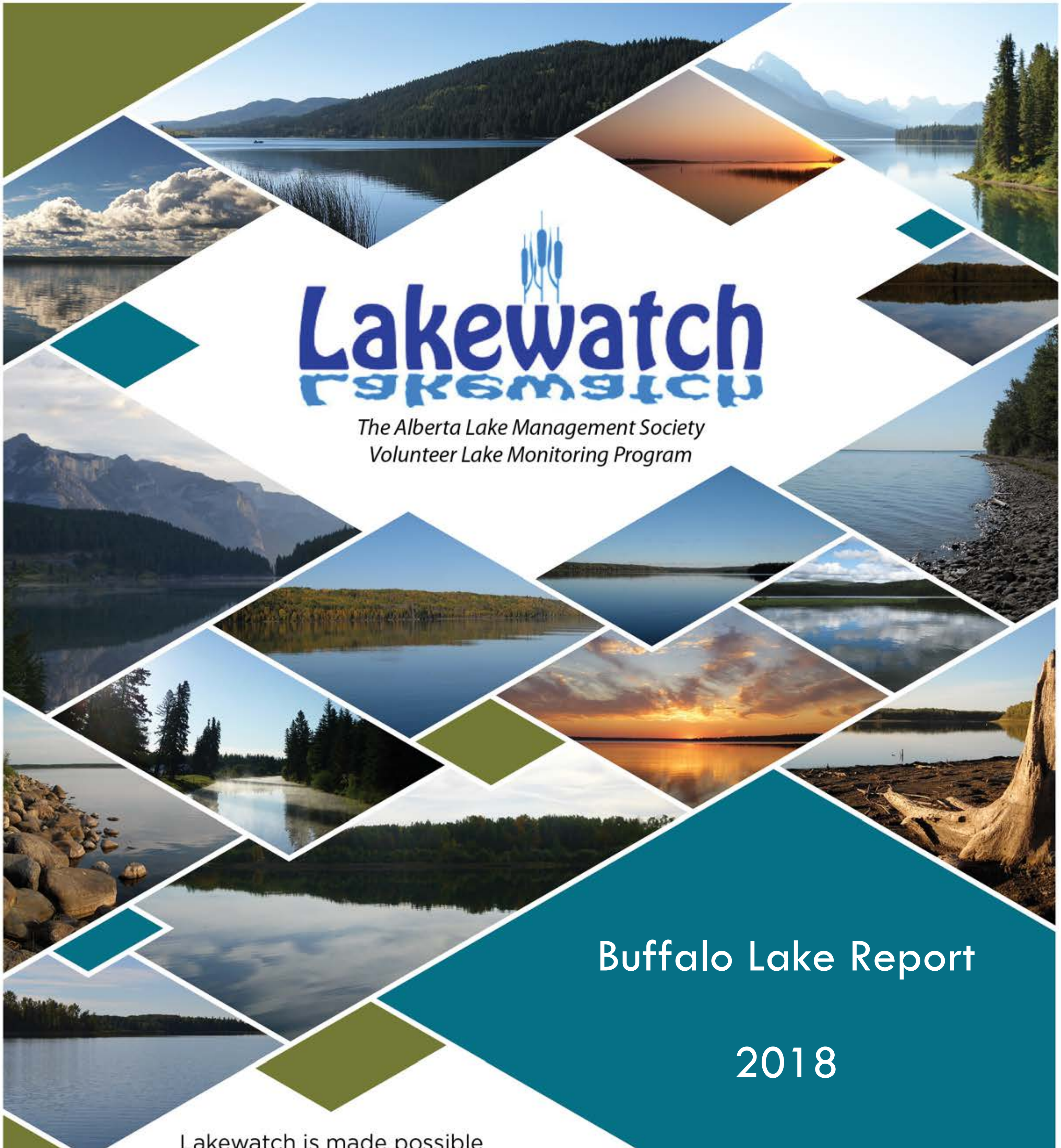


Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Buffalo Lake Report

2018

Lakewatch is made possible
with support from:

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.

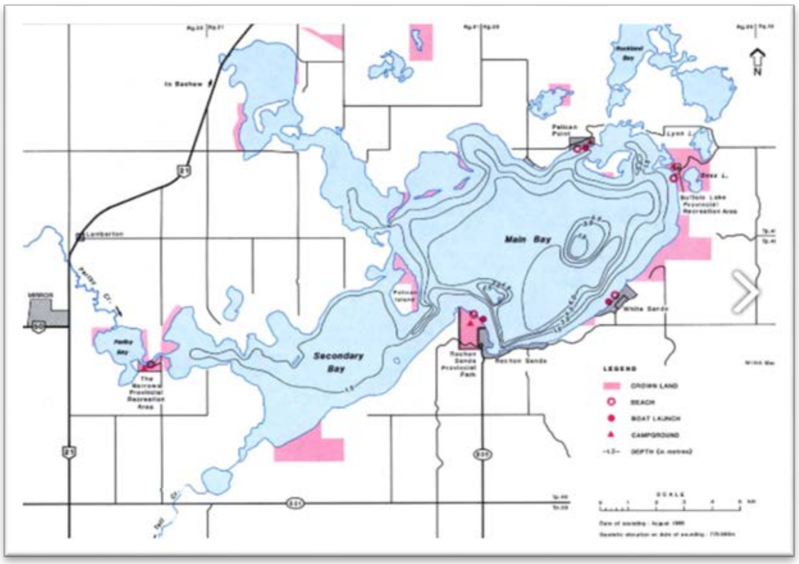
If you require data from this report, please contact ALMS for the raw data files.

ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thanks Marc DeCnodder for his commitment to collecting data at Buffalo 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.

BUFFALO LAKE

Buffalo Lake is located in central Alberta, 40 km northeast of Red Deer. It resides in the counties of Camrose, Stettler and Lacombe. Buffalo Lake is host to four public recreation areas, with camping, picnic areas, swimming and boat launches.



Bathymetric map of Buffalo Lake (Source: Prepas & Mitchell 1990)

The Lake has four natural basins- Main Bay is the largest and deepest, Secondary Bay is smaller and very shallow, The Narrows is the channel west of Secondary Bay and is a popular fishing area, and Parlby Bay is shallow and home to dense aquatic plants and waterfowl. The lake was labelled as Buffalo Lake in 1814 on a map by David Thompson, named for its resemblance to a Buffalo with the legs to the north and the head to the east [1]. Buffalo were likely attracted to the lake with the surrounding trembling aspen and fescue grassland habitat. The lake was a favourite camping area for Cree and Blackfoot, and in 1858, Father Lacombe, a young missionary, travelled for two days to help the group of Blackfoot people dying from scarlet fever on the east shore of Buffalo Lake [2]. The settlement on the southwest side of Buffalo Lake was established in 1883 and was one of the first in central Alberta [2].

