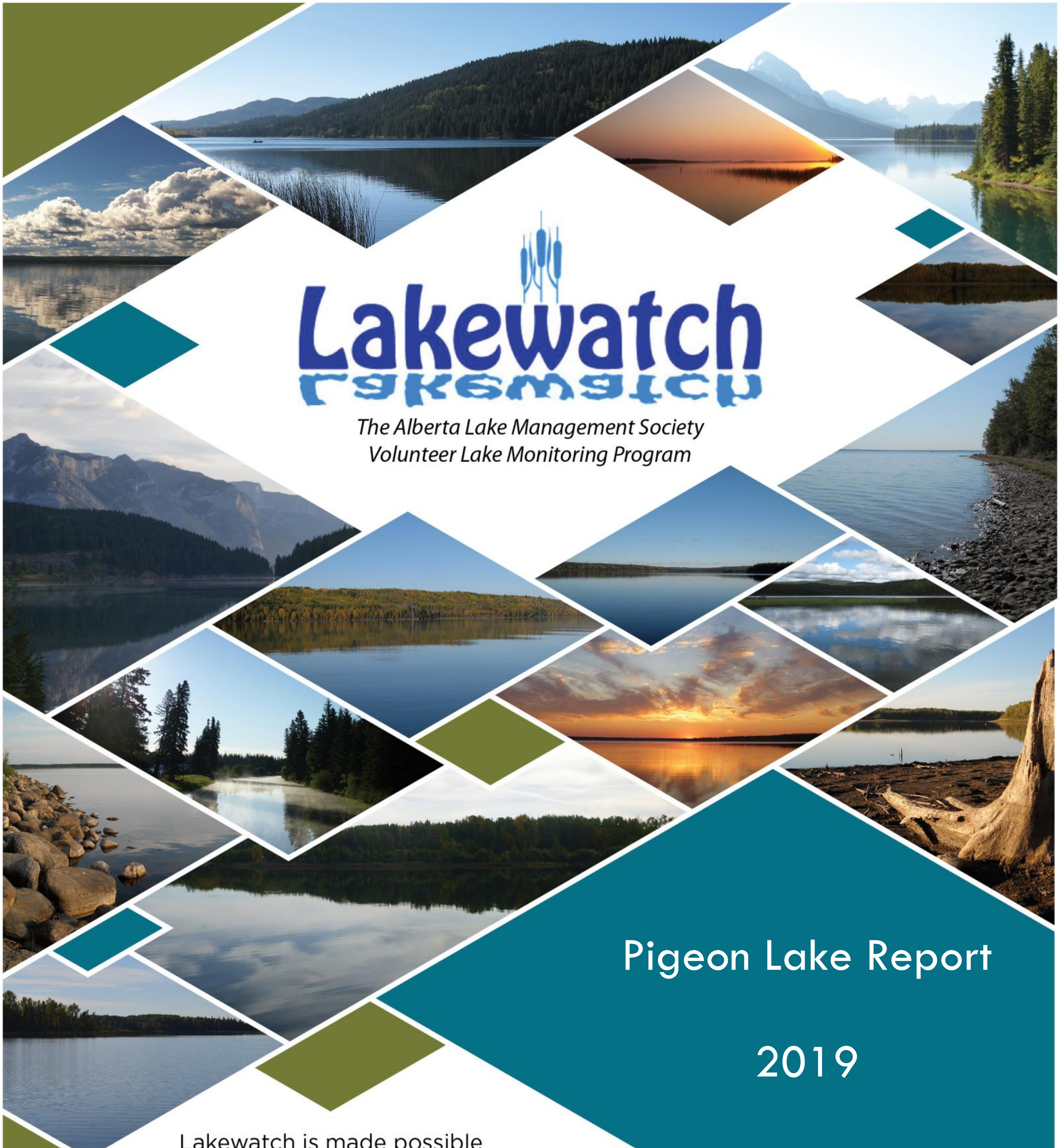

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Pigeon Lake Report

2019

Lakewatch is made possible with support from:

Alberta Environment and Parks

Pigeon Lake Watershed Association

Lacombe County

LICA Environmental Stewards

ALBERTA LAKE MANAGEMENT SOCIETY'S LAKEWATCH PROGRAM

LakeWatch has several important objectives, one of which is to collect and interpret water quality data from Alberta's Lakes. Equally important is educating lake users about aquatic environments, encouraging public involvement in lake management, and facilitating cooperation and partnerships between government, industry, the scientific community and lake users. LakeWatch reports are designed to summarize basic lake data in understandable terms for the widest audience, and are not meant to be a complete synopsis of information about specific lakes. Additional information is available for many lakes that have been included in LakeWatch, and readers requiring more information are encouraged to seek those sources.

ALMS would like to thank all who express interest in Alberta's aquatic environments, and particularly those who have participated in the LakeWatch program. These leaders in stewardship give us hope that our water resources will not be the limiting factor in the health of our environment.

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

ACKNOWLEDGEMENTS

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

PIGEON LAKE

Pigeon Lake at Poplar Bay 2017 (Photo by Laura Redmond)

Pigeon Lake is a large (96.32 km^2), shallow (average depth = 6m) lake located in the counties of Wetaskiwin and Leduc. It is a popular recreational lake within easy driving distance from the cities of Edmonton, Leduc, and Wetaskiwin. Pigeon Lake lies within the Battle River watershed. Water flows into the lake through intermittent streams draining the west and northwest portions of the watershed. The outlet, Pigeon Lake Creek, at the southeast margin of the lake, drains toward the Battle River.[1] The lake's drainage basin is small (176.62 km^2) but heavily developed with agriculture, oil and gas, and community developments.[2]

The lake name is a translation from the Cree Mehmew Sâkâhikan, which means 'Dove Lake', but by 1858 the name Pigeon Lake was in use.[3] It has been suggested that the name Pigeon Lake refers to the huge flocks of Passenger Pigeons that once ranged in the area.[1] The lake was also previously known as Woodpecker Lake, and the Stoney name is recorded as Ke-gemni-wap-ta.[3] The water quality of Pigeon Lake is typical of large, productive, shallow lakes in Alberta, with water remaining quite green for most of the summer. However, residents have recently expressed concern over perceptions of deteriorating water quality as a result of recurring blue-green algal blooms, fish kills, and beach advisories[4]. Due to these concerns, there has been a demand to examine ways to reduce the frequency and intensity of cyanobacteria blooms. In 2013, data was collected to prepare a nutrient budget for Pigeon Lake - this report was later released in 2014 and it outlines areas of interest when considering watershed and in-lake management options[5]. In 2018 the Pigeon Lake Watershed Association released their Pigeon Lake Watershed Management Plan which can be accessed via www.plwmp.ca.

The watershed area for Pigeon Lake is 176.62 km^2 and the lake area is 97.32 km^2. The lake to watershed ratio of Pigeon Lake is 1:2. A map of the Pigeon Lake watershed area can be found http://alms.ca/wp-content/uploads/2016/12/Pigeon.pdf.

