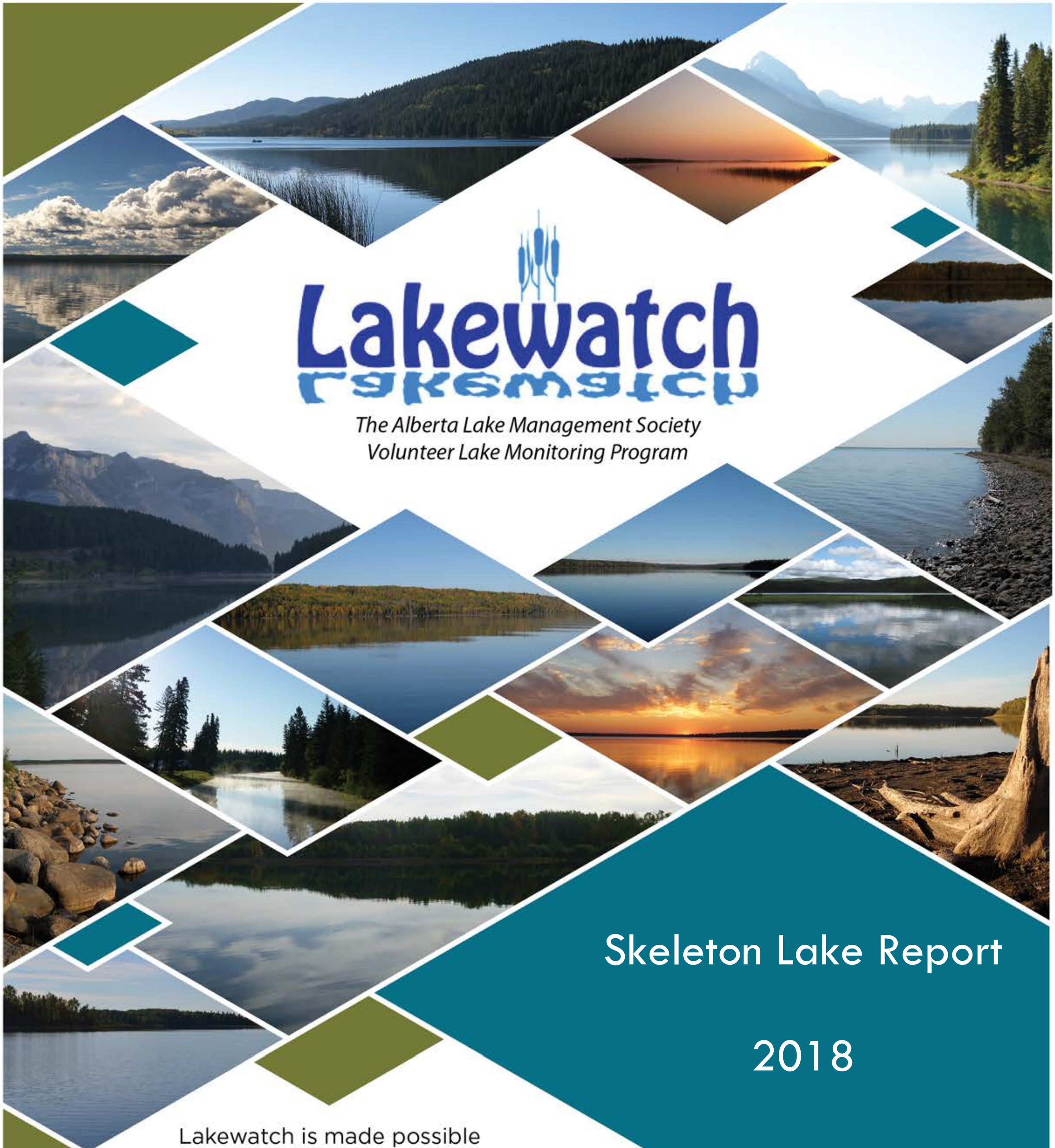


Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Skeleton Lake Report

2018

Lakewatch is made possible
with support from:

Alberta

Pigeon Lake Watershed Association

Jackfish Lake

MD61 Wainwright

LICA Environmental Stewards

Red Deer River Watershed Alliance

Cargill

ALBERTA LAKE MANAGEMENT SOCIETY'S LAKEWATCH PROGRAM

LakeWatch has several important objectives, one of which is to collect and interpret water quality data on Alberta Lakes. Equally important is educating lake users about their aquatic environment, 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 a lay 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 would like to use this data for your own purposes, please contact ALMS for the raw data files.

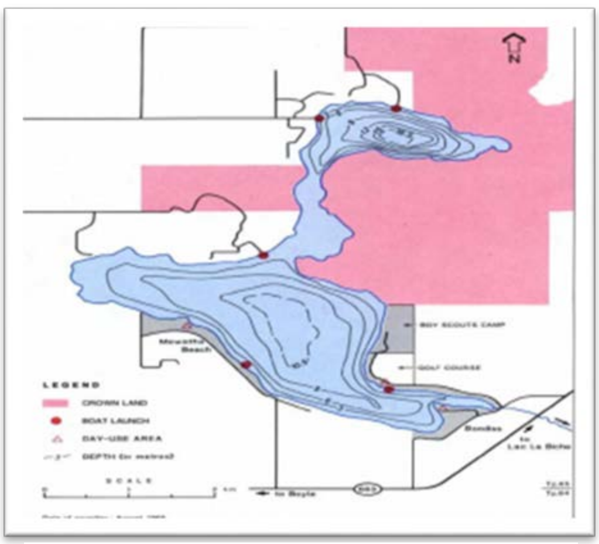
ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks to Orest Kitt and Marc Vincent for their commitment to collecting data at Skeleton Lake. We would also like to thank Alanna Robertson, Lindsay Boucher and Shona Derlukewich, who were summer technicians in 2018. Executive Director Bradley Peter and Program Coordinator Laura Redmond were instrumental in planning and organizing the field program. This report was prepared by Caitlin Mader 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—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.

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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. On one visit per season, metals are collected at the profile site by hand grab from the surface and at some lakes, 1 m off bottom using a Kemmerer.

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). In lakes where mercury samples are taken, they are analyzed by the Biogeochemical Analytical Service Laboratory (BASL).

Invasive Species: Monitoring for invasive quagga and zebra mussels involved two components: monitoring for juvenile mussel veligers using a 63 µm plankton net at three sample sites and monitoring for attached adult mussels using substrates installed at each lake.

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 aep.alberta.ca/water.

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 TP, chlorophyll-*a,* 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 2 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.

The average total phosphorus (TP) concentration for Skeleton Lake North was 32 µg/L (Table 2), and for Skeleton Lake South was 40 µg/L, with both basins falling into the eutrophic, or highly 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 2018 for Skeleton Lake North was 19.6 µg/L and for Skeleton Lake South was 31.6 µg/L (Table 2). This puts the north basin in the eutrophic classification and the south basin in the hypereutrophic classification. In Skeleton Lake North, chlorophyll-*a* decreased over the course of the sampling season, and was significantly correlated with TP ($r = 0.89$, $p = 0.04$). In the south basin, chlorophyll-*a* peaked on August 25, measuring 49.6 µg/L (Figure 1).

The average total Kjeldahl nitrogen (TKN) concentration of the north basin was 1.6 mg/L and the TKN concentration of the south basin was 1.5 mg/L. TKN was correlated with chlorophyll-*a* concentrations in Skeleton Lake North ($r = 0.96$, $p = 0.001$) and Skeleton Lake South ($r = 0.998$, $p < 0.01$).

Average pH of Skeleton North was 8.79 in 2018, buffered by moderate alkalinity (192 mg/L $CaCO_3$) and bicarbonate (208 mg/L HCO_3). Calcium and magnesium were the dominant ions contributing to a low conductivity of 390 µS/cm (Table 2).

Average pH of Skeleton South was 8.70 in 2018, buffered by moderate alkalinity (220 mg/L $CaCO_3$) and bicarbonate (242 mg/L HCO_3). Magnesium and sodium were the dominant ions contributing to a low conductivity of 420 µS/cm (Table 2).

METALS

Samples were analyzed for metals (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.

Metals were measured once at both Skeleton Lake North and South on August 11. In 2018, all measured values fell within their respective guidelines (Table 3).

