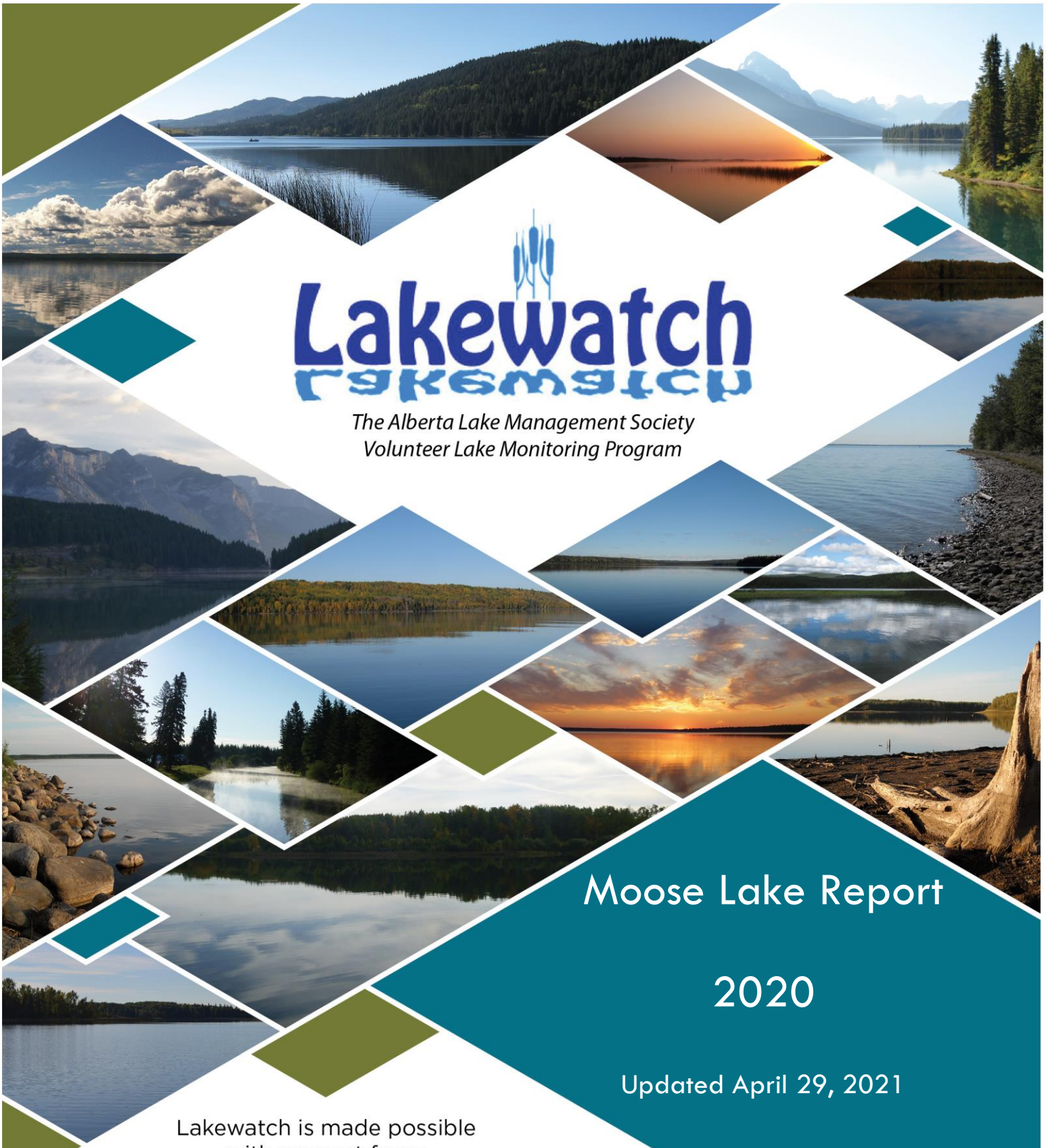


Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Moose Lake Report

2020

Updated April 29, 2021

Lakewatch is made possible with support from:

Alberta Environment and Parks
Pigeon Lake Watershed Association
Moose Lake Watershed Society
Lacombe County
LICA Environmental Stewards

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.

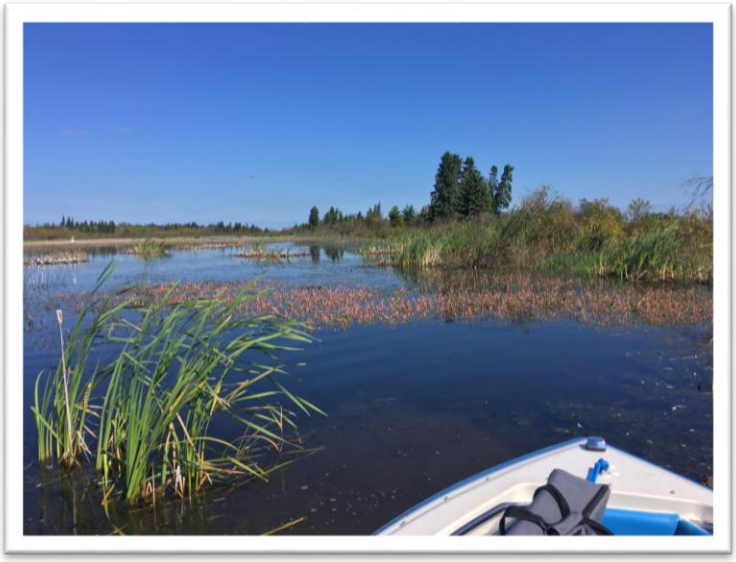
If you require data from this report, please contact ALMS for the raw data files

ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks to Mark Feiger, Cody Fedun and Kellie Nichiporik for their commitment to collecting data at Moose Lake. The Moose Lake Watershed Society contributed the funds to make the enhanced sampling possible at Moose Lake in 2020. We would also like to thank Kyra Ford and Ryan Turner, who were summer technicians in 2020. 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 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 comprises 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.



Moose Lake—photo by Elashia Young 2017

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.

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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/

METHODS

Profiles: Profile data is measured at the deepest spot in the main basin of the lake. At the profile site, temperature, dissolved oxygen, pH, conductivity and redox potential are measured at 0.5 – 1.0 m intervals. Additionally, Secchi depth is measured at the profile site and used to calculate the euphotic zone. For select lakes, metals are collected at the profile site by hand grab from the surface on one visit over the season.

Composite samples: At 10-sites across the lake, water is collected from the euphotic zone and combined across sites into one composite sample. This water is collected for analysis of water chemistry, chlorophyll-a, nutrients and microcystin. Quality control (QC) data for total phosphorus was taken as a duplicate true split on one sampling date. ALMS uses the following accredited labs for analysis: Routine water chemistry and nutrients are analyzed by Bureau Veritas, chlorophyll-*a* and metals are analyzed by Innotech Alberta, and microcystin is analyzed by the Alberta Centre for Toxicology (ACTF).

Invasive Species: : Invasive mussel monitoring involved sampling with a 63 µm plankton net at three sample sites twice through the summer season to determine the presence of juvenile dreissenid mussel veligers, and spiny water flea. Technicians also harvested potential Eurasian watermilfoil (*Myriophyllum spicatum)* samples and submitted them for further analysis at the Alberta Plant Health Lab to genetically differentiate whether the sample was the invasive Eurasian watermilfoil or a native watermilfoil. In addition, select lakes were subject to a bioblitz, where a concerted effort to sample the lake's aquatic plant diversity took place.

