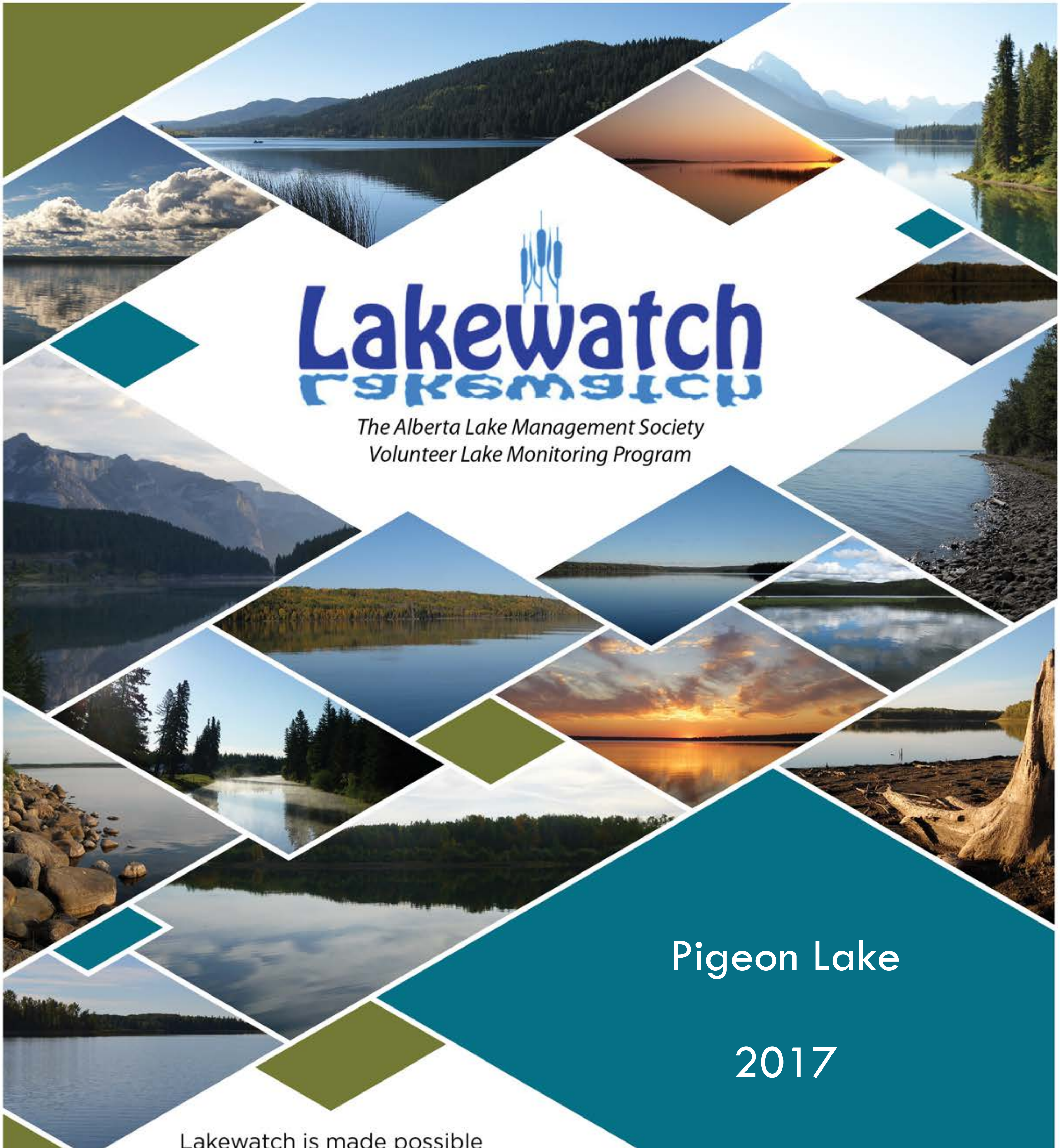

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Pigeon Lake

2017

Lakewatch is made possible
with support from:

Cargill Helping the world thrive
Jackfish Lake
Pigeon Lake Watershed Association
LICA Lakeland Industry & Community Association
Red Deer River Watershed Alliance
Beaver River Watershed Alliance
Alberta Environment and Parks

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 people prove that ecological apathy can be overcome and give us hope that our water resources will not be the limiting factor in the health of our environment.

ALMS is happy to discuss the results of this report with our stakeholders. If you would like information or a public presentation, contact us at info@alms.ca.

ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. We would like to extend a special thanks to Daren and Sawyer Lorentz for the time and energy put into sampling Pigeon Lake in 2017. We would also like to thank Elashia Young and Melissa Risto who were summer technicians in 2017. Executive Director Bradley Peter and LakeWatch Coordinator Laura Redmond was instrumental in planning and organizing the field program. This report was prepared by Laura Redmond and Bradley Peter. The Beaver River Watershed, the Lakeland Industry and Community Association, Environment Canada, and Alberta Environment and Parks are major sponsors of the LakeWatch program.

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 very 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 throughout the watershed.[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 2017 the Pigeon Lake Watershed Association released their draft 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. 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 Innovates Technology Futures (AITF), 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. Mann Kendall tests are used with non-normal data to assess unidirectional trends over time in a dataset (a non-parametric linear regression).

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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 47.2 µg/L (Table 2), falling into the eutrophic, or productive, trophic classification. This average falls within the range of historical values previously observed (Appendix A). TP increased over the course of the sampling season, peaking in September (Figure 1).