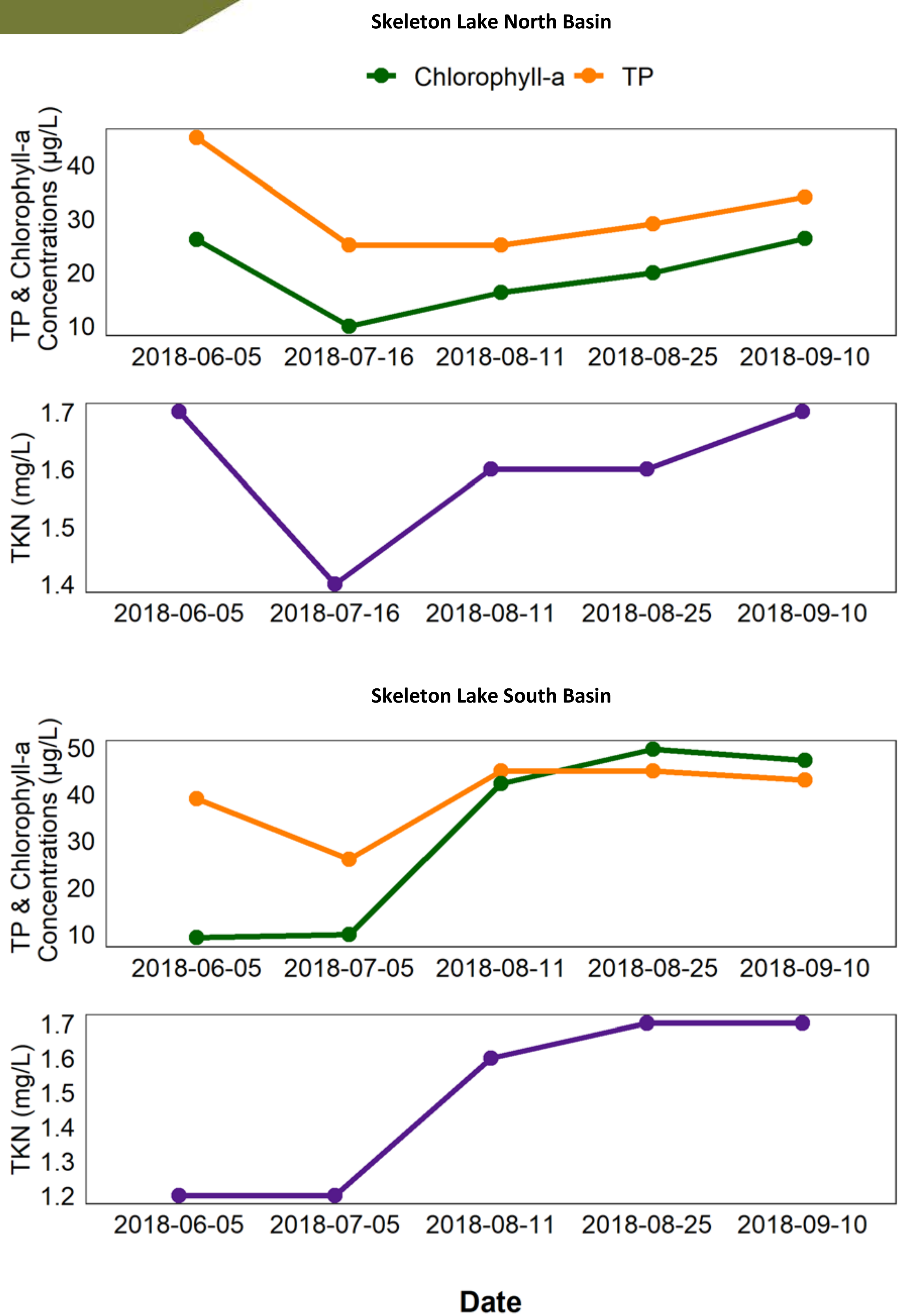


Figure 1- Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured five times over the course of the summer at Skeleton Lake North (top) and Skeleton Lake South (bottom).

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 2018, the average Secchi depth of Skeleton Lake North was 1.03 m and Skeleton Lake South was 1.18 m (Table 2). Water clarity measured as Secchi depth was lowest on June 5 in the north basin and increased over the course of the sampling season. Secchi depth in the south basin stayed within 0.5 and 2 m in 2018 (Figure 2).

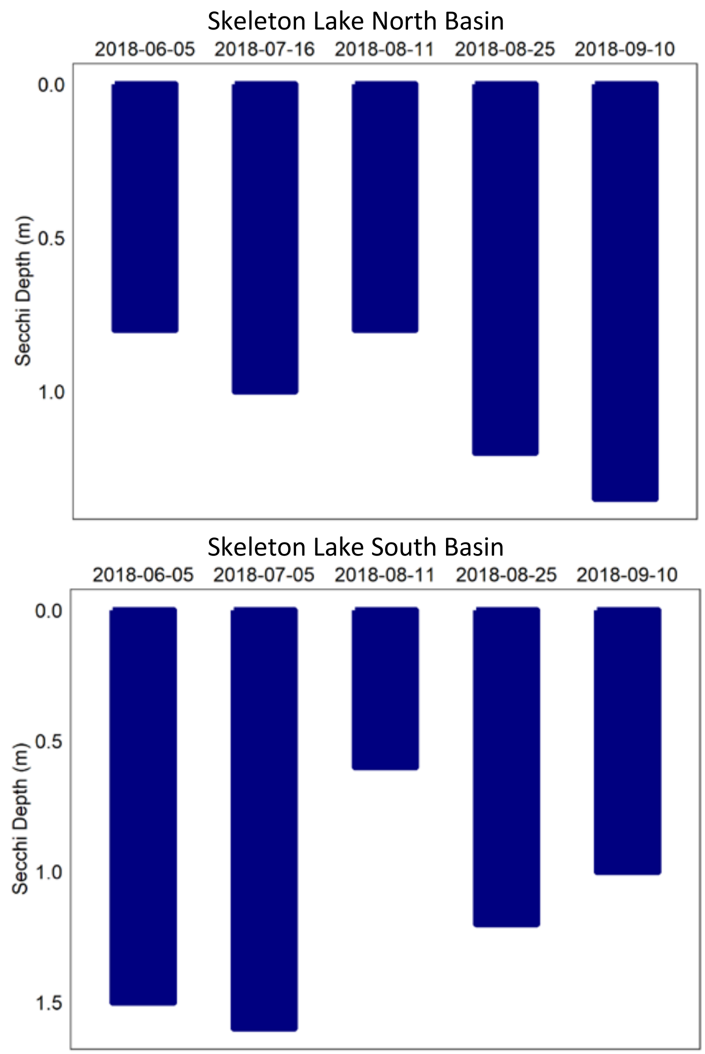


Figure 2 – Secchi depth values measured five times over the course of the summer at Skeleton Lake North (top) and Skeleton Lake South (bottom) in 2018.

WATER TEMPERATURE AND DISSOLVED OXYGEN

Water temperature and dissolved oxygen 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 22.2 °C measured at a depth of 2 meters on August 11 (Figure 3a). The lake was strongly stratified for the extent of the sampling season, with the thermocline between 5 and 10 meters deep.

Skeleton Lake North remained well oxygenated at the surface throughout the summer, measuring above the CCME guidelines of 6.5 mg/L for the Protection of Aquatic Life (Figure 3b). 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 21.6 °C measured at a depth of 1 meter on August 11 (Figure 3a). The lake was well mixed for the sampling season although weak stratification was observed on August 11.

Skeleton Lake South remained well oxygenated at the surface throughout the summer, measuring above the CCME guidelines of 6.5 mg/L for the Protection of Aquatic Life (Figure 3b). 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 in August, likely due to decomposition. The entire water column was well oxygenated in June and September.

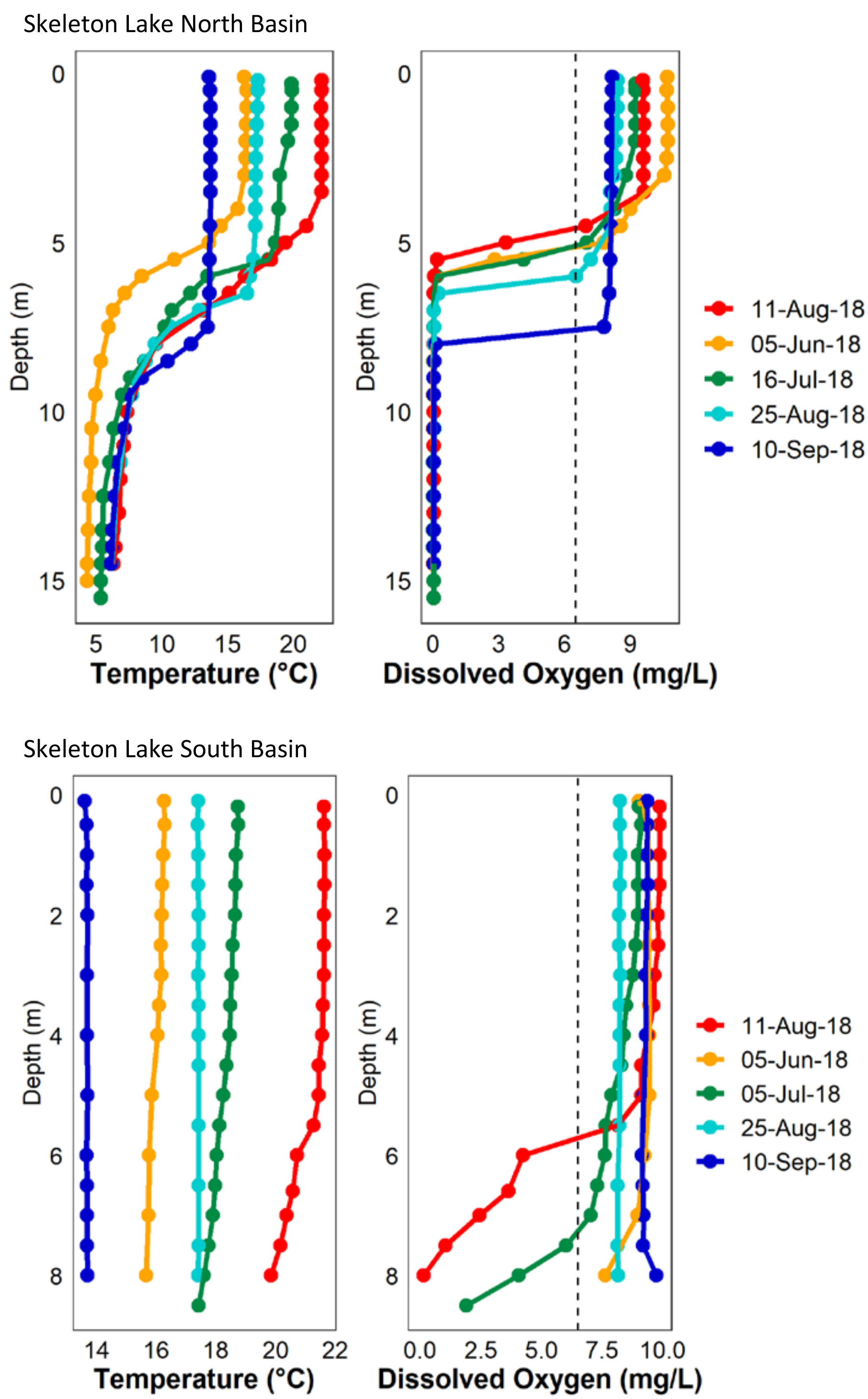


Figure 3 – a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Skeleton Lake North (top) and Skeleton Lake South (bottom) measured five times over the course of the summer of 2017. The vertical dashed line in figures 3b top and bottom represents the CCME guidelines of 6.5 mg/L DO for the Protection of Aquatic Life.

