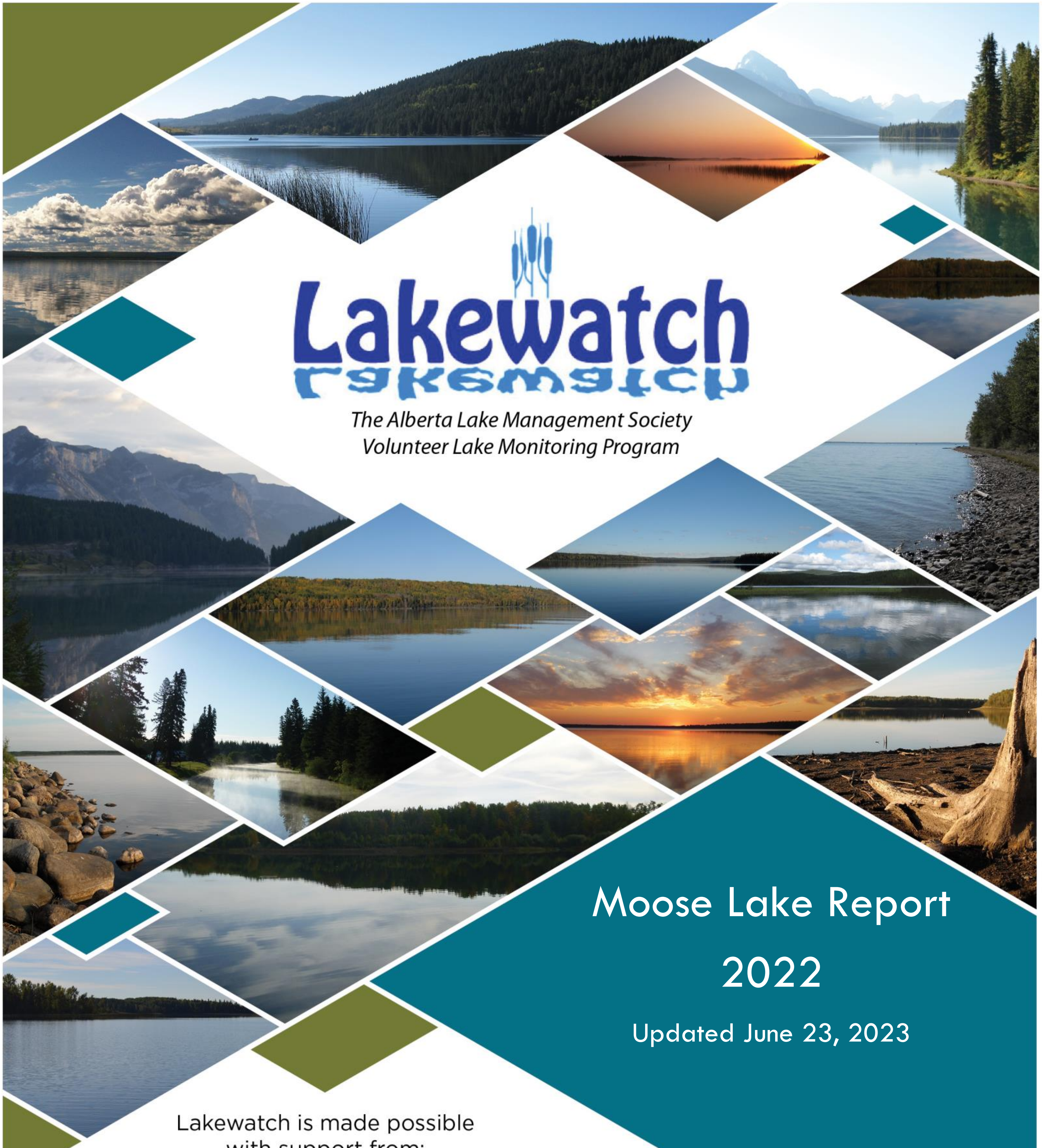

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Moose Lake Report
2022

Updated June 23, 2023

Lakewatch is made possible with support from:

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LICA ENVIRONMENTAL STEWARDS

PIGEON LAKE WATERSHED ASSOCIATION

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.

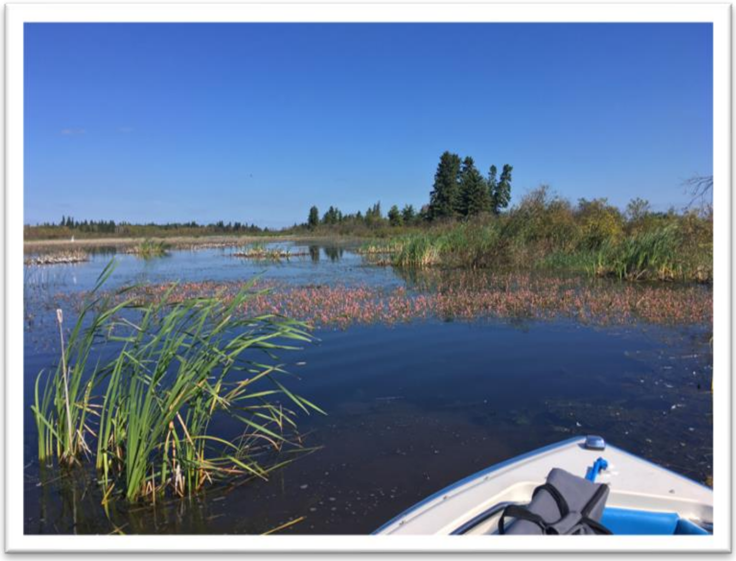
ALMS would like to thank all who express interest in Alberta's aquatic environments, and particularly those who have participated in the LakeWatch program. These leaders in stewardship give us hope that our water resources will not be the limiting factor in the health of our environment.

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 Cody Fedun, Grant Ferbey, Mitch Sylvestre, and Dan Lastiwka for their commitment to collecting data at Moose 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.

MOOSE LAKE



Moose Lake—photo by Elashia Young 2017

Moose Lake is located 240 km northeast of Edmonton and 3.5 km west of the Town of Bonnyville. Moose Lake has over 64 km of irregular shoreline within a 40 km^2 lake surface area. The lake is comprised of four main bays with a maximum depth of 19 m and a mean depth of 5.6 m. A sounding (whole lake depth measurement) was last conducted in 1962.

The lake was once known by its French name Lac d'Orignal, which was inspired by the abundance of moose in the area.[1] In 1789, Angus Shaw established a trading post for the North West Company on the northwest shore of Moose Lake, one of the earliest European settlements known to Alberta. Later, in the early 1900's, French Canadian settlers began arriving in the area. In 1928, the railway was extended from St. Paul to Bonnyville. [1]

Moose Lake's abundance of natural resources was in high demand to supply a rapidly expanding population. Mink farming, agriculture, and three commercial fish-packing plants were in operation by 1936.[1] Walleye, northern pike, and yellow perch are the most popular sport fish; however, the lake also contains cisco, lake whitefish, burbot, suckers, and forage fish. Moose Lake is still heavily used, particularly on summer weekends. Shoreline development is intense and includes cottage subdivisions, campgrounds, and summer villages. Aquatic reeds fringe the shoreline, which is predominantly sheltered. Dominant emergent plants include bulrush (*Scirpus validus*) and cattail (*Typha latifolia*). Common submergent plants are pondweeds (*Potamogeton* spp.) and northern watermilfoil (*Myriophyllum sibiricum*). Moose Lake also provides excellent habitat to a variety of waterfowl, although residents are concerned that the current high population level of cormorants (*Phalacrocorax auritus)* in the region, are contributing to poor water quality conditions at Moose Lake.

