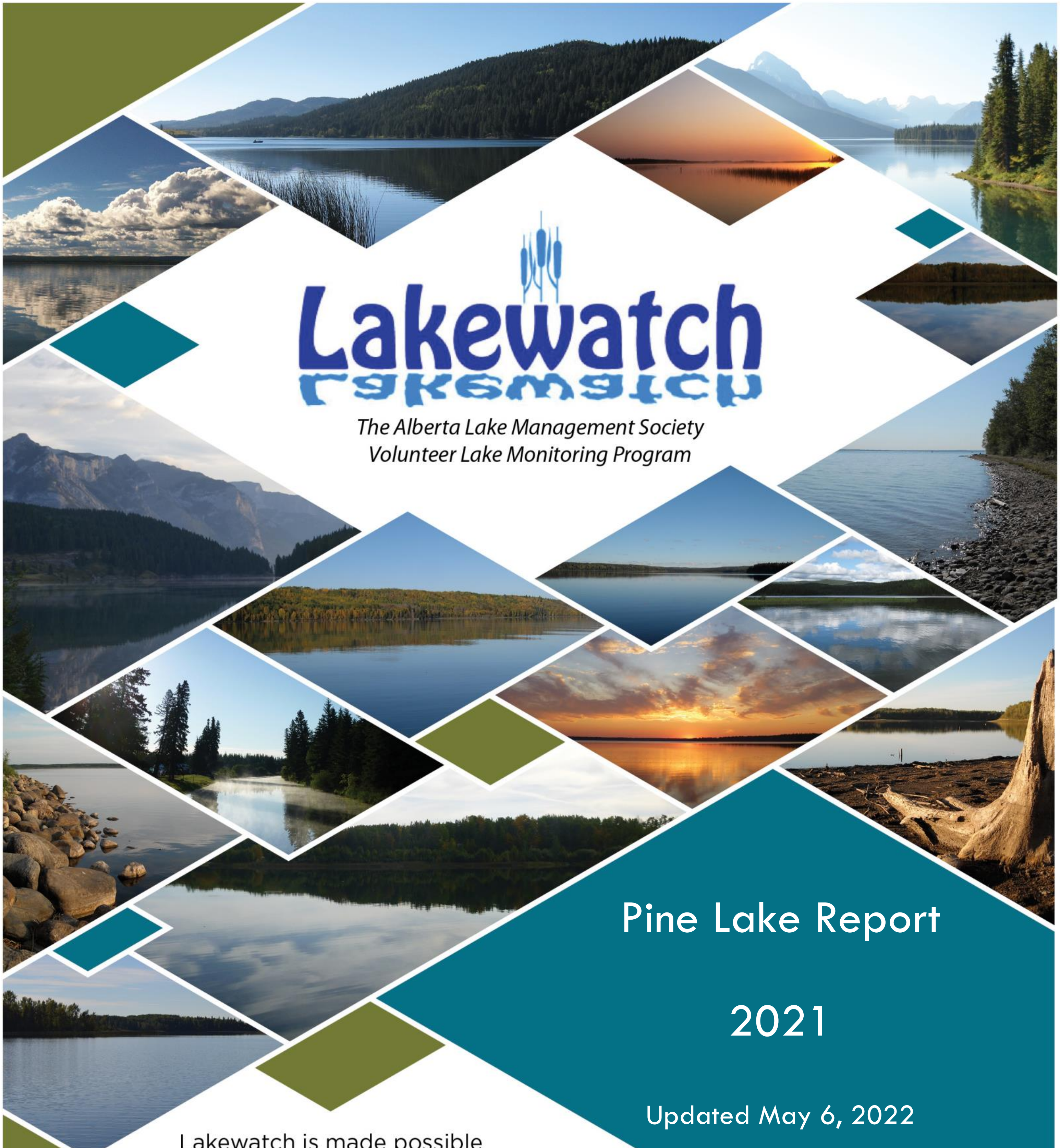

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Pine Lake Report

2021

Updated May 6, 2022

Lakewatch is made possible
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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 Thomas Matthews for his commitment to collecting data at Pine 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

PINE LAKE

Pine Lake is a small eutrophic lake southeast of Red Deer, Alberta. Pine Lake is subject to cyanobacterial blooms, and public concern over deteriorating water quality prompted the Alberta government to initiate a lake restoration program in 1991. The Pine Lake Restoration Program was designed as a pilot project for future lake and watershed projects in Alberta.

Pine Lake—photo by Jessica Davis 2011

An advisory committee, that represented all members of the community, directed early planning and problem diagnosis by the Alberta government. A diagnostic study, in 1992, determined that approximately 61% of the total phosphorus (TP) loading was from sediment release and other internal sources, while about 36% was from surface runoff. Monitoring of Pine Lake determined that algal growth was mainly limited by the supply of phosphorus.[1] There have been four critical areas identified for watershed restoration, on four streams, that are affected by livestock operations and sewage release. These streams contributed 72% of the phosphorus loading in 1992.

The advisory committee later formed the Pine Lake Restoration Society, a non-profit organization with representatives from all stakeholders, which raised funds and worked with technical advisors from the Alberta government. The Pine Lake Restoration Society implemented a four-year work plan in 1995 that addressed phosphorus loading from all sources. The main objective of the restoration program was to restore Pine Lake to a 'natural' level of algal productivity (as determined by paleolimnology). The Pine Lake Restoration Society and other individuals in the basin completed beneficial management practice (BMP) projects at various agricultural sites. Other organizations also improved wastewater treatment at a resort and two camps near the shoreline of Pine Lake.

Following an evaluation of the different alternatives to remove or treat phosphorus released from lake sediments, hypolimnetic withdrawal was selected as the preferred method of treatment. Hypolimnetic withdrawal has been successfully used to reduce TP concentration in various lakes, mainly in Europe, but had never been attempted in Alberta. The hypolimnetic withdrawal system at Pine Lake, installed in 1998, consists of a weir that regulates lake levels, and a gravity-fed pipeline that withdraws cool, phosphorus-rich water from near the bottom of the lake (the hypolimnion) of the south basin and discharges it through a vault with control valves to a stilling basin on Ghostpine Creek.

[1] Sosiak, A. J and Trew, D.O. (1996). Pine Lake restoration project. Diagnostic Study (1992). Obtained from: http://environment.gov.ab.ca/info/library/7764.pdf

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 Pine Lake was 76 µg/L (Table 2), falling into the eutrophic, or highly productive trophic classification. This value is in the mid-range of historical averages. TP was lowest during the July 9th sampling event at 54 µg/L, and was highest at the end of the season at 110 µg/L during the September 11th sampling event (Figure 1).

Average chlorophyll-*a* concentration in 2021 was 53.8 µg/L (Table 2), falling into the hypereutrophic, or very highly productive trophic classification. Chlorophyll-*a* was lowest during the June 18th sampling event at 5.1 µg/L, and increased through the season and peaked at 88.2 µg/L on September 11th (Figure 1).

The average TKN concentration was 2.1 mg/L (Table 2) and varied from 1.9 mg/L to 2.5 mg/L, having the highest levels during the September sampling event (Figure 1).

