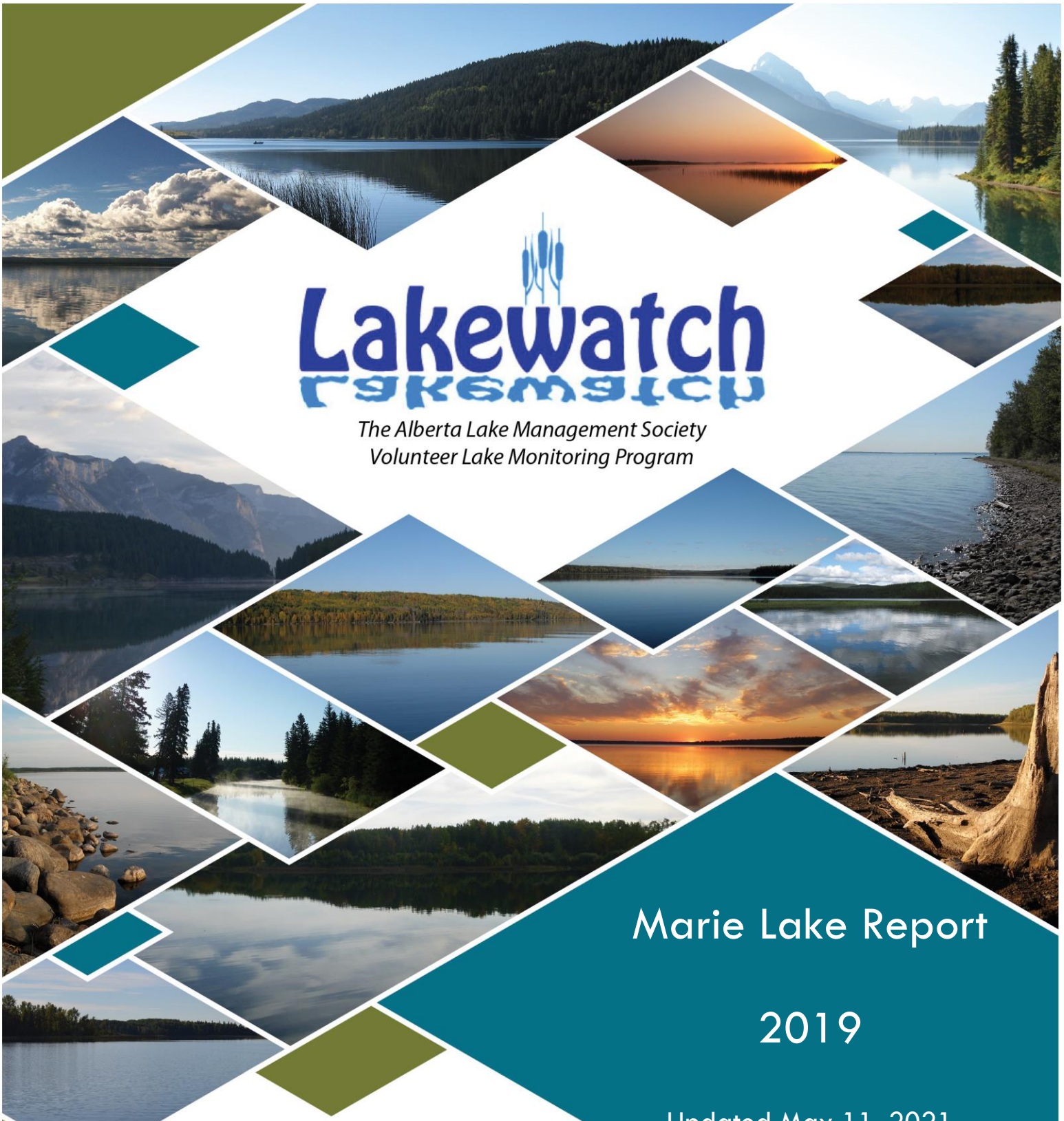


# Lakewatch

*The Alberta Lake Management Society*
*Volunteer Lake Monitoring Program*

# Marie 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.

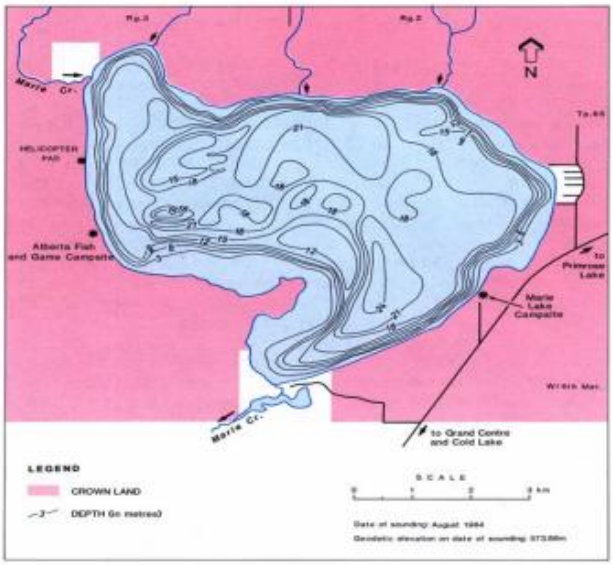
If you require data from this report, please contact ALMS for the raw data files.

# ACKNOWLEDGEMENTS

The LakeWatch program is made possible through the dedication of its volunteers. A special thank you to Roy Bibeau, Dean Wood, and Paul Kip for their time sampling Marie Lake. 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.

# MARIE LAKE

Marie Lake is located in the Beaver River Watershed, and lies approximately 26 km northeast of the Town of Cold Lake, in the central mixed wood natural subregion of Alberta.[1] Marie Lake is named after the Cree word Methae or Merai meaning "a fish", and may specifically refer to the burbot (Lota lota) prevalent throughout most of Alberta.[2] The Cree arrived in the late eighteenth century during the growth of the fur trade via a popular trade route from Waterhen, Saskatchewan. Their arrival resulted in the displacement of the Beaver, Blackfoot, and Slavey tribes that were common in the area.[2] Marie Lake is over 26 m deep (Figure 2) with a slow flushing rate (a residence time of 14.5 years). It is mesotrophic and has a small littoral zone for its surface area of 36 km$^2$ .