Average chlorophyll-*a* concentration in 2017 was 57.7 µg/L (Table 2), placing Pigeon Lake into the hypereutrophic classification. This is the highest Chlorophyll-*a* average since 2011 at Pigeon Lake (Appendix A). Chlorophyll-*a* concentrations were highest on September 15, reaching a maximum concentration of 157 µg/L. Chlorophyll-*a* concentrations were significantly correlated with TP ($r = 0.88$, $p = 0.046$).

Finally, the average TKN concentration was 1.3 mg/L (Table 2), and the maximum concentration was measured on September 15. TKN and chlorophyll-*a* trends were also significantly correlated ($r = 0.98$, $p = 0.0044$).

Average pH was measured as 8.63 in 2017, buffered by moderate alkalinity (160 mg/L $CaCO_3$) and bicarbonate (178 mg/L HCO_3). Calcium and sodium were the dominant ions contributing to a low conductivity of 316 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 Pigeon Lake on August 25 at the surface. In 2017, all measured values fell within their respective guidelines (Table 3).

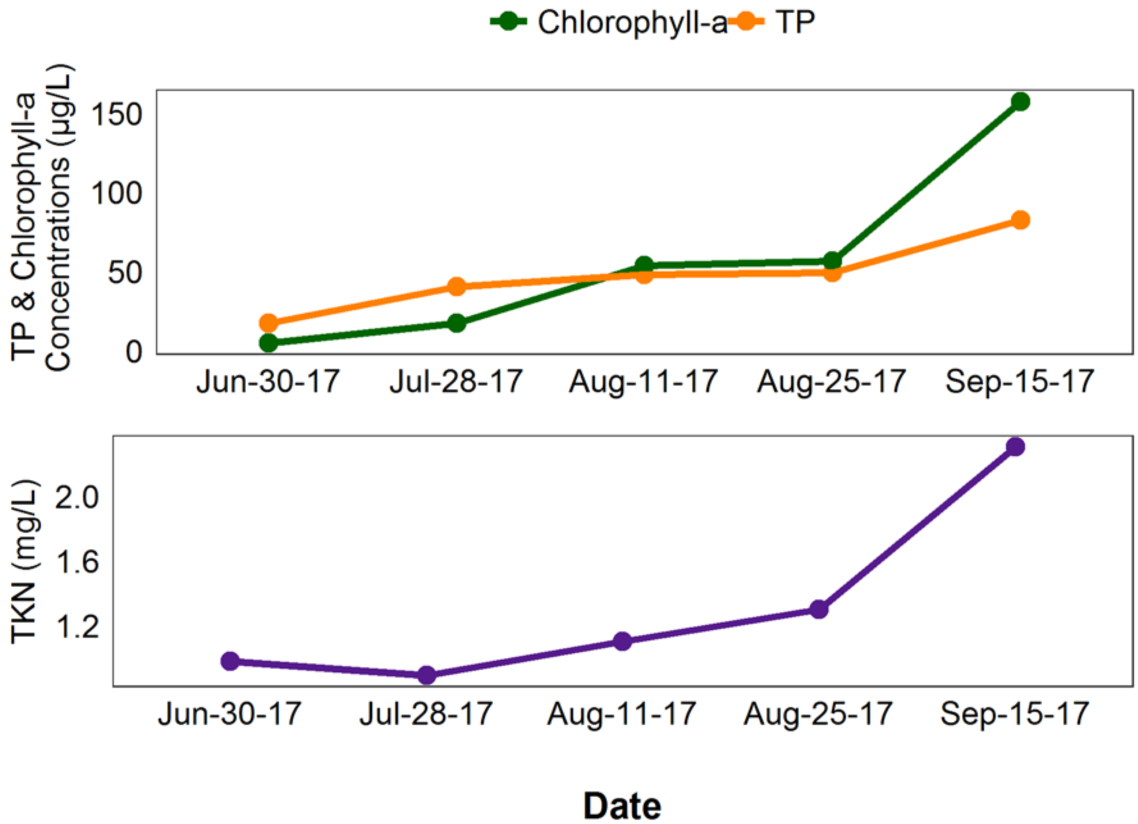


Figure 1- Total Phosphorus (TP), Chlorophyll-*a*, and Total Kjeldahl Nitrogen (TKN) concentrations measured five times over the course of the summer at Pigeon Lake.

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 2017 was 1.85 m (Table 2). Water clarity measured as Secchi depth decreased over the course of the sampling season. The decreasing water clarity is likely associated with increasing algae biomass in the warmer months of the summer.

