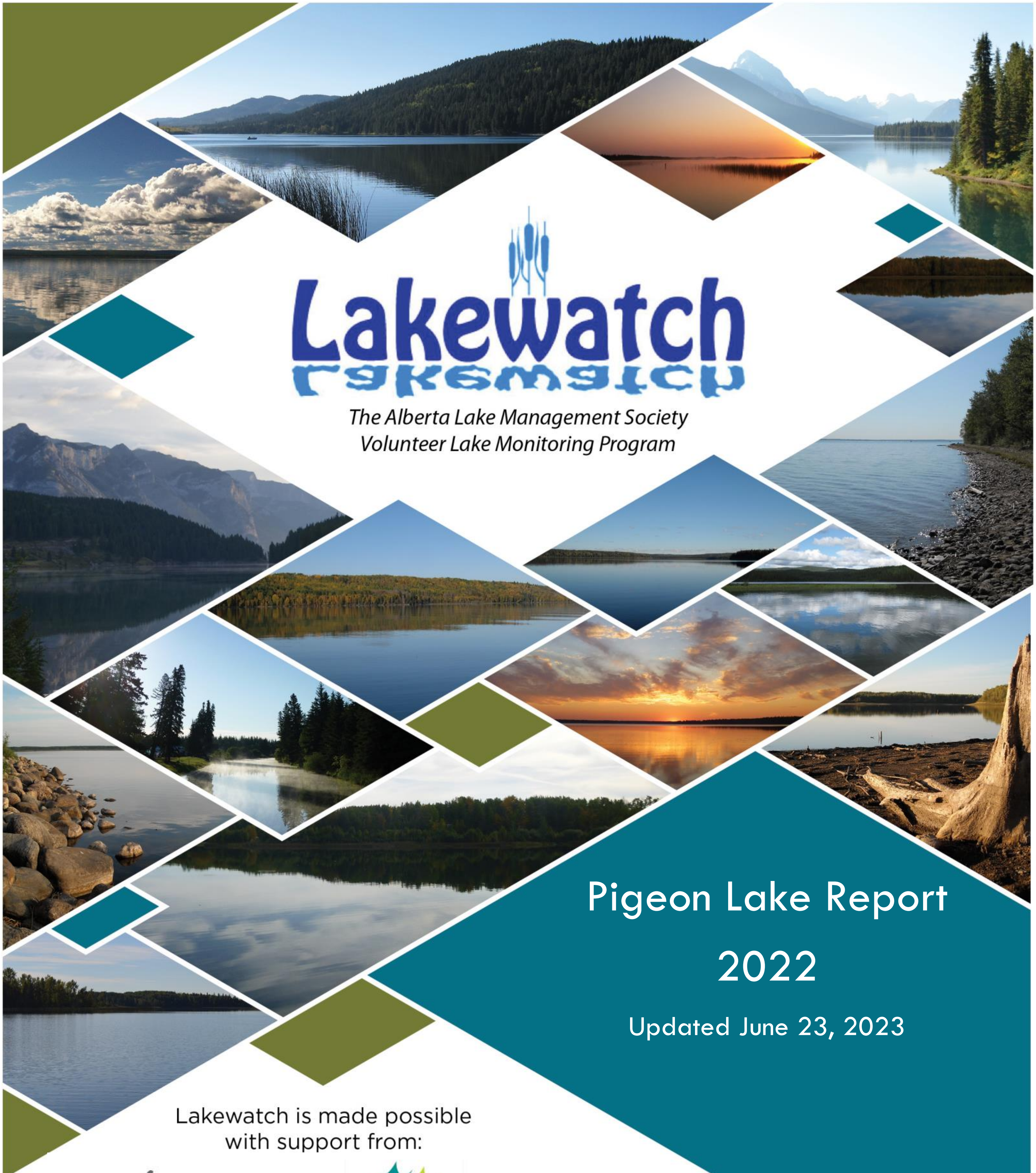

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Pigeon Lake Report 2022

Updated June 23, 2023

Lakewatch is made possible with support from:

Alberta

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LICA ENVIRONMENTAL STEWARDS

PIGEON LAKE WATERSHED ASSOCIATION

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 Daren Lorentz for his commitment to collecting data at Pigeon Lake. We would also like to thank Kurstyn Perrin and Dominic Wong, who were summer technicians in 2022. Executive Director Bradley Peter and Program Manager Caleb Sinn were instrumental in planning and organizing the field program. This report was prepared by Caleb Sinn and Bradley Peter.

PIGEON LAKE

Pigeon Lake at Pigeon Lake Provincial Park beach in 2018 (Photo by Bradley Peter)

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 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 established.[3] It has been suggested that the name Pigeon Lake refers to the huge flocks of Passenger Pigeons that once lived 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 due to 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.

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 27 µg/L (Table 2), falling into the mesotrophic, or moderate productivity trophic classification. This value falls on the middle to low end of all previously observed historical averages going back to 1983 (Table 2). TP ranged from a minimum of 8.7 µg/L on July 21st, to a maximum of 54 µg/L on September 9th (Figure 1).

Average chlorophyll-*a* concentration in 2022 was 21.8 µg/L (Table 2), falling into the eutrophic, or highly productive trophic classification. Chlorophyll-*a* was highest during the September 9th sampling event at 40.2 µg/L, and lowest at 4.8 µg/L on June 21st.

The average TKN concentration was 1.0 mg/L (Table 2) and displayed consistent levels through the season except for the final sampling event in September, where the level increased appreciably (Figure 1).

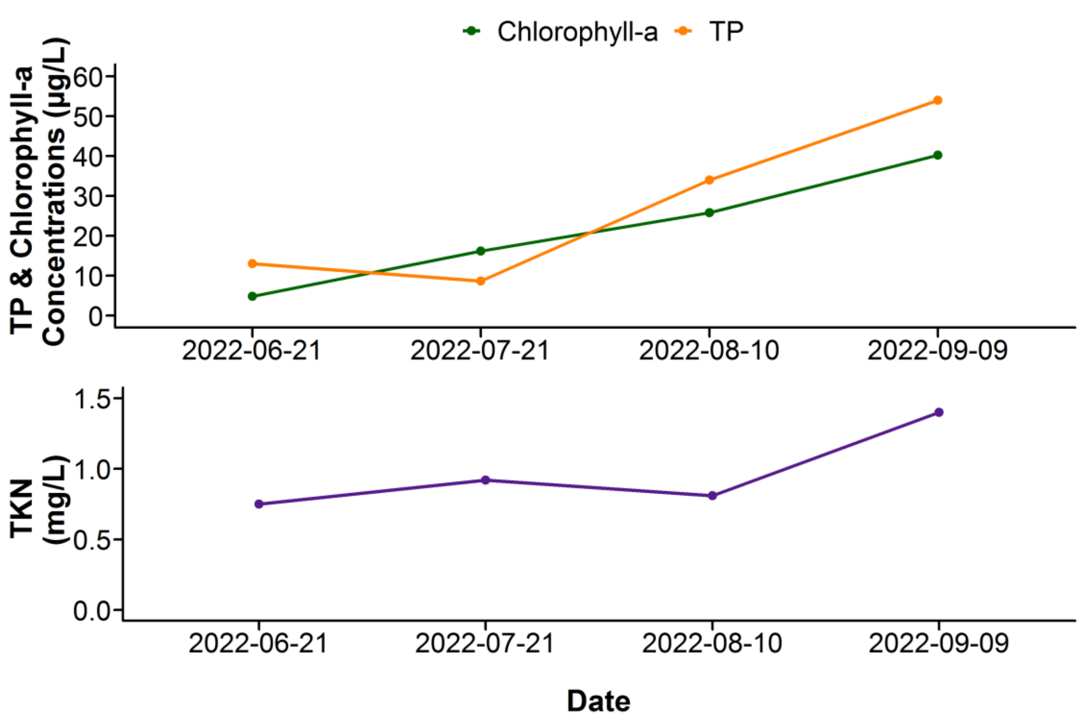


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Pigeon Lake.

