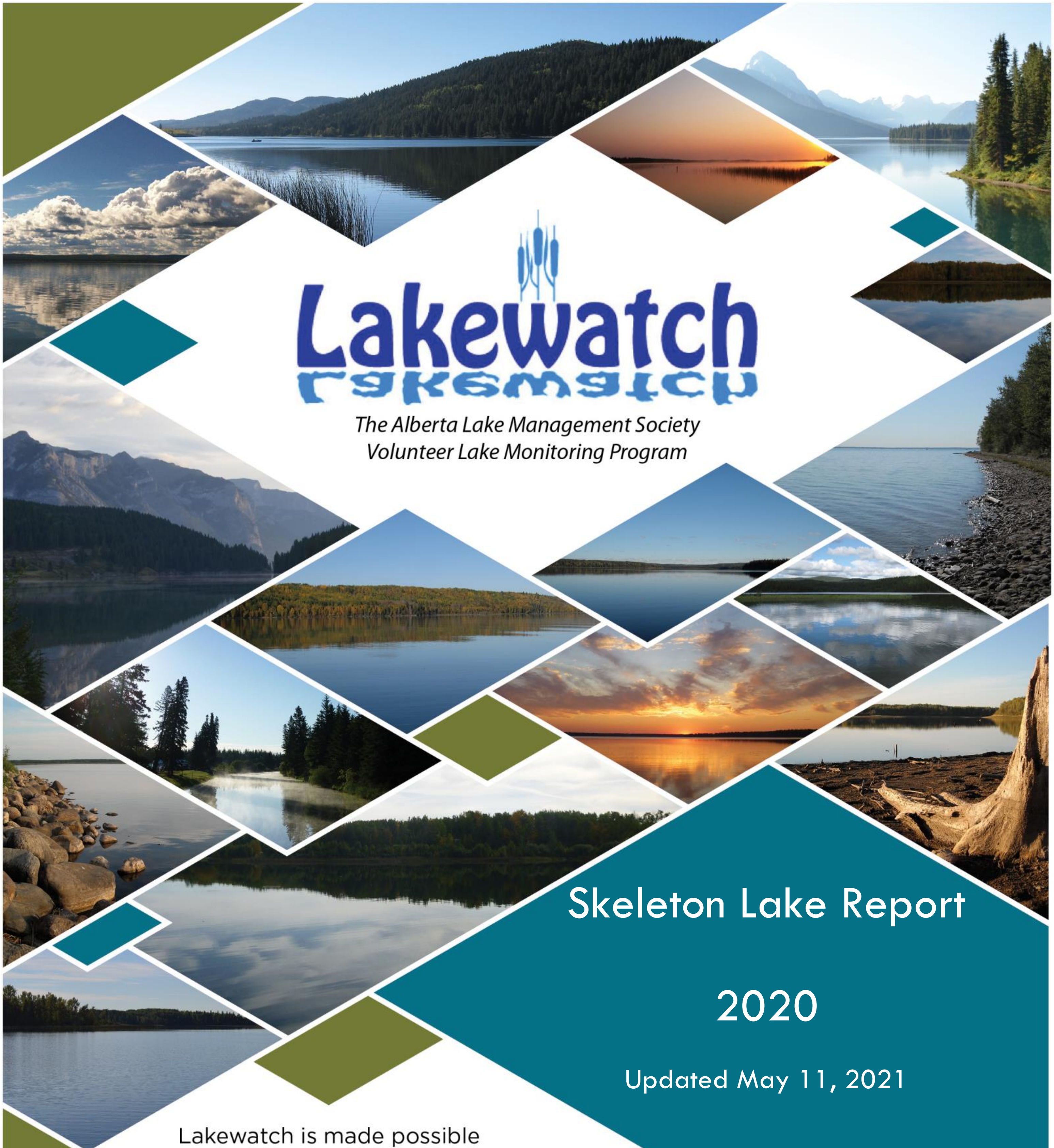


Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Skeleton Lake Report

2020

Updated May 11, 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.

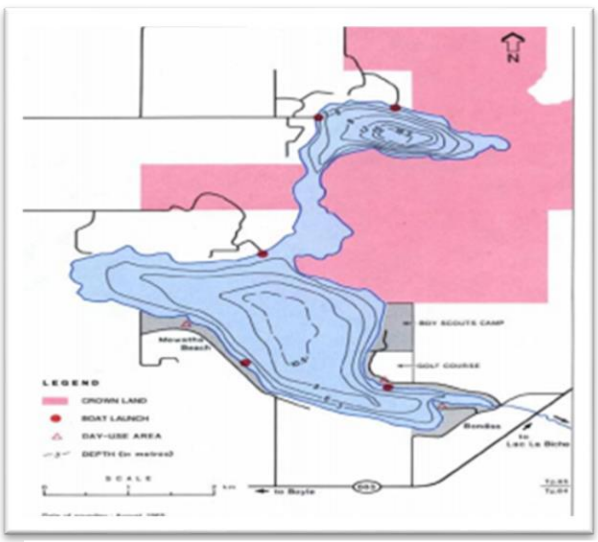
ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks to Orest Kitt and Rick Tiedemann for their commitment to collecting data at Skeleton Lake. 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.

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 considers 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 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.

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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 and Table 4 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 in size and depth. These differences significantly impact how the basins mix throughout the summer, and this difference is reflected in how the parameters change throughout the season.

The average total phosphorus (TP) concentration for Skeleton Lake North was 43 µg/L (Table 3), and for Skeleton Lake South was 29 µg/L, with the north basin falling into the eutrophic, or highly productive trophic class and the south basin in the mesotrophic, or moderately productive trophic class (Table 3 and Table 4).

Average chlorophyll-*a* concentrations in 2020 for Skeleton Lake North was 18.8 µg/L and for Skeleton Lake South was 21.4 µg/L (Table 3 and Table 4). This puts both of the basins in the eutrophic, or highly productive classification. This is a change from 2019, where the North basin was hypereutrophic, and the South basin was mesotrophic. In Skeleton Lake North, chlorophyll-*a* fluctuated greatly over the course of the sampling season, and was not significantly correlated with TP ($r = 1.00$, $p = 0.083$). In the south basin, chlorophyll-*a* was lowest in June, then increased and remained consistent the rest of the summer (Figure 1).

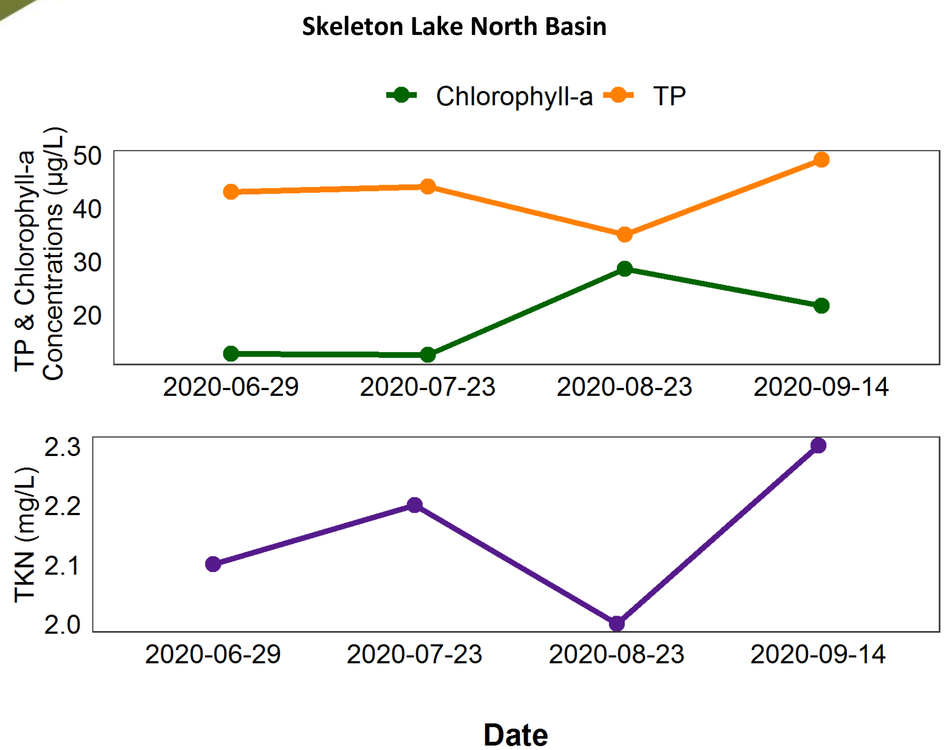
The average total Kjeldahl nitrogen (TKN) concentration of the north basin was 2.2 mg/L and the TKN concentration of the south basin was 1.5 mg/L. TKN was significantly correlated with TP concentrations in Skeleton Lake North over the 2020 sampling season ($r = 0.96$, $p = 0.042$).

Average pH of Skeleton North was 8.44 in 2020, buffered by moderate alkalinity (198 mg/L $CaCO_3$) and bicarbonate (233 mg/L HCO_3). With bicarbonate excluded, calcium, magnesium and sodium were the dominant ions contributing to a low conductivity of 415 µS/cm (Figure 2, top; Table 3). Average pH of Skeleton South was 8.49 in 2020, buffered by moderate alkalinity (195 mg/L $CaCO_3$) and bicarbonate (230 mg/L HCO_3). With bicarbonate excluded, calcium, magnesium and sodium were the dominant ions contributing to a low conductivity of 420 µS/cm (Figure 2, bottom; Table 4). Both basins rank in the average range of ion levels compared to other lakes sampled in the LakeWatch 2020 season (Figure 2). Both basins were almost identical in their ion levels, with the exception of slightly higher levels of sulphate and more variable levels of bicarbonate in the North basin.

METALS

Samples were analyzed for metals (Table 5 and Table 6). 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 each basin on August 23rd. In 2020, all measured values fell within their respective guidelines (Table 5 and Table 6). Refer to Table 5 and Table 6 to see historical values for the North and South basins, respectively.



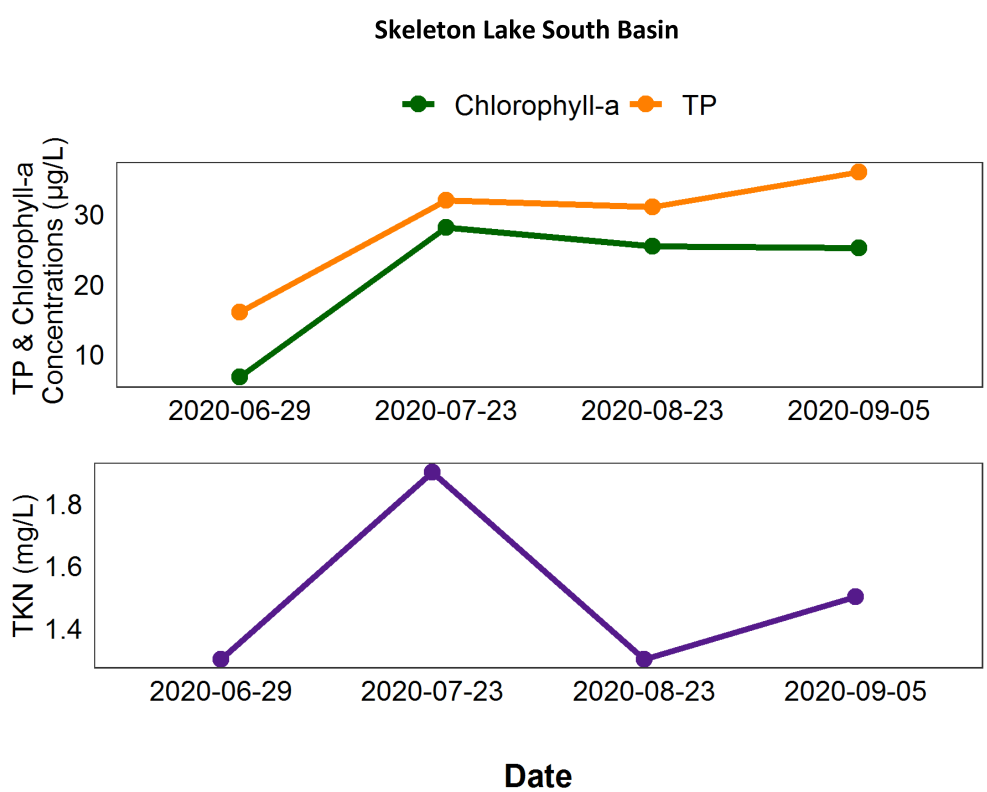


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four over the course of the summer at Skeleton Lake North (top) and Skeleton Lake South (bottom) in the summer of 2020.

