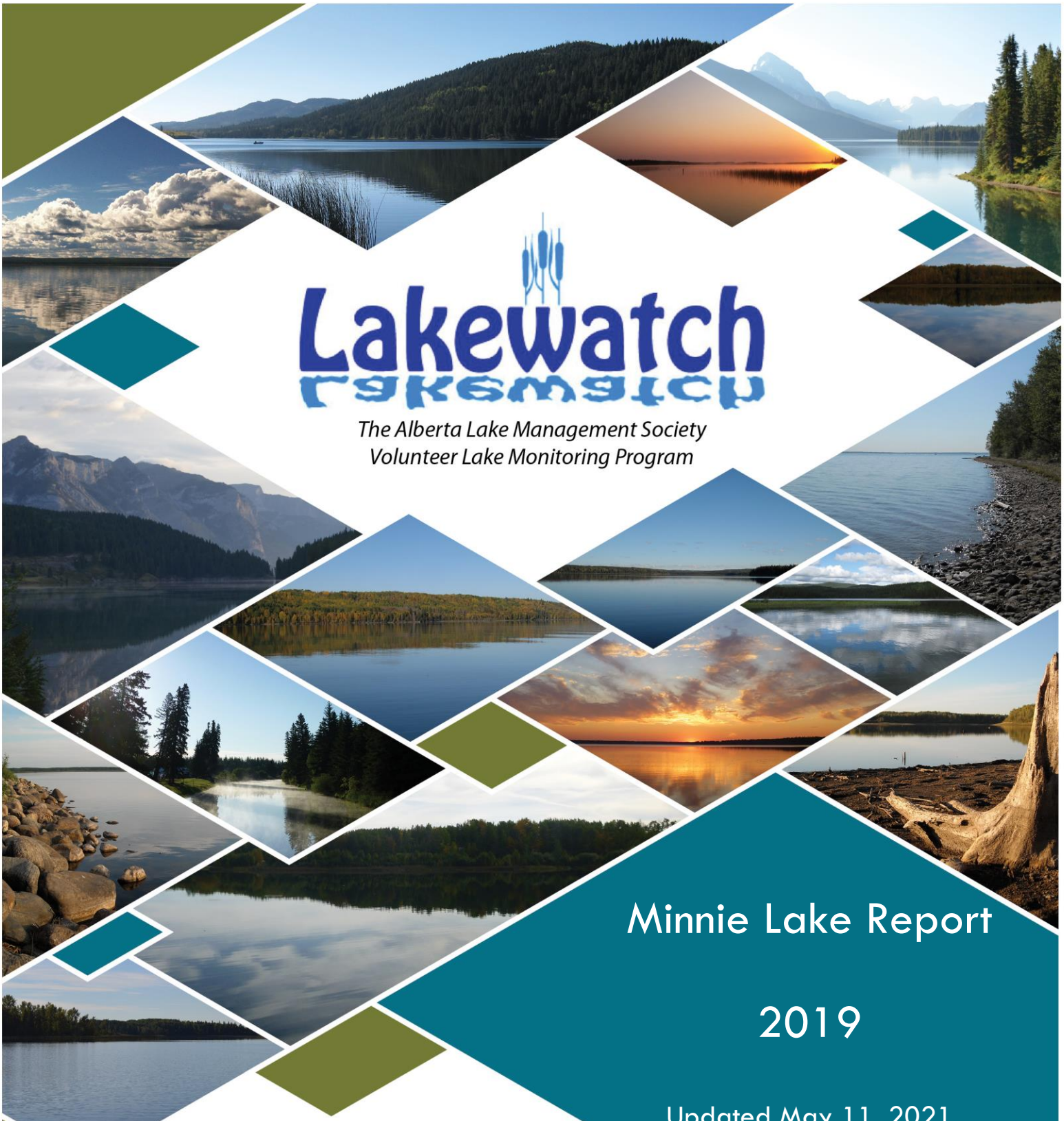

Lakewatch

The Alberta Lake Management Society
Volunteer Lake Monitoring Program

Minnie Lake Report

2019

Updated May 11, 2021

Lakewatch is made possible with support from:

Alberta Environment and Parks

Pigeon Lake Watershed Association

Lacombe County

LICA Environmental Stewards

ALBERTA LAKE MANAGEMENT SOCIETY'S LAKEWATCH PROGRAM

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

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

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

ACKNOWLEDGEMENTS

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

MINNIE LAKE

Minnie Lake is a small lake located west of Bonnyville and northeast of Glendon within the Beaver River Watershed. The lake is 2 km long and 0.6 km wide, with a surface area of 0.84 km^2. Mean depth is 8.3 m and maximum depth is about 23 m, though water levels have decreased since these values were calculated.

Minnie Lake- photo by Laura Redmond 2017

The shoreline of the lake hosts two municipal campsites, private cabins and recreational properties, agricultural land, and boreal forest. Minnie Lake is spring-fed by the Beverly channel aquifer and surface runoff from precipitation.

In 2006-2007 the lake experienced a winterkill, which decimated stocks of northern pike and yellow perch that previously supported a recreational fishery. Fish populations have not recovered to date.

The watershed area for Minnie Lake is 4.43 km^2 and the lake area is 0.67 km^2. The lake to watershed ratio of Minnie Lake is 1:7. A map of the Minnie Lake watershed area can be found at http://alms.ca/wp-content/uploads/2016/12/Minnie.pdf

METHODS

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

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

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

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

Data analysis is done using the program R.[1] Data is reconfigured using packages tidyr [2] and dplyr [3] and figures are produced using the package ggplot2 [4]. Trophic status for each lake is classified based on lake water characteristics using values from Nurnberg (1996)[5]. The Canadian Council for Ministers of the Environment (CCME) guidelines for the Protection of Aquatic Life are used to compare heavy metals and dissolved oxygen measurements. Pearson's Correlation tests are used to examine relationships between total phosphorus (TP), chlorophyll-*a,* total kjeldahl nitrogen (TKN) and Secchi depth, providing a correlation coefficient (r) to show the strength (0-1) and a p-value to assess significance of the relationship. For lakes with >10 years of long term data, trend analysis is done with non-parametric methods. The seasonal Kendall test estimates the presence of monotonic (unidirectional) trends across individual seasons (months) and is summed to give an overall trend over time. For lakes that had multiple samplings in a single month, the value closest to the middle of the month was used in analysis.