Data Storage and Analysis: Data is stored in the Water Data System (WDS), a module of the Environmental Management System (EMS) run by Alberta Environment and Parks (AEP). Data goes through a complete validation process by ALMS and AEP. Users should use caution when comparing historical data, as sampling and laboratory techniques have changed over time (e.g. detection limits). For more information on data storage, see AEP Surface Water Quality Data Reports at www.alberta.ca/surface-water-quality-data.aspx.
Data analysis is done using the program R.[1] Data is reconfigured using packages tidyr [2] and dplyr [3] and figures are produced using the package ggplot2 [4]. Trophic status for each lake is classified based on lake water characteristics using values from Nurnberg (1996)[5]. The Canadian Council for Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life are used to compare heavy metals and dissolved oxygen measurements. Pearson's Correlation tests are used to examine relationships between total phosphorus (TP), chlorophyll-*a,* total kjeldahl nitrogen (TKN) and Secchi depth, providing a correlation coefficient (r) to show the strength (0-1) and a p-value to assess significance of the relationship. For lakes with >10 years of long term data, trend analysis is done with non-parametric methods. The seasonal Kendall test estimates the presence of monotonic (unidirectional) trends across individual seasons (months) and is summed to give an overall trend over time. For lakes that had multiple samplings in a single month, the value closest to the middle of the month was used in analysis.

[1] R Core Team (2016). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
[2] Wickman, H. and Henry, L. (2017). tidyr: Easily Tidy Data with 'spread ( )' and 'gather ( )' Functions. R package version 0.7.2. https://CRAN.R-project.org/package=tidyr.
[3] Wickman, H., Francois, R., Henry, L. and Muller, K. (2017). dplyr: A Grammar of Data Manipulation. R package version 0.7.4. http://CRAN.R-project.org/package=dplyr.
[4] Wickham, H. (2009). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York.
[5] Nurnberg, G.K. (1996). Trophic state of clear and colored, soft- and hardwater lakes with special consideration of nutrients, anoxia, phytoplankton and fish. Lake and Reservoir Management 12: 432-447.

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 64 µg/L (Table 2), falling within the eutrophic, or highly productive trophic classification. This value is within the range of measured historical averages. TP was lowest when first sampled on June 16 at 51 µg/L, and peaked at 79 µg/L on August 21 (Figure 1).

Average chlorophyll-*a* concentration in 2019 was 51.9 µg/L (Table 2), falling into the hypereutrophic, or very highly productive trophic classification. Concentrations of chlorophyll-*a* ranged from a minimum of 7.6 µg/L on June 12 to a maximum of 76.4 µg/L on July 21st. Concentrations remained high through August and September.

Finally, the average TKN concentration was 2.0 mg/L (Table 2) with concentrations ranging from 1.3 – 2.5 mg/L.

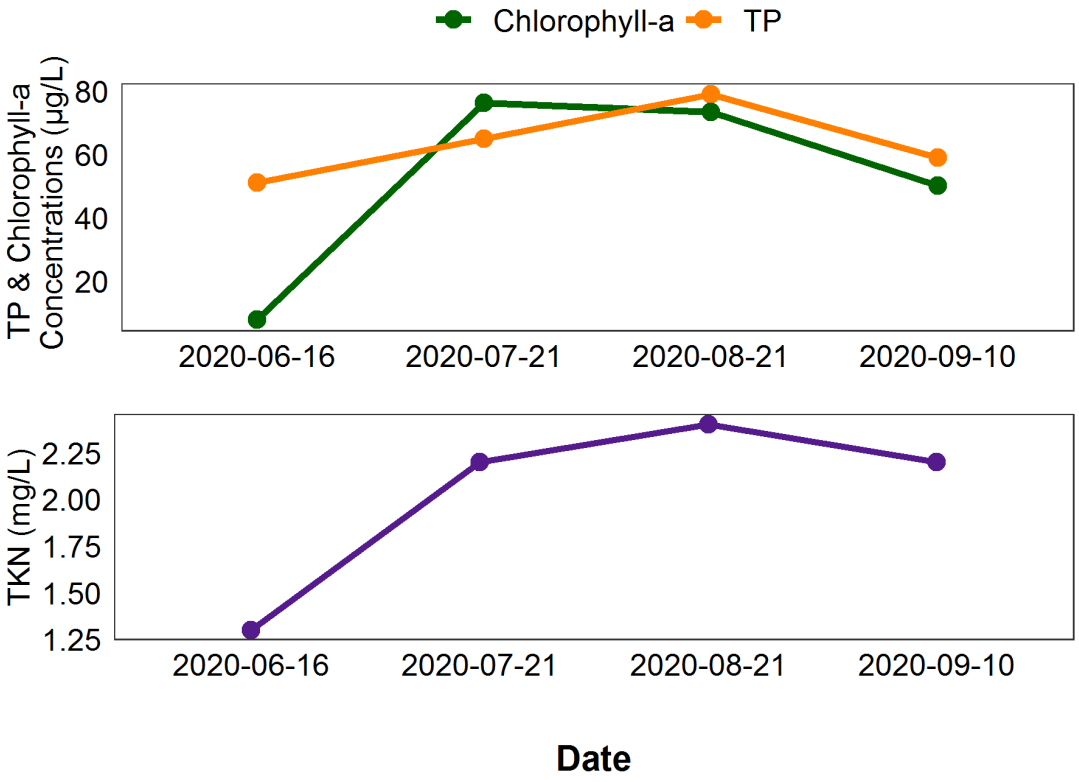


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Moose Lake, 2020.

Average pH was measured as 8.80 in 2020, buffered by moderate alkalinity (295 mg/L $CaCO_3$) and bicarbonate (308 mg/L HCO_3). Aside from bicarbonate, the dominant ions were sulphate and sodium, contributing to a moderate conductivity of 875 µS/cm (Figure 2, top; Table 2). Moose Lake is on the higher end of ion levels compared to other LakeWatch lakes sampled in 2020 (Figure 2, bottom).

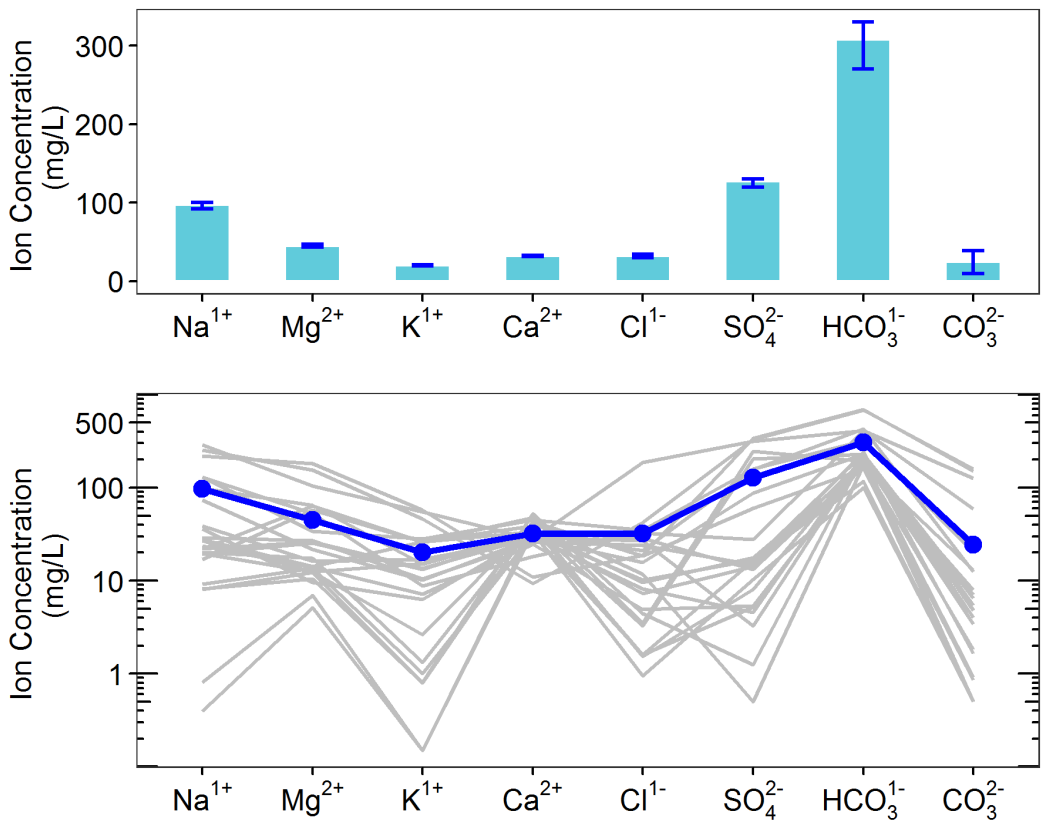


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Moose Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Moose Lake (blue line) compared to 25 lake basins (gray lines) sampled through the LakeWatch program in 2020 (note $\log_{10}$ scale on y-axis of bottom figure).