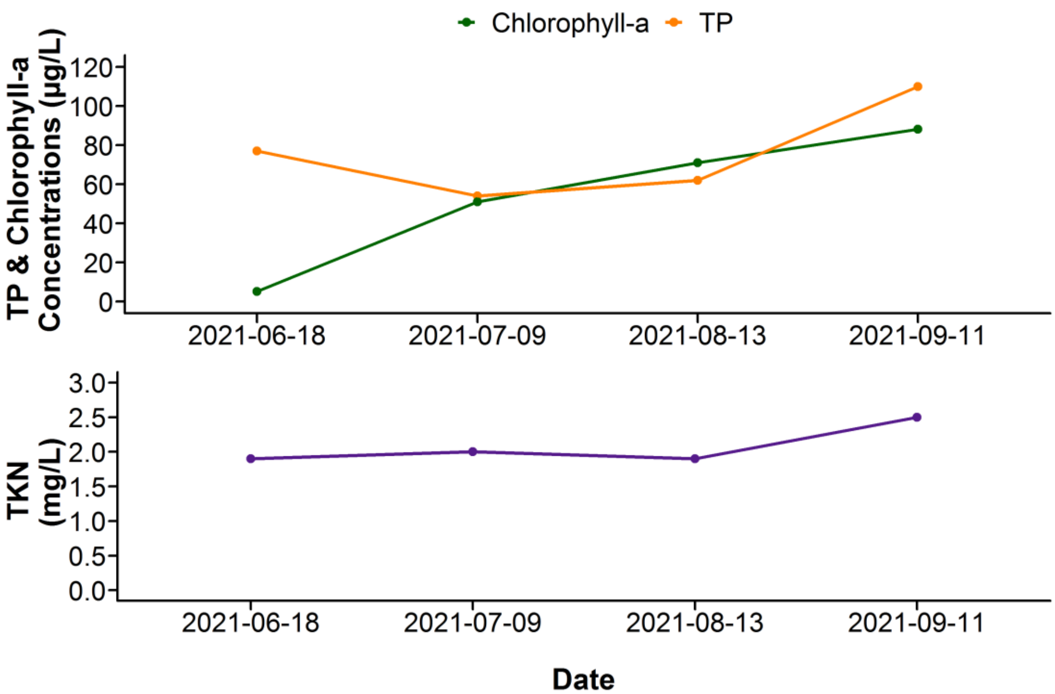


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Pine Lake.

Average pH was measured as 8.79 in 2021, buffered by high alkalinity (315 mg/L $CaCO_3$) and bicarbonate (335 mg/L HCO_3). Aside from bicarbonate, sodium and sulphate were relatively higher than other major ions, but together contributed to a moderate conductivity of 792 µS/cm (Table 2). Pine Lake is in the moderate to high range of ion levels compared to other LakeWatch lakes sampled in 2021 (Figure 2, bottom).

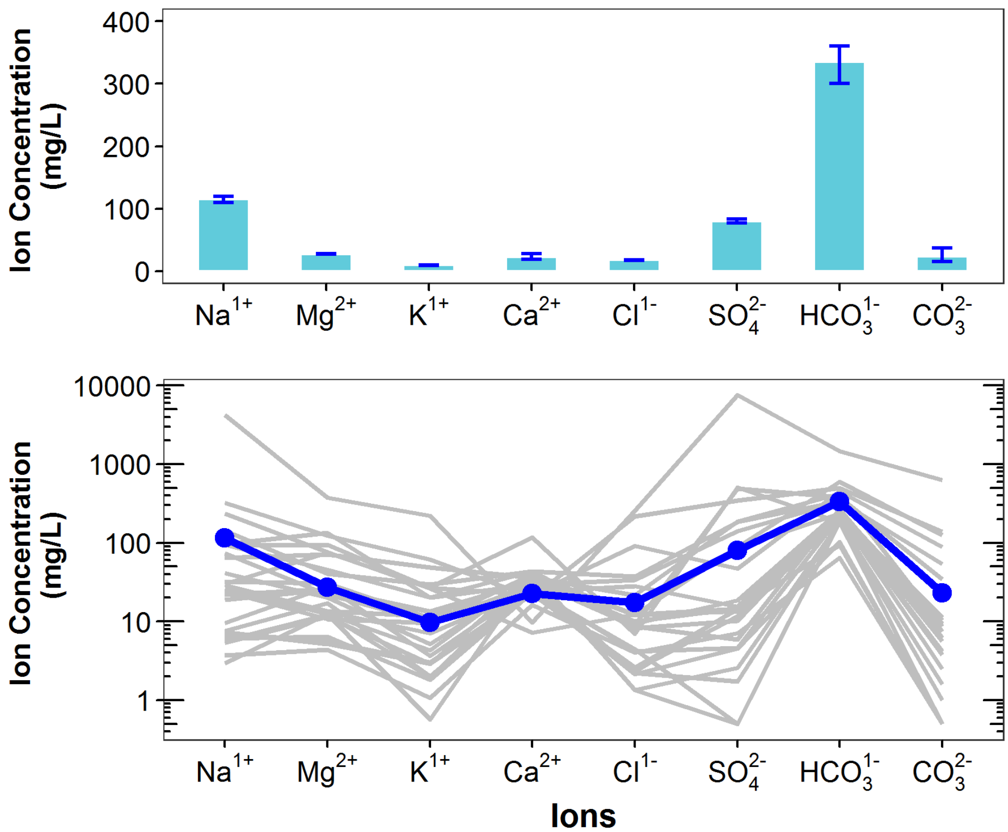


Figure 2. Average levels of cations (sodium = Na^{1+}, magnesium = Mg^{2+}, potassium = K^{1+}, calcium = Ca^{2+}) and anions (chloride = Cl^{1-}, sulphate = SO_4^{2-}, bicarbonate = HCO_3^{1-}, carbonate = CO_3^{2-}) from four measurements over the course of the summer at Pine Lake. Top) bars indicate range of values measured, and bottom) Schoeller diagram of average ion levels at Pine 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 measured at Pine Lake in 2021, and no metal exceeded the CCME guidelines for the protection of aquatic life, chronic (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 Pine Lake in 2021 was 3.80 m, corresponding to an average Secchi depth of 1.90 m (Table 2). The euphotic depth was very deep during the June 18th sampling event at 8.40 m depth, but decreased appreciably by the next sampling event, to only 1.70 m during the July 9th sampling event (Figure 3). Euphotic depth increased slightly during the August and September sampling events.

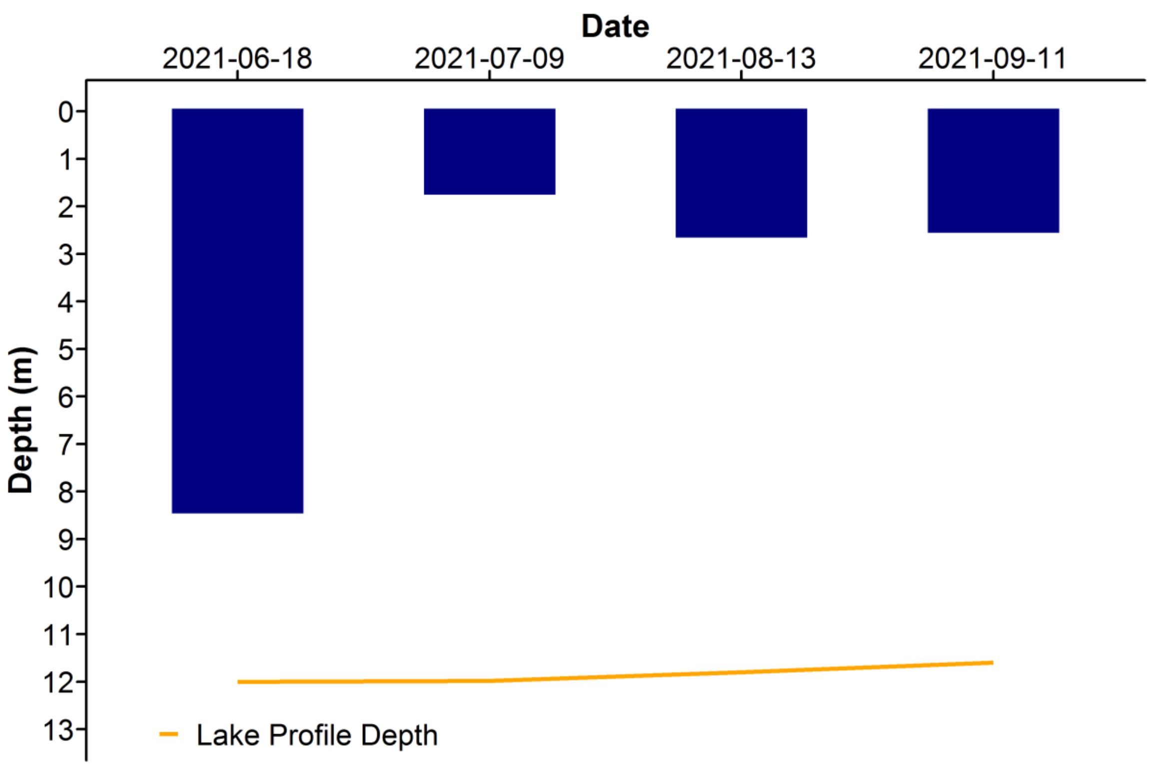


Figure 3. Euphotic depth values measured four times over the course of the summer at Pine Lake in 2021.