Average pH was measured as 8.24 in 2022, buffered by moderate alkalinity (162 mg/L $CaCO_3$) and bicarbonate (200 mg/L HCO_3). Aside from bicarbonate, calcium and sodium were in highest abundance, and together contributed to a low conductivity of 328 µS/cm (Figure 2, top; Table 2). Pigeon Lake is in the low range of ion levels, compared to other LakeWatch lakes sampled in 2022. (Figure 2, bottom).

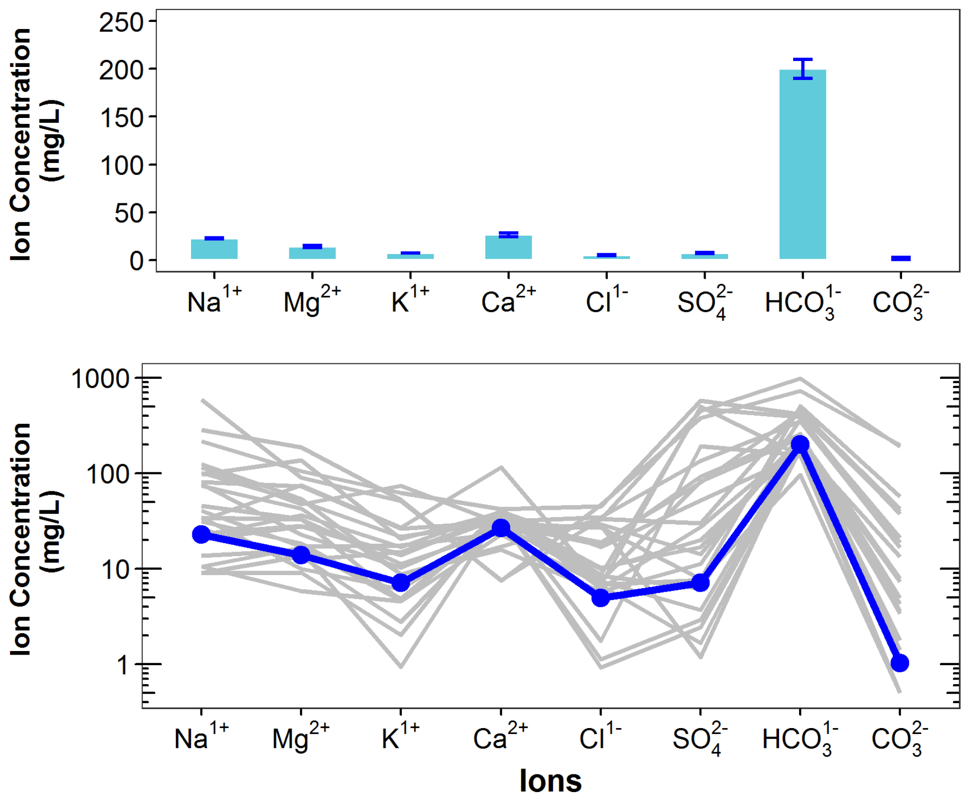


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Pigeon Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Pigeon Lake (blue line) compared to 26 lake basins (gray lines) sampled through the LakeWatch program in 2022 (note log_{10} scale on y-axis of bottom figure).

Metals

Metals will naturally be present in aquatic environments due to in-lake processes or the erosion of rocks, or introduced to the environment from human activities such as urban, agricultural, or industrial developments. Many metals have a unique guideline as they may become toxic at higher concentrations. Where current metal data are not available, historical concentrations for 27 metals have been provided (Table 3).

Metals were not measured at Pigeon Lake in 2022, but historical metal data can be found in Table 3.

WATER CLARITY AND EUPHOTIC DEPTH

Water clarity is influenced by suspended materials, both living and dead, as well as dissolved colored compounds in the water column. During the melting of snow and ice in spring, lake water can become turbid (cloudy) from silt transported into the lake. Lake water usually clears in late spring, but then becomes more turbid with increased algal growth as the summer progresses. The easiest and most widely used measure of lake water clarity is the Secchi depth. Two times the Secchi depth equals the euphotic depth – the depth to which there is enough light for photosynthesis.

The average euphotic depth of Pigeon Lake in 2022 was 4.88 m, corresponding to an average Secchi depth of 2.44 m (Table 2). Euphotic depth varied over the season, ranging from as deep as 5.90 m on July 21st, to 3.60 m on September 9th (Figure 3). Secchi depth was significantly negatively correlated with chlorophyll-*a* ($r = -0.98$, $p = 0.020$).

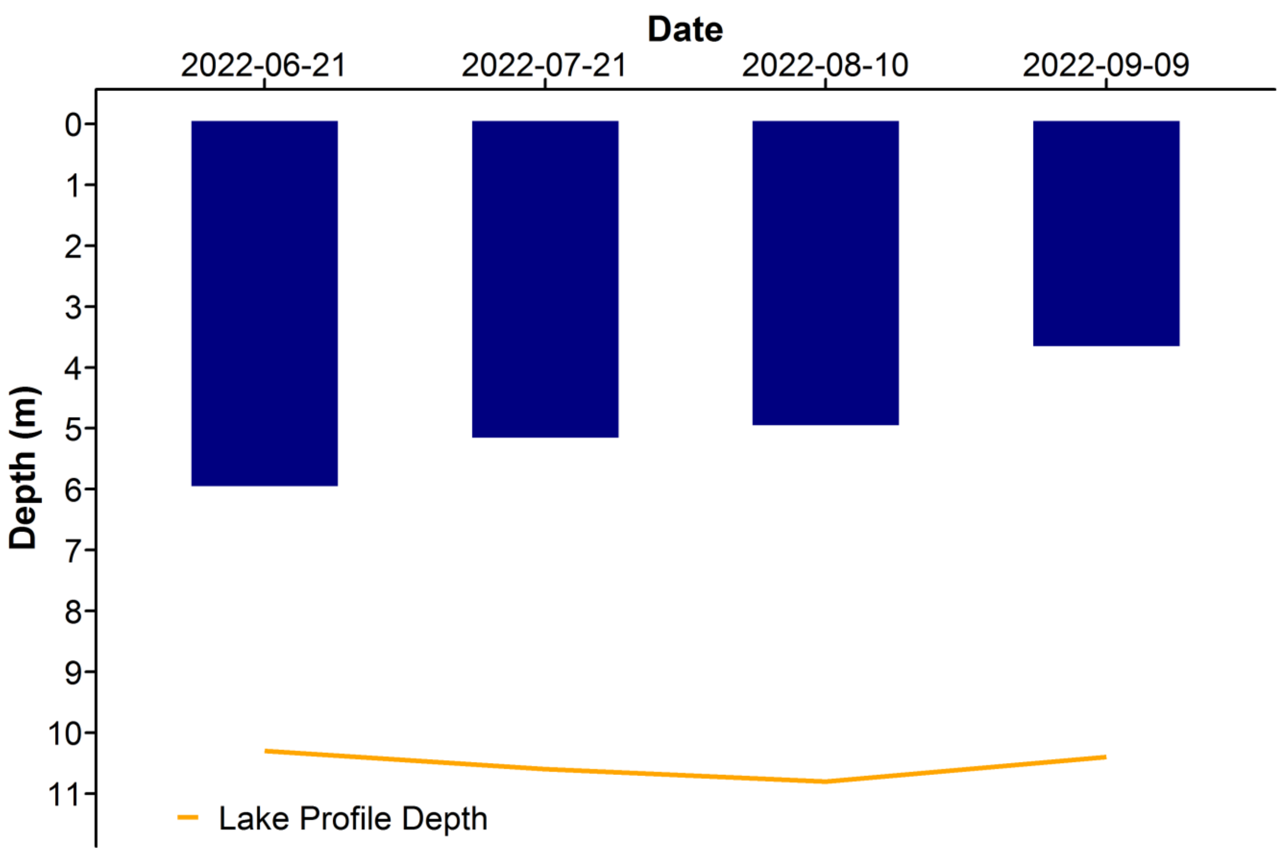


Figure 3. Euphotic depth values measured four times over the course of the summer at Pigeon Lake in 2022.