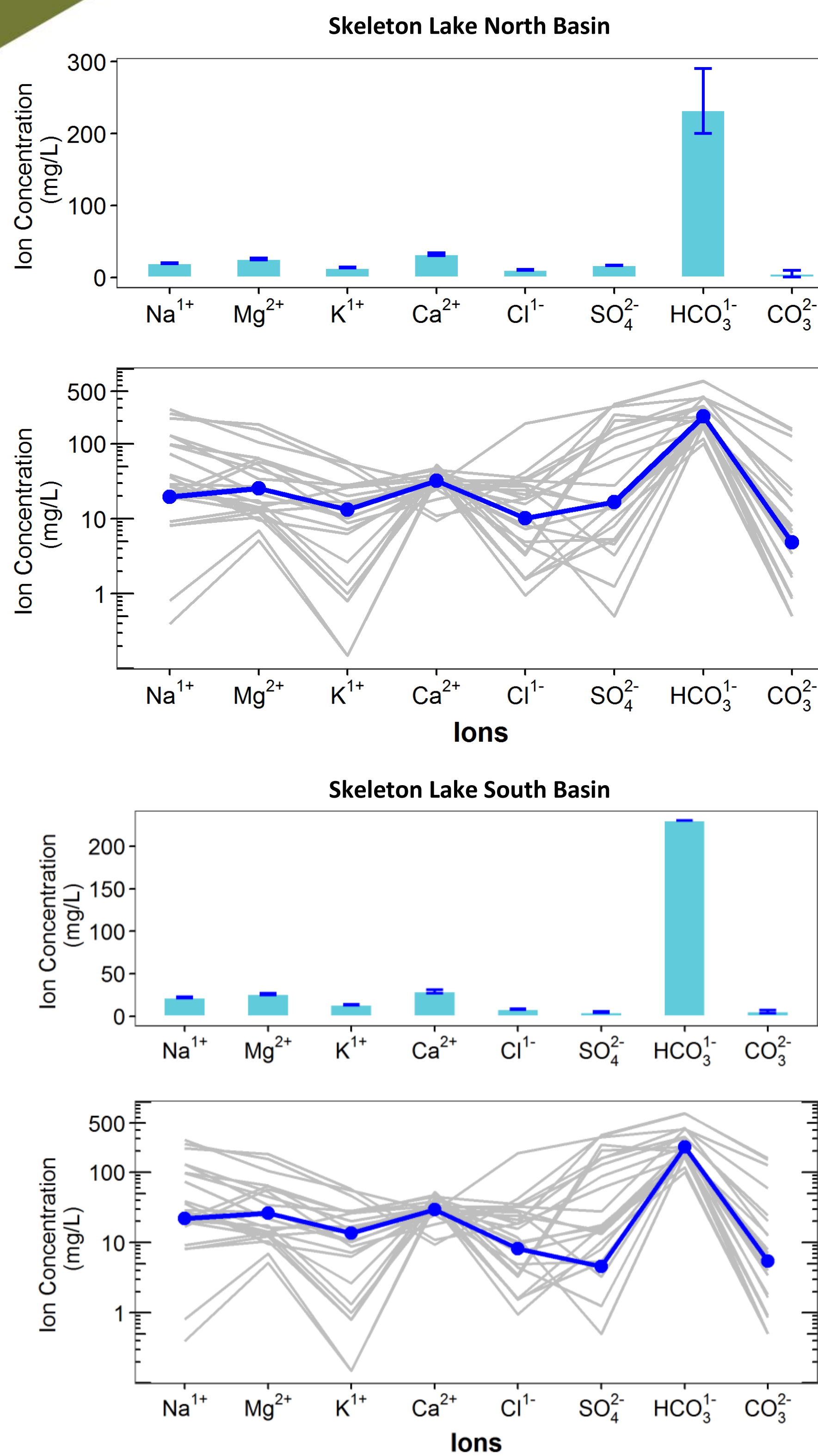


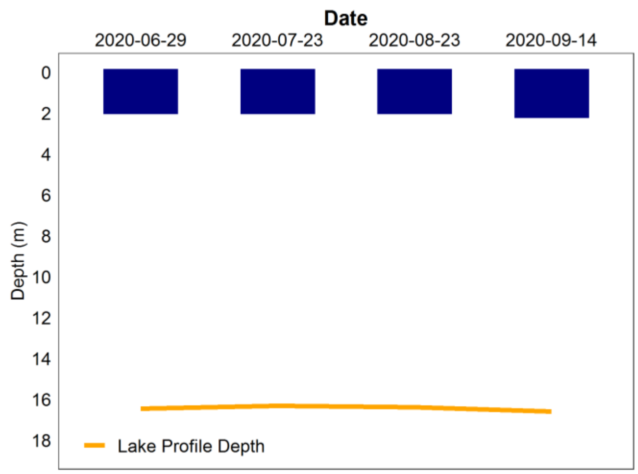
Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Skeleton Lake North (top pair of figures), and Skeleton Lake South (bottom pair of figures). Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at either Skeleton Lake North or South (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).

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.

In 2020, the average euphotic depth of Skeleton Lake North was 1.95 m and Skeleton Lake South was 3.03 m. Euphotic depth was greatest on September 14th in the North basin at 2.10 m, but was otherwise stable in the earlier season samplings at 1.90m (Figure 3). Low euphotic depths in recent years in the North Basin of Skeleton Lake are likely due to blooms of a toxic cyanobacteria species from the genus *Planktothrix*. Euphotic depth was the greatest in the South basin on June 29th at 3.60 m, then the lowest on July 23rd at 2.50 m, where after the euphotic depth increased through August and September (Figure 3).

Skeleton Lake North Basin



Skeleton Lake South Basin

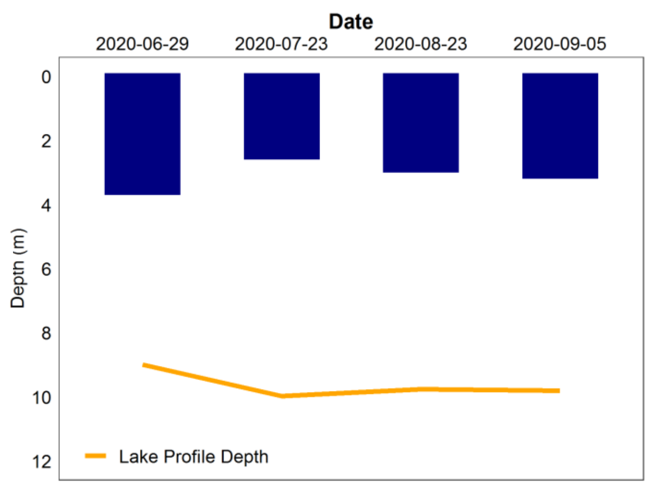


Figure 3. Secchi depth values measured four and two times over the course of the summer at Skeleton Lake North (top) and Skeleton Lake South (bottom), respectively in 2020.

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 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 21.0°C measured at the surface on July 23rd, and a minimum temperature of 5.0°C measured near the bottom at 16 m on June 29th. (Figure 4a top). The lake was strongly stratified for the extent of the sampling season, with the thermocline between 4 – 9 m deep, depending on the sampling date, and with the depth of thermocline increasing from June to September. This indicates the lake does not mix during the summer season.

Skeleton Lake North remained fairly well oxygenated at the surface throughout the summer, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 4b top). However, during the September sampling events surface levels were only around 6.7 mg/L, and remained at that level to 7.5 m depth, after which dissolved oxygen levels were below the CCME guideline. On the other sampling days, levels were above the CCME guideline to approximately 3 – 5 m depth. During each sampling event, once dissolved oxygen levels disappeared, they quickly became anoxic, or less than 1 mg/L. In September, the lake was anoxic below 8.5 m, and during the earlier sampling events, the lake was anoxic below approximately 5 – 7 m depth. During thermal stratification, oxygen levels reach 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 1.1°C measured at the surface on July 23rd, and a minimum temperature of 14.8°C measured at 9 m near the bottom on June 29th (Figure 4a bottom). Relatively weak thermal stratification was only present during the June 28th sampling event, with a thermocline present at around 5.5 m depth. Very slight stratification was present on July 23rd. These profile indicate that Skeleton Lake South will frequently mix in the summer.

Skeleton Lake South remained well oxygenated at the surface across each sampling event, and even to lake bottom during the August and September sampling events, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 4b bottom). During the June and July sampling events, levels fell below 6.5 mg/L at 5 m and 6 m respectively. Dissolved oxygen levels went anoxic (less than 1 mg/L) at 8 m and below on June 23rd.

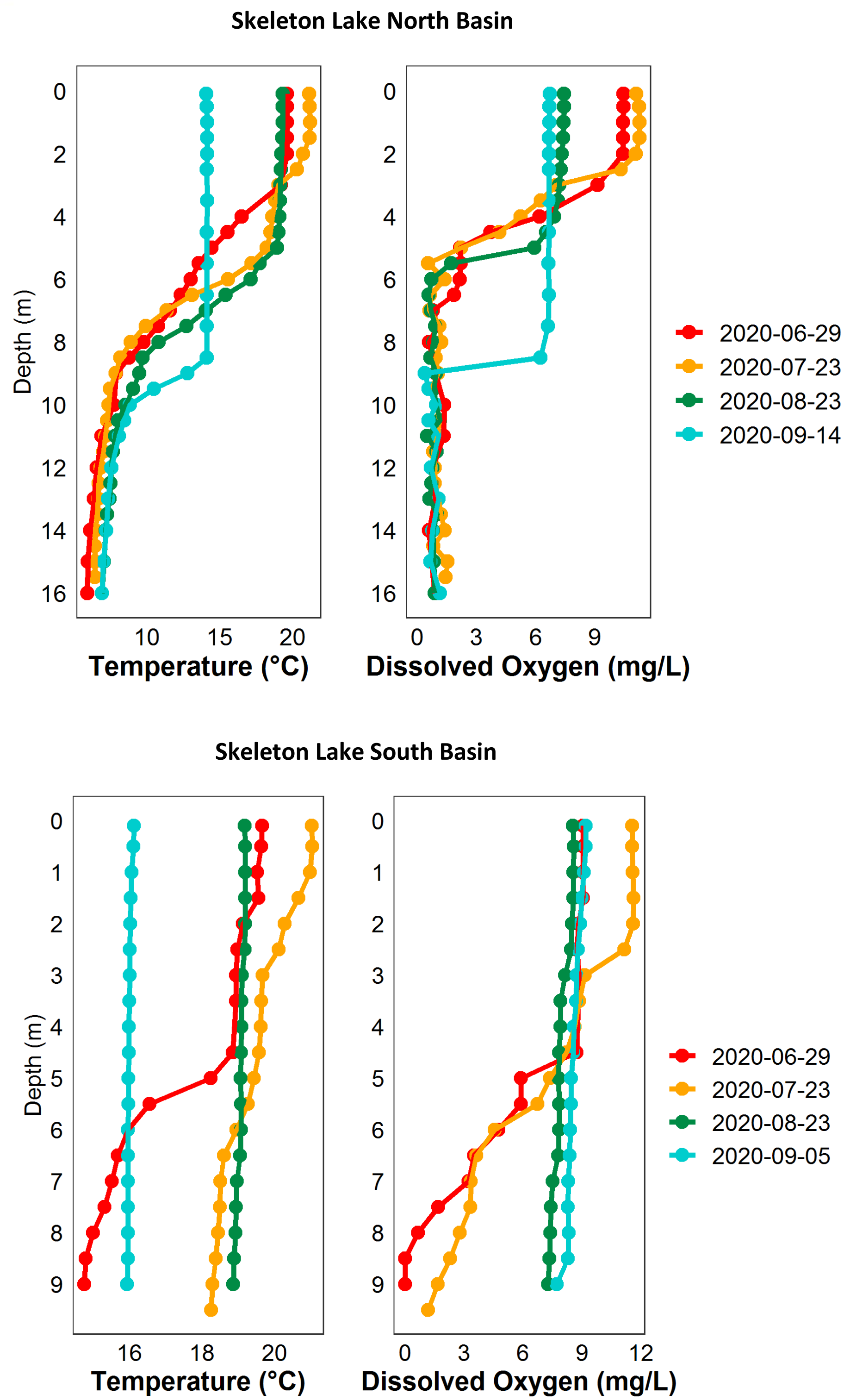


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Skeleton Lake North (top) and Skeleton Lake South (bottom) measured four and two times, respectively over the course of the summer of 2020.

