



*The Alberta Lake Management Society  
Volunteer Lake Monitoring Program*

## Pigeon Lake Report

# 2021

Updated May 6, 2022

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 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 Keri Malanchuk and Brittany Onysyk, who were summer technicians in 2021. 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.

BEFORE READING THIS REPORT, CHECK  
OUT [A BRIEF INTRODUCTION TO  
LIMNOLOGY](#) AT [ALMS.CA/REPORTS](#)

## PIGEON LAKE

Pigeon Lake is a large (96.32 km<sup>2</sup>), 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.<sup>1</sup> The lake's drainage basin is heavily developed with agriculture, oil and gas, and community developments.<sup>2</sup>



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

The lake name is a translation from the Cree Mehmew Sâkâhikan, which means 'Dove Lake', but by 1858 the name Pigeon Lake was established.<sup>3</sup> It has been suggested that the name Pigeon Lake refers to the huge flocks of Passenger Pigeons that once lived in the area.<sup>1</sup> The lake was also previously known as Woodpecker Lake, and the Stoney name is recorded as Ke-gemni-wap-ta.<sup>3</sup> 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<sup>4</sup>. 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<sup>5</sup>. In 2018 the Pigeon Lake Watershed Association released their Pigeon Lake Watershed Management Plan which can be accessed via [www.plwmp.ca](http://www.plwmp.ca).

The watershed area for Pigeon Lake is 176.62 km<sup>2</sup> and the lake area is 97.32 km<sup>2</sup>. 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>.

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

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

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

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

<sup>5</sup> Teichreb, C. (2014). Pigeon Lake Phosphorus Budget. Alberta Environment and Sustainable Resource Development. 28 pp.



## 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 29 µg/L (Table 2), falling into the mesotrophic, or moderately productive trophic classification. This value is in the mid to low-range of historical averages. TP was lowest early in the season at 17 µg/L during the June 4<sup>th</sup> sampling event, and increased later in the season at a peak of 39 µg/L during the August 4<sup>th</sup> sampling event (Figure 1). TP had a significantly positive correlation with TKN ( $r = 0.995$ ,  $p = 0.005$ ).

Average chlorophyll-*a* concentration in 2021 was 30.3 µg/L (Table 2), falling into the hypereutrophic, or very highly productive trophic classification. Chlorophyll-*a* was lowest during the June 4<sup>th</sup> sampling event at 7.0 µg/L, and increased later in the season and peaked at 51.1 µg/L on September 22<sup>nd</sup> (Figure 1). Chlorophyll-*a* concentrations had a significantly positive correlation with TP ( $r = 0.99$ ,  $p = 0.01$ ).

The average TKN concentration was 1.1 mg/L (Table 2) and varied from 0.82 mg/L to 1.3 mg/L, having the highest levels during the August and September sampling events (Figure 2). TKN was significantly positively correlated with chlorophyll-*a* ( $r = 0.97$ ,  $p = 0.03$ ).

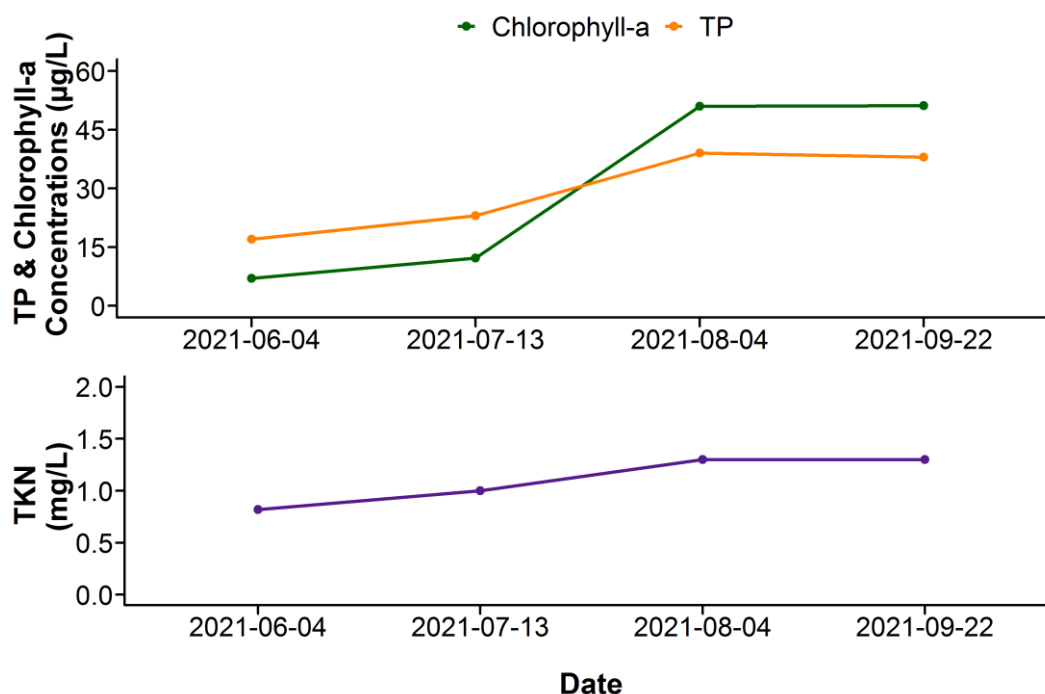


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Pigeon Lake.

Average pH was measured as 8.47 in 2021, buffered by moderate alkalinity (182 mg/L  $\text{CaCO}_3$ ) and bicarbonate (218 mg/L  $\text{HCO}_3^-$ ). Bicarbonate was by far the most dominant ion, but calcium, sodium and magnesium were slightly higher than the other ions (Figure 2, top.) Together, the ions contributed to a low conductivity of 332  $\mu\text{S}/\text{cm}$  (Table 2). Pigeon Lake is in the moderate to low range of ion levels compared to other LakeWatch lakes sampled in 2021 (Figure 2, bottom).