The watershed area for Moose Lake is 808.01 km^2 and the lake area is 40.53 km^2. The lake to watershed ratio of Moose Lake is 1:20. A map of the Moose Lake watershed area can be found at http://alms.ca/wp-content/uploads/2016/12/Moose.pdf. Moreover, multi-basin monitoring of Moose Lake was conducted in 2016 and 2017, the results of which can be found at www.alms.ca. A phosphorus budget for the lake was completed by Associated Environmental in 2021.[2]

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

[2] https://laraonline.ca/wp-content/uploads/2021/12/Final_rpt_AE_MooseLakePbudget_Sep-2021.pdf. Accessed May 2022.

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 Moose Lake was 40 µg/L (Table 2), falling into the eutrophic, highly productive trophic classification. This value falls on the middle to lower end of all previously observed historical averages going back to 1983 (Table 2). TP ranged from a minimum of 32 µg/L on July 15th, to a maximum of 50 µg/L on August 6th (Figure 1).

Average chlorophyll-*a* concentration in 2022 was 32.9 µg/L (Table 2), falling into the hypereutrophic, or very highly productive trophic classification. Chlorophyll-*a* was highest during the September 14th sampling event at 66.0 µg/L, and lowest at 8.0 µg/L on June 21st.

The average TKN concentration was 1.8 mg/L (Table 2), and displayed increasing levels through the season (Figure 1). TKN and chlorophyll-*a* were significantly positively correlated ($r = 0.97$, $p = 0.033$).

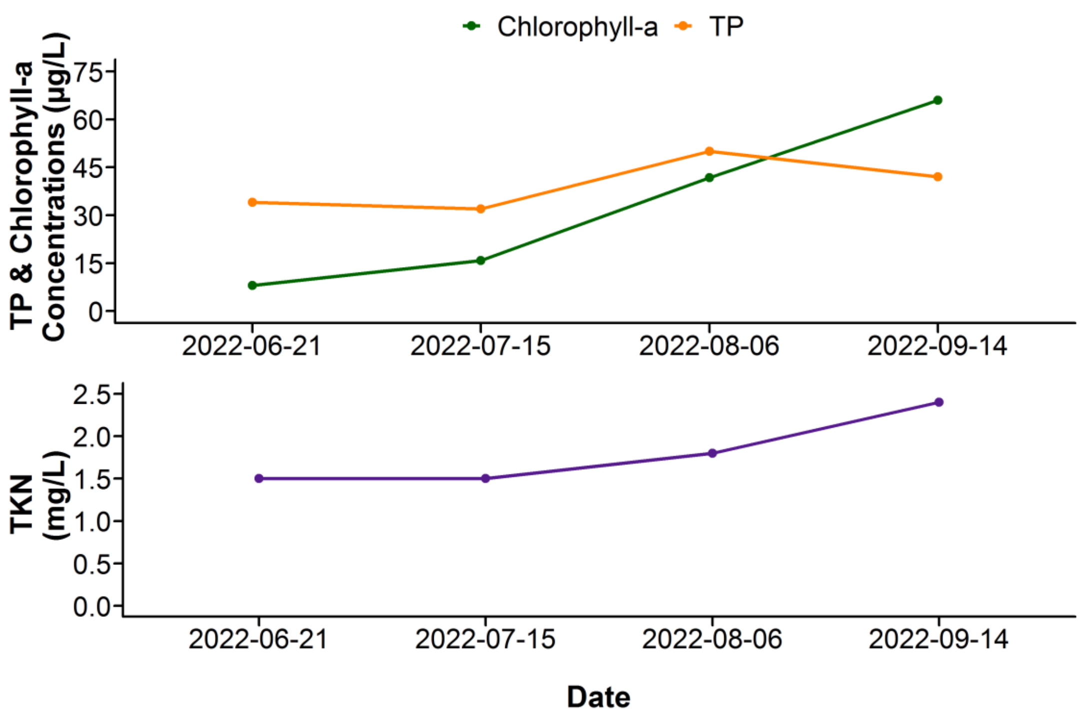


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Moose Lake.

Average pH was measured as 8.66 in 2022, buffered by high alkalinity (312 mg/L $CaCO_3$) and bicarbonate (348 mg/L HCO_3). Aside from bicarbonate, sulphate, sodium and magnesium were in highest abundance, and together contributed to a high conductivity of 918 µS/cm (Figure 2, top; Table 2). Moose Lake is in the high range of ion levels, compared to other LakeWatch lakes sampled in 2022. (Figure 2, bottom).

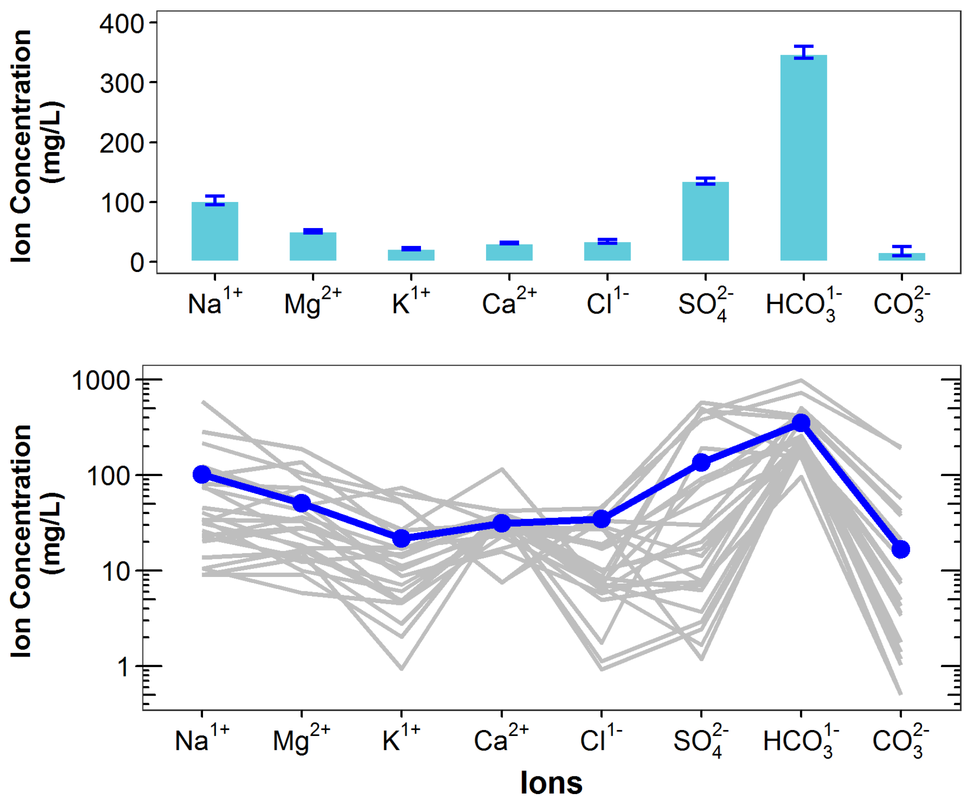


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Moose Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Moose 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 Moose Lake in 2022, and no metals exceeded the CCME 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 Moose Lake in 2022 was 3.24 m, corresponding to an average Secchi depth of 1.62 m (Table 2). Euphotic depth varied over the season, ranging from as deep as 4.50 m on July 15th, to 1.30 m on September 14th (Figure 3). Secchi depth was significantly negatively correlated with chlorophyll-*a* ($r = -0.98$, $p = 0.018$).