METALS

Samples were analyzed for metals once throughout the summer (Table 3). In total, 27 metals were sampled for. It should be noted that many metals are naturally present in aquatic environments due to the weathering of rocks and may only become toxic at higher levels.

A sample for metals analysis was collected at Moose Lake on August 21st, 2020. All values fell below the CCME guidelines (Table 3). Refer to Table 3 to see historical values for Moose Lake.

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 2020 was 2.03 m, corresponding to an average Secchi depth of 1.02 m, which is on the lower end of Moose Lake's historical range for Secchi depth (Table 3). Euphotic depth followed a similar trend as chlorophyll-a, starting deep in June, and then remaining shallow for the rest of the summer (Figure 3).

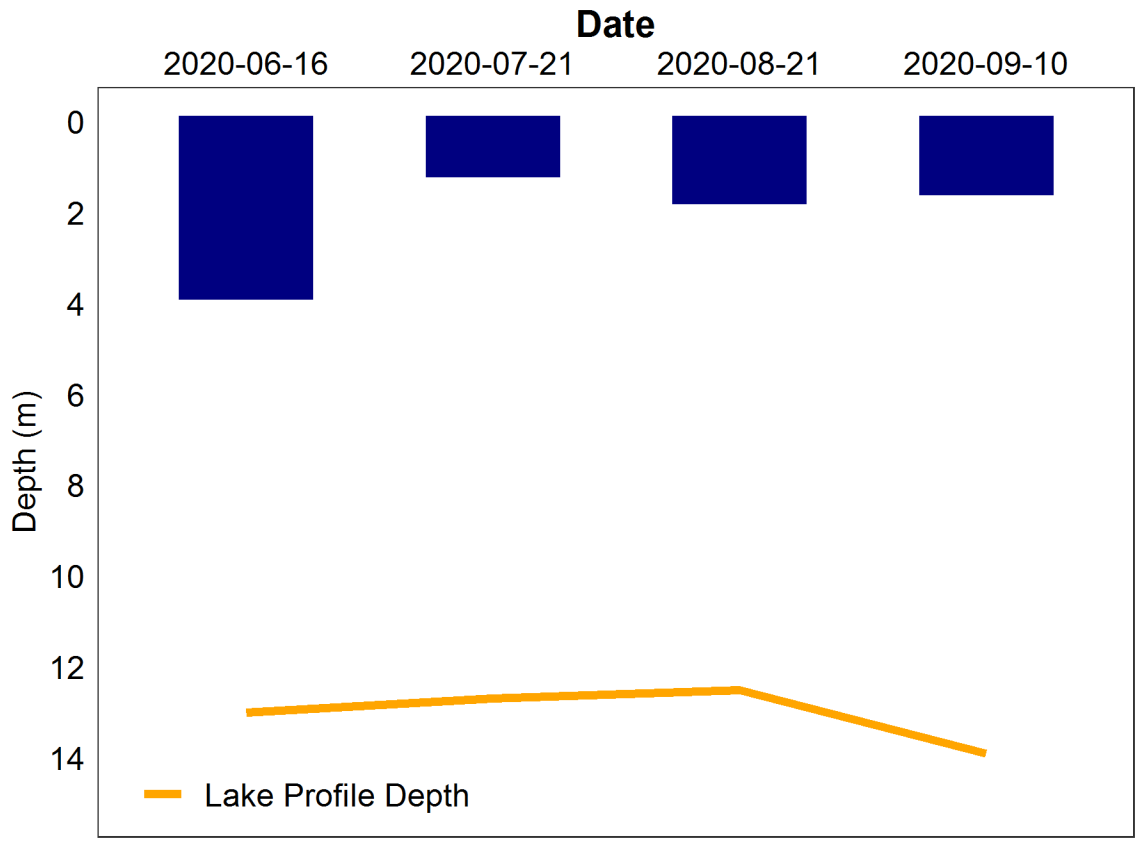


Figure 3. Secchi depth values measured four times over the course of the summer at Moose Lake in 2020.

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.

Temperatures of Moose Lake varied throughout the summer, with a maximum temperature of 20.4°C measured at the surface on July 21st, and a minimum temperature of 12.9°C measured at 13.0 m, near bottom, on June 16th (Figure 4a). The lake was not strongly stratified during any of the sampling trips, indicating partial or complete mixing of the main basin near Bonnyville Beach throughout the season.

Moose Lake remained well oxygenated in the upper water column throughout most of the summer. Concentrations measured above the CCME guidelines of 6.5 mg/L dissolved oxygen in the top 10m during the June 16th and July 21st sampling events, and above 13m on the September 10th sampling event (Figure 4b). However, the oxygen levels were fairly low during the August 21st sampling event, with levels below 6.5 mg/L below 3.5 m. This is likely due to large levels of cyanobacteria that were present in the preceding few weeks (Figure 1 illustrates peak of chlorophyll-*a* at July 21st, technician observed high levels of cyanobacteria during July 21st sampling, and surface oxygen levels were supersaturated on July 21st in Figure 4b, also indicative of intense bloom) that are beginning to settle and decay, leading to respiration and a decrease in oxygen levels. Dissolved oxygen recovered in the water column during the September 10th sampling event, as the lake began to cool and mix (Figures 4a & 4b).

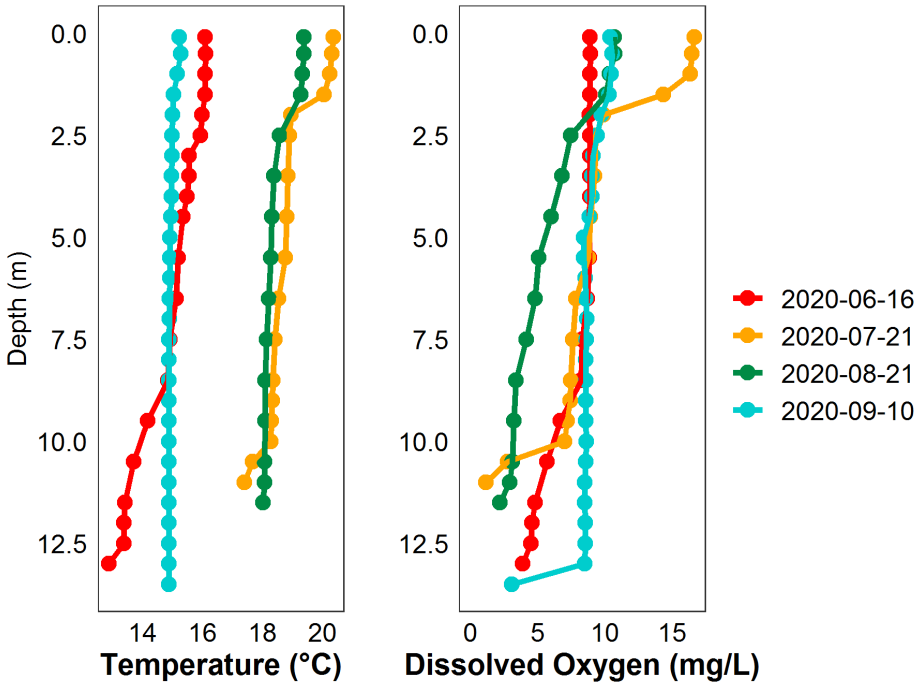


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Moose Lake measured four times over the course of the summer of 2020.