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 Pine Lake varied throughout the summer, with the July 13th sampling date having the warmest temperatures at 26.5°C (Figure 4a). Surface temperatures measured from Pine Lake during this sampling were the highest recorded from any lake sampled through the LakeWatch program in 2021. The lake was weakly stratified during all sampling events except September 11th.

Pine 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 July 9th sampling event displayed supersaturated levels of dissolved oxygen in surface waters (Figure 8). The lake's bottom waters were anoxic (<1.0 mg/L dissolved oxygen) during all sampling events, except September 11th.

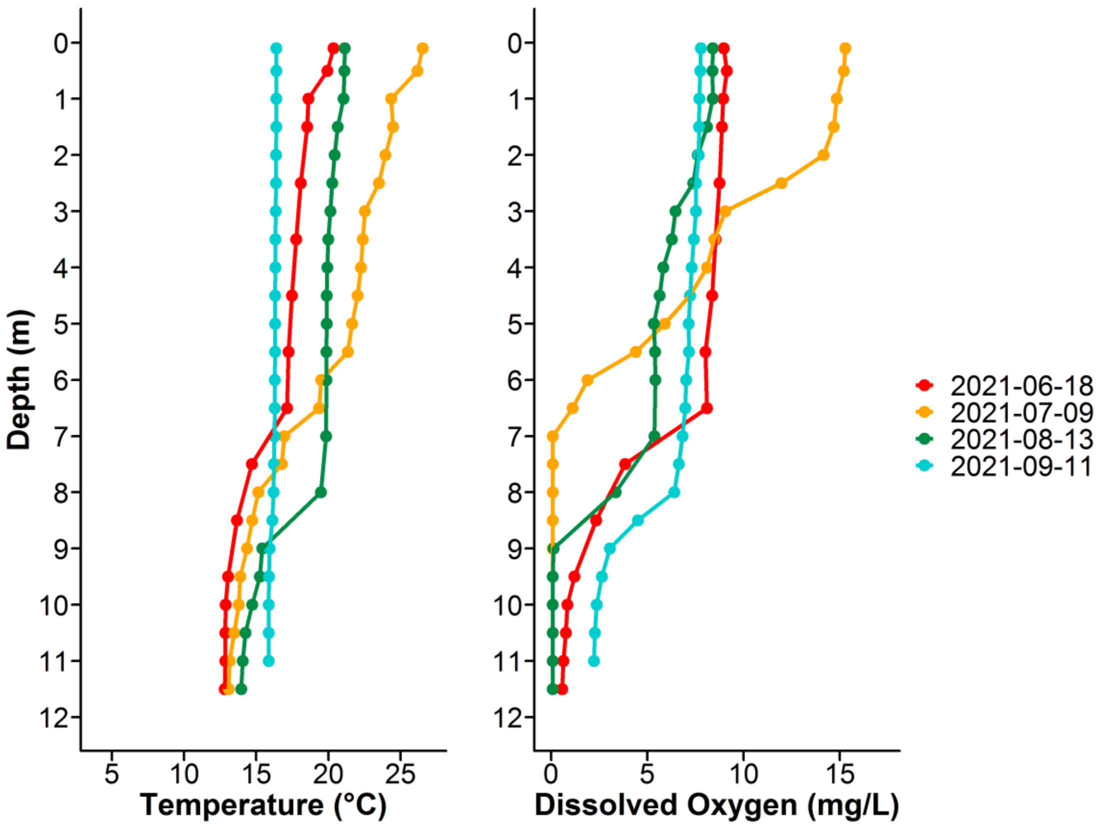


Figure 4. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Pine Lake (primary profile location) measured four times over the course of the summer of 2021 at Pine Lake.

Profile measurements from the south basin (S), and in the north basin (N) were similar in that weak temperature stratification was present, only during the June and July sampling events (Figures 5a and 6a). Both sites displayed anoxia in bottom waters during in June (Figures 5b and 6b). Oxygen levels were below 6.5 mg/L throughout the whole water column in September, at the S profile location, in addition to being anoxic just above the bottom. Bottom waters were also anoxic in the N basin during the July sampling event.

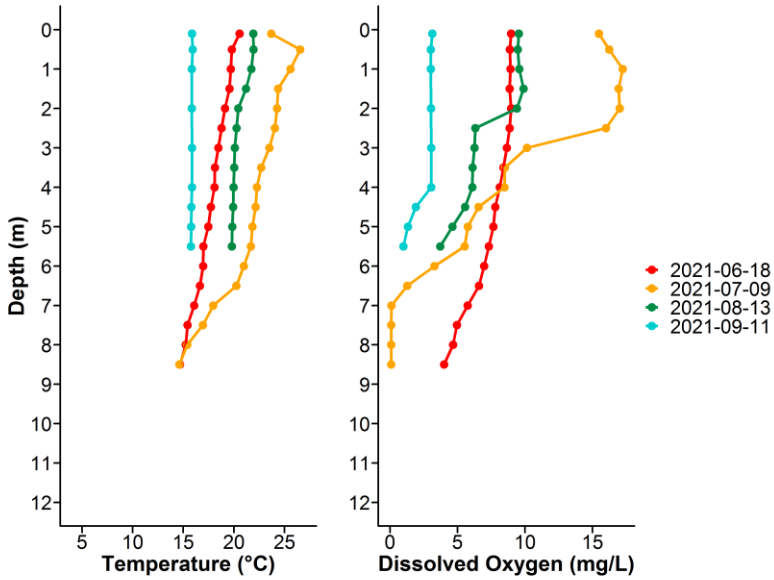


Figure 5. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Pine Lake (S - south basin profile location) measured four times over the course of the summer of 2021.

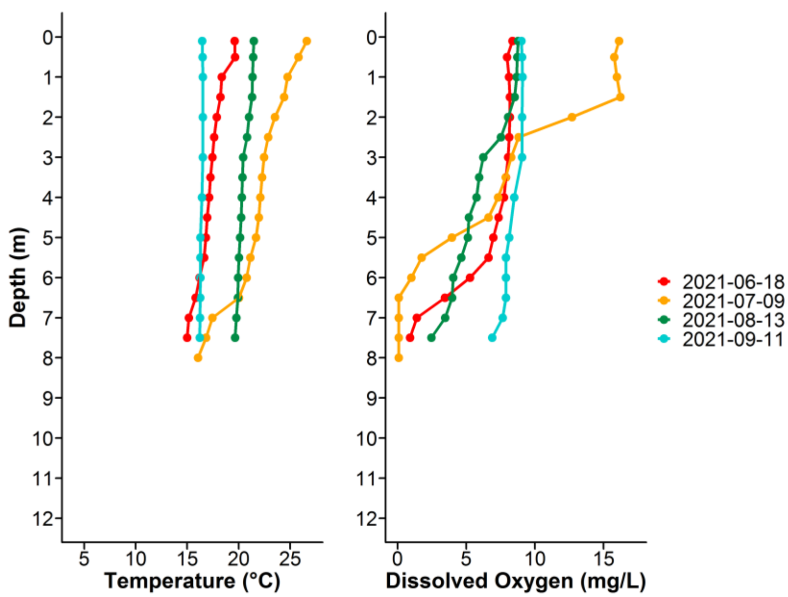


Figure 6. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Pine Lake (N - north basin profile location) measured four times over the course of the summer of 2021.

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 Pine Lake fell below the recreational guideline of 10 μg/L during every sampling event in 2021 (Table 1), and the seasonal average is the on moderate to low end of historical averages (Table 2). 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 Pine Lake in 2021.

Date	**Microcystin Concentration (μg/L)**
18-Jun-21	0.15
9-Jul-21	0.14
13-Aug-21	0.63
11-Sep-21	1.80
Average	0.68

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 Pine 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.

A watermilfoil specimen was collected from Pine Lake on June 11th, and was confirmed to be the native Northern Watermilfoil.