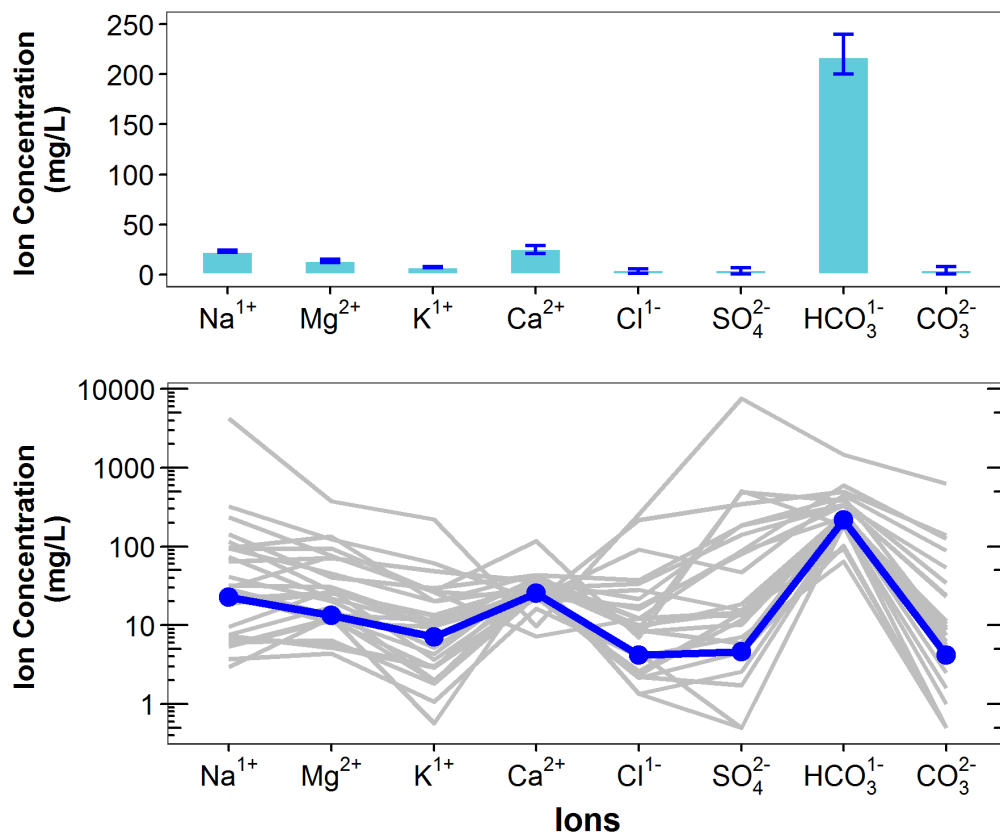


Figure 2. Average levels of cations (sodium =  $\text{Na}^+$ , magnesium =  $\text{Mg}^{2+}$ , potassium =  $\text{K}^+$ , calcium =  $\text{Ca}^{2+}$ ) and anions (chloride =  $\text{Cl}^-$ , sulphate =  $\text{SO}_4^{2-}$ , bicarbonate =  $\text{HCO}_3^-$ , carbonate =  $\text{CO}_3^{2-}$ ) from four 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 25 lake basins (gray lines) sampled through the LakeWatch program in 2021 (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 2021, but Table 3 displays historical metal concentrations.

## 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 2021 was 5.18 m, corresponding to an average Secchi depth of 2.59 m (Table 2). The euphotic depth was very deep during the June 4<sup>th</sup> sampling event at 8.40 m depth, but decreased through the season to a low of 3.1 m on August 4<sup>th</sup>, followed by a slight increase again during the September 22<sup>nd</sup> sampling event, to 3.60 m (Figure 3).

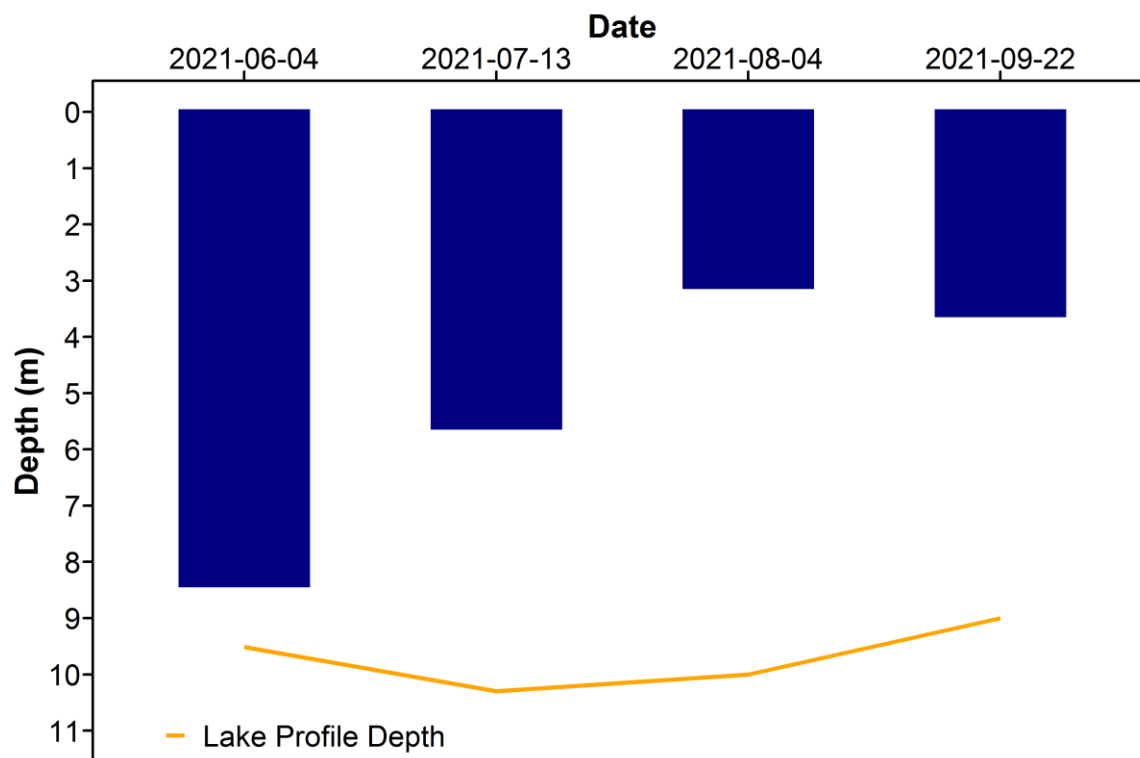


Figure 3. Euphotic depth values measured four times over the course of the summer at Pigeon Lake in 2021.

## 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 temperatures of Pigeon Lake varied throughout the summer, with the July 13<sup>th</sup> sampling date having the warmest temperatures at 22.4°C (Figure 4a). The lake was weakly stratified during the June sampling event, and was mixed during all other sampling events.

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 June 4<sup>th</sup> sampling event displayed an increase in oxygen levels corresponding to the depth of the thermocline, about 5 m, indicating increased algal growth at this depth. Oxygen levels only dropped below 6.5 mg/L during the June 4<sup>th</sup>, July 13<sup>th</sup> and August 4<sup>th</sup> sampling events, at 8.5 m, 6.5 m, and 9 m, respectively. Anoxia (dissolved oxygen <1.0 mg/L) was not detecting during any sampling event.