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[1]Mitchell, P. and Prepas, E. (1990). Atlas of Alberta Lakes, University of Alberta Press. Retrieved from http://sunsite.ualberta.ca/projects/alberta-lakes/

[2] Teichreb, C., Peter, B. and Dyer, A. (2013). 2013 Overview of Pigeon lake Water Quality, Sediment Quality, and Non-Fish Biota. 2 pp.

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

[4] Aquality Environmental Consulting. (2008). Pigeon Lake State of Watershed Report. Prepared for Pigeon Lake Watershed Alliance. Retrieved from: www.plwa.ca.

[5] Teichreb, C. (2014). Pigeon Lake Phosphorus Budget. Alberta Environment and Sustainable Resource Development. 28 pp.

METHODS

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

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

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

Data Storage and Analysis: Data is stored in the Water Data System (WDS), a module of the Environmental Management System (EMS) run by Alberta Environment and Parks (AEP). Data goes through a complete validation process by ALMS and AEP. Users should use caution when comparing historical data, as sampling and laboratory techniques have changed over time (e.g. detection limits). For more information on data storage, see AEP Surface Water Quality Data Reports at www.alberta.ca/surface-water-quality-data.aspx.

Data analysis is done using the program R.[1] Data is reconfigured using packages tidyr [2] and dplyr [3] and figures are produced using the package ggplot2 [4]. Trophic status for each lake is classified based on lake water characteristics using values from Nurnberg (1996)[5]. The Canadian Council for Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life are used to compare heavy metals and dissolved oxygen measurements. Pearson's Correlation tests are used to examine relationships between total phosphorus (TP), chlorophyll-*a,* total kjeldahl nitrogen (TKN) and Secchi depth, providing a correlation coefficient (r) to show the strength (0-1) and a p-value to assess significance of the relationship.

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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 Pigeon Lake was 22 µg/L (Table 2), falling into the mesotrophic, or moderately productive trophic classification. This value falls within the range of historical averages. Detected TP was lowest when first sampled in June at 14 µg/L, and peaked at 34 µg/L in September (Figure 1).

Average chlorophyll-*a* concentrations in 2019 was 15 µg/L (Table 2), falling into the category of eutrophic, or highly productive trophic classification. Chlorophyll-*a* was highest in September at 28.7 µg/L and reached its lowest point of 4.6 µg/L on July 15.

Finally, the average TKN concentration was 0.8 mg/L (Table 2) with concentrations peaking on September 12 at 1.0 mg/L.

Average pH was measured as 8.51 in 2019, buffered by moderate alkalinity (168 mg/L $CaCO_3$) and bicarbonate (195 mg/L HCO_3). Calcium was the dominant ion contributing to a low conductivity of 333 µS/cm (Table 2).

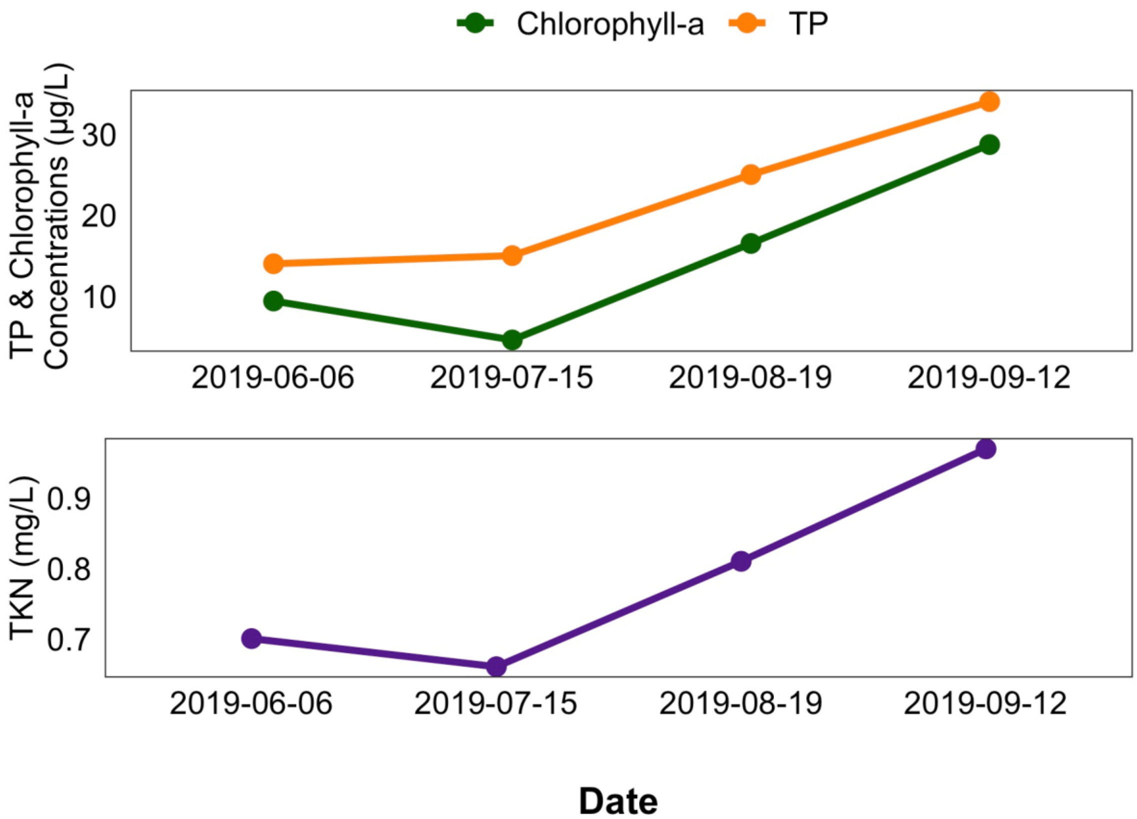


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Pigeon Lake.

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 in Pigeon Lake in 2019. Table 3 presents historical metal concentrations from previously measured years.

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 Pigeon Lake in 2019 was 2.94 m (Table 2). This depth was shallowest on August 19, indicating relatively lower water clarity. Secchi depth was deepest on July 15, indicating higher water clarity (Figure 2).

