MEMORANDUM
Comfort Lake-Forest Lake Watershed District

Date:	April 15, 2024
To:	CLFLWD Board of Managers
From:	Mike Kinney, District Administrator
Subject:	2023 Water Quality Monitoring Report

District Wide

Background/Discussion

The purpose of this agenda item is to provide the Board with the Final 2023 Water Quality Monitoring Report for acceptance. The draft report was distributed to Managers before the March 28th Board meeting. Emmons & Olivier Resources (EOR) gave a presentation of the 2023 monitoring results at the April 11th Board Meeting. The attached final draft of the report reflects all edits and/or comments received prior to the Aprill 11th Board meeting and/or shared at that meeting.

Recommended Motion

Manager _____________ moves to accept the 2023 Water Quality Monitoring Report from Emmons & Olivier Resources as presented in this memo. Seconded by Manager____________.

Attached

2023 Final Water Quality Monitoring Report

Prepared by: EOR

For the Comfort Lake-Forest Lake Watershed District

2023 Comfort Lake-Forest Lake Water Monitoring Report

Cover Image

Moody Lake, 2023

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGMENTS

Several organizations and individuals were directly involved in many aspects of this project, such as data collection and analysis, as well as technical and administrative assistance.

Comfort Lake-Forest Lake Watershed District (CLFLWD) Board of Managers

Stephen Schmaltz
Christopher Loth
Jackie Anderson
Douglas Toavs
Dave Bakke

Comfort Lake-Forest Lake Watershed District (CLFLWD)

Mike Kinney
Blayne Eineichner
Garrett Miller
Emily Heinz

Emmons and Olivier Resources, Inc.

Cecilio Olivier, PE
Greg Graske, PE
Anne Wilkinson, PhD
Trevor Rundhaug, PE
Mike Majeski
Paul Nation, PE
Bill Yu, EIT
John Sarafolean

Metropolitan Council

Brian Johnson
Sarah Voth
Monica Lorentz
Steven Louwerse

Instrumental Research, inc

Sue Melchoir

Citizen Assisted Monitoring Program (CAMP) Volunteers

Amy Vislisel
Stephen Schmaltz
Doug Joens
Wally Ostlie
Tom Furey
Joel Simonson

The CLFLWD would also like to thank the landowners who allowed access to their property to monitoring locations.

EXECUTIVE SUMMARY

The Comfort Lake-Forest Lake Watershed District (CLFLWD) has a robust water quality monitoring program. Each year, surface water data (both quality and quantity) is collected throughout the District, with the intent of understanding how much progress has been made in meeting water quality goals, and to guide short-term and long-term project implementation. This monitoring program is fundamental to the District's Adaptive Management approach to watershed management.

There were two types of monitoring conducted in the 2023 monitoring season (Lake Monitoring, and Long-term Stream Monitoring). There are numerous applications for surface water monitoring data, such as calibration of hydrologic and hydraulic (H&H) models, estimation of pollutant loads to key water resources, assessment of the effectiveness of projects/practices implemented by the District, and evaluation of long-term trends in water quality.

Climate

2023 is considered an average precipitation year over it's entirety, however 2023 exhibited seasonal extremes. There was above average precipitation in March, April, September and then below average/ drought conditions for much of the monitoring season (May - August). These conditions limited the quantity and frequency of data collected in 2023.

Lake Monitoring

The District's Lake monitoring program is broken down into five primary categories that include sentinel monitoring, routine monitoring, rotational monitoring, limited monitoring, and internal load monitoring. In 2023, 11 lakes were monitored for surface water quality, and lake level data was collected on eight of these waterbodies. Of those lakes, six of them were also monitored for; lake depth profiles, bottom and metalimnion ortho-phosphate (orthoP) to assess internal P loading, and chloride pollution.

Overall, the 2023 average growing season lake water quality was excellent with most of the lakes in the District meeting State standards. In fact, only Elwell Lake did not meet water quality goals for all water quality parameters (WQ). In 2023, ten lakes received A/B+ grades. Only one lake had less than average lake grades. All lakes experienced equivalent or improved WQ in 2023 compared to 2022.

Internal loading monitoring consisted of dissolved oxygen and temperature profiles, along with metalimnion and bottom water orthoP measurements in six lakes with completed or planned alum treatments.

- Shields Lake and Moody Lake alum treatments continue to work. However, Moody Lake's hypolimnion orthoP concentrations have increased since 2022. Moody Lake should continue to be monitored for signs of internal loading.
- Forest Lake – East had extremely high bottom orthoP concentrations by August that seems to be affecting the surface TP concentrations.

- Forest Lake – Middle had extremely high bottom orthoP concentrations by August. However, an alum treatment was conducted in September which reduced the hypolimnetic concentration significantly.
- Comfort Lake and Little Comfort Lake showed signs of increasing bottom orthoP concentrations, but it was not evident that this increase in orthoP concentration impacted surface water quality at this point.

There are two primary seasonal water quality (TP, chlorophyll, and Secchi depth) drivers observed in CLFLWD lakes in 2023. The first is large snow melt discharge in the spring. The following lakes exhibited high concentrations in the spring driven by snow melt discharge: Bone, Comfort, Little Comfort, Moody, and Shields Lakes. Those lakes had peak TP and chlorophyll-a concentrations and decreased Secchi depth in the spring followed by an improvement in water quality. The second driver is fall turnover or late season precipitation, in which water quality deteriorates after the lake turnovers due to destratification in the fall. The lakes driven by fall turnover or late season precipitation are Elwell and Forest Lake East, which start to degrade in water quality at the end of the season.

Chloride Impairment is defined as chloride concentrations above the State Standard of 230 mg/L for four days or 860 mg/L for one measurement. Most of the lakes that were monitored exhibited chloride levels below 230 mg/L. Little Comfort and Comfort Lake had chloride concentrations which exceeded water quality standards (230 mg/L) in the bottom water during the growing season which improved in the fall. Based on the seasonal variability, the chloride conditions seem to be driven by precipitation. Chloride could have been flushed into the lakes during the heavy snow melt. During the dry growing season, elevated chloride concentrations persisted in the bottom of the lake. When precipitation increased in the fall the chloride was flushed from the system. It is important to note that the elevated chloride concentrations were observed in the bottom water and not in habitats within the lake which are most vulnerable to elevated chloride concentrations. Chloride monitoring should continue in these lakes, and EOR recommends that supplementary chloride grab samples be paired with the chloride profiles to confirm the elevated concentrations observed in Comfort Lake and Little Comfort Lake.

Stream Monitoring

The purpose of long-term stream monitoring is to understand the status of District resources, identify changes over time, and define problems at the watershed or sub watershed level. Six long-term monitoring sites are monitored each year to track large-scale pollutant load reduction trends within each of the four Lake Management Districts (LMDs): Comfort LMD, Little Comfort LMD, Forest LMD, and Bone LMD. There are three lake outlet sites with long-term records in CLFLWD: Bone Lake (BL2), Forest Lake (FL1), and Comfort Lake (CL1). There are three lake inlet sites with long-term records in CLFLWD: Bone Lake North Inlet (BL2), Comfort Lake Inlet (CL2), and Little Comfort Lake Inlet at Itasca Avenue (LC1).

Stream water quality is good at CL2 and BL1, as observed by stream chemistry concentrations that are below state standards. There were seasonal exceedances of total phosphorus and total suspended solids stream standards in the fall at CL1 and FL1. BL2 and LC1 sites experienced elevated total phosphorus and total suspended solids exceeding state standards during most of the season. The only instance of flow-weighted mean concentration (FWMC) central region reference values was LC1 which exceeds FWMC for total phosphorus. Notably nitrogen levels are very low, and no chloride readings exceeded state standards District-wide.

Recommendations

The following are recommendations for future monitoring based on 2023 monitoring results.

Lake Monitoring

1. Continue monitoring the major lakes of the District using the Met Council CAMP Program. Rotate monitoring of the smaller lakes of the district as per the 10-year monitoring plan.
2. Collect hypolimnion and metalimnion water samples on Comfort, Forest East and Middle, and Little Comfort and only hypolimnion samples on Moody, and Shields Lakes to further evaluate internal P loading.
3. Collect follow up sediment cores for Forest Lake alum treatment to evaluate the second dose.
4. Collect additional hypolimnion water samples on Comfort Lake and Littler Comfort Lake to evaluate chloride levels in these systems.

Stream Monitoring

1. Evaluate the extent of tailwater impacts to water elevations by looking at stage data in Little Comfort Lake and Comfort Lake, and comparing water elevations to what is being seen at the LC1 monitoring site. These lake elevations should be measured on the same day to make it easier to compare water levels.
2. Modeling - To better understand the impact of LC1 on the Little Comfort Lake system, it is recommended that this data be evaluated using the District's H&H model. This would allow for a more accurate and robust understanding of how such damming activities influence an accurate calculation of Little Comfort Lake's pollutant loads.
3. Refine telemetry of select stream sites to make data collection more efficient.

1. INTRODUCTION

The Comfort Lake-Forest Lake Watershed District (CLFLWD) water quality monitoring program provides the District with an understanding how much progress has been made in meeting water quality goals, and guides short-term and long-term projects' implementation. This report summarizes the lake monitoring and long-term stream monitoring data that was collected in 2023. See Appendix F or an explanation of each parameter collected. It also provides an update on lake and stream water quality trends, lake progress towards meeting State's standards and District's water quality goals, and overall observations of the District's surface water system. This report also includes one-page lake factsheets (Appendix A), highlighting lake characteristics, current conditions, and long-term trends.

1.1. Data collected in 2023

There were two different types of monitoring conducted in the 2023 monitoring season (Lake Monitoring, and Long-term Stream Monitoring), which are described in Table 1. Included in Table 2 is the type of data that was collected and its purpose. Figure 1 shows the monitoring locations by monitoring type.

Table 1. Monitoring types for 2023

Monitoring Type	Types of data collected	Purpose
Lake Monitoring (shown in purple in Figure 1)	• Lake water elevations • Surface water quality • Dissolved Oxygen concentrations and Temperature profiles • Bottom water phosphorus concentration • Chloride	To assess progress in meeting State's standards and District's goals in lakes across the District shown in Figure 1.
Long-term creek & stream Monitoring (shown in green in Figure 1, also called Legacy sites).	• Creek/stream and culverts' inlets/outlets survey elevations • Continuous water stage (water levels in the creek/stream) • Rating curves to estimate water flow rates at different water levels) • Water quality samples to determine pollutants' concentrations and loads. • Field observations about site conditions and other factors potentially affecting monitoring results.	To understand the annual loads and flows discharged from the lake management districts (LMDs) for the purpose of tracking large-scale pollutant reductions within the District.

1.2. Data collection purpose

There are numerous applications for surface water monitoring data, such as calibration of hydrologic and hydraulic (H&H) models, estimation of pollutant loads to key water resources, assessment of the effectiveness of projects/practices implemented by the District, and evaluation of long-term trends in water quality (Table 2). The type, amount, and precision of data needed for each of these efforts may vary based on how it will be used to inform assessment and decision making. Therefore, to use District's resources efficiently, it is important to determine beforehand what monitoring data is needed and how the data will be used.

Table 2. Uses of monitoring data

Decision tool	Description/Use
H&H Modeling	Characterizing rate and volume of runoff in a drainage to determine where flooding issues may occur across a landscape.
Pollutant loading	Characterizing pollutants discharged from a drainage area during a specific time interval to determine the impact of a particular drainage area on downstream water resources.
Project effectiveness	Measuring flows and concentrations of pollutants at the inlet and outlet of built practices to assess the effectiveness of projects in achieving the water quality/quantity benefits for which they were designed.
Water Quality Trends	Evaluating progress in achieving State standards and District's water quality goals.

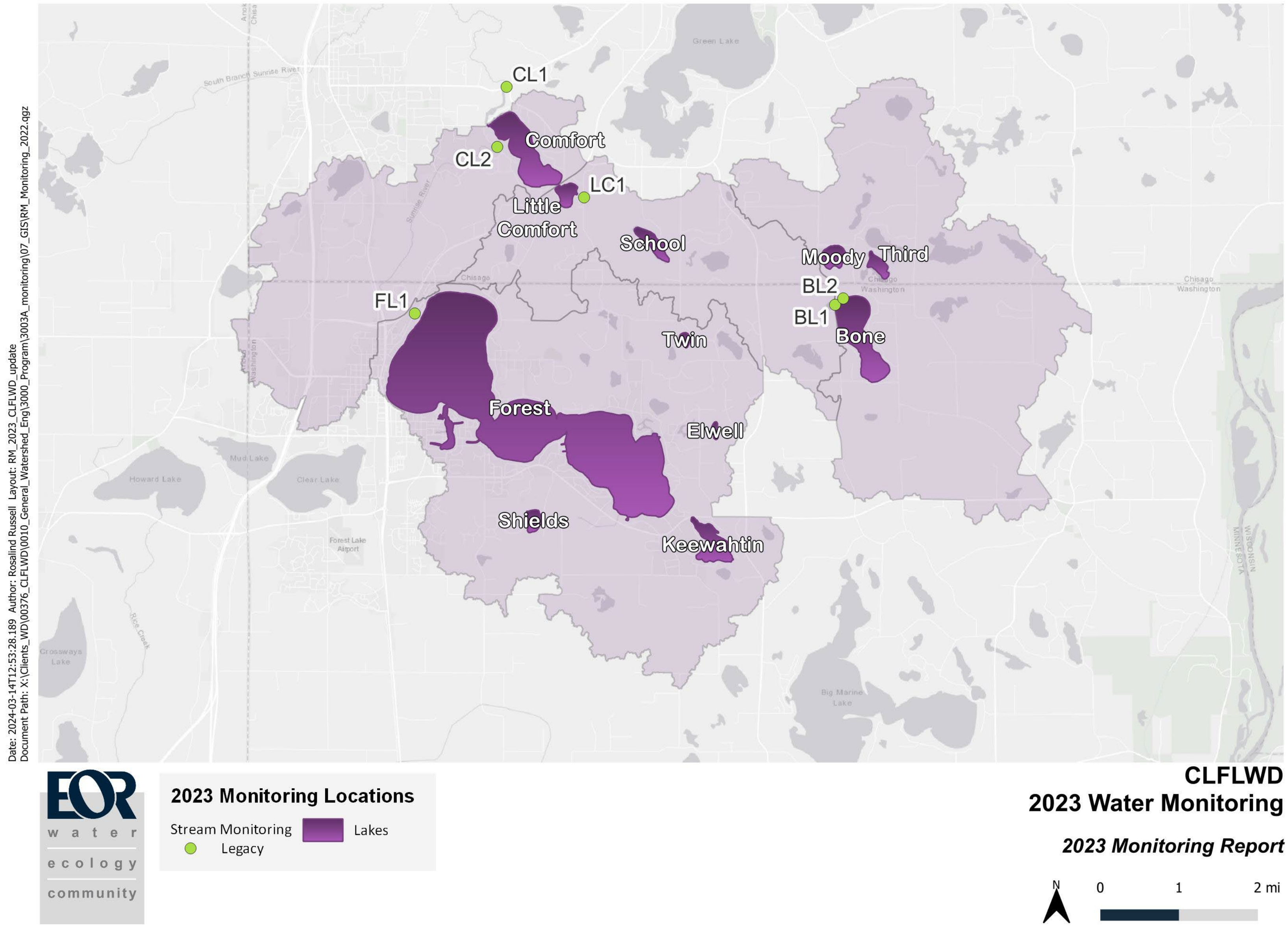


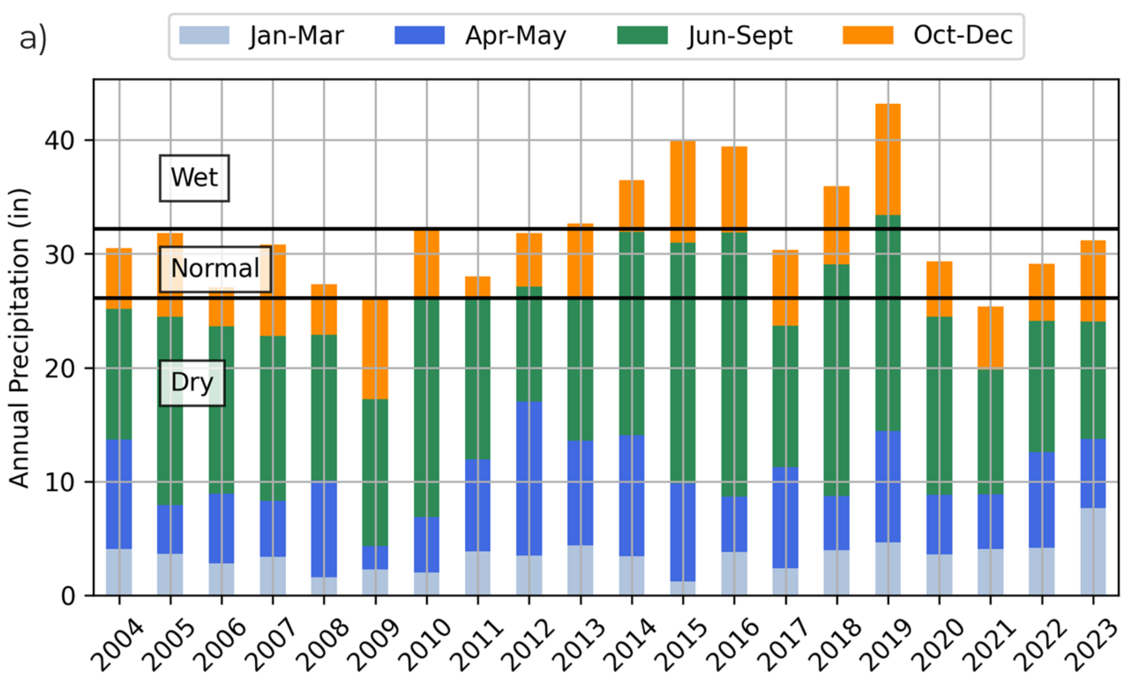
Figure 1. 2023 Water monitoring locations and monitoring types in Comfort Lake Forest Lake Watershed District

1.3. 2023 climate conditions

Climate conditions are important to fully understand and put monitoring results and analysis in perspective. For instance, wet years may show low pollutant concentrations in the runoff, but because it is a wet year with higher runoff volumes, total pollutant loads may be higher than average. On the flip side, dry years may show high pollutant concentrations, but lower runoff volumes may result in lower total pollutant loads. Statewide climate trends are discussed in Appendix E.

1.3.1. Monthly precipitation and temperatures

Annual precipitation in the last 20 years is summarized in Figure 2a. Monthly precipitation and temperature in 2023 are summarized in Figure 2b and compared to the 1991-2020 normal monthly precipitation and temperature based on precipitation data retrieved from the Minnesota State Climatology Office for Forest Lake, MN (at T32N, R21W, S13). In 2023, the spring and fall months (March, April, September, and October) all exhibited precipitation levels higher than the 1991-2020 precipitation averages. The summer months (May through August) were all dryer than normal, contributing to drought-like conditions within the tributaries that were being monitored. March and April were colder than normal, while May through October were near or exceeding normal temperatures. The peak flow was observed in early spring for all sites which then decreased to low flow conditions for the rest of the season.



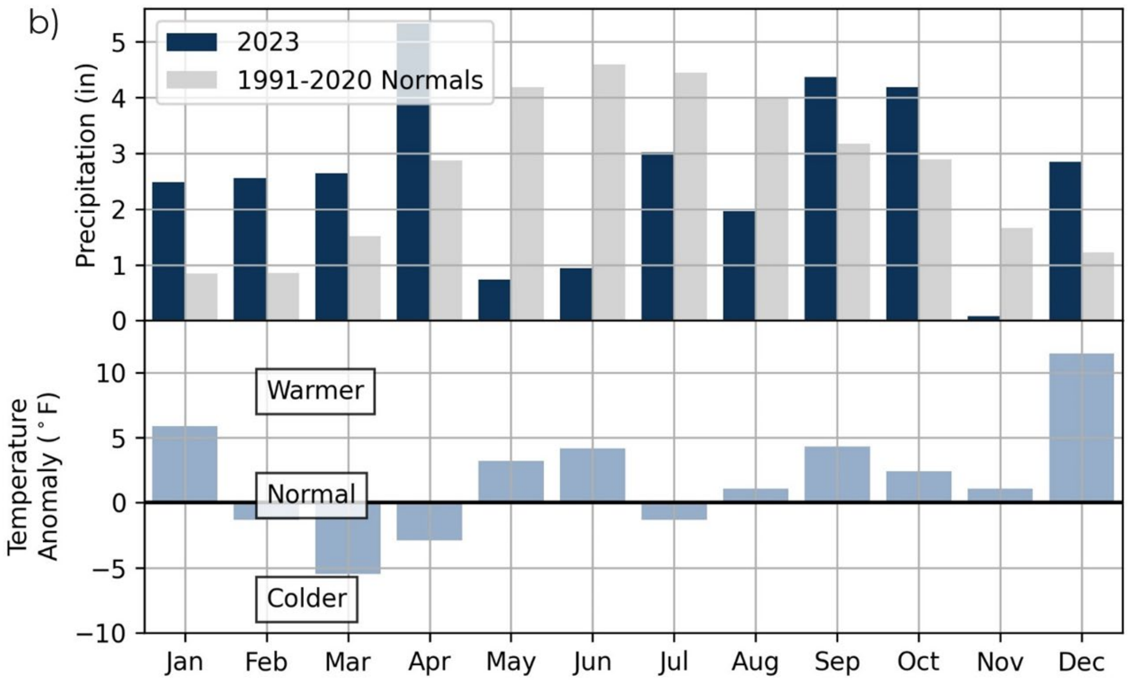


Figure 2. a) Annual precipitation summaries for 2004-2023 for Forest Lake at Township 32N, Range 21W, Section 13

b)2023 monthly precipitation and temperature for Forest Lake at Township 32N, Range 21W, Section 13

2. LAKE MONITORING

The District's Lake monitoring program is broken down into five primary categories that include sentinel monitoring, routine monitoring, rotational monitoring, limited monitoring, and internal load monitoring. A description of these is shown in Table 3 below.

Table 3. 2022-2031 Lake monitoring recommendations

Monitoring Type	Description	Applicable District lakes
Sentinel monitoring	Surface water monitoring (total phosphorus, chlorophyl-a, Secchi Depth) 14 times a year, every year. Using the CAMP protocol and volunteers in some instances.	Moody, Bone, Forest, and Shields, Little Comfort, and Comfort
Routine monitoring	Surface water monitoring seven times a year, for two consecutive years every five years	School, Keewahtin,
Rotational monitoring	Surface water monitoring seven times a year, for two consecutive years every ten years	Lendt, Second, Third, Twin, Elwell, Heims Birch, and Neilson
Limited monitoring	No specified parameters or frequency of collection	Cranberry (limited access), Fourth (wetland) Clear, First, and Sea
Internal loading monitoring	Dissolved oxygen and temperature profiles, and fourteen bottom water phosphorus measurements for two consecutive years every five years	Lakes with completed or planned alum treatments

2.1. Lake Monitoring Summary

In 2023, eleven lakes were monitored for surface water quality, and lake level data was collected on eight of these waterbodies. Of those lakes, six of them were also monitored for lake depth profiles, bottom and metalimnion ortho-phosphate (orthoP) to assess internal P loading, and chloride pollution. The lakes and the respective parameters that were collected for each are shown in Table 4.

Table 4. Lakes monitored in the 2023 monitoring season and the respective parameters collected.

Lake	DNR ID	Monitoring type	Surface WQ (CAMP)	Lake Levels	Dissolved Oxygen and Temp Profiles	Bottom and Metalimnion orthoP	Chloride
Bone	82005400	Sentinel	X	X			
Comfort	13005300	Sentinel, internal loading	X	X	X	X	X
Forest (West)	82015900	Sentinel	X	X			
Forest (Middle)	82015900	Sentinel, internal loading	X	X	X	X	X

Lake	DNR ID	Monitoring type	Surface WQ (CAMP)	Lake Levels	Dissolved Oxygen and Temp Profiles	Bottom and Metalimnion orthoP	Chloride
Forest (East)	82015900	Sentinel, internal loading	X	X	X	X	X
Moody	13002300	Sentinel, internal loading	X	X	X	X	X
Little Comfort	13005400	Sentinel, internal loading	X	X	X	X	X
Shields	82016200	Sentinel, internal loading	X	X	X	X	X
Keewahtin	82008000	Routine	X	X			
School		Routine	X	X			
Third Lake	13002400	Rotational	X				
Twin Lake	82015700	Rotational	X				
Elwell	82007900	Rotational	X				

2.1.1. Water Quality Methods

Lake surface water quality is sampled for total phosphorus (TP), chlorophyll-a and Secchi depth transparency using the MN Metropolitan Council CAMP protocol. TP represents the amount of nutrients in a lake that fuel algae growth. Phosphorus sources include soil erosion, stormwater runoff, leaf litter and other organic materials, manure runoff and wastewater (including septic tanks). Chlorophyll-a represents the number of algae in the surface water. Algae blooms reduce water clarity (as measured by Secchi depth) and can cause unpleasant odors. They can also use dissolved oxygen in the lake critical for fish and reduced aquatic plant growth that supports important habitat for fish and aquatic invertebrates. Secchi transparency depth is a measure of water clarity and is measured by lowering a Secchi disk in the lake. The depth at which the Secchi disk is still visible is the Secchi depth. More algae in the water results in more turbidity or cloudiness of the water and lower (shallower) Secchi depth; less algae in the water results in clearer water and higher (deeper) Secchi depth as shown.

Lake grades were assigned to each lake in 2023 and for the average of the last five years (2019-2023) for total phosphorus, chlorophyll-a, Secchi depth, and overall lake water quality (the average of the TP, Chlorophyll-a and Secchi grades). Lake grades followed the Met Council water quality grading system developed in 1989 (Table 5).

The Met Council's Lake Grading System is as follows:

- A = No impairment
- B = Some impairment
- C = Impaired
- D = Severely impaired
- F = Total impairment

Table 5. Metropolitan Council Lake Water Quality Grading System

Grade	Total phosphorus (TP), µg/L	Chlorophyll-a (Chl.-a), µg/L	Secchi depth (ft)
A	<23	<10	>9.8
B	23-32	10-20	7.2-9.8
C	32-68	20-48	3.9-7.2
D	68-152	48-77	2.3-3.9
F	>152	>77	<2.3

2.2. Results

To view the full results of the lake monitoring effort by lake for 2023, see Appendix A. Please note, chloride data and the additional hypolimnion and metalimnion data collected for Little Comfort Lake, Comfort Lake, Shields Lake, Forrest Lake East, Forest Lake Middle, and Moody Lake are included in Appendix B and Appendix C.

2.2.1. Surface Water Quality

State Water Quality Standards-10 Year Average

Table 6 shows the standards and the level of compliance of all District's lakes. Lakes meeting all State Lake Water Quality Standards over a 10-year average are: Keewahtin Lake, Comfort Lake, and Third Lake. Lakes meeting two of the three State Lake Water Quality Standards over a 10-year average are: Bone Lake, Forest Lake, and School Lake. Finally, Little Comfort Lake is meeting one of the three State Lake Water Quality Standards over a 10-year average. Moody Lake is the only lake not meeting any of the lake water quality standards. However, Moody lake water quality has significantly improved due to recent improvements within the lake and the watershed. In fact, the lake grade for 2023 is a B+ (see Table 8). Note Twin and Elwell lakes do not have enough data to compute 10-year averages.

Table 6. Progress towards state water quality standards

Lakes (In order of increasing TP)	Total Phosphorus (µg/L)			Chlorophyll-a (µg/L)			Secchi Depth (ft)		
	2014 - 2023 Average	Years of Data (N)	Standard	2014 - 2023 Average	Years of Data (N)	Standard	2014 - 2023 Average	Years of Data (N)	Standard
GENERAL LAKES									
Keewahtin	**14.3**	10	**40 ✓**	**2.7**	10	**14 ✓**	**4.4**	10	**4.6 ✓**
Comfort *	**29.7**	10	**40 ✓**	**13.5**	10	**14 ✓**	**5.9**	10	**4.6 ✓**
Bone *	**32.2**	10	**40 ✓**	**17.0**	10	**14**	**5.1**	10	**4.6 ✓**
Forest	**32.4**	10	**40 ✓**	**15.2**	10	**14**	**6.2**	10	**4.6 ✓**
Little Comfort *	**45.7**	10	**40**	**18.7**	10	**14**	**5.5**	10	**4.6 ✓**
Moody *	**78.2**	10	**40**	**42.2**	10	**14**	**3.1**	10	**4.6**
SHALLOW LAKES									
Third	**19.5**	4	**60 ✓**	**4.4**	4	**20 ✓**	**4.7**	9	**3.3 ✓**
Twin	**26.9**	2	n/a	**6.0**	2	n/a	**4.1**	2	n/a
Elwell	**56.2**	3	n/a	**32.7**	3	n/a	**2.1**	3	n/a
School *	**42.8**	6	**60 ✓**	**24.9**	6	**20**	**4.4**	6	**3.3 ✓**
Shields *	**146.1**	10	**60**	**39.1**	10	**20**	**4.0**	10	**3.3 ✓**

N = number of years data has been collected within the 2014-2023 period.

***** = Impaired, included in the 2010 Six Lakes TMDL Study

****** = Impaired, included in the 2014 Sunrise River Watershed TMDL Study but no data collected within the last 10-years

Lake names in bold = Lakes that have been assigned goals different from State Water Quality Standards

✓ = meets Standard; ## = does not meet Standard; n/a = insufficient data

Total Phosphorus District Goals – Five Year Average

Lakes meeting the 2040 District TP goals over a 5-year average include: Keewahtin Lake, Third Lake, Bone Lake, Forest Lake-East, Forest Lake-West basin, Comfort Lake, Moody Lake, Twin Lake, Shields Lake, School Lake, and Elwell Lake (Table 7). Lakes not meeting 2040 District TP goals are Forest Lake-Middle and Little Comfort Lake (Table 7).

Secchi disk District goals– Five Year Average

Lakes meeting the 2040 District Secchi Depth goals (last column in Table 7) over a 5-year average include: Keewahtin Lake, Third Lake, Twin Lake, Forest Lake – East, School Lake, Moody Lake and Shields Lake. Lakes not meeting 2040 District Secchi Depth goals include Elwell Lake, Little Comfort Lake, Forest Lake-Middle, Comfort Lake, Forest Lake-West, and Bone Lake (see Table 7).

Table 7. Secchi Depth 5-Year Average and progress to pre-development conditions (2040 goals) in all District Lakes

Lake	Total Phosphorus			Secchi Depth		
	Existing 5-year Average TP (2019-2023) (ug/L)	2040 District Goal	Year	Existing 5-year Average Secchi Depth (2019-2023) (ft)	2040 District Goal	Year
Bone	25.1	30✓	5	5.8	7	5
Comfort	24.7	30✓	5	6.8	7	5
Elwell	56.2	60✓	3	2.1	3.3	3
Forest (M)	36.7	30	5	6.7	7	5
Forest Lake (E)	29.6	30✓	5	7.6	7✓	5
Forest Lake (W)	23.5	30✓	5	6.9	7	5
Forest Lake	29.9	30✓	5	7	7✓	5
Keewahtin Lake	14	20✓	5	12.7	10✓	5
Little Comfort	36.7	30	5	6.7	7✓	5
Moody	39.8	40✓	5	4.7	4.6✓	5
School	35.7	60✓	4	5.8	3.3✓	4
Shields	52.9	60✓	5	5.6	4.3✓	5
Third	16.9	60✓	3	5	3.3✓	4
Twin	26.9	60✓	2	4.1	3.3✓	2

Lake Grades

Most of the lakes monitored in 2023 in the District received A/B grades using Met Council's Lake Grading System (Table 8). Keewahtin Lake had the best water quality with A grades across all the categories. In 2023, Comfort, Forest, Little Comfort, Moody, School, Shields, Third and Twin Lakes received A/B+ grades. Elwell Lake had the worst water quality with a D grade. Elwell Lake grade is based on three years of data. Fourth Lake grade is based only on data collected in 2019.

Table 8. CLFLWD Lake Water Quality Grades for 2023 and most recent 5-year average (2019-2023)

Lake	DNR ID	Acres	TP		Chl.-a		Secchi		Overall	
			2023	5-yr Avg	2023	5-yr Avg	2023	5-yr Avg	2023	5-yr Avg
Bone	82-0054-00	221	A	B	B	B	C	C	B	B-
Comfort	13-0053-00	218	A	B	A	A	B	C	A-	B
Elwell	82-0079-00	16	D	C	F	C	F	F	F+	D+
Forest (West)	82-0156-00	1,086	B	B	B	A	C	C	B-	B
Forest (Middle)	82-0156-00	364	A	C	A	B	B	C	A-	C+
Forest (East)	82-0156-00	790	A	B	A	B	B	B	A-	B
Forest (All Basins)	*82-0156-00*	*2,240*	A	B	A	B	B	C	A-	B-
Keewahtin	82-0080-00	75	A	A	A	A	A	A	A	A
Little Comfort	13-0054-00	36	A	C	A	B	B	C	A-	C+
Moody	13-0023-00	45	A	C	A	C	C	C	B+	C
School	13-0057-00	47	A	C	B	B	B	C	B+	C+
Shields	82-0162-00	30	A	C	A	C	C	C	B+	C
Third Lake	13-0024-00	42	A	A	A	A	C	C	B+	B+
Twin Lake	82-0157-00	19	B	B	A	A	C	C	B	B

A: No impairment blue, **B:** Some impairment green, **C:** Is impaired yellow, **D:** Severely impaired orange, **F:** Total impairment red

Lake Water Quality Trends

Long-term lake water quality trends were calculated using Kendall's Tau statistical analysis which essentially reports how consistently a water quality parameter increases or decreases over time. Kendall's Tau for short-term period (since 2013) and long-term period (for the entire monitoring period, beginning with the earliest available year) were determined for each lake. Monitoring data available from the MPCA EDA Surface Water Database was used in the analysis. Many lakes had large gaps in their monitoring records and therefore, only short-term trends could be determined, as noted in Table 9 below.

- **No trend** indicates the water quality parameter is not consistently increasing or decreasing from year to year over the time-period AND that this is a statistically significant "no change".
- **Improving** or **declining** trends mean the water quality parameter is consistently increasing or decreasing from year to year over the time-period but NOT in a statistically significant way.
- **Significantly improving** or **significantly declining** means that the water quality parameter is consistently increasing or decreasing from year to year over the time-period AND does that in a statistically significant way. The percent change in the parameter over the entire time-period is reported for statistically significant trends.

- **NA** means that there was insufficient data to determine a statistical trend. At least 4 samples must be collected per year to be included in the trend analysis, and at least 75% of all years in the total period of record have at least 4 samples collected per year. Ten lakes do not have enough monitoring data to determine long-term trends in water quality.

Lake water quality trends are shown in Table 9 for those lakes with sufficient data to calculate trends. Overall, most District lakes have improving trends in lake water quality. Forest Lake-East is exhibiting declining total phosphorus water quality trends, however an alum treatment on Forest Lake-Middle was applied in Fall 2023 to improve TP conditions in Forest Lake-Middle and East. Lake Keewahtin is experiencing a declining trend in Secchi depth however it is significantly deeper (12 ft) than the water quality standard (3.3 ft) and is not close to an impairment. The decrease trend is driven by shallow Secchi depths recorded in 2020 and 2012.

Table 9. Lake Water Quality Trends

Lake	Total Phosphorus Trend	Chlorophyll-a Trend	Secchi Disk Trend
Bone	**Significantly Improving since 2013**	Improving since 2001	Improving since 1984 **Significantly Improving since 2013**
Comfort	Improving since 1994	Improving since 1994 **Significantly Improving since 2014**	Improving since 1987 **Significantly Improving since 2014**
Forest – West	**Significantly Improving since 1984** **Significantly Improving since 2013**	**Significantly Improving since 2001** **Significantly Improving since 2013**	Improving since 1984 **Significantly Improving since 2013**
Forest – Middle	Improving since 2013	Improving since 2013	Improving since 2013
Forest – East	Declining since 2013	Improving since 2013	Improving since 2013
Keewahtin	Improving since 2013	Improving since 2013	Improving since 1974 Declining since 2013
Little Comfort	**Significantly Improving Since 2013**	Improving since 2013	Improving since 2013
Moody	**Significantly Improving since 2005** **Significantly Improving since 2013**	Improving since 2005	Improving since 2005
Shields	Improving since 1993 **Significantly Improving since 2013**	Improving since 2001	Improving since 1993

Short-term trends are noted for the most-recent 10-years (since 2013)

Long-term trends are noted for the period of record for each lake, with the earliest year noted.

2.2.2. Internal Loading

Internal loading monitoring of dissolved oxygen, temperature profiles, and metalimnion and bottom water phosphorus measurements took place in six lakes with completed or planned alum treatments. See internal Appendix A for temperature and dissolved oxygen profiles and Appendix B for metalimnion and bottom orthoP concentrations. Some important general observations regarding internal loading include:

- Seasonal increases in orthophosphate can be measured in the hypolimnion (bottom water) while the water column is stratified.

- The lake's physical characteristics and morphology are also important factors for internal loading: including a) mixing conditions and b) diffusion across the thermocline.

Internal loading conclusions (summarized in Table 10):

1. Comfort Lake and Little Comfort Lake showed signs of increasing bottom P concentrations, but this increased P concentration was not enough to impact surface water quality in either lake in 2023.
2. Forest Lake – Middle had extremely high bottom P concentrations by August. However, an alum treatment was conducted in September which reduced the hypolimnetic concentration significantly.
    a. Collect follow-up sediment cores in Forest Lake-Middle in 2024 to determine the effectiveness of the 2023 alum treatment.
3. Forest Lake – East had extremely high bottom P concentrations by August that seems to be affecting the surface TP concentrations.
    a. In late September, there was a turnover event (driven by fall storms) which mixed high orthophosphate concentrations from the bottom of the lake to the surface and lead to a peak in surface TP and a reduction of bottom orthoP.
4. Shields Lake and Moody Lake alum treatments continue to work.
    a. However, Moody Lake's hypolimnion orthophosphate concentrations have increased from 60 µg/L to 200 µg/L since last year. This is still only a fraction of the pre-treatment concentrations which was a max TP of~2000 µg/L. Note that in the hypolimnion the majority of Total P is orthoP.
    b. Moody lake should continue to be monitored for signs of internal loading to see if the trend in increases is continuing and by how much. The concern is that the longevity of the alum treatment may have been shortened due to high snowmelt runoff bringing in excess sediments.
5. Additional metalimnion (lake's middle layer) samples collected in the lakes confirmed bottom P concentrations had little impact on surface water quality in 2023.
    a. On Little Comfort Lake the metalimnion concentrations increased on 8/9/2023. However, this event did not affect surface TP concentrations on Little Comfort Lake. See Appendix B for data.

Table 10. Internal Loading Results

Lake	Alum Treatment	Seasonal Increase**	Mixing Influence***	Diffusion Influence****
Comfort Lake	Potential	Yes	No	No
Forest Lake - Middle	2023	Yes	Yes	No
Forest Lake -East	Potential	Yes	Yes	Yes
Little Comfort Lake	Potential (but not currently recommended)	Yes	No	Yes
Moody Lake	2018/2019	Yes	No	No

Lake	Alum Treatment	Seasonal Increase**	Mixing Influence***	Diffusion Influence****
Shields Lake	2019/2020	No	No	No

** Seasonal increase is another risk factor, but is also a natural part of stratified lakes

*** Mixing Influence is identified as a noticeable increase in surface TP after fall turnover or another mixing event

**** Diffusion Influence is identified as any correlations in the bottom and metalimnion orthoP at the time the lake was stratified

2.2.3. Seasonal Water Quality Trends

Seasonal water quality trend data is available in Appendix A. There are two primary seasonal drivers observed in CLFLWD lakes in 2023. The first is large snow melt discharge in the spring. The following lakes exhibited high concentrations in the Spring driven by snow melt discharge; Bone, Comfort, Little Comfort, Moody, and Shields Lakes. Those lakes had peak TP and chlorophyll-a concentrations and decreased Secchi depth in the spring followed by an improvement in water quality. The second driver is fall turnover or later season precipitation, in which water quality deteriorates after the lake turnovers due to destratification in the fall. The lakes driven by fall turnover or late season precipitation are Elwell and Forest Lake East, which start to degrade in water quality at the end of the monitoring season.

2.2.4. 2023 Lake Monitoring Results

Appendix A contains the individual monitoring result pages for each lake monitored in 2023. These figures compare the 2023 surface water quality parameters to past monitoring years. In general, the historic 5-year average water quality parameters improved from the 10-year average on all lakes, except for Elwell and Forest Lake-Middle (Forest Lake – Middle received an alum treatment in the Fall of 2023). Overall, 2023 lake water quality was similar or better than in 2022, and the majority of the District lakes are meeting state water quality standards.

2.2.5. Chloride

The 2023 chloride profiles are shown in Figure 9 through Figure 13 of Appendix C. Chloride Impairment is defined as chloride concentrations above the State Standard of 230 mg/L for four days or 860 mg/L for one measurement. Most of the lakes that were monitored exhibited chloride levels below 230 mg/L, except Comfort Lake and Little Comfort Lake. Chloride concentrations exceeding the chronic standard were observed in the bottom waters of Comfort Lake from mid-August to early October. Chloride concentrations exceeding the chronic standard were observed in Little Comfort Lake from early June to late September. The chloride concentrations in both lakes decreased in the fall to meet state standards. Elevated chloride concentrations could be due to high snow melt input in the early spring followed by low flow conditions which increased the residence time of both lakes. When precipitation increased in the fall the chloride seems to have been flushed from the system. Other sources of chloride to lakes can be septic systems which collect discharge from water softeners and runoff from agricultural fertilizers. It is important to note that the elevated chloride concentrations were observed in the bottom water and not in habitats in the lake which are most vulnerable to elevated chloride concentrations. Alternatively, there is a possibility that there was a malfunction of the probe which interfered with the chloride sensor and gave falsely elevated concentrations.

Chloride monitoring should continue in the lakes because it is an emerging pollutant of concern in the Metro Area (MPCA 2016). EOR recommends that supplementary chloride grab samples be paired with the chloride profiles to confirm the elevated concentrations observed in Comfort Lake and Little Comfort Lake. Depending on the chloride concentrations observed in 2024, a future diagnostic study could be recommended to investigate source tracking in ditches, septic systems, agricultural inflows, highway 8, etc.

2.3. Conclusions and Recommendations

Table 11 are conclusions specific to each of the District's lakes monitored in 2023. These conclusions are based on 5-year averages meeting state and District standard, comparison between the 5 and 10-year WQ results, comparison of 2022 and 2023 growing season averages, and the status of 2023 WQ meeting state standards. These data are all outlined in Appendix A.

