Comfort Lake-Forest Lake Watershed District

2019 Water Monitoring Report

Picture: Lake Keewahtin, May 16, 2009

COMFORT LAKE
- WATERSHED DISTRICT -
FOREST LAKE
Protecting Your Water Resources

5/29/2020

ACKNOWLEDGEMENTS

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

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INTRODUCTION

The purpose of long-term site monitoring is to understand the status of District resources, identify changes over time, and identify and define problems at the watershed or subwatershed level. Lakes and streams monitored in 2019 are shown in Figure 5 below. A summary of the in-lake summer average phosphorus concentrations and stream monitoring phosphorus loads from 2019 are included on Figure 5. In addition, this section includes a summary of historical climate records and significant events that occurred in 2019 that may have an impact on current or future water quality conditions.

Climate Context

Climate context is important for understanding water quality because the amount and timing of annual rainfall can impact the pollutant loads discharging to lakes and streams. There are typically higher pollutant loads in wet years due to greater runoff over the landscape. However, extremely wet years can sometimes result in better lake water quality due to greater flushing of water through the lake (shorter residence times) and less algae growth. Seasonal frequency and intensity of rainfall is not currently assessed in this report, but can result in greater pollutant loads through wetland pulsing and greater soil erosion. Lake water quality is also impacted by ice/snow depth, ice off date, and temperature - which impact the duration and depth of stratification. Lake temperatures and stratification are illustrated for each lake in Appendix A.

2019 Precipitation Data

Annual gridded precipitation in 2004-2019 for the District is summarized in Figure 1 based on precipitation data retrieved from the Minnesota State Climatology Office for Forest Lake, MN (at T32N, R21W, S13). The 2019 annual rainfall in Forest Lake was 40.85 inches, the second wettest year on record for Forest Lake (annual precipitation in 1975 was 43 inches). The average total annual rainfall between 1981 and 2010 was 31 inches per year. The Minnesota State Climatology Office defines wet years as years with total annual rainfall greater than the 70th percentile for the period of record (or 32.81 inches) and dry years as years with total annual rainfall less than the 30th percentile for the period of record (or 26.5 inches), and normal rainfall years as years with total annual rainfall between the 30th and 70th percentile for the period of record (or between 26.5 and 32.81 inches). Normal rainfall is indicated by the blue shaded box in Figure 1. Years where the top of the annual precipitation bar is above the blue box are wet years, within the blue box are normal years, and below the blue box are dry years. Wet rainfall years since 2004 included 2007, 2010, and 2014-2016, and 2018-2019. Below average rainfall years since 2004 included 2009.

Monthly gridded precipitation in 2019 for the District is summarized in Figure 3 and compared to the 1981-2010 normal monthly precipitation based on precipitation data retrieved from the Minnesota State Climatology Office for Forest Lake, MN (at T32N, R21W, S13). Monthly precipitation in 2019 exceeded the 1981-2010 normal in February, April, May, July, September, October and December. Monthly precipitation in 2019 was greater than 5 inches in May, July, September and October. There were 7 rainfall events in 2019 that produced over 1.5 inches of rain:

- 3.79 inches over 9/29-10/6
- 2.23 inches over 10/21-10/23
- 2.01 inches over 5/17-5/19
- 1.95 inches over 4/19-4/22
- 1.88 inches on 7/29
- 1.7 inches on 5/9
- 1.65 inches over 9/11-9/13

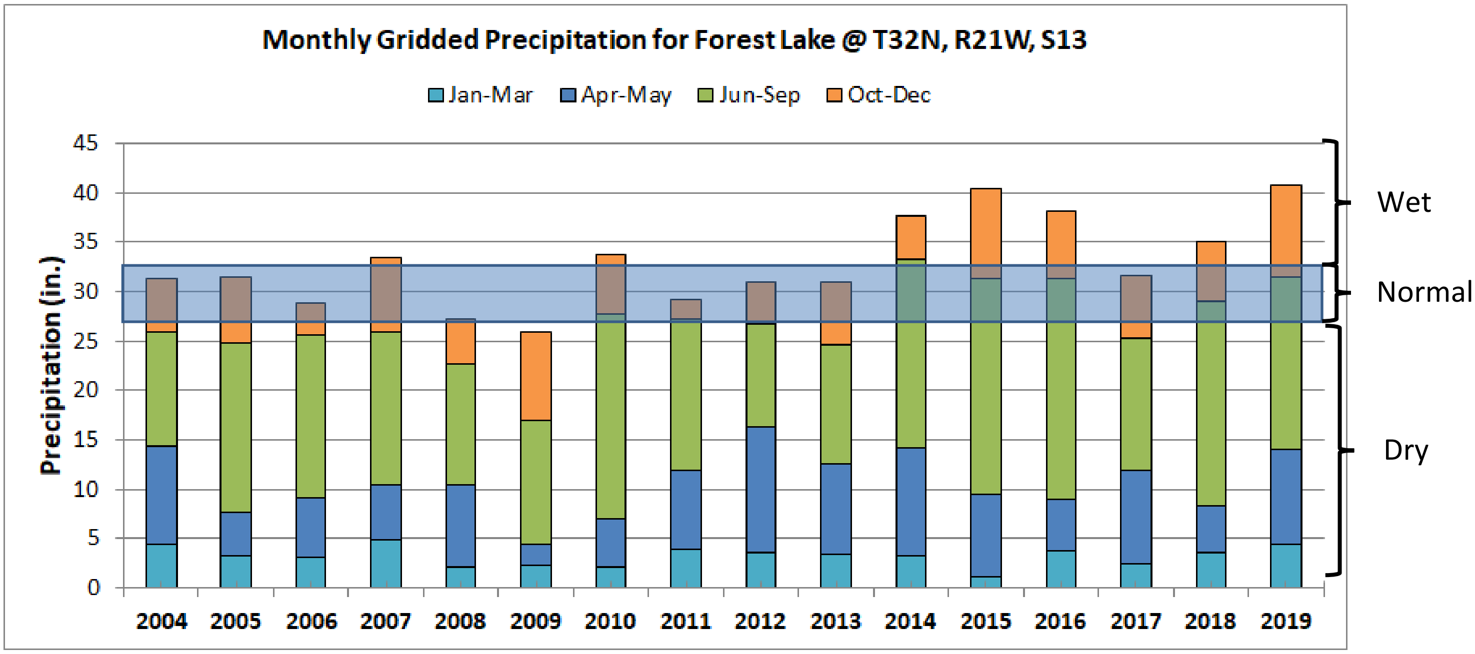


Figure 1. 2004-2019 Annual Gridded Precipitation for Forest Lake at Township 32N, Range 21W, Section 13

http://climateapps.dnr.state.mn.us/gridded_data/precip/monthly/monthly_gridded_precip.asp

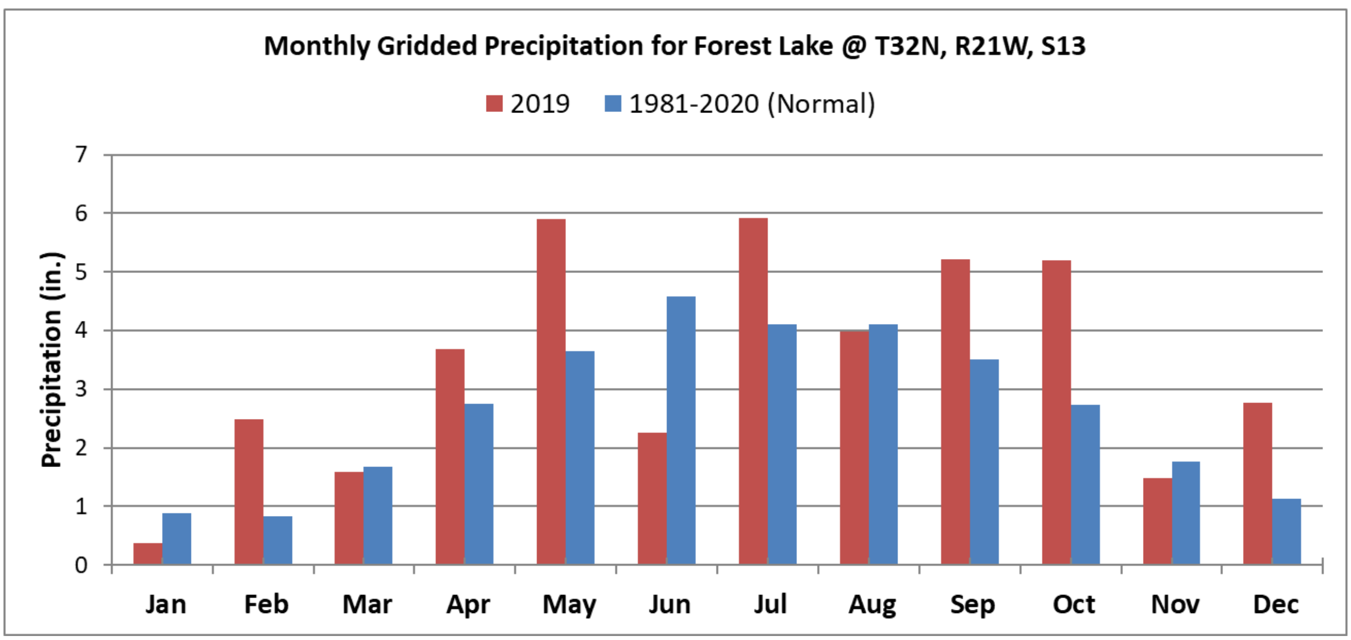


Figure 2. 2019 Monthly Gridded Precipitation for Forest Lake at Township 32N, Range 21W, Section 13

http://climateapps.dnr.state.mn.us/gridded_data/precip/monthly/monthly_gridded_precip.asp

State Wide Climate Trends

According to data developed by the Minnesota State Climatology Office, the average annual temperature and precipitation have shifted to a much warmer and wetter condition, respectively, in the last 30 years (1987-2018) compared to the 30 years prior (1895-1986). This trend is shown in Figure 3. In this figure, 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 green dots represent the conditions between 1895 and 1986, while the red dots represent the conditions between 1987 and 2018. As shown in the figure, there is a shift in the latter years into the upper right quadrant, representing higher temperatures and more precipitation.

With that, there are two key trends that have been observed by climatologists in Minnesota relating to climate conditions:

1. Wetter conditions due to more precipitation, more snow, and more frequent and larger extremes.
2. Increasing temperatures especially at night, during winter, and when it is cold.

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

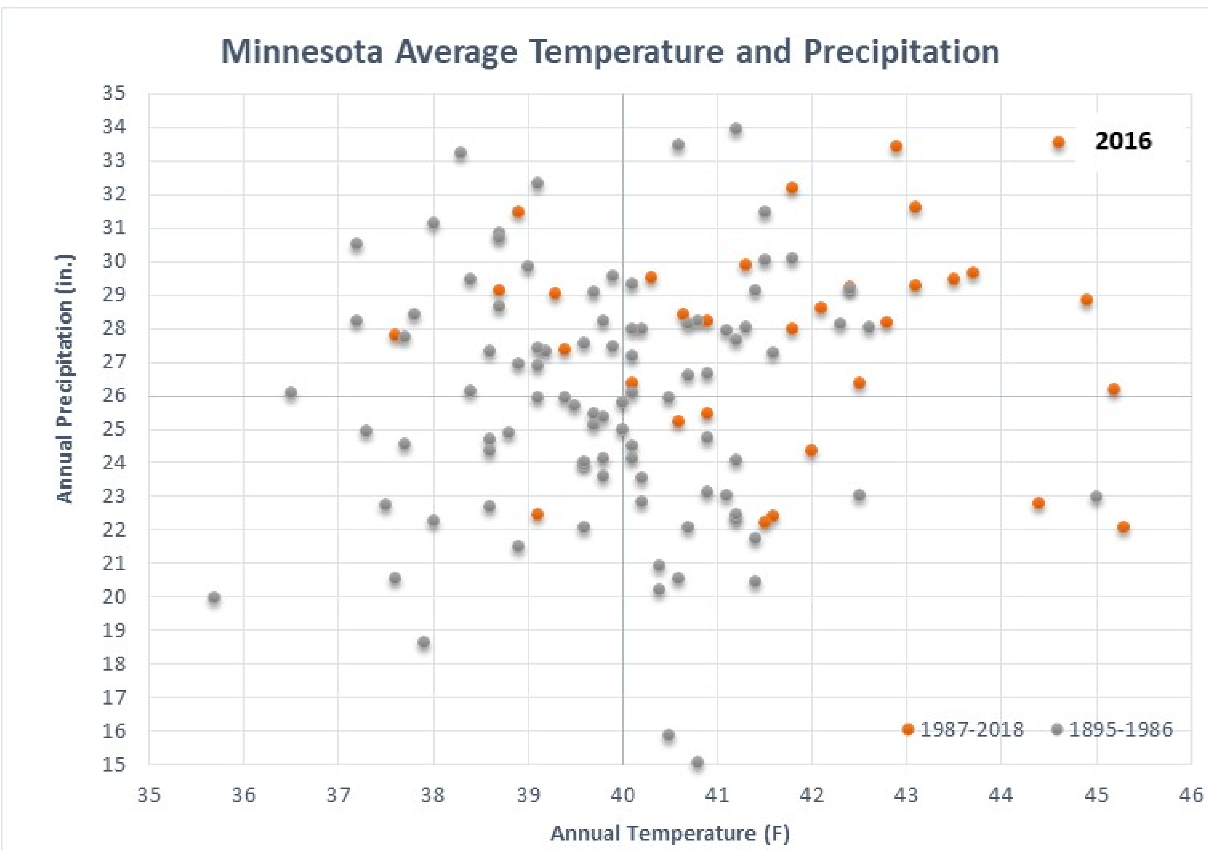


Figure 3. Minnesota Average Temperature and Precipitation (Source: MN State Climatology Office)

2019 Significant Events

The purpose of this section is to record significant rain events, unusual weather patterns, notable landscape changes, notable permit violations and/or BMP construction projects that occurred in 2019 that may have had the potential to impact water quality data collected in 2019 or in the future.

- 2019 was the second wettest year on record in Forest Lake.
- Seven rainfall events produced greater than 1.5 inches of rainfall, with the largest rainfall event of 3.79 inches over 9/29-10/6.
- An EF1 tornado began near Keewahtin Lake and traveled northeast across Bone Lake at 4:28 PM CDT on July 28 (Figure 4).
- Six juvenile zebra mussels were discovered in Bone Lake on May 28. There was a zebra mussel rapid response treatment in Bone Lake at the boat launch near the Bone Lake Outlet on June 17.
- The zebra mussel population in Forest Lake is continuing to increase since they were first detected in 2015. Zebra mussels were first detected in Comfort Lake in 2017.
- Total control of curlyleaf pondweed was achieved in Moody Lake following a May 20 herbicide treatment, and in Shields Lake following a May 20 herbicide treatment. There was poor control of curlyleaf pondweed in Bone Lake following a June 6 herbicide treatment.
- On September 30 and October 18, 71 common carp were removed from Shields Lake with a total biomass removal of 1,006 lbs.
- The second of two planned alum treatments was completed in Moody Lake on October 20-23. The first of two planned alum treatments was completed in Shields Lake on October 24-26.
- The Shields Lake Stormwater Harvest and Reuse System was installed in the winter and spring of 2019.

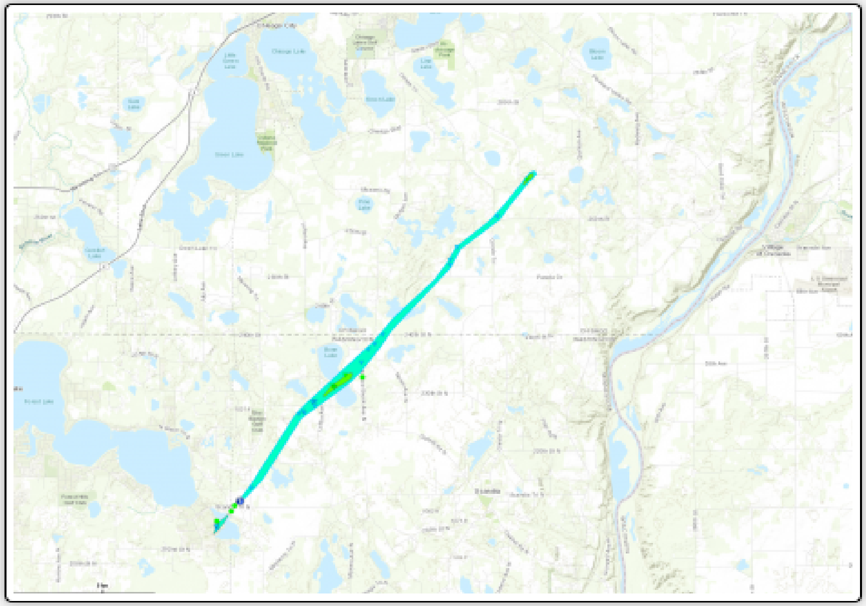
Tornado - Forest Lake, Scandia, & Lindstrom, MN
WASHINGTON, CHISAGO COUNTIES

Date	7/28/2019
Time (Local)	4:28 PM CDT
EF Rating	EF1
Est. Peak Winds	90 mph
Path Length	7.6 miles
Max Width	1/4 mile
Injuries/Deaths	0/0

Summary:

A tornado spun up on the south side of Sylvan lake (east of Forest Lake), and continued northeast on a broken path through Bone Lake, then entered Chisago County, east of Morgan St, on 240th Street North. The tornado continued along a broken path with damage south of Spider Lake where it destroyed a barn, then it damaged a private wedding venue along Olinda & 259th Street. The worst damage occurred to a farm near on 268th Street, east of Olympic Trail. The damage was rated an EF1 with severe damage to a shed and pole barn. Other damage was mainly confined to trees snapped or uprooted along the tornadoes path.

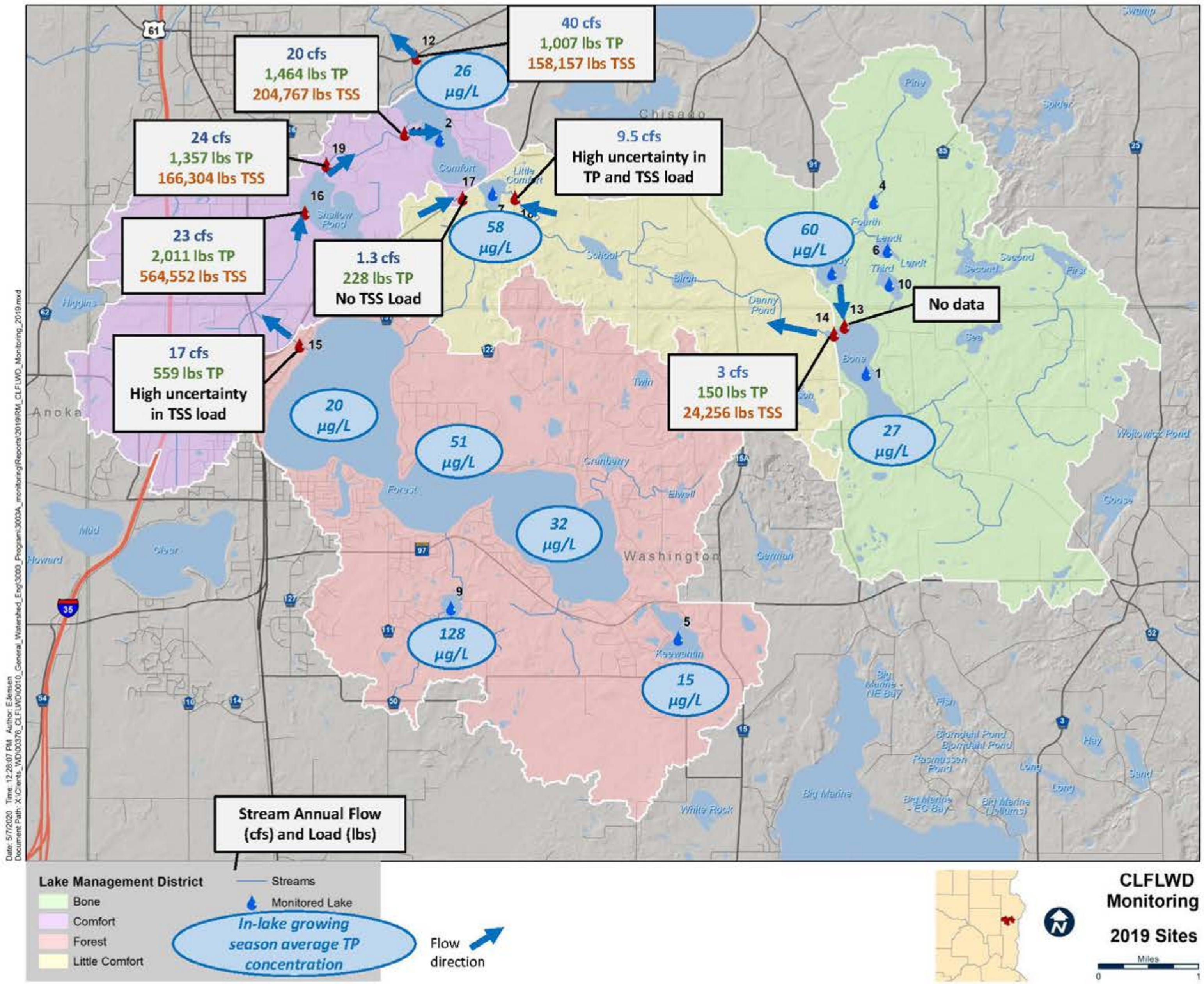
Track Map



EF0 EF1 EF2 EF3 EF4 EF5 TSTM UKN

Downloadable KMZ File

Figure 4. July 28, 2019 Tornado Summary from the National Weather Service (https://www.weather.gov/mpx/28Jul2019_Tornadoes)



Lake and Stream Monitoring Site Key	
1	Bone
2	Comfort
3	Forest
4	Fourth
5	Keewahtin
6	Lendt
7	Little Comfort
8	Moody
9	Shields
10	Third
11	Big Comfort Inlet
12	Big Comfort Outlet
13	Bone Lake North Inlet
14	Bone Lake Outlet
15	Forest Lake Outlet
16	Greenway Avenue
17	Heath Ave
18	Little Comfort Inlet
19	Sunrise @ 256th

Figure 5. Lakes and stream monitoring sites in 2019 (cfs = stream runoff volume in cubic feet per second, lbs = stream phosphorus load in pounds per year)

LAKES

There are 19 named lakes in the Comfort Lake Forest-Lake Watershed. These lakes have significant aesthetic and recreational value. They also serve as a home to a wide variety of plants, fish, mammals, reptiles, and migratory waterfowl. The quality of water in these lakes is a key variable in how the lake is used, both by humans and animals. Poor water quality can result in decreased opportunities for recreation and loss of habitat for plants and animals. More specifically, poor water quality can lead to nuisance algae blooms, odor problems, fish kills, and shifts in fish populations toward less desirable species such as carp and bullhead. Improving and protecting lake water quality is a high priority for the Comfort Lake-Forest Lake Watershed District.

Regularly assessing water quality allows resource managers to compare lakes to one another, measure change over time, and prioritize management actions. Monitoring of lake water quality has been conducted in the Comfort Lake-Forest Lake Watershed District as far back as the 1970's. Water quality data over the years has been collected by a number of organizations including the Comfort Lake Forest- Lake Watershed District, the Washington Conservation District, Metropolitan Council, the MN Department of Natural Resources, the MN Pollution Control Agency, and citizen volunteers.

What is the purpose of collecting lake data?

Surface Water Quality

Lake surface water quality is typically sampled for total phosphorus, chlorophyll-a and Secchi depth transparency. Total phosphorus 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 septics). Chlorophyll-a represents the amount of algae in the surface water. Algae blooms reduce water clarity (as measured by Secchi depth) and can cause unpleasant odors, a loss of dissolved oxygen in the lake necessary 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 over the side of a boat. The deepest depth at which the Secchi disk is visible is the Secchi depth. More algae in the water results in more turbidity or cloudiness of the water and lower (more shallow) Secchi depth; less algae in the water results in clearer water and higher (deeper) Secchi depth. Surface water quality generally varies seasonally for Minnesota lakes, with lower phosphorus and chlorophyll-a and deeper Secchi depth in spring and fall, with peak concentrations and lowest water clarity typically in July and August.

More Phosphorus = More Algae = Less Clarity

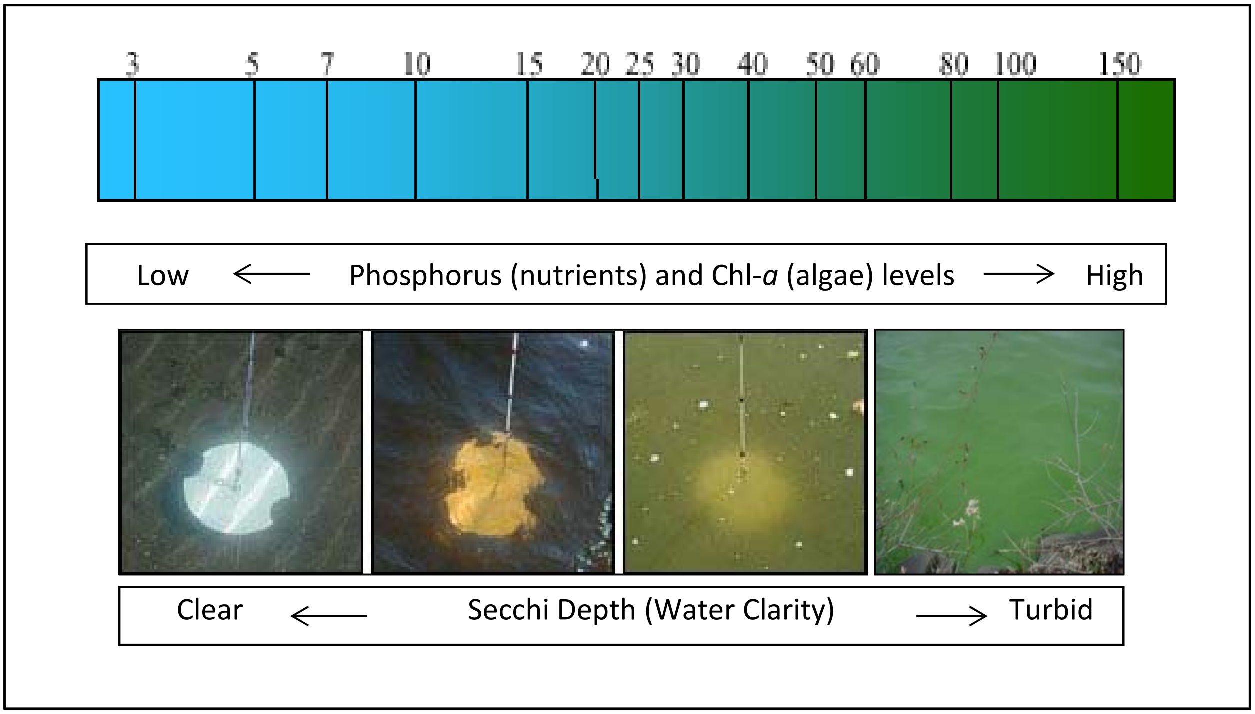


Figure 6. Relationships between lake phosphorus and algae levels with water clarity (WCD)

Lake Grades

Lake grades were assigned to each lake in 2019 and for the average of the last five years (2015-2019) for total phosphorus, chlorophyll-a, Secchi depth, and overall lake water quality (the average of the TP, Chl-a and Secchi grades) according to the following Met Council water quality grading system developed in 1989:

Table 1. 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

Dissolved Oxygen and Temperature

Dissolved oxygen (DO) and temperature depth profiles measure the dissolved oxygen concentration and temperature every meter in a lake from the surface to the bottom, typically measured at the deepest point in the lake. The temperature profile is used to see how strongly the lake stratifies, or separates into a distinct warm surface layer and a cool bottom layer. The lake temperature at the interface between these two layers is characterized by a very rapid change from warm to cooler temperatures. This can often be felt when swimming in a lake in the summer where the surface water feels warm but your toes feel cool when sticking them straight down into the water. The dissolved oxygen profile is used to show the amount of oxygen depletion of the bottom waters. Algae grows in the surface water where there is sufficient sunlight and then dies and decomposes in the bottom waters which consume oxygen. Decomposition of organic matter in the lake sediments can also consume oxygen.

Bottom Water Phosphorus

Bottom water phosphorus samples were collected from select lakes that have historic, or suspected of having future, internal phosphorus loading issues. Bottom water phosphorus represents the amount of phosphorus released from lake sediments when the lake water is stratified. When the bottom waters become mostly depleted of oxygen, phosphorus that is bound to iron in the sediments is released into the bottom waters. Phosphorus will accumulate in the bottom waters over the summer. Too much phosphorus accumulation in the bottom waters is called internal loading. When internal loading is sufficiently high, it can diffuse up into the surface waters and decrease surface water quality. The impact of internal loading on lake surface water quality is most notable after severe storm events and in the fall when lake stratification weakens and the surface and bottom waters mix.

Lake Levels

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

What lake data was collected in 2019?

Data collected from CLFLWD lakes in 2019 is inventoried in Table 2 below.

Table 2. CFLWD Lake Data Collected in 2019

Lake	DNR Public Water Classification	DNR ID	Acres	Lake levels	DO/Temp profiles	Surface WQ	Bottom water TP
Birch	Wetland	82-0054-00	33				
Bone	Lake	82-0054-00	221	X	X	X	X
Comfort	Lake	13-0053-00	218	X	X	X	
Elwell	Wetland	82-0079-00	16	X	X	X	
Forest (West)	Lake	82-0156-00	1,086	X	X	X	X
Forest (Middle)	Lake		364		X	X	X
Forest (East)	Lake		790		X	X	X
Fourth Lake	Wetland	13-0022-00	8	X	X	X	
Heims Lake	Lake	13-0056-00	90				
Keewahtin	Lake	82-0080-00	75	X	X	X	
Lendt Lake	Wetland	13-0103-00	42	X	X	X	
Little Comfort	Lake	13-0054-00	36		X	X	X
Moody	Wetland	13-0023-00	45	X	X	X	X
Nielsen	Wetland	82-0055-00	37				
School	Wetland	13-0057-00	47				
Sea	Wetland	82-0053-00	50				
Second	Lake	13-0025-00	75			X	
Shields	Wetland	82-0162-00	30	X	X	X	
Third Lake	Lake	13-0024-00	42	X	X	X	
Twin Lake	Wetland	82-0157-00	19	X	X	X	

Acronym List: DNR ID = Minnesota Department of Natural Resources Identification, DO = dissolved oxygen, Temp = temperature, WQ = water quality, TP = total phosphorus

2019 Lake Water Quality Summary

The lake water quality grades based on 2019 and the most recent 5-year average (2015-2019) are provided in Table 3. In 2019, Keewahtin Lake was the only lake in the District to receive a lake water quality grade of A. Bone, Comfort, Lendt, Second, Sea, Third, and Twin Lakes received a lake water quality grade of B. Forest Lake is on the border between a lake water quality grade of B and C. Shields and Nielsen Lakes have the worst lake water quality grades in the District, with five year average grades of F. Although Shields Lake's 2019 lake water quality grade of D was a slight improvement from the five year average.