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 Skeleton Lake fell below the recreational guideline for the entire sampling period of 2018 (Table 1). Microcystin was below the detection limit on three trips to Skeleton Lake North (Table 1A). These three trips are included as 0.05 when calculating seasonal average.

Table 1 – A) Microcystin concentrations measured five times at Skeleton Lake North in 2018.

Date	Microcystin Concentration (μg/L)
05-Jun-18	<0.10
16-Jul-18	<0.10
11-Aug-18	<0.10
25-Aug-18	0.15
10-Sep-18	0.20
Average	0.10

Table 1 – B) Microcystin concentrations measured five times at Skeleton Lake South in 2018.

Date	Microcystin Concentration (μg/L)
05-Jun-18	0.11
05-Jul-18	0.16
11-Aug-18	0.69
25-Aug-18	1.46
10-Sep-18	1.55
Average	0.79

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 algae 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 two components: monitoring for juvenile mussel veligers using a plankton net and monitoring for attached adult mussels using substrates installed in each lake. In 2018, no mussels were detected in either basin of Skeleton Lake.

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 between from 2012 and 2017, and has remained relatively stable (Figure 4a). In 2015, the north basin decreased to 621.0 m ASL, about a 1 m decrease from the previous year.

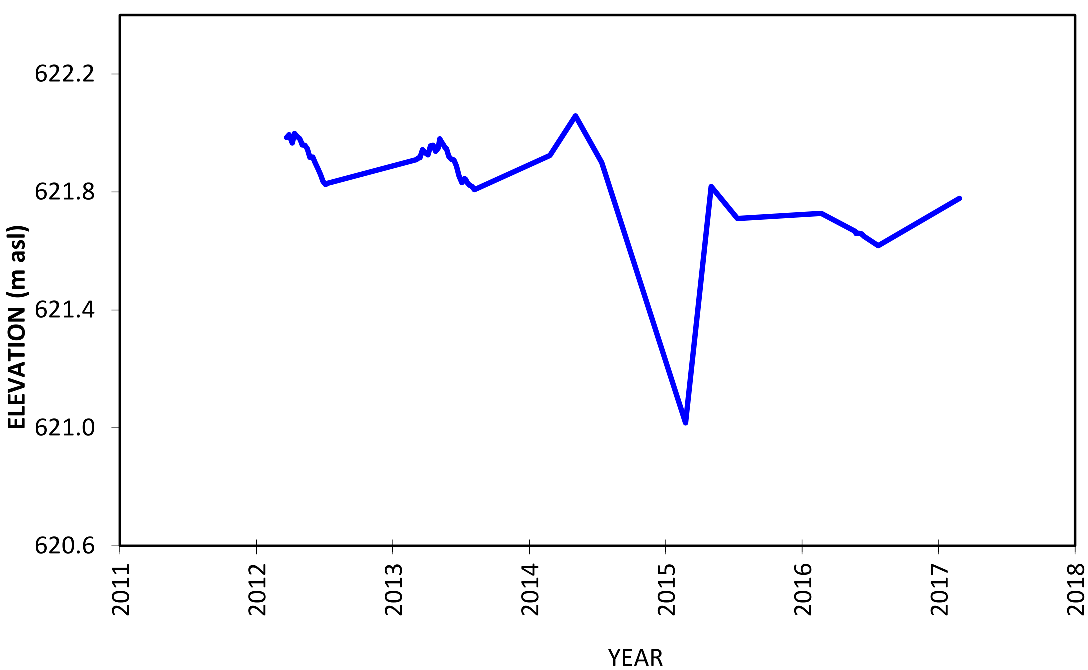


Figure 4a- Water levels measured in metres above sea level (m ASL) from 2012-2017 from the North basin of Skeleton Lake. Data retrieved from Alberta Environment.

Water levels in Skeleton Lake South have been monitored since 1965 and have been decreasing since the late 1990s (Figure 4b). Decreasing water levels in Skeleton Lake have separated the two basins.

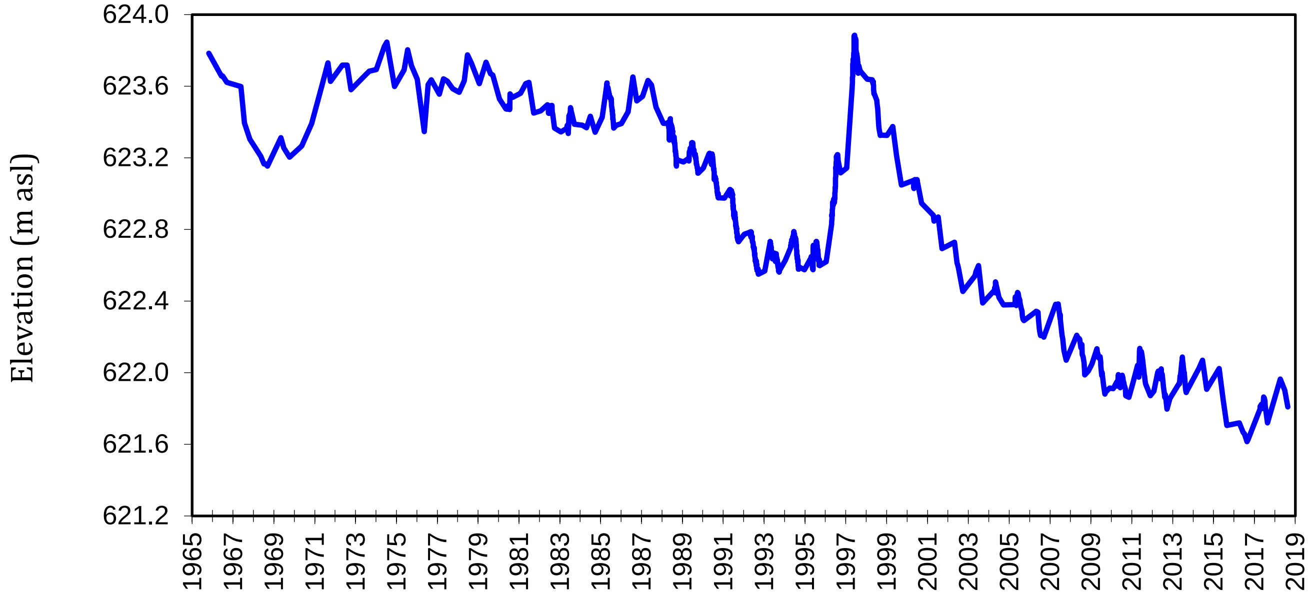


Figure 4b. Water levels in Skeleton Lake South between 1965 and 2019. Data retrieved from Alberta Environment and Parks.

Table 2: Average Secchi depth and water chemistry values for Skeleton Lake North.

Parameter	1985	1986	2005	2010	2011	2012	2013	2014	2015	2016	2017	2018
TP (µg/L)	24.3	36.3	32.7	47.8	44.5	36.0	47.6	25.2	26	28	31.4	32
TDP (µg/L)	7.8	10.7	11.0	16.0	11.8	14.4	28.2	10.6	11	9	7.6	7.66
Chlorophyll-*a* (µg/L)	9.2	10.7	11.0	8.6	17.2	8.6	7.56	5.76	7.46	9.2	11.2	19.6
Secchi depth (m)	/	/	2.63	1.75	1.40	2.45	2.35	2.81	2.00	1.4	1.88	1.03
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
NO_2-N and NO_3-N (µg/L)	2.25	3.67	3.00	4.40	6.00	2.50	2.5	22	2.3	2.5	2.32	4.2
NH_3-N (µg/L)	21.2	32.5	12.7	82.8	24.3	21.2	23.2	33.4	25	25	27.6	20.4
DOC (mg/L)	14.8	14.6	16.6	18.6	14.3	17.8	18.2	18.97	17	18.4	16.6	19
Ca (mg/L)	23.3	24.3	21.3	23.0	22.1	25.1	24.17	31	25	24.2	25	23.8
Mg (mg/L)	18.7	18.8	23.5	25.9	26.7	25.0	26.9	21.23	26	27.6	27.6	25.8
Na (mg/L)	13.3	13.5	17.5	18.7	19.6	17.6	18.7	20.8	20	21.2	20.8	19.6
K (mg/L)	8.43	8.45	10.60	10.77	11.60	11.90	13.5	12.24	13	14.2	13.4	12.8
SO_4^{2-} (mg/L)	2.5	2.5	5.0	6.3	1.5	4.2	7.5	2.17	7.6	7.6	8.1	8.86
Cl^- (mg/L)	1.5	1.3	3.2	3.4	4.4	5.6	5.1	6	6.8	6.82	7.4	8.08
CO_3 (mg/L)	4.1	10.8	12.0	9.7	11.8	8.7	17.4	9.78	11	9.96	18	13.8
HCO_3 (mg/L)	198.08	194.43	204.00	217.67	229.25	226.40	212.8	235.6	228	226	206	208
pH	8.53	8.58	8.79	8.71	8.72	8.67	8.86	8.578	8.70	8.70	8.83	8.79
Conductivity (µS/cm)	318.3	323.7	334.5	372.3	388.0	388.4	390.4	390	402	392	390	390
Hardness (mg/L)	134.8	138.0	150.0	164.0	165.0	165.7	171	165	170	174	176	164
TDS (mg/L)	172.2	174.5	192.5	205.0	210.0	210.0	217.3	214.7	222	224	222	216
Microcystin (µg/L)	/	/	0.078	0.142	0.230	0.169	0.129	0.08	0.08	0.198	0.08	0.13
Total Alkalinity (mg/L $CaCO_3$)	169.8	171.5	186.5	195.0	208.0	200.0	204	192.6	204	200	198	192