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 the end of this report for descriptions of technical terms.

Surface water temperatures at Pigeon Lake varied throughout the summer, with the July 21st sampling date having the warmest temperature of 21.1°C (Figure 4a). The lake was completely mixed during each sampling event, with consistent temperatures throughout the water column on each sampling date.

Pigeon Lake was well oxygenated in the surface waters on all sampling dates, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 4b). The lake was also well oxygenated throughout deeper areas as well on each sampling event, only dropping slightly to 6.24 mg/L at above the bottom sediments at 10.0 m on the June 21st sampling. The lake otherwise displayed consistent dissolved oxygen levels, despite the variation in water temperature during each sampling event.

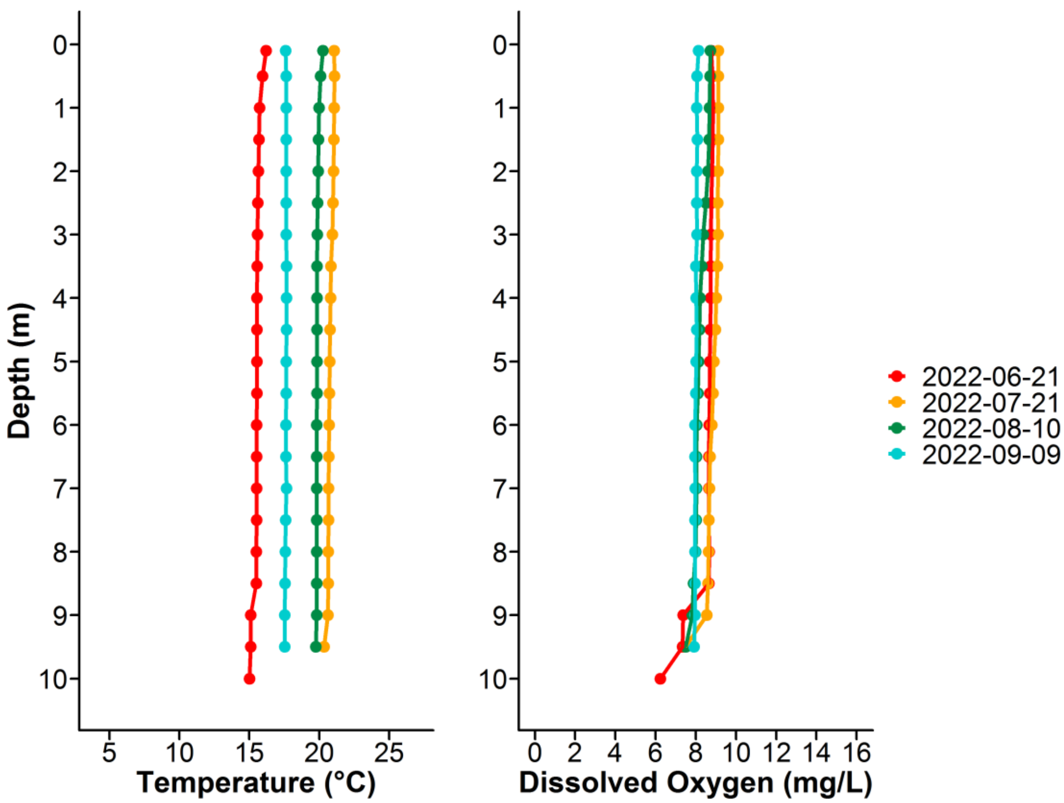


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Pigeon Lake measured four times over the course of the summer of 2022.

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 one of the most common cyanobacteria toxins. In Alberta, recreational guidelines for microcystin are set at 10 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 Pigeon Lake fell below the recreational guideline of 10 µg/L during every sampling event in 2022. In addition, microcystin levels from the June 6th and July 21st sampling events were below the laboratory detection limit of 0.10 µg/L. A value of 0.05 µg/L is assigned when a value is below detection, in order to calculate an average. Despite low levels of microcystin detected during each sampling event, caution should be observed in areas of the lake where significant cyanobacteria accumulation occurs.

Table 1. Microcystin concentrations measured four times at Pigeon Lake in 2022.

Date	Microcystin Concentration (µg/L)
6-Jun-22	<0.1
21-Jul-22	<0.1
10-Aug-22	0.18
9-Sep-22	0.21
Average	0.12

INVASIVE SPECIES MONITORING

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

Monitoring for aquatic invasive species involved sampling with a 63 µm plankton net at three sample sites. This monitoring is designed to detect juvenile Dreissenid mussel veligers and spiny water flea. In 2022, no mussels or spiny water flea were detected at Pigeon Lake.

Eurasian watermilfoil is a non-native aquatic plant that poses a threat to aquatic habitats in Alberta because it grows in dense mats preventing light penetration through the water column, reduces oxygen levels when the dense mats decompose, and outcompetes native aquatic plants. Eurasian watermilfoil can look similar to the native Northern watermilfoil, thus genetic analysis is ideal for suspect watermilfoil species identification.

No watermilfoil specimens were collected from Pigeon Lake in 2022.

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 at Pigeon Lake in 2022 were near or slightly below the historical average (Figure 5). Historical data indicates that since the beginning of the record in 1972, the lake has seen a very slight downward trajectory of water levels. Despite this downward trend, there has been considerable variability over the 50 year record.