Bathymetric map of Marie Lake (Alberta Environment)

Marie Lake- Photo by: Randi Newton 2012

The shoreline is primarily sandy with macrophytes (aquatic plants) limited to a couple areas. A large macrophyte bed is located along the west shore stretching towards the north, and another lies on the western edge of the south bay. Macrophyte beds are dominated by bulrush, pondweed, and northern watermilfoil[1] . The low productivity of the shoreline does not provide suitable habitat for semi-aquatic wildlife; however, the macrophytes beds are very important for maintaining a productive fishery. Sport fish include lake whitefish, walleye, northern pike, yellow perch, and burbot.

The watershed area for Marie Lake is 396.51 km$^2$ and the lake area is 37.39 km$^2$. The lake to watershed ratio of Marie Lake is 1:11. A map of the Marie Lake watershed area can be found at http://alms.ca/wp-content/uploads/2016/12/Marie.pdf.

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[1] Nat. Regions Committee, 2006. Nat. Regions and Subregions of AB. Compiled by D.J. Downing and WW Pettapiece. GoA Pub. No. T/852

[2] Mitchell, P. and E. Prepas. 1990. Atlas of Alberta Lakes, University of Alberta Press. Retrieved from http://sunsite.ualberta.ca/projects/alberta-lakes/

# 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.

[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.***

Total phosphorus (TP) in Marie Lake had an average concentration of 11 µg/L in 2019, putting it in the mesotrophic trophic classification (Table 2). TP was relatively constant throughout the summer, fluctuating by only 4 µg/L (Figure 1).

Chlorophyll-*a* concentrations remained low over the course of the summer, with an average concentration of 4.0 µg/L in 2019 (Table 2). This puts Marie Lake in the mesotrophic trophic status class. A maximum concentration of 7.5 µg/L was reached on October 4 (Figure 1).

Marie Lake had an average TKN concentration of 0.5 mg/L over four sampling dates in 2019 (Table 2). Like TP, TKN was relatively consistent over the course of the season (Figure 1).

Average pH measured as 8.34 in 2019, buffered by moderate alkalinity (140 mg/L $CaCO_3$) and bicarbonate (168 mg/L $HCO_3$). Aside from bicarbonate, calcium was the only dominant ions contributing to a relatively low conductivity measure of 265 µS/cm (Table 2).

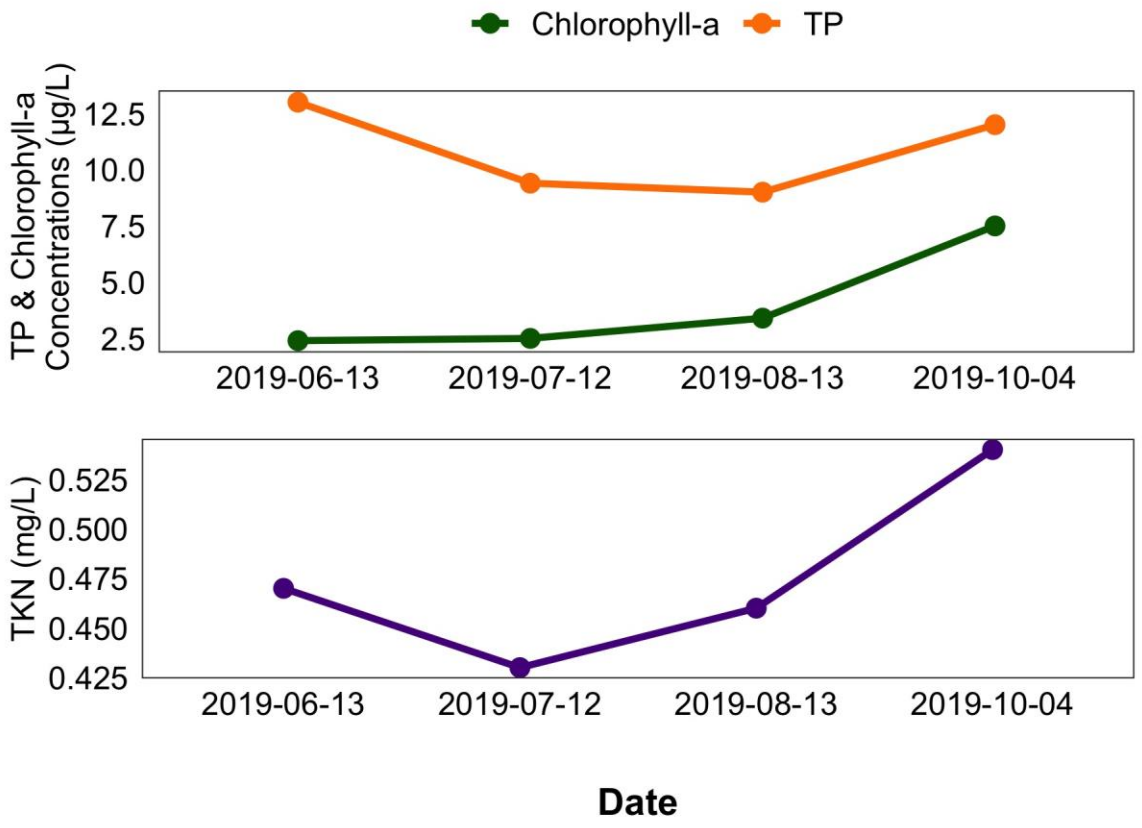



Figure 1. Total Phosphorus (TP), Total Kjeldahl Nitrogen (TKN), and Chlorophyll-*a* concentrations measured four times over the course of the summer at Marie Lake, 2019.

## 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 at Marie Lake in 2019 and all measured values fell within their respective guidelines (Table 3).

# 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.***

Average Secchi depth in 2019 was 3.98 m, classifying Marie lake as mesotrophic, or moderately productive (Figure 2). A maximum Secchi depth of 5.50 m was recorded on July 12, but Secchi depth remained relatively constant throughout the sampling season.