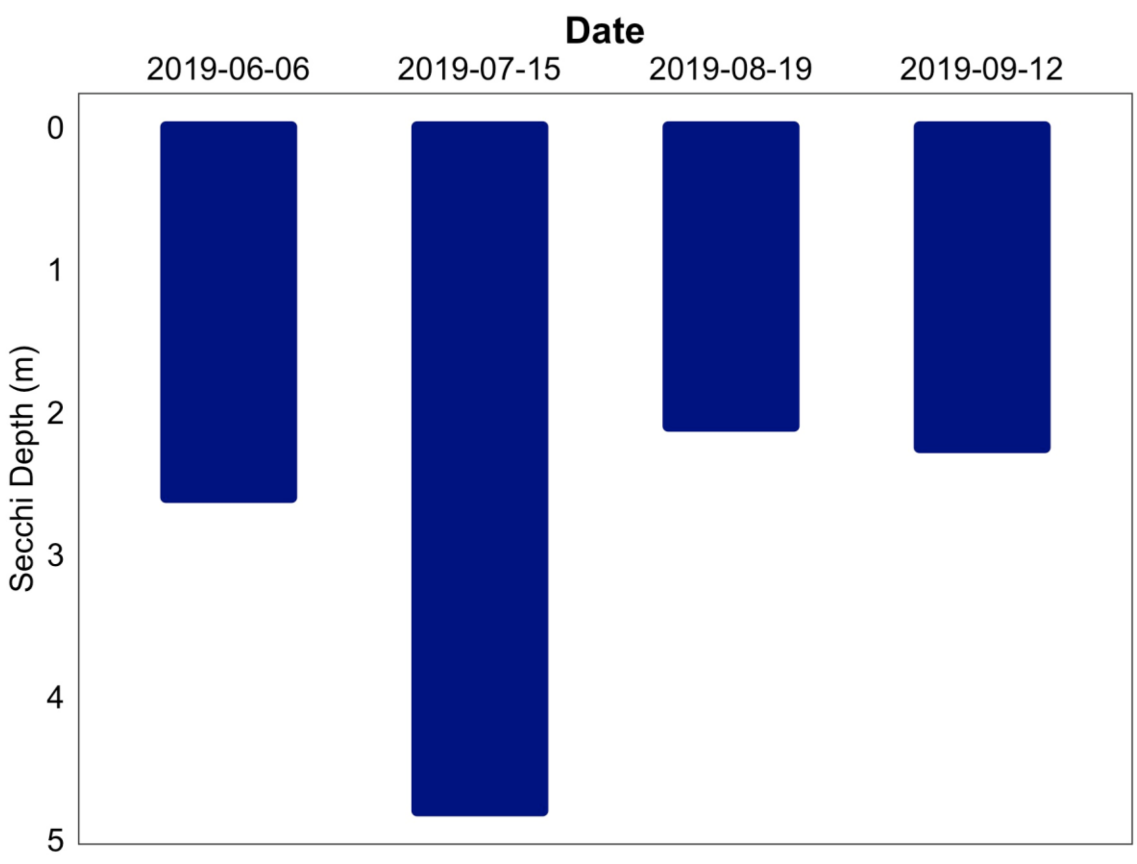


Figure 2. Secchi depth values measured four times over the course of the summer at Pigeon Lake in 2019.

WATER TEMPERATURE AND DISSOLVED OXYGEN

Water temperature and dissolved oxygen (DO) profiles in the water column can provide information on water quality and fish habitat. The depth of the thermocline is important in determining the depth to which dissolved oxygen from the surface can be mixed. Please refer to ALMS' Brief Introduction to Limnology for descriptions of technical terms.

Temperatures of Pigeon Lake varied throughout the summer, with a minimum temperature of 13.9 °C through the entire water column on June 6, and a maximum temperature of 18.6 °C measured at the surface on July 15 (Figure 3a). The lake was not stratified during any of the samplings, with temperatures remaining relatively constant from top to bottom. This indicates partial or complete mixing throughout the season.

Pigeon Lake remained well oxygenated through most of the water column throughout the summer, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 3b). The oxygen level fell below this level close to lake bottom on August 19.

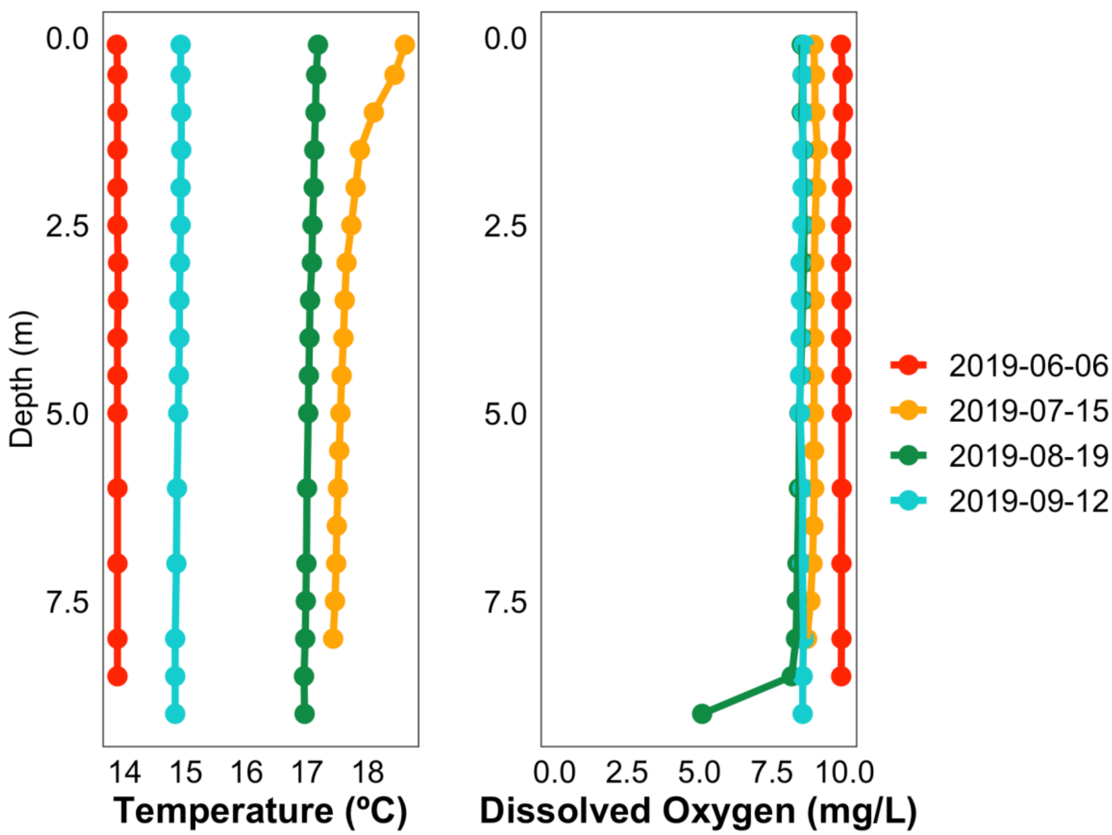


Figure 3. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Pigeon Lake measured four times over the course of the summer of 2019.

MICROCYSTIN

Microcystins are toxins produced by cyanobacteria (blue-green algae) which, when ingested, can cause severe liver damage. Microcystins are produced by many species of cyanobacteria which are common to Alberta's Lakes, and are thought to be the one of the most common cyanobacteria toxins. In Alberta, recreational guidelines for microcystin are set at 20 μg/L. Blue-green algae advisories are managed by Alberta Health Services. Recreating in algal blooms, even if microcystin concentrations are not above guidelines, is not recommended.

Composited microcystin levels in Pigeon Lake fell below the recreational guideline of 20 μg/L on each sampling date (Table 1). Caution should still be observed when recreating in visible cyanobacteria blooms.

Table 1. Microcystin concentrations measured five times at Pigeon Lake in 2019.