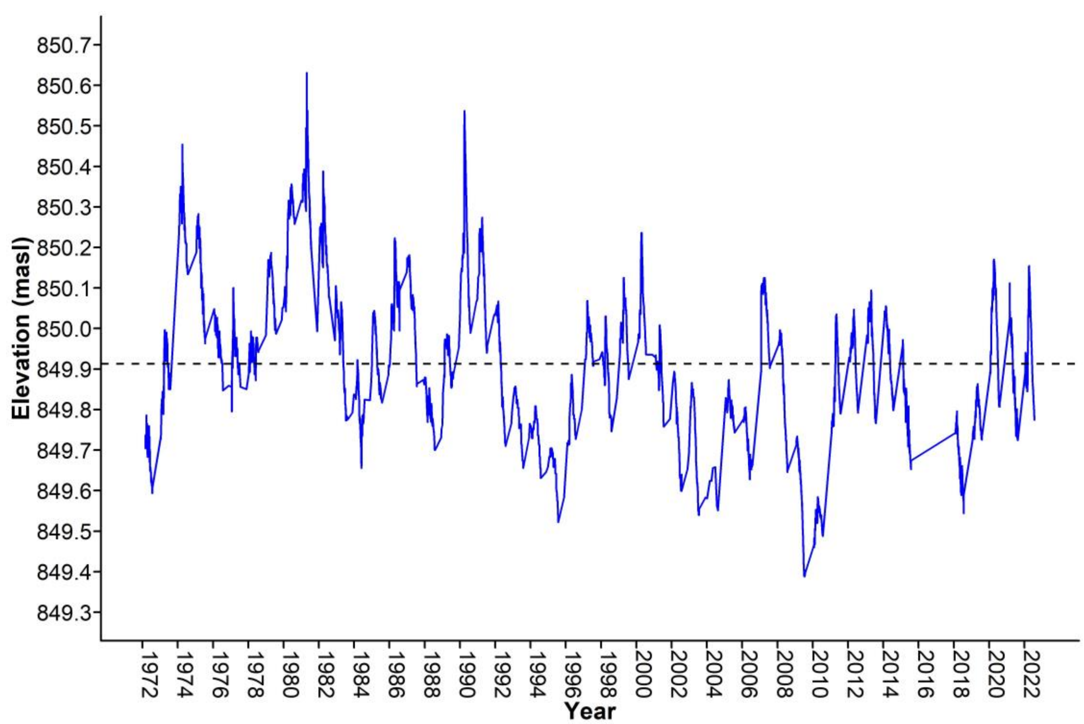


Figure 5. Water levels measured at Pigeon Lake in metres above sea level (masl) from 1972-2022. Data retrieved from Alberta Environment and Parks and/or Environment and Climate Change Canada. Black dashed line represents historical yearly average water level.

WEATHER & LAKE STRATIFICATION

Air temperature will directly impact lake temperatures, and result in different temperature layers (stratification) throughout the lake, depending on its depth. Wind will also impact the degree to which a lake mixes, and how it will stratify. The amount of precipitation that falls within a lake's watershed will have important implications, depending on the context of the watershed and the amount of precipitation that has fallen. Solar radiation represents the amount of energy that reaches the earth's surface, and has implications for lake temperature & productivity.

Pigeon Lake experienced a warmer, wetter, and slightly less windy summer with more solar radiation than normal (Figure 6). It is interesting that despite the low wind during most of the sampling events, there was no appreciable temperature decrease with depth. This would indicate that stratification events in the lake are rare and may only occur on very hot and very calm days and would be short lived.

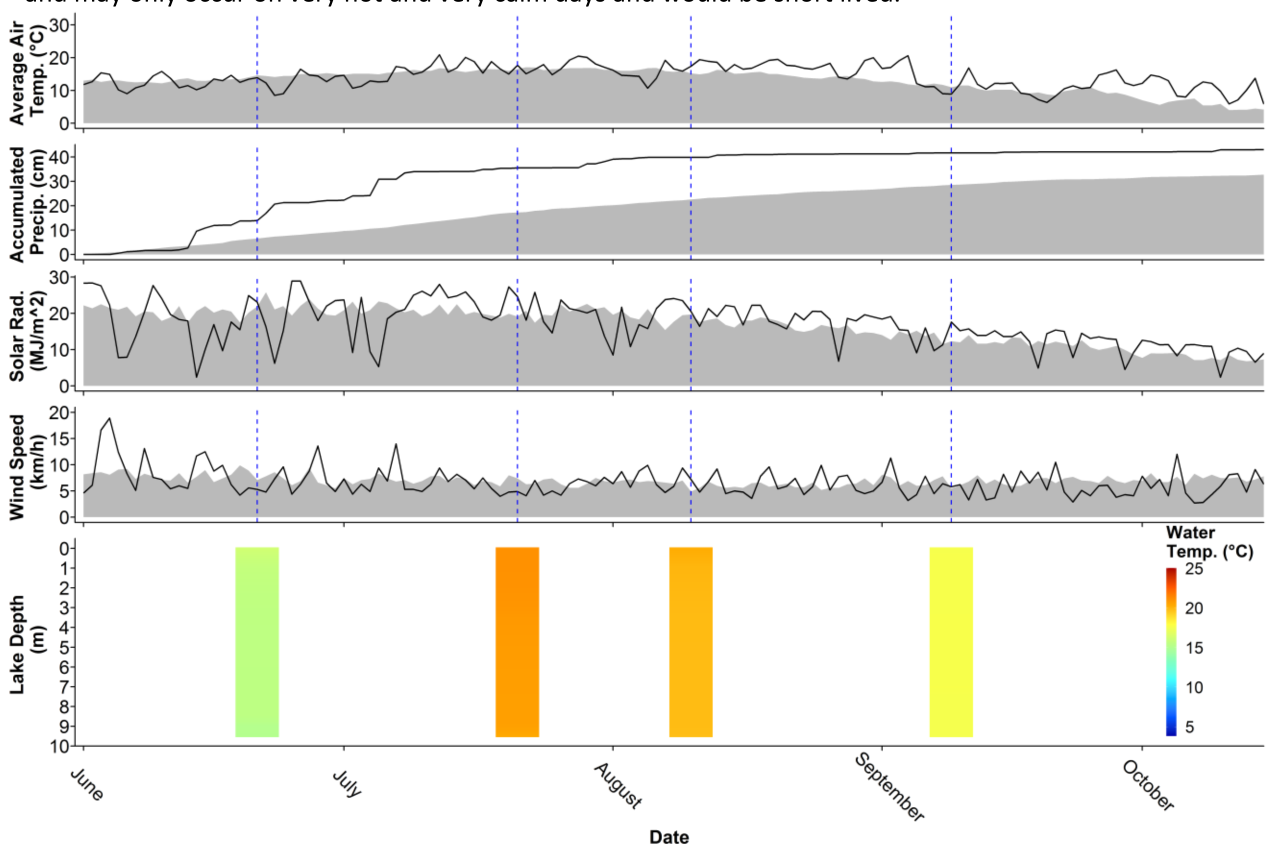


Figure 6. Average air temperature (°C) and accumulated precipitation (cm) measured from the 'Battle River Headwaters' weather station, wind speed (km/h) solar radiation (MJ/m^2) measured from the 'Breton Plots' weather station, as well as Pigeon Lake temperature profiles, interpolated (°C). Black lines indicate 2022 levels, gray indicates long-term normals, and blue lines indicate sampling dates for Pigeon Lake over the summer. Further information about the weather data provided is available in the LakeWatch 2022 Methods report. Weather data provided by Agriculture, Forestry and Rural Economic Development, Alberta Climate Information Service (ACIS) https://acis.alberta.ca (retrieved March 2023).