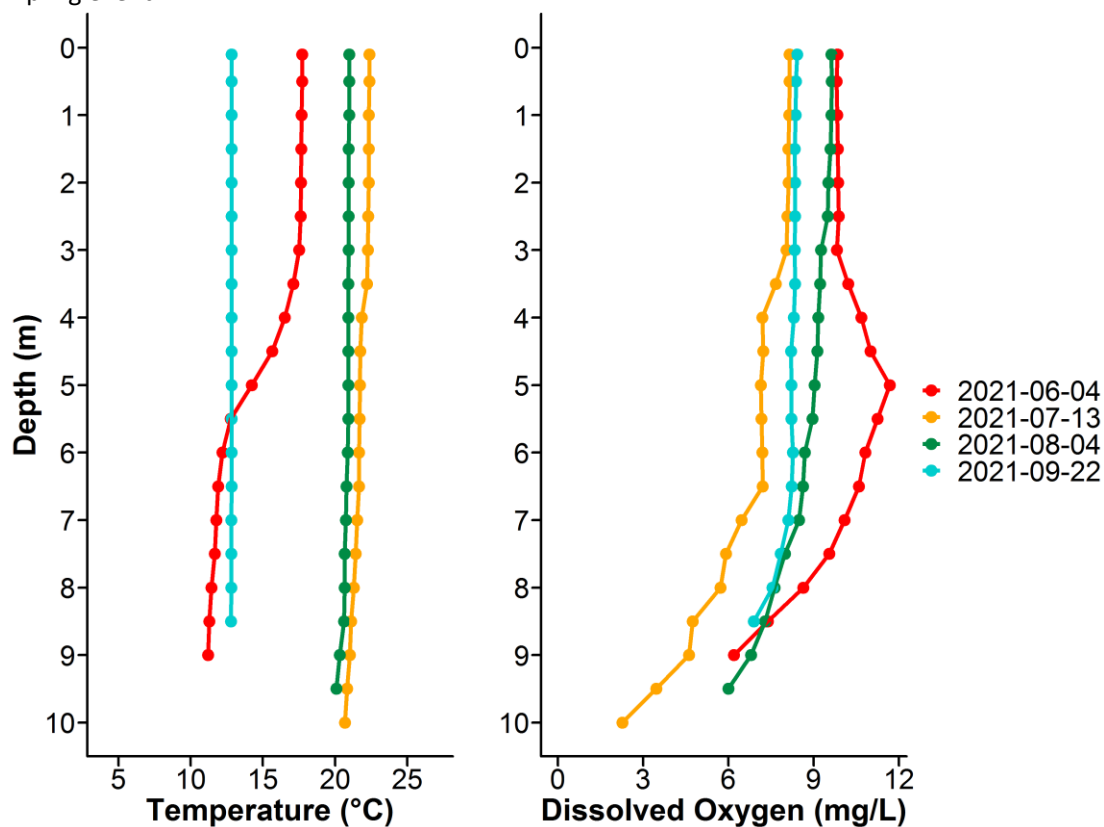


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Pigeon Lake measured four times over the course of the summer of 2021.



## 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 2021 (Table 1), and the seasonal average is on the moderate to low end of historical averages (Table 2). In addition, microcystin levels from June 4<sup>th</sup> were below the laboratory detection limit of 0.10 µg/L. A value of 0.05 µg/L is assigned to this date in order to calculate an average. Even though low levels of microcystin were detected, caution should always be observed when recreating around cyanobacteria.

Table 1. Microcystin concentrations measured four times at Pigeon Lake in 2021.

| Date      | Microcystin Concentration (µg/L) |
|-----------|----------------------------------|
| 4-Jun-21  | <0.1                             |
| 13-Jul-21 | 0.12                             |
| 4-Aug-21  | 0.47                             |
| 22-Sep-21 | 0.26                             |
| Average   | 0.22                             |

## 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 involved sampling with a 63 µm plankton net at three sample sites, to look for juvenile mussel veligers and spiny water flea in each lake sampled. In 2021, 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 suspect watermilfoil was observed or collected from Pigeon Lake in 2021.

## 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 2021 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.

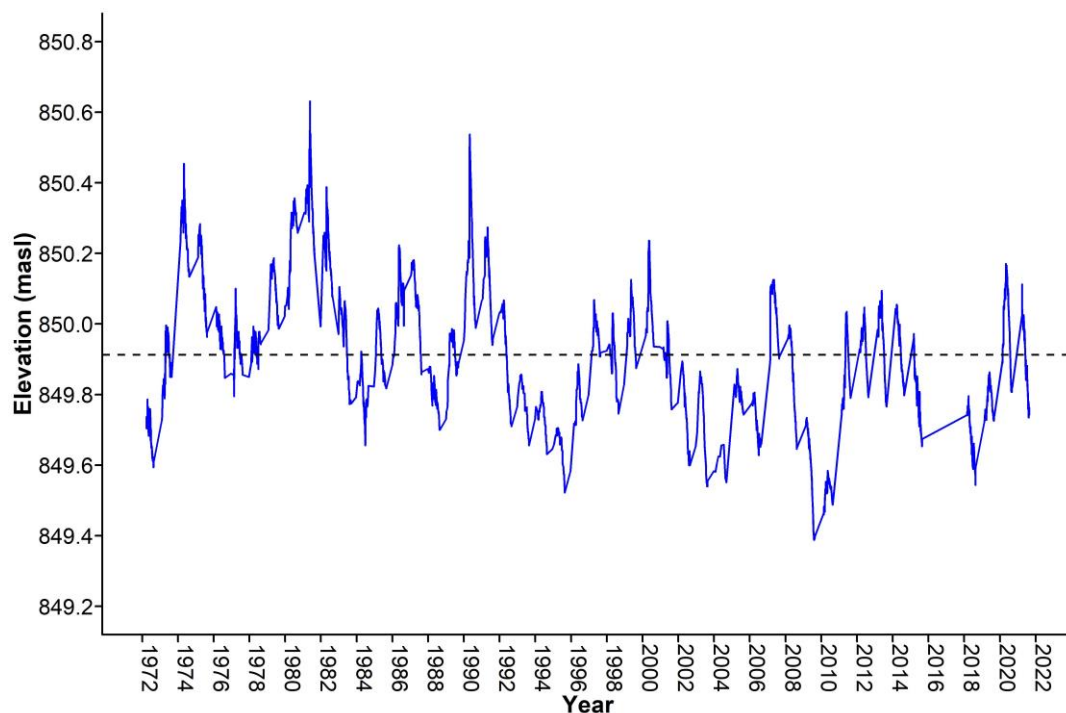


Figure 5. Water levels measured at Pigeon Lake in metres above sea level (masl) from 1972-2021. Data retrieved from Alberta Environment and Parks and Environment Canada. Black dashed line represents historical yearly average water level.

## 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, drier, slightly less windy summer with slightly more solar radiation compared to normal (Figure 6). A few warm spells prior to the July 13<sup>th</sup> sampling likely resulted in relatively high whole-lake temperatures. At some point during the June 4<sup>th</sup> and July 13<sup>th</sup> sampling events, the lake completely mixed, or turned over, likely during a significant windy spell in late June.