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.

Microcystin levels in both Skeleton Lake basins fell below the recreational guideline for the entire sampling period within 2020 (Table 1a and 1b). However, Skeleton North was significantly higher, with notably high levels in June. In recent years, a toxic species of cyanobacteria of the genus *Planktothrix* has been observed in Skeleton Lake North – this is likely creating high levels of microcystin. The microcystin level on June 29th in the South basin was below the laboratory detection limit of 0.1 µg/L. For this reason, half the value (0.05 µg/L) was used to calculate the average microcystin concentration.

Table 1a. Microcystin concentrations measured four times at Skeleton Lake North in 2020.

Date	Microcystin Concentration (µg/L)
29-Jun-20	11.56
23-Jul-20	1.24
23-Aug-20	1.53
14-Sep-20	3.26
Average	4.40

Table 1b. Microcystin concentrations measured twice at Skeleton Lake South in 2020.

Date	Microcystin Concentration (µg/L)
29-Jun-20	<0.10
23-Jul-20	0.15
23-Aug-20	0.44
5-Sep-20	0.60
Average	0.31

Invasive Species Monitoring

Dreissenid mussels pose a significant concern for Alberta because they impair the function of water conveyance infrastructure and adversely impact the aquatic environment. These invasive mussels can change lake conditions which can then lead to toxic cyanobacteria blooms, decrease the amount of nutrients needed for fish and other native species, and cause millions of dollars in annual costs for repair and maintenance of water-operated infrastructure and facilities. Spiny water flea pose a concern for Alberta because they alter the abundance and diversity of native zooplankton as they are aggressive zooplankton predators. Through over-predation, they will impact higher trophic levels such as fish. They also disrupt fishing equipment by attaching in large numbers to fishing lines.

Monitoring involved sampling with a 63 µm plankton net at three sample sites to look for juvenile mussel veligers and spiny water flea in each lake sampled. No mussels or spiny water flea were detected at Skeleton Lake North or South 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 suspect watermilfoil species identification.

No suspect watermilfoil was observed or collected from Skeleton 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.

Historically, the North and South basins were connected by open water. For some time, the narrows between the two basins were un-navigable due to extensive aquatic plant growth in the shallow water. However, in 2020 the narrow were navigable with the presence of open water between the two basins.

Water levels in Skeleton Lake North have been monitored from 2012 to 2020, and have remained relatively stable until 2020, where levels increased by about 1 m (Figure 5a).

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 (Figure 5b). Levels then recovered to the intial historical range for a brief time in the late 1990s before plummeting to lowest levels on record, where they remained until 2020, where levels increased by a 1 m, just like the North basin.

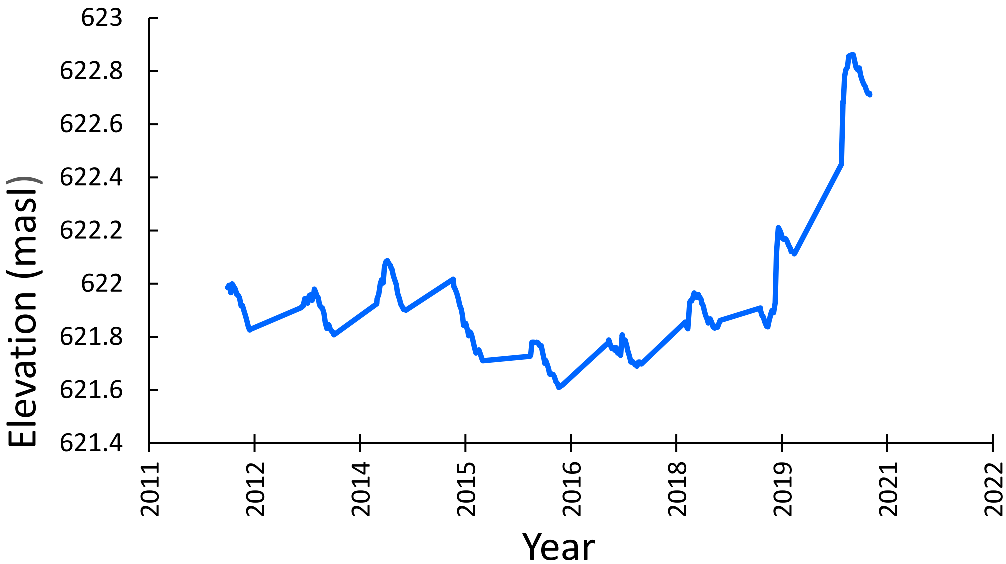


Figure 5a. Water levels measured in metres above sea level (masl) from 2012-2020 in the North Basin of Skeleton Lake. Data retrieved from Alberta Environment and Parks.

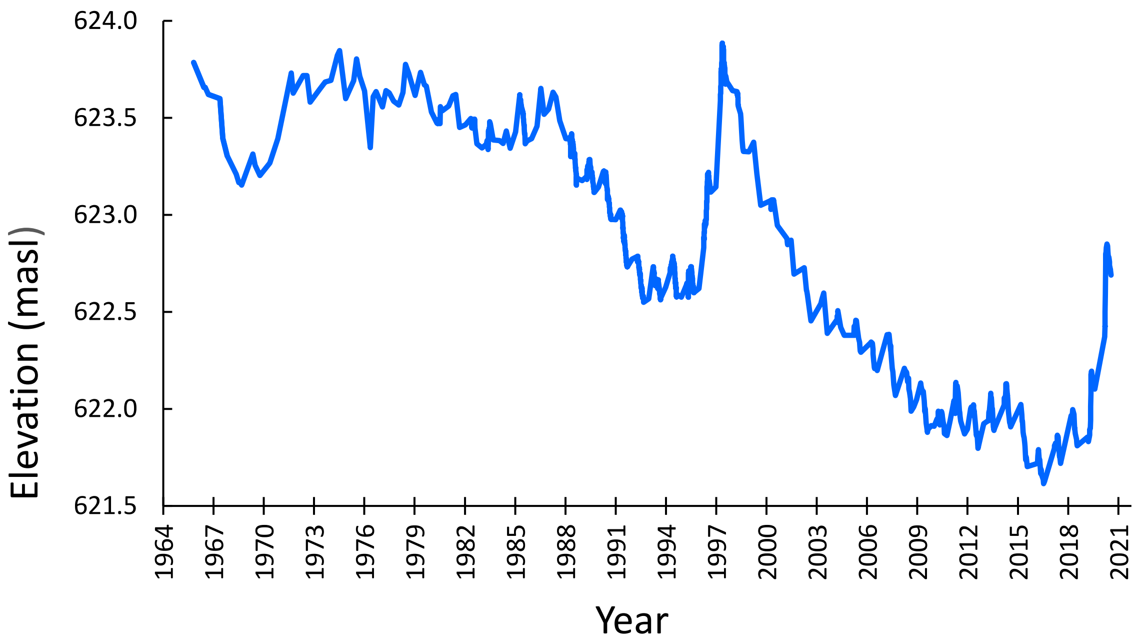


Figure 5b. Water levels measured in metres above sea level (masl) from 1965-2020 in the South Basin of Skeleton Lake. Data retrieved from Alberta Environment and Parks.

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

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

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

Parameter	2016	2017	2018	2019	2020
TP (µg/L)	28	31	32	42	43
TDP (µg/L)	9	8	8	5	11
Chlorophyll-*a* (µg/L)	9.2	11.2	19.6	27.3	18.8
Secchi depth (m)	1.40	1.88	1.03	0.90	0.98
TKN (mg/L)	1.5	1.6	1.6	1.9	2.2
NO_2-N and NO_3-N (µg/L)	3	2	4	2	3
NH_3-N (µg/L)	25	28	20	36	83
DOC (mg/L)	18	17	19	19	20
Ca (mg/L)	24	25	24	23	32
Mg (mg/L)	28	28	26	27	26
Na (mg/L)	21	21	20	21	20
K (mg/L)	14	13	13	13	13
SO_4^{2-} (mg/L)	8	8	9	10	17
Cl^- (mg/L)	7	7	8	9	10
CO_3 (mg/L)	10	18	14	13	5
HCO_3 (mg/L)	226	206	208	215	232
pH	8.70	8.83	8.79	8.83	8.44
Conductivity (µS/cm)	392	390	390	393	415
Hardness (mg/L)	174	176	164	168	185
TDS (mg/L)	224	222	216	223	238
Microcystin (µg/L)	0.20	0.08	0.13	2.63	4.40
Total Alkalinity (mg/L $CaCO_3$)	200	198	192	195	198

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

Parameter	1985	1986	2005	2006	2008	2009	2010	2011	2012
TP (µg/L)	31	47	29	40	45	40	59	45	40
TDP (µg/L)	8	11	8	13	13	14	15	12	12
Chlorophyll-*a* (µg/L)	14.8	24.2	12.1	15.0	19.3	12.4	22.3	17.2	17.3
Secchi depth (m)	2.00	1.60	2.28	1.60	1.65	1.63	1.40	1.40	1.81
TKN (mg/L)	1.1	1.3	1.2	1.2	1.3	1.1	1.6	1.4	1.4
NO_2-N and NO_3-N (µg/L)	2	3	6	14	13	13	25	6	4
NH_3-N (µg/L)	14	37	13	27	19	27	22	24	21
DOC (mg/L)	14	15	14	15	17	15	16	14	14
Ca (mg/L)	26	25	23	26	23	24	21	22	26
Mg (mg/L)	19	19	23	23	27	24	25	27	26
Na (mg/L)	14	14	19	20	20	21	22	20	21
K (mg/L)	9	9	11	12	12	13	12	12	13
SO_4^{2-} (mg/L)	3	3	3	4	3	5	3	2	2
Cl^- (mg/L)	2	1	3	3	4	4	5	4	5
CO_3 (mg/L)	5	9	6	10	9	10	9	12	9
HCO_3 (mg/L)	208	192	226	233	224	231	229	229	247
pH	8.53	8.72	8.66	8.71	8.73	8.76	8.80	8.72	8.64
Conductivity (µS/cm)	333	327	360	389	374	381	391	388	406
Hardness (mg/L)	143	140	152	158	168	159	157	165	170
TDS (mg/L)	181	178	204	214	211	218	214	210	222
Microcystin (µg/L)	/	/	0.15	0.18	0.24	0.34	0.31	0.23	0.22
Total Alkalinity (mg/L $CaCO_3$)	178	175	203	210	205	211	210	208	218