Date	Microcystin Concentration (μg/L)
06-Jun-19	0.05
15-Jul-19	0.11
19-Aug-19	0.05
12-Sep-19	0.05
Average	0.07

INVASIVE SPECIES MONITORING

Dreissenid mussels pose a significant concern for Alberta because they impair the function of water conveyance infrastructure and adversely impact the aquatic environment. These invasive mussels have been linked to creating toxic cyanobacteria blooms, decreasing the amount of nutrients needed for fish and other native species, and causing millions of dollars in annual costs for repair and maintenance of water-operated infrastructure and facilities.

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

Eurasian watermilfoil is non-native aquatic plant that poses a threat to aquatic habitats in Alberta because it grows in dense mats preventing light penetration through the water column, reduces oxygen levels when the dense mats decompose, and outcompetes native aquatic plants.

Suspect samples collected from Pigeon Lake on August 10 were confirmed to be the native Northern watermilfoil (*Myriophyllum sibiricum)*.

WATER LEVELS

There are many factors influencing water quantity. Some of these factors include the size of the lake's drainage basin, precipitation, evaporation, water consumption, ground water influences, and the efficiency of the outlet channel structure at removing water from the lake. Requests for water quantity monitoring should go through Alberta Environment and Parks Monitoring and Science division.

Water levels in Pigeon Lake have remained relatively stable since Environment Canada began monitoring the lake in 1972 (Figure 4). Since 1972, Pigeon Lake water levels fluctuated between a maximum of 850.6 m asl and a minimum of 849.4 m asl. Data from Environment Canada was only available until 2015. A weir at the mouth of the outlet was installed in 1983 by ESRD to maintain water levels at 849.935 meters above sea level (m asl). In 2008, monitoring revealed that the weir had risen 0.15 m due to frost heaving. In 2013, the height was adjusted by ESRD to bring the structure back to the intended level of 849.935 m asl.[1]

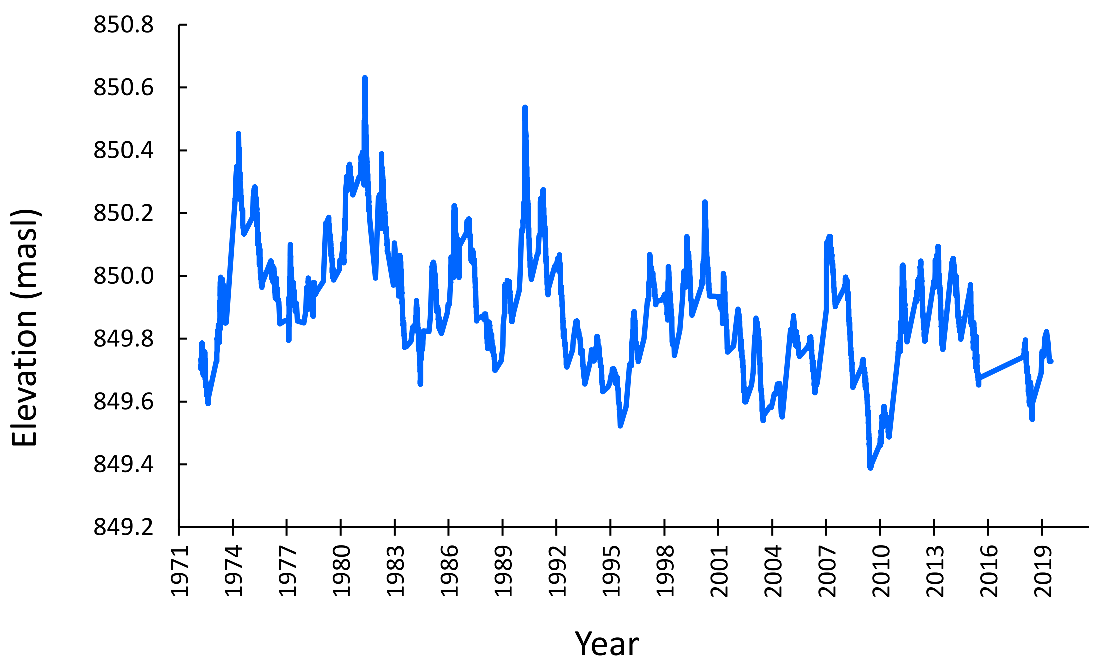


Figure 4. Water levels measured in meters above sea level (masl) from 1972-2019. Data retrieved from Environment Canada (1972 – 2018), and Alberta Environment and Parks (2019).

[1] Teichreb, C., Peter, B. and Dyer, A. (2013). 2013 Overview of Pigeon lake Water Quality, Sediment Quality, and Non-Fish Biota. 2 pp.

Table 2a. Average Secchi depth and water chemistry values for Pigeon Lake. Historical values are given for reference.

Parameter	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
TP (µg/L)	27	35	23	29	29	43	29	26	34	38	36	29	32
TDP (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Chlorophyll-*a* (µg/L)	9.9	14.1	13.8	16.1	9.9	25.7	9.2	11.9	17.4	18.6	16.1	16.6	17.5
Secchi depth (m)	3.19	1.94	2.19	3.08	2.25	1.63	2.35	2.32	2.14	1.72	1.98	2.13	2.20
TKN (mg/L)	0.9	/	/	/	/	/	/	/	/	/	/	/	0.9
NO_2-N and NO_3-N (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
NH_3-N (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
DOC (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Ca (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Mg (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Na (mg/L)	15	15	16	15	15	17	16	14	14	17	17	17	18
K (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
SO_4^{2-} (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Cl^- (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
CO_3 (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
HCO_3 (mg/L)	181	178	184	169	176	171	187	175	177	174	175	177	168
pH	8.37	8.43	8.35	8.57	8.50	8.36	8.32	8.50	8.46	8.45	8.56	8.60	8.61
Conductivity (µS/cm)	283	288	292	280	293	279	302	294	293	286	287	290	282
Hardness (mg/L)	112	103	113	110	111	109	120	122	121	111	113	114	111
TDS (mg/L)	157	154	158	151	157	151	163	158	156	152	154	155	156
Total Alkalinity (mg/L $CaCO_3$)	152	153	153	147	154	145	156	153	150	146	148	150	149
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/

Table 2b. Average Secchi depth and water chemistry values for Pigeon Lake. Historical values are given for reference.

