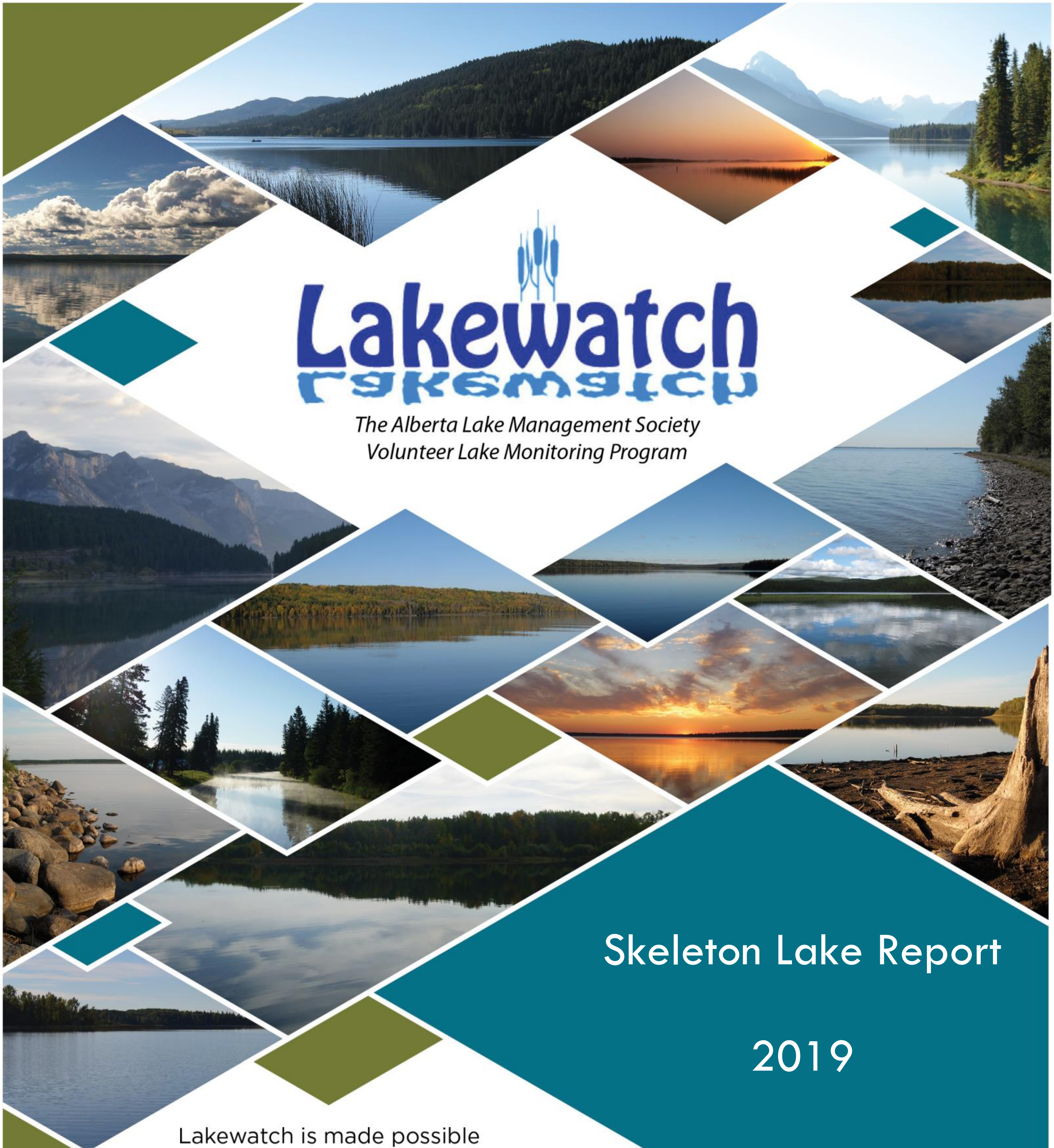


Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Skeleton Lake Report

2019

Lakewatch is made possible with support from:

Alberta Environment and Parks

Pigeon Lake Watershed Association

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.

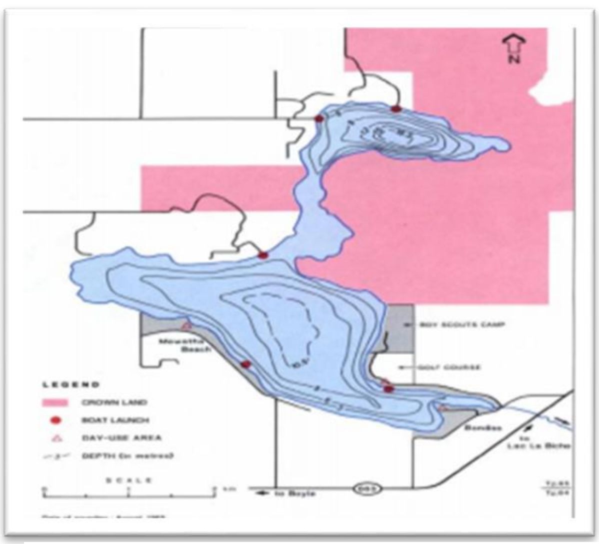
ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks to Orest Kitt, Marc Vincent, and Mark Stanton for their commitment to collecting data at Skeleton Lake. We would also like to thank Sarah Davis Cornet, Caleb Sinn, and Pat Heney, who were summer technicians in 2019. Executive Director Bradley Peter and Program Coordinator Caitlin Mader were instrumental in planning and organizing the field program. This report was prepared by Pat Heney and Bradley Peter, and Caleb Sinn.

SKELETON LAKE

Skeleton Lake is located in the western portion of the Beaver River watershed. The lake's name is a translation of the Cree Cîpay Sâkâhikan, which means "place of the skeletons". It is thought that a Cree chief is buried along the shores of the lake.[1] The lake is located within the County of Athabasca, 160 km northeast of the city of Edmonton and 6.5 km northeast of the village of Boyle. Skeleton Lake has an extensively developed shoreline with the summer villages of Mewatha and Bondiss on the southern shore of the lake and additional cottage developments on the north shore.

Skeleton Lake, North Basin — photo by Elashia Young 2017



Bathymetric map of Skeleton Lake (Alberta Environment)

Skeleton Lake used to be the main source of drinking water for the Town of Boyle but has received its drinking water from the Athabasca River since 2007. The watershed is located in the Dry Mixedwood subregion of the Boreal Mixedwood natural region.[2] Several small intermittent streams flow into the lake and drain a watershed that is four times the size of the lake.[3] The outlet is a small creek located at the southeast end of the lake, and drains eastward into Amisk Lake. Beaver dams, however, often block the outlet. Tree cover in the watershed is primarily trembling aspen and secondarily white spruce, balsam poplar, and white birch. Peatlands are also significant, and most agricultural activities in the watershed take place in the southern and northwestern sections.

Recently, water levels have receded in the lake such that the north and south basins no longer have surface water connectivity. Thus, the LakeWatch sampling samples the north and south basins separately.

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[1] Aubrey, M. K. 2006. Concise place names of Alberta. Retrieved from http://www.albertasource.ca/placenames/resources/searchcontent.php?book=1

[2] Strong, W.L. and K.R. Leggat. 1981. Ecoregions of Alberta. Alta. En. Nat. Resour., Resour. Eval. Plan. Div., Edmonton.

[3] 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 Maxxam Analytics, 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. 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.

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[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 3 for a complete list of parameters.

Nutrient and water chemistry values in Skeleton Lake will differ between the North basin and the South basin due to differences and size and depth. The differences in size and depth significantly impact how the basins mix throughout the summer, and this difference is reflected in how the parameters change throughout the season. Unfortunately, due to scheduling difficulties, the south basin was only sampled twice this season in June and July.

The average total phosphorus (TP) concentration for Skeleton Lake North was 42 µg/L (Table 3), and for Skeleton Lake South was 15 µg/L, with the north basin falling into the eutrophic, or highly productive trophic classification and the south basin in the mesotrophic, or moderately productive trophic classification. The north basin began the season with a much higher TP concentration than the South (Figure 1).

Average chlorophyll-*a* concentrations in 2019 for Skeleton Lake North was 27.2 µg/L and for Skeleton Lake South was 6.3 µg/L (Table 3). This puts the north basin in the hypereutrophic classification and the south basin in the mesotrophic classification. In Skeleton Lake North, chlorophyll-*a* fluctuated greatly over the course of the sampling season, and was significantly correlated with TP ($r = 0.95$, $p = 0.05$). In the south basin, chlorophyll-*a* was higher in July than in June (Figure 1). Correlation analysis could not be done on Skeleton South since there were only two samplings in 2019.