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 Pine Lake in 2021 were near or slightly below the historical average (Figure 7). Historical data indicates that since the beginning of the record, 1964, the lake does not appear to losing or gaining water in a single trajectory. Rather, the lake has seen variation of water levels of about 0.8m over time.

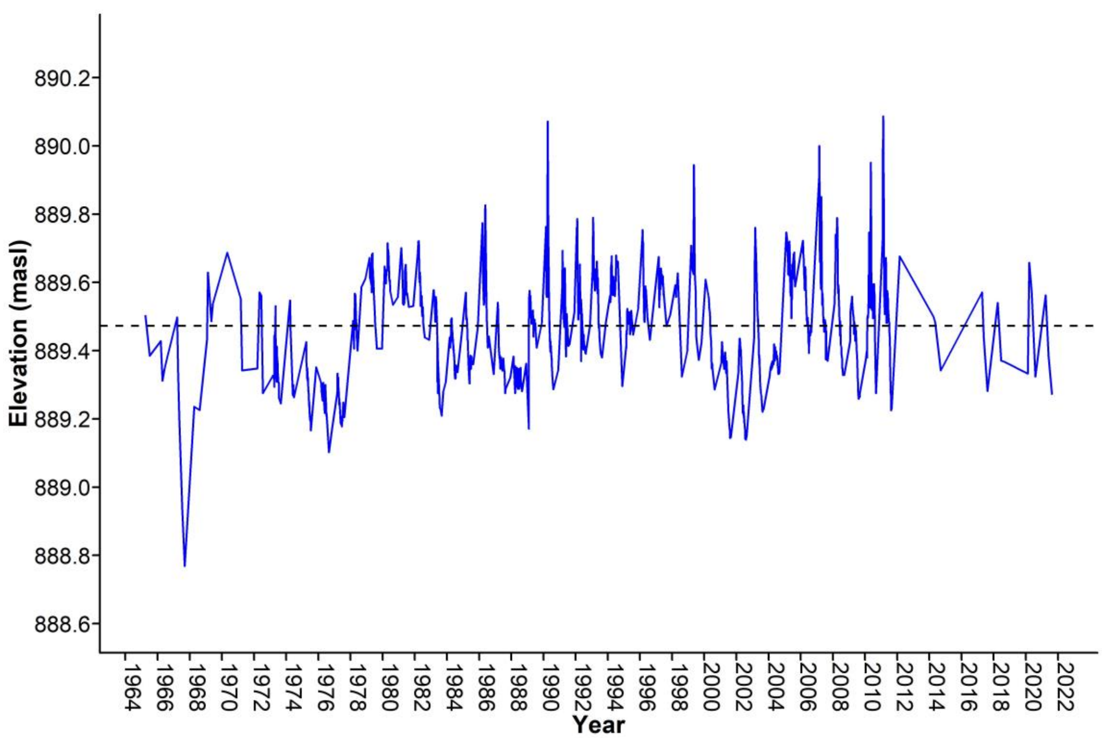


Figure 7. Water levels measured at Pine Lake in metres above sea level (masl) from 1964-2021. Data retrieved from Alberta Environment and Parks. Black dashed line represents historical yearly average water level.

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.

Pine Lake experienced a warmer, drier, slightly more windy summer with slightly more solar radiation compared to normal (Figure 8). A few warm spells prior to the July 9th sampling likely resulted in very high near-surface water temperatures. At some point during the August 13th and September 11th sampling events, the lake completely mixed, or turned over, likely during a significant windy spells in late August and early September, coupled with cooler air temperatures. With air temperatures being below the historical normal and relatively cool at this time, surface waters of the lake cooled by nearly 5°C.

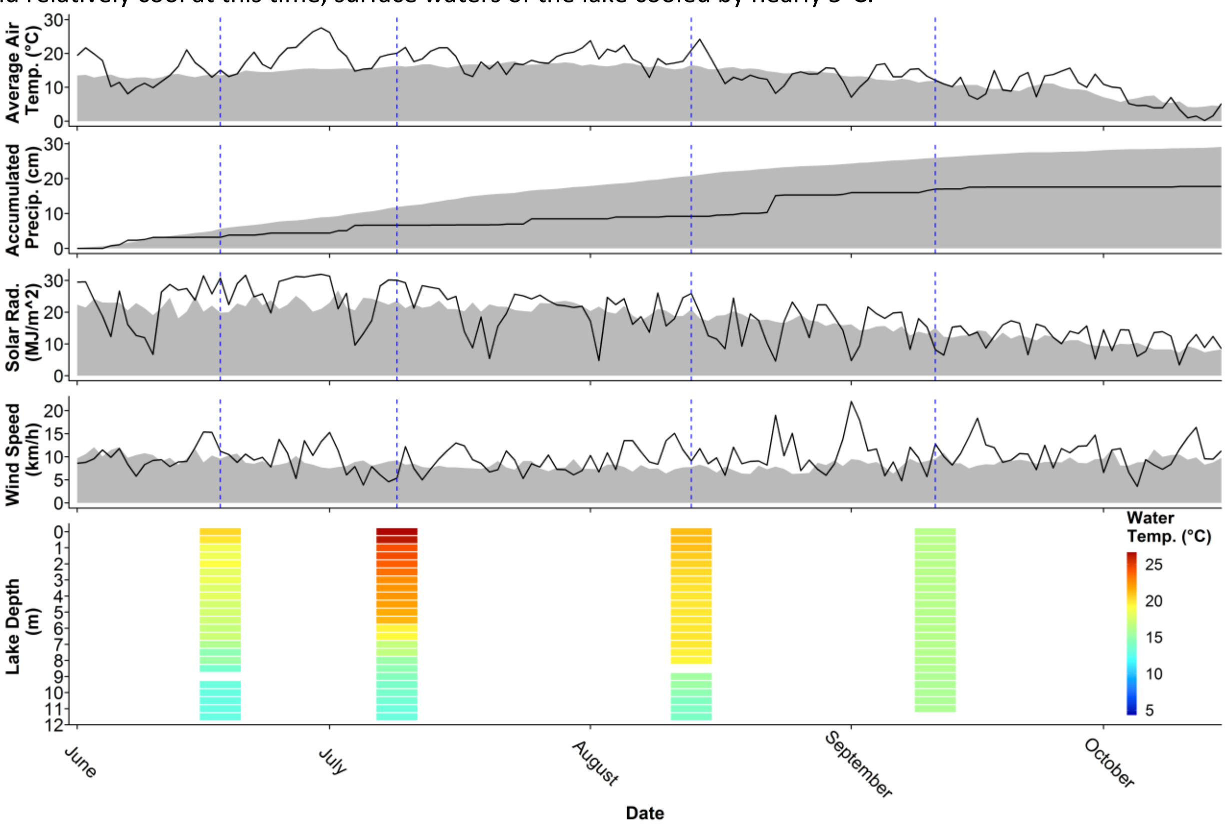


Figure 8. Average air temperature (°C), accumulated precipitation (cm), wind speed (km/h), and solar radiation (MJ/m^2) measured from Divide Hills AGCM, with Pine Lake temperature profiles (°C) at the bottom. Black lines indicate 2021 levels, gray indicates long-term normals, and blue lines indicate sampling dates for Pine 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).

HISTORICAL DATA

Pine Lake has been extensively monitored by Alberta Environment, and has composite lake sampling data that dates back to 1983. Over the years, Pine Lake has been sampled many different ways, likely to answer specific questions. For instance, there are four different codes in the Alberta Environment database denoting different spatial samplings of the lake.

There is composite lake data for the North Side Region, Middle Region, and South Side Region, and there is also data which represents composite data from the whole lake. As this report aims to report data on Pine Lake as a whole, and not to differentiate certain areas of the lake, the data tables represent the most complete, whole lake data. This means that for years where both the North, Middle and South regions were sampled at the same time, the values were averaged to capture a more accurate picture of the whole lake. Whole lake data is reported as is. Generally, sampling occurred once a month from May till October, but some months had multiple samplings during certain years, and in some years sampling did not occur in certain months. This sort of variability in sampling frequency is typical of water quality data, as well as environmental data more generally. Otherwise, Pine Lake has a remarkably complete dataset with monthly sampling occurring in 27 years of the past 39 years.

