	-0.51
The extent of the trend	Slope (units per Year)	-1.82	0.33	5.80	-0.20
The statistic used to find significance of the trend	Z	-4.80	2.99	3.07	-4.88
Number of samples included	n	51	52	45	52
The significance of the trend	p	1.56×10^{-6}*	2.81×10^{-3}*	2.18×10^{-3}*	1.08×10^{-6}*

*$p < 0.05$ is significant within 95%