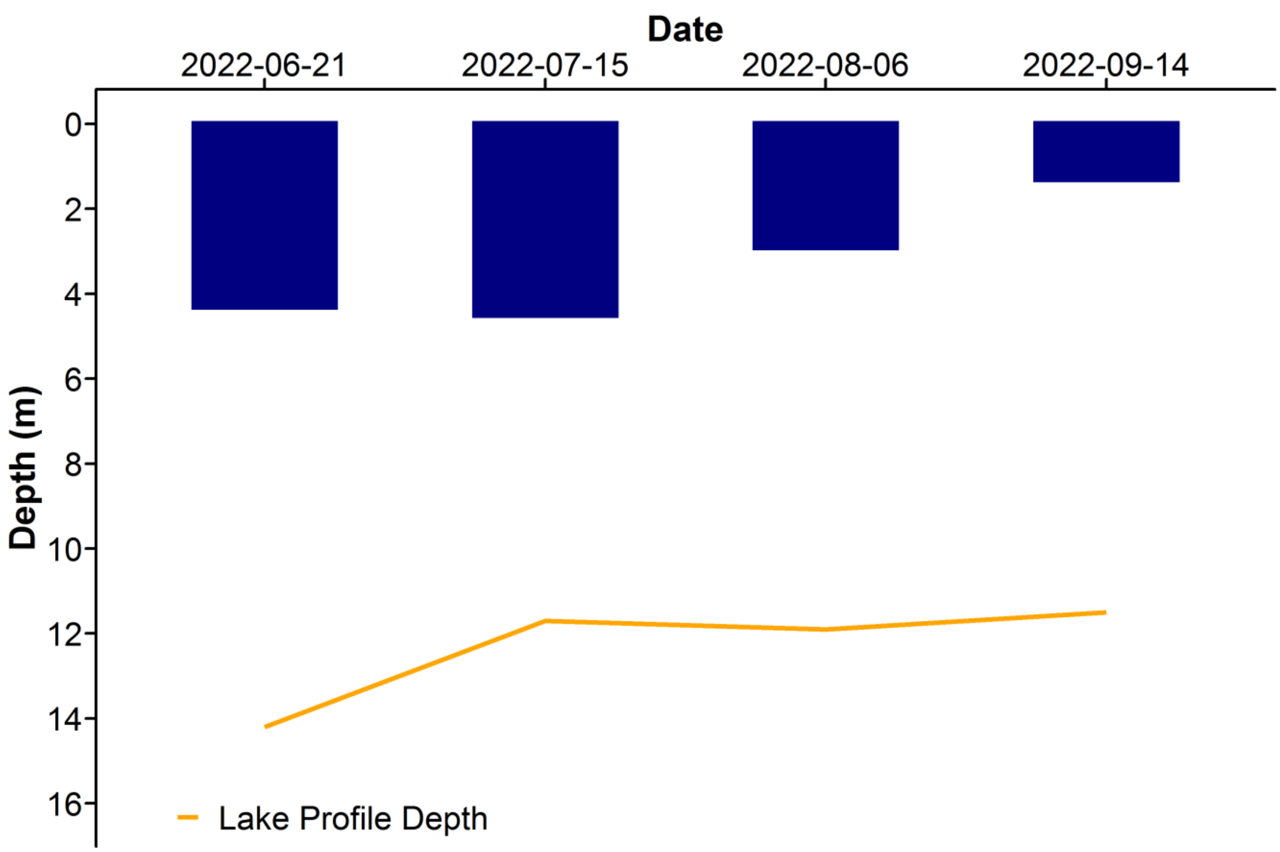


Figure 3. Euphotic depth values measured four times over the course of the summer at Moose Lake in 2022.

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 Moose Lake varied throughout the summer, with the August 6th sampling date having the warmest temperatures at 22.0°C (Figure 4a). The lake was mixed during each sampling event, with slight stratification evident during the June 21st sampling event.

Moose 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 June and July sampling events, oxygen depletion occurred in the bottom waters, reaching anoxia (<1.0 mg/L only during the July sampling event, at 11.0 m depth). High levels of surface oxygen during the September 14th sampling event coincide with high a chlorophyll-*a* level during that sampling event, indicating a high rate of photosynthesis from abundant algae or cyanobacteria during that sampling event.

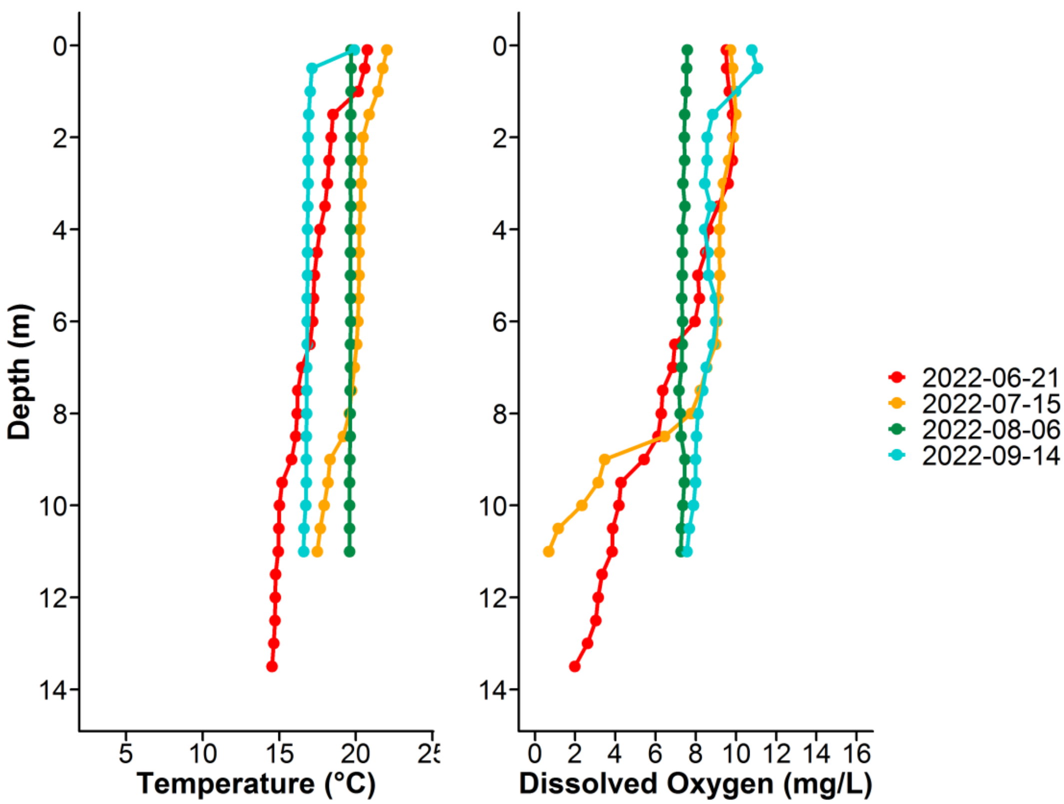


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Moose Lake measured four times over the course of the summer of 2022.

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 Moose Lake fell below the recreational guideline of 10 μg/L during every sampling event in 2022. In addition, microcystin levels from the June 21st 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 Moose Lake in 2022.

Date	Microcystin Concentration (μg/L)
21-Jun-22	<0.1
15-Jul-22	0.15
6-Aug-22	0.80
14-Sep-22	0.69
Average	0.42

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 Moose 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.

No watermilfoil specimens were collected from Moose Lake in 2022.

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 Moose Lake have been extremely variable since measurements were first taken in 1950. The highest levels were observed in 1966, and the lowest levels were observed in 1993 and between 2002-2004, with over a 2m difference between these extremes. In recent years, relatively high-water years took place between 2017-2019, then dropped through the summer of 2020 and have remained at the historical average level through 2021 and 2022.

