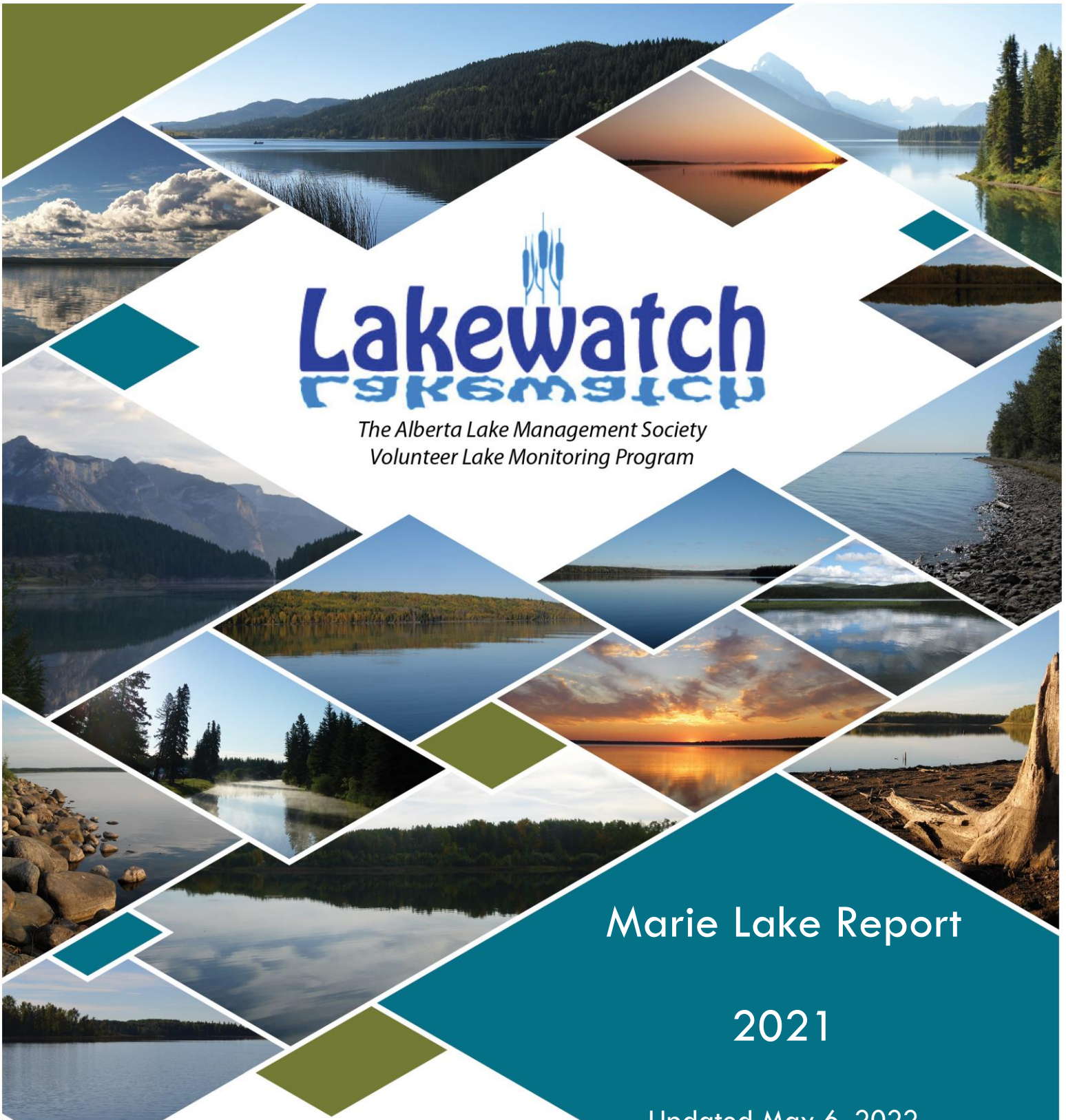


Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Marie Lake Report

2021

Updated May 6, 2022

Lakewatch is made possible with support from:

Alberta
LICA Environmental Stewards
Pigeon Lake Watershed Association
MD 61
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.

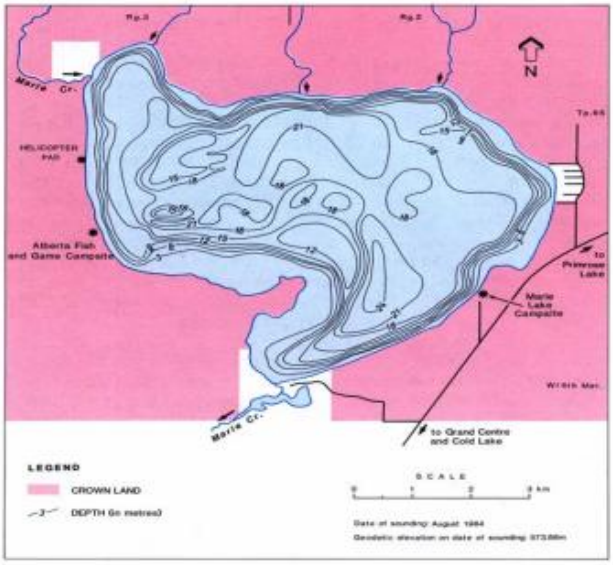
ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks to Dean & Pam Wood and Steve Vinek for their commitment to collecting data at Marie 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

MARIE LAKE

Marie Lake is located in the Beaver River Watershed, and lies approximately 26 km northeast of the Town of Cold Lake, in the central mixed wood natural subregion of Alberta.[1] Marie Lake is named after the Cree word Methae or Merai meaning "a fish", and may specifically refer to the burbot (Lota lota) prevalent throughout most of Alberta.[2] The Cree arrived in the late eighteenth century during the growth of the fur trade, via a popular trade route from Waterhen, Saskatchewan. Their arrival resulted in the displacement of the Beaver, Blackfoot, and Slavey tribes that were common in the area.[2] Marie Lake is over 26 m deep (Figure 2) with a slow flushing rate (a residence time of 14.5 years). It is mesotrophic and has a small littoral zone for its surface area of 36 km^2.



Bathymetric map of Marie Lake (Alberta Environment)

The shoreline is primarily sandy with macrophytes (aquatic plants) limited to a couple areas. A large macrophyte bed is located along the west shore stretching towards the north, and another lies on the western edge of the south bay. Macrophyte beds are dominated by bulrush, pondweed, and northern watermilfoil.[1] Sport fish include lake whitefish, walleye, northern pike, yellow perch, and burbot.

Marie Lake. Photo by Randi Newton, 2012

The watershed area for Marie Lake is 396.51 km^2 and the lake area is 37.39 km^2. The lake to watershed ratio of Marie Lake is 1:11. A map of the Marie Lake watershed area can be found at: http://alms.ca/wp-content/uploads/2016/12/Marie.pdf.

[1] Nat. Regions Committee, 2006. Nat. Regions and Subregions of AB. Compiled by D.J. Downing and WW Pettapiece. GoA Pub. No. T/852

[2] Mitchell, P. and E. Prepas. 1990. Atlas of Alberta Lakes, University of Alberta Press. Retrieved from http://sunsite.ualberta.ca/projects/alberta-lakes/

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 Marie Lake was 7 µg/L (Table 2), falling into the oligotrophic, or low productivity trophic classification. This value is on the lower end of historical averages. TP was lowest on the August 24th sampling event at 4.6 µg/L, and was highest at the end of the season at 11.0 µg/L on September 21st (Figure 1).