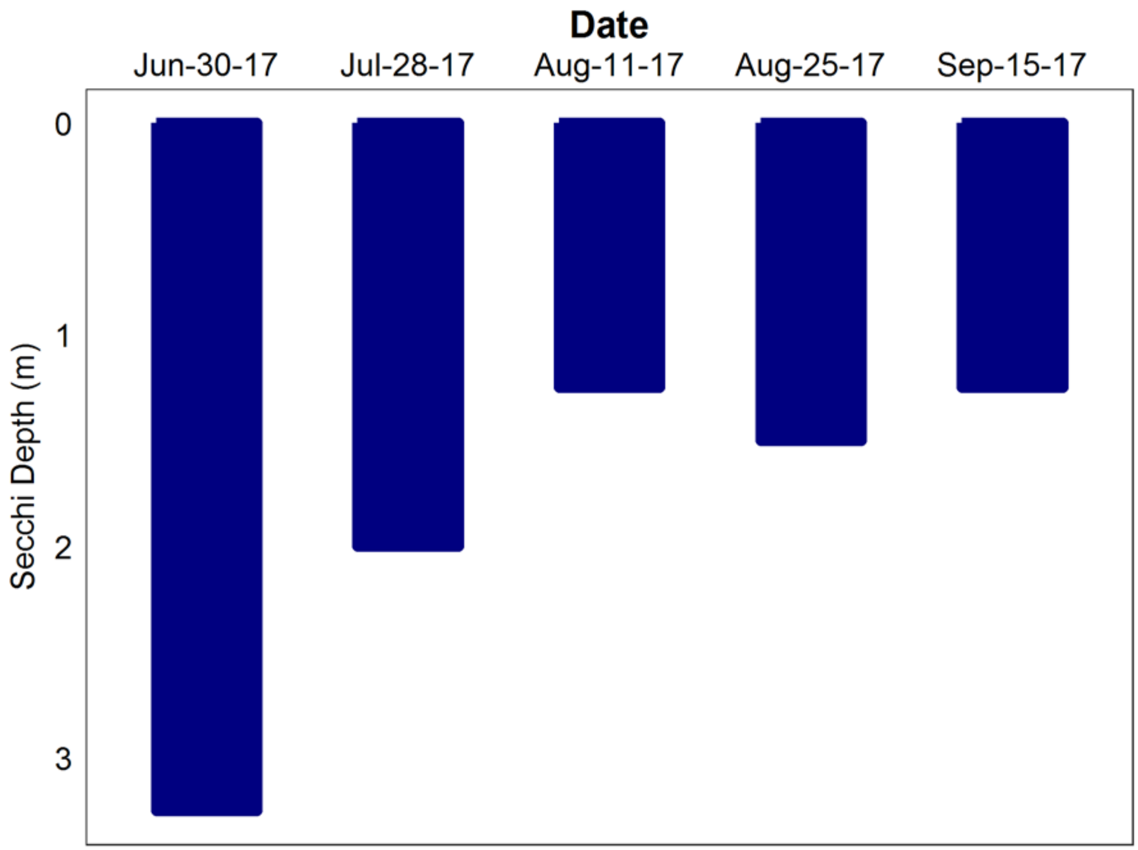


Figure 2 – Secchi depth values measured five times over the course of the summer at Pigeon Lake in 2017.

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 Pigeon Lake varied throughout the summer, with a maximum temperature of 20.7 °C measured at the surface on August 11 (Figure 3a). Given its shallow maximum depth (9 m) and large fetch, Pigeon Lake was well mixed and stratification was not observed during 2017 sampling.

Pigeon Lake 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). On August 11, oxygen was supersaturated at the surface, likely due to photosynthesis by cyanobacteria.

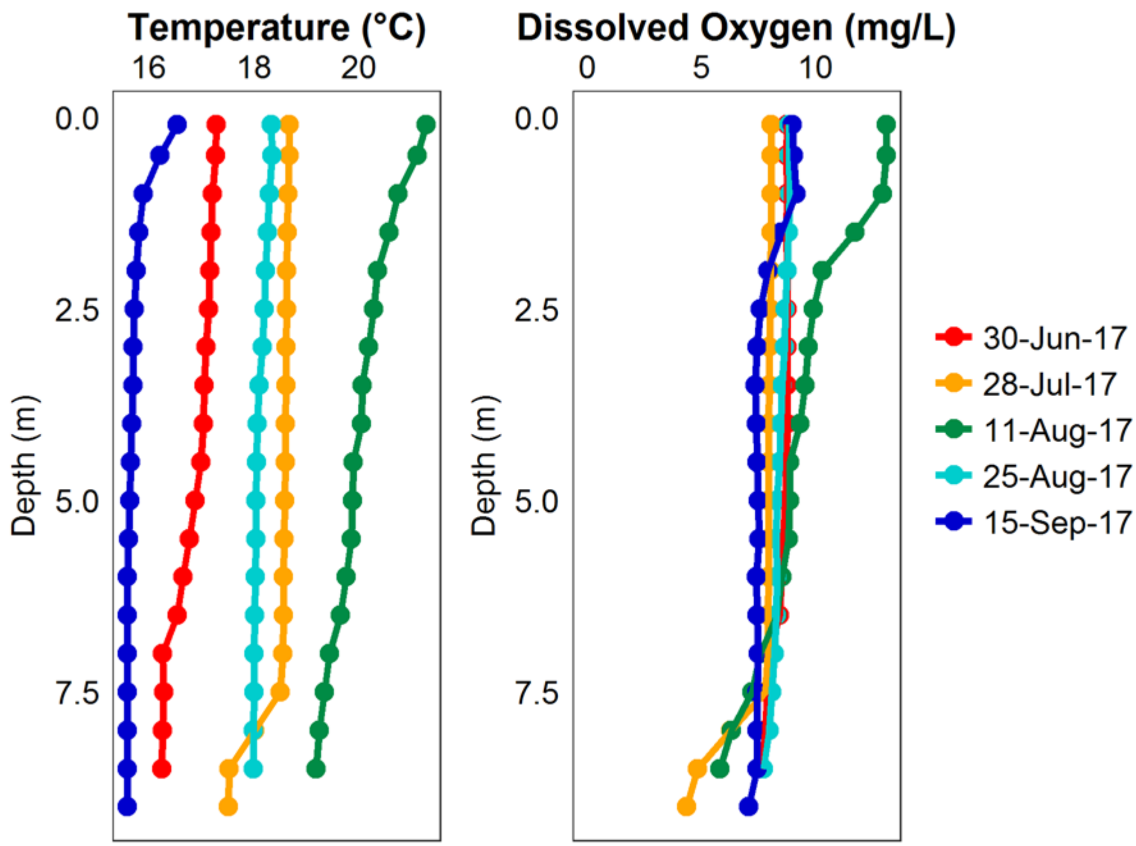


Figure 3 – a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Pigeon Lake measured five times over the course of the summer of 2017.