Table 11: Lake Monitoring Conclusion Summary

Lake	5-year WQ Average Meeting State Standards	5-year WQ Average Meeting District Standards	5-year WQ Average vs 10-year Average**	2023 WQ vs 2022 WQ**	2023 WQ Meeting State Standards
Bone	✓	✓	+	+	✓
Comfort	✓	✓	+	+	✓
Elwell	**n/a**	**n/a**	**n/a**	-	x
Forest Lake – East*	*TP and Secchi*	✓	+	+	✓
Forest Lake – Middle	x	x	=	+	✓
Forest Lake – West	✓	✓	+	-	✓
Little Comfort	✓	✓	+	=	✓
Keewahtin	✓	✓	+	=	✓
Moody	✓	✓	+	+	✓
School	✓	✓	+	+	✓
Shields	*TP and Secchi*	✓	+	=	✓
Third	✓	✓	+	=	✓
Twin	**n/a**	**n/a**	**n/a**	**n/a**	✓

✓ = meets Standard; **x** = does not meet Standard; **n/a** = insufficient data

*If not all three WQ are meeting standards or goals, those meeting the standard are specified in the table.

** + indicates an improvement, - indicates a decline, = indicates similar results

The following future monitoring is recommended based on the 2023 data:

1. Continued hypolimnion orthoP monitoring is recommended to continue, specifically:
   - Forest Lake – Middle and Forest Lake – East
     - There was high internal loading in both lakes.
     - Forest Lake – Middle received an alum treatment in Fall of 2023. Follow-up sediment coring and hypolimnetic orthoP is necessary to evaluate the effectiveness of the alum treatment.
   - Moody Lake
     - The alum treatment is still effective in reducing internal loading in the lake compared to pre-treatment conditions; however hypolimnetic orthoP concentrations have increased compared to previous years. Additional years of orthoP data will elucidate Moody Lake's response to the alum treatment and the expected longevity.
     - Moody Lake Capstone BMPs will likely have a positive impact on long-term water quality.

- Comfort Lake and Little Comfort Lake showed signs of increasing bottom orthoP concentrations and should continue to be monitored for internal loading parameters to inform potential future internal loading management.

2. Supplementary chloride grab samples to pair with the chloride profiles to confirm the elevated concentrations observed in Little Comfort and Comfort Lake.

3. STREAM MONITORING

Streams are assessed by the Minnesota Pollution Control Agency (MPCA) for their ability to support aquatic life and aquatic recreation designated uses. Those designated uses are:

- Protection of "aquatic life" means protection of the aquatic community from the direct harmful effects of toxic substances, and protection of human and wildlife consumers of fish or other aquatic organisms.
- Protection of "aquatic recreation" means protection of the ability to recreate on and in Minnesota's waters.

CLFLWD streams are Class 2B Waters, according to MPCA standards (Minn. R. 7050.0222). These types of streams are described as cool- and warm-water fisheries (not protected for drinking water). Class 2B Water Quality Standards are shown in Table 12.

Table 12. MPCA Class 2B Water Quality Standards

Parameter	Class 2B Waters Standard
Chloride (Chronic)	< 230 mg/L
Low Dissolved Oxygen (DO)	> 5 mg/L as daily minimum
pH	> 6.5 or < 8.5
Total Suspended Solids (TSS)	< 30 mg/L*
Total Phosphorus (TP)	< 100 µg/L**

***** May be exceeded no more than 10% of the time (Apr. 1-Sept. 30)

****** June-September 10-year average

3.1. Purpose of collecting stream data

Multiple water quality parameters were monitored and analyzed at each stream site in 2023. The purpose of this monitoring was to assess and document the current water quality conditions of the streams, identify problem resources or areas, and to continue a long-term baseline monitoring program which will enable the District to identify trends. It is also imperative to track these water quality standards at each stream monitoring site to determine if the waters are meeting State water quality standards and whether they are impaired.

The purpose of long-term stream monitoring is to understand the status of District resources, identify changes over time, and define problems at the watershed or sub watershed level. There are 3 lake outlet sites with long-term records in CLFLWD: Bone Lake, Forest Lake, and Comfort Lake. Data from these sites is useful for calibrating H&H models and tracking total flow and loads discharged from the lakes over time to downstream waters.

There are 3 lake inlet sites with long-term records in CLFLWD: Bone Lake North Inlet, Comfort Lake Inlet, and Little Comfort Lake Inlet at Itasca Avenue. Data from these sites are useful for calibrating H&H models, tracking total flow and loads discharged to lakes over time, and can provide some information on how climate and landscape changes influence water quality over time.

3.2. Long-term Monitoring (Legacy)

Six long-term monitoring sites (Figure 1) are monitored each year to track large-scale pollutant load reduction trends within each of the four Lake Management Districts (LMDs): Comfort LMD, Little Comfort LMD, Forest LMD, and Bone LMD. All these sites have ISCO units, which collect stage data (water levels) to measure flow at the sites. Flow levels trigger the collection of samples for water quality analysis. The samples are collected over a 24-hour period and are composited into one sample that would be representative of the concentration of pollutants during the event. This composited sampling reduces the lab analysis cost and provides more accurate results that represent an entire event, rather than just a point in time.

3.3. Long-term Monitoring Summary

As shown in Table 13, water quality samples were composited during 2023. Unfortunately, a rating curve could not be established at BL1 due to errors in benchmark data. Those errors were fixed in the middle of the season however there was not enough data to create a seasonal curve. Thus, pollutant loads cannot be accurately calculated. Additionally, for statistical validity, sites with less than five samples are considered insufficient by the FLUX32 program for load calculations, thus FL1 is excluded from the analysis. FL1 experienced extremely low flow due to drought-like conditions throughout the summer.

Table 13. Long-term monitoring sites

Lake Management District	Site Description	Site code	# of water quality samples (2023)
Bone Lake	Bone Lake North Inlet	BL1	6
	Bone Lake Outlet	BL2	8
Comfort Lake	Comfort Lake Outlet	CL1	9
	Comfort Lake Inlet	CL2	8
Forest Lake	Forest Lake Outlet	FL1	4
Little Comfort Lake	Little Comfort Lake Inlet	LC1	9

3.4. Results

Stream water chemistry composite sample results for total suspended solids, phosphorus, nitrogen, iron, and chloride are reported in Appendix D.

- Bone Lake Inlet and Outlet (Table 16 and Table 15)
- Comfort Lake Outlet and Inlet (Table 17 and Table 18)
- Little Comfort Inlet (Table 19)
- Forest Lake Outlet (Table 20)

Appendix D shows the flow conditions from each of the long-term monitoring sites. Unfortunately, flow data could not be computed for FL1 and BL1 due to insufficient data. Total runoff volume, TP and total suspended solids (TSS) loads, and flow weighted mean concentrations (FWMC) were determined using FLUX32. Table 14 summarizes the long-term monitoring site results. Most of the sites had high uncertainty in the load calculations, likely due to long periods of low flow conditions. A summary of the water quality monitoring at the long-term stream monitoring sites is in Appendix D.

The peak flow was observed in early spring for all sites which then decreases to low flow conditions for the rest of the season. In 2023, nitrogen levels were very low, and no chloride readings exceeded State standards District-wide at all sites. Stream water quality was good at CL2 (Comfort Lake inlet) and BL1 (Bone Lake inlet), as observed by stream chemistry concentrations that were below state standards. The only instance of FWMC (flow-weighted mean concentration) values was LC1 (Little Comfort inlet), which had an exceedance for total phosphorus. It is important to note there is a very high coefficient of variation (i.e., high uncertainty > 0.5) for LC1 and many other sites and the data should be verified with additional years of data. There were several seasonal exceedances of total phosphorus and total suspended solids stream standards in the fall at CL1 (Comfort Lake outlet) and FL1 (Forest Lake outlet). In addition, BL2 (Bone Lake outlet) and LC1 (Little Comfort inlet) experienced elevated total phosphorus and total suspended solids exceeding state standards during most of the 2023 monitoring season. These exceedances are likely due to low flow conditions in the growing season.

3.5. Conclusions and Recommendations

In 2023, the peak flow was observed in early spring for all sites which then decreased to low flow conditions for the rest of the season. Low flow conditions lead to elevated TP and TSS concentrations at most sites. However, the only instance of elevated flow-weighted mean concentration values was Little Comfort inlet. It is important to note there is a very high coefficient of variation (i.e., high uncertainty > 0.5) for the FWMC calculations at most of the sites and the data should be verified with additional years of data.

Due to the many challenges present in collecting, interpreting, and analyzing data from the long-term stream monitoring sites, especially during periods of drought, EOR recommends a more comprehensive approach to measuring loads within these sites. This can be accomplished by developing a thorough statistical model.

Currently, data is summarized each year, without using past data to help fill key gaps in stage, discharge, and water quality. In developing a customized statistical model, data from previous years can be used to develop daily estimates that can then be verified with annual data and discrete water quality sampling points. This would also allow for more targeted sampling and data collection, focused on filling key data gaps. The goal, as it has been the case in past monitoring efforts, is to keep improving methods that would result in a better and more accurate assessment of water quality trends across the District and a better understanding of the dynamic nature of these systems.

Table 14. 2022 Long-term Stream Monitoring Site Concentrations and Loads.

Monitoring Site		MPCA Station ID	Drainage Area (acres)	Days of Flow	Number of Sample Events	Flow			Total Phosphorus			Total Suspended Solids		
						Daily Mean (cfs)	Volume (ac-ft)	Runoff depth (in)	FWMC (µg/L)	Load (lbs.)	CV	FWMC (mg/L)	Load (lbs.)	CV
Central Region Reference FWMC									**<100**			**< 30**		
Long-term Sites														
Bone Lake North Inlet	BL1	S004-471	2,479	*	*	*	*	*	*	*	*	*	*	*
Bone Lake Outlet	BL2	S004-463	5,495	194	7	4	1,626	4	**55**	**244**	**> 0.5**	**7**	**30,647**	**> 0.5**
Big Comfort Outlet	CL1	S004-468	24,558	170	8	18	7,194	4	**64**	**1,251**	**> 0.5**	**11**	**208,357**	**> 0.5**
Big Comfort Inlet	CL2	S001-223	13,625	197	7	6	1,918	2	63	327	< 0.5	6	30,202	< 0.5
Forest Lake Outlet	FL1	S004-466	8,719	*	*	*	*	*	*	*	*	*	*	*
Little Comfort Inlet	LC1	S001-232	10,513	197	8	5	1,894	2	**157**	**806**	**> 0.5**	**28**	**143,657**	**> 0.5**

* Not enough samples to calculate FWMC and loads.

Bolded values have very high coefficient of variation (i.e., high uncertainty > 0.5) and should be used with caution.

Shaded FWMC values exceed the Central Region Reference values.

4. CONCLUSION AND SUMMARY

2023 was a challenging year due to dry conditions throughout the monitoring season. The results should thus be considered within that context and used as part of a greater multi-year data set to allow the development of conclusions or management actions. The following are takeaways from the 2023 lake and stream monitoring efforts.

4.1. Lake Monitoring

The main takeaways for the 2023 lake monitoring season include:

1. There are two primary seasonal drivers observed in CLFLWD lakes in 2023, a) large snow melt discharge in the spring and b) after the lake turnovers after destratification in the fall. Poor water quality was noted on several lakes during both of these periods.
2. Overall, 2023 average growing season lake water quality was excellent with most of the lakes in the District meeting State standards for either TP and chlorophyll-a or Secchi depth criteria. In fact, only Elwell lake did not meet any of the three water quality parameter goals..
3. In general, 2023 water quality was similar or better than in 2022 and most lakes are meeting state water quality standards.
4. In 2023, ten lakes received A/B+ grades. Only Elwell lake had less than average lake grades.
5. The historic 5-year average water quality parameters improved from the 10-year average, except for Elwell and Forest Lake-Middle (which the latter received an alum treatment in the Fall of 2023).
6. Overall, most District lakes have improving trends in lake water quality. Forest Lake-East is exhibiting declining total phosphorus water quality trends. However, an alum treatment on Forest Lake-Middle was applied in Fall 2023 to improve TP conditions in Forest Lake-Middle and East. Lake. Keewahtin is experiencing a slight declining trend in Secchi depth, yet it still maintains excellent water clarity – average of 12ft of clarity depth as compared to the water quality standard of 3.3 ft.
7. Shields and Moody Lake's alum treatments are still effectively reducing internal loading.
8. Moody Lake is the only lake not meeting any of the lake water quality standards at the 10 year average. However, Moody lake water quality has significantly improved due to improvements within the lake and the watershed. In fact, water quality trends started to show significant improvement since 2018 and the lake grade for 2023 is a B+.
9. Only Little Comfort and Comfort Lake have chloride concentrations which exceeded water quality standards (230 mg/L) in the bottom water during the growing season and improved in the fall. Based on the season variability, the chloride conditions seem to be driven by precipitation. Chloride could have been flushed into the lakes during the heavy snow melt. During the dry growing season, elevated chloride concentrations persisted in the bottom of the lake. When precipitation increased in the fall, the chloride was flushed from the system. It is important to note that the elevated chloride concentrations were observed in the bottom water and not in habitats in the lake which are most vulnerable to elevated chloride concentrations.

Lake Monitoring Recommendations

The following future monitoring is recommended based on the 2023 data:

1. Continue monitoring the major lakes of the District using the Met Council CAMP Program. Rotate monitoring of the smaller lakes of the district as per the 10-year monitoring plan.
2. Collect hypolimnion and metalimnion water samples on Comfort, Forest East and Middle, and Little Comfort and only hypolimnion samples on Moody, and Shields Lakes to further evaluate internal P loading.

3. Collect additional hypolimnion water samples on Comfort Lake and Littler Comfort Lake to evaluate chloride levels in these systems.
4. Collect follow up sediment cores for Forest Lake alum treatment to evaluate the second dose.

4.2. Stream monitoring

The main takeaways for the 2023 stream monitoring season include:

1. The only instance of FWMC central region reference values exceedance was Little Comfort Lake Inlet, which exceeded FWMC for total phosphorus. It is important to note there is a very high coefficient of variation (i.e., high uncertainty > 0.5) for LC1 and many other sites and should be verified with additional years of data.
2. Nitrogen levels were very low, and no chloride readings exceeded State standards District-wide at all sites.
3. Stream water quality was good at Comfort Lake Inlet and Bone Lake North Inlet, as observed by stream chemistry concentrations that are below state standards.
4. In 2023, there were seasonal exceedances of TP and TSS stream standards in the fall at Comfort Lake Outlet and Forest Lake Outlet. Bone Lake Outlet and Little Comfort Lake Inlet experienced elevated total phosphorus and total suspended solids exceeding state standards during most of the season.

Stream Monitoring Recommendations

The following are recommendations for future monitoring based on 2023 monitoring results.

1. Evaluate the extent of tailwater impacts to water elevations by looking at stage data in Little Comfort Lake and Comfort Lake, and comparing water elevations to what is being seen at the LC1 monitoring site. These lake elevations should be measured on the same day to make it easier to compare water levels.

2. Modeling - To better understand the impact of LC1 on the Little Comfort Lake system, it is recommended that this data be evaluated using the District's H&H model. This would allow for a more accurate and robust understanding of how such damming activities influence an accurate calculation of Little Comfort Lake's pollutant loads.

3. Refine telemetry of stream sites to make data collection more efficient.

APPENDIX A. LAKE MONITORING SHEETS

Information on how to read the information provided in the individual lake summaries is provided in the Bone Lake example. Individual lake summaries were developed for the lakes with District goals that were monitored in 2022:

1. Bone
2. Comfort
3. Elwell
4. Forest Lake – West Basin
5. Forest Lake – Middle Basin
6. Forest Lake – East Basin
7. Heims
8. Keewahtin
9. Little Comfort
10. Lendt
11. Moody
12. School
13. Shields
14. Third
15. Twin

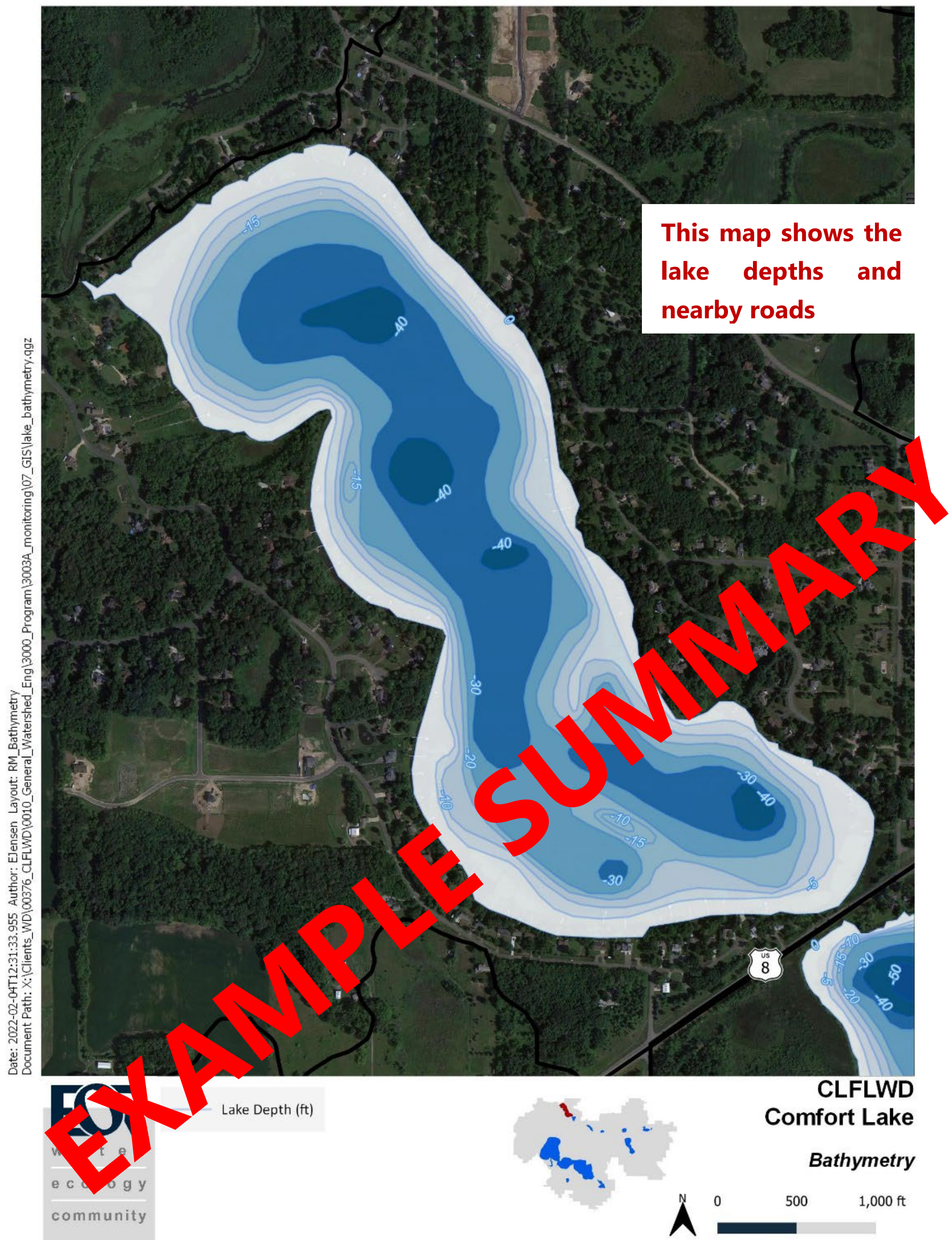
EXAMPLE LAKE

Fast Facts:

DNR Lake ID: 13-0053-00
County: Chisago
Surface Area: 218 acres
Littoral Area (depths less than 15 feet): 90 acres
Maximum Depth: 47 feet
Shore Length: 3.24 miles

Some basic information about the lake, such as how big it is and where it is

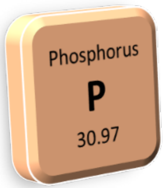
This map shows the lake depths and nearby roads



EXAMPLE LAKE

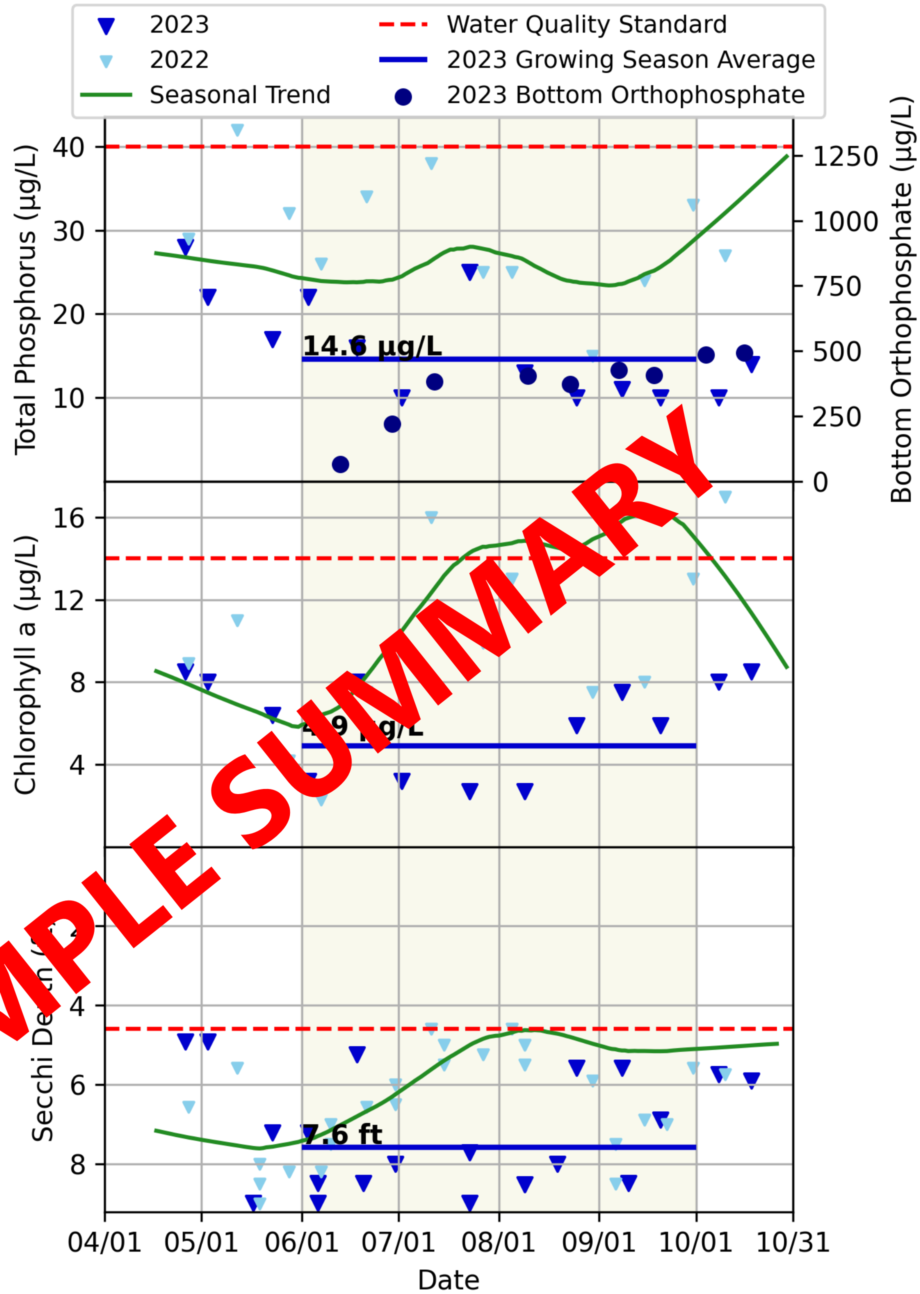
2023 Surface Water Quality Summary

Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



Algae:
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

Clarity:
June-Sept. Average Secchi Depth (Secchi, ft)



This figure shows all of the water quality samples collected in 2023. Each dot represents one sample date. Navy triangles were collected from surface water in 2023; Light blue triangles were collected in 2023, where available black dots were collected from bottom water and correspond to the secondary axis. The growing season (June-September) is shaded in tan. These samples were used to calculate a growing season average that is labeled in black and represents the navy line and the green line represents the 10-year seasonal average. The red line represents the State water quality standard for each parameter. Points above the line

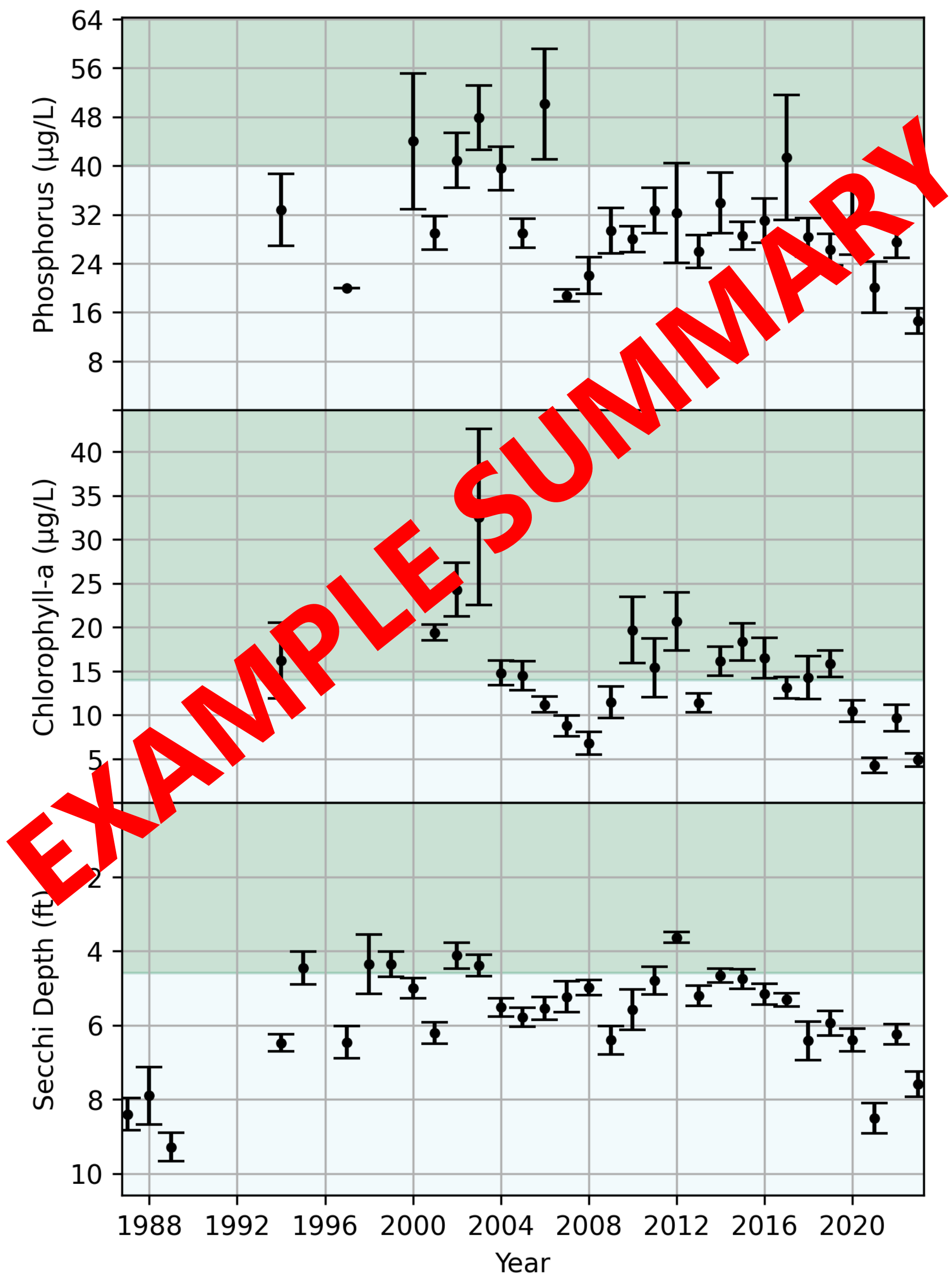
EXAMPLE LAKE

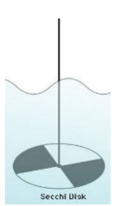
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**29.7**	**13.5**	**5.9**
2040 District Goal	<30	n/a	>7.0
5-year Average (2019-2023)	**24.7**	**9.8**	**6.8**

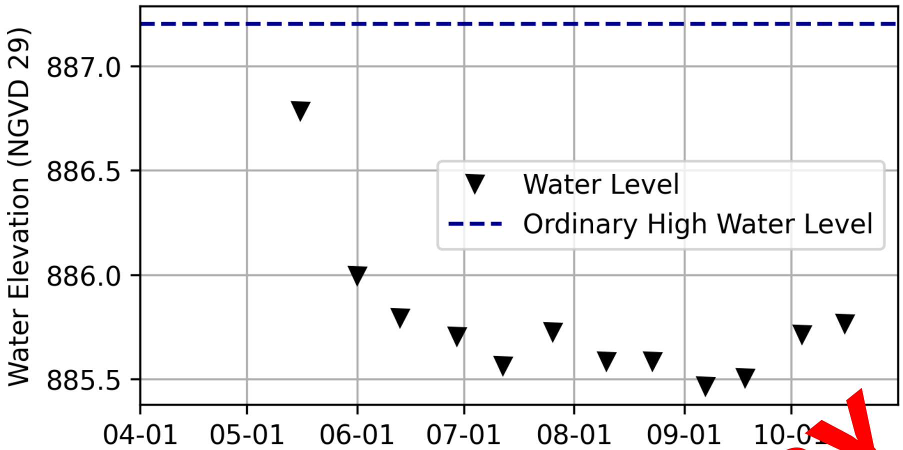
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)

This figure shows the growing season average by year for each parameter. Each dot represents the annual growing season average, and the vertical line represents the standard error, or the variability in samples collected during that year.The <u>darker green area</u> represents growing season average concentrations where water quality is not meeting the State water quality standards. The <u>light blue area</u> represents growing season average concentrations that are meeting the State water quality standards the



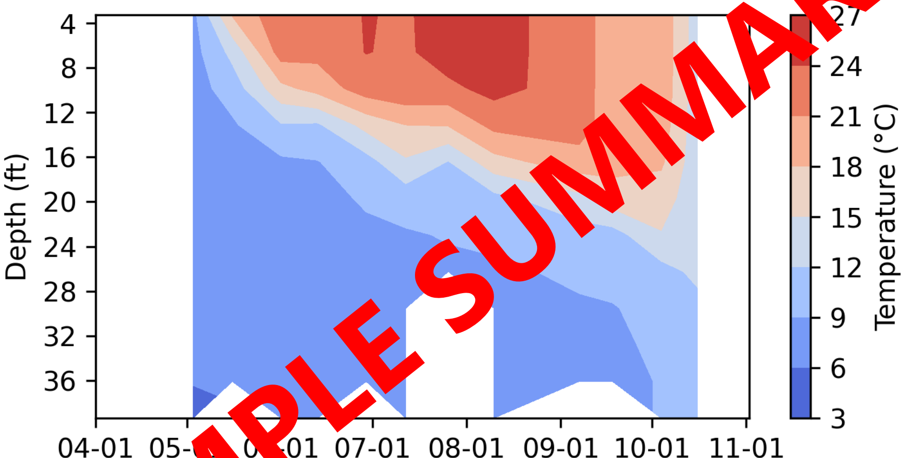


EXAMPLE LAKE



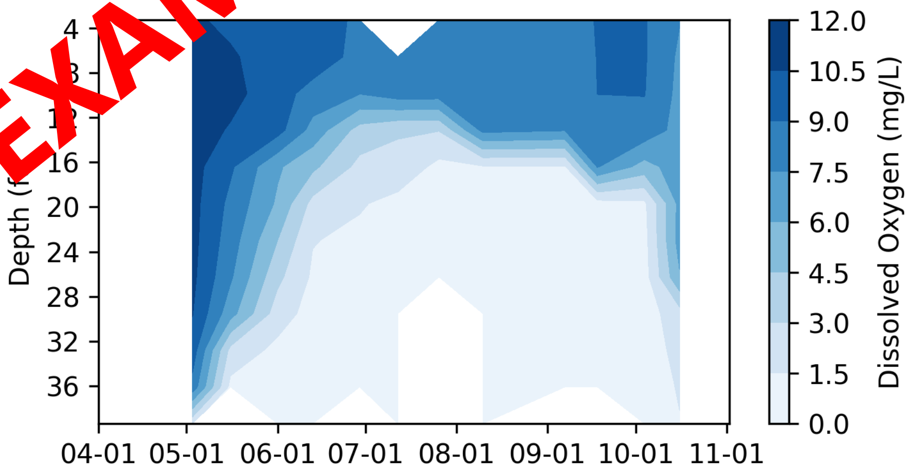
2023 Lake Levels

This figure shows the lake level measurements for 2022. Each triangle represents one measurement. The date is shown along the bottom of the figure as MM-DD. The dashed blue line shows the Ordinary High Water level.



2023 Temperature Profiles

This figure shows the temperature conditions throughout the water column throughout the monitoring period. The cooler colors represents cooler temperatures and the warmer colors represent warmer temperatures. The date is shown along the bottom of the figure as MM-DD.



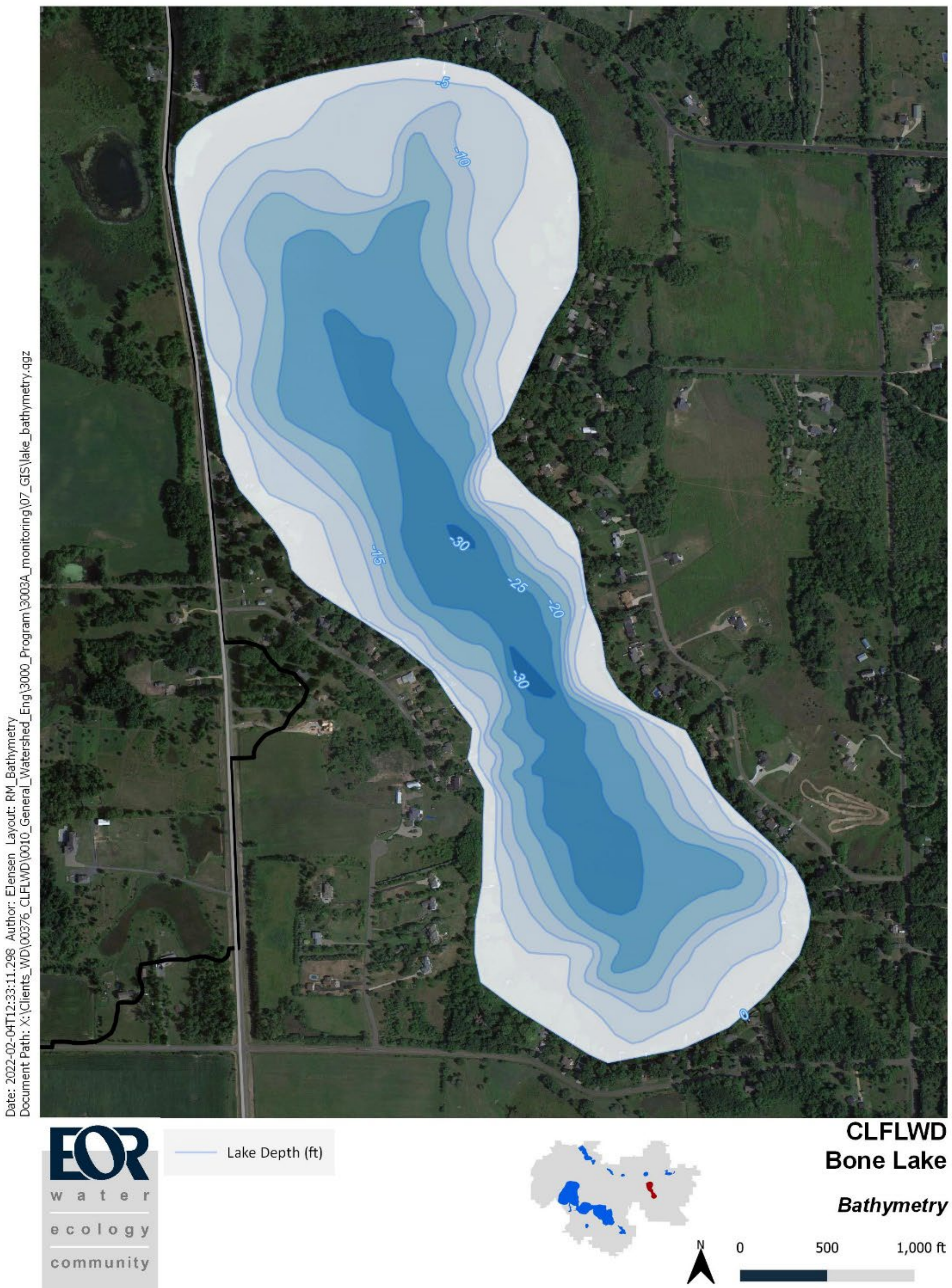
2023 Dissolved Oxygen Profiles

This figure shows the dissolved oxygen conditions throughout the water column throughout the monitoring period. The lightest blue represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading. The date is shown along the bottom of the figure as MM-DD.

BONE LAKE

Fast Facts:

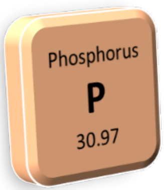
DNR Lake ID: 82-0054-00
County: Washington
Surface Area: 221 acres
Littoral Area (depths less than 15 feet): 124 acres
Maximum Depth: 30 feet
Shore Length: 3.01 miles
DNR Shoreland Classification: Recreational Development



BONE LAKE

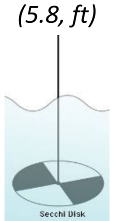
2023 Surface Water Quality Summary

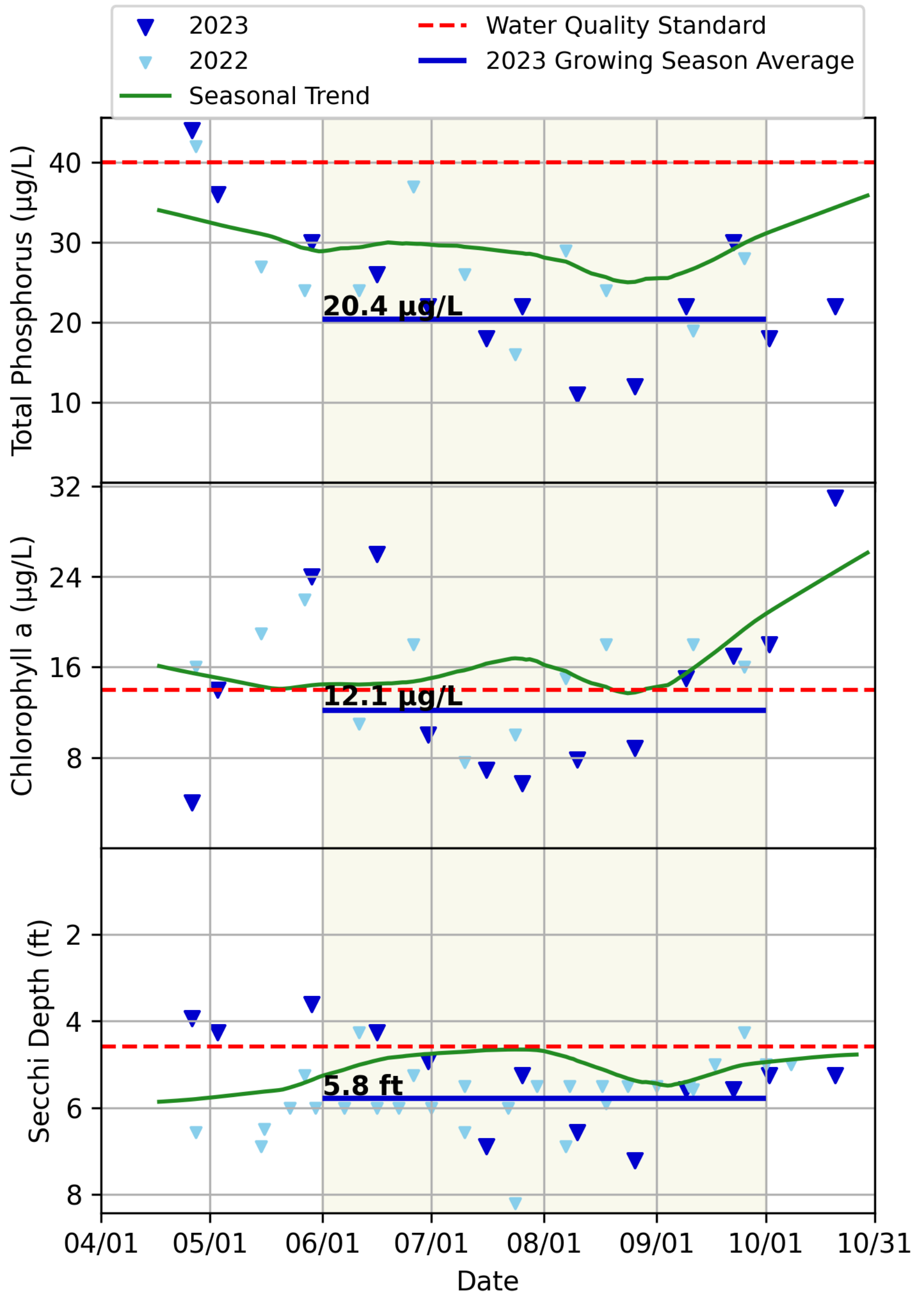
Nutrients:
June-Sept. Average Total Phosphorus (20.4, µg/L)



Algae:
June-Sept. Average Chlorophyll-a (12.1, µg/L)

Clarity:
June-Sept. Average Secchi Depth (5.8, ft)



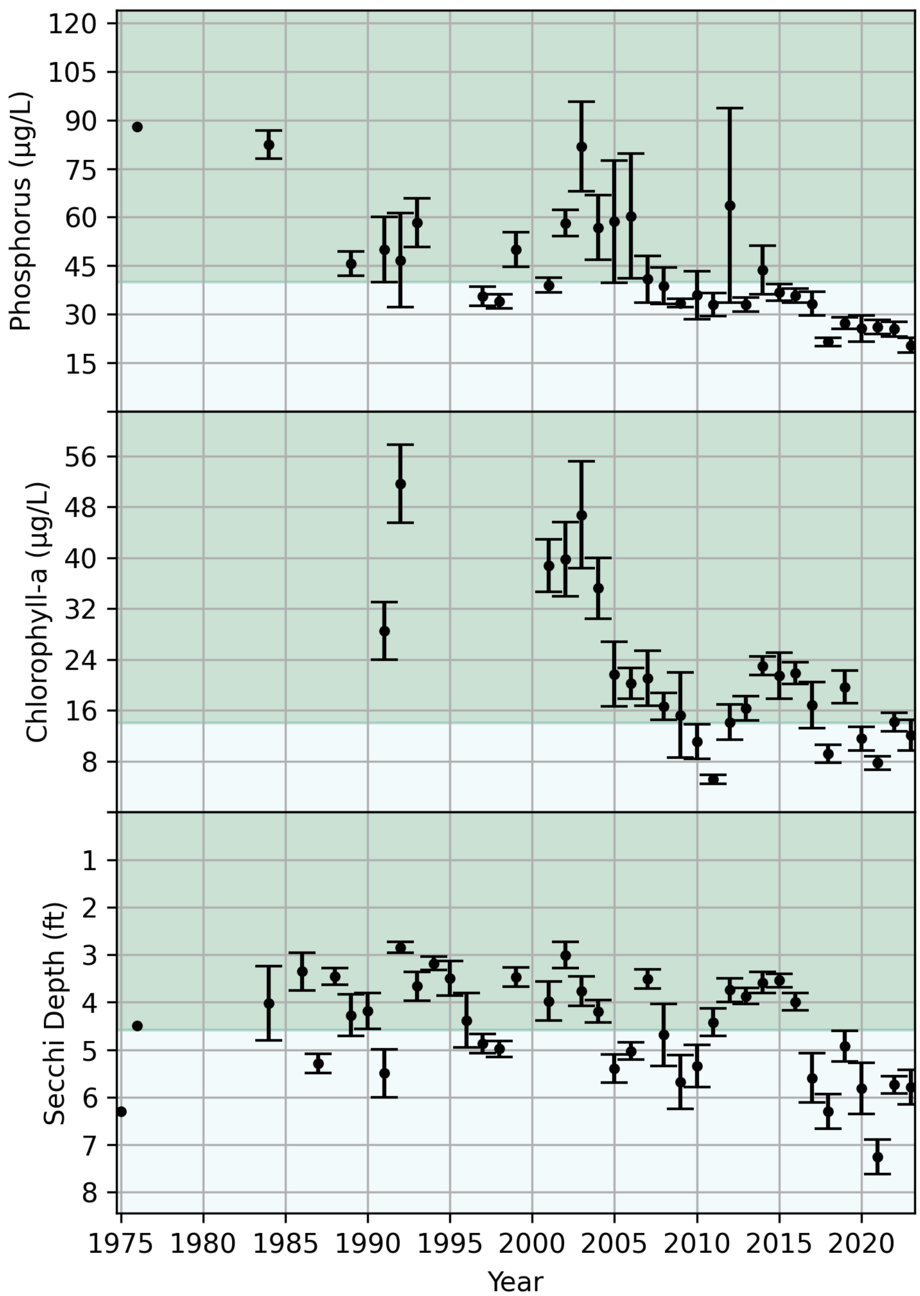


Water quality improved in 2023 compared to 2022 and all water quality parameters are meeting the state standards.