Average chlorophyll-*a* concentration in 2021 was 4.3 µg/L (Table 2), falling into the mesotrophic, or moderately productive trophic classification. Chlorophyll-*a* was lowest during the July 26th sampling event at 3.1 µg/L, and slightly increased later in the season and peaked at 5.4 µg/L on August 24th (Figure 1).

The average TKN concentration was 0.5 mg/L (Table 2) and varied very little through the season, from 0.42 mg/L to 0.65 mg/L (Figure 1).

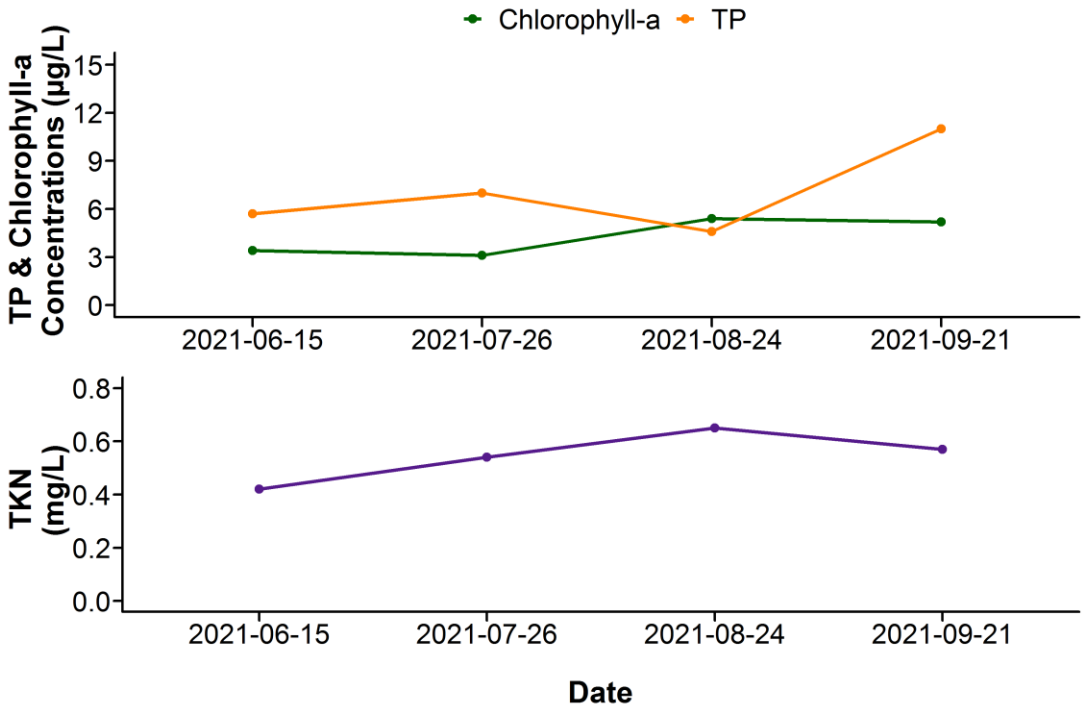


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Marie Lake.

Average pH was measured as 8.00 in 2021, buffered by low alkalinity (150 mg/L $CaCO_3$) and bicarbonate (182 mg/L HCO_3). Aside from bicarbonate, calcium was the dominant ion, contributing to a low conductivity of 255 µS/cm (Figure 2, top; Table 2). Marie Lake is in the low range of ion levels compared to other LakeWatch lakes sampled in 2021, with the exception of calcium, where it was moderate to high compared to most of the other lakes (Figure 2, bottom).

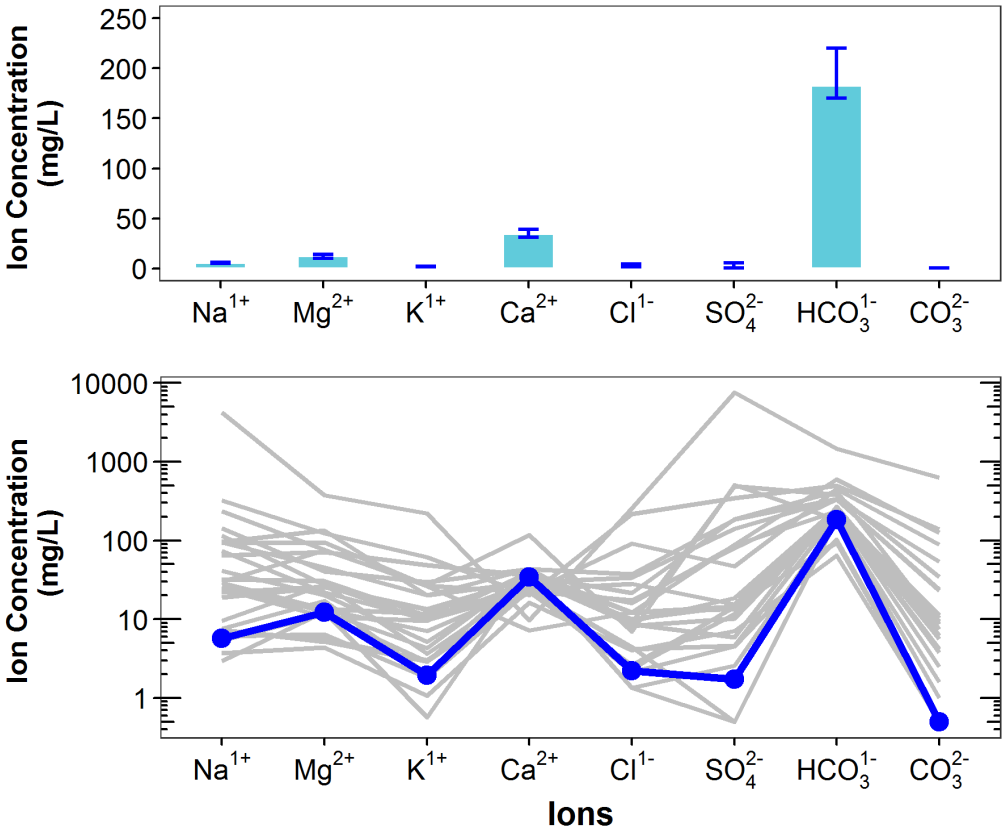


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Marie Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Marie 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 measured at Marie Lake in 2021, and no metal exceeds CCME guidelines (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 Marie Lake in 2021 was 8.16 m, corresponding to an average Secchi depth of 4.08 m (Table 2). The euphotic depth was consistently deep throughout the first three sampling events, being at around 9 m depth, and then dropped substantially during the September 21st sampling event, decreasing to 5.3 m (Figure 3).