The average total Kjeldahl nitrogen (TKN) concentration of the north basin was 1.9 mg/L and the TKN concentration of the south basin was 1.1 mg/L. TKN was not significantly correlated with chlorophyll-*a* concentrations in Skeleton Lake North over the 2019 sampling season ($r = 0.83$, $p = 0.17$).

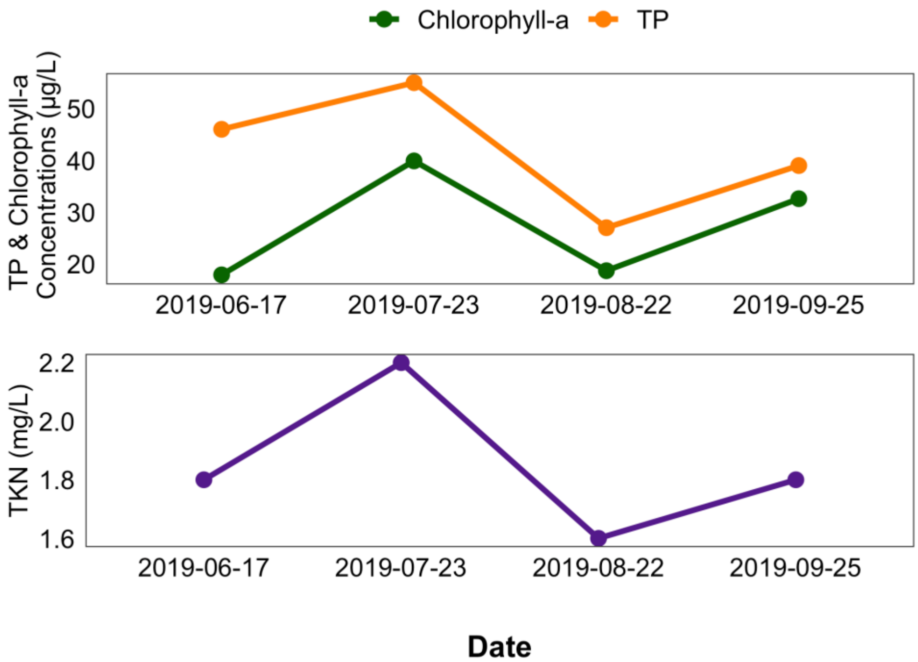
Average pH of Skeleton North was 8.83 in 2019, buffered by moderate alkalinity (195 mg/L $CaCO_3$) and bicarbonate (215 mg/L HCO_3). Calcium and magnesium were the dominant ions contributing to a low conductivity of 393 µS/cm (Table 3). Average pH of Skeleton South was 8.72 in 2019, buffered by moderate alkalinity (230 mg/L $CaCO_3$) and bicarbonate (250 mg/L HCO_3). Magnesium and sodium were the dominant ions contributing to a low conductivity of 435 µS/cm (Table 3).

METALS

Samples were analyzed for metals (Table 4). 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.

Metals were measured once at Skeleton Lake North on September 25. In 2019, all measured values fell within their respective guidelines (Table 5). Metals were not measured at Skeleton Lake South in 2019. Refer to Table 6 to see historical values.

Skeleton Lake North Basin



Skeleton Lake South Basin

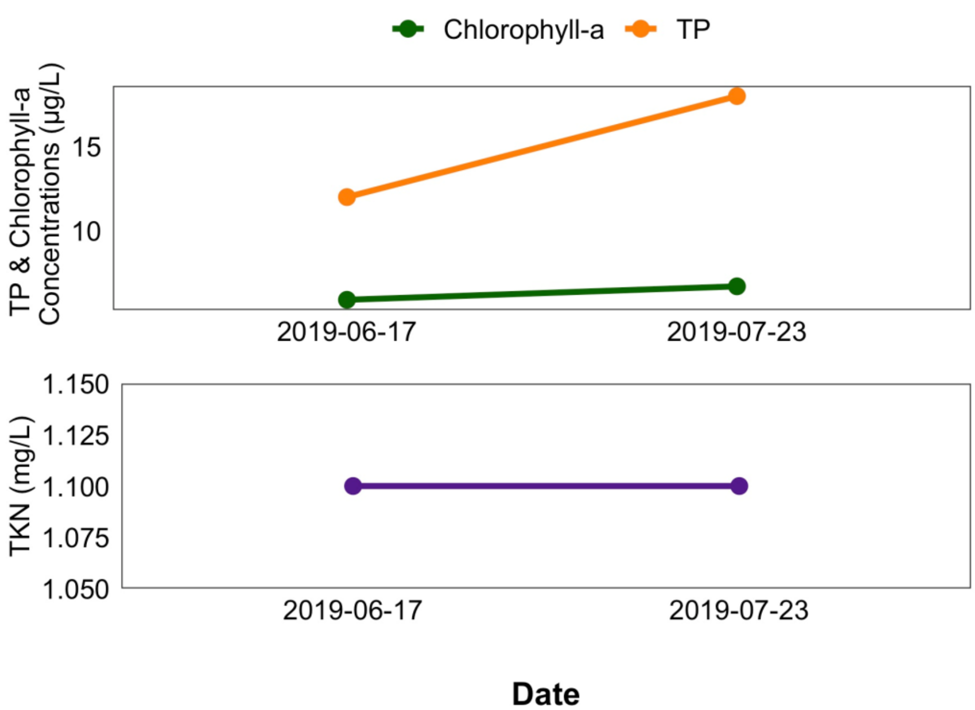


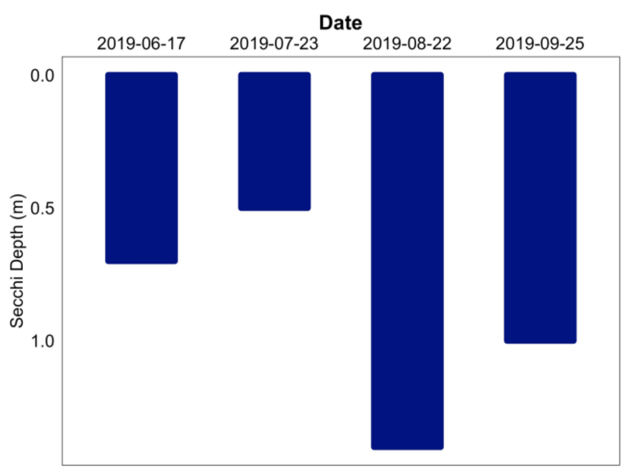
Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four and two times over the course of the summer at Skeleton Lake North (top) and Skeleton Lake South (bottom), respectively.

WATER CLARITY AND SECCHI 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.

In 2019, the average Secchi depth of Skeleton Lake North was 0.90 m and Skeleton Lake South was 2.45 m (Table 3). Water clarity measured as Secchi depth was lowest on June 17 in the north basin, and was variable throughout the season. Secchi depth in the south basin remained about 2m on both trips in 2019 (Figure 2).

Skeleton Lake North Basin



Skeleton Lake South Basin

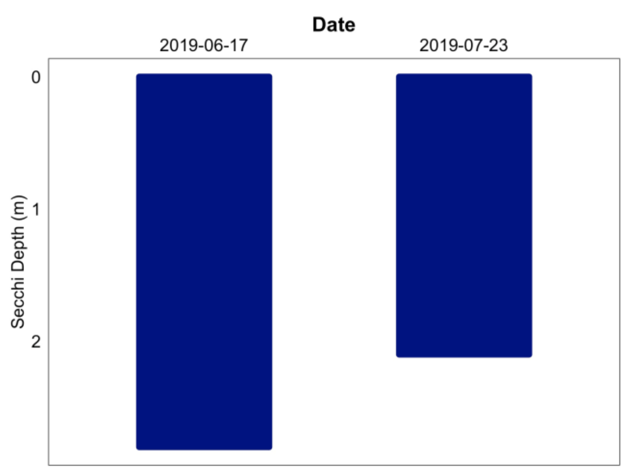


Figure 2. Secchi depth values measured four and two times over the course of the summer at Skeleton Lake North (top) and Skeleton Lake South (bottom), respectively in 2019.

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 ALMS' Brief Introduction to Limnology for a description of technical terms.

Skeleton Lake North:

Temperatures of Skeleton Lake North varied throughout the summer, with a maximum temperature of 22.4 °C measured at the surface on July 23 (Figure 3a top). The lake was strongly stratified for the extent of the sampling season, with the thermocline between 4.5m and 11m deep.