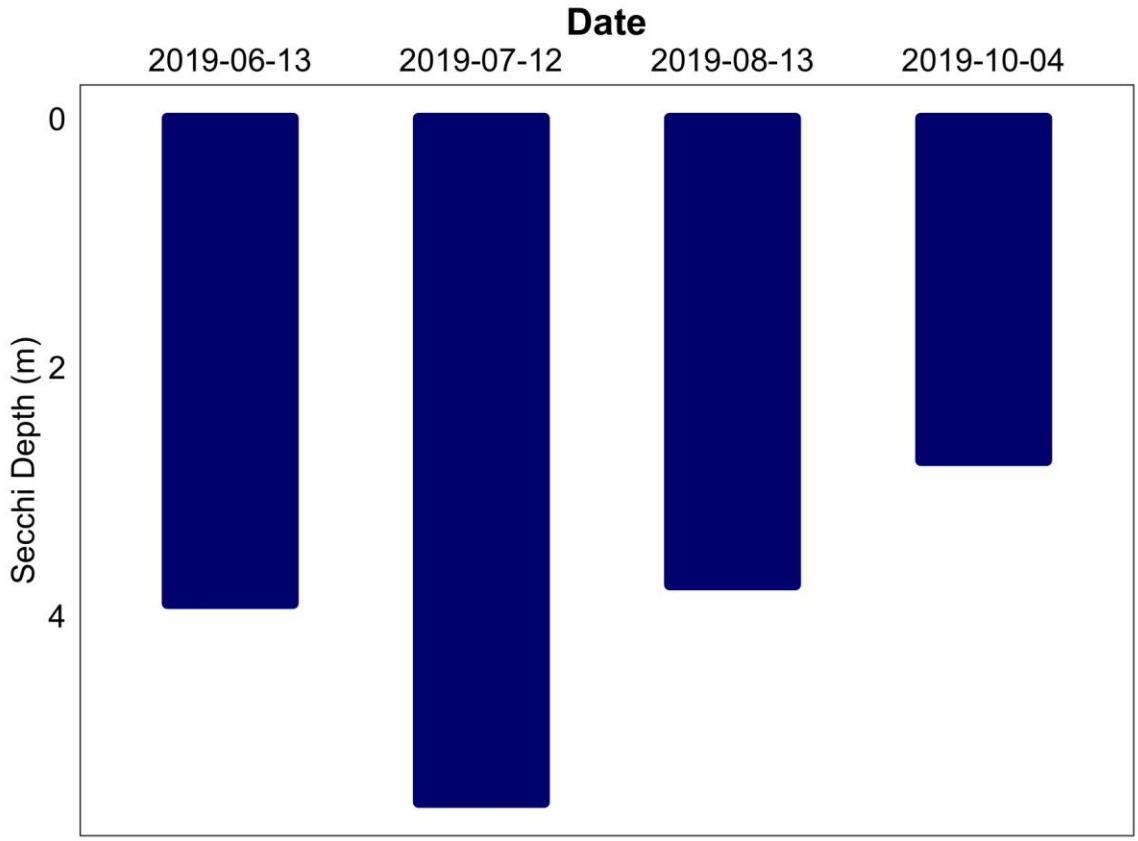



Figure 2. Secchi depth values measured four times over the course of the summer at Marie Lake in 2019.

# 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.***

Marie Lake water temperatures varied throughout the summer (Figure 3a). A maximum temperature of 18.5 °C was observed on August 13. Given that Marie Lake is quite deep, it reached thermal stratification on all sampling visits, aside from October 4, with the thermocline deepening as the surface water warmed over the course of the summer.

Marie Lake remained well oxygenated at the surface throughout the summer, measuring above the Canadian Council for Ministers of the Environment guidelines of 6.5 mg/L for the Protection of Aquatic Life (Figure 3b). Marie reached anoxic conditions at the bottom in July, August, and October. This could be due to the separation of atmospheric oxygen from the surface by way of thermal stratification.

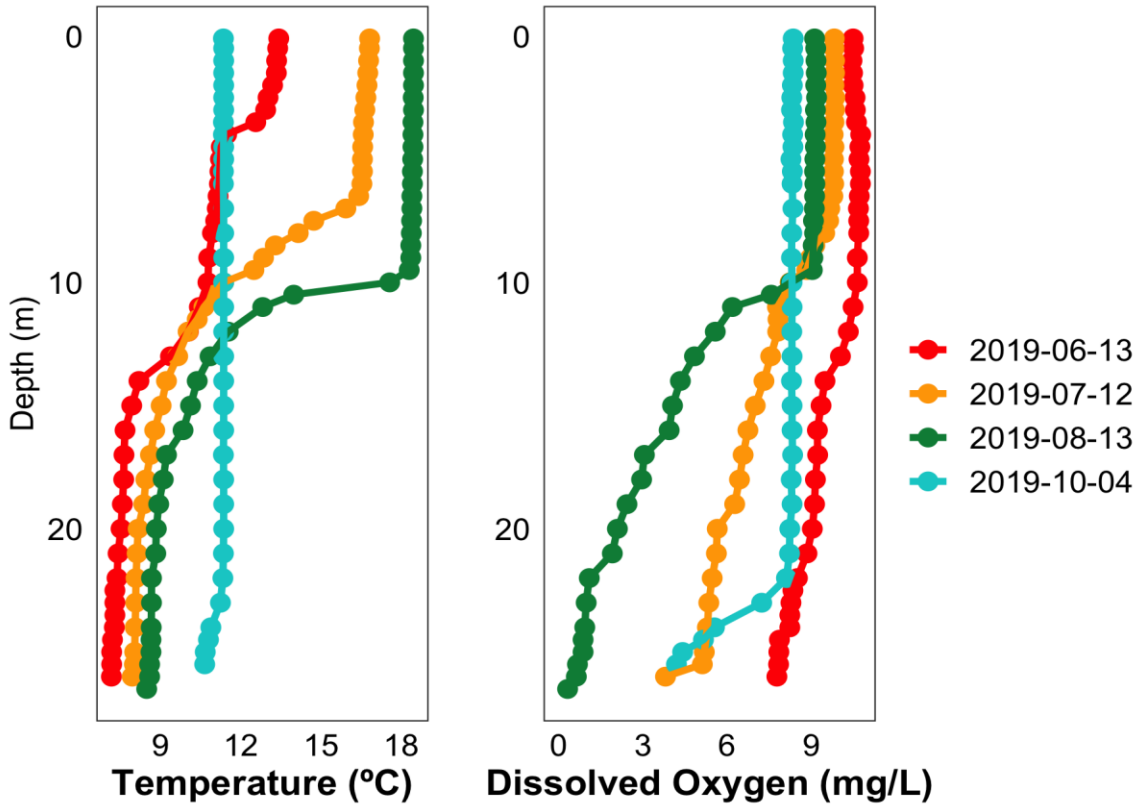



Figure 3. a) Temperature (°C) and b) dissolved oxygen (mg/L) profiles for Marie Lake measured four times over the course of the summer of 2019.