Buffalo Lake supports fisheries for northern pike, burbot, white sucker and brook stickleback, which are all tolerant of high salinity and alkalinity.

The watershed area for Buffalo Lake is 1476 km^2 and the lake area is 96 km^2. The lake to watershed ratio of Buffalo Lake is 1:15. A map of the Buffalo Lake watershed area can be found at http://alms.ca/lake-watershed-maps/.

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[1] Alta. Cult. Multicult. n.d.

[2] Lamerton Hist. Soc. 1974.

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 Alberta Innotech, 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.

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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.

The average total phosphorus (TP) concentration for Buffalo Lake was 44 µg/L (Table 2), falling into the category of eutrophic, or highly productive trophic classification. This value falls within the range of historical averages. Detected TP was lowest when first sampled on June 19 at µg/L, and peaked at 54 µg/L on July 24 (Figure 1).

Average chlorophyll-*a* concentrations in 2018 was 11 µg/L (Table 2), falling into the eutrophic, or productive trophic classification. Like TP, Chlorophyll-*a* fluctuated slightly throughout the season, from a minimum of 6.2 µg/L in June to a maximum of 18 µg/L in late July.

Finally, the average TKN concentration was 2.6 mg/L (Table 2) with concentrations peaking at 2.7 mg/L on August 9.

Average pH was measured as 9.18 in 2018, buffered by high alkalinity (1100 mg/L $CaCO_3$) and bicarbonate (990 mg/L HCO_3). Sodium and sulphate were the dominant ions contributing to a high conductivity of 2675 µS/cm (Table 2). The high conductivity may help to suppress the growth of blue-green algae/cyanobacteria.

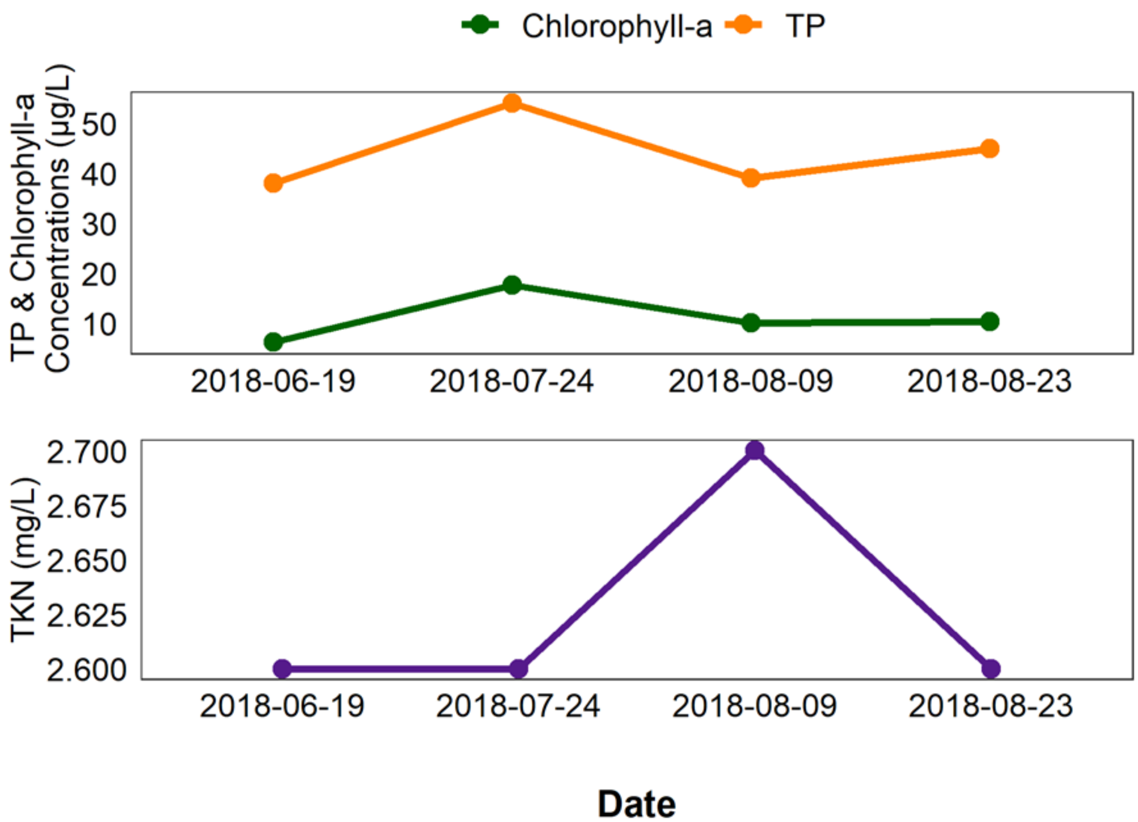

Figure 1- Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Buffalo Lake.

METALS

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

Metals were not measured at Buffalo Lake in 2018, but historical data is available in Table 3.

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.

The average Secchi depth of Buffalo Lake in 2018 was 1.35 m (Table 2). Secchi depth was shallow throughout the season, varying by only 0.6 m between its highest and lowest points.