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 the one of the most common cyanobacteria toxins. In Alberta, recreational guidelines for microcystin are set at 20 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.

Whole lake composite levels of microcystin in Moose Lake fell below the recreational guideline of 20 µg/L. However, a concentration of 3.85 µg/L on August 21st indicates that microcystin toxins may be present in high concentrations at specific locations around the lake and recreating near visible cyanobacteria should be avoided. Multi-basin sampling of microcystin in previous years has demonstrated how variable toxin concentrations can be between basins. In 2020, the death of a dog was attributed to exposure to cyanobacteria bloom accumulation on the shoreline.

Table 1. Microcystin concentrations measured four times at Moose Lake in 2020.

Date	Microcystin Concentration (µg/L)
16-Jun-20	0.11
21-Jul-20	2.62
21-Aug-20	3.85
10-Sep-20	1.30
Average	1.97

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 using a 63 µm plankton net at three sample sites to look for juvenile mussel veligers in each lake sampled during July and August sampling events. No mussels or spiny water fleas were detected at Moose Lake in the summer of 2020.

Eurasian watermilfoil is 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 watermilfoil species identification.

No suspect watermilfoil was observed or collected from Moose Lake in 2020.

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 in Moose Lake have varied within a 2 m range since Alberta Environment began monitoring the lake in 1950 (Figure 5). Water levels were at their lowest in the mid-1990s and early 2000s, and have since increased to average levels within the recorded historical range. In 2017, levels increased by over 0.5 m, likely due to high rain fall in the region, which caused flooding in developments built below the historical high water mark. In 2018, discussion was underway between the MD of Bonnyville, stakeholders, and Alberta Environment to remove a weir between the lake and the Moose River in an attempt to lower water levels. No consensus was reached as to whether this action would be effective in lowering water levels[2], and as of 2020 the timeline for the removal is relatively unknown, and is still dependant on environmental approvals, stakeholder input, and public consultation.[3]

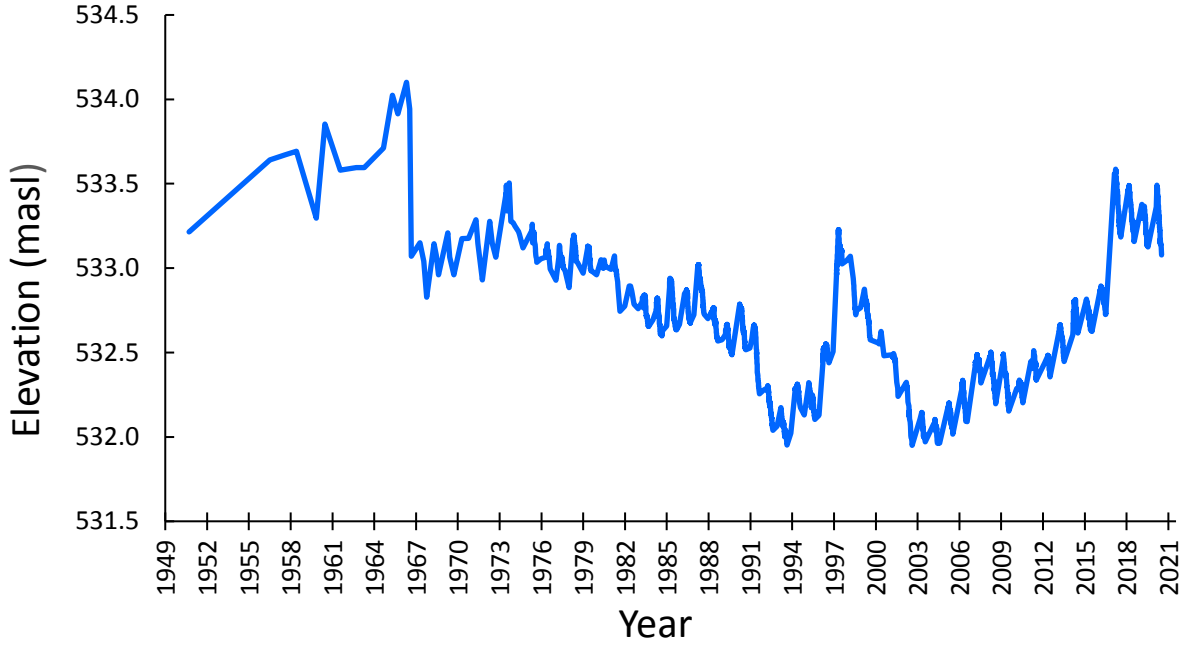


Figure 5. Water levels measured in metres above sea level (masl) from 1950-2020. Data retrieved from Alberta Environment and Parks.

[2] Bonnyville Nouvelle, April 17, 2018. Retrieved 2018/02/06 from https://www.bonnyvillenouvelle.ca/article/alberta-environment-considers-removal-moose-lake-weir-20180417

[3] Lakeland Connect, June 26, 2020. Retrieved 2021/03/04 from https://lakelandconnect.net/2020/06/26/moose-lake-weir-to-be-removed/

Table 2a. Average Secchi depth and water chemistry values for Moose Lake. Historical averages are provided for comparison.

Parameter	1983	1984	1985	1986	1987	1988	1990	1991	1992	1993	1994
TP (µg/L)	37	46	25	40	50	42	51	54	45	40	41
TDP (µg/L)	/	/	/	/	/	/	/	/	/	/	12
Chlorophyll-*a* (µg/L)	13.7	16.2	12.5	17.6	21.5	16.0	22.3	31.1	15.7	21.0	22.7
Secchi depth (m)	2.25	1.94	3.76	2.55	2.48	2.50	2.18	3.38	2.68	3.00	2.11
TKN (mg/L)	/	/	1	/	/	/	/	/	/	/	1
NO_2-N and NO_3-N (µg/L)	25	25	25	25	10	8	5	10	3	4	3
NH_3-N (µg/L)	/	/	/	/	/	/	/	/	/	/	17
DOC (mg/L)	/	/	/	/	/	/	/	/	/	/	18
Ca (mg/L)	24	24	26	27	28	27	22	23	23	26	24
Mg (mg/L)	33	34	36	36	36	40	40	42	44	44	45
Na (mg/L)	62	65	64	66	63	74	78	74	76	83	84
K (mg/L)	12	11	12	12	12	12	13	12	13	13	14
SO_4^{2-} (mg/L)	82	84	88	92	94	102	107	106	113	117	115
Cl^- (mg/L)	12	13	13	13	14	13	14	15	14	16	16
CO_3 (mg/L)	/	17	9	12	14	11	12	26	16	22	30
HCO_3 (mg/L)	/	273	289	289	283	302	295	275	300	330	330
pH	8.40	8.68	8.63	8.63	8.65	8.58	8.70	8.94	8.70	8.85	8.99
Conductivity (µS/cm)	657	641	667	678	681	715	709	706	736	780	787
Hardness (mg/L)	/	198	214	216	217	234	218	229	235	245	242
TDS (mg/L)	370	381	390	400	400	429	433	432	444	472	475
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	244	252	252	257	257	267	262	268	273	289	295

Table 2b. Average Secchi depth and water chemistry values for Moose Lake. Historical averages are provided for comparison.