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

Parameter	2013	2014	2015	2017	2018	2019*	2020
TP (µg/L)	40	51	27	39	40	15	29
TDP (µg/L)	20	59	9	7	7	6	5
Chlorophyll-*a* (µg/L)	12.12	29.8	14.1	27.3	31.6	6.3	21.4
Secchi depth (m)	1.59	1.56	2.50	1.40	1.18	2.45	1.52
TKN (mg/L)	1.3	1.4	1.4	1.5	1.5	1.1	1.5
NO_2-N and NO_3-N (µg/L)	3	38	2	2	4	2	2
NH_3-N (µg/L)	21	56	25	32	34	8	24
DOC (mg/L)	14	17	16	15	15	16	15
Ca (mg/L)	25	21	24	24	24	24	29
Mg (mg/L)	26	26	26	30	27	28	26
Na (mg/L)	22	24	21	25	25	25	22
K (mg/L)	18	14	13	15	14	14	14
SO_4^{2-} (mg/L)	5	2	2	2	3	3	5
Cl^- (mg/L)	4	5	6	6	7	7	8
CO_3 (mg/L)	16	22	13	17	13	11	5
HCO_3 (mg/L)	228	255	243	236	242	250	230
pH	8.75	8.80	8.72	8.79	8.71	8.73	8.49
Conductivity (µS/cm)	410	398	413	422	420	435	420
Hardness (mg/L)	168	159	167	184	172	175	180
TDS (mg/L)	230	233	227	240	238	240	225
Microcystin (µg/L)	0.24	0.40	0.37	0.50	0.79	0.13	0.31
Total Alkalinity (mg/L $CaCO_3$)	214	209	220	222	220	230	195

* Only sampled in June and July, 2019

Table 5a. 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	Guidelines
Aluminum µg/L	26.04	13.9	14.75	11.735	10.75	16.2	100[a]
Antimony µg/L	0.03635	0.02885	0.0307	0.0326	0.032	0.0315	/
Arsenic µg/L	0.8565	0.8685	0.574	0.8165	0.7735	0.828	5
Barium µg/L	48.95	50.85	51.1	49.05	48.5	53.75	/
Beryllium µg/L	0.00585	0.0052	0.00645	0.0015	0.004	0.004	100[c,d]
Bismuth µg/L	0.00195	0.00215	0.0321	0.0143	0.0022 5	0.00925	/
Boron µg/L	122.5	105.5	104.85	93.5	97.05	94.3	1500
Cadmium µg/L	0.0057	0.001	0.001	0.001	0.002	0.002	0.26[b]
Chromium µg/L	0.242	0.0765	0.1535	0.28	0.105	0.075	/
Cobalt µg/L	0.01845	0.01115	0.00955	0.02615	0.007	0.0185	1000[d]
Copper µg/L	0.1633	0.154	0.3698	0.1402	0.13	0.175	4[b]
Iron µg/L	7.73	3.59	7.2	21.95	2.875	7.5	300
Lead µg/L	0.0151	0.0137	0.01055	0.0168	0.0135	0.0275	7[b]
Lithium µg/L	31.7	33	28.1	26.65	27.95	28.7	2500[e]
Manganese µg/L	35.4	43.9	29	16.05	12.55	31.55	200[e]
Molybdenum µg/L	0.0627	0.05335	0.02955	0.03915	0.037	0.041	73[c]
Nickel µg/L	0.0025	0.0025	0.0025	0.05425	0.004	0.004	150[b]
Selenium µg/L	0.05	0.096	0.05	0.082	0.03	0.03	1
Silver µg/L	0.0013	0.003175	0.00153	0.007125	0.001	0.001	0.25
Strontium µg/L	176	187	166	180	180	194.5	/
Thallium µg/L	0.00073	0.0006	0.00123	0.0004	0.0005	0.0104	0.8
Thorium µg/L	0.00803	0.00625	0.0313	0.01075	0.0012	0.00045	/
Tin µg/L	0.015	0.015	0.38175	0.0377	0.0065	0.026	/
Titanium µg/L	0.336	0.676	0.2735	0.7785	0.2025	0.73	/
Uranium µg/L	0.1965	0.202	0.18	0.1995	0.211	0.205	15
Vanadium µg/L	0.214	0.1855	0.2035	0.1865	0.19	0.19	100[d,e]
Zinc µg/L	0.3085	0.41	0.4175	0.2805	0.55	0.25	30

Values represent means of total recoverable metal concentrations.
[a] Based on pH ≥ 6.5
[b] Based on water hardness > 180mg/L (as CaCO3)
[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 5b. 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)	2016	2017	2018	2019	2020	Guidelines
Aluminum µg/L	6.6	4.5	2.8	7.9	3.4	100[a]
Antimony µg/L	0.03	0.028	0.03	0.0029	0.039	/
Arsenic µg/L	0.745	0.77	0.84	0.85	0.94	5
Barium µg/L	50.9	49.5	49.7	51.6	57.1	/
Beryllium µg/L	0.004	0.0015	0	0.0015	0.0015	100[c,d]
Bismuth µg/L	5.00E-04	0.0015	0	0.0015	0.0015	/
Boron µg/L	103	96.5	94.6	93	88.9	1500
Cadmium µg/L	0.001	0.005	0.01	0.005	0.005	0.26[b]
Chromium µg/L	0.015	0.05	0.1	0.05	0.05	/
Cobalt µg/L	0.001	0.039	0.02	0.041	0.04	1000[d]
Copper µg/L	0.32	0.27	0.1	0.04	0.04	4[b]
Iron µg/L	3.8	3	2.3	16	9.9	300
Lead µg/L	0.007	0.014	0.01	0.009	0.005	7[b]
Lithium µg/L	32.7	31.6	29.6	27.2	25.7	2500[e]
Manganese µg/L	26	7.66	6.74	43.6	43.7	200[e]
Molybdenum µg/L	0.026	0.038	0.04	0.052	0.081	73[c]
Nickel µg/L	0.004	0.08	0.08	0.11	0.13	150[b]
Selenium µg/L	0.2	0.1	0.2	0.4	0.3	1
Silver µg/L	0.001	5.00E-04	0	5.00E-04	5.00E-04	0.25
Strontium µg/L	193	183	197	204	202	/
Thallium µg/L	0.00045	0.001	0	0.001	0.001	0.8
Thorium µg/L	0.00045	0.001	0	0.001	0.002	/
Tin µg/L	0.023	0.03	0.06	0.03	0.03	/
Titanium µg/L	0.26	0.2	0.29	0.4	0.42	/
Uranium µg/L	0.201	0.22	0.23	0.211	0.217	15
Vanadium µg/L	0.14	0.171	0.14	0.171	0.221	100[d,e]
Zinc µg/L	0.3	0.4	0.2	0.4	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 CaCO3)
[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 6a. 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

Metals (Total Recoverable)	2008	2009	2010	2011	2012	2013	Guidelines
Aluminum μg/L	24.1	12.8	22.95	23.2	7.88	12.655	100[a]
Antimony μg/L	0.033	0.032	0.03335	0.0326	0.0236	0.02795	/
Arsenic μg/L	1.01	0.983	1.065	0.948	0.367	1.0065	5
Barium μg/L	55.8	57.3	55.55	56.2	44	57.7	/
Beryllium μg/L	0.0045	<0.003	0.0015	0.0048	0.0015	0.0015	100[c,d]
Bismuth μg/L	0.0036	0.004	0.002	0.0014	0.0057	0.0038	/
Boron μg/L	102.5	109.6	97	106	87.2	100.9	1500
Cadmium μg/L	<0.002	0.0023	0.00695	0.0045	0.0035	0.0024	0.26[b]
Chromium μg/L	0.115	0.188	0.1395	0.15	0.106	0.196	/
Cobalt μg/L	0.023	0.0203	0.01325	0.0171	0.0084	0.0285	1000[d]
Copper μg/L	0.171	0.27	0.1303	0.181	0.508	0.1805	4[b]
Iron μg/L	49.2	70.4	41	53.4	48.5	40.2	300
Lead μg/L	0.0285	0.0283	0.02505	0.0327	0.0126	0.02665	7[b]
Lithium μg/L	30.6	36.1	28.05	33.2	21.9	29.15	2500[e]
Manganese μg/L	44.5	62.1	49.75	58.1	40.3	50.15	200[e]
Molybdenum μg/L	0.103	0.114	0.09395	0.103	0.0643	0.0823	73[c]
Nickel μg/L	<0.005	0.204	0.0025	0.0025	0.0025	0.16175	150[b]
Selenium μg/L	0.144	0.12	0.076	0.138	0.05	0.05	1
Silver μg/L	0.0036	0.0069	0.00255	0.00025	0.0022	0.02725	0.25
Strontium μg/L	185	185	188	186	134	197.5	/
Thallium μg/L	0.00115	0.00185	0.001	0.001	0.00015	0.000365	0.8
Thorium μg/L	0.0093	0.0017	0.0096	0.0066	0.0084	0.00655	/
Tin μg/L	0.0483	<0.03	0.03015	0.015	0.0327	0.015	/
Titanium μg/L	1.21	0.762	0.904	1.1	0.26	1.43	/
Uranium μg/L	0.121	0.11	0.1145	0.12	0.0612	0.09055	15
Vanadium μg/L	0.207	0.208	0.2095	0.217	0.101	0.145	100[d,e]
Zinc μg/L	0.373	0.996	0.5025	0.399	0.361	0.346	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 6b. 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)	2014	2017	2018	2020	Guidelines
Aluminum µg/L	18.5	21.5	1.8	3.2	100[a]
Antimony µg/L	0.0455	0.04	0.03	0.038	/
Arsenic µg/L	1.36	1.04	1.03	1.2	5
Barium µg/L	45.8	56.1	55.3	59.5	/
Beryllium µg/L	0.004	0.0015	0	0.0015	100[c,d]
Bismuth µg/L	0.0005	0.0015	0	0.0015	/
Boron µg/L	94.75	105	106	96.1	1500
Cadmium µg/L	0.008	0.005	0.005	0.005	0.26[b]
Chromium µg/L	0.215	0.05	0.05	0.05	/
Cobalt µg/L	0.022	0.042	0.02	0.023	1000[d]
Copper µg/L	0.535	0.46	0.08	0.1	4[b]
Iron µg/L	13.45	28.4	18.2	20.9	300
Lead µg/L	0.0265	0.029	0	0.008	7[b]
Lithium µg/L	39.7	33.8	32	27.2	2500[e]
Manganese µg/L	34.15	44.3	23.5	43.3	200[e]
Molybdenum µg/L	0.087	0.097	0.09	0.174	73[c]
Nickel µg/L	0.0595	0.18	0.09	0.1	150[b]
Selenium µg/L	0.07	0.1	0.1	0.1	1
Silver µg/L	0.001	0.002	0	0.0005	0.25
Strontium µg/L	208.5	190	211	200	/
Thallium µg/L	0.00068	0.001	0	0.001	0.8
Thorium µg/L	0.00563	0.001	0	0.001	/
Tin µg/L	0.0195	0.03	0.03	0.03	/
Titanium µg/L	0.985	1	0.88	0.54	/
Uranium µg/L	0.196	0.105	0.1	0.102	15
Vanadium µg/L	0.265	0.225	0.09	0.256	100[d,e]
Zinc µg/L	1.3	2.7	0.5	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.

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 both the north and south basins of Skeleton Lake. Both basins were first sampled through LakeWatch in 2005 and last sampled in 2020 – this date range has been used for the trend analysis. 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. Data is presented below for the different parameters in each lake as both line and box-and-whisker plots. Detailed methods are available in the *ALMS Guide to Trend Analysis on Alberta Lakes.*

In the north basin, chlorophyll-*a* has and TDS have significantly increased over the sampling period, and Secchi depth has significantly decreased. There has been not significant trend detected for TP in the north basin.

In the south basin, TDS has significantly increased over the sampling period, and TP significantly decreased during the sampling period. No significant trends were detected for chlorophyll-*a* and Secchi depth.