Parameter	**1996**	**1997**	**1983**	**2003**	**2005**	**2006**	**2008**	**2010**	**2011**	**2013**	**2014**
TP (µg/L)	38	30	35	63	27	60	26	41	75	27	46
TDP (µg/L)	/	/	/	/	6	38	9	13	19	8	16
Chlorophyll-*a* (µg/L)	18.5	12.8	15.0	36.9	9.2	21.9	8.0	21.9	66.2	12.3	19.2
Secchi depth (m)	1.80	2.50	1.50	1.38	1.90	2.70	4.42	2.75	1.25	3.23	2.31
TKN (mg/L)	/	/	0.6	1.1	0.7	1.1	0.7	1.0	1.5	0.8	0.7
NO_2-N and NO_3-N (µg/L)	/	/	1	/	3	29	13	8	16	6	26
NH_3-N (µg/L)	/	/	3	/	3	124	16	72	109	28	25
DOC (mg/L)	/	/	/	/	/	7	/	7	/	/	8
Ca (mg/L)	/	/	/	/	29	21	27	24	20	28	23
Mg (mg/L)	/	/	/	/	13	14	13	14	13	13	11
Na (mg/L)	15	19	/	19	20	21	20	22	20	21	24
K (mg/L)	/	/	/	/	6	7	6	6	6	7	7
SO_4^{2-} (mg/L)	/	/	/	/	7	10	5	9	3	6	5
Cl^- (mg/L)	/	/	/	/	4	3	3	3	3	3	4
CO_3 (mg/L)	/	/	/	/	8	5	3	1	9	3	6
HCO_3 (mg/L)	163	190	/	169	183	180	198	195	161	195	192
pH	8.66	8.17	/	8.56	8.60	8.50	8.37	8.57	8.74	8.34	8.59
Conductivity (µS/cm)	293	304	/	/	313	287	322	310	287	320	314
Hardness (mg/L)	106	130	/	103	125	119	121	116	100.2	122	104
TDS (mg/L)	151	169	/	/	177	173	175	174	153	176	182
Total Alkalinity (mg/L $CaCO_3$)	149	156	/	151	163	155	166	160	147	164	157
Microcystin (µg/L)	/	/	/	/	/	/	/	0.09	0.17	0.14	0.97

Table 2c. Average Secchi depth and water chemistry values for Pigeon Lake. Historical values are given for reference.

Parameter	2015	2016	2017	2018	2019
TP (µg/L)	61	26	47	33	22
TDP (µg/L)	11	6	4	5	6
Chlorophyll-*a* (µg/L)	41	28	58	39	15
Secchi depth (m)	1.65	3.36	1.85	2.29	2.94
TKN (mg/L)	1.3	0.9	1.3	1.0	0.8
NO_2-N and NO_3-N (µg/L)	3	3	2	9	6
NH_3-N (µg/L)	31	25	21	16	11
DOC (mg/L)	8	7	8	8	8
Ca (mg/L)	20	26	25	25	27
Mg (mg/L)	13	14	15	14	14
Na (mg/L)	21	24	24	24	24
K (mg/L)	6	7	7	7	7
SO_4^{2-} (mg/L)	5	6	5	7	7
Cl^- (mg/L)	4	4	5	5	5
CO_3 (mg/L)	4	6	8	7	4
HCO_3 (mg/L)	178	184	178	188	195
pH	8.48	8.60	8.63	8.56	8.51
Conductivity (µS/cm)	298	320	316	328	333
Hardness (mg/L)	101	124	120	124	125
TDS (mg/L)	166	190	182	196	195
Total Alkalinity (mg/L $CaCO_3$)	154	160	160	164	168
Microcystin (µg/L)	2.32	0.13	0.47	0.58	0.07

Table 3. Concentrations of metals were last measured in Pigeon Lake in August 2017. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

Metals (Total Recoverable)	**2003**	**2012**	**2014**	**2015**	**2016**	**2017**	**Guidelines**
Aluminum μg/L	14.9	5.13	10.55	14.3	7.2	5.1	100[a]
Antimony μg/L	0.05	0.06685	0.089	0.0785	0.066	0.064	/
Arsenic μg/L	1.67	1.375	2.285	2.145	2.06	1.87	5
Barium μg/L	78.5	89.75	77.35	74.1	73.5	78.1	/
Beryllium μg/L	0.02	0.00675	0.004	0.004	0.004	0.0015	100[c,d]
Bismuth μg/L	0.0025	0.00125	0.0005	0.00325	0.001	0.0015	/
Boron μg/L	27.9	29.85	27.4	28.5	31.1	27.3	1500
Cadmium μg/L	0.01	0.00325	0.002	0.004	0.005	0.005	0.26[b]
Chromium μg/L	0.27	0.015	0.5235	0.09	0.04	0.05	/
Cobalt μg/L	0.11	0.00605	0.006565	0.018	0.005	0.021	1000[d]
Copper μg/L	1.08	0.2255	0.4155	0.235	0.5	0.22	4[b]
Iron μg/L	39	2.04	15.75	144.2	20.6	14.3	300
Lead μg/L	0.145	0.0167	0.245	0.0595	0.028	0.032	7[b]
Lithium μg/L	8.6	9.09	8.29	9.175	11.2	9.47	2500[e]
Manganese μg/L	54.1	16.9	15.75	49.65	6.48	27.5	200[e]
Molybdenum μg/L	0.62	0.704	0.731	0.728	0.907	0.711	73[c]
Nickel μg/L	0.16	0.0025	0.3465	0.0205	0.219	0.88	150[b]
Selenium μg/L	0.25	0.103	0.35	0.03	0.21	0.1	1
Silver μg/L	0.0025	0.0015	0.00681	0.002	0.003	0.0005	0.25
Strontium μg/L	245	234	261	233	249	231	/
Thallium μg/L	0.0015	0.00105	0.00291	0.000875	0.0075	0.003	0.8
Thorium μg/L	0.0015	0.008725	0.003575	0.011425	0.01	0.005	/
Tin μg/L	0.05	0.0549	0.0231	0.0355	0.027	0.03	/
Titanium μg/L	1.5	0.8925	1.4355	3.125	1	1.37	/
Uranium μg/L	0.086	0.1805	0.1945	0.167	0.161	0.144	15
Vanadium μg/L	0.26	0.1545	0.456	0.14	0.26	0.189	100[d,e]
Zinc μg/L	1.5	0.899	1.56	0.65	0.9	0.3	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 Pigeon Lake. In sum, non-significant increases were observed in TP and secchi depth, and significant increasing trends were observed in chlorophyll-*a* and TDS. Secchi depth can be subjective and is sensitive to variation in weather - trend analysis must be interpreted with caution. Data is presented below as both 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.*

Table 4. Summary table of trend analysis on Pigeon Lake data from 2003 to 2019.