# MICROCYSTIN

***Microcystins are toxins produced by cyanobacteria (blue-green algae) which, when ingested, can cause severe liver damage. Microcystins are produced by many species of cyanobacteria which are common to Alberta's Lakes, and are thought to be the one of the most common cyanobacteria toxins. In Alberta, recreational guidelines for microcystin are set at 20 µg/L. Blue-green algae advisories are managed by Alberta Health Services. Recreating in algal blooms, even if microcystin concentrations are not above guidelines, is not recommended.***

Microcystin levels in Marie Lake fell below the recreational guideline of 20 µg/L in 2019. In fact, microcystin levels fell below the limit of detection on all 4 sampling events.

Table 1. Microcystin concentrations measured four times at Marie Lake in 2019. A value of 0.05 has been used for samples which fell below the detection limit of 0.1 µg/L.

| Date | Microcystin Concentration (µg/L) |
|---|---|
| 13-Jun-19 | 0.05 |
| 12-Jul-19 | 0.05 |
| 13-Aug-19 | 0.05 |
| 04-Oct-19 | 0.05 |
| **Average** | 0.05 |

# 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 Marie 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 Marie Lake.

# WATER LEVELS

***There are many factors influencing water quantity. Some of these factors include the size of the lake's drainage basin, precipitation, evaporation, water consumption, ground water influences, and the efficiency of the outlet channel structure at removing water from the lake. Requests for water quantity monitoring should go through Alberta Environment and Parks Monitoring and Science division.***

Water levels in Marie Lake have remained relatively stable since Environment Canada began monitoring the lake in 1980 (Figure 4). Since 1980, Marie Lake water levels have fluctuated between 573.1 masl and 574.4 masl.

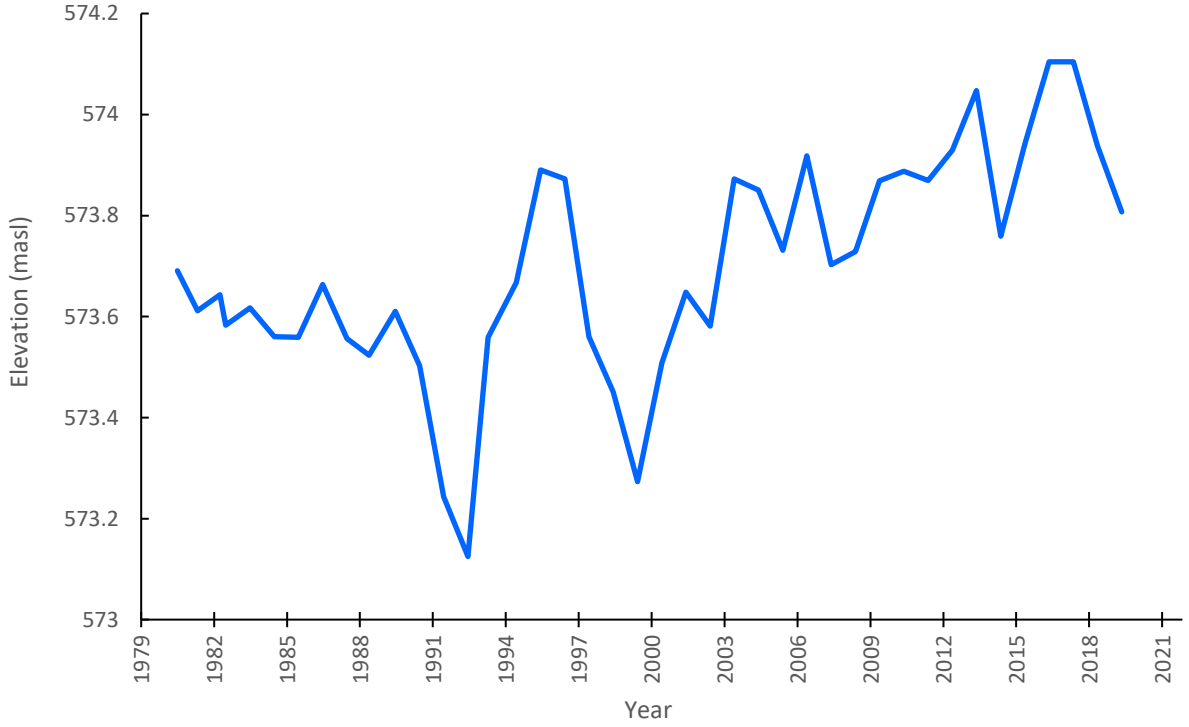



Figure 4. Water levels measured in meters above sea level (masl) from 1980- 2019. Data retrieved from Environment Canada (1980-2016), and Alberta Environment and Parks (2017-2019).

