

# 2025 LONG LAKE ASSOCIATION LAKE SCIENCE REPORT



In collaboration with:



Authors:

Michael Schwartz - Benzie Conservation District  
Brian Stitt - Northwestern Michigan College

# **TABLE OF CONTENTS**

|                               |   |
|-------------------------------|---|
| Introduction.....             | 4 |
| Executive Summary.....        | 5 |
| Sampling Locations.....       | 7 |
| Equipment and Parameters..... | 8 |
| Termonology.....              | 9 |

---

|   |           |
|---|-----------|
| <b>Section 1: 2025 Lake Monitoring.....</b> | <b>10</b> |
| Secchi Disk Transparency.....               | 10        |
| Temperature and Dissolved Oxygen.....       | 11        |
| Conductivity.....                           | 13        |
| pH.....                                     | 14        |
| Nitrate/Nitrite-Nitrogen.....               | 15        |
| Calcium.....                                | 17        |
| Chlorophyll-a.....                          | 19        |
| Phosphorus.....                             | 21        |
| Water Levels.....                           | 24        |
| Plankton.....                               | 24        |
| <b>2025 Lake Chemistry Figures.....</b>     | <b>26</b> |
| Secchi Disk Transparency.....               | 26        |
| Temperature and Dissolved Oxygen.....       | 29        |
| Conductivity.....                           | 32        |
| pH.....                                     | 36        |
| Nitrate/Nitrite-Nitrogen.....               | 40        |
| Calcium.....                                | 42        |
| Chlorophyll-a.....                          | 44        |
| Phosphorus.....                             | 46        |
| Water Levels.....                           | 47        |
| Plankton.....                               | 48        |

|  |        |
|--|--------|
| <b>Section 2: Historical Analysis</b> .....    | 50     |
| Temperature and Dissolved Oxygen.....          | 50     |
| Secchi Disk Transparency.....                  | 50     |
| Nitrate/Nitrite-Nitrogen.....                  | 52     |
| Calcium.....                                   | 53     |
| Chlorophyll-a.....                             | 54     |
| Phosphorus.....                                | 55     |
| <b>Historical Lake Chemistry Figures</b> ..... | 57     |
| Temperature and Dissolved Oxygen.....          | 57     |
| Secchi Disk Transparency.....                  | 58     |
| Nitrate/Nitrite-Nitrogen.....                  | 60     |
| Calcium.....                                   | 61     |
| Chlorophyll-a.....                             | 62     |
| Phosphorus.....                                | 65     |
| <br>Acknowledgements.....                      | <br>72 |
| References Cited.....                          | 73     |

# **INTRODUCTION**

In 2025, the Long Lake Association continued its comprehensive water quality monitoring program. The program is headed by LLA Lake Science Committee co-chairs Len Klein and Karen Baker, and consists of testing conducted for the Michigan Cooperative Lake Monitoring Program (CLMP) and other independent sampling for parameters not included in CLMP. This dual-headed approach aims to cover a wide range of water quality parameters and ensure accurate results.

The association continued its water quality internship program with Northwestern Michigan College. This year's intern was Brian Stitt, who is enrolled in both the Freshwater Studies and Water Quality Environmental Technologies programs. This year the association also decided to begin an internship program with Benzie Conservation District. This was done to broaden the scope of the program and partner with a growing organization in local environmental protection. Their intern was Michael Schwartz, who is a graduate of Michigan Tech with degrees in Wildlife Ecology Management and Fish Biology.

Samples collected for CLMP are turned in and tested by Michigan Department of Environment, Great Lakes, and Energy (EGLE). These results are then posted to an online, publicly accessible database on the CLMP website. Independent monitoring conducted by the association is completed by Great Lakes Environmental Center (GLEC) and SOS Analytical. These results, CLMP results, and any additional research conducted are included in the annual Long Lake Association Water Quality Report, available on their website.

Data received from monitoring is compared to historical data and other local lakes to determine any changes or trends that may need additional investigation. Results are also used to determine Trophic Status Index (TSI), a measurement of a lake's overall health and status. This year samples were collected from locations on Long, Mickey, and Ruth Lakes.

This report is a complete review of the 2025 lake monitoring program. Section 1 will include a review of all testing conducted throughout the season. A historical analysis of trends will be included in Section 2.

# **2025 EXECUTIVE SUMMARY OF RESULTS**

Water quality monitoring in 2025 was conducted on Long, Mickey, and Ruth Lakes, yielding overall fairly consistent results to previous years. No abnormal increases were observed, indicating no new unknown sources of contamination. Some of the parameters measured, including total Calcium across all three lakes and depth phosphorus in Mickey Lake were the lowest recorded measurements since monitoring began. Long, Mickey, and Ruth Lakes all remain healthy and clean aquatic environments.

## ***Long Lake***

All parameters measured in Long Lake over the 2025 season remained consistent with historical averages, with many showing a decrease when compared to recent years.

*Transparency* slightly decreased from 2024, and fell just below the historical average. *Water temperature* and *dissolved oxygen* levels remained very consistent with previous years and historically. *Nitrate/Nitrite* levels showed a decrease from previous years and fell below historical averages. Many of the samples taken registered below the minimum testing detection limit for GLEC. *Calcium* levels this season measured at the lowest concentration recorded since monitoring began. *Phosphorus* levels for both surface and depth monitoring decreased when compared to last season and fall in line with historical averages. Sediment samples indicated a very low amount of stored phosphorus. 2025 *Chlorophyll-a* levels were slightly below both the 2024 and the overall historical average concentrations.

All parameters measured indicate oligotrophic status for Long Lake.

## ***Mickey Lake***

All parameters measured in Mickey Lake over the 2025 season remained consistent with historical averages, with many showing an improvement when compared to recent years.

*Transparency* increased from 2024, and fell above the historical average. *Water temperature* and *dissolved oxygen* levels remained very consistent with previous years and historically. *Nitrate/Nitrite* levels registered very low, with many of the samples taken registered below the minimum testing detection limit for GLEC. *Calcium* levels this season measured at the lowest concentration recorded since monitoring began. *Phosphorus* levels for both surface and depth monitoring decreased when compared to last season and historical averages. Depth phosphorus was measured at the lowest average yearly concentration since monitoring began. Sediment samples indicated a very low amount of stored phosphorus. *Chlorophyll-a* concentrations averaged slightly above 2024 results, but remained below the long term historical average.

Parameters indicate an oligo-mesotrophic status for Mickey Lake.

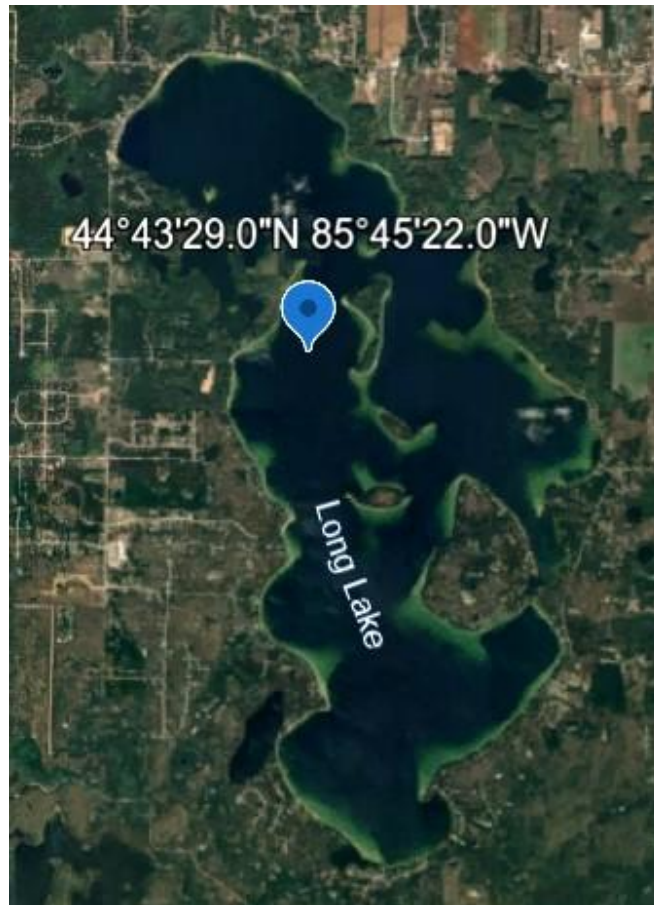
### ***Ruth Lake***

All parameters measured in Ruth Lake over the 2025 season remained fairly consistent with historical averages, with many showing an improvement when compared to recent years.

*Transparency* increased from 2024, and fell above the historical average. *Water temperature* and *dissolved oxygen* levels remained very consistent with previous years and historically. *Nitrate/Nitrite* levels registered very low, with many of the samples taken registered below the minimum testing detection limit for GLEC. *Calcium* levels this season measured at the lowest concentration recorded since monitoring began. *Phosphorus* levels showed mixed results when compared to last season and historical averages. Surface phosphorus slightly increased compared to last year, but still fell below the historical average. Depth phosphorus showed a slight decrease from last year's data. *Chlorophyll-a* concentrations did average above both the 2024 and the overall historical average, though the 2025 average still fell within Ruth's historical chlorophyll-a range.

Parameters measured indicate a meso-eutrophic status for Ruth Lake.

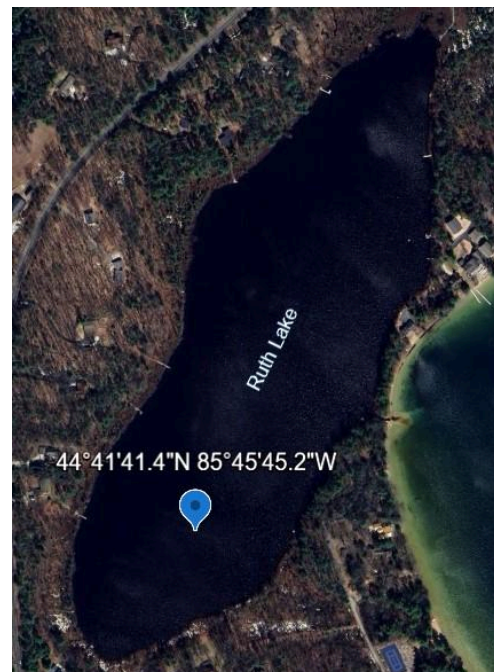
# SAMPLING LOCATIONS



Long Lake = 85' - 90' Depth



Mickey Lake = 30' - 35' Depth



Ruth Lake = 15' - 20' Depth

# **EQUIPMENT AND PARAMETERS**

- **YSI Pro DSS Hydrolab** - A digital, handheld, multi-parameter water quality meter. Uses replaceable sensors installed into a probe that are calibrated using calibration solutions. The probe is attached to a cable and lowered to specific depths throughout the water column.
  - Dissolved Oxygen
  - Temperature
  - PH
  - Conductivity
- **Secchi Disk** - A 8 inch disk with alternating black and white quadrants. The disc is lowered through the water column until it can no longer be seen.
  - Turbidity (Clarity)
- **Van Dorn Sampler** - A device that collects water samples from a specific depth. It consists of a tube with stoppers at both ends that are held open as the device is lowered. A messenger weight is then sent down the line to trigger the stoppers to close, capturing a water sample at the desired location.
  - Depth Phosphorus
  - Depth Nitrate-Nitrite
- **Composite Water Column Sampler** - Bottle capped with a stopper containing two tubes. The bottle is quickly lowered to specific depth then slowly retrieved, capturing a sample that represents the entire column.
  - Chlorophyll-a
- **Bottles provided by CLMP, GLEC, or SOS for surface grabs** - Some bottles come pre-treated with a preservative.
  - Surface Phosphorus
  - Surface Nitrate-Nitrite
  - Calcium
- **Plankton Net** - A conical or cylindrical funnel-shaped net, typically made of fine mesh, that is towed through the water to collect plankton for study.
  - Plankton composition
- **Ponar Sediment Grabber** - A claw, or grab, sampler used to retrieve sediment samples from the lake bottom.
  - Sediment Phosphorus
- **Other Parameters**
  - Water Levels

# TERMINOLOGY

**Benthic** - Lake bottom.

**Eutrophication** - process in which nutrients accumulate in a body of water, resulting in an increased growth of organisms that may deplete the oxygen in the water. This can be a natural process that takes thousands of years, or much quicker because of human actions (cultural eutrophication).

**Stratification** - The formation of distinct, layered zones within a body of water due to differences in temperature. This also affects the amount of dissolved oxygen available within each layer.

- Epilimnion - The warm, less dense top surface layer that is warmed by the sun and mixed by wind and waves.
- Metalimnion (Thermocline) - Denser middle layer that experiences a sharp decline in temperature, and possibly a slight increase in DO. Acts as a barrier that prevents heat exchange between Epilimnion and Hypolimnion.
- Hypolimnion - Deepest layer with little circulation. Contains cold, dense water and little to no dissolved oxygen.

**Trophic Status Index (TSI)** - Classification system that rates a body of water based on the amount of biological activity they contain. The TSI is rated on a scale of 0 -100.

- Oligotrophic (TSI 0 - 39) - Lakes that have low concentrations of nutrients, low biological productivity, and generally have clear water.
- Mesotrophic (TSI 40 - 59) - Lakes with moderate levels of nutrients and biological activity.
- Eutrophic (TSI ) - Lakes with high levels of nutrients and biological activity. Often characterised by green, murky water and algal blooms.
- Hypereutrophic (TSI ) - Lakes with extremely high levels of nutrients and biological activity. These lakes contain water with poor quality and have harmful algal blooms.

**Carlson's Trophic Status Index Formula -**

- Secchi Trophic Status Index =  $60 - 33.2 \log_{10} \times SD$
- Total Phosphorus Trophic Status Index =  $4.2 + 33.2 \log_{10} \times TP$
- Chlorophyll a TSI =  $30.6 + 22.6 \log_{10} \times CHL$

\* Where,

SD = Average secchi depth in meters

TP = Average summer and fall total phosphorus concentration ( $\mu\text{g/L}$ )

CHL = Average chlorophyll-a concentration ( $\mu\text{g/L}$ ).

# SECTION 1

## **2025 LAKE MONITORING**

### **Secchi Disk Transparency**

#### ***Background***

Secchi disk transparency is the measure of the available light in the water column, or the overall clarity of water, and is influenced by light absorption and scattering, water color (tannins), or the presence of suspended particles like silt, clay, algae, and organic matter (US Environmental Protection Agency 2025), (Dodds 2010). Monitoring transparency with a secchi disk has been considered an international standard in water quality monitoring dating back to 1865 (Bednarz et al. 2019). In large, this is due to its simplicity and cost effectiveness (Rivera-Ruiz 2024). Transparency influences biological processes, including the ability of submerged aquatic plants, algae, and phytoplankton to photosynthesize, controlling overall biomass and growth rates (Kirk 1994).

#### ***Testing Frequency and Methods***

Transparency measurements were collected using a secchi disk at the deepest basin in Long, Mickey, and Ruth Lakes from May to September, with weekly measurements occurring on Long and Mickey Lake, and three annual measurements occurring on Ruth Lake. To measure transparency, a secchi disk is lowered off the shaded side of an anchored boat until the disk is no longer visible, and then raised until visible again, with the recorded secchi measurement being the average between these two depths.

#### ***Long Lake***

Transparency measurements took place over 17 sampling events on Long Lake throughout 2025, resulting in an overall average transparency of 26.4 feet throughout the season (Table A-1). Transparency was clearest in the spring months, with the deepest secchi reading occurring during the first sampling event of the year on May 13th, with a depth of 49.5 feet (Figure A-1). This single event marked the deepest secchi reading of not only Long Lake, but of any lake participating in CLMP in 2025 (MiCorps 2025). Water clarity decreased steadily ( $R^2=0.68$ ) throughout the sampling season, with the lowest secchi reading taking place during the second to last sampling event on August 27th with a depth of 17.5 feet (Figure A-1).

The decrease in transparency throughout the 2025 sampling season is to be expected, and is something that is typically observed on oligotrophic lakes (Stadelmann 2001). These decreases in clarity are a result of natural increases in productivity that occur as sunlight and warmer water temperatures promote algae growth (Stadelmann 2001).

### ***Mickey Lake***

Like on Long Lake, transparency measurements took place over 17 sampling events on Mickey Lake throughout the 2025 sampling season, resulting in an overall average transparency of 17.8 feet (Table A-1). Transparency results varied throughout the 2025 season, ranging from the deepest secchi depth of 21.5 feet recorded on May 27th and on July 8th, to the lowest secchi depth of 14.5 feet, recorded on July 2 (Figure A-2). Unlike Long Lake, no clear trend ( $R^2=0.0002$ ) in transparency was observed on Mickey Lake throughout 2025.

### ***Ruth Lake***

Transparency measurements were conducted three times on Ruth Lake throughout the 2025 sampling season, resulting in an overall average transparency of 4.8 feet (Table A-1). The clearest transparency result was observed on September 4th at 6.5 feet, and the lowest result on July 21st at 3.5 feet (Figure A-3). Overall, the limited number of sampling events on Ruth Lake make it difficult to observe any potential trends.

In comparison to Long and Mickey Lakes, Ruth Lake exhibited low transparency. This is to be expected of a eutrophic lake, and is a result of high productivity. While low transparency is commonly associated with poor water quality, this is unlikely to be the case on Ruth Lake. Overall, Ruth Lake can be categorized as being a fairly wild lake, having very limited shoreline development. This, coupled with a lack of any consistent inlet make it unlikely that Ruth's low transparency stems from artificial sources. It is likely that the high productivity on Ruth Lake is a result of the natural eutrophication process.

## **Temperature, Dissolved Oxygen, Conductivity, pH**

### ***Testing Frequency and Methods***

Monitoring for temperature, dissolved oxygen, conductivity, and pH in Long and Mickey Lakes was conducted every two weeks from May through mid-September. Monitoring was conducted on Ruth Lake on three occasions (May, July, September).

Once anchored over the testing location, the YSI probe is lowered to a multitude of specific depth points for readings. The results are then put into a table to create a water column profile that allows determination of stratified layers and changes in conductivity and pH. The results for dissolved oxygen and temperature are also entered into the CLMP database.

# Temperature and Dissolved Oxygen

## ***Background***

Water temperature plays a critical role in the health and stratification of a freshwater lake. In the spring as the ice melts, the water temperature is consistent from surface to the bottom. This allows the water to mix freely and distribute nutrients throughout, a process known as “spring turnover”. Warm water is less dense than cold water, which causes the lake to form distinct layers based on temperature as the summer progresses. The lake will turnover once again in the fall when surface temperatures begin to drop, causing the now denser water to sink into the water column and redistribute oxygen and nutrients throughout.

The amount of dissolved oxygen available is directly correlated to the water temperature and stratification layers. As water temperature increases, its ability to contain dissolved oxygen decreases. Colder water has the ability to contain more dissolved oxygen, which occasionally creates an increase in dissolved oxygen in the metalimnion. The density differences of the stratified layers restrict mixing, and wave energy does not reach great depths, which causes the hypolimnion to become an anoxic environment.

The temperature and amount of dissolved oxygen available is critical for organisms to survive. Different species have specific temperature and oxygen preferences for survival, growth, and reproduction. This often makes the location of the metalimnion important due to its ideal ranges of temperature and oxygen available.

## ***Long Lake***

Water temperature and dissolved oxygen levels in Long Lake showed little change when compared to recent years. Long Lake began to stratify in early July (see figure B-5), and became fully stratified in late July (see figure B-7). The epilimnion ranged from the surface to a depth of 30 ft. Water temperature and dissolved oxygen levels remain fairly constant throughout the epilimnion, about 25.5° C and 8.3 mg/L respectively.

The metalimnion ranged from 30 ft to 45 ft. Through this layer water temperature and dissolved oxygen both significantly decreased. Water temperature decreased from 25°C to 15°C, while dissolved oxygen dropped from 8.3 mg/L to <1.0 mg/L.

The hypolimnion ranged from 45 ft to the lake bottom (85 ft). On the lake bottom, water temperature registered at 14.4° C, and dissolved oxygen registered at 0.17 mg/L.

## ***Mickey Lake***

Water temperature and dissolved oxygen levels in Mickey Lake showed little change when compared to recent years. Mickey Lake began to stratify in late June (see figure B-13), and became fully stratified by mid-July (see figure B-15). The epilimnion ranged

from the surface to a depth of 15 ft. Water temperature and dissolved oxygen levels remained fairly constant throughout the epilimnion, about 25°C and 9 mg/L respectively.

The metalimnion ranged from 15 ft to 25 ft. Through this layer the water temperature decreased from 25°C to 15°C. Reduced water temperatures created a spike in oxygen from 9 mg/L to 12.5 mg/L at 20 ft before beginning to decrease (see figure ).

The hypolimnion ranged from 25 ft to the lake bottom (35 ft). On the lake bottom, water temperature registered at 12.1° C, and dissolved oxygen registered at 0.38 mg/L.

### ***Ruth Lake***

Water temperature and dissolved oxygen levels in Ruth Lake showed little change when compared to recent years. Ruth Lake is much shallower than Long or Mickey (18 ft), and as a result it does not stratify in layers. In mid-summer, water temperature ranged from 23.7° C at the surface to 12.1° C at the bottom. Dissolved oxygen registered at 7.51 mg/L at the surface to 0.22 mg/L at the lake bottom (see figure B-20).

## **Conductivity**

### ***Background***

Conductivity is the measure of the water's ability to conduct an electrical current. This also serves as a measure of the amount of dissolved ions like salt, various minerals, and other inorganic solids. Natural geology and human pollution both play a factor in the conductivity of a fresh water lake. Freshwater naturally has a low to moderate range, typically between 0 - 1,500 microsiemens per centimeter (µS/cm).

Conductivity is seen as a useful general measure of water quality. Significant changes in conductivity could then be an indicator that a discharge or some other source of pollution has entered the water body (EPA, Indicators: Conductivity).

### ***Long Lake***

Conductivity levels in Long Lake were very low throughout the 2025 season, and slightly decreased from 2024. This indicates a body of water that is low in nutrients, biological activity, and pollution. On average across the season, conductivity levels ranged from 157.4 µS/cm at the surface to 169.2 µS/cm on the bottom (see figure C-1). The highest recorded reading of the season was 170.8 µS/cm (see figure C-10).

### ***Mickey Lake***

Conductivity levels in Mickey Lake were very low throughout the 2025 season, and slightly decreased from 2024. This indicates a body of water that is low in nutrients, biological activity, and pollution. On average across the season, conductivity levels ranged from 142.5 µS/cm at the surface to 169.2 µS/cm on the bottom (see figure C-11). The highest recorded reading of the season was 206.1 µS/cm (see figure C-10).

This reading was abnormally higher than any other reading taken over the season, and could have been altered by contact with bottom sediment. The second highest reading of the summer was 174.3  $\mu\text{S}/\text{cm}$  (see figure C-13).

### ***Ruth Lake***

Conductivity levels in Ruth Lake were very low throughout the 2025 season, and slightly decreased from 2024. This indicates a body of water that is low in nutrients, biological activity, and pollution. On average across the season, conductivity levels ranged from 56.7  $\mu\text{S}/\text{cm}$  at the surface to 91.3  $\mu\text{S}/\text{cm}$  on the bottom (see figure C-21). The highest recorded reading of the season was 106.6  $\mu\text{S}/\text{cm}$  (see figure C-24).

## **pH**

### ***Background***

pH is the abbreviation for powers of hydrogen, and is the measure of water acidity or basicity. Specifically, it is the measure of negative logarithm of hydrogen ion ( $\text{H}^+$ ) concentration (mol/L) in an aqueous solution. It is measured on a scale of 0 - 14, with 7 being neutral. pH below 7 is considered acidic, pH above 7 is considered alkaline (basic).

$$\text{pH} = -\log_{10}(\text{H}^+)$$

pH affects most chemical and biological processes in water. Different species require different ranges of pH, with the optimal for most aquatic organisms falling between pH 6.5 - 8. Natural geology, industrial activity, acid rain, and combustion emissions can increase/decrease the pH of a body of water (EPA, pH).

### ***Long Lake***

pH levels in Long Lake fell within normal range for a healthy freshwater lake across the 2025 season, but did slightly increase from last year. On average it registered slightly alkaline, averaging 8.2 at the surface and decreasing to 7.1 on the bottom (see figure D-1). Notice how the decrease in pH from the surface to bottom follows a similar curve to temperature and dissolved oxygen. The highest reading of 8.51 was recorded at 32.5 ft depth in mid-July (see figure D-7).

### ***Mickey Lake***

pH levels within Mickey Lake registered lightly alkaline across the 2025 season, and remained consistent with last year's results. On average, pH registered at 8.5 at the surface and decreased to 6.7 at the bottom (see figure D-11). The highest reading of the season was 8.93, recorded at 22.5 ft in early May (see figure D-12)

## ***Ruth Lake***

pH levels within Ruth Lake registered within normal range for a healthy freshwater lake across the 2025 season, and remained consistent with last year's results. On average Ruth lake is slightly acidic, registering 7.1 at the surface and decreasing to 6.4 on the bottom (see figure D-21). The lowest reading of the year read 6.32 at 17.5 ft in July (see figure D-23).