The 2019 growing season average lake water quality data for all lakes monitored in 2019 is provided in Table 4.

Table 3. CLFLWD Lake Water Quality Grades for 2019 and most recent 5-year average (2015-2019)

Lake	DNR ID	Acres	TP		Chl-a		Secchi		Overall	
			2019	5-yr Avg	2019	5-yr Avg	2019	5-yr Avg	2019	5-yr Avg
Bone	82-0054-00	221	B	B	B	B	C	C	B-	B-
Birch	13-0042-00	33		D		B		C		C
Comfort	13-0053-00	218	B	B	B	B	C	C	B-	B-
Elwell	82-0079-00	16	C	C	B	B	F	F	C-	C-
Forest (West)	82-0156-00	1,086	A	B	A	B	C	C	B+	B-
Forest (Middle)	82-0156-00	364	C	C	B	B	C	C	C+	C+
Forest (East)	82-0156-00	790	B	C	B	B	B	C	B	C+
Forest (All Basins)	*82-0156-00*	*2,240*	C	C	B	B	B	C	B-	C+
Fourth Lake	13-0022-00	8	D	D	C	C	F	F	D	D
Heims	13-0056-00	90		C				D		C-
Keewahtin	82-0080-00	75	A	A	A	A	A	A	A	A
Lendt Lake	13-0103-00	42	A	A	A	A	C	C	B+	B+
Little Comfort	13-0054-00	36	C	C	C	C	C	C	C	C
Moody	13-0023-00	45	C	D	C	D	D	F	C-	D-
Nielsen	82-0055-00	37		D		F		F		F+
Second	13-0025-00	75	B	B	A	A	B	B	B+	B+
School	13-0057-00	47		C		C		D		C-
Sea	82-0053-00	50		C		A		C		B-
Shields	82-0162-00	30	D	F	D	D	D	F	D	F+
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

5-yr Avg = Most recent five year average (2015-2019)

Table 4. 2019 Growing Season Average Lake Water Quality Data

Lake	DNR ID	Acres	2019 Growing Season (June-September) Average		
			Total Phosphorus (ug/L)	Chlorophyll-a (ug/L)	Secchi depth (feet)
Bone	82-0054-00	221	27	19.7	4.9
Comfort	13-0053-00	218	26	16.2	5.3
Elwell	82-0079-00	16	48	11.9	2.2
Forest (West)	82-0156-00	1,086	20	7.8	7.1
Forest (Middle)		364	51	19.5	7.0
Forest (East)		790	32	17.1	7.9
Fourth Lake	13-0022-00	8	87	29.1	2.3
Keewahtin	82-0080-00	75	15	2.7	13.4
Lendt Lake	13-0103-00	42	18	4.5	4.4
Little Comfort	13-0054-00	36	58	25	4.5
Moody	13-0023-00	45	60	41	2.4
Second	13-0025-00	75	23	7.9	8.7
Shields	82-0162-00	30	128	52	2.5
Third Lake	13-0024-00	42	19	3.9	4.9
Twin Lake	82-0157-00	19	28	5.6	4.2

Progress towards District Lake Water Quality Goals

Progress of lakes towards achieving their respective District 2020, 2030, and 2040 goals are shown for phosphorus and Secchi depth are shown in Table 5. The lakes are listed in order of increasing in-lake phosphorus concentration, and therefore, in order of progress towards achieving their respective District goals, from closest to furthest. Keewhatin Lake currently meets its 2040 District goal; Bone, Comfort and Forest Lakes currently meet the 2020 District goals for phosphorus; and Comfort and Forest Lakes currently meet the 2030 District goals for Secchi depth (from Table 1 of the 2012-2021 Watershed Management Plan).

Based on the fact that Bone, Comfort and Forest Lakes currently meet the 2030 District goals for TP, the Lake Associations requested slight reductions to the 2030 District goals (more stringent) during the 2017 Watershed Management Plan minor amendment (proposed as shown in Table 5). Note that the TP and Secchi District goals are based on scientifically based relationships between lake clarity responses to TP concentrations (Figure 7). For example, a growing season average in-lake phosphorus concentration of 20 µg TP/L is expected to result in water clarity of 10 feet (~3 meters), 30 µg TP/L with water clarity of 7 feet (~2.1 meters), 33 µg TP/L with water clarity of 6 feet (~1.8 meters), and 40 µg TP/L with water clarity of 5 feet (~1.5 meters).

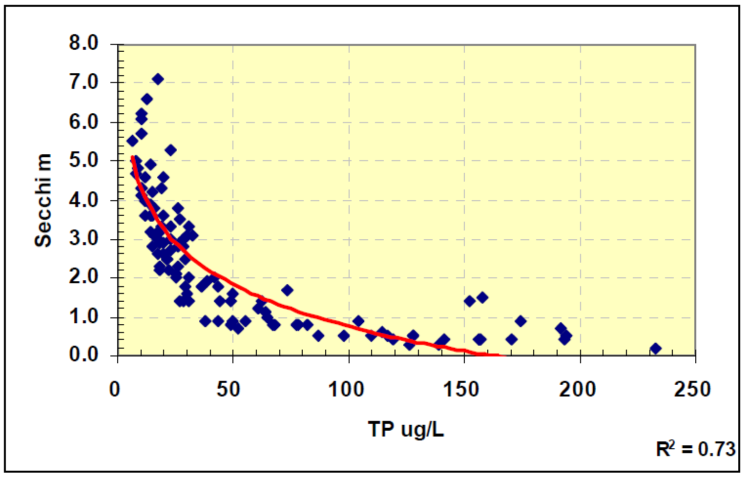


Figure 7. Summer-mean TP and Secchi relationships based on MN reference lake data

(Figure 4a from Heiskary and Wilson. 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, Third Edition. Minnesota Pollution Control Agency, 176 pp.

Table 5. Progress towards District phosphorus and Secchi goals

Lakes (in order of increasing TP)	2019 Growing Season Average	10-Year Average		5-Year Average				
		2010-2019	Years of Data	Existing (2015-2019)	Years of Data	2020 District Goal	2030 District Goal	2040 District Goal
Phosphorus Concentration (µg/L)								
Keewahtin	**15**	**16**	9	**16**	4	**20 ✓**	**20 ✓**	**20 ✓**
Comfort	**26**	**33**	10	**31**	5	**40 ✓**	**33 ✓**	**30**
Bone	**27**	**35**	10	**31**	5	**40 ✓**	**30**	**30**
Forest	**34**	**35**	10	**36**	5	**37 ✓**	**33**	**30**
Forest East	**32**	**36**	9	**37**	5	**37 ✓**	**33**	**30**
Forest Middle	**51**	**38**	9	**39**	5	**37 ✓**	**33**	**30**
Forest West	**20**	**34**	10	**32**	5	**37 ✓**	**33 ✓**	**30**
Heims	**--**	**43**	2	**33**	1	**40 ✓**	**40 ✓**	**40 ✓**
School	**--**	**52**	2	**52**	2	**50**	**40**	**40**
Little Comfort	**58**	**56**	10	**61**	5	**40**	**40**	**30**
Birch	**--**	**97**	2	**97**	2	**60**	**60**	**60**
Moody	**60**	**103**	10	**93**	5	**60**	**40**	**40**
Shields	**128**	**212**	8	**208**	5	**100**	**60**	**60**
Secchi Depth (ft)								
Keewahtin	**13.4**	**14.8**	9	**13.8**	4	**10 ✓**	**10 ✓**	**10 ✓**
Comfort	**5.3**	**5.4**	10	**6.0**	5	**5 ✓**	**5 ✓**	**7**
Bone	**4.9**	**4.7**	10	**5.1**	5	**4 ✓**	**7**	**7**
Forest	**7.3**	**5.9**	10	**6.5**	5	**5 ✓**	**6 ✓**	**7**
Forest East	**7.9**	**6.6**	9	**7.2**	5	**5 ✓**	**6 ✓**	**7 ✓**
Forest Middle	**7.0**	**6.4**	9	**7.0**	5	**5 ✓**	**6 ✓**	**7 ✓**
Forest West	**7.1**	**5.0**	10	**5.4**	5	**5 ✓**	**6**	**7**
Heims	**--**	**2.8**	1	**2.8**	1			
School	**--**	**2.7**	2	**2.7**	2	**4**	**4.6**	**4.6**
Little Comfort	**4.5**	**4.7**	10	**4.1**	5	**5**	**5**	**7**
Birch	**--**	**4.2**	2	**4.2**	2	**3.3 ✓**	**3.3 ✓**	**3.3 ✓**
Moody	**2.4**	**2.5**	10	**2.2**	5	**3.3**	**4.6**	**4.6**
Shields	**2.5**	**2.9**	8	**2.3**	5	**4.26**	**4.26**	**4.26**

✓ = meets District Goal; ## = does not meet District Goal

Note that the Forest Lake and Bone Lake 2030 goals are proposed changes that will be considered during the next major plan amendment.

Progress towards State Lake Water Quality Standards

Table 6 illustrates the progress of lakes towards achieving their respective State water quality standards. Comfort (2002), Bone (2004), Little Comfort (2012), Moody (2008), School (2008), Shields (2006), and Second (2012) Lakes were listed as impaired for eutrophication due to excess nutrients by the State of Minnesota (the year the lake was added to the 303(d) list is included in parentheses after the lake name) and were included in a TMDL study.

All State water quality standards are based on growing season (June-September) averages. To be added to the impaired waters list, a lake must not meet the phosphorus standard AND not meet either the chlorophyll-a or Secchi depth standard based on at least 8 samples collected from at least 2 years within the most recent 10 year period. To be removed from the impaired waters list, a lake must meet the phosphorus standard AND the chlorophyll-a or Secchi depth standard based on at least 8 samples collected from at least 2 years within the most recent 10 year period. In addition, there must be an improving trend in TP or management activities in place to maintain improved chlorophyll-*a* or Secchi observations. The local entity must provide information that details how the response conditions will be met over time for a lake to be de-listed.

Lakes that were historically impaired but currently meet the State water quality standards based on the most recent 10-year period (2010-2019) are Bone and Comfort Lakes. Fourth Lake was not previously identified as impaired, but does not meet the State water quality standards based on the most recent 10-year period (2009-2018). Little Comfort and School Lakes are still impaired but close to meeting State water quality standards (that is to say, they achieve one of the three standards) and should be a focus for implementation efforts. Sea and Keewahtin Lakes meet the State water quality standards for phosphorus, chlorophyll-*a*, and Secchi depth. Birch Lake meets the State standards for Secchi depth and chlorophyll-a, but has high phosphorus concentrations.

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)		
	2010 - 2019 Average	Years of Data	Standard	2010 - 2019 Average	Years of Data	Standard	2010 - 2019 Average	Years of Data	Standard
GENERAL LAKES									
Bone *	**35**	*10*	**40 ✓**	**16**	10	**14**	**4.7**	10	**4.6 ✓**
Comfort *	**33**	*10*	**40 ✓**	**16**	10	**14**	**5.4**	10	**4.6 ✓**
Forest	**35**	*10*	**40 ✓**	**17**	10	**14**	**5.9**	10	**4.6 ✓**
Keewahtin	**16**	*9*	**40 ✓**	**3**	9	**14 ✓**	**14.8**	9	**4.6 ✓**
Little Comfort *	**56**	*10*	**40**	**21**	10	**14**	**4.7**	10	**4.6 ✓**
Moody *	**103**	*10*	**40**	**59**	10	**14**	**2.5**	10	**4.6**
SHALLOW LAKES									
Birch	**97**	*2*	**60**	**18**	2	**20 ✓**	**4.2**	2	**3.3 ✓**
Fourth	**92**	*3*	**60**	**29**	1	n/a	**2.1**	3	**3.3**
Heims	**43**	*2*	**60 ✓**		0	n/a	**2.8**	1	n/a
Lendt	**16**	*3*	**60 ✓**	**5**	1	n/a	**4.7**	3	**3.3 ✓**
Sea	**50**	*2*	**60 ✓**	**9**	2	**20 ✓**	**4.5**	2	**3.3 ✓**
Second **	**23**	*1*	n/a	**8**	1	n/a	**8.7**	1	n/a
School *	**52**	*2*	**60 ✓**	**41**	2	**20**	**2.7**	2	**3.3**
Shields *	**212**	*8*	**60**	**50**	8	**20**	**2.9**	8	**3.3**
Third	**22**	*3*	**60 ✓**	**4**	1	n/a	**4.3**	2	**3.3 ✓**

N = number of years data has been collected with the 2009-2018 time 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 have District Goals; ## ✓= meets Standard; ## = does not meet Standard, *n/a = insufficient data*

Lake Water Quality Trends

Long-term lake water quality trends were calculated using the Kendall's Tau statistical analysis which essentially reports how consistently a water quality parameter (such as TP or Secchi) increases or decreases over time. Short-term (since 2010) and long-term (for the entire monitoring period beginning with the earliest available year) were determined for each lake for all monitoring data available from the MPCA EDA Surface Water Database. Many lakes had large gaps in their monitoring records and therefore, only short-term trends could be determined, as noted in Table 7 below.

- **No trend** indicates that the water quality parameter is not consistently increasing or decreasing from year to year over the time period, AND this is a statistically significant no change.
- **Improving** or **declining** trends means that 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 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.

Table 7. Lake Water Quality Trends (EOR)

Lake	Total Phosphorus Trend	Chlorophyll-a Trend	Secchi Disk Trend
Bone	**Significantly Improving (-41%) since 2010**	Improving since 2001	Improving since 1984
Comfort	Improving since 1994	Improving since 2010	**Significantly Improving (+25%) since 2010**
Forest – West	**Significantly Improving (-47%) since 2010**	**Significantly Improving (-67%) since 2010**	**Significantly Improving (+74%) since 2010**
Forest – Middle	Declining since 2010	Declining since 2010	**Significantly Improving (+54%) since 2010**
Forest – East	Declining since 2010	Declining since 2010	**Significantly Improving (+57%) since 2010**
Keewahtin	Improving since 1979	Improving since 2001	**Significantly Improving (+29%) since 1974**
Little Comfort	Declining since 2010	**Significantly Declining (+110%) since 2010**	**Significantly Declining (-24%) since 2010**
Moody	**Significantly Improving (-57%) since 2005**	Improving since 2005	Improving since 2005
Shields	Improving since 1993	NA	**Significantly Declining (-63%) since 1993**

NA = not enough data available to determine a long-term trend in water quality

Short-term trends are noted for the most-recent 10-years (since 2010)

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

STREAMS

Streams are assessed by the Minnesota Pollution Control Agency for their ability to support aquatic life and aquatic recreation designated uses. 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 considered to be Class 2B Waters, according to the Minnesota Pollution Control Agency (MPCA). These types of streams are described as cool- and warm-water fisheries (not protected for drinking water) and are held to certain water quality standards as set by the MPCA (Minn. R. 7050.0222. The state standards can be found in Table 8. It is important to track these water quality standards at each site to determine if the waters are meeting state goals and whether or not they are impaired. For the purposes of identifying instances in which the 2B standards are not meeting MPCA thresholds, only discrete (grab) samples taken manually are considered in this report.

Multiple water quality parameters were monitored and analyzed at each stream site in 2019. 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 Comfort Lake-Forest Lake Watershed District (CLFLWD) to identify trends associated with land use changes in the watershed.

Table 8. 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 ug/L**

**May be exceeded no more than ten percent of the time, April 1-September 30*

***June-September 10-year average*

The following is the description for the *Escherichia (E.) coli* standard:

> "Not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31."

What is the purpose of collecting stream data?

<u>Location</u>

- Lake outlets – there are 3 lake outlet sites with long-term records in CLFLWD: Bone Lake, Forest Lake and Comfort Lake. Data from these sites are useful for calibrating H&H models and tracking total flow and loads discharged from the lakes over time to downstream waters. However, data from these sites is greatly influenced by lake water quality and does not provide information on how landscape changes influence water quality over time.

- Lake inlets – 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.

Physical Parameters

- **Temperature (degrees Celsius) –** a measure of the temperature of the 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 survive best in colder water, whereas others prefer warmer water. Benthic macroinvertebrates are also sensitive to temperature and will move in the stream to find their optimal temperature. If temperatures are outside this optimal range for a prolonged period of time, organisms are stressed and can die. Warm temperatures (typically above 20 degrees Celsius, or 68 degrees Fahrenheit) can stress or cause mortality in coldwater fish species; there are no known stream cold water fish species in the District.

- **Dissolved oxygen (mg/L) –** a measure of the amount of dissolved oxygen available in the water to support aquatic life. The stream system both produces and consumes oxygen. It gains oxygen from the atmosphere and from plants as a result of photosynthesis. Running water, because of its churning, dissolves more oxygen than still water, such as that 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 (Table 5.3) 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. Dissolved oxygen levels below 5 mg/L can cause stress or mortality in fish and macroinvertebrates.

- **pH –** a measure of the acidity of the water. pH affects many chemical and biological processes in the water. For example, different organisms flourish within different ranges of pH. The largest variety of aquatic animals prefer a range of 6.5-8.0. pH outside this range reduces the diversity in the stream because it stresses the physiological systems of most organisms and can reduce reproduction. 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, particularly to sensitive species like rainbow trout.

- **Specific conductance (µS/cm) –** a measure of the 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 have a low conductivity when in 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 (25 C). 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.

- **Turbidity (total suspended solids and total volatile solids, mg/L)** - Turbidity is a measure of water clarity 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 concentration of dissolved oxygen (DO) because warm water holds less DO than cold. 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.

Nutrients

- **Phosphorus (mg/L) –** 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).

- **Nitrogen –** forms of nitrogen include ammonia (NH3), nitrates (NO3), and nitrites (NO2). Nitrates are essential plant nutrients, but in excess amounts they can cause significant water quality problems. Together with phosphorus, nitrates in excess amounts can accelerate 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.

Bacteria

- ***Escherichia coli*** **–** Members of two bacteria groups, coliforms and fecal streptococci, are used as indicators of possible sewage contamination because they are commonly found in human and animal feces. Although they are generally not harmful themselves, they indicate the possible presence of pathogenic (disease-causing) bacteria, viruses, and protozoans that also live in human and animal digestive systems. Therefore, their presence in streams suggests that pathogenic microorganisms might also be present and that swimming and eating shellfish might be a health risk. Since it is difficult, time-consuming, and expensive to test directly for the presence of a large variety of pathogens, water is usually tested for coliforms and fecal streptococci instead. Sources of fecal contamination to surface waters include wastewater treatment plants, on-site septic systems, domestic and wild animal manure, and storm runoff. *E. coli* is a species of fecal coliform bacteria that is specific to fecal material from humans and other warm-blooded animals.

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.

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.

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 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. Higher loads may represent more precipitation or more phosphorus load sources compared to lower loads.

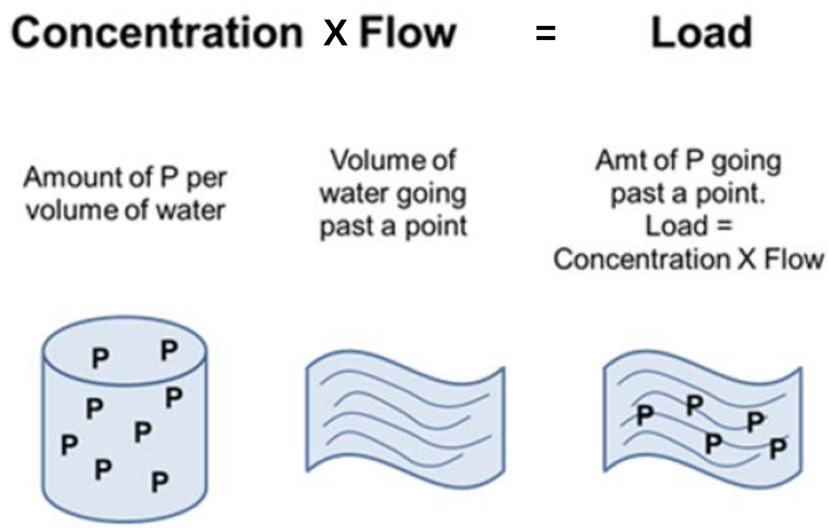


Figure 8. Relationship between stream flow and pollutant concentrations and loads

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 best management practices (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.

What stream data was collected in 2019?

Nine stream sites were monitored in 2019 by WCD and EOR; EOR monitored the Little Comfort Inlet at Heath Avenue, all other sites were monitored by WCD. Continuous stream stage, flow measurements to develop stage-discharge rating curves, and stream water chemistry grab and composite samples were collected at all WCD sites (temperature, dissolved oxygen, pH, specific conductance, solids, phosphorus, nitrogen, bacteria and chloride). Continuous stream stage, flow measurements to develop stage-discharge rating curves, and total phosphorus grab samples were collected at the Heath Avenue Outlet. The annual hydrographs with total phosphorus and total suspended solids concentrations are shown as figures and all water chemistry data collected by sample data is included in a table for each individual stream site in Appendix B.

Table 9. 2019 Stream Monitoring Site, Period and Technique Summary

Map Site ID	Stream Site	Flow Monitoring Period	Monitoring Technique
15	**Forest Lake Outlet**	5/3/19 9:30 – 10/20/19 21:15. Stage data indicates that the blockage in the Hwy 8 culvert was removed 8/12/19 7:00, was reinstalled 8/17/19 12:30, and then removed again 8/19/19 7:30. Power failures occurred and no data was recorded during the following time periods: 10/18/19 3:45 – 10/18/19 10:00, 10/18/19 20:30 – 10/19/19 11:30, 10/19/19 14:45 – 10/20/19 11:00	Automated Discharge, Composite & Grab Samples
14	**Bone Lake Outlet**	5/6/19 10:30 – 10/29/19 10:45. A power failure occurred and no data was recorded during the following time period: 10/25/19 3:00 – 10/25/19 8:15	Automated Discharge, Composite & Grab Samples
13	**Bone Lake North Inlet**	No continuous stage and discharge data were collected at this site in 2019. The area-velocity (A/V) sensor was installed on 5/6/19 9:21 and was damaged shortly thereafter.	Grab Samples Only
12	**Sunrise River at Big Comfort Lake Outlet**	5/3/2019 11:15 – 10/29/2010 10:00	Automated Discharge, Composite & Grab Samples
11	**Sunrise River at Big Comfort Lake Inlet**	5/6/19 11:30 – 10/29/19 9:30 A power failure and equipment malfunction occurred at the very end of the recorded dataset and no data was recorded after 10/7/19 10:45.	Automated Discharge, Composite & Grab Samples. No rating curve
18	**Little Comfort Lake Inlet at Itasca Avenue**	5/21/19 11:00 – 10/27/19 0:30 A power failure occurred at the very end of the recorded dataset	Automated Discharge, Composite & Grab Samples. No rating curve
17	**Little Comfort Lake Inlet at Heath Avenue**	5/17/19 – 10/25/19	Automated Stage, Discrete Discharge & Grab Samples
16	**Sunrise River at Greenway Avenue**	5/6/19 11:45 – 10/29/19 10:45	Automated Discharge, Composite & Grab Samples
19	**Sunrise River at 256th Street**	5/3/19 10:15 – 10/29/19 10:45 A/V sensor was damaged and no data was recorded during the following time period: 10/2/19 7:30 – 10/11/19 9:00	Automated Discharge, Composite & Grab Samples

2019 Stream Water Quality Summary

Stream water chemistry grab and composite sample results for temperature, dissolved oxygen, pH, specific conductance, total suspended solids, phosphorus, nitrogen, bacteria and chloride are reported for each individual stream site in Appendix B. Stream water quality is generally good throughout the District as observed by stream chemistry concentrations generally below state standards for all sites with a handful of samples exceeding standards for dissolved oxygen, total phosphorus, total suspended solids and *E. coli* as noted below. Stream dissolved oxygen levels were low at several sites during the summer months which usually corresponded to warm stream temperatures or wetland influences in the drainage area. Notably nitrogen levels are very low and no chloride readings exceeded state standards District-wide.

- **Bone Lake North Inlet** (see Table 11 in Appendix B: low dissolved oxygen (< 5 mg/L) levels were observed on all sample dates except 10/24, and high total phosphorus (130-370 µg/L) was observed in June through August. Temperatures were generally below 20 degrees C. Low DO and high TP are characteristic of wetland discharge; this site is at the downstream end of the Moody Lake outlet which flows through a large wetland complex between Moody and Bone Lakes.

- **Bone Lake Outlet** (see Table 12 in Appendix B): there was one high total phosphorus reading on 3/27 (140 µg/L), but water temperatures were above 20 degrees C in June through August (21-26 degrees C). Low stream chemistry readings are characteristic of lake outlet sites.

- **Forest Lake Outlet** (see Table 13 in Appendix B): all stream chemistry readings were below standards. Low stream chemistry readings are characteristic of lake outlet sites.

- **Little Comfort Inlet at Itasca Avenue** (see Table 14 in Appendix B): there was one low dissolved oxygen reading on 7/24 (4 mg/L) which corresponded with a high water temperature reading of 22 degrees C, total phosphorus concentrations were above 100 µg/L in March and April (110-180 µg/L) and on 10/19 (405 µg/L), there was one unusually high TSS (1,560 mg/L) and TP (2,430 µg/L) concentration on 7/15 likely due to contamination of the sample during collection, and there were two *E. coli* readings above 126 org/100 mL on 6/25 (156 org/100 mL) and 10/24 (517 org/100 mL).

- **Little Comfort Inlet at Heath Avenue** (see Table 15 in Appendix B): total phosphorus concentrations ranged from 110-310 µg/L during the months of July through September. The two TSS samples collected on 7/15 and 8/16 were well below 30 mg/L (7.7-8 mg/L). This drainage area is dominated by wetland drainage which is typically characterized by high TP and low TSS concentrations.

- **Sunrise River at Greenway Avenue** (see Table 16 in Appendix B): two low dissolved oxygen readings were observed on 7/24 (3.5 mg/L with a corresponding temperature of 22 degrees C) and 8/22 (4.2 mg/L), total phosphorus concentrations were above 100 µg/L on 4/30, 5/9, 7/15, 7/30, and 9/13 ranging from 110-190 µg/L, two TSS concentrations were above 30 mg/L on 7/30 (57 mg/L) and 8/18 (296 mg/L), and two *E. coli* concentration were above 126 org/100 mL on 6/25 (129 org/100 mL) and 8/22 (249 org/100 mL).

- **Sunrise River at 256th St.** (see Table 17 in Appendix B): two low dissolved oxygen readings were observed on 7/24 (2.7 mg/L with a corresponding temperature of 22 degrees C) and 8/22 (4.9 mg/L with a corresponding temperature of 20 degrees C), total phosphorus concentrations were above 100 µg/L on 6/25, 7/15, and 7/30 ranging from 110-160 µg/L, one TSS concentration was above 30 mg/L on 7/16 (45 mg/L), and one *E. coli* concentration was above 126 org/100 mL on 6/25 (172 org/100 mL).

- **Big Comfort Outlet** (see Table 18 in Appendix B): stream temperatures were above 20 degrees C on 7/24 (22 degrees C) and 8/22 (24 degrees C) and dissolved oxygen levels were below 5 mg/L on 6/25, 7/24, and 8/22 (3.3-4.3 mg/L. Besides the periods of high stream temperature and low dissolved oxygen levels, other water chemistry parameters were below state standards.

Total volume, total phosphorus and total suspended solids load and flow-weighted mean concentration (FWMC) were determined using FLUX32 for all stream sites and presented in Table 10 below. The Central Region Reference stream FWMCs are 100 µg/L for total phosphorus and 30 mg/L for total suspended solids. Stream FWMCs in 2019 were below the Central Region Reference stream FWMCs except the Heath Avenue Outlet. There was a 33% reduction in TP loads and a 71% reduction in TSS loads between the monitoring sites upstream and downstream of Shallow Pond (Sunrise River at 256th and Sunrise River at Greenway). These reductions are similar to but a little lower than the past reduction observed from Shallow Pond (43% TP). Monitoring should continue at the sites upstream and downstream of Shallow Pond to determine if the reduction effectiveness of this wetland begins to decline over time in the future.

Note that there was an unacceptably high level of uncertainty reported by FLUX32 in the 2019 load calculation for TP and TSS at the Little Comfort Inlet at Itasca Avenue and for TSS at the Forest Lake Outlet. Recall that stream loads are based on applying event mean concentrations to daily baseflow and storm event flows across an entire monitoring period based on a limited number of grab samples collected (typically 8-14). Because we cannot collect continuous water quality concentrations, there is inherent uncertainty in the statistical methods we use to estimate concentrations on days without a sample; this uncertainty is measured by a coefficient of variation (CV) in FLUX32. CVs below 0.2 indicate low uncertainty, CVs between 0.2 and 0.5 indicate moderate uncertainty, and CVs above 0.5 indicate unacceptably high uncertainty in estimated loads. In addition, significant runoff can occur in the spring when air temperatures are still too cold to safely deploy monitoring equipment without the risk of freezing sensors or bursting tubes; therefore, total annual flow is often slightly (5-10%) underestimated. However, this underestimate is acceptable because it is lower in magnitude than the variability in flow observed from year to year.

The historic annual flow and TP and TSS FWMC/loads are included for all stream sites in Appendix E for comparison with 2019. Measured flow and loads in 2019 were within or near the lower end of the historic ranges observed for all long-term sites since 2004. While 2019 was the second wettest year on record, some of the runoff resulting from this high-water year occurred before and after the stream monitoring period resulting in low to average flow and loads observed in 2019. Monthly precipitation in 2019 exceeded the 1981-2010 normal in February, April, May, July, September, October and December. High monthly precipitation is likely to have the greatest increase on annual loads when it occurs during the spring and early summer before vegetation is fully established (particularly cultivated crops and trees) that stabilize the soil and take up runoff through evapotranspiration. However, most of the months with high precipitation occurred in July or later, once vegetation was fully established on the land.

This highlights the importance of interpreting stream loads in the context of the sample period conditions and the historic variability observed at that site. Stream water quality tends to be more variable than lake water quality due to the large number of factors that influence runoff and pollutant discharge, especially when comparing across years. Stream water quality data is best interpreted within the same year across sites to reduce the influence of year to year weather variability.