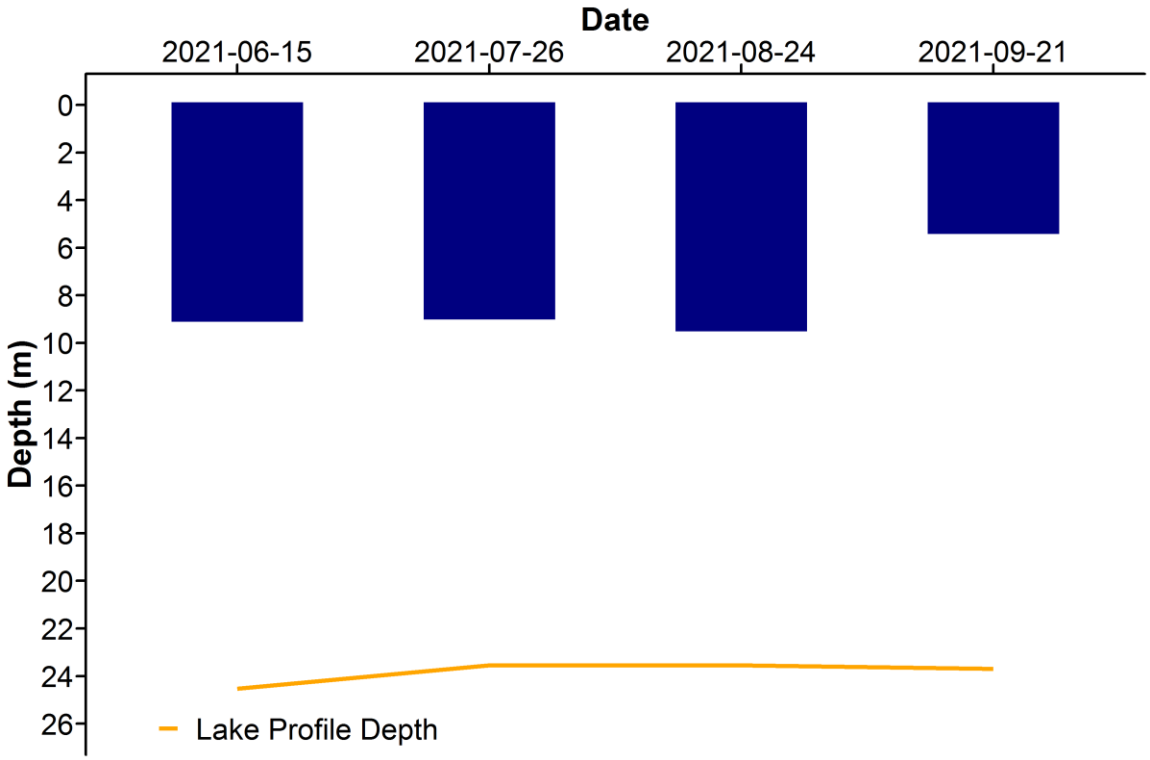


Figure 3. Euphotic depth values measured four times over the course of the summer at Marie Lake in 2021.

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 Marie Lake varied throughout the summer, with the July 26th sampling date having the warmest temperatures at 18.9°C (Figure 4a). The lake was stratified during each sampling event, and the thermocline, or depth of greatest temperature change indicating the divide between lake layers, decreased through the season from approximately 8m on June 15th to nearly 20 m on September 21st.

Marie 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). Oxygen levels decreased appreciably at depths corresponding to the thermocline on all sampling dates except June 15th, where oxygen levels remained high below the thermocline, and were above 6.5 mg/L at the bottom. The lake was otherwise anoxic (<1.0 mg/L dissolved oxygen) at the bottom during every other sampling event.

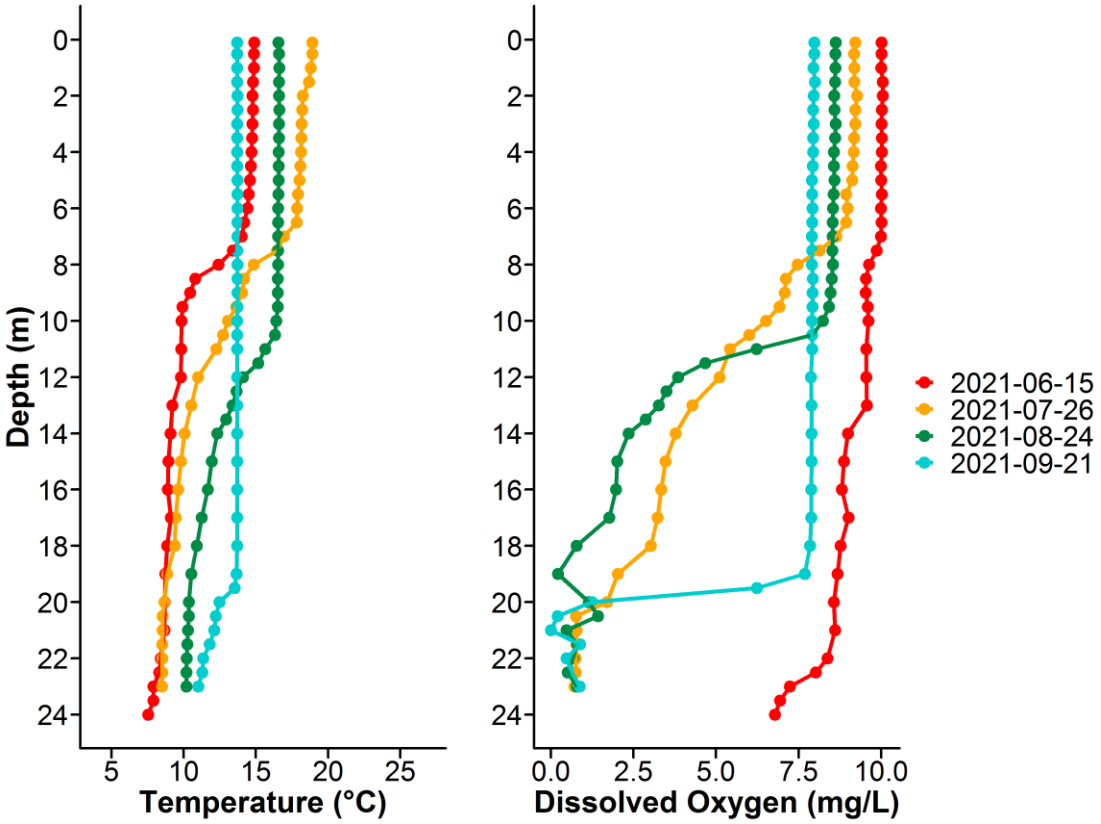


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Marie Lake measured four times over the course of the summer of 2021.

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 Marie Lake fell below the recreational guideline of 10 µg/L during every sampling event in 2021, which is consistent with recent historical averages (Table 2). In addition, microcystin levels from each date were below the laboratory detection limit of 0.10 µg/L. A value of 0.05 µg/L is assigned to each date that is below detection, in order to calculate an average.

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

Date	Microcystin Concentration (µg/L)
15-Jun-21	<0.1
26-Jul-21	<0.1
24-Aug-21	<0.1
21-Sep-21	<0.1
Average	0.05

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 Marie 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 Marie Lake during the July 26th sampling event, 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 Marie Lake are only available up to 2020 (Figure 5). Historical data indicates the lake has been at or above the historical average for the previous 18 years, up until 2020.