Table 2: 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
TP (µg/L)	31.4	46.7	28.8	39.8	45.4	40.3	58.8	44.5	40.3	39.6	50.7	27	38.6	40
TDP (µg/L)	7.8	10.7	8.4	12.6	13.4	13.5	14.8	11.8	11.8	20.2	59.0	9.0	6.62	6.7
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
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	1.4	1.18
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
NO_2-N and NO_3-N (µg/L)	2.1	2.8	6.0	14.0	12.7	12.5	24.8	6.0	3.5	2.5	38.0	2.0	2.26	4.2
NH_3-N (µg/L)	13.6	37.2	12.8	27.0	19.2	26.8	22.0	24.3	21.0	21	55.6	25	31.8	34
DOC (mg/L)	13.6	14.6	14.4	14.9	16.5	14.6	15.8	14.3	14.2	14.3	17.4	16	15.2	15.2
Ca (mg/L)	26.3	25.0	23.4	25.5	22.8	23.6	21.3	22.1	25.8	25	21.3	24	24.2	23.8
Mg (mg/L)	19.0	19.0	23.4	23.0	26.9	24.4	25.1	26.7	25.7	25.6	25.8	26	29.8	27.4
Na (mg/L)	13.6	13.8	19.2	20.1	20.2	21.3	21.7	19.6	20.9	21.77	24.4	21	25.4	24.6
K (mg/L)	8.59	8.64	10.85	11.50	11.50	12.50	11.93	11.60	13.25	17.7	14.1	13	15	14.4
SO_4^{2-} (mg/L)	2.5	2.5	3.0	3.7	3.0	5.0	2.9	1.5	1.5	4.83	2.2	2.0	2.46	2.98
Cl^- (mg/L)	1.8	1.4	3.1	3.4	3.8	4.2	4.7	4.4	4.8	4.33	5.3	5.8	6.24	7.38
CO_3 (mg/L)	4.6	9.0	5.7	9.7	8.8	10.1	9.0	11.8	9.4	16	21.88	13	17.02	13.08
HCO_3 (mg/L)	208.40	191.62	226.00	232.50	223.67	231.33	229.33	229.25	246.75	227.8	255.2	243	236	242
pH	8.53	8.72	8.66	8.71	8.73	8.76	8.80	8.72	8.64	8.75	8.8	8.72	8.79	8.71
Conductivity (µS/cm)	333.4	327.2	360.0	389.3	374.3	381.3	390.7	388.0	405.8	410.2	398.0	413	422	420
Hardness (mg/L)	143.4	140.4	152.0	158.3	168.0	159.0	156.7	165.0	170.0	168	159	167	184	172
TDS (mg/L)	181.1	178.1	204.0	213.8	211.3	218.3	214.0	210.0	222.0	230.3	233	227	240	238
Microcystin (µg/L)	/	/	0.148	0.178	0.240	0.340	0.306	0.230	0.218	0.2356	0.402	0.370	0.50	0.794
Total Alkalinity (mg/L $CaCO_3$)	178.2	175.2	202.5	210.0	205.3	211.0	210.3	208.0	218.0	213.6	209.2	220	222	220

Table 3: 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	Guidelines
Aluminum μg/L	26.04	13.9	14.75	11.735	10.75	16.2	6.6	4.5	2.8	100[a]
Antimony μg/L	0.03635	0.02885	0.0307	0.0326	0.032	0.0315	0.03	0.028	0.03	/
Arsenic μg/L	0.8565	0.8685	0.574	0.8165	0.7735	0.828	0.745	0.77	0.84	5
Barium μg/L	48.95	50.85	51.1	49.05	48.5	53.75	50.9	49.5	49.7	/
Beryllium μg/L	0.00585	0.0052	0.00645	0.0015	0.004	0.004	0.004	0.0015	0	100[c,d]
Bismuth μg/L	0.00195	0.00215	0.0321	0.0143	0.00225	0.00925	5.00E-04	0.0015	0	/
Boron μg/L	122.5	105.5	104.85	93.5	97.05	94.3	103	96.5	94.6	1500
Cadmium μg/L	0.0057	0.001	0.001	0.001	0.002	0.002	0.001	0.005	0.01	0.26[b]
Chromium μg/L	0.242	0.0765	0.1535	0.28	0.105	0.075	0.015	0.05	0.1	/
Cobalt μg/L	0.01845	0.01115	0.00955	0.02615	0.007	0.0185	0.001	0.039	0.02	1000[d]
Copper μg/L	0.1633	0.154	0.3698	0.1402	0.13	0.175	0.32	0.27	0.1	4[b]
Iron μg/L	7.73	3.59	7.2	21.95	2.875	7.5	3.8	3	2.3	300
Lead μg/L	0.0151	0.0137	0.01055	0.0168	0.0135	0.0275	0.007	0.014	0.01	7[b]
Lithium μg/L	31.7	33	28.1	26.65	27.95	28.7	32.7	31.6	29.6	2500[e]
Manganese μg/L	35.4	43.9	29	16.05	12.55	31.55	26	7.66	6.74	200[e]
Molybdenum μg/L	0.0627	0.05335	0.02955	0.03915	0.037	0.041	0.026	0.038	0.04	73[c]
Nickel μg/L	0.0025	0.0025	0.0025	0.05425	0.004	0.004	0.004	0.08	0.08	150[b]
Selenium μg/L	0.05	0.096	0.05	0.082	0.03	0.03	0.2	0.1	0.2	1
Silver μg/L	0.0013	0.003175	0.001525	0.007125	0.001	0.001	0.001	5.00E-04	0	0.25
Strontium μg/L	176	187	166	180	180	194.5	193	183	197	/
Thallium μg/L	0.000725	0.0006	0.001225	0.0004	0.00045	0.0104	0.00045	0.001	0	0.8
Thorium μg/L	0.008025	0.00625	0.0313	0.01075	0.001175	0.00045	0.00045	0.001	0	/
Tin μg/L	0.015	0.015	0.38175	0.0377	0.0065	0.026	0.023	0.03	0.06	/
Titanium μg/L	0.336	0.676	0.2735	0.7785	0.2025	0.73	0.26	0.2	0.29	/
Uranium μg/L	0.1965	0.202	0.18	0.1995	0.211	0.205	0.201	0.22	0.23	15
Vanadium μg/L	0.214	0.1855	0.2035	0.1865	0.19	0.19	0.14	0.171	0.14	100[d,e]
Zinc μg/L	0.3085	0.41	0.4175	0.2805	0.55	0.25	0.3	0.4	0.2	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 3: 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 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.

LONG TERM TRENDS-
SKELTON LAKE SOUTH AND NORTH BASINS

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 2018. 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 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 generally increased over the sampling period, but not significantly. Total Phosphorus has decreased during the sampling period, and while this trend is not significant, it is very nearly so. 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 1 a): Summary table of trend analysis on Skeleton Lake North data from 2005 to 2018.