Table 10. 2019 Stream Monitoring Site Concentrations and Loads

Monitoring Site	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 (ug/L)	Load (lbs)	CV	FWMC (mg/L)	Load (lbs)	CV
Central Region Reference FWMC							**< 100**			**< 30**		
256th Street	13,311	172	12	23.6	8,050	7.3	62	1,357	0.16	7.6	166,304	0.29
Big Comfort Inlet	13.625	155	9	19.8	6,075	5.4	88.6	1,464	0.4	12.4	204,767	0.29
Big Comfort Outlet	24,558	180	10	39.7	14,191	6.9	26.1	1,007	0.10	4.1	158,157	0.39
Bone Lake Outlet	5,495	177	10	2.9	1,014	2.2	54.2	150	0.27	8.8	24,256	0.46
Forest Lake Outlet	8,719	171	6	17.0	5,777	8.0	35.6	559	0.13	**6.0**	**94,568**	**0.64**
Greenway Avenue	12,628	177	13	23.4	8,209	7.8	90.1	2,011	0.23	25.3	564,552	0.49
Heath Avenue Outlet	963	162	8	1.3	427	5.3	196	228	0.46	*	*	*
Little Comfort Inlet	10,513	160	7	9.5	3,012	3.4	**209**	**1,712**	**0.63**	**159**	**1,302,325**	**0.76**

Flow Weighted Mean Concentration (FWMC)

**Not enough grab samples collected to calculate a load or FWMC*

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

APPENDIX A – 2019 INDIVIDUAL LAKE SUMMARIES

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 2019:

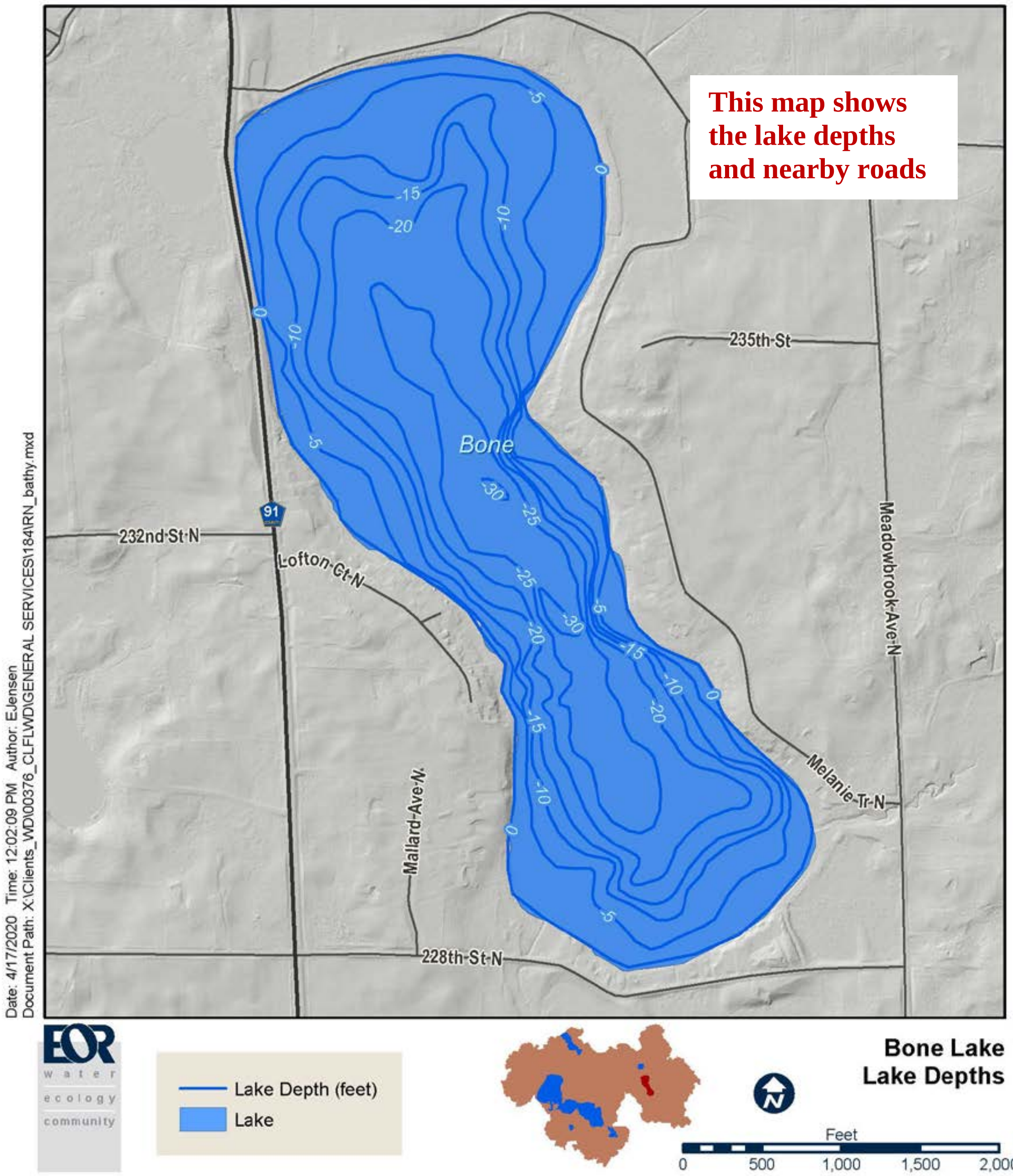
1. Big Comfort
2. Bone
3. Forest Lake – East Basin
4. Forest Lake – Middle Basin
5. Forest Lake – West Basin
6. Keewahtin
7. Little Comfort
8. Moody
9. Shields

Example Lake Summary (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

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



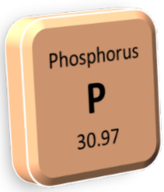
BONE LAKE

2019 Surface Water Quality Summary

Nutrients:

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

27 ug/L



Algae:

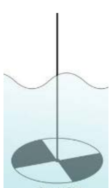
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

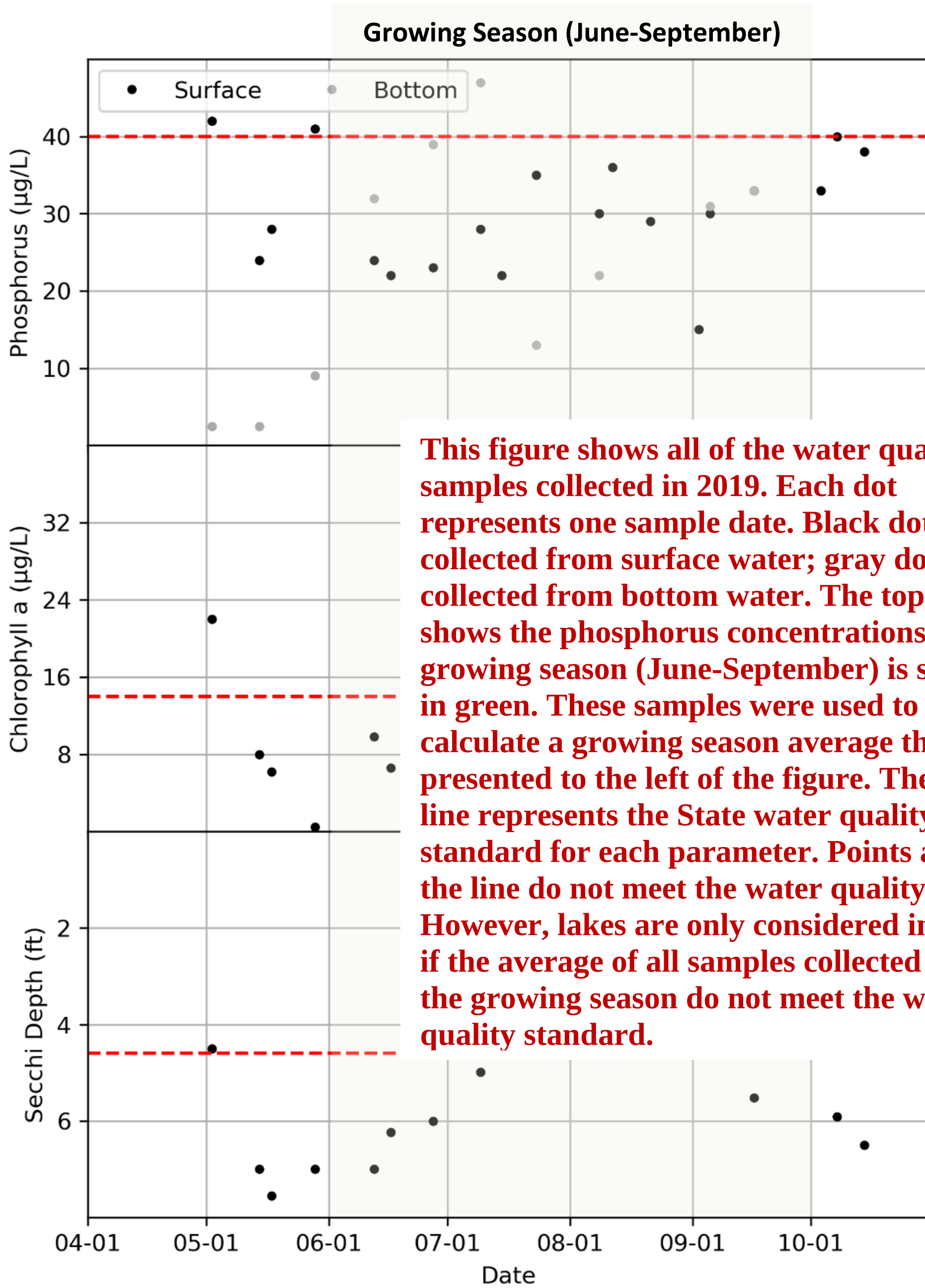
19.7 ug/L

Clarity:

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

4.9 feet





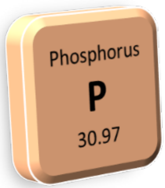
This figure shows all of the water quality samples collected in 2019. Each dot represents one sample date. Black dots were collected from surface water; gray dots were collected from bottom water. The top figure shows the phosphorus concentrations. The growing season (June-September) is shaded in green. These samples were used to calculate a growing season average that is presented to the left of the figure. The red line represents the State water quality standard for each parameter. Points above the line do not meet the water quality sample. However, lakes are only considered impaired if the average of all samples collected during the growing season do not meet the water quality standard.

BONE LAKE

Historical Water Quality Summary

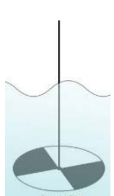
	Phosphorus	Chl-a	Secchi
State Standard	< 40	< 14	>4.6 feet
10-year Average (2010-2019)	35	16.4	4.7
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	31	18.8	5.1

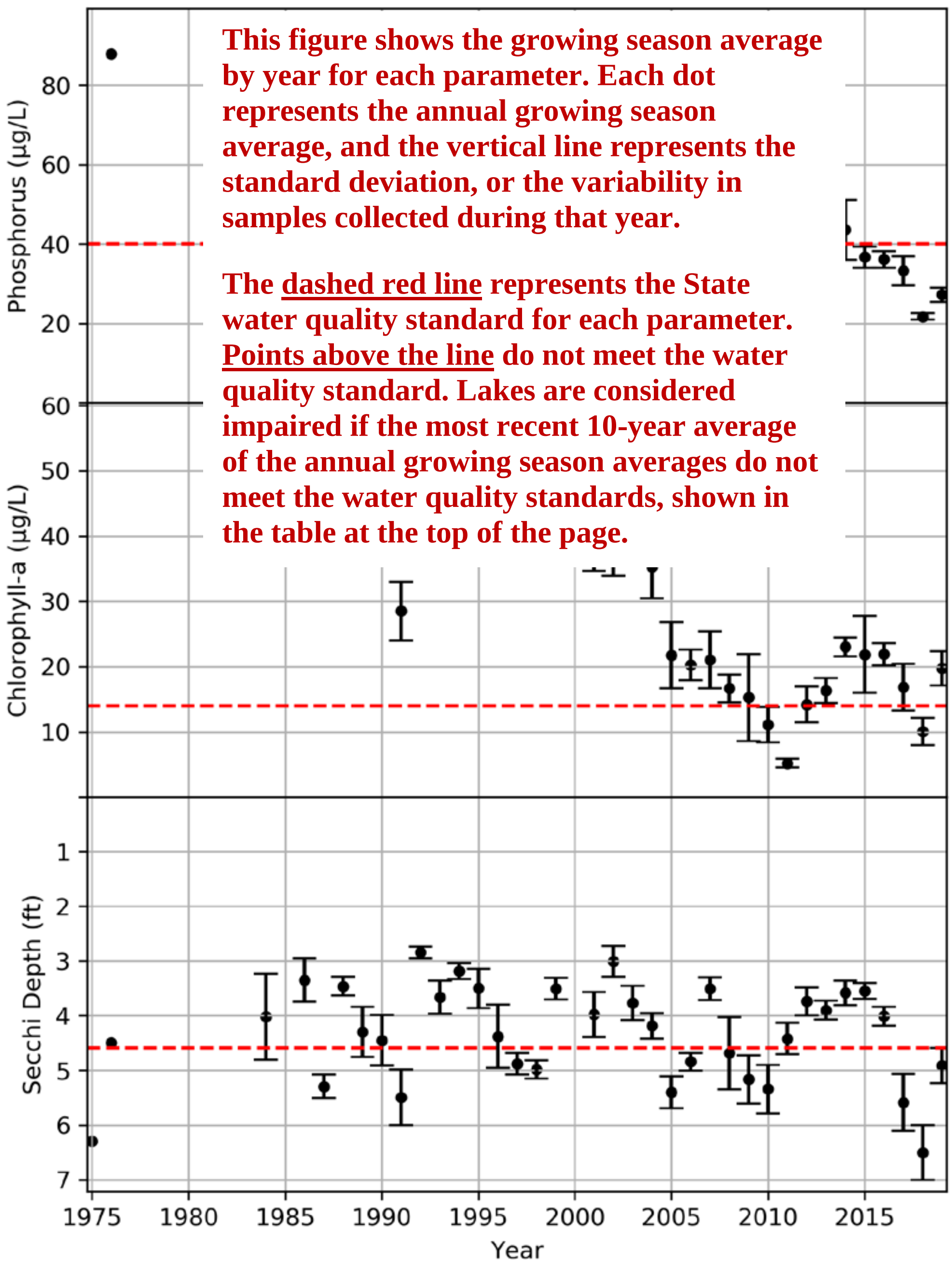
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



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

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





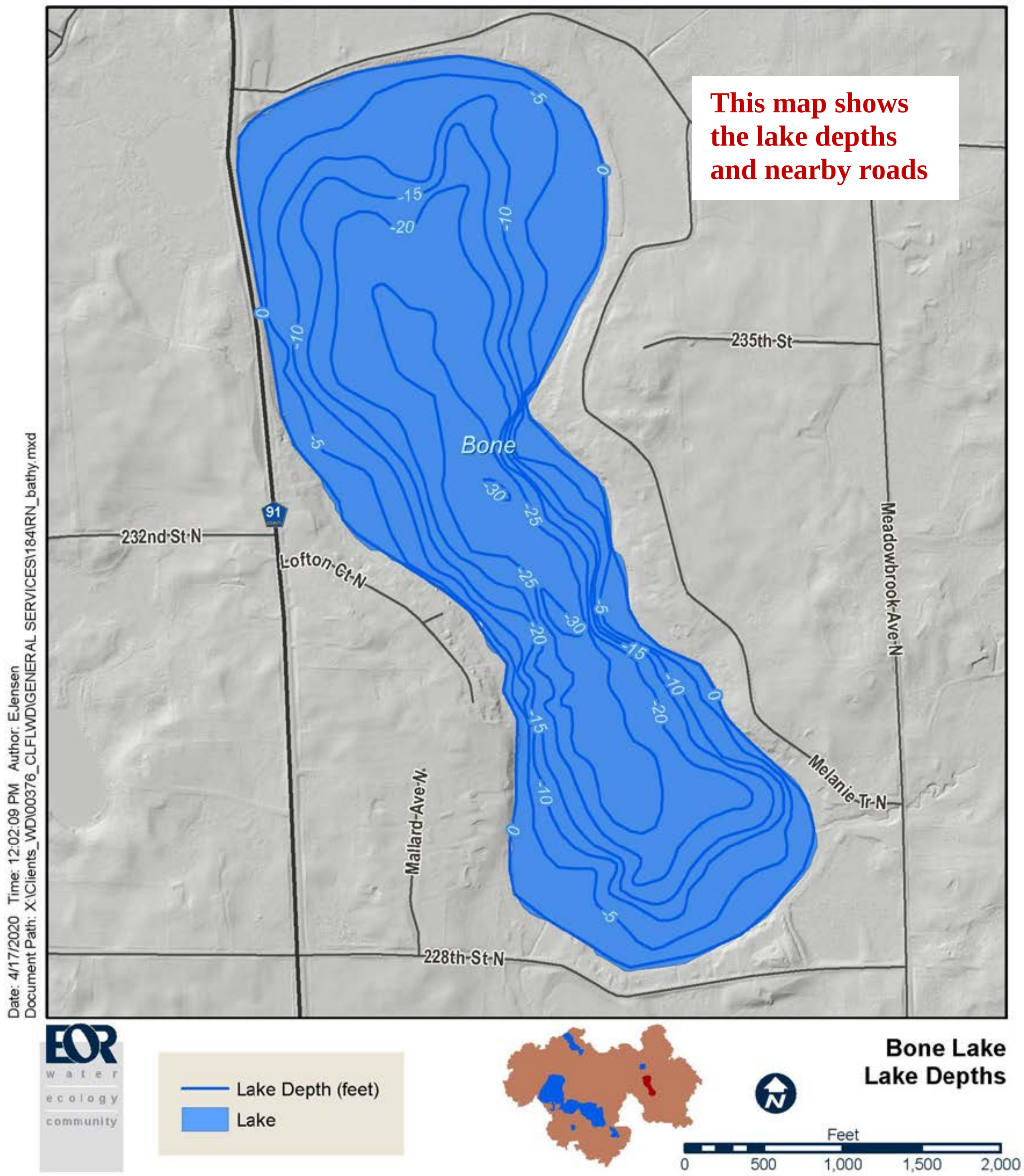
Example Lake Summary (BONE LAKE)

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

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



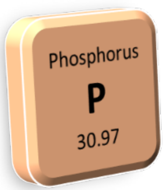
BONE LAKE

2019 Surface Water Quality Summary

Nutrients:

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

27 ug/L



Algae:

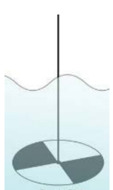
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

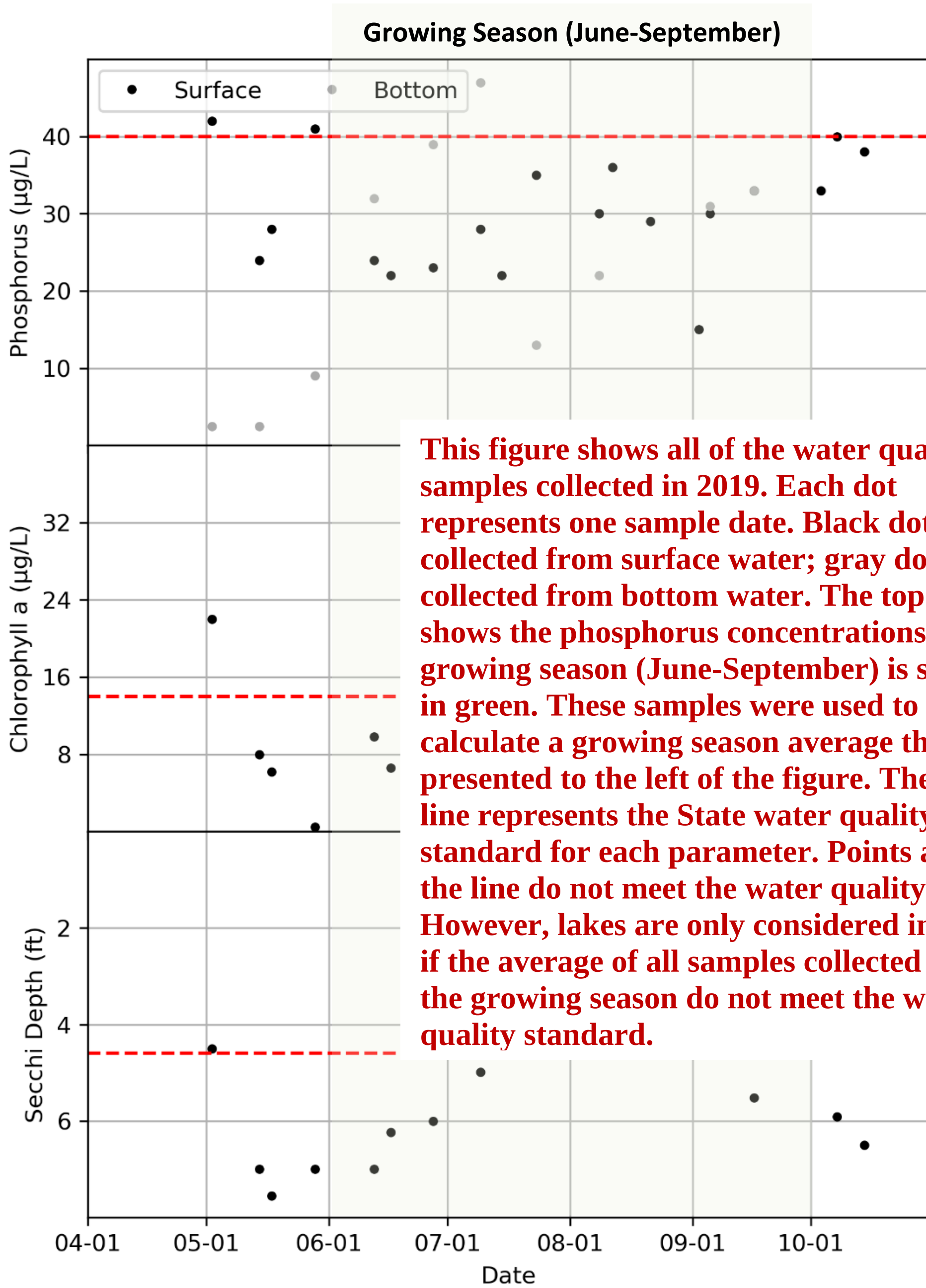
19.7 ug/L

Clarity:

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

4.9 feet





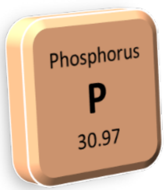
This figure shows all of the water quality samples collected in 2019. Each dot represents one sample date. Black dots were collected from surface water; gray dots were collected from bottom water. The top figure shows the phosphorus concentrations. The growing season (June-September) is shaded in green. These samples were used to calculate a growing season average that is presented to the left of the figure. The red line represents the State water quality standard for each parameter. Points above the line do not meet the water quality sample. However, lakes are only considered impaired if the average of all samples collected during the growing season do not meet the water quality standard.

BONE LAKE

Historical Water Quality Summary

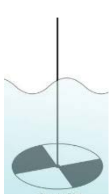
	Phosphorus	Chl-a	Secchi
State Standard	< 40	< 14	>4.6 feet
10-year Average (2010-2019)	35	16.4	4.7
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	31	18.8	5.1

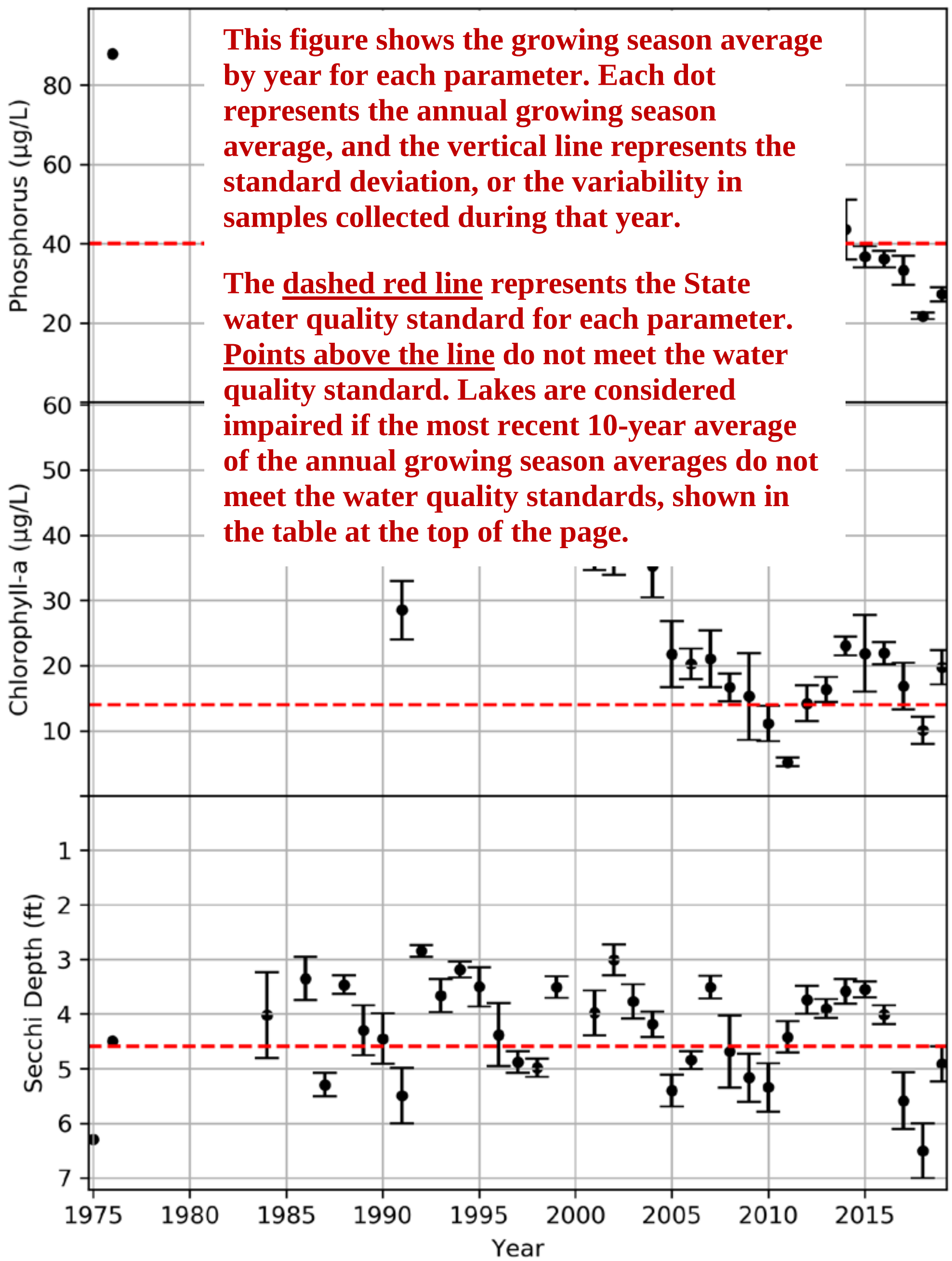
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)

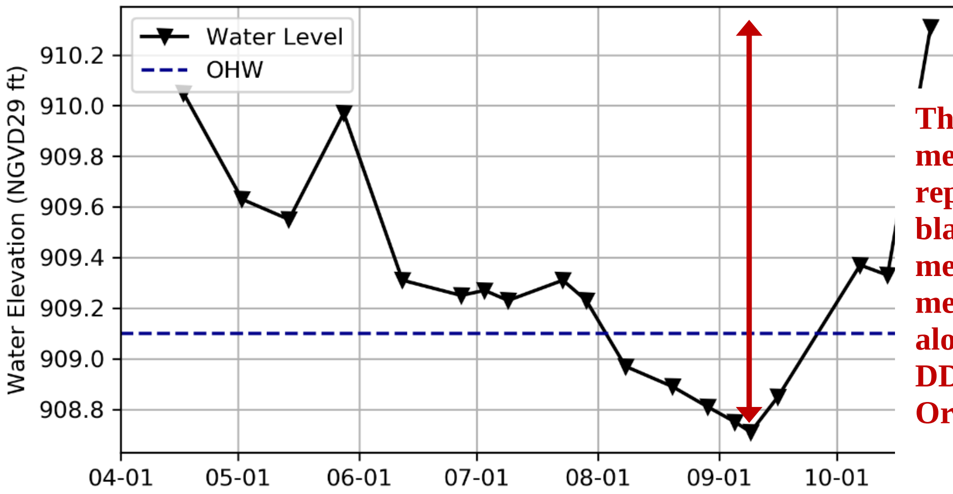


Algae:
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

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

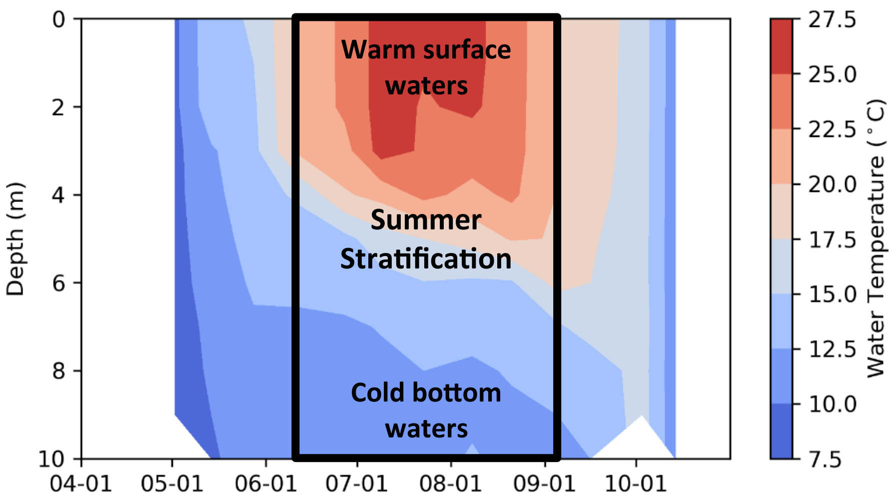






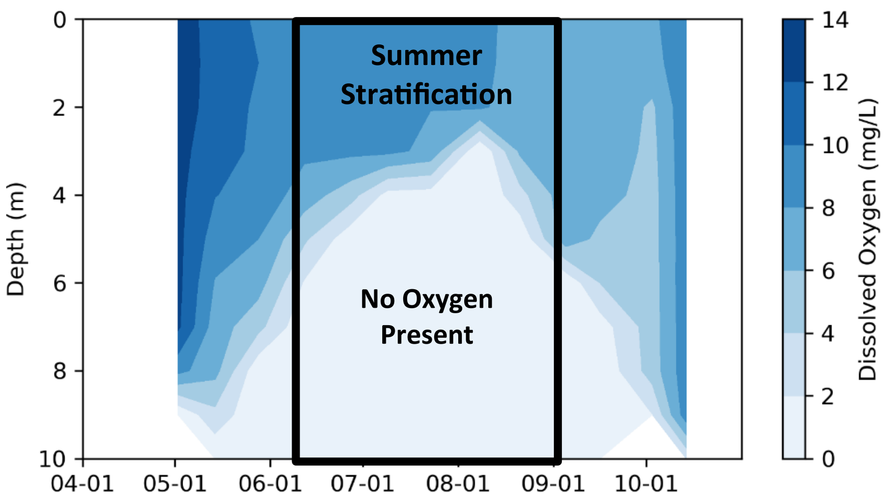
2019 Lake Levels

This figure shows the lake level measurements for 2019. Each triangle represents one measurement. The black line connects the individual measurements but is not an actual measurement. The date is shown along the bottom of the figure as MM-DD. The dashed blue line shows the Ordinary High Water level.