Skeleton Lake North remained well oxygenated at the surface throughout the summer, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 3b top). During thermal stratification, oxygen levels reached anoxia near the bottom due to separation from atmospheric oxygen that is circulated at the lake's surface.

Skeleton Lake South:

Temperatures of Skeleton Lake South varied throughout the summer, with a maximum temperature of 22.4 °C measured at the surface on July 23 (Figure 3a bottom). Thermal stratification was observed around 5 – 7m on both sampling trips.

Skeleton Lake South remained well oxygenated at the surface across two sampling events, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 3b bottom). During thermal stratification, oxygen levels reached anoxia near the bottom due to separation from oxygen that is circulated at the lake surface. Oxygen levels declined near the bottom on both sampling trips due to separation from atmospheric oxygen that is circulated at the lake's surface.

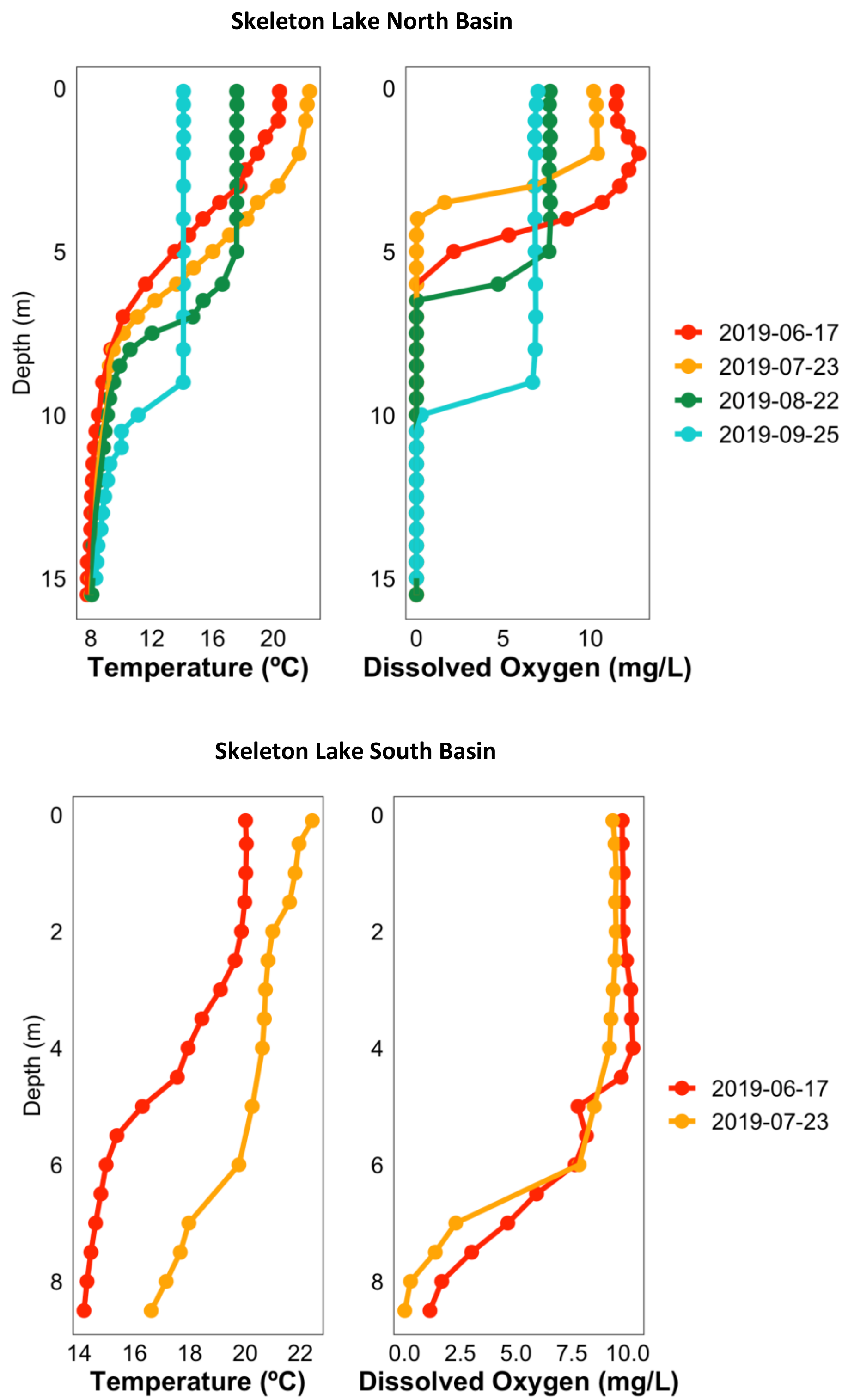


Figure 3. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Skeleton Lake North (top) and Skeleton Lake South (bottom) measured four and two times, respectively over the course of the summer of 2019.

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.

Microcystin levels in both Skeleton Lake basins fell below the recreational guideline for the entire sampling period within 2019 (Table 1a and 1b). However, Skeleton North was significantly higher, with levels in July being the peak. Throughout the season at the North basin, more turbid water quality was observed. Slightly brown colonies were observed in littoral areas, and were subsequently sampled for microcystin and microscope analysis.

Table 1a. Microcystin concentrations measured four times at Skeleton Lake North in 2019.

Date	Microcystin Concentration (μg/L)
17-Jun-19	2.11
23-Jul-19	5.82
22-Aug-19	0.68
25-Sep-19	1.9
Average	2.63

Table 1b. Microcystin concentrations measured twice at Skeleton Lake South in 2019

Date	Microcystin Concentration (μg/L)
17-Jun-19	0.14
23-Jul-19	0.11
Average	0.13

At the North basin, more turbid water conditions were observed beginning in winter 2019 and persisting throughout the summer. Slightly brown macro-colonies were observed in littoral areas, and were sampled on July 23 for identification and microcystin analysis. The microcystin level of this collected colony was 359.55 µg/L, confirming the cyanobacteria colony produces levels of microcystin in exceedance of recreational guidelines. A cyanobacteria species part of the *Planktothrix* genus is likely the cause of the turbid water conditions, and the elevated microcystin levels in the North basin. Figure 4 below is a picture of a sample collected from a degrading colony collected in a littoral area of Skeleton North basin during the July 23 sampling.

Figure 4. Picture of colony collected littoral zone at Skeleton Lake North Basin on July 23, 2019, responsible for 359.55 µg/L microcystin. Picture taken through microscope, and is likely a species in the *Planktothrix* genus.

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 have been linked to creating toxic cyanobacteria blooms, decreasing the amount of nutrients needed for fish and other native species, and causing millions of dollars in annual costs for repair and maintenance of water-operated infrastructure and facilities.

Monitoring involved using a 63 µm plankton net at three sample sites to look for juvenile mussel veligers in each lake sampled. No mussels were detected at Skeleton Lake North or South in the summer of 2019.

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.

No milfoil, native or Eurasian, was observed at Skeleton Lake North in 2019. Suspect samples collected from Skeleton Lake South on July 23 were confirmed to be the native Northern watermilfoil (*Myriophyllum sibiricum)*.

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 Skeleton Lake North have been monitored from 2012 to 2019, and have remained relatively stable (Figure 5a). In 2015, the north basin decreased to 621.0 m asl, about a 1 m decrease from the previous year. However, as of 2019 the levels have increased a little more than 1m compared to the low of 2015.