Table 2a. Average Secchi depth and water chemistry values for Pigeon Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	**1983**	**1984**	**1985**	**1986**	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**
TP (µg/L)	27	35	22	29	29	43	29	26	34	38	35	32	29
TDP (µg/L)	11	/	/	/	/	/	/	/	/	/	/	/	9
Chlorophyll-*a* (µg/L)	9.9	14.1	16.1	16.1	9.8	25.7	9.2	11.9	17.4	18.6	16.1	21.4	13.6
Secchi depth (m)	3.2	1.95	2.35	3.1	2.25	1.66	2.36	2.34	2.16	1.72	1.98	1.83	2.4
TKN (mg/L)	0.9	/	/	/	/	/	/	/	/	/	/	/	0.8
NO_2-N and NO_3-N (µg/L)	22	25	25	25	10	12	6	13	2	8	2	9	5
NH_3-N (µg/L)	25	/	/	/	/	/	/	/	/	/	/	/	6
DOC (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	7
Ca (mg/L)	29	25	27	26	28	24	30	29	29	26	26	26	24
Mg (mg/L)	10	10	11	11	10	12	11	12	12	11	11	12	12
Na (mg/L)	15	15	16	15	15	17	16	14	14	17	17	17	18
K (mg/L)	6	5	5	5	5	5	5	5	5	5	5	5	5
SO_4^{2-} (mg/L)	4	3	2	2	2	3	6	4	5	4	3	3	6
Cl^- (mg/L)	1	0	2	0	2	1	2	1	1	2	2	2	2
CO_3 (mg/L)	2.5	5.4	2.5	7.8	5.4	4.3	3.8	5.7	2.7	6	5.3	5.5	6.5
HCO_3 (mg/L)	180	178	177	168	176	170	184	175	177	174	175	176	168
pH	8.37	8.43	8.37	8.57	8.50	8.36	8.32	8.50	8.46	8.45	8.56	8.59	8.61
Conductivity (µS/cm)	283	288	283	280	293	279	302	294	293	286	287	290	282
Hardness (mg/L)	112	103	111	110	111	109	120	122	121	111	113	114	110
TDS (mg/L)	160	154	154	151	158	151	165	158	156	152	154	154	156
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	152	152	147	147	154	145	156	153	150	146	148	150	148

Table 2b. Average Secchi depth and water chemistry values for Pigeon Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	**1996**	**1997**	**1998**	**2003**	**2005**	**2006**	**2008**	**2010**	**2011**	**2012**	**2013**	**2014**
TP (µg/L)	38	30	/	63	28	60	26	41	75	28	27	46
TDP (µg/L)	/	/	/	10	6	38	8	13	19	7	8	16
Chlorophyll-*a* (µg/L)	18.5	12.8	/	36.8	9.2	21.9	9.2	21.9	66.2	24	12.6	19.2
Secchi depth (m)	1.8	2.5	1.8	1.4	1.9	2.7	4.43	2.77	1.27	3.15	3.23	2.32
TKN (mg/L)	/	/	/	1.1	0.7	1.1	0.7	1	1.5	0.9	0.8	0.7
NO_2-N and NO_3-N (µg/L)	/	/	/	10	3	29	13	8	16	4	6	26
NH_3-N (µg/L)	/	/	/	14	2	124	16	72	109	16	25	25
DOC (mg/L)	/	/	/	/	/	7	/	7	/	/	/	8
Ca (mg/L)	22	31	/	/	30	24	27	/	/	/	/	/
Mg (mg/L)	12	13	/	/	13	14	13	/	/	/	/	/
Na (mg/L)	15	19	/	19	20	21	20	22	20	21	21	24
K (mg/L)	4	6	/	6	6	7	6	6	/	/	/	7
SO_4^{2-} (mg/L)	5	6	/	5	8	10	5	9	3	6	6	5
Cl^- (mg/L)	2	0	/	2	4	3	3	3	3	4	3	4
CO_3 (mg/L)	9	0.2	/	7.5	7	4.7	3.3	0.5	8.7	5.5	3.3	6.1
HCO_3 (mg/L)	163	190	/	168	184	180	198	195	161	190	195	180
pH	8.66	8.17	/	8.55	8.50	8.50	8.37	8.57	8.74	8.53	8.34	8.59
Conductivity (µS/cm)	293	304	/	/	314	287	322	310	287	318	320	314
Hardness (mg/L)	106	130	/	103	127	119	121	116	100	113	122	104
TDS (mg/L)	151	169	/	156	178	173	175	174	153	173	176	182
Microcystin (µg/L)	/	/	/	/	/	/	/	0.09	0.17	/	0.14	0.97
Total Alkalinity (mg/L $CaCO_3$)	149	156	/	151	163	155	166	160	147	165	164	157

Table 2c. Average Secchi depth and water chemistry values for Pigeon Lake. Historical values are given for reference. Number of sample trips are inconsistent between years.

Parameter	2015	2016	2017	2018	2019	2020	2021	2022
TP (µg/L)	61	26	47	33	22	44	29	27
TDP (µg/L)	11	6	4	6	6	10	6	6
Chlorophyll-*a* (µg/L)	40.8	27.9	57.7	39.2	14.8	38.6	30.3	21.8
Secchi depth (m)	1.66	3.36	1.88	2.3	2.95	2.17	2.6	2.44
TKN (mg/L)	1.3	0.8	1.3	1	0.8	1.2	1.1	1
NO_2-N and NO_3-N (µg/L)	2	2	2	7	6	9	7	9
NH_3-N (µg/L)	31	25	21	12	11	34	15	8
DOC (mg/L)	8	7	8	8	8	7	8	7
Ca (mg/L)	20	26	25	25	26	25	25	26
Mg (mg/L)	13	14	15	14	14	14	13	14
Na (mg/L)	21	24	24	24	24	24	23	23
K (mg/L)	6	7	7	7	7	7	7	7
SO_4^{2-} (mg/L)	4	6	5	7	7	5	5	7
Cl^- (mg/L)	4	4	4	5	5	5	4	5
CO_3 (mg/L)	3.6	5.6	7.6	6.6	3.7	1.8	4.2	1
HCO_3 (mg/L)	178	184	178	188	195	182	218	200
pH	8.48	8.61	8.63	8.56	8.51	8.39	8.47	8.24
Conductivity (µS/cm)	298	320	316	328	332	318	332	328
Hardness (mg/L)	101	124	120	124	125	120	118	122
TDS (mg/L)	166	190	182	196	195	170	195	195
Microcystin (µg/L)	2.32	0.13	0.47	0.58	0.07	0.25	0.22	0.12
Total Alkalinity (mg/L $CaCO_3$)	154	160	160	164	168	150	182	162

Table 3. Concentrations of metals measured in Pigeon Lake. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Note that metal sample collection method changed in 2016 from composite to single surface grab at the profile location.

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	0.18[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	50,1000[c,d]
Copper µg/L	1.08	0.2255	0.4155	0.235	0.5	0.22	2.76[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	4.01[b]
Lithium µg/L	8.6	9.09	8.29	9.175	11.2	9.47	2500[d]
Manganese µg/L	54.1	16.9	15.75	49.65	6.48	27.5	170[e]
Molybdenum µg/L	0.62	0.704	0.731	0.728	0.907	0.711	73
Nickel µg/L	0.16	0.0025	0.3465	0.0205	0.219	0.88	109.8[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[c,d]
Zinc µg/L	1.5	0.899	1.56	0.65	0.9	0.3	30[f]

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

[b] Based on 2022 avg. water hardness (as CaCO3) with CCME equation

[c] Based on CCME Guidelines for Agricultural use (Livestock).

[d] Based on CCME Guidelines for Agricultural Use (Irrigation).

[e] Based on CCME Manganese variable calculation (https://ccme.ca/en/chemical/129#_aql_fresh_concentration), using 2022 avg. water hardness (as CaCO3) and avg. pH

[f] Based on 2022 avg. water hardness (as CaCO3), avg. pH, and avg. DOC with CCME equation

A forward slash (/) indicates an absence of data or guideline

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, significant increasing trends were observed in chlorophyll-*a*, TDS, and Secchi Depth, and no significant trend was detected for TP. Secchi depth can be subjective and is sensitive to variation in weather; therefore, trend analysis must be interpreted with caution. Data is presented below as both line and box-and-whisker plots. 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 1983 to 2022.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	1983-2022	No Change
Chlorophyll-*a*	1983-2022	Increasing
Total Dissolved Solids	1983-2022	Increasing
Secchi Depth	1983-2022	Increasing

Definitions:

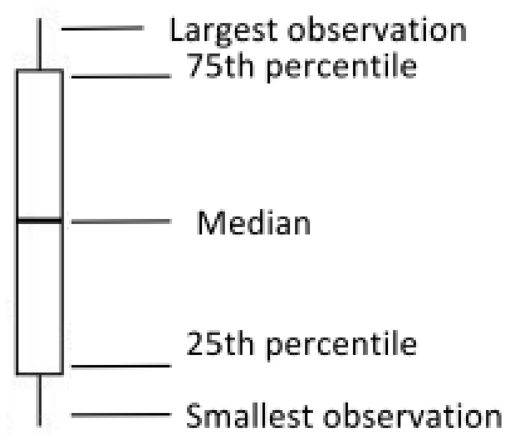
Median: the value in a range of ordered numbers that falls in the middle.