Parameter	Date Range	Trend	Probability
Total Phosphorus	1983-2019	Increasing	Not significant
Chlorophyll-*a*	1983-2019	Increasing	Significant
Total Dissolved Solids	1983-2019	Increasing	Significant
Secchi Depth	1983-2019	Increasing	Not significant

Definitions:

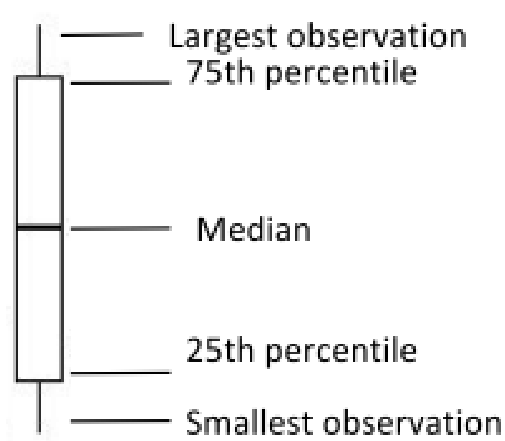
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

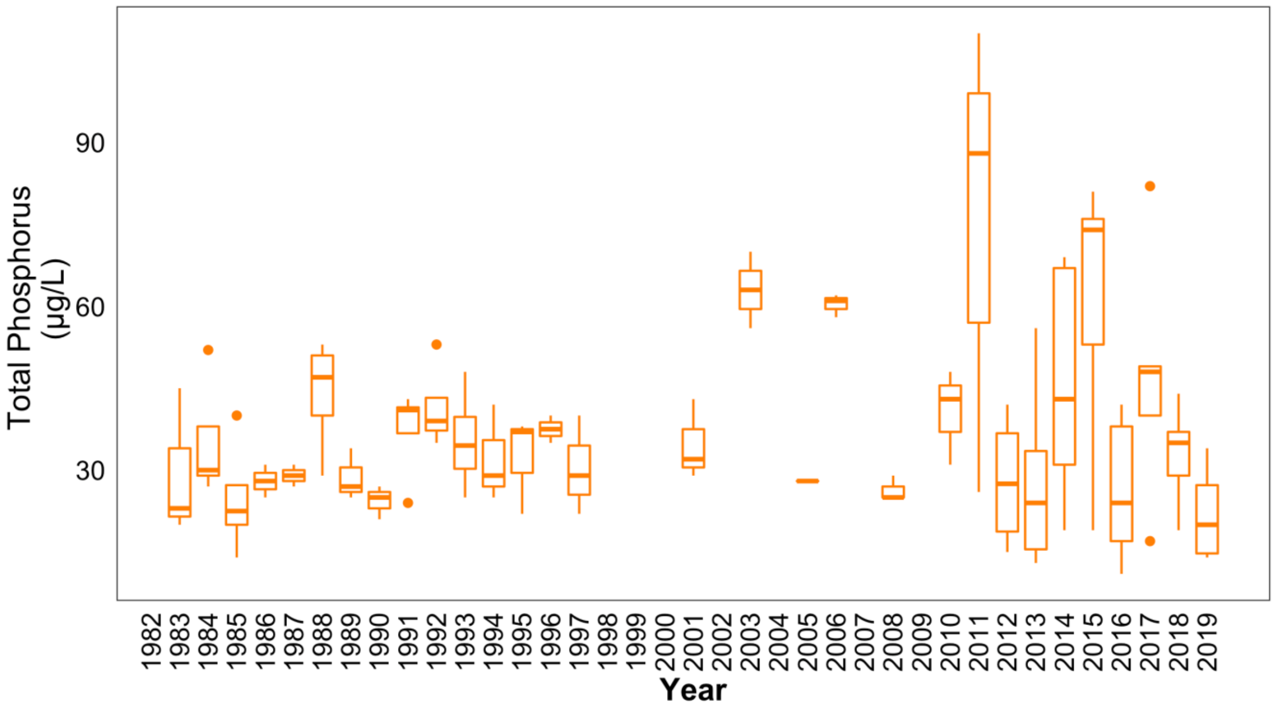
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

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)

Trend analysis of TP over time showed that it has not significantly changed in Pigeon Lake since 1982 (Tau = 2.75×10^{-2}, $p = 0.70$). Recent recent years show greater variation in total phosphorous levels than have been seen historically.



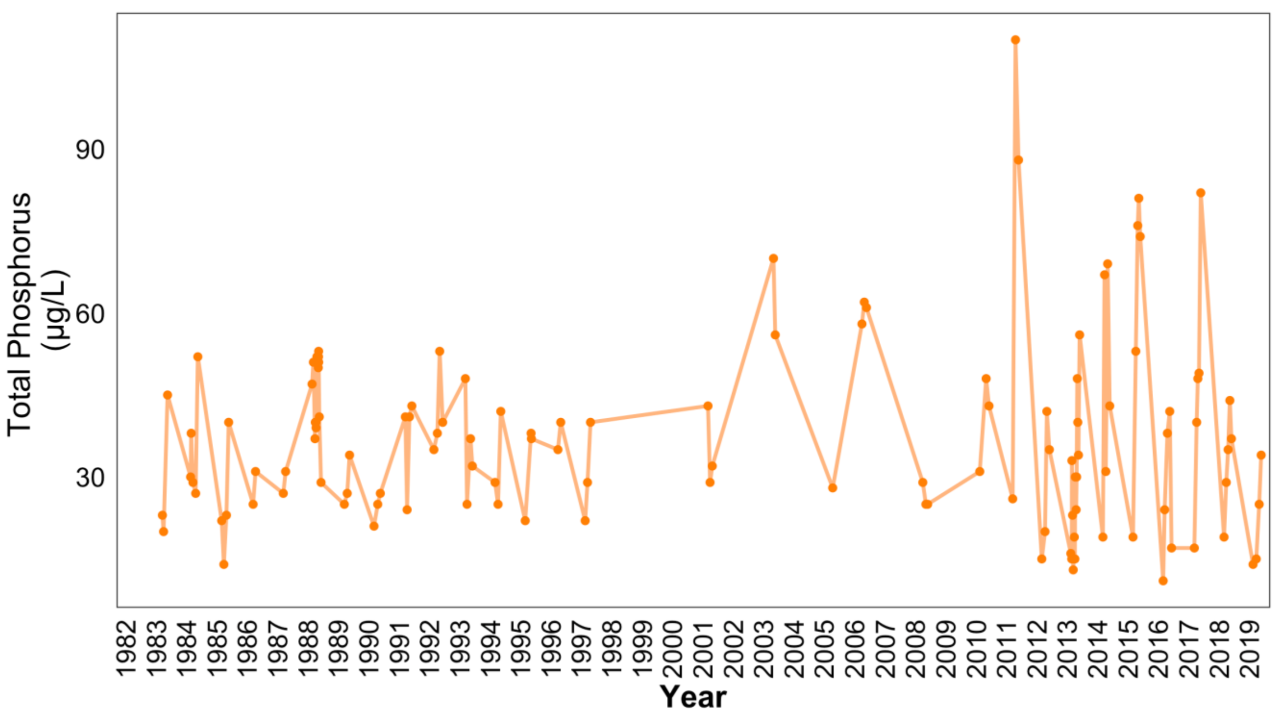


Figure 5. Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 1983 and 2019 (n = 94). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Chlorophyll-*a* has increased significantly over time at Pigeon Lake (Tau = 0.17, $p < 0.01$). The rate of change is very low, with the slope of the trend suggesting an increase of around 3.29 µg/decade over the 35 years sampled. Chlorophyll-*a* trends follow TP trends with correlation over time (r = 0.67, p = <0.001).