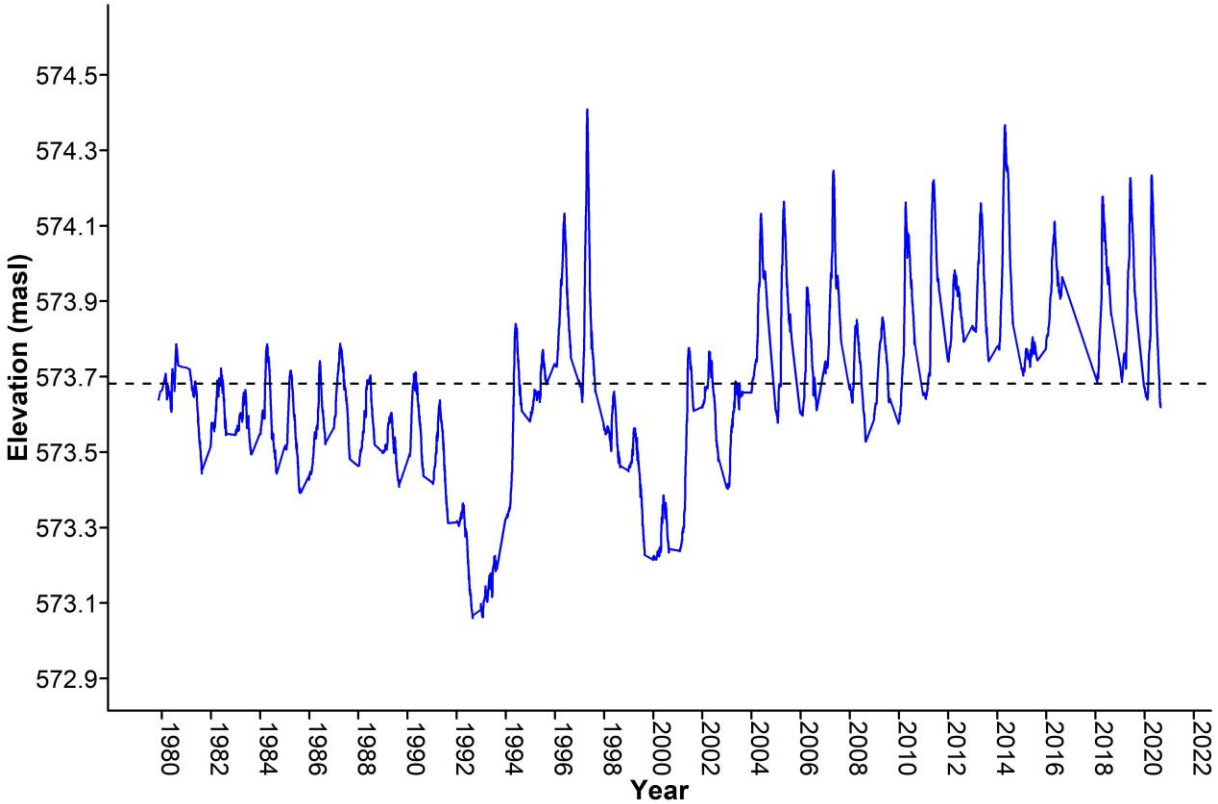


Figure 5. Water levels measured at Marie Lake in metres above sea level (masl) from 1980-2020. Data retrieved from Environment Canada. Black dashed line represents historical yearly average water level.

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.

Marie Lake experienced a warmer and slightly windier summer compared to normal (Figure 5). A few warm spells prior to the July 26th sampling likely resulted in relatively high near-surface lake temperatures. Deep mixing was evident during the September 26th sampling event, likely due to decreasing air temperatures and frequent wind-driven mixing.

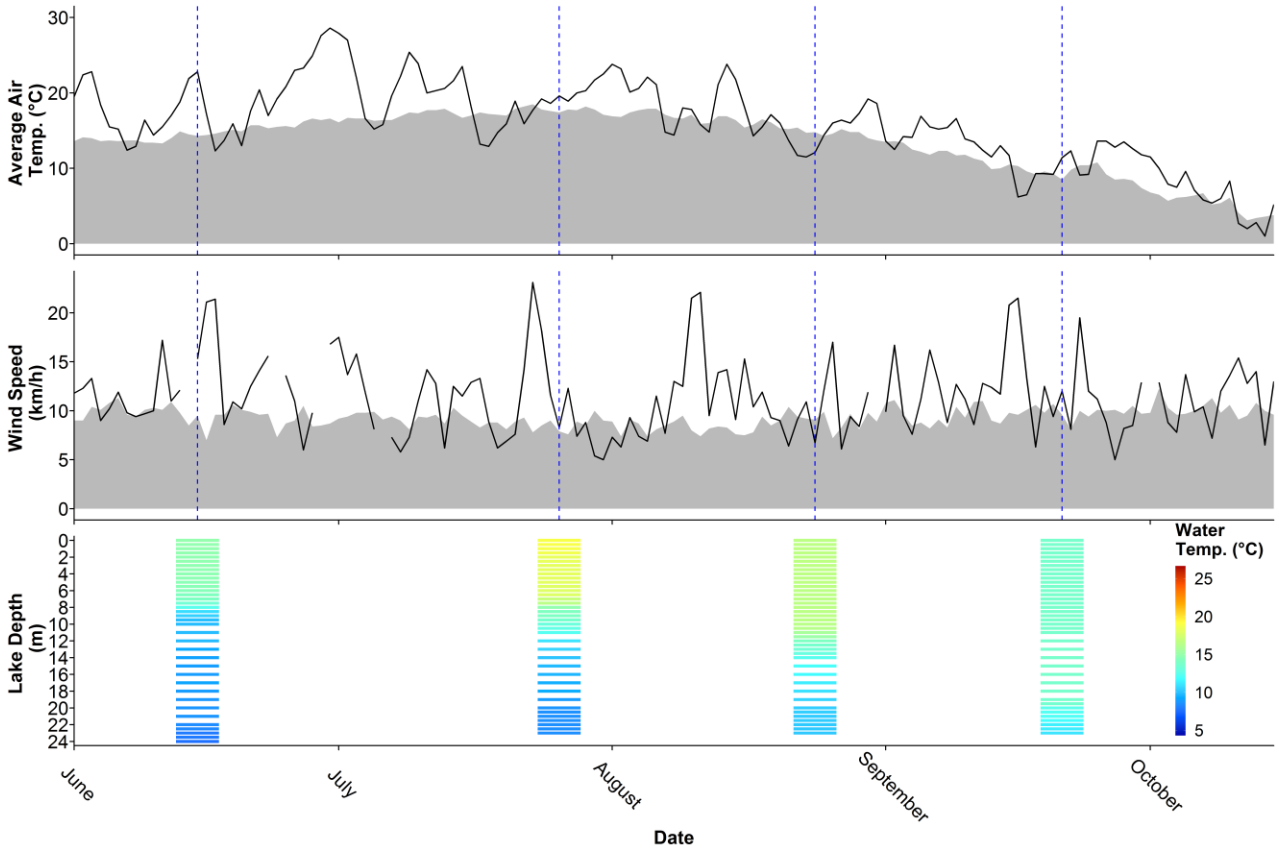


Figure 6. Average air temperature (°C) and wind speed (km/h) measured from Cold Lake A, with Marie Lake temperature profiles (°C) at the bottom. Black lines indicate 2021 levels, gray indicates long-term normals, and blue lines indicate sampling dates for Marie Lake over the summer. Further information 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). *Note: Solar Radiation and Precipitation not available at Cold Lake A.