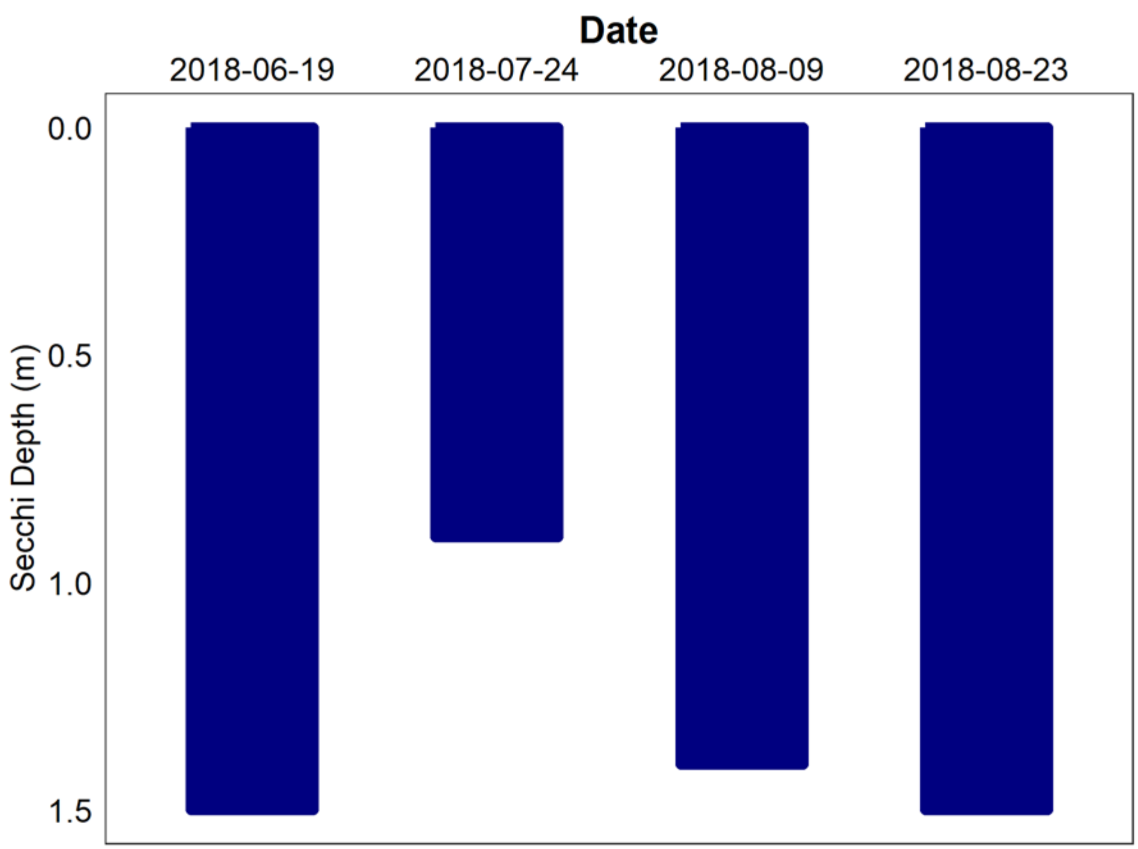

Figure 2 – Secchi depth values measured five times over the course of the summer at BUFFALO Lake in 2018.

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 the end of this report for descriptions of technical terms.

Temperatures of Buffalo Lake varied throughout the summer, with a minimum temperature of 9.5°C at the surface on September 20, and a maximum temperature of 22.15°C measured at the surface on August 9 (Figure 3a). The lake was not stratified during any of the sampling trips, with temperatures fairly constant from top to bottom, which indicates complete mixing throughout the season.

Buffalo Lake remained well oxygenated through most of the water column throughout the summer, measuring above the CCME guidelines of 6.5 mg/L for the Protection of Aquatic Life (Figure 3b). The oxygen level fell below this guideline on lake bottoms on August 9 and 23, likely due to decomposition of organic matter in the sediment.

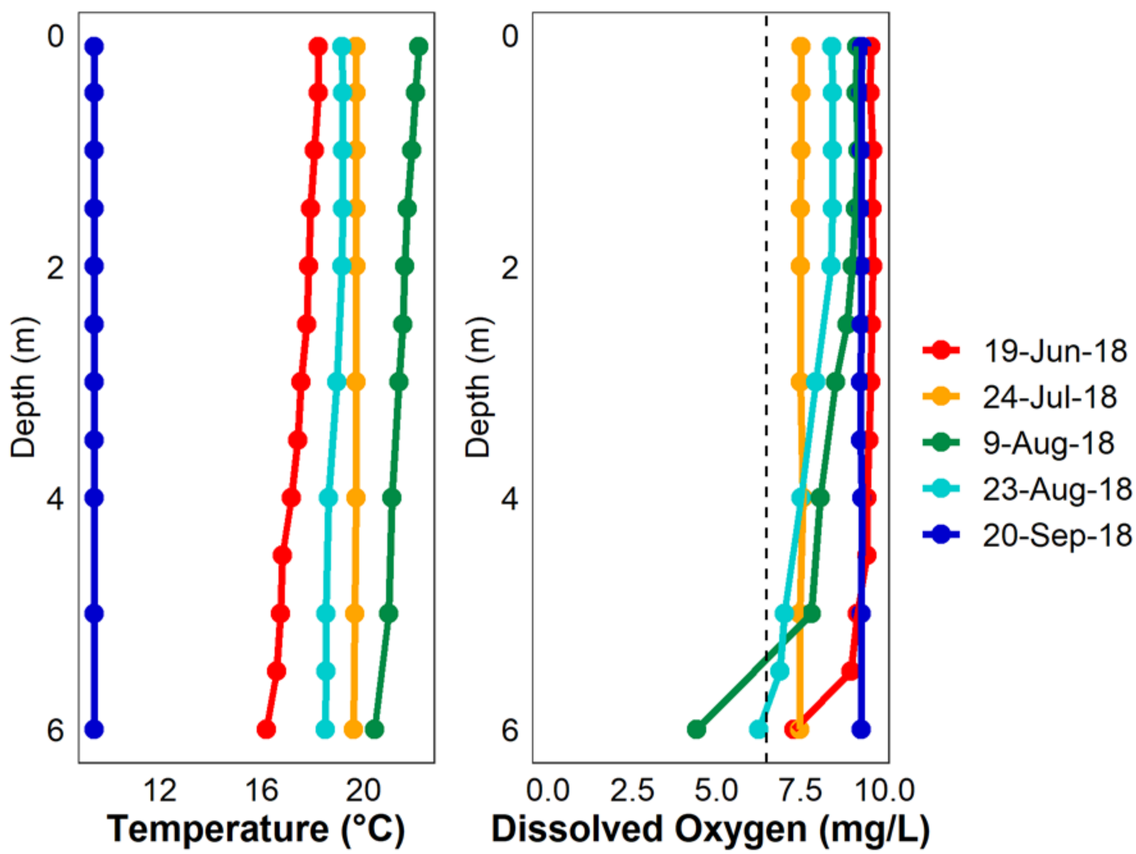

Figure 3 – a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Buffalo Lake measured five times over the course of the summer of 2018.

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 Buffalo Lake fell below the recreational guideline of 20 μg/L for at the locations and times sampled in Buffalo Lake in 2018.

Table 1 – Microcystin concentrations measured four times at Buffalo Lake in 2018.

Date	Microcystin Concentration (μg/L)
19-Jun-18	0.23
24-Jul-18	0.47
09-Aug-18	0.30
23-Aug-18	0.49
19-Jun-18	0.23
Average	**0.37**

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 mussels (veligers) using a plankton net and monitoring for attached adult mussels using substrates installed in each lake. No mussels have been detected in Buffalo 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 Buffalo Lake have remained relatively stable since Environment Canada began monitoring the lake in 1965 (Figure 4). Since 1965, Buffalo Lake water levels have fluctuated between a maximum of 781.4 m asl and a minimum of 779.7 m asl.