## **Nitrate/Nitrite-Nitrogen**

### ***Background***

Nitrogen is an essential element that promotes growth in plants and animals. Nitrogen exists in both “reactive” and “unreactive” forms. In its unreactive form nitrogen is abundant on Earth, making up 70% of our atmosphere. Despite its abundance, unreactive nitrogen is unusable by most organisms (May and Rector 2011). Nitrogen in its reactive form is uncommon on Earth. Its scarcity in its reactive form makes nitrogen a limiting nutrient (Wetzel 2001). Naturally, unreactive nitrogen is most frequently converted to its reactive state of ammonium ( $\text{NH}_4$ ) through bacterial processes (Vitousek 1997). Humans have doubled the abundance of reactive nitrogen through fertilizer production, in which unreactive nitrogen is artificially converted to ammonia ( $\text{NH}_3$ ). Burning of fossil fuels and elimination of storage pools have also contributed to significant increases in reactive nitrogen abundance (Nieder and Benbi 2022), (May and Rector 2011).

Much of the reactive nitrogen applied to agricultural fields and residential or commercial lawns is not used by organisms immediately, and enters our waterways through runoff and erosion. Like on land, this increase in reactive nitrogen in waterbodies contributes to higher productivity, and allows for increased plant and algae growth. This increase in productivity leads to artificial eutrophication and decreases overall water quality (EPA 2011), (May and Rector 2011).

Nitrogen sampling is not a standard part of CLMP sampling procedures. Due to the known adverse effects that can result from increased nitrogen concentrations in waterbodies, the Long Lake Association elects to monitor nitrate/nitrite-nitrogen concentrations in Long, Mickey, and Ruth Lakes as an addition to the CLMP protocol.

### ***Testing Frequency and Methods***

Nitrate/nitrite-nitrogen is analyzed from the same water samples analyzed for total phosphorus. Samples were collected from surface waters and near bottom from the sampling location on Long, Mickey, and Ruth Lakes. This sampling was conducted three times on each lake throughout the season; once immediately after ice melt in spring, once in July, and once in September.

Samples were collected in sample bottles prefilled with  $\text{H}_2\text{SO}_4$  (preservative) by GLEC. Surface samples were collected by dipping the prefilled bottle below the water until

nearly full. Care is taken to prevent overflowing, which would result in flushing the preservative out of the bottle. Depth samples were collected using a Van Dorn, just above (around five to ten feet) the lake bottom. Van Dorn sampling was done after collecting a YSI profile to ensure an accurate depth was known. Samples were processed by GLEC at a method detection limit (MDL) of 2.2µg/L.

### ***Long Lake***

Nitrate/nitrite-nitrogen results in Long Lake were fairly consistent at both surface and depth throughout 2025, with deep water samples averaging slightly higher than surface samples (Figure E-1). Surface water concentrations measured highest in May at 4.6µg/L, and were below detection level (2.2µg/L) in July and September. Depth samples peaked at 8 µg/L in July and measured below detection in both May and September (Figure E-2). The average concentration for all sampling dates and depths in Long Lake in the 2025 season was 3.57µg/L (Table E-1).

It is important to note that the detection limit for nitrate/nitrite-nitrogen at GLEC is 2.2µg/L, and four out of the six samples collected at Long Lake were measured below detection. For the purpose of analysis, these samples have been recorded at 2.2µg/L, despite them truly being below this level. Therefore, actual nitrate/nitrite-nitrogen concentrations in Long Lake are lower than the results analyzed in this report.

### ***Mickey Lake***

Like Long Lake, nitrate/nitrite-nitrogen results in Mickey Lake remained consistent throughout the 2025 season for both surface and depth samples, with surface samples averaging slightly higher than at depth (Figure E-1). Surface water concentrations measured highest in May at 2.8µg/L, and were below detection level in July and September. Deep water nitrate/nitrite-nitrogen concentrations on Mickey Lake measured below the 2.2µg/L detection limit in all 2025 sampling events (Figure E-2). The overall average nitrate/nitrite-nitrogen concentration for all sampling dates and depths in Mickey Lake in the 2025 season was 2.3µg/L (Table E-1). It must be noted that with five of the six nitrate/nitrite-nitrogen concentration results measuring below the 2.2µg/L detection limit, the actual average can be assumed to be lower than 2.3µg/L.

### ***Ruth Lake***

Like Long and Mickey Lakes, nitrate/nitrite-nitrogen results in Ruth Lake remained very consistent across all sampling events in 2025 at both surface and depth, with surface concentrations averaging slightly higher than depth (Figure E-1). Nitrate/nitrite-nitrogen concentrations were highest in May for both surface and deep water samples at 4.1µg/L and 4.7µg/L, respectively. Concentrations were below the detection limit for all other surface and depth nitrate/nitrite-nitrogen samples collected on Ruth Lake in 2025 (Figure E-2). The overall average nitrate/nitrite-nitrogen concentration for all sampling dates and depths in Ruth Lake in the 2025 season was 2.9µg/L (Table E-1). Like with Long and Mickey Lakes, it is important to note that with four of the six

nitrate/nitrite-nitrogen samples measuring below detection limit, the actual nitrate/nitrite-nitrogen concentration averages on Ruth Lake are lower than the values generated for the analysis in this report.

## Calcium

### **Background**

Calcium is an essential structural element for all organisms, greatly contributing to strength of bones, teeth, shells, and plant cell walls and membranes (White and Broadley 2003), (Higgins 2019). Calcium concentrations vary greatly in waterbodies, and are influenced by geology, soil types, vegetation, and precipitation (Potasznik and Szymczyk 2015), (Higgins 2019).

Monitoring calcium concentrations is highly beneficial in assessing potential establishment and extent of zebra (*Dreissena polymorpha*) and quagga (*Dreissena bugensis*) mussel populations. While long term reproductive success of zebra mussels is dependent on more than just calcium, calcium concentrations are generally considered one of the most significant limiting factors of their success (Mellina & Rasmussen 1994), (Whittier et al. 2008). Continuing to monitor calcium concentrations is beneficial in monitoring the zebra mussel infestation on Long and Mickey lake, and can be used to assess the potential of their spread into Ruth Lake.

### **Testing Frequency and Methods**

Calcium concentration sampling has been regularly monitored on Long Lake, Mickey Lake, and Ruth Lake dating back to 2017, and is conducted independently from CLMP. Sampling procedures consist of surface water grabs conducted 3 times per season for each lake. Samples are processed by SOS analytical in Traverse City.

### **Long Lake**

Calcium concentrations in Long Lake decreased throughout the 2025 sampling season, having measured highest in May at 23.3 mg/L compared to July at 21.5 mg/L and September at 17.9 mg/L (Figure F-1), combining for an overall average of 20.9 mg/L in 2025 (Table F-1). This 2025 average was the lowest recorded average since calcium concentrations have been monitored on Long Lake. Previously, the 2022 field season marked the lowest average annual calcium concentrations, having been slightly lower than 2025 at 21.3 mg/L (Table F-2). Given the minimal change, along with calcium concentration monitoring being a relatively new addition to sampling on Long Lake, it is difficult to place any significance on these 2025 results. For now, continuing to monitor calcium concentrations on Long Lake in future seasons is highly beneficial for establishing baseline data, and will increase the opportunity to capture any potential trends that may be occurring.

Currently, calcium concentrations in Long Lake are trending on the lower end of what is generally considered optimal for zebra mussel success in North American waterbodies (Whittier 2008). Typically, zebra mussels reach optimal abundance and shell growth in waterbodies with concentrations of calcium greater than 28 mg/L, reach “moderate” densities in waters with 20-28mg/L, are considered “limited” in waterbodies with calcium concentrations ranging between 12-20 mg/L, and are very unlikely to establish in waterbodies with less than 12mg/L of calcium (Bruce 2025), (Whittier 2008), (Cohen & Weinstein 2001). Seasonal calcium averages in Long Lake since 2017 have ranged from 20.9 to 24.25mg/L (Table F-2), categorizing Long Lake as conducive to “moderate” zebra mussel densities.

### ***Mickey Lake***

Like Long Lake, calcium concentrations on Mickey Lake were slightly lower in 2025 than any year since consistent calcium monitoring began in 2017, with 2025 sampling events resulting in an overall average of 20.1 mg/L (Table F-1). The previous lowest annual average was from the 2019 sampling season at 20.2 mg/L (Table F-2). 2025 Mickey Lake calcium concentrations varied from 20.5 mg/L in May, to 18.6 mg/L in July, and were highest in September at 21.2 mg/L (Figure F-1). Again, it is difficult to place any significance on 2025 results being slightly lower than previously observed calcium concentrations on Mickey, but continuing to monitor calcium in the future will be beneficial for establishing baseline data, capturing any trends, and for tracking the potential extent of Mickey Lakes ongoing zebra mussel infestation. Like Long Lake, Mickey Lake can be categorized as being conducive to “moderate” zebra mussel densities (Bruce 2025), (Whittier 2008), (Cohen & Weinstein 2001).

### ***Ruth Lake***

Like Long and Mickey Lakes, 2025 annual average calcium concentrations were slightly lower in 2025 compared to averages from any other previous year since calcium monitoring began in 2017, with the 2025 concentrations averaging 6.1 mg/L (Table F-1). Previously, the lowest calcium concentrations on Ruth Lake were observed in 2019 and in 2023, when concentrations averaged 6.7 mg/L (Table F-2). 2025 Ruth Lake calcium concentrations decreased throughout the sampling season from 7.0 mg/L in May, to 5.9 mg/L in July, and 5.3 mg/L in September (Figure F-1). Similar to Long and Mickey Lake, minimal significance can be placed on 2025 Ruth Lake calcium concentrations averaging lower than any previous sampling seasons.

Continuing to monitor calcium concentrations on Ruth Lake can be used as a risk analysis for the potential spread of zebra mussels into Ruth Lake. Currently, zebra mussel establishment has not been observed in Ruth, despite its intermittent connectivity to Long Lake. It can be inferred that this is likely due to the relatively low calcium concentrations present in Ruth Lake. Generally, zebra mussel establishment is considered unlikely in waterbodies with less than 12mg/L of calcium (Bruce 2025), (Whittier 2008), (Cohen & Weinstein 2001).

Seasonal average calcium concentrations have exceeded this threshold only once on Ruth Lake since consistent calcium monitoring began. This occurred during the first year of incorporating calcium into the LLA monitoring program in 2017, when Ruth Lake concentrations averaged 16.1 mg/L (Table F-2). It is unclear what factored into Ruth Lake calcium concentrations being significantly higher in 2017 than in any year since, or with what degree of frequency calcium reaches these levels on Ruth. Continuing to monitor calcium on Ruth Lake will be beneficial for establishing baseline data, and in determining how often calcium meets the minimum requirements for zebra mussel establishment.

## Chlorophyll-a

### ***Background***

Chlorophyll is the green pigment that is present in plant cells which enables the absorption of sunlight during photosynthesis. Monitoring of chlorophyll-a is conducted as an indicator of overall algal biomass in waterbodies. Chlorophyll-a greatly influences the overall trophic status of lakes. Concentrations of chlorophyll-a vary seasonally and over time, but slowly increase overall as lakes experience natural eutrophication over thousands of years. Due to the normal variance in concentrations, long term monitoring of chlorophyll-a consisting of numerous sampling events per season is crucial. Observing clear and consistent increases in chlorophyll-a concentrations over shorter time periods is often attributed to excessive nutrient loading (Bednarz 2015).

Table 1. Trophic State Classification (Chapra, 1997)

Chlorophyll a ( $\mu\text{g/L}$ )

- Oligotrophic = < 4
- Mesotrophic = 4 - 10
- Eutrophic = > 10

### ***Testing Frequency and Methods***

Chlorophyll-a concentrations are monitored on Long, Mickey, and Ruth Lakes as a part of CLMP, with additional chlorophyll-a sampling taking place to supplement CLMP procedures. CLMP chlorophyll-a sampling is collected across five sampling events occurring from May through September. Samples are collected throughout the entirety of the photic zone (twice the secchi depth) with the use of a composite sampler. Upon collection, algae is filtered, frozen, and stored by LLA interns. Samples are sent to EGLE at the conclusion of the field season for analysis.

In addition to the CLMP protocol, LLA conducts additional chlorophyll-a sampling. These samples are obtained throughout the entirety of the photic zone (twice the secchi depth) using the same composite sampler used for CLMP chlorophyll-a sampling. Water samples are sent directly to GLEC lab for analysis.

It is important to note that 2025 MiCORPS CLMP results are still pending at the time of writing this report. Therefore, the 2025 chlorophyll-a results addressed in this report are limited to the three samples conducted outside of CLMP protocol, and processed by GLEC. CLMP results will be provided at a later date, and presented in an independent report generated by CLMP.

### ***Long Lake***

Long Lake chlorophyll-a concentrations remained fairly consistent throughout all three sampling events in 2025. Results measured lowest in May at 0.26µg/L, were highest in July at 1.69µg/L, and were 0.68µg/L in September (Figure G-1). Chlorophyll-a concentrations have been monitored on Long Lake fairly consistently since 1993, with some variability in the number of annual sampling events and occasional years with no data. Long term monitoring has yielded a chlorophyll-a historical average of 1.22µg/L (Table G-1). 2025 chlorophyll-a concentrations averaged 0.88µg/L, measuring slightly below this overall historical average of 1.22µg/L (Table G-1), (Figure G-2). These historical and 2025 chlorophyll-a averages are in line with what would be expected of an oligotrophic lake like Long Lake (Table 1), (Chapra 1997).

### ***Mickey Lake***

Like Long Lake, chlorophyll-a concentrations remained fairly consistent in Mickey Lake throughout all three sampling events in 2025, with the highest concentrations coming from May sampling at 2.64µg/L, the lowest concentrations occurring in July at 0.93µg/L, and September sampling resulting in 2.2µg/L (Figure G-1). These sampling events combined for an overall chlorophyll-a concentration average of 1.92µg/L throughout the 2025 field season (Table G-1), (Figure G-2). This 2025 average is slightly below Mickey Lakes long term historical chlorophyll-a concentration average of 3.37µg/L (Table G-1), (Figure G-2). This long term historical average is a result of fairly consistent chlorophyll-a sampling occurring on Mickey Lake since 2014.

Mickey Lake 2025 and historical chlorophyll-a concentrations categorize Mickey Lake as being on the more productive side of an Oligotrophic waterbody (Chapra 1997). Occasional chlorophyll-a concentration results on Mickey Lake have reached into those of a mesotrophic lake, thus indicating that Mickey Lake can be classified as oligo/mesotrophic. This is consistent with other parameter results indicating that Mickey Lake falls between oligotrophic and mesotrophic.

### ***Ruth Lake***

In comparison to Long and Mickey Lakes, Ruth lake exhibited the greatest variability in chlorophyll-a concentrations, increasing throughout the 2025 sampling season from 4.66µg/L in May, to 9.45µg/L in July, and 16.57µg/L in September (Figure G-1). These 2025 sampling results combine for an average chlorophyll-a concentration of 10.23µg/L, which is slightly higher than Ruth Lake's historical average of 9.06µg/L (Table G-1), (Figure G-2).

These September 2025 chlorophyll-a concentrations were slightly higher than any previous concentrations measured on Ruth Lake since consistent monitoring began in 2014. Previously, the highest chlorophyll-a concentration captured on Ruth Lake was 14.95µg/L captured in 2020 (Figure O-5). Chlorophyll-a data results are limited for Ruth Lake, making it difficult to draw any definitive conclusions. It is reasonable to assume that chlorophyll-a may commonly reach concentrations of this level on Ruth Lake, given that a handful of historical samples are just slightly below September's concentration of 16.57µg/L (Figure O-5). Continuing to monitor chlorophyll-a concentrations on Ruth Lake will be beneficial in establishing baseline data.

## **Phosphorus**

### ***Background***

Phosphorus is an important nutrient required for all life. The most common form of phosphorus used by biological organisms is phosphate (PO<sub>4</sub>). Phosphorus plays a major role in the formation of DNA, cellular energy, and cell membranes. It is often viewed as a “limiting nutrient” because its limited amount in a water body restricts organic growth (EPA, Indicators: Phosphorus).

Phosphorus is stored in a lake's sediment. This stored phosphorus is released back into the water when stratification creates a hypolimnion layer with anoxic conditions. This process is known as internal loading. Human factors such as faulty septic systems and use of fertilizers can cause runoff into the lake and increase phosphorus levels (Anderson, 2020).

### ***Testing Frequency and Methods***

Total Phosphorus water samples for surface and depth were collected and turned in for analysis by CLMP and GLEC. Dual testing is done to ensure accurate results.

Total phosphorus concentrations were sampled for both surface and depth. Samples were collected three times during the season - once immediately after ice melt in spring, once in July (summer), and once in September (autumn). For the purposes of TSI calculation, only the summer and autumn surface samples are included in the calculations.

Surface samples were collected using a sample bottle provided by CLMP/GLEC. The bottle is rinsed at the site with lake water, then a sample is obtained by slightly submerging the bottle in the lake until full.

Depth samples were completed using a Van Dorn Sampler. First the total depth of the sampling location is determined. The Van Dorn sampler is then lowered to a depth just above the lake bottom, where a sample is collected.

## Trophic State Classification (Chapra, 1997)

Total Phosphorus ( $\mu\text{g/L}$ )

- Oligotrophic =  $< 10$
- Mesotrophic =  $10 - 20$
- Eutrophic =  $> 20$

Sediment samples were collected from Long and Mickey Lakes in September. The sample for Long Lake was collected at  $44.70383^\circ$ ,  $-85.74432^\circ$ , the sample for Mickey Lake was collected at the same location as all the rest of the sampling. Once anchored over the location, a ponar grab sampler is dropped to the bottom. When it makes contact, a pressure clip releases and causes the ponar to close or grab, retrieving a sample of sediment. Sediment is then carefully transferred from the ponar into jars supplied by GLEC for testing.

Normal sediment phosphorus levels can vary with environment, but generally fall within 600 - 900 mg/kg.

### ***Long Lake***

Total phosphorus levels in Long Lake across the 2025 season remained in oligotrophic status and indicate a healthy lake environment. Surface and depth total phosphorus levels each showed slight decreases from the previous years monitoring (2024).

The total surface phosphorus average for 2025 was  $8.63 \mu\text{g/L}$ , down from  $8.8 \mu\text{g/L}$  in 2024. This is slightly higher than the historical average (1993 - present) of  $7.72 \mu\text{g/L}$  (see figure P-1). This falls into the oligotrophic status on the TSI scale. The maximum reading of  $10.1 \mu\text{g/L}$  falls right on the oligotrophic/mesotrophic line (see figure H-1).

The total depth phosphorus average for 2025 was  $9.96 \mu\text{g/L}$ , down from  $10.5 \mu\text{g/L}$  in 2024. This is lower than the historical average (1997 - present) of  $12.43 \mu\text{g/L}$ . This falls into the oligotrophic status on the TSI scale. The maximum of  $12.4$  equaled the 2024 maximum, and was taken during when anoxic conditions on the lake bottom triggered internal loading (see figure H-1).

The sediment phosphorus level for Long Lake registered at 283 mg/kg. This is very low and indicates an oligotrophic lake that does not experience high levels of internal loading.

### ***Mickey Lake***

Total phosphorus levels in Mickey Lake across the 2025 season fell into oligotrophic status and indicate a healthy lake environment. Surface and depth total phosphorus levels each showed decreases from the previous years monitoring (2024).

The total surface phosphorus average for 2025 was 5.33 µg/L, a significant drop from 11.2 µg/L in 2024. This is also lower than the historical average (1993 - present) of 10.55 µg/L (see figure P-5). This falls into the oligotrophic status on the TSI scale. The maximum surface reading was 6.5 (see figure H-2).

The total depth phosphorus average for 2025 was the lowest recorded yearly average on record at 7.03 µg/L, slightly down from 7.45 µg/L in 2024. This is well below the historical average (2014 - present) of 13.67 µg/L (see figure P-5). This falls into the oligotrophic status on the TSI scale. The maximum depth reading was 8.1 µg/L (see figure H-2).

The sediment phosphorus level for Mickey Lake registered at 422 mg/kg. This is low and indicates an oligotrophic lake that does not experience high levels of internal loading.

### ***Ruth Lake***

Total phosphorus levels in Ruth Lake across the 2025 season fell into the low-end of mesotrophic status. This indicates a healthy lake environment with a higher level of organic activity. Surface and depth total phosphorus levels showed mixed results when compared to last year's monitoring.

The total surface phosphorus average for 2025 was 12.2 µg/L, a slight increase from 11.8 µg/L in 2024. This is below the historical average (2006 - present) of 15.52 µg/L (see figure P-9). This falls into the mesotrophic status on the TSI scale. The maximum surface reading was 14.2 µg/L (see figure H-3).

The total depth phosphorus average for 2025 was 12.33 µg/L, significantly down from 17.2 µg/L in 2024. This is well below the historical average (2019 - present) of 18.08 µg/L (see figure P-11). This also falls into the mesotrophic status on the TSI scale. The maximum depth reading was 17.7 µg/L (see figure H-3).

## **Water Levels**

### ***Background***

Long Lake is characterized as a kettle lake, having no inlet and draining through only one surface outlet of Sucker Creek, which is the headwater of the Platte River. Two culverts are present at the outlet of Long Lake, which serve to maintain a long term average lake level of 847 feet above sea level. These culverts are installed at an invert of 846.01 and 846.15 feet above sea level. This has resulted in no flow during periods of low water, such as the summer of 2024 (Figure I-1). In addition to discharge out of Sucker Creek, Long Lake discharge occurs through groundwater exiting the wetlands located at the north end. These wetlands then flow to Cedar Run, before entering Lake Leelanau, and eventually Lake Michigan (Smits 2025).

With no inlet, Long Lake relies almost entirely on groundwater for recharge, resulting in very consistent water levels and discharge flow. Average minimum discharge typically remains ~14 cubic feet per second (ft<sup>3</sup>/s) peaking in April at 17ft<sup>3</sup>/s, and dropping to 13ft<sup>3</sup>/s in August. (Smits 2025). Consistent Long Lake water level data dating back to 2008 is available on the Long Lake Township website through the Documents on Demand center.

### ***Water Level Results***

Seasonal water level trends over the past three seasons for Long and Mickey Lakes over are depicted in Figure I-1. As expected, water levels on Long and Mickey Lakes declined somewhat steadily throughout 2025 from April through October. Water level recording began in April, measuring at their peak of 847.6 feet above sea level, and measured lowest in October at 846.9 feet. Overall, the changes in water levels observed in 2025 were less drastic than what was observed in 2024 when levels peaked in March at 848 feet and fell to 846.6 feet by November (Figure I-1).

## **Plankton**

### ***Testing Frequency and Methods***

Plankton trawls were conducted on two occasions on Long and Mickey Lakes in 2025. Trawls were pulled behind a pontoon boat for approximately five minutes. Samples were examined under a microscope and identified to genus and species when possible. In addition to trawl sampling on Long and Mickey, plankton sampling was attempted on Ruth Lake. Due to Ruth's shallow depth and abundant aquatic plant life, trawl sampling was not attempted, and instead surface water grab samples were collected and analyzed under a microscope. No plankton was observed in these grab samples.

A summary table of plankton samples collected on Long and Mickey Lakes and their relative abundance can be found in Table J-1 and Table J-2. Most commonly observed specimens on Long Lake in 2025 consisted of Anabaena, Ceratium, and Trichome (Table J-1). Trawls yielded a greater diversity in the plankton community on Mickey Lake compared to Long Lake. Most commonly observed specimens on Mickey Lake consisted of Ceratium and Keratella (Table J-2).

Healthy plankton communities are crucial for the overall health of aquatic ecosystems, significantly contributing to biological processes such as oxygen production and carbon cycling (Indicators: Phytoplankton 2025). Additionally, successful recruitment of fish and other organisms into their adult forms depend on plankton serving as the base of aquatic food webs (Abo-Taleb 2019).

Plankton communities are heavily impacted by the introduction of zebra mussels, which typically results in drastic reductions in overall phytoplankton diversity (Makarewicz et

al. 1999). Continuing to monitor plankton communities can provide a better understanding of the immediate impacts zebra mussels are having on Long and Mickey Lakes. Furthermore, the invasion of quagga mussels is an increasing threat to Long and Mickey Lakes, and would likely result in even more drastic impacts to plankton communities and overall system function. Developing a baseline of plankton communities prior to this potential invasion is critical for monitoring any impacts that would follow.