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 1983 (Tau = -0.008, p = 0.90).

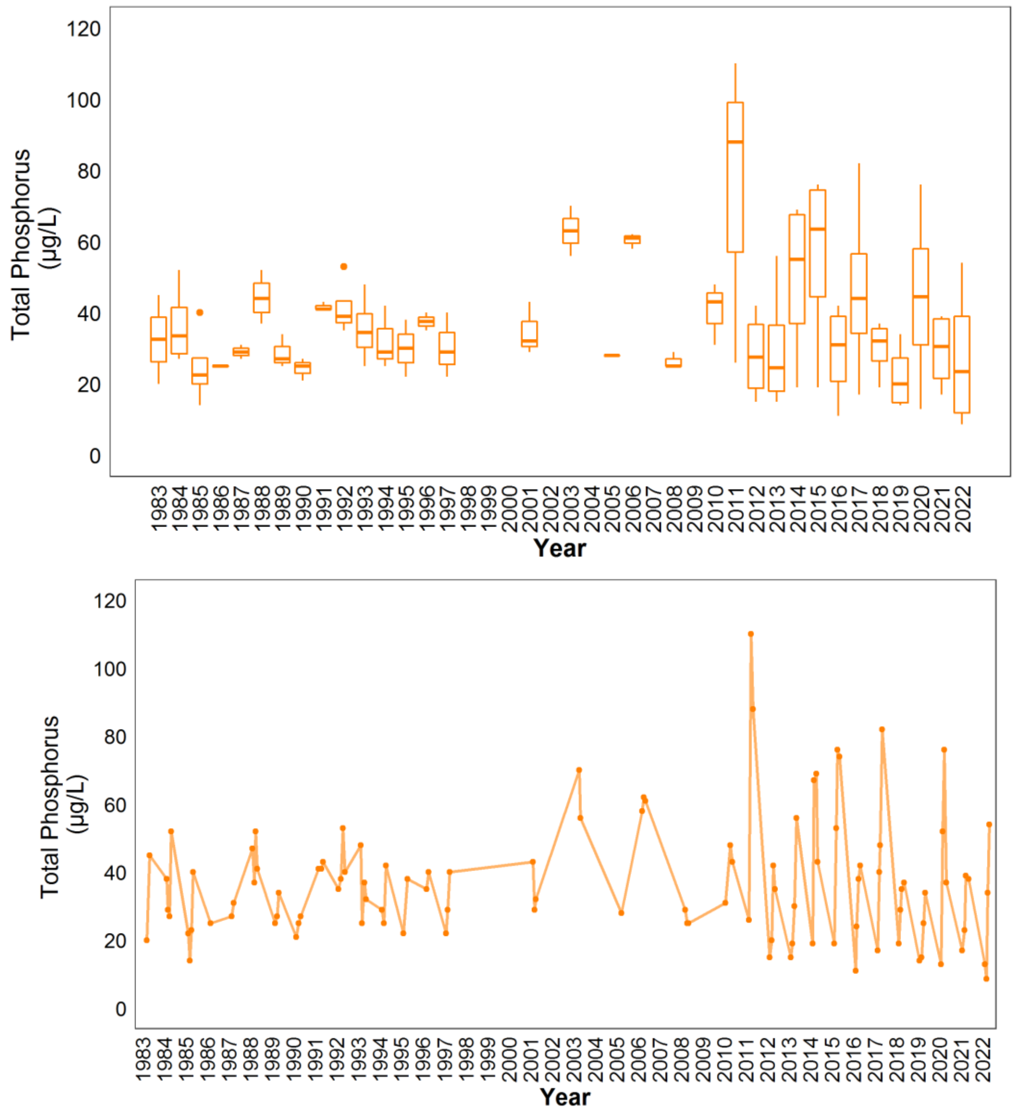


Figure 7. Monthly total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 1983 and 2022 (n = 106). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Trend analysis of chlorophyll-*a* over time showed that it has significantly increased in Pigeon Lake since 1983 (Tau = 0.13, p = 0.048).