Parameter	1995	1996	1997	2003	2004	2005	2006	2009	2010	2011
TP (µg/L)	43	31	48	53	38	51	59	43	47	49
TDP (µg/L)	/	/	/	15	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	19.0	46.1
Secchi depth (m)	1.98	3.45	2.75	2.25	2.69	2.15	1.30	3.06	1.56	2.88
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)	22	25	25	22	20	25	25	14	8	4
NH_3-N (µg/L)	/	/	/	33	38	16	23	43	24	31
DOC (mg/L)	18	/	/	/	18	18	18	18	18	17
Ca (mg/L)	23	31	28	25	25	25	25	24	21	24
Mg (mg/L)	45	44	43	54	50	47	48	48	51	56
Na (mg/L)	87	84	84	111	112	114	115	117	129	114
K (mg/L)	15	15	15	12	17	20	17	20	19	20
SO_4^{2-} (mg/L)	125	124	113	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	13	15	29	29	35	32	30	28	18
HCO_3 (mg/L)	321	322	314	343	350	335	346	348	358	372
pH	8.76	8.56	8.64	8.87	8.86	8.99	8.81	8.90	8.85	8.70
Conductivity (µS/cm)	793	808	776	/	935	868	947	954	965	974
Hardness (mg/L)	241	268	246	284	267	255	261	260	260	290
TDS (mg/L)	489	/	/	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	339	334

Table 2c. Average Secchi depth and water chemistry values for Moose Lake. Historical averages are provided for comparison.

Parameter	2012	2013	2014	2015	2016	2017	2018	2019	2020
TP (µg/L)	53	109	74	33	34	69	91	49	64
TDP (µg/L)	18	41	31	10	12	12	18	15	13
Chlorophyll-*a* (µg/L)	26.8	50.0	14.3	14.6	29.6	40.7	94.1	38.0	51.9
Secchi depth (m)	1.84	0.96	3.66	2.60	1.75	1.10	1.30	2.48	1.01
TKN (mg/L)	1.7	2.0	1.6	1.6	1.5	2.1	2.2	1.7	2.0
NO_2-N and NO_3-N (µg/L)	3	3	36	7	3	10	14	2	2
NH_3-N (µg/L)	20	19	87	36	38	52	106	24	37
DOC (mg/L)	18	24	17	16	16	17	19	18	18
Ca (mg/L)	25	26	26	25	27	28	29	31	32
Mg (mg/L)	49	53	48	52	57	54	49	47	45
Na (mg/L)	107	116	129	110	120	110	103	99	97
K (mg/L)	21	24	21	18	22	21	21	20	20
SO_4^{2-} (mg/L)	161	151	150	168	160	148	145	138	128
Cl^- (mg/L)	28	28	34	33	32	31	31	31	32
CO_3 (mg/L)	29	36	29	27	25	23	27	21	24
HCO_3 (mg/L)	359	342	413	366	368	348	338	348	308
pH	8.87	8.90	8.71	8.80	8.79	8.75	8.81	8.75	8.80
Conductivity (µS/cm)	993	989	996	990	994	934	918	905	875
Hardness (mg/L)	263	282	262	280	302	294	273	268	263
TDS (mg/L)	597	602	639	618	628	586	575	557	528
Microcystin (µg/L)	1.00	0.23	0.60	0.54	1.59	1.04	3.72	1.96	1.97
Total Alkalinity (mg/L $CaCO_3$)	342	371	339	344	342	322	325	320	295

Table 3a. Concentrations of metals measured in Moose Lake on in each sampling year since 2003. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Concentrations that exceed these guidelines are displayed in red.

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	0.26[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	1000[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[e]
Manganese µg/L	9.28	8.14	7.26	7.55	7.2	5.615	200[e]
Molybdenum µg/L	0.590	0.846	0.705	0.598	0.556	0.628	73[c]
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[d,e]
Zinc µg/L	2.98	7.9	4.335	0.722	0.498	0.68	30

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

[b] Based on water hardness > 180mg/L (as $CaCO_3$)

[c] CCME interim value.

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

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

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

Table 3b. Concentrations of metals measured in Moose Lake on in each sampling year since 2003. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Concentrations that exceed these guidelines are displayed in red.

Metals (Total Recoverable)	2018	2020	Guidelines
Aluminum µg/L	1.3	3.7	100[a]
Antimony µg/L	0.055	0.054	/
Arsenic µg/L	2.18	2.03	5
Barium µg/L	50.6	51.8	/
Beryllium µg/L	<0.003	<0.003	100[c,d]
Bismuth µg/L	<0.003	<0.003	/
Boron µg/L	172	151	1500
Cadmium µg/L	<0.01	<0.01	0.26[b]
Chromium µg/L	<0.1	<0.1	/
Cobalt µg/L	0.036	0.032	1000[d]
Copper µg/L	0.3	<0.08	4[b]
Iron µg/L	12.6	8.7	300
Lead µg/L	0.036	0.007	7[b]
Lithium µg/L	54.1	44.6	2500[e]
Manganese µg/L	11.1	21	200[e]
Molybdenum µg/L	0.555	0.458	73[c]
Nickel µg/L	0.410	0.11	150[b]
Selenium µg/L	0.400	0.5	1
Silver µg/L	0.002	<0.001	0.25
Strontium µg/L	305	293	/
Thallium µg/L	<0.002	<0.002	0.8
Thorium µg/L	<0.002	0.003	/
Tin µg/L	<0.06	<0.06	/
Titanium µg/L	0.69	0.57	/
Uranium µg/L	0.44	0.324	15
Vanadium µg/L	0.282	0.582	100[d,e]
Zinc µg/L	5.4	0.5	30

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5
[b] Based on water hardness > 180mg/L (as $CaCO_3$)
[c] CCME interim value.
[d] Based on CCME Guidelines for Agricultural use (Livestock Watering).
[e] Based on CCME Guidelines for Agricultural Use (Irrigation).
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 increases were observed in TP, Chlorophyll-*a*, and TDS. A significant decreasing trend was observed in Secchi depth. Secchi depth can be subjective and is sensitive to variation in weather - 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 2020.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	1983-2020	Increasing
Chlorophyll-*a*	1983-2020	Increasing
Total Dissolved Solids	1983-2020	Increasing
Secchi Depth	1983-2020	Decreasing

Definitions:

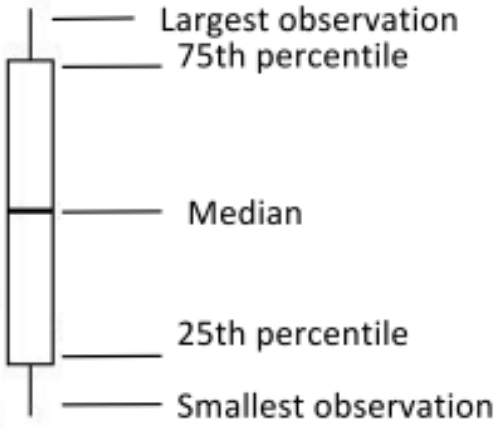
Median: the value in a range of ordered numbers that falls in the middle.

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 = 0.19, $p < 0.01$). In addition, there appears to be an increase in variability within and between seasons in recent years (Figure 6).