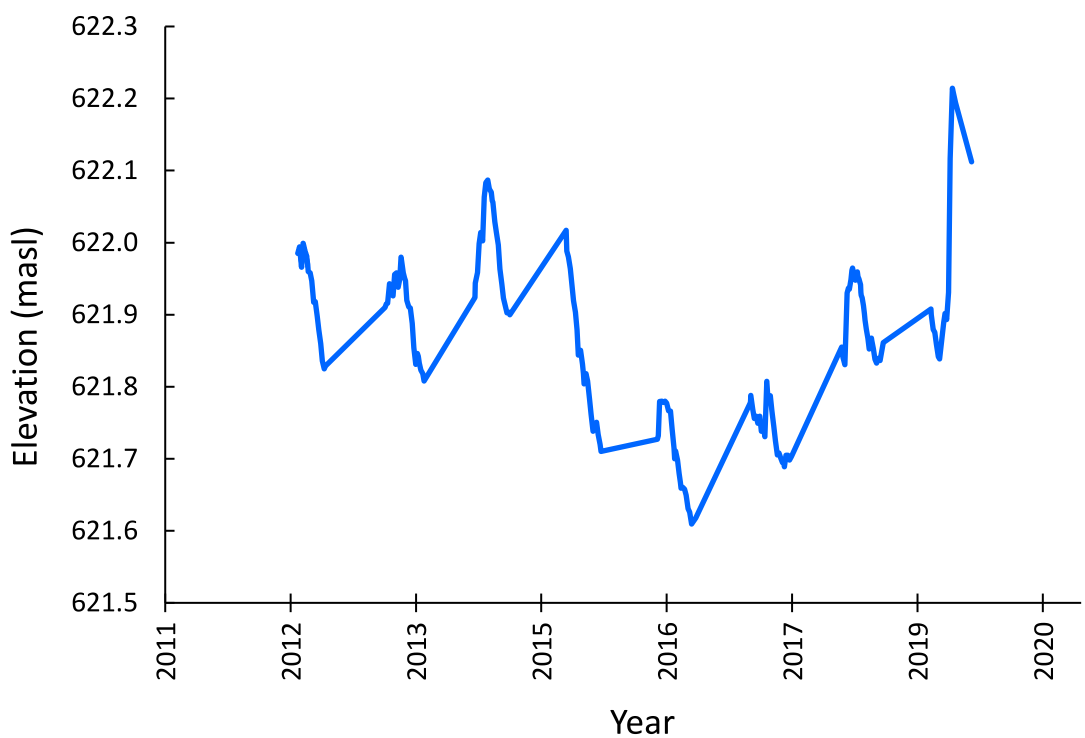


Figure 5a. Water levels measured in metres above sea level (masl) from 2012-2019 in the North Basin of Skeleton Lake. Data retrieved from Alberta Environment and Parks.

Water levels in Skeleton Lake South have been monitored since 1965. There was a significant decrease in water levels in the late 1980s and early 1990s, but then levels recovered to a historical range for a brief time in the late 1990s before plummeting to lowest levels on record, where they have remained ever since.

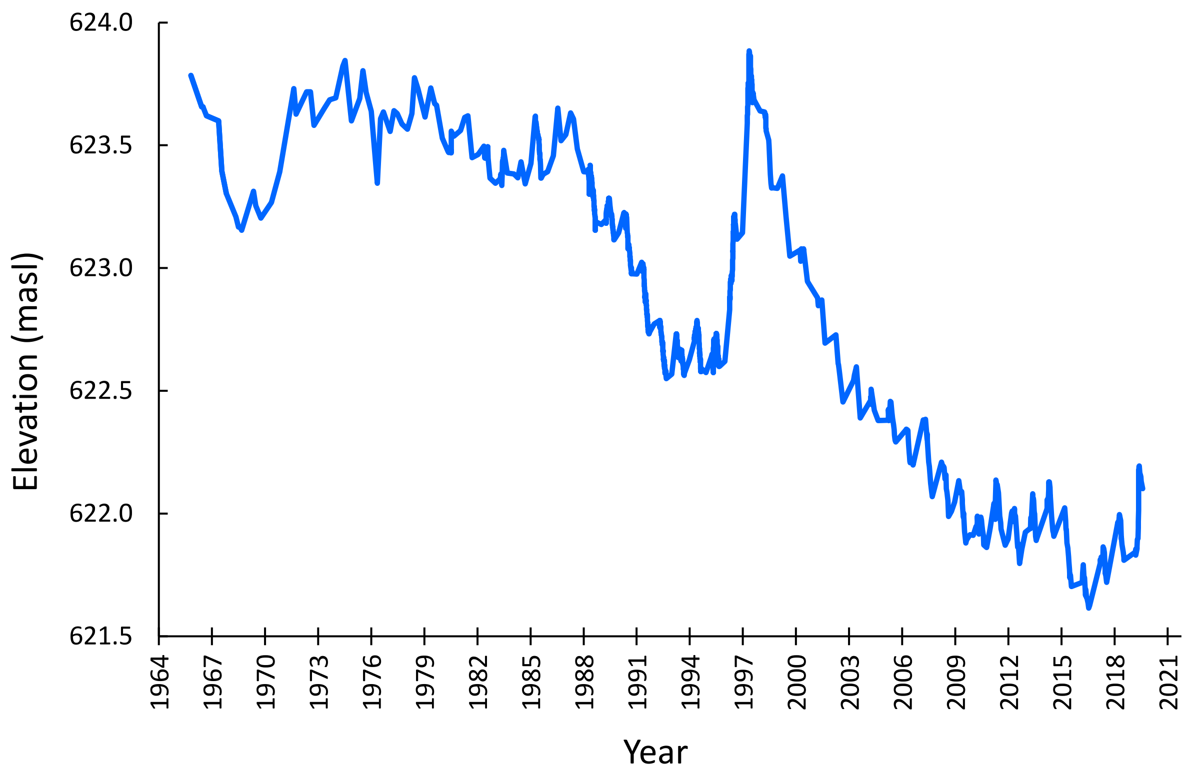


Figure 5b. Water levels in Skeleton Lake South between 1965 and 2019. Data retrieved from Alberta Environment and Parks.

Table 3. Average Secchi depth and water chemistry values for Skeleton Lake North.

Parameter	1985	1986	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
TP (µg/L)	24	36	33	48	45	36	48	25	26	28	31	32	42
TDP (µg/L)	8	11	11	16	12	14	28	11	11	9	8	8	5
Chlorophyll-*a* (µg/L)	9.2	10.7	11.0	8.6	17.2	8.6	7.6	5.8	7.5	9.2	11.2	19.6	27.3
Secchi depth (m)	/	/	2.63	1.75	1.40	2.45	2.35	2.81	2.00	1.40	1.88	1.03	0.90
TKN (mg/L)	1.2	1.1	1.3	1.6	1.4	1.5	1.5	1.2	1.5	1.5	1.6	1.6	1.9
NO_2-N and NO_3-N (µg/L)	2	4	3	4	6	3	3	22	2	3	2	4	2
NH_3-N (µg/L)	21	33	13	83	24	21	23	33	25	25	28	20	36
DOC (mg/L)	15	15	17	19	14	18	18	19	17	18	17	19	19
Ca (mg/L)	23	24	21	23	22	25	24	31	25	24	25	24	23
Mg (mg/L)	19	19	24	26	27	25	27	21	26	28	28	26	27
Na (mg/L)	13	14	18	19	20	18	19	21	20	21	21	20	21
K (mg/L)	8	8	11	11	12	12	14	12	13	14	13	13	13
SO_4^{2-} (mg/L)	3	3	5	6	2	4	8	2	8	8	8	9	10
Cl^- (mg/L)	2	1	3	3	4	6	5	6	7	7	7	8	9
CO_3 (mg/L)	4	11	12	10	12	9	17	10	11	10	18	14	13
HCO_3 (mg/L)	198	194	204	218	229	226	213	236	228	226	206	208	215
pH	8.53	8.58	8.79	8.71	8.72	8.67	8.86	8.58	8.70	8.70	8.83	8.79	8.83
Conductivity (µS/cm)	318	324	335	372	388	388	390	390	402	392	390	390	393
Hardness (mg/L)	135	138	150	164	165	166	171	165	170	174	176	164	168
TDS (mg/L)	172	175	193	205	210	210	217	215	222	224	222	216	223
Microcystin (µg/L)	/	/	0.08	0.14	0.23	0.17	0.13	0.08	0.08	0.20	0.08	0.13	2.63
Total Alkalinity (mg/L $CaCO_3$)	170	172	187	195	208	200	204	193	204	200	198	192	195

Table 4. Average Secchi depth and water chemistry values for Skeleton Lake South.