Table 2a. Average Secchi depth and water chemistry values for Pine Lake. Historical values are given for reference. Number of sample trips are inconsistent between years. (W=whole lake composite, NMS=average of North, Middle and South region composites).

Parameter	**1983**	**1984**	**1989**	**1991**	**1992**	**1993**	**1994**	**1995**	**1995**	**1996**	**1997**	**1998**	**1999**
TP (µg/L)	50	58	46	74	88	104	100	76	78	109	90	84	64
TDP (µg/L)	22	/	25	42	36	49	45	43	52	54	52	59	35
Chlorophyll-*a* (µg/L)	11.9	26.3	15.9	13	47	30.4	26.1	13.7	12.6	21.5	22.2	11.7	13.6
Secchi depth (m)	2.5	1.84	2.4	2.85	1.86	2.33	2.45	3.36	/	2.61	1.96	3.06	3.16
TKN (mg/L)	1.4	1.3	1.4	/	2	1.7	2	1.6	1.6	1.5	1.9	1.9	1.5
NO_2-N and NO_3-N (µg/L)	25	5	4	27	33	11	28	28	8	24	27	22	10
NH_3-N (µg/L)	40	72	44	/	135	88	181	114	78	179	176	208	114
DOC (mg/L)	/	/	16	/	18	18	18	18	18	18	17	19	17
Ca (mg/L)	22	23	19	27	26	27	26	26	25	28	/	25	26
Mg (mg/L)	23	25	24	26	25	24	25	25	25	24	/	24	24
Na (mg/L)	103	108	115	95	99	96	98	99	100	103	96	108	102
K (mg/L)	10	10	10	9	9	9	10	10	10	10	10	10	10
SO_4^{2-} (mg/L)	80	84	81	69	69	64	63	66	66	63	60	63	65
Cl^- (mg/L)	4	6	6	6	7	7	8	8	8	11	8	9	10
CO_3 (mg/L)	19	22.8	29.1	17.2	12.5	13.1	12.6	13.3	14	13.4	13.8	12.9	12.5
HCO_3 (mg/L)	331	343	332	339	363	360	363	354	354	351	342	368	355
pH	8.8	8.73	8.93	8.76	8.6	8.63	8.61	8.61	8.65	8.56	8.61	8.58	8.6
Conductivity (µS/cm)	707	726	741	697	703	692	696	692	696	708	675	720	710
Hardness (mg/L)	149	160	147	172	167	167	166	168	166	171	155	160	163
TDS (mg/L)	424	450	448	416	420	412	414	422	423	432	405	433	426
Microcystin (µg/L)	/	/	/	/	/	/	/	/	/	/	/	/	/
Total Alkalinity (mg/L $CaCO_3$)	304	319	321	307	308	306	308	313	314	310	304	322	312
Basin Sampled	W	NMS	NMS	NMS	NMS	NMS	NMS	W	NMS	NMS	NMS	NMS	NMS

Table 2b. Average Secchi depth and water chemistry values for Pine Lake. Historical values are given for reference. Number of sample trips are inconsistent between years. (W=whole lake composite, NMS=average of North, Middle and South region composites).

Parameter	**2000**	**2001**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2011**	**2013**	**2015**	**2017**	**2021**
TP (µg/L)	60	67	55	68	70	81	86	79	68	93	68	69	79	76
TDP (µg/L)	36	35	26	27	33	32	42	34	34	31	47	30	25	27
Chlorophyll-*a* (µg/L)	11.6	17.5	17.9	38	19.2	32.7	27.5	37.1	22.5	30.8	17.8	26.7	38	53.8
Secchi depth (m)	3.31	3.47	3.18	1.74	2.53	1.84	1.7	1.25	1.88	1.3	1.95	1.75	1.4	1.93
TKN (mg/L)	1.6	1.5	1.5	1.9	1.8	1.9	1.9	1.9	1.8	2	1.7	2.9	1.9	2.1
NO_2-N and NO_3-N (µg/L)	43	19	10	9	11	2	31	10	9	6	9	4	7	10
NH_3-N (µg/L)	111	77	98	119	156	134	126	135	65	134	82	62	84	108
DOC (mg/L)	16	/	/	18	17	19	/	17	18	19	18	17	19	17
Ca (mg/L)	/	/	/	/	/	/	/	/	/	/	/	26	29	23
Mg (mg/L)	/	/	/	/	/	/	/	/	/	/	/	27	28	27
Na (mg/L)	104	/	124	132	129	128	107	109	115	84	90	95	110	115
K (mg/L)	10	/	10	10	10	11	10	10	10	9	9	9	10	10
SO_4^{2-} (mg/L)	70	/	79	84	78	82	64	68	76	56	62	70	70	80
Cl^- (mg/L)	8	/	10	10	10	12	13	13	13	12	12	15	16	18
CO_3 (mg/L)	13.5	/	22.8	21.3	17.7	17	14.6	9.7	14.3	11.3	12.6	21.2	21.6	23
HCO_3 (mg/L)	360	/	356	373	381	387	356	370	372	334	332	315	336	335
pH	8.59	/	8.77	8.79	8.66	8.68	8.67	8.46	8.61	8.60	8.63	8.80	8.77	8.79
Conductivity (µS/cm)	/	/	/	790	764	786	721	729	755	659	697	690	742	792
Hardness (mg/L)	165	/	152	156	148	153	172	170	168	174	185	178	192	168
TDS (mg/L)	434	/	469	489	477	487	437	444	464	393	408	418	452	465
Microcystin (µg/L)	/	/	/	/	0.88	0.29	/	0.43	1.19	0.27	/	2.51	2.25	0.68
Total Alkalinity (mg/L $CaCO_3$)	318	/	331	342	342	346	316	320	328	293	293	295	312	315
Basin Sampled	NMS	NMS	W	W	W	W	NMS	W	W	W	W	W	W	W

Table 3. Concentrations of metals measured in Pine 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	2004	2013	2015	2017	2021	Guidelines
Aluminum μg/L	24.9	30.55	26.2	49.15	97.1	14.9	100[a]
Antimony μg/L	0.057	0.078	0.0915	0.0955	0.52	0.1	/
Arsenic μg/L	1.14	1.145	1.37	1.395	7.11	1.54	5
Barium μg/L	56.2	58.6	59.7	52.2	298	51.9	/
Beryllium μg/L	0.17	0.00225	0.0015	0.006	0.0055	0.0015	100[c,d]
Bismuth μg/L	0.0065	0.00115	0.115	0.031	0.0055	0.0015	/
Boron μg/L	67.7	80.3	85.8	89.8	469	96.9	1500
Cadmium μg/L	0.01	0.0037	0.0039	0.0085	0.025	0.005	0.24[b]
Chromium μg/L	0.36	0.334	0.402	0.615	0.25	0.1	/
Cobalt μg/L	0.065	0.063	0.115	0.12	0.641	0.143	50,1000[c,d]
Copper μg/L	0.83	1.57	0.468	1.265	4.29	0.38	3.67[b]
Iron μg/L	/	9	36.2	47.7	105	14.1	300
Lead μg/L	0.165	0.12665	0.0544	0.0945	0.165	0.037	6.14[b]
Lithium μg/L	34.8	43.55	35.5	38	196	45.1	2500[d]
Manganese μg/L	10.86	10.475	7.42	12.8	66.4	6.33	130[e]
Molybdenum μg/L	0.68	0.7	0.835	0.923	5.06	1.18	73
Nickel μg/L	0.045	0.195	0.527	0.5595	2.38	0.48	141.45[b]
Selenium μg/L	0.35	0.05	0.177	0.15	2.3	0.2	1
Silver μg/L	0.0025	0.00025	0.0277	0.004	0.01	0.0005	0.25
Strontium μg/L	255.67	283.5	284	264	1420	277	/
Thallium μg/L	0.033	0.0007	0.0005	0.0052	0.016	0.001	0.8
Thorium μg/L	0.0015	0.00555	0.0966	0.1132	0.083	0.002	/
Tin μg/L	0.05	0.015	0.0352	0.0365	0.15	0.03	/
Titanium μg/L	1.7	1.32	0.95	1.795	4.7	0.54	/
Uranium μg/L	0.71	0.7565	1.25	1.27	6.38	1.28	15
Vanadium μg/L	0.397	0.3755	0.573	0.655	2.95	0.764	100[c,d]
Zinc μg/L	4.36	7.69	0.772	0.85	3.3	3.2	30[f]

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

[b] Based on 2021 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 2021 avg. water hardness (as CaCO3) and avg. pH

[f] Based on 2021 avg. water hardness (as CaCO3), avg. pH, and avg. DOC with CCME equation

[g] 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

Pine Lake has a fairly unique water quality dataset, as explained above in the Historical Data section. For years where the North, Middle, and South regions were sampled at the same time each month, the data was averaged between each region and included in the trend analysis. These steps were taken to best capture the trends for Pine Lake as a whole. May and October data were excluded from analysis, in following the ALMS method of trend analysis, as more years in the historical record did not have sampling events in May and October than those that did. This step was taken to minimize the bias of historical May and October data on the overall trend analysis.