Table 7a. Summary table of trend analysis on Skeleton Lake North data from 2005 to 2020.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	2005-2020	No Change
Chlorophyll-*a*	2005-2020	Increasing
Total Dissolved Solids	2005-2020	Increasing
Secchi Depth	2005-2020	Decreasing

Table 7b. Summary table of trend analysis on Skeleton Lake South data from 2005 to 2020.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	2005-2020	Decreasing
Chlorophyll-*a*	2005-2020	No Change
Total Dissolved Solids	2005-2020	Increasing
Secchi Depth	2005-2020	No Change

Definitions:

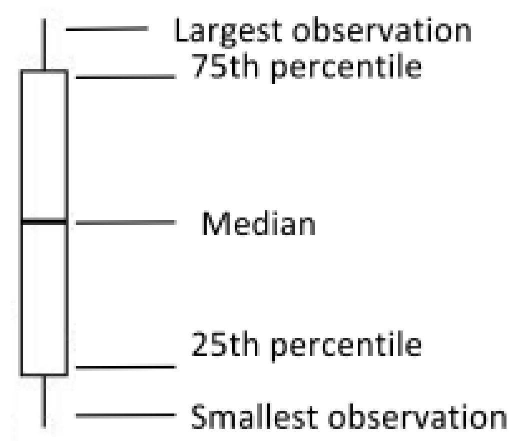
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

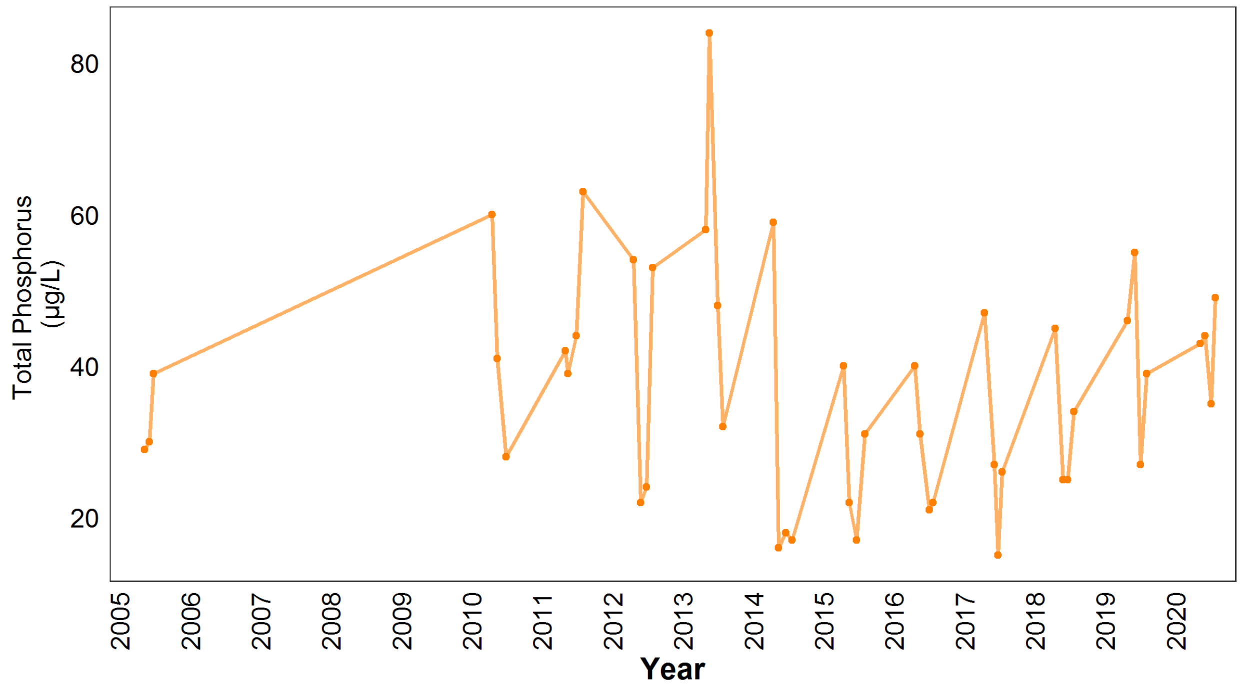
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

Box and Whisker Plot: a box-and-whisker plot, or boxplot, is a way of displaying all of our annual data. The median splits the data in half. The 75th percentile is the upper quartile of the data, and the 25th percentile is the lower quartile of the data. The top and bottom points are the largest and smallest observations.



Total Phosphorus (TP) – North Basin

TP has not significantly changed in Skeleton Lake North since 2005 (Tau = -0.05, p = 0.64).



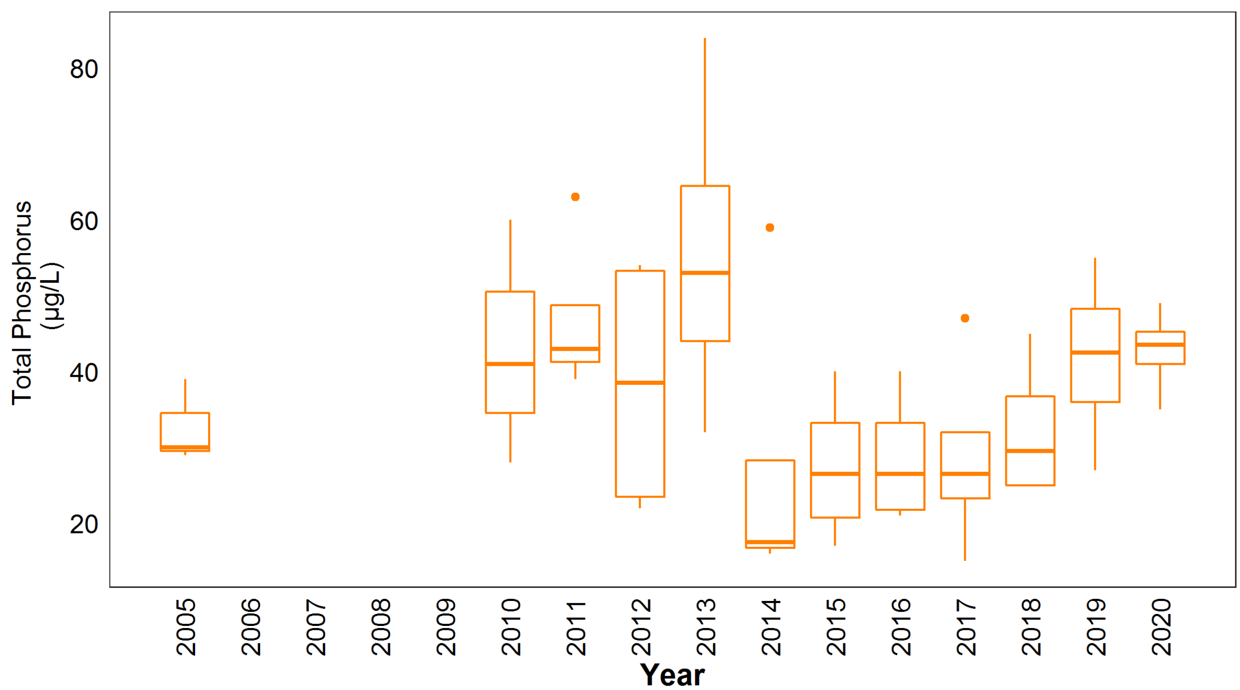
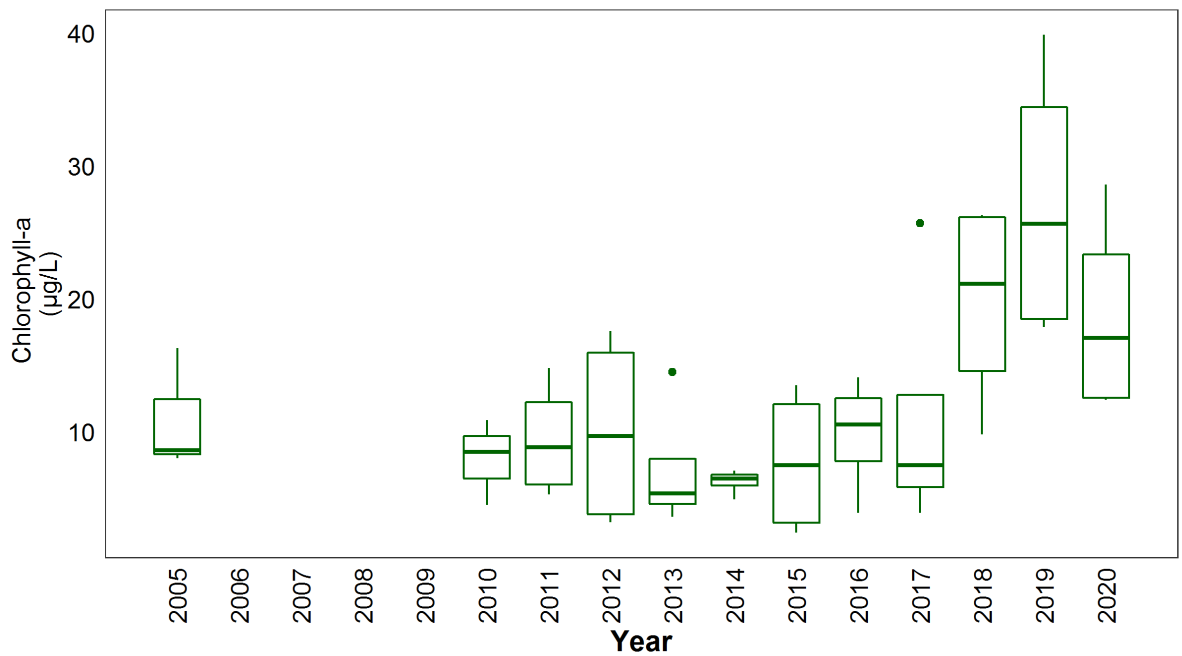


Figure 7. Monthly total phosphorus (TP) concentrations at Skeleton Lake North measured between June and September over the long term sampling dates between 2005 and 2020 (n = 46). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a* – North Basin

Chlorophyll-*a* has significantly increased in Skeleton Lake North since 2005 (Tau = 0.31, p = 0.0082) (Figure 2a). Chlorophyll-*a* and Total Phosophorus concentrations are significantly correlated over time (r = 0.30, p = 0.044).