BONE LAKE

Historical Water Quality Summary

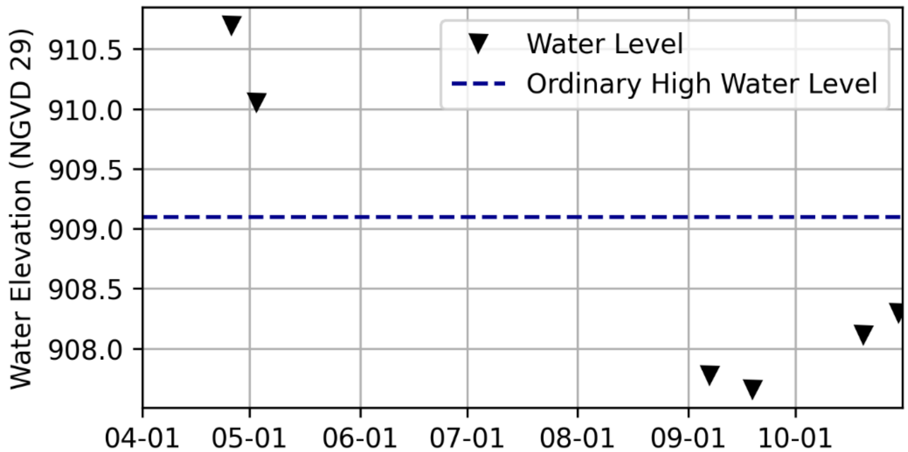
	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**31.2**	**17.0**	**5.1**
2040 District Goal	<30	n/a	>7.0
5-year Average (2019-2023)	**25.1**	**13.6**	**5.8**



The 5 year WQ averages are meeting state standards and District goals. The 5 year WQ average is better than the 10 year WQ average. The 2023 data improved compared to 2022. The 2023 WQ is meeting the water quality standards.

BONE LAKE

2023 Lake Levels

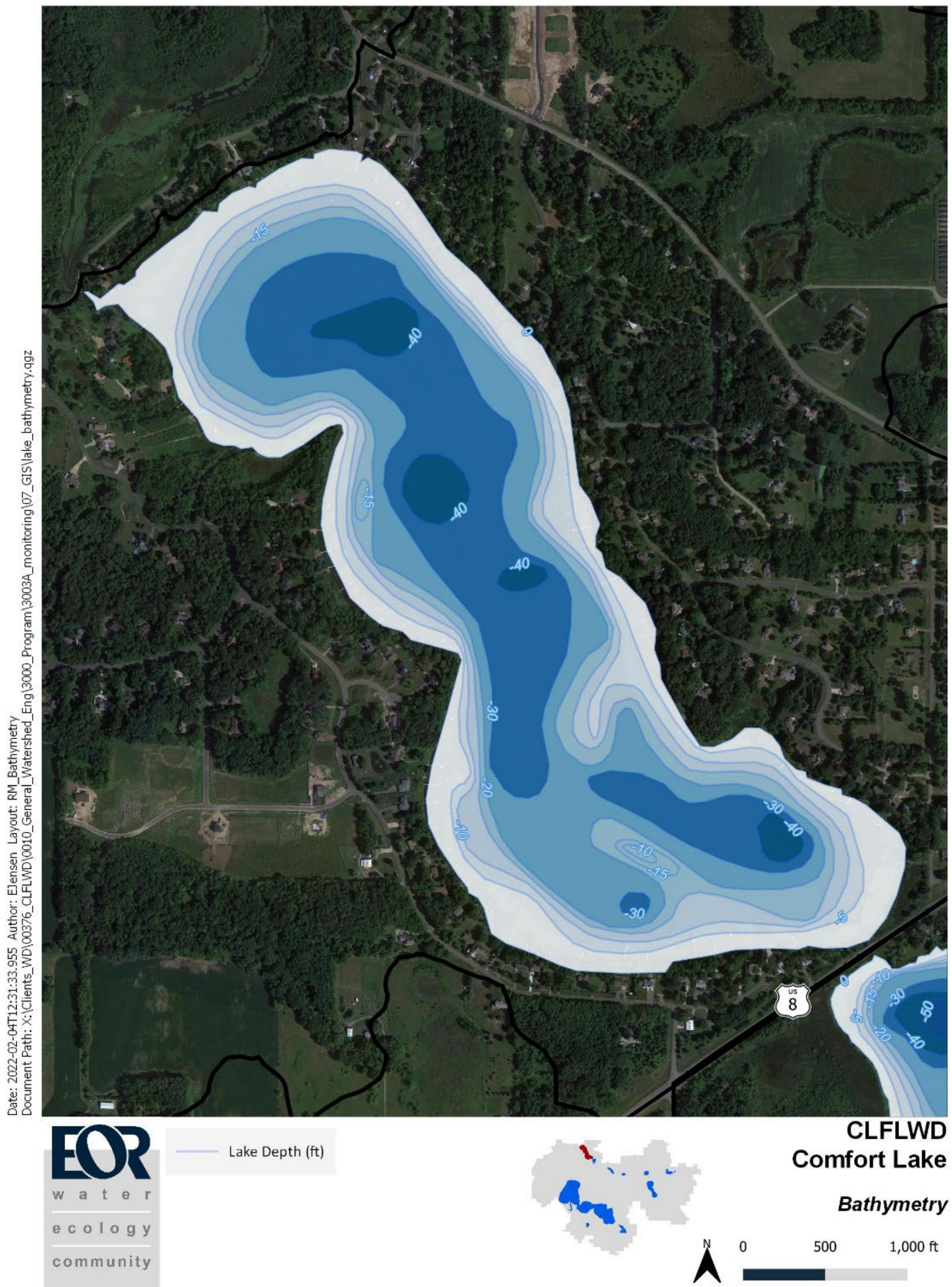


Lake levels ranged over a total of 3 feet; from a maximum of 910.7 feet on April 26, 2023 to a minimum of 907.7 feet on September 19, 2023.

COMFORT LAKE

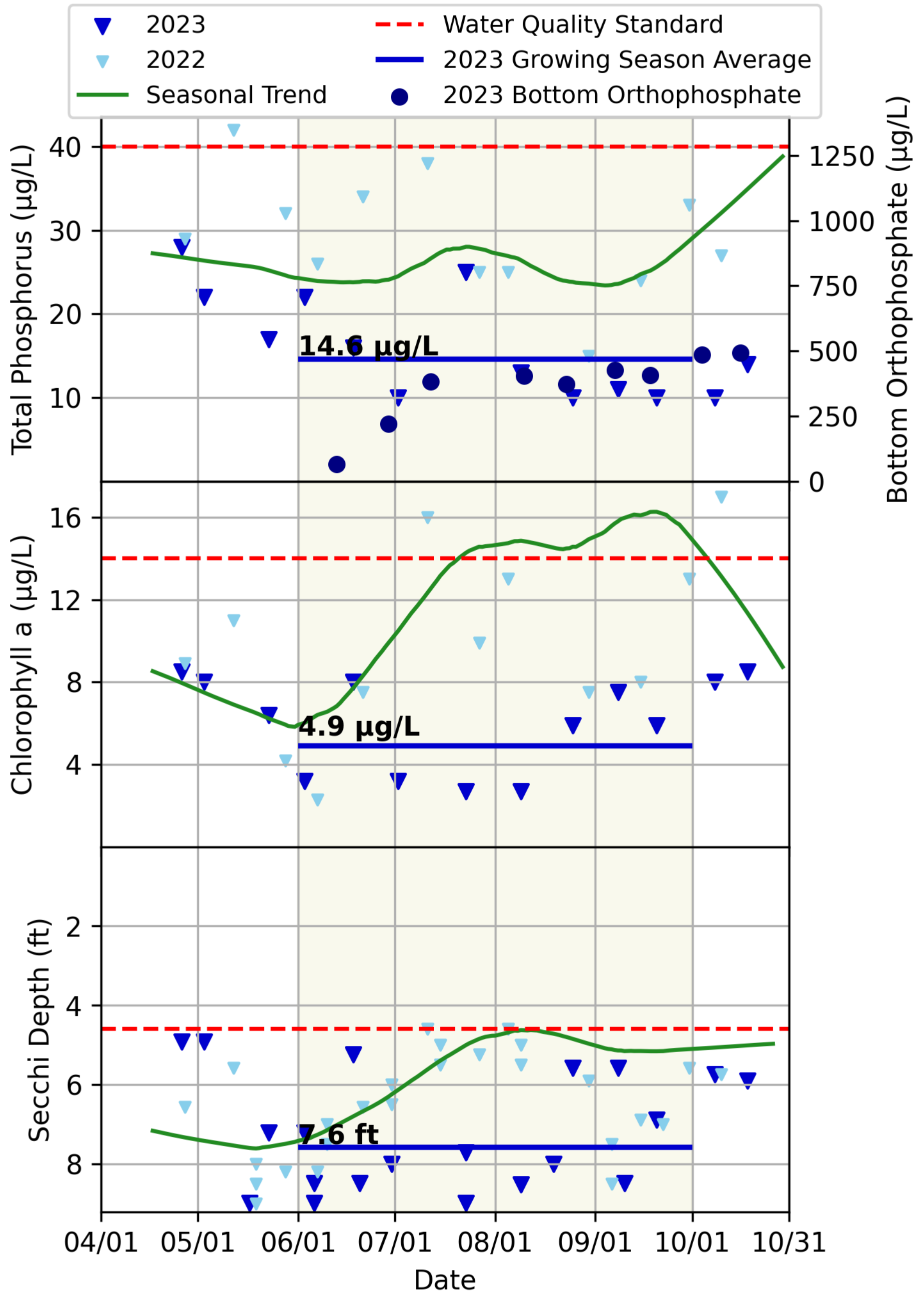
Fast Facts:

DNR Lake ID: 13-0053-00
County: Chisago
Surface Area: 218 acres
Littoral Area (depths less than 15 feet): 90 acres
Maximum Depth: 47 feet
Shore Length: 3.24 miles
DNR Shoreland Classification: General Development



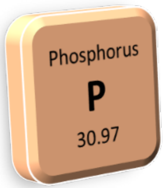
COMFORT LAKE

2023 Surface Water Quality Summary



Nutrients:

June-Sept. Average Total Phosphorus (14.6, µg/L)

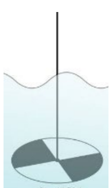


Algae:

June-Sept. Average Chlorophyll-a (4.9, µg/L)

Clarity:

June-Sept. Average Secchi Depth (7.6, ft)

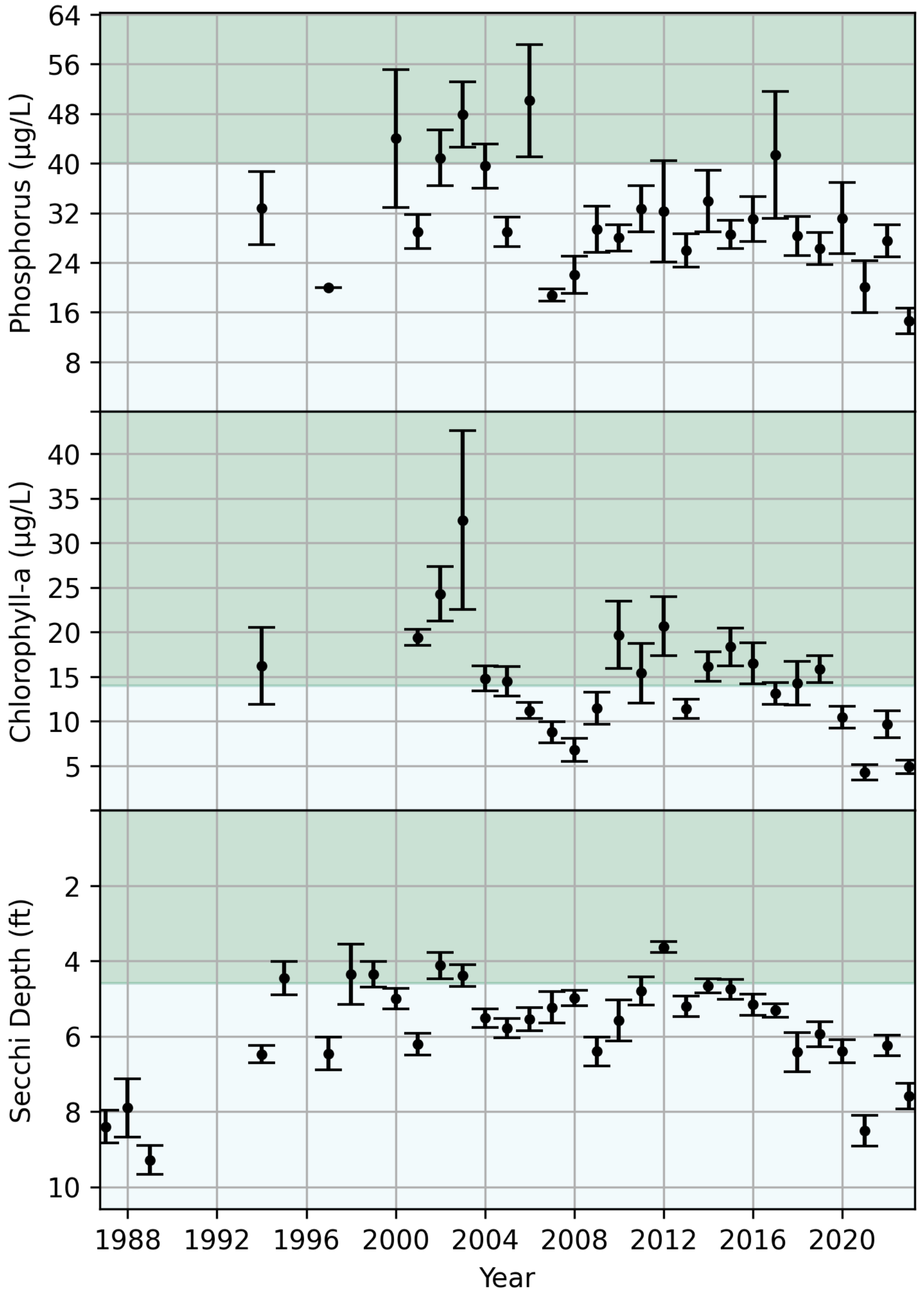


Water quality improved in 2023 compared to 2022 and all water quality parameters are meeting the state standards.

COMFORT LAKE

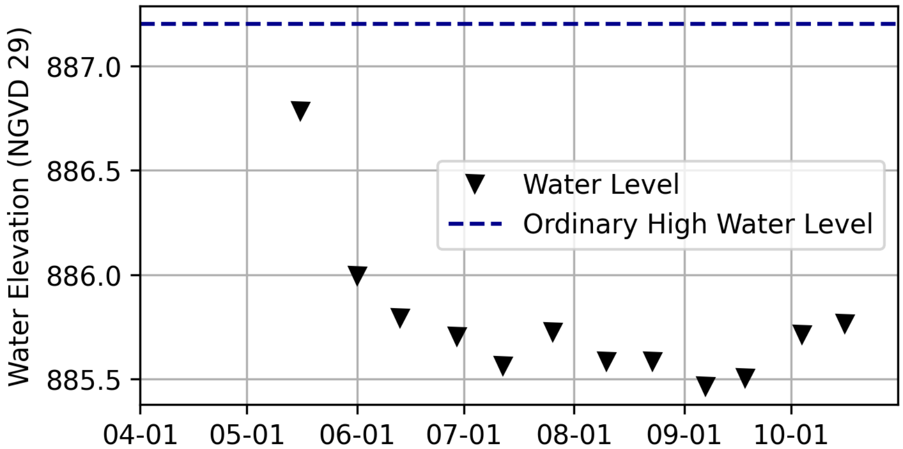
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**29.7**	**13.5**	**5.9**
2040 District Goal	<30	n/a	>7.0
5-year Average (2019-2023)	**24.7**	**9.8**	**6.8**



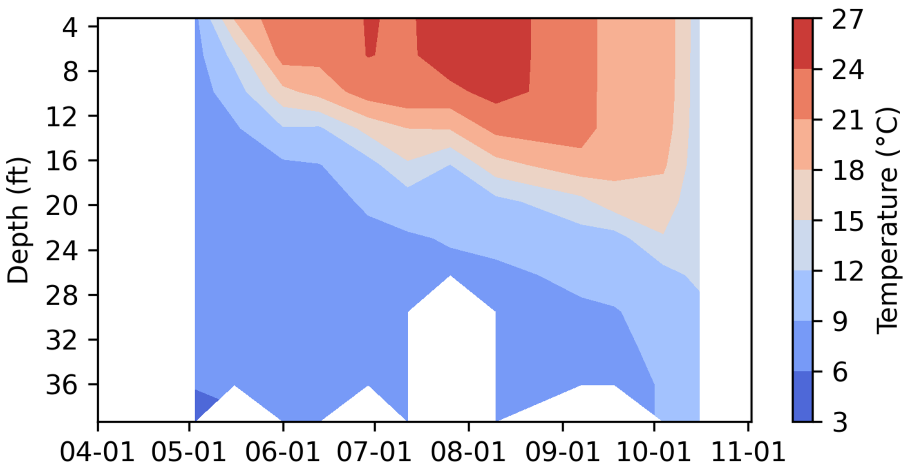
For all of the water quality parameters, both the 10 year and 5 year averages are meeting state standards and District goals. The 5 year average is better than the 10 year average. The 2023 data improved compared to 2022. The 2023 WQ is meeting the water quality standards.

COMFORT LAKE



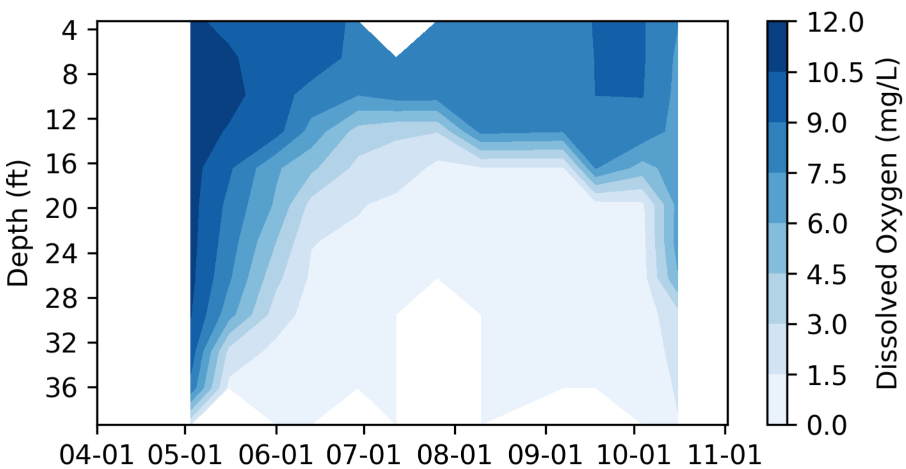
2023 Lake Levels

Lake levels ranged over a total of 1.3 feet; between a minimum of 885.5 feet on September 7, 2022 and a maximum of 886.8 feet on May 16, 2023 compared to the OHWL 887.2.



2023 Temperature Profiles

The lake was stratified from mid May through October



2023 Dissolved Oxygen Profiles

Internal loading was possible starting in mid-May. Bottom P increased after this time. Fall turnover is beginning at the end of the monitoring period in mid-October.

ELWELL LAKE

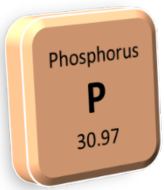
Fast Facts:

DNR Lake ID: 82-0079-00
County: Washington
Surface Area: 16 acres
Littoral Area (depths less than 15 feet): NA acres
Maximum Depth: NA feet
Shore Length: NA miles
DNR Shoreland Classification: Natural Environment

ELWELL LAKE

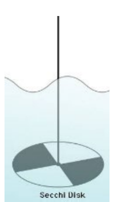
2023 Surface Water Quality Summary

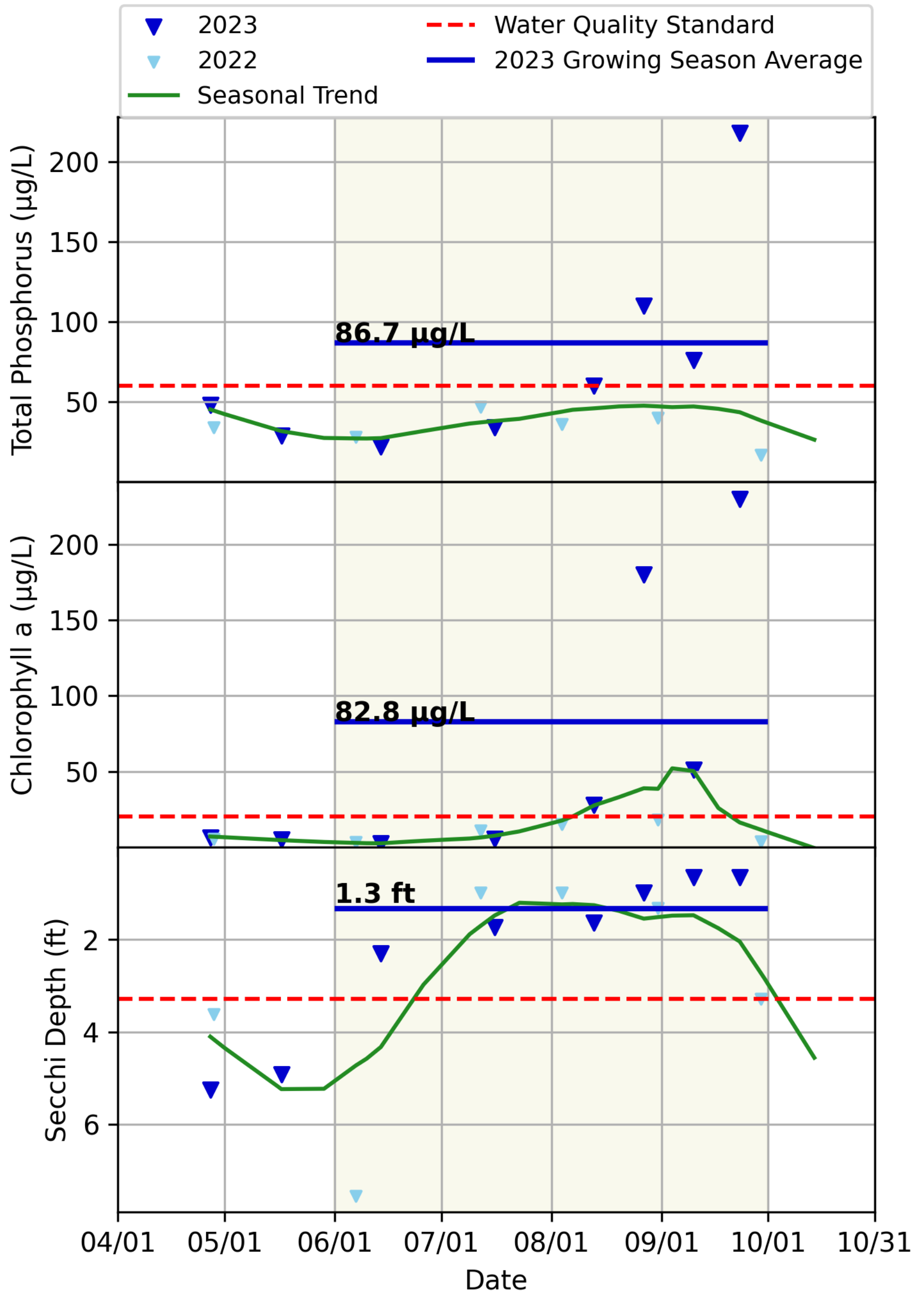
Nutrients:
June-Sept. Average Total Phosphorus (86.7, µg/L)



Algae:
June-Sept. Average Chlorophyll-a (82.8, µg/L)

Clarity:
June-Sept. Average Secchi Depth (1.3, ft)



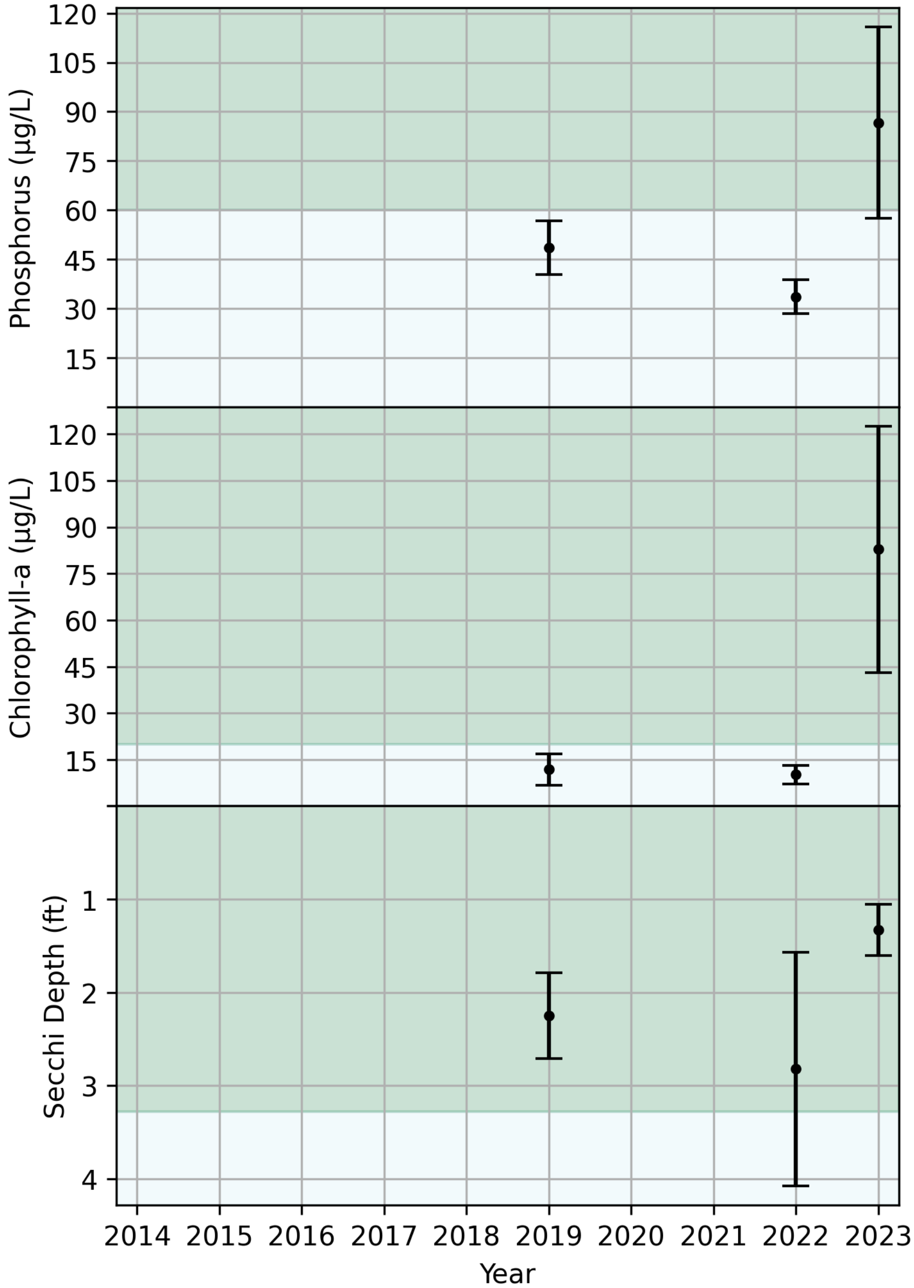


For most of the season the water quality trends match those observed in 2022. However, there is high TP and chlorophyll concentrations in late August and mid-September which increased seasonal average. All water quality standards are not meeting state standards.

ELWELL LAKE

Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<60	<20	>3.3
10-year Average (2014-2023)	**56.2**	**32.7**	**2.1**
2040 District Goal	<60	n/a	>3.3
5-year Average (2019-2023)	**56.2**	**32.7**	**2.1**

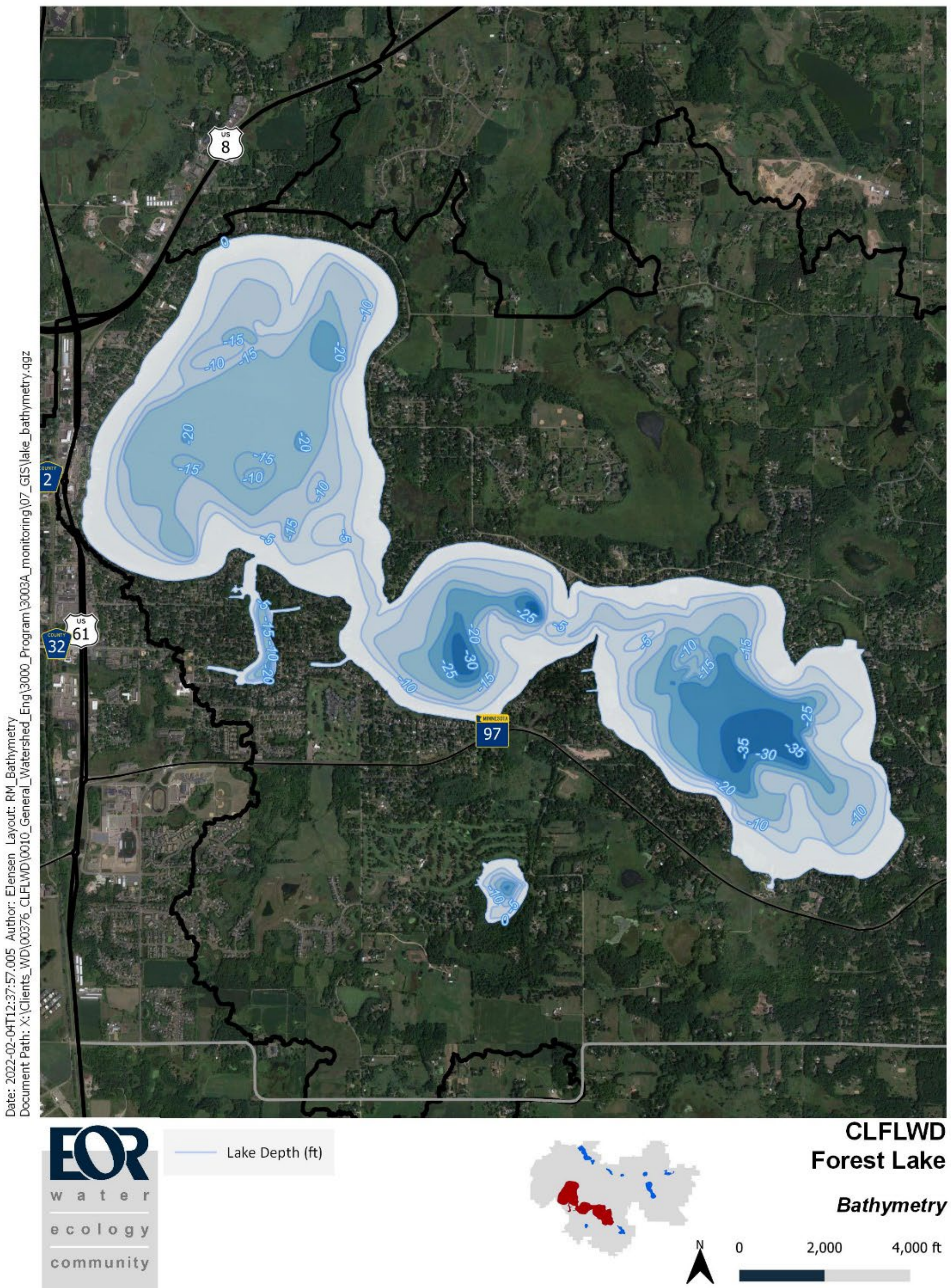


There are only three years of monitoring data from 2019, 2022, and 2023. In 2023, the water quality parameters are not meeting state standards. There is high variability amon

FOREST LAKE

Fast Facts:

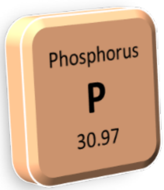
DNR Lake ID: 82-0159-00
County: Washington
Surface Area: 2,271 acres
Littoral Area (depths less than 15 feet): 1,531 acres
Maximum Depth: 37 feet
Shore Length: 15.71 miles
DNR Shoreland Classification: General Development
Outlet: Forest Lake discharges to the Sunrise River which flows to Comfort Lake



FOREST LAKE – WEST BASIN

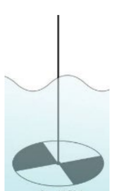
2023 Surface Water Quality Summary

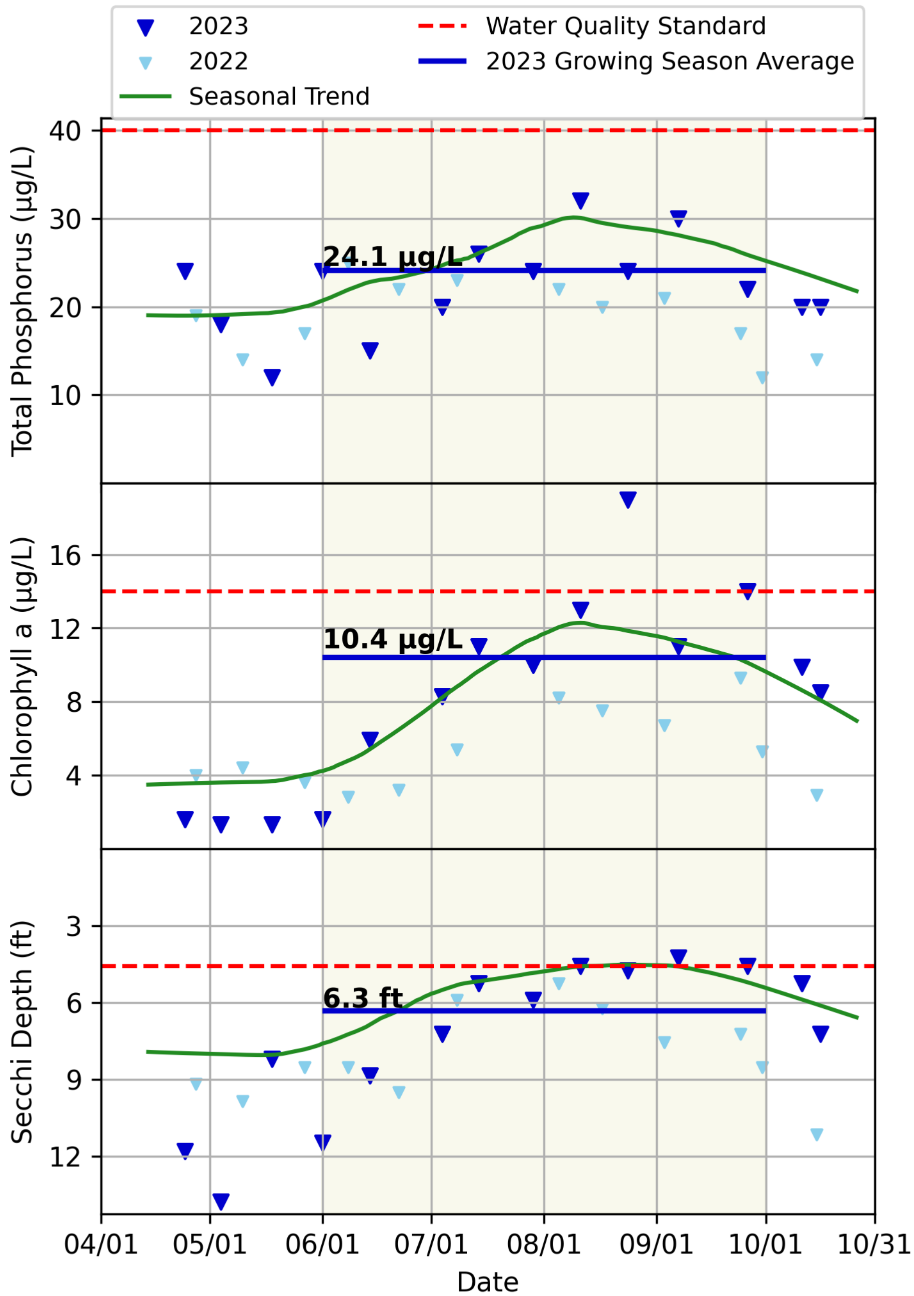
Nutrients:
June-Sept. Average Total Phosphorus (24.1, µg/L)



Algae:
June-Sept. Average Chlorophyll-a (10.4, µg/L)

Clarity:
June-Sept. Average Secchi Depth (6.3, ft)



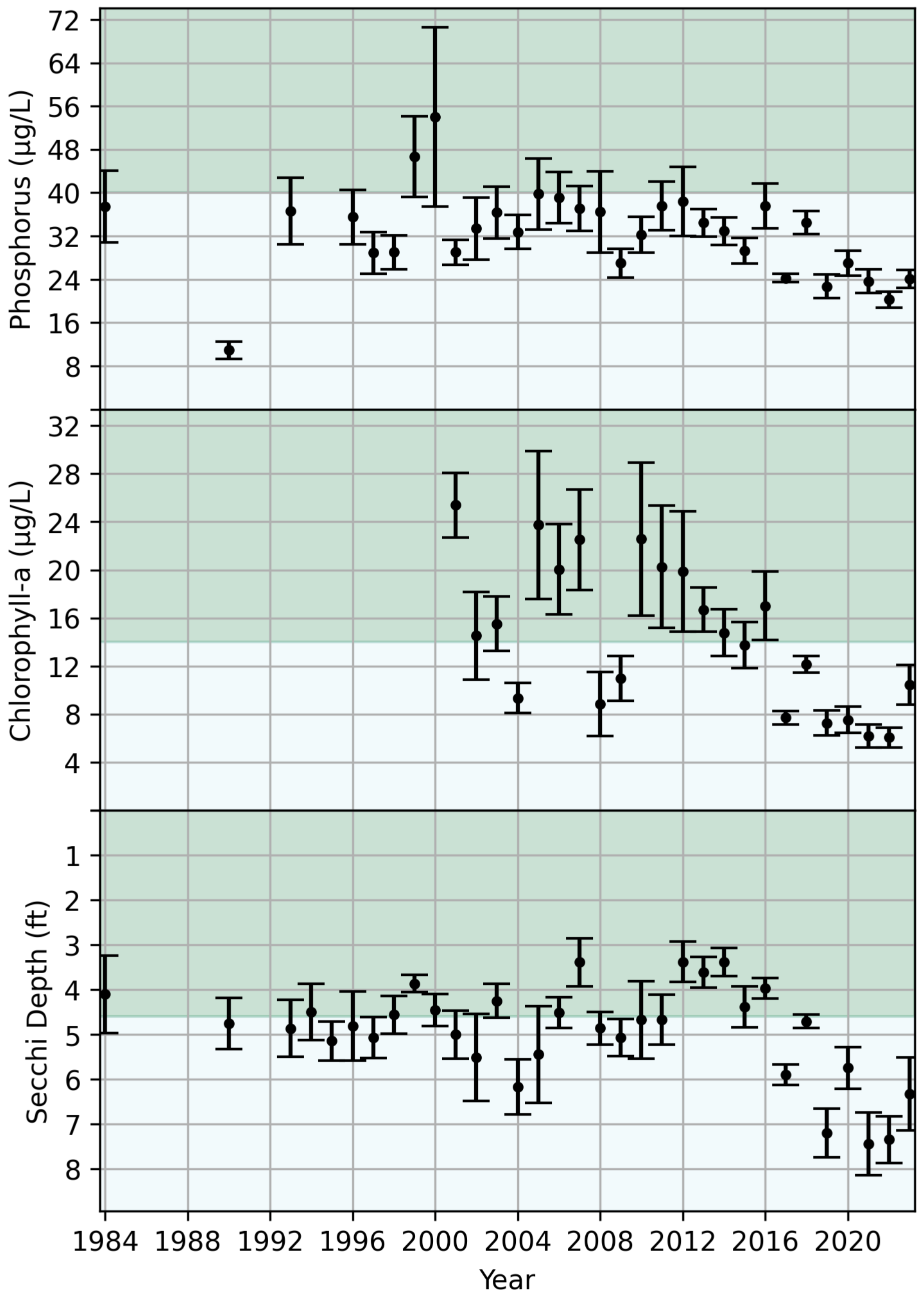


All water quality parameters peaked in August which led to exceedances in chlorophyll-a and Secchi depth though all water quality parameters are meeting state standards for the seasonal average.