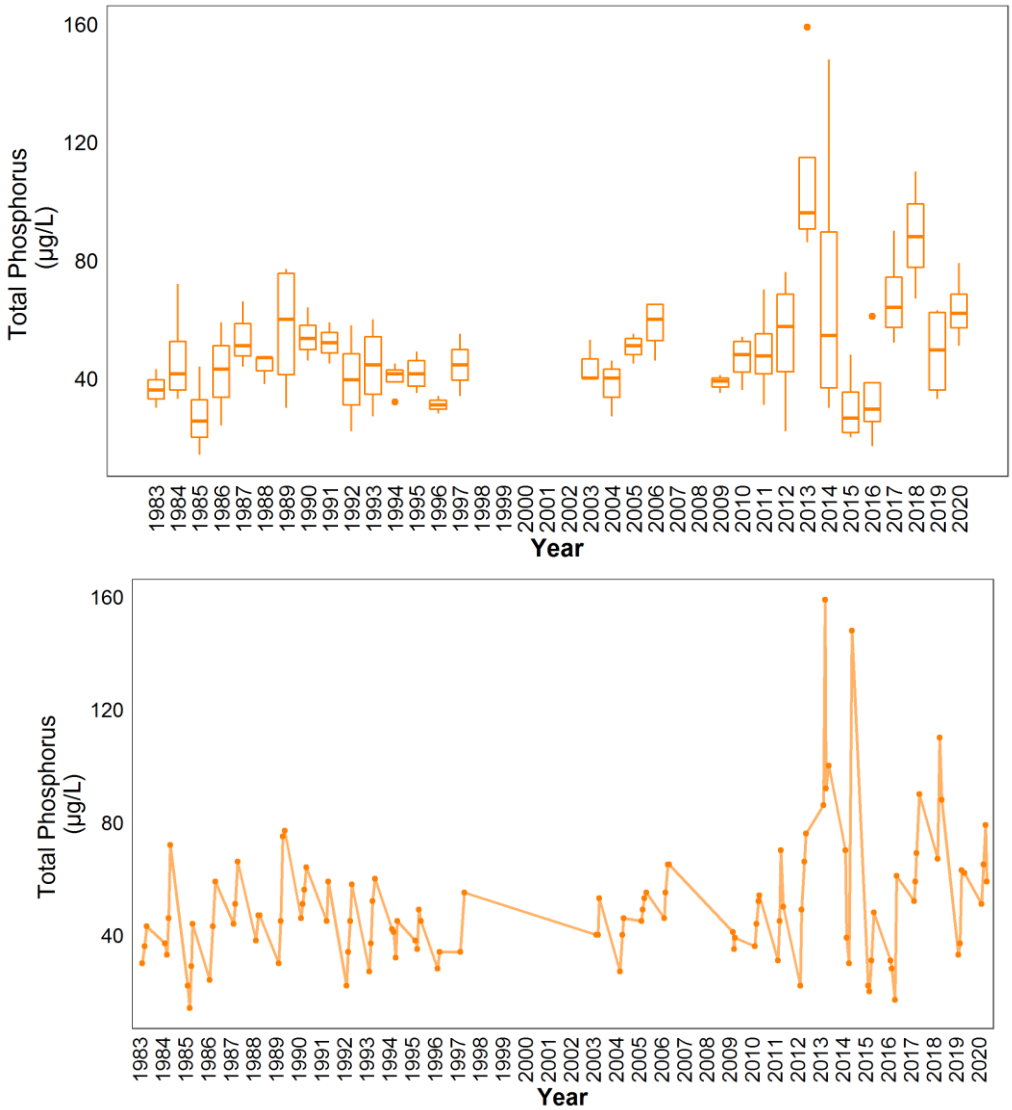


Figure 6. Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 1983 and 2020 (n = 110). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Chlorophyll-*a* has increased significantly over time at Moose Lake (Tau = 0.17, p = 0.011). Chlorophyll-*a* trends follow TP trends with correlation over time (r = 0.53, $p = 2.82 \times 10^{-9}$). In addition, there appears to be an increase in variability within and between seasons in recent years (Figure 7).

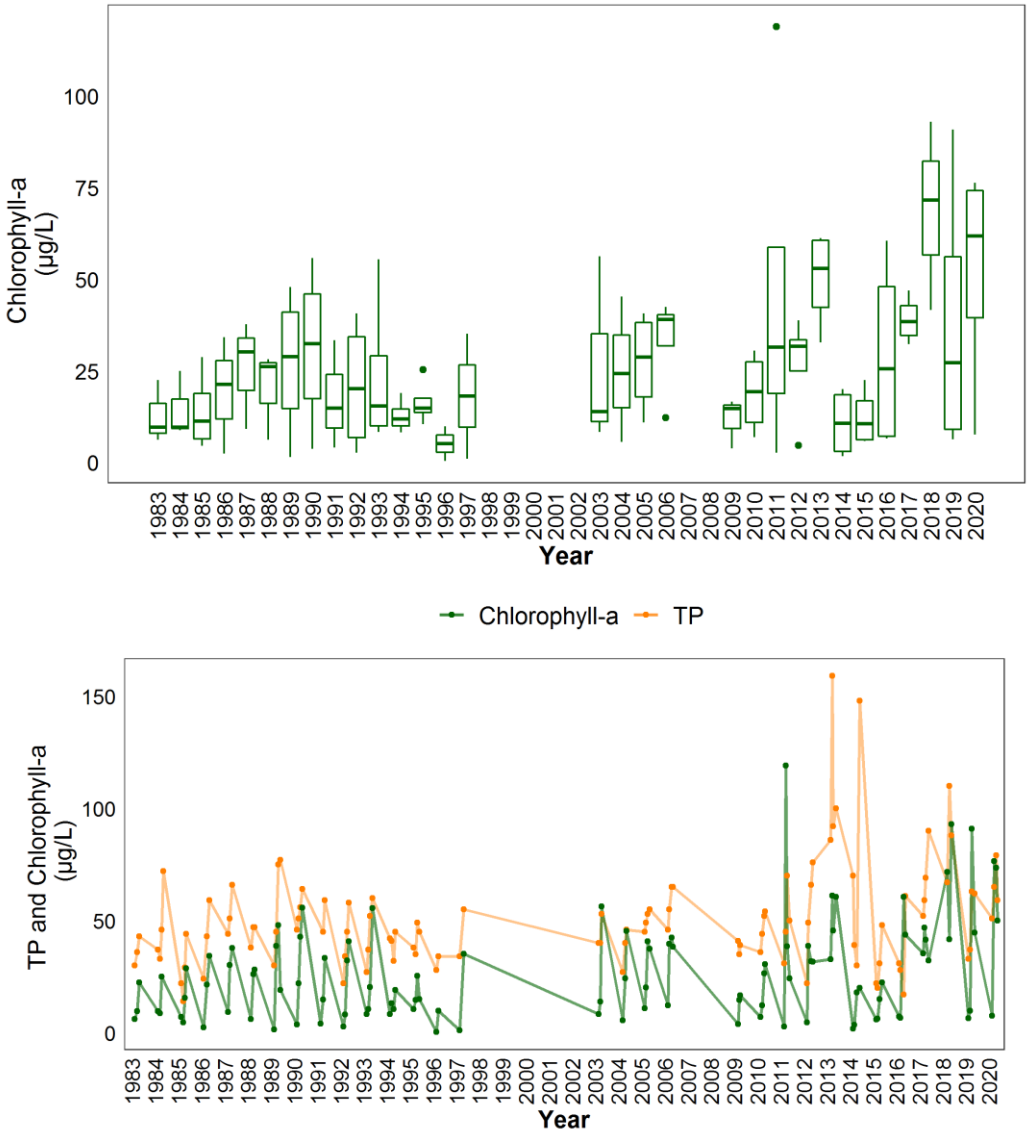


Figure 7. Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 1983 and 2020 (n = 110). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 1983 and 2020 (Tau = 0.54, $p < 0.001$) in Moose Lake. However, levels since 2017 have appeared to steadily decrease (Figure 8), potentially due to the diluting impact of increasing water levels, also having a large increase in 2017, with levels remaining relatively high (Figure 5). TDS is still nearly 160 mg/L greater than when TDS was first measured in 1983 (Figure 8).