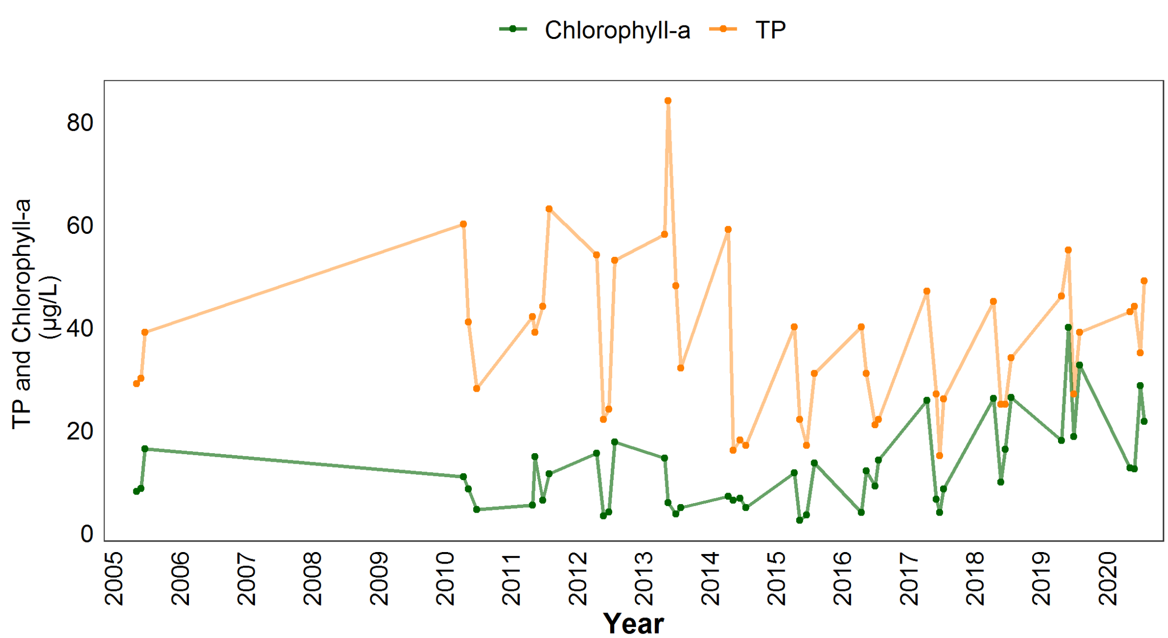
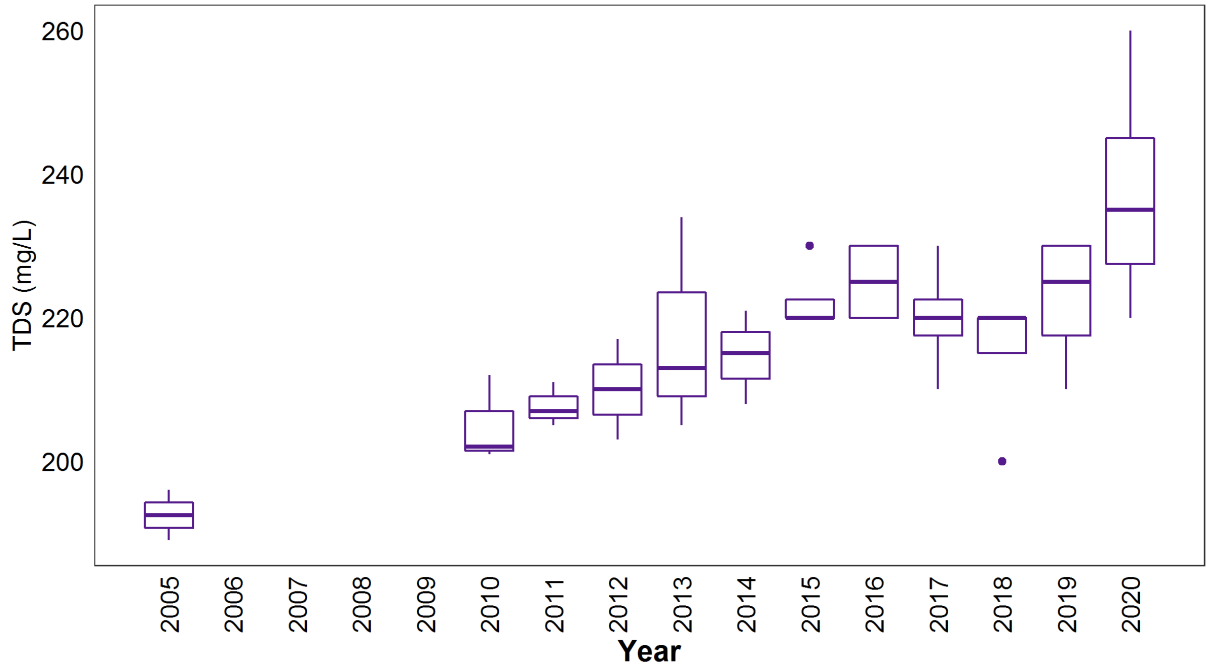


Figure 8. Monthly chlorophyll-*a* concentrations measured in Skeleton Lake North between June and September over the long term sampling dates between 2005 and 2020 (n = 46). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS) - North Basin

Trend analysis showed a significant increasing trend in TDS since 2005 in Skeleton Lake North (Tau = 0.51, $p < 0.001$). This could be attributed to decreasing water levels.



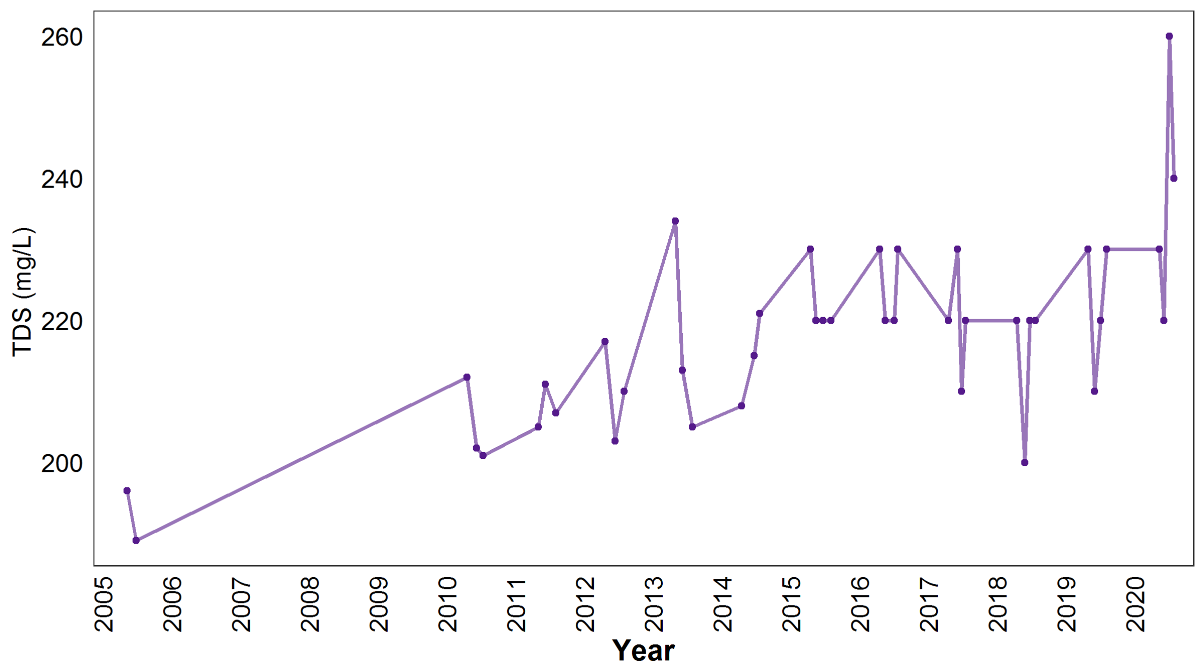
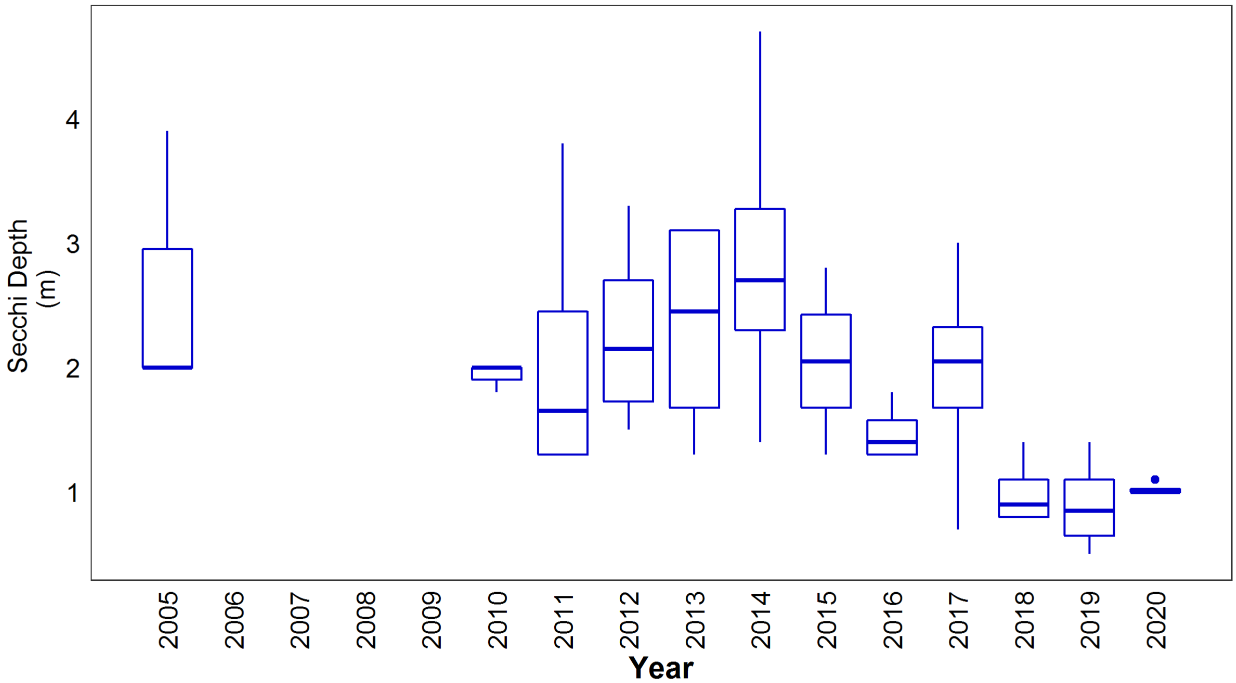


Figure 9. Monthly TDS values measured at Skeleton Lake North between June and September over the long term sampling dates between 2005 and 2020 (n = 41). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth - North Basin

Water clarity measured as Secchi depth in Skeleton Lake North has undergone a statistically significant decrease since 2005 (Tau =-0.43, $p < 0.001$). The most recent three years have had both the lowest Secchi depth medians since 2005, and also some of the least variable (Figure 10).