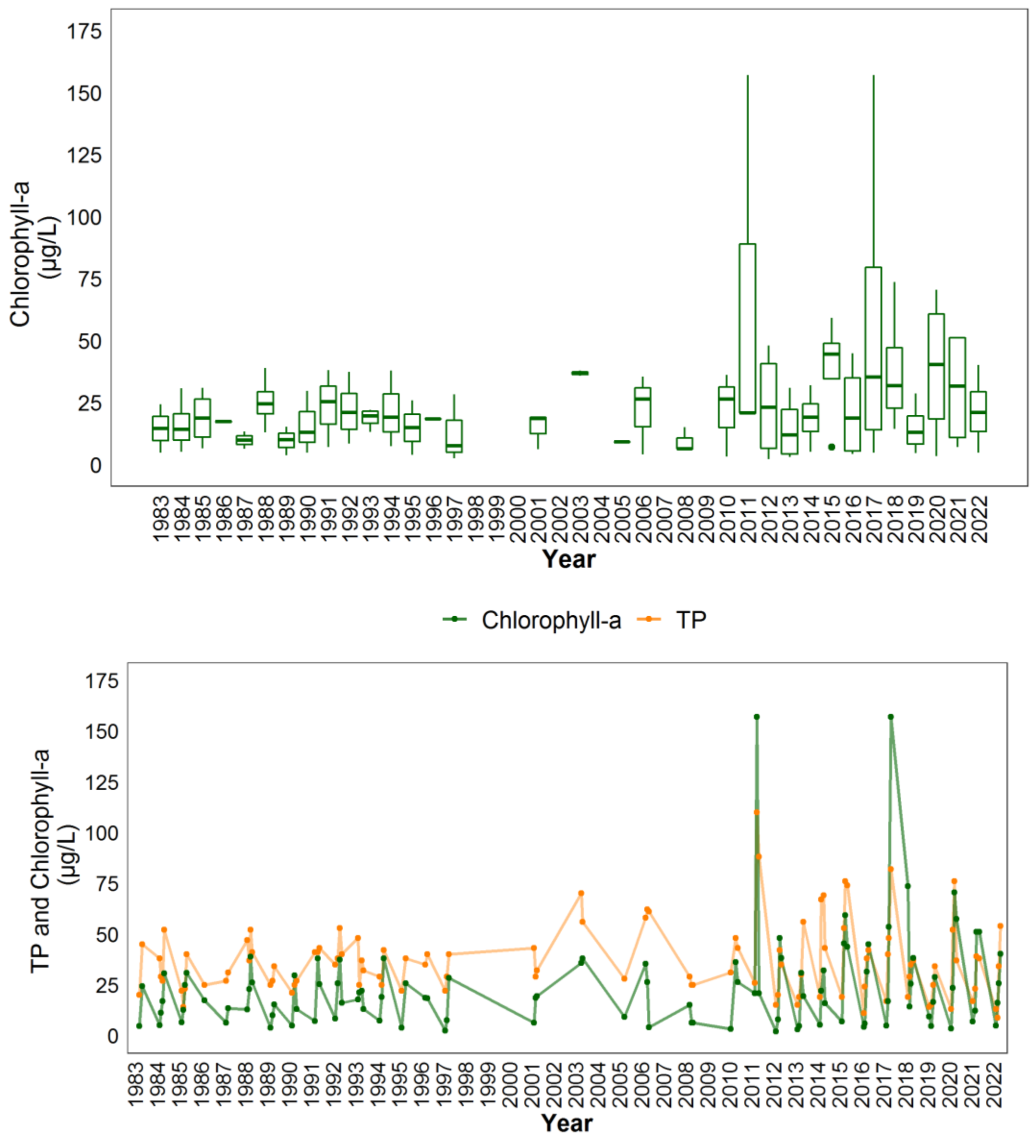


Figure 8. Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 1983 and 2022 (n = 106). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 1983 and 2022 (Tau = 0.59, p = <0.001) in Pigeon Lake (Figure 9).

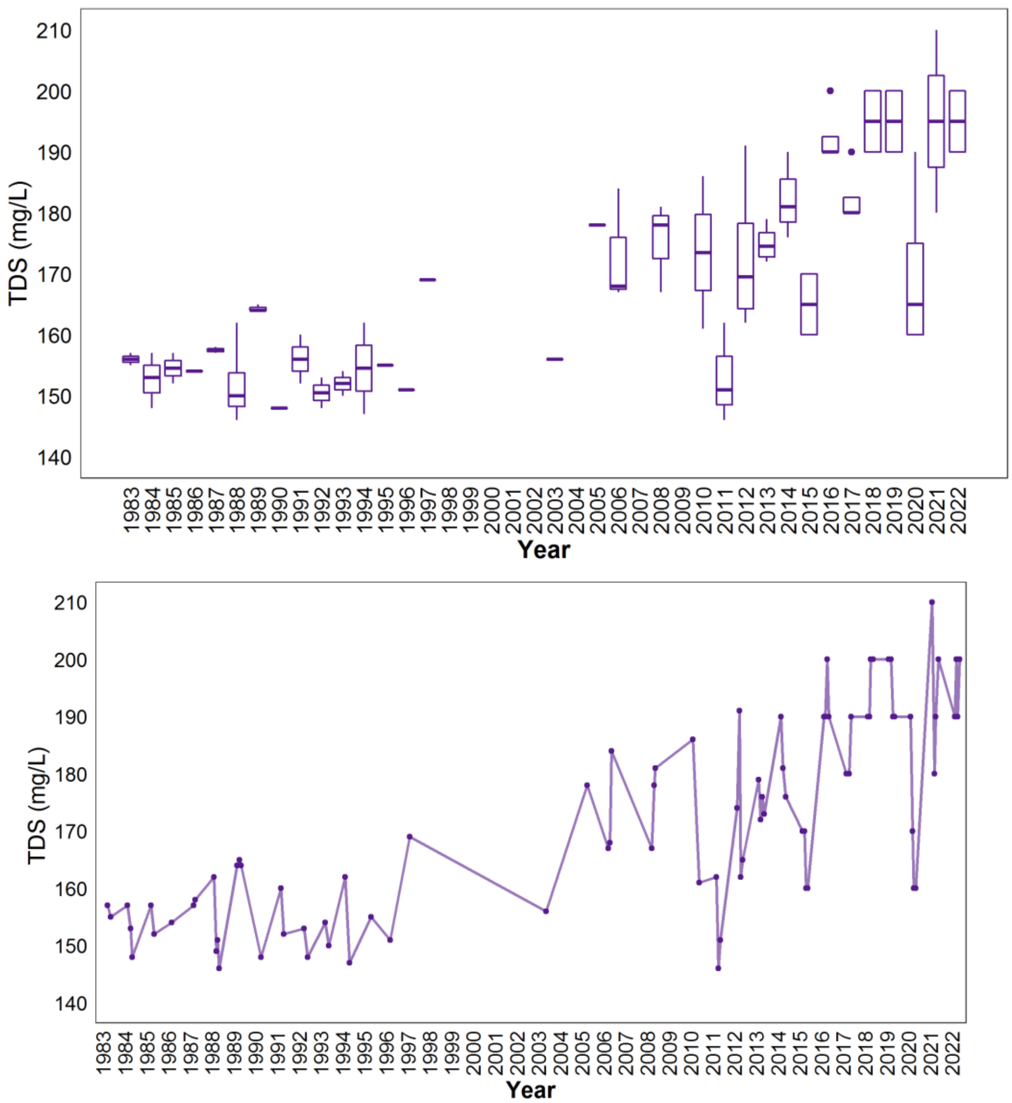


Figure 9. Monthly TDS values measured between June and September over the long term sampling dates between 1983 and 2022 (n = 85). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Due to the significant increasing trend of TDS in Pigeon Lake, exploring the specific major ions which may be driving this trend is important to determine. Trend analysis of major ions at Pigeon Lake indicates that alkalinity (bicarbonate, carbonate) and sodium are likely the key parameters that are driving the increase in TDS (Figure 10). These two parameters display the greatest magnitude of change over time (slopes), but also follow the trajectory of TDS. While the slopes of chloride, magnesium, and potassium are smaller, their increasing trends are also significant, and their trajectories also follow the trajectory of TDS over time.