In 1985, Alberta Environment commenced the Parlby Creek-Buffalo Lake Water Management project in order to stabilize water levels, secure water supplies, enhance wildlife and fish habitat and provide flooding control. A full supply level (FSL) target of 780.85 m was established, but natural fluctuation of lake water levels were maintained[3].

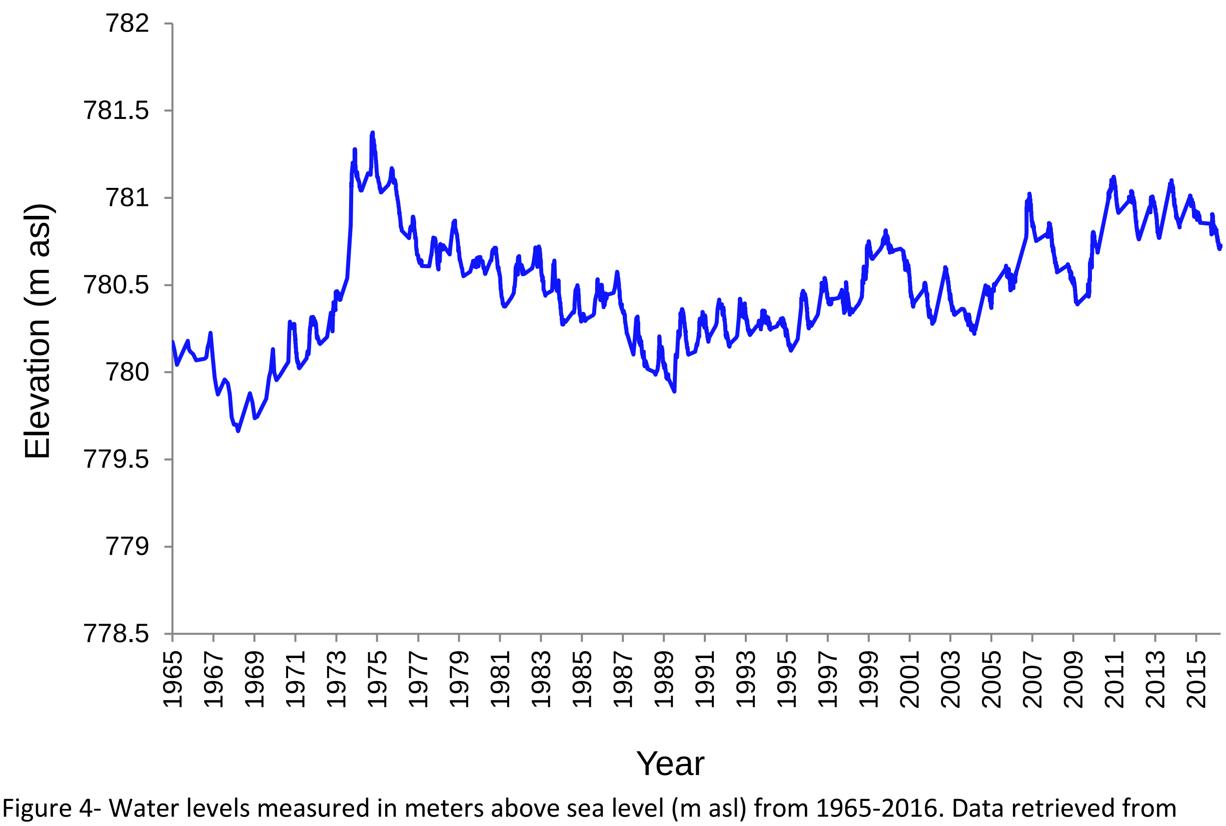

Figure 4- Water levels measured in meters above sea level (m asl) from 1965-2016. Data retrieved from Environment Canada.

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[3]Government of Alberta. 2010. Buffalo Lake Integrated Shoreland Management Plan.

Parameter	1984	1985	1986	1989	1990	1992	1993	1994	1995
TP (µg/L)	65	44	58	80	69	66	/	79	66
TDP (µg/L)	/	/	/	/	/	/	/	/	36
Chlorophyll-*a* (µg/L)	9.5	8.3	6.2	14.0	12.2	10.8	19.1	4.1	8.2
Secchi depth (m)	3.36	2.22	2.88	1.59	2.00	2.10	1.37	2.05	1.97
TKN (mg/L)	/	2.50	/	/	/	/		/	2.
NO_2 and NO_3 (µg/L)	0.03	0.03	0.03	0.01	0.01	0.01	/	0.01	0.01
NH_3 (µg/L)	/	/	/	/	/	/	/	/	0.03
DOC (mg/L)	/	/	/	/	/	/	/	/	42.45
Ca (mg/L)	7.7	6.7	7.4	5.5	6.0	11.5	/	5.0	4.6
Mg (mg/L)	73.3	81.0	77.0	84.6	87.0	77.0	/	85.0	85.4
Na (mg/L)	508.3	535.0	520.0	612.3	590.0	484.5	/	600.0	603.7
K (mg/L)	37.3	39.8	38.4	42.5	41.8	35.1	/	42.3	42.8
SO_4^{2-} (mg/L)	411.7	390.0	401.0	477.5	477.5	402.0	/	495.0	506.6
Cl^- (mg/L)	12.3	13.0	11.6	14.8	14.1	14.1	/	15.8	16.3
CO_3 (mg/L)	/	172	161	212	210	158	/	199	199
HCO_3 (mg/L)	976	997	952	1032	1004	1060	/	1235	1049
pH	9.20		9.26	9.32	9.34	9.27	/	9.48	9.30
Conductivity (µS/cm)	2450	2640	2536	2878	2795	2410	/	2850	2821
Hardness (mg/L)	320	349	334	362	374	346	/	362	363
TDS (mg/L)	1677	1720	1686	1957	1921	1625	/	1951	1974
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	1043.67	1091.00	1050.80	1199.88	1173.50	1001.00	/	1179.00	1192.00

Table 2A: Average Secchi depth and water chemistry values for Buffalo Lake.

Table 2B: Continued- Average Secchi depth and water chemistry values for Buffalo Lake.