FOREST LAKE – WEST BASIN

Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**28.5**	**11.0**	**5.3**
2040 District Goal	<30	n/a	>7.0
5-year Average (2019-2023)	**23.5**	**7.5**	**6.9**

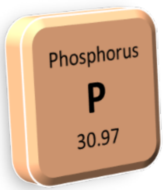


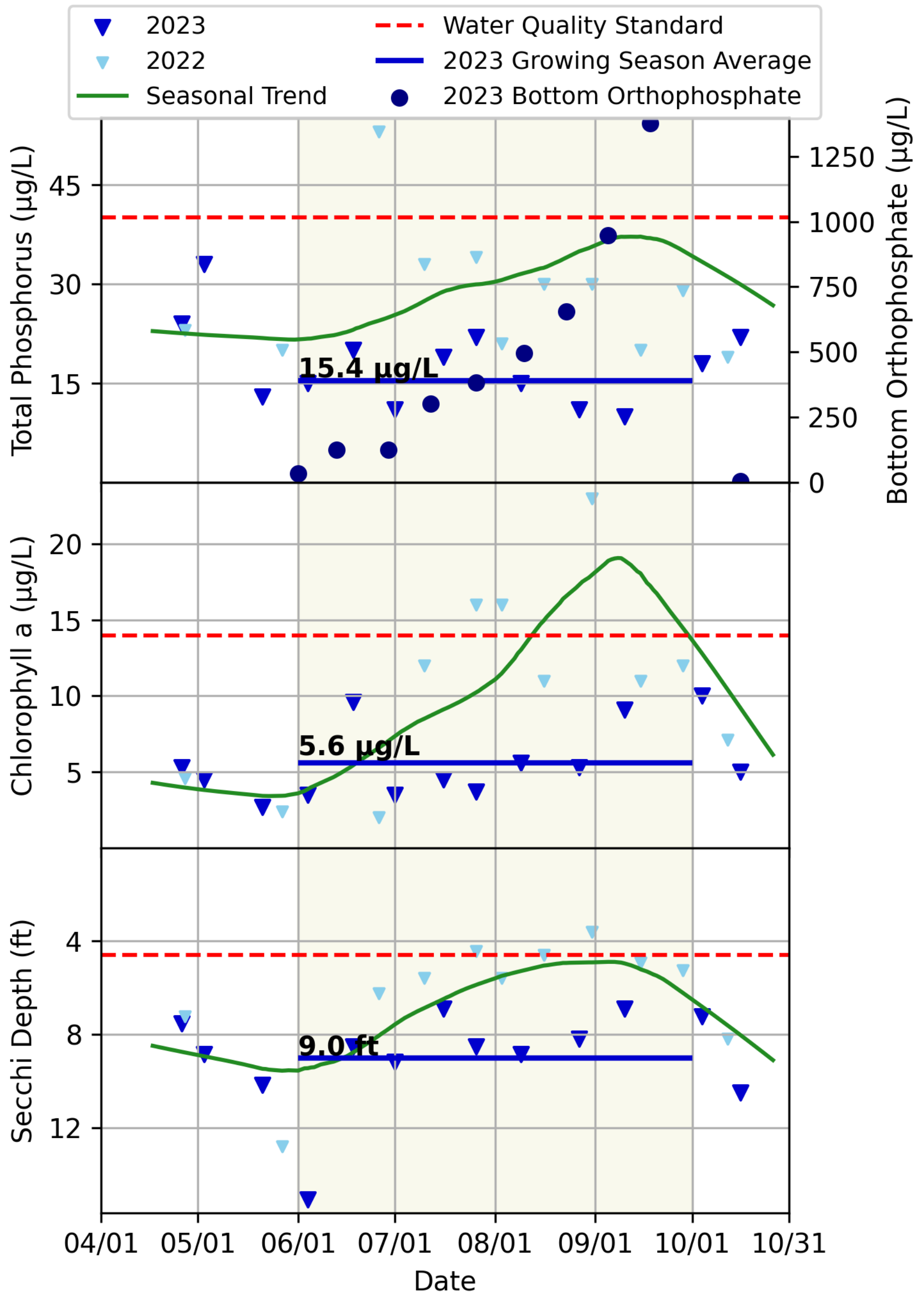
For all of the water quality parameters, both the 10 year and 5 year average are meeting state standards and District goals. The 5 year average is better than the 10 year average. The 2023 water quality data is slightly worse than in 2022 but 2023 data and historic averages are all meeting the state standards and District goals.

FOREST LAKE – MIDDLE BASIN

2023 Surface Water Quality Summary

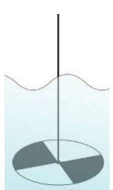
Nutrients:
June-Sept. Average Total Phosphorus (15.4 µg/L)





Algae:
June-Sept. Average Chlorophyll-a (5.6, µg/L)

Clarity:
June-Sept. Average Secchi Depth (9.0, ft)

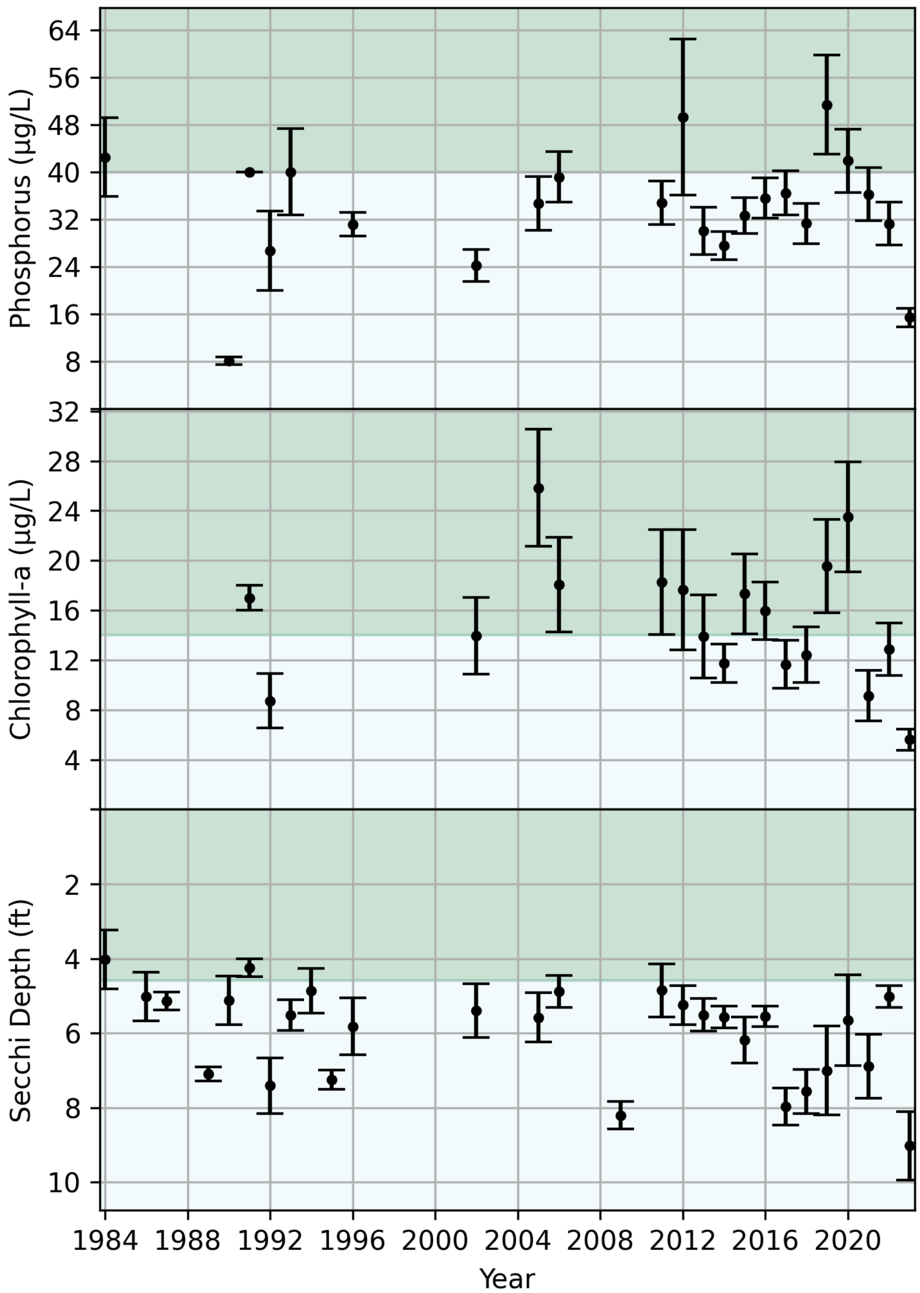


Water quality improved in 2023 compared to 2022 and all water quality parameters are meeting the state standards. It is important to note that there is a precipitous increase in the orthophosphate collected from the bottom of the lake which is evidence of internal loading. An alum treatment was performed in late September which drastically reduced the orthophosphate concentrations at the lake bottom.

FOREST LAKE – MIDDLE BASIN

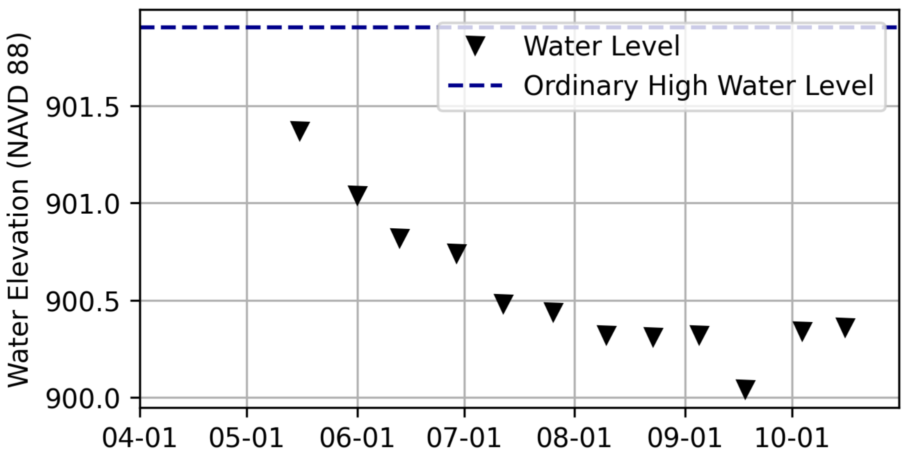
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**34.2**	**14.1**	**6.5**
2040 District Goal	<30	n/a	>7.0
5-year Average (2019-2023)	**36.7**	**14.5**	**6.7**



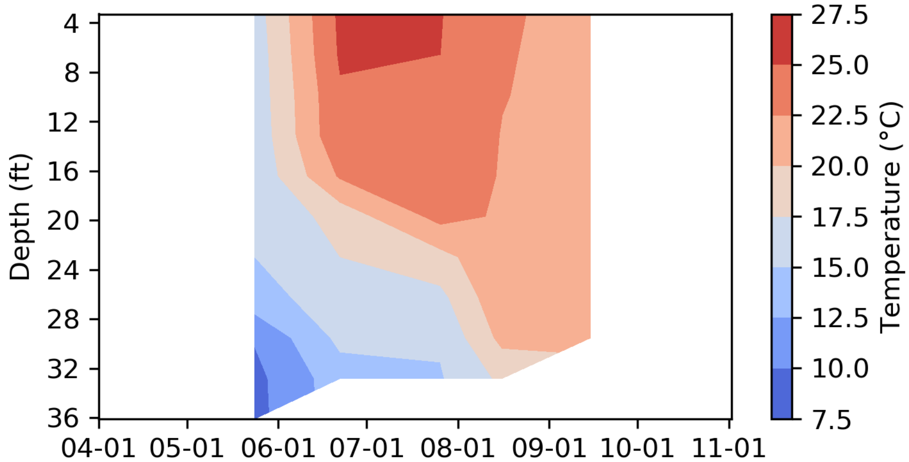
Historic TP averages are meeting state standards but not meeting District goals. Historic chlorophyll-a averages are not meeting state standards nor District goals. Historic Secchi depth averages are meeting both state standards and District goals. Data from 2023 showed improved water quality in each water quality parameter and all parameters are meeting water quality standards. An alum treatment was completed in this basin in the Fall 2023 that should help to continue this recent trend into the future.

FOREST LAKE – MIDDLE BASIN



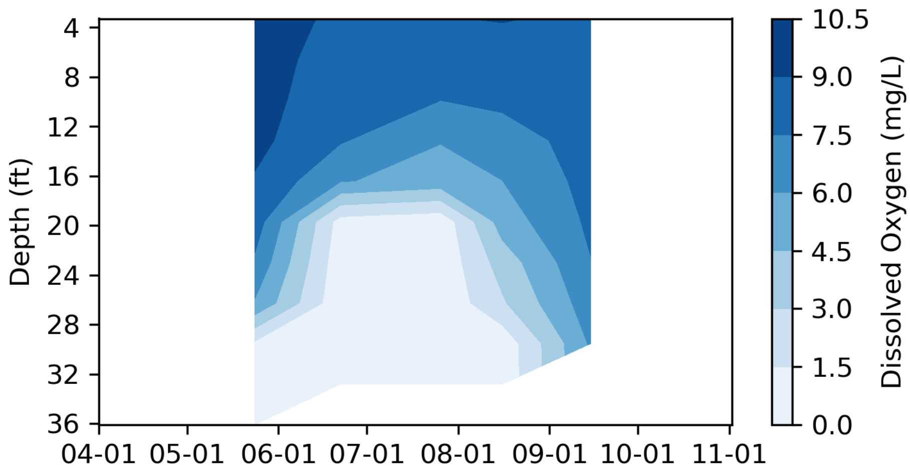
2023 Lake Levels

Lake levels ranged over a total of 1.3 feet; between a minimum of 900.04 feet on September 18, 2023 and a maximum of 901.4 feet on May 16, 2023.



2023 Temperature Profiles

The lake was stratified from mid June until mid-August leading to lake turnover during the growing season.



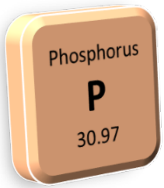
2023 Dissolved Oxygen Profiles

Internal loading was possible from late May until late August. Bottom P concentrations increased to high levels by July.

FOREST LAKE – EAST BASIN

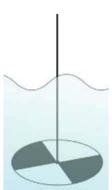
2023 Surface Water Quality Summary

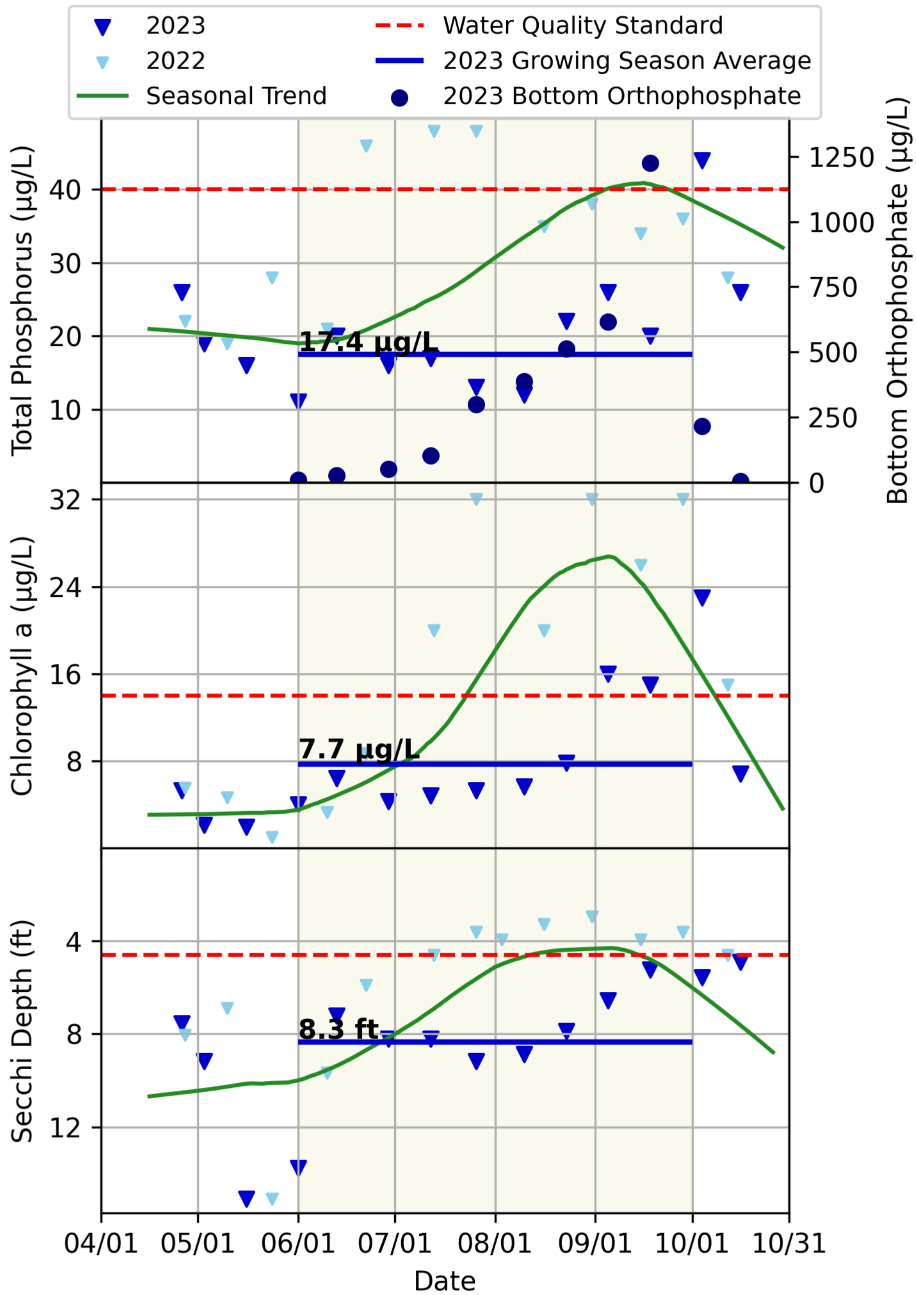
Nutrients:
June-Sept. Average Total Phosphorus (17.4 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (7.7, µg/L)

Clarity:
June-Sept. Average Secchi Depth (8,3 ft)



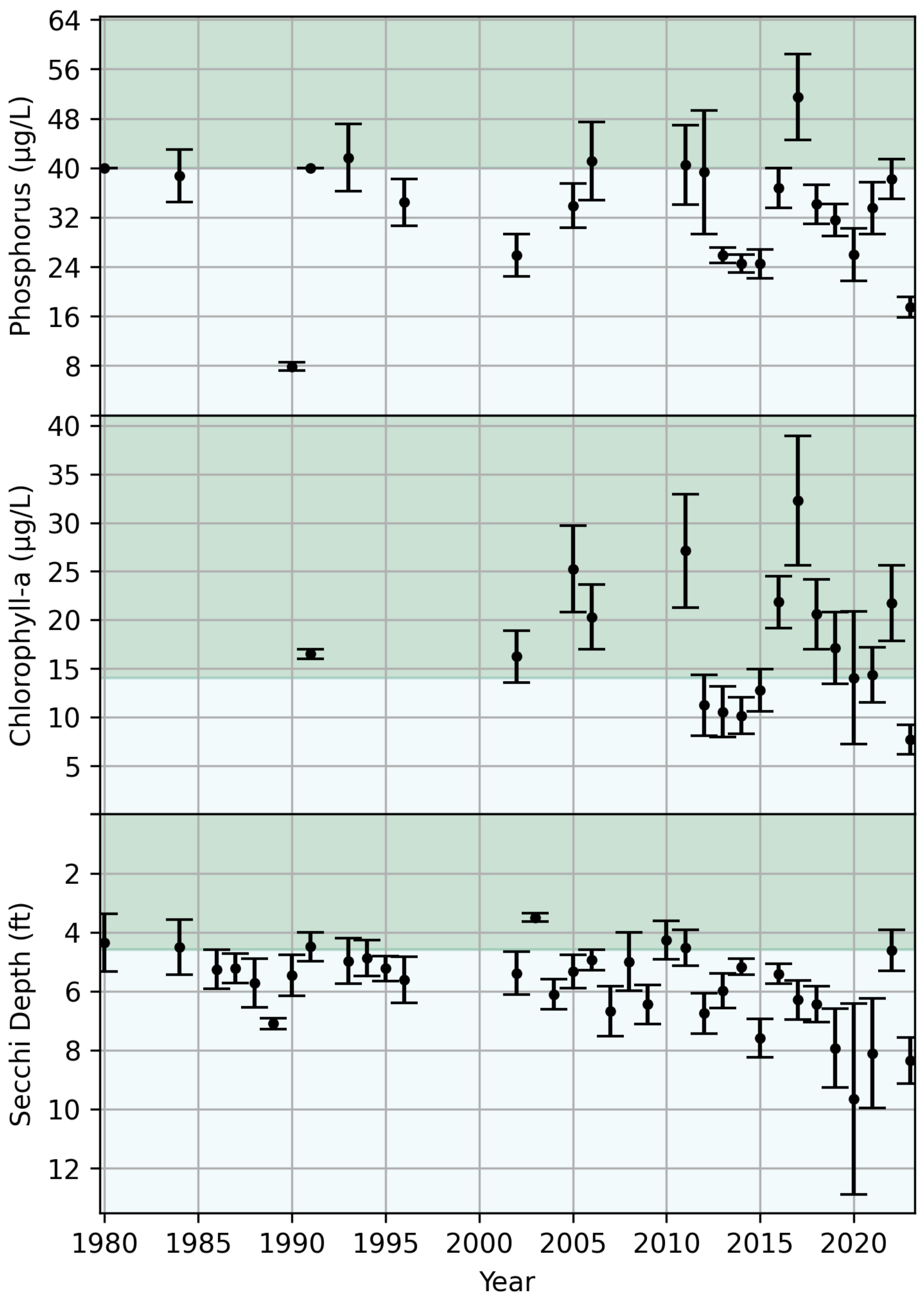


The 2023 growing season averages are all meeting state standards. In general, all water quality parameters are improved compared to 2022. However, orthophosphate concentration measure from the bottom water precipitously increased through the season. In late September, there appears to be an exchange between the bottom lake layer and the surface layer which mixed high orthophosphate concentrations from the bottom of the lake to the

FOREST LAKE – EAST BASIN

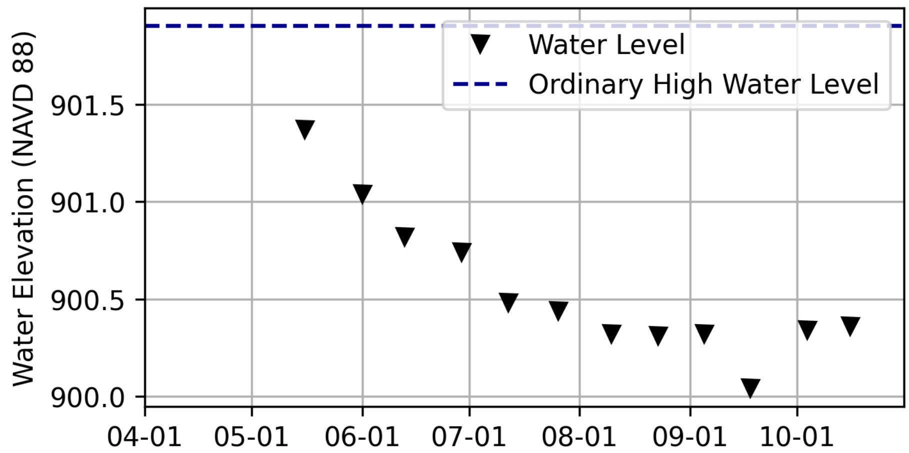
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**34.2**	**19.3**	**6.6**
2040 District Goal	<30	n/a	>7.0
5-year Average (2019-2023)	**29.6**	**15.1**	**7.6**



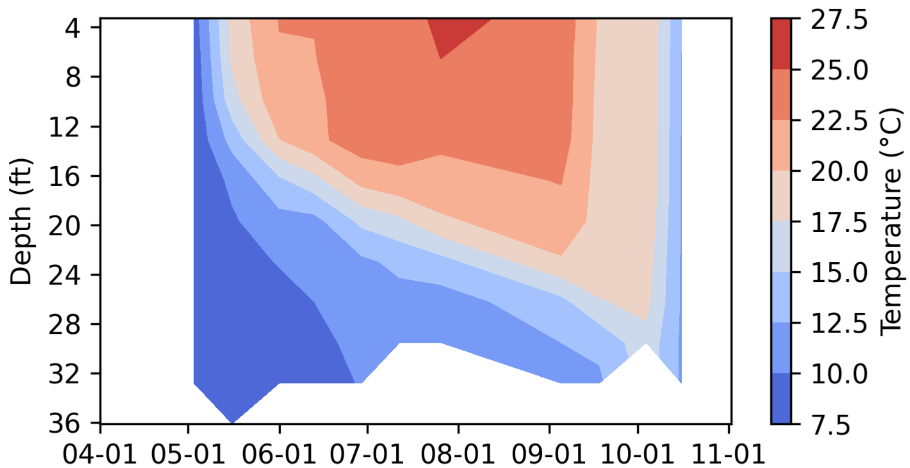
The 5 year average data is improved compared to the 10 year average data and is meeting state standards and District goals for TP and Secchi depth. Historic Chlorophyll-a averages are not meeting water quality standards. The 2023 water quality has improved compared to 2022 and is meeting the state water quality standards.

FOREST LAKE – EAST BASIN



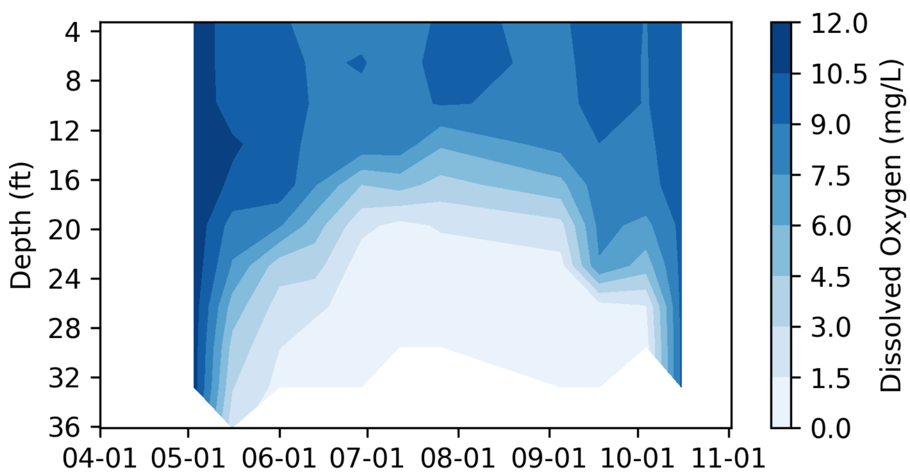
2023 Lake Levels

Lake levels ranged over a total of 1.3 feet; between a minimum of 900.04 feet on September 18, 2022 and a maximum of 901.4 feet on May 16, 2023.



2023 Temperature Profiles

The lake was stratified starting in June until October when the lake destratifies.



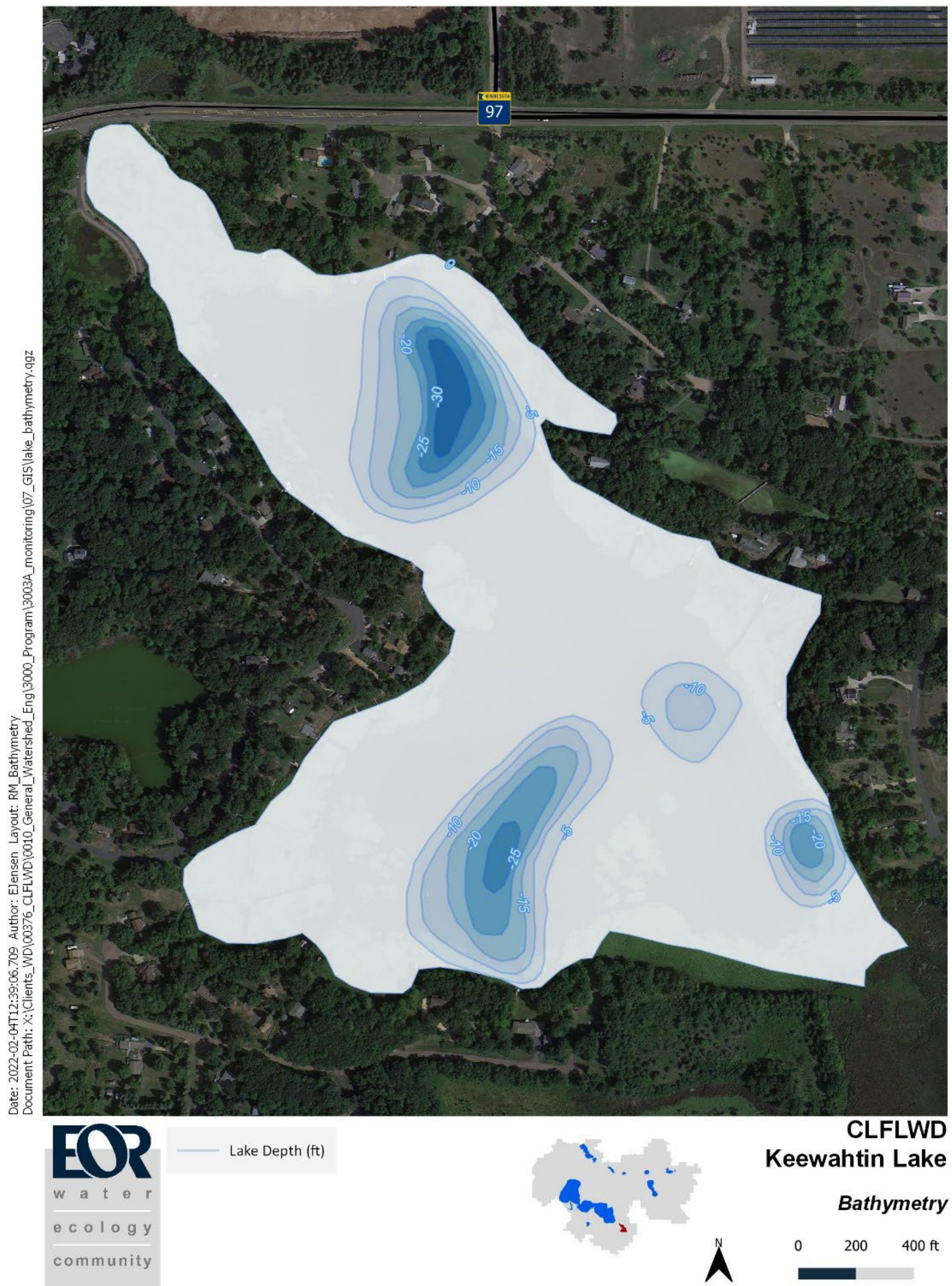
2023 Dissolved Oxygen Profiles

Internal loading was possible starting in June until mid October. Bottom P concentrations increased until October.

KEEWAHTIN LAKE

Fast Facts:

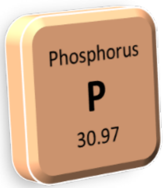
DNR Lake ID: 82-0080-00
County: Washington
Surface Area: 92 acres
Littoral Area (depths less than 15 feet): 67 acres
Maximum Depth: 34 feet
Shore Length: 2.2 miles
DNR Shoreland Classification: Recreational Development



KEEWAHTIN LAKE

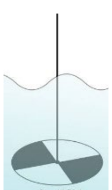
2023 Surface Water Quality Summary

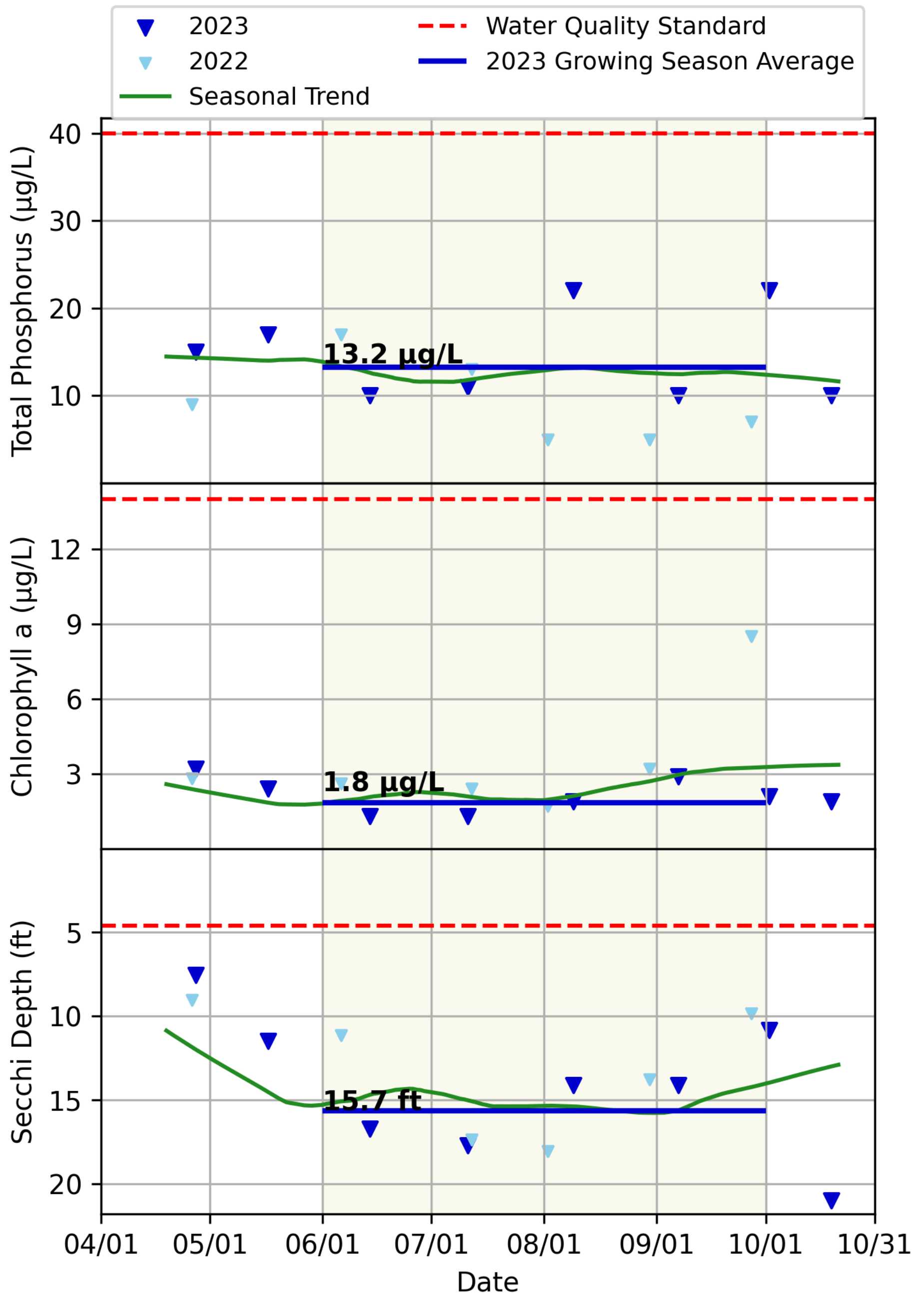
Nutrients:
June-Sept. Average Total Phosphorus (13.2 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (1.8 µg/L)

Clarity:
June-Sept. Average Secchi Depth (15.7, ft)



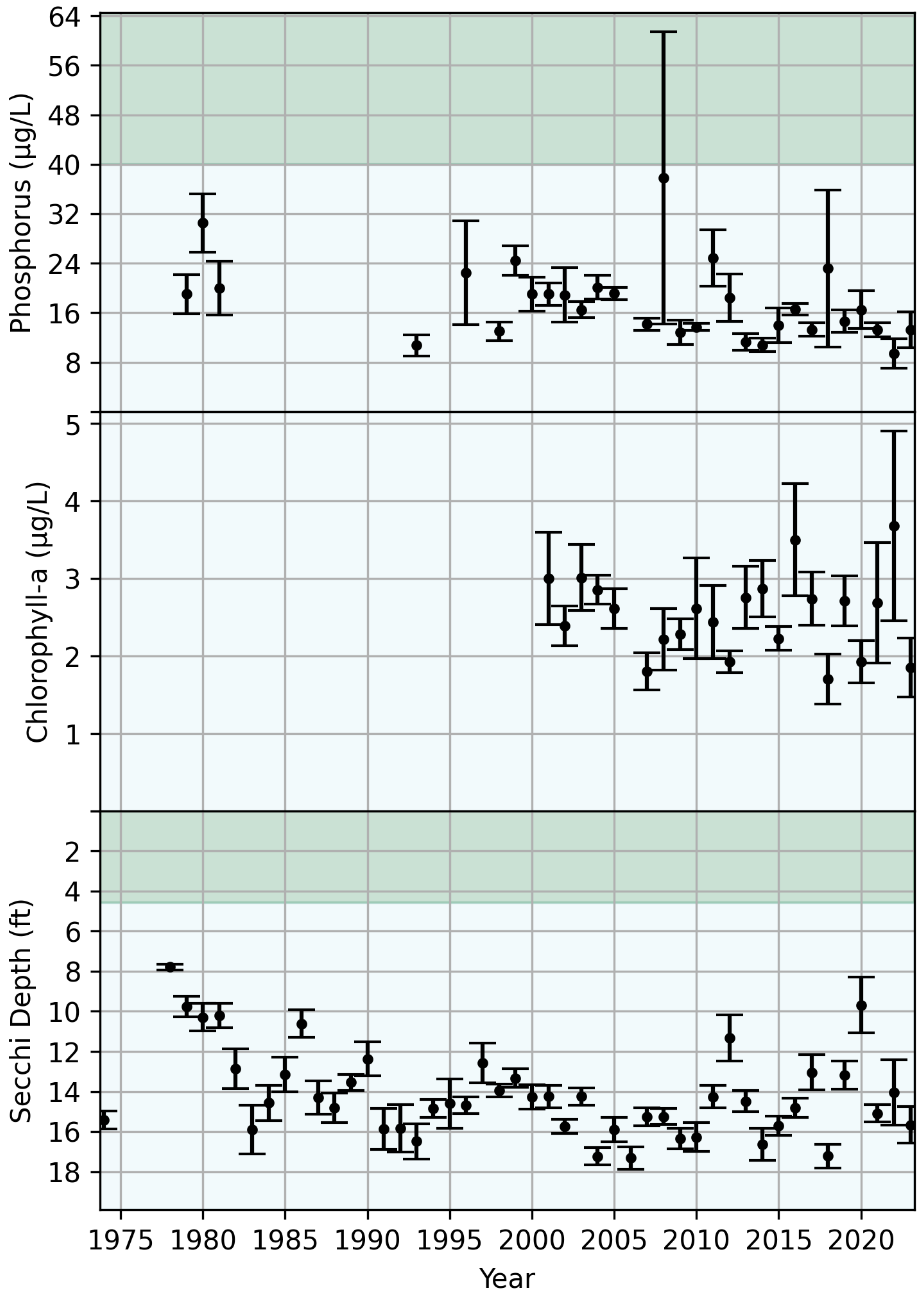


Water quality parameters were meeting the state water quality standards. Water quality was similar in 2023 and 2022. The water quality is consistent throughout the season.

KEEWAHTIN LAKE

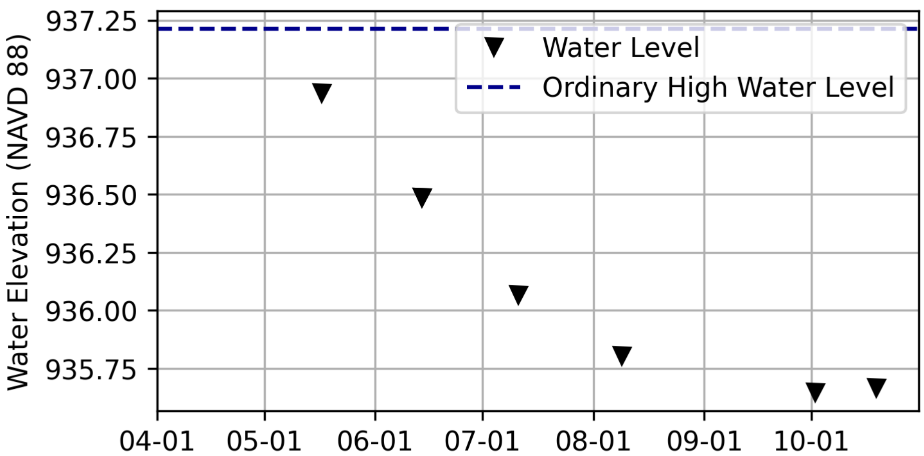
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**14.3**	**2.7**	**14.3**
2040 District Goal	<20	n/a	>10.0
5-year Average (2019-2023)	**14.0**	**2.6**	**12.7**



Historic water quality averages are meeting state standards and District goals. The 5 year averages show improved water quality compared to the 10 year averages. The 2023 data improved compared to 2022. The 2023 WQ is meeting the water quality standards.

KEEWAHTIN LAKE



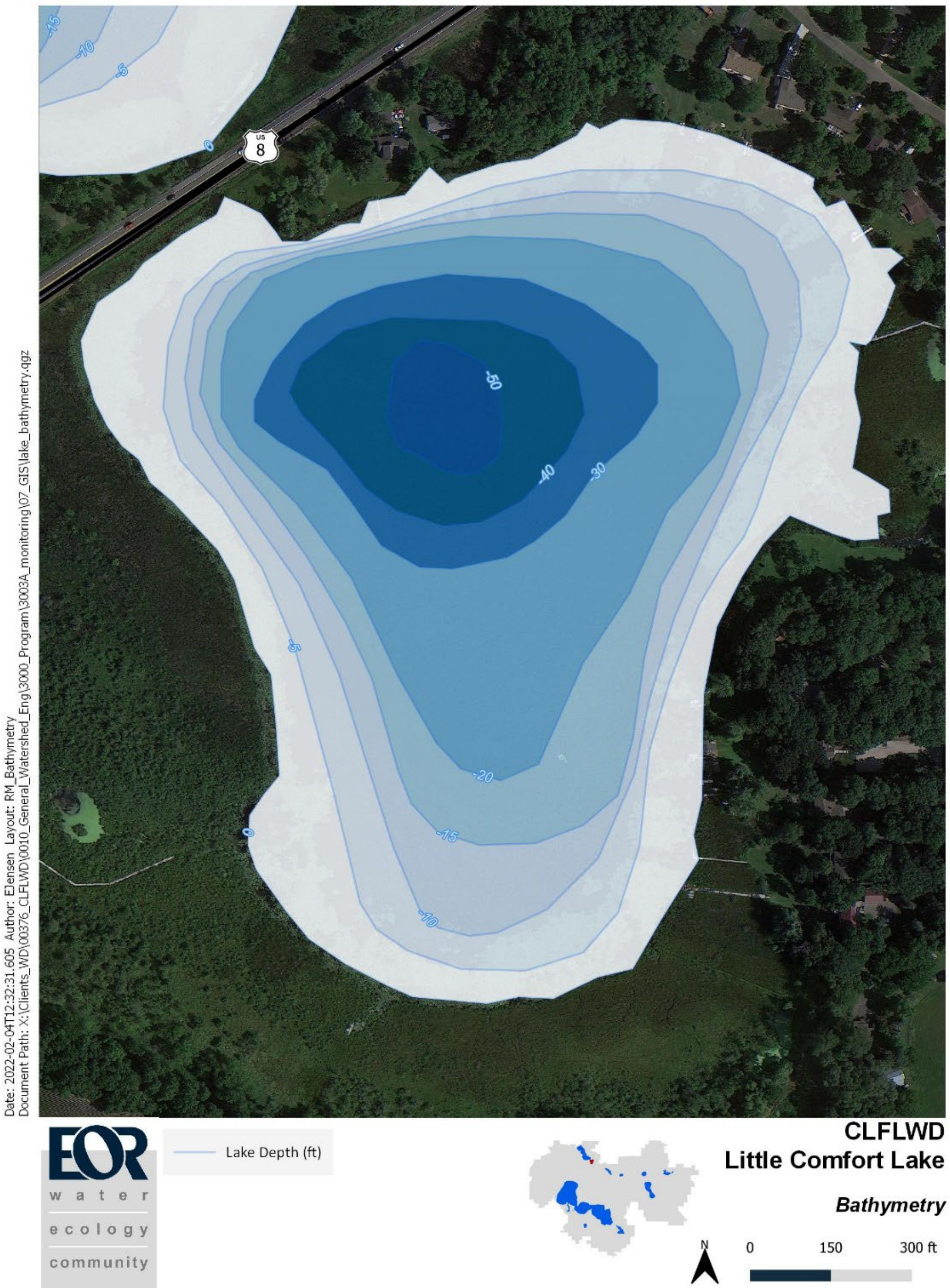
2023 Lake Levels

Lake levels ranged over a total of 1.3 feet; between a minimum of 935.6 feet on October 2, 2023, and a maximum of 936.9 feet on May 17, 2023.