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 Pigeon Lake measured below the recreational guideline for the entire sampling period of 2017 (Table 1).

Table 1 – Microcystin concentrations measured five times at Pigeon Lake in 2017.

Date	Microcystin Concentration (µg/L)
Jun-30-17	0.05
Jul-28-17	0.16
Aug-11-17	0.30
Aug-25-17	0.73
Sep-15-17	1.13
Average	0.47

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. No mussels have been detected in Pigeon Lake during monitoring from 2013-2017.

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]

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

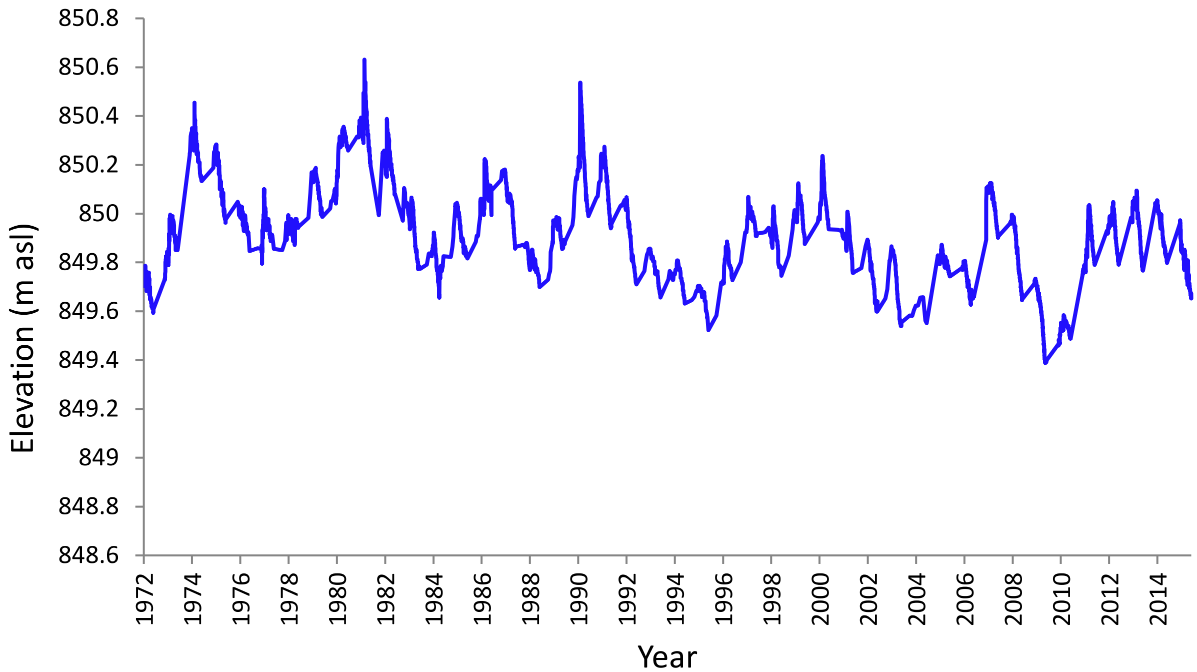


Figure 4- Water levels measured in meters above sea level (m asl) from 1972-2015. Data retrieved from Environment Canada.

Table 2: 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	34.9	22.5	29.3	29	42.6	29.1	26.1	33.8	38	35.5	29.1	32.1
TDP (μg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Chlorophyll-*a* (μg/L)	9.91	14.1	13.8	16.13	9.85	25.7	9.2	11.94	17.4	18.6	16.08	16.6	17.53
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	2.2
TKN (mg/L)	0.945	/	640	/	/	/	/	/	/	/	/	/	0.850
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	15.3	16.3	15	15	17.1	16.12	14.33	14	17	17	17	17.5
K (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
SO_4^{2-} (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Cl^- (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
CO_3 (mg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
HCO_3 (mg/L)	180.5	178.2	184	168.62	176.15	170.52	187.3	175.3	176.7	174	174.7	176.5	167.5
pH	8.37	8.43	8.35	8.57	8.5	8.36	8.32	8.5	8.46	8.45	8.56	8.6	8.61
Conductivity (μS/cm)	283.25	288	292.25	280.3	293	279	302.2	293.7	292.7	285.7	286.7	290	281.5
Hardness (mg/L)	112.13	103.25	113	109.7	111	109.25	119.95	122	120.7	110.7	113.3	113.5	110.5
TDS (mg/L)	156.7	153.7	157.9	151.21	157.41	151.1	163	157.7	155.7	152.3	154	154.5	156
Microcystin (μg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	151.75	152.95	152.58	147	153.5	144.9	155.8	152.7	150	146	148	149.5	148.5