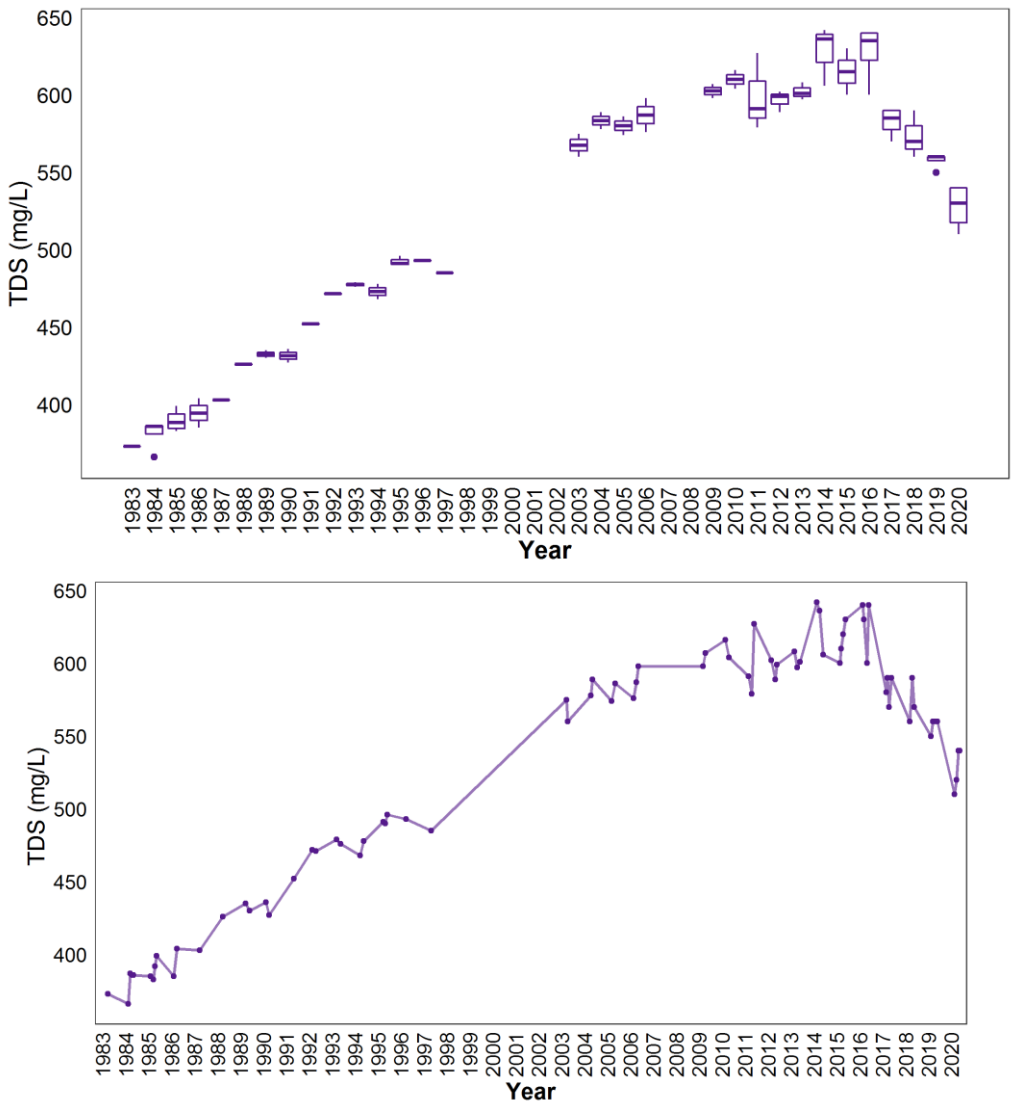


Figure 8. Monthly TDS values measured between June and September over the long term sampling dates between 1983 and 2020 (n = 77). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Secchi depth has significantly decreased (become less clear) in Moose Lake since 1983 (Tau = -0.17, *p* = 0.016).

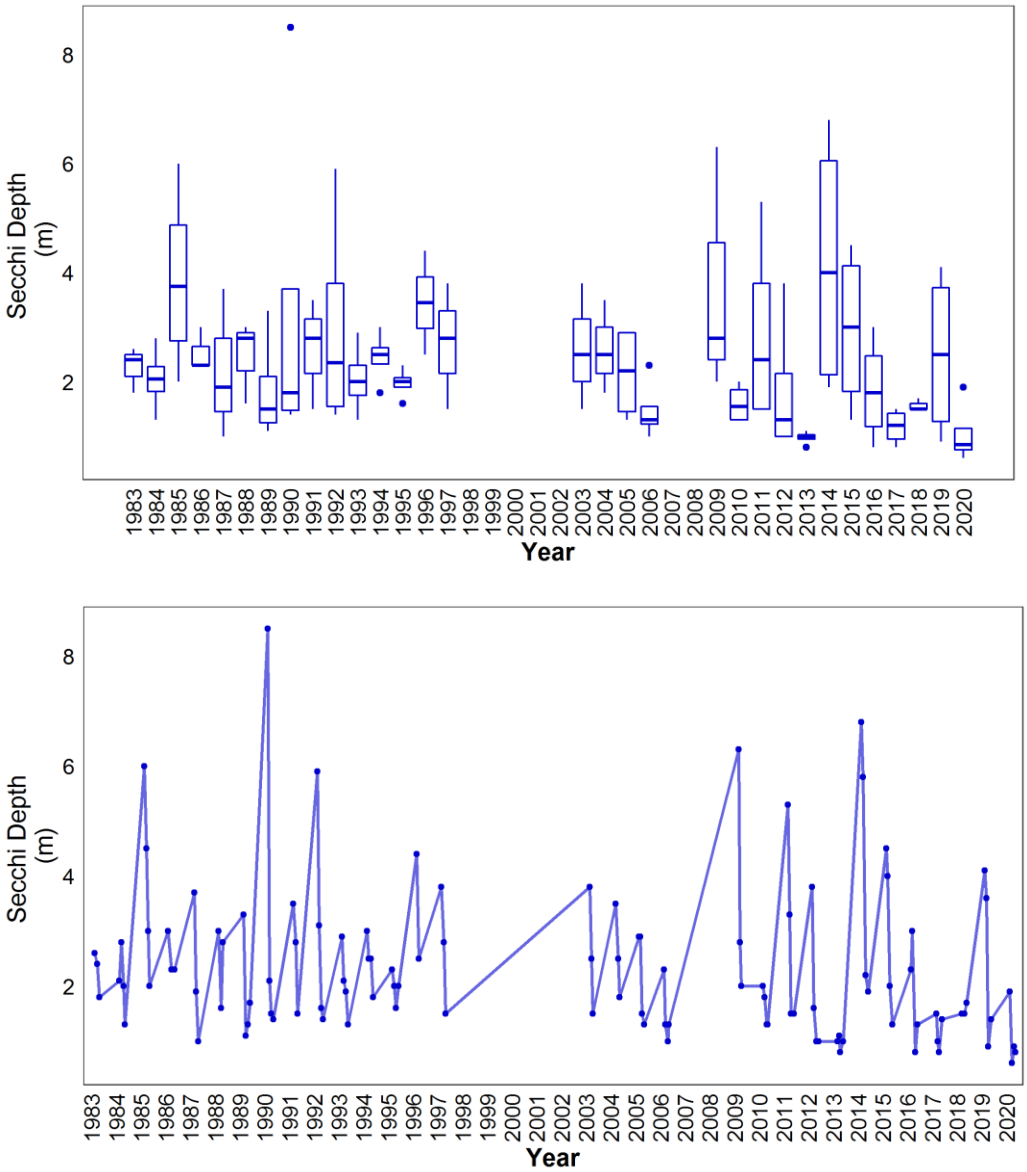


Figure 9. Monthly Secchi depth values measured between June and September over the long term sampling dates between 1983 and 2020 (n = 112). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