Monitoring plankton communities is also important to help ensure safe recreational use of waterbodies, as monitoring can help detect potentially harmful *Microcystis* (cyanobacteria). Several species of *Microcystis* are known to produce toxins that are harmful to humans, and populations are often known to increase in waters infested with zebra mussels. This is a result of zebra mussels selectively feeding on other species of plankton, eliminating competition of *Microcystis* (Zhang 2025). *Microcystis* specimens were observed in both Long and Mickey Lakes in 2025, so continuing to conduct annual plankton composition monitoring could help observe potential changes to *microcystis* occurrences in the future.

# **2025 LAKE CHEMISTRY FIGURES**

## **A. Transparency**

Table A-1. 2025 secchi transparency depth (ft) results for Long, Mickey, and Ruth Lakes.

| <b>2025 Secchi Depth (ft) Results - All Lakes</b> |                          |                    |                          |                  |                          |
|---|--------------------------|--------------------|--------------------------|------------------|--------------------------|
| <b>Long Lake</b>                                  |                          | <b>Mickey Lake</b> |                          | <b>Ruth Lake</b> |                          |
| <b>Date</b>                                       | <b>Secchi Depth (ft)</b> | <b>Date</b>        | <b>Secchi Depth (ft)</b> | <b>Date</b>      | <b>Secchi Depth (ft)</b> |
| 5/13/2025   | 49.5                     | 5/13/2025          | 16.5                     | 5/15/2025        | 4.5                      |
| 5/19/2025   | 37                       | 5/19/2025          | 17                       | 7/21/2025        | 3.5                      |
| 5/27/2025   | 45.5                     | 5/27/2025          | 21.5                     | 9/4/2025         | 6.5                      |
| 6/4/2025  | 34                       | 6/3/2025           | 16.5                     |                  |                          |
| 6/12/2025   | 32                       | 6/12/2025          | 19                       |                  |                          |
| 6/21/2025   | 19.5                     | 6/17/2025          | 15                       |                  |                          |
| 6/24/2025   | 19                       | 6/23/2025          | 19                       |                  |                          |
| 7/3/2025  | 25                       | 7/2/2025           | 14.5                     |                  |                          |
| 7/8/2025  | 29                       | 7/8/2025           | 21.5                     |                  |                          |
| 7/18/2025   | 21.5                     | 7/18/2025          | 18.5                     |                  |                          |
| 7/22/2025   | 21.5                     | 7/22/2025          | 17                       |                  |                          |
| 7/29/2025   | 22                       | 7/29/2025          | 17.5                     |                  |                          |
| 8/4/2025  | 18.5                     | 8/7/2025           | 17                       |                  |                          |
| 8/13/2025   | 19.5                     | 8/13/2025          | 18                       |                  |                          |
| 8/21/2025   | 18.5                     | 8/20/2025          | 17.5                     |                  |                          |
| 8/27/2025   | 17.5                     | 8/28/2025          | 18                       |                  |                          |
| 9/2/2025  | 19.5                     | 9/2/2025           | 18                       |                  |                          |
| 2025 Average                                      | 26.4                     | 2025 Average       | 17.8                     | 2025 Average     | 4.8                      |

### 2025 Long Lake Transparency

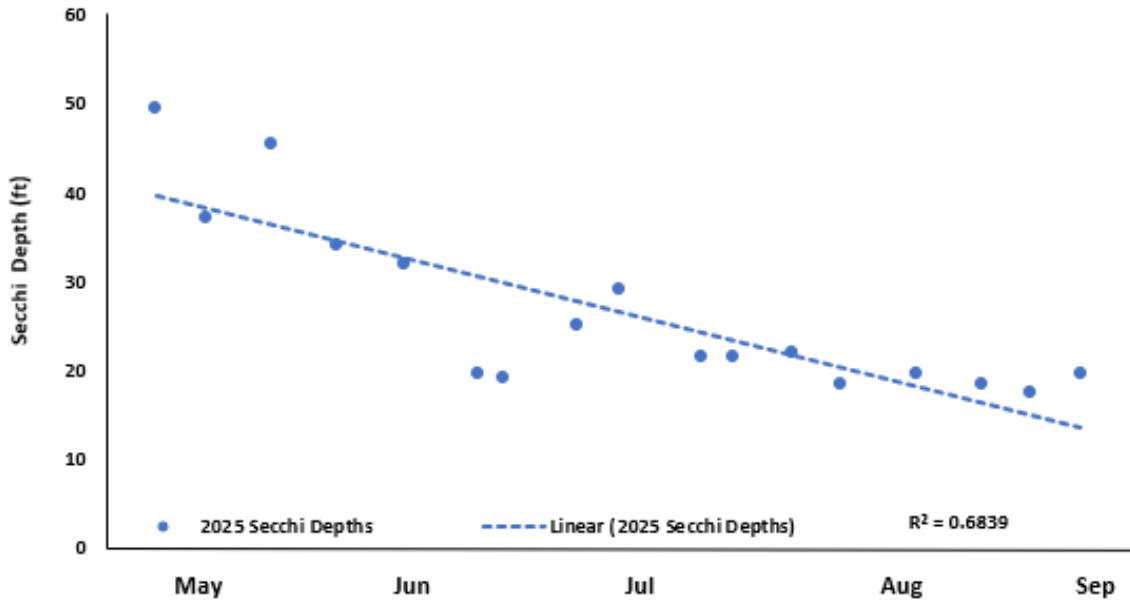


Figure A-1. Individual 2025 secchi transparency (ft) results, Long Lake.

### 2025 Mickey Lake Transparency

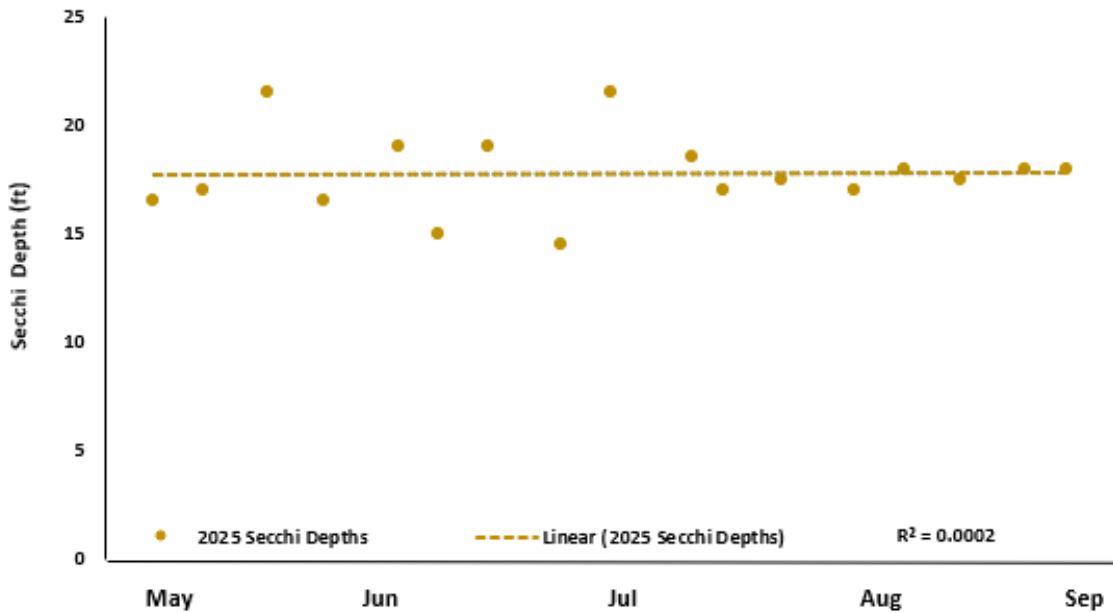


Figure A-2. Individual 2025 secchi transparency (ft) results, Mickey Lake.

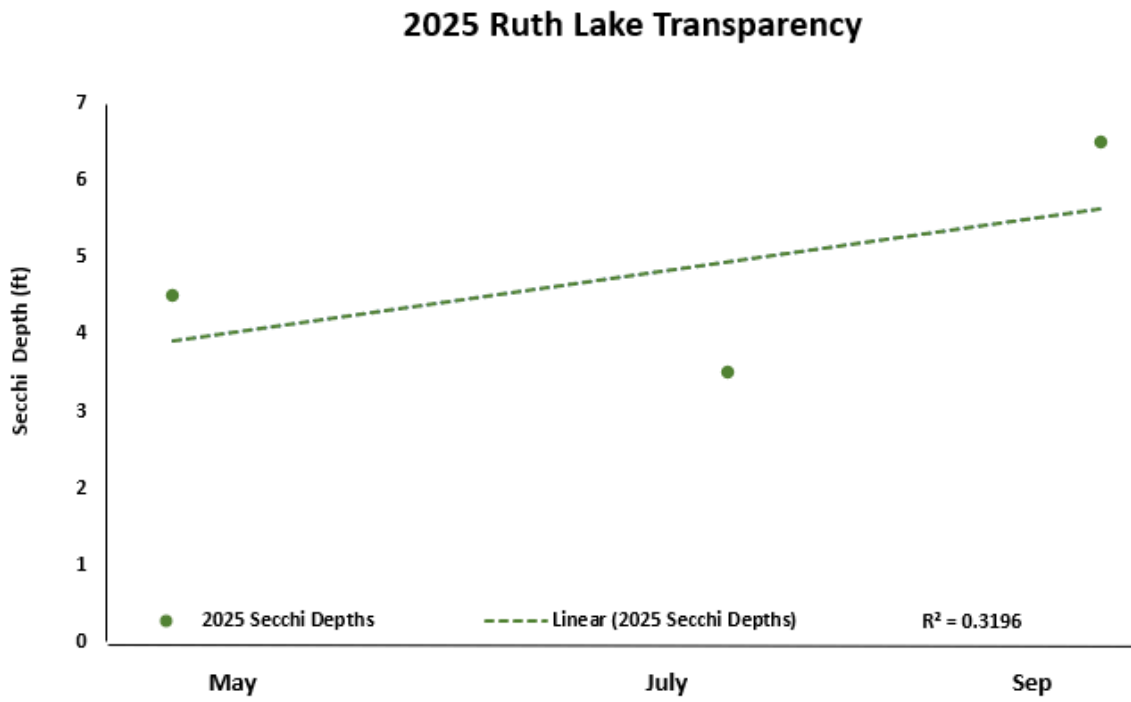


Figure A-3. Individual 2025 secchi transparency (ft) results, Ruth Lake.

## B. Temperature and Dissolved Oxygen

### Long Lake

Figure: B-1

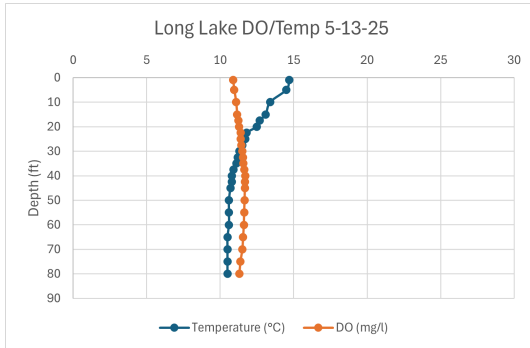


Figure: B-2

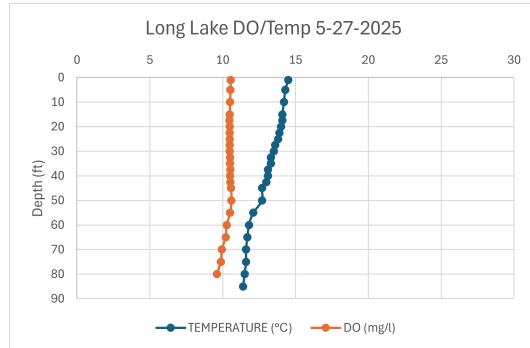


Figure: B-3

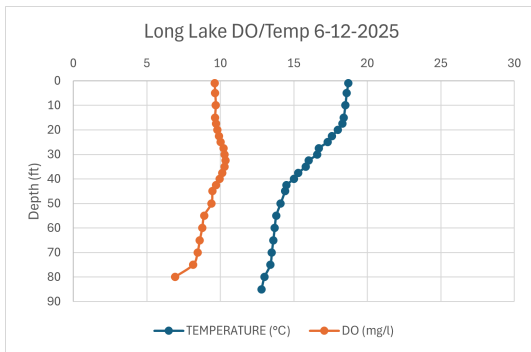


Figure B-4

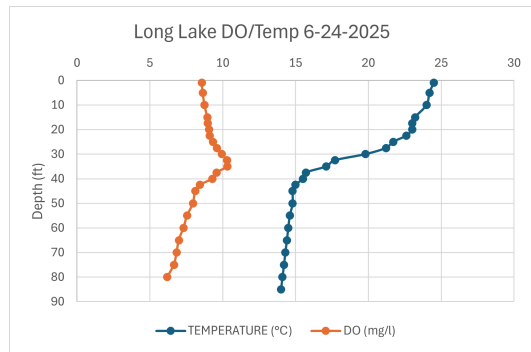


Figure: B-5

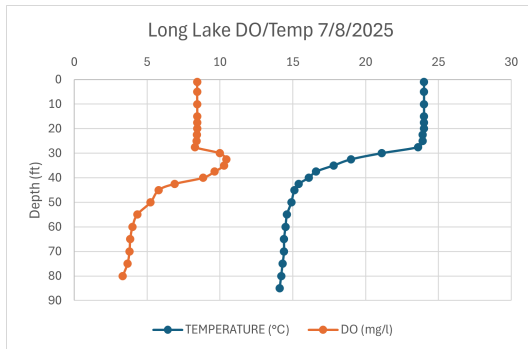


Figure: B-6

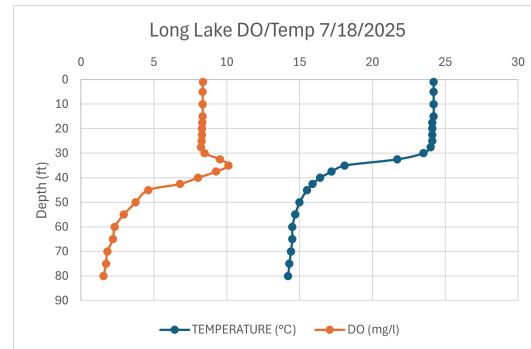


Figure: B-7

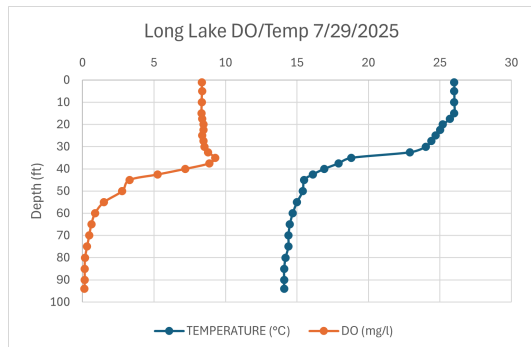


Figure: B-8

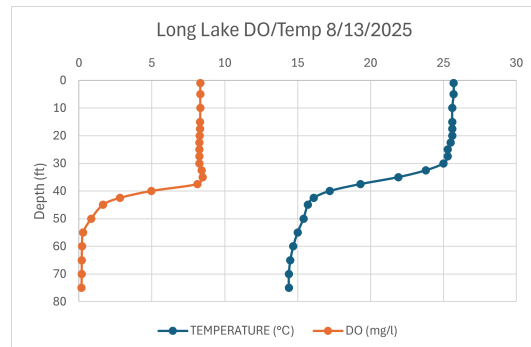
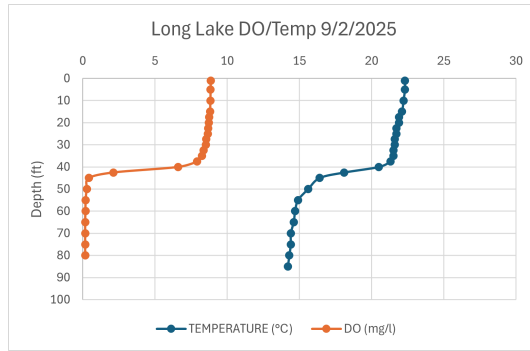


Figure: B-9



## Mickey Lake

Figure: B-10

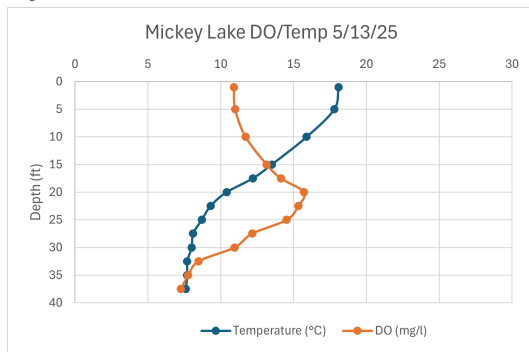


Figure: B-11

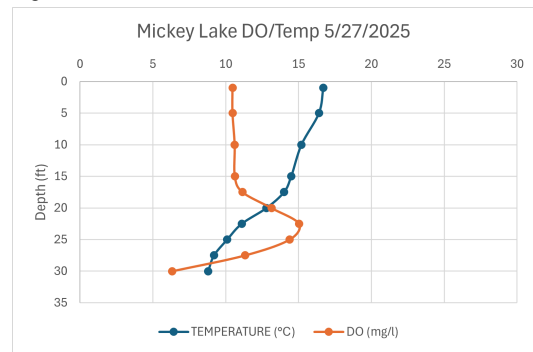


Figure: B-12

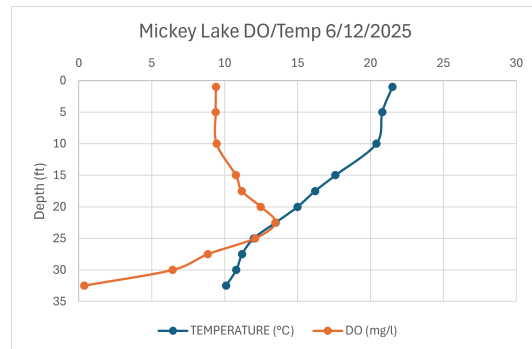


Figure: B-13

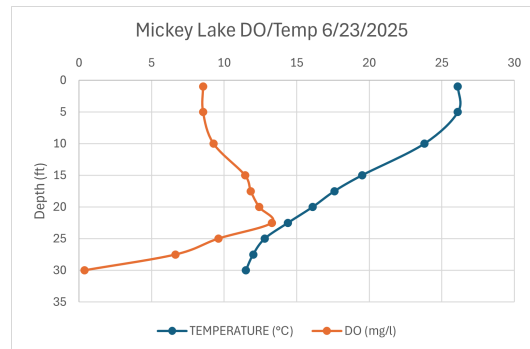


Figure: B-14

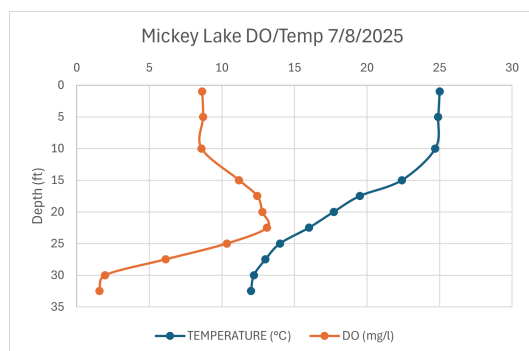


Figure: B-15

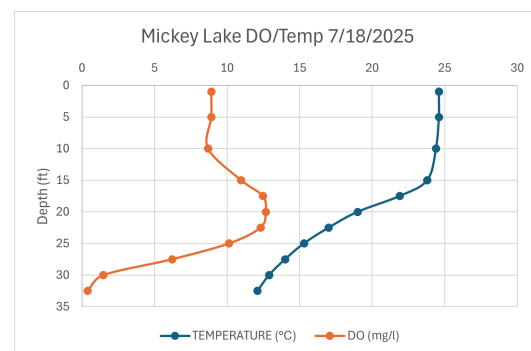


Figure: B-16

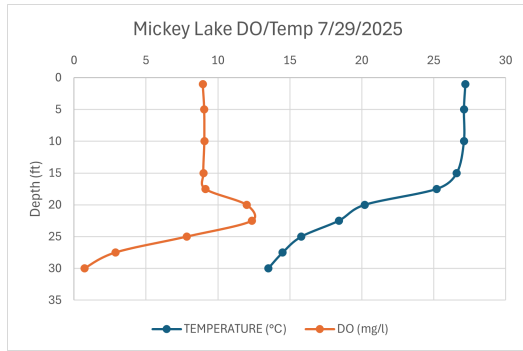


Figure: B-17

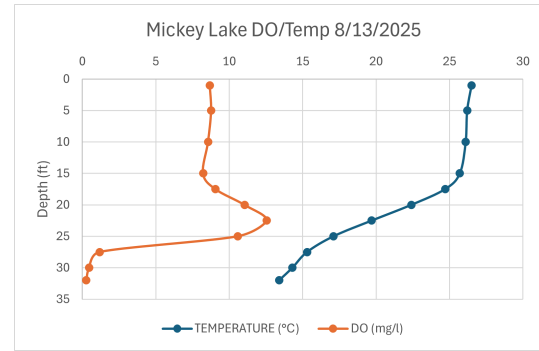
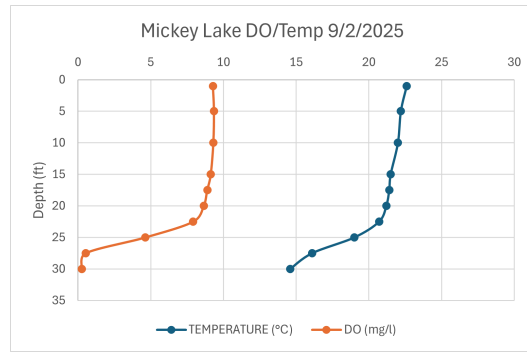


Figure: B-18



### Ruth Lake

Figure: B-19

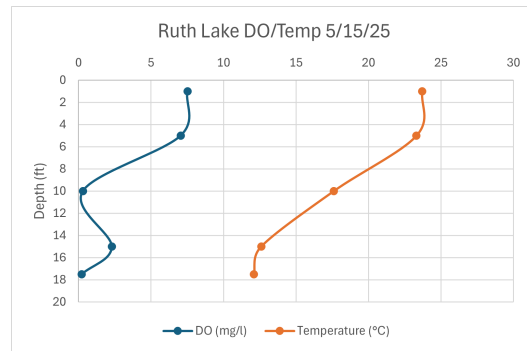


Figure: B-20

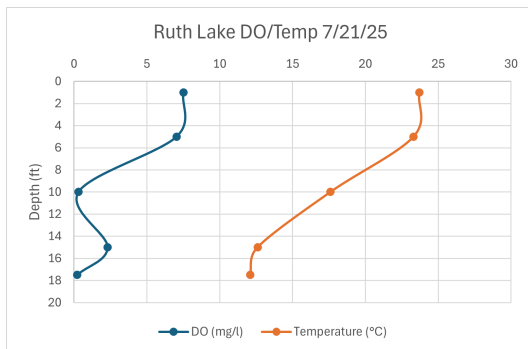
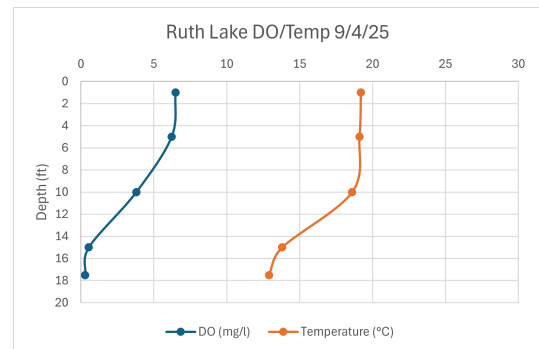