Parameter	Date Range	Trend	Probability
Total Phosphorus	2005-2018	Decreasing	Nearly significant
Chlorophyll-*a*	2005-2018	Increasing	Non-significant
Total Dissolved Solids	2005-2018	Increasing	Significant
Secchi Depth	2005-2018	Decreasing	Significant

b): Summary table of trend analysis on Skeleton Lake South data from 2005 to 2018

Parameter	Date Range	Trend	Probability
Total Phosphorus	2005-2018	Decreasing	Nearly significant
Chlorophyll-*a*	2005-2018	Increasing	Significant
Total Dissolved Solids	2005-2018	Increasing	Significant
Secchi Depth	2005-2018	Decreasing	Significant

Definitions:

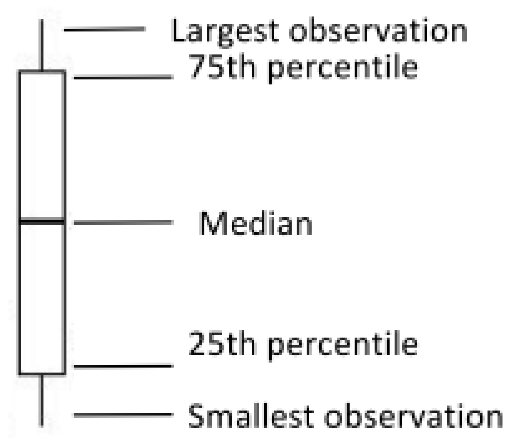
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

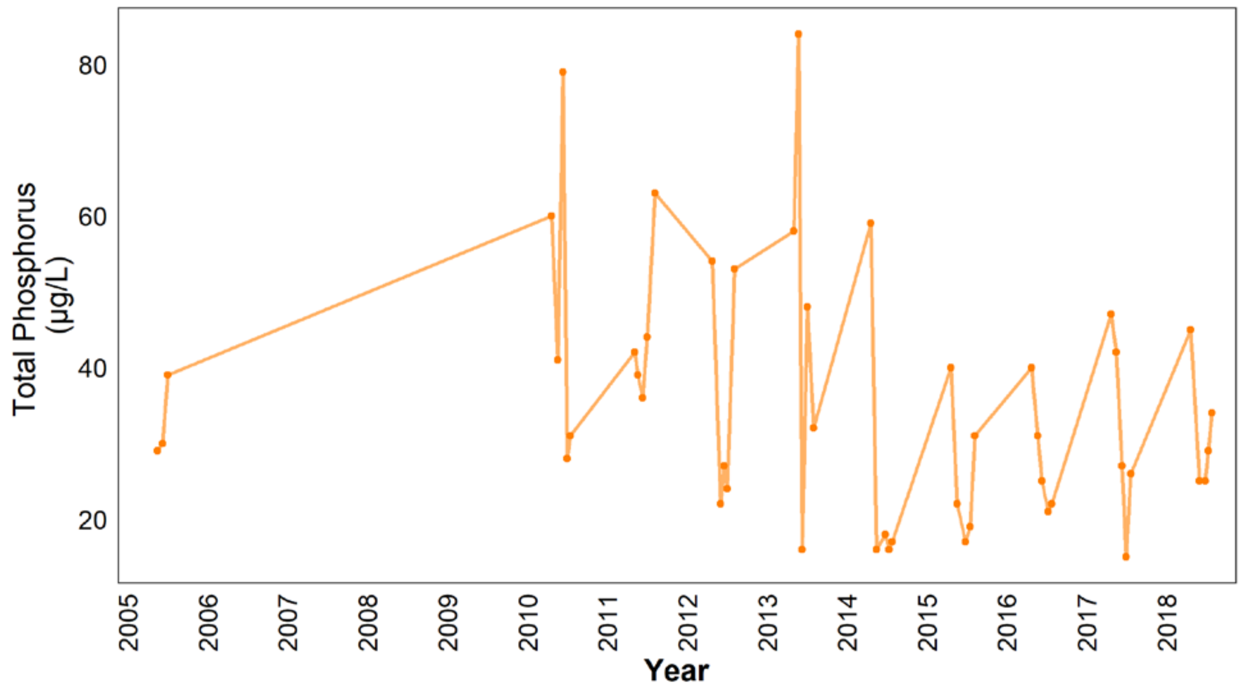
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

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 that is very nearly significant (Tau = -0.26, p = 0.05).



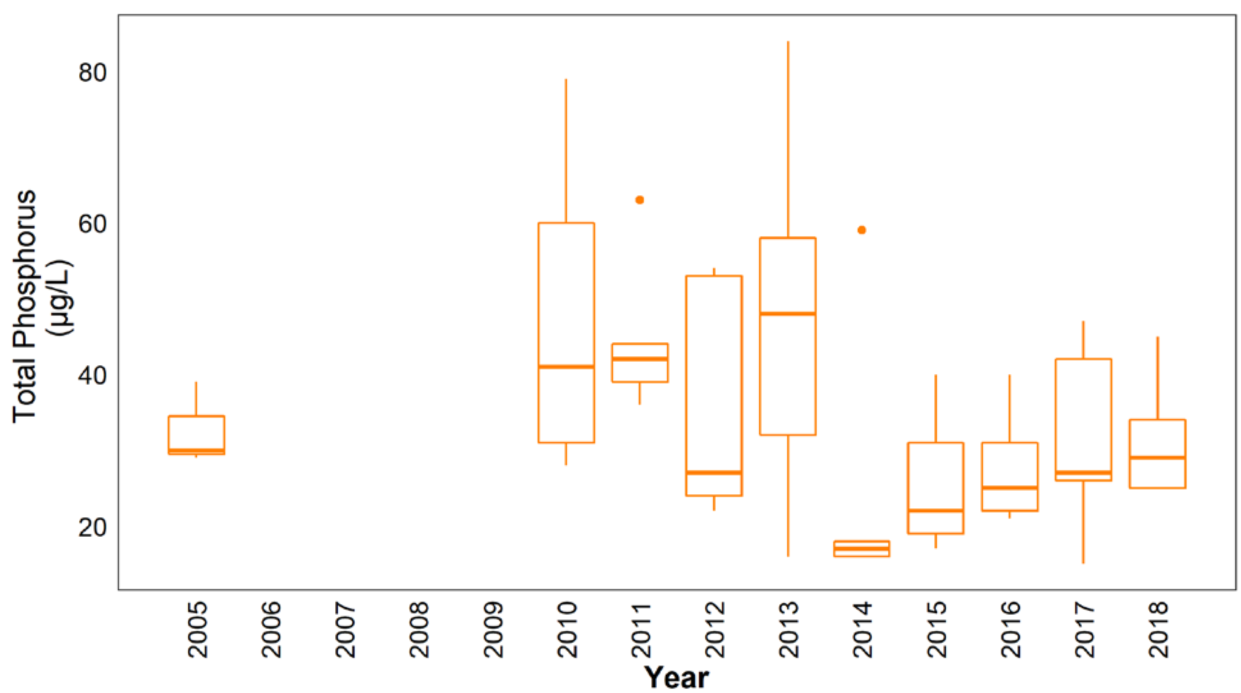


Figure 1a- Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 2005 and 2018 (n = 38). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Total Phosphorus (TP) – South Basin

TP has not significantly changed in Skeleton Lake South since sampling began in 2005 (Figure 1b), but a slightly decreasing trend is very nearly significant (Tau = -0.22, p = 0.052). TP data from June and July were removed from the dataset as the samples exceeded laboratory hold times and were not considered reliable.

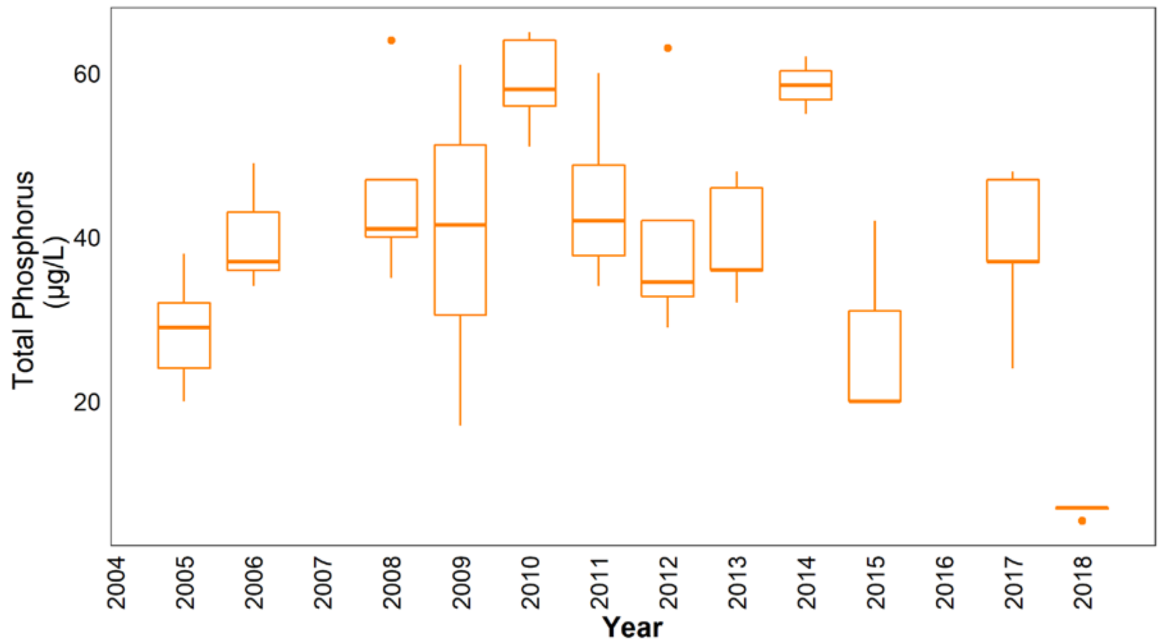


Figure 1b- Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 2005 and 2018 (n = 42). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a* – North Basin

Chlorophyll-*a* has not significantly increased or decreased since sampling began on Skeleton Lake North in 2005 (Tau = 0.11, p=0.47) (Figure 2a). Chlorophyll-*a* and Total Phosophorus concentrations are significantly correlated over time (t=2.04, p = 0.046, r= 0.29).