Parameter	1996	1997	1998	1999	2000	2001	2002	2007	2014	2016	2018
TP (µg/L)	72	80	68	68	61	62	57	32	41	46	44
TDP (µg/L)	36	39	36	34	34	34	33	13	26	15	15.75
Chlorophyll-*a* (µg/L)	10.0	12.9	12.7	13.9	7.4	14.6	6.9	7.0	5.7	12.1	11.075
Secchi depth (m)	1.67	1.74	1.88	1.80	2.38	2.50	2.13	2.20	1.93	1.61	1.325
TKN (mg/L)	2.43	2.73	2.20	2.23	1.70	2.17	2.28	2.42	2.23	2.63	2.625
NO_2 and NO_3 (µg/L)	0.01	0.02	0.01	0.03	0.02	0.01	0.01	0.00	0.01	5.90	13.925
NH_3 (µg/L)	0.16	0.05	0.05	0.05	0.07	0.03	0.08	0.12	0.04	25	33
DOC (mg/L)	/	/	/	/	37.60	/	/	33.95	/	36	39.5
Ca (mg/L)	5.1	7.0	6.5	5.5	7.3	6.8	5.5	7.3	/	9.4	8.775
Mg (mg/L)	80.0	80.4	77.4	69.8	74.9	75.8	74.3	67.4	/	82.3	73.75
Na (mg/L)	577.0	572.3	529.4	504.4	574.0	554.5	613.3	519.0	525.8	557.5	537.5
K (mg/L)	44.7	44.3	41.8	39.0	43.4	43.5	42.2	38.5	/	46.3	43.75
SO_4^{2-} (mg/L)	485.0	463.3	468.8	395.4	442.7	454.0	466.8	412.5	405.3	407.5	417.5
Cl^- (mg/L)	17.0	17.8	16.8	17.2	17.0	17.3	18.9	20.1	21.7	26.0	28
CO_3 (mg/L)	194	190	192	197	174	187	209	177	176	185	172.5
HCO_3 (mg/L)	1035	1048	1001	976	954	924	1032	943	950	945	990
pH	9.16	9.23	9.16	9.05	8.99	9.09	9.24	9.17	9.19	9.22	9.1825
Conductivity (µS/cm)	2864	2818	/	2722	2543	2508	2735	2563	2600	2650	2675
Hardness (mg/L)	342	348	336	300	327	330	318	295	334	365	325
TDS (mg/L)	1921	1899	1826	1710	1805	1796	1940	1705	1723	1775	1775
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	0.37	0.3725
Total Alkalinity (mg/L $CaCO_3$)	1175	1177	1142	1128	1072	1070	1193	1070	1073	1100	1100

*Historical averages have been adjusted to current significant figures to improve legibility. Raw data can be retrieved from:
http://environment.alberta.ca/apps/EdwReportViewer/DetailedLakeWaterQuality.aspx
Number of sampling events varies between years.

Table 3: Concentrations of metals were last measured in Buffalo Lake in 2016. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Values over these levels are presented in red.

Metals (Total Recoverable)	**1993**	**2014**	**2016**	**Guidelines**
Aluminum µg/L	/	104.75	64.5	100[a]
Antimony µg/L	/	0.438	0.441	6[d]
Arsenic µg/L	7.8	7.21	7.8	5
Barium µg/L	/	39.5	39.1	1000[d]
Beryllium µg/L	/	0.0075	0.004	100[c,e]
Bismuth µg/L	/	0.0005	0.003	/
Boron µg/L	/	347	382	1500
Cadmium µg/L	/	0.006	0.003	0.23[b]
Chromium µg/L	/	0.53	0.16	/
Cobalt µg/L	/	0.134	0.157	1000[e]
Copper µg/L	/	1.05	1.77	4[b]
Iron µg/L	/	97.7	110	300
Lead µg/L	/	0.069	0.075	7[b]
Lithium µg/L	/	134	155	2500[f]
Manganese µg/L	/	2.06	2.83	200[f]
Molybdenum µg/L	/	2.09	2.01	73[c]
Nickel µg/L	/	0.621	0.75	150[b]
Selenium µg/L	/	0.25	1.18	1
Silver µg/L	/	0.003	0.003	0.25
Strontium µg/L	/	231	218	/
Thallium µg/L	/	0.0013	0.0015	0.8
Thorium µg/L	/	0.0201	0.018	/
Tin µg/L	/	0.045	0.019	/
Titanium µg/L	/	2.66	2.53	/
Uranium µg/L	/	/	2.77	15
Vanadium µg/L	/	1.69	1.71	100[e,f]
Zinc µg/L	/	1.6	2.5	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 Canadian Drinking Water Quality guideline values.
[e] Based on CCME Guidelines for Agricultural use (Livestock Watering).
[f] Based on CCME Guidelines for Agricultural Use (Irrigation).
A forward slash (/) indicates an absence of data or guidelines

LONG TERM DATA

Buffalo Lake presents a fairly unique dataset, and thus has been analyzed slightly differently than other lakes with long term data. Data is available for the parameters of interest dating back to 1984, and the lake was consistently monitored until 2002. However, a gap in the data from 2003 to 2013 when only one year of data was collected (in 2007) disrupts our ability to draw some conclusions from statistical analyses. Normally, we conduct trend analysis on the entire time series of data at a lake, which is a way of understanding the overall direction of change over time, and whether we're seeing a real pattern or something that is likely to happen by chance. At Buffalo Lake, we can still perform trend analysis to get a broad picture of how the lake has changed over time. However, only 3 years of data in the past ten years, it is hard to know if these years are bucking the trend, or give the impression of continuing the trend due to random year-to-year variation. While the seasonal Kendall tests can be used to evaluate the trend over the period when sampling was frequent, there are too few years sampled to answer the question "Have these values been increasing or decreasing over the past ten years?"

To accommodate for the unusual pattern of data collection, we have conducted two types of analysis on Buffalo Lake's water data; Trend analysis to understand the overall trend between 1984 and 2002, and a Wilcox test, to determine whether there is a detectable difference between the averages seen in the most recent 3 years and historical averages.

Trend analysis was conducted on the parameters total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth to look for changes from 1984 to 2002 in Buffalo Lake. In sum, non-significant increases were observed in chlorophyll-*a,* significant increasing trends were observed in Secchi depth and TDS, and significant decreasing trends were observed in TP. Secchi depth can be subjective and is sensitive to variation in weather - trend analysis must be interpreted with caution.

Wilcoxon rank-sum test were performed for each of these four parameters, in order to determine if there was a change between recent years as a group, and historical data as a group. Only total Phosphorus (TP) displayed a significant difference, with recent samples showing significantly less TP than historical records. Because we have so few recent points, a difference in average needs to be very large and consistent for us to conclude that it hasn't happened by chance. This means that differences might still exist in the other parameters, but we can't yet differentiate them from chance.

Table 1: Summary table of trend analysis on Buffalo Lake data from 1984 to 2018.