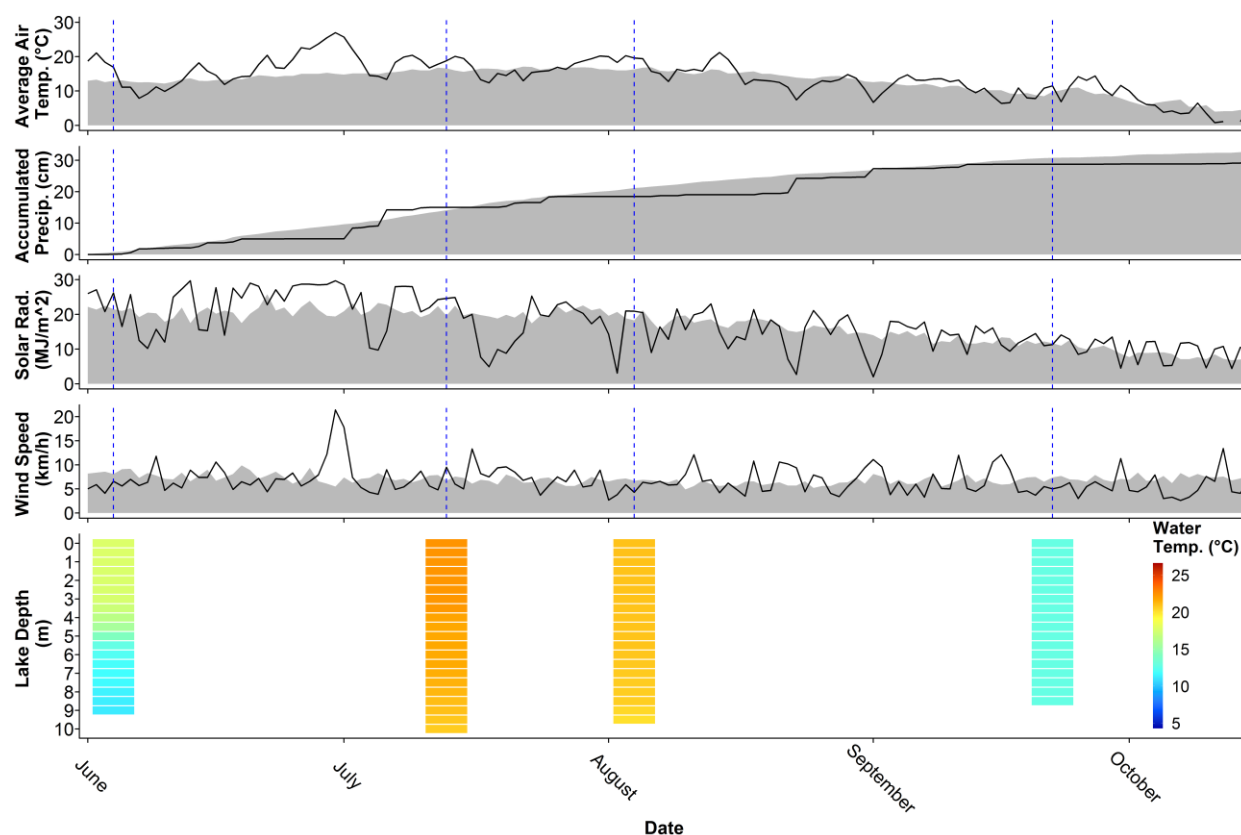


Figure 6. Average air temperature (°C), accumulated precipitation (cm), and wind speed (km/h) measured from Hoselaw AGCM, as well as solar radiation (MJ/m<sup>2</sup>) measured from Dupre AGCM, with Pigeon Lake temperature profiles (°C) at the bottom. Black lines indicate 2021 levels, gray indicates 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 2021 Methods report. Weather data provided by Agriculture, Forestry and Rural Economic Development, Alberta Climate Information Service (ACIS) <https://acis.alberta.ca> (retrieved April 2022).

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- <i>a</i> (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 <sub>2</sub> -N and NO <sub>3</sub> -N (µg/L) | 22   | 25   | 25   | 25   | 10   | 12   | 6    | 13   | 2    | 8    | 2    | 9    | 5    |
| NH <sub>3</sub> -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 <sub>4</sub> <sup>2-</sup> (mg/L)             | 4    | 3    | 2    | 2    | 2    | 3    | 6    | 4    | 5    | 4    | 3    | 3    | 6    |
| Cl <sup>-</sup> (mg/L)                           | 1    | 0    | 2    | 0    | 2    | 1    | 2    | 1    | 1    | 2    | 2    | 2    | 2    |
| CO <sub>3</sub> (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 <sub>3</sub> (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 <sub>3</sub> )       | 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- <i>a</i> (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 <sub>2</sub> -N and NO <sub>3</sub> -N (µg/L) | /    | /    | /    | 10   | 3    | 29   | 13   | 8    | 16   | 4    | 6    | 26   |
| NH <sub>3</sub> -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 <sub>4</sub> <sup>2-</sup> (mg/L)             | 5    | 6    | /    | 5    | 8    | 10   | 5    | 9    | 3    | 6    | 6    | 5    |
| Cl <sup>-</sup> (mg/L)                           | 2    | 0    | /    | 2    | 4    | 3    | 3    | 3    | 3    | 4    | 3    | 4    |
| CO <sub>3</sub> (mg/L)                           | 9    | 0.2  | /    | 7.5  | 7    | 4.7  | 3.3  | 0.5  | 8.7  | 5.5  | 3.3  | 6.1  |
| HCO <sub>3</sub> (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 <sub>3</sub> )       | 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 |
|--|------|------|------|------|------|------|------|
| TP (µg/L)  | 61   | 26   | 47   | 33   | 22   | 44   | 29   |
| TDP (µg/L)                                       | 11   | 6    | 4    | 6    | 6    | 10   | 6    |
| Chlorophyll- <i>a</i> (µg/L)                     | 40.8 | 27.9 | 57.7 | 39.2 | 14.8 | 38.6 | 30.3 |
| Secchi depth (m)                                 | 1.66 | 3.36 | 1.88 | 2.3  | 2.95 | 2.17 | 2.6  |
| TKN (mg/L)                                       | 1.3  | 0.8  | 1.3  | 1    | 0.8  | 1.2  | 1.1  |
| NO <sub>2</sub> -N and NO <sub>3</sub> -N (µg/L) | 2    | 2    | 2    | 7    | 6    | 9    | 7    |
| NH <sub>3</sub> -N (µg/L)                        | 31   | 25   | 21   | 12   | 11   | 34   | 15   |
| DOC (mg/L)                                       | 8    | 7    | 8    | 8    | 8    | 7    | 8    |
| Ca (mg/L)  | 20   | 26   | 25   | 25   | 26   | 25   | 25   |
| Mg (mg/L)  | 13   | 14   | 15   | 14   | 14   | 14   | 13   |
| Na (mg/L)  | 21   | 24   | 24   | 24   | 24   | 24   | 23   |
| K (mg/L)   | 6    | 7    | 7    | 7    | 7    | 7    | 7    |
| SO <sub>4</sub> <sup>2-</sup> (mg/L)             | 4    | 6    | 5    | 7    | 7    | 5    | 5    |
| Cl <sup>-</sup> (mg/L)                           | 4    | 4    | 4    | 5    | 5    | 5    | 4    |
| CO <sub>3</sub> (mg/L)                           | 3.6  | 5.6  | 7.6  | 6.6  | 3.7  | 1.8  | 4.2  |
| HCO <sub>3</sub> (mg/L)                          | 178  | 184  | 178  | 188  | 195  | 182  | 218  |
| pH   | 8.48 | 8.61 | 8.63 | 8.56 | 8.51 | 8.39 | 8.47 |
| Conductivity (µS/cm)                             | 298  | 320  | 316  | 328  | 332  | 318  | 332  |
| Hardness (mg/L)                                  | 101  | 124  | 120  | 124  | 125  | 120  | 118  |
| TDS (mg/L)                                       | 166  | 190  | 182  | 196  | 195  | 170  | 195  |
| Microcystin (µg/L)                               | 2.32 | 0.13 | 0.47 | 0.58 | 0.07 | 0.25 | 0.22 |
| Total Alkalinity (mg/L CaCO <sub>3</sub> )       | 154  | 160  | 160  | 164  | 168  | 150  | 182  |