4.3. LITTLE COMFORT LAKE

Fast Facts:

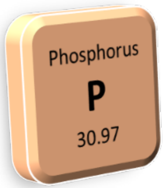
DNR Lake ID: 13-0054-00
County: Chisago
Surface Area: 37 acres
Littoral Area (depths less than 15 feet): 16 acres
Maximum Depth: 56 feet
Shore Length: 1.04 miles
DNR Shoreland Classification: General Development



LITTLE COMFORT LAKE

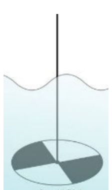
2023 Surface Water Quality Summary

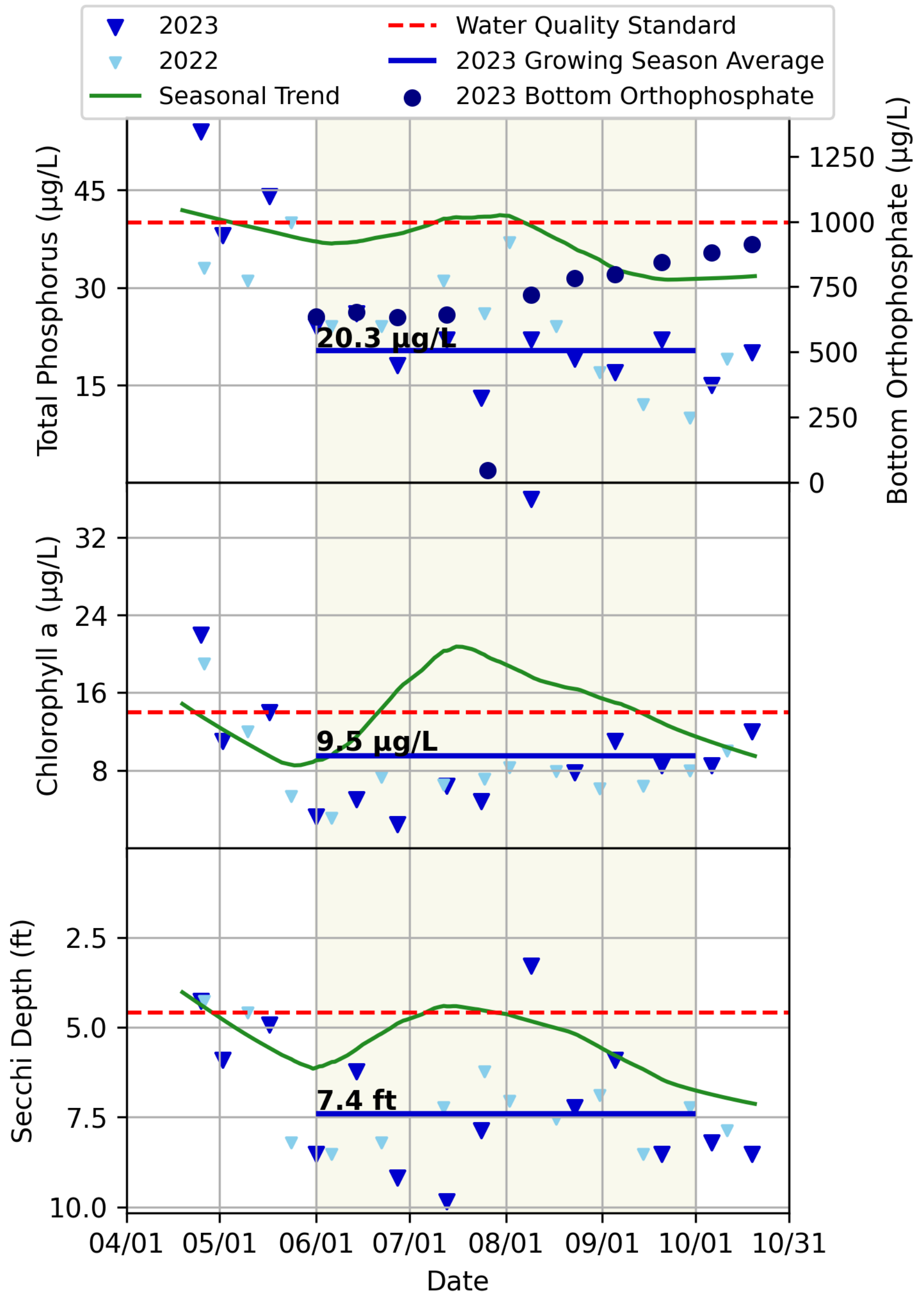
Nutrients:
June-Sept. Average Total Phosphorus (20.3 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (9.5 µg/L)

Clarity:
June-Sept. Average Secchi Depth (7.4 ft)



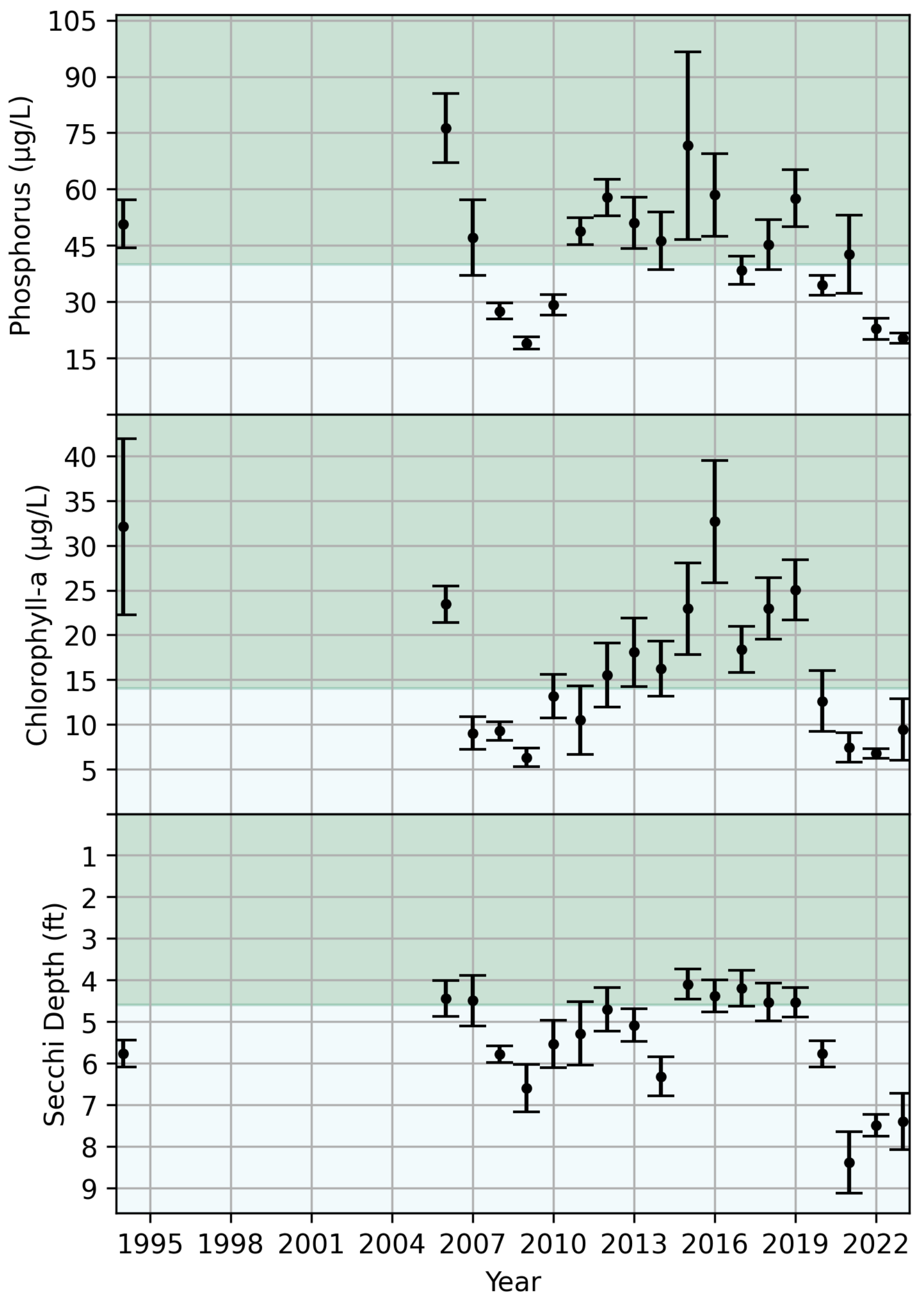


Water quality improved in 2023 compared to 2022 except in the beginning of the monitoring period and before the growing season when there is an influence from spring runoff. The growing season averages for all water quality parameters are meeting the state standards. It is important to note that there is a precipitous increase in the orthophosphate collected from the bottom of the lake which is evidence of internal loading.

LITTLE COMFORT LAKE

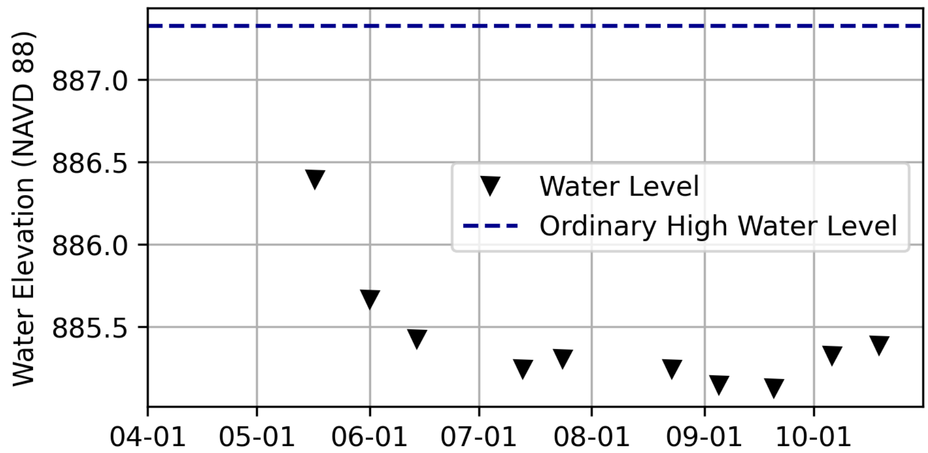
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**45.7**	**18.7**	**5.5**
2040 District Goal	<30	n/a	>7.0
5-year Average (2019-2023)	**36.7**	**12.8**	**6.7**



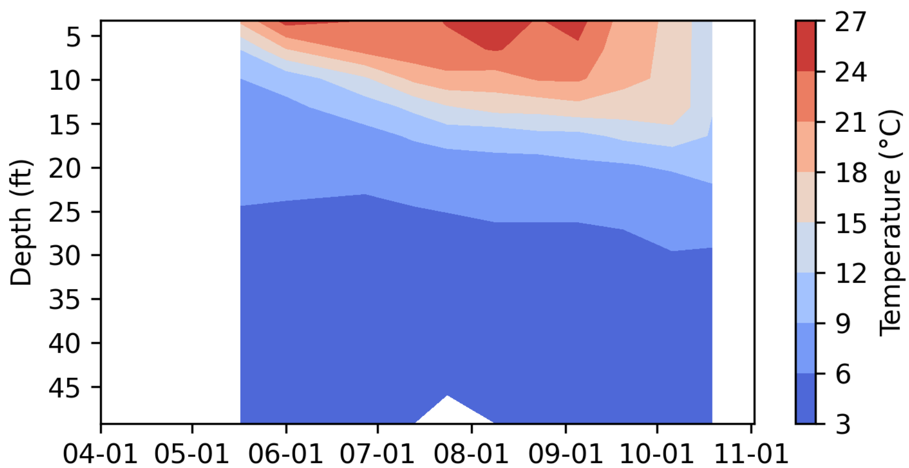
The 5 year averages show improved water quality compared to the 10 year averages. The 5 year water quality averages are meeting state standards and District goals. The 2023 data is similar to 2022.

LITTLE COMFORT LAKE



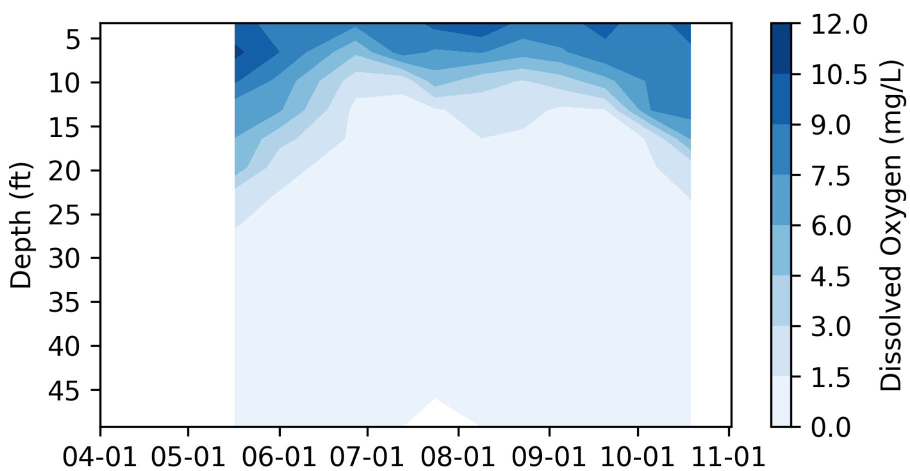
2023 Lake Levels

Lake levels ranged over a total of 1.3 feet; between a minimum of 885.1 feet on September 20, 2022 and a maximum of 886.4 feet on May 17, 2022 compared to the OHWL 887.2.



2023 Temperature Profiles

The lake was stratified for the entire monitoring season to fall turnover starting in mid-September.



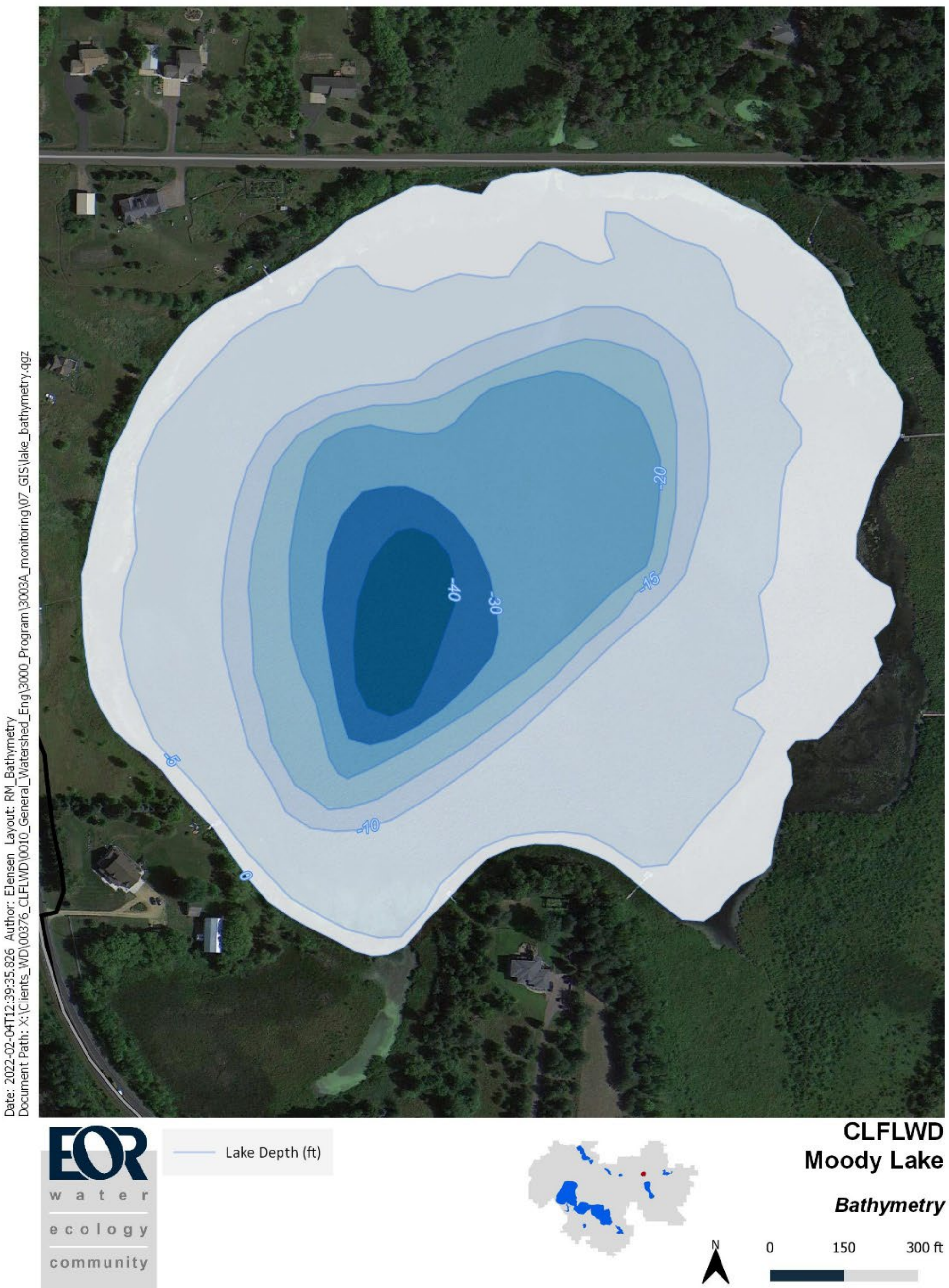
2023 Dissolved Oxygen Profiles

Internal loading was possible starting for the entire monitoring period. Bottom P concentrations increased throughout most of the monitoring season.

MOODY LAKE

Fast Facts:

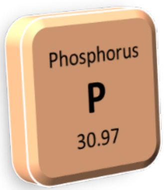
DNR Lake ID: 13-0023-00
County: Chisago
Surface Area: 45 acres
Littoral Area (depths less than 15 feet): 22 acres
Maximum Depth: 48 feet
Shore Length: 1.04 miles
DNR Shoreland Classification: Natural Environment



MOODY LAKE

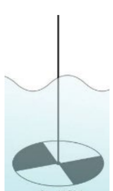
202 Surface Water Quality Summary

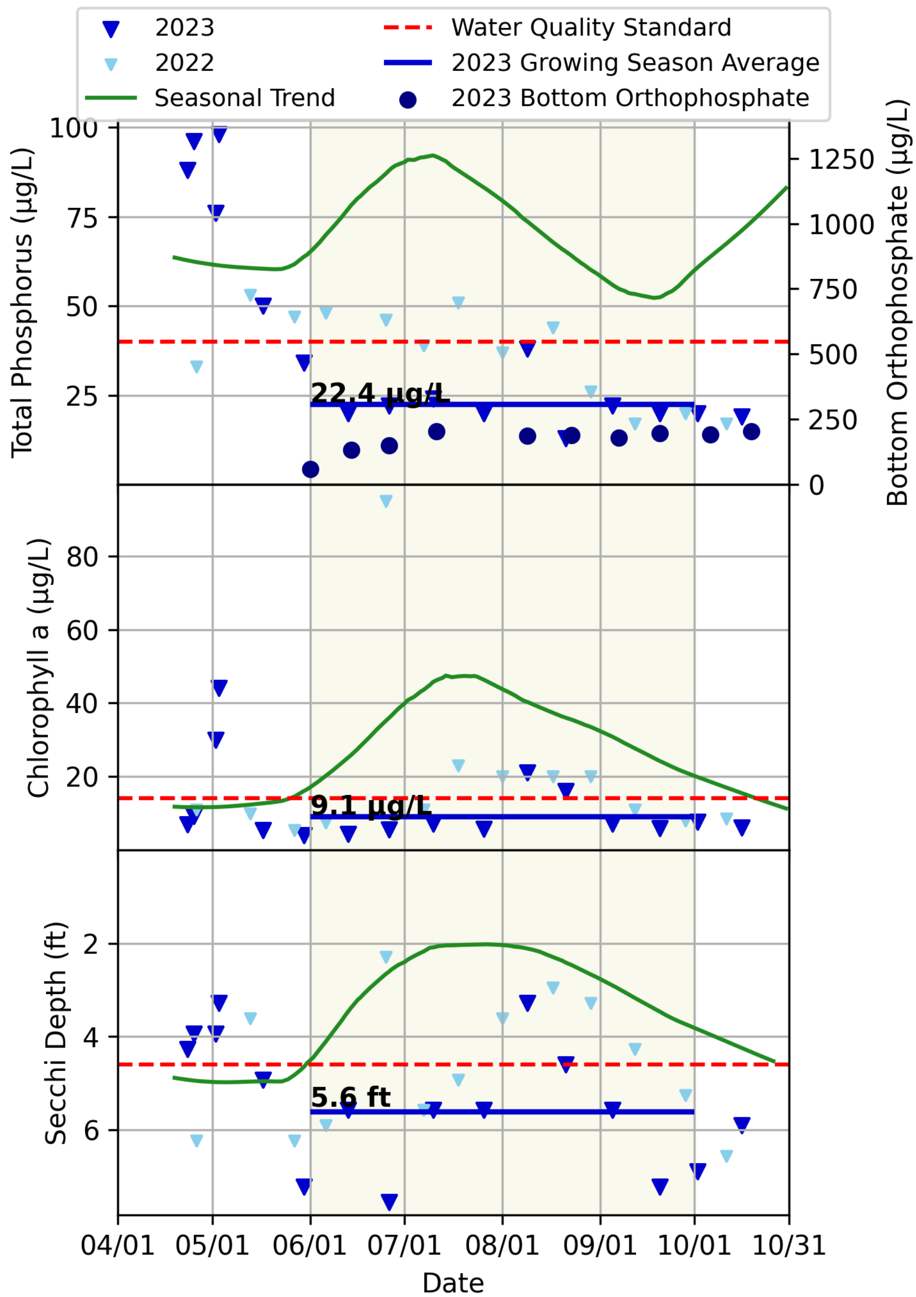
Nutrients:
June-Sept. Average Total Phosphorus (22.4 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (9.1 µg/L)

Clarity:
June-Sept. Average Secchi Depth (5.6 ft)



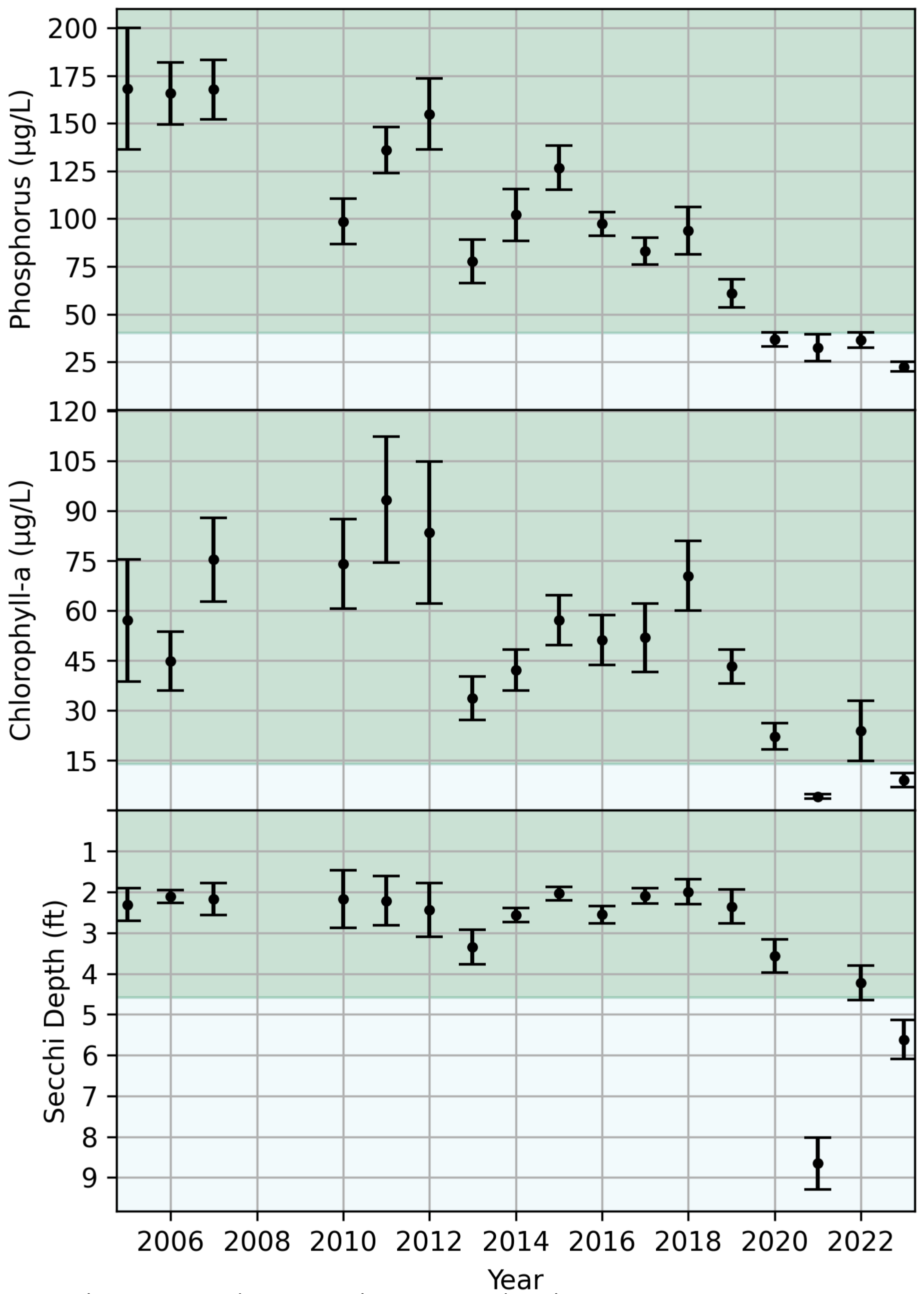


Water quality improved in 2023 compared to 2022, except in the beginning of the monitoring period and before the growing season when there is an influence from spring runoff. There is a mid-season peak of TP and chlorophyll-a which lead to decreased water clarity in August, however conditions improved by the end of August. The growing season averages for all water quality parameters are meeting the state standards.

MOODY LAKE

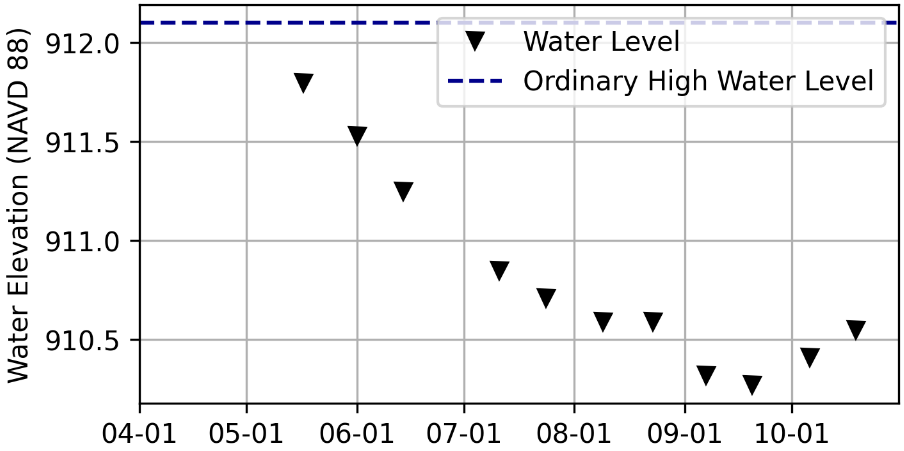
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<40	<14	>4.6
10-year Average (2014-2023)	**78.2**	**42.2**	**3.1**
2040 District Goal	<40	n/a	>4.6
5-year Average (2019-2023)	**39.8**	**22.6**	**4.7**



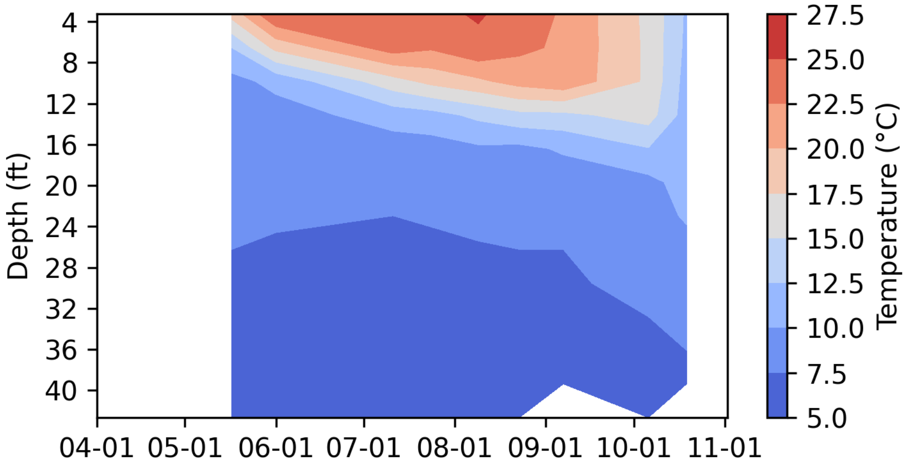
The 5 year averages show improved water quality compared to the 10 year averages. 5 year water quality average is meeting state standards and District goals for TP. The 2023 data is improved compared to 2022. The 2023 WQ is meeting the water quality standards.

MOODY LAKE



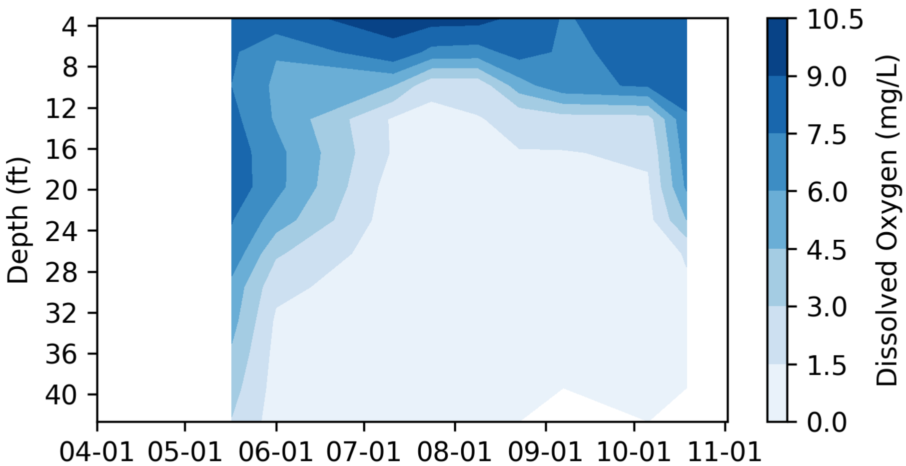
2023 Lake Levels

Lake levels ranged over a total of 1 foot; between a minimum of 910.8 feet on October 11, 2022 and a maximum of 911.80 feet on May 24, 2022.



2023 Temperature Profiles

The lake was stratified starting in June until fall turnover is observed in October.



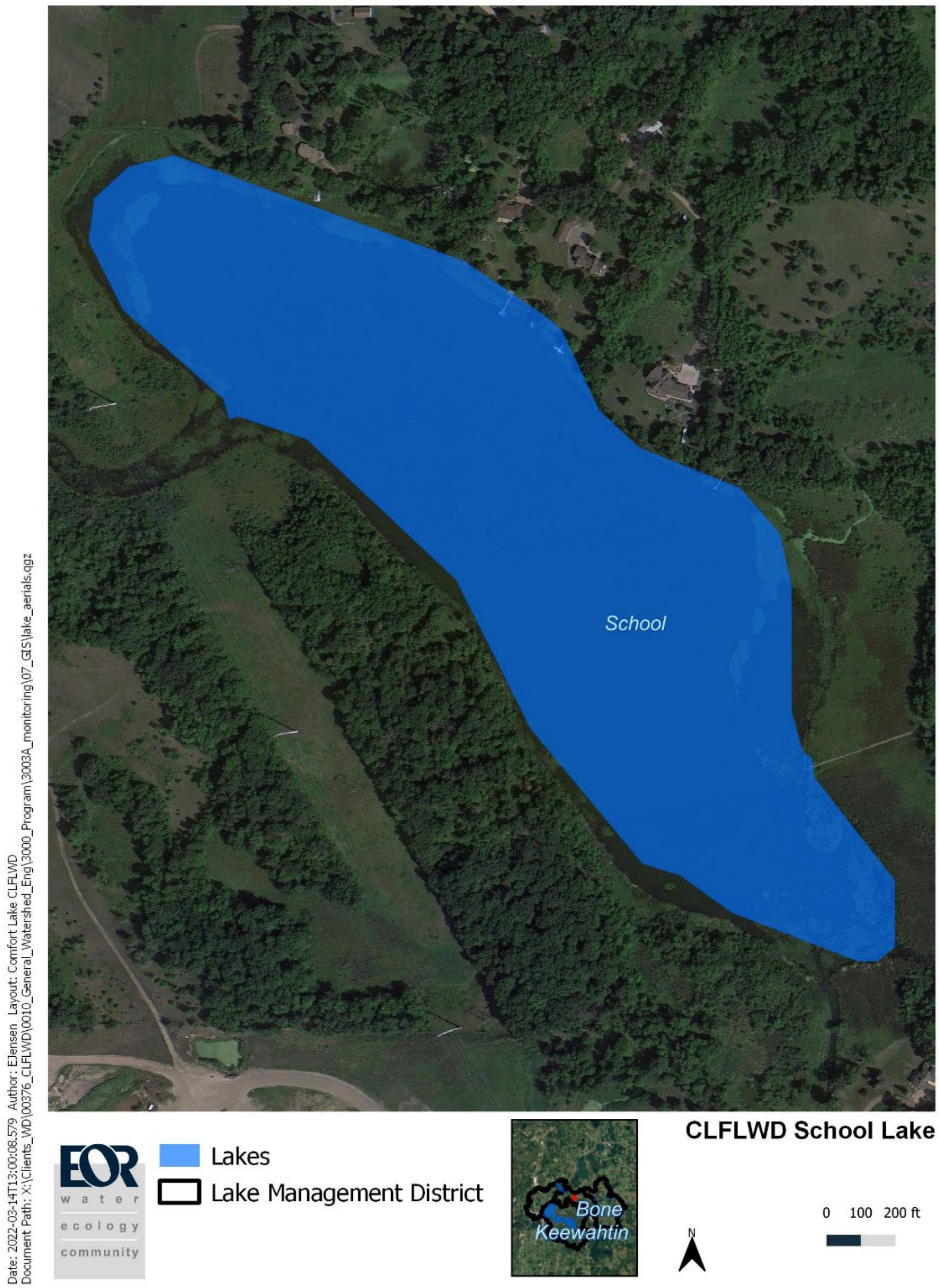
2023 Dissolved Oxygen Profiles

Internal loading was possible starting in late-May, but bottom P concentrations remained relatively low but have increased compared to 2022.

SCHOOL LAKE

Fast Facts:

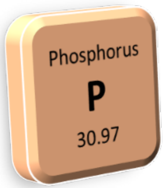
DNR Lake ID: 13-0044-00
County: Chisago
Surface Area: 49 acres
Littoral Area (depths less than 15 feet): 32 acres
Maximum Depth: 24 feet
Shore Length: 1.36 miles
DNR Shoreland Classification: Natural Environment



SCHOOL LAKE

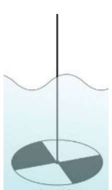
2023 Surface Water Quality Summary

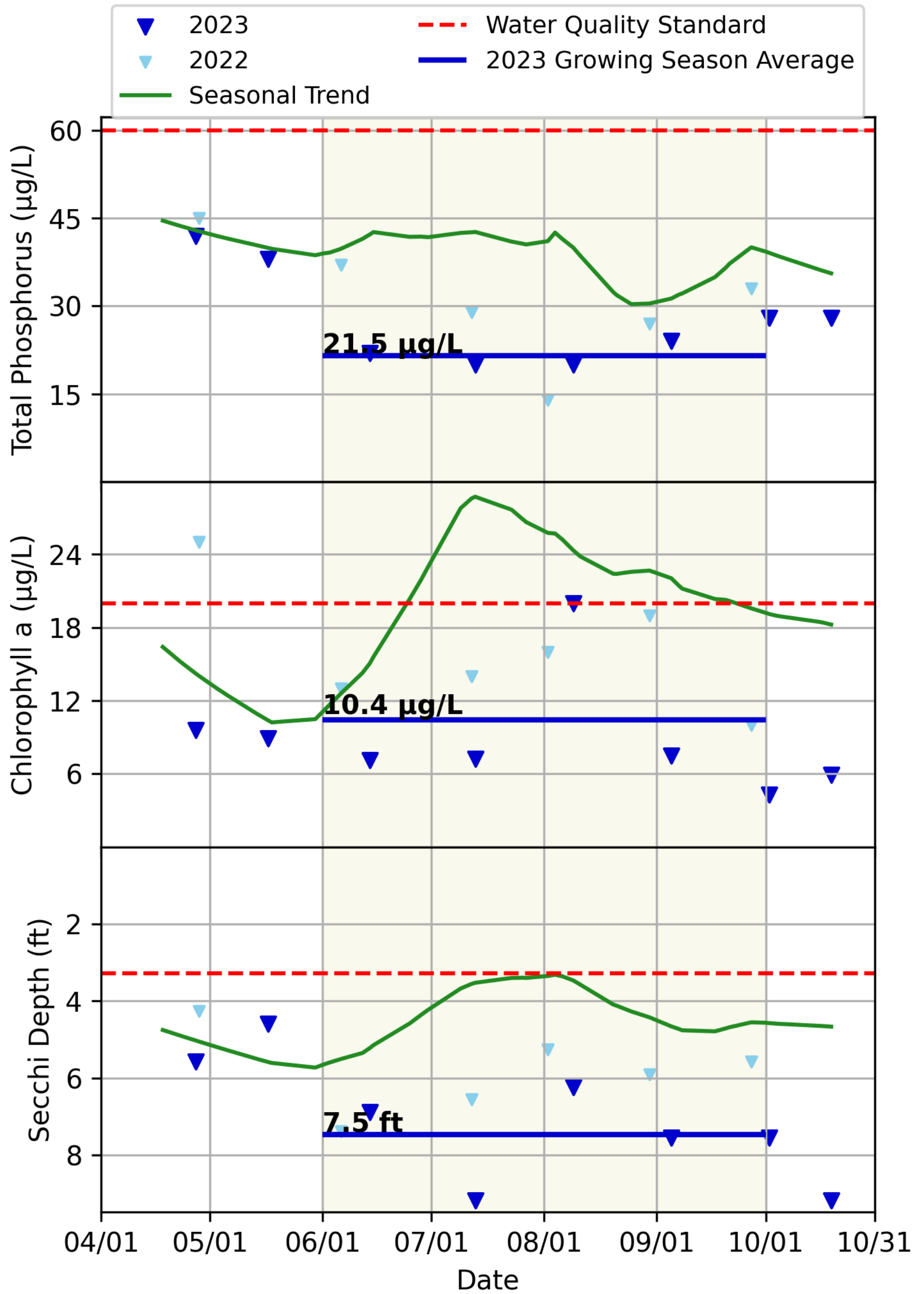
Nutrients:
June-Sept. Average Total Phosphorus (21.5 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (10.4 µg/L)

Clarity:
June-Sept. Average Secchi Depth (7.5 ft)



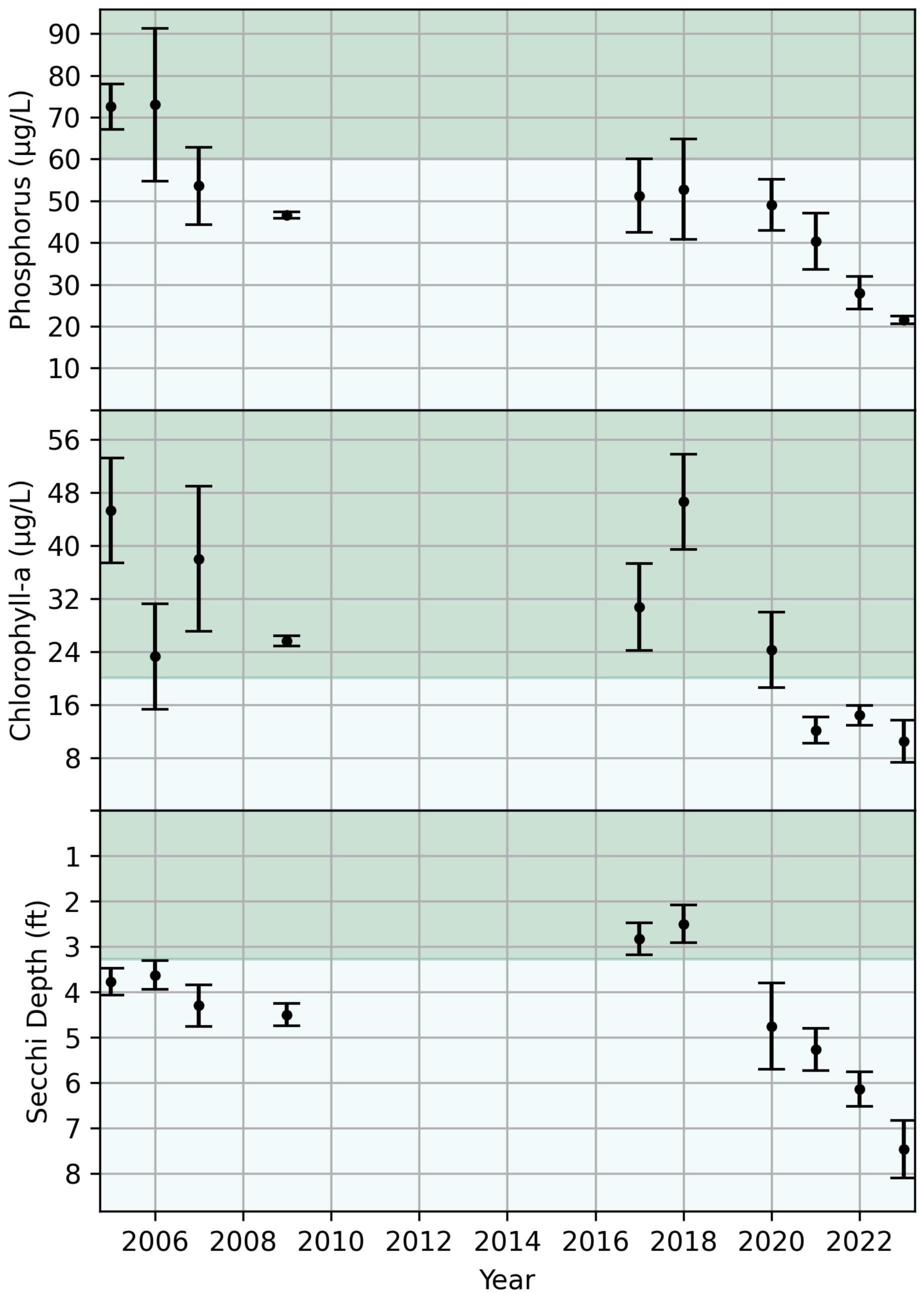


All water quality parameters were meeting the state water quality standards. Water quality was similar in 2023 and 2022.