Figure: B-21



# C. Conductivity

## Long Lake

Figure: C-1

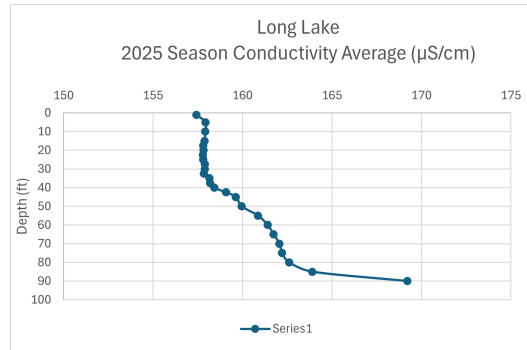


Figure: C-2

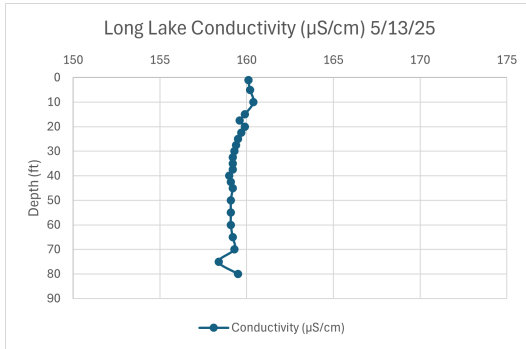


Figure: C-3

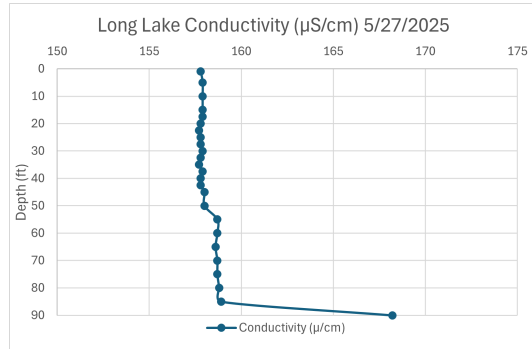


Figure: C-4

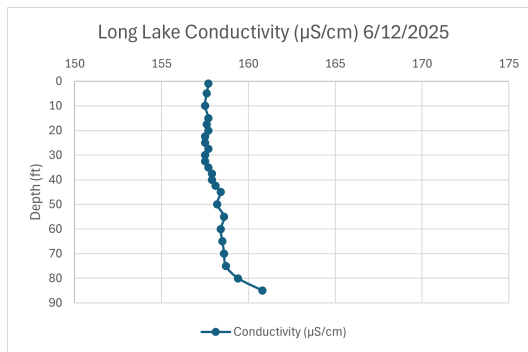


Figure: C-5

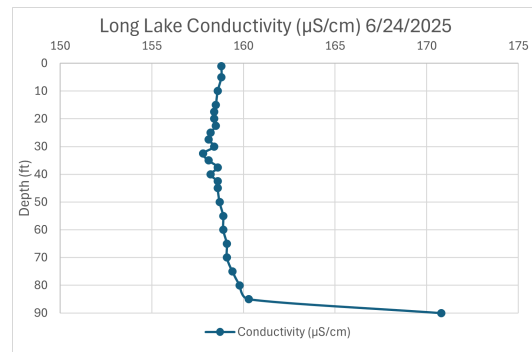


Figure: C-6

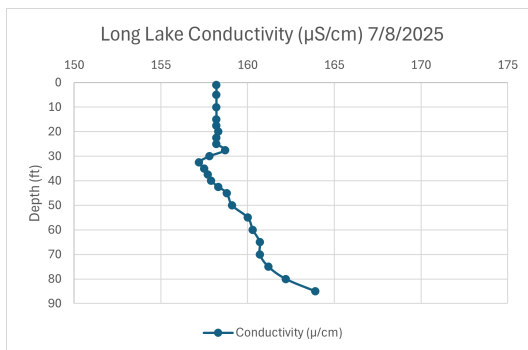


Figure: C-7

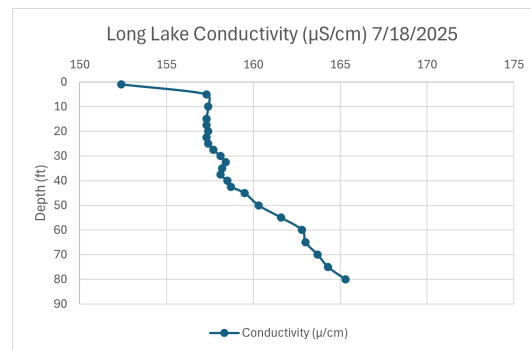


Figure: C-8

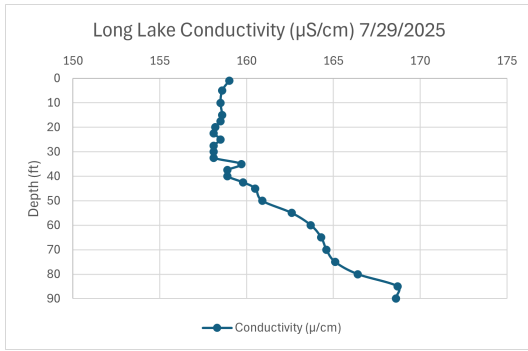


Figure: C-9

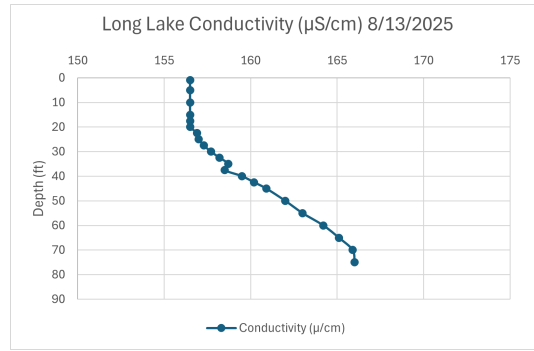
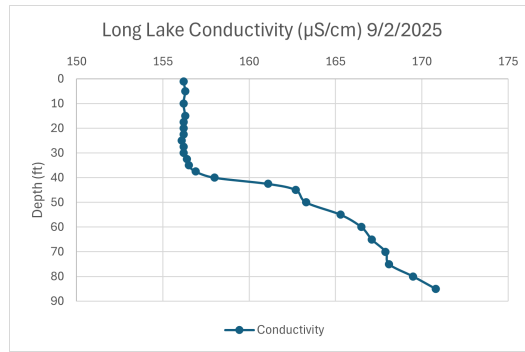


Figure: C-10



## Mickey Lake

Figure: C-11

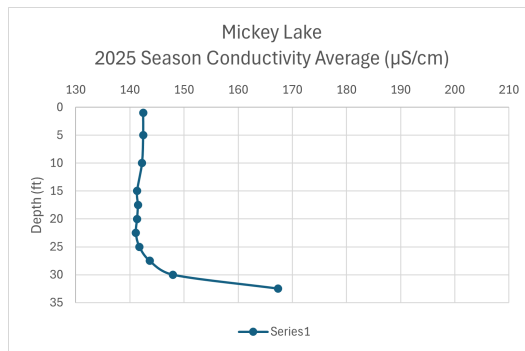


Figure: C-12

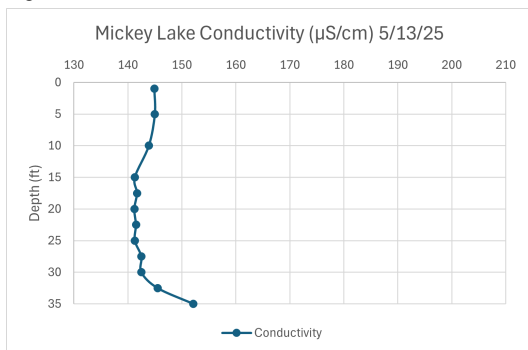


Figure: C-13

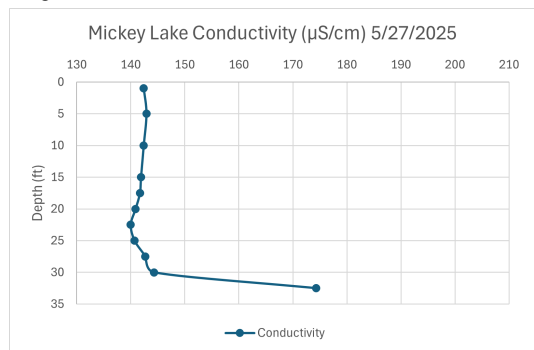


Figure: C-14

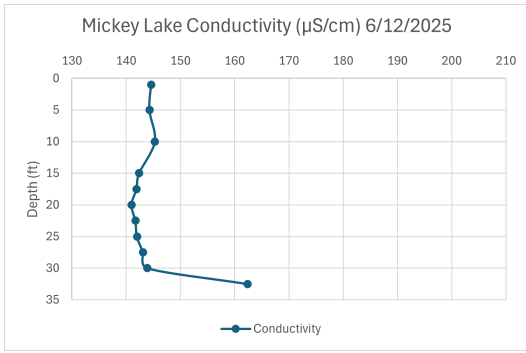


Figure: C-15

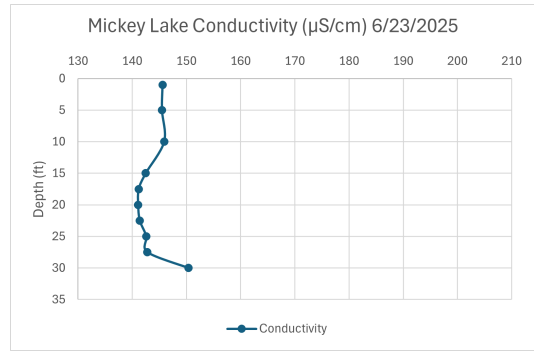


Figure: C-16

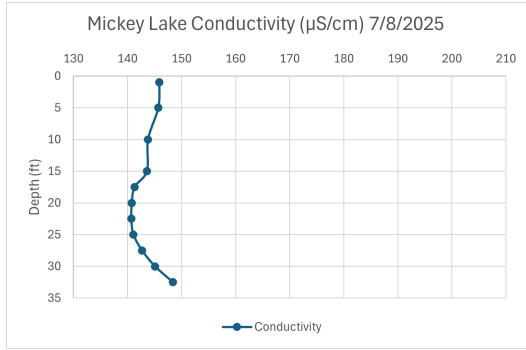


Figure: C-17

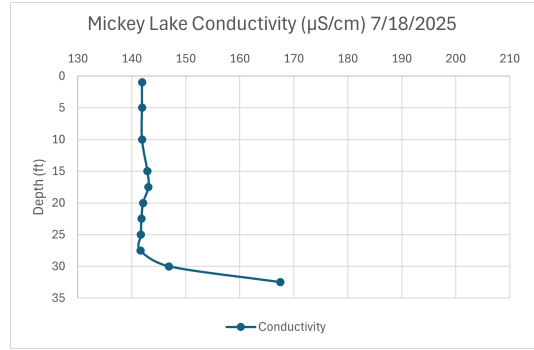


Figure: C-18

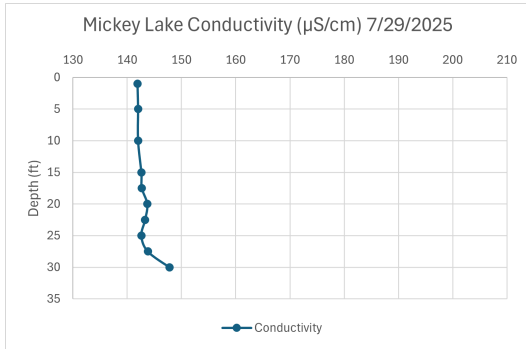


Figure: C-19

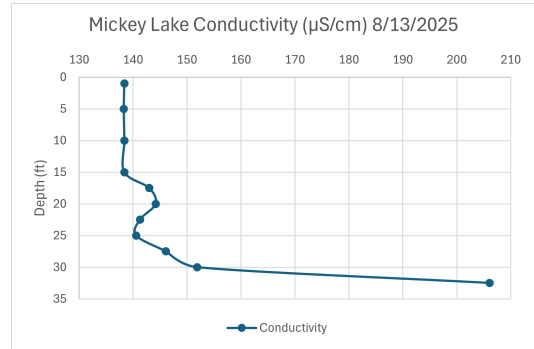
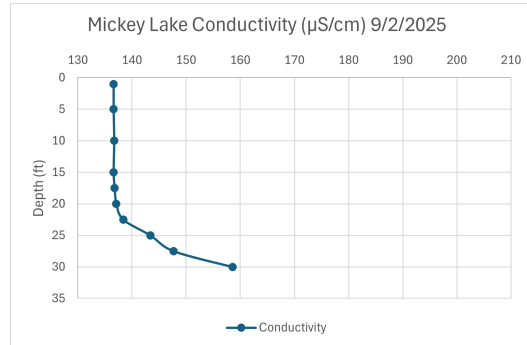


Figure: C-20



# Ruth Lake

Figure: C-21

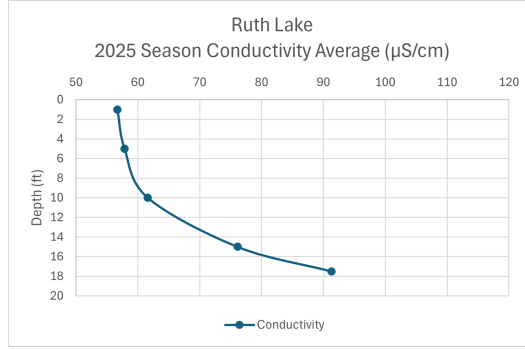


Figure: C-22

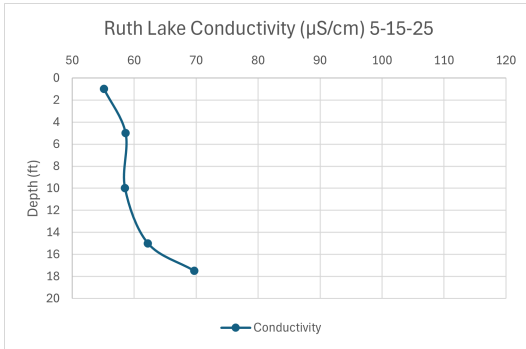


Figure: C-23

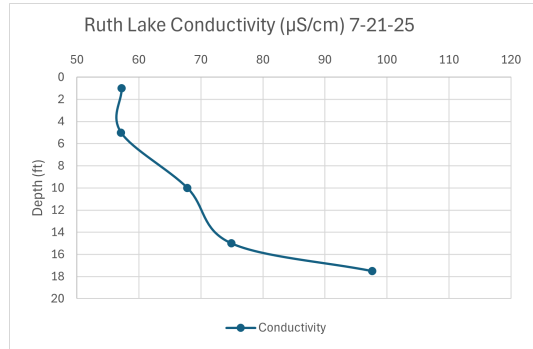
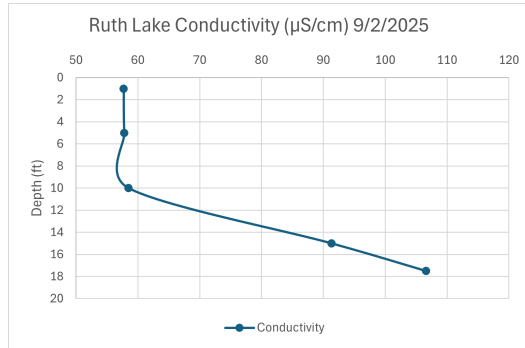


Figure: C-24



# D. pH

## Long Lake

Figure: D-1

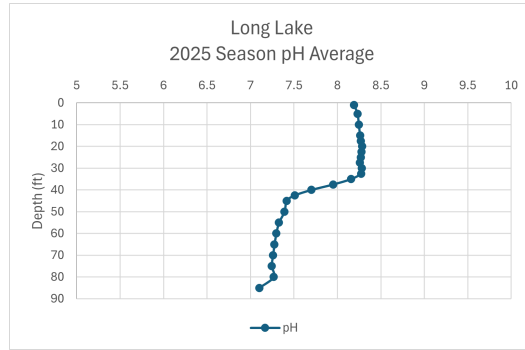


Figure: D-2

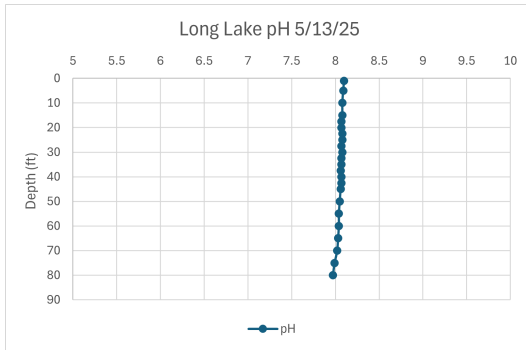


Figure: D-3

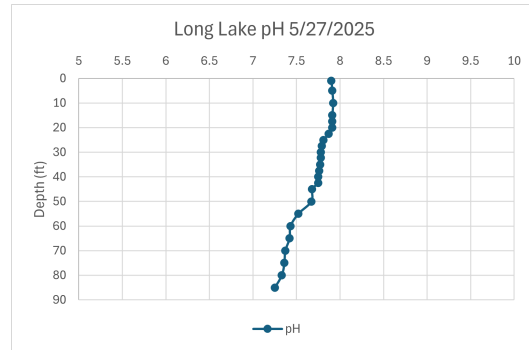


Figure: D-4

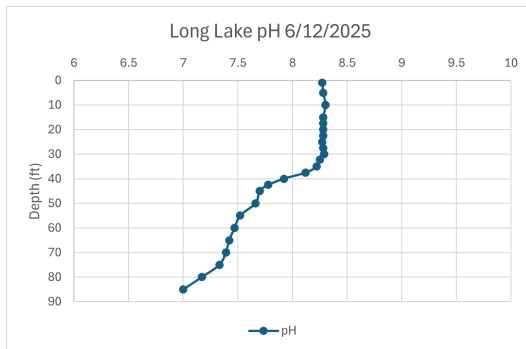


Figure: D-5

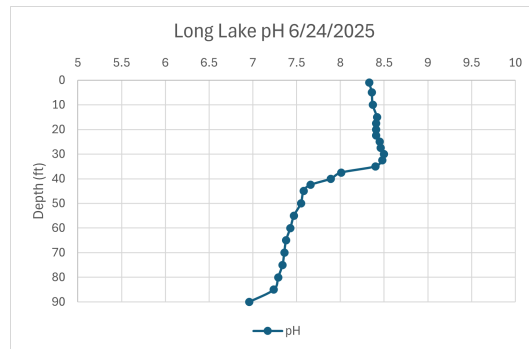


Figure: D-6

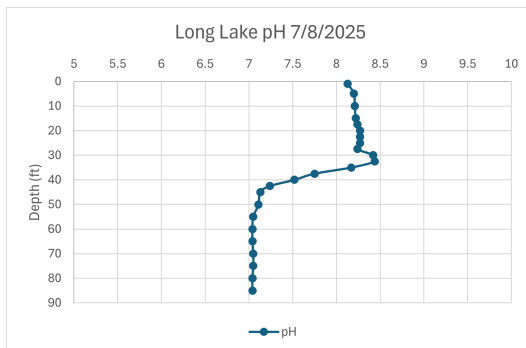


Figure: D-7

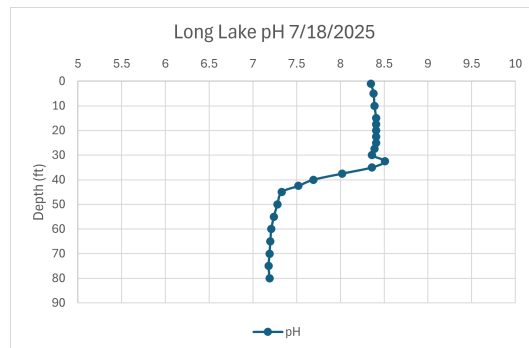


Figure: D-8

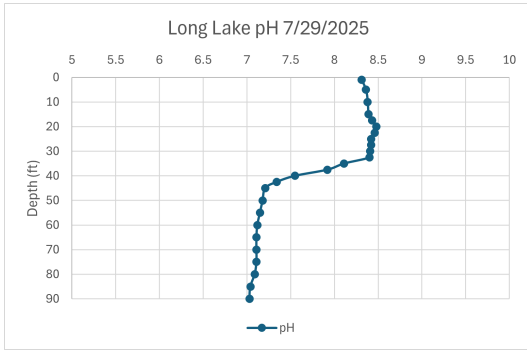


Figure: D-9

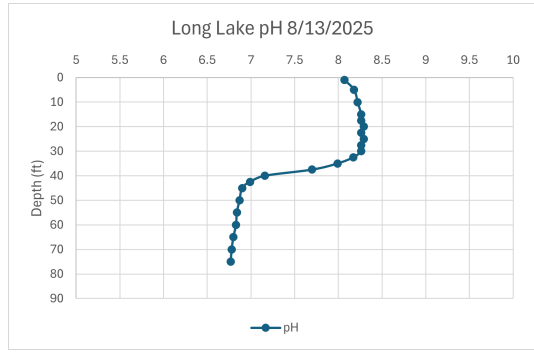
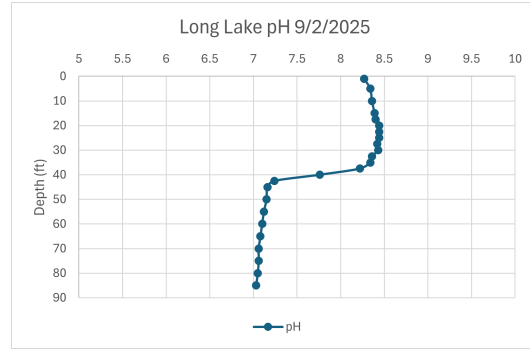


Figure: D-10



## Mickey Lake

Figure: D-11

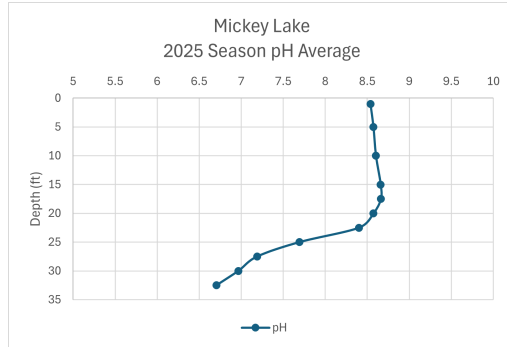


Figure: D-12

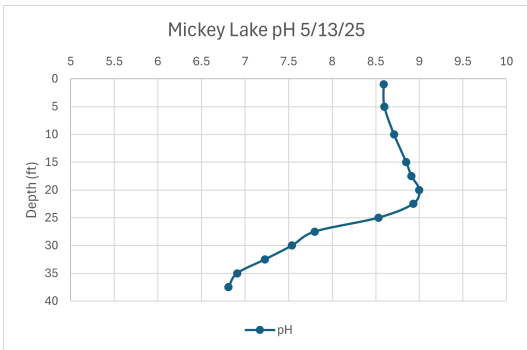


Figure: D-13

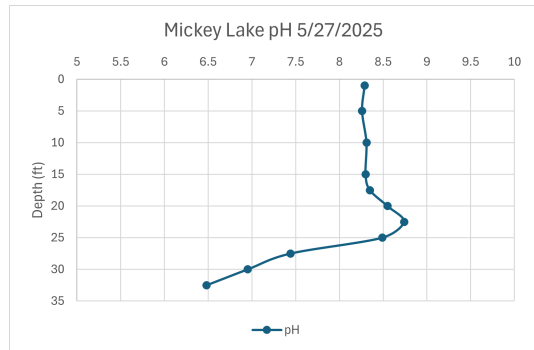


Figure: D-14

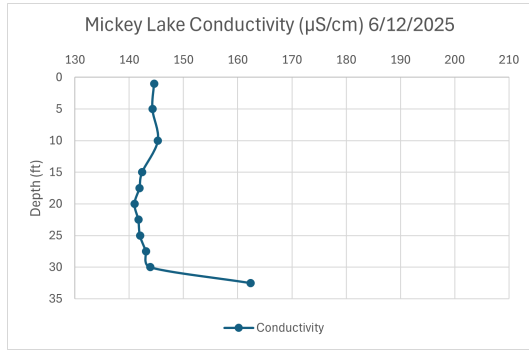


Figure: D-15

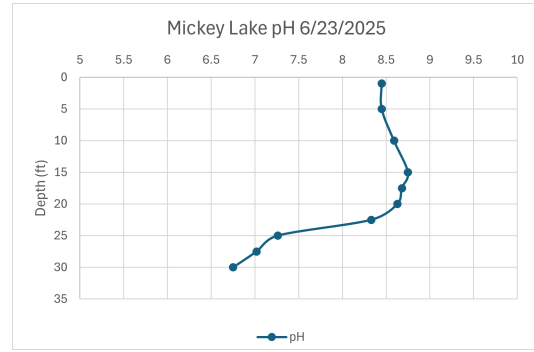


Figure: D-16

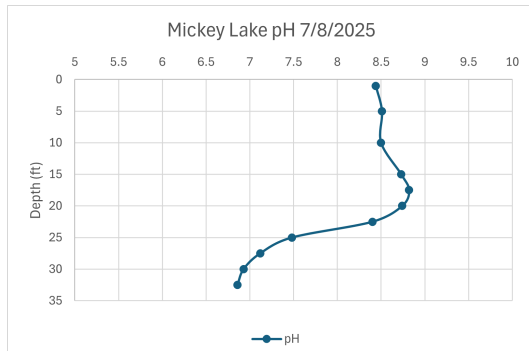


Figure: D-17

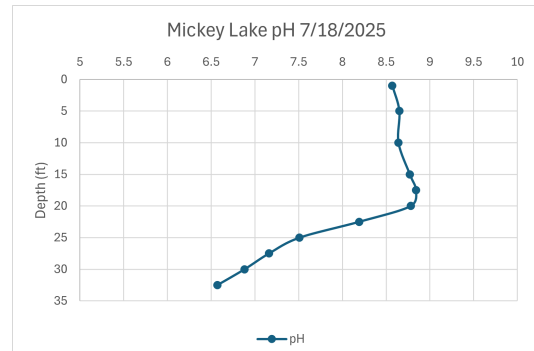


Figure: D-18

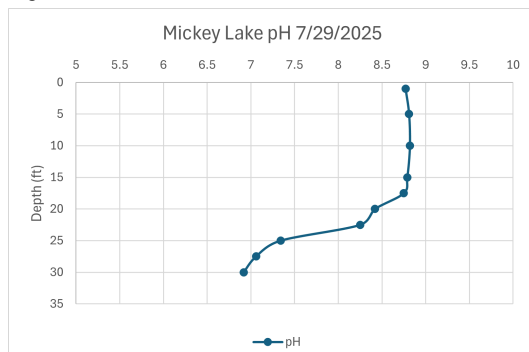


Figure: D-19

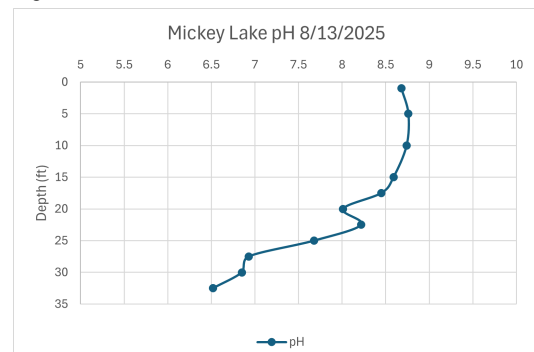
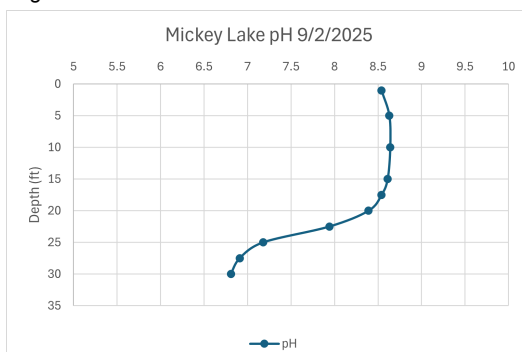