Parameter	1985	1986	2005	2006	2008	2009	2010	2011	2012	2013	2014	2015	2017	2018	2019
TP (µg/L)	31	47	29	40	45	40	59	45	40	40	51	27	39	40	15
TDP (µg/L)	8	11	8	13	13	14	15	12	12	20	59	9	7	7	6
Chlorophyll-*a* (µg/L)	14.8	24.2	12.1	15.0	19.3	12.4	22.3	17.2	17.3	12.12	29.8	14.1	27.3	31.6	6.3
Secchi depth (m)	2.00	1.60	2.28	1.60	1.65	1.63	1.40	1.40	1.81	1.59	1.56	2.50	1.40	1.18	2.45
TKN (mg/L)	1.1	1.3	1.2	1.2	1.3	1.1	1.6	1.4	1.4	1.3	1.4	1.4	1.5	1.5	1.1
NO_2-N and NO_3-N (µg/L)	2	3	6	14	13	13	25	6	4	3	38	2	2	4	2
NH_3-N (µg/L)	14	37	13	27	19	27	22	24	21	21	56	25	32	34	8
DOC (mg/L)	14	15	14	15	17	15	16	14	14	14	17	16	15	15	16
Ca (mg/L)	26	25	23	26	23	24	21	22	26	25	21	24	24	24	24
Mg (mg/L)	19	19	23	23	27	24	25	27	26	26	26	26	30	27	28
Na (mg/L)	14	14	19	20	20	21	22	20	21	22	24	21	25	25	25
K (mg/L)	9	9	11	12	12	13	12	12	13	18	14	13	15	14	14
SO_4^{2-} (mg/L)	3	3	3	4	3	5	3	2	2	5	2	2	2	3	3
Cl^- (mg/L)	2	1	3	3	4	4	5	4	5	4	5	6	6	7	7
CO_3 (mg/L)	5	9	6	10	9	10	9	12	9	16	22	13	17	13	11
HCO_3 (mg/L)	208	192	226	233	224	231	229	229	247	228	255	243	236	242	250
pH	8.53	8.72	8.66	8.71	8.73	8.76	8.80	8.72	8.64	8.75	8.80	8.72	8.79	8.71	8.73
Conductivity (µS/cm)	333	327	360	389	374	381	391	388	406	410	398	413	422	420	435
Hardness (mg/L)	143	140	152	158	168	159	157	165	170	168	159	167	184	172	175
TDS (mg/L)	181	178	204	214	211	218	214	210	222	230	233	227	240	238	240
Microcystin (µg/L)	/	/	0.15	0.18	0.24	0.34	0.31	0.23	0.22	0.24	0.40	0.37	0.50	0.79	0.13
Total Alkalinity (mg/L $CaCO_3$)	178	175	203	210	205	211	210	208	218	214	209	220	222	220	230

Table 5. Concentrations of metals measured in Skeleton Lake North. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

Metals (Total Recoverable)	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	Guidelines
Aluminum µg/L	26.04	13.9	14.75	11.735	10.75	16.2	6.6	4.5	2.8	7.9	100[a]
Antimony µg/L	0.03635	0.02885	0.0307	0.0326	0.032	0.0315	0.03	0.028	0.03	0.0029	/
Arsenic µg/L	0.8565	0.8685	0.574	0.8165	0.7735	0.828	0.745	0.77	0.84	0.85	5
Barium µg/L	48.95	50.85	51.1	49.05	48.5	53.75	50.9	49.5	49.7	51.6	/
Beryllium µg/L	0.00585	0.0052	0.00645	0.0015	0.004	0.004	0.004	0.0015	0	0.0015	100[c,d]
Bismuth µg/L	0.00195	0.00215	0.0321	0.0143	0.00225	0.00925	5.00E-04	0.0015	0	0.0015	/
Boron µg/L	122.5	105.5	104.85	93.5	97.05	94.3	103	96.5	94.6	93	1500
Cadmium µg/L	0.0057	0.001	0.001	0.001	0.002	0.002	0.001	0.005	0.01	0.005	0.26[b]
Chromium µg/L	0.242	0.0765	0.1535	0.28	0.105	0.075	0.015	0.05	0.1	0.05	/
Cobalt µg/L	0.01845	0.01115	0.00955	0.02615	0.007	0.0185	0.001	0.039	0.02	0.041	1000[d]
Copper µg/L	0.1633	0.154	0.3698	0.1402	0.13	0.175	0.32	0.27	0.1	0.04	4[b]
Iron µg/L	7.73	3.59	7.2	21.95	2.875	7.5	3.8	3	2.3	16	300
Lead µg/L	0.0151	0.0137	0.01055	0.0168	0.0135	0.0275	0.007	0.014	0.01	0.009	7[b]
Lithium µg/L	31.7	33	28.1	26.65	27.95	28.7	32.7	31.6	29.6	27.2	2500[e]
Manganese µg/L	35.4	43.9	29	16.05	12.55	31.55	26	7.66	6.74	43.6	200[e]
Molybdenum µg/L	0.0627	0.05335	0.02955	0.03915	0.037	0.041	0.026	0.038	0.04	0.052	73[c]
Nickel µg/L	0.0025	0.0025	0.0025	0.05425	0.004	0.004	0.004	0.08	0.08	0.11	150[b]
Selenium µg/L	0.05	0.096	0.05	0.082	0.03	0.03	0.2	0.1	0.2	0.4	1
Silver µg/L	0.0013	0.003175	0.00153	0.007125	0.001	0.001	0.001	5.00E-04	0	5.00E-04	0.25
Strontium µg/L	176	187	166	180	180	194.5	193	183	197	204	/
Thallium µg/L	0.00073	0.0006	0.00123	0.0004	0.0005	0.0104	0.00045	0.001	0	0.001	0.8
Thorium µg/L	0.00803	0.00625	0.0313	0.01075	0.0012	0.00045	0.00045	0.001	0	0.001	/
Tin µg/L	0.015	0.015	0.38175	0.0377	0.0065	0.026	0.023	0.03	0.06	0.03	/
Titanium µg/L	0.336	0.676	0.2735	0.7785	0.2025	0.73	0.26	0.2	0.29	0.4	/
Uranium µg/L	0.1965	0.202	0.18	0.1995	0.211	0.205	0.201	0.22	0.23	0.211	15
Vanadium µg/L	0.214	0.1855	0.2035	0.1865	0.19	0.19	0.14	0.171	0.14	0.171	100[d,e]
Zinc µg/L	0.3085	0.41	0.4175	0.2805	0.55	0.25	0.3	0.4	0.2	0.4	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 6. Concentrations of metals measured in Skeleton Lake South. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

Metals (Total Recoverable)	2008	2009	2010	2011	2012	2013	2014	2017	2018	Guidelines
Aluminum μg/L	24.1	12.8	22.95	23.2	7.88	12.655	18.5	21.5	1.8	100[a]
Antimony μg/L	0.033	0.032	0.03335	0.0326	0.0236	0.02795	0.0455	0.04	0.03	/
Arsenic μg/L	1.01	0.983	1.065	0.948	0.367	1.0065	1.36	1.04	1.03	5
Barium μg/L	55.8	57.3	55.55	56.2	44	57.7	45.8	56.1	55.3	/
Beryllium μg/L	0.0045	<0.003	0.0015	0.0048	0.0015	0.0015	0.004	0.0015	0	100[c,d]
Bismuth μg/L	0.0036	0.004	0.002	0.0014	0.0057	0.0038	0.0005	0.0015	0	/
Boron μg/L	102.5	109.6	97	106	87.2	100.9	94.75	105	106	1500
Cadmium μg/L	<0.002	0.0023	0.00695	0.0045	0.0035	0.0024	0.008	0.005	0.01	0.26[b]
Chromium μg/L	0.115	0.188	0.1395	0.15	0.106	0.196	0.215	0.05	0.1	/
Cobalt μg/L	0.023	0.0203	0.01325	0.0171	0.0084	0.0285	0.022	0.042	0.02	1000[d]
Copper μg/L	0.171	0.27	0.1303	0.181	0.508	0.1805	0.535	0.46	0.08	4[b]
Iron μg/L	49.2	70.4	41	53.4	48.5	40.2	13.45	28.4	18.2	300
Lead μg/L	0.0285	0.0283	0.02505	0.0327	0.0126	0.02665	0.0265	0.029	0	7[b]
Lithium μg/L	30.6	36.1	28.05	33.2	21.9	29.15	39.7	33.8	32	2500[e]
Manganese μg/L	44.5	62.1	49.75	58.1	40.3	50.15	34.15	44.3	23.5	200[e]
Molybdenum μg/L	0.103	0.114	0.09395	0.103	0.0643	0.0823	0.087	0.097	0.09	73[c]
Nickel μg/L	<0.005	0.204	0.0025	0.0025	0.0025	0.16175	0.0595	0.18	0.09	150[b]
Selenium μg/L	0.144	0.12	0.076	0.138	0.05	0.05	0.07	0.1	0.2	1
Silver μg/L	0.0036	0.0069	0.00255	0.00025	0.0022	0.02725	0.001	0.002	0	0.25
Strontium μg/L	185	185	188	186	134	197.5	208.5	190	211	/
Thallium μg/L	0.00115	0.00185	0.001	0.001	0.00015	0.000365	0.00068	0.001	0	0.8
Thorium μg/L	0.0093	0.0017	0.0096	0.0066	0.0084	0.00655	0.00563	0.001	0	/
Tin μg/L	0.0483	<0.03	0.03015	0.015	0.0327	0.015	0.0195	0.03	0.06	/
Titanium μg/L	1.21	0.762	0.904	1.1	0.26	1.43	0.985	1	0.88	/
Uranium μg/L	0.121	0.11	0.1145	0.12	0.0612	0.09055	0.196	0.105	0.1	15
Vanadium μg/L	0.207	0.208	0.2095	0.217	0.101	0.145	0.265	0.225	0.09	100[d,e]
Zinc μg/L	0.373	0.996	0.5025	0.399	0.361	0.346	1.3	2.7	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- SKELTON LAKE NORTH BASIN

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 both the north and south basins of Skeleton Lake. Both basins were first sampled in 2005 and last sampled in 2019. However, the north basin was not sampled from 2006 through 2009, leaving a four year gap in the data. While trend analysis is still possible given this gap, inferences made from the data are less reliable. Additionally, due to a lack of data for the south basin in 2019, only the north basin long term trends have been updated. Refer to the 2018 Skeleton Lake report to view the latest Skeleton South trend analysis. Data is presented below for the different parameters in each lake as both a line graph (all data points used in analysis) and a box-and-whisker plot. Detailed methods are available in the *ALMS Guide to Trend Analysis on Alberta Lakes.*

In the north basin, chlorophyll-*a* has significantly increased over the sampling period. Total Phosphorus has decreased during the sampling period. An increasing trend in total dissolved solids is significant, as is a decreasing trend in Secchi depth.