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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 Minnie Lake was 41 µg/L (Table 2), falling into the category of eutrophic, or highly productive trophic classification. This value falls within the range of historical averages. Detected TP was lowest when sampled in August at 27 µg/L, and highest in the July sampling at 62 µg/L (Figure 1).

Average chlorophyll-*a* concentration in 2019 was 19.4 µg/L (Table 2), falling into the eutrophic, or highly productive trophic classification. Chlorophyll-*a* peaked in the middle of the season, with a minimum of 13.4 µg/L in August to a maximum of 27.9 µg/L in July.

Finally, the average TKN concentration was 1.6 mg/L (Table 2) with concentrations steady throughout the season.

Average pH was measured as 8.85 in 2019, buffered by moderate alkalinity (360 mg/L $CaCO_3$) and bicarbonate (347 mg/L HCO_3). Aside from bicarbonate, sulphate was the dominant ion contributing to a high conductivity of 1400 µS/cm (Table 2).

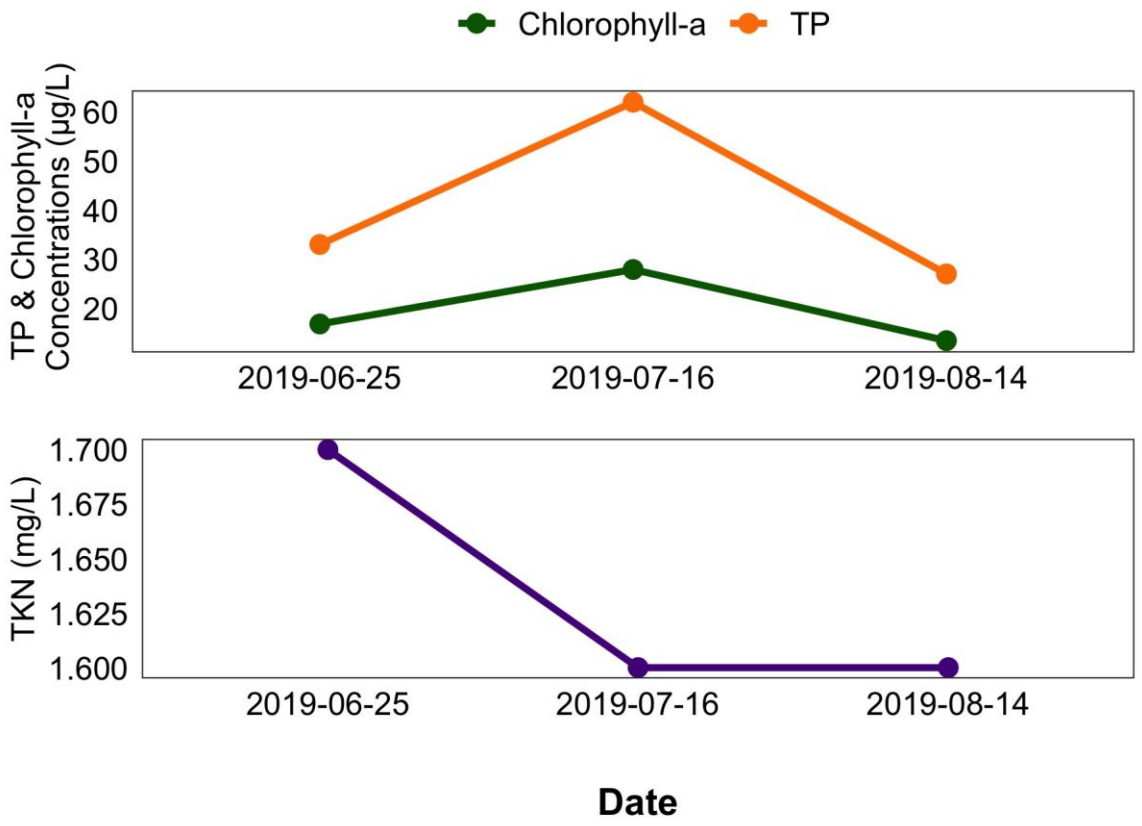


Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured three times over the course of the summer at Minnie Lake.

METALS

Samples were analyzed for metals once throughout the summer (Table 3). In total, 27 metals were sampled for. It should be noted that many metals are naturally present in aquatic environments due to the weathering of rocks and may only become toxic at higher levels.

Metals were measured once on August 14 at Minnie Lake at the surface. Arsenic in Minnie Lake exceeded the CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (Table 3), however, groundwater concentrations of arsenic are known to be elevated in this area of Alberta and exceedances are not uncommon in Minnie 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 Minnie Lake in 2019 was 1.58 m (Table 2), remaining very consistent throughout the season (Figure 2).