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

Parameter	1979	1980	1981	1986	1993	1997	1999	2003	2004	2007	2008	2009	2010
TP (µg/L)	30	\	16	16	6	15	\	12	14	14	17	20	20
TDP (µg/L)	30	\	7	5	3	6	\	4	4	4	7	11	6
Chlorophyll-*a* (µg/L)	\	6.6	4.6	5.9	\	3.6	\	4	5	2.6	2.7	3.2	3.1
Secchi depth (m)	\	2.8	3.01	5	6	3.85	5.3	5.15	3.72	3.6	3.84	3.38	2.98
TKN (mg/L)	1.1	0.7	0.7	0.6	0.5	0.5	\	0.5	0.6	0.5	0.6	0.6	0.7
NO_2-N and NO_3-N (µg/L)	6	4	4	0	2	3	\	5	3	2	6	5	6
NH_3-N (µg/L)	20	34	35	22	9	12	\	6	8	12	15	16	11
DOC (mg/L)	\	10	10	10	9	10	\	\	10	11	11	10	11
Ca^{2+} (mg/L)	\	30	30	30	32	31	\	\	\	\	\	\	\
Mg^{2+} (mg/L)	13	12	12	13	13	12	\	\	\	\	\	\	\
Na^{+} (mg/L)	5	6	6	5	6	6	\	6	5	7	6	6	6
K^{+} (mg/L)	2	2	2	2	2	2	\	2	2	2	2	2	2
SO_4^{2-} (mg/L)	2	2	2	2	4	3	\	6	2	2	2	3	5
Cl^{-} (mg/L)	0	1	1	0	0	1	\	0	1	1	1	1	1
CO_3^{2-} (mg/L)	\	\	\	7.2	5	2.5	\	4.3	6.3	7	4	9	0.5
HCO_3^{-} (mg/L)	\	\	\	154	174	159	\	176	171	166	173	166	174
pH	8.4	8.12	7.85	8.7	8.6	8.55	\	8.44	8.44	8.42	8.41	8.51	8.33
Conductivity (µS/cm)	258	256	252	252	271	256	\	276	274	266	266	264	263
Hardness (mg/L)	125	126	\	128	133	128	\	144	133	134	132	127	120
TDS (mg/L)	136	135	134	139	147	136	\	155	145	146	144	143	139
Microcystin (µg/L)	\	\	\	\	\	\	\	\	1.50	\	\	\	\
Total Alkalinity (mg/L $CaCO_3$)	136	135	134	139	148	136	\	152	151	147	146	146	143

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

Parameter	2012	2014	2016	2019	2021
TP (µg/L)	12	11	20	11	7
TDP (µg/L)	8	6	3	4	2
Chlorophyll-*a* (µg/L)	1.5	1.9	4	4	4.3
Secchi depth (m)	5.96	5	3.52	4	4.1
TKN (mg/L)	0.5	0.5	0.7	0.5	0.5
NO_2-N and NO_3-N (µg/L)	2	20	2	3	5
NH_3-N (µg/L)	17	13	25	16	12
DOC (mg/L)	10	23	10	12	10
Ca^{2+} (mg/L)	\	\	34	34	34
Mg^{2+} (mg/L)	\	\	14	12	12
Na^{+} (mg/L)	6	7	7	6	6
K^{+} (mg/L)	2	2	2	2	2
SO_4^{2-} (mg/L)	2	2	0	0	2
Cl^{-} (mg/L)	1	1	0	1	2
CO_3^{2-} (mg/L)	14.7	2	1.7	1.6	0.5
HCO_3^{-} (mg/L)	148	170	170	168	182
pH	8.58	8.39	8.26	8.34	8
Conductivity (µS/cm)	268	262	266	265	255
Hardness (mg/L)	133	136	142	138	138
TDS (mg/L)	142	145	148	140	150
Microcystin (µg/L)	1.16	\	0.05	0.05	0.05
Total Alkalinity (mg/L $CaCO_3$)	146	142	142	140	150

Table 3. Concentrations of metals measured in Marie 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)	2007	2008	2010	2012	2014	2016	2019	2021	Guidelines
Aluminum µg/L	9.1	4.2	12.25	3.705	16.5	7.3	6.7	8.4	100[a]
Antimony µg/L	0.012	0.024	0.0232	0.0201	0.019	0.077	0.021	0.019	/
Arsenic µg/L	0.51	0.67	0.6575	0.619	0.635	2.2	0.56	0.56	5
Barium µg/L	33.3	32.1	32.2	33.6	31.6	10.6	28.6	31.2	/
Beryllium µg/L	<0.003	<0.003	0.0062	0.0039	0.004	0.004	0.0015	0.0015	100[c,d]
Bismuth µg/L	<0.001	0.0013	0.00195	0.0075	0.0005	0.0005	0.0015	0.0015	/
Boron µg/L	17.7	23	18.95	38.65	22.2	170	18.8	19.6	1500
Cadmium µg/L	<0.002	0.0029	0.01085	0.0018	0.002	0.001	0.005	0.005	0.21[b]
Chromium µg/L	0.08	0.139	0.05285	0.04935	0.09	0.015	0.05	0.05	/
Cobalt µg/L	<0.001	0.0073	0.0009	0.0005	0.001	0.024	0.019	0.024	50,1000[c,d]
Copper µg/L	0.13	<0.05	0.1555	0.276	0.29	0.84	0.04	0.19	3.10[b]
Iron µg/L	39.9	3.28	23.15	2	12.9	7.5	13.8	10.6	300
Lead µg/L	0.021	0.0674	0.0161	0.003	0.047	0.012	0.002	0.004	4.77[b]
Lithium µg/L	4.37	7.25	6.31	6.75	7.01	58.2	6.78	7.05	2500[d]
Manganese µg/L	21.9	9.07	19.785	11.41	4.3	9.12	6	9.59	390[e]
Molybdenum µg/L	0.154	0.172	0.19	0.173	0.164	0.326	0.178	0.156	73
Nickel µg/L	<0.005	0.086	0.0025	0.0025	0.004	0.219	0.1	0.13	121.75[b]
Selenium µg/L	0.06	<0.1	0.05	0.05	0.03	0.42	0.1	0.1	1
Silver µg/L	<0.0005	<0.0005	0.00655	0.00025	0.001	0.001	<0.01	0.0005	0.25
Strontium µg/L	90.8	91	84.35	88.7	84.7	60.2	77.6	80	/
Thallium µg/L	<0.0003	<0.003	0.002575	0.00015	0.00045	0.0014	0.001	0.001	0.8
Thorium µg/L	0.007	<0.003	0.00545	0.00015	0.001	0.0021	0.001	0.001	/
Tin µg/L	0.03	0.0315	0.015	0.015	0.014	0.017	0.03	0.12	/
Titanium µg/L	1.38	1.03	1.095	0.4205	0.5	0.41	0.3	0.46	/
Uranium µg/L	0.08	0.0662	0.0676	0.0606	0.051	0.369	0.058	0.052	15
Vanadium µg/L	0.14	0.112	0.12055	0.08575	0.1	0.2	0.056	0.054	100[c,d]
Zinc µg/L	0.64	0.175	0.798	0.2915	1.2	1.3	0.4	0.6	39.37[f]

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

[b] Based on 2021 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 2021 avg. water hardness (as CaCO3) and avg. pH

[f] Based on 2021 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 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 Marie Lake. In sum, a significant decreasing trend was detected for TDS, and no changes were detected for TP, chlorophyll-*a*, or Secchi depth. Since a significant trend was determine for TDS, additional analysis on major ions was conducted. 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 Marie Lake data from 2003 to 2021.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	2003-2021	No change
Chlorophyll-*a*	2003-2021	No change
Total Dissolved Solids	2003-2021	Decreasing
Secchi Depth	2003-2021	No change

Definitions:

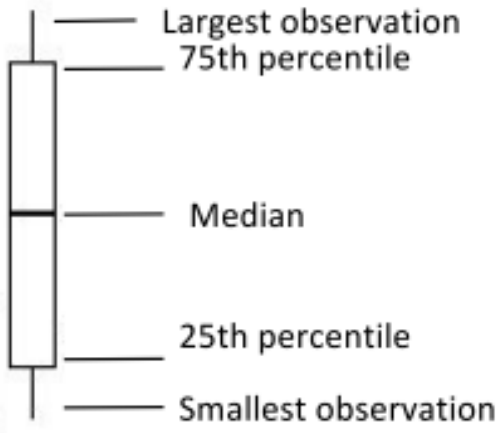
Median: the value in a range of ordered numbers that falls in the middle.