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

| Parameter | 1980 | 1981 | 2002 | 2003 | 2004 | 2007 | 2008 | 2009 | 2010 | 2012 | 2014 | 2016 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TP (µg/L) | / | 15 | 13 | 12 | 14 | 14 | 17 | 20 | 20 | 12 | 13 | 20 | 11 |
| TDP (µg/L) | / | 8 | 5 | 4 | 4 | 5 | 7 | 11 | 6 | 8 | 6 | 3 | 4 |
| Chlorophyll-a (µg/L) | 6.5 | 4.6 | 2.1 | 4.0 | 5.0 | 2.6 | 2.7 | 3.3 | 3.1 | 1.5 | 1.9 | 4.0 | 4.0 |
| Secchi depth (m) | 2.50 | 3.00 | 4.60 | 5.13 | 3.70 | 3.57 | 3.80 | 3.38 | 2.95 | 5.95 | 5.00 | 3.50 | 3.98 |
| TKN (mg/L) | / | / | 0.5 | 0.5 | 0.6 | 0.5 | 0.6 | 0.6 | 0.7 | 0.5 | 0.5 | 0.7 | 0.5 |
| NO2 and NO3 (µg/L) | <1 | / | 2 | 5 | 3 | 3 | 7 | 5 | 6 | 3 | 20 | 3 | 3 |
| NH3 (µg/L) | / | <22 | 9 | 7 | 7 | 12 | 15 | 16 | 11 | 17 | 13 | 25 | 17 |
| DOC (mg/L) | / | / | / | / | 10 | 11 | 11 | 10 | 11 | 10 | 23 | 10 | 12 |
| Ca (mg/L) | 30 | / | 35 | 34 | 33 | 34 | 33 | 32 | 27 | 33 | 33 | 34 | 34 |
| Mg (mg/L) | 12 | / | 12 | 14 | 12 | 12 | 12 | 12 | 13 | 13 | 13 | 14 | 13 |
| Na (mg/L) | 6 | / | 6 | 6 | 5 | 7 | 6 | 7 | 6 | 6 | 7 | 7 | 6 |
| K (mg/L) | 2 | / | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| SO42- (mg/L) | <3 | / | 1 | 6 | 2 | 2 | 2 | 3 | 5 | 2 | 2 | 1 | 1 |
| Cl- (mg/L) | <1 | / | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| CO3 (mg/L) | / | / | / | 4 | 6 | 7 | 4 | 9 | 1 | 15 | 2 | 2 | 2 |
| HCO3 (mg/L) | / | / | / | 176 | 171 | 166 | 173 | 166 | 174 | 148 | 174 | 170 | 168 |
| pH | / | / | / | 8.44 | 8.44 | 8.42 | 8.41 | 8.51 | 8.33 | 8.58 | 8.39 | 8.26 | 8.34 |
| Conductivity (µS/cm) | / | / | / | 276 | 274 | 266 | 266 | 264 | 263 | 268 | 262 | 266 | 265 |
| Hardness (mg/L) | / | / | / | 144 | 133 | 134 | 132 | 127 | 120 | 142 | 136 | 142 | 138 |
| TDS (mg/L) | / | / | / | 155 | 145 | 146 | 144 | 143 | 139 | 133 | 145 | 148 | 140 |
| Microcystin (µg/L) | / | / | / | / | 1.50 | / | / | / | / | 1.16 | / | 0.05 | 0.05 |
| Total Alkalinity (mg/L CaCO3) | 135 | / | 147 | 152 | 151 | 147 | 146 | 146 | 143 | 146 | 142 | 142 | 140 |

Table 3. Concentrations of metals measured once in Marie Lake. The CCME heavy metal Guidelines for the Protection of Freshwater Aquatic Life (unless otherwise indicated) are presented for reference.

| Metals (Total Recoverable) | 2007 | 2008 | 2010 | 2012 | 2014 | 2016 | 2019 | Guidelines |
|---|---|---|---|---|---|---|---|---|
| Aluminum µg/L | 9.1 | 4.2 | 12.25 | 3.705 | 16.5 | 7.3 | 6.7 | 100[a] |
| Antimony µg/L | 0.012 | 0.024 | 0.0232 | 0.0201 | 0.019 | 0.077 | 0.021 | 6[d] |
| Arsenic µg/L | 0.51 | 0.67 | 0.6575 | 0.619 | 0.635 | 2.2 | 0.56 | 5 |
| Barium µg/L | 33.3 | 32.1 | 32.2 | 33.6 | 31.6 | 10.6 | 28.6 | 1000[d] |
| Beryllium µg/L | <0.003 | <0.003 | 0.0062 | 0.0039 | 0.004 | 0.004 | 0.0015 | 100[c,e] |
| Bismuth µg/L | <0.001 | 0.0013 | 0.00195 | 0.0075 | 0.0005 | 5.00E-04 | 0.0015 | / |
| Boron µg/L | 17.7 | 23 | 18.95 | 38.65 | 22.2 | 170 | 18.8 | 1500 |
| Cadmium µg/L | <0.002 | 0.0029 | 0.01085 | 0.0018 | 0.002 | 0.001 | 0.005 | 0.26[b] |
| Chromium µg/L | 0.08 | 0.139 | 0.05285 | 0.04935 | 0.09 | 0.015 | 0.05 | / |
| Cobalt µg/L | <0.001 | 0.0073 | 0.0009 | 0.0005 | 0.001 | 0.024 | 0.019 | 1000[e] |
| Copper µg/L | 0.13 | <0.05 | 0.1555 | 0.276 | 0.29 | 0.84 | 0.04 | 4[b] |
| Iron µg/L | 39.9 | 3.28 | 23.15 | 2 | 12.9 | 7.5 | 13.8 | 300 |
| Lead µg/L | 0.021 | 0.0674 | 0.0161 | 0.003 | 0.047 | 0.012 | 0.002 | 7[b] |
| Lithium µg/L | 4.37 | 7.25 | 6.31 | 6.75 | 7.01 | 58.2 | 6.78 | 2500[f] |
| Manganese µg/L | 21.9 | 9.07 | 19.785 | 11.41 | 4.3 | 9.12 | 6 | 200[f] |
| Molybdenum µg/L | 0.154 | 0.172 | 0.19 | 0.173 | 0.164 | 0.326 | 0.178 | 73[c] |
| Nickel µg/L | <0.005 | 0.086 | 0.0025 | 0.0025 | 0.004 | 0.219 | 0.1 | 150[b] |
| Selenium µg/L | 0.06 | <0.1 | 0.05 | 0.05 | 0.03 | 0.42 | 0.1 | 1 |
| Silver µg/L | <0.0005 | <0.0005 | 0.00655 | 0.00025 | 0.001 | 0.001 | <0.01 | 0.25 |
| Strontium µg/L | 90.8 | 91 | 84.35 | 88.7 | 84.7 | 60.2 | 77.6 | / |
| Thallium µg/L | <0.0003 | <0.003 | 0.002575 | 0.00015 | 0.00045 | 0.0014 | 0.001 | 0.8 |
| Thorium µg/L | 0.007 | <0.003 | 0.00545 | 0.00015 | 0.001 | 0.0021 | 0.001 | / |
| Tin µg/L | 0.03 | 0.0315 | 0.015 | 0.015 | 0.014 | 0.017 | 0.03 | / |
| Titanium µg/L | 1.38 | 1.03 | 1.095 | 0.4205 | 0.5 | 0.41 | 0.3 | / |
| Uranium µg/L | 0.08 | 0.0662 | 0.0676 | 0.0606 | 0.051 | 0.369 | 0.058 | 15 |
| Vanadium µg/L | 0.14 | 0.112 | 0.12055 | 0.08575 | 0.1 | 0.2 | 0.056 | 100[e,f] |
| Zinc µg/L | 0.64 | 0.175 | 0.798 | 0.2915 | 1.2 | 1.3 | 0.4 | 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 Canadian Drinking Water Quality guideline values.