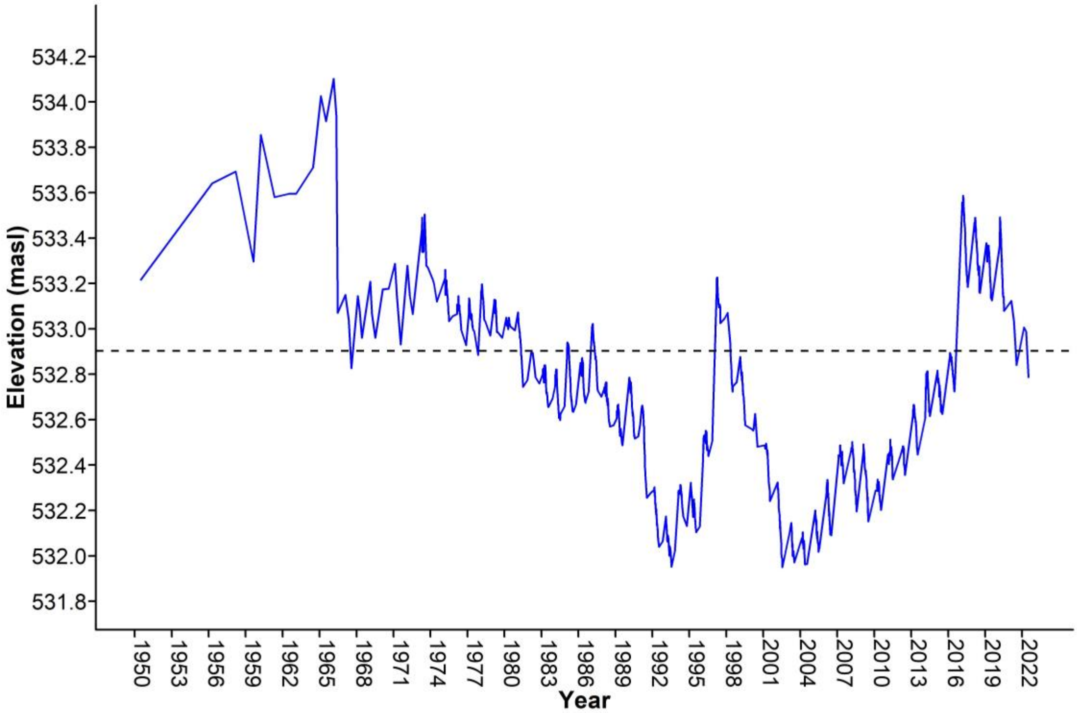


Figure 5. Water levels measured at Moose Lake in metres above sea level (masl) from 1950-2022. Data retrieved from Alberta Environment and Parks and/or Environment and Climate Change Canada. Black dashed line represents historical yearly average water level.

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.

Moose Lake experienced a warmer, drier, and slightly windier summer with more solar radiation than normal (Figure 6). The high surface water temperatures during the July sampling event coincided with a period of high temperatures and low wind.

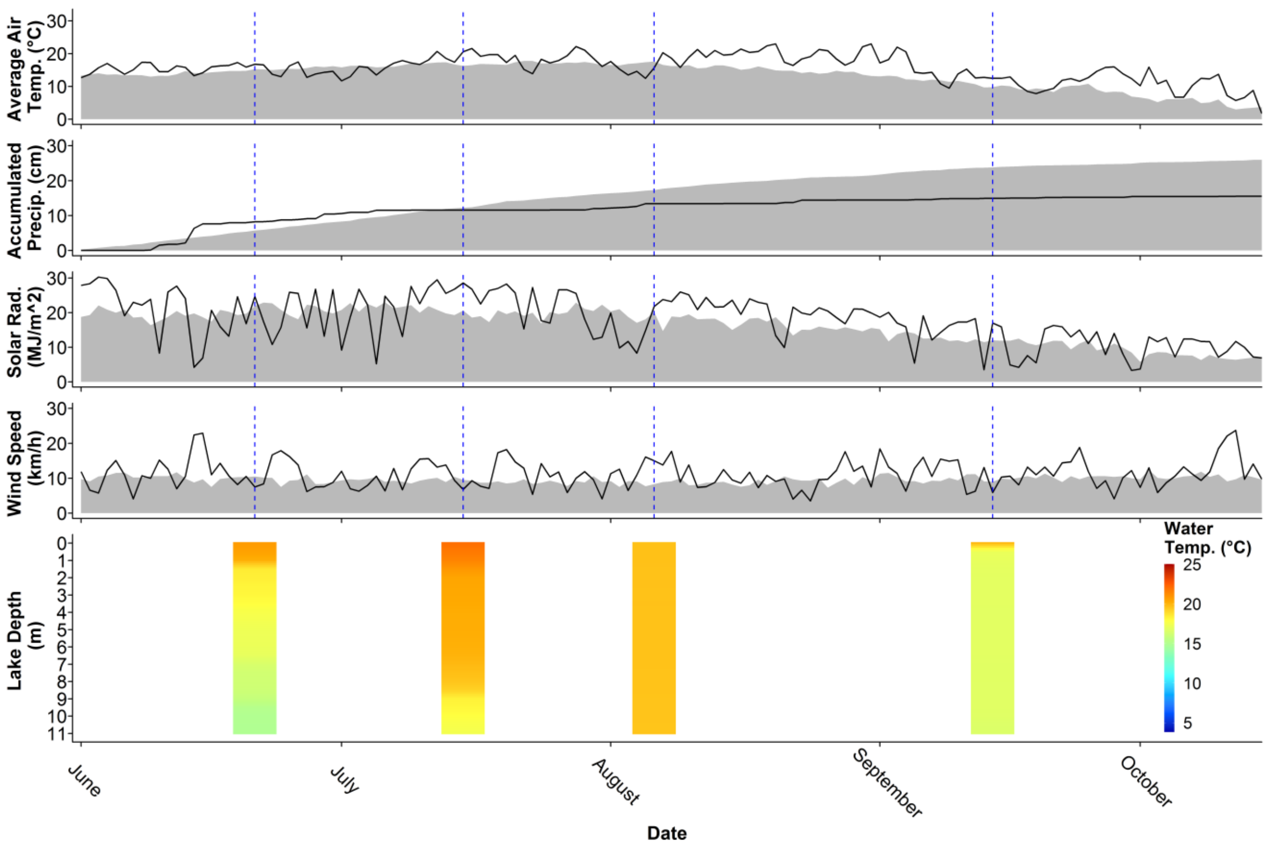


Figure 6. Average air temperature (°C) accumulated precipitation (cm), and wind speed (km/h) measured from 'Hoselaw AGCM' weather station, as well as solar radiation (MJ/m^2) measured from 'Dupre AGCM,' as well as Moose Lake temperature profiles, interpolated (°C). Black lines indicate 2022 levels, gray indicates long-term normals, and blue lines indicate sampling dates for Moose 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 Moose Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	1983	1984	1985	1986	1987	1988	1990	1991	1992	1993	1994
TP (µg/L)	36	46	25	40	50	42	51	54	44	40	41
TDP (µg/L)	/	/	/	/	/	/	/	/	/	/	12
Chlorophyll-*a* (µg/L)	13.7	16.2	12.5	17.6	21.5	16	22.3	31.1	15.7	21	22.7
Secchi depth (m)	2.25	1.94	3.76	2.55	2.48	2.5	2.18	3.38	2.68	3	2.11
TKN (mg/L)	/	/	1.3	/	/	/	/	/	/	/	1.4
NO_2-N and NO_3-N (µg/L)	25	25	25	25	10	8	5	10	2	4	3
NH_3-N (µg/L)	/	/	/	/	/	/	/	/	/	/	17
DOC (mg/L)	/	/	/	/	/	/	/	/	/	/	18
Ca (mg/L)	24	24	26	27	28	27	22	23	22	26	24
Mg (mg/L)	32	34	36	36	36	40	40	42	44	44	44
Na (mg/L)	62	64	64	66	62	74	78	74	76	82	84
K (mg/L)	12	11	12	12	12	12	12	12	13	13	14
SO_4^{2-} (mg/L)	82	84	88	92	94	102	107	106	112	117	115
Cl^- (mg/L)	12	12	12	13	14	13	14	15	14	16	16
CO_3 (mg/L)	/	16.8	9	11.6	14.4	11.5	12.1	25.5	16	21.5	29.5
HCO_3 (mg/L)	/	273	289	289	283	302	294	275	300	330	330
pH	8.40	8.68	8.62	8.63	8.65	8.58	8.70	8.93	8.70	8.84	8.99
Conductivity (µS/cm)	656	641	667	678	681	715	708	706	736	780	787
Hardness (mg/L)	/	198	214	216	216	234	218	228	235	245	242
TDS (mg/L)	370	381	390	400	400	429	432	432	444	472	474
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	244	252	252	257	256	267	262	268	272	289	295