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 of TP over time showed that it has not significantly changed in Marie Lake since 2003 (Tau = -0.20, *p* = 0.13; Table 5).

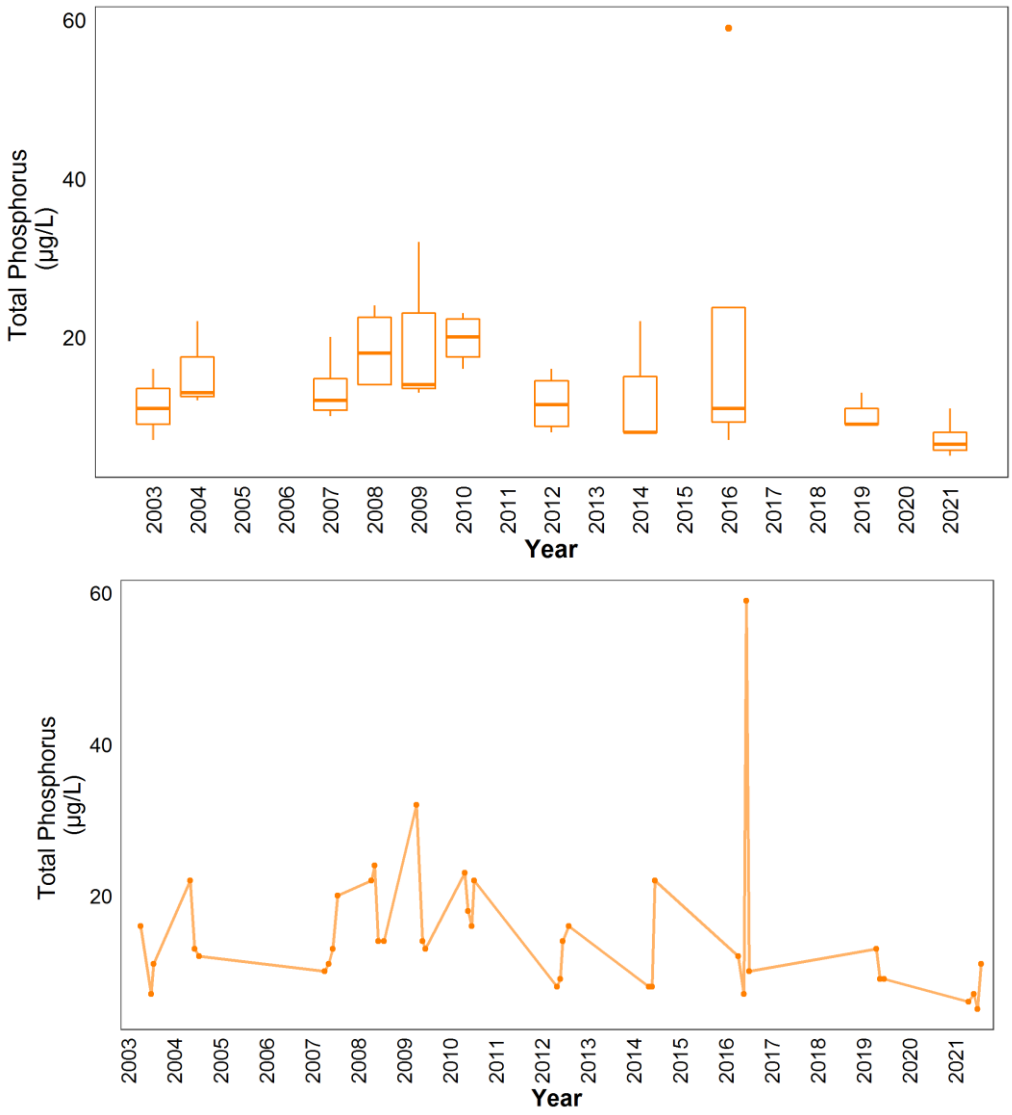


Figure 6. Monthly total phosphorus (TP) concentrations measured between June and September on sampling dates between 2003 and 2021 (n = 39). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Chlorophyll-*a* has not changed significantly at Marie Lake since 2003 (Tau = -0.08, *p* = 0.52; Table 5). TP and chlorophyll-*a* were not significantly correlated (r = 0.09, *p* = 0.59).