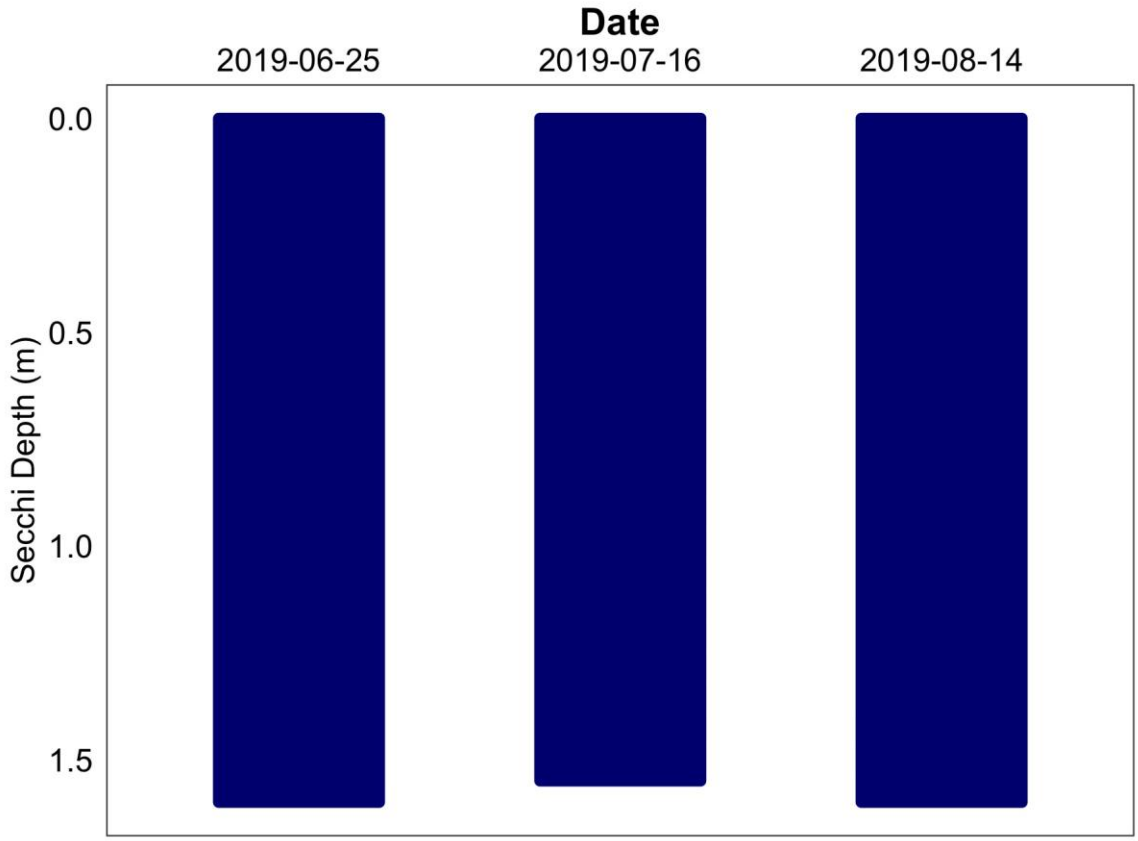


Figure 2. Secchi depth values measured three times over the course of the summer at Minnie Lake in 2019.

WATER TEMPERATURE AND DISSOLVED OXYGEN

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

Temperatures of Minnie Lake varied throughout the summer, with a minimum temperature of 4.71°C at 22.5 m on June 25, and a maximum temperature of 22°C measured at the surface on July 16 (Figure 3a). The lake was strongly stratified during all sampling trips, with a steep temperature gradient between 5 and 10 meters and temperatures consistently below 6°C in the bottom 10 meters of the lake. This indicates that the top, warmer layer mixes very little with the bottom layer, and is a typical pattern in deep temperate lakes.

Minnie Lake remained well oxygenated through the upper 4.5 meters of the water column throughout the summer, measuring above the CCME guidelines of 6.5 mg/L dissolved oxygen (Figure 3b). The oxygen level fell below this depth within the bottom layer of the water column, which is typical of stratified lakes with little mixing between top and bottoms layers of the water column. The dissolved oxygen profile obtained on June 25 shows a sharp spike in DO concentration at 4.5 m depth. This pattern in DO profiles has previously been associated with whiting events (blooms of picocyanobacteria that cause a milky colour in the lake), or a metalimnetic bloom of *Planktothrix* sp. cyanobacteria. These phenomena have been documented at Minnie Lake in previous years, but for 2019 in particular, technicians noticed water collected at 4.5m depth was pink in colour, matching the phenomena of a *Planktothrix* sp. bloom.

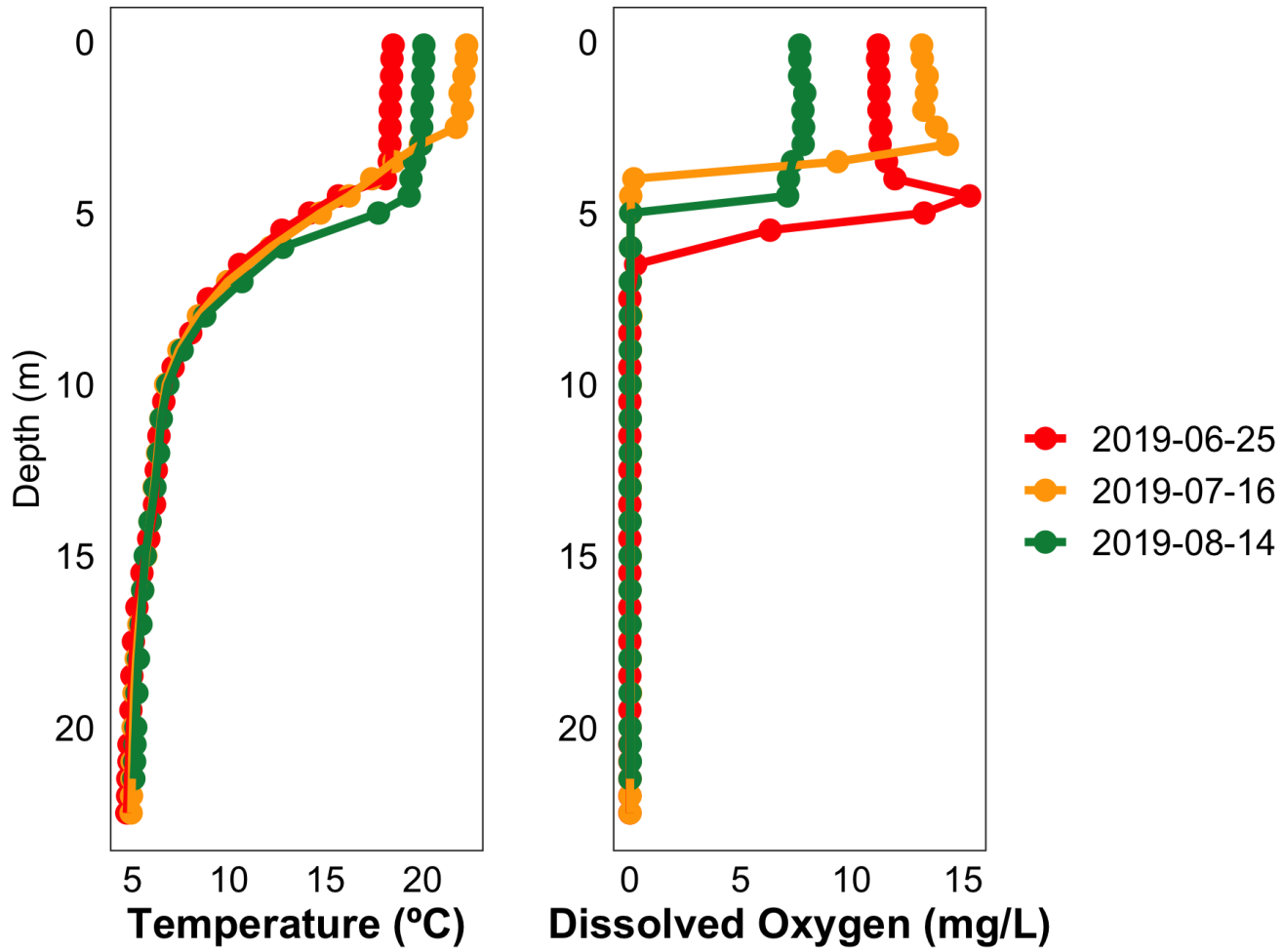


Figure 3. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Minnie Lake measured three times over the course of the summer of 2019.