2019 Temperature Profiles

This figure shows the lake temperatures. The top of the figure is the lake surface and the bottom of the figure is the lake bottom. Red represents warm water, blue represents cold water. The date is shown along the bottom of the figure as MM-DD. The black box shows the time period when the lake is stratified into a distinct layer of warm water at the surface and a layer of cold water at the bottom. The lake surface and bottom waters do not mix during this period.



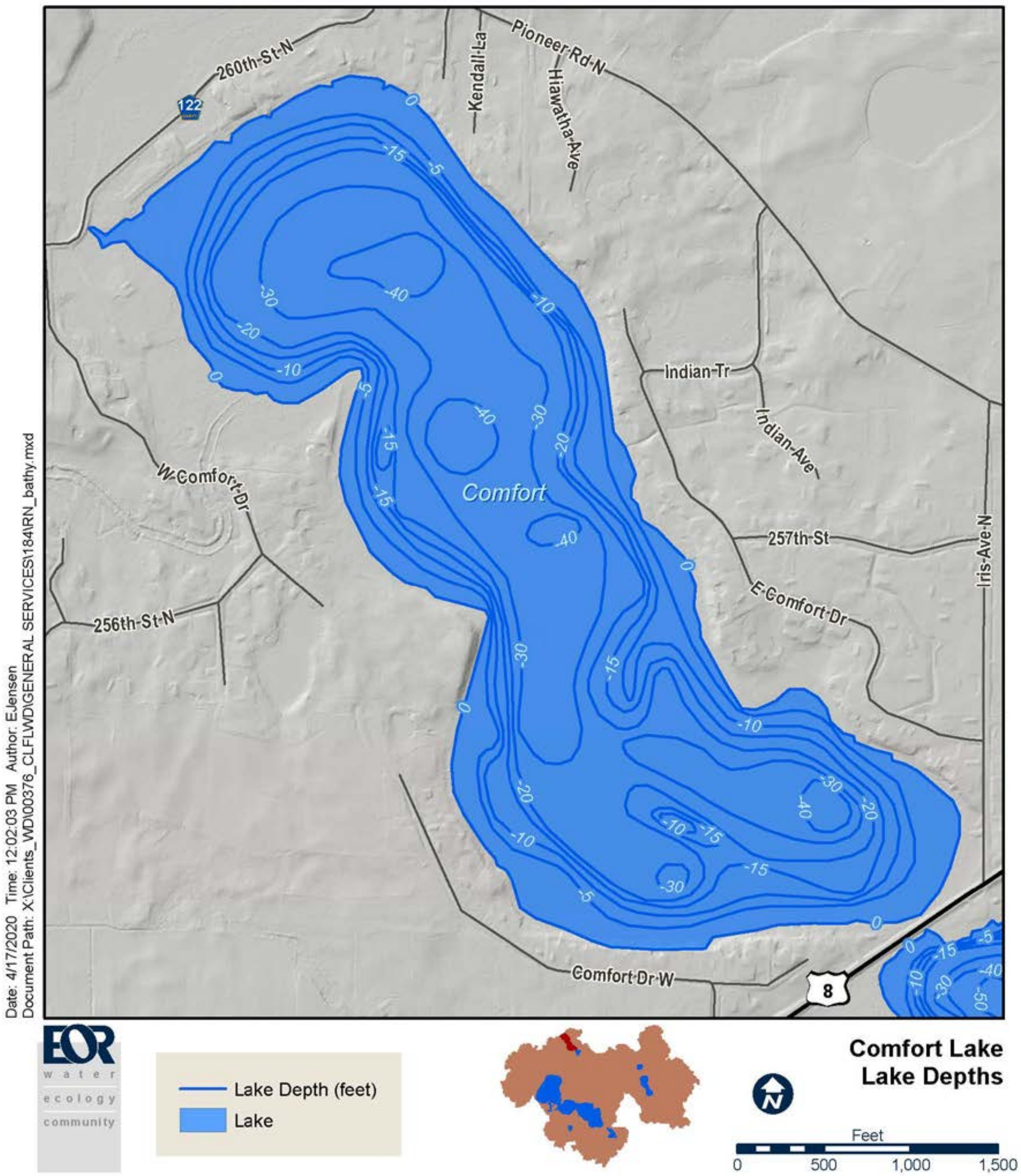
2019 Dissolved Oxygen

This figure shows the lake dissolved oxygen levels. The top of the figure is the lake surface and the bottom of the figure is the lake bottom. Dark blue represents oxygen rich water, gray represents water with little to no oxygen. The date is shown along the bottom of the figure as MM-DD. The black box shows the time period when the lake is stratified. The larger the extent of the gray coloring in the black box represents a greater potential for sediment phosphorus release (internal loading).

BIG 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



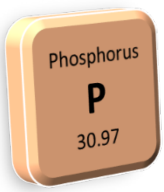
BIG COMFORT LAKE

2019 Surface Water Quality Summary

Nutrients:

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

26 µg/L



Algae:

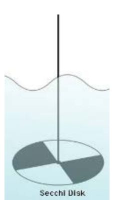
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

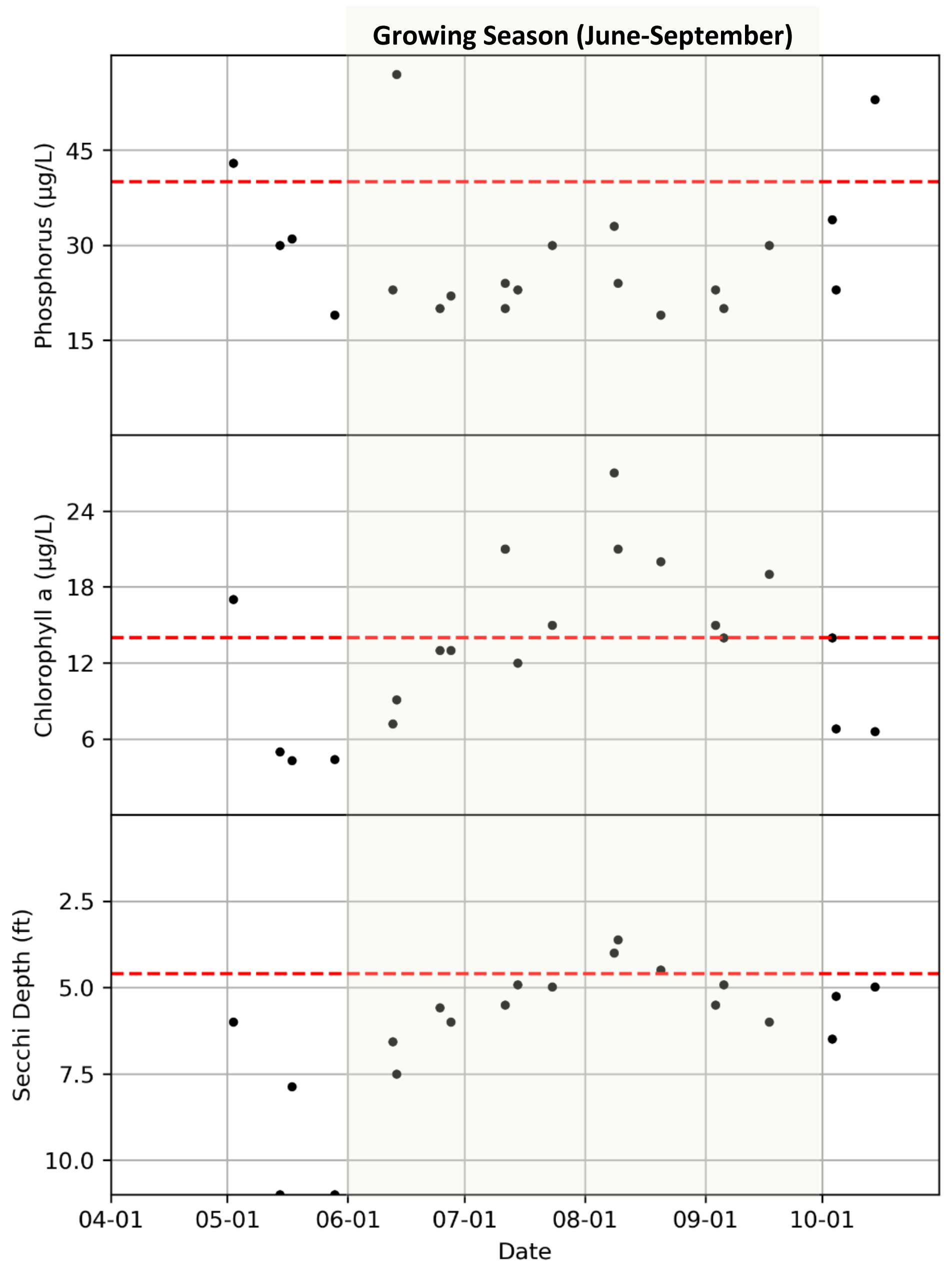
16 µg/L

Clarity:

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

5.3 feet





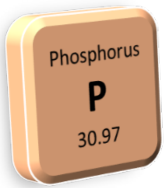
State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

BIG COMFORT LAKE

Historical Water Quality Summary

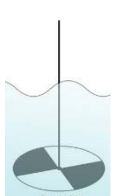
	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6
10-year Average (2010-2019)	33	16	5.4
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	31	15	6.0

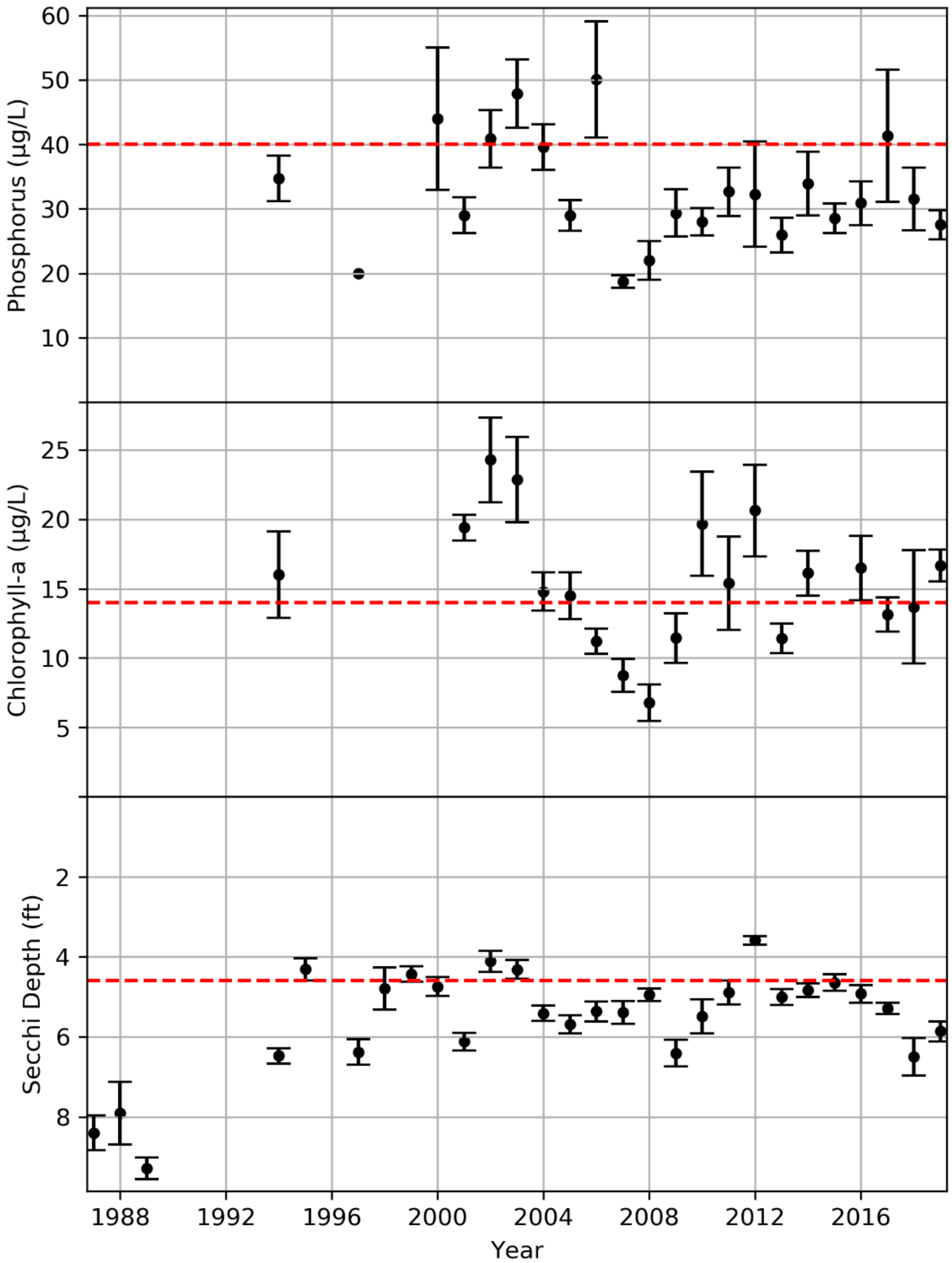
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



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

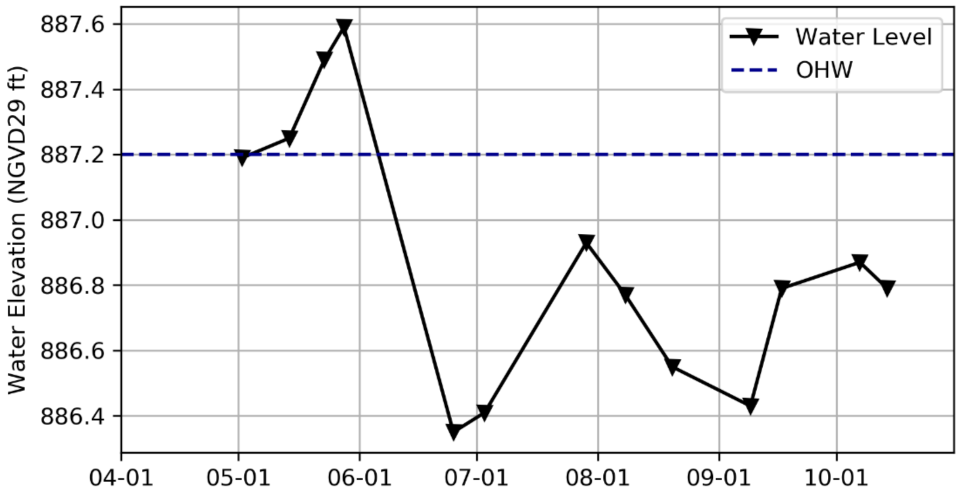
Clarity:
June-Sept. Average Secchi Depth (Secchi, ft)





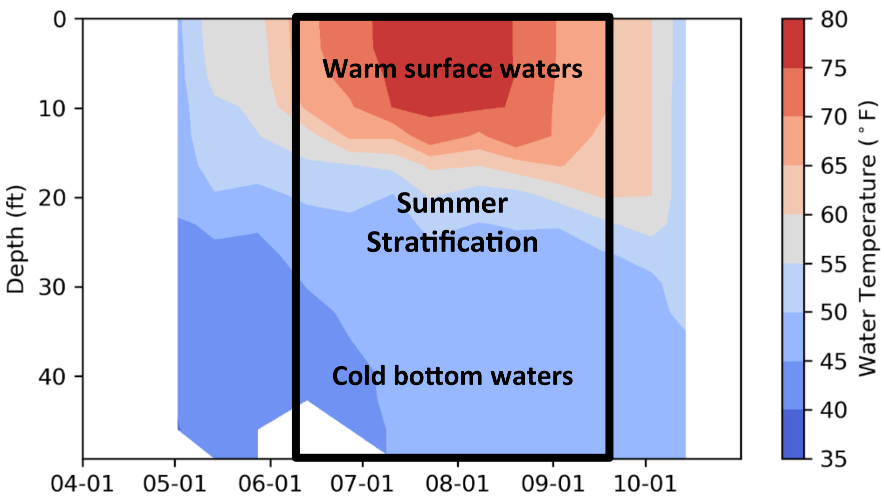
State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

BIG COMFORT LAKE



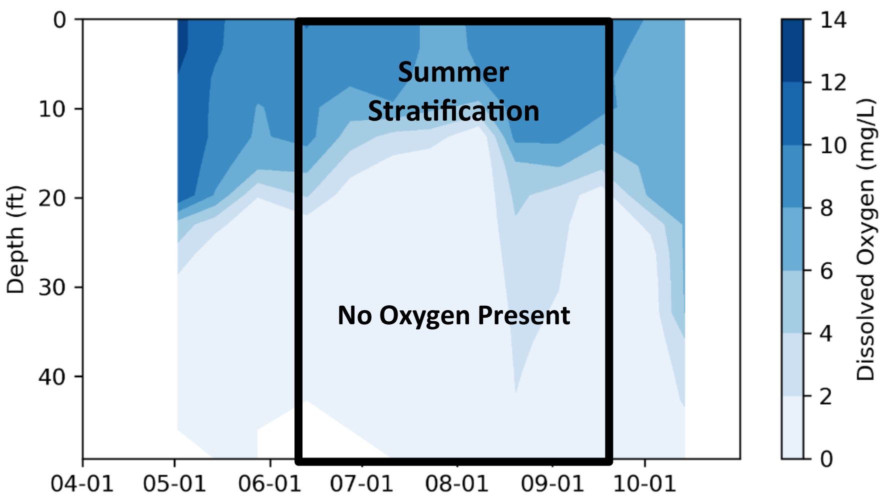
2019 Lake Levels

Lake levels ranged over a total of 1.24 feet; between a minimum of 886.35 feet on June 25, 2019 and a maximum of 887.59 feet on May 28, 2019.



2019 Temperature Profiles

The lake was stratified from mid-June until mid-September.



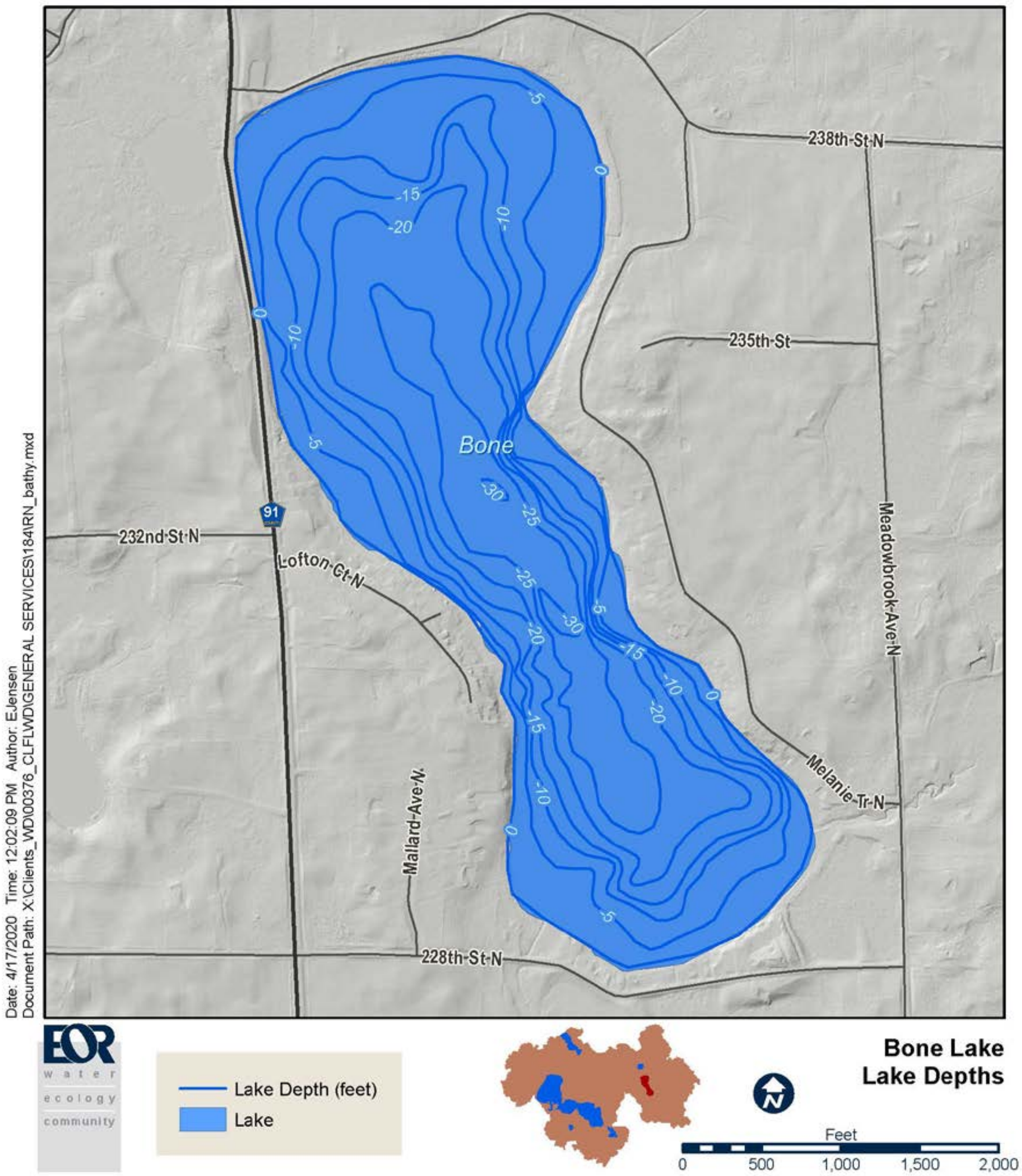
2019 Dissolved Oxygen Profiles

Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible throughout the growing season. A potential mixing event may have occurred mid-August as indicated by the small spike in bottom water oxygen.

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



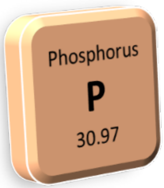
BONE LAKE

2019 Surface Water Quality Summary

Nutrients:

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

27 µg/L



Algae:

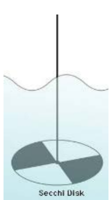
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

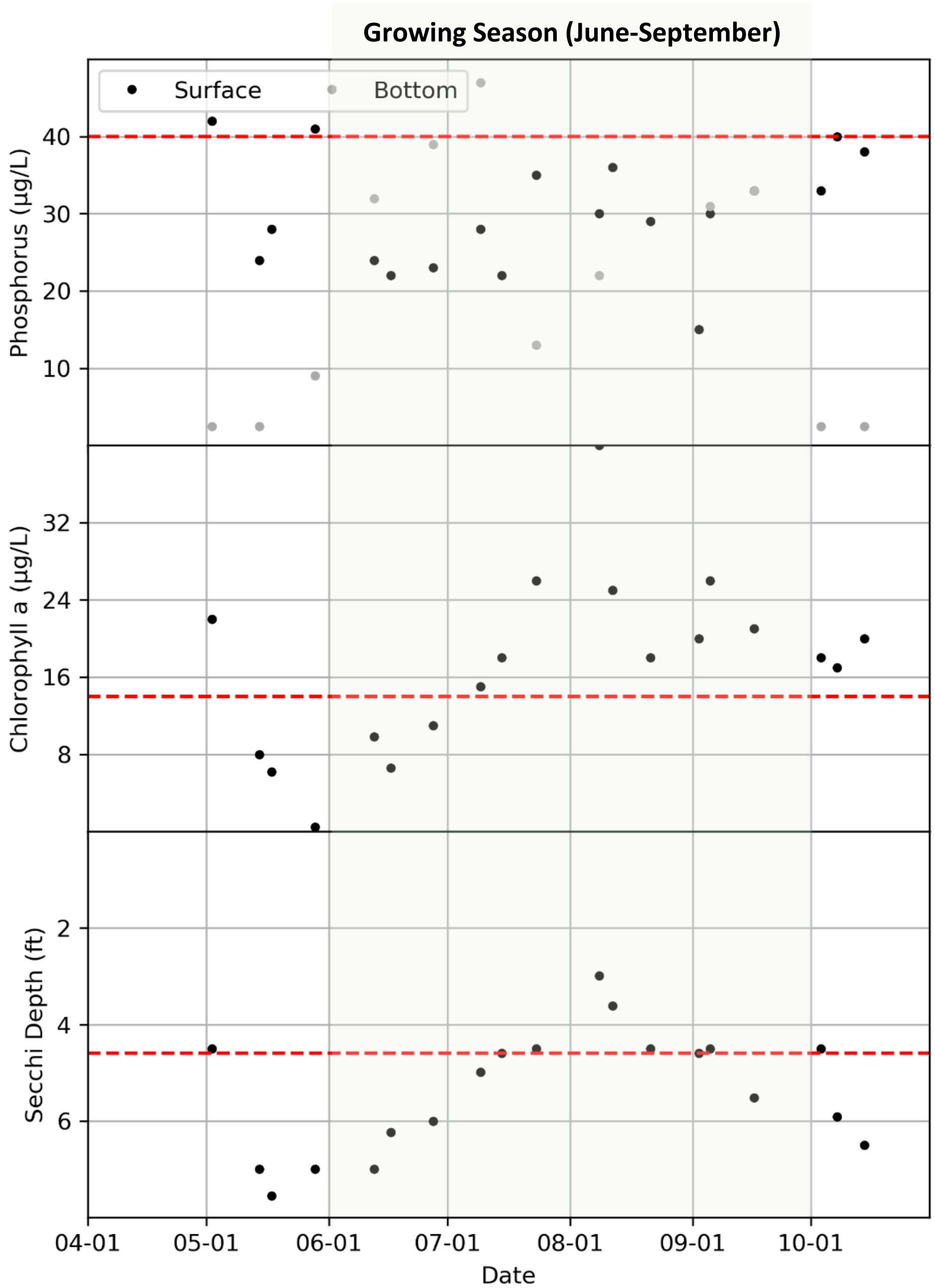
20 µg/L

Clarity:

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

4.9 feet





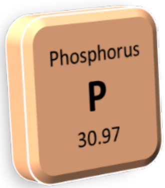
State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

BONE LAKE

Historical Water Quality Summary

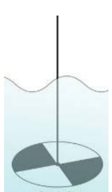
	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6 feet
10-year Average (2010-2019)	35	16	4.7
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	31	19	5.1

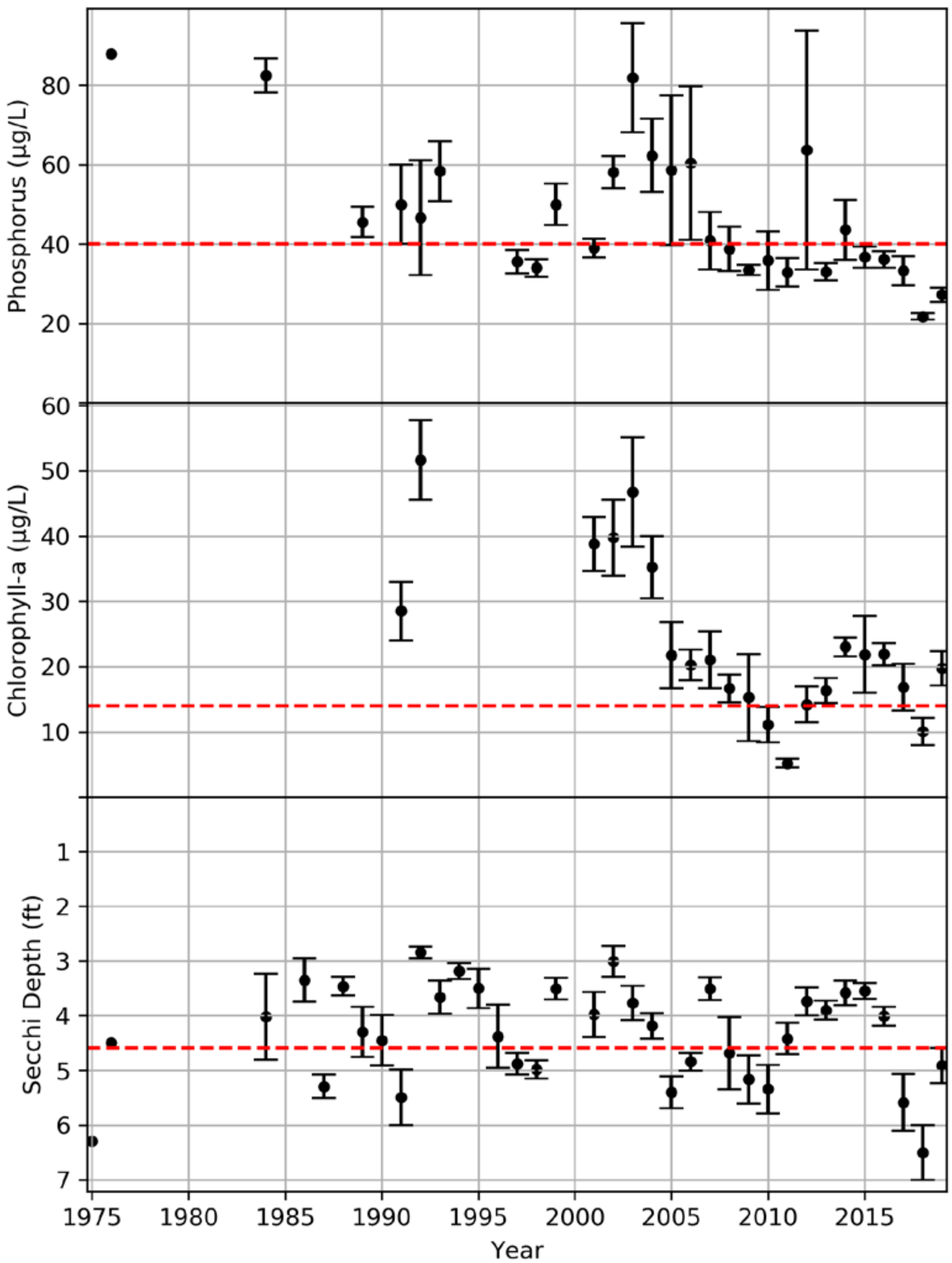
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



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

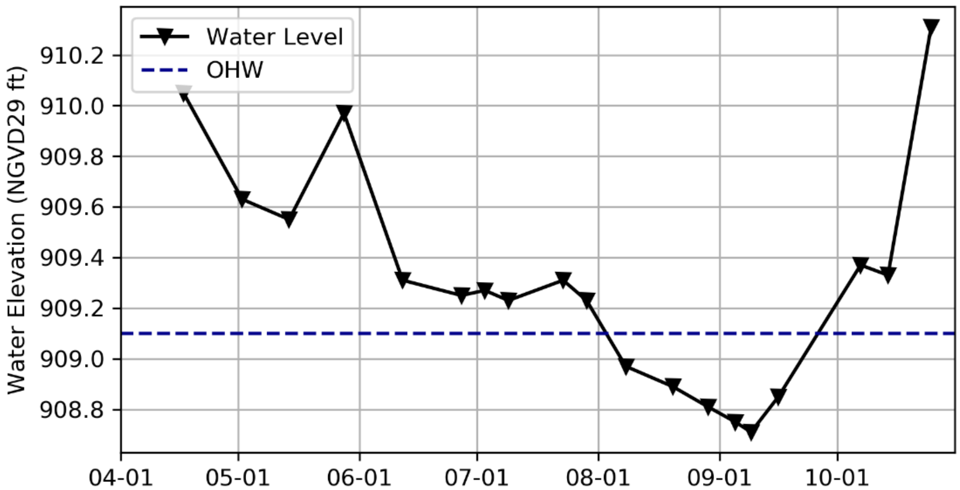
Clarity:
June-Sept. Average Secchi Depth (Secchi, ft)





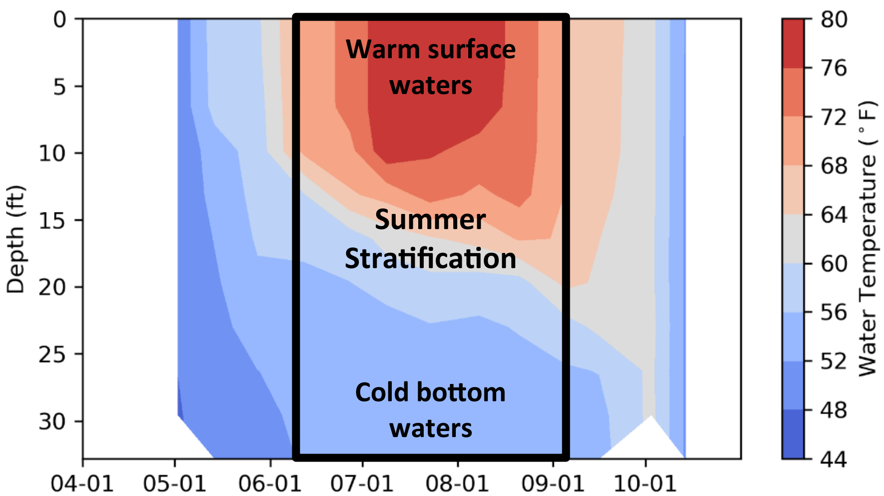
State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

BONE LAKE



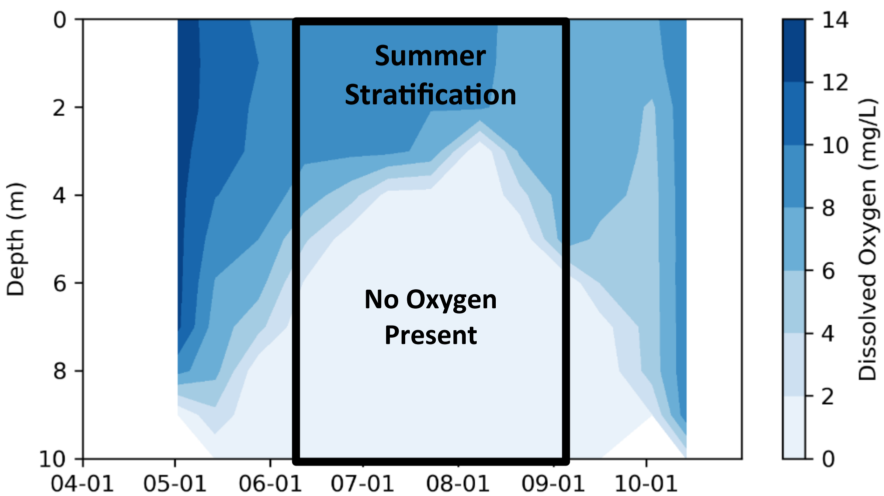
2019 Lake Levels

Lake levels ranged over a total of 1.6 feet; between a minimum of 908.71 feet on September 9, 2019 and a maximum of 910.31 feet on October 25, 2019.