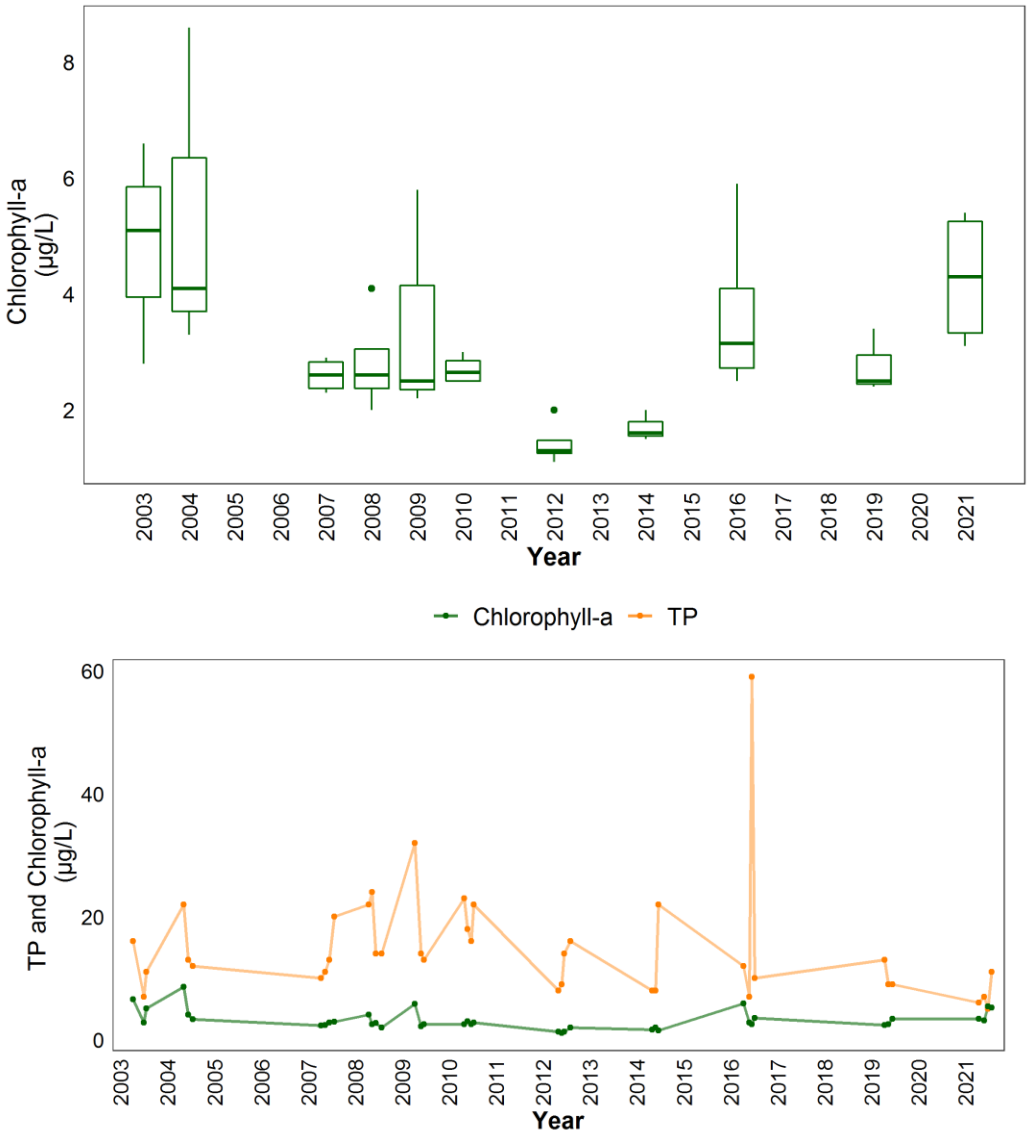


Figure 7. Monthly chlorophyll-*a* concentrations measured between June and September on sampling dates between 2003 and 2021 (n = 39). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant decreasing trend in TDS between 2003 and 2021 (Tau = -0.26, p = 0.034) in Marie Lake. However, TDS levels in 2021 displayed a wider range than has been observed since 2003, and this is primarily due to a high TDS value from the July 26th, 2021 sampling event (170 mg/L). This high TDS value could reflect the impact of increased lake evaporation caused by multiple heat waves and high wind events leading up to the July 26th sampling event (Figure 6).

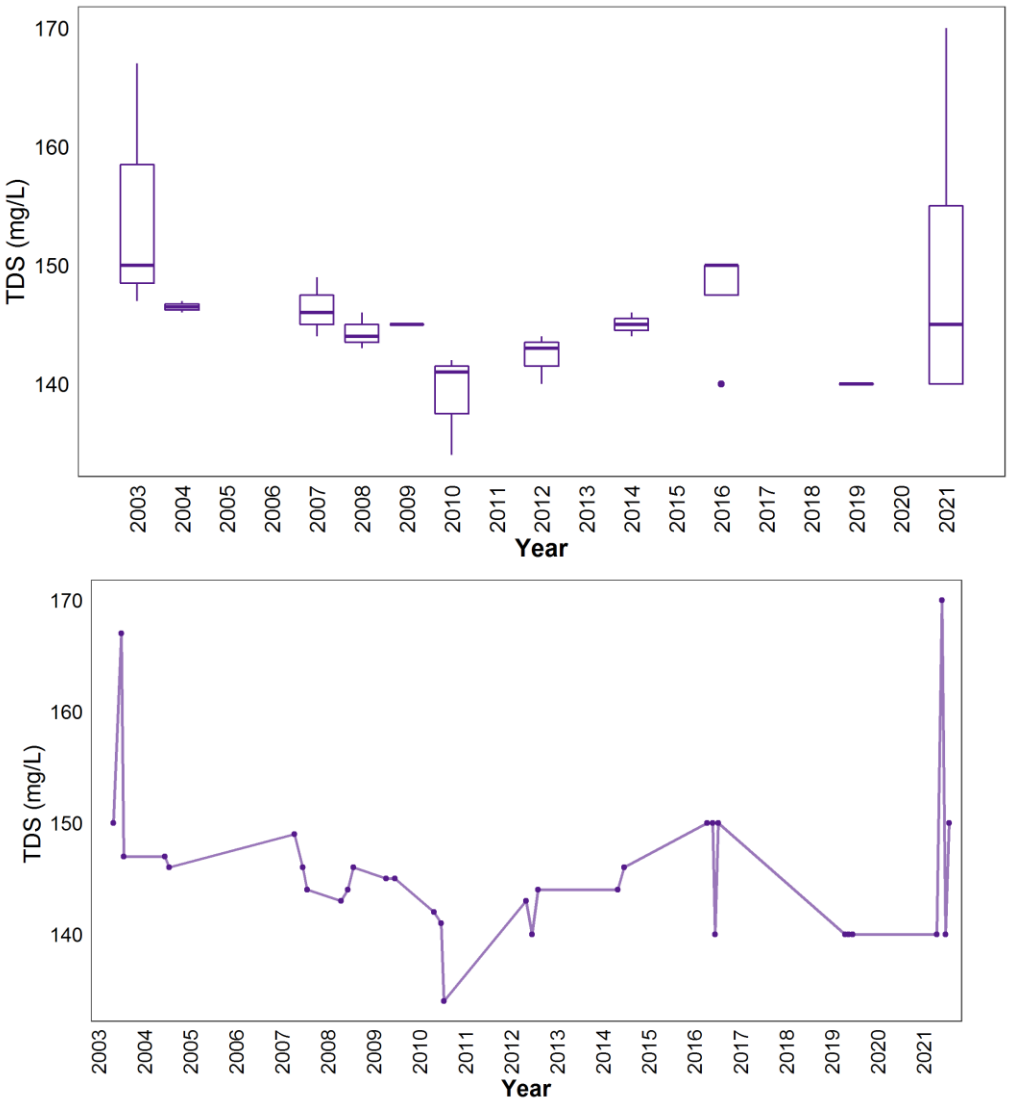


Figure 8. Monthly TDS values measured between June and September on sampling dates between 2003 and 2021 (n = 32). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Due to the significant decreasing trend of TDS in Marie Lake, exploring the specific major ions which may be driving this trend is important to determine. Trend analysis of major ions at Marie Lake indicates that alkalinity, indicative of bicarbonate and carbonate, a term in the calculation of TDS, is likely the key parameter that is driving the decrease in TDS (Figure 9). Interestingly, chloride is the only parameter that is slightly increasing over time. It is possible that the slight decreasing trends are related to slightly increasing water levels between 2003 and 2021 (Figure 5).