MICROCYSTIN

Microcystins are toxins produced by cyanobacteria (blue-green algae) which can cause severe liver damage when ingested and skin irritation with prolonged contact. 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 Minnie Lake fell below the recreational guideline of 20 µg/L at the locations and times sampled in Minnie Lake in 2019.

Table 1. Microcystin concentrations measured three times at Minnie Lake in 2019.

Date	Microcystin Concentration (µg/L)
25-Jun-19	0.52
16-Jul-19	1.36
14-Aug-19	0.36
Average	0.75

INVASIVE SPECIES MONITORING

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

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

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

No milfoil, native or Eurasian, was observed at Minnie Lake in 2019.

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 fluctuate seasonally in Minnie Lake. The highest recorded level at Minnie Lake was in 1981 when records first began. (Figure 4) Since then, water levels have steadily dropped by approximately 3 m, with lowest levels on record being in 2013 and 2015. However, since then levels have come up almost 1m.

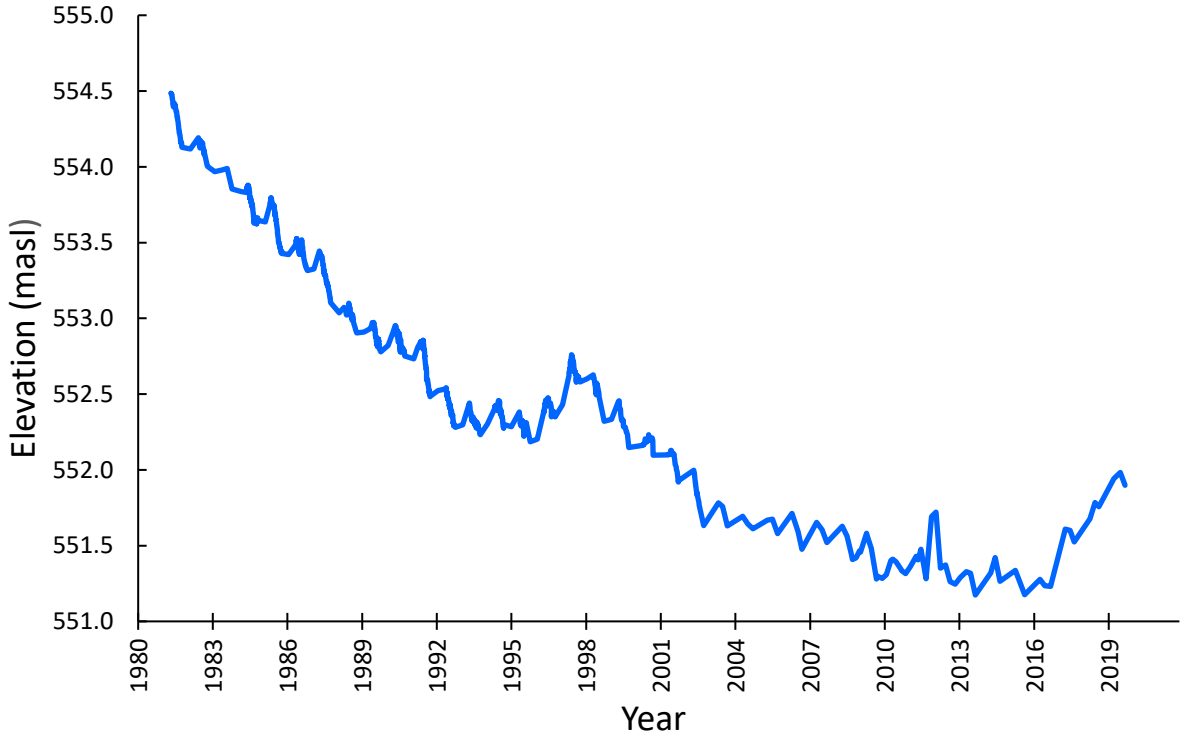


Figure 4. Historical surface water elevation in masl (meters above seal level) at Minnie lake from 1981 to 2019. Data retrieved from Alberta Environment and Parks.

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

Parameter	1978	1979	1985	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
TP (µg/L)	/	/	21	40	4	39	52	45	32	34	24	19	29	28	41
TDP (µg/L)	/	/	11	24	23	27	26	22	21	24	11	8	10	9	11
Chlorophyll-*a* (µg/L)	/	/	6.0	5.3	4.0	3.4	5.2	6.4	3.0	4.1	4.8	7.0	9.4	8.1	19.4
Secchi depth (m)	/	/	/	4.50	2.20	4.70	3.90	3.80	3.30	3.70	2.60	1.90	1.90	2.30	1.58
TKN (mg/L)	/	/	1.2	1.5	1.5	1.6	1.8	1.7	1.6	1.5	1.5	1.5	1.5	1.5	1.6
NO_2-N and NO_3-N (µg/L)	/	/	6	21	8	12	14	11	3	38	3	3	2	4	2
NH_3-N (µg/L)	/	/	50	6	36	99	35	42	24	50	31	25	22	39	15
DOC (mg/L)	/	/	13	18	20	20	19	19	22	18	18	19	18	19	20
Ca (mg/L)	29	30	19	27	26	22	26	24	23	23	26	23	29	34	36
Mg (mg/L)	90	87	91	120	121	123	131	121	144	124	144	142	136	130	130
Na (mg/L)	62	61	68	94	97	97	96	96	99	103	96	97	93	94	93
K (mg/L)	12	9	13	23	19	19	19	20	21	20	20	20	20	20	19
SO_4^{2-} (mg/L)	223	211	197	399	421	409	400	451	391	433	440	428	420	423	467
Cl^- (mg/L)	3	3	4	7	7	8	7	8	7	8	8	8	8	8	9
CO_3 (mg/L)	/	/	21	26	31	23	29	28	45	38	37	38	32	27	46
HCO_3 (mg/L)	340	398	368	408	390	412	393	398	359	425	376	360	354	368	347
pH	8.90	8.60	8.60-8.90	8.63	8.80	8.65	8.77	8.73	8.88	8.78	8.82	8.86	8.84	8.72	8.85
Conductivity (µS/cm)	922	981	992	1340	1323	1370	1350	1368	1418	1360	1400	1400	1320	1375	1400
Hardness (mg/L)	442	435	422	562	564	562	605	558	649	567	660	634	630	628	640
TDS (mg/L)	614	611	595	897	914	903	902	943	906	948	962	932	912	918	973
Microcystin (µg/L)	/	/	/	0.13	0.11	0.08	0.11	0.14	0.09	0.08	0.07	0.11	0.12	0.27	0.75
Total Alkalinity (mg/L $CaCO_3$)	324	316	338	378	372	376	371	373	369	352	370	356	344	348	360