2019 Temperature Profiles

The lake was stratified from mid-June until early September.



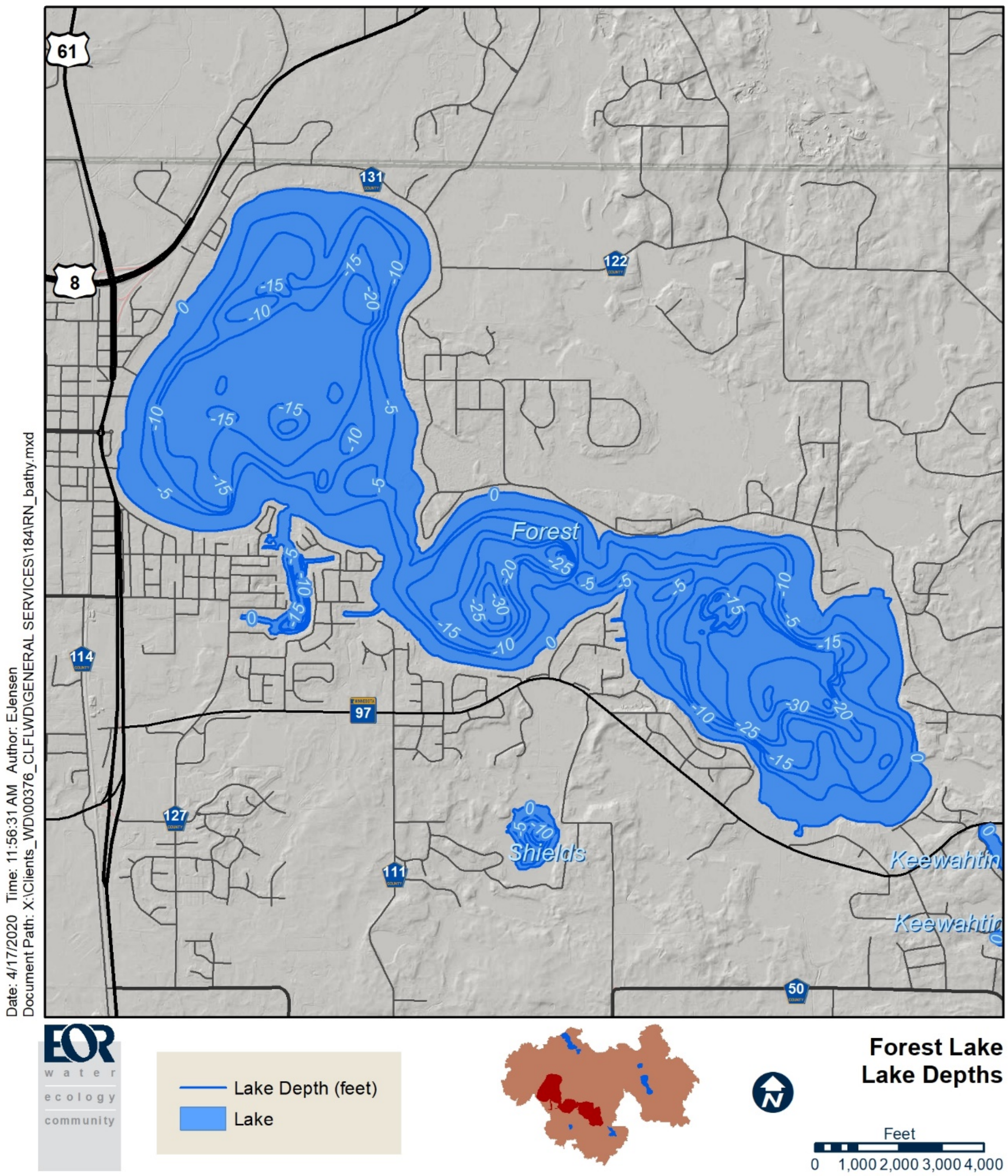
2019 Dissolved Oxygen Profiles

Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible from early June until mid-September.

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

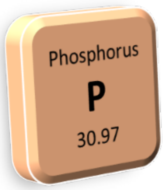


FOREST LAKE – WEST BASIN

2019 Surface Water Quality Summary

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

20 µg/L

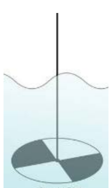


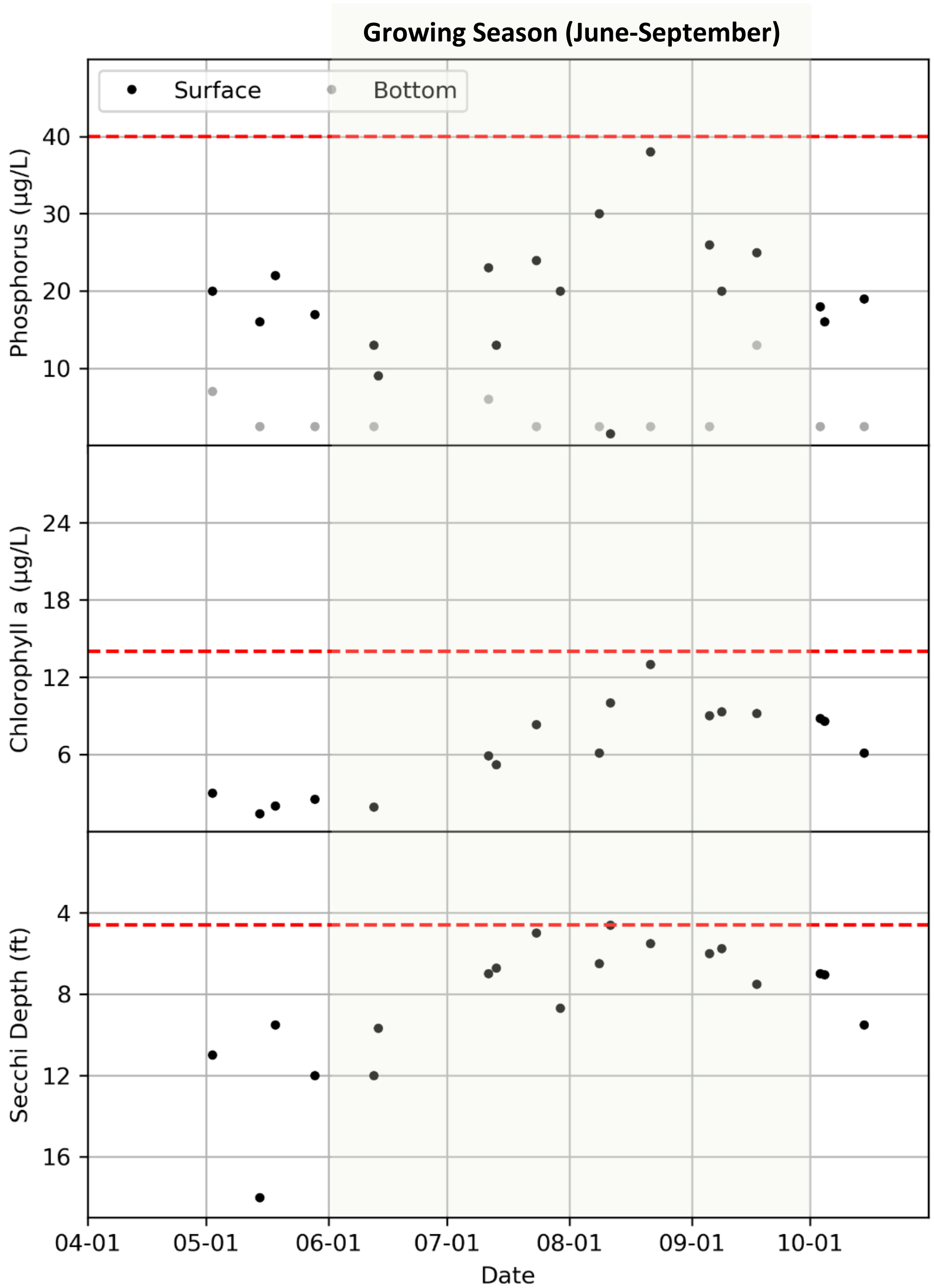
Algae:
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

8 µg/L

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

7.1 feet





State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

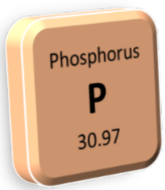
FOREST LAKE – WEST BASIN

Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6
10-year Average (2010-2019)	34	16	5.0
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	32	12	5.4

Nutrients:

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

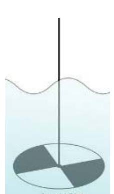


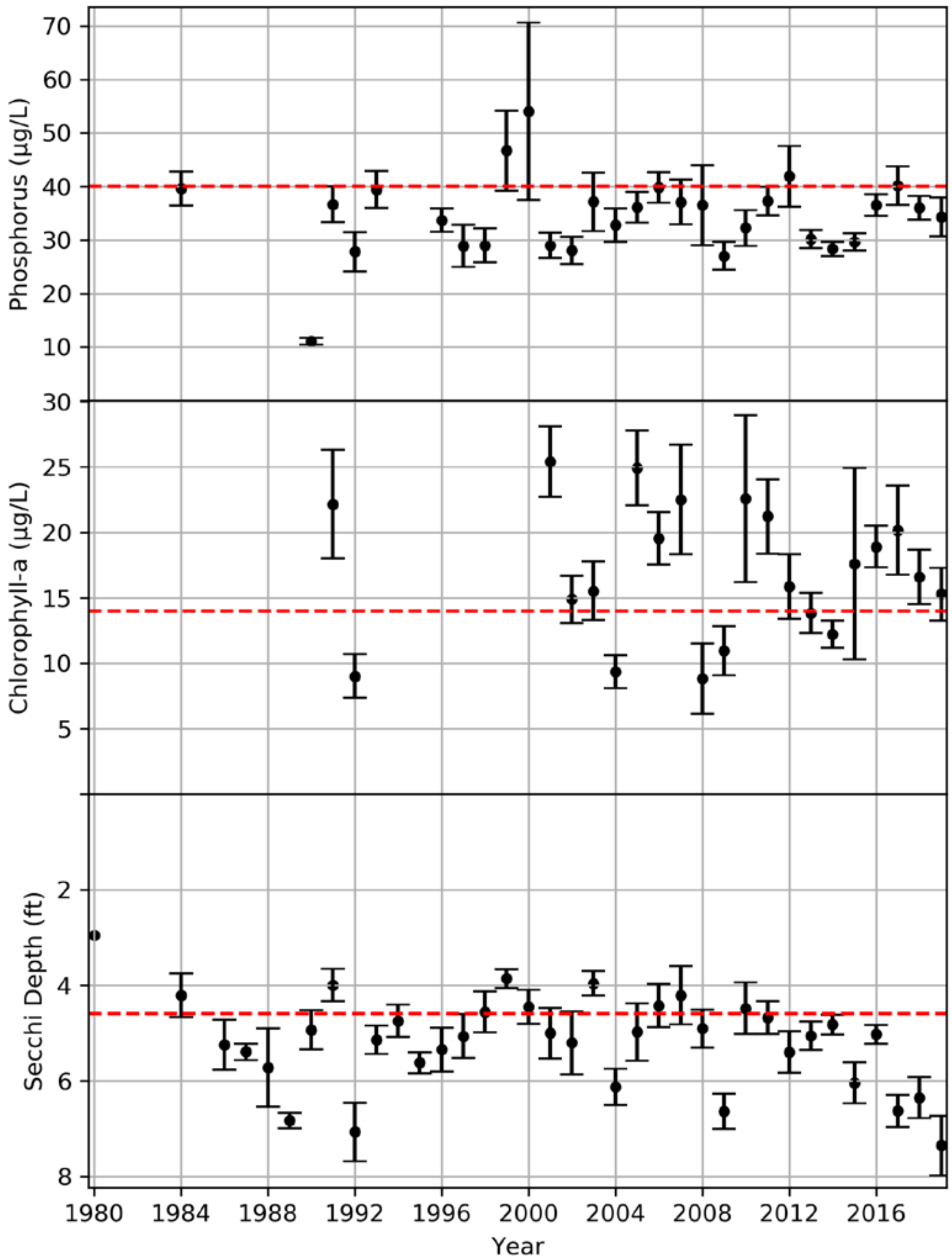
Algae:

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

Clarity:

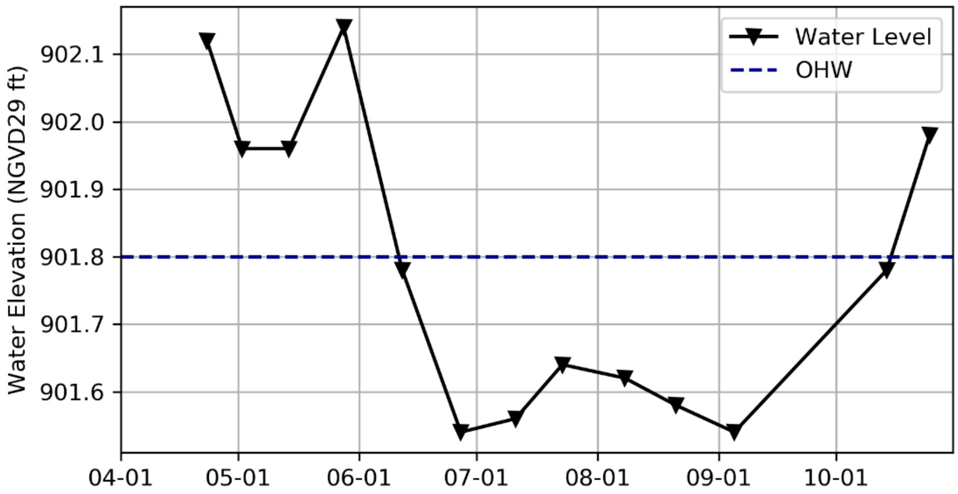
June-Sept. Average Secchi Depth (Secchi, ft)





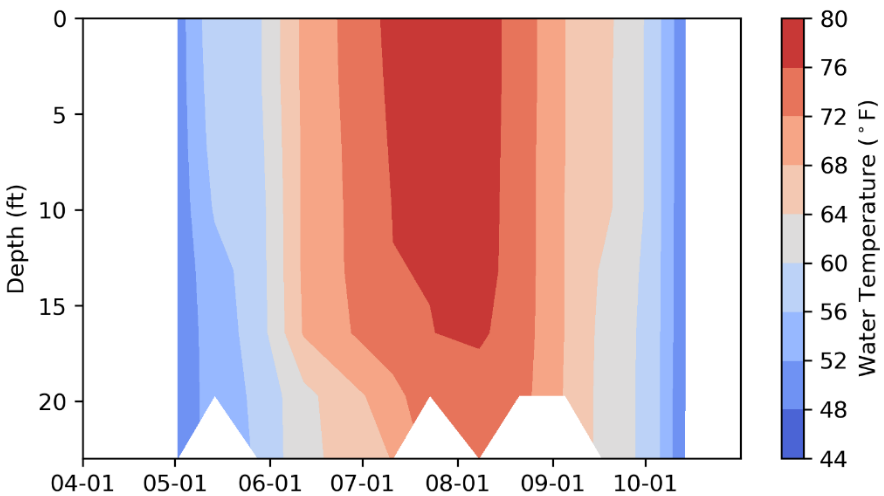
State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

FOREST LAKE – WEST BASIN



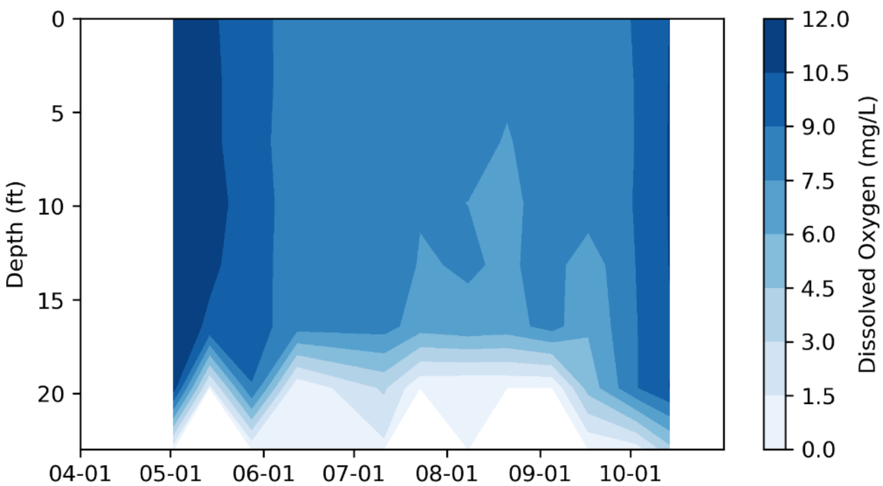
2019 Lake Levels

Lake levels ranged over a total of 0.6 feet; between a minimum of 901.54 feet on June 27 and September 5, 2019 and a maximum of 902.14 feet on May 28, 2019.



2019 Temperature Profiles

The lake was well mixed during the growing season.



2019 Dissolved Oxygen Profiles

Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

There was no extended period of low oxygen in the bottom waters.

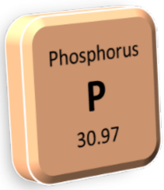
FORESt LAKE – MIDDLE BASIN

2019 Surface Water Quality Summary

Nutrients:

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

51 µg/L



Algae:

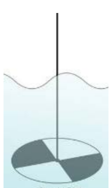
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

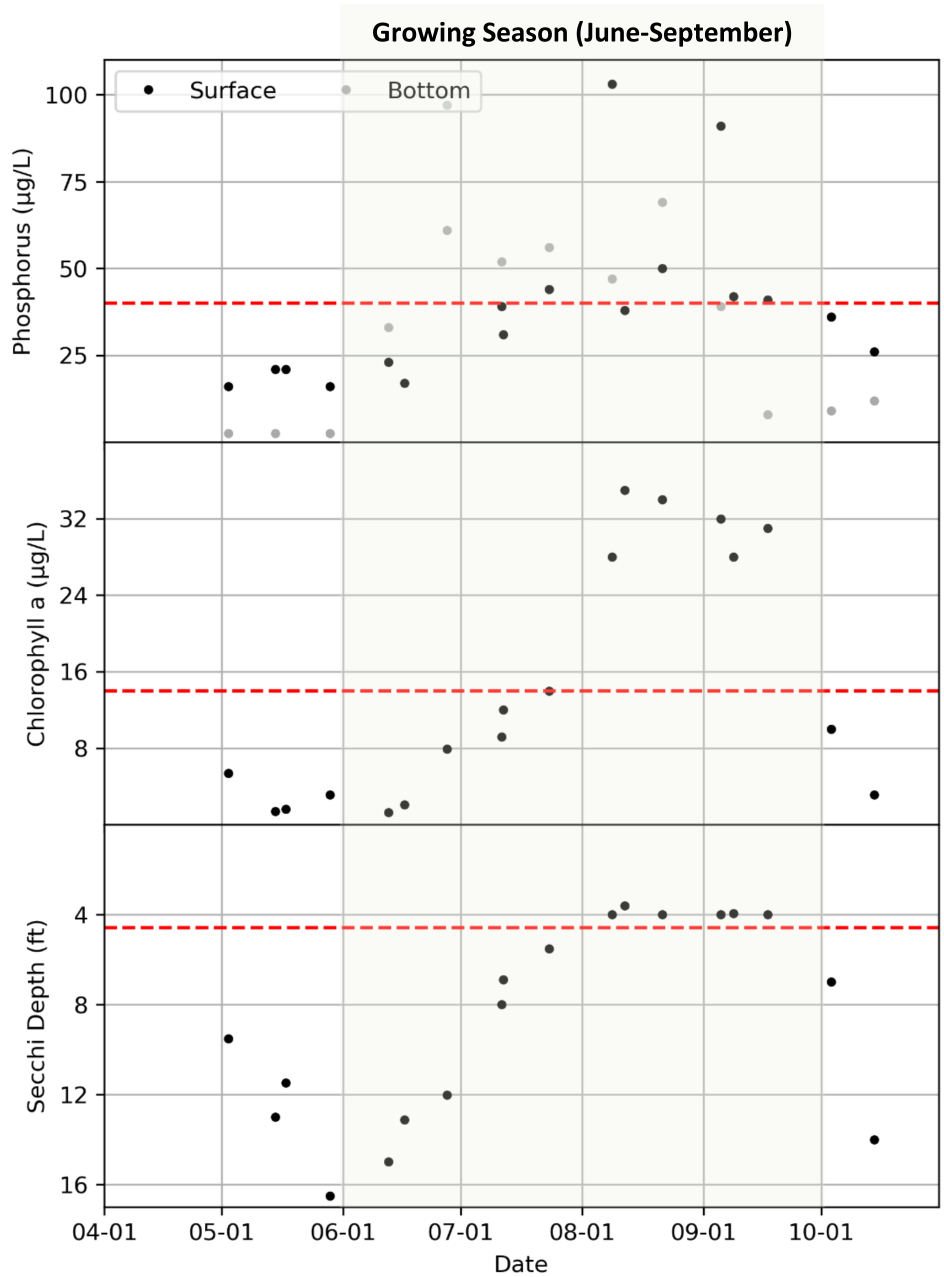
20 µg/L

Clarity:

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

7.0 feet





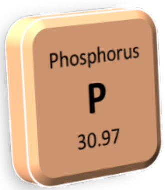
State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

FOREST LAKE – MIDDLE BASIN

Historical Water Quality Summary

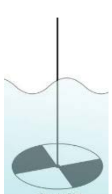
	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6
10-year Average (2010-2019)	38	16	6.4
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	39	16	7.0

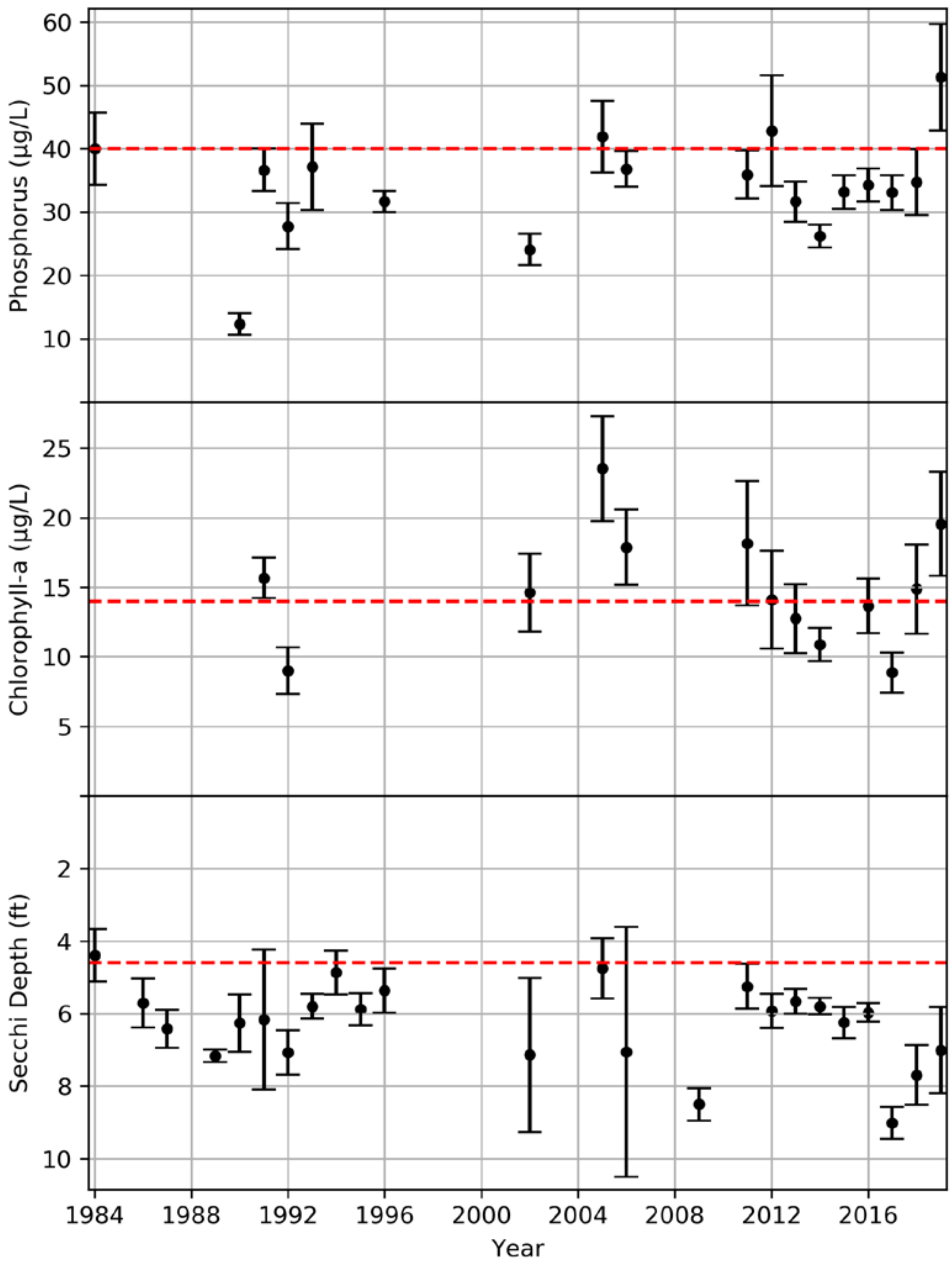
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



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

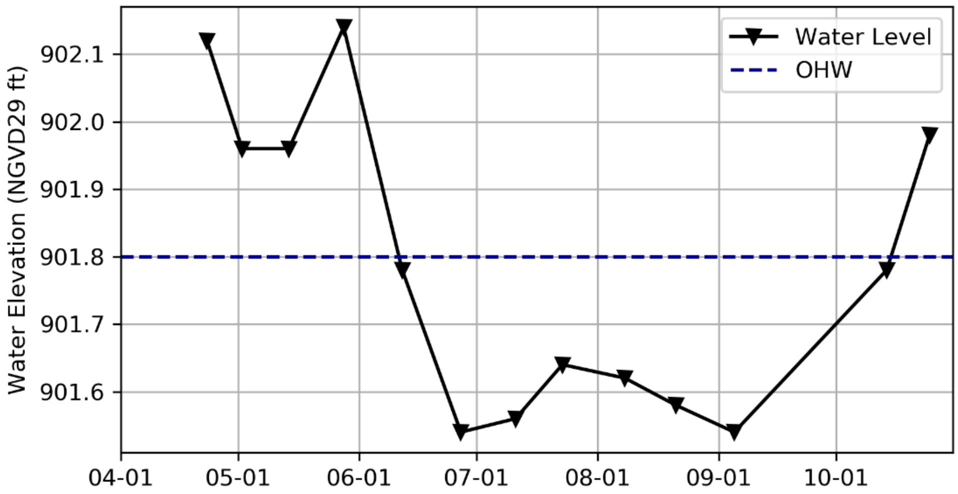
Clarity:
June-Sept. Average Secchi Depth (Secchi, ft)





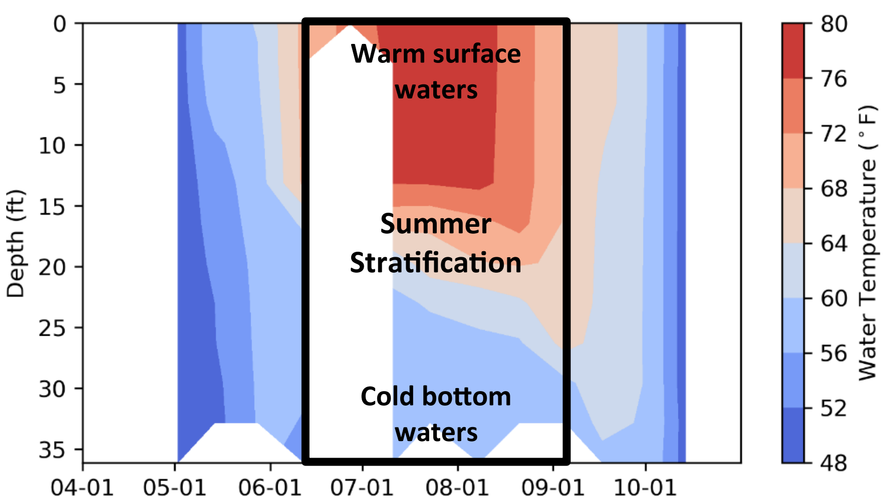
State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

FOREST LAKE – MIDDLE BASIN



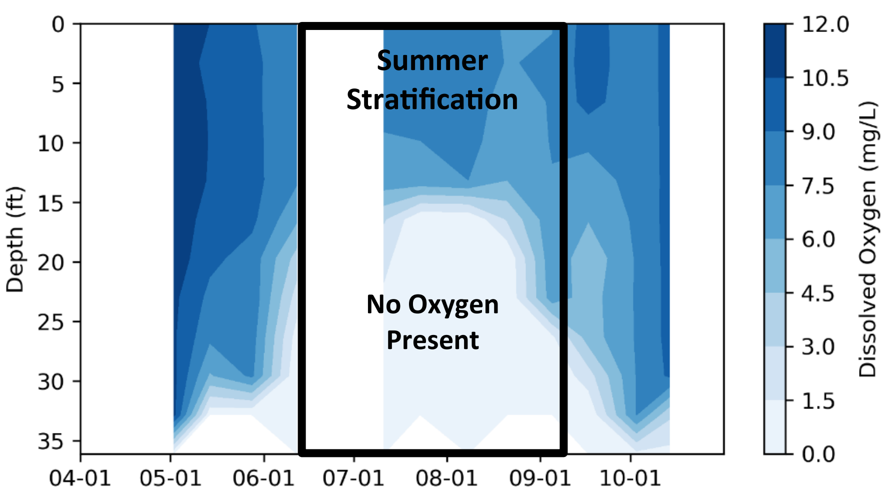
2019 Lake Levels

Lake levels ranged over a total of 0.6 feet; between a minimum of 901.54 feet on June 27 and September 5, 2019 and a maximum of 902.14 feet on May 28, 2019.