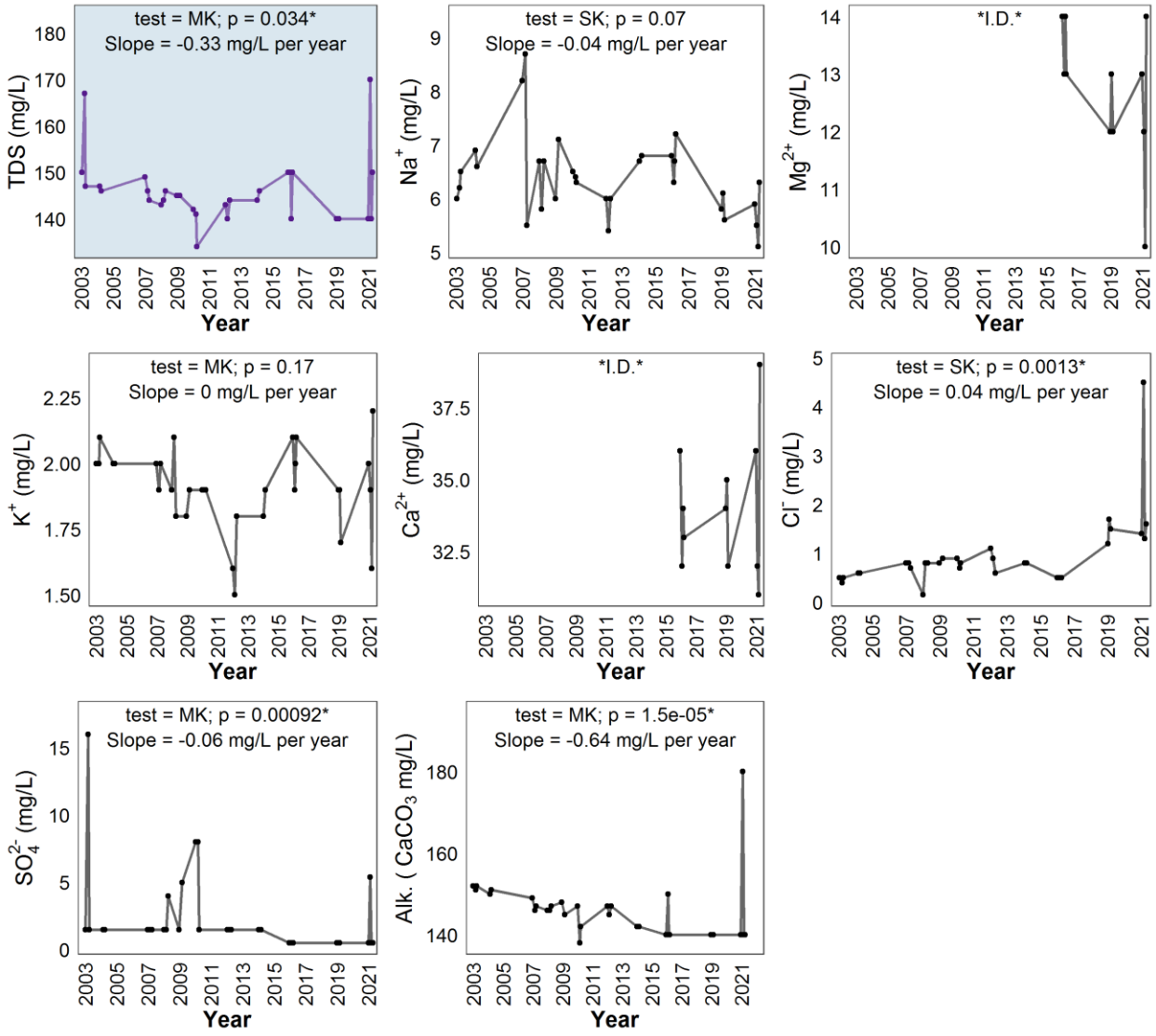


Figure 9. Concentrations of TDS (top left, blue panel), major ions (sodium = Na^+, magnesium = Mg^{2+}, potassium = K^+, calcium = Ca^{2+}, chloride = Cl^-, sulphate = SO_4^{2-}), and total alkalinity (Alk., as mg/L $CaCO_3$) measured monthly between June and September on sampling dates between 2003 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 that it has not significantly changed in Marie Lake since 2003 (Tau = 0.18, *p* = 0.18; Table 5).

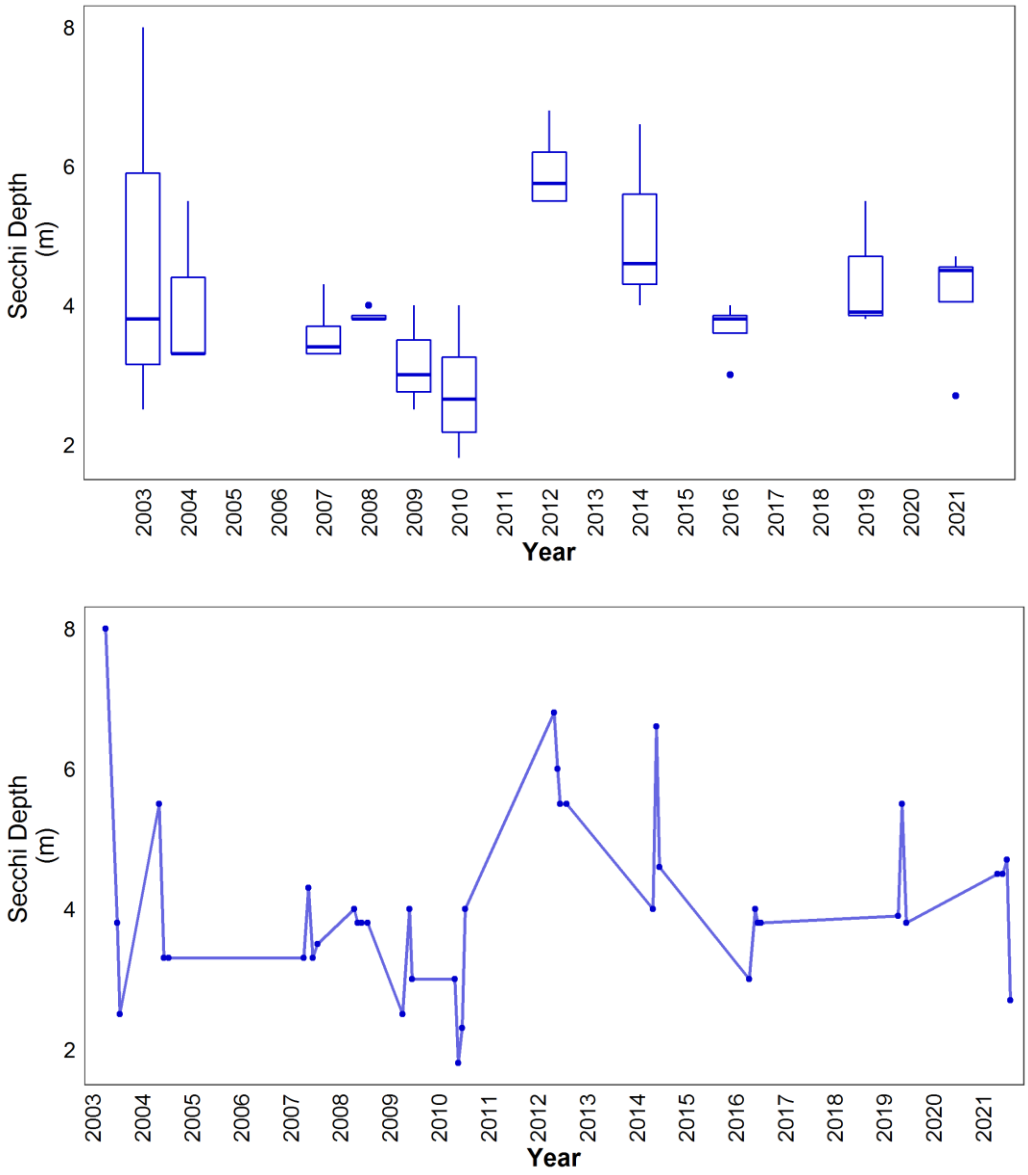


Figure 10. Monthly Secchi depth values measured between June and September on sampling dates between 2003 and 2021 (n = 39). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

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 2003-2021 on Marie Lake data.

Definition	Unit	Total Phosphorus (TP)	Chlorophyll-a	Total Dissolved Solids (TDS)	Secchi Depth
Statistical Method	-	Seasonal Kendall	Seasonal Kendall	Mann Kendall	Seasonal Kendall
The strength and direction (+ or -) of the trend between -1 and 1	Tau	-0.20	-0.08	-0.26	0.18
The extent of the trend	Slope (units per year)	-0.29	-0.033	-0.33	0.042
The statistic used to find significance of the trend	Z	-1.52	-0.64	-2.11	1.34
Number of samples included	n	39	39	32	39
The significance of the trend	*p*	0.13	0.52	0.034*	0.18

*$p < 0.05$ is significant within 95%