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 Pine Lake. In sum, significant increasing trends were detected for chlorophyll-*a* and TDS, a decreasing trend was detected for Secchi depth, and no significant trend was detected for TP. Secchi depth can be subjective and is sensitive to variation in weather - trend analysis must be interpreted with caution. Data is presented below as both 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 Pine Lake data from 1983 to 2021.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	1983-2021	No change
Chlorophyll-*a*	1983-2021	Increasing
Total Dissolved Solids	1983-2021	Increasing
Secchi Depth	1983-2021	Decreasing

Definitions:

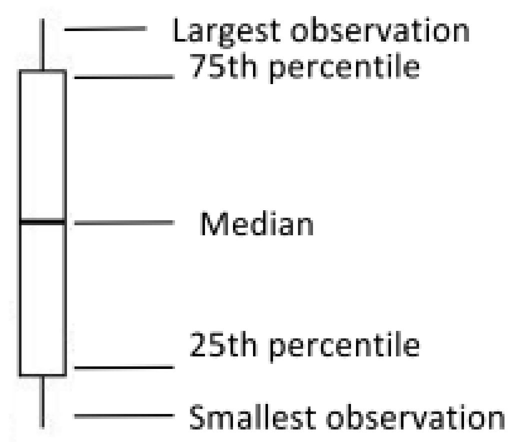
Median: the value in a range of ordered numbers that falls in the middle.

Trend: a general direction in which something is changing.

Monotonic trend: a gradual change in a single direction.

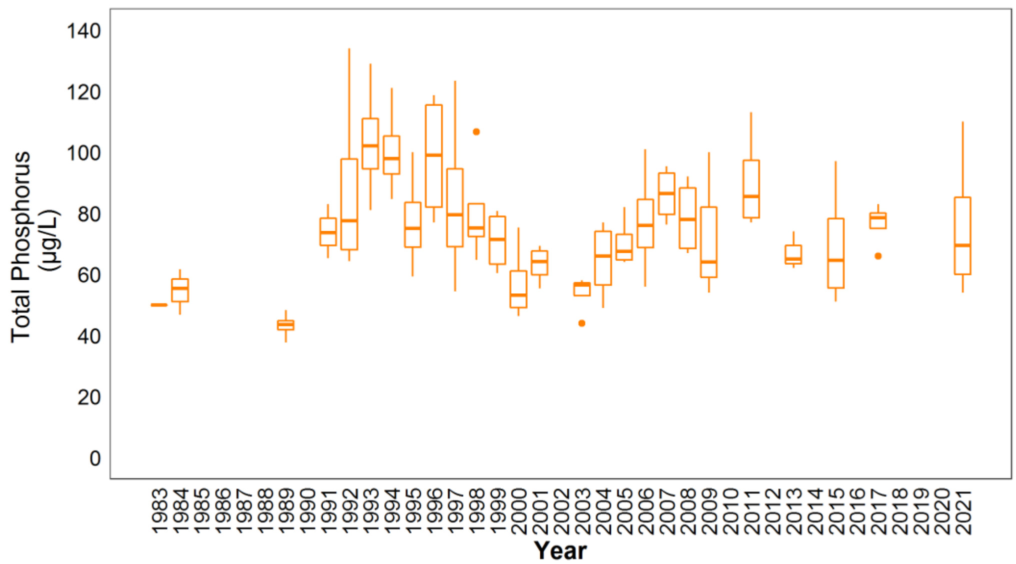
Statistically significant: The likelihood that a relationship between variables is caused by something other than random chance. This is indicated by a p-value of <0.05. Variability: the extent by which data is inconsistent or scattered.

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 indicates there is no significant trend of TP in Pine Lake since 1983 (Tau = 1.91 x 10^{-2}, p = 0.78; Table 5).



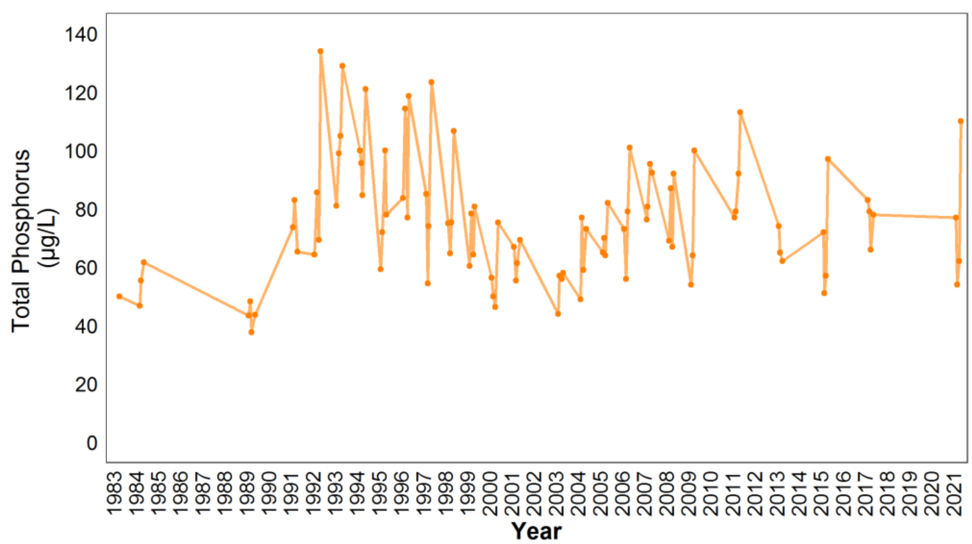
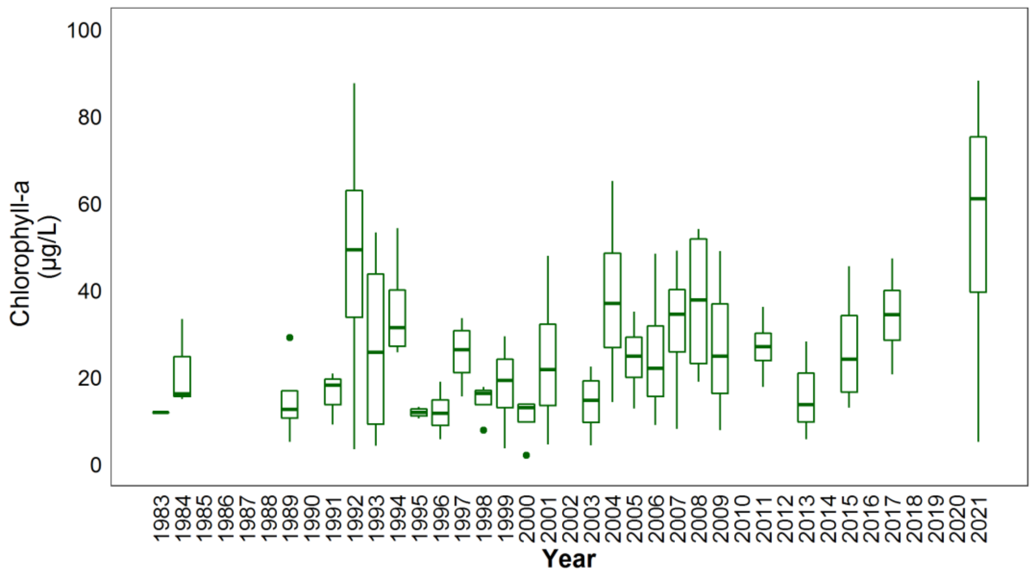


Figure 9. Monthly total phosphorus (TP) concentrations measured between June and September on sampling dates between 1983 and 2021 (n = 97). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Chlorophyll-*a*

Chlorophyll-*a* has been significantly increasing in Pine Lake since 1983 (Tau = 0.23, *p* = <0.001; Table 5). TP and chlorophyll-*a* were significantly correlated (r = 0.42, *p* = 2.12 x 10^{-5}).