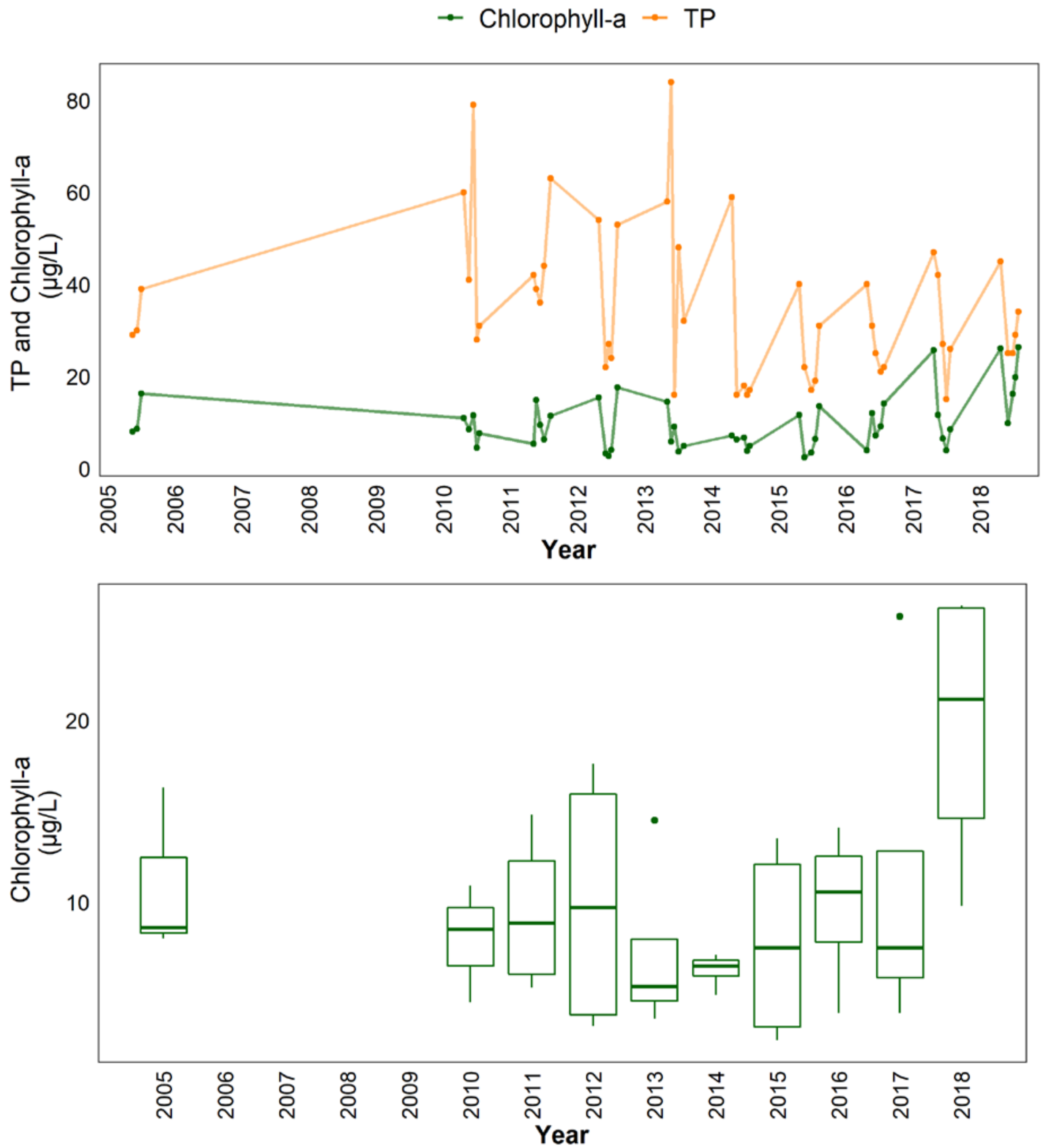


Figure 2a-Monthly chlorophyll-*a* concentrations in the north basin measured between June and September over the long term sampling dates between 2005 and 2018 (n = 38). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Chlorophyll-*a* – South Basin

Chlorophyll-*a* has not significantly increased or decreased since sampling began on Skeleton Lake South in 2005 (Tau = 0.27, p=0.04)(2b). Chlorophyll-*a* and Total Phosophorus concentrations are almost, but not quite significantly correlated over time (t=1.71, p = 0.09, r= 0.23).

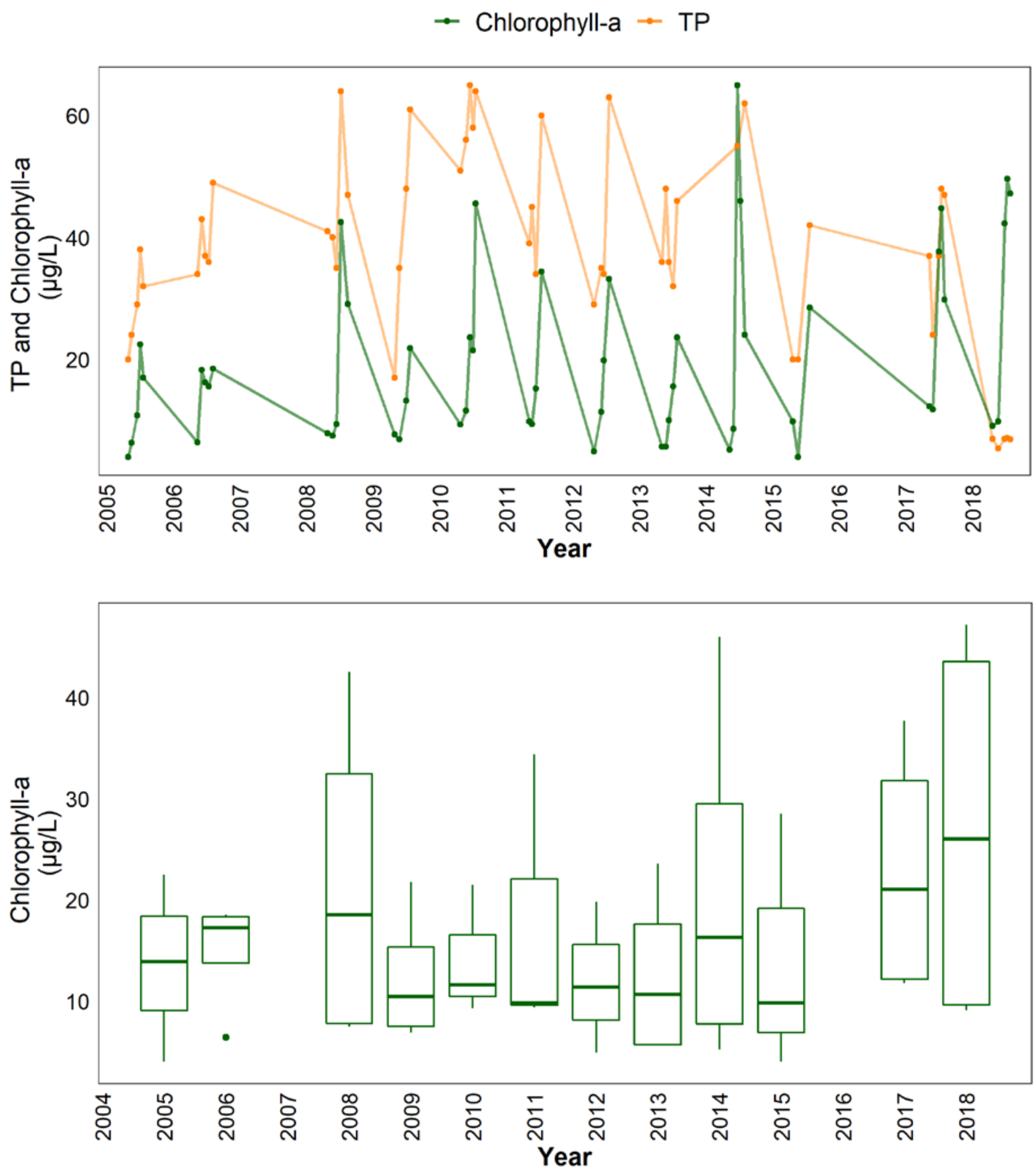
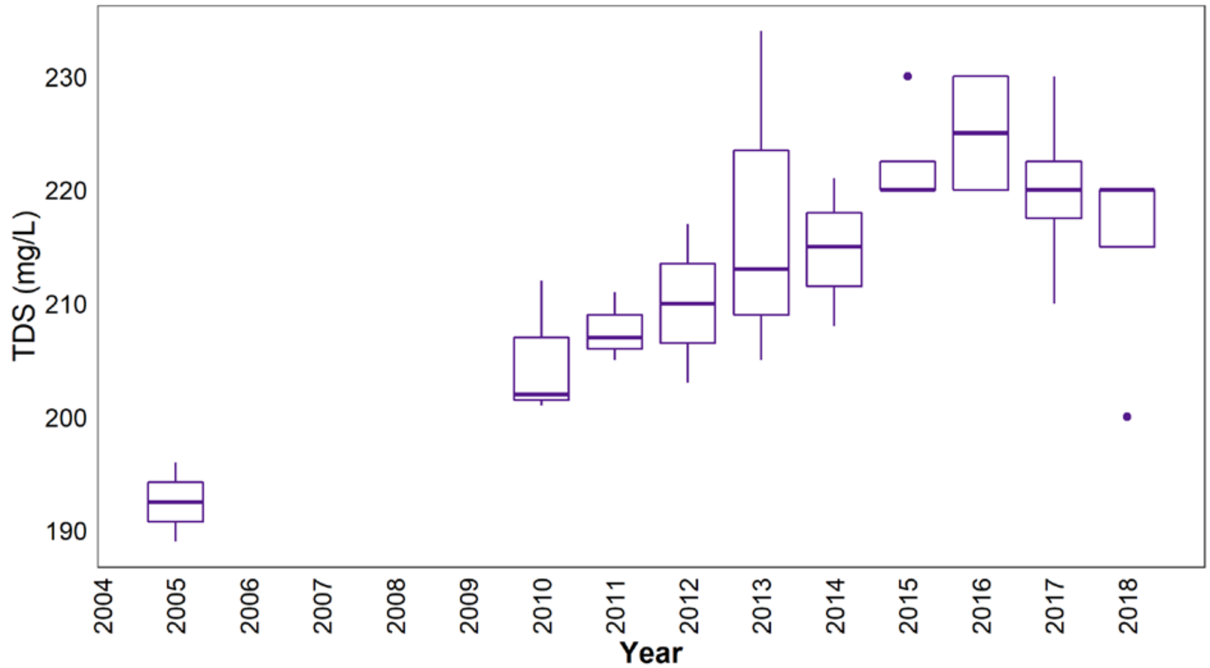


Figure 2b-Monthly chlorophyll-*a* concentrations in the south basin measured between June and September over the long term sampling dates between 2005 and 2018 (n = 44). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line 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 = 0.47, $p < 0.001$). This could be attributed to decreasing water levels. However, this trend has slowed in the past two years sampled (Figure 3a).