2019 Temperature Profiles

The lake was stratified from mid-June until early September.



2019 Dissolved Oxygen Profiles

Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible from early June until early September.

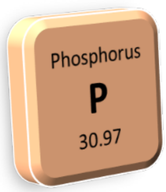
FOREST LAKE – EAST BASIN

2019 Surface Water Quality Summary

Nutrients:

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

32 µg/L



Algae:

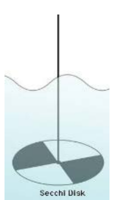
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

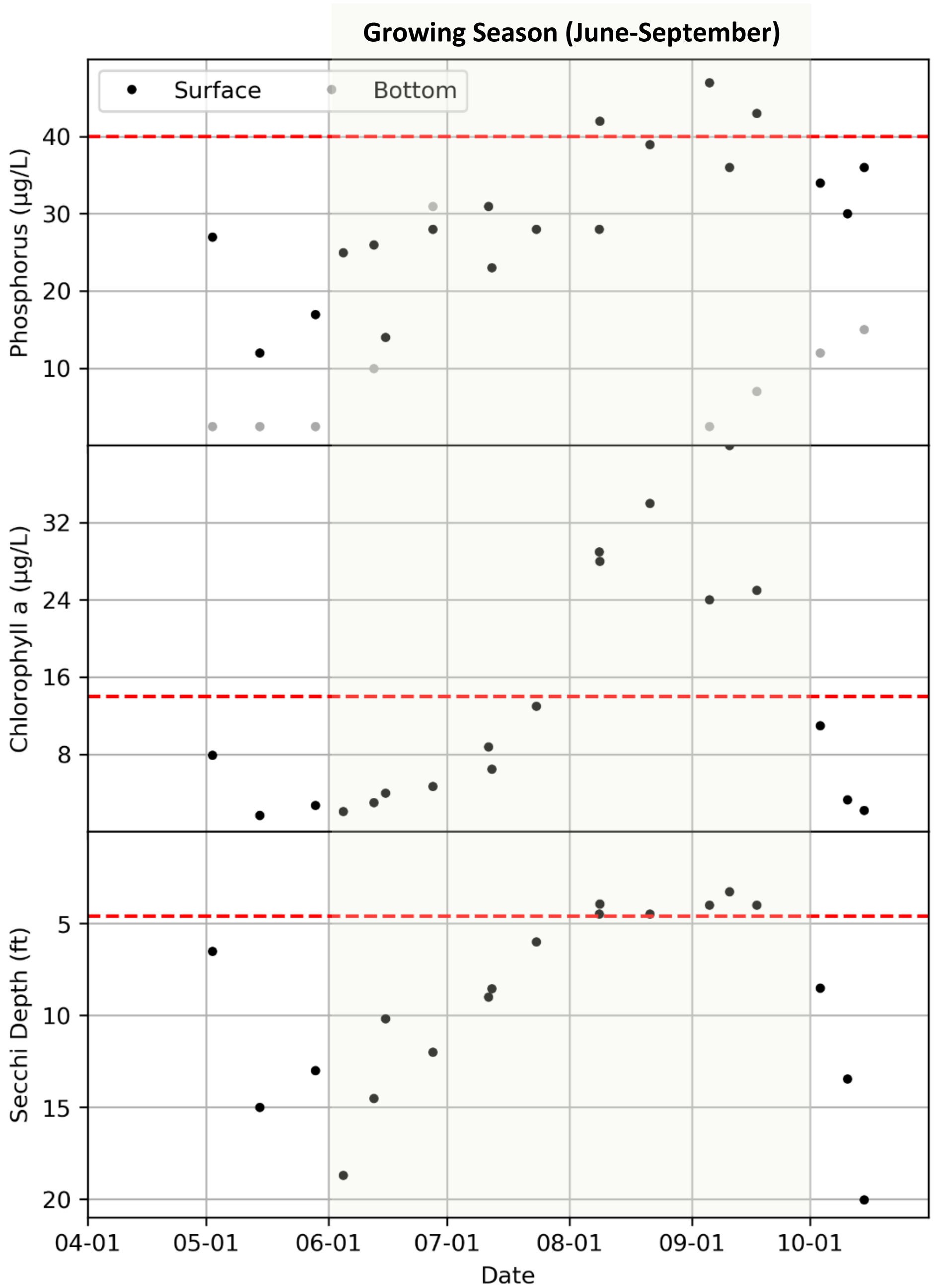
17 µg/L

Clarity:

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

7.9 feet





State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

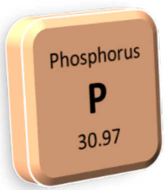
FOREST LAKE – EAST BASIN

Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6
10-year Average (2010-2019)	36	17	6.6
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	37	19	7.2

Nutrients:

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

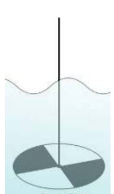


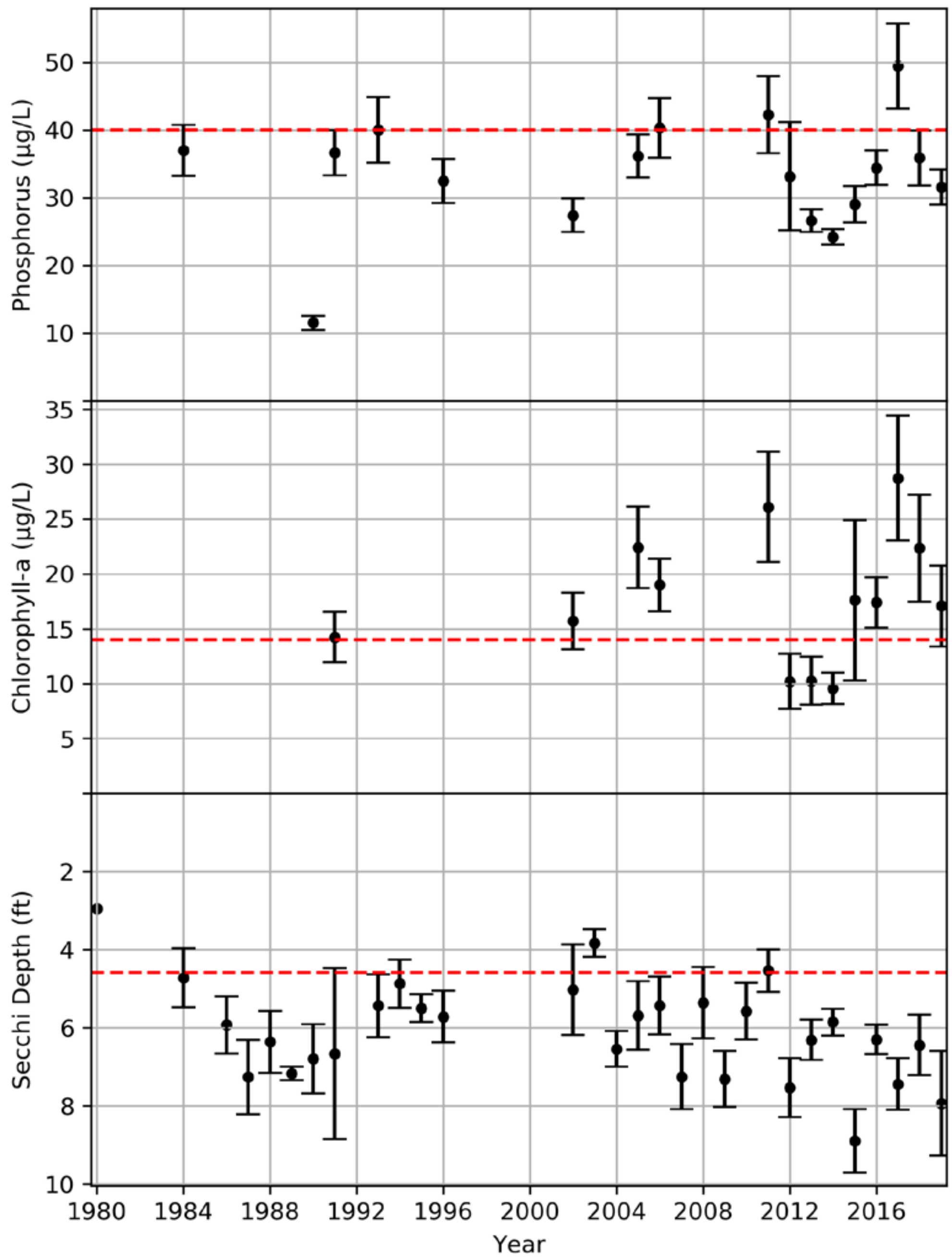
Algae:

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

Clarity:

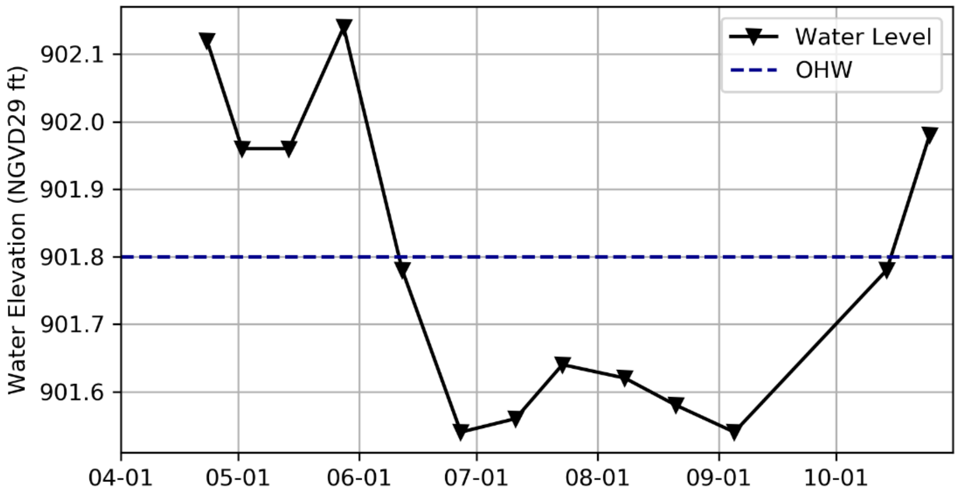
June-Sept. Average Secchi Depth (Secchi, ft)





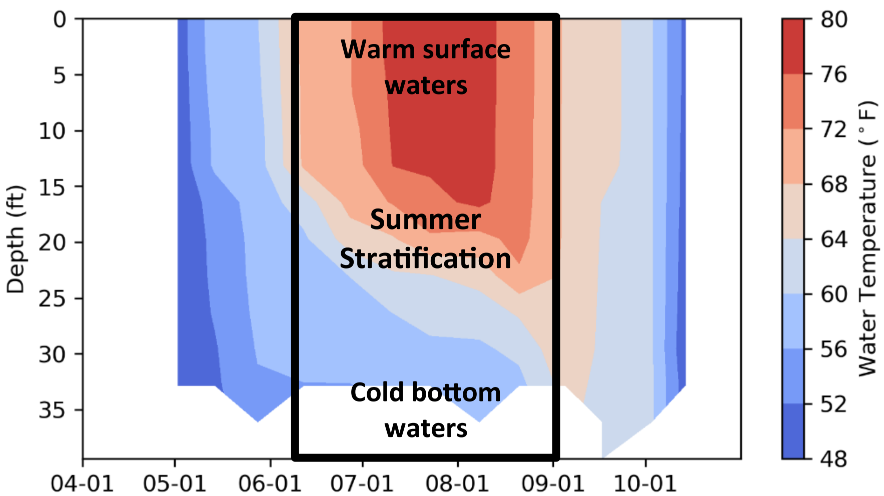
State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

FOREST LAKE – EAST BASIN



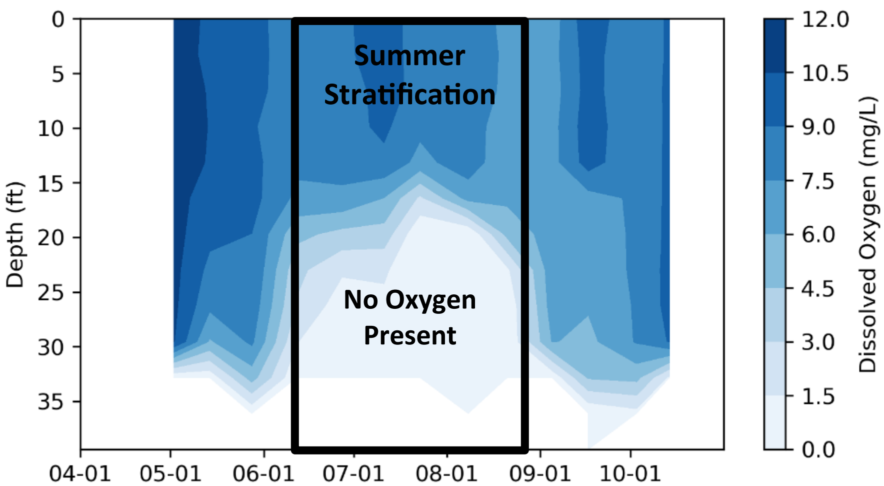
2019 Lake Levels

Lake levels ranged over a total of 0.6 feet; between a minimum of 901.54 feet on June 27 and September 5, 2019 and a maximum of 902.14 feet on May 28, 2019.



2019 Temperature Profiles

The lake was stratified from mid-June until early September.



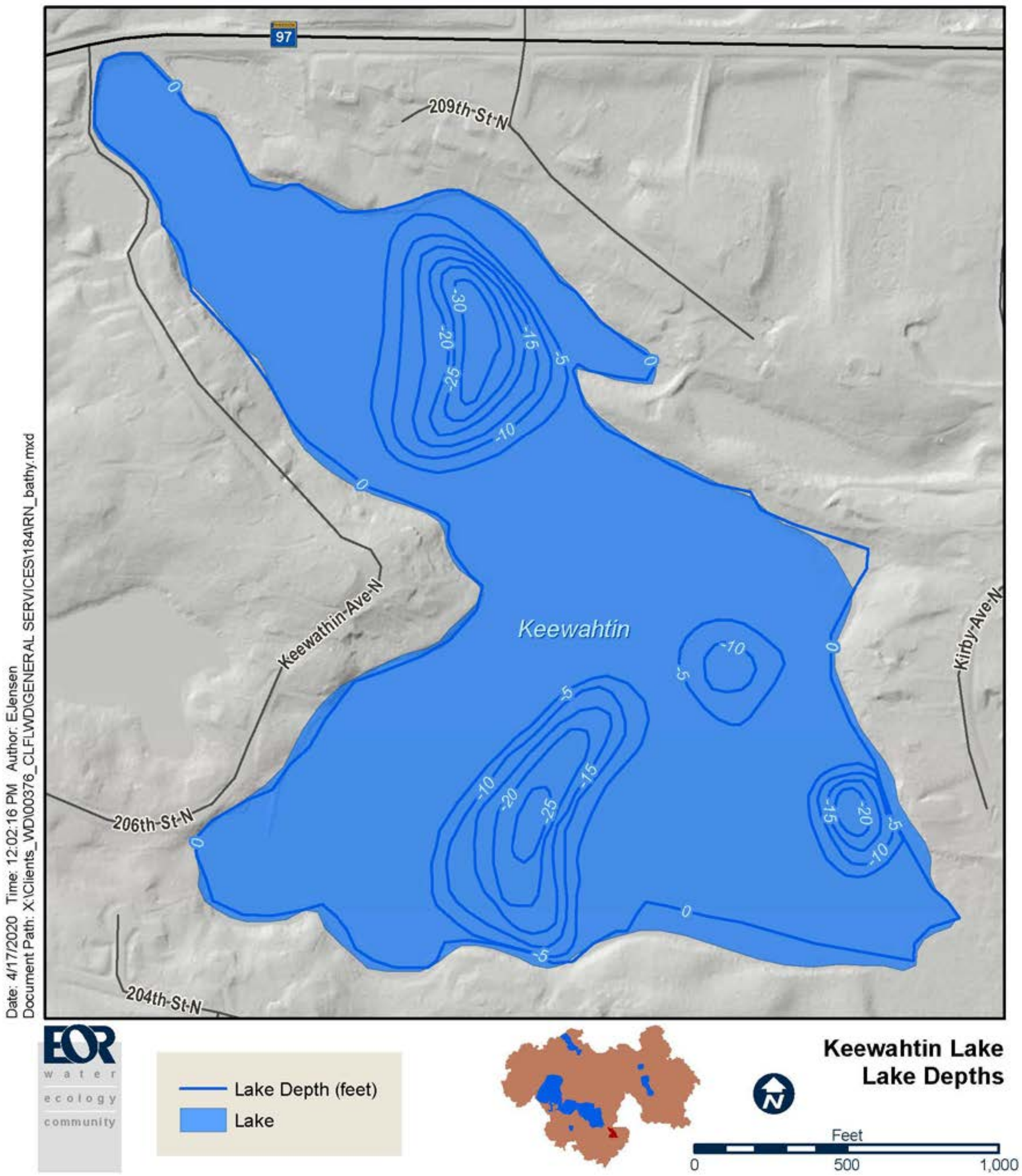
2019 Dissolved Oxygen Profiles

Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible from mid-June until early September.

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



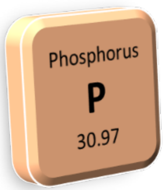
KEEWAHTIN LAKE

2019 Surface Water Quality Summary

Nutrients:

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

15 ug/L



Algae:

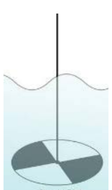
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

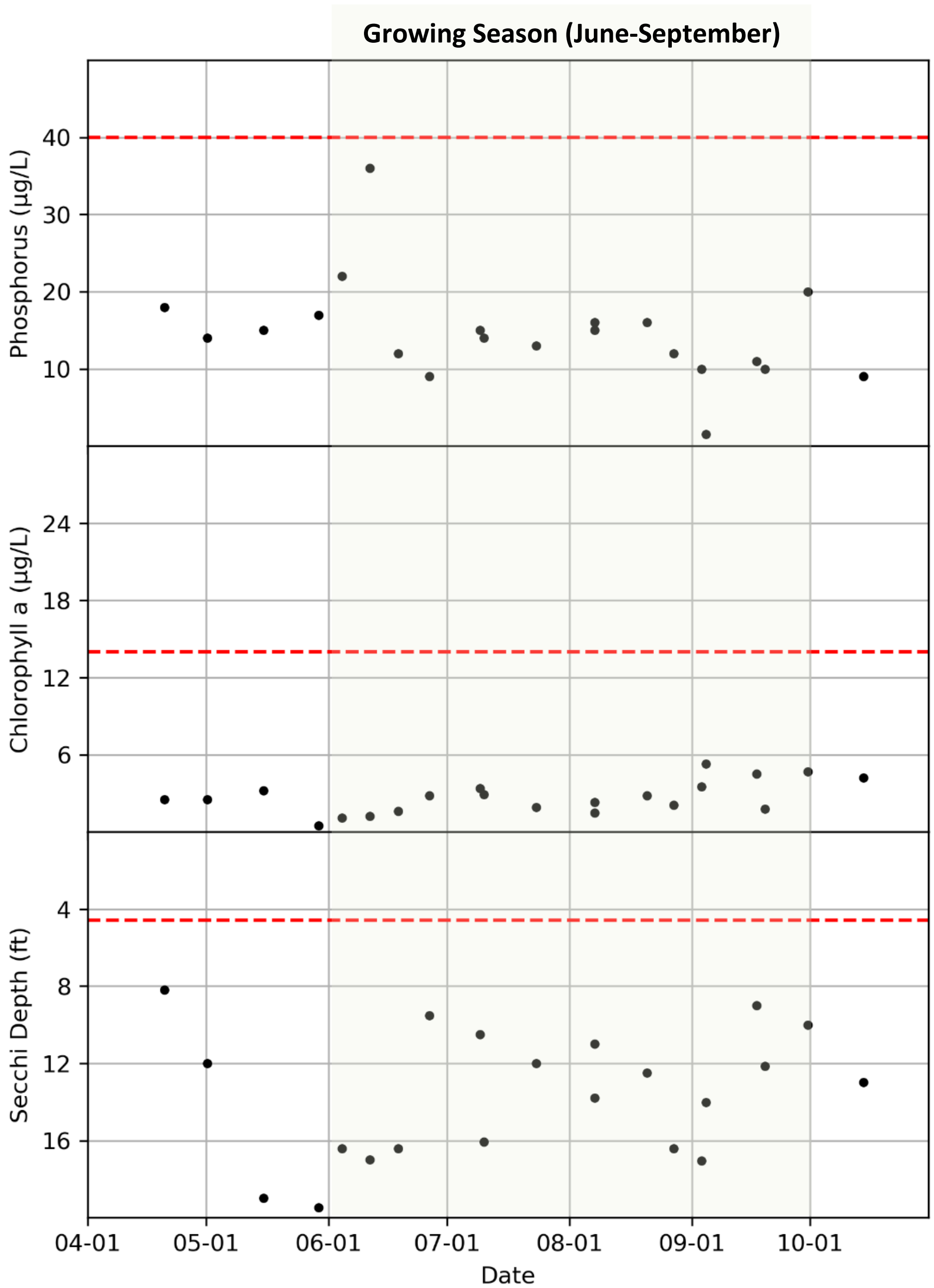
3 ug/L

Clarity:

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

13.4 feet





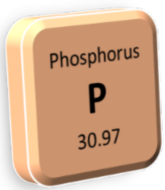
State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

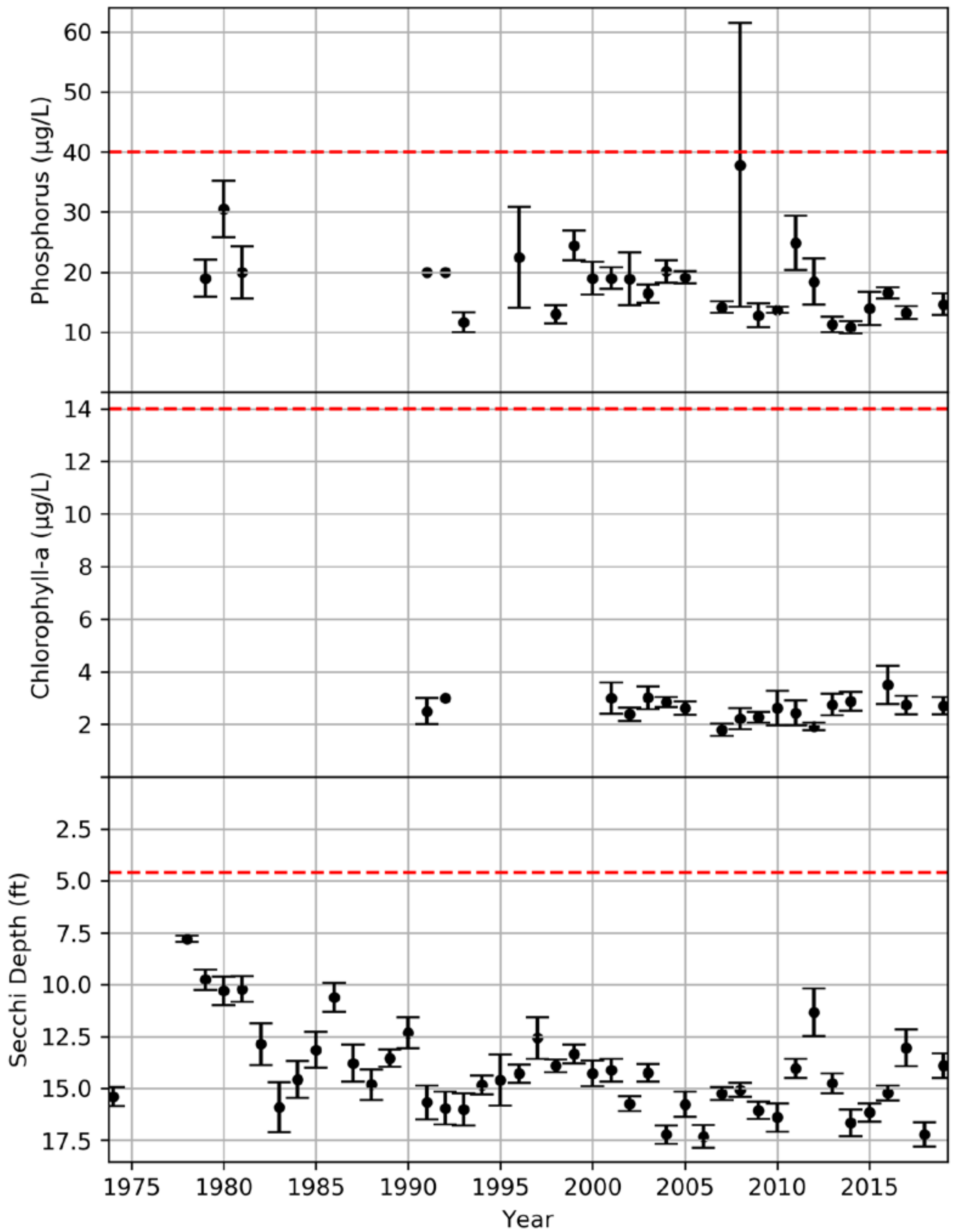
KEEWAHTIN LAKE

Historical Water Quality Summary

	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6
10-year Average (2010-2019)	16	3	14.8
2040 District Goal	< 20	n/a	> 10
5-year Average (2015-2019)	16	3	13.8

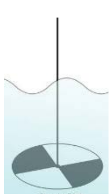
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)





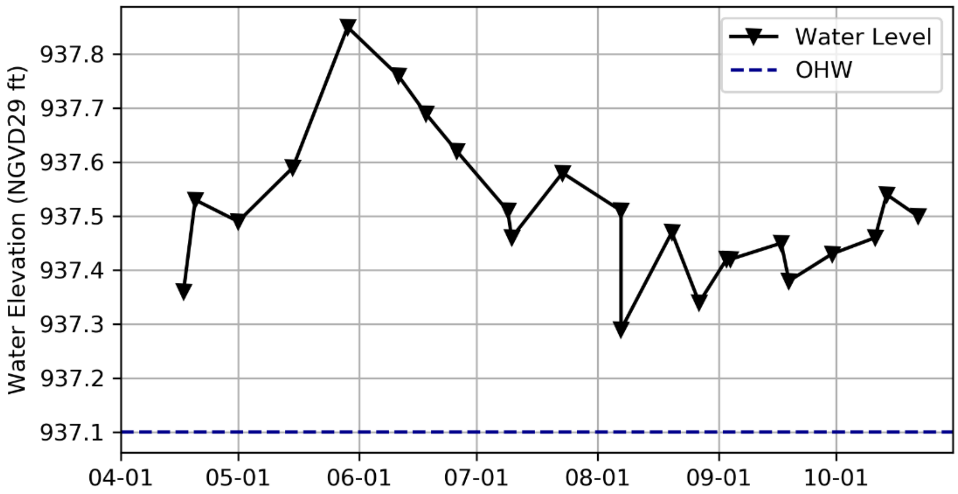
Algae:
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

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



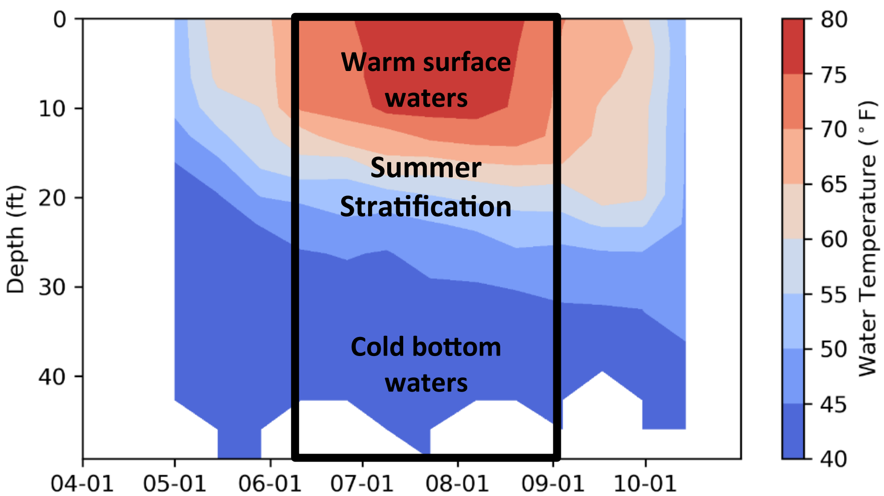
State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

KEEWAHTIN LAKE



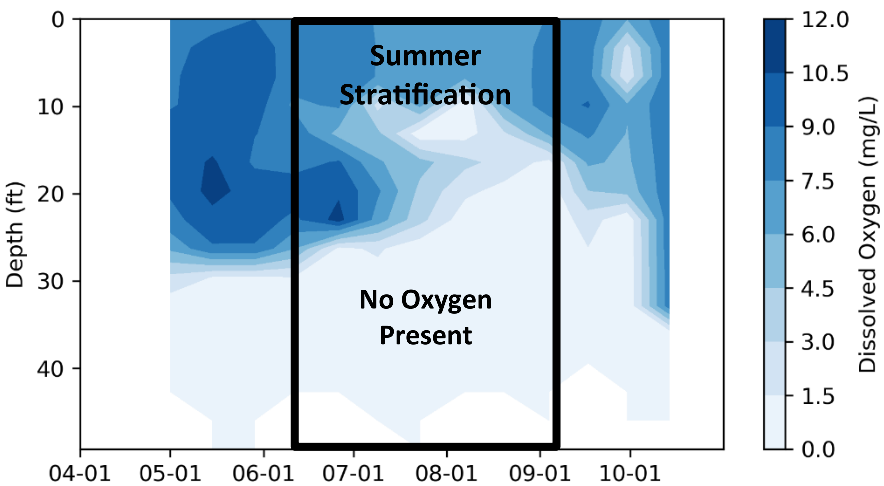
2019 Lake Levels

Lake levels ranged over a total of 0.6 feet; between a minimum of 937.29 feet on August 7, 2019 and a maximum of 937.85 feet on May 29, 2019. The water levels were above the Ordinary High Water level during 2019.