Table 3a. Concentrations of metals measured once in Minnie Lake. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Values in red exceed the recommended guidelines.

Metals (Total Recoverable)	2008	2009	2010	2011	2013	2014	Guidelines
Aluminum µg/L	13.7	13	14.26	14.84	22.55	17.4	100[a]
Antimony µg/L	0.382	0.375	0.392	0.3725	0.3685	0.349	/
Arsenic µg/L	9.15	9.33	9.56	9.07	9.83	9.875	5
Barium µg/L	20.6	18.7	18.5	18.25	12.65	12.35	/
Beryllium µg/L	<0.003	<0.003	0.005	0.0015	0.0057	0.004	100[c,d]
Bismuth µg/L	0.0073	0.0057	0.00385	0.0005	0.00795	0.0005	/
Boron µg/L	162	205.5	159.5	204.5	186.5	185	1500
Cadmium µg/L	0.0124	0.0187	0.01725	0.01385	0.0036	0.00186	0.26[b]
Chromium µg/L	0.494	0.394	0.169	0.2575	0.3065	0.292	/
Cobalt µg/L	0.111	0.092	0.0972	0.07485	0.09775	0.0687	1000[d]
Copper µg/L	0.332	2.09	0.6815	1.0825	1.3	0.9025	4[b]
Iron µg/L	10.9	43.6	16.1	8.9	29.3	16.85	300
Lead µg/L	0.0274	0.0544	0.0851	0.03275	0.0617	0.01115	7[b]
Lithium µg/L	74.1	101.5	84.05	106.5	93.95	92.95	2500[e]
Manganese µg/L	8.61	6.36	5.905	15.75	4.515	6.78	200[e]
Molybdenum µg/L	0.799	0.727	0.746	0.735	0.6685	0.5695	73[c]
Nickel µg/L	0.271	0.665	0.3805	0.15125	0.5225	0.3475	150[b]
Selenium µg/L	0.2	0.292	0.232	0.228	0.089	0.123	1
Silver µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.25
Strontium µg/L	74	69.7	55	73.25	49.7	58.7	/
Thallium µg/L	0.0026	0.0029	0.00555	0.000275	0.0015	0.00085	0.8
Thorium µg/L	0.0628	0.00215	0.01825	0.01015	0.0321	0.01137	/
Tin µg/L	0.0308	<0.03	0.015	0.015	0.015	0.00825	/
Titanium µg/L	0.667	0.691	1.0995	0.686	1.1145	0.685	/
Uranium µg/L	2.3	2.08	2.16	2.14	2.1	2.165	15
Vanadium µg/L	1.31	1.22	1.165	1.06	1.035	1.04	100[d,e]
Zinc µg/L	1.58	1.34	1.165	1.48	1.465	1.58	30

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

[b] Based on water hardness > 180mg/L (as $CaCO_3$)

[c] CCME interim value.

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

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

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

Table 3b. Concentrations of metals measured once in Minnie Lake. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference. Values in red exceed the recommended guidelines.

Metals (Total Recoverable)	2015	2016	2017	2018	2019	Guidelines
Aluminum µg/L	9.95	7.1	3.9	1.8	6.1	100[a]
Antimony µg/L	0.3985	0.415	0.395	0.4	0.344	/
Arsenic µg/L	10.36	8.34	9.65	7.7	8.91	5
Barium µg/L	14.9	12	17.4	22.4	15.8	/
Beryllium µg/L	0.004	0.004	0.0055	0.0	0.0015	100[c,d]
Bismuth µg/L	0.0005	5.00E-04	0.0055	0.0	0.0015	/
Boron µg/L	185	187	194	170.0	184	1500
Cadmium µg/L	0.002	0.001	0.025	0.0	0.005	0.26[b]
Chromium µg/L	0.125	0.07	0.25	0.1	0.05	/
Cobalt µg/L	0.0875	0.102	0.124	0.1	0.105	1000[d]
Copper µg/L	1.665	1.48	2.7	0.2	0.04	4[b]
Iron µg/L	13.1	10.7	9	5.8	7.6	300
Lead µg/L	0.029	0.03	0.01	0.0	0.006	7[b]
Lithium µg/L	89.3	101	99.8	91.4	94.4	2500[e]
Manganese µg/L	7.38	2.94	5.44	3.9	6.97	200[e]
Molybdenum µg/L	0.6185	0.597	0.484	0.5	0.5	73[c]
Nickel µg/L	0.3825	0.775	1.87	0.4	0.18	150[b]
Selenium µg/L	0.085	0.12	0.5	0.7	0.7	1
Silver µg/L	<0.01	<0.01	<0.01	<0.01	<0.01	0.25
Strontium µg/L	76	50.1	84.4	119.0	93.5	/
Thallium µg/L	0.00045	9.00E-04	0.011	<0.01	0.001	0.8
Thorium µg/L	0.002225	0.0086	0.01	0.0	0.004	/
Tin µg/L	0.0135	0.01	0.15	0.1	0.03	/
Titanium µg/L	0.875	0.54	0.42	0.4	0.41	/
Uranium µg/L	2.26	2.31	2.02	2.1	2.16	15
Vanadium µg/L	1.265	1.36	0.957	0.7	0.573	100[d,e]
Zinc µg/L	1.55	2.3	3.8	1.9	1	30

Values represent means of total recoverable metal concentrations.

[a] Based on pH ≥ 6.5

[b] Based on water hardness > 180mg/L (as $CaCO_3$)

[c] CCME interim value.