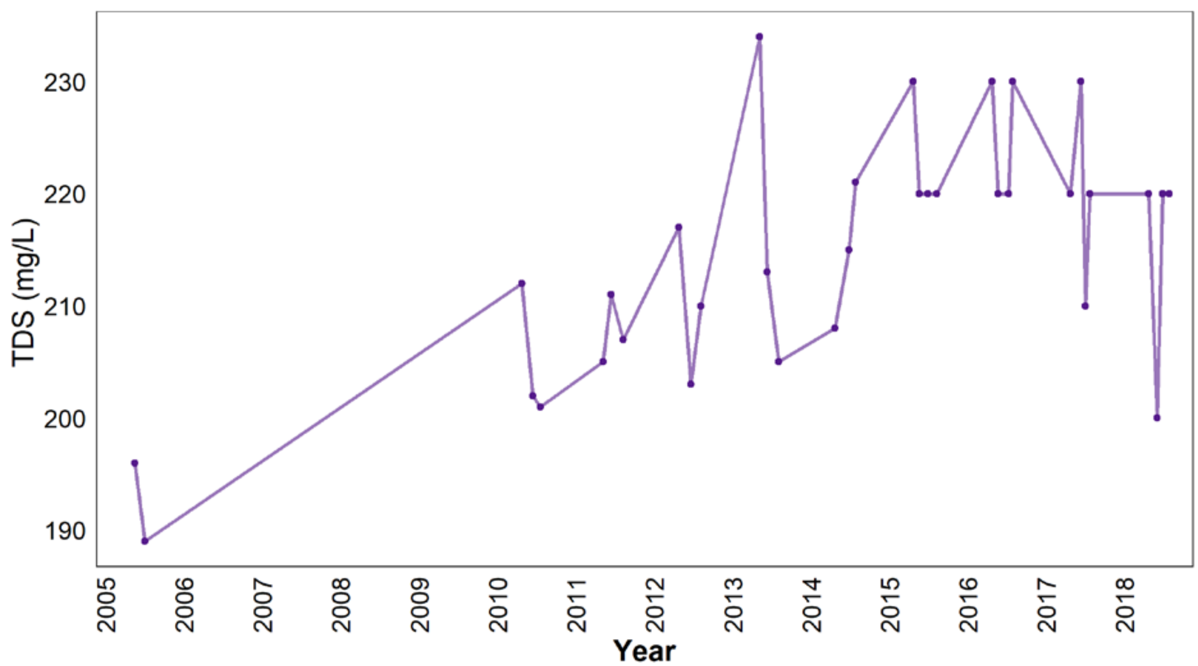


Figure 3a- Monthly TDS values measured between June and September over the long term sampling dates between 2005 and 2018 (n = 33). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Total Dissolved Solids (TDS)- South Basin

Trend analysis showed an increasing trend in TDS since 2005 in Skeleton Lake South (Tau = 0.59, $p < 0.001$) (Figure 3b). This could be attributed to decreasing water levels.

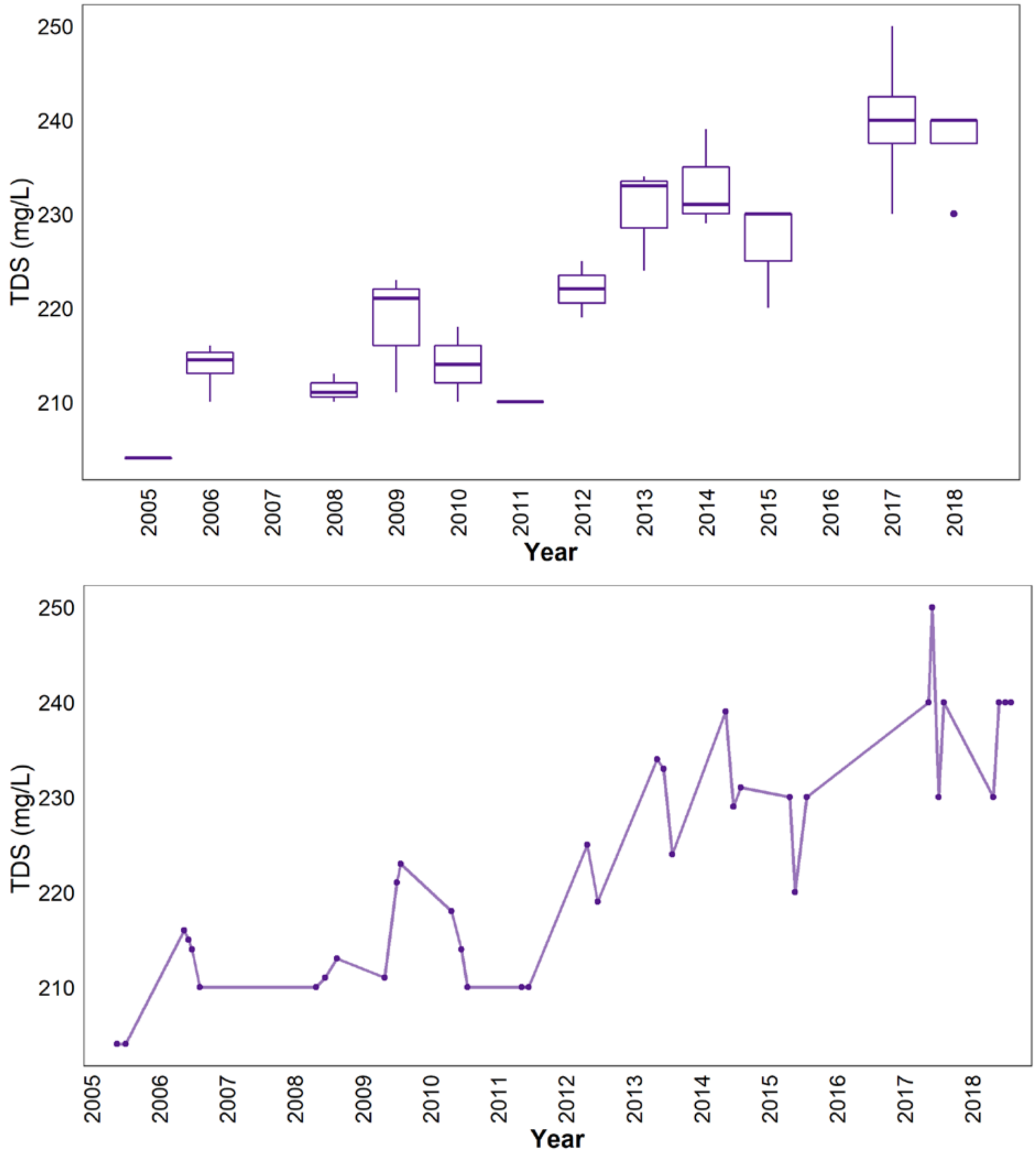


Figure 3b- Monthly TDS values measured between June and September over the long term sampling dates between 2005 and 2018 (n = 36). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

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 (Tau =-0.25, p = 0.04) (Figure 4a).