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 1983-2020 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	0.19	0.17	0.54	-0.17
The extent of the trend	Slope	0.33	0.21	5.95	-0.016
The statistic used to find significance of the trend	Z	2.78	2.54	6.51	-2.42
Number of samples included	n	110	110	77	112
The significance of the trend	*p*	5.49×10^{-3}*	0.011*	7.45×10^{-11}*	0.016*

*$p < 0.05$ is significant within 95%

ENHANCED SAMPLING

In 2020, an enhanced sampling project took place at Moose Lake, and was funded by the Moose Lake Watershed Society. This work follows up on enhanced sampling projects completed in 2016 and 2017, in an effort to better understand the nuances of water quality across Moose Lake. The enhanced sampling has focused on the differences between the basins in Moose Lake, as it has been observed over time that different basins across Moose Lake may display different water quality. This may in part be due to the shape of Moose Lake, in which a few distinct basins with different depth profiles, connectivity, and hydrology function slightly different from one another.

The basins sampled in 2020 were Franchere Bay in the west, Main Basin (Bonnyville Beach Basin) in the central region, and Vezeau Bay in the northeast (Figure 10). In each of the basins, spatial composites euphotic sampling was completed to capture nutrient and biological information in each of the basins. In additional, samples near the bottom of each basin were taken for total phosphorus, to detect the presence and relative abundance of internal phosphorus loading. The enhanced sampling was completed three times, June 16th, August 21st and September 10th, the same days the whole lake was sampled (aside from the July 21st sampling event).

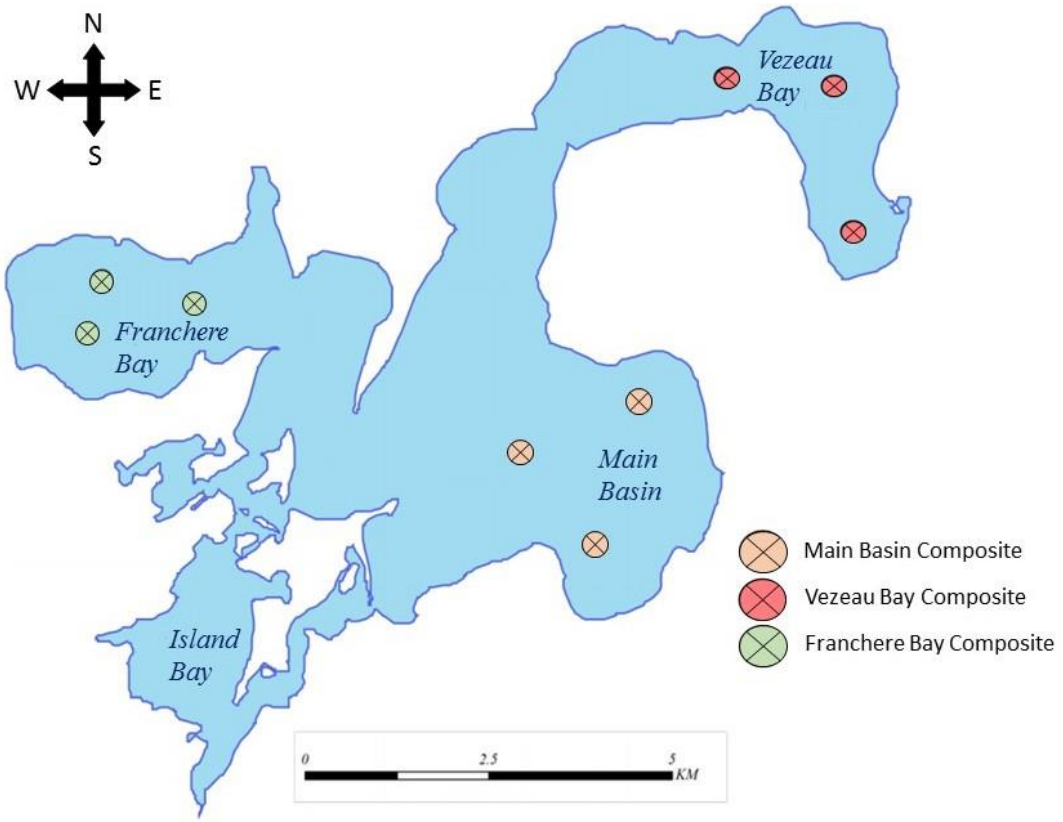


Figure 10. Composite sampling sites for Franchere Bay, Main Basin (Bonnyville Beach Basin), and Vezeau Bay for the Moose Lake enhanced sampling completed in summer 2020.

Table 6. Results of enhanced sampling at Moose Lake in 2020. Spatial composite euphotic sampling was performed in Main Basin (Bonnyville Beach Bay), Vezeau Bay, and Franchere Bay to provide nutrient (TP, TDP, TKN, ammonia) and biological (chlorophyll-*a,* microcystin) data. Secchi depth was taken in each basin, and a bottom grab was taken in each basin as well to determine bottom TP levels. Depth of bottom grabs were 11m, 12m, and 9m for each of Main Basin, Vezeau Bay and Franchere Bay, respectively. *Note Secchi depth averages from Vezeau Bay and Franchere Bay no to include data from September 10th sampling event – Secchi depth not completed at those basins during September sampling.

Basin	Sample Date	TP (µg/L)	Bottom TP (µg/L)	TDP (µg/L)	TKN (mg/L)	Ammonia (µg/L)	Chlorophyll-*a* (µg/L)	Microcystin (µg/L)	Secchi depth (m)
Main Basin (Bonnyville Beach Bay)	16-June	27	28	8	1.3	22	6.3	-	1.90
	21-August	80	85	11	2.3	29	70.0	3.1	0.85
	10-September	53	62	15	2.1	19	43.1	-	0.75
	AVERAGE	**53**	**58**	**11**	**1.9**	**23**	**39.8**	**-**	**1.17**
Vezeau Bay	16-June	32	57	16	1.4	29	5.4	-	2.00
	21-August	79	390	12	2.2	25	83.3	2.98	1.00
	10-September	65	63	12	2.1	22	62.2	-	-
	AVERAGE	**59**	**170**	**13**	**1.9**	**25**	**50.3**	**-**	**1.5***
Franchere Bay	16-June	100	100	75	1.6	30	10.6	-	3
	21-August	94	130	24	2.8	31	102	5.92	1.5
	10-September	68	80	15	2.2	22	56.4	-	-
	AVERAGE	**87**	**103**	**38**	**2.2**	**28**	**56.3**	**-**	**1.13***

Data for each sampling event at each basin is presented in Table 6. In summary, nutrient levels varied in each basin throughout the season. For Main Basin and Vezeau Bay, nutrient levels were highest during the August 21st sampling event, corresponding with high levels of chlorophyll-*a.* Franchere Bay on the other hand displayed the highest nutrient levels during the June 16th and August 21st sampling event, depending on the parameter, but chlorophyll-*a* was also greatest during the August 21st sampling event.

In comparing the basins to one another, Franchere Bay had the highest average levels of all nutrients and biological data (including the August 21st microcystin data), with the exception of Bottom TP, which Vezeau Bay was the highest due to a very large value during the August 21st sampling event. Chlorophyll-*a* levels were similar across each basin, with Main Basin having slightly lower values compared to the other two sampled basins.