Parameter	Date Range	Trend	Probability	Recent years different from historical?
Chlorophyll-*a*	1984-2002	Increasing	Non-significant	Non-significant
Total Phosphorus	1984-2002	None	Non-significant	Significantly less TP
Total Dissolved Solids	1984-2002	Decreasing	Non-significant	Non-significant
Secchi Depth	1984-2002	Decreasing	Significant	Non-significant

Data is presented below as both a line graph (all data points) or a box-and-whisker plot. Detailed methods are available in the *ALMS Guide to Trend Analysis on Alberta Lakes.*

Definitions:

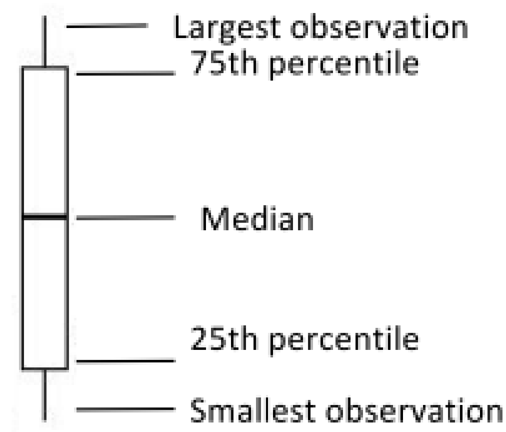
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

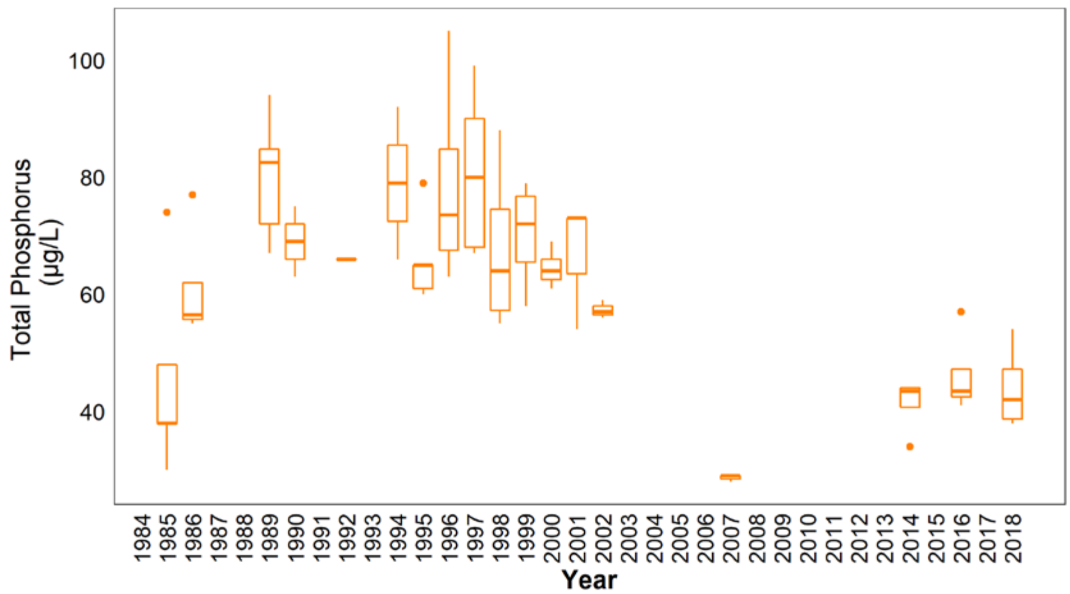
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

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)

Total phosphorus (TP) did not change significantly between 1984 and 2002 at Buffalo Lake (Tau = 0.02, p = 0.92). However, total phosphorous sampled from 2014 to 2018 was significantly lower than that sampled in the 1984 to 2002 time period (W = 45, p =0.002).



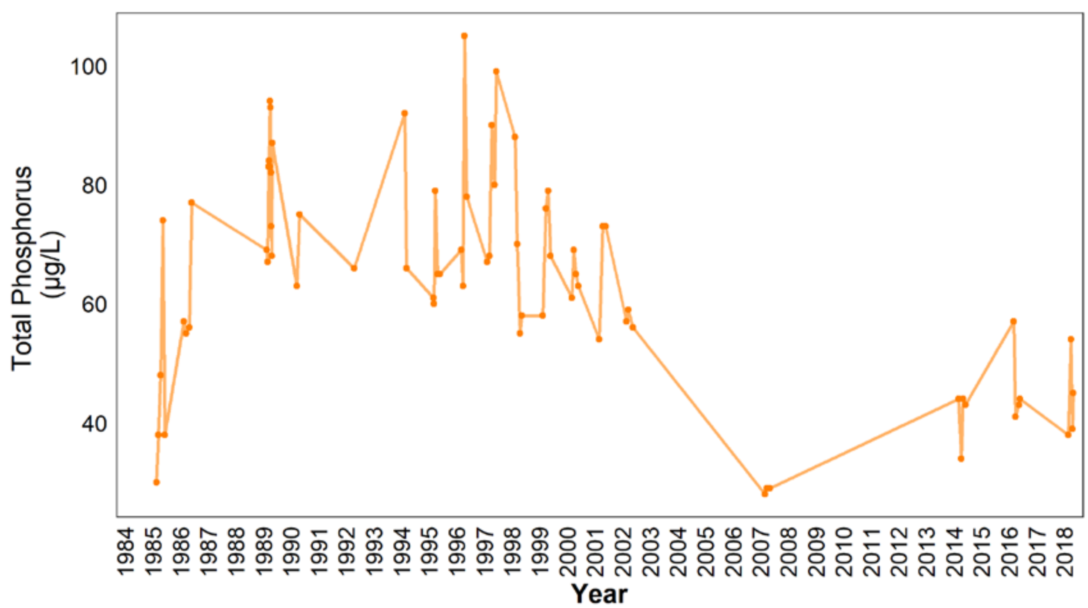
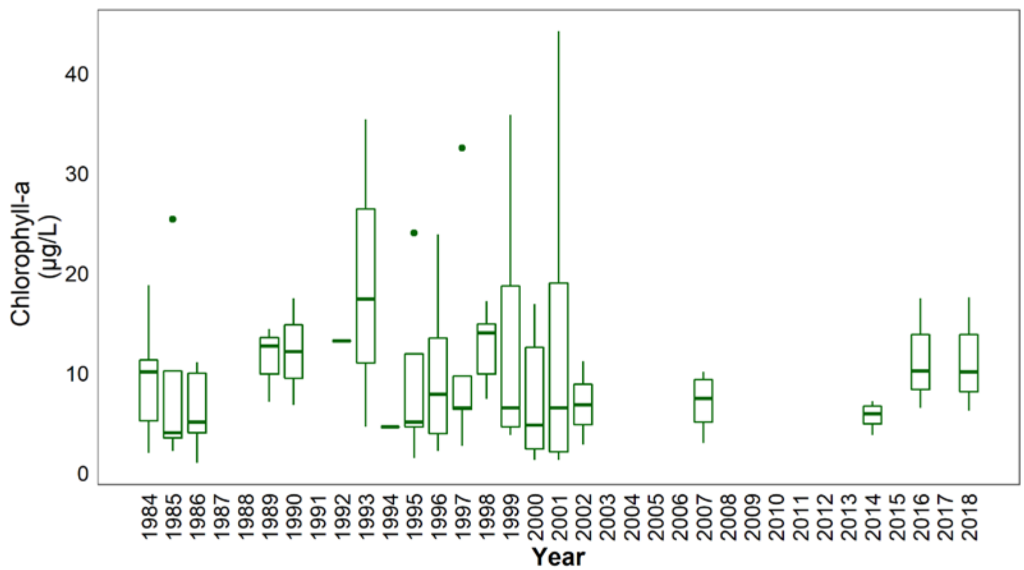