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

[f] 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 Marie Lake. In sum, significant decreasing trends were observed in chlorophyll-*a* and TDS. 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 Marie Lake data from 2003 to 2019.

| Parameter | Date Range | Direction of Significant Trend |
|---|---|---|
| **Total Phosphorus** | 2003-2019 | No Change |
| **Chlorophyll-*a*** | 2003-2019 | Decreasing |
| **Total Dissolved Solids** | 2003-2019 | Decreasing |
| **Secchi Depth** | 2003-2019 | No Change |

## Definitions:

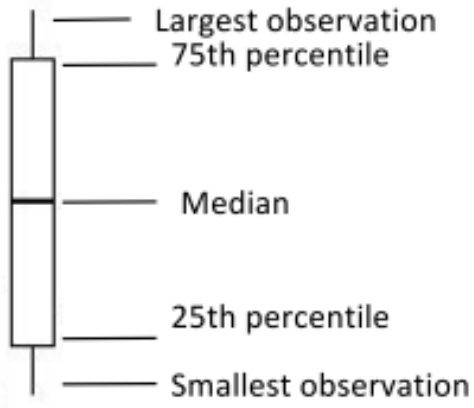
***Median: the value in a range of ordered numbers that falls in the middle.***

***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$^{th}$ percentile is the upper quartile of the data, and the 25$^{th}$ percentile is the lower quartile of the data. The top and bottom points are the largest and smallest observations.***



## Total Phosphorus (TP)

TP has not significantly changed over the course of data collection at Marie Lake (Tau = -0.10, *p* = 0.42).

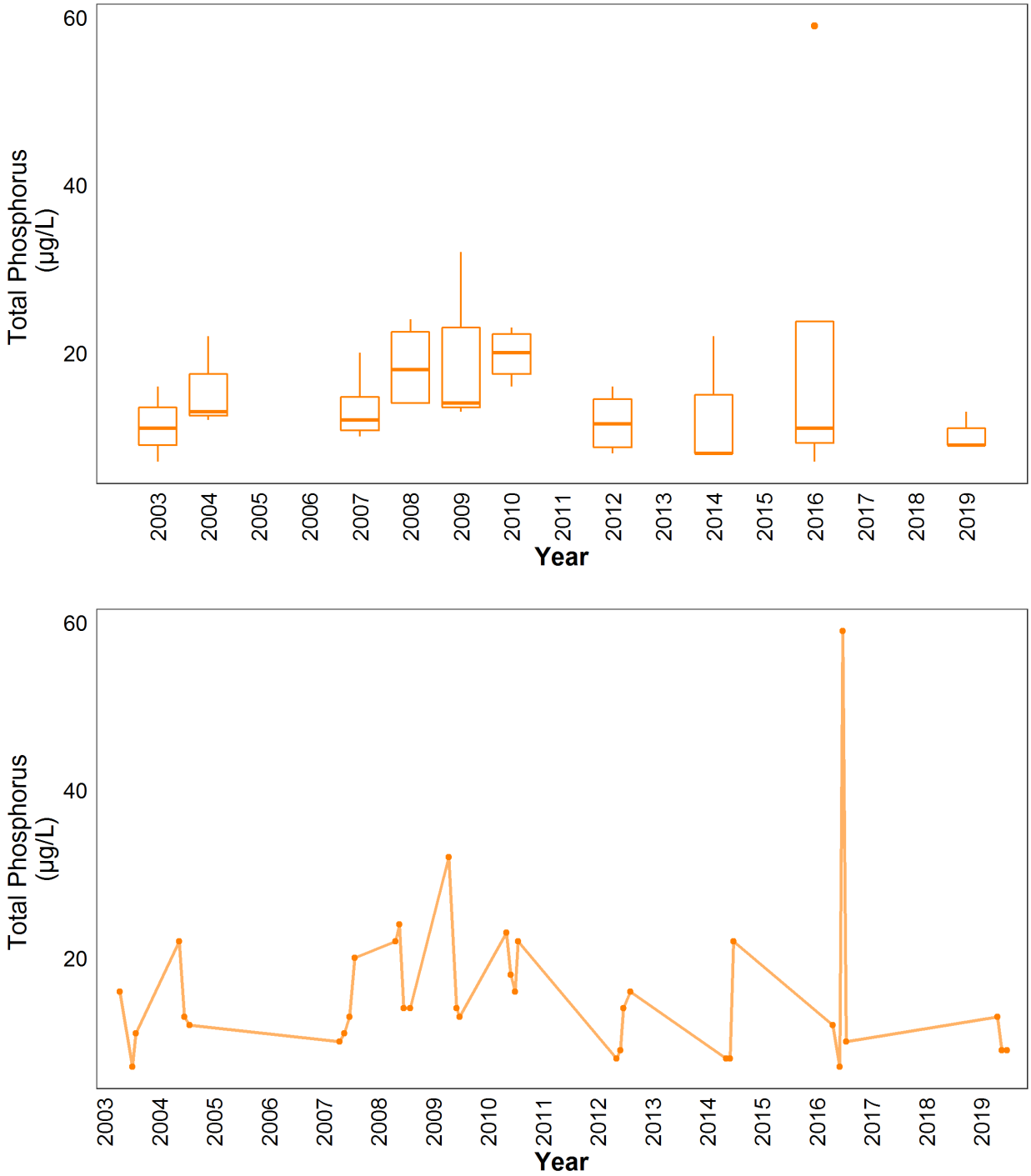



Figure 5. Total phosphorus (TP) concentrations measured between June and September over the long term sampling dates between 2003 and 2019 (n = 35). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

## Chlorophyll-*a*

Chlorophyll-*a* has significantly decreased, although only slightly, over the course of data collection at Marie Lake (Tau = -0.29, $p$ = 0.036).