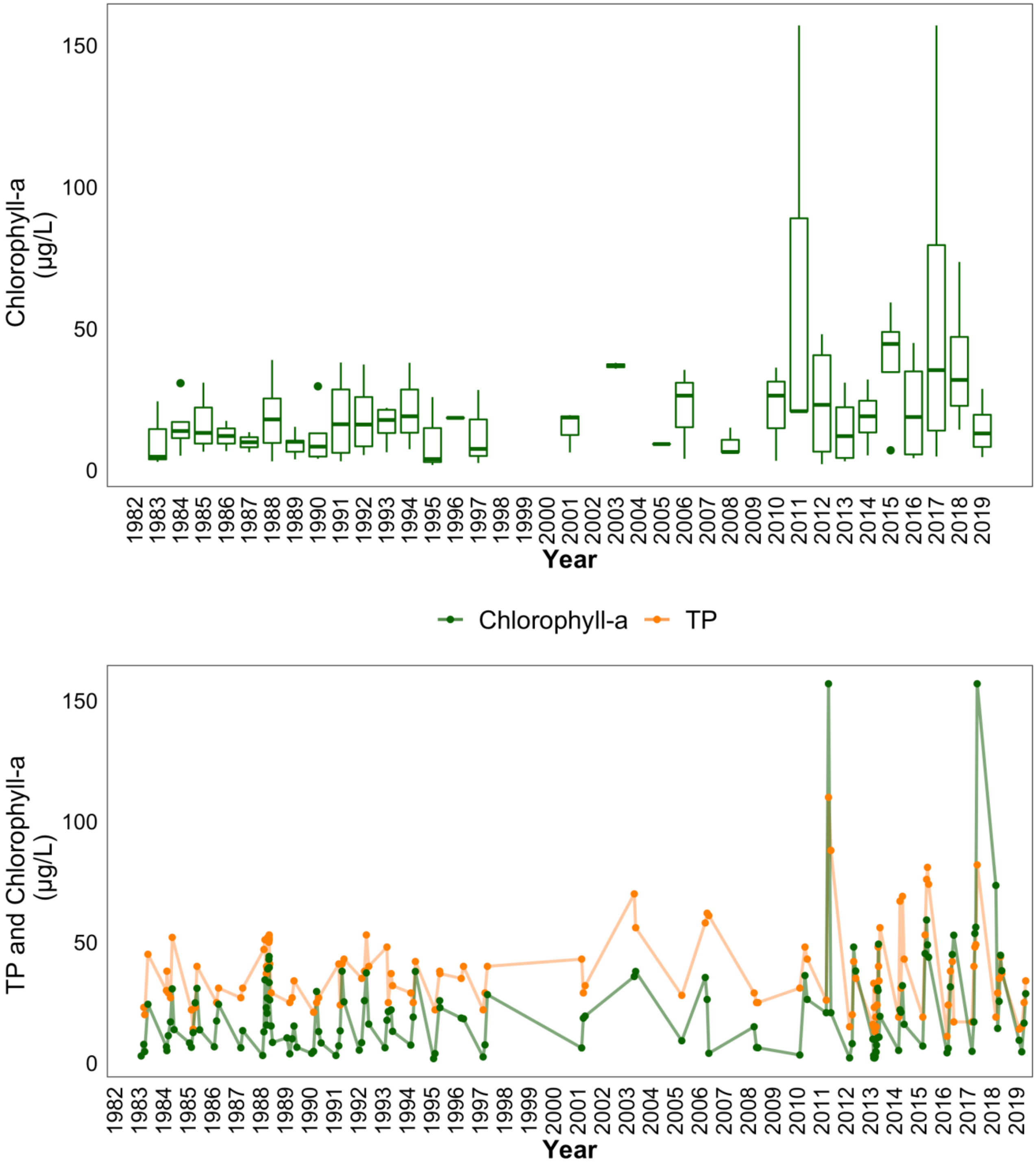
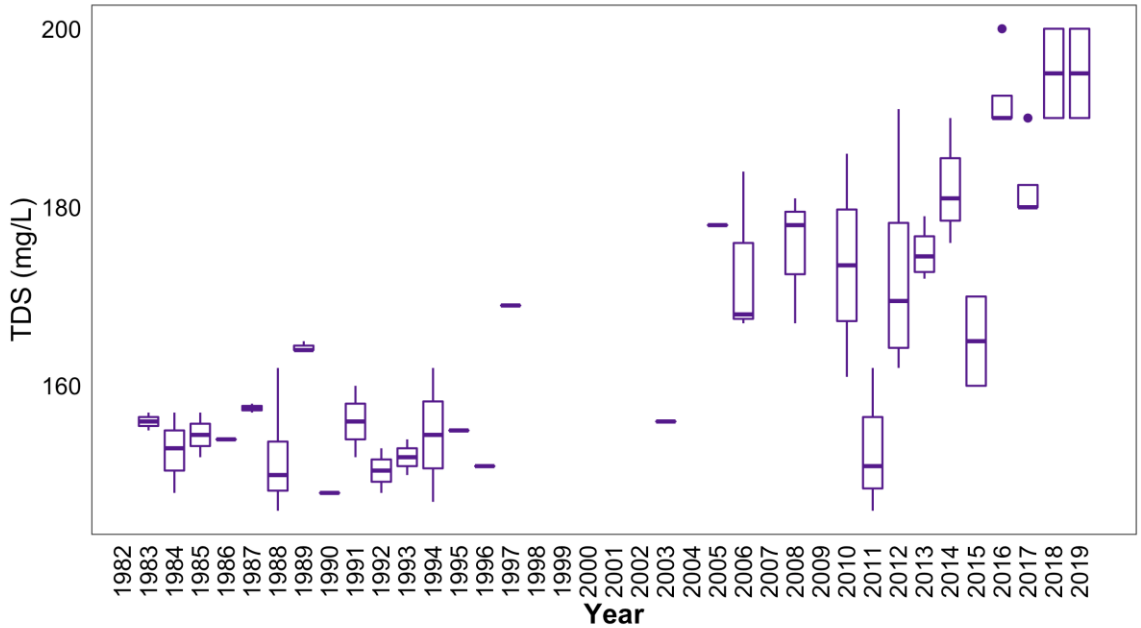


Figure 6. Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 1983 and 2019 (n = 105). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significantly increasing trend in TDS since 1983 in Pigeon Lake (Tau = 0.57, p = <0.001).