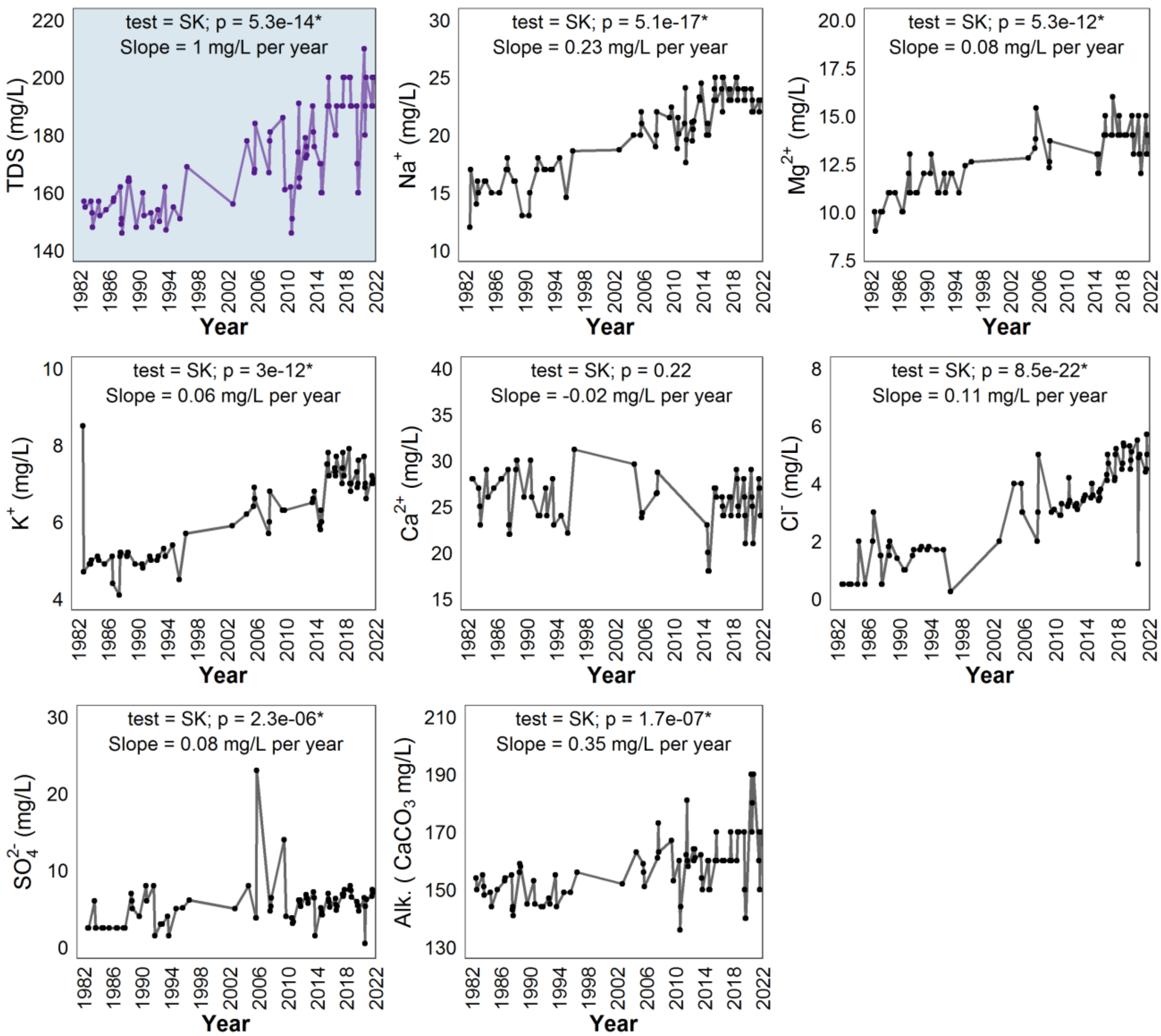


Figure 10. Concentrations of TDS (top left, blue panel), major ions (sodium = Na^+, magnesium = Mg^{2+}, potassium = K^+, calcium = Ca^{2+}, chloride = Cl^-, sulphate = SO_4^{2-}), and total alkalinity (Alk., as mg/L $CaCO_3$) measured monthly between June and September on sampling dates between 1983 and 2022. Also represented is the monotonic trend results for each parameter; test used (MK = Mann Kendall, SK = Seasonal Kendall), significance of test (p; assessed as significance when $p < 0.05$, marked with '*' if significant), and the slope of the trend. Test selection follows method outline in the *ALMS Guide to Trend Analysis on Alberta Lakes.* Note that some ions had insufficient data (*I.D.*) therefore trends were not calculated. The value closest to the 15^{th} day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Trend analysis of Secchi depth over time showed that it has significantly increased (the lake has become clearer) in Pigeon Lake since 1983 (Tau = 0.19, p = 0.009).

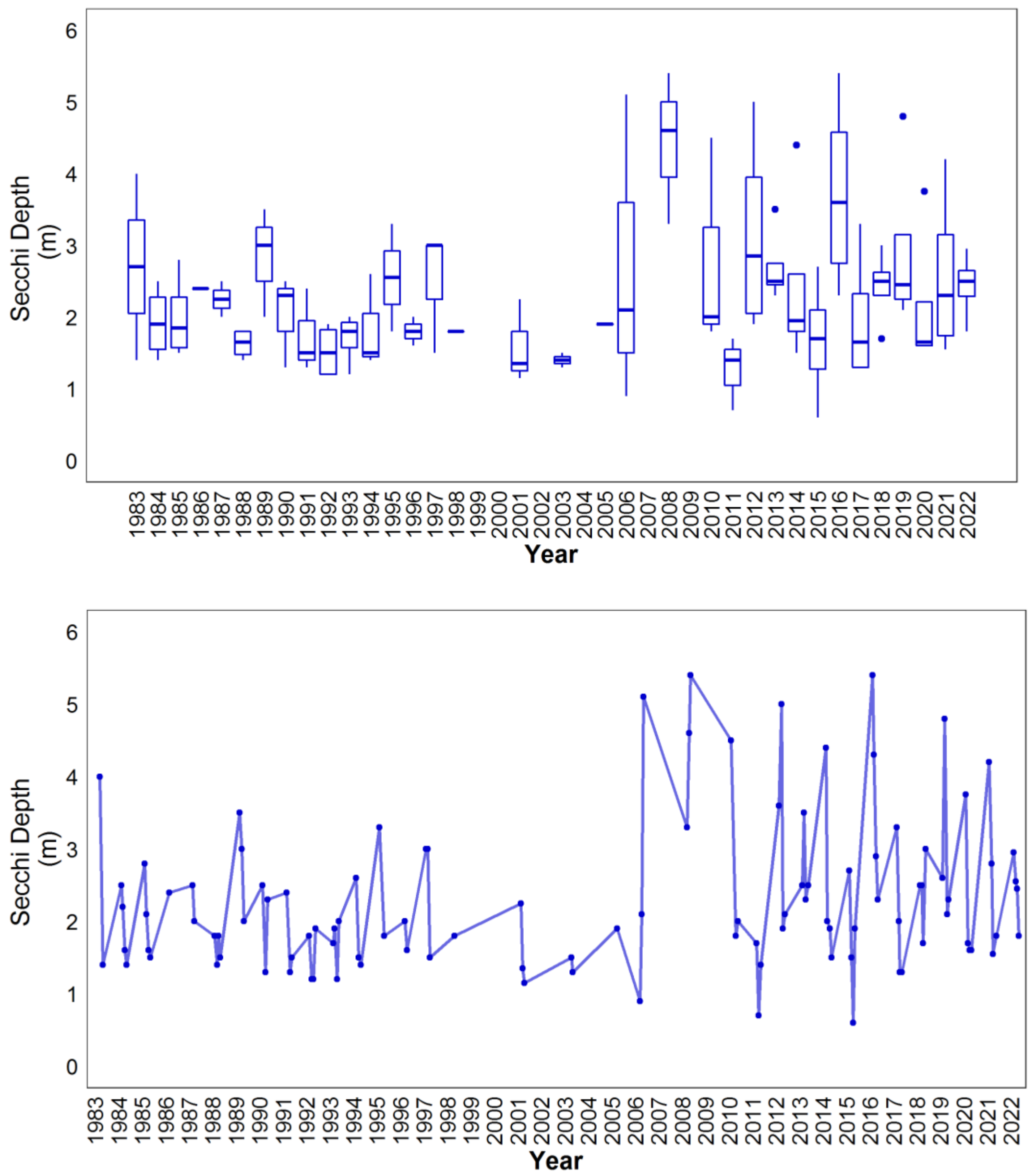


Figure 11. Monthly Secchi depth values measured between June and September on sampling dates between 1983 and 2022 (n = 107). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 5. Results of trend tests using total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from June to September, for sampled years from 1983-2022 on Pigeon Lake data.

Definition	Unit	Total Phosphorus (TP)	Chlorophyll-a	Total Dissolved Solids (TDS)	Secchi Depth
Statistical Method	-	Mann Kendall	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall
The strength and direction (+ or -) of the trend between -1 and 1	Tau	-0.01	0.13	0.59	0.19
The extent of the trend	Slope (units per Year)	<0.01	0.14	1.00	0.01
The statistic used to find significance of the trend	Z	-0.12	1.98	7.52	2.61
Number of samples included	n	106	106	85	107
The significance of the trend	*p*	0.90	0.048*	5.31×10^{-14}*	9.18×10^{-3}*

*$p < 0.05$ is significant within 95%