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 <sup>a</sup>       |
| 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 <sup>c,d</sup>     |
| 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 <sup>b</sup>      |
| 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 <sup>c,d</sup> |
| Copper µg/L                | 1.08   | 0.2255   | 0.4155   | 0.235    | 0.5    | 0.22   | 2.76 <sup>b</sup>      |
| 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 <sup>b</sup>      |
| Lithium µg/L               | 8.6    | 9.09     | 8.29     | 9.175    | 11.2   | 9.47   | 2500 <sup>d</sup>      |
| Manganese µg/L             | 54.1   | 16.9     | 15.75    | 49.65    | 6.48   | 27.5   | 170 <sup>e</sup>       |
| 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 <sup>b</sup>     |
| 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 <sup>c,d</sup>     |
| Zinc µg/L                  | 1.5    | 0.899    | 1.56     | 0.65     | 0.9    | 0.3    | 30 <sup>f</sup>        |

Values represent means of total recoverable metal concentrations.

<sup>a</sup> Based on pH ≥ 6.5

<sup>b</sup> Based on 2017 avg. water hardness (as CaCO<sub>3</sub>) with CCME equation

<sup>c</sup> Based on CCME Guidelines for Agricultural use (Livestock).

<sup>d</sup> Based on CCME Guidelines for Agricultural Use (Irrigation).

<sup>e</sup> Based on CCME Manganese variable calculation ([https://ccme.ca/en/chemical/129#\\_aql\\_fresh\\_concentration](https://ccme.ca/en/chemical/129#_aql_fresh_concentration)), using 2017 avg. water hardness (as CaCO<sub>3</sub>) and avg. pH

<sup>f</sup> Based on 2017 avg. water hardness (as CaCO<sub>3</sub>), avg. pH, and avg. DOC with CCME equation

<sup>g</sup> Did not exceed guideline due to effect of relatively lower pH value in 2014 on Manganese variable calculation.

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, significant increasing trends were detected for 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 2021.

| Parameter              | Date Range | Direction of Significant Trend |
|------------------------|------------|--------------------------------|
| Total Phosphorus       | 1983-2021  | No change                      |
| Chlorophyll- <i>a</i>  | 1983-2021  | Increasing                     |
| Total Dissolved Solids | 1983-2021  | Increasing                     |
| Secchi Depth           | 1983-2021  | Increasing                     |

## Definitions:

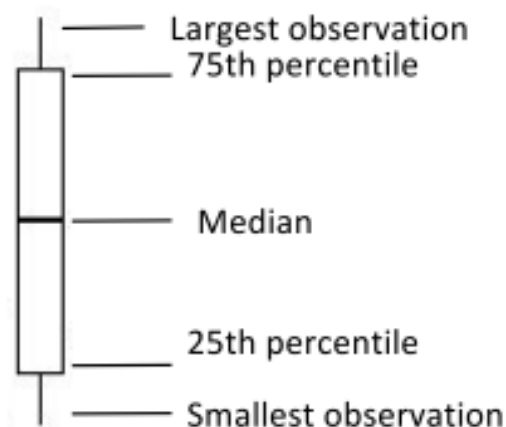
**Median:** the value in a range of ordered numbers that falls in the middle.

**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 75<sup>th</sup> percentile is the upper quartile of the data, and the 25<sup>th</sup> percentile is the lower quartile of the data. The top and bottom points are the largest and smallest observations.



## Total Phosphorus (TP)

Trend analysis indicates there is no significant trend of TP in Pigeon Lake since 1983 ( $\text{Tau} = 1.63 \times 10^{-2}$ ,  $p = 0.81$ ; Table 5).