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

Parameter	**1996**	**1997**	**2001**	**2003**	**2005**	**2006**	**2008**	**2010**	**2011**	**2013**	**2014**	**2015**	**2016**	**2017**
TP (µg/L)	37.5	29.9	35	63	26.5	60.3	26.3	40.7	74.7	27.3	45.8	60.6	26	47.2
TDP (µg/L)	/	/	/	/	6	38	9	13	19.1	7.69	16.4	11.2	6	4.1
Chlorophyll-*a* (µg/L)	18.5	12.77	15	36.9	9.2	21.9	7.98	21.92	66.2	12.28	19.24	40.84	27.9	57.7
Secchi depth (m)	1.8	2.5	1.5	1.38	1.9	2.7	4.42	2.75	1.25	3.23	2.31	1.65	3.36	1.85
TKN (mg/L)	/	/	0.611	1.075	0.71	1.1	0.67	1.033	1.5	0.78	0.72	1.338	0.85	1.3
NO_2-N and NO_3-N (µg/L)	/	/	1	/	3	29	13	7.67	15.9	5.91	26	2.5	2.5	2.26
NH_3-N (µg/L)	/	/	3	/	2.5	124	16	72.3	108.9	28.39	24.6	31	25	20.5
DOC (mg/L)	/	/	/	/	/	7	/	7.35	/	/	8.3	7.8	7.06	7.9
Ca (mg/L)	/	/	/	/	28.85	21.13	27.2	23.75	19.5	27.62	22.83	19.8	25.8	24.6
Mg (mg/L)	/	/	/	/	12.65	14.12	12.87	13.85	12.5	12.84	11.43	12.6	14.2	14.6
Na (mg/L)	14.6	18.6	/	18.7	20	21	20.33	21.95	20.1	20.57	23.6	20.8	23.8	24
K (mg/L)	/	/	/	/	6.1	6.63	6.17	6.3	6.2	6.59	6.6	6.1	7.4	7.34
SO_4^{2-} (mg/L)	/	/	/	/	7.3	10.2	5.47	9	3.38	6.38	5.03	4.5	6	5.36
Cl^- (mg/L)	/	/	/	/	4	3.33	3.33	3.05	3.03	3.19	3.5	3.8	3.72	4.46
CO_3 (mg/L)	/	/	/	/	8	4.67	3.33	0.5	8.7	3.27	5.92	3.61	5.56	7.62
HCO_3 (mg/L)	163	190	/	168.5	183	180	198	195	161	194.53	191.6	178	184	178
pH	8.66	8.17	/	8.56	8.6	8.5	8.37	8.57	8.74	8.34	8.59	8.48	8.60	8.63
Conductivity (µS/cm)	293	304	/	/	313	287	321.7	309.5	286.7	320	314	298	320	316
Hardness (mg/L)	106	130	/	103	125	119	121	116	100.2	122	103.9	100.8	124	120
TDS (mg/L)	151	169	/	/	176.5	173	175.33	173.5	153	176	182.3333	166	190	182
Microcystin (µg/L)	/	/	/	/	/	/	/	0.087	0.173	0.1354	0.972	2.318	0.13	0.47
Total Alkalinity (mg/L $CaCO_3$)	149	156	/	151	163	155.3	165.7	160	146.7	164	156.8	154	160	160

Table 3: Concentrations of metals measured once in Pigeon Lake on August 25. 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 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

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, no significant changes were observed in total phosphorus, chlorophyll-*a* and Secchi depth, and significant increasing trends were observed in TDS. Secchi depth can be subjective and is sensitive to variation in weather - trend analysis must be interpreted with caution. In addition, variability was significantly greater post-2002 compared to pre-2002 across all parameters. 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 1: Summary table of trend analysis on Pigeon Lake data from 1983 to 2017.

Parameter	Date Range	Trend	Probability
Total Phosphorus	1983-2017	Increasing	Non-significant
Chlorophyll-*a*	1983-2017	Increasing	Non-significant
Total Dissolved Solids	1983-2017	Increasing	Significant
Secchi Depth	1983-2017	Increasing	Non-significant

Definitions:

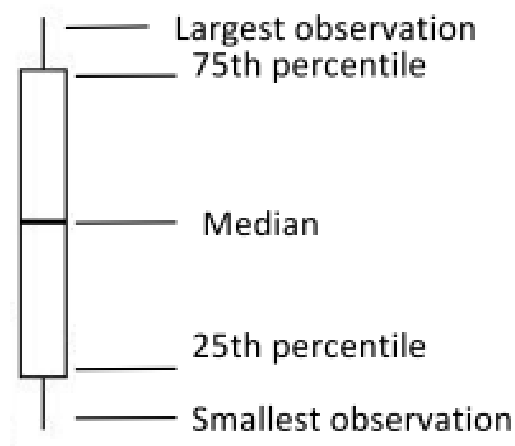
Median: the value in a range of ordered numbers that falls in the middle.

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.