SCHOOL LAKE

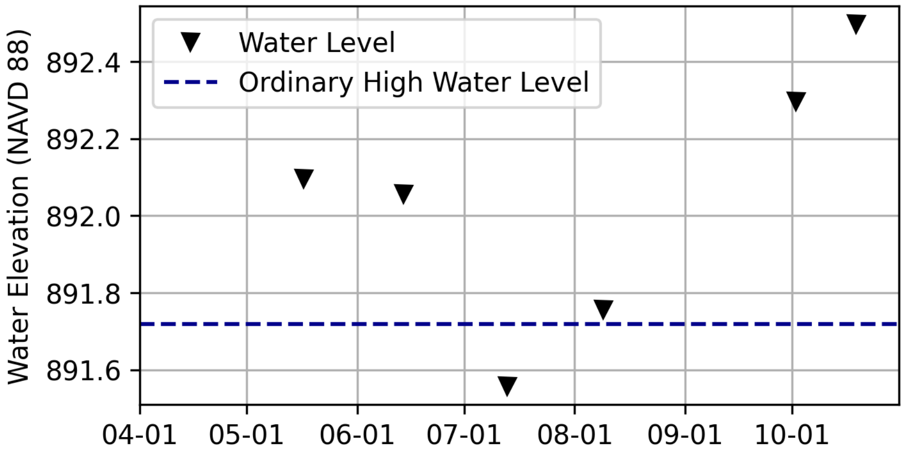
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<60	<20	>3.3
10-year Average (2014-2023)	**42.8**	**24.9**	**4.4**
2040 District Goal	<60	n/a	>3.3
5-year Average (2019-2023)	**35.7**	**14.6**	**5.8**



The 5 year historic water quality averages are meeting state standards and District goals. The 5 year averages show improved water quality compared to the 10 year averages. 2023 data is improved compared to 2022.

SCHOOL LAKE



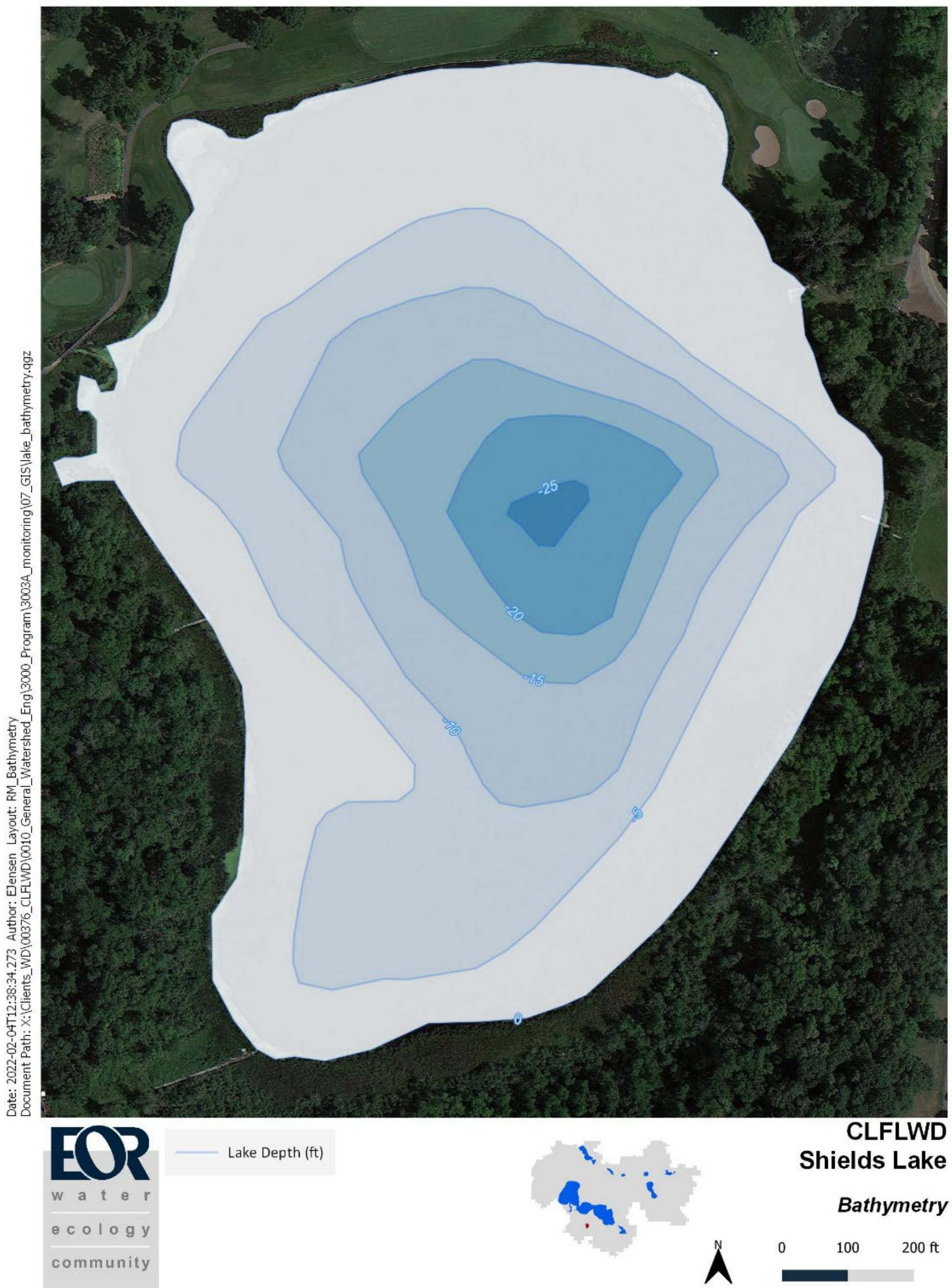
2023 Lake Levels

Lake levels ranged over a total of 0.9 feet; between a minimum of 891.6 feet on July 13, 2023, and a maximum of 892.5 feet on October 19, 2023 (due to beaver activity near the lake outflow).

SHIELDS LAKE

Fast Facts:

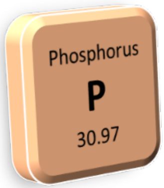
DNR Lake ID: 82-0162-00
County: Washington
Surface Area: 30 acres
Littoral Area (depths less than 15 feet): 22 acres
Maximum Depth: 27 feet
Shore Length: 0.85 miles
DNR Shoreland Classification: Natural Environment



SHIELDS LAKE

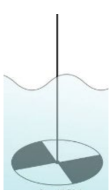
2023 Surface Water Quality Summary

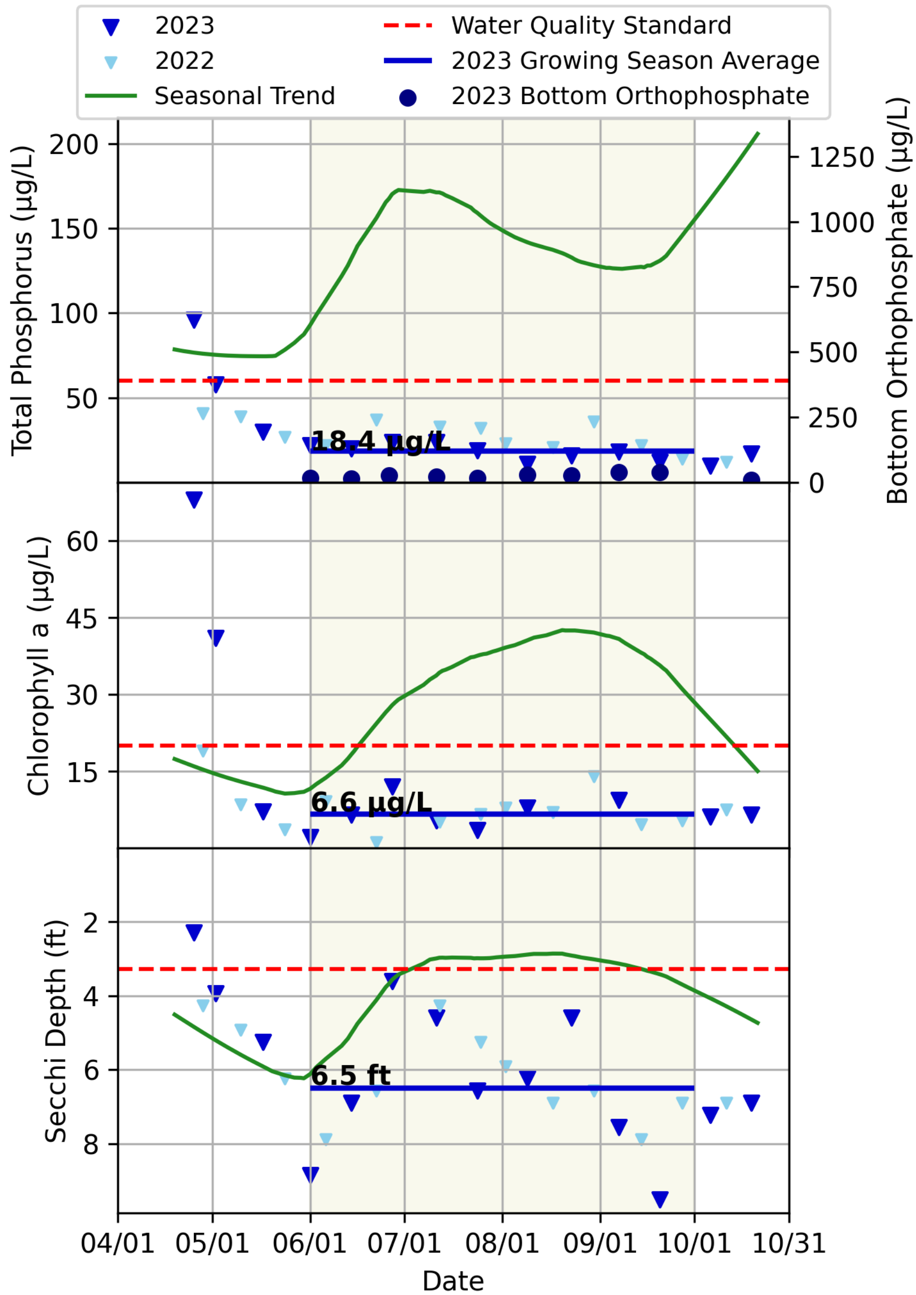
Nutrients:
June-Sept. Average Total Phosphorus (18.4 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (6.6 µg/L)

Clarity:
June-Sept. Average Secchi Depth (6.5 ft)



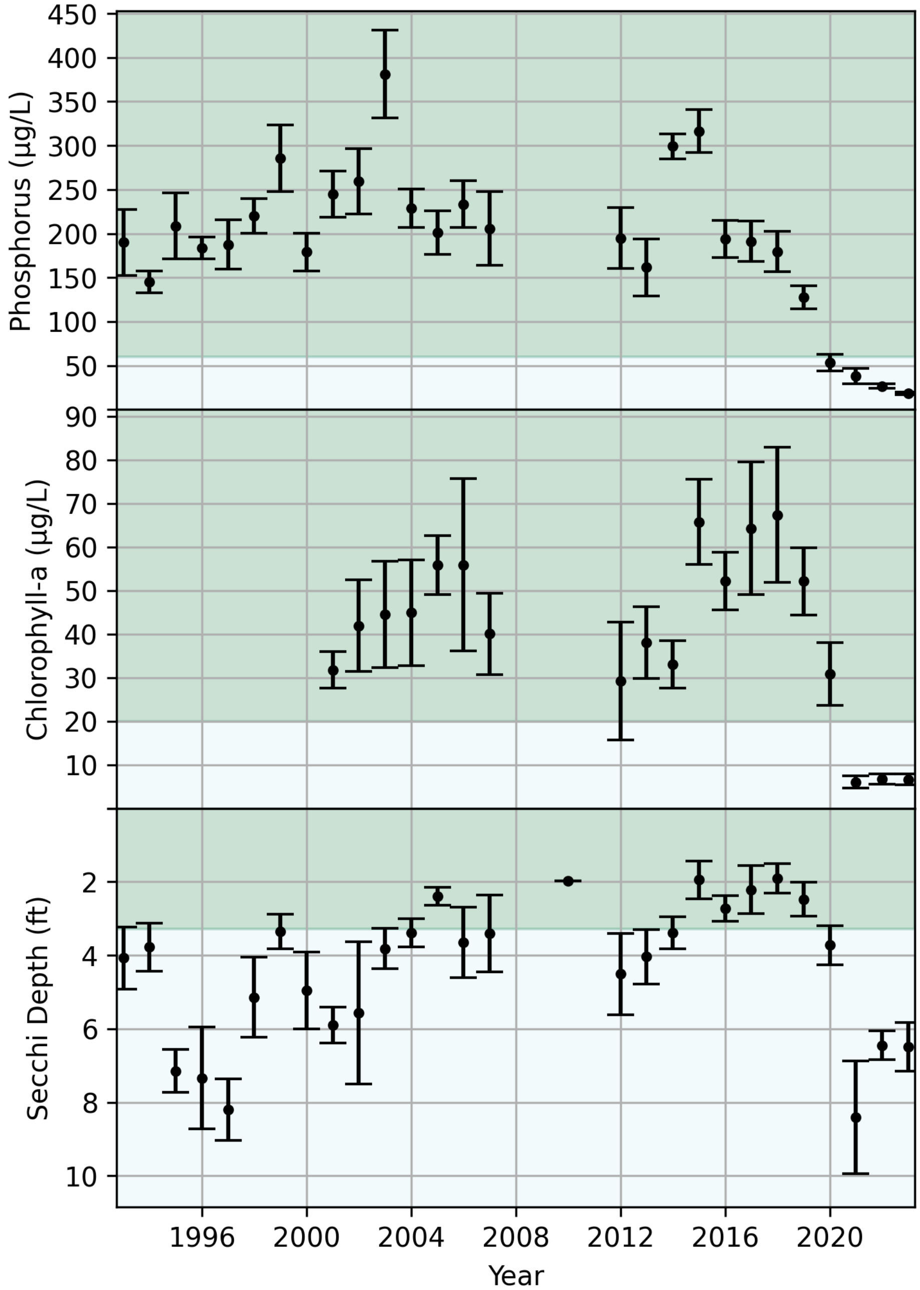


Water quality parameters are similar in 2023 compared to 2022, except in the beginning of the monitoring period and before the growing season when there is an influence from spring runoff. The growing season averages for all water quality parameters are meeting the state standards. Orthophosphate concentrations remained low.

SHIELDS LAKE

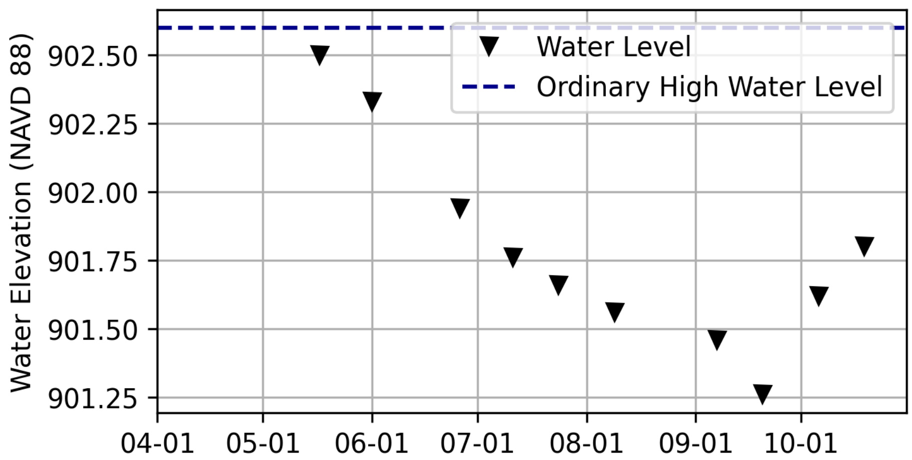
Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<60	<20	>3.3
10-year Average (2014-2023)	**146.1**	**39.1**	**4.0**
2040 District Goal	<60	n/a	>4.3
5-year Average (2019-2023)	**52.9**	**20.6**	**5.6**



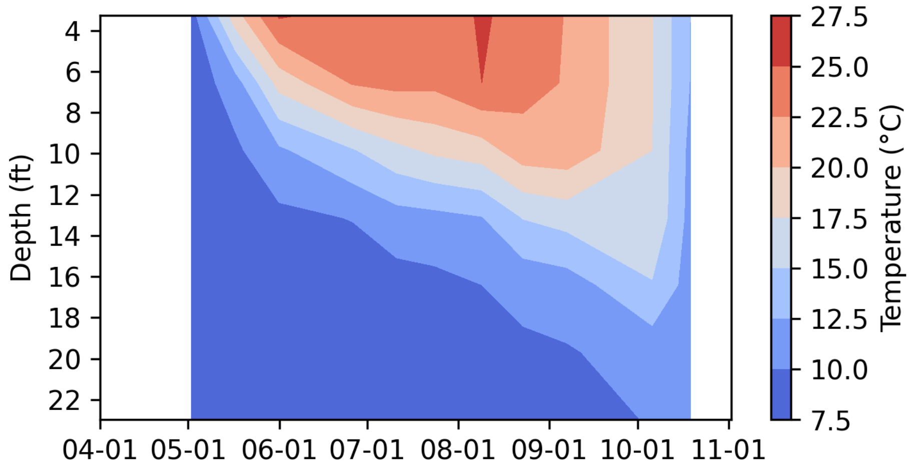
The 5 year averages show improved water quality compared to the 10 year averages. The 5 year water quality averages are nearly meeting state standards and District goals. The 2023 conditions were similar to that of 2022.

SHIELDS LAKE



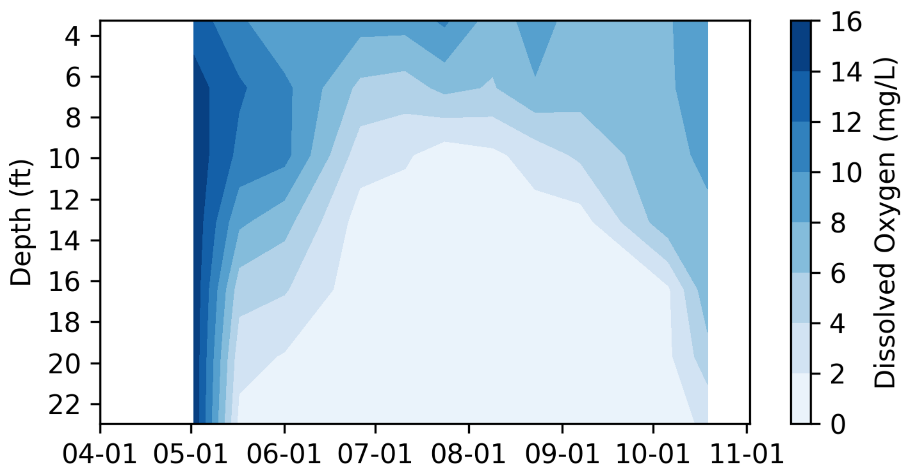
2023 Lake Levels

Lake levels ranged over a total of 1.2 feet; between a minimum of 901.3 feet on September 20, 2023 and a maximum of 902.5 feet on May 17, 2022.



2023 Temperature Profiles

The lake was stratified starting in mid-May until fall lake turnover is observed in mid October.



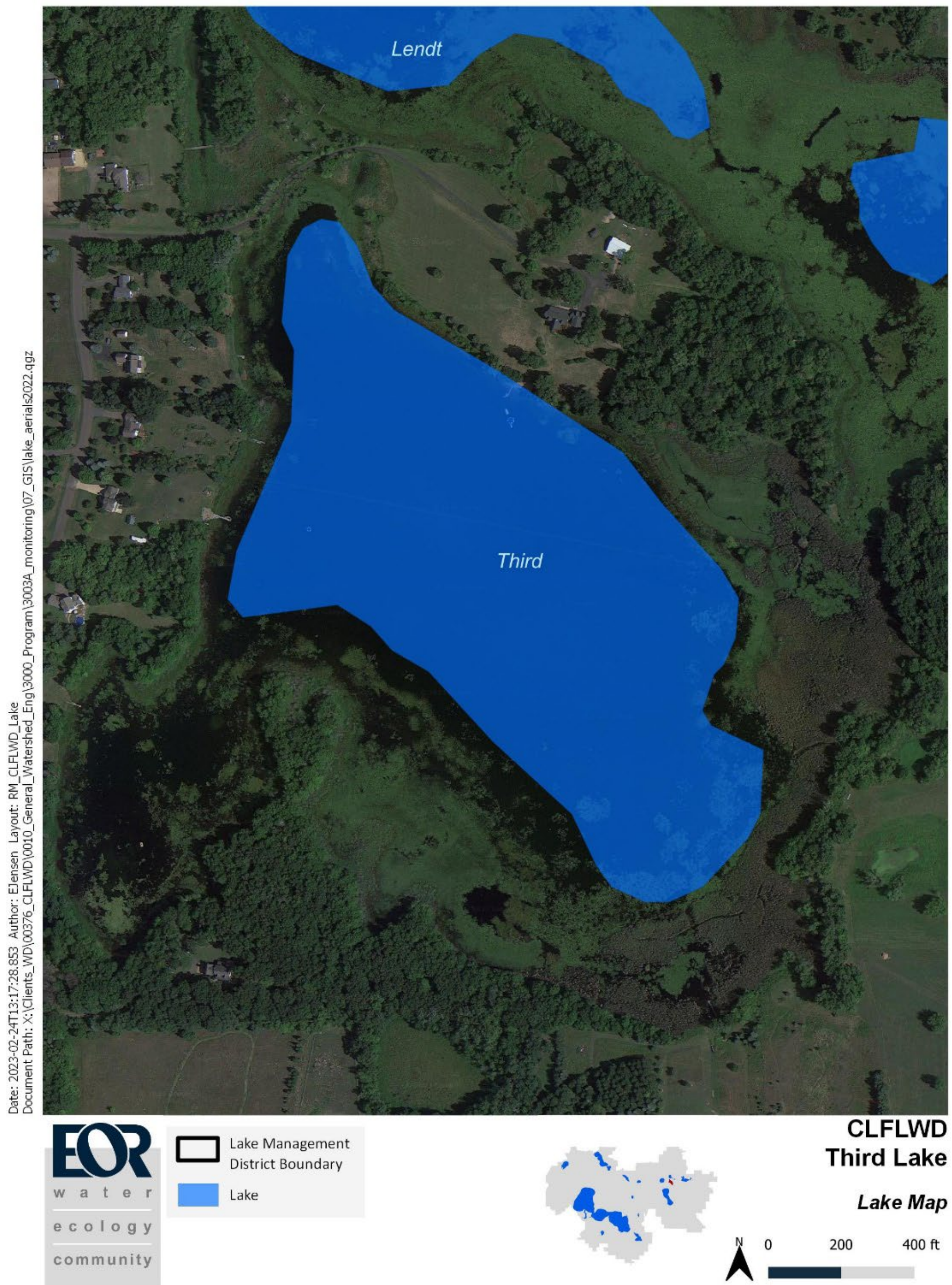
2023 Dissolved Oxygen Profiles

Internal loading was possible from Mid-May to late October but, bottom P concentrations remained low.

THIRD LAKE

Fast Facts:

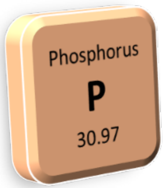
DNR Lake ID: 13-0024-00
County: Chisago
Surface Area: 42 acres
Littoral Area (depths less than 15 feet): NA acres
Maximum Depth: NA feet
Shore Length: NA miles
DNR Shoreland Classification: Natural Environment



THIRD LAKE

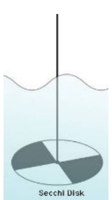
2023 Surface Water Quality Summary

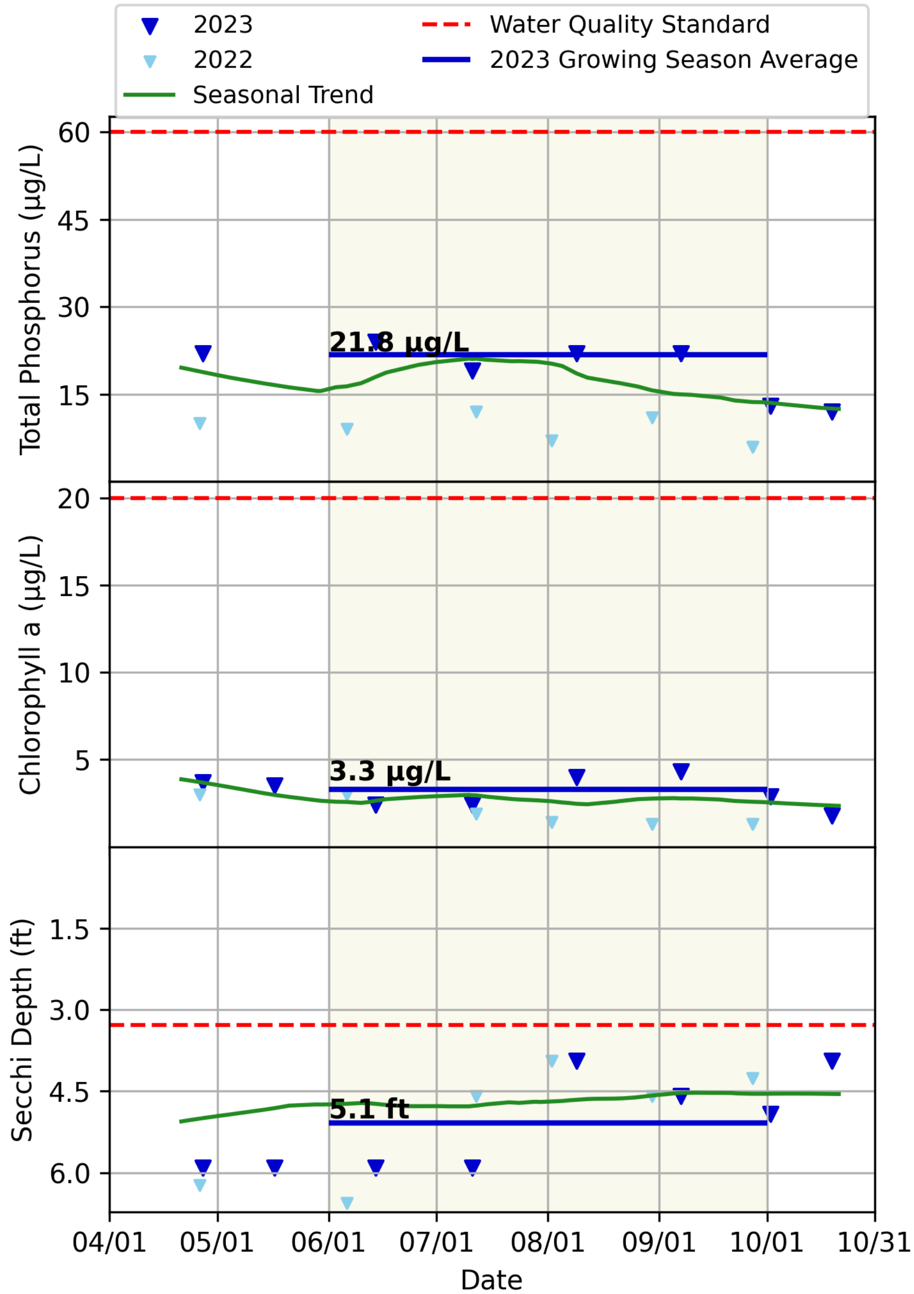
Nutrients:
June-Sept. Average Total Phosphorus (21.6 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (3.3 µg/L)

Clarity:
June-Sept. Average Secchi Depth (5.1 ft)



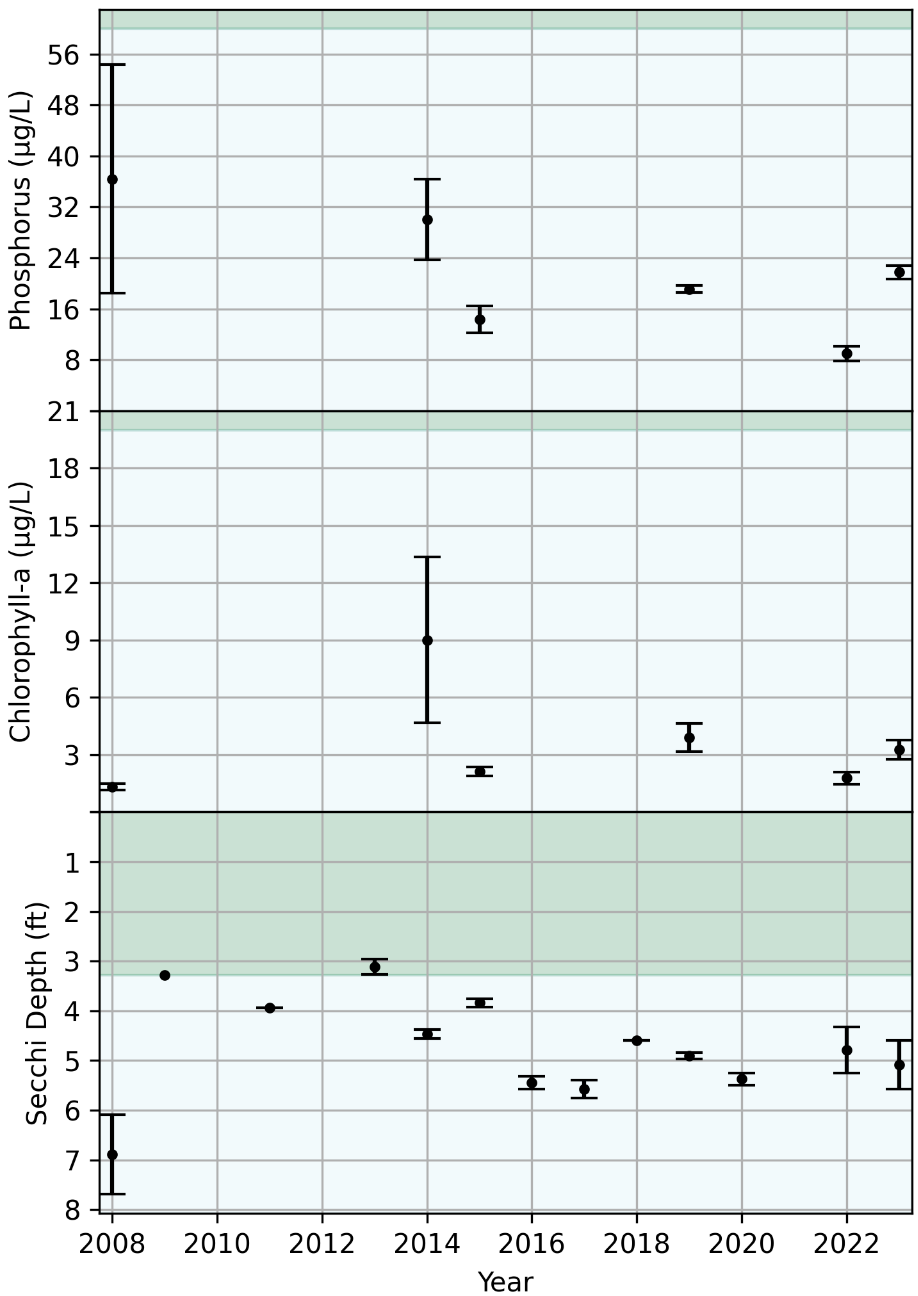


Water quality parameters were meeting the state water quality standards. Water quality was similar in 2023 and 2022. The water quality is consistent throughout the season.

THIRD LAKE

Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<60	<20	>3.3
10-year Average (2014-2023)	**19.5**	**4.4**	**4.7**
2040 District Goal	<60	n/a	>3.3
5-year Average (2019-2023)	**16.9**	**3.2**	**5.0**

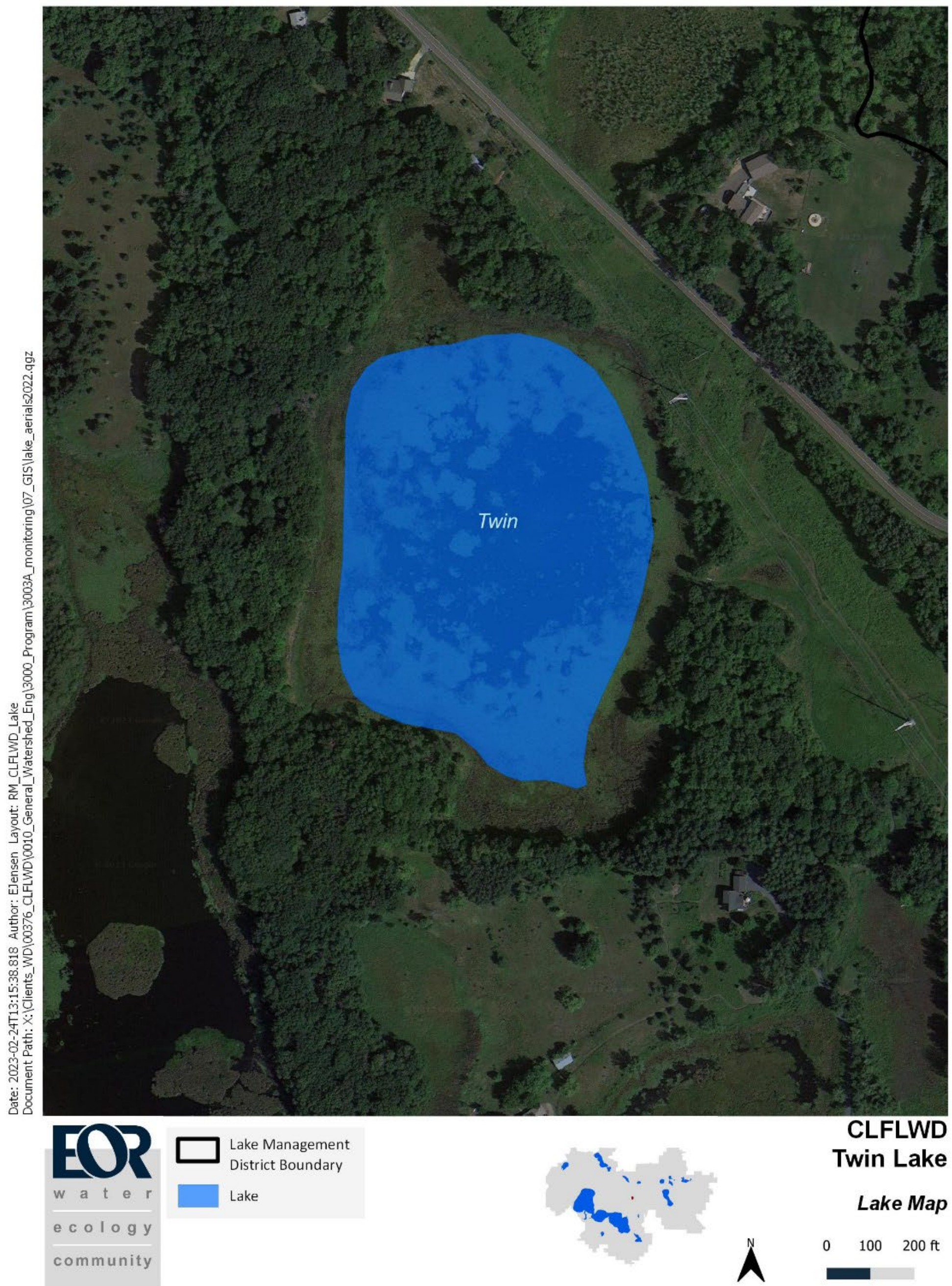


Historic water quality averages are meeting state standards and District goals. The 5 year averages show improved water quality compared to the 10 year averages.

TWIN LAKE

Fast Facts:

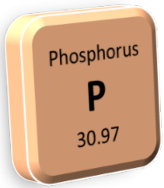
DNR Lake ID: 82-0157-00
County: Chisago
Surface Area: 13 acres
Littoral Area (depths less than 15 feet): NA acres
Maximum Depth: NA feet
Shore Length: NA miles
DNR Shoreland Classification: Natural Environment



TWIN LAKE

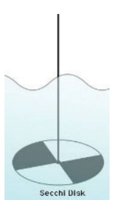
2023 Surface Water Quality Summary

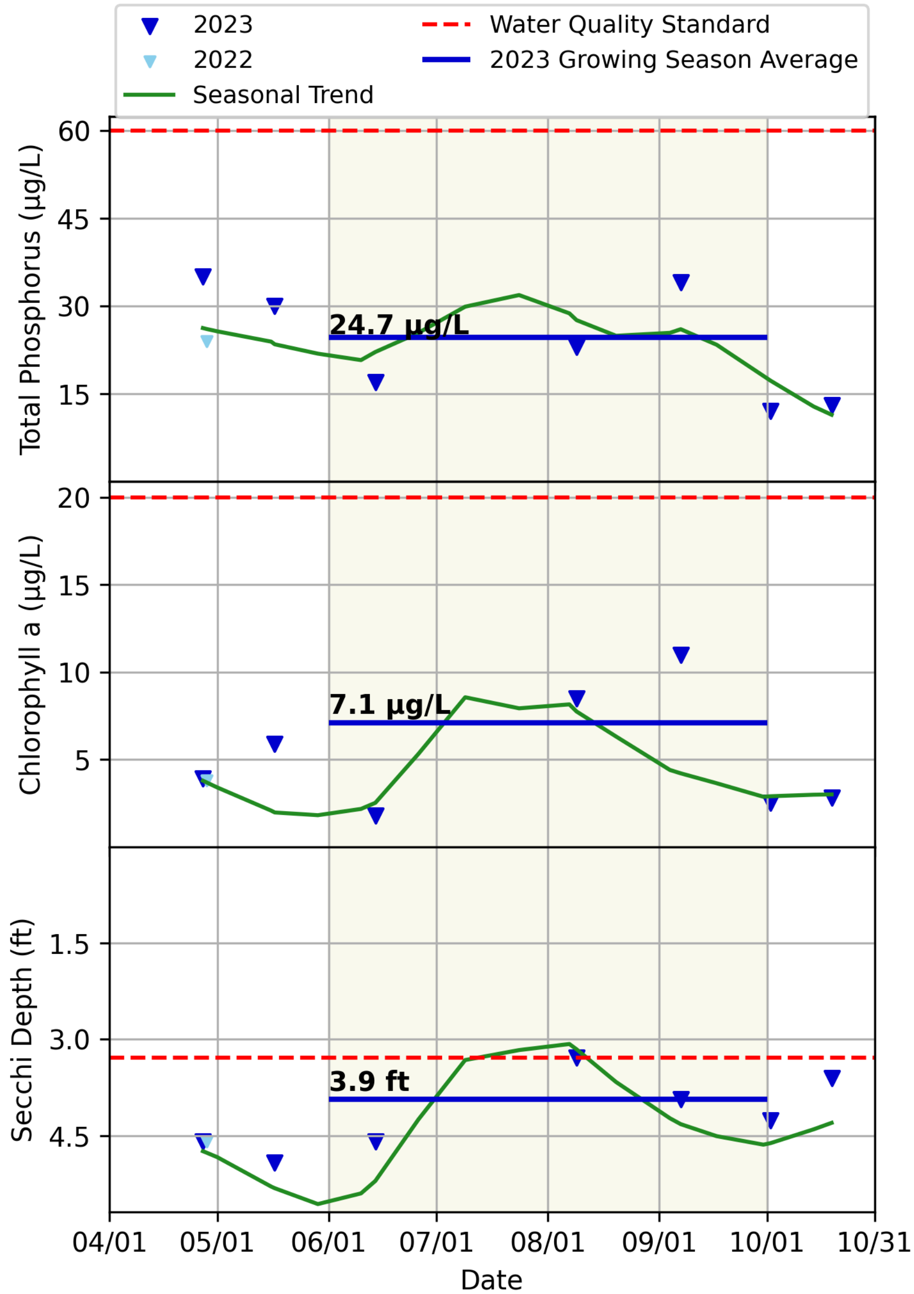
Nutrients:
June-Sept. Average Total Phosphorus (24.7 µg/L)



Algae:
June-Sept. Average Chlorophyll-a (7.1 µg/L)

Clarity:
June-Sept. Average Secchi Depth (3.9 ft)



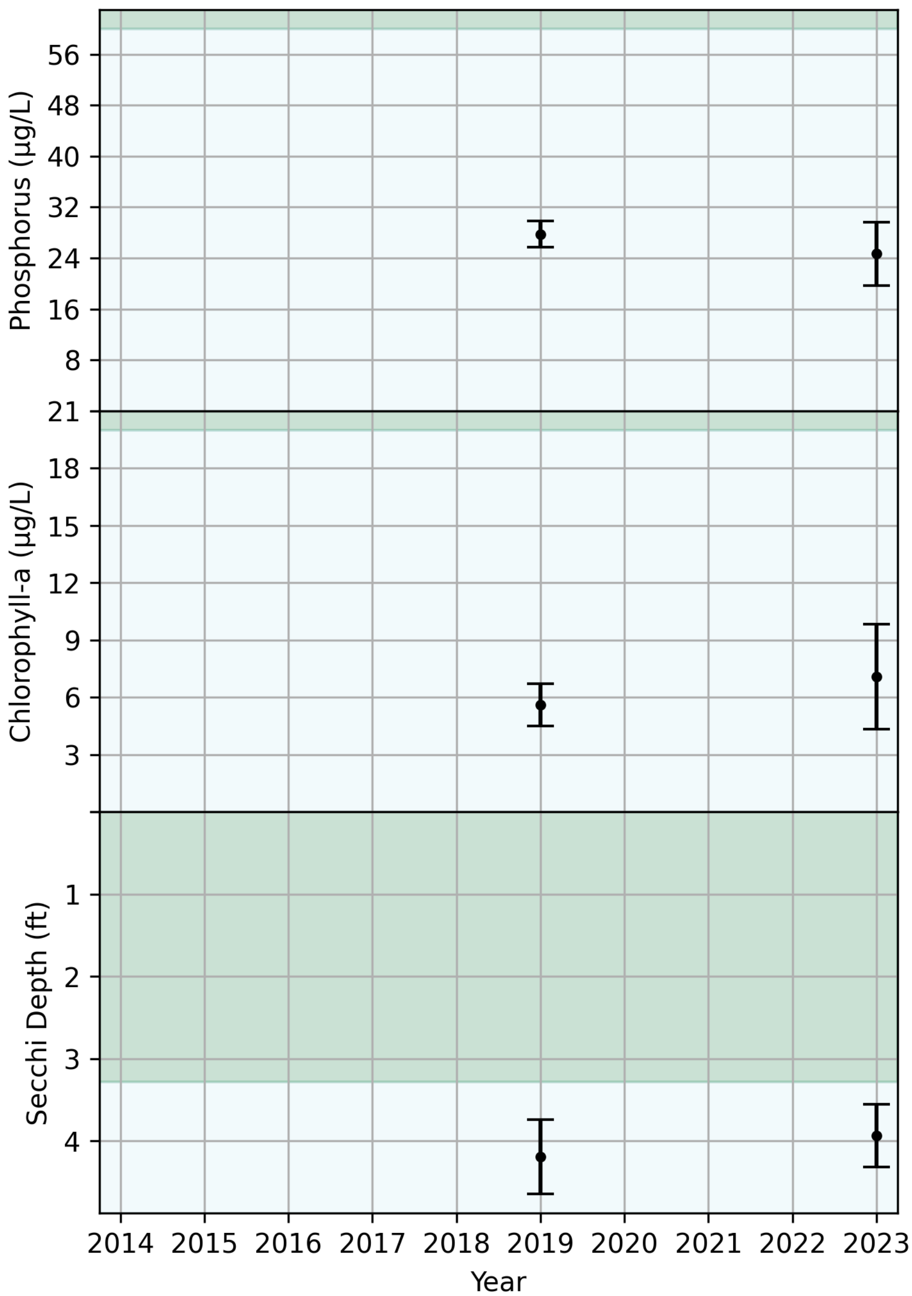


Water quality parameters were meeting the state water quality standards. The water quality is consistent throughout the season.