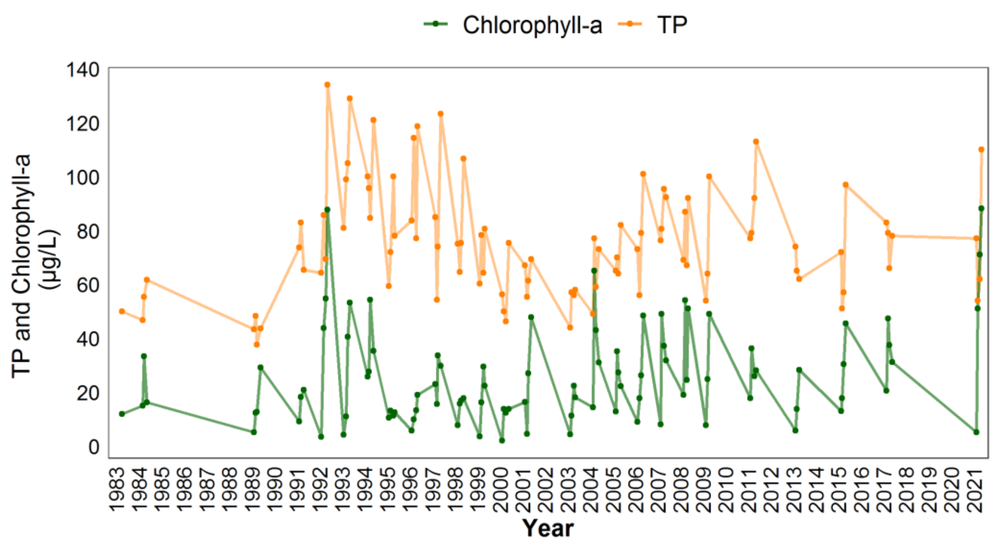


Figure 10. Monthly chlorophyll-*a* concentrations measured between June and September on sampling dates between 1983 and 2021 (n = 97). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Line graph is overlain by TP concentrations.

Total Dissolved Solids (TDS)

Trend analysis showed a significant increasing trend in TDS between 1983 and 2021 (Tau = 0.20, *p* = 0.012) in Pine Lake. Despite the overall increasing trajectory of TDS over time, the variability over time follows the variability in lake levels over time (Figure 7) – periods of high water levels line up with relatively lower TDS levels, and periods of lower water levels line up with relatively higher TDS levels.

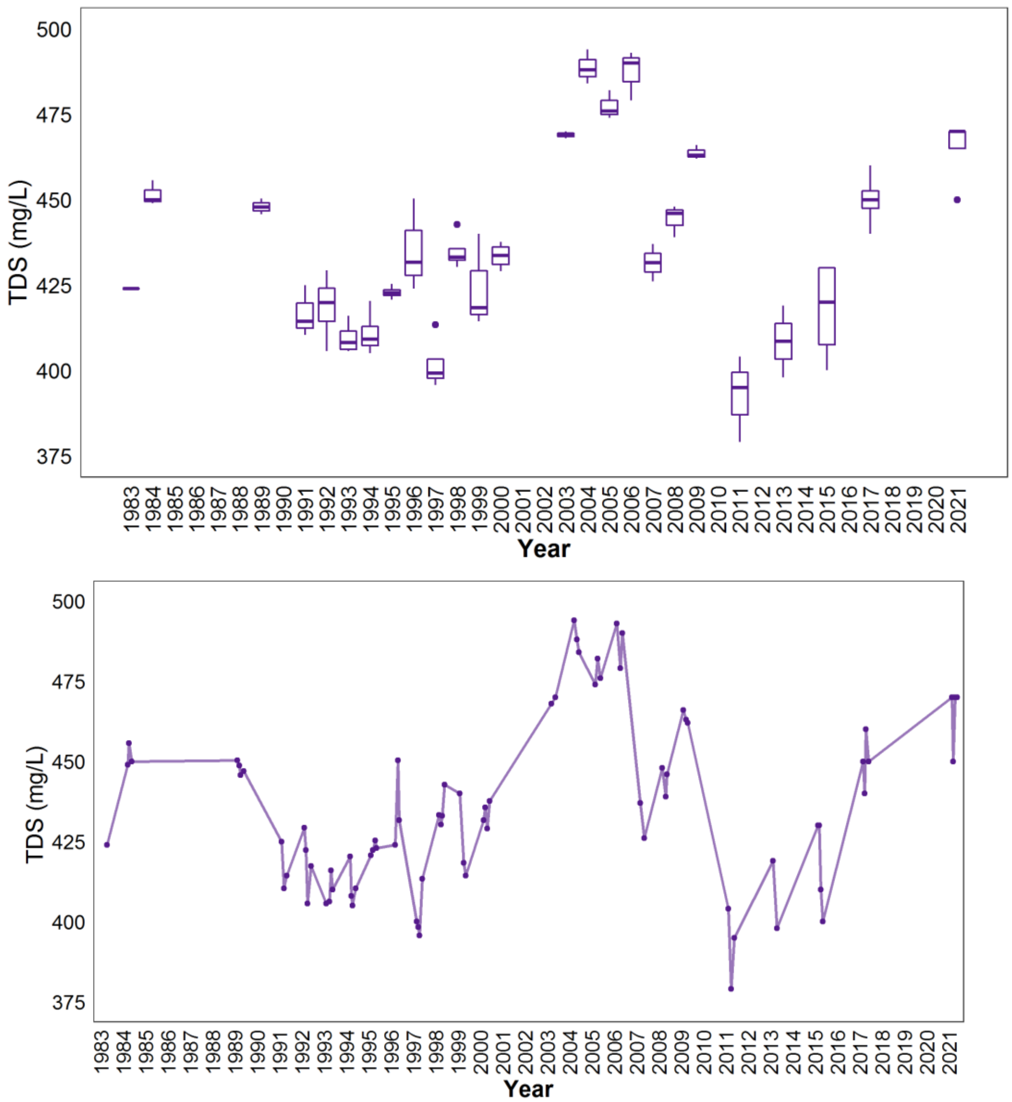


Figure 11. Monthly TDS values measured between June and September on sampling dates between 1983 and 2021 (n = 81). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Due to the significant increasing trend of TDS in Pine Lake, exploring the specific major ions which may be driving this trend is important to determine. Trend analysis of major ions at Pine Lake indicates that chloride 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 between the two, only sodium following the trajectory of TDS over time, and chloride displays a more steady increase in levels over time. While the trends of sulphate and alkalinity were not significant, their trajectories over time follow that of TDS fairly closely.