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

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

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

LONG TERM TRENDS

Trend analysis was conducted on the parameters total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth to look for changes over time in Minnie Lake. In summary, significant decreasing trends were observed in TP and Secchi depth, and a significant increasing trend was observed in chlorophyll-*a*. Secchi depth can be subjective and is sensitive to variation in weather - trend analysis must be interpreted with caution. Data is presented below for the different parameters in each lake 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 Minnie Lake data from 2008 to 2019.

Parameter	Date Range	Direction of Significant Trend
Total Phosphorus	2008-2019	Decreasing
Chlorophyll-*a*	2008-2019	Increasing
Total Dissolved Solids	2008-2019	No Change
Secchi Depth	2008-2019	Decreasing

Definitions:

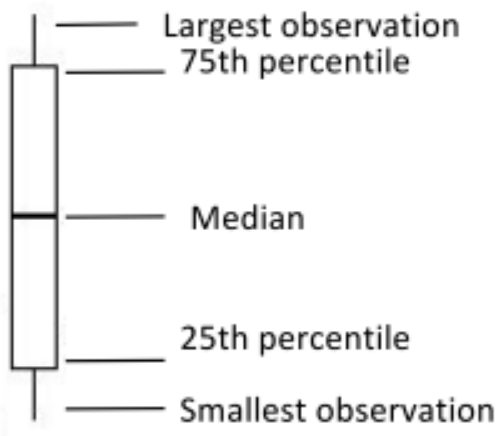
Median: the value in a range of ordered numbers that falls in the middle.

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)

Total phosphorus (TP) has decreased significantly over the course of data collection at Minnie Lake (Tau = -0.43, $p < 0.001$).

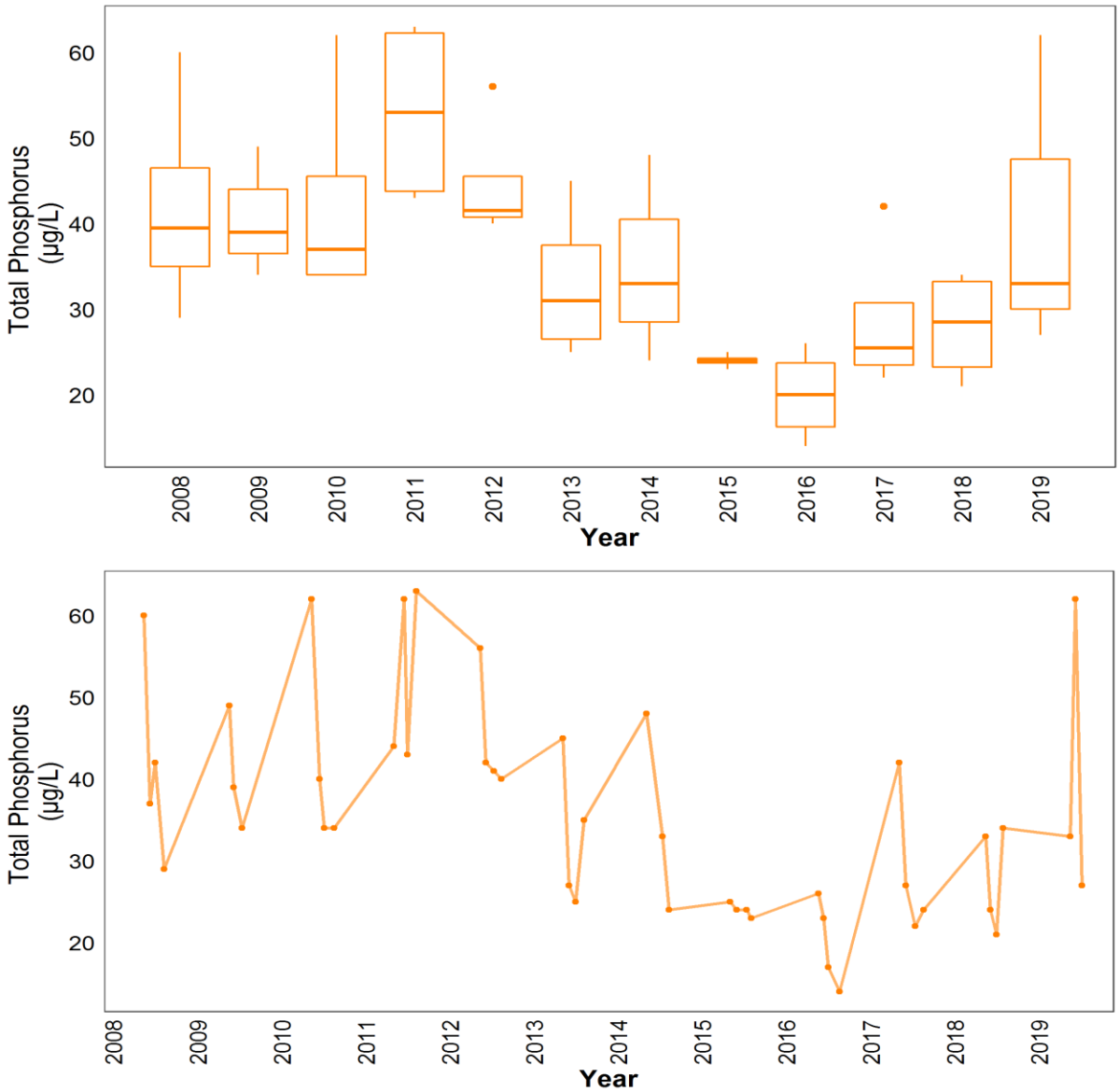


Figure 5. Total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 2008 and 2019 (n = 45). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples. Note: One outlier from July 14, 2017 was removed because the sample exceeded hold time at the lab and was not an accurate value.

Chlorophyll-*a*

Chlorophyll-*a* has been increased significantly since sampling began at Minnie Lake (Tau = 0.40, $p < 0.001$; Table 2).