Figure: D-20



# Ruth Lake

Figure: D-21

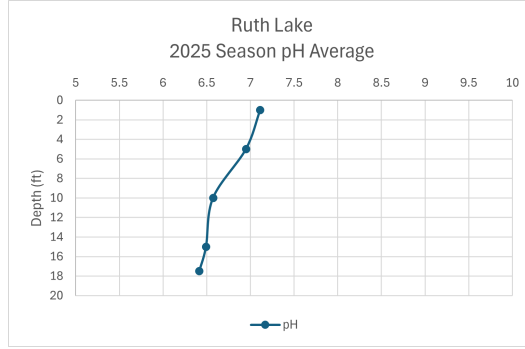


Figure: D-22

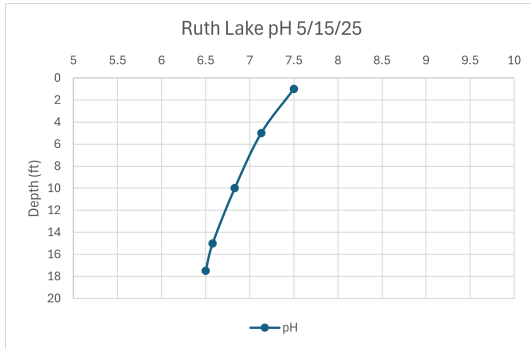


Figure: D-23

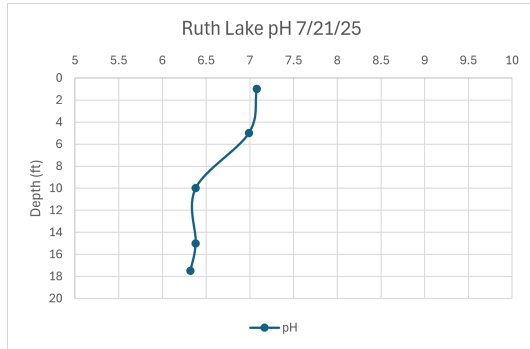
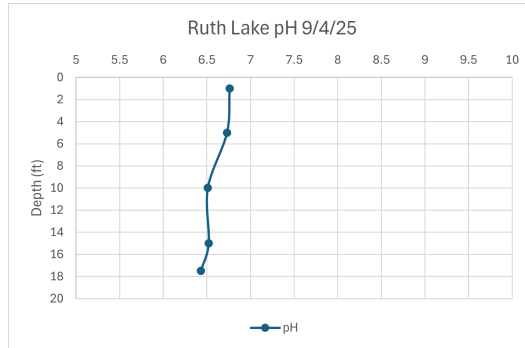


Figure: D-24



E. Nitrate/Nitrite

2025 Nitrate/Nitrite - All Lakes

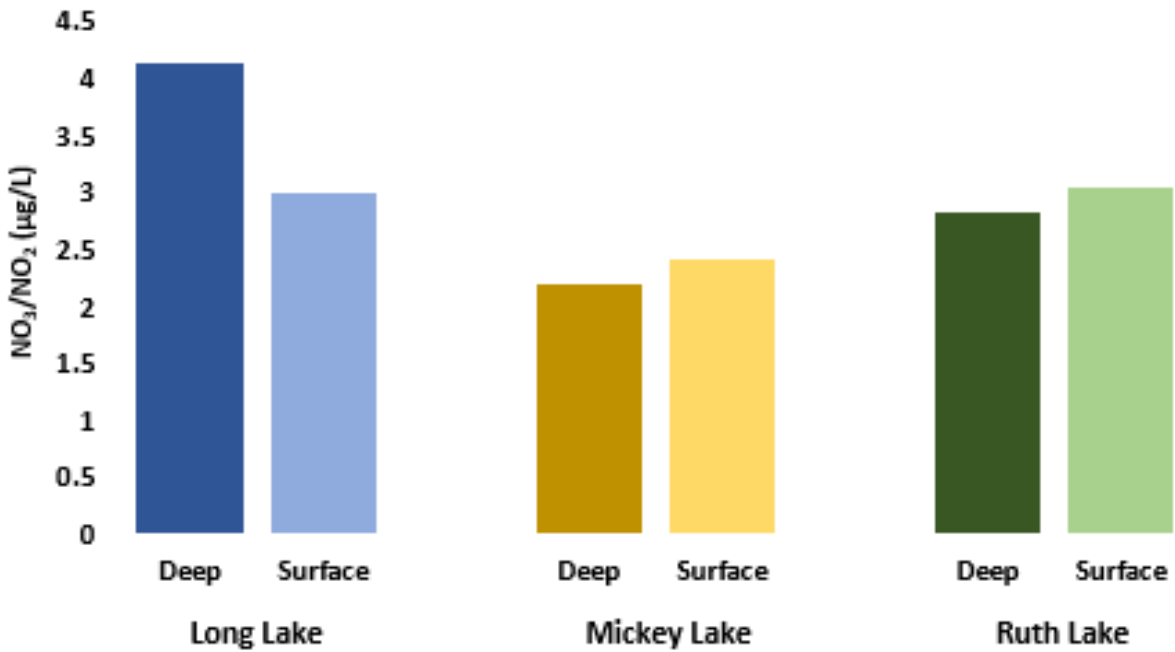


Figure E-1. Average 2025 surface and deep water nitrate/nitrite-nitrogen concentrations (µg/L) from all sampling events (n=3) on Long, Mickey, and Ruth Lakes.

2025 Nitrate/Nitrite - Nitrogen (All Lakes)

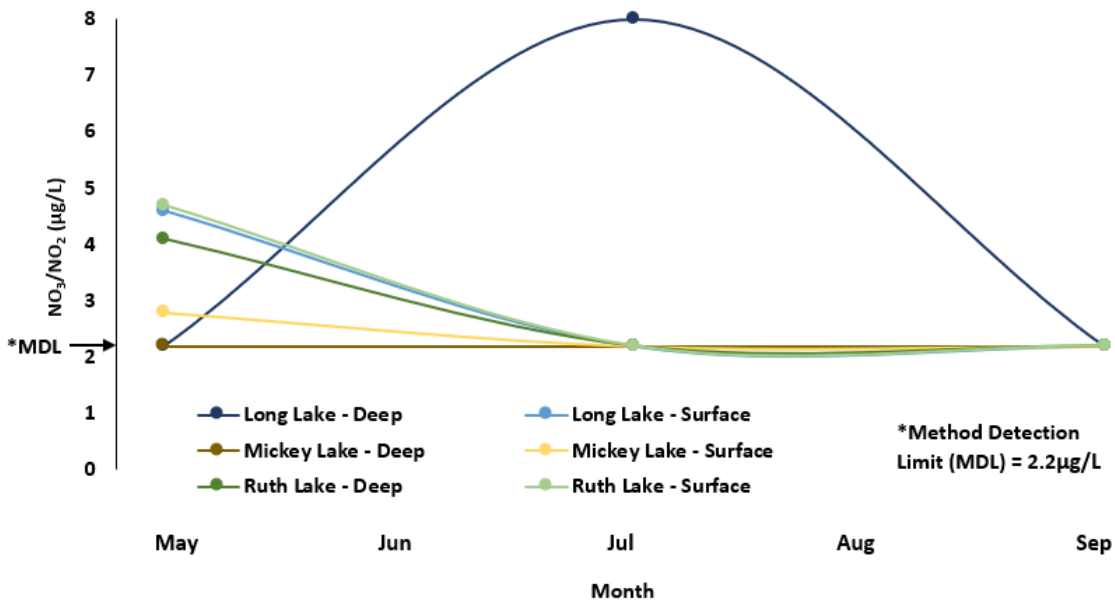


Figure E-2. Individual 2025 surface and deep water nitrate/nitrite-nitrogen concentration (µg/L) results collected from Long, Mickey, and Ruth Lakes.

Table E-1. 2025 Long, Mickey, and Ruth Lake average nitrate/nitrite-nitrogen concentrations ( $\mu\text{g/L}$ ) for all depth and surface samples combined.

| <b>2025 Nitrate/Nitrite - Nitrogen Averages<br/>(Deep and Surface Combined)</b> |                 |
|---|-----------------|
| Site  | $\mu\text{g/L}$ |
| Long Lake   | 3.57            |
| Mickey Lake   | 2.30            |
| Ruth Lake   | 2.93            |

**F. Calcium**

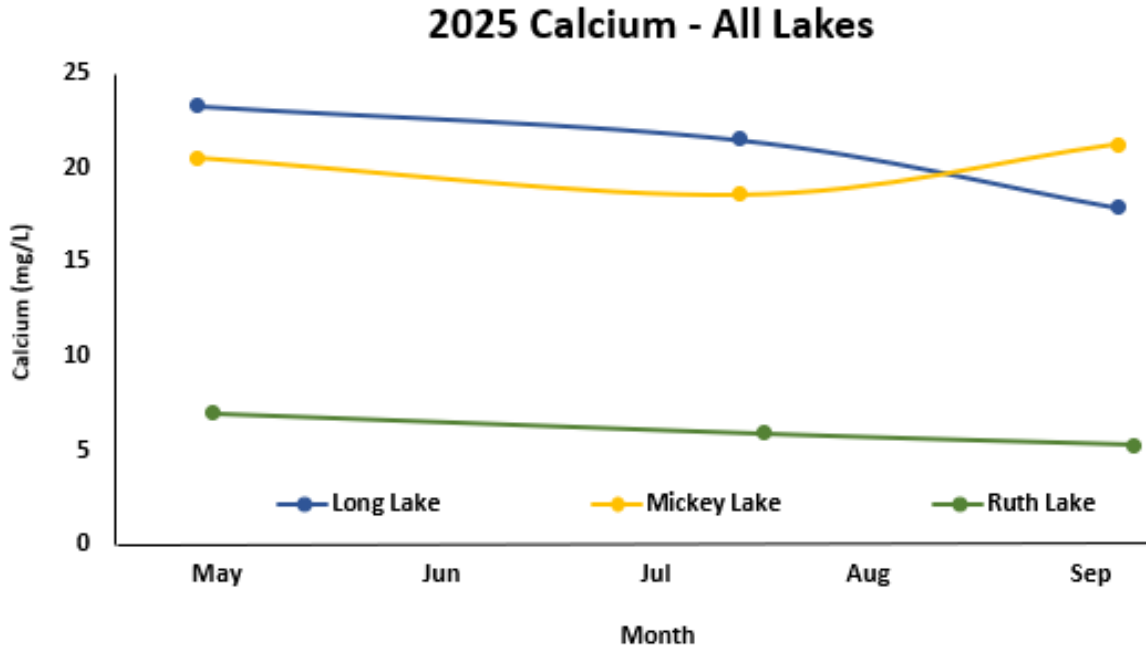


Figure F-1. Individual 2025 surface water calcium concentrations (mg/L) on Long, Ruth, and Mickey Lakes.

Table F-1. Long, Mickey, and Ruth Lake surface water calcium concentration averages (mg/L); historical (2017 through 2025) and 2025 compared.

| <b>2025 and Historical Calcium</b> |              |      |
|------------------------------------|--------------|------|
| Site                               |              | mg/L |
| Long Lake                          | 2025 Avg     | 20.9 |
|                                    | Historic Avg | 22.3 |
| Mickey Lake                        | 2025 Avg     | 20.1 |
|                                    | Historic Avg | 21.2 |
| Ruth Lake                          | 2025 Avg     | 6.1  |
|                                    | Historic Avg | 8.1  |

Table F-2. Annual average surface water calcium concentration (mg/L) from 2017 through 2025 on Long, Mickey, and Ruth Lakes.

| <b>Seasonal Calcium Averages (mg/L)</b> |           |             |           |
|---|-----------|-------------|-----------|
| Year                                    | Long Lake | Mickey Lake | Ruth Lake |
| 2017                                    | 22.7      | 21.2        | 16.1      |
| 2018                                    | 23.0      | 22.9        | 7.3       |
| 2019                                    | 21.6      | 20.2        | 6.7       |
| 2021                                    | 24.3      | 22.3        | 8.3       |
| 2022                                    | 21.3      | 20.7        | 7.0       |
| 2023                                    | 22.1      | 21.8        | 6.7       |
| 2024                                    | 22.9      | 20.8        | 6.9       |
| 2025                                    | 20.9      | 20.1        | 6.1       |
| Overall Historical Average              | 22.3      | 21.2        | 8.1       |

## G. Chlorophyll-a

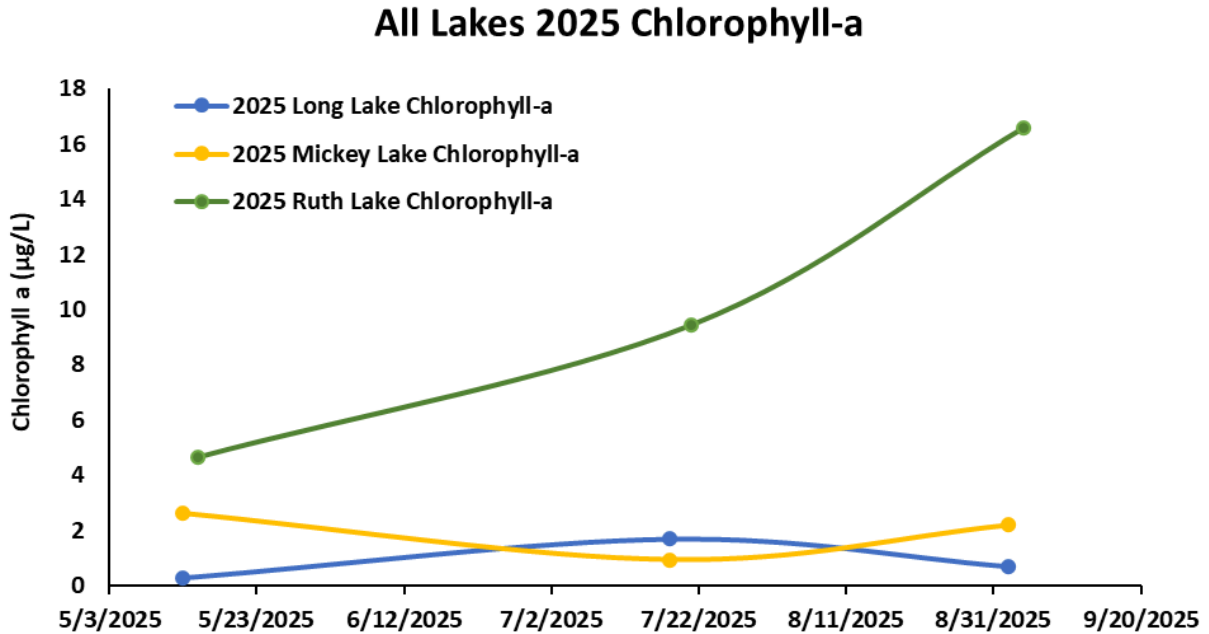


Figure G-1. 2025 individual chlorophyll-a concentration (µg/L) results on Long, Mickey, and Ruth Lakes.

Table G-1. Long, Mickey, and Ruth Lake chlorophyll-a concentration averages (µg/L); historical and 2025 compared.

| <b>2025 and Historical Chlorophyll a</b> |              |       |
|--|--------------|-------|
| Site                                     |              | µg/L  |
| Long Lake                                | 2025 Avg     | 0.88  |
|  | Historic Avg | 1.22  |
| Mickey Lake                              | 2025 Avg     | 1.92  |
|  | Historic Avg | 3.37  |
| Ruth Lake                                | 2025 Avg     | 10.23 |
|  | Historic Avg | 9.06  |

## 2025 Chlorophyll a - All Lakes

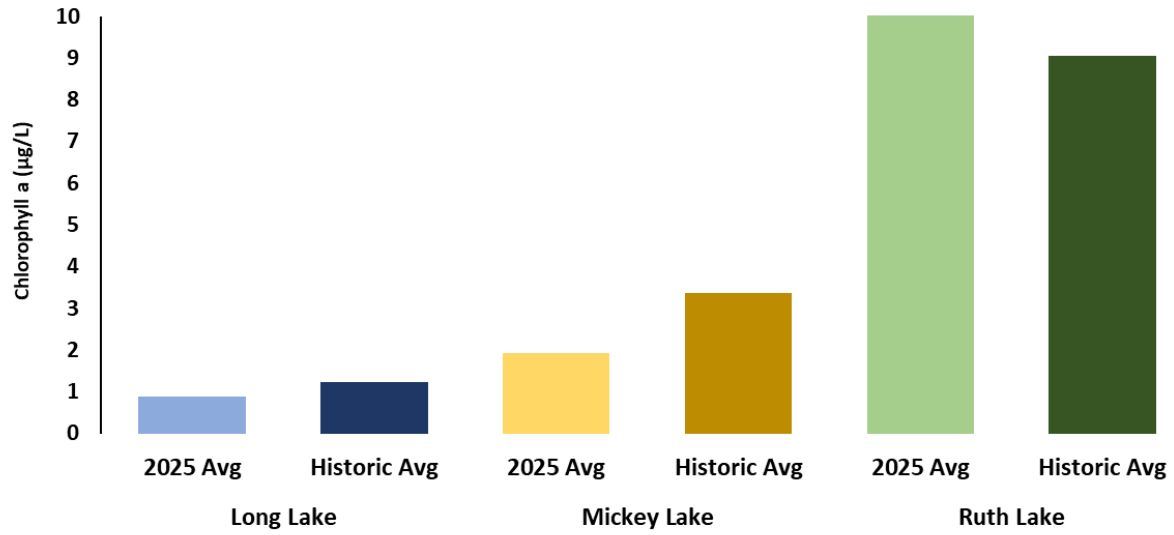
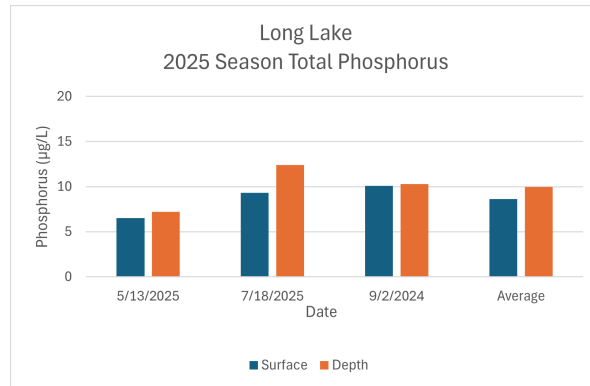


Figure G-2. Long, Mickey, and Ruth Lake chlorophyll-a concentration ( $\mu\text{g/L}$ ) averages; historical and 2025 compared.

## H. Phosphorus.

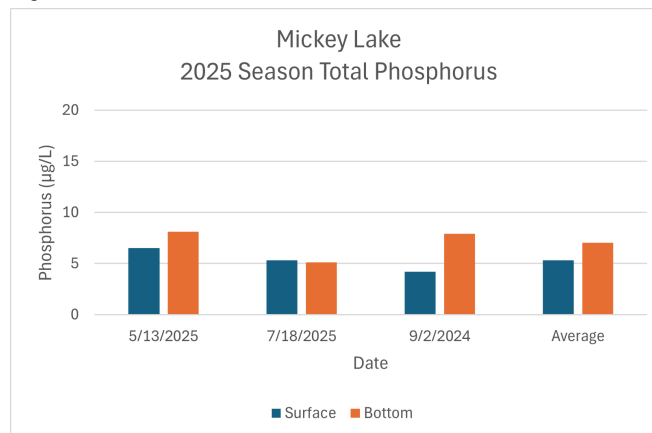
### Long Lake

Figure: H-1



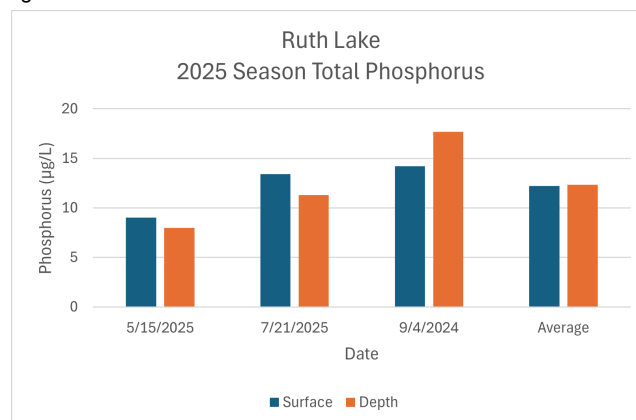
### Mickey Lake

Figure: H-2



### Ruth Lake

Figure: H-3



I. Water Levels.

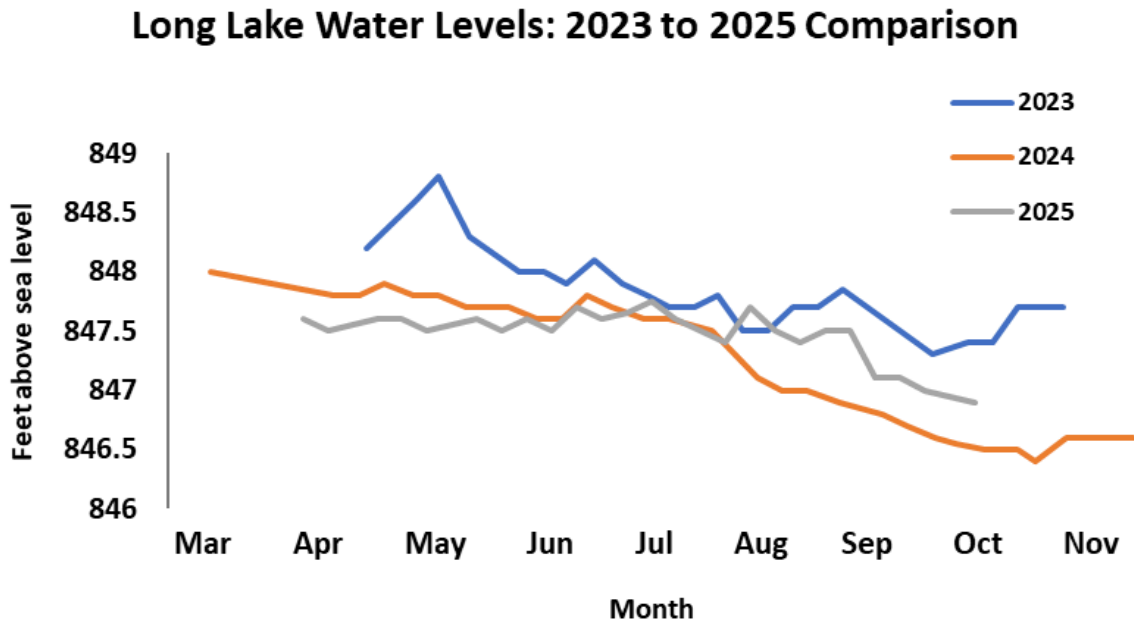


Figure I-1. Long/Mickey Lake water levels measured in feet above sea level, 2023, 2024, and 2025 compared.