Figure 1- Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 1984 and 2018 (n = 57). The value closest to the 15^{th} day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Chlorophyll-*a* did not change significantly between 1984 and 2002 (Tau = 0.01, *p* = 0.88, Table 2). More recent years sampled were not significantly different from the historical dataset (W=30.5, p= 0.50). When the entire time period is examined, TP and Chlorophyll *a* did not significantly correlate, although they came very close to doing so (r=0.39, p=0.07).



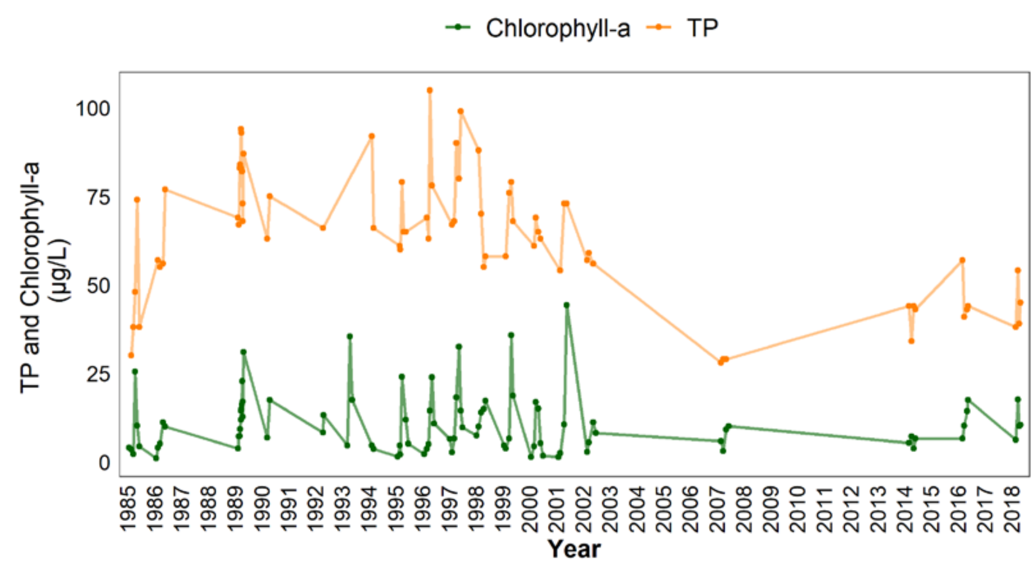
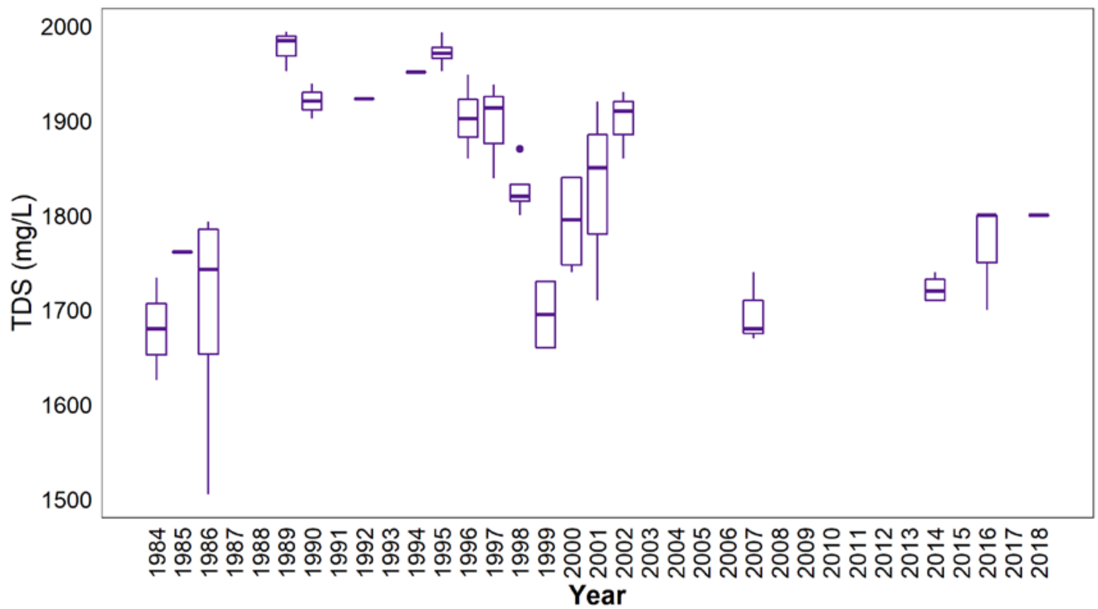


Figure 2-Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 1984 and 2018 (N=74). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Total dissolved solids did not change significantly between 1984 and 2002 (Tau = -0.08, p = 0.46, Table 2). More recent years sampled were not significantly different from the historical dataset (W=33, p= 0.25).