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

Parameter	**1995**	**1996**	**1997**	**2003**	**2004**	**2005**	**2006**	**2009**	**2010**	**2011**
TP (µg/L)	43	31	48	52	38	50	59	43	46	49
TDP (µg/L)	17	/	/	14	15	13	17	20	17	18
Chlorophyll-*a* (µg/L)	17.6	5.2	16.8	39.5	22.6	27.3	35.5	15.7	19	46.1
Secchi depth (m)	1.98	3.45	2.78	2.28	2.7	2.15	1.34	3.1	1.6	2.9
TKN (mg/L)	1.6	/	/	1.7	1.5	1.6	1.8	1.6	1.7	1.6
NO_2-N and NO_3-N (µg/L)	6	/	/	16	3	2	2	8	8	4
NH_3-N (µg/L)	23	/	/	33	38	16	23	43	24	31
DOC (mg/L)	18	/	/	/	18	18	18	18	18	17
Ca (mg/L)	23	32	28	/	/	/	/	/	/	/
Mg (mg/L)	45	45	42	/	/	/	/	/	/	/
Na (mg/L)	87	84	84	111	112	114	115	117	124	114
K (mg/L)	15	14	15	12	17	20	17	20	19	20
SO_4^{2-} (mg/L)	125	124	118	149	156	151	155	165	164	156
Cl^- (mg/L)	18	17	19	23	25	25	25	28	29	27
CO_3 (mg/L)	19	14.5	16.2	29.3	28.5	35	31.7	30.3	27.5	18
HCO_3 (mg/L)	321	322	314	343	350	334	346	348	358	372
pH	8.76	8.56	8.64	8.87	8.86	8.99	8.81	8.90	8.85	8.69
Conductivity (µS/cm)	793	808	776	/	934	868	947	954	964	974
Hardness (mg/L)	241	268	246	284	266	255	261	260	260	290
TDS (mg/L)	489	493	480	573	584	580	587	604	610	599
Microcystin (µg/L)	/	/	/	/	/	0.418	0.080	0.593	0.113	1.18
Total Alkalinity (mg/L $CaCO_3$)	295	288	284	330	334	333	336	336	338	335

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

Parameter	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
TP (µg/L)	53	109	74	33	34	69	91	49	64	54	40
TDP (µg/L)	18	41	31	10	12	12	18	15	13	11	10
Chlorophyll-*a* (µg/L)	26.8	50	14.3	14.6	29.6	40.7	94	38	51.9	48.1	32.9
Secchi depth (m)	1.85	0.98	3.68	2.62	1.78	1.10	1.32	2.50	1.05	1.50	1.62
TKN (mg/L)	1.7	2	1.6	1.6	1.5	2.1	2.2	1.7	2	2.1	1.8
NO_2-N and NO_3-N (µg/L)	2	2	36	7	2	10	14	2	2	3	5
NH_3-N (µg/L)	20	18	87	36	38	52	104	24	37	28	28
DOC (mg/L)	18	24	18	16	16	17	18	18	18	17	18
Ca (mg/L)	/	/	/	25	27	28	29	31	32	30	31
Mg (mg/L)	/	/	/	52	57	54	49	47	45	45	50
Na (mg/L)	107	116	128	110	120	110	102	99	97	94	101
K (mg/L)	21	24	21	18	22	21	21	20	20	20	22
SO_4^{2-} (mg/L)	161	151	150	168	160	148	145	138	128	140	135
Cl^- (mg/L)	28	28	32	32	32	31	31	31	32	34	34
CO_3 (mg/L)	28.8	36.2	29.2	26.2	24.8	22.6	27	21.2	24.4	23.8	16
HCO_3 (mg/L)	358	342	353	366	368	348	338	348	308	332	348
pH	8.87	8.90	8.71	8.80	8.79	8.75	8.81	8.75	8.80	8.79	8.66
Conductivity (µS/cm)	993	989	996	990	994	934	918	905	875	925	918
Hardness (mg/L)	263	282	253	280	302	294	272	268	262	260	282
TDS (mg/L)	597	602	628	618	628	586	575	558	528	555	565
Microcystin (µg/L)	1.00	0.23	0.60	0.54	1.59	1.04	4.72	1.96	1.97	3.64	0.42
Total Alkalinity (mg/L $CaCO_3$)	342	341	339	344	342	322	325	320	295	312	312

Table 3a. Concentrations of metals measured in Moose 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)	2003	2004	2005	2009	2010	2011	Guidelines
Aluminum µg/L	14.75	4.95	3.34	16.05	10.7	4.08	100[a]
Antimony µg/L	0.075	0.065	0.065	0.058	0.053	0.056	/
Arsenic µg/L	1.99	2.03	2.19	2.12	2.16	2.085	5
Barium µg/L	46.1	50.2	47.8	45.4	44.9	46	/
Beryllium µg/L	0.06	0.002	0.002	0.004	0.002	0.004	100[c,d]
Bismuth µg/L	0.00575	0.001	0.006	0.006	0.001	0.001	/
Boron µg/L	169.5	172	176	197	185	202	1500
Cadmium µg/L	0.030	0.007	0.005	0.005	0.005	0.004	0.37[b]
Chromium µg/L	0.33	0.87	0.61	0.30	0.22	0.22	/
Cobalt µg/L	0.010	0.014	0.021	0.011	0.007	0.030	50,1000[c,d]
Copper µg/L	0.56	0.75	0.61	0.49	0.26	0.50	4[b]
Iron µg/L	3.25	1	37	8.05	7.65	22.8	300
Lead µg/L	0.079	0.047	0.080	0.216	0.011	0.013	7[b]
Lithium µg/L	40.05	53.4	57.3	61.2	53.1	70.75	2500[d]
Manganese µg/L	9.28	8.14	7.26	7.55	7.2	5.615	190[e]
Molybdenum µg/L	0.590	0.846	0.705	0.598	0.556	0.628	73
Nickel µg/L	0.030	0.003	0.110	<0.005	0.003	0.163	150[b]
Selenium µg/L	0.525	0.270	0.276	0.396	0.375	0.358	1
Silver µg/L	0.0025	0.003	0.001	0.002	0.002	0.008	0.25
Strontium µg/L	282.5	309	307.5	303	281	287.5	/
Thallium µg/L	0.0925	0.002	0.029	0.004	0.002	<0.002	0.8
Thorium µg/L	0.004	0.009	0.019	0.002	0.008	0.012	/
Tin µg/L	0.08	0.02	0.02	0.04	0.02	0.03	/
Titanium µg/L	0.65	0.67	0.86	1.13	0.76	0.49	/
Uranium µg/L	0.43	0.44	0.59	0.45	0.43	0.46	15
Vanadium µg/L	0.45	0.39	0.38	0.29	0.24	0.26	100[c,d]
Zinc µg/L	2.98	7.9	4.335	0.722	0.498	0.68	30[f]

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5
[b] Based on 2022 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 2022 avg. water hardness (as CaCO3) and avg. pH
[f] Based on 2022 avg. water hardness (as CaCO3), avg. pH, and avg. DOC with CCME equation
A forward slash (/) indicates an absence of data or guideline