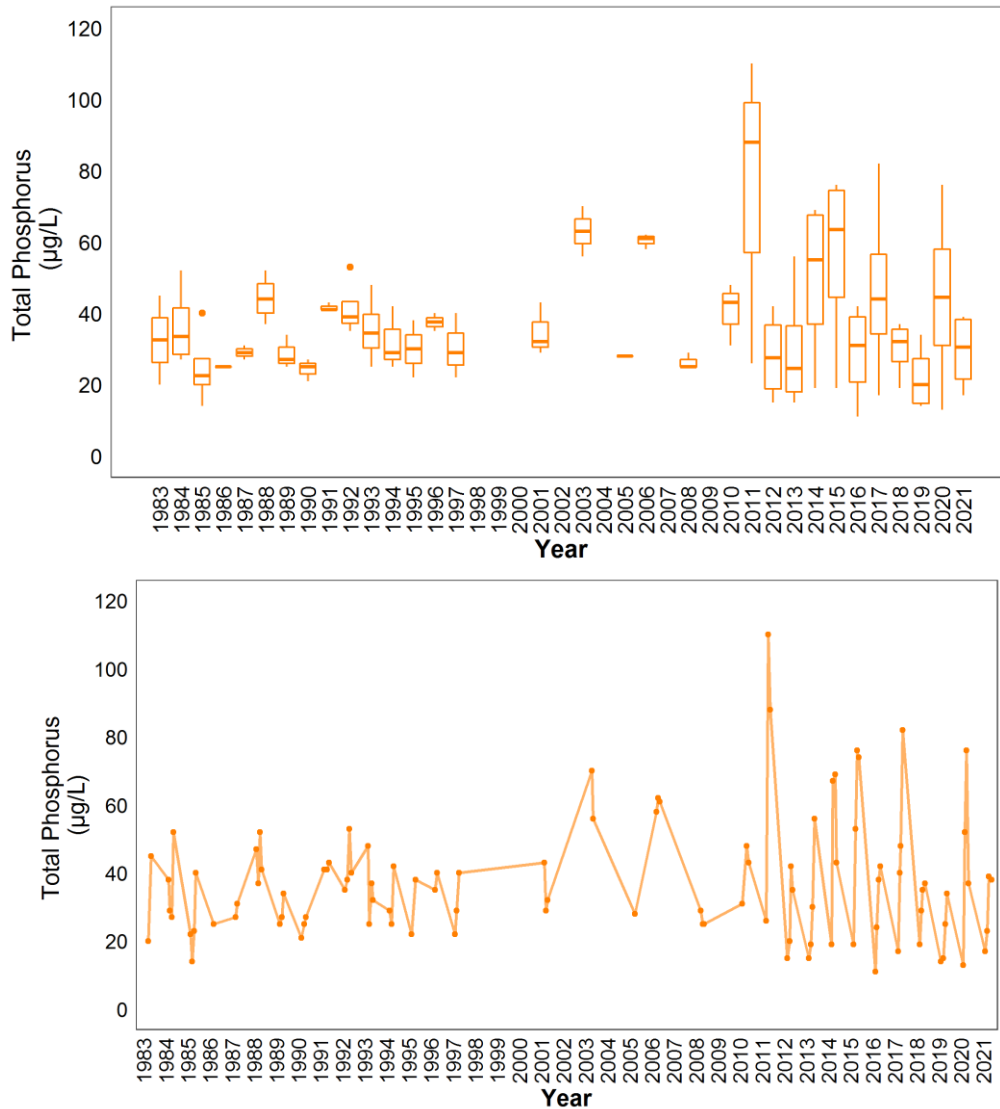


Figure 6. Monthly total phosphorus (TP) concentrations measured between June and September on sampling dates between 1983 and 2021 ( $n = 102$ ). The value closest to the 15<sup>th</sup> day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

## Chlorophyll-*a*

Chlorophyll-*a* has been significantly increasing in Pigeon Lake since 1983 (Tau = 0.14,  $p = 0.038$ ; Table 5). TP and chlorophyll-*a* were significantly correlated ( $r = 0.67$ ,  $p = 1.33 \times 10^{-14}$ ).

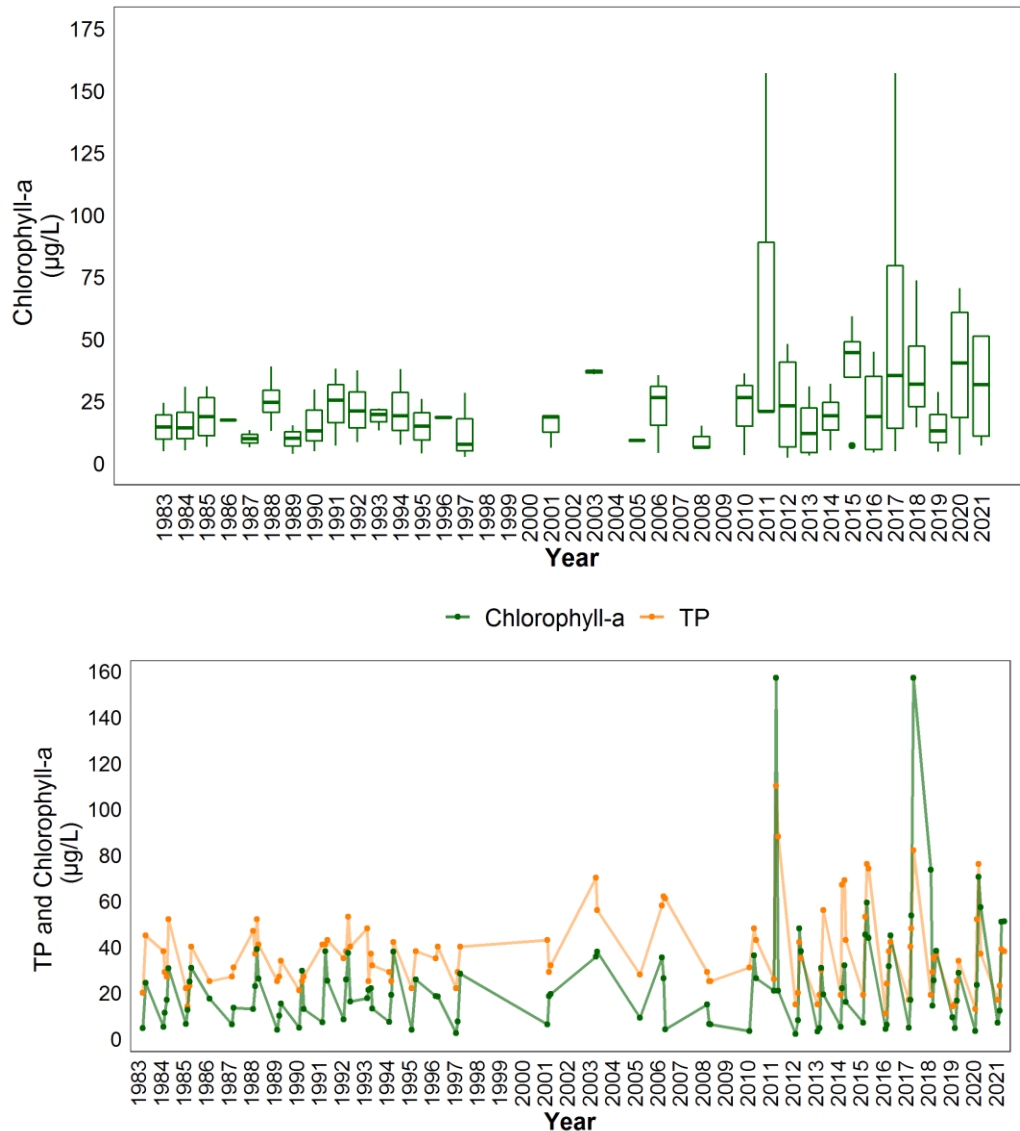


Figure 7. Monthly chlorophyll-*a* concentrations measured between June and September on sampling dates between 1983 and 2021 ( $n = 102$ ). The value closest to the 15<sup>th</sup> day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

## Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 1983 and 2021 (Tau = 0.58,  $p = <0.001$ ) in Pigeon Lake. Though the magnitude of change is slight (slope = 0.96 mg/L per year), the increasing level could be related to the slight downward trajectory of water levels in the lake since the early 1980s (Figure 5).