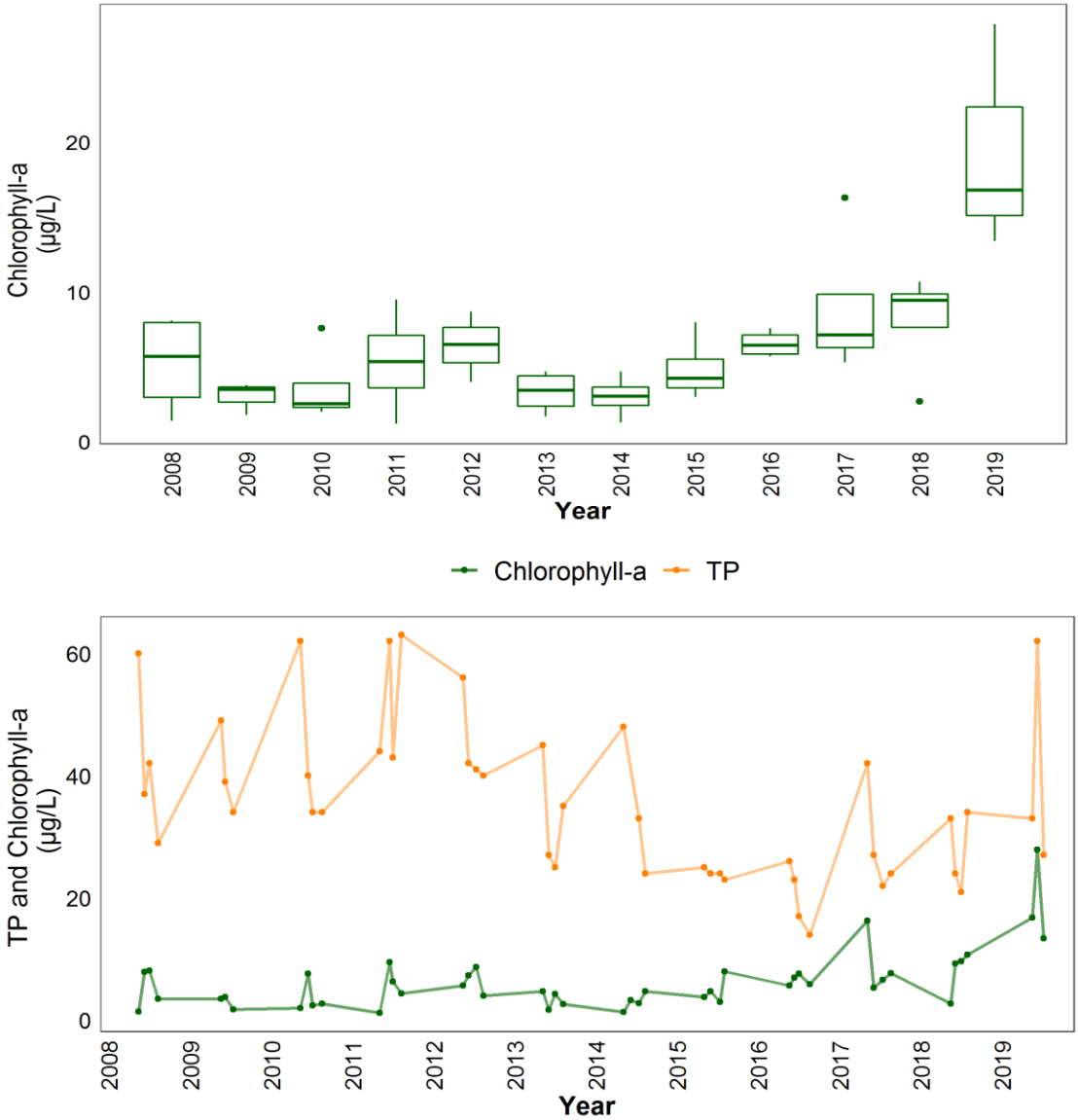


Figure 6. Monthly chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 2008 and 2019 (n = 46). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Total Dissolved Solids (TDS)

Total dissolved solids have not significantly changed since sampling began in 2008 (Tau= 0.18, *p* = 0.10).