Table 3b. Concentrations of metals measured in Moose 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)	2018	2020	2021	2022	Guidelines
Aluminum μg/L	1.3	3.7	5.9	7.9	100[a]
Antimony μg/L	0.055	0.054	0.045	0.051	/
Arsenic μg/L	2.18	2.03	2	1.84	5
Barium μg/L	50.6	51.8	50.8	52.4	/
Beryllium μg/L	<0.003	<0.003	0.0015	0.0015	100[c,d]
Bismuth μg/L	<0.003	<0.003	0.0015	0.0015	/
Boron μg/L	172	151	154	178	1500
Cadmium μg/L	<0.01	<0.01	0.005	0.005	0.37[b]
Chromium μg/L	<0.1	<0.1	0.1	0.05	/
Cobalt μg/L	0.036	0.032	0.068	0.017	50,1000[c,d]
Copper μg/L	0.3	<0.08	0.16	0.15	4[b]
Iron μg/L	12.6	8.7	7.7	9.9	300
Lead μg/L	0.036	0.007	0.007	0.014	7[b]
Lithium μg/L	54.1	44.6	49.7	47.4	2500[d]
Manganese μg/L	11.1	21	22.6	22.2	190[e]
Molybdenum μg/L	0.555	0.458	0.484	0.432	73
Nickel μg/L	0.410	0.11	0.16	0.13	150[b]
Selenium μg/L	0.400	0.5	0.5	0.1	1
Silver μg/L	0.002	<0.001	0.0005	0.0005	0.25
Strontium μg/L	305	293	279	282	/
Thallium μg/L	<0.002	<0.002	0.001	0.001	0.8
Thorium μg/L	<0.002	0.003	0.003	0.006	/
Tin μg/L	<0.06	<0.06	0.03	0.03	/
Titanium μg/L	0.69	0.57	0.5	0.23	/
Uranium μg/L	0.44	0.324	0.343	0.337	15
Vanadium μg/L	0.282	0.582	0.267	0.162	100[c,d]
Zinc μg/L	5.4	0.5	0.9	1.3	30[f]

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5
[b] Based on 2022 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 2022 avg. water hardness (as CaCO3) and avg. pH
[f] Based on 2022 avg. water hardness (as CaCO3), avg. pH, and avg. DOC with CCME equation
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 Moose Lake. In sum, significant increasing trends were observed in TP, chlorophyll-*a*, and TDS, and a significant decreasing trend was detected for 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 Moose Lake data from 1983 to 2022.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	1983-2022	Increasing
Chlorophyll-*a*	1983-2022	Increasing
Total Dissolved Solids	1983-2022	Increasing
Secchi Depth	1983-2022	Decreasing

Definitions:

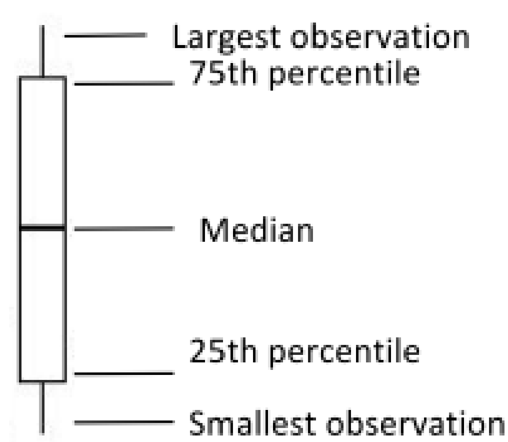
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

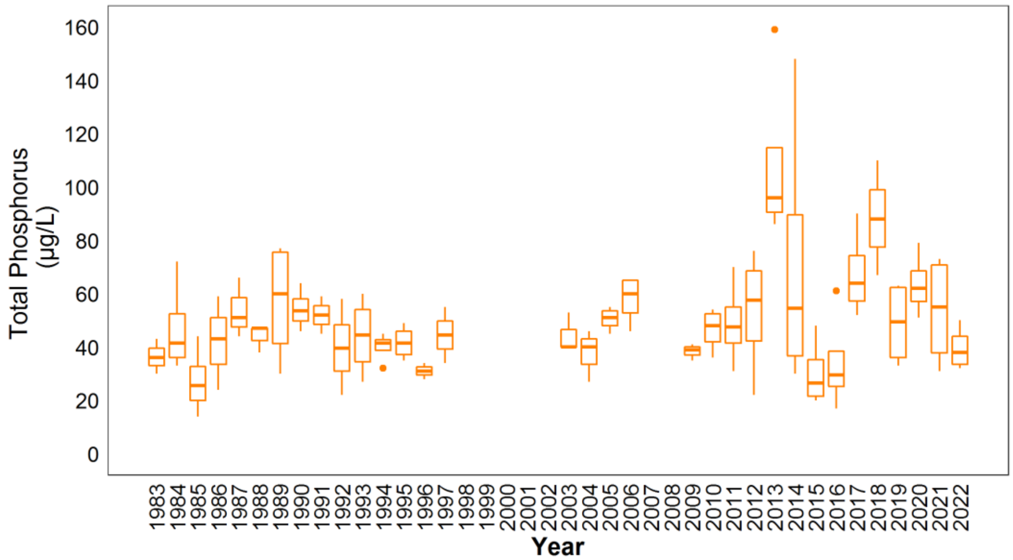
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

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 increased in Moose Lake since 1983 (Tau = 0.14, *p* = 0.03).



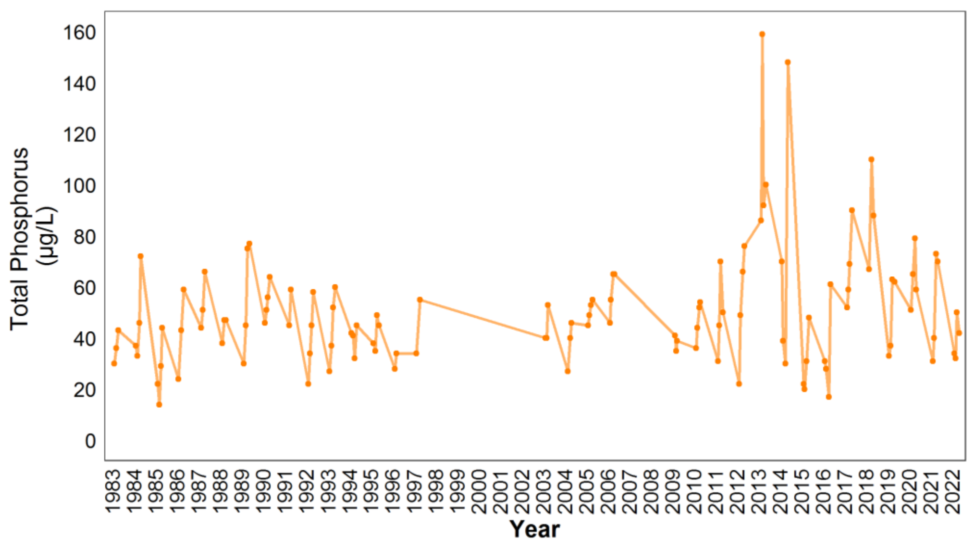
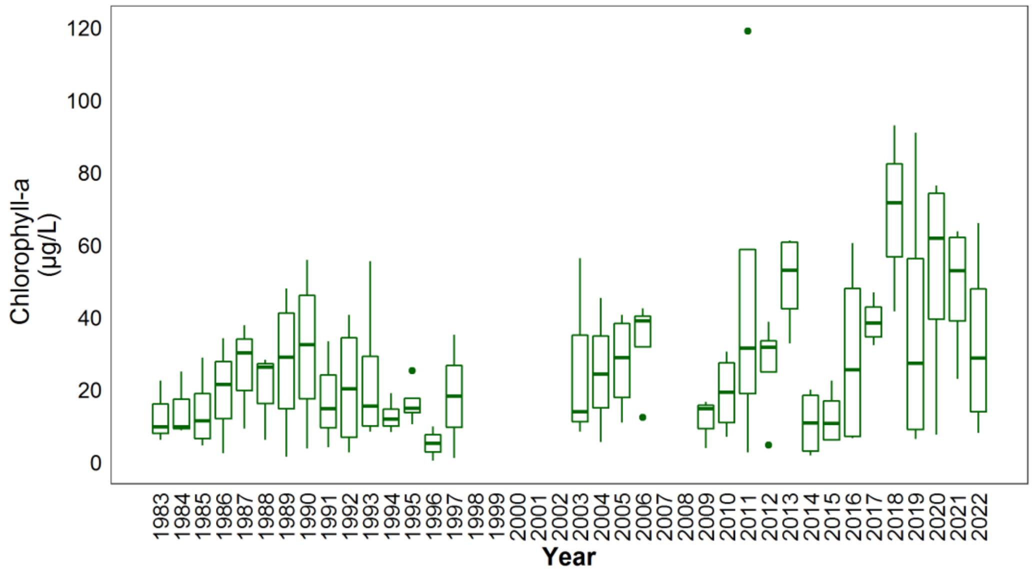


Figure 7. Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 1983 and 2022 (n = 118). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Trend analysis of chlorophyll-*a* over time showed that it has significantly increased in Moose Lake since 1983 (Tau = 0.23, p = <0.001).