In the south basin, non-significant increases were observed in chlorophyll-*a.* A decreasing trend for Total Phosphorus is very close to statistical significance. There is a statistically significant decreasing trend in Secchi depths, but as Secchi depth can be subjective and is sensitive to variation in weather - trend analysis must be interpreted with caution. Significant increases were observed in TDS.

Table 7. Summary table of trend analysis on Skeleton Lake North data from 2005 to 2019.

Parameter	Date Range	Trend	Probability
Total Phosphorus	2005-2019	Decreasing	Not significant
Chlorophyll-*a*	2005-2019	Increasing	Significant
Total Dissolved Solids	2005-2019	Increasing	Significant
Secchi Depth	2005-2019	Decreasing	Significant

Definitions:

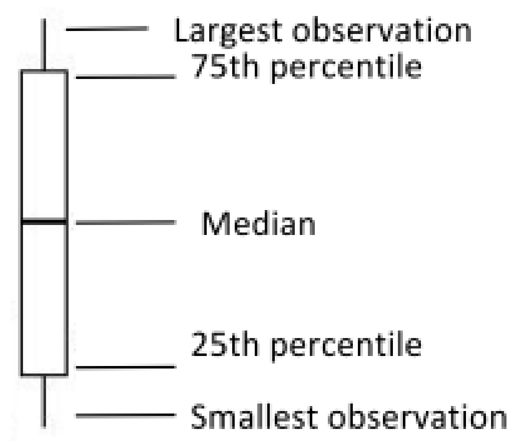
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

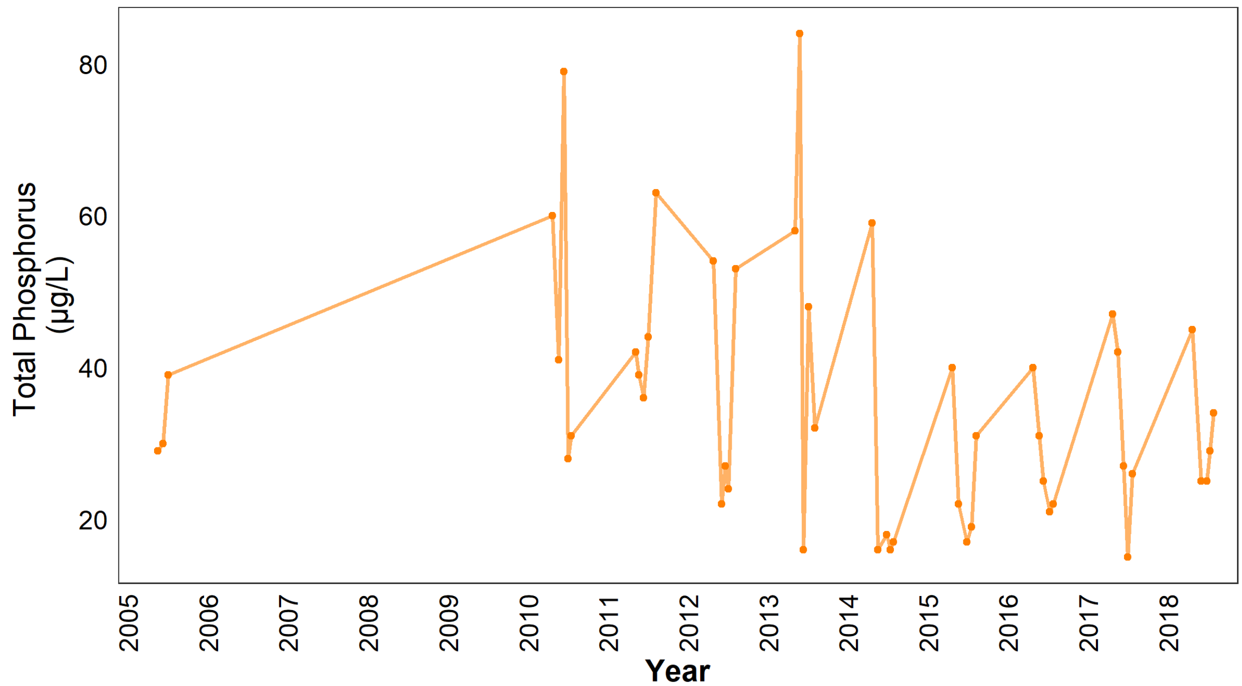
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

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) – North Basin

TP has not significantly changed in Skeleton Lake North since sampling began in 2005 (Figure 1a), but the trend shows a slight decrease (Tau = -0.12, p = 0.264).



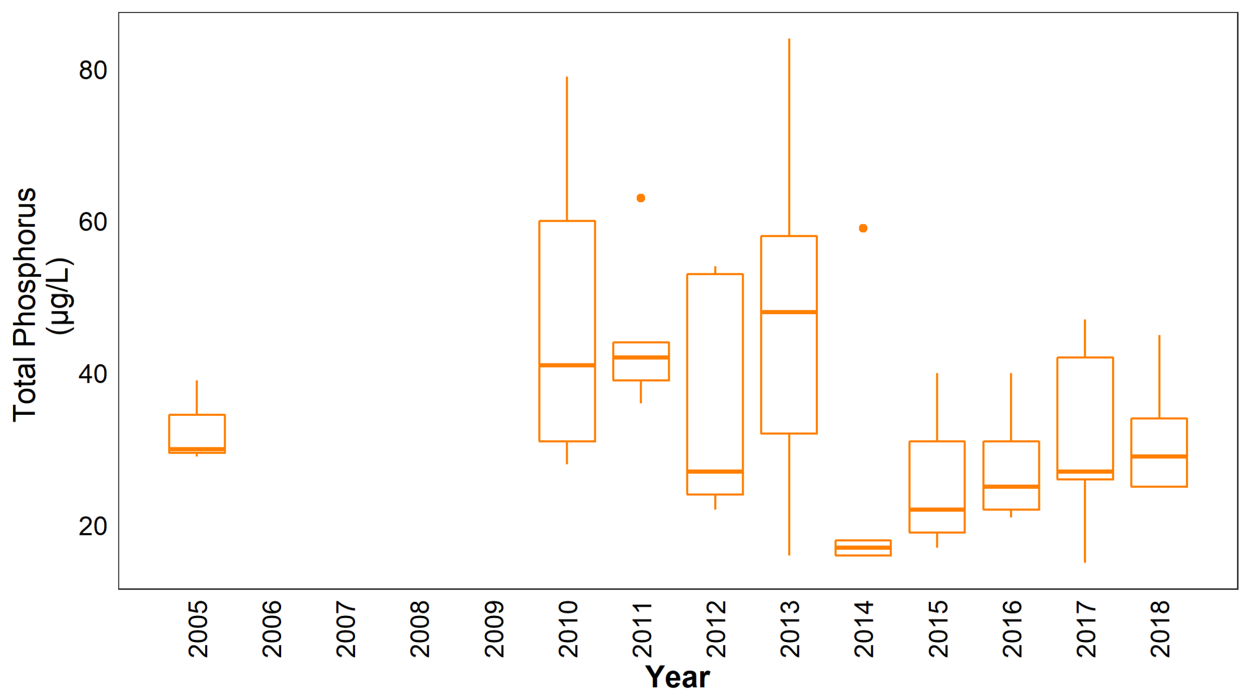
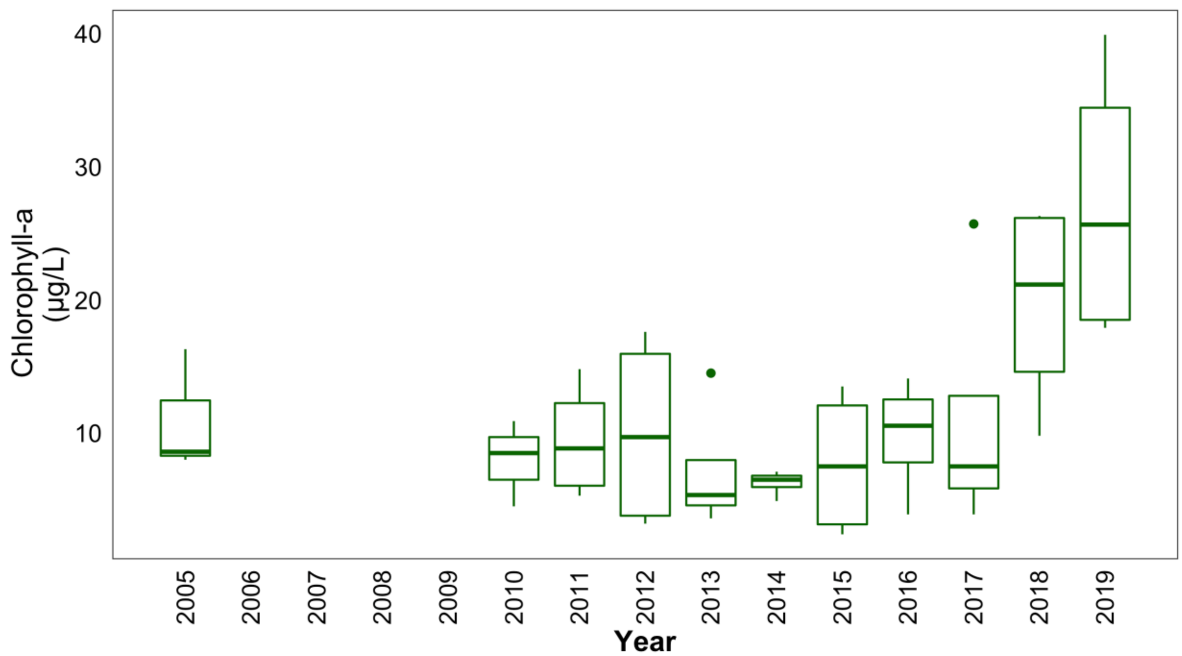