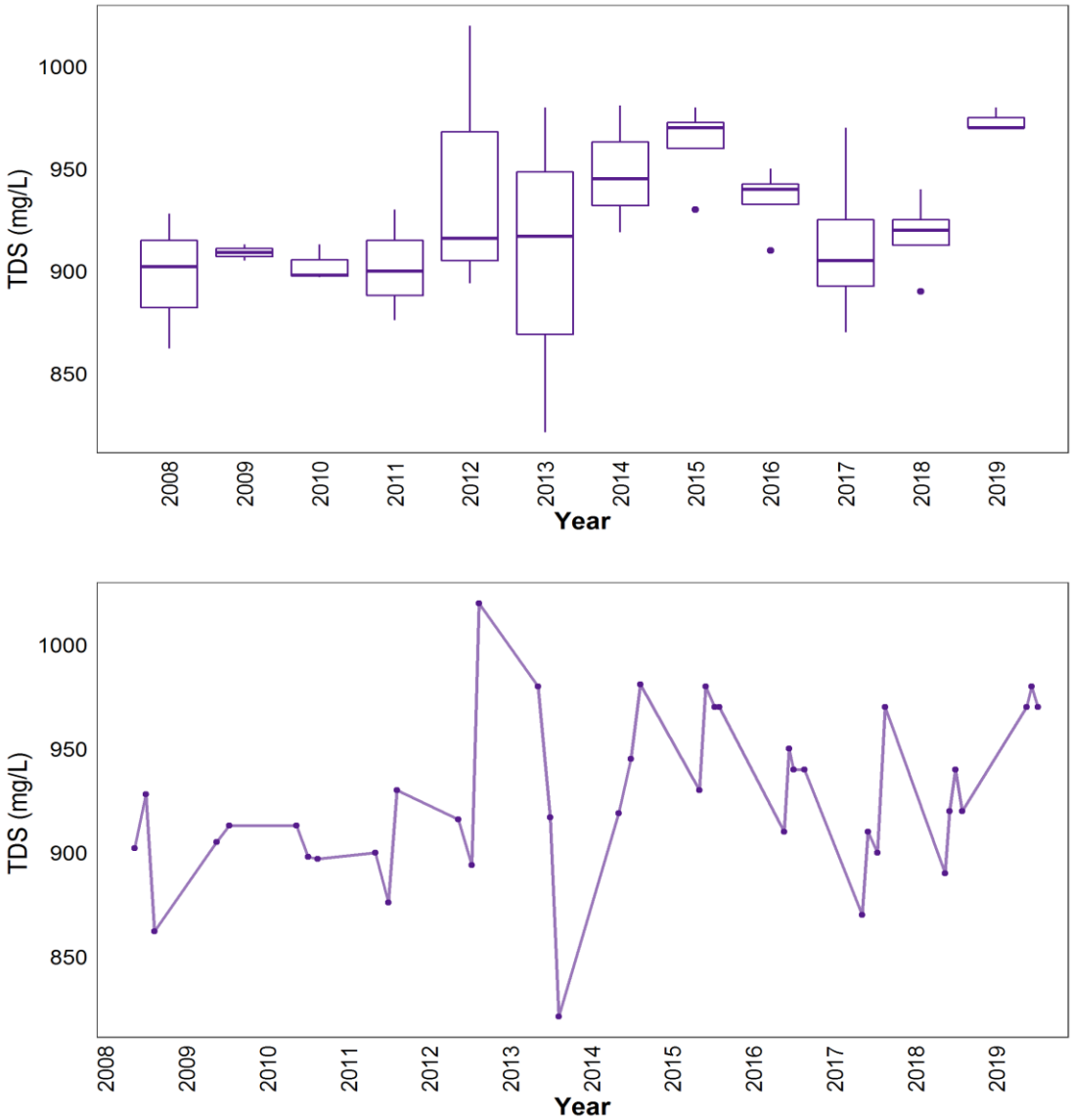
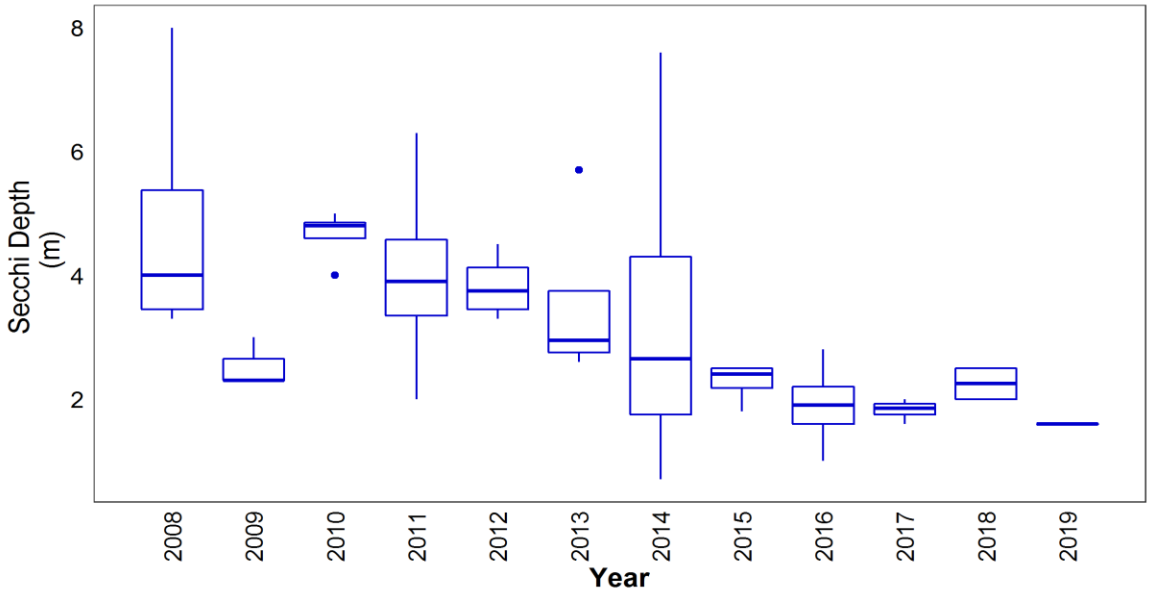


Figure 7. Monthly TDS values measured between June and September over the long term sampling dates between 2008 and 2019 (n = 39). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Secchi Depth

Trend analysis found that water quality measured as Secchi depth has decreased (become less clear) over the sampling period (Tau = -0.55, *p* <0.001).



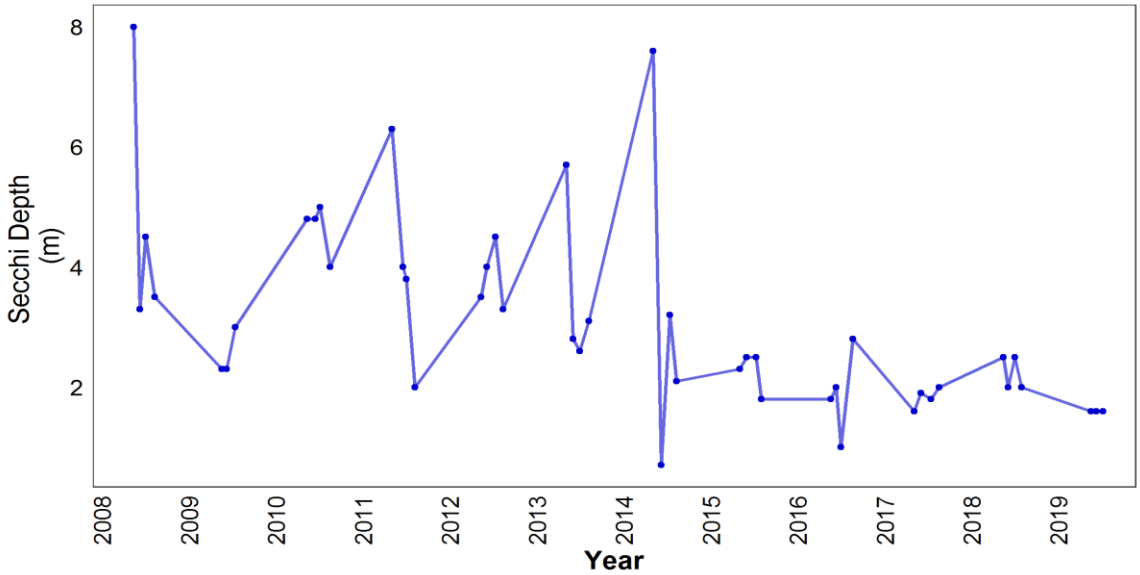


Figure 8. Monthly Secchi depth values measured between June and September over the long term sampling dates between 2008 and 2019 (n = 46). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 5. Results of Seasonal Kendall trend tests using monthly total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from June to September on Minnie 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	-0.43	0.40	0.18	-0.55
The extent of the trend	Slope	-1.87	0.58	3.00	-0.26
Number of samples included	n	45	46	39	46
The significance of the trend	*p*	0.00015*	0.00075*	0.10	9.54×10^{-6}*

*$p < 0.05$ is significant within 95%