TWIN LAKE

Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	<60	<20	>3.3
10-year Average (2014-2023)	**26.9**	**6.0**	**4.1**
2040 District Goal	<60	n/a	>3.3
5-year Average (2019-2023)	**26.9**	**6.0**	**4.1**



There are only two years of monitoring data from 2019 to 2023. All water quality parameters are meeting state standards and District goals. Water quality is similar between 2019 and 2023.

APPENDIX B. INTERNAL LOADING PLOTS

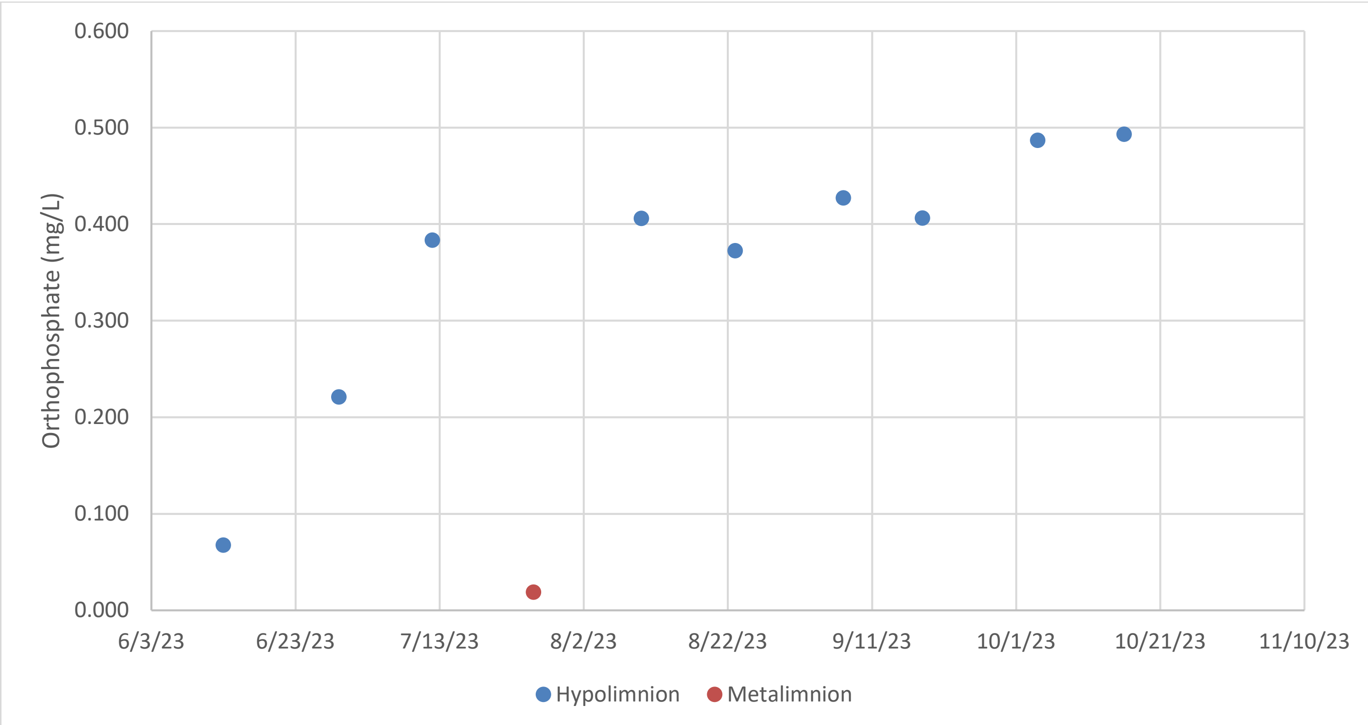


Figure 3: Comfort Lake OrthoP Comparison

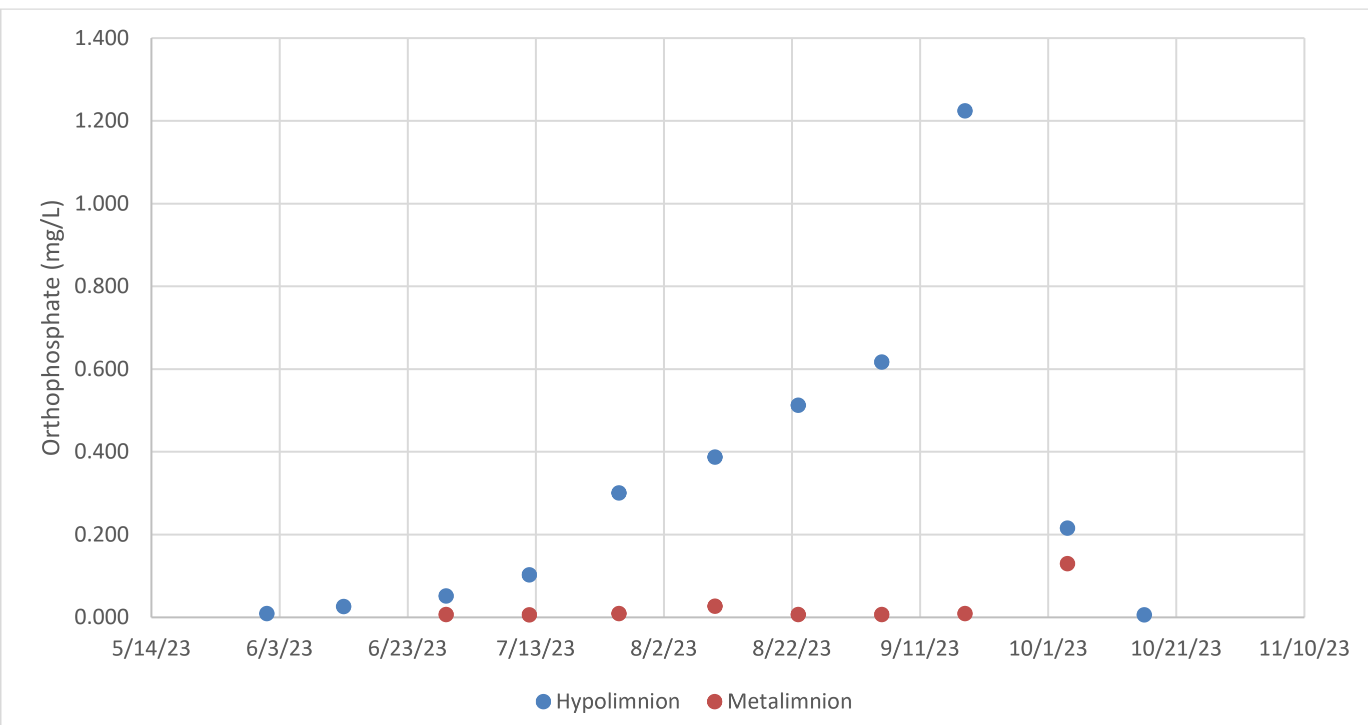


Figure 4: Forest Lake East OrthoP Comparison

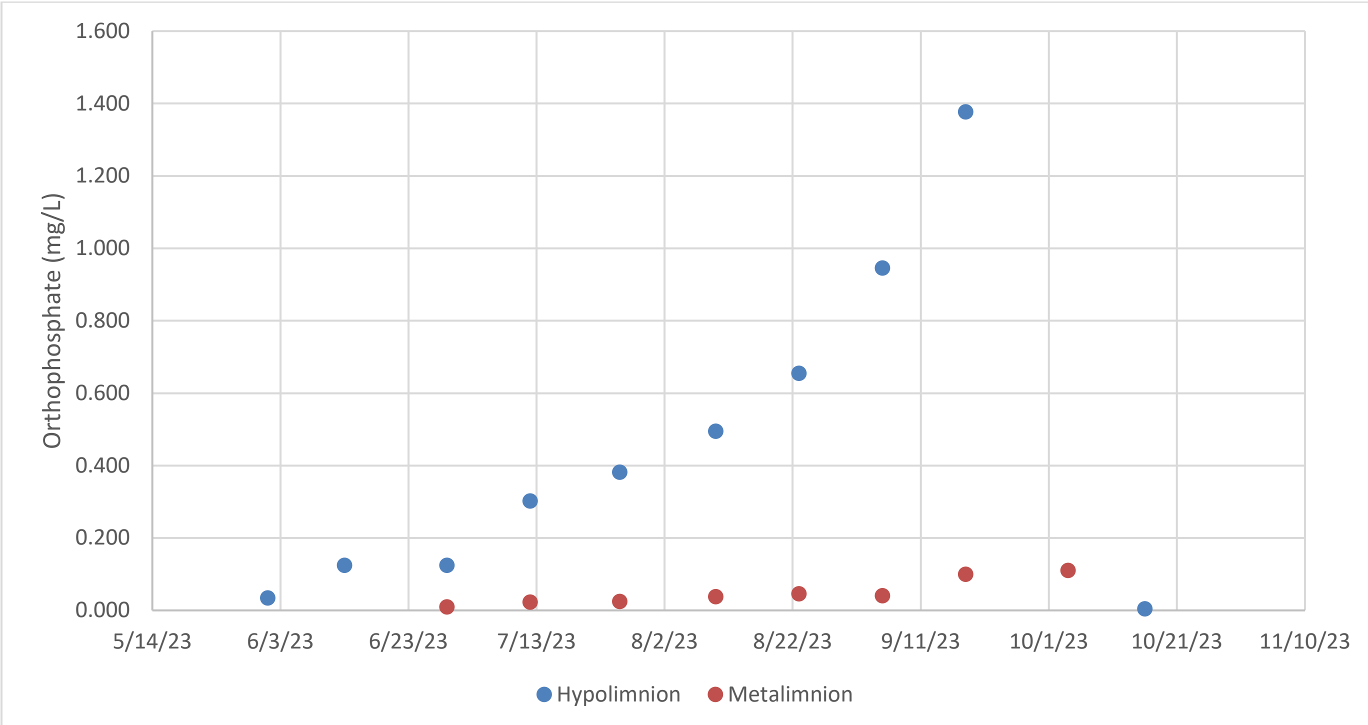


Figure 5: Forest Lake Middle OrthoP Comparison

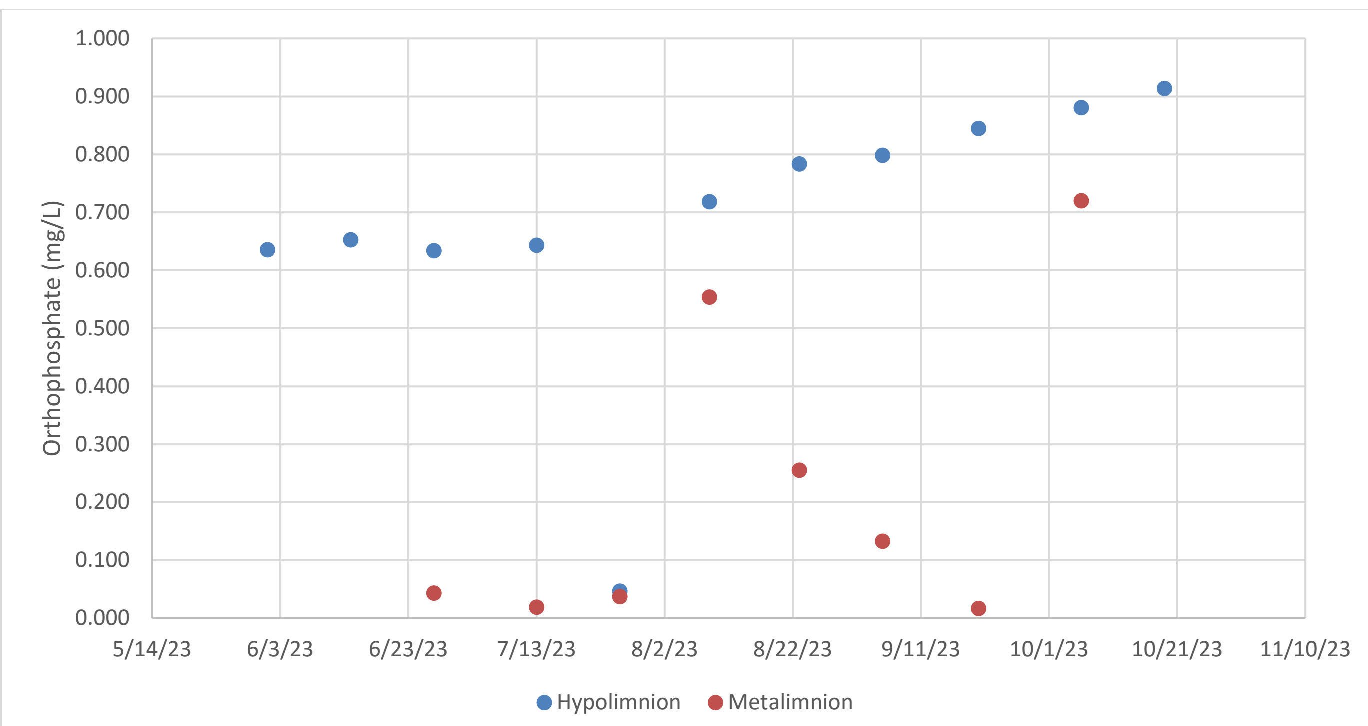


Figure 6: Little Comfort Lake OrthoP Comparison

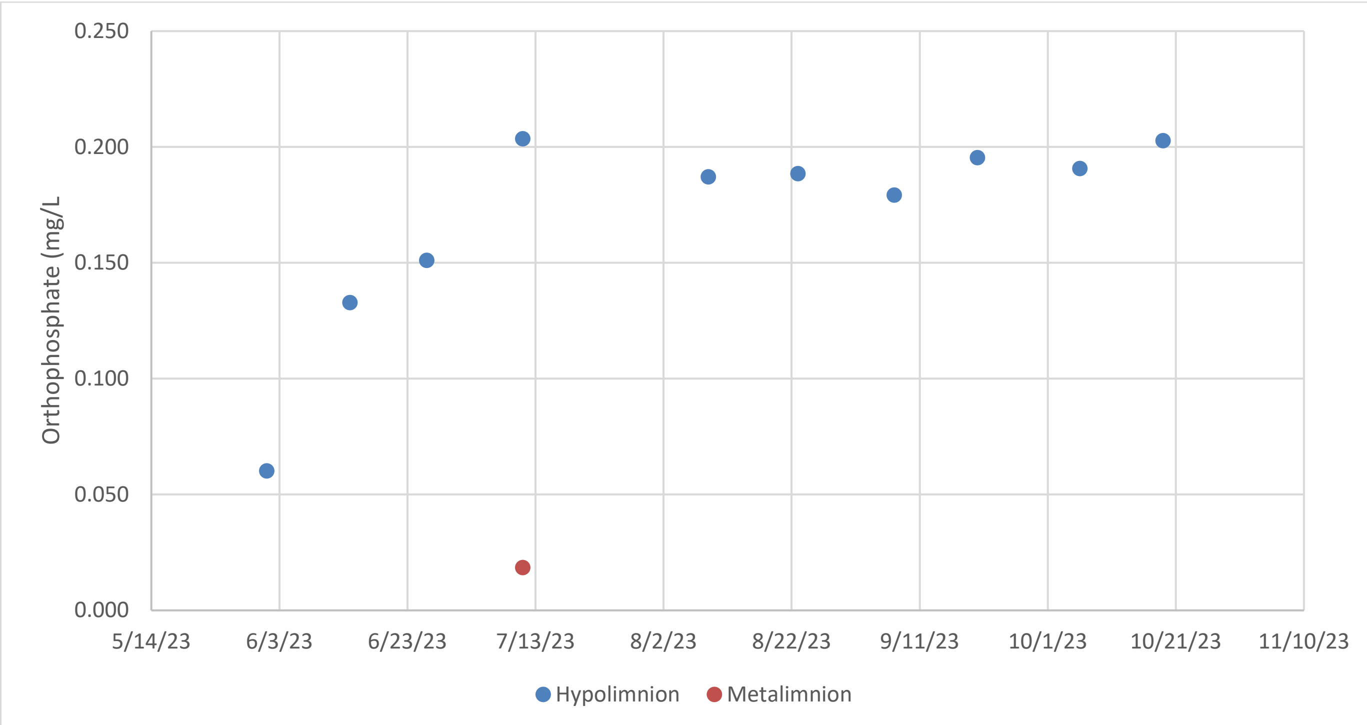


Figure 7: Moody Lake OrthoP Comparison

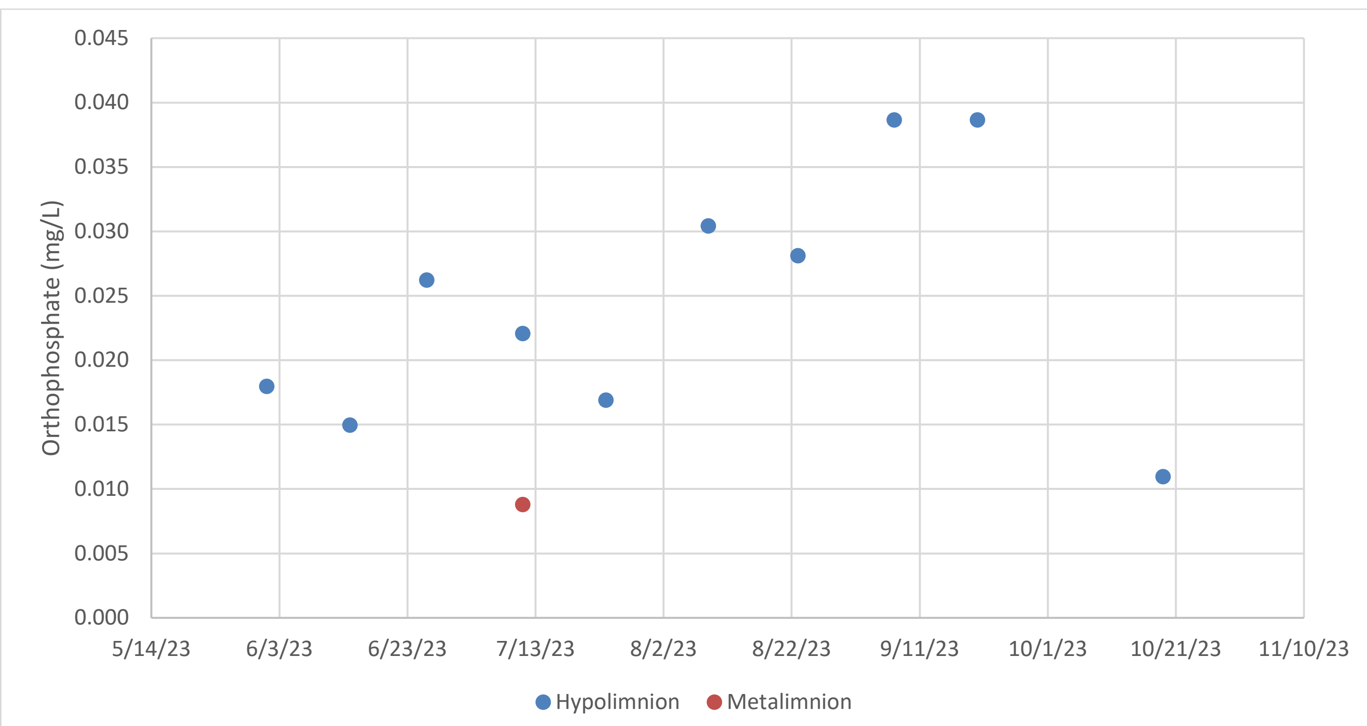


Figure 8: Shields Lake OrthoP Comparison

APPENDIX C. CHLORIDE PROFILES

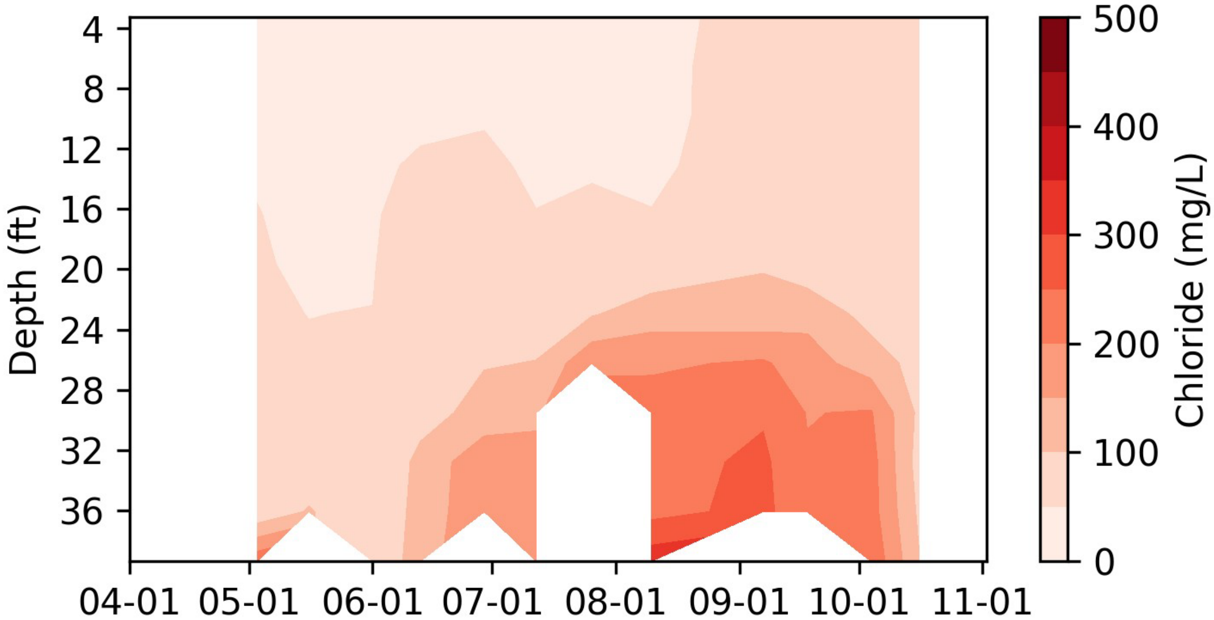


Figure 9. 2022 Comfort Lake Chloride Profiles

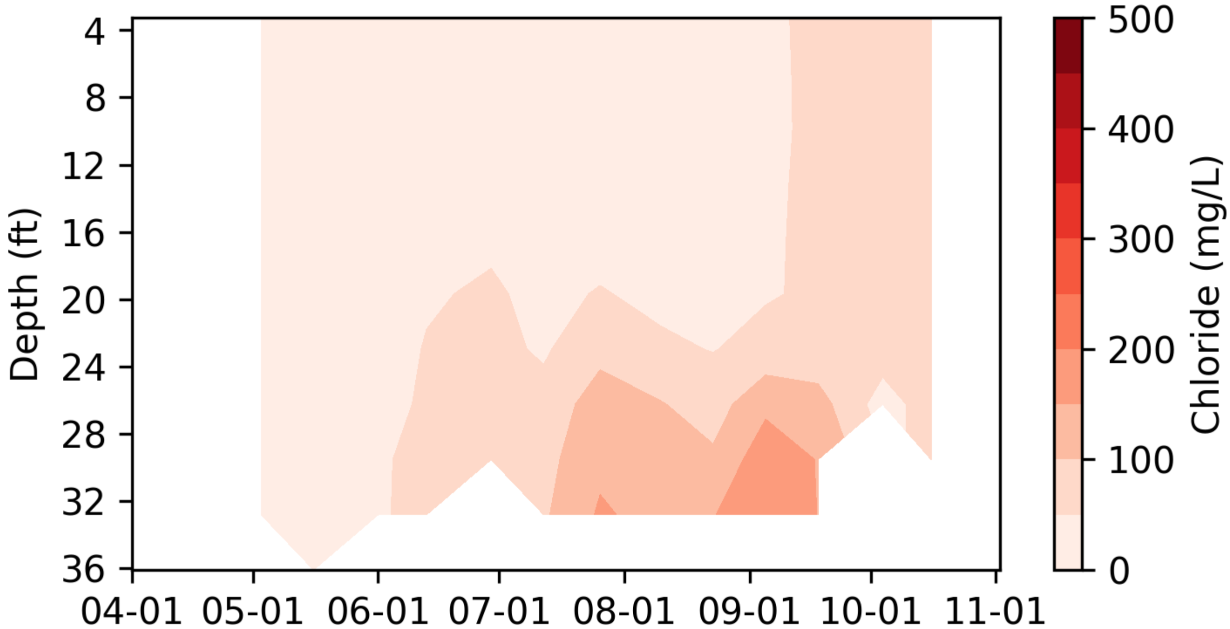


Figure 10. 2023 Forest Lake – Middle basin chloride profiles

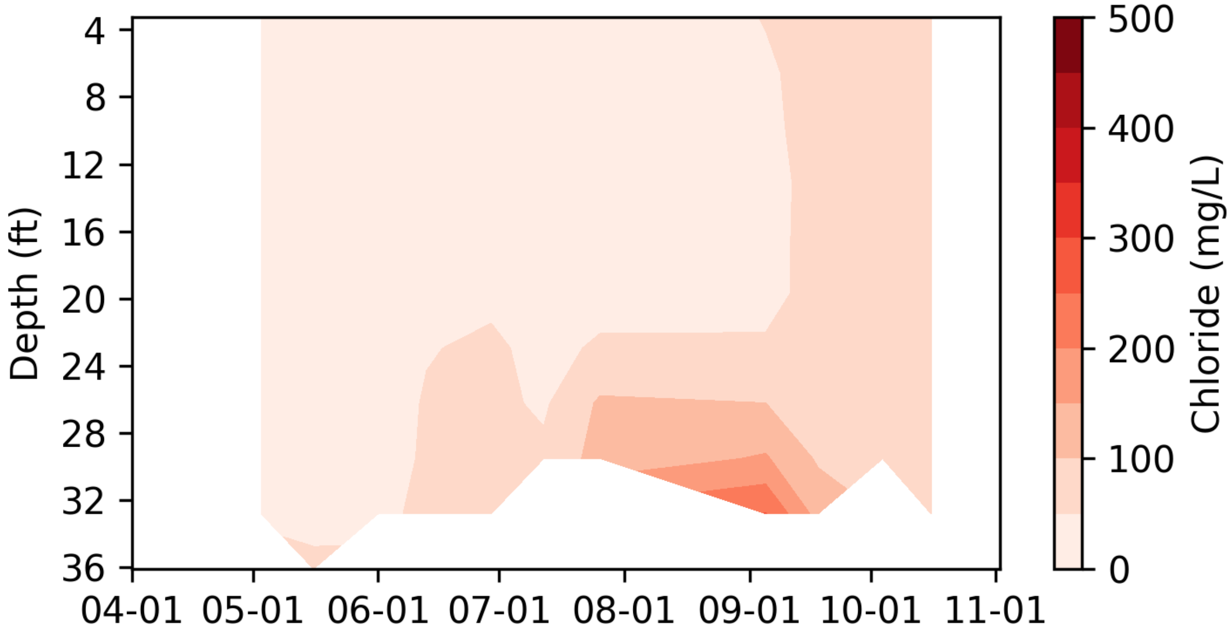


Figure 11. 2023 Forest Lake – East basin chloride Profiles

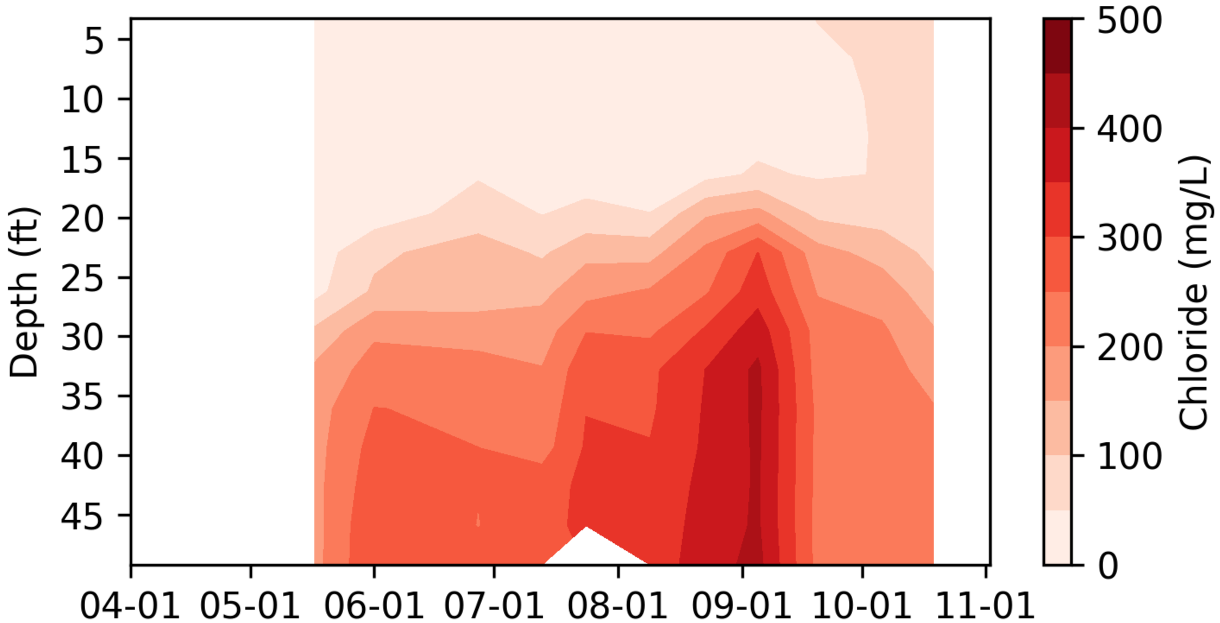


Figure 12. 2023 Little Comfort Lake chloride profiles

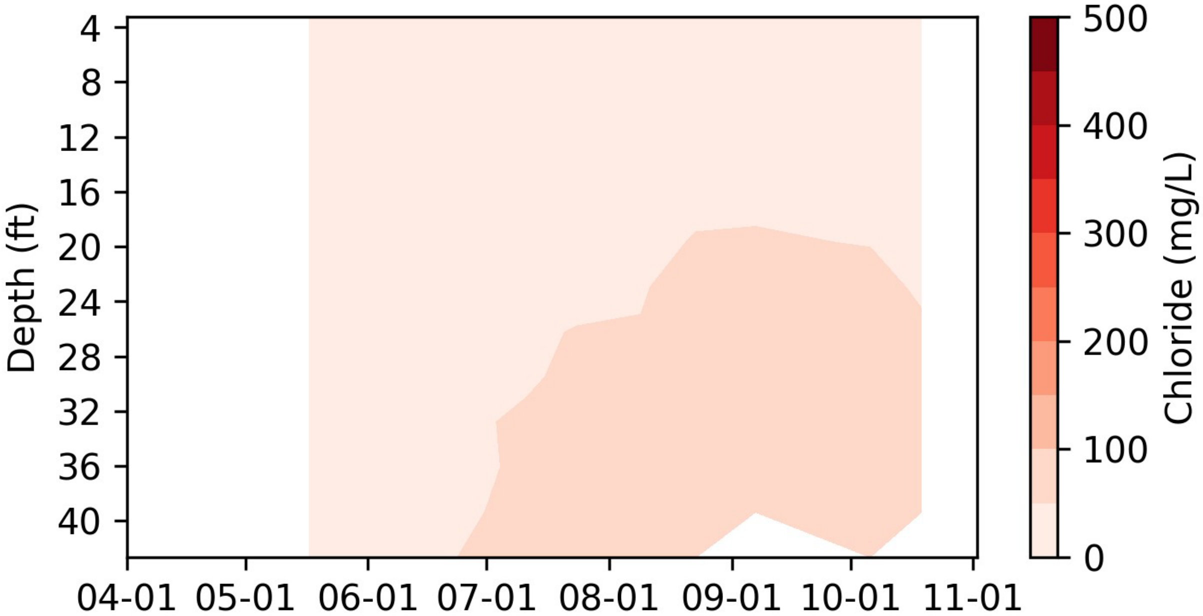


Figure 13. 2023 Moody Lake chloride profiles

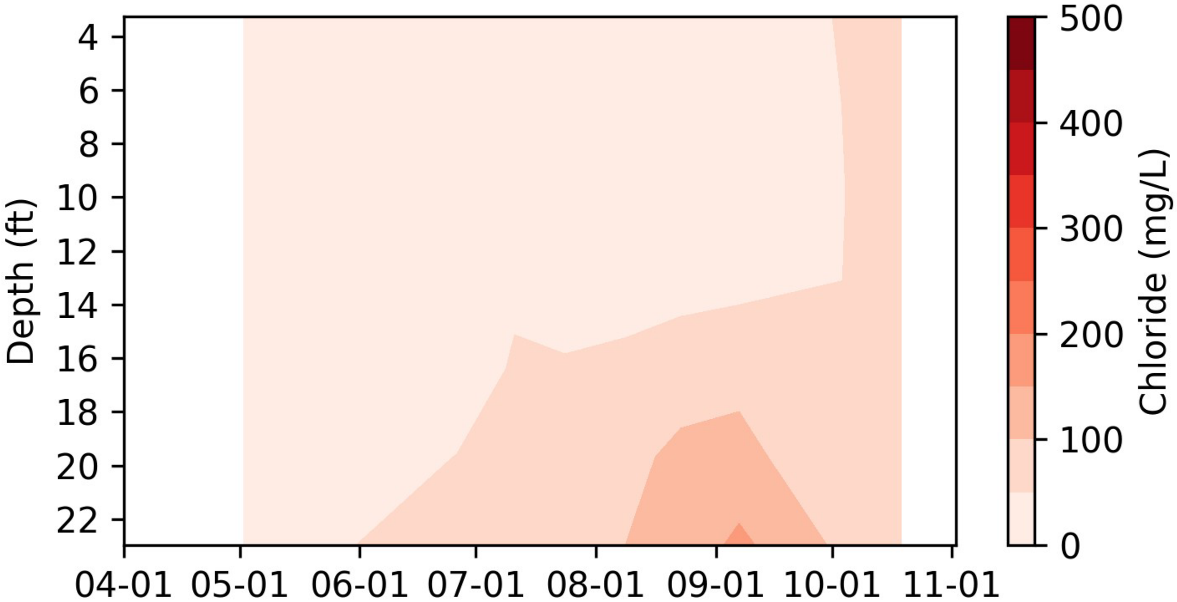


Figure 14. 2023 Shields Lake chloride profiles

APPENDIX D. 2023 LONG-TERM STREAM SITE SUMMARY

Appendix D.1. Bone Lake Management District

Table 15. BL1 2023 Stream Water Chemistry Sample Results

Red values do not meet the MN Class 2B standard.

Date/Time	Chloride (mg/L)	Iron (mg/L)	TKN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	Nitrate-Nitrite (mg/L)	NH4-N (mg/L)	TSS (mg/L)	TVS (mg/L)
MN Class 2B Standards	< 230			< 0.1						<30	
4/10/2023	13.3	0.5	0.97	0.094	0.021	0.51	0.06	0.51	0.22	4	3
4/19/2023	11.3	0.5	0.77	0.054	0.014	0.45	0.06	0.45	0.06	3	3
10/13/2023	18.4		1.91	0.097	0.042	1.18	0.06	1.18	0.37	3	3
10/23/2023	20.3		1.63	0.074	0.025	0.2	0.06	0.2	0.12	5	5

TKN = Total Kjeldahl Nitrogen which is a measure of nitrogen contained in organic form

TP = total phosphorus which is the measure of all particulates, dissolved, inorganic and organic forms of phosphorus

Ortho-P = ortho-phosphorus which is a measure of all dissolved inorganic forms of phosphorus

NO3-N = nitrate-nitrogen which is a measure of inorganic nitrogen in nitrate form

NO2-N = nitrite-nitrogen which is a measure of inorganic nitrogen in nitrite form

NH4-N = ammonia-nitrogen which is a measure of inorganic nitrogen in ammonia form

TSS = total suspended solids which is a measure of all solids in inorganic and organic form

TVS = total volatile solids which is a measure of all solids in organic form

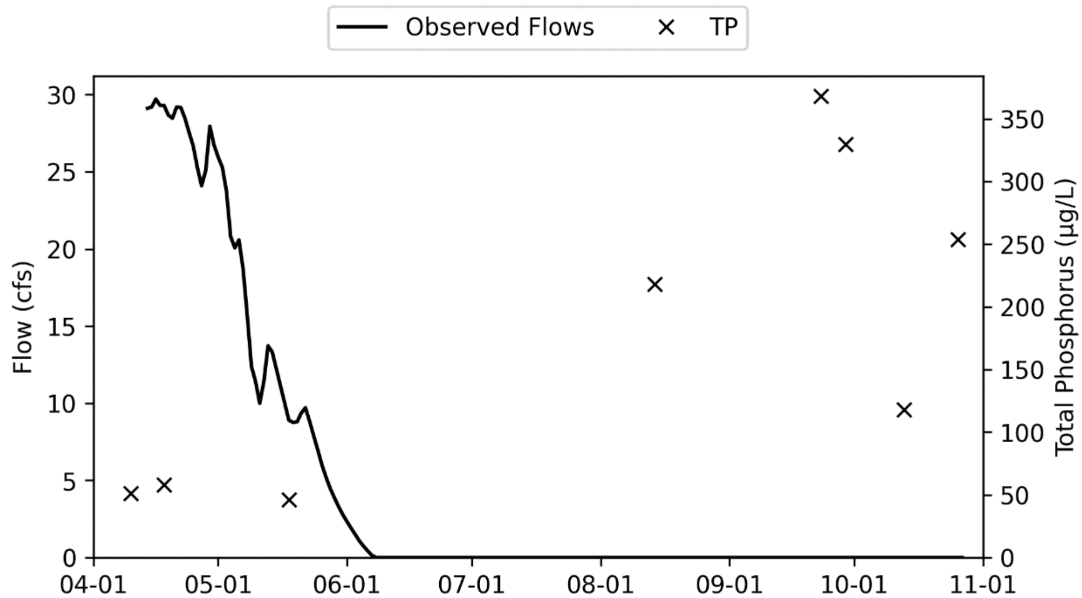


Figure 15. BL2 (outlet) TP and Daily Flow

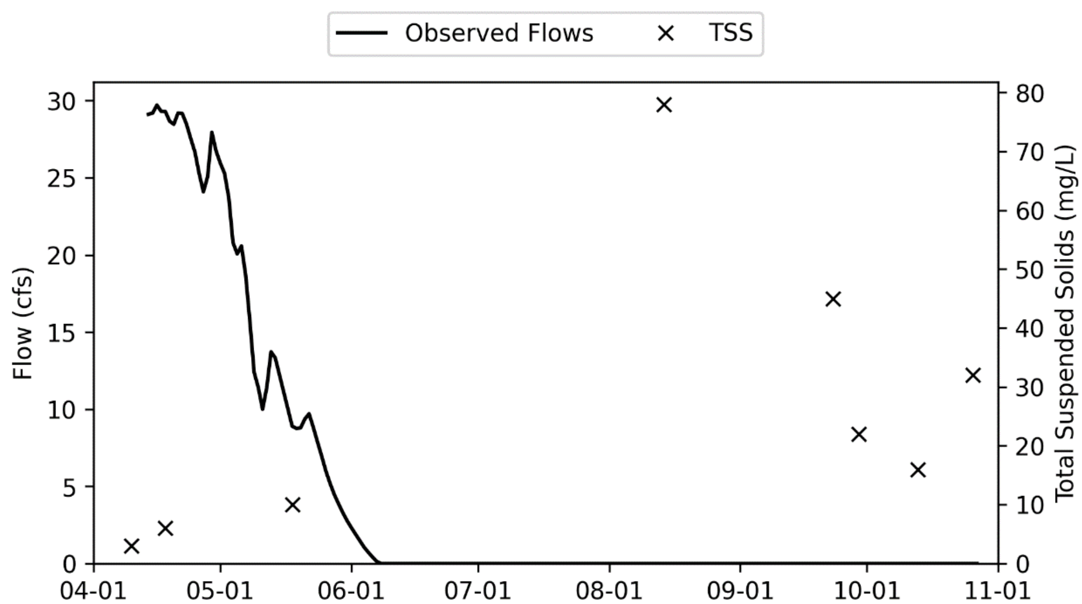


Figure 16. BL2 (outlet) TSS and Daily Flow

Table 16. BL2 2023 Stream Water Chemistry Sample Results

Red values do not meet the MN Class 2B standard.