Figure 6. Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 2005 and 2019 (n = 42). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a* – North Basin

Chlorophyll-*a* has significantly increased since sampling began on Skeleton Lake North in 2005 (Tau = 0.25, p=0.018) (Figure 2a). Chlorophyll-*a* and Total Phosophorus concentrations are significantly correlated over time (t=2.31, p = 0.025, r= 0.31).



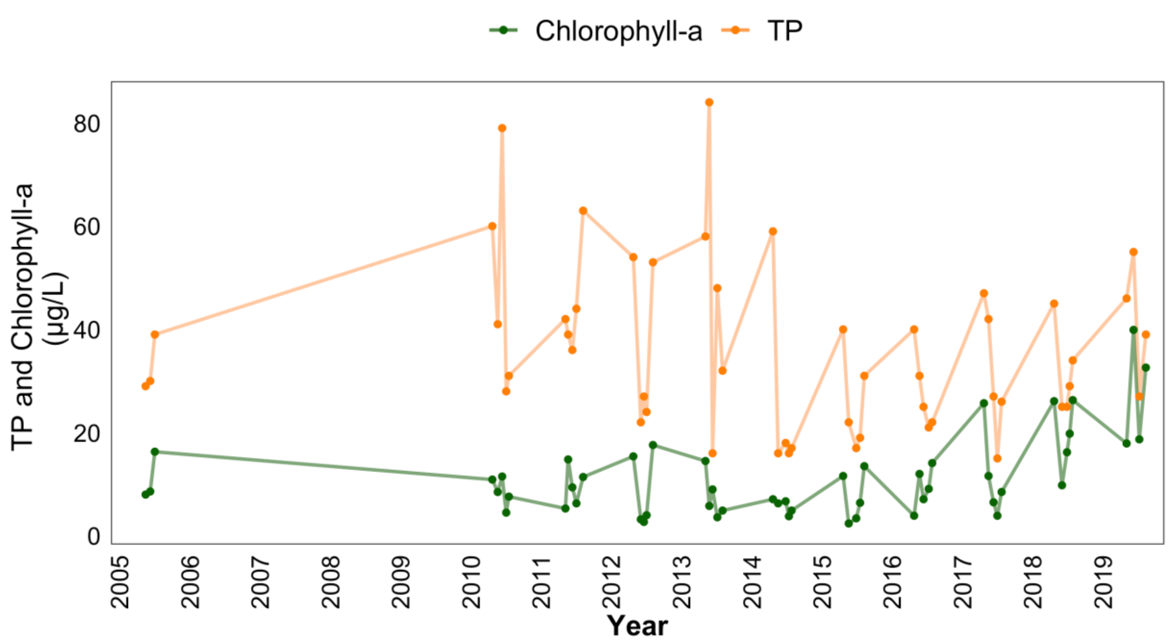
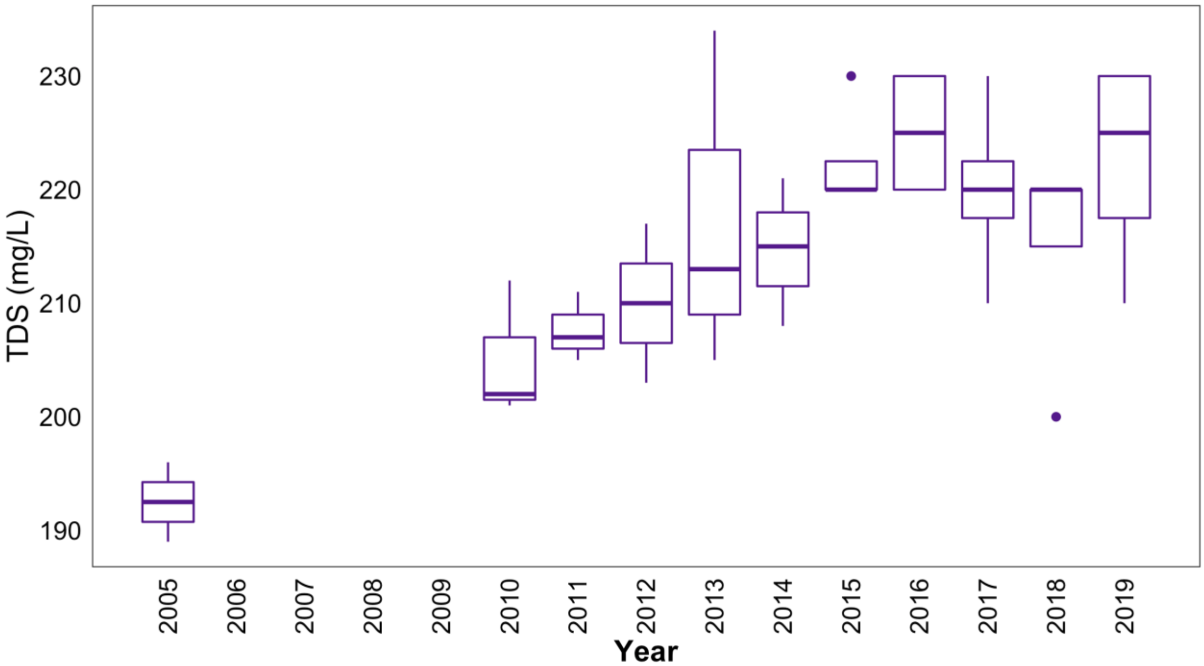


Figure 7. Monthly chlorophyll-*a* concentrations in the north basin measured between June and September over the long term sampling dates between 2005 and 2019 (n = 44). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)- North Basin

Trend analysis showed an increasing trend in TDS since 2005 in Skeleton Lake North (Tau = 0.41, $p < 0.001$). This could be attributed to decreasing water levels. However, this trend has slowed in the past two years sampled (Figure 3a).