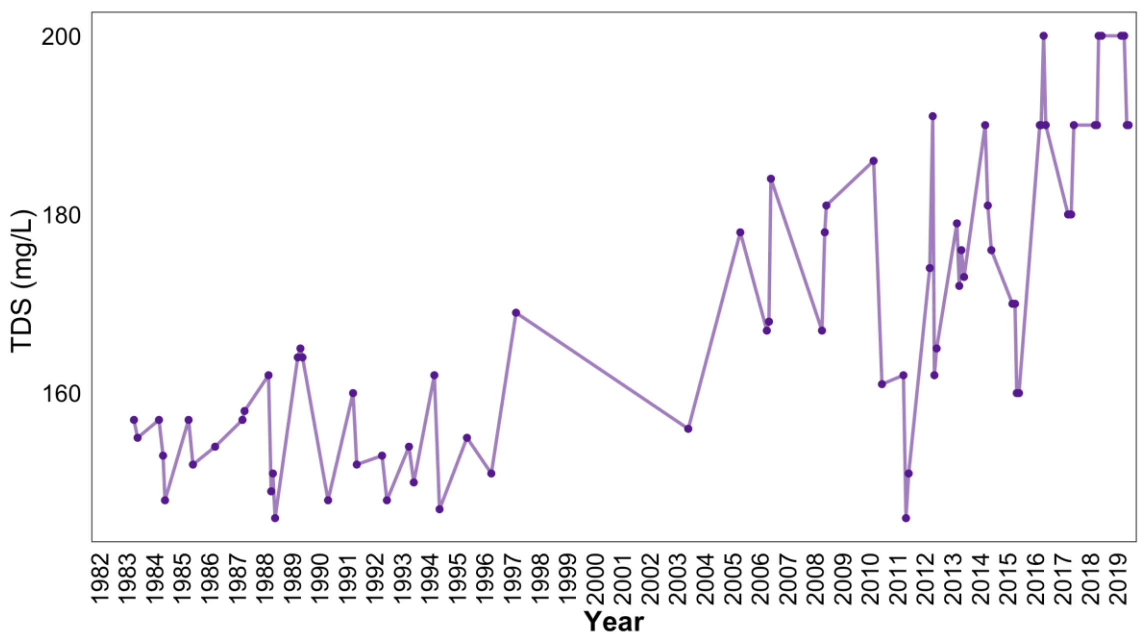
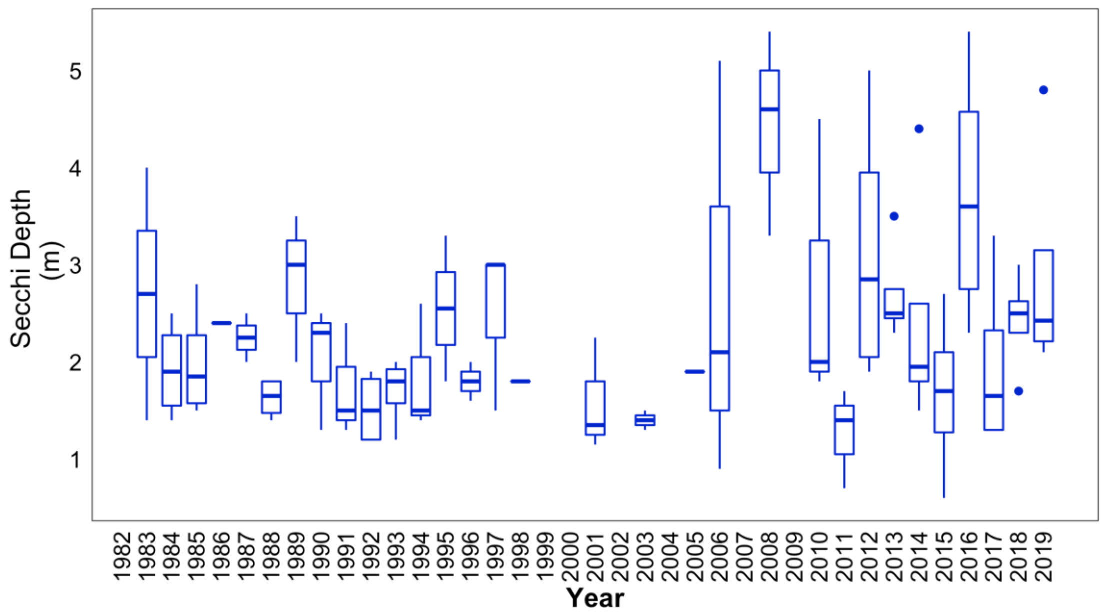


Figure 7. Monthly TDS values measured between June and September over the long term sampling dates between 1983 and 2019 (n = 73). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Secchi depth has not changed significantly in Pigeon Lake since 1983 (Tau = 0.16, p = 0.01). Recent years show much greater variation both within and between seasons.



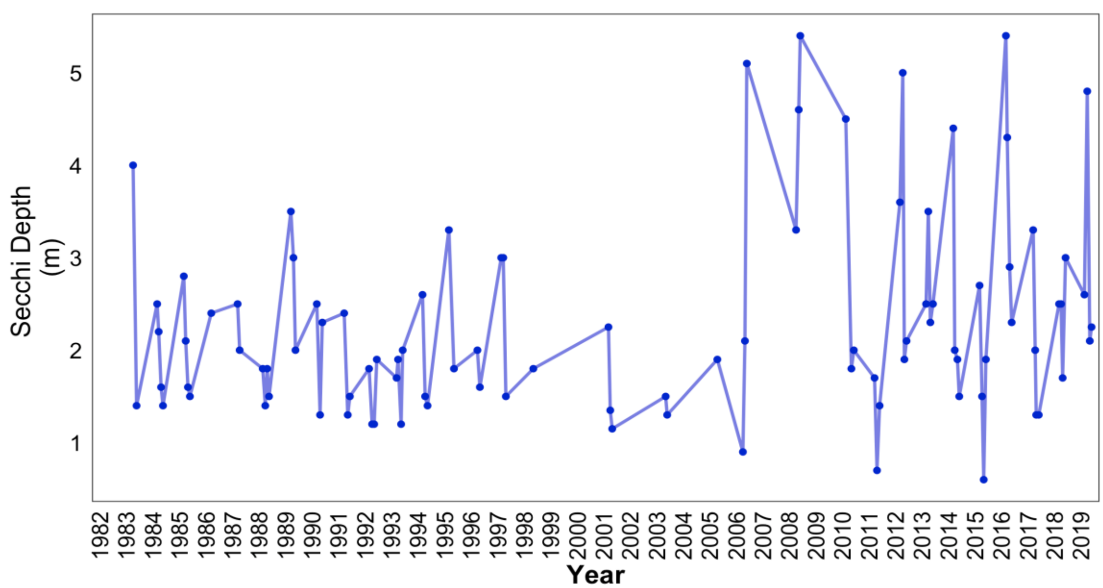


Figure 8. Monthly Secchi depth values measured between June and September over the long term sampling dates between 1983 and 2019 (n = 95). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 5. Results of trend tests using total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from June to September on Pigeon Lake data.

Definition	Unit	Total Phosphorus (TP)	Chlorophyll-a	Total Dissolved Solids (TDS)	Secchi Depth
Statistical Method	-	Mann Kendall	Mann Kendall	Seasonal Kendall	Seasonal Kendall
The strength and direction (+ or -) of the trend between -1 and 1	Tau	2.75×10^{-2}	0.17	0.57	0.13
The extent of the trend	Slope	9.46×10^{-5}	0.0008	2.86×10^{-3}	3.48×10^{-5}
The statistic used to find significance of the trend	Z	0.389	2.59	7.11	1.81
Number of samples included	n	94	109	73	95
The significance of the trend	p	0.70	<0.01*	1.14×10^{-12}*	0.07

*$p < 0.05$ is significant within 95%