Date/Time	Chloride (mg/L)	Iron (mg/L)	TKN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	Nitrate-Nitrite (mg/L)	NH4-N (mg/L)	TSS (mg/L)	TVS (mg/L)
MN Class 2B Standards	< 230			< 0.1						**<30**	
4/10/2023	16.6	0.5	1	0.02	0.01	0.27	0.06	0.27	0.35	3	3
4/18/2023	15.5	0.5	1.1	0.058	0.01	0.26	0.06	0.26	0.26	6	5
8/14/2023	19	1	2.49	0.218	0.011	0.33	0.06	0.33	0.29	78	30
9/23/2023	28.4		3.55	0.149	0.041	0.39	0.06	0.39	0.82	45	22
9/29/2023	40.7		2.01	0.075	0.031	0.2	0.12	0.31	0.3	22	12
10/13/2023	53.3		1.37	0.118	0.019	0.26	0.06	0.26	0.1	16	8
10/26/2023	131		1.89	0.254	0.01	0.2	0.06	0.2	0.47	32	12

TKN = Total Kjeldahl Nitrogen which is a measure of nitrogen contained in organic form

TP = total phosphorus which is the measure of all particulates, dissolved, inorganic and organic forms of phosphorus

Ortho-P = ortho-phosphorus which is a measure of all dissolved inorganic forms of phosphorus

NO3-N = nitrate-nitrogen which is a measure of inorganic nitrogen in nitrate form

NO2-N = nitrite-nitrogen which is a measure of inorganic nitrogen in nitrite form

NH4-N = ammonia-nitrogen which is a measure of inorganic nitrogen in ammonia form

TSS = total suspended solids which is a measure of all solids in inorganic and organic form

TVS = total volatile solids which is a measure of all solids in organic form

Appendix D.2. Comfort Lake Management District

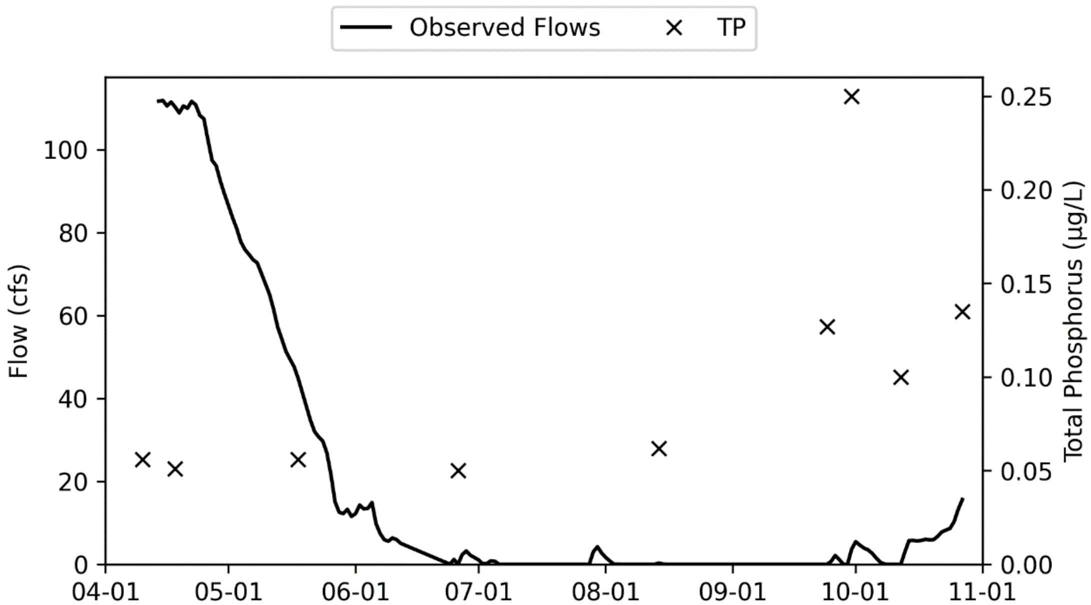


Figure 17. CL1 (outlet) TP and Daily Flow

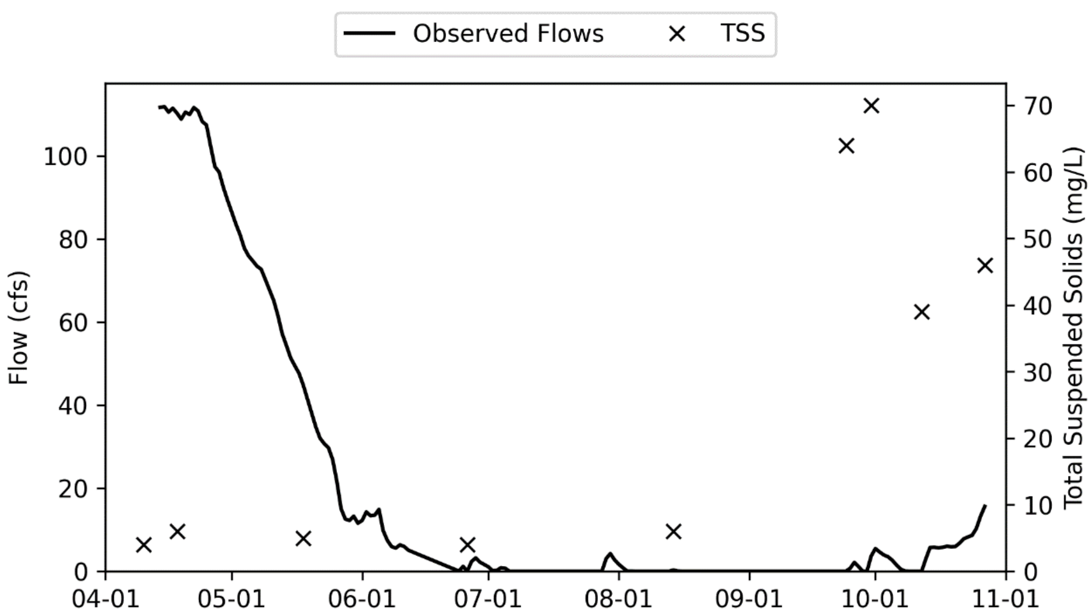


Figure 18. CL1 (outlet) TSS and Daily Flow

Table 17. CL1 2023 Stream Water Chemistry Sample Results

Red values do not meet the MN Class 2B standard.

Date/Time	Chloride (mg/L)	Iron (mg/L)	TKN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	Nitrate-Nitrite (mg/L)	NH4-N (mg/L)	TSS (mg/L)	TVS (mg/L)
MN Class 2B Standards	< 230			< 0.1						<30	
4/10/2023	60.9	0.5	0.89	0.056	0.01	0.91	0.06	0.91	0.11	4	3
4/18/2023	48.8	0.5	0.94	0.023	0.01	0.5	0.06	0.5	0.13	6	4
8/14/2023	39.9	0.5	0.9	0.062	0.01	0.2	0.06	0.2	0.06	6	6
9/24/2023	42.4		1.94	0.127	0.01	0.2	0.06	0.2	0.06	64	32
9/30/2023	41.9		3.17	0.25	0.01	0.2	0.06	0.2	0.06	70	38
10/12/2023	45.5		1.41	0.1	0.01	0.2	0.06	0.2	0.06	39	20
10/27/2023	43.5		2.1			0.36	0.06	0.36		46	22

TKN = Total Kjeldahl Nitrogen which is a measure of nitrogen contained in organic form

TP = total phosphorus which is the measure of all particulates, dissolved, inorganic and organic forms of phosphorus

Ortho-P = ortho-phosphorus which is a measure of all dissolved inorganic forms of phosphorus

NO3-N = nitrate-nitrogen which is a measure of inorganic nitrogen in nitrate form

NO2-N = nitrite-nitrogen which is a measure of inorganic nitrogen in nitrite form

NH4-N = ammonia-nitrogen which is a measure of inorganic nitrogen in ammonia form

TSS = total suspended solids which is a measure of all solids in inorganic and organic form

TVS = total volatile solids which is a measure of all solids in organic form

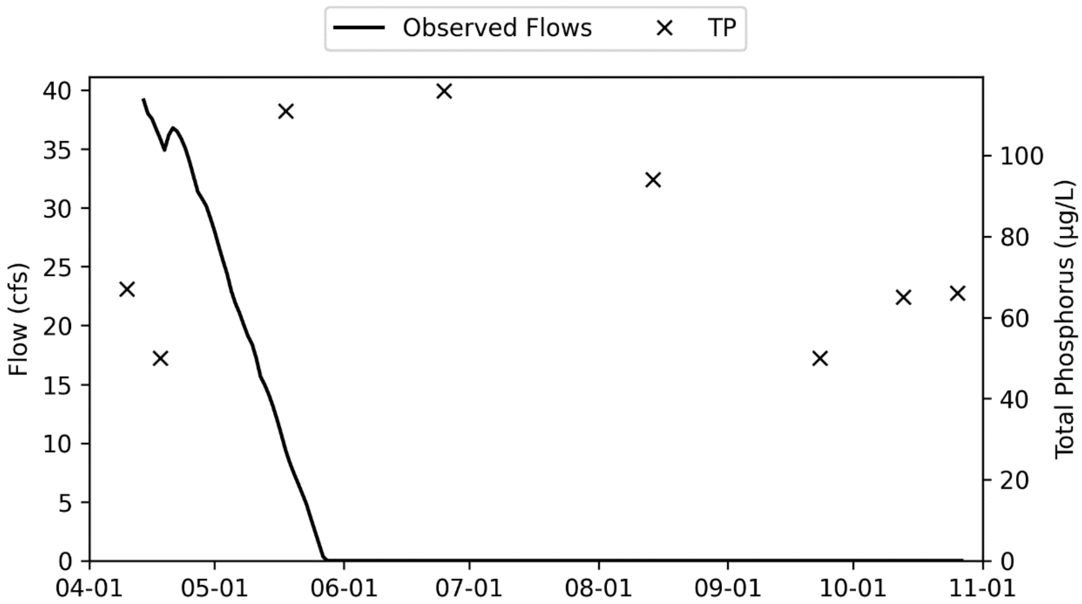


Figure 19. CL2 (inlet) TP and Daily Flow

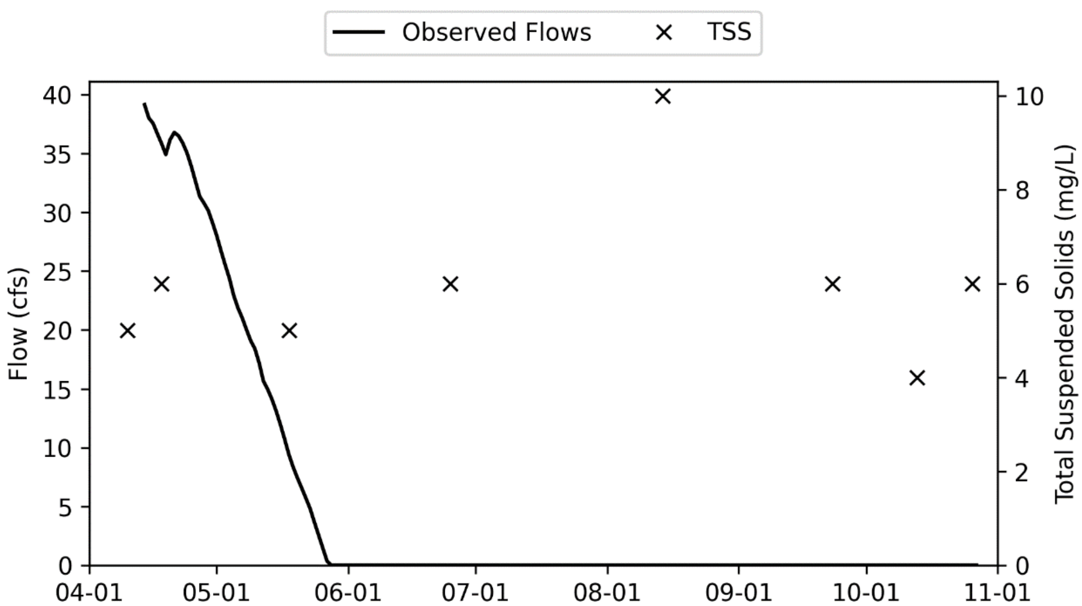


Figure 20. CL2 (inlet) TSS and Daily Flow

Table 18. CL2 2023 Stream Water Chemistry Sample Results

Red values do not meet the MN Class 2B standard.

Date/Time	Chloride (mg/L)	Iron (mg/L)	TKN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	Nitrate-Nitrite (mg/L)	NH4-N (mg/L)	TSS (mg/L)	TVS (mg/L)
MN Class 2B Standards	< 230			< 0.1						**<30**	
4/10/2023	56.2	0.5	1	0.067	0.012	1.29	0.06	1.29	0.13	5	3
4/18/2023	53	0.5	1.8	0.05	0.01	0.38	0.06	0.38	0.06	6	4
8/14/2023	36.8	0.61	0.64	0.094	0.021	2.03	0.06	2.03	0.06	10	5
9/23/2023	38.2		0.69	0.05	0.01	1.48	0.06	1.48	0.06	6	3
10/13/2023	72.1		0.68	0.065	0.01	0.65	0.06	0.65	0.06	4	3
10/26/2023	132		0.98	0.066	0.014	0.26	0.06	0.26	0.06	6	4

TKN = Total Kjeldahl Nitrogen which is a measure of nitrogen contained in organic form

TP = total phosphorus which is the measure of all particulates, dissolved, inorganic and organic forms of phosphorus

Ortho-P = ortho-phosphorus which is a measure of all dissolved inorganic forms of phosphorus

NO3-N = nitrate-nitrogen which is a measure of inorganic nitrogen in nitrate form

NO2-N = nitrite-nitrogen which is a measure of inorganic nitrogen in nitrite form

NH4-N = ammonia-nitrogen which is a measure of inorganic nitrogen in ammonia form

TSS = total suspended solids which is a measure of all solids in inorganic and organic form

TVS = total volatile solids which is a measure of all solids in organic form

Appendix D.3. Little Comfort Lake Management District

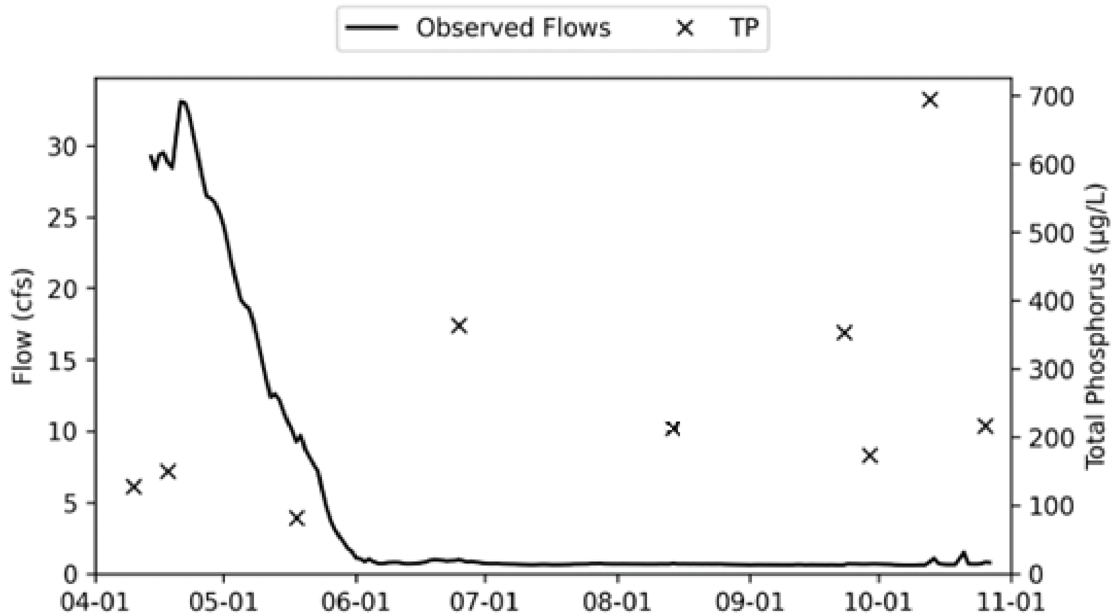


Figure 21. LC1 (inlet) TP and Daily Flow

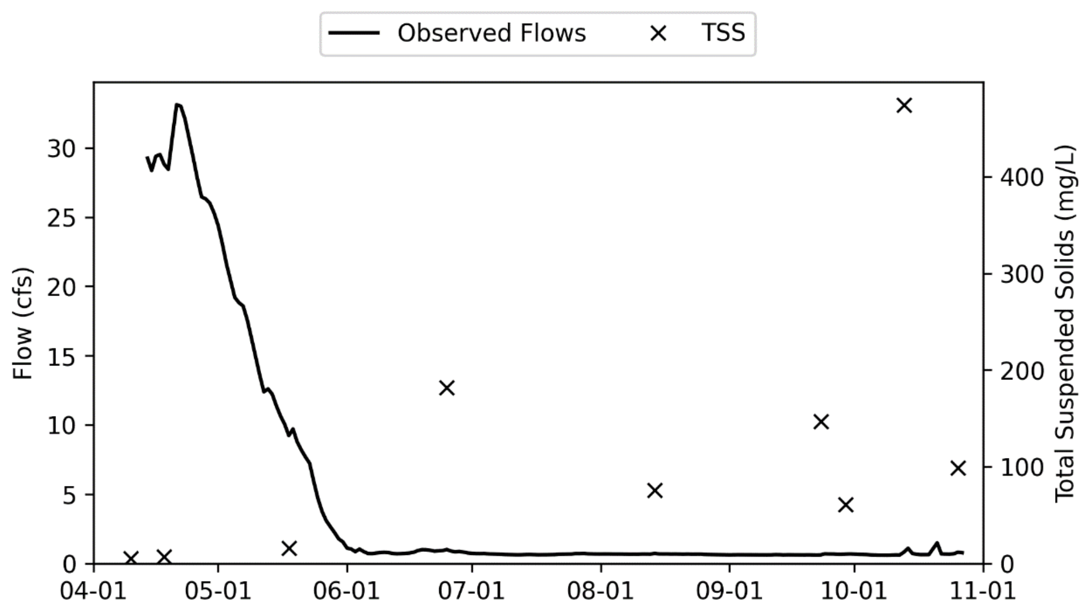


Figure 22. LC1 (inlet) TSS and Daily Flow

Table 19. LC1 2023 Stream Water Chemistry Sample Results

Red values do not meet the MN Class 2B standard.

Date/Time	Chloride (mg/L)	Iron (mg/L)	TKN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	Nitrate-Nitrite (mg/L)	NH4-N (mg/L)	TSS (mg/L)	TVS (mg/L)
MN Class 2B Standards	< 230			< 0.1						<30	
4/10/2023	17.3	0.5	0.91	0.128	0.065	1.16	0.06	1.16	0.17	5	3
4/18/2023	18.1	0.5	0.89	0.15	0.01	0.25	0.06	0.25	0.06	7	5
8/14/2023	20.2	2.1	2.28	0.05	0.011	0.2	0.06	0.2	0.06	76	40
9/23/2023	24.2		2.26	0.353	0.033	0.35	0.06	0.35	0.06	147	65
9/29/2023	25		1.76	0.174	0.022	0.2	0.06	0.2	0.06	61	28
10/13/2023	23		6.31	0.695	0.018	0.23	0.06	0.23	0.06	474	217
10/26/2023	24.4		0.28	0.217	0.015	0.2	0.06	0.2	0.06	99	45

TKN = Total Kjeldahl Nitrogen which is a measure of nitrogen contained in organic form

TP = total phosphorus which is the measure of all particulates, dissolved, inorganic and organic forms of phosphorus

Ortho-P = ortho-phosphorus which is a measure of all dissolved inorganic forms of phosphorus

NO3-N = nitrate-nitrogen which is a measure of inorganic nitrogen in nitrate form

NO2-N = nitrite-nitrogen which is a measure of inorganic nitrogen in nitrite form

NH4-N = ammonia-nitrogen which is a measure of inorganic nitrogen in ammonia form

TSS = total suspended solids which is a measure of all solids in inorganic and organic form

TVS = total volatile solids which is a measure of all solids in organic form

Appendix D.4. Forest Lake Management District

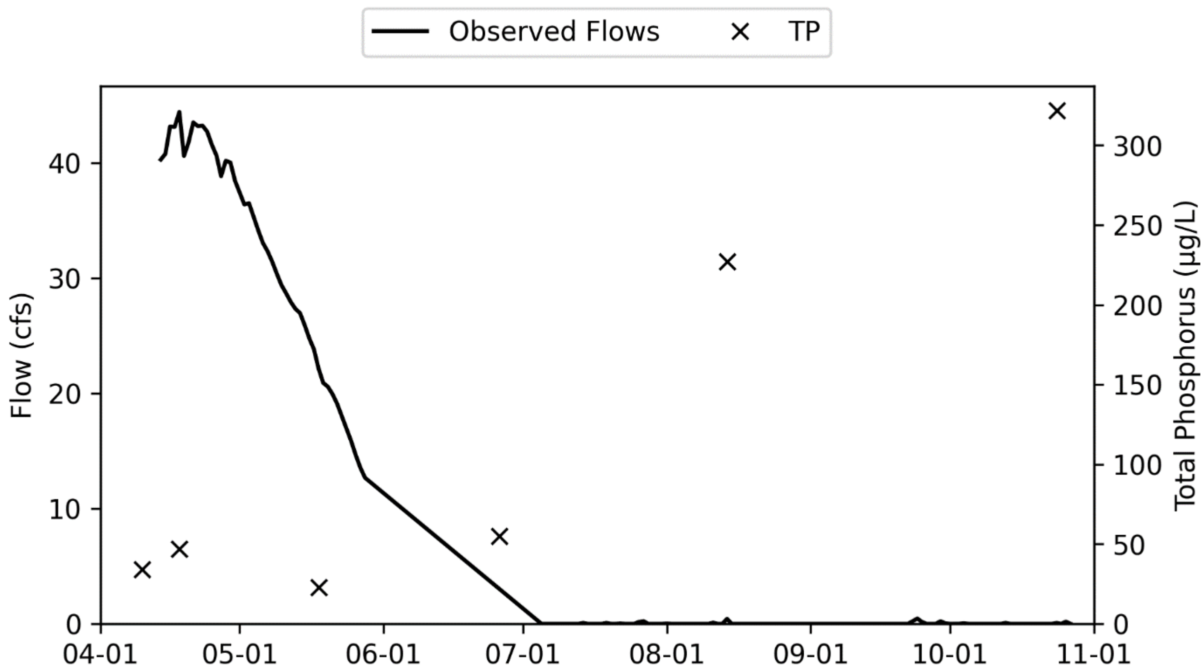


Figure 23. FL1 (outlet) TP and Daily Flow

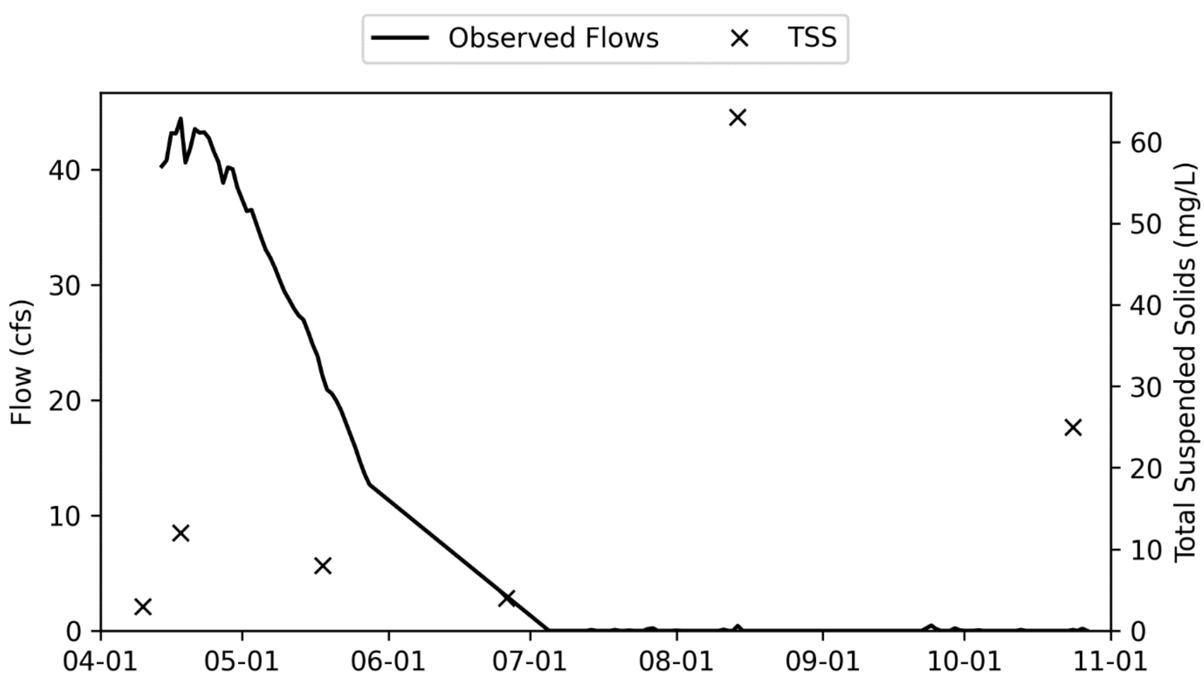


Figure 24. FL1 (outlet) TSS and Daily Flow

Table 20. FL1 2023 Stream Water Chemistry Sample Results

Red values do not meet the MN Class 2B standard.

Date/Time	Chloride (mg/L)	Iron (mg/L)	TKN (mg/L)	TP (mg/L)	Ortho-P (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	Nitrate-Nitrite (mg/L)	NH4-N (mg/L)	TSS (mg/L)	TVS (mg/L)
MN Class 2B Standards	< 230			< 0.1						**<30**	
4/10/2023	29.3	0.5	0.53	0.02	0.01	1.13	0.06	1.13	0.09	3	3
4/18/2023	32.9	0.5	0.84	0.047	0.01	0.28	0.06	0.28	0.06	12	8
8/14/2023	12.2	1.1	1.16	0.227	0.058	0.41	0.06	0.41	0.06	63	31
10/24/2023	10		1.03	0.322	0.176	0.48	0.06	0.48	0.06	25	15

TKN = Total Kjeldahl Nitrogen which is a measure of nitrogen contained in organic form

TP = total phosphorus which is the measure of all particulates, dissolved, inorganic and organic forms of phosphorus

Ortho-P = ortho-phosphorus which is a measure of all dissolved inorganic forms of phosphorus

NO3-N = nitrate-nitrogen which is a measure of inorganic nitrogen in nitrate form

NO2-N = nitrite-nitrogen which is a measure of inorganic nitrogen in nitrite form

NH4-N = ammonia-nitrogen which is a measure of inorganic nitrogen in ammonia form

TSS = total suspended solids which is a measure of all solids in inorganic and organic form

TVS = total volatile solids which is a measure of all solids in organic form

APPENDIX E. STATE-WIDE CLIMATE TRENDS

State-wide temperatures in 2023 were warmer than average and the total 2023 precipitation was below average. The data developed by the PRISM Climate Group shows that the average annual temperature and precipitation have shifted to much warmer and wetter conditions in the last 30 years (1994-2023) compared to the years prior (1895-1993). This trend is shown in Figure 25. Annual precipitation is displayed in inches on the Y-axis and annual average temperature is shown in Fahrenheit on the X-axis. The four quadrants represent the following conditions:

- Upper left quadrant: lower temperatures, higher precipitation
- Lower left quadrant: lower temperatures, lower precipitation
- Lower right quadrant: higher temperatures, lower precipitation
- Upper right quadrant: higher temperatures, higher precipitation

The **grey dots** represent the conditions between 1895 and 1993, while the **golden dots** represent the conditions between 1994 and 2023. As shown in the figure, there is a shift in the later years into the upper right quadrant, representing higher temperatures and more annual precipitation. This is consistent with climate change predictions.

Regarding Minnesota, there are two key trends that have been observed by State's climatologists:

1. Wetter conditions due to more precipitation, more snow, and more frequent and larger storm events.
2. Increasing temperatures especially at night and during winter. In general, cold days are becoming less cold.

Regarding droughts and high temperatures, the State Climatologist has not observed heat extremes or droughts getting worse in Minnesota, but these are projected to get worse by mid-century.

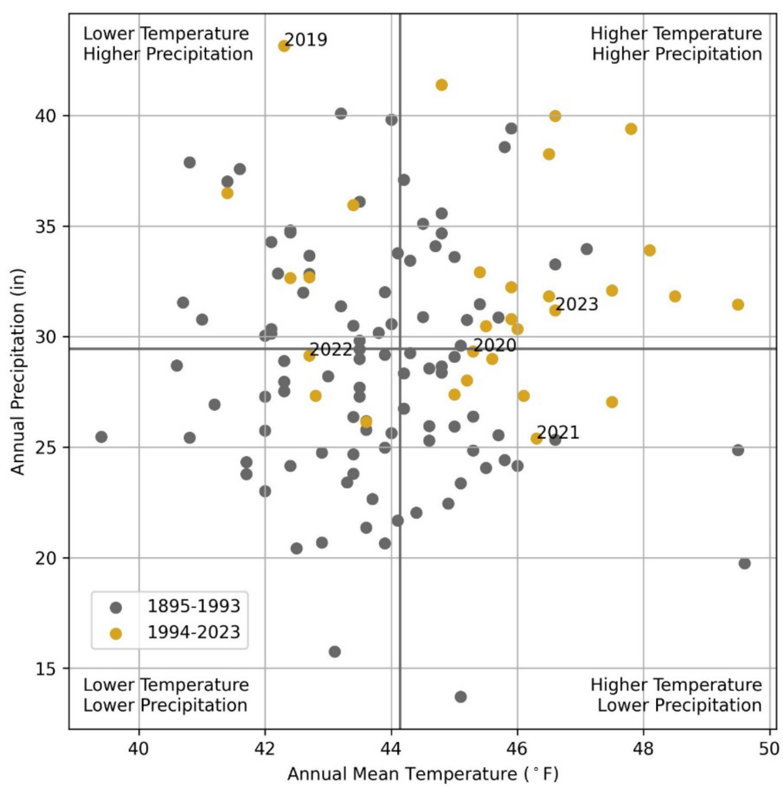


Figure 25. The shifting climate quadrants, comparing precipitation and temperature in 1895-1993 to 1994-2023 (PRISM Climate Group 2022)

APPENDIX F. ANALYSIS PARAMETERS

Appendix F.1. Lake Levels

The surface water elevation of the lakes is recorded during monitoring events and reported to DNR. These lake levels can be used to calibrate hydraulic and hydrologic (H&H) models used to identify and design the best management practices.

Appendix F.2. Internal Loading

It is common for a lake to show some temperature stratification (see Appendix A) during the summer months, when the temperature at the lake surface is higher and decreases abruptly with depth. The water temperature at the lower layers in the lake is cooler and pretty much constant. Water (and associated pollutants) vertical movement between layers is mostly the result of temperature differential (temperature gradient). Since at lower layers the temperature gradient is low, not a lot of vertical movement takes place during lake stratification.

Stratification also prevents the exchange of oxygenated water from the surface to the lower layers. With time, the layers at the bottom of the lake become anoxic (no oxygen). In an anoxic situation, phosphorus that is bound to iron (and other metals) in the sediments is released and stays at the lower layers of the lake over the summer. Phosphorus accumulation at the bottom waters is called "internal loading".

When internal loading is sufficiently high, phosphorus can diffuse up into the surface waters and decrease surface water quality. The release of phosphorus from the bottom layers to the lake's surface is most notable after severe storm events and winds that mix the lake waters. In the Fall, when lake temperature stratification weakens due to reduced ambient temperatures, the surface and bottom waters mix (the lake "turns"). If a significant accumulation of phosphorus in the lower layers exist when the lake turns, it will be transferred to the surface waters with the consequent impact on water quality.

Alum treatment is one commonly used management practice for reducing this source of phosphorus. The alum (aluminum sulfate) binds with the phosphorus, a process known as flocculation, and traps the phosphorus in the sediment so it cannot migrate and be dissolved into the water column. Typically, Lakes that have completed or are planning alum treatments are monitored for internal loading. This is to assess whether an alum treatment is needed or, if already completed, how effective it was in binding phosphorus.

Monitoring for internal loading assessment includes collecting dissolved oxygen and temperature profiles to determine the length of summer stratification and collecting bottom water phosphorus concentrations to determine if phosphorus is accumulating in bottom waters over time.

Appendix F.3. Chloride

Every winter, roads and other paved surfaces require a significant amount of de-icing material to prevent unsafe conditions. The most common deicer by far is salt. The main component in salt is sodium-chloride. Salt helps prevent ice buildup and melts ice from paved surfaces. However, salt dissolves into the melted ice water and it breaks down leaving the Chloride in the runoff. This runoff eventually reaches water resources like rivers and lakes. Because deicing with salt is so common, it is one of the biggest contributors of excess chloride in our groundwater and drinking water sources.

Another major source of chloride in the environment is water softeners. Home water softener systems often use chloride to react with the sources of water hardness (calcium and magnesium). If your home has softened water, you may have noticed that it tastes a little salty. However, just as overly salty food is bad for your health, overly salty water acts in the same way. Unfortunately, chloride is very difficult to remove and as a result, the softened water that leaves houses often ends up letting chloride into the environment too. There are not many natural processes that can remove chloride and reduce harmful levels in the environment, and our water treatment plants do not have technologies to remove chloride except through one costly, energy-intensive process.

Although chloride exists naturally in the environment at low levels, it is toxic to aquatic life at high levels. In low concentrations, chloride supports key biological functions; at toxic levels, chloride impacts the growth and reproduction of aquatic species, their food sources, and critical biological functions in amphibians. This is largely because chloride disrupts the natural process of molecules flowing in and out of cells. In high environmental concentrations, chloride can force water to leak out of cells while preventing other critical molecules from entering—a necessary biological function for aquatic and amphibious species.

If aquatic life is exposed to such excessive concentrations of chlorides for too long, their cells get stressed and can even die. Another issue is the link between low dissolved oxygen and high chloride levels, which is another reason high chloride levels are harmful for aquatic life. Chloride can change the density of the water entering a waterbody and prevent the natural exchange of gases from the bottom of a lake to the top. Chloride measurements were collected in the lakes using a probe for the first time in 2021, but due to possible calibration issues, the concentrations could not be verified as accurate and therefore were not reported.

Appendix F.4. Temperature

Water temperature affects the oxygen content of the water (oxygen levels become lower as temperature increases), the rate of photosynthesis by aquatic plants, the metabolic rates of aquatic organisms, and the sensitivity of organisms to toxic wastes, parasites, and diseases. Aquatic organisms from microbes to fish are dependent on certain temperature ranges for their optimal health. Optimal temperatures for fish depend on the species. Some species survive best in colder water, whereas others prefer warmer water. Benthic macroinvertebrates are also sensitive to temperature changes and will move in the stream to find their optimal temperature range. If temperatures are outside this optimal range for a prolonged period, organisms are stressed and can die. Warm temperatures (typically above 20 degrees Celsius, or 68 degrees Fahrenheit) can stress or cause mortality in cold water fish species. At this point, there are no known stream cold water fish species in the District.

Appendix F.5. Dissolved oxygen

The amount of dissolved oxygen (DO) available in the water is key to support aquatic life. A stream system both produces and consumes oxygen. It gains oxygen from the atmosphere and from plants because of photosynthesis. Running water, because of its churning, dissolves more oxygen than still water, such as in a reservoir behind a dam.

Respiration by aquatic animals, decomposition, and various chemical reactions consume oxygen. If more oxygen is consumed than is produced, dissolved oxygen levels decline and some sensitive animals may move away, weaken, or die. DO levels fluctuate seasonally and over a 24-hour period. They vary with water temperature and altitude. Cold water holds more oxygen than warm water and water holds less oxygen at higher altitudes. Thermal discharges, such as water used to cool machinery in a manufacturing plant or a power plant, raise the temperature of water and lower its oxygen content.

Aquatic animals are most vulnerable to lowered DO levels in the early morning on hot summer days when stream flows are low, water temperatures are high, and aquatic plants have not been producing oxygen since sunset. DO levels below 5 mg/L can cause stress or mortality in fish and macroinvertebrates.

Appendix F.6. Water acidity

pH is a measure of the acidity of the water. pH affects many chemical and biological processes. Different organisms flourish within different pH ranges. The largest variety of aquatic animals prefer a range of 6.5-8.0. pHs outside this range reduces the diversity in the stream. Low pH can also allow toxic elements and compounds to become mobile and "available" for uptake by aquatic plants and animals. This can produce conditions that are toxic to aquatic life.

Appendix F.7. Specific conductance

Specific conductance **is** a measure of the ability of water to pass an electrical current. Conductivity in water is affected by the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminum cations (ions that carry a positive charge).

Organic compounds like oil, phenol, alcohol, and sugar do not conduct electrical current very well and therefore lower the water. Conductivity is also affected by temperature: the warmer the water, the higher the conductivity. For this reason, conductivity is reported as conductivity at 25 degrees Celsius. Distilled water has a conductivity in the range of 0.5 to 3 µmhos/cm. The conductivity of rivers in the United States generally ranges from 50 to 1500 µmhos/cm. Studies of inland fresh waters indicate that streams supporting good mixed fisheries have a range between 150 and 500 µhos/cm. Conductivity outside this range could indicate that the water is not suitable for certain species of fish or macroinvertebrates.

Appendix F.8. Turbidity

Turbidity is a measure of water clarity or how much the material suspended in water decreases the passage of light through the water. Suspended materials include soil particles (clay, silt, and sand), algae, plankton, microbes, and other substances. These materials are typically in the size range of 0.004 mm (clay) to 1.0 mm (sand). Turbidity can affect the color of the water. Higher turbidity increases water temperatures because suspended particles absorb more heat. This, in turn, reduces the dissolved oxygen concentration. Higher turbidity also reduces the amount of light penetrating the water, which reduces photosynthesis and the production of DO. Suspended materials can clog fish gills, reducing resistance to disease in fish, lowering growth rates, and affecting egg and larval development. As the particles settle, they can blanket the stream bottom, especially in slower waters, and smother fish eggs and benthic macroinvertebrates. The Minnesota Class 2B water quality standard for TSS is 30 mg/L.

Appendix F.9. Phosphorous

Both phosphorus and nitrogen are essential nutrients for the plants and animals that make up the aquatic food web. Since phosphorus is the nutrient in short supply in most fresh waters, even a modest increase in phosphorus can, under the right conditions, set off a whole chain of undesirable events in a stream including accelerated plant growth, algae blooms, low dissolved oxygen, and the death of certain fish, invertebrates, and other aquatic animals.

There are many sources of phosphorus, both natural and human. These include soil and rocks, wastewater treatment plants, runoff from fertilized lawns and cropland, failing septic systems, runoff from animal manure storage areas, disturbed land areas, drained wetlands, water treatment, and commercial cleaning preparations.

Phosphorus has a complicated story. Pure, "elemental" phosphorus (P) is rare. In nature, phosphorus usually exists as part of a phosphate molecule (PO4). Phosphorus in aquatic systems occurs as organic phosphate and inorganic phosphate. Organic phosphate consists of a phosphate molecule associated with a carbon-based molecule, as in plant or animal tissue. Phosphate that is not associated with organic material is inorganic. Inorganic phosphorus is the form required by plants. Animals can use either organic or inorganic phosphate. Both organic and inorganic phosphorus can either be dissolved in the water or suspended (attached to particles in the water column).

Appendix F.10. Nitrogen

Forms of nitrogen include ammonia (NH3), nitrates (NO3), and nitrites (NO2). Nitrates are essential plant nutrients, but in excessive amounts can cause significant water quality problems. Together with phosphorus, nitrates can accelerate lake eutrophication, causing dramatic increases in aquatic plant growth and changes in the types of plants and animals that live in the stream. This, in turn, affects dissolved oxygen, temperature, and other indicators. Excess nitrates can cause hypoxia (low levels of dissolved oxygen) and can become toxic to warm-blooded animals at higher concentrations (10 mg/L or higher) under certain conditions.

The natural level of ammonia or nitrate in surface water is typically low (less than 1 mg/L). In the effluent of wastewater treatment plants, it can range up to 30 mg/L. Sources of nitrates include wastewater treatment plants, runoff from fertilized lawns and cropland, failing on-site septic systems, runoff from animal manure storage areas, and industrial discharges that contain corrosion inhibitors.

Nitrates from land sources end up in rivers and streams more quickly than other nutrients like phosphorus. This is because they dissolve in water more readily than phosphates, which have an attraction for soil particles. As a result, nitrates serve as a better indicator of the possibility of a source of sewage or manure pollution during dry weather. Water that is polluted with nitrogen-rich organic matter might show low nitrates. Decomposition of the organic matter lowers the dissolved oxygen level, which in turn slows the rate at which ammonia is oxidized to nitrite (NO2) and then to nitrate (NO3). Under such circumstances, it might be necessary to also monitor for nitrites or ammonia, which are considerably more toxic to aquatic life than nitrate. There is currently no nitrate standard to protect aquatic life in Minnesota; nitrate levels must be below 10 mg/L in drinking water sources.

Appendix F.11. Flow

Stream flow is the total volume of water going past a point. Higher stream flows may represent more precipitation or more runoff generated by precipitation due to greater imperviousness (such as in developed landscapes) or drainage (such as ditched landscapes) in a watershed.

Appendix F.12. Runoff Depth

Runoff depth is the depth of the total volume of water going past a point if it were evenly distributed across the monitoring site drainage area. Runoff depth normalizes stream flow to annual precipitation. Higher runoff depth may represent more runoff generated by precipitation due to greater imperviousness or drainage in a watershed.

Appendix F.13. Pollutant Load

The District measures continuous stream flow and collects water quality concentration samples to model the total pollutant load discharged to and from District lakes. Load can be thought as the total amount of phosphorus or other pollutants moving past a point in the stream and is equal to the amount of pollutant per volume of water times the total volume of water going past a point (Figure 26). Higher loads may represent more precipitation or more phosphorus concentration sources compared to lower loads.

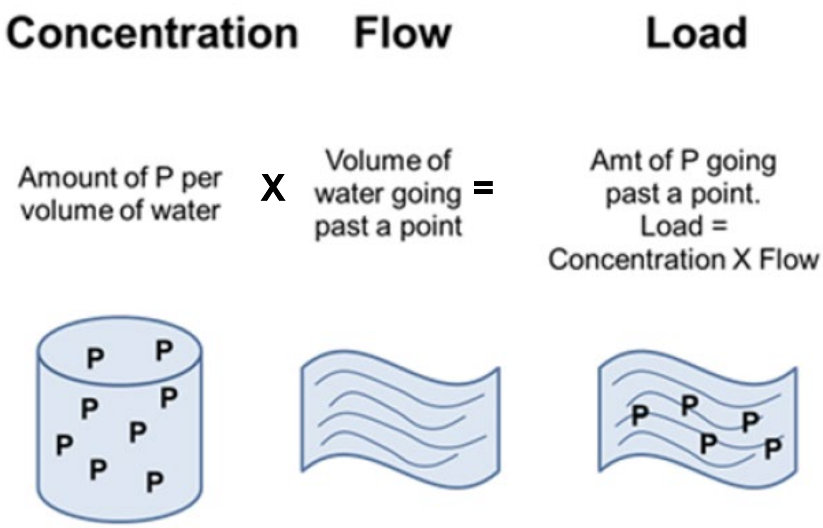


Figure 26. Relationship between stream flow and pollutant concentrations and loads

Appendix F.14. Flow-weighted Mean Concentration

The flow-weighted mean concentration (FWMC) is calculated as the total annual load divided by the total annual flow. The FWMC indicates how much pollutant is discharged relative to the flow. The phosphorus FWMC tends to have a greater impact on lake water quality than the total phosphorus load. The state lake water quality standards for deep lakes in the North Central Hardwood Forests region of 40 µg/L can typically be met when watershed runoff TP FWMC are less than 100 µg/L. For example, if the TP load and flow both increase to a lake, resulting in a similar TP FWMC, the higher TP load will have less impact on lake water quality because the time the load spends in the lake decreases under higher flows (water flows in and out of the lake faster).

Total flow and pollutant loads are most influenced by the amount and timing of precipitation, in addition to changes in land use, and implementation of BMPs. During wet years, pollutant loads may be higher due to overall higher watershed runoff and flows, even without any significant changes in land use or BMP implementation that influence the amount of pollutant loads. In this way, flow weighted mean pollutant concentrations are better indicators of watershed changes, such as land use changes or implementation of BMPs, than total phosphorus loads.