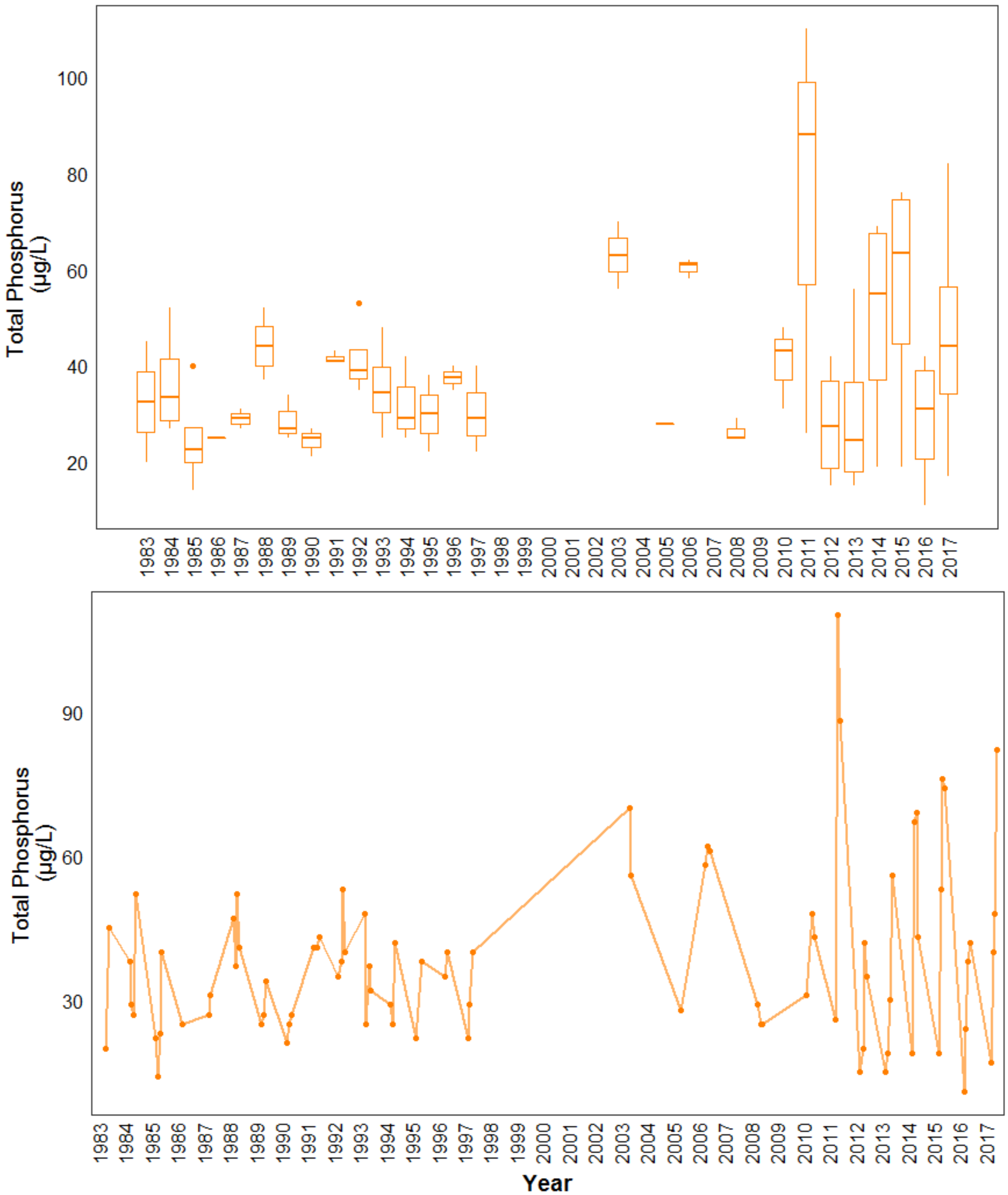
Box and Whisker Plot: a box-and-whisker plot, or boxplot, is a way of displaying all of our annual data. The median splits the data in half. The 75th percentile is the upper quartile of the data, and the 25th percentile is the lower quartile of the data. The top and bottom points are the largest and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



Total Phosphorus (TP)

Total phosphorus (TP) has not changed significantly over the course of data collection at Pigeon Lake ($p = 0.116$; Table 2). TP variability has also increased post-2002. Before 1998, TP was less variable between samplings and years. The Levene test showed an increase in the variability of the data after 2002 ($p < 0.001$).

Figure 1-Monthly total phosphorus (TP) concentrations measured between June and September over the long



term sampling dates between 1983 and 2017 (n = 83). 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 not changed significantly over the course of data collection at Pigeon Lake (Tau = 0.118, p = 0.114; Table 2). Chlorophyll-*a* trends follow TP trends closely, and Chlorophyll-*a* is correlated with TP over time (r = 0.72, $p < 0.001$). Since 2002, variability of chlorophyll-*a* data has greatly increased (Figure 2) as proven by the Levene test (p = 0.0085).