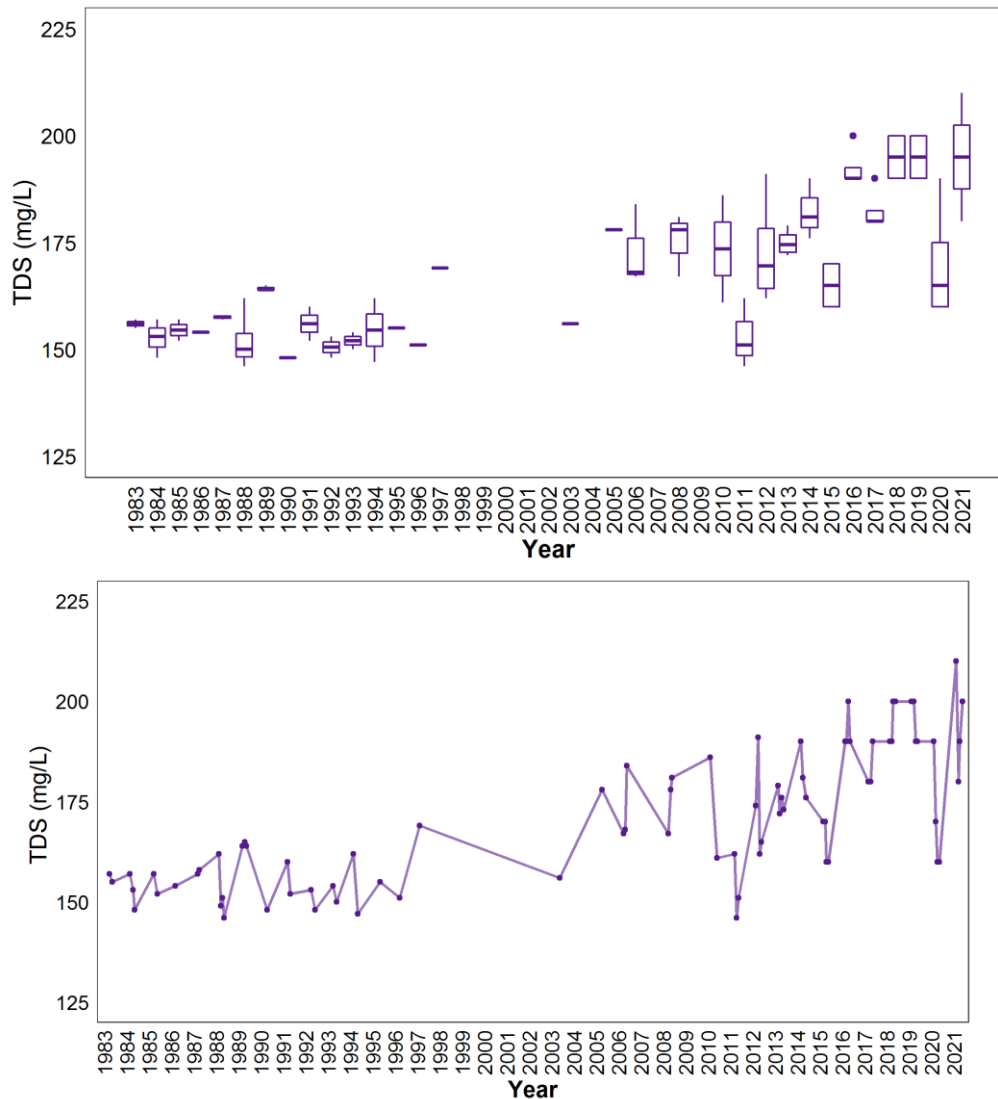


Figure 8. Monthly TDS values measured between June and September on sampling dates between 1983 and 2021 ( $n = 81$ ). The value closest to the 15<sup>th</sup> day of the month was chosen to represent the monthly value in cases with multiple monthly samples.



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 9). 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.