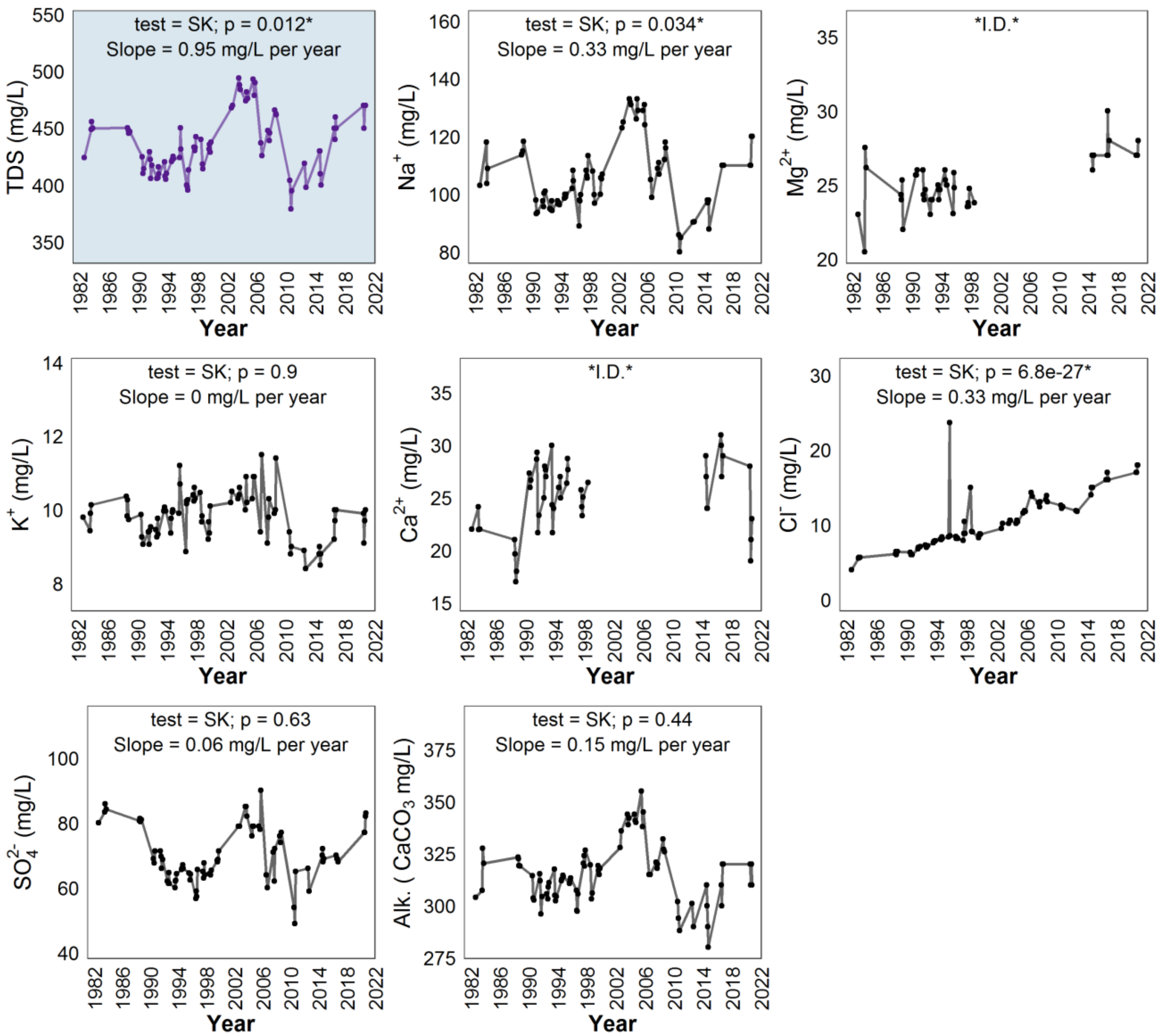
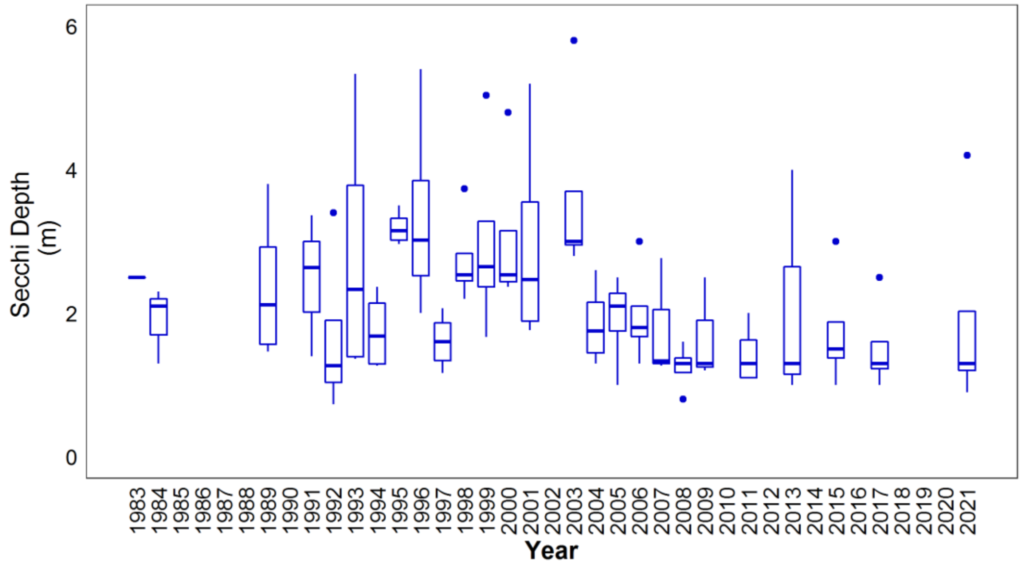


Figure 12. Concentrations of TDS (top left, blue panel), major ions (sodium = Na^+, magnesium = Mg^{2+}, potassium = K^+, calcium = Ca^{2+}, chloride = Cl^-, sulphate = SO_4^{2-}), and total alkalinity (Alk., as mg/L $CaCO_3$) measured monthly between June and September on sampling dates between 1983 and 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 15th 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 decreasing in Pine Lake since 1983 (Tau = -0.26, p = <0.001; Table 5).



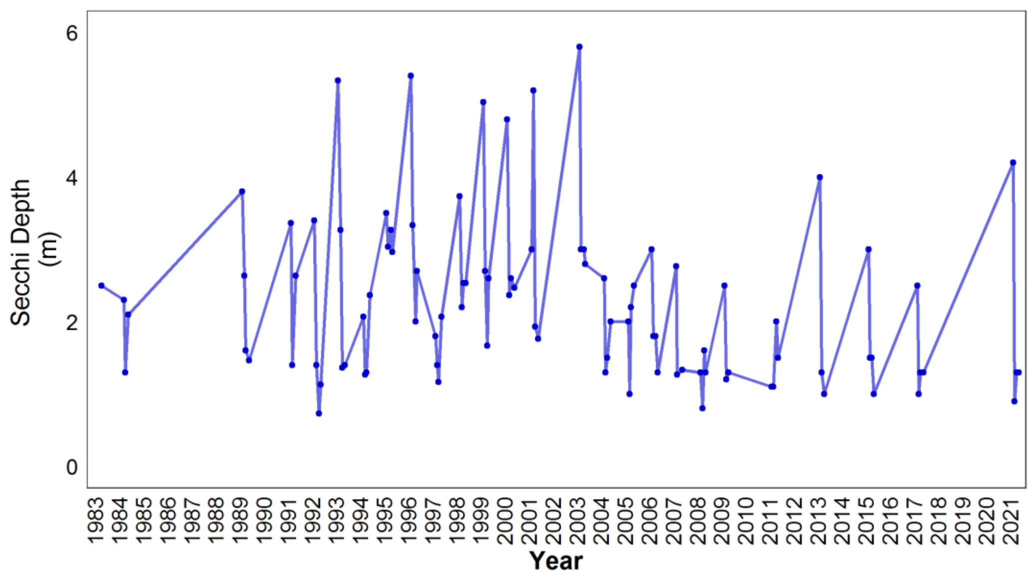


Figure 13. Monthly Secchi depth values measured between June and September on sampling dates between 1983 and 2021 (n = 96). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

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 1983-2021 on Pine Lake data.

Definition	Unit	Total Phosphorus (TP)	Chlorophyll-a	Total Dissolved Solids (TDS)	Secchi Depth
Statistical Method	-	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall	Seasonal Kendall
The strength and direction (+ or -) of the trend between -1 and 1	Tau	1.91×10^{-2}	0.23	0.20	-0.26
The extent of the trend	Slope (units per year)	5.25×10^{-2}	0.42	0.95	-3.33×10^{-2}
The statistic used to find significance of the trend	Z	0.28	3.23	2.50	-3.62
Number of samples included	n	97	97	81	96
The significance of the trend	*p*	0.78	1.23×10^{-3}*	1.23×10^{-2}*	2.96×10^{-4}*

*$p < 0.05$ is significant within 95%