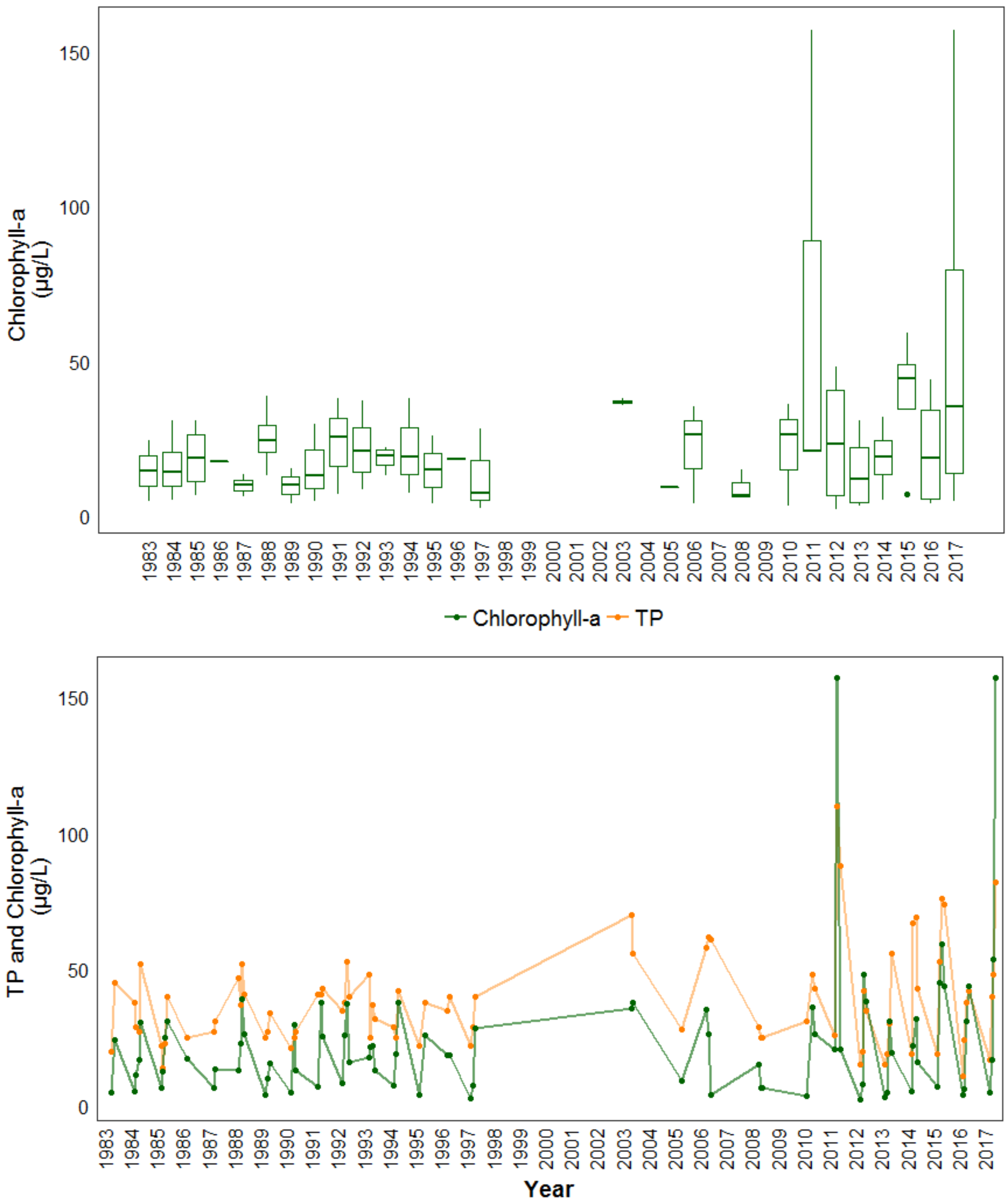


Figure 2-Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 1983 and 2017 (n = 83). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

TDS has significantly increased in Pigeon Lake since 1983 (Table 2). Trend analysis showed a significant increasing trend (Tau= 0.49, $p < 0.001$). Since 2002, the variability of TDS has also increased ($p = 0.00077$).