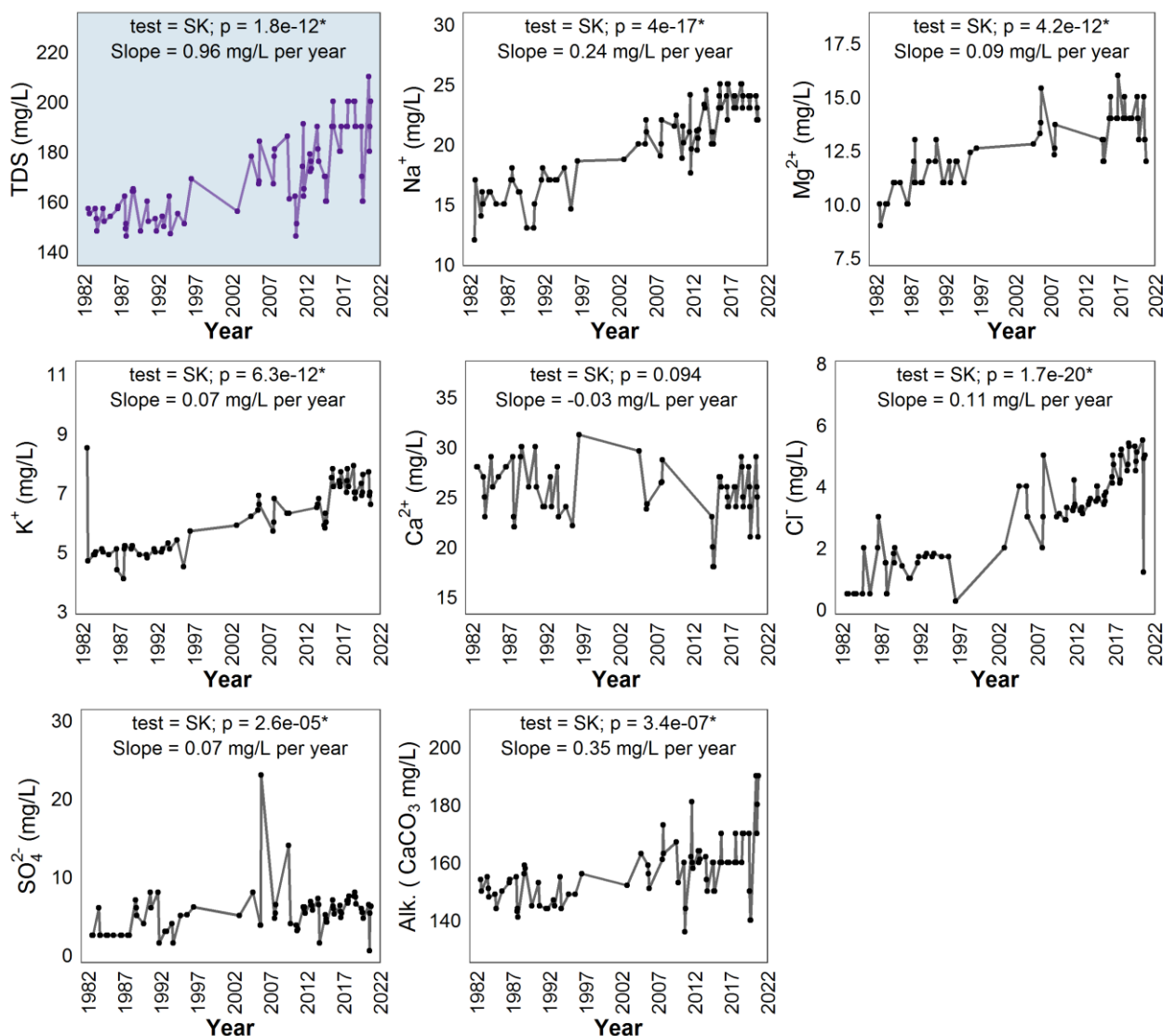


Figure 9. Concentrations of TDS (top left, blue panel), major ions (sodium = Na<sup>+</sup>, magnesium = Mg<sup>2+</sup>, potassium = K<sup>+</sup>, calcium = Ca<sup>2+</sup>, chloride = Cl<sup>-</sup>, sulphate = SO<sub>4</sub><sup>2-</sup>), and total alkalinity (Alk., as mg/L CaCO<sub>3</sub>) measured monthly between June and September on sampling dates between 1983 and 2021. 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<sup>th</sup> 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 indicates that it is significantly increasing in Pigeon Lake since 1983 (Tau = 0.18,  $p = 0.017$ ; Table 5). Visualizations of Secchi depth over time indicates that the variation in Secchi depth appears to be greater in recent years (Figure 9). Levene's test of homogeneity of variance indicates that variance from before the year 2001 compared to 2001 and later is significantly different ( $F = 8.45$ ,  $p = 0.0045$ ).

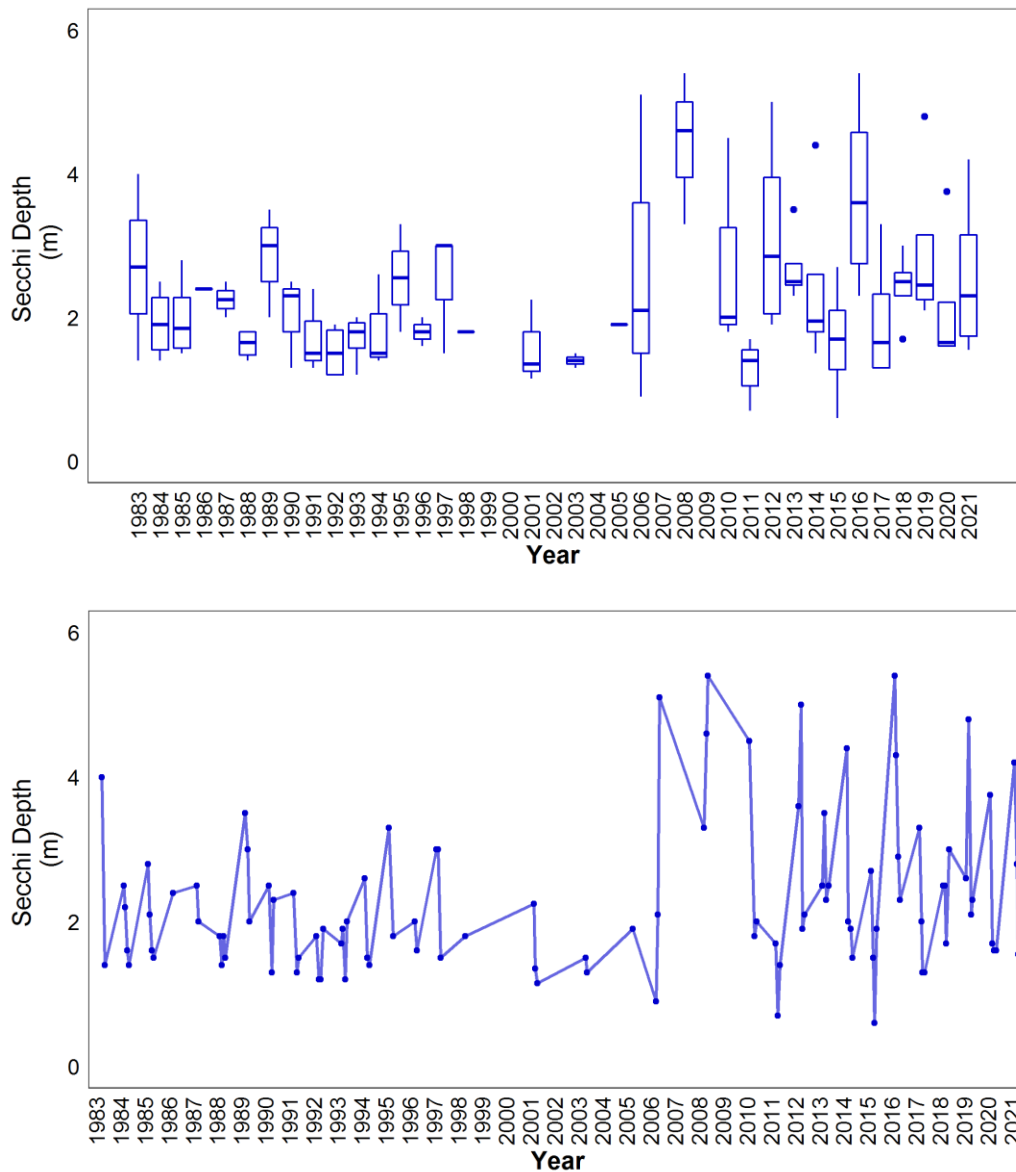


Figure 9. Monthly Secchi depth values measured between June and September on sampling dates between 1983 and 2021 ( $n = 103$ ). The value closest to the 15<sup>th</sup> day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

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 1983-2021 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                    | $1.63 \times 10^{-2}$ | 0.14             | 0.58                         | 0.18                  |
| The extent of the trend   | Slope (units per year) | 0                     | 0.17             | 0.96                         | $1.25 \times 10^{-2}$ |
| The statistic used to find significance of the trend              | Z                      | 0.24                  | 2.08             | 7.05                         | 2.38                  |
| Number of samples included  | n                      | 102                   | 102              | 81                           | 103                   |
| The significance of the trend                                     | <i>p</i>               | 0.81                  | 0.038*           | $1.75 \times 10^{-12}$ *     | 0.017*                |

\**p* < 0.05 is significant within 95%