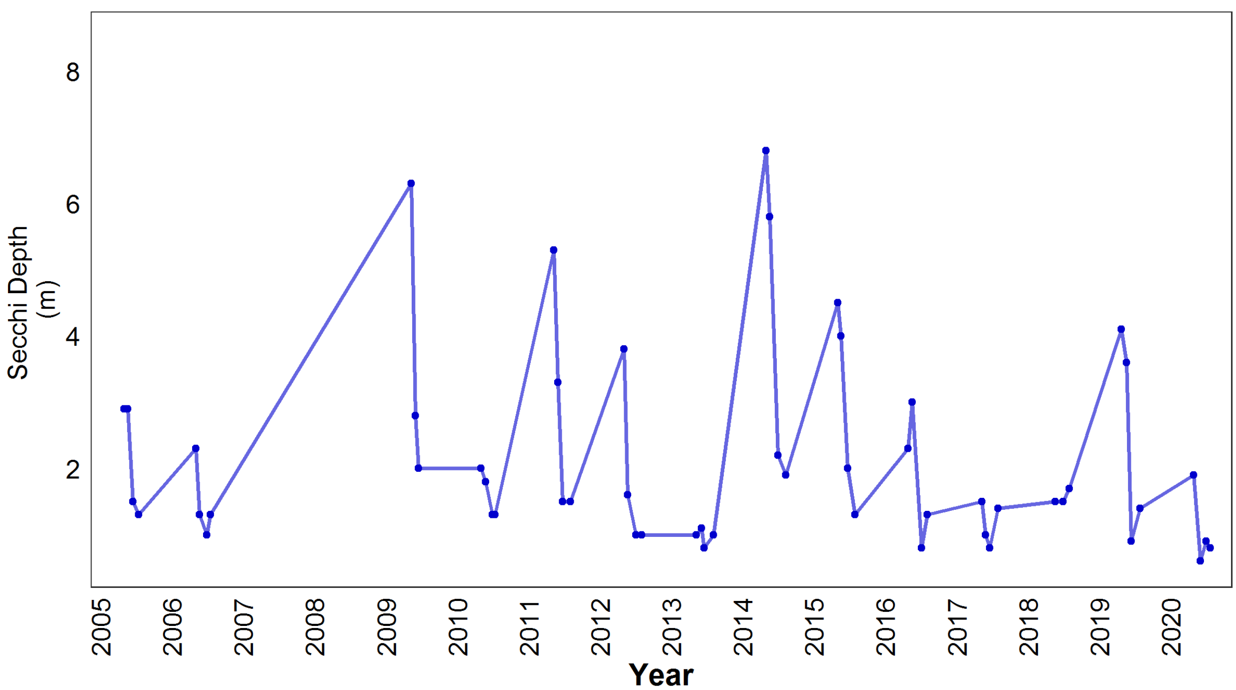
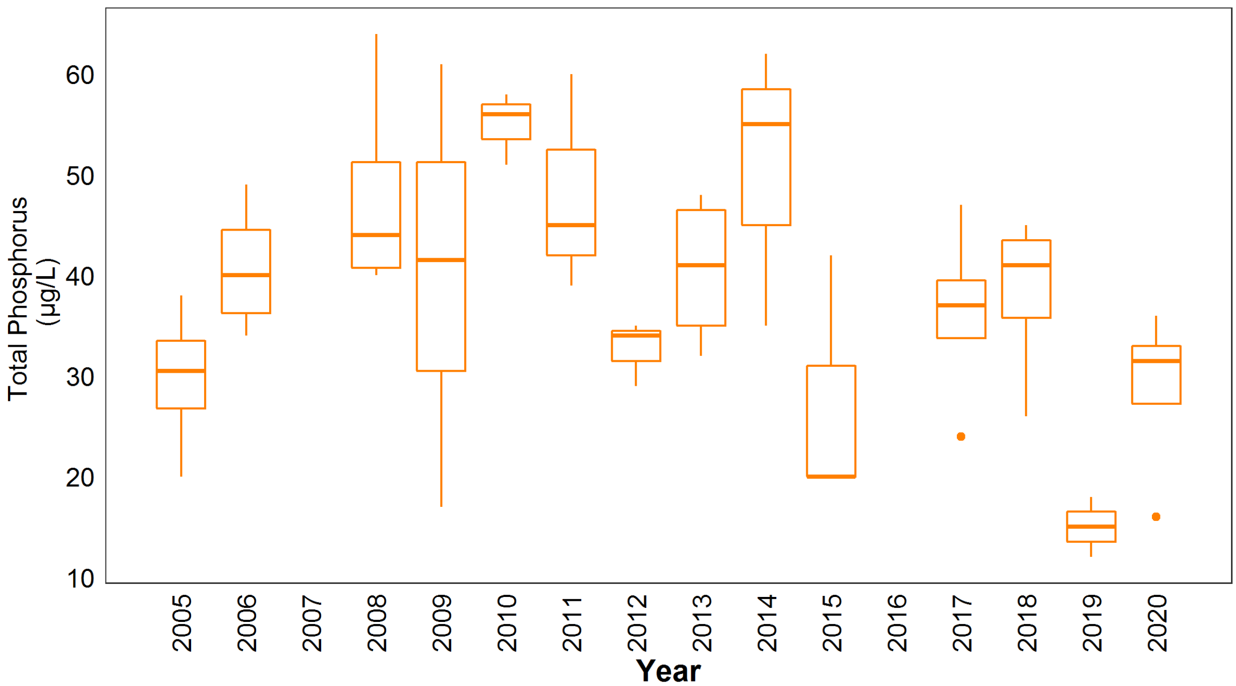


Figure 10. Monthly Secchi depth values measured at Skeleton Lake North between June and September over the long term sampling dates between 2005 and 2020 (n = 46). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Total Phosphorus (TP) – South Basin

TP has significantly decreased in Skeleton Lake South since 2005 (Tau = -0.24, p = 0.028). Some TP data from 2014 were removed from the dataset as the samples exceeded laboratory hold times and were not considered reliable (see Skeleton Lake 2014 LakeWatch report for more details). Also note that 2019 data is only from June and July.



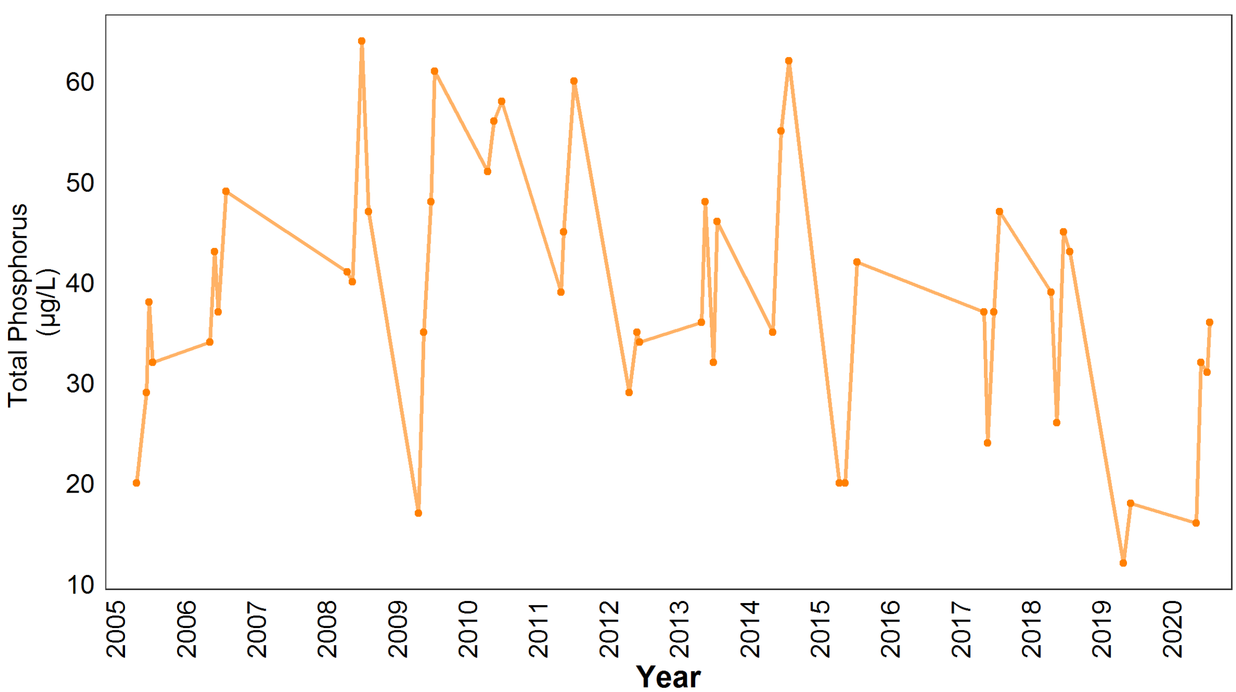
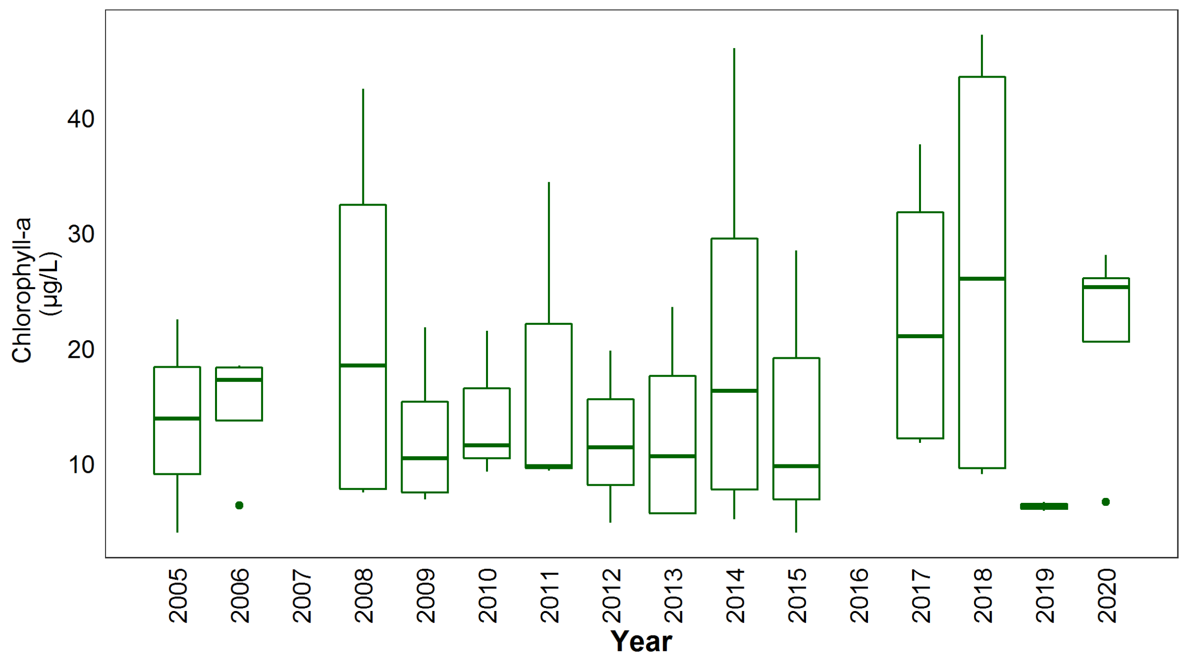


Figure 11. Monthly total phosphorus (TP) concentrations measured at Skeleton Lake South between June and September over the long term sampling dates between 2005 and 2020 (n = 49). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a* – South Basin

Chlorophyll-*a* has not significantly changed in Skeleton Lake South since 2005 (Tau = 0.22, p=0.083). Note that 2019 data is only from June and July. Chlorophyll-*a* and Total Phosophorus concentrations are significantly correlated over time (r = 0.51, *p* = 0.0002).



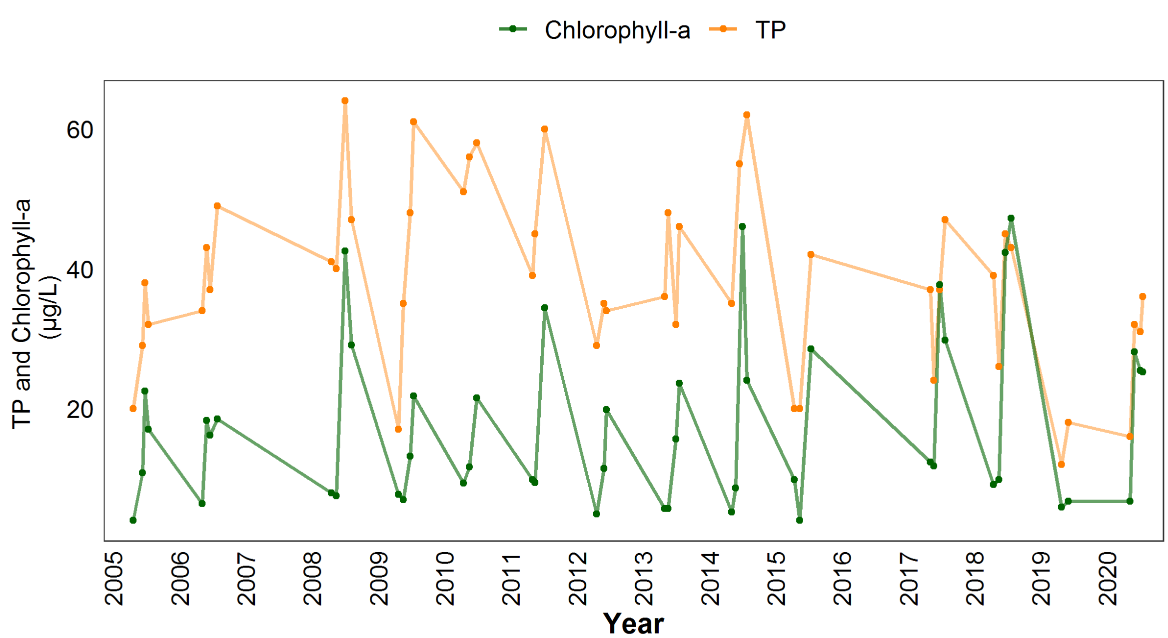
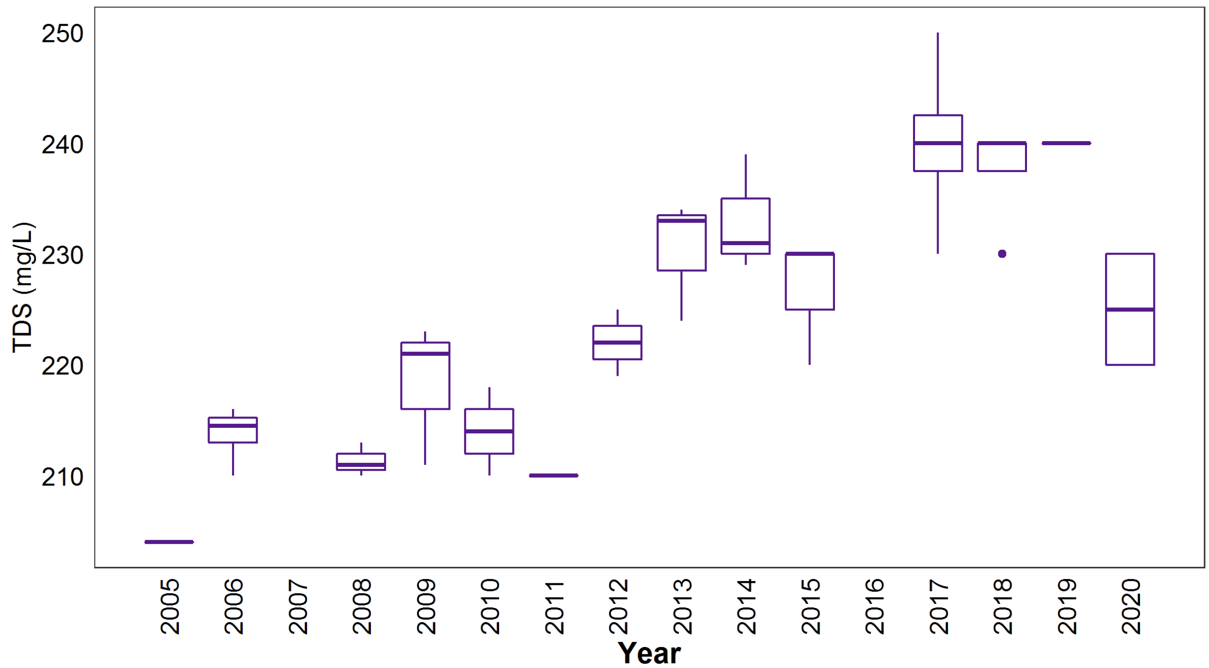