## J. Plankton

Table J-1. 2025 Long Lake plankton trawl results and relative abundance of each genus observed.

| <b>2025 Long Lake Plankton Data</b> |                           |
|-------------------------------------|---------------------------|
| <b>Genus</b>                        | <b>Relative Abundance</b> |
| <b>Blue-Green Algae</b>             |                           |
| Anabaena                            | XX                        |
| Microcystis                         | X                         |
| <b>Diatoms</b>                      |                           |
| Asterionella                        | X                         |
| Fragillaria                         |                           |
| <b>Dinoflagellates</b>              |                           |
| Ceratium                            | XX                        |
| <b>Green Algae</b>                  |                           |
| Crucigenia fenestrata               | ?                         |
| Pediastrum boryanum                 |                           |
| <b>Other</b>                        |                           |
| Trichome                            | XX                        |
| <b>Parasites</b>                    |                           |
| Ducellieria chodatil (Oomycete)     | X                         |
| <b>Zooplankton</b>                  |                           |
| Asplanchna (Rotifer)                |                           |
| Keratella cochlearis (Rotifer)      | X                         |
| Nauplius                            | X                         |

Table J-2. 2025 Mickey Lake plankton trawl results and relative abundance of each genus observed.

| <b>2025 Mickey Lake Plankton Data</b> |                           |
|---------------------------------------|---------------------------|
| <b>Genus</b>                          | <b>Relative Abundance</b> |
| <b>Blue-Green Algae</b>               |                           |
| Anabaena                              | X                         |
| Microcystis                           | X                         |
| <b>Diatoms</b>                        |                           |
| Asterionella                          | X                         |
| Fragillaria                           | X                         |
| <b>Dinoflagellates</b>                |                           |
| Ceratium                              | XXX                       |
| <b>Green Algae</b>                    |                           |
| Crucigenia fenestrata                 |                           |
| Pediastrum boryanum                   | X                         |
| <b>Other</b>                          |                           |
| Trichome                              |                           |
| <b>Parasites</b>                      |                           |
| Ducellieria chodatil (Oomycete)       | X                         |
| <b>Zooplankton</b>                    |                           |
| Asplanchna (Rotifer)                  | X                         |
| Keratella cochlearis (Rotifer)        | XXX                       |
| Nauplius                              |                           |

## SECTION 2

### **HISTORICAL ANALYSIS**

Data utilized throughout this historical analysis has been collected through several decades of water quality monitoring on Long Lake and its surrounding waterbodies. Worth mentioning are several recent reports which have contributed greatly to the collection of significant water quality data, including Kaiser and Talty (2024), Mills and Cole (2022), Mills and Walters (2021), Hull, Preston, and DePauw (2019), Porter, Cottrell, and DePauw (2018), DePauw and Cooper (2017), Rhodes and Cooper (2016), and Great Lakes Environmental Center (2014).

#### **Temperature and Dissolved Oxygen**

##### ***Long Lake***

Temperature and dissolved oxygen has been monitored semi-regularly on Long Lake since the early 1990's. When comparing temperature, dissolved oxygen, and the location of stratified layers over the course of four decades (1996 - 2025), Long Lake has remained very consistent. Surface temperature over 2025 registered higher than historical averages, while depth temperature remained consistent. Dissolved oxygen levels in both the surface and depth remained very consistent over this time period. The location of the metalimnion was also very consistent, with a range of 30 - 45 ft. See figures I-1 through I-4.

##### ***Mickey Lake***

Temperature and dissolved oxygen has been monitored semi-regularly on Mickey Lake since the early 1990's. When comparing temperature, dissolved oxygen, and the location of stratified layers over the course of four decades (1996 - 2025), Mickey Lake has remained very consistent. Surface temperature over 2025 registered higher than historical averages, while depth temperature remained consistent. Dissolved oxygen levels in both the surface and depth remained very consistent over this time period. The location of the metalimnion was also very consistent, with a range of 15 - 25 ft. See figures I-5 through I-8.

#### **Transparency**

##### ***Long Lake***

A significant transparency data set exists for Long Lake. This includes 779 secchi readings dating back to 1979. A summary of this historical data set can be seen in Table

L-1. Noteworthy results include Long Lake's deepest secchi reading of 65 feet, recorded in 2017, and shallowest recording of 10 feet, recorded in 1985. The overall historical transparency average on Long Lake is 26.8 feet. Historical trends indicate that annual transparency averages have increased ( $R^2=0.1786$ ) on Long Lake over time (Figure L-1).

It is important to note that while increases in transparency do commonly result from increased water quality, this is not always the case. Invasive zebra and quagga mussels contribute to significant increases in water clarity due to their predation on plankton (MacIsaac 1996). The establishment of zebra mussels in Long Lake in 2021 is a likely contributor to increased water clarity on Long Lake in recent years, however the start of increased transparency trends pre-date zebra mussel infestation in Long Lake. This indicates that the increased transparency occurring on Long Lake is likely in part due to increasing overall water quality. Continuing to monitor transparency regularly on Long Lake is highly important for monitoring overall water quality, and for examining the impact of zebra mussels.

### ***Mickey Lake***

Somewhat regular secchi readings have been conducted on Mickey Lake dating back to 2011, combining for a data set of 74 results. A summary of this historical data set can be seen in Table L-2. Noteworthy results include Mickey Lake's deepest secchi reading of 29.5 feet captured in 2014, and shallowest recording of 7 feet, captured in 2019. The overall historical transparency average on Mickey Lake is 16.3 feet. Annual transparency averages have decreased ( $R^2=0.0712$ ) on Mickey Lake over time (Figure L-2), though the limited data set makes it difficult to determine if this is an established trend. Continuing to monitor transparency on Mickey Lake in the future will better allow for determining any potential trend that may be occurring, and is important for monitoring how zebra mussels are impacting Mickey.

### ***Ruth Lake***

Somewhat regular secchi readings have been conducted on Ruth Lake dating back to 2014, combining for a data set of 20 results. A summary of Ruth Lakes historical secchi readings can be seen in Table L-3. Noteworthy results include Ruth Lake's deepest secchi reading of 6.5 feet from 2025, and shallowest reading of 2 feet, which has been recorded in 2017, 2019, and 2021. The overall historical transparency average on Ruth Lake is 3.1 feet. Annual transparency averages have increased ( $R^2=0.416$ ) on Ruth Lake over time (Figure L-3), though limited data makes it difficult to determine if this is a trend. Continuing to monitor transparency on Ruth Lake in the future will better allow for determining any potential trend, and is critical for establishing baseline water quality data.

## **Nitrate/Nitrite**

### ***Long Lake***

Overall, results for nitrate/nitrite-nitrogen concentrations in Long Lake were low in 2025 in comparison to historical results. It is important to note that inconsistent sampling of nitrate/nitrite-nitrogen has occurred over time. The most complete and comparable data set of Long Lake nitrate/nitrite-nitrogen results are spring and summer surface water samples, which were collected consistently between 1993 and 2005, and from 2021 to present. While nitrate/nitrite-nitrogen samples were collected on Long Lake between 2005 and 2021, these samples were processed using a much higher detection limit of 1000µg/L. All of the nitrate/nitrite-nitrogen results came in below detection limit throughout this time period, and have been excluded from the overall averages gathered for this report.

Analysis of the remaining historical data in this dataset indicates an overall nitrate/nitrite-nitrogen average of 35.8µg/L, and a downward trend in concentrations over time (Figure M-1). High variability exists in Long Lake surface water nitrate/nitrite-nitrogen concentrations, ranging from as low as 1.4µg/L in 2005, to as high as 245µg/L in 2003 (Table M-1).

Further analysis would be required in order to confidently explain the high variability and overall downward trend in nitrate/nitrite-nitrogen concentrations occurring on Long Lake. High variability in nitrate/nitrite-nitrogen concentrations is a common observation in waterbodies, and none of the historical results have fallen outside of what is generally accepted as normal for an Oligotrophic lake. Generally, lakes of Oligotrophic Status are categorized as having Nitrate-Nitrogen concentrations below 300µg/L (Massachusetts Water Watch Partnership 2016).

In general, long term nitrate/nitrite-nitrogen results are quite low on Long Lake, which may indicate that nitrate/nitrite-nitrogen is limiting on Long Lake. It is highly important to continue monitoring nitrate/nitrite-nitrogen concentrations on Long Lake. If Long Lake is in fact nitrate/nitrite-nitrogen limited, even small inputs from external sources (i.e. fertilizer runoff) could contribute to increases in productivity (Grankvist 2024).

### ***Mickey Lake***

Historically, there have been fewer nitrate/nitrite-nitrogen samples collected on Mickey Lake than on Long Lake, making it difficult to determine trends over time. Most of the nitrate/nitrite-nitrogen samples were processed during the time period when a higher detection limit of 1000µg/L was being used in sample processing. Continuing to analyze nitrate/nitrite-nitrogen on Mickey Lake is highly important for establishing baseline data and long term monitoring. The limited nitrate/nitrite-nitrogen data that does exist indicates that like Long Lake, nitrate/nitrite-nitrogen concentrations are very low on Mickey Lake. This could indicate that nitrate/nitrite-nitrogen is limiting on Mickey Lake,

and that even small inputs from external sources (i.e. fertilizer runoff) could result in increases in productivity (Grankvist 2024).

### ***Ruth Lake***

Like Mickey Lake, few nitrate/nitrite-nitrogen samples have been collected on Ruth Lake, and it is difficult to establish trends over time. Most of the nitrate/nitrite-nitrogen samples were processed during the time period when a higher detection limit of 1000µg/L was being used in sample processing. The limited data that does exist indicates that like Long and Mickey Lakes, nitrate/nitrite-nitrogen concentrations on Ruth Lake are very low. This may indicate that nitrate/nitrite-nitrogen could be limiting on Ruth, increasing the importance of continuing to monitor nitrate/nitrite-nitrogen on Ruth. Like on Long and Mickey, if nitrate/nitrite-nitrogen is in fact limiting on Ruth, even small inputs from external sources (i.e. fertilizer runoff) could result in increases in productivity (Grankvist 2024).

## **Calcium**

### ***Long Lake***

Historical data indicates that calcium concentrations have remained very consistent on Long Lake since monitoring began in 2017, with seasonal averages ranging from a record low of 20.9 mg/L in 2025, to a record high of 24.25 mg/L in 2021 (Figure N-1), and an overall historical average of 22.3 mg/L (Table N-1). As mentioned earlier in this report, calcium concentrations in Long Lake are trending on the lower end of what is generally considered optimal in North American waterbodies (Whittier 2008). This is likely limiting the full potential of zebra mussel densities on Long Lake. Continuing to monitor calcium concentrations will allow for an indication of potential changes in zebra mussel success in Long Lake.

### ***Mickey Lake***

Similarly to Long Lake, calcium concentrations have remained very steady on Mickey Lake since monitoring began in 2017, with seasonal averages ranging from a record low of 20.1 mg/L in 2025, to a record high of 22.9 mg/L in 2018 (Figure N-1), and an overall historical average of 21.2 mg/L (Table N-1). Like on Long Lake, historical data indicates that Mickey Lake can be categorized as having calcium concentrations conducive for “moderate” zebra mussel densities (Bruce 2025), (Whittier 2008), (Cohen & Weinstein 2001). Continuing to monitor calcium concentrations on Mickey Lake will allow for an indication of potential changes in extent of zebra mussels in Mickey Lake.

### ***Ruth Lake***

Analysis of previous calcium concentration data on Ruth Lake indicates that concentrations have remained very steady on Ruth Lake, aside from the first sampling year in 2017. Calcium concentrations averaged 16.1 mg/L in 2017, and have since

ranged between 8.3 mg/L and 6.1 mg/L (Figure N-1). Ruth Lake's overall historical average calcium concentration is the lowest of the three lakes monitored at 8.1 mg/L (Table N-1). Continuing to monitor calcium concentrations on Ruth Lake is highly important for determining the potential spread of zebra mussels from Long Lake to Ruth Lake. To date, 2017 was the only year when calcium concentrations on Ruth Lake exceeded what is generally considered conducive to supporting zebra mussels. Continuing to monitor calcium on Ruth Lake will be beneficial for establishing baseline data, and in determining how often calcium meets the minimum requirements for zebra mussel establishment.

## **Chlorophyll-a**

### ***Long Lake***

Historical chlorophyll-a data exists for Long Lake dating back to 1993, resulting in an overall average concentration of 1.22µg/L. Relative to this historical data set, 2025 chlorophyll-a results averaged slightly below the overall historical average at 0.88 µg/L (Table O-1), (Figure O-1). Examination of long term chlorophyll-a concentrations since 1993 reveals a slight upward trend ( $R^2=0.0597$ ) occurring on Long Lake (Figure O-2). All recent chlorophyll-a concentration results have still remained within the range of historical concentrations recorded on Long Lake. This historical range is defined by a historical high of 5.2 µg/L, and a historical low of 0.1 µg/L (Figure O-2).

It is also noteworthy that while an overall increase in average chlorophyll-a has occurred from 1993 to present, a decline in chlorophyll-a can be observed when focusing only on 2020 to present (Figure O-3). This timeline coincides with reports of zebra mussel populations becoming more prevalent on Long Lake starting in 2021. It is well cited that the establishment of zebra mussels commonly results in reduced chlorophyll-a concentrations (Qualls et al. 2007), (Bellinger 2024), (Fahnenstiel et al. 1993). It is unclear whether the decline in average chlorophyll-a concentrations on Long Lake in recent years is in fact a trend, or if it can be attributed to the increase of zebra mussels. Continuing to monitor chlorophyll-a on Long Lake will better depict any potential trend that may be occurring, and will be beneficial in understanding the immediate impact zebra mussels are having on Long Lake.

### ***Mickey Lake***

Overall, Mickey Lake has demonstrated minimal variation in chlorophyll-a concentration results since 2014, with virtually no trends ( $R^2 = 5E-05$ ) appearing (Figure O-4). To date, the current highest recorded chlorophyll-a concentration of 11.85 µg/L was recorded in 2022, and the record low of 0.92 µg/L in 2019 (Figure O-4). Chlorophyll-a data does not date as far back on Mickey Lake as it does on Long Lake, so continuing to monitor chlorophyll-a on Mickey Lake is highly important for the establishment of baseline data.

This continuation of chlorophyll-a sampling is also critical for monitoring the impacts resulting from Mickey Lakes ongoing zebra mussel infestation.

### ***Ruth Lake***

Limited chlorophyll-a concentration data has been collected on Ruth Lake dating back to 2014. Analysis of this historical data reveals an overall historical average of 9.06 µg/L (Table O-1). Historical chlorophyll-a concentrations have ranged from a record low of 4.51 µg/L in 2019 to a record high of 16.57 µg/L 2025 (Figure O-5). Continuing to monitor chlorophyll-a concentrations on Ruth Lake will be beneficial in establishing baseline data.

## **Phosphorus**

### ***Long Lake***

Historical phosphorus data exists for Long Lake dating back to 1993. Surface phosphorus was monitored annually from 1993 through 2005. From 2005 to 2017 it was monitored every three years, and has been monitored annually since (see figure P-1). Depth phosphorus was monitored sporadically from 1997 until 2017 when annual monitoring began (see figure P-3).

Since 1993, a total of 170 surface phosphorus readings have been taken on Long Lake. Note - 19 samples were taken in 1997, 33 samples were taken in 2000, and 15 samples were taken in 2003. Over this timeframe, the average surface phosphorus of Long Lake registers at 7.72 µg/L. The highest recorded year was 2001 with a recorded 12.83 µg/L. The lowest recorded year was 2021 with a recorded 3.64 µg/L, See figure P-1. This average falls into oligotrophic status.

Since 1997, a total of 94 depth phosphorus readings have been taken on Long Lake. Note - 27 samples were taken in 2000. Over this timeframe, the average depth phosphorus of Long Lake registers at 12.43 µg/L. The highest recorded year was 2005 with a recorded 33.17 µg/L, but this sample was suspected to be contaminated with sediment. The next highest recorded year was 1999 with a recorded 13.47. The lowest recorded year was 2018 with a recorded 6.62 µg/L. See figure P-3. This average falls into oligotrophic status.

### ***Mickey Lake***

Historical phosphorus data exists for Long Lake dating back to 1993. Surface phosphorus monitoring occurred on an almost annual basis from 1993 through 2003. No monitoring occurred from 2003 through 2014. Annual surface monitoring began again in 2017 (see figure P-5). Depth phosphorus monitoring began in 2014, and has been conducted annually since 2017 (see figure P-7).

Since 1993, a total of 58 surface phosphorus readings have been taken on Mickey Lake. Over this timeframe, the average surface phosphorus of Mickey Lake registers at 10.55 µg/L. The highest recorded year was 1997 with a recorded 16 µg/L. The lowest recorded year was 2023 with a recorded 3.97 µg/L. See figure P-5. This average falls into oligotrophic status.

Since 2014, a total of 26 depth phosphorus readings have been taken on Mickey Lake. Over this timeframe, the average depth phosphorus of Mickey Lake registers at 13.67 µg/L. The highest recorded year was 2023 with a recorded 18.9 µg/L. The lowest recorded year was 2025 with a recorded 7.03 µg/L. See figure P-7. This average falls into oligotrophic status.

### ***Ruth Lake***

Historical phosphorus data exists for Ruth Lake dating back to 2006. Surface phosphorus monitoring occurred three years from 2006 through 2017. Annual surface monitoring began in 2017 (see figure P-9). With the exception of 2021, depth phosphorus has been monitored annually since 2019 (see figure P-11).

Since 2006, a total of 28 surface phosphorus readings have been taken on Ruth Lake. Over this timeframe, the average surface phosphorus of Ruth Lake registers at 15.52 µg/L. The highest recorded year was 2020 with a recorded 27.8 µg/L. The lowest recorded year was 2006 with a recorded 6.3 µg/L. See figure P-9. This average falls into oligotrophic status.

Since 2014, a total of 10 depth phosphorus readings have been taken on Ruth Lake. Over this timeframe, the average depth phosphorus of Ruth Lake registers at 18.08 µg/L. The highest recorded year was 2020 with a recorded 29.95 µg/L. The lowest recorded year was 2023 with a recorded 5.2 µg/L (only 1 sample). See figure P-11. This average falls into oligotrophic status.

# HISTORICAL ANALYSIS GRAPHS

## K. Temperature and Dissolved Oxygen

### Long Lake

Figure: I-1

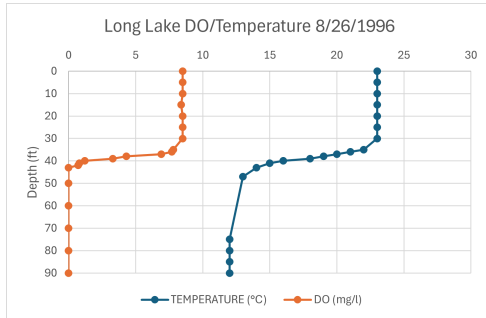


Figure: I-2

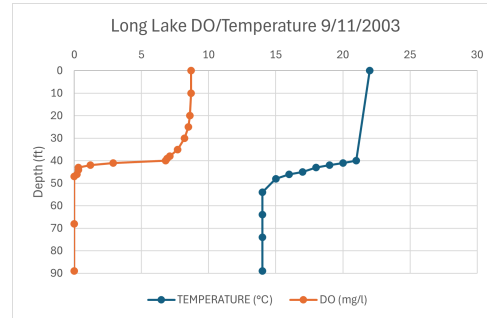


Figure: I-3

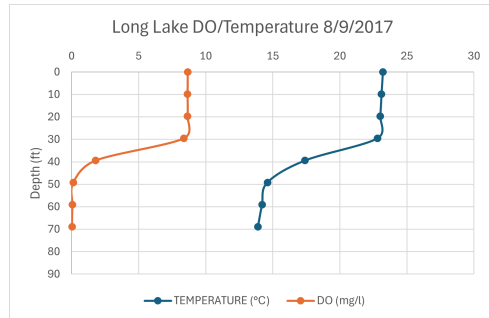
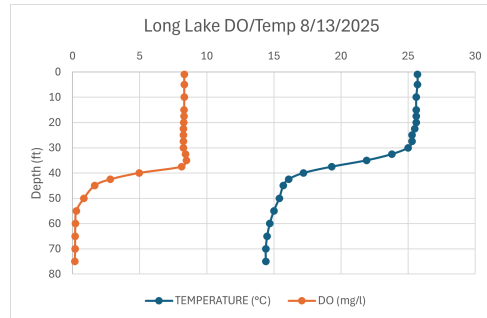


Figure: I-4



### Mickey Lake

Figure: I-5

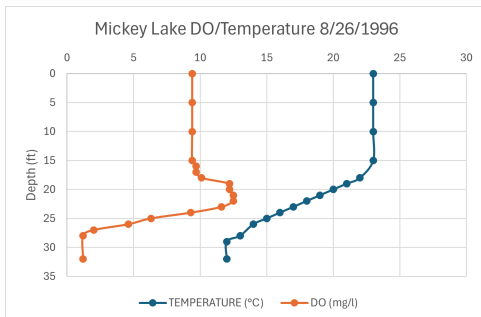


Figure: I-6

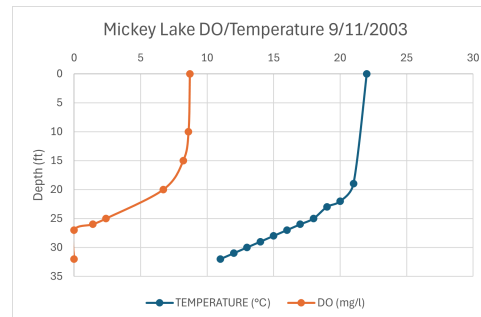


Figure: I-7

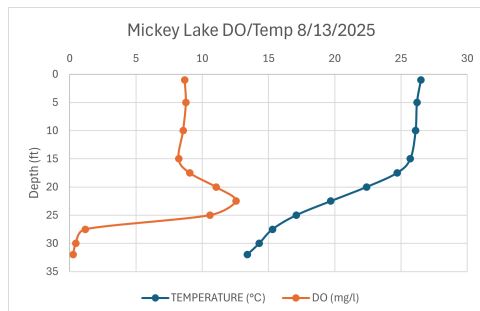
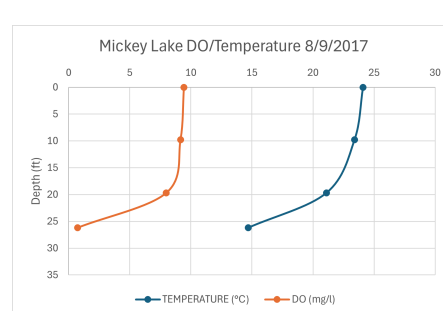


Figure: I-8



## L. Transparency

### Long Lake Historical Transparency

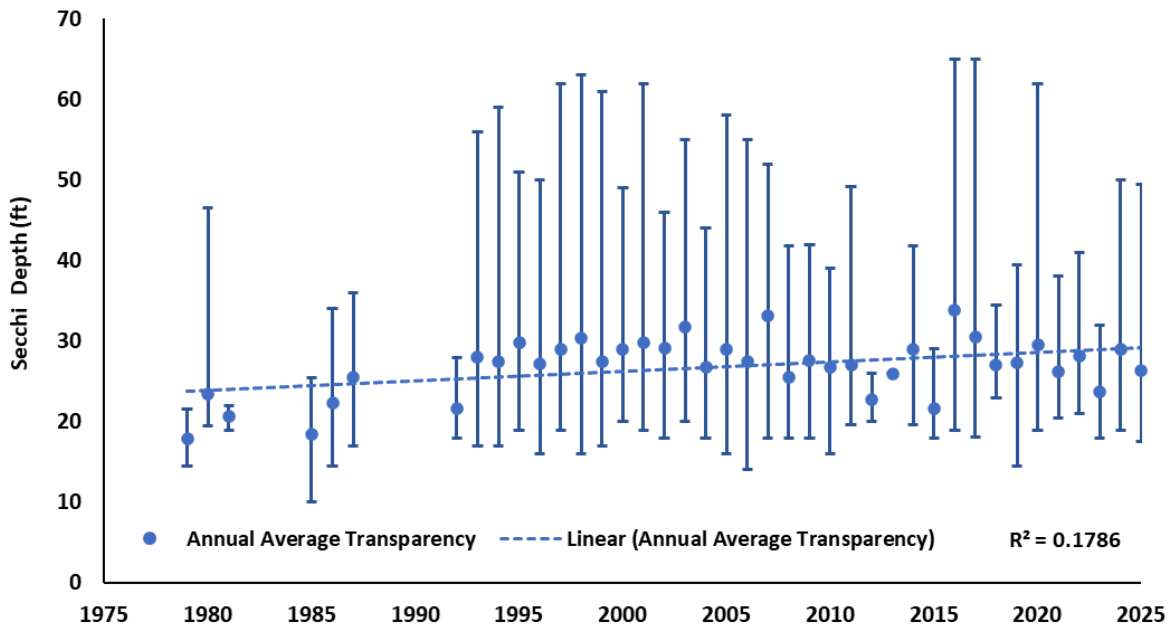


Figure L-1. Long Lake historical transparency (ft) from 1979 to current, with annual averages plotted as points and seasonal maximum and minimum secchi depths depicted as the upper and lower error.