2019 Temperature Profiles

The lake was stratified from mid-June until early September.



2019 Dissolved Oxygen Profiles

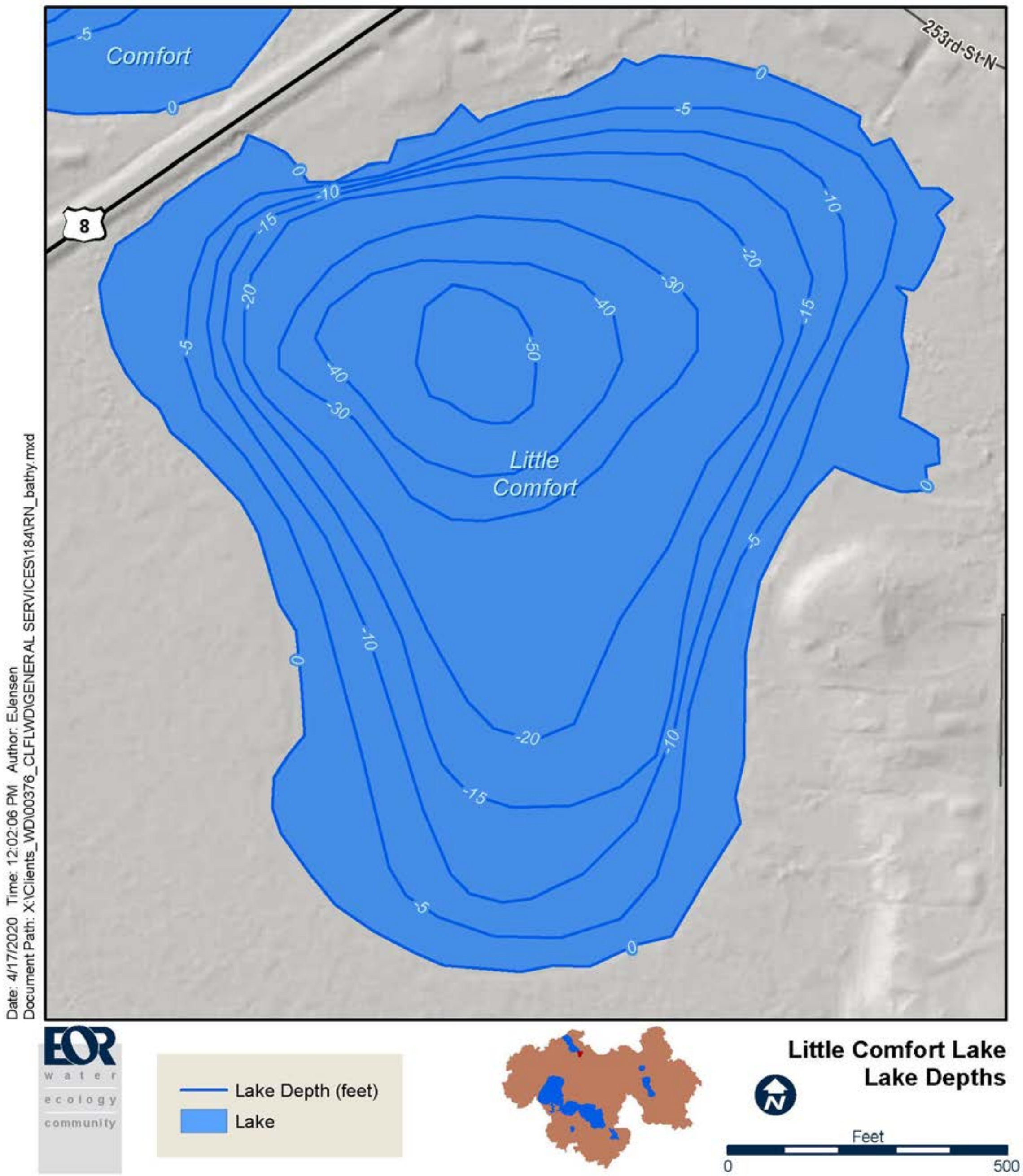
Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible throughout the growing season.

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



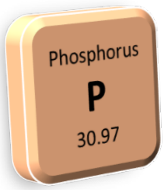
LITTLE COMFORT LAKE

2019 Surface Water Quality Summary

Nutrients:

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

52 µg/L



Algae:

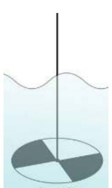
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

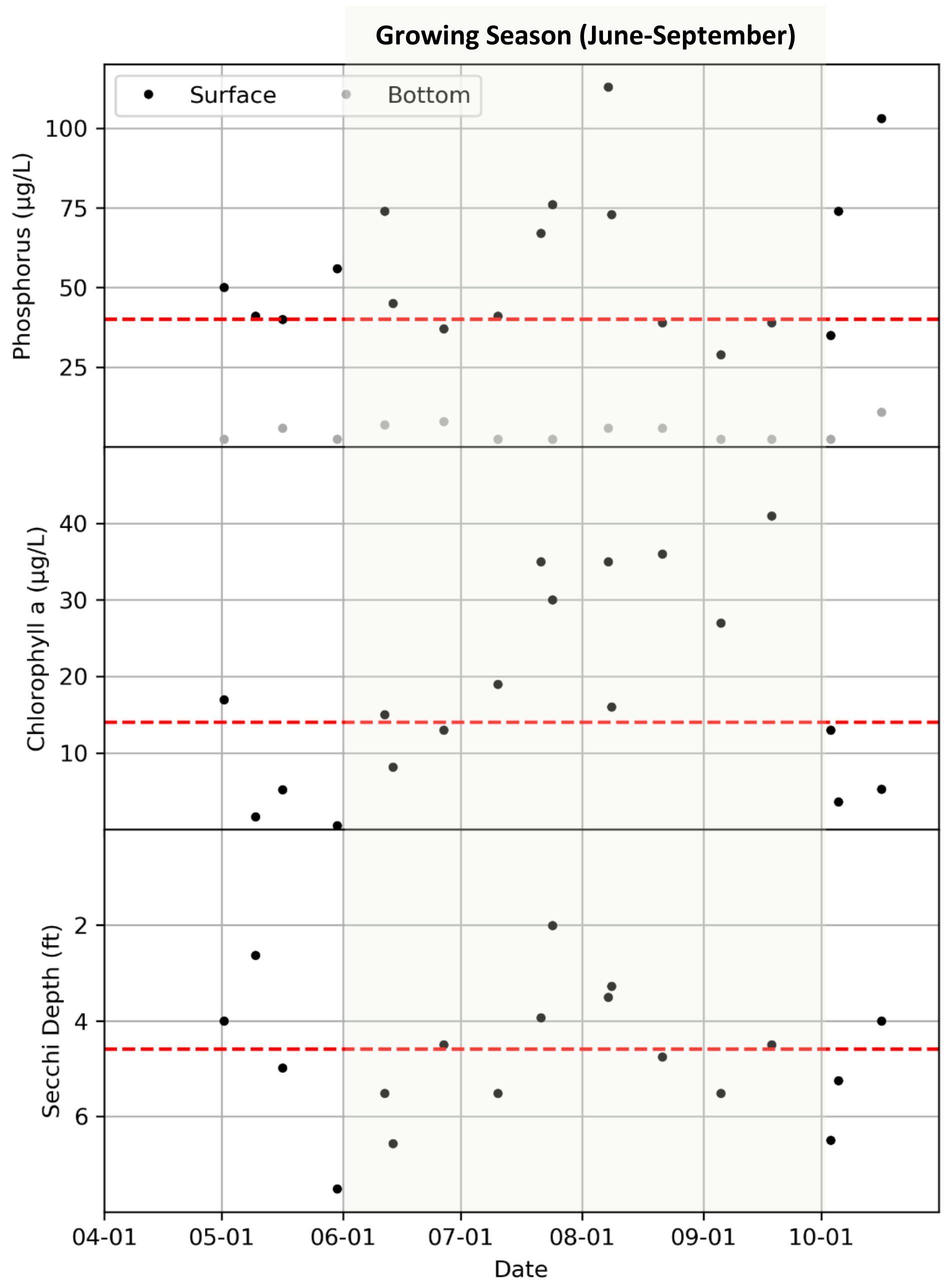
25 µg/L

Clarity:

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

4.5 feet





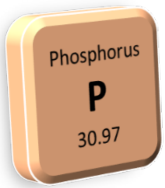
State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

LITTLE COMFORT LAKE

Historical Water Quality Summary

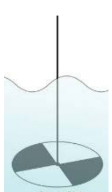
	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6
10-year Average (2010-2019)	56	21	4.7
2040 District Goal	< 30	n/a	> 7.0
5-year Average (2015-2019)	61	28	4.1

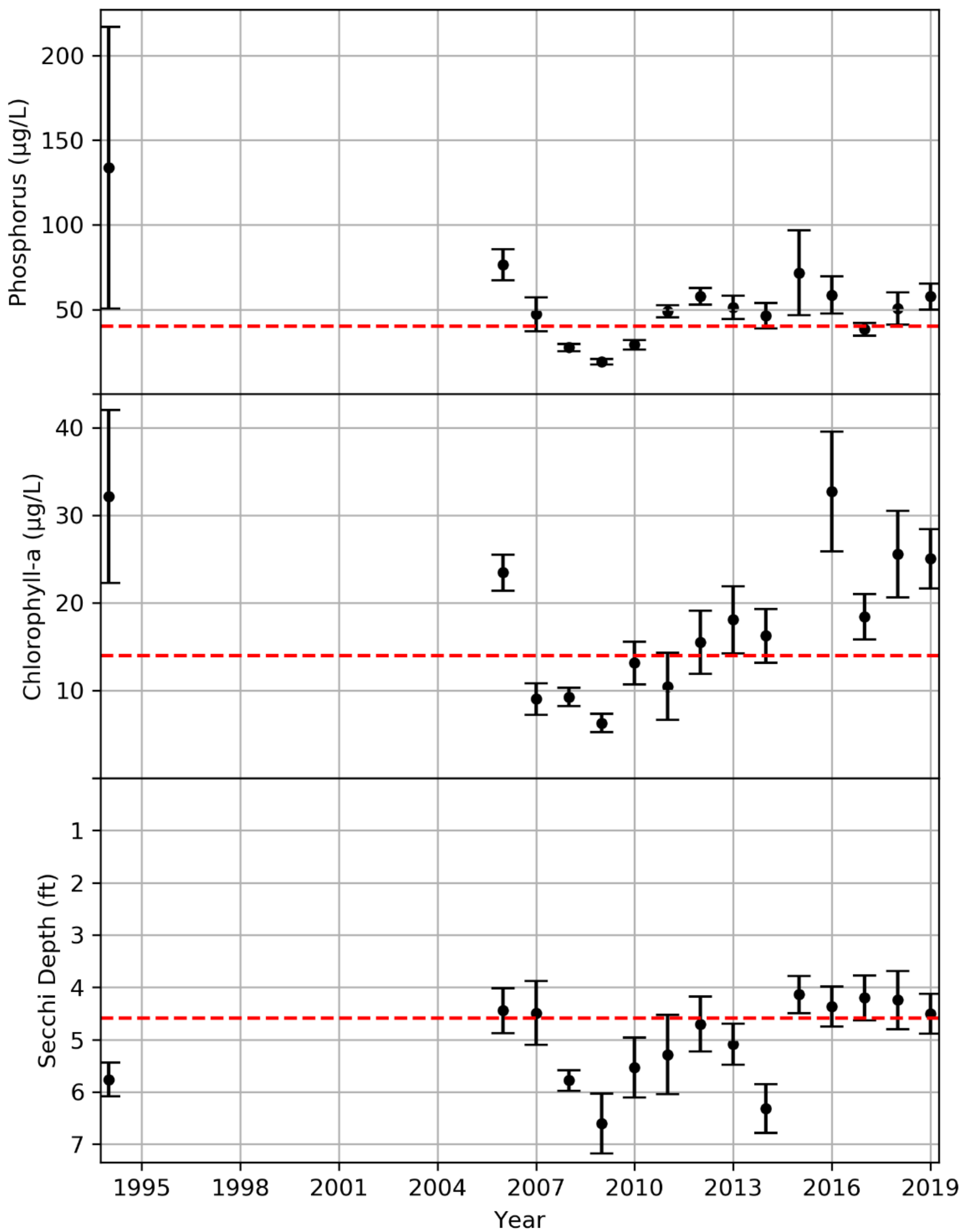
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



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

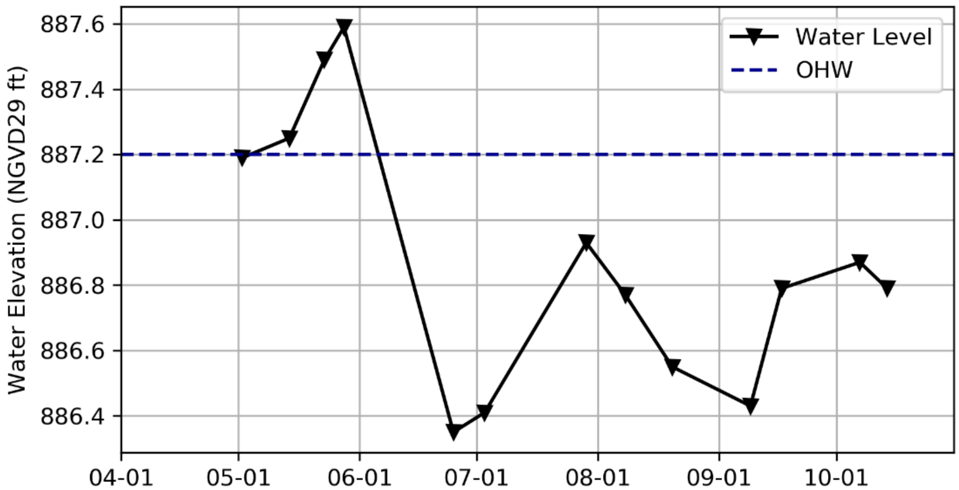
Clarity:
June-Sept. Average Secchi Depth (Secchi, ft)





State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

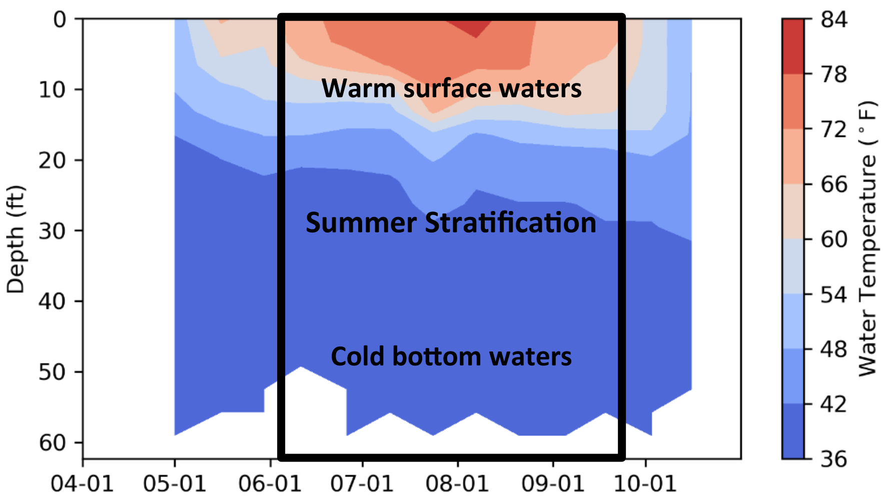
LITTLE COMFORT LAKE



2019 Lake Levels

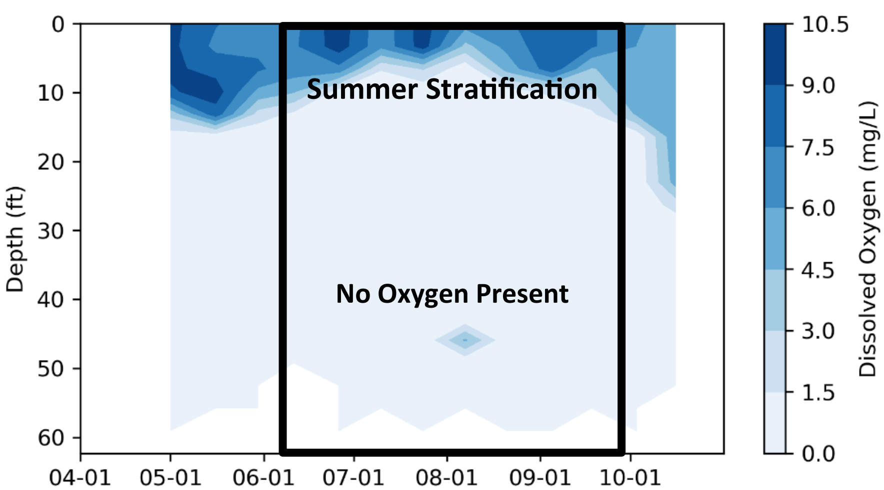
No lake levels are monitored on Little Comfort Lake; they are assumed to be similar to Big Comfort Lake:

Lake levels ranged over a total of 1.24 feet; between a minimum of 886.35 feet on June 25, 2019 and a maximum of 887.59 feet on May 28, 2019.



2019 Temperature Profiles

The lake was stratified from early June until late September.



2019 Dissolved Oxygen Profiles

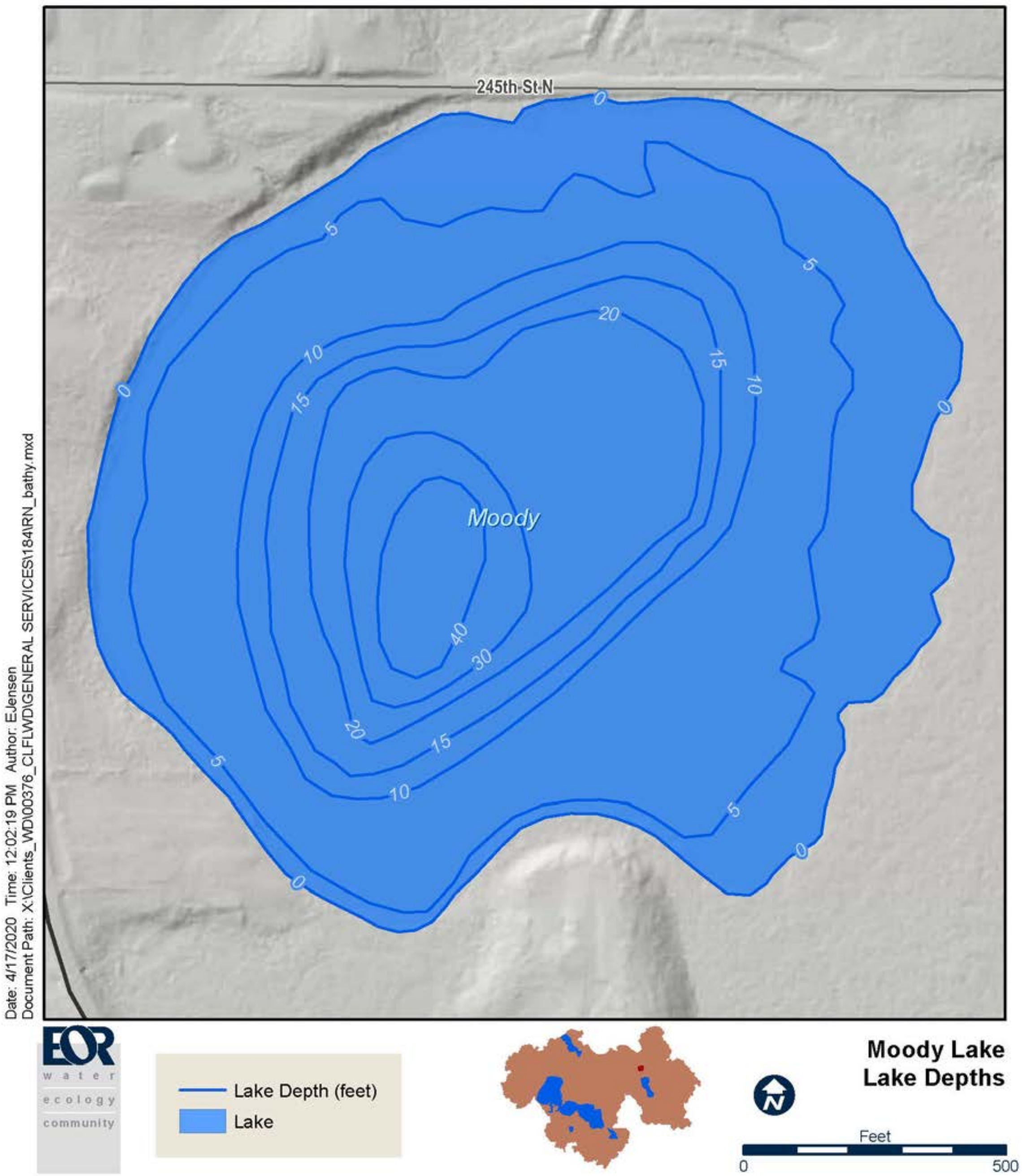
Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible throughout the growing 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



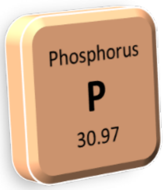
MOODY LAKE

2019 Surface Water Quality Summary

Nutrients:

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

60 µg/L



Algae:

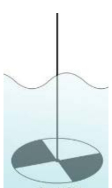
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

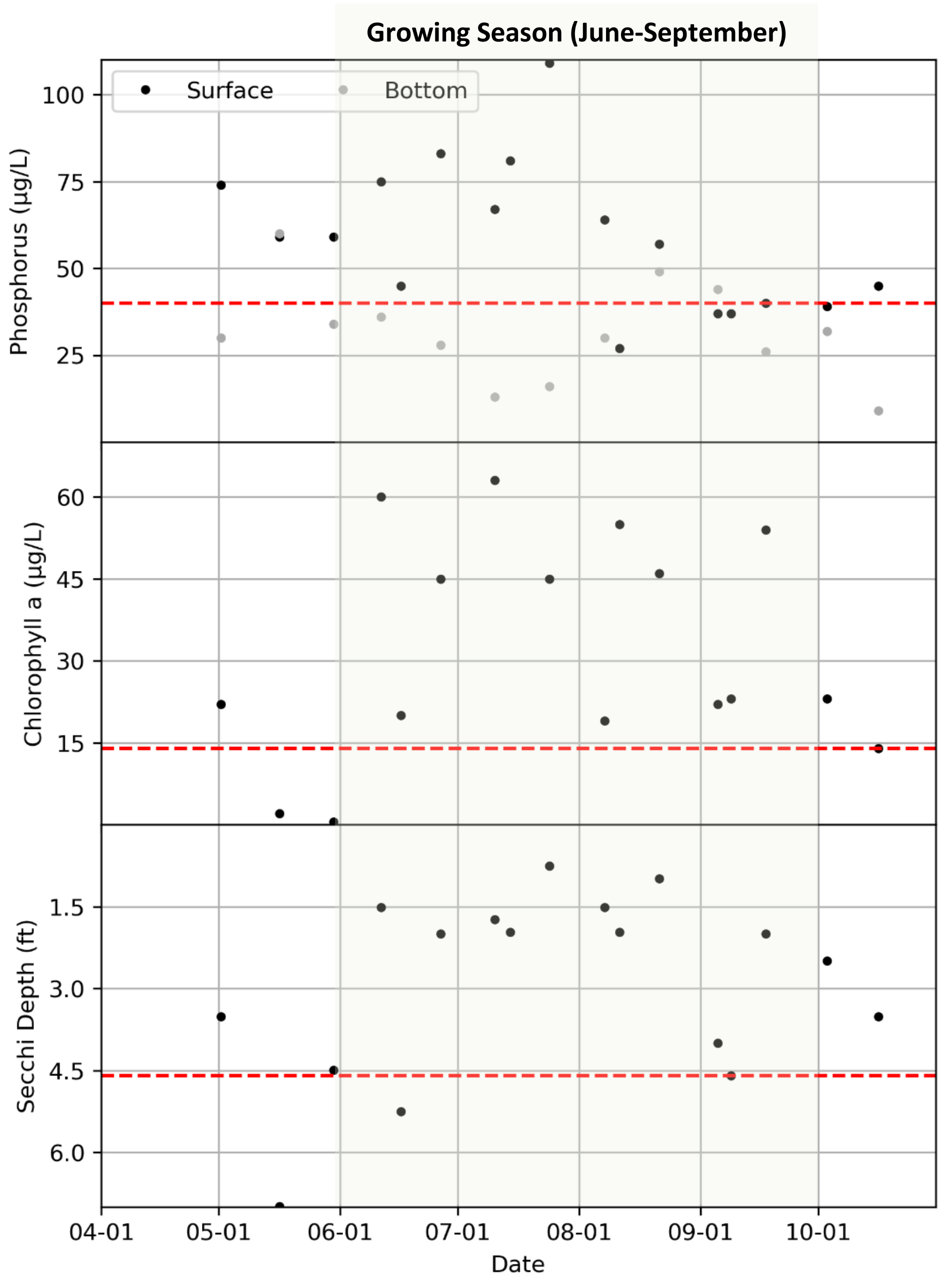
41 µg/L

Clarity:

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

2.4 feet





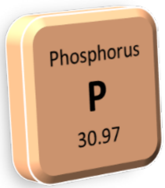
State standard are shown with a dashed red line. Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

MOODY LAKE

Historical Water Quality Summary

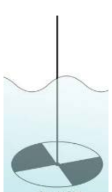
	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 40	< 14	> 4.6
10-year Average (2010-2019)	103	59	2.5
2040 District Goal	< 40	n/a	> 4.6
5-year Average (2015-2019)	93	52	2.2

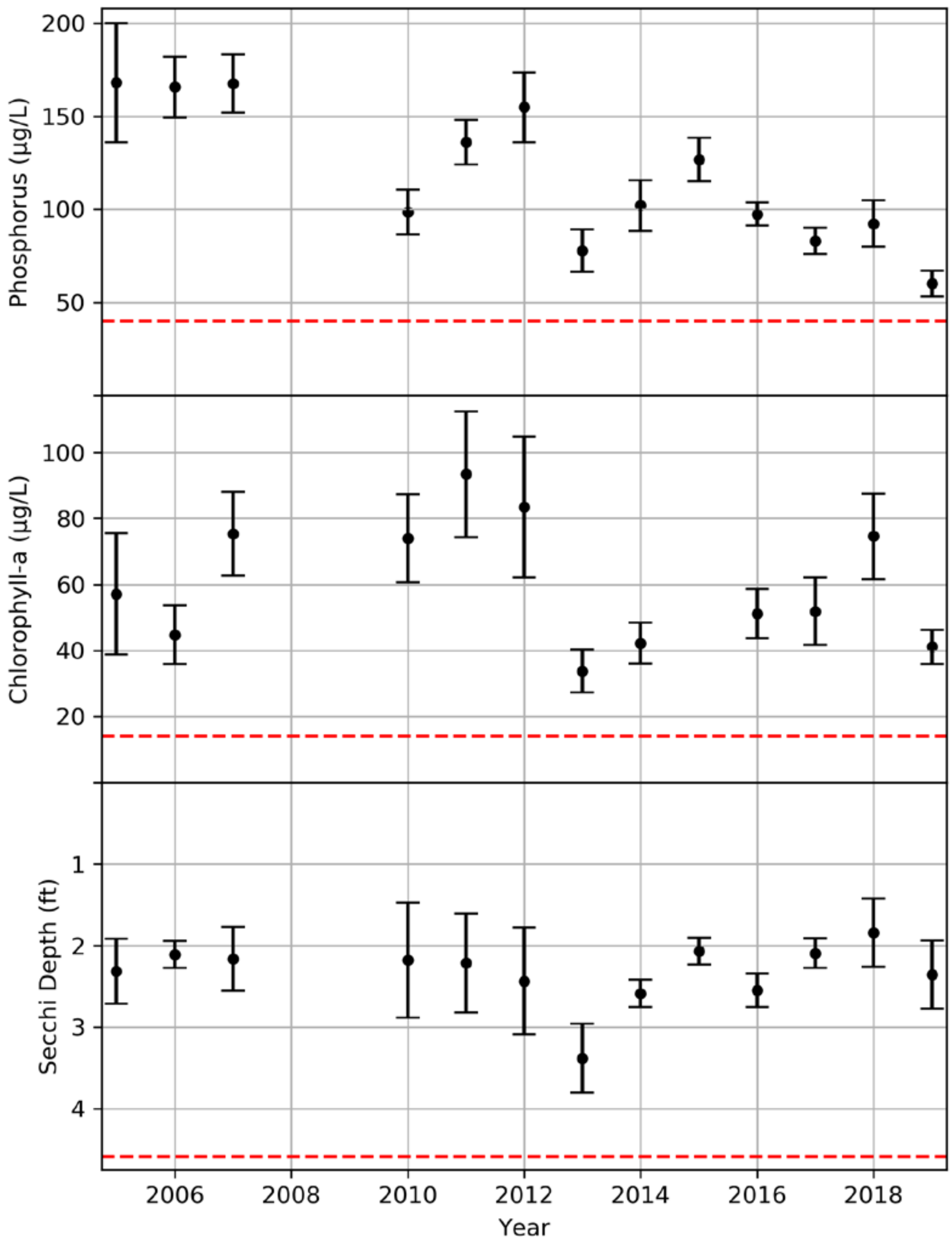
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