Figure 12. Monthly chlorophyll-*a* concentrations measured in Skeleton Lake South between June and September over the long term sampling dates between 2005 and 2020 (n = 50). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS) - South Basin

Trend analysis showed a significant increasing trend in TDS since 2005 in Skeleton Lake South (Tau = 0.61, $p < 0.001$). This could be attributed to decreasing water levels. However, this trend has appeared to slow and possibly be changing in more recent years (Figure 13). Note that 2019 data is only from June and July.



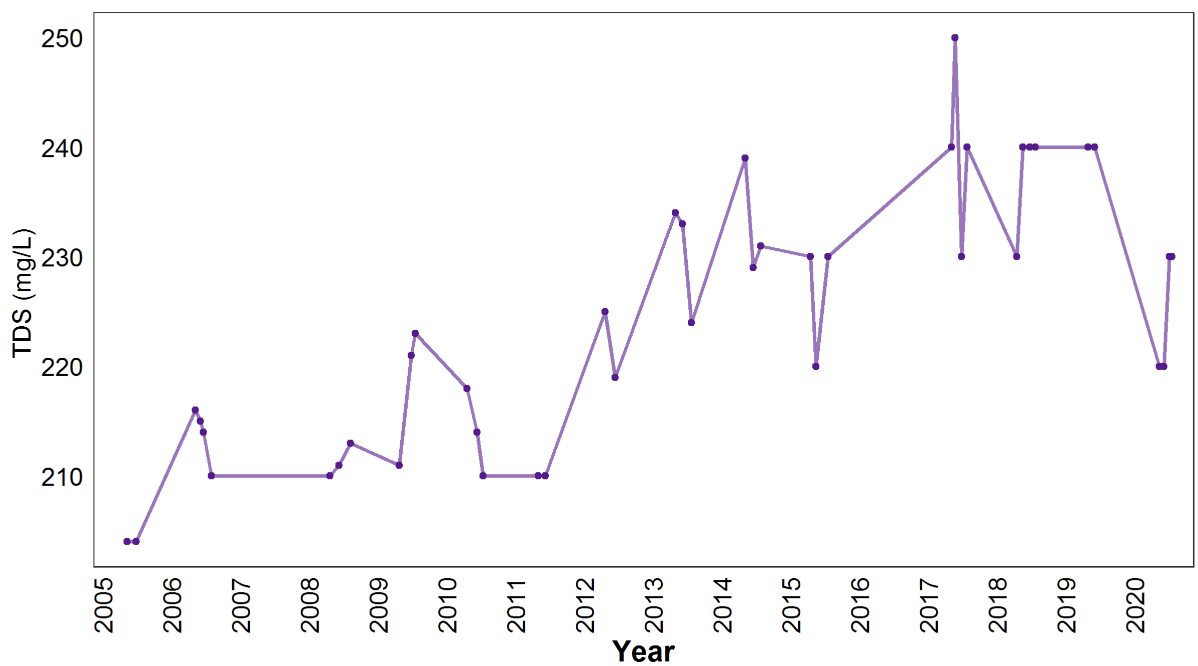
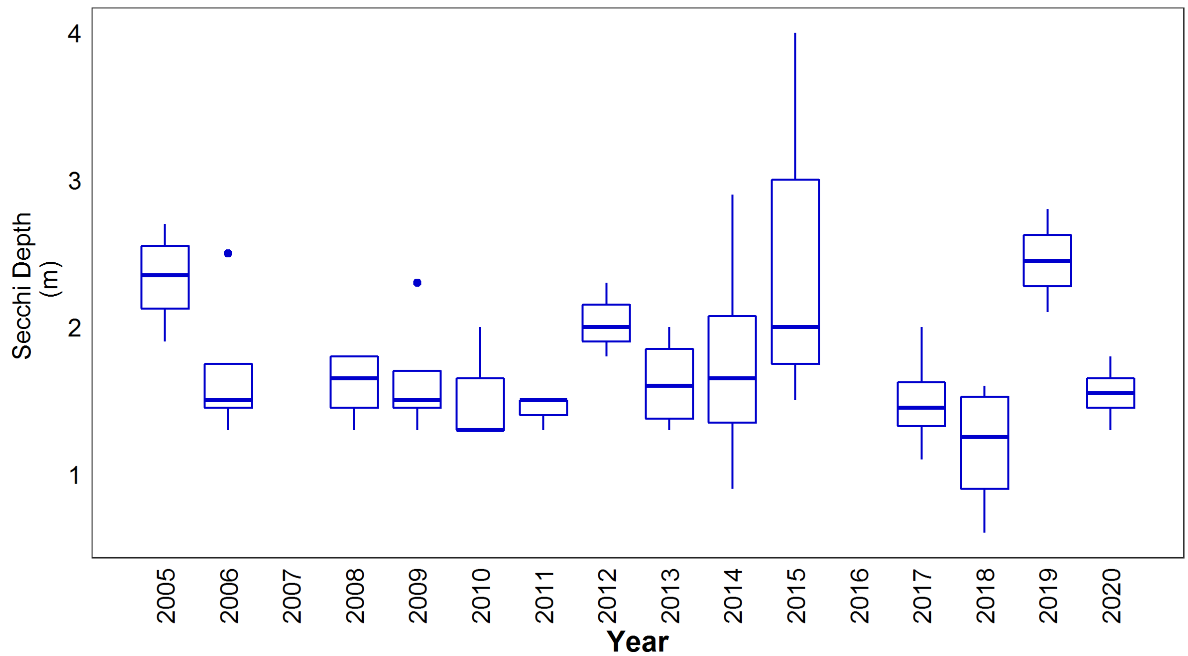


Figure 13. Monthly TDS values measured in Skeleton Lake South between June and September over the long term sampling dates between 2005 and 2020 (n = 42). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth - South Basin

Water clarity measured as Secchi depth in Skeleton Lake South has not significantly changed since 2005, (Tau =-0.17, p = 0.15). Note that 2019 data is only from June and July.



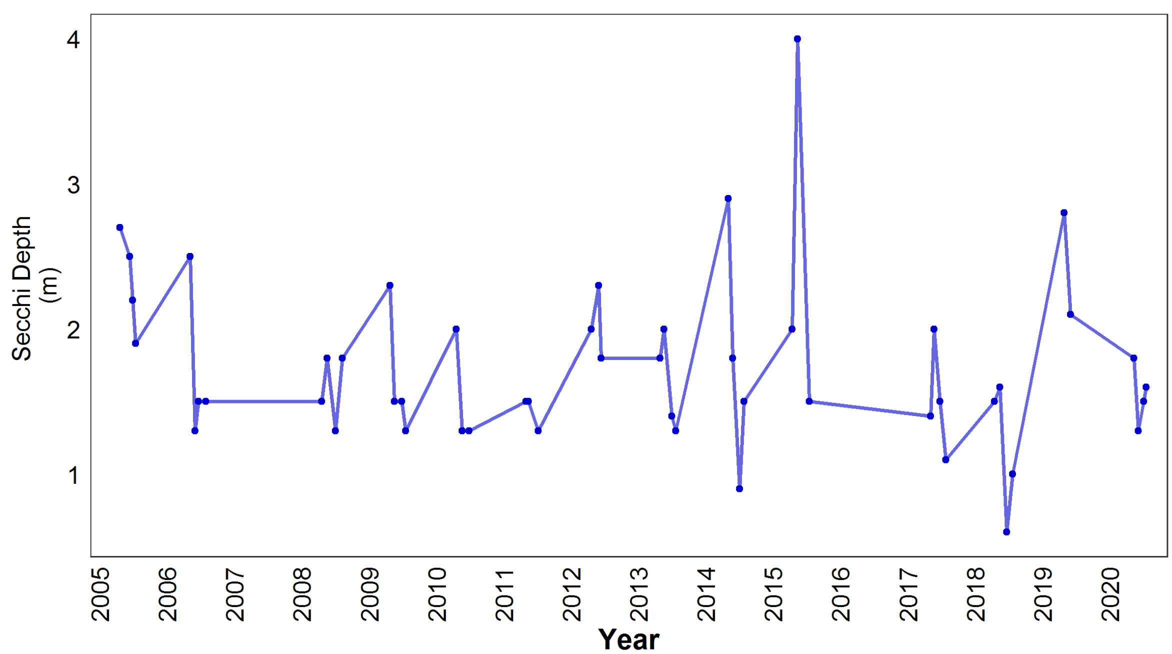


Figure 14. Monthly Secchi depth values measured in Skeleton Lake South between June and September over the long term sampling dates between 2005 and 2020 (n = 50). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 8a. North Basin: Results of Seasonal Kendall 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	-0.05	0.31	0.51	-0.43
The extent of the trend	Slope	-0.38	0.81	2.41	-0.12
The statistic used to find significance of the trend	Z	-0.47	2.64	4.35	-3.83
Number of samples included	n	46	46	41	46
The significance of the trend	*p*	0.64	0.0082*	1.35×10^{-5}*	1.28×10^{-4}*

*$p < 0.05$ is significant within 95%

Table 8b. South Basin: Results of Seasonal Kendall 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	-0.24	0.22	0.61	-0.17
The extent of the trend	Slope	-0.75	0.23	2.10	-0.022
The statistic used to find significance of the trend	Z	-2.19	1.74	5.00	-1.44
Number of samples included	n	49	50	42	50
The significance of the trend	*p*	0.028*	0.083	5.69×10^{-7}*	0.15

*$p < 0.05$ is significant within 95%