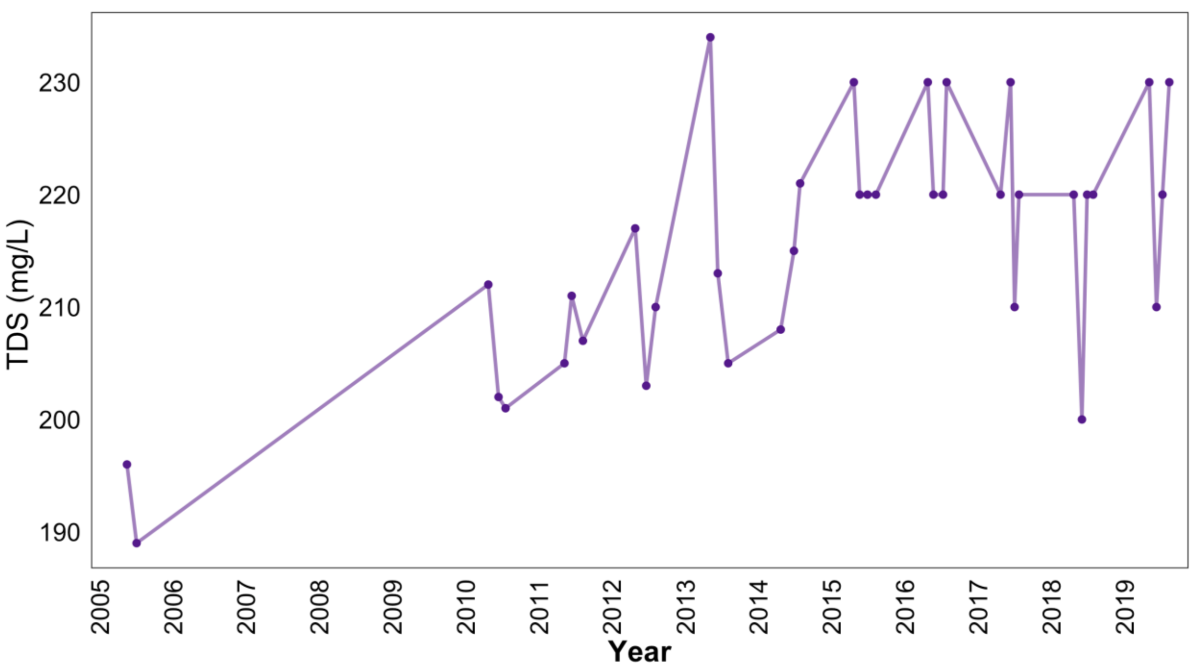
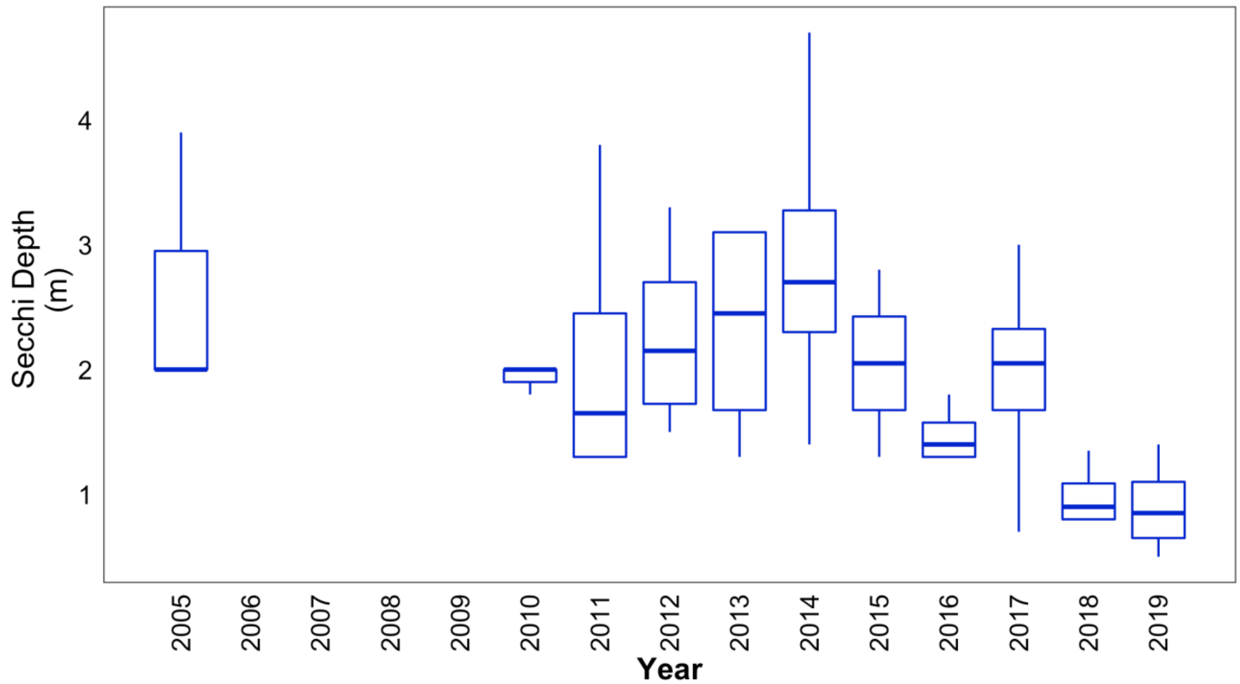


Figure 8. Monthly TDS values measured between June and September over the long term sampling dates between 2005 and 2019 (n = 37). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth- North Basin

Water clarity measured as Secchi depth in Skeleton Lake North has undergone a very slight but statistically significant decrease since 2005, with the last 2 years being more pronounced (Tau =-0.36, $p < 0.001$).



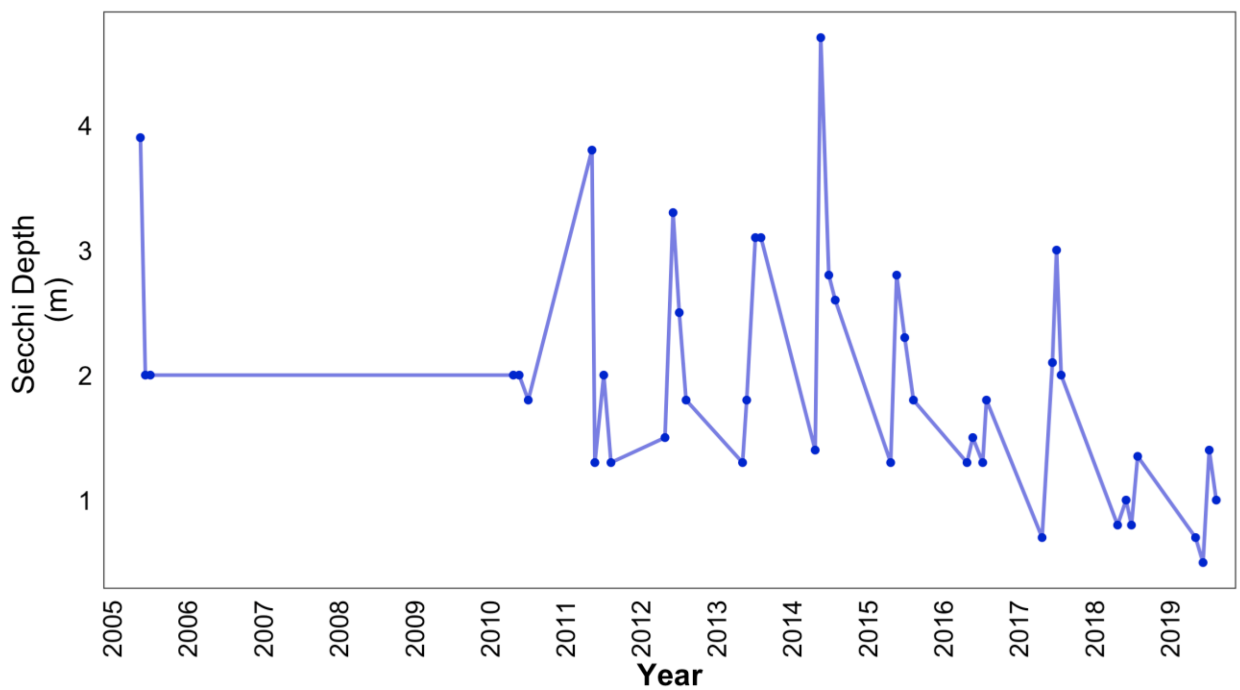


Figure 9. Monthly Secchi depth values measured between June and September over the long term sampling dates between 2005 and 2019 (n = 42). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 8. North Basin: Results of trend tests using monthly total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from June to September on Skeleton Lake North 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	-0.12	0.25	0.41	-0.36
The extent of the trend	Slope	-0.002	0.0021	5.21×10^{-3}	-0.0003
The statistic used to find significance of the trend	Z	-1.12	2.36	3.61	-3.32
Number of samples included	n	42	42	37	42
The significance of the trend	*p*	0.264	0.018*	0.0003*	0.0009*

*$p < 0.05$ is significant within 95%