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

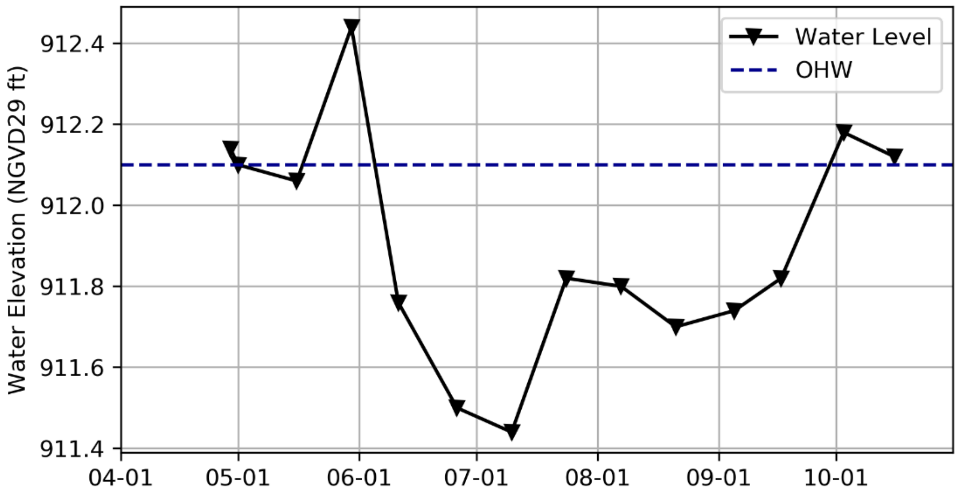
Clarity:
June-Sept. Average Secchi Depth (Secchi, ft)





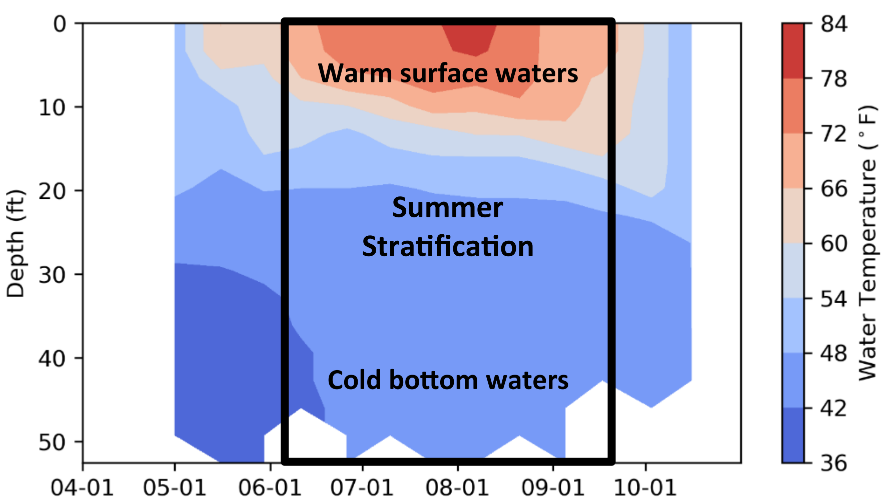
State standard are shown with a dashed red line: Phosphorus = 40 µg/L, Chlorophyll-a = 14 µg/L, Secchi Depth = 4.6 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

MOODY LAKE



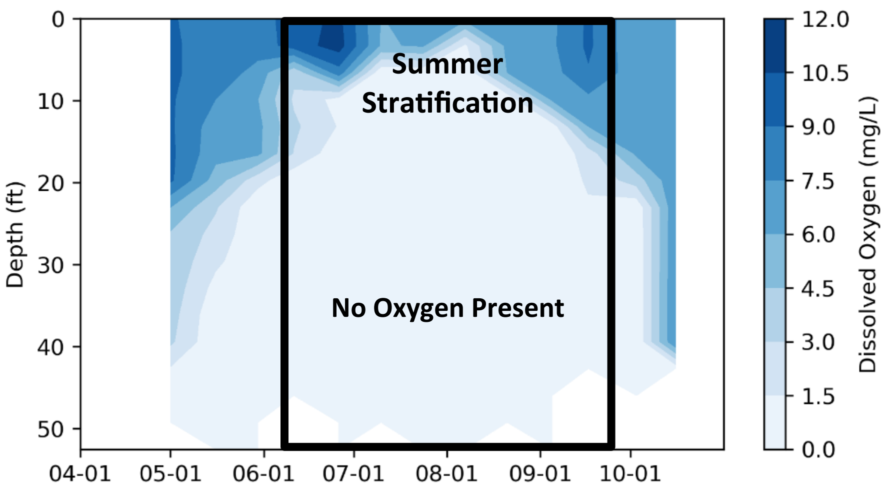
2019 Lake Levels

Lake levels ranged over a total of 1.0 feet; between a minimum of 911.44 feet on July 10, 2019 and a maximum of 912.44 feet on May 30, 2019.



2019 Temperature Profiles

The lake was stratified from early June until late September.



2019 Dissolved Oxygen Profiles

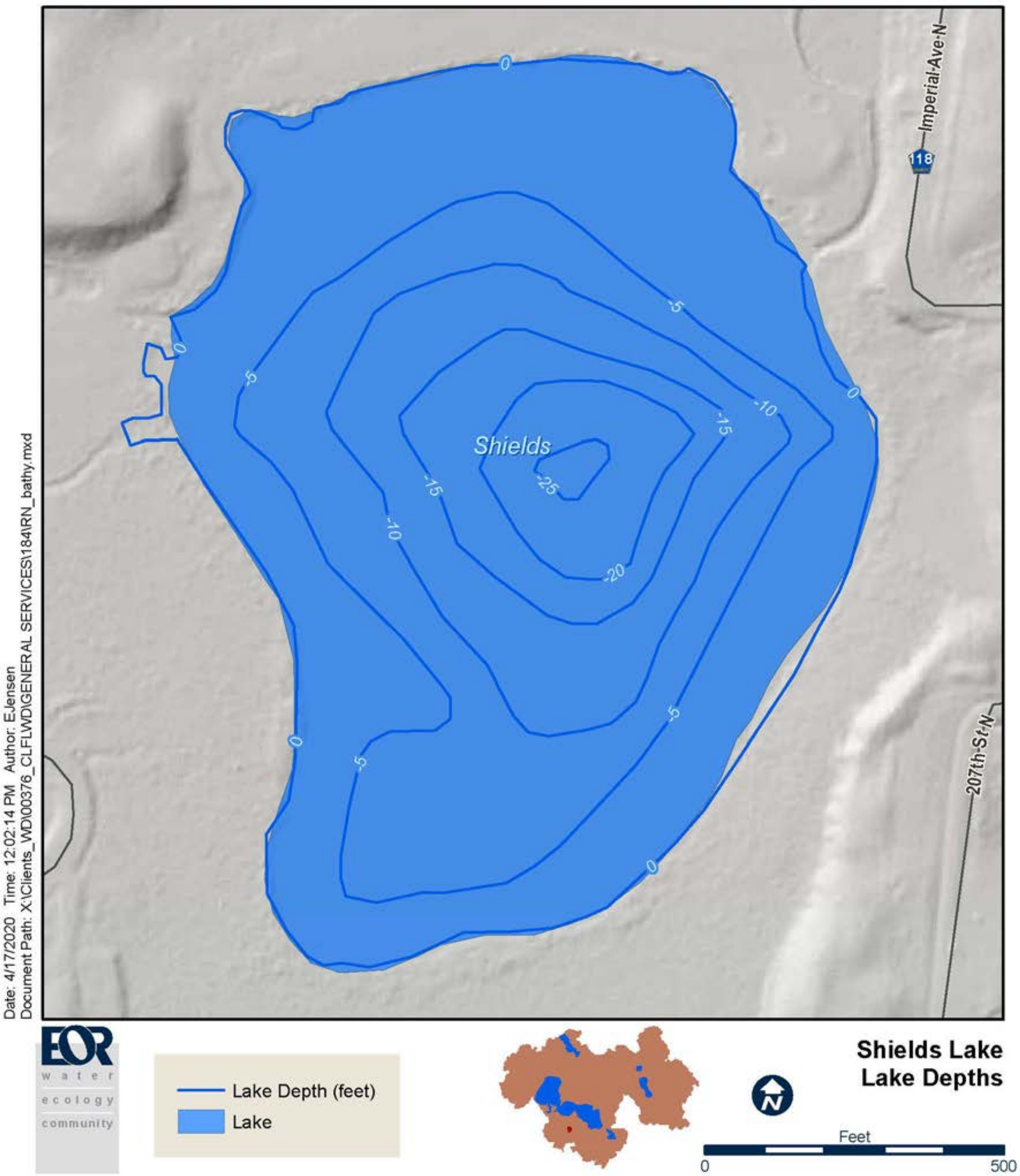
Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible from early June until late September.

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



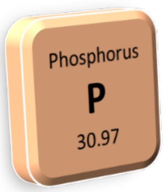
SHIELDS LAKE

2019 Surface Water Quality Summary

Nutrients:

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

128 ug/L



Algae:

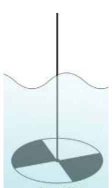
June-Sept. Average Chlorophyll-a (Chl-a, µg/L)

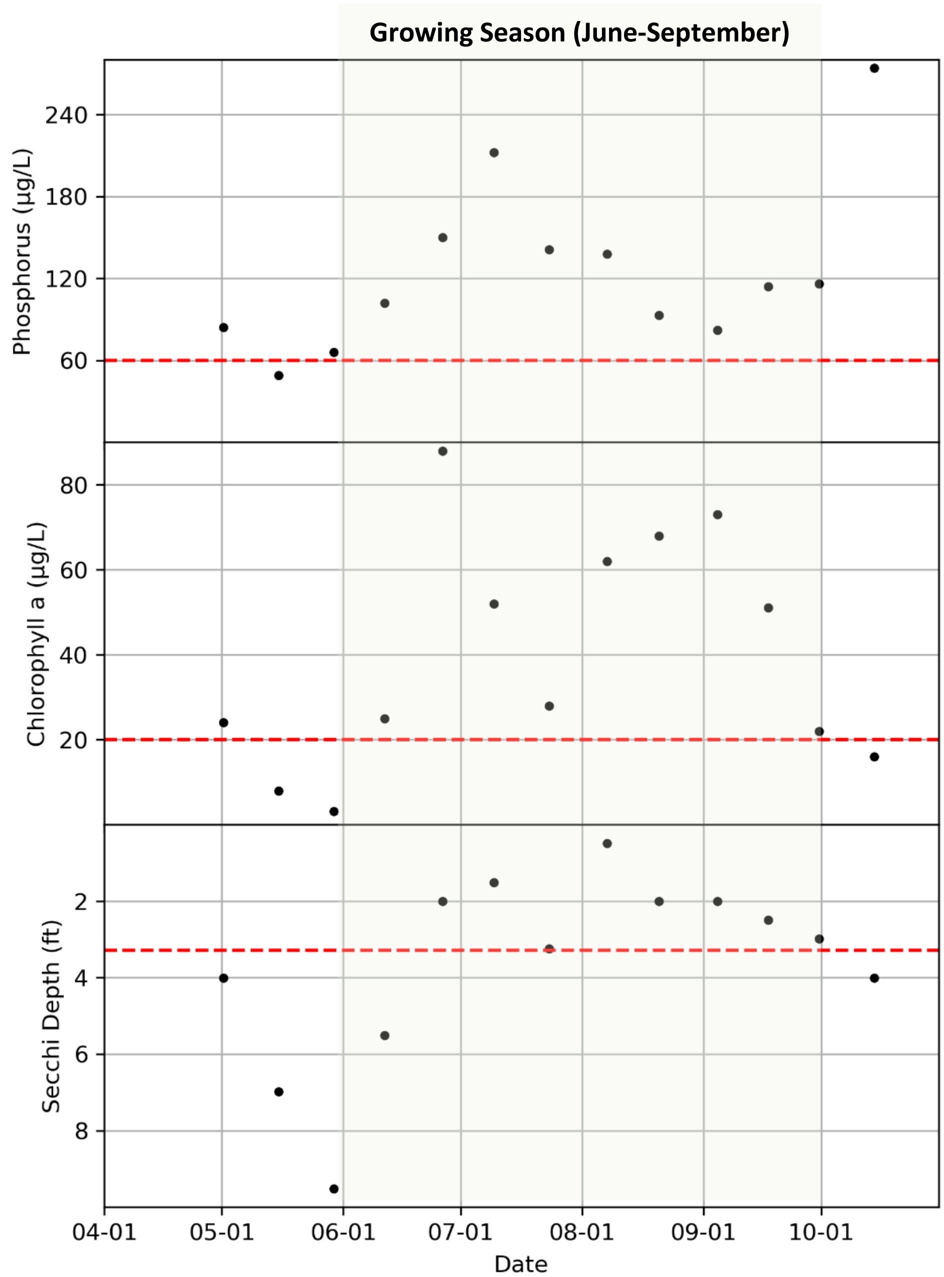
52 ug/L

Clarity:

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

2.5 feet





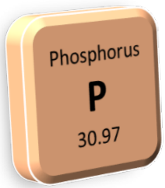
State standard are shown with a dashed red line. Phosphorus = 60 µg/L, Chlorophyll-a = 20 µg/L, Secchi Depth = 3.3 feet. Sample points are shown in black dots. Points above the line are worse than the State standard. Points below the line are better than the State standard.

SHIELDS LAKE

Historical Water Quality Summary

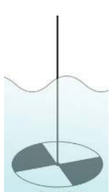
	Phosphorus (µg/L)	Chl-a (µg/L)	Secchi (feet)
State Standard	< 60	< 20	> 3.3
10-year Average (2010-2019)	212	50	2.9
2040 District Goal	< 60	n/a	> 4.3
5-year Average (2015-2019)	208	60	2.3

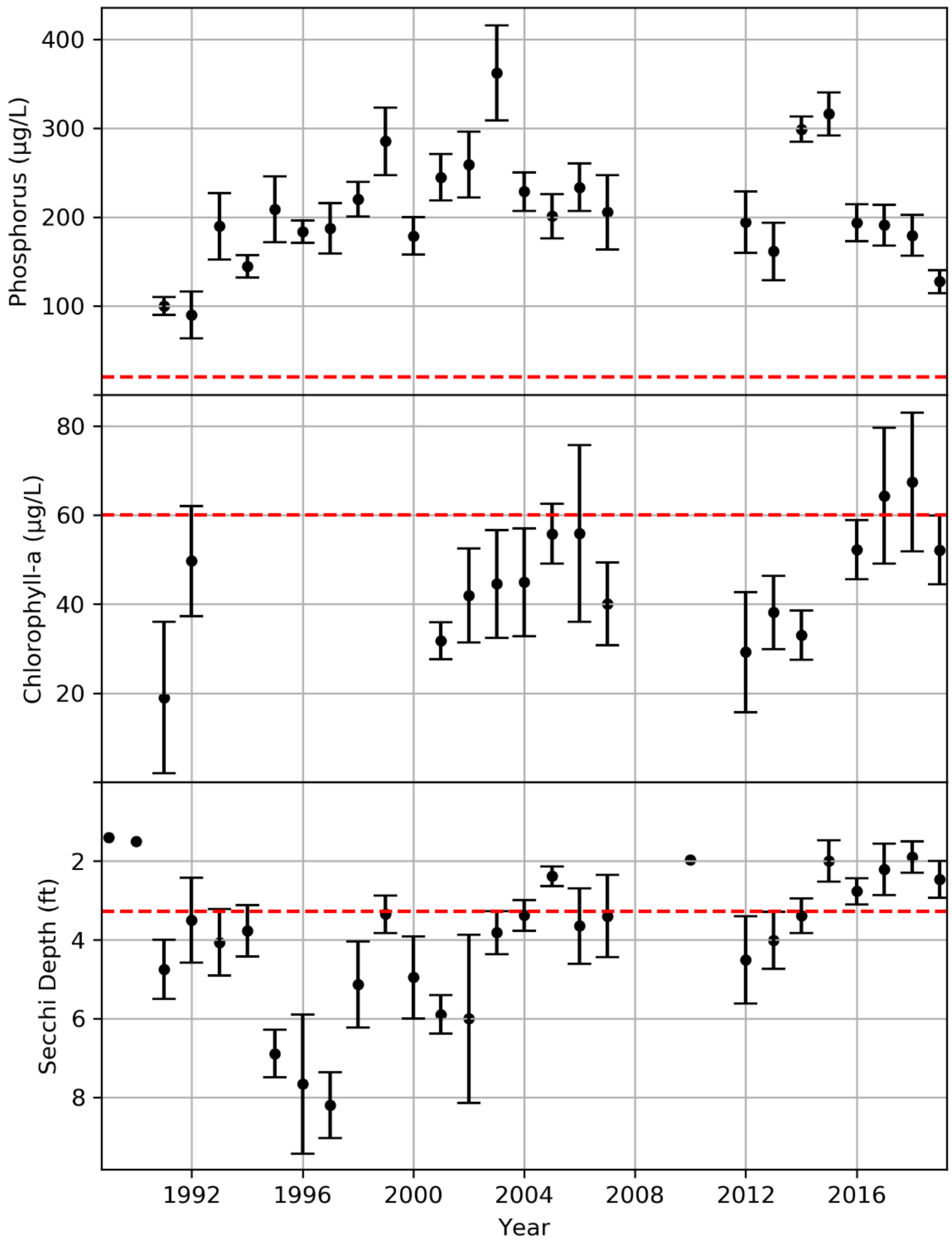
Nutrients:
June-Sept. Average Total Phosphorus (TP, µg/L)



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

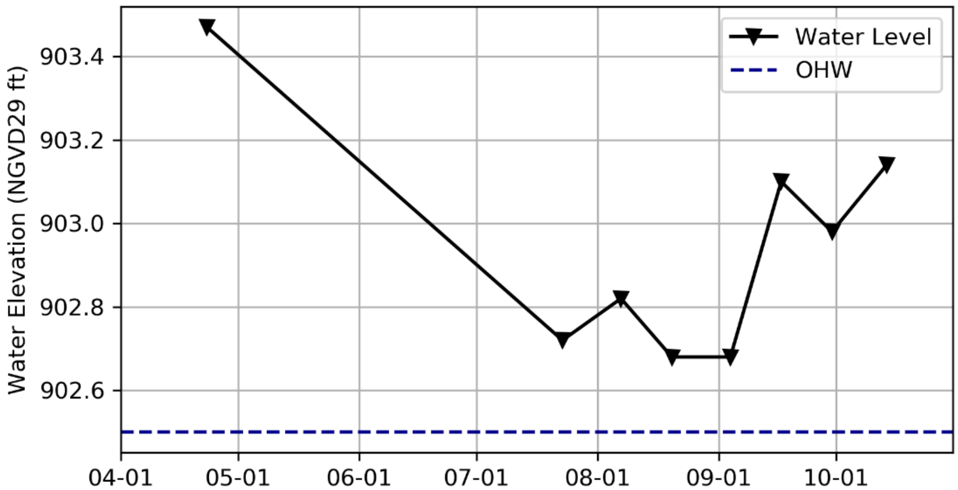
Clarity:
June-Sept. Average Secchi Depth (Secchi, ft)





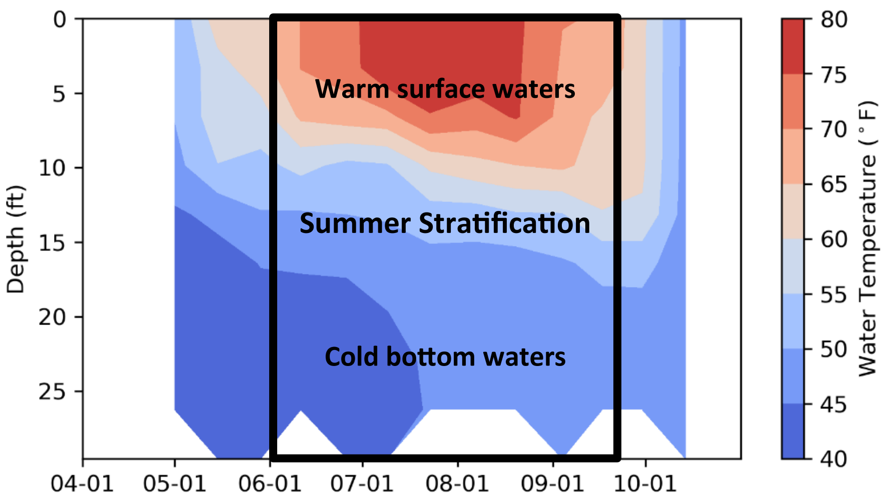
State standard are shown with a dashed red line: Phosphorus = 60 µg/L, Chlorophyll-a = 20 µg/L, Secchi Depth = 3.3 feet. Growing season averages are shown as black points. Points above the line are worse than the State standard. Points below the line are better than the State standard.

SHIELDS LAKE



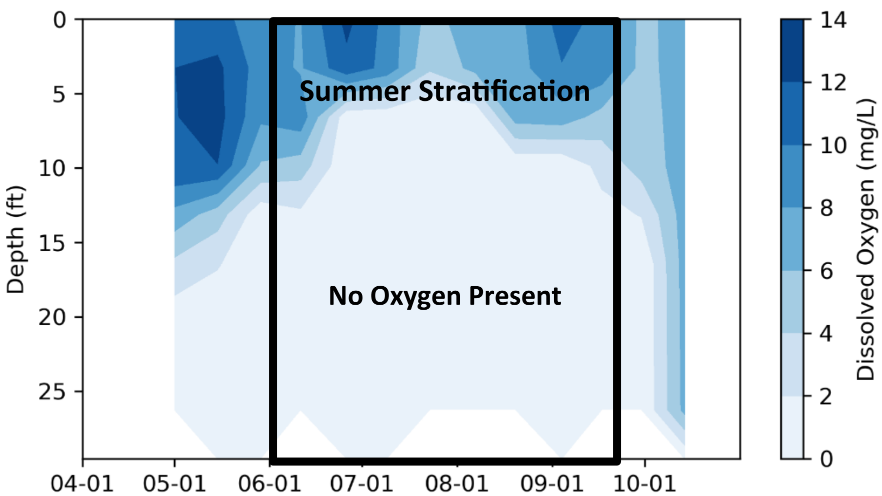
2019 Lake Levels

Lake levels ranged over a total of 0.8 feet; between a minimum of 902.68 feet on September 4, 2019 and a maximum of 903.47 feet on April 23, 2019.



2019 Temperature Profiles

The lake was stratified from early June until late September.



2019 Dissolved Oxygen Profiles

Grey represents the duration and depths where no oxygen is present and sediment phosphorus can be released and contribute to internal loading.

Internal loading was possible throughout the growing season.

APPENDIX B – 2019 INDIVIDUAL STREAM SITE SUMMARIES

Bone Lake North Inlet

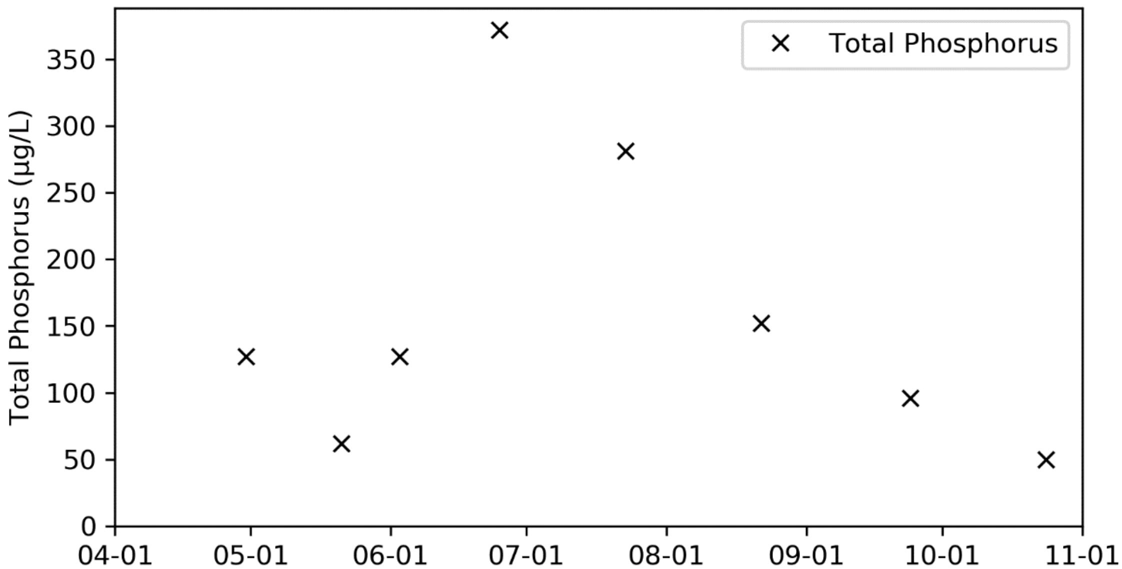


Figure 9. Total phosphorus concentration by sample date at Bone Lake North Inlet (2019)

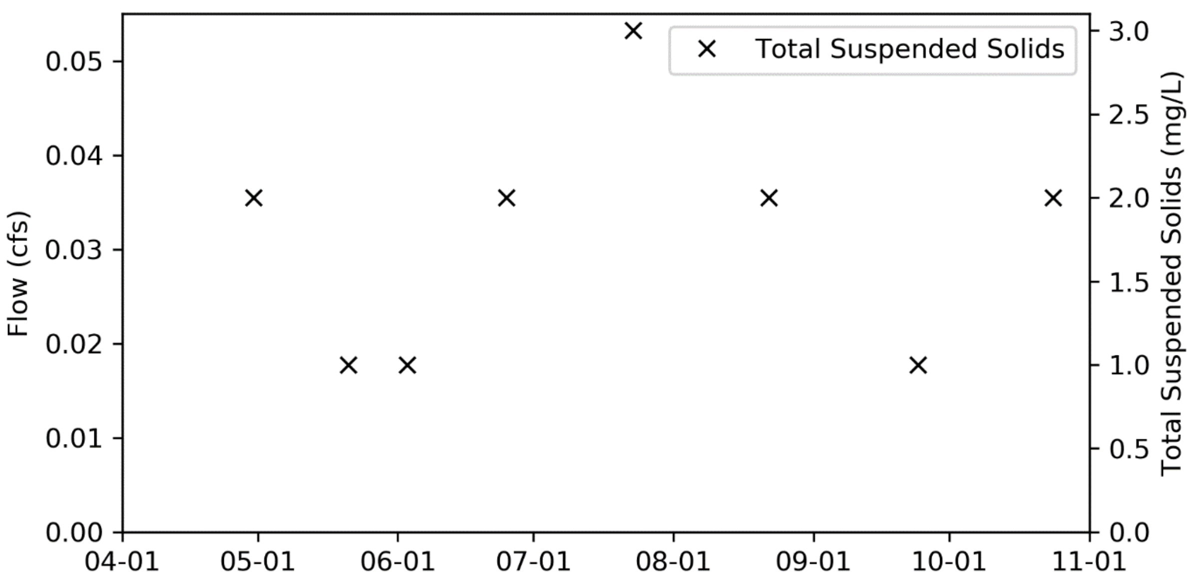


Figure 10. Total suspended solids concentration by sample date at Bone Lake North Inlet

Table 11. Bone Lake North Inlet (S004-471) 2019 Stream Water Chemistry Sample Results

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

Date/Time	Collection	Temp. (deg. C)	D.O. (mg/L)	pH	Sp. Cond. (uS/cm)	TP (µg/L)	TDP (µg/L)	NH4-N (mg/L)	TKN (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TSS (mg/L)	TVS (mg/L)	*E. coli* (MPN/100mL)	Chloride (mg/L)
MN Class 2B Standards		< 20	< 5	6.5-9.5		< 100						> 30		< 126	< 230
3/27/19 15:30	Grab	2.2	**2.15**	6.8	174	134	63	0.38	1.3	0.1	<0.03	3	3		11.7
4/30/19 10:00	Grab	7.9	**3.38**	7.06	154	127	55	<0.02	1	<0.20	<0.06	~2	~2	16	11.7
5/21/19 11:37	Grab					62	~45	<0.02	<0.08	<0.20	<0.06	<1	<1		9.4
6/3/19 9:25	Grab	17.3	**2.63**	7.4	152	**127**	58	<0.02	0.93	<0.20	<0.06	~1	~1	29	10.8
6/25/19 8:50	Grab	18.3	**0.45**	7.15	197	**372**	281	0.68	1.5	<0.20	<0.06	~2	~2	91	9.1
7/23/19 11:05	Grab	**20.7**	**0.29**	6.87	182	**281**	158	0.46	1.6	<0.20	<0.06	~3	~2	80	8.7
8/22/19 11:33	Grab	19.4	**0.64**	7.11	190	**152**	111	0.38	1.1	<0.20	<0.06	<2	<2	93	9.7
9/24/19 8:55	Grab	17.1	**0.45**	7.22	181	96	69	0.18	1.1	1.54	<0.06	<1	<1	118	11.8
10/24/19 8:58	Grab	7.4	5.82			50	~23	0.2	0.92	<0.20	<0.06	~2	~2	93	9.1

Temp. = temperature in degrees Celsius
D.O. = dissolved oxygen
Sp. Cond. = specific conductance
TP = total phosphorus
TDP = total