### Mickey Lake Historical Transparency

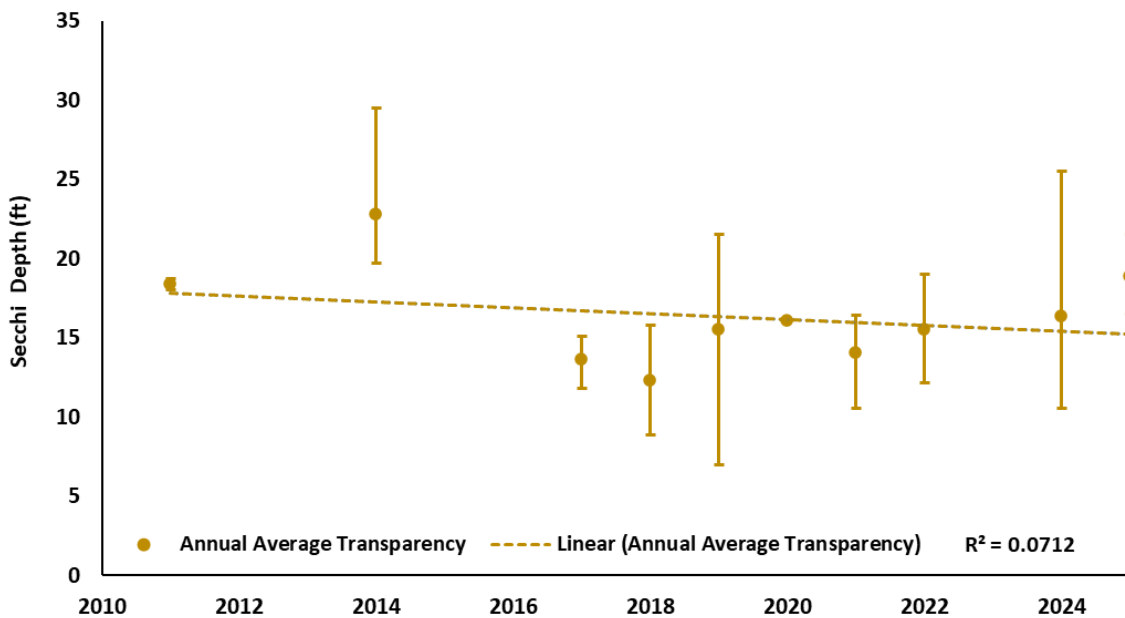


Figure L-2. Mickey Lake historical transparency (ft) from 2011 to current, with annual averages plotted as points and seasonal maximum and minimum secchi depths depicted as the upper and lower error.

## Ruth Lake Historical Transparency

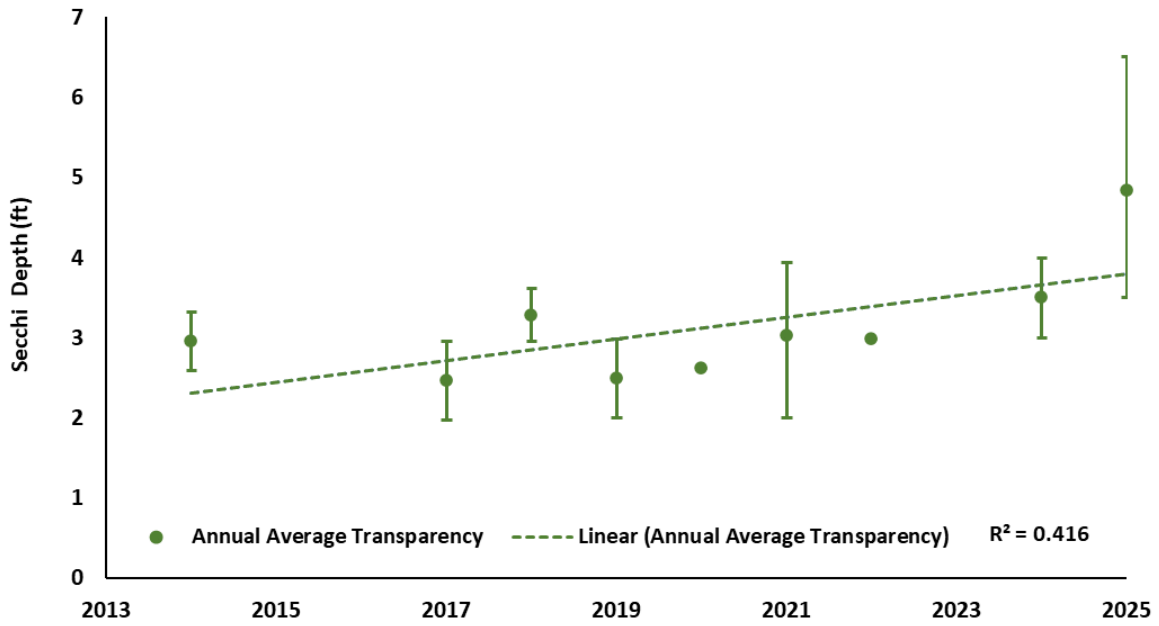


Figure L-3. Ruth Lake historical transparency (ft) from 2014 to current, with annual averages plotted as points and seasonal maximum and minimum secchi depths depicted as the upper and lower error.

## M. Nitrate/Nitrite

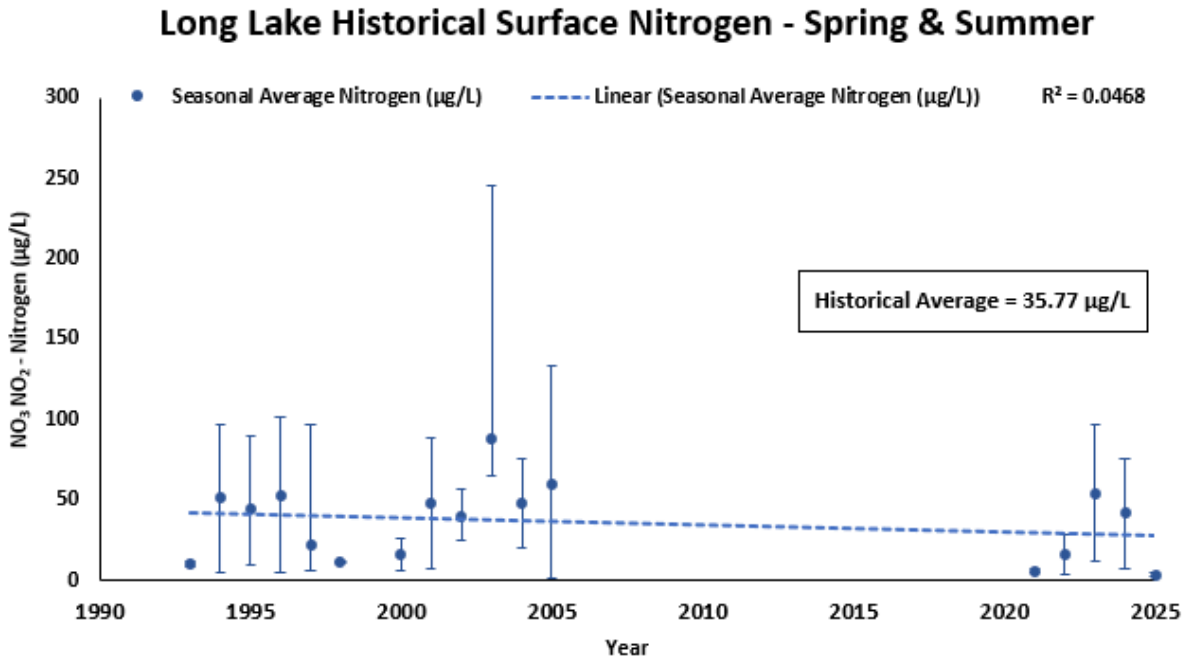


Figure M-1. Long Lake historical spring and summer surface nitrate/nitrite-nitrogen concentrations ( $\mu\text{g/L}$ ) with annual averages plotted as points and seasonal maximum and minimum concentrations depicted as the upper and lower error.

N. Calcium

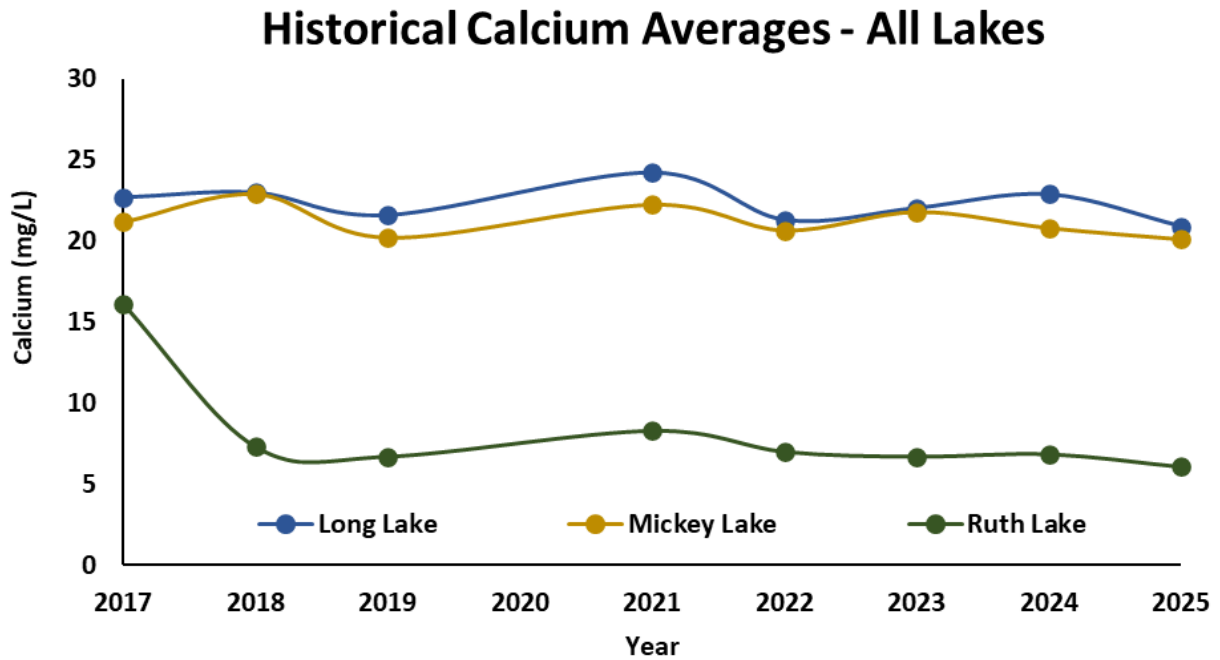


Figure N-1. Historical calcium concentration seasonal averages (mg/L) on Long, Mickey, and Ruth Lakes.

Table N-1. Historical calcium concentration seasonal averages (mg/L) on Long, Mickey, and Ruth Lakes.

| <b>Seasonal Calcium Averages (mg/L)</b> |           |             |           |
|---|-----------|-------------|-----------|
| Year                                    | Long Lake | Mickey Lake | Ruth Lake |
| 2017                                    | 22.7      | 21.2        | 16.1      |
| 2018                                    | 23.0      | 22.9        | 7.3       |
| 2019                                    | 21.6      | 20.2        | 6.7       |
| 2021                                    | 24.3      | 22.3        | 8.3       |
| 2022                                    | 21.3      | 20.7        | 7.0       |
| 2023                                    | 22.1      | 21.8        | 6.7       |
| 2024                                    | 22.9      | 20.8        | 6.9       |
| 2025                                    | 20.9      | 20.1        | 6.1       |
| Overall Historical Average              | 22.3      | 21.2        | 8.1       |

## O. Chlorophyll-a

Table O-1. Long, Mickey, and Ruth Lake chlorophyll-a concentration averages; historical and 2025 compared.

| 2025 and Historical Chlorophyll a |              |       |
|-----------------------------------|--------------|-------|
| Site                              |              | µg/L  |
| Long Lake                         | 2025 Avg     | 0.88  |
|                                   | Historic Avg | 1.22  |
| Mickey Lake                       | 2025 Avg     | 1.92  |
|                                   | Historic Avg | 3.37  |
| Ruth Lake                         | 2025 Avg     | 10.23 |
|                                   | Historic Avg | 9.06  |

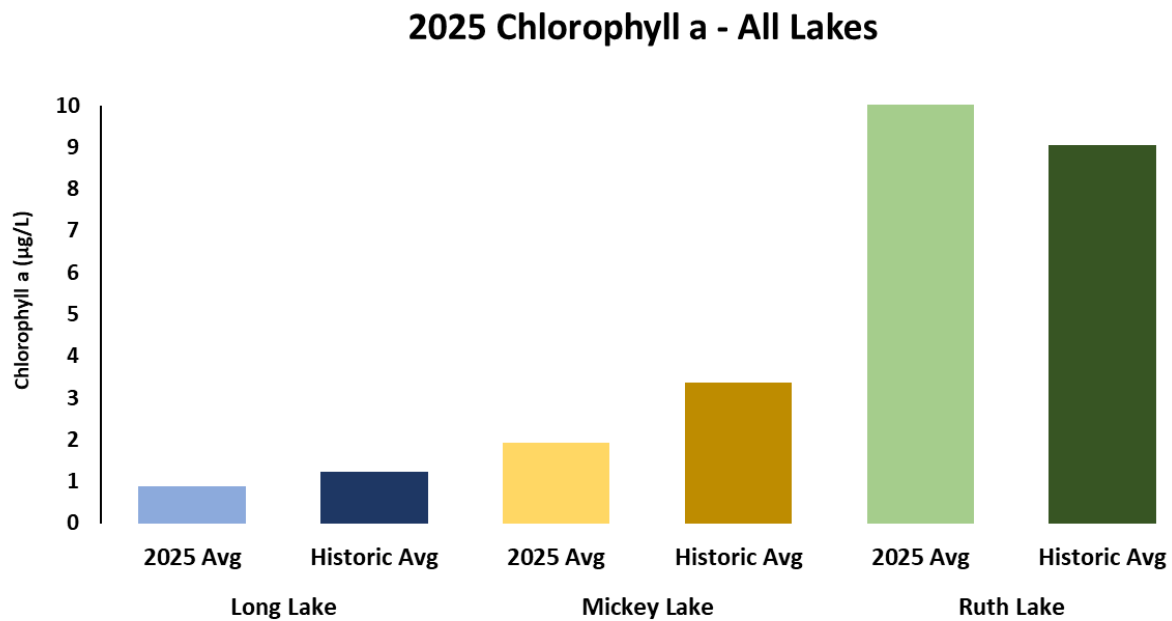


Figure O-1. Long, Mickey, and Ruth Lake chlorophyll-a concentration (µg/L) averages; historical and 2025 compared.

## Long Lake Historical Chlorophyll-a (1993-2025)

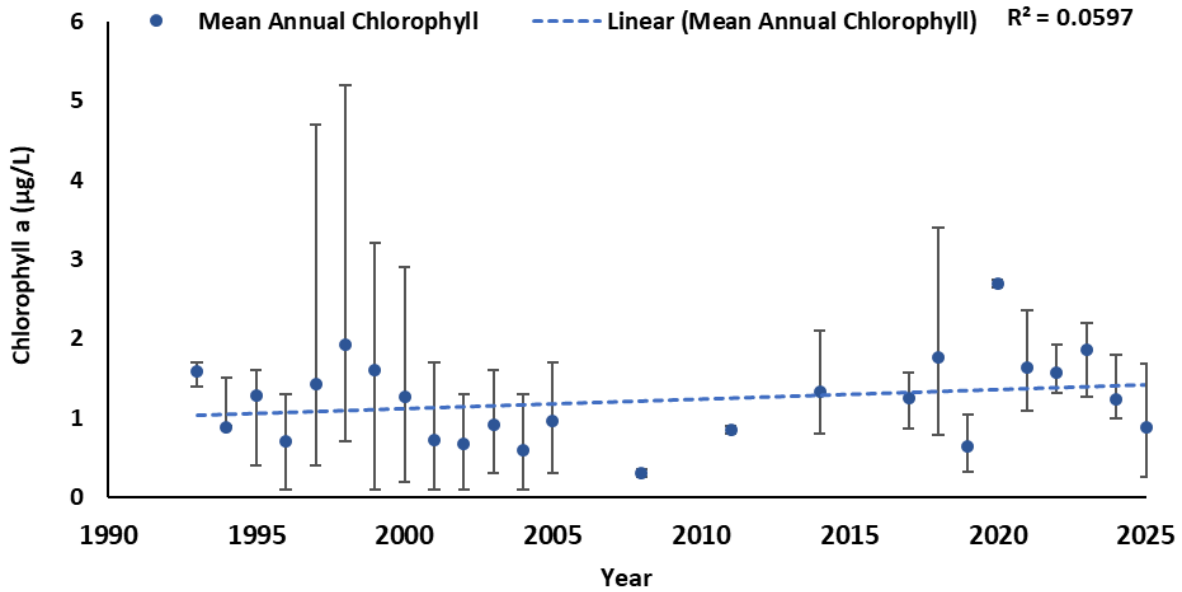


Figure O-2. Historical Long Lake chlorophyll-a concentrations from 1993 to current, with annual averages plotted as points and seasonal maximum and minimum concentrations depicted as the upper and lower error.

## Long Lake Historical Chlorophyll-a (2020-2025)

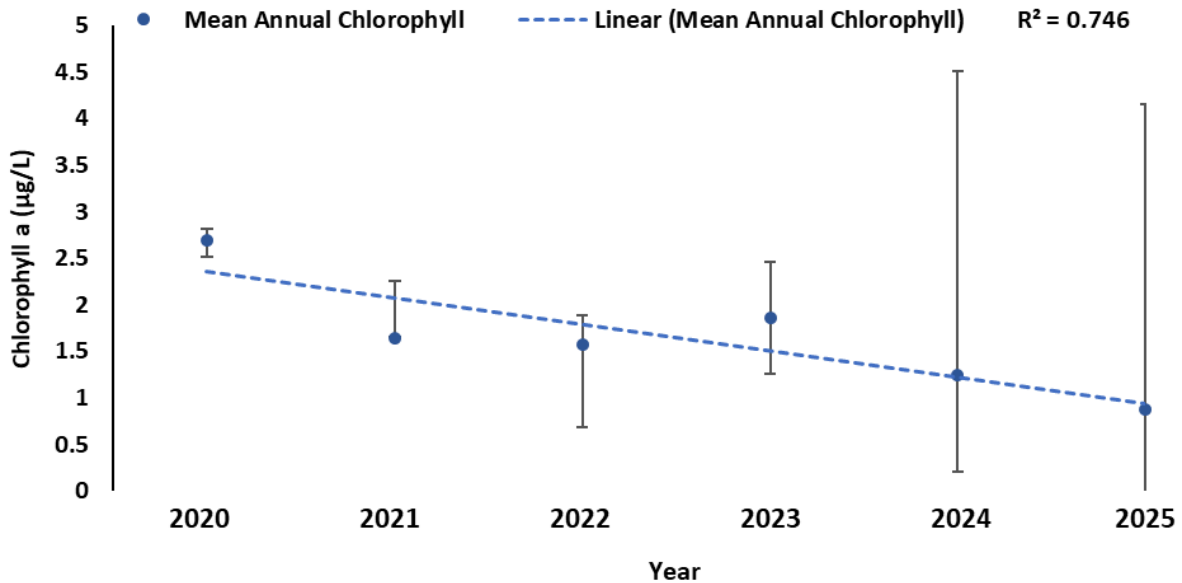


Figure O-3. Long Lake chlorophyll-a concentrations, 2020 to 2025 only, with annual averages plotted as points and seasonal maximum and minimum concentrations depicted as the upper and lower error.

### Mickey Lake Historical Chlorophyll a

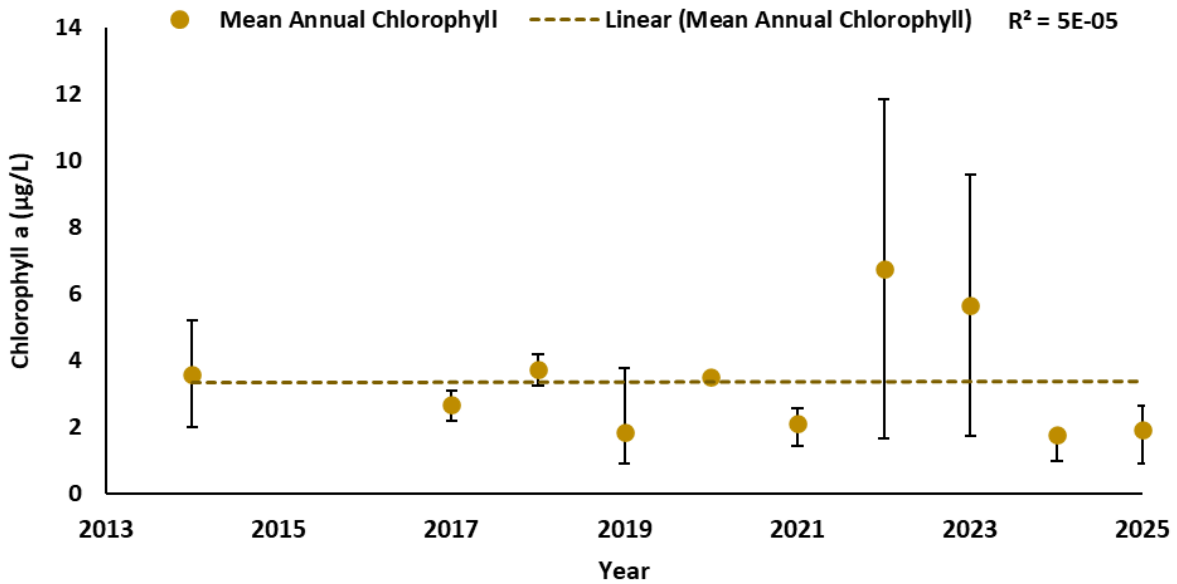


Figure O-4. Historical Mickey Lake chlorophyll-a concentrations from 2014 to current, with annual averages plotted as points and seasonal maximum and minimum concentrations depicted as the upper and lower error.

### Ruth Lake Historical Chlorophyll a

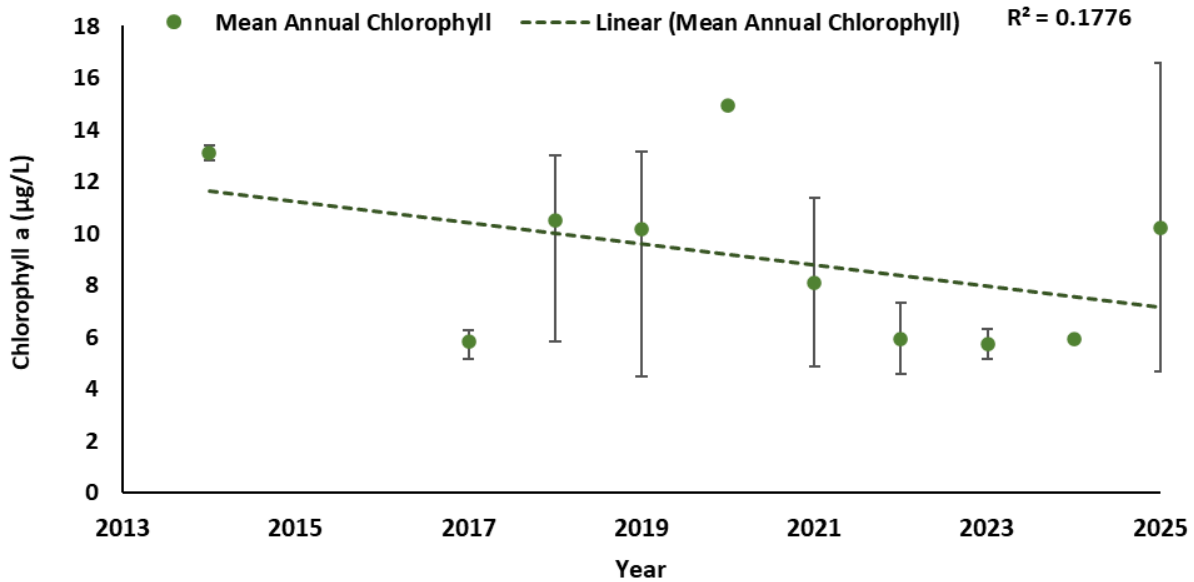


Figure O-5. Historical Ruth Lake chlorophyll-a concentrations from 2014 to current, with annual averages plotted as points and seasonal maximum and minimum concentrations depicted as the upper and lower error.