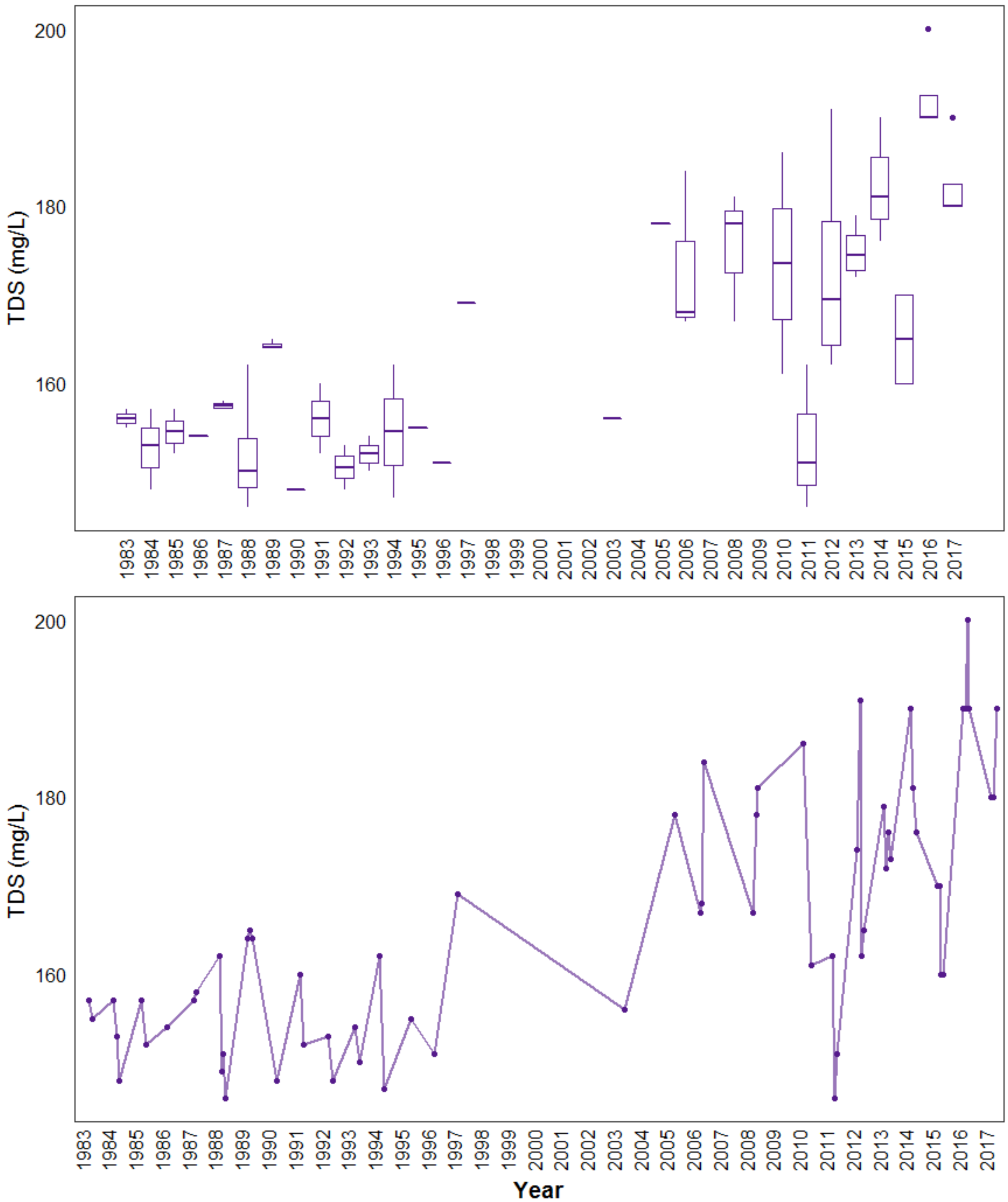


Figure 3-Monthly TDS concentrations (mg/L) measured between June and September over the long term sampling dates between 1983 and 2017 (n = 65). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Trend analysis found no significant trends in Secchi depth over the sampling period (Tau = 0.48, *p* = 0.518). A Levene test revealed that variation in Secchi depths have increased post-2002 (*p* = 0.00436).

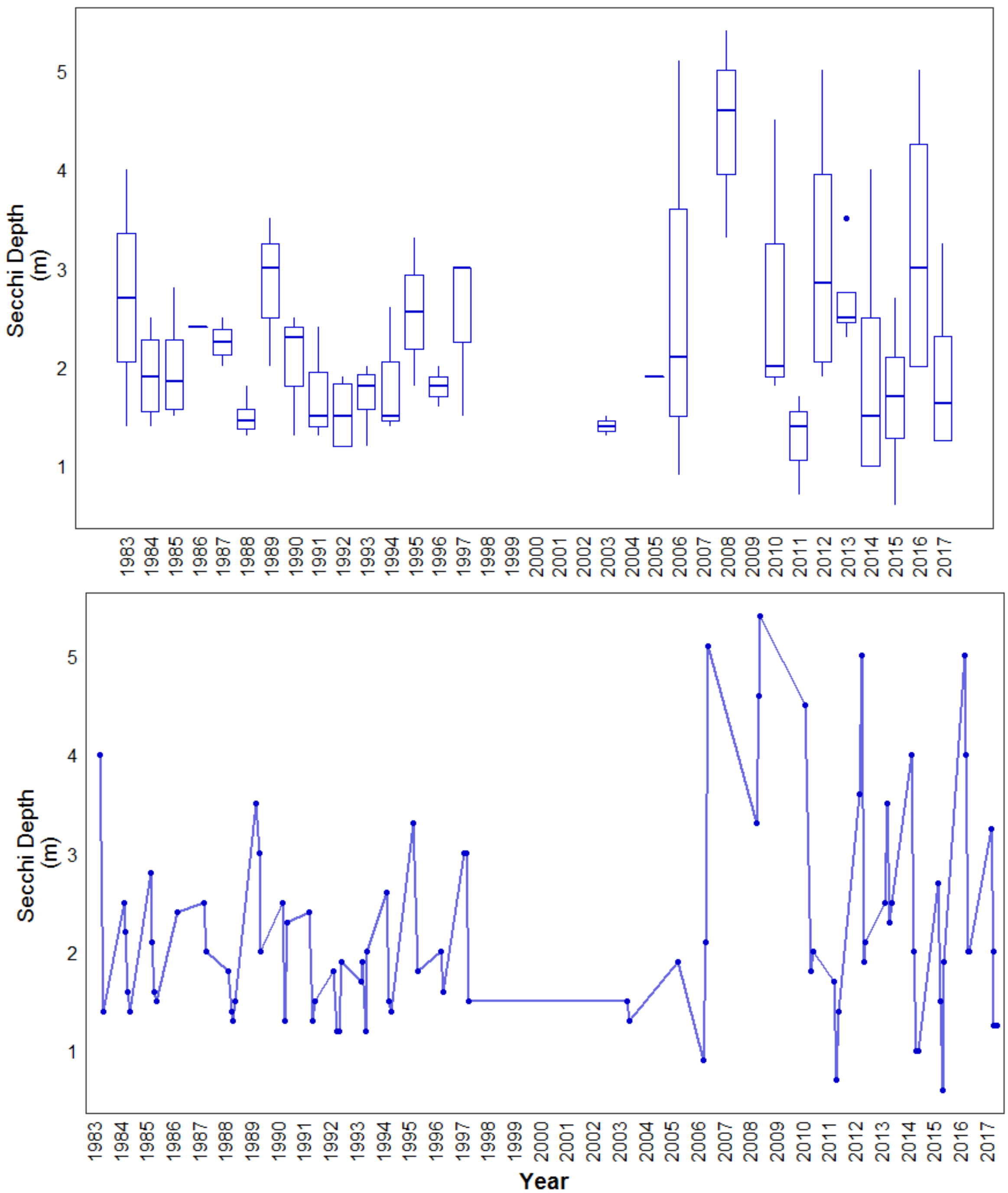


Figure 4-Monthly Secchi depth values measured between June and September over the long term sampling dates between 1983 and 2017 (n = 83). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 2- Results of Mann-Kendall Trend tests using monthly 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	Mann Kendall	Mann Kendall
The strength and direction (+ or -) of the trend between -1 and 1	**Tau**	0.12	0.12	0.49	0.048
The extent of the trend	**Slope**	0.00068	0.00058	0.0022	0.000011
The statistic used to find significance of the trend	**Z**	1.57	1.58	5.73	0.64
Number of samples included	**n**	83	83	65	84
The significance of the trend	***p***	0.116	0.114	1×10^{-8}*	0.518

*$p < 0.05$ is significant within 95%