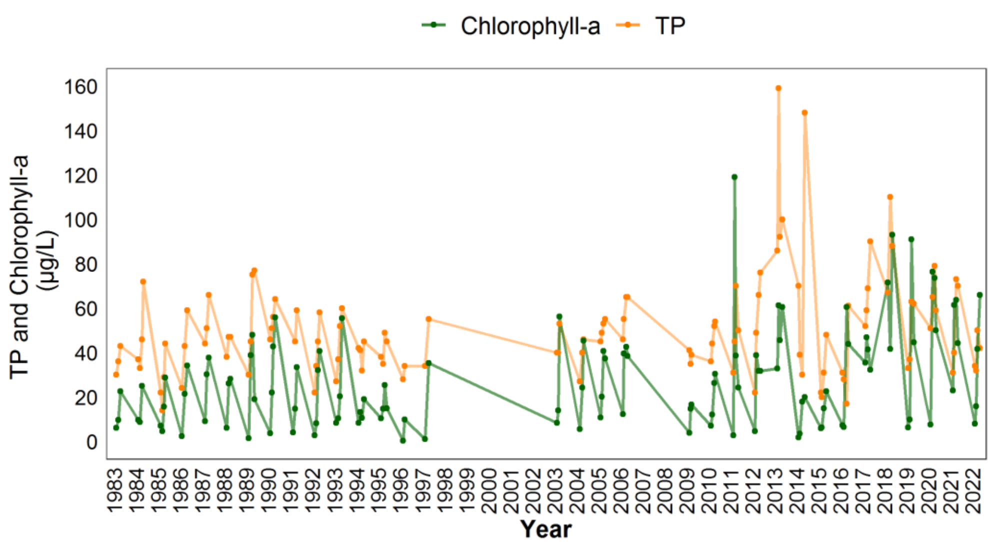


Figure 8. Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 1983 and 2022 (n = 118). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 1983 and 2022 (Tau = 0.44, p = <0.001) in Moose Lake (Figure 9).

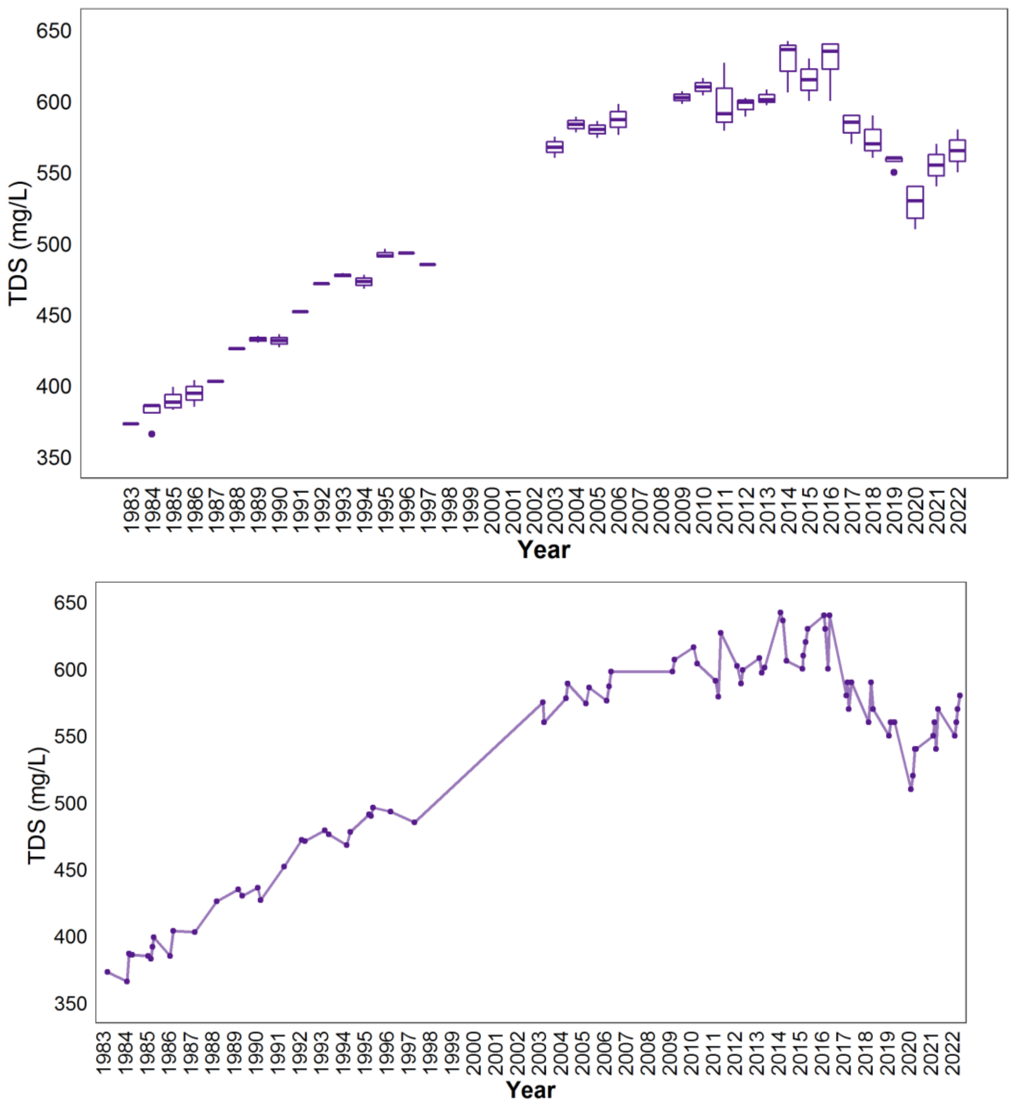


Figure 9. Monthly TDS values measured between June and September over the long term sampling dates between 1983 and 2022 (n = 85). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Due to the significant increasing trend of TDS in Moose Lake, exploring the specific major ions which may be driving this trend is important to determine. Trend analysis of major ions at Moose Lake indicates that alkalinity (bicarbonate, carbonate), sulphate, sodium, and chloride are the key parameters driving the historical increase in TDS (Figure 10). Interestingly, while alkalinity, sodium and sulphate display recent declines, chloride did not display recent declines, and is the parameter increasing at the most steady rate.