## P. Phosphorus

### Long Lake

Figure: P-1

| LONG LAKE HISTORICAL TOTAL SURFACE PHOSPHORUS |            |            |             |         |
|---|------------|------------|-------------|---------|
| YEAR  | MIN (µg/L) | MAX (µg/L) | MEAN (µg/L) | SAMPLES |
| 1993  | 5          | 9          | 7.25        | 4       |
| 1994  | 4          | 19         | 8.5         | 6       |
| 1995  | 6          | 10         | 8.25        | 4       |
| 1996  | 6          | 14         | 10          | 4       |
| 1997  | 5.8        | 28         | 11.09       | 19      |
| 1998  | 4          | 18.2       | 9.99        | 9       |
| 1999  | 2.8        | 7.9        | 5.67        | 6       |
| 2000  | 3.1        | 34.4       | 8.77        | 33      |
| 2001  | 8          | 16         | 12.83       | 6       |
| 2002  | 7          | 11         | 8.5         | 6       |
| 2003  | 9          | 18         | 11.27       | 15      |
| 2004  | 11         | 13         | 11.83       | 6       |
| 2005  | 1.8        | 12.9       | 8.65        | 6       |
| 2006  | #N/A       | #N/A       | #N/A        | #N/A    |
| 2007  | #N/A       | #N/A       | #N/A        | #N/A    |
| 2008  | 1.2        | 3.6        | 2.2         | 3       |
| 2009  | #N/A       | #N/A       | #N/A        | #N/A    |
| 2010  | #N/A       | #N/A       | #N/A        | #N/A    |
| 2011  | 5          | 5.4        | 5.2         | 2       |
| 2012  | #N/A       | #N/A       | #N/A        | #N/A    |
| 2013  | #N/A       | #N/A       | #N/A        | #N/A    |
| 2014  | 2.2        | 2.8        | 2.47        | 3       |
| 2015  | #N/A       | #N/A       | #N/A        | #N/A    |
| 2016  | #N/A       | #N/A       | #N/A        | #N/A    |

|         |       |        |        |             |
|---------|-------|--------|--------|-------------|
| 2017    | 2.5   | 6.1    | 3.95   | 6           |
| 2018    | 4.9   | 11.2   | 6.97   | 6           |
| 2019    | 6.3   | 7.7    | 6.68   | 6           |
| 2020    | 7.5   | 11.3   | 9.4    | 2           |
| 2021    | 1.2   | 4.9    | 3.64   | 5           |
| 2022    | 3.6   | 17.7   | 7.18   | 4           |
| 2023    | 4.5   | 9.8    | 5.375  | 4           |
| 2024    | 8.5   | 9.1    | 8.8    | 2           |
| 2025    | 6.5   | 10.1   | 8.63   | 3           |
| Average | 5.096 | 12.444 | 7.7238 | TOTAL = 170 |

Figure: P-2

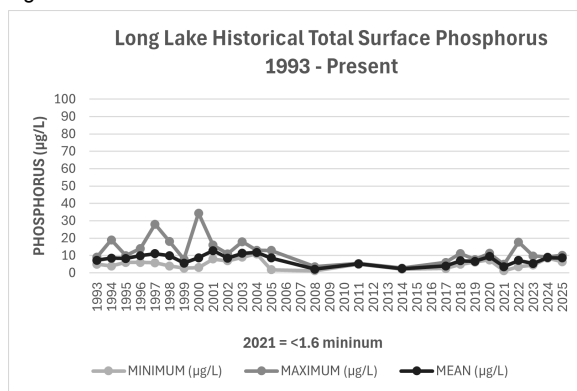
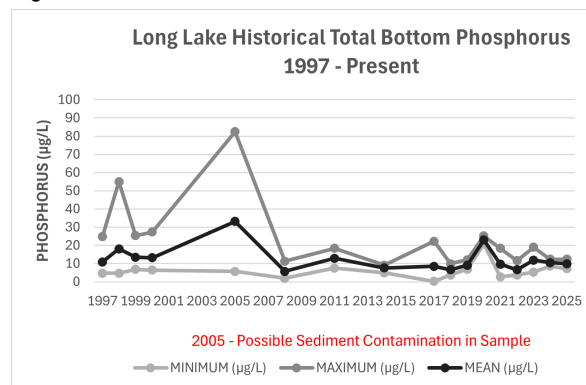


Figure: P-3

| LONG LAKE HISTORICAL TOTAL BOTTOM PHOSPHORUS |                |                |             |         |
|--|----------------|----------------|-------------|---------|
| YEAR   | MINIMUM (µg/L) | MAXIMUM (µg/L) | MEAN (µg/L) | SAMPLES |
| 1997   | 4.7            | 24.9           | 10.87       | 6       |
| 1998   | 4.7            | 55             | 18.1        | 6       |
| 1999   | 6.8            | 25.4           | 13.47       | 6       |
| 2000   | 6.4            | 27.4           | 13.25       | 27      |
| 2001   | #N/A           | #N/A           | #N/A        | #N/A    |
| 2002   | #N/A           | #N/A           | #N/A        | #N/A    |
| 2003   | #N/A           | #N/A           | #N/A        | #N/A    |
| 2004   | #N/A           | #N/A           | #N/A        | #N/A    |
| 2005   | 5.7            | 82.5           | 33.17       | 3       |

|         |             |             |             |            |
|---------|-------------|-------------|-------------|------------|
| 2006    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2007    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2008    | 1.9         | 11.3        | 5.77        | 3          |
| 2009    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2010    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2011    | 7.5         | 18.4        | 12.95       | 2          |
| 2012    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2013    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2014    | 4.9         | 9.1         | 7.63        | 3          |
| 2015    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2016    | #N/A        | #N/A        | #N/A        | #N/A       |
| 2017    | 0.3         | 22.3        | 8.53        | 7          |
| 2018    | 3.7         | 9.9         | 6.62        | 6          |
| 2019    | 6.9         | 12.1        | 9.18        | 6          |
| 2020    | 20.8        | 25.2        | 23          | 2          |
| 2021    | 2.7         | 18.4        | 9.78        | 4          |
| 2022    | 3.7         | 11.6        | 6.63        | 4          |
| 2023    | 5.3         | 19          | 11.925      | 4          |
| 2024    | 8.6         | 12.4        | 10.5        | 2          |
| 2025    | 7.2         | 12.4        | 9.96        | 3          |
| Average | 5.988235294 | 23.37058824 | 12.43147059 | Total = 94 |

Figure: P-4



## Mickey Lake

Figure: P-5

| MICKEY LAKE HISTORICAL TOTAL SURFACE PHOSPHORUS |                |                |             |         |
|---|----------------|----------------|-------------|---------|
| YEAR  | MINIMUM (µg/L) | MAXIMUM (µg/L) | MEAN (µg/L) | SAMPLES |
| 1993  | 9              | 9              | 9           | 1       |
| 1994  | #N/A           | #N/A           | #N/A        | 0       |
| 1995  | 13             | 13             | 13          | 2       |
| 1996  | 8              | 9              | 8.5         | 2       |
| 1997  | 12             | 20             | 16          | 2       |
| 1998  | 11             | 15             | 13.67       | 3       |
| 1999  | #N/A           | #N/A           | #N/A        | 0       |
| 2000  | 12             | 24             | 17          | 6       |
| 2001  | 12             | 16             | 13.83       | 6       |
| 2002  | #N/A           | #N/A           | #N/A        | 0       |
| 2003  | 11             | 20             | 14.5        | 6       |
| 2004  | #N/A           | #N/A           | #N/A        | 0       |
| 2005  | #N/A           | #N/A           | #N/A        | 0       |
| 2006  | #N/A           | #N/A           | #N/A        | 0       |
| 2007  | #N/A           | #N/A           | #N/A        | 0       |
| 2008  | #N/A           | #N/A           | #N/A        | 0       |
| 2009  | #N/A           | #N/A           | #N/A        | 0       |
| 2010  | #N/A           | #N/A           | #N/A        | 0       |
| 2011  | #N/A           | #N/A           | #N/A        | 0       |
| 2012  | #N/A           | #N/A           | #N/A        | 0       |
| 2013  | #N/A           | #N/A           | #N/A        | 0       |
| 2014  | 7              | 8.1            | 7.55        | 2       |
| 2015  | #N/A           | #N/A           | #N/A        | 0       |
| 2016  | #N/A           | #N/A           | #N/A        | 0       |
| 2017  | 7.71           | 8.9            | 8.3         | 5       |
| 2018  | 9.1            | 18.9           | 12.5        | 3       |

|         |             |             |           |            |
|---------|-------------|-------------|-----------|------------|
| 2019    | 6.5         | 10.5        | 8.88      | 4          |
| 2020    | 8.3         | 9.4         | 8.85      | 2          |
| 2021    | 8.3         | 11.1        | 9.43      | 4          |
| 2022    | 6.2         | 10.6        | 8.4       | 2          |
| 2023    | 1.4         | 7           | 3.97      | 3          |
| 2024    | 2.5         | 8.7         | 11.2      | 2          |
| 2025    | 4.2         | 6.5         | 5.33      | 3          |
| Average | 8.289444444 | 12.53888889 | 10.550556 | Total = 58 |

Figure: P-6

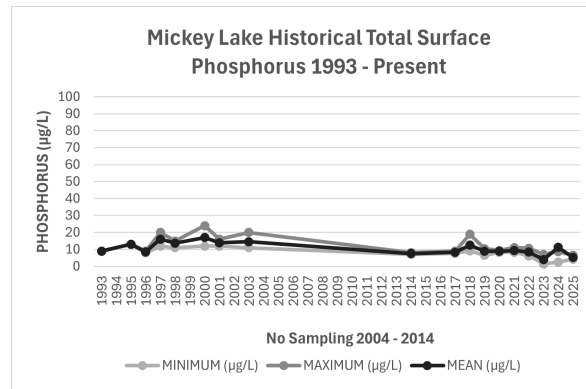
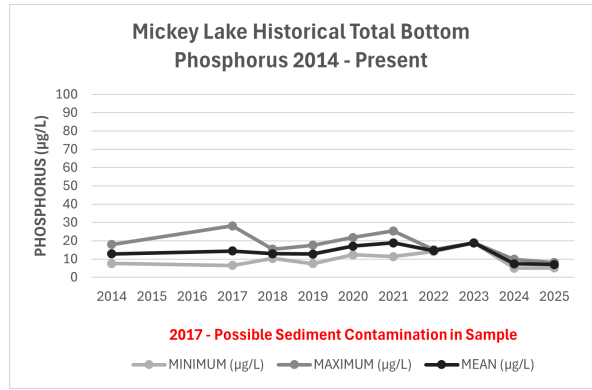


Figure: P-7

| MICKEY LAKE HISTORICAL TOTAL BOTTOM PHOSPHORUS |                |                |             |         |
|--|----------------|----------------|-------------|---------|
| YEAR   | MINIMUM (µg/L) | MAXIMUM (µg/L) | MEAN (µg/L) | SAMPLES |
| 2014   | 7.6            | 18             | 12.8        | 2       |
| 2015   | #N/A           | #N/A           | #N/A        | 0       |
| 2016   | #N/A           | #N/A           | #N/A        | 0       |
| 2017   | 6.5            | 28.1           | 14.43       | 4       |
| 2018   | 10.4           | 15.4           | 12.9        | 2       |
| 2019   | 7.5            | 17.6           | 12.7        | 4       |
| 2020   | 12.3           | 21.8           | 17.05       | 2       |
| 2021   | 11.3           | 25.4           | 18.88       | 4       |
| 2022   | 14.1           | 15.1           | 14.6        | 2       |
| 2023   | 18.9           | 18.9           | 18.9        | 1       |
| 2024   | 5              | 9.9            | 7.45        | 2       |
| 2025   | 5.1            | 8.1            | 7.03        | 3       |

|         |      |       |        |            |
|---------|------|-------|--------|------------|
| Average | 9.87 | 17.83 | 13.674 | Total = 26 |
|---------|------|-------|--------|------------|

Figure: P-8



### Ruth Lake

Figure: P-9

| RUTH LAKE HISTORICAL TOTAL SURFACE PHOSPHORUS |                |                |             |         |
|---|----------------|----------------|-------------|---------|
| YEAR  | MINIMUM (µg/L) | MAXIMUM (µg/L) | MEAN (µg/L) | SAMPLES |
| 2006  | 5.5            | 7.1            | 6.3         | 2       |
| 2007  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2008  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2009  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2010  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2011  | 6.3            | 6.6            | 6.45        | 2       |
| 2012  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2013  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2014  | 11.4           | 14.4           | 13.06       | 5       |
| 2015  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2016  | #N/A           | #N/A           | #N/A        | #N/A    |
| 2017  | 13.7           | 17.8           | 15.75       | 2       |
| 2018  | 15.4           | 26.6           | 21          | 2       |
| 2019  | 14.9           | 25.2           | 20.05       | 2       |
| 2020  | 23.4           | 32.2           | 27.8        | 2       |
| 2021  | 19.6           | 35.4           | 27.5        | 2       |
| 2022  | 4.8            | 20.4           | 12.5        | 2       |
| 2023  | 6.2            | 17.4           | 11.8        | 2       |
| 2024  | 8              | 15.6           | 11.8        | 2       |

| RUTH LAKE HISTORICAL TOTAL SURFACE PHOSPHORUS |             |             |         |            |
|---|-------------|-------------|---------|------------|
| 2025  | 9           | 14.2        | 12.2    | 3          |
| Average                                       | 11.51666667 | 19.40833333 | 15.5175 | Total = 28 |

Figure: P-10

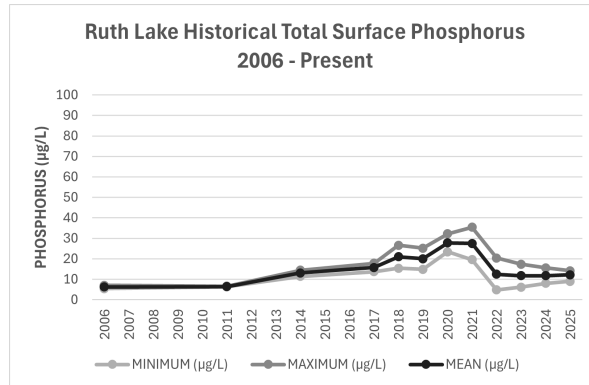
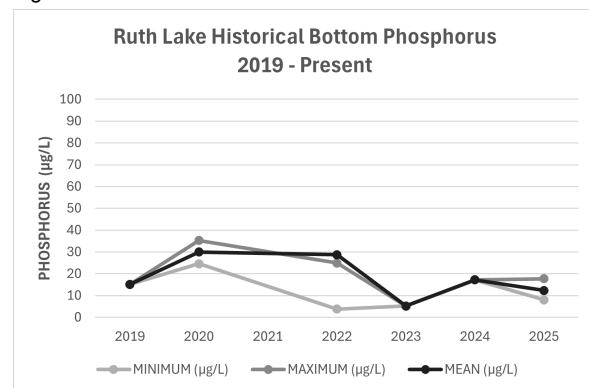


Figure: P-11

| RUTH LAKE HISTORICAL TOTAL BOTTOM PHOSPHORUS |                |                |             |            |
|--|----------------|----------------|-------------|------------|
| YEAR   | MINIMUM (µg/L) | MAXIMUM (µg/L) | MEAN (µg/L) | SAMPLES    |
| 2019   | 15.1           | 15.1           | 15.1        | 1          |
| 2020   | 24.6           | 35.3           | 29.95       | 2          |
| 2021   | #N/A           | #N/A           | #N/A        | #N/A       |
| 2022   | 3.8            | 24.9           | 28.7        | 2          |
| 2023   | 5.2            | 5.2            | 5.2         | 1          |
| 2024   | 17.2           | 17.2           | 17.2        | 1          |
| 2025   | 8              | 17.7           | 12.33       | 3          |
| Average                                      | 12.31666667    | 19.23333333    | 18.08       | Total = 10 |

Figure: P-12



# ACKNOWLEDGEMENTS

Water quality monitoring on Long, Mickey, and Ruth Lakes could not have happened without the generous commitment of time, leadership, and access to these waters. Sincere gratitude is owed to all who have contributed to the ongoing efforts aiming to preserve these waterbodies for future generations. In particular, special recognition is deserved to the Long Lake Association members and board, Long Lake Association Lake Science co-chairs Karen Baker and Len Klein, 2025 boat captains Pete Doren and Rick Dahlstrom, and Ruth Lake residents Janice and Paul Moy. Additionally, annual monitoring efforts are made possible by the continued financial support provided by the Long Lake Association, Long Lake Township, Green Lake Township, and the Oleson Foundation. We have greatly enjoyed the opportunity to monitor these magnificent waters, and took great pride in continuing the success that was established before us.

# REFERENCES CITED

- Abo-Taleb, H. (2019). Importance of plankton to fish community. *Biological research in aquatic science*, 83(1).
- Anderson, Pam, et al. August 2020, Minnesota State and Regional Government Review of Internal Phosphorus Load Control  
<https://www.pca.state.mn.us/sites/default/files/wq-s1-98.pdf>
- Bednarz, R, H. Wandell, P. Steen, P. W. Dimond, J. Latimore, and M. Wilmes. 2015, revised 2019. Cooperative Lakes Monitoring Program Manual. Michigan Department of Environment, Great Lakes, and Energy Report Number MI/DEQ/WRD-15/004.
- Bellinger BJ, Davis SL (2024) Zebra mussel (*Dreissena polymorpha*) population dynamics and associated water quality impacts along their southern United States colonization front. *Aquatic Invasions* 19(4): 389-412.
- Bruce, M. (2025). Localized Risk Assessment Guide for Zebra Mussel Colonization: A Resource to Support People in New Brunswick Carrying Out Aquatic Management and Conservation Efforts. Canadian Rivers Institute, University of New Brunswick
- Chapra, S.C. (1997) *Surface Water-Quality Modeling*. New York: McGraw-Hill
- Cohen, A. N., & Weinstein, A. (2001). Zebra mussel's calcium threshold and implications for its potential distribution in North America. San Francisco Estuary Institute.
- DePauw, K., Cooper, C. (2017) 2017 Water Quality Report and Historical Analysis Long Lake Mickey Lake Ruth Lake [Unpublished report]. Long Lake Association.
- Dodds, W. K., & Whiles, M. R. (2010). Chapter 3-Movement of light, heat, and chemicals in water. Dodds, WK, Whiles, MR, Eds, 45-64.
- EPA, (2025), Indicators: Conductivity  
<https://www.epa.gov/national-aquatic-resource-surveys/indicators-conductivity>
- EPA, (2025), Indicators: Phosphorus  
<https://www.epa.gov/national-aquatic-resource-surveys/indicators-phosphorus>

- EPA, (2011), Nitrogen oxides emissions, Available:  
<http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewInd&lv=list.listByAlpha&r=219685&subtop=34>
- EPA, (2025), pH <https://www.epa.gov/caddis/ph>
- EPA, (2021), Turbidity  
[https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet\\_turbidity.pdf](https://www.epa.gov/system/files/documents/2021-07/parameter-factsheet_turbidity.pdf)
- Fahnenstiel GL, Bridgeman TB, Lang GA, McCormik MJ, Nalepa TF. 1993. Phytoplankton productivity in Saginaw Bay, Lake Huron: Effects of zebra mussel (*Dreissena polymorpha*) colonization. *Journal of Great Lakes Research* 21:465–475.
- Grankvist, J. (2024). Nitrogen as a limiting factor for phytoplankton biomass in nutrient poor lakes (Vol. 1999, No. 2). SLU, Dept. of Environmental Assessment.
- Great Lakes Environmental Center. (2014). Water Quality Monitoring Long Lake Mickey Lake Ruth Lake [unpublished report]. Long Lake Association
- Higgins, S. (2019). Calcium: Why it matters in fresh water—and the risks of low levels. International Institute for Sustainable Development Experimental Lakes Area.
- Hull, A., Preston, M., DePauw, K. (2019). 2019 Water Quality Report and Historical Analysis Long Lake Mickey Lake Ruth Lake [Unpublished report]. Long Lake Association.
- Indicators: Phytoplankton (2025, January 10). US Environmental Protection Agency.  
<https://www.epa.gov/national-aquatic-resource-surveys/indicators-phytoplankton#:~:text=Why%20are%20phytoplankton%20Important?,the%20global%20temperature%20and%20climate>.
- Kaiser, T., Talty, B. (2024). Long LAke Association Water Quality Monitoring Report 2024: Long Lake Watershed [Unpublished report]. Long Lake Association.
- Kirk, J. T. (1994). Light and photosynthesis in aquatic ecosystems. Cambridge university press.
- Maclsaac, H. J. (1996). Potential abiotic and biotic impacts of zebra mussels on the inland waters of North America. *American zoologist*, 36(3), 287-299.

- Makarewicz, J.C., Lewis, T.W., and Bertram, P. 1999. Phytoplankton composition and biomass in the offshore waters of Lake Erie: Pre- and post-Dreissena introduction (1983–1993). *J. Great Lakes Res.* 25:135–148.
- Massachusetts Water Watch Partnership. (2016). University of Massachusetts. <https://www.umass.edu/mwwp/resources/factsheets.html>
- May, G., & Rector, N. (2011). What is reactive N and why should I care?. *Michigan State University Extension*.
- Mellina, E., & Rasmussen, J. B. (1994). Patterns in the distribution and abundance of zebra mussel (*Dreissena polymorpha*) in rivers and lakes in relation to substrate and other physicochemical factors. *Canadian journal of fisheries and aquatic sciences*, 51(5), 1024-1036.
- MiCorps: Michigan Clean Water Corps [@micorpsmi]. (2025, August 5). *Data dive: The deepest secchi dive this season comes from Long Lake, Grand Traverse County*. Instagram. <https://www.instagram.com/micorpsmi/p/DM-RHrCO7e0/>
- Mills, K., Cole, S. (2022) 2022 Water Quality Report and Historical Analysis Long Lake Mickey Lake Ruth Lake [Unpublished report]. Long Lake Association.
- Mills, K., Walters, M. (2021) 2021 Water Quality Report and Historical Analysis Long Lake Mickey Lake Ruth Lake [Unpublished report]. Long Lake Association.
- Nieder, R., & Benbi, D. K. (2022). Reactive nitrogen compounds and their influence on human health: an overview. *Reviews on Environmental Health*, 37(2), 229-246.
- Porter, S., Cottrell, A., DePauw, K. (2018) 2018 Water Quality Report and Historical Analysis Long Lake Mickey Lake Ruth Lake [Unpublished report]. Long Lake Association.
- Potasznik, A., & Szymczyk, S. (2015). Magnesium and calcium concentrations in the surface water and bottom deposits of a river-lake system. *Journal of Elementology*, 20(3).
- Rhodes, J., Cooper, C. (2016). Water Quality Bathymetry and Water Quality Monitoring Fern Lake Page Lake Ruth Lake [Unpublished report]. Long Lake Association.
- Stadelmann, T. H., Brezonik, P. L., & Kloiber, S. (2001). Seasonal patterns of chlorophyll a and Secchi disk transparency in lakes of East-Central Minnesota: Implications for design of ground-and satellite-based monitoring programs. *Lake and Reservoir Management*, 17(4), 299-314.

- Qualls, T. M., Dolan, D. M., Reed, T., Zorn, M. E., & Kennedy, J. (2007). Analysis of the impacts of the zebra mussel, *Dreissena polymorpha*, on nutrients, water clarity, and the chlorophyll-phosphorus relationship in lower Green Bay. *Journal of Great Lakes Research*, 33(3), 617-626.
- Rivera-Ruiz, D., Arumí, J. L., Lillo-Saavedra, M., Esse, C., Arancibia-Ávila, P., Urrutia, R., ... & Ogashawara, I. (2024). Secchi Depth Retrieval in Oligotrophic to Eutrophic Chilean Lakes Using Open Access Satellite-Derived Products. *Remote Sensing*, 16(22), 4327.
- Smits, A. (2025, May 1). *Grand Traverse County Drain Commissioner presentation to Long Lake Association*. Long Lake Association Special Meeting, Gilbert Lodge, Traverse City, MI, United States.  
<https://youtu.be/x-SXJ3zpVmA?si=uXP6LEjPEG03VJu->
- Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G. E., Matson, P. A., Schindler, D. W., ... & Tilman, D. G. (1997). Human alteration of the global nitrogen cycle: sources and consequences. *Ecological applications*, 7(3), 737-750.
- "Water transparency, Secchi disc." US Environmental Protection Agency, 25 Sept. 2025, [cdxapps.epa.gov/oms-substance-registry-services/substance-details/1646140](https://cdxapps.epa.gov/oms-substance-registry-services/substance-details/1646140).
- Wetzel, R. G. (2001). *Limnology: lake and river ecosystems*. gulf professional publishing.
- White, P. J., & Broadley, M. R. (2003). Calcium in plants. *Annals of botany*, 92(4), 487-511.
- Whittier TR, Ringold PL, Herlihy AT, Pierson SM. (2008). A calcium-based invasion risk assessment for zebra and quagga mussels (*Dreissena* spp). *Frontiers in Ecology and the Environment* 6:180-184.
- Zhang, F., Kim, J., Costa Jr, O. S., Liang, S., & Lee, J. (2025). Potential Linkage Between Zebra Mussel Establishment, Cyanobacterial Community Composition, and Microcystin Levels in United States Lakes. *Toxins*, 17(9), 447.