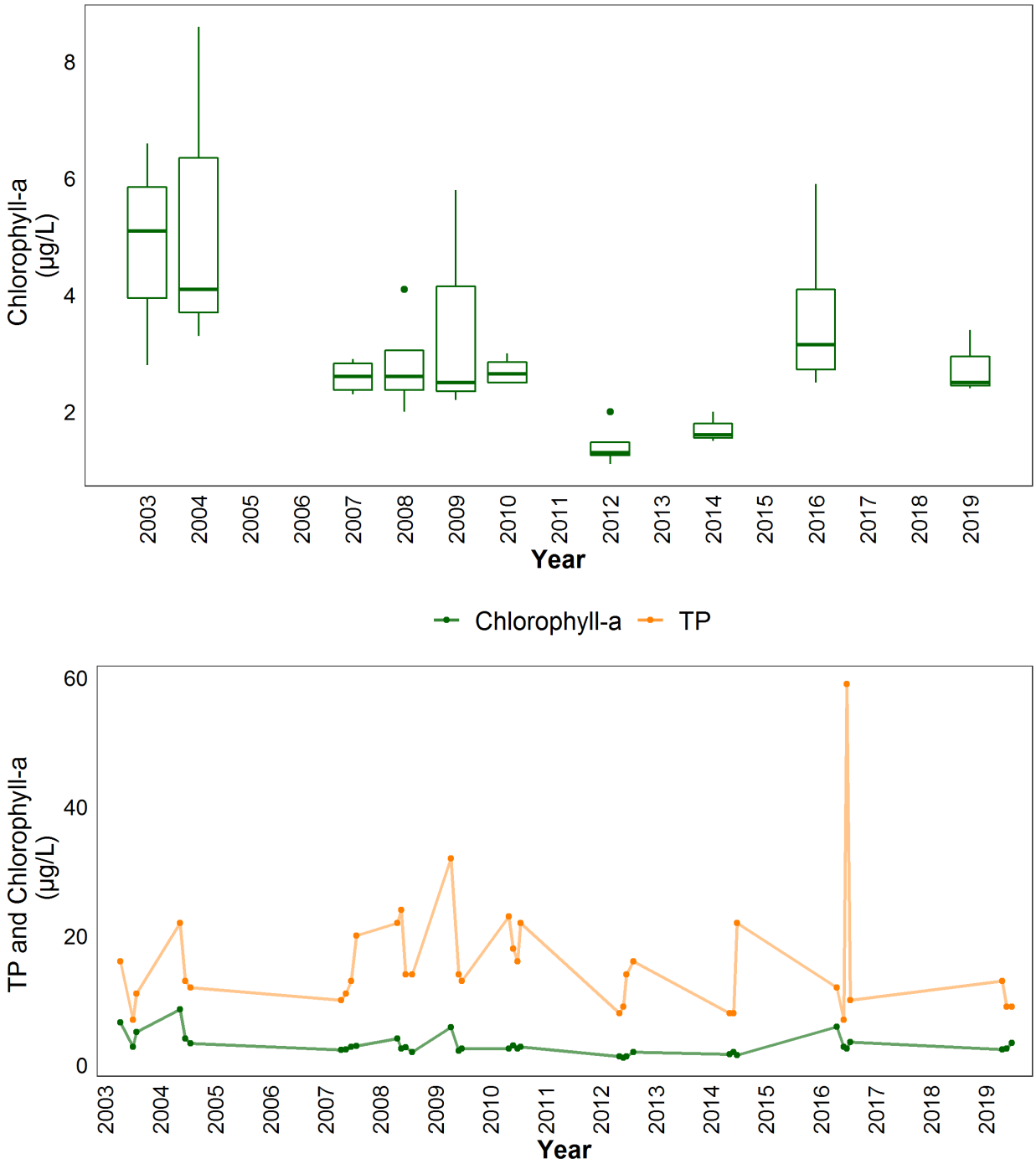



Figure 6. Chlorophyll-*a* concentrations measured between June and September over the long term sampling dates between 2003 and 2019 (n = 35). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

## Total Dissolved Solids (TDS)

Trend analysis on TDS shows a significant decrease over the course of sampling (Tau = -0.46, *p* = 0.0032).