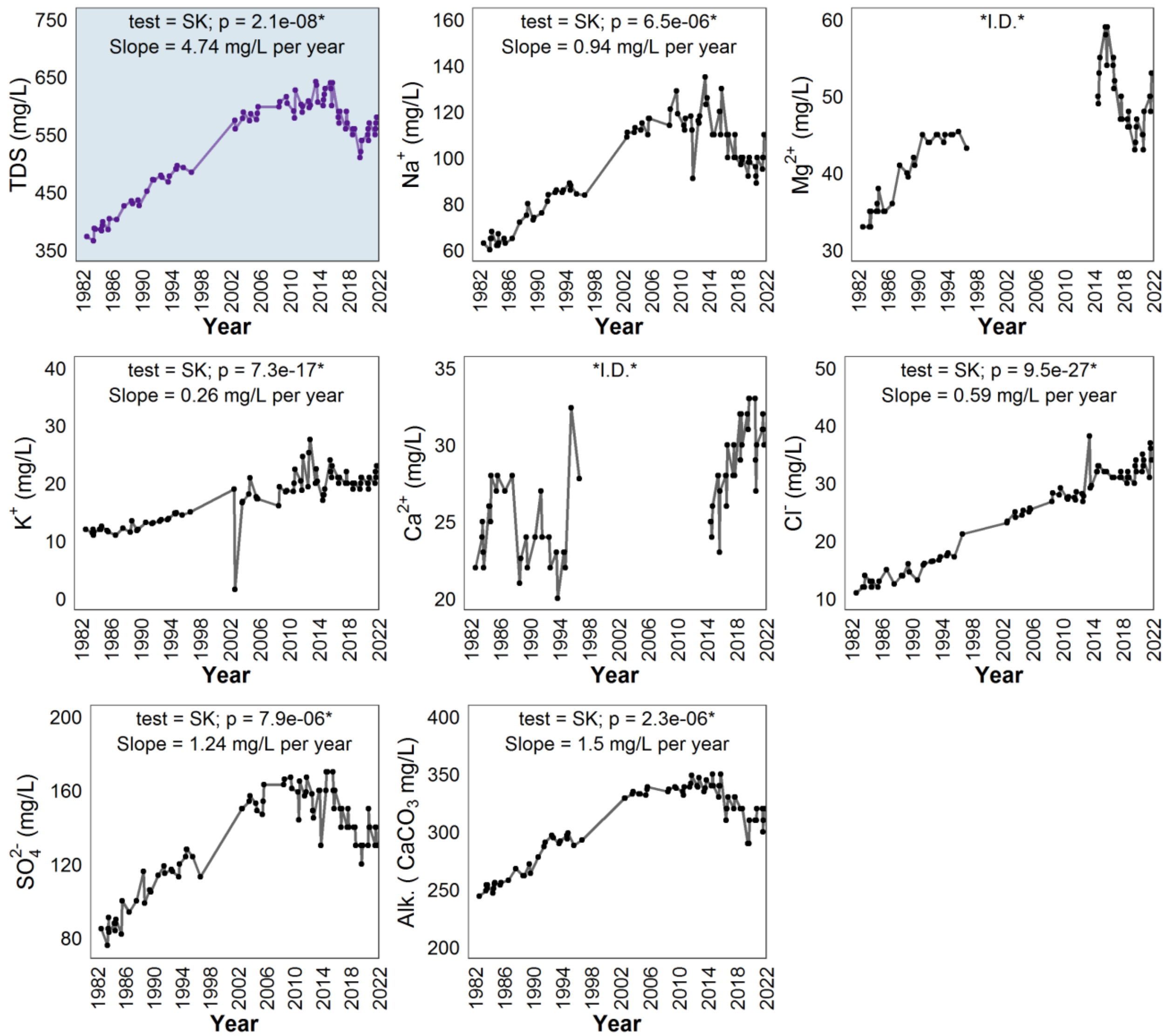
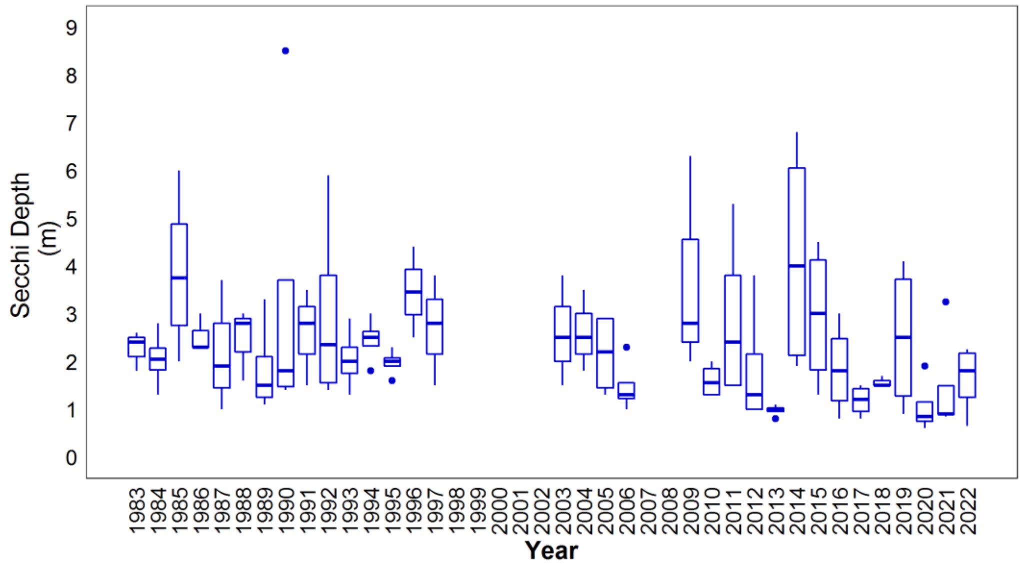


Figure 10. Concentrations of TDS (top left, blue panel), major ions (sodium = Na^{+}, magnesium = Mg^{2+}, potassium = K^{+}, calcium = Ca^{2+}, chloride = Cl^{-}, sulphate = SO_4^{2-}), and total alkalinity (Alk., as mg/L $CaCO_3$) measured monthly between June and September on sampling dates between 1983 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 Moose Lake since 1983 (Tau = -0.22, *p* = <0.001).



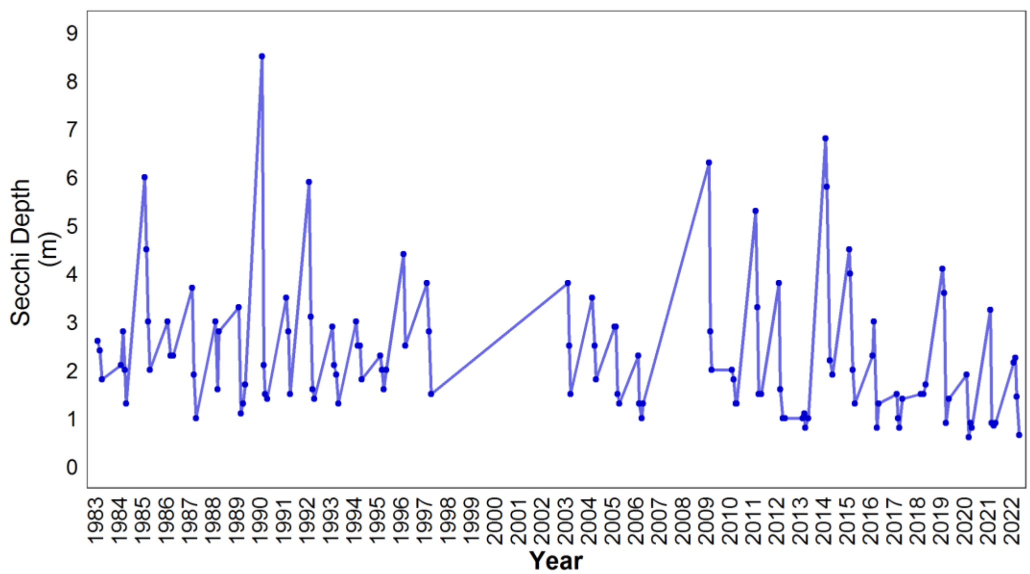


Figure 11. Monthly Secchi depth values measured between June and September on sampling dates between 1983 and 2022 (n = 120). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

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 1983-2022 on Moose 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	0.14	0.23	0.44	-0.22
The extent of the trend	Slope (units per Year)	0.23	0.28	4.74	-0.02
The statistic used to find significance of the trend	Z	2.18	3.43	5.61	-3.34
Number of samples included	n	118	118	85	120
The significance of the trend	*p*	0.03*	6.06×10^{-4}*	2.07×10^{-8}*	8.53×10^{-4}*

*$p < 0.05$ is significant within 95%