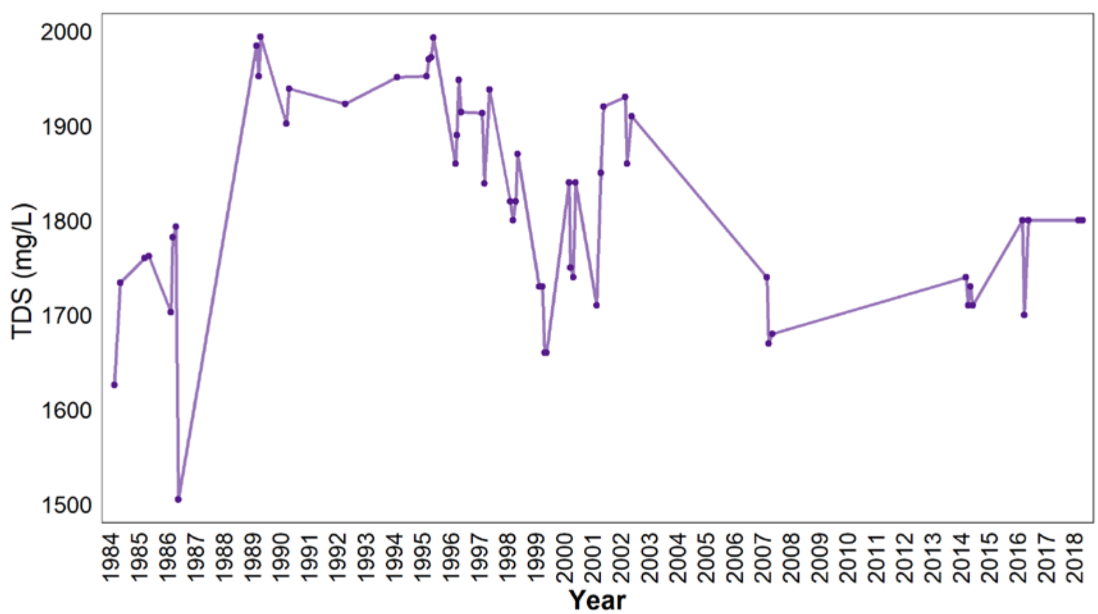


Figure 3-Monthly TDS values measured between June and September over the long term sampling dates between 1984 and 2018 (n = 55). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Secchi depth significantly decreased 1984 and 2002 (Tau = -0.25, p = 0.02, Table 2). However, more recent years sampled were not significantly different from the historical dataset (W=37, p= 0.16), meaning that this trend may have stabilized in the intervening years. The consecutive decreases in Secchi depth from 2014 to 2018 could indicate the recurrence of a decreasing trend in Secchi depth, but constitutes too few data points do draw statistical conclusions.

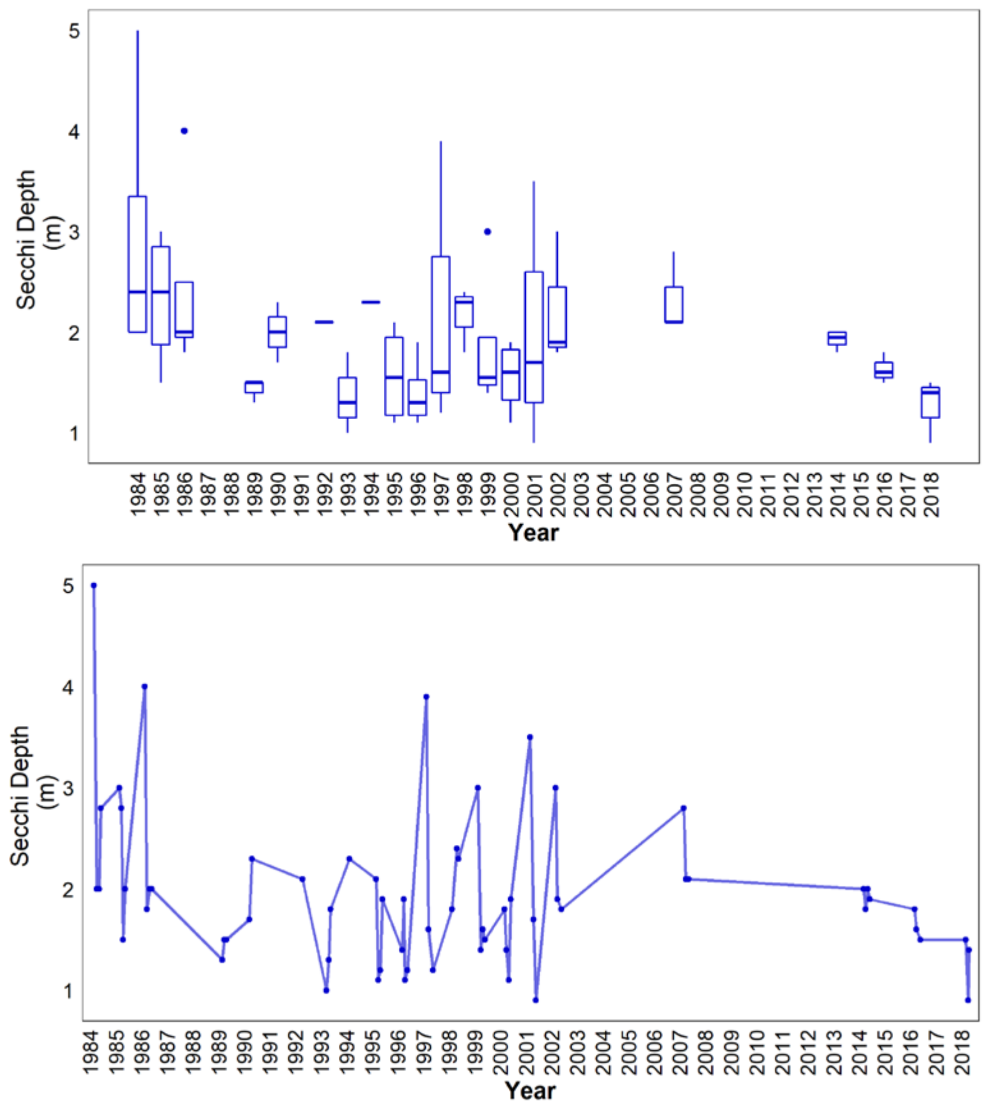


Figure 4-Monthly Secchi depth values measured between June and September over the long term sampling dates between 1984 and 2018 (n = 59). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 2- Results of Seasonal Kendall Trend test using monthly total phosphorus (TP), chlorophyll-*a* and Secchi depth data from June to September on Buffalo Lake data.

Definition	**Unit**	**Total Phosphorus (TP)**	**Chlorophyll-a**	**Total Dissolved Solids (TDS)**	**Secchi Depth**
Statistical Method	-	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall
The strength and direction (+ or -) of the trend between -1 and 1	Tau	-0.02	0.01	-0.08	-0.25
The extent (slope) of the trend	Slope	0.00	0.02	-3.79	-0.03
The statistic used to find significance of the trend	Z	-0.10	0.15	-0.74	-2.30
Number of samples included	n	57	74	55	59
The significance of the trend	*p*	0.92	0.88	0.46	0.02*
Wilcoxon rank sum test for historical vs. recent	W	45	30.5	33	37
Significance of Wilcox test	*p*	0.002*	0.50	0.25	0.16

*$p < 0.05$ is significant within 95%