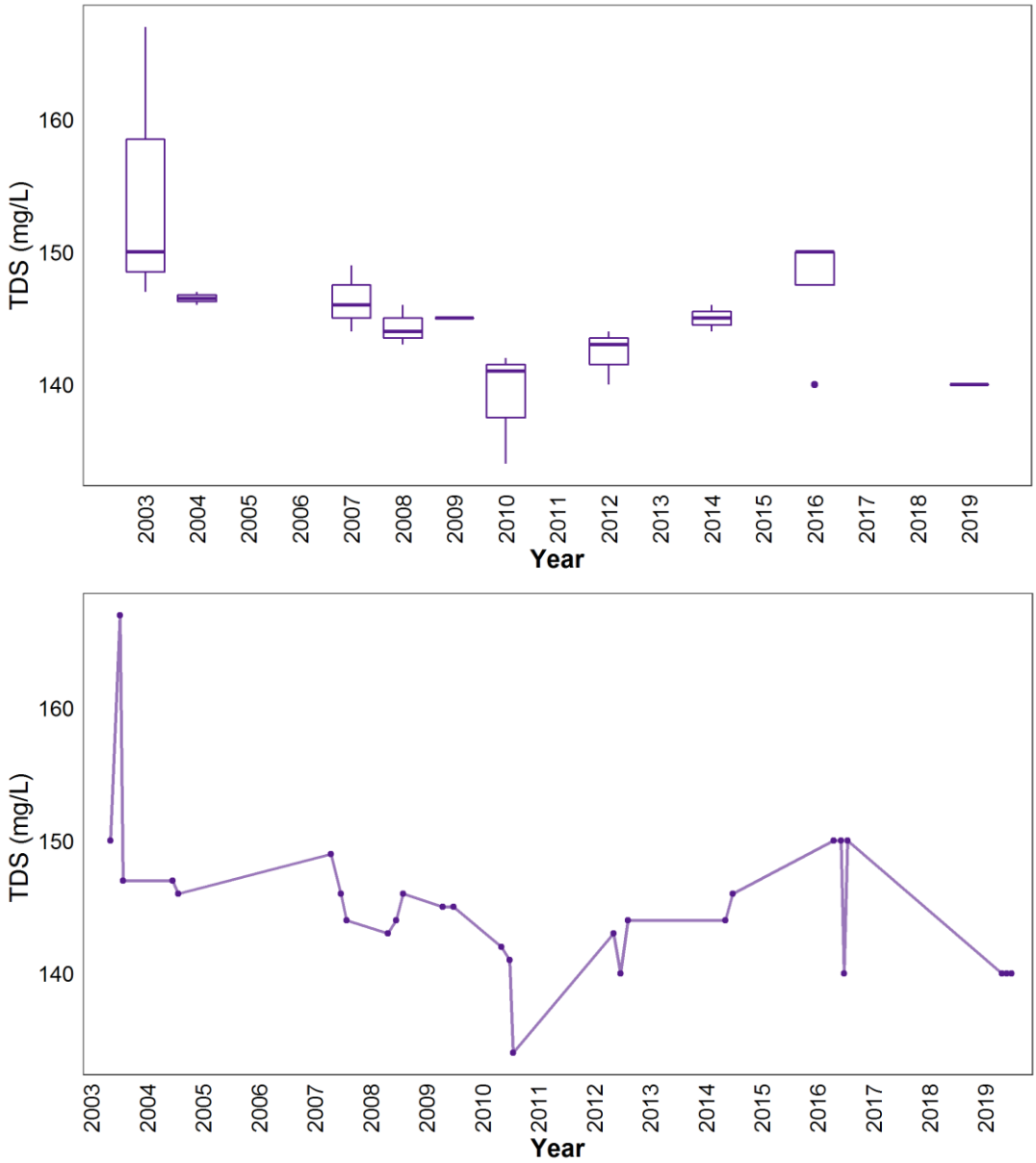



Figure 7. TDS measured between June and September over the long term sampling dates between 2003 and 2019 (n = 28). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

## Secchi Depth

Trend analysis found that water clarity measured as Secchi depth has not changed over the sampling period (Tau = 0.18, *p* = 0.28).

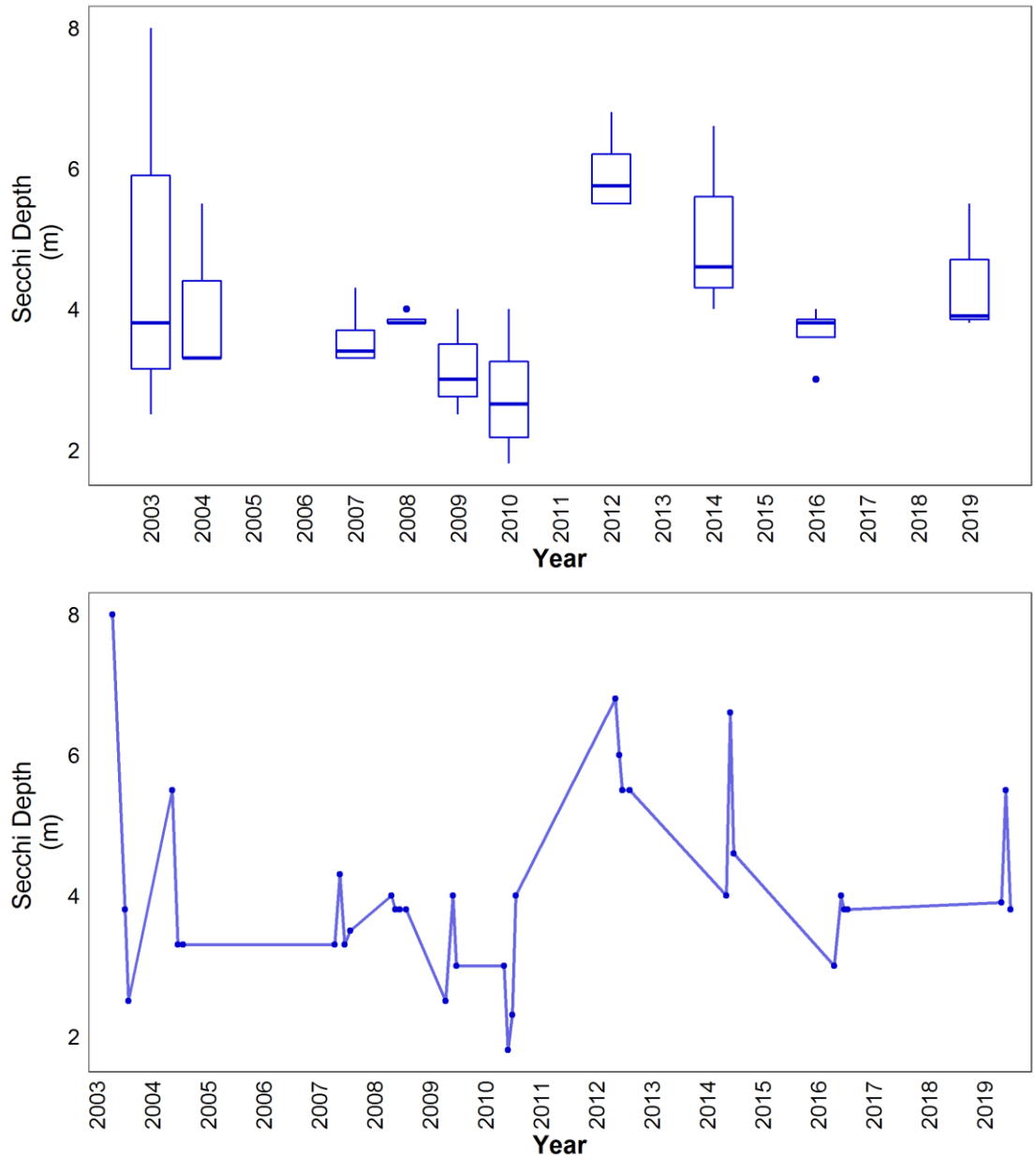



Figure 8. Secchi depth values measured between June and September over the long term sampling dates between 2003 and 2019 (n = 35). The value closest to the 15th day of the month was chosen to represent the monthly value in cases with multiple monthly samples.

Table 5. Results of Season Kendall and Mann-Kendall Trend tests using total phosphorus (TP), chlorophyll-*a*, total dissolved solids (TDS) and Secchi depth data from June to September on Marie Lake data.

| Definition | Unit | Total Phosphorus (TP) | Chlorophyll-a | Total Dissolved Solids (TDS) | Secchi Depth |
|---|---|---|---|---|---|
| **Statistical Method** | - | Mann Kendall | Seasonal Kendall | Seasonal Kendall | Seasonal Kendall |
| **The strength and direction (+ or -) of the trend between -1 and 1** | Tau | -0.10 | -0.29 | -0.46 | 0.18 |
| **The extent of the trend** | Slope | -0.00045 | -0.10 | -0.50 | 0.04 |
| **Number of samples included** | n | 35 | 35 | 28 | 35 |
| **The significance of the trend** | *p* | 0.42 | 0.036* | 0.0032* | 0.28 |

*$p < 0.05$ is significant within 95%