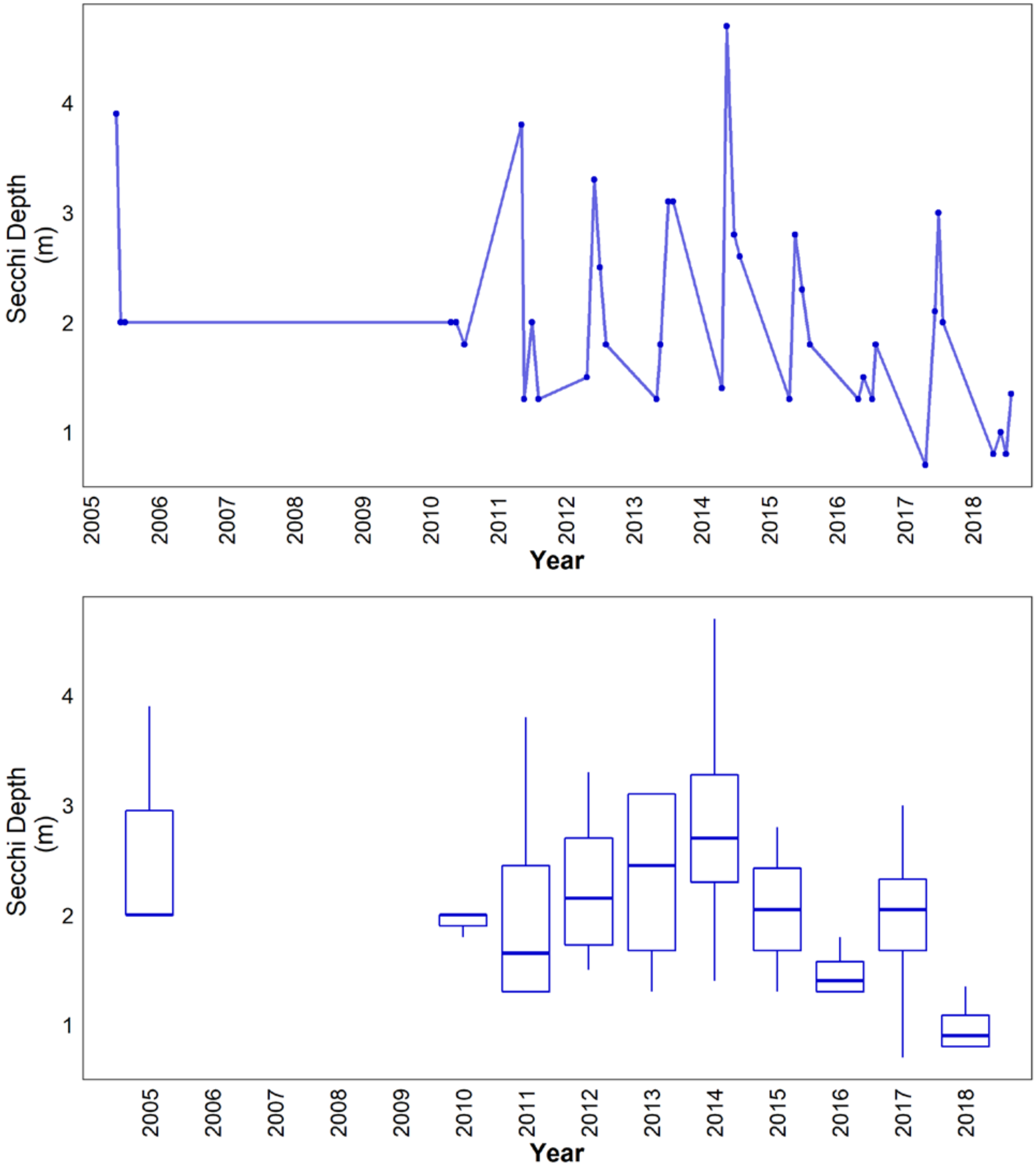
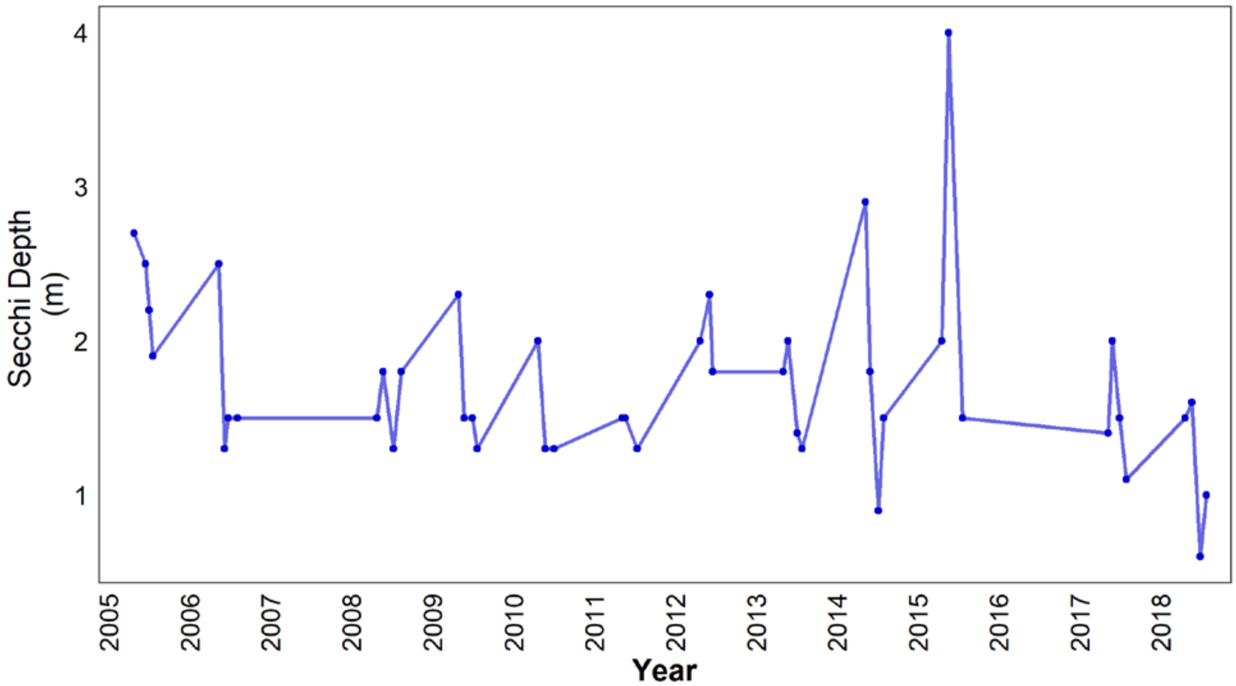


Figure 4a- Monthly Secchi depth values measured between June and September over the long term sampling dates between 2005 and 2018 (n = 38). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth- South Basin

Water clarity measured as Secchi depth in Skeleton Lake South has not significantly significant decreased or increased since 2005 (Tau =-0.22, p = 0.052) (Figure 4b).



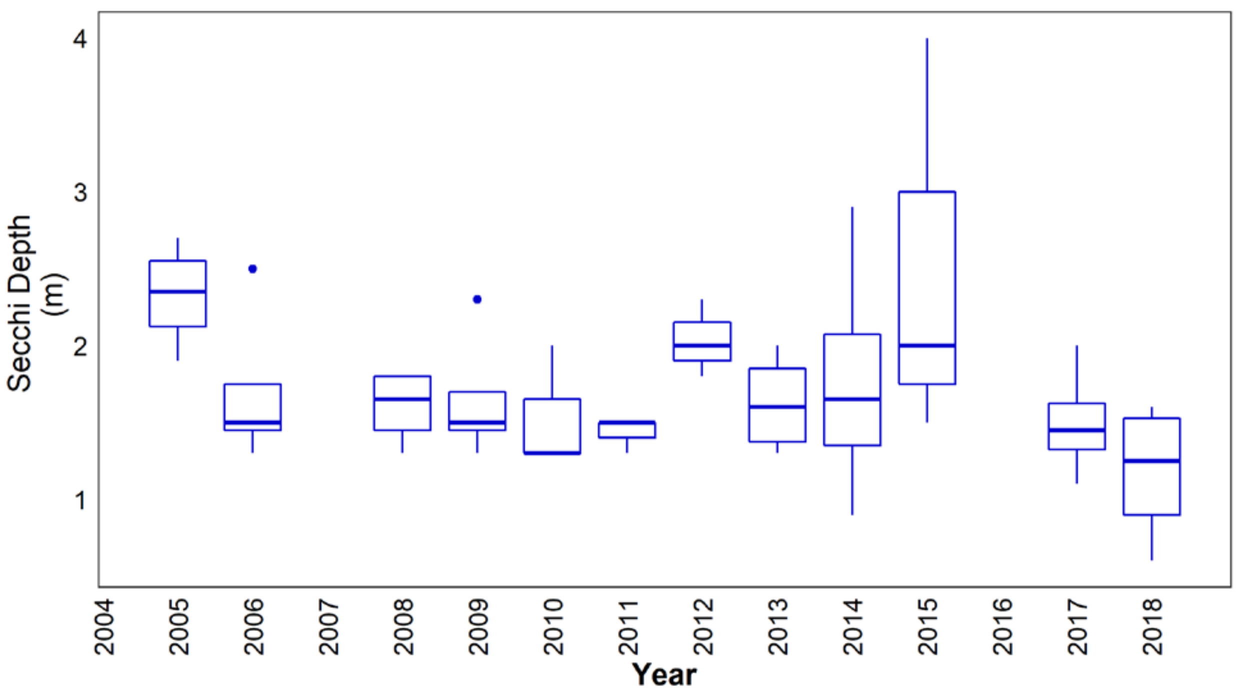


Figure 4b- Monthly Secchi depth values measured between June and September over the long term sampling dates between 2005 and 2018 (n = 44). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 2a)- 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 South 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	-0.26	0.11	0.47	-0.25
The extent of the trend	Slope	-1.56	0.25	2.35	-0.09
The statistic used to find significance of the trend	Z	-1.96	0.72	3.35	-2.07
Number of samples included	n	38	38	33	38
The significance of the trend	*p*	0.05	0.47	8.1×10^{-4}*	0.04*

*$p < 0.05$ is significant within 95%

Table 2b): South 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 South 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	-0.22	0.27	0.71	-0.27
The extent of the trend	Slope	-1.0	0.41	2.57	-0.05
The statistic used to find significance of the trend	Z	-1.95	2.03	5.21	-2.14
Number of samples included	n	42	44	36	44
The significance of the trend	*p*	0.052	0.04*	1.85×10^{-7}*	0.03*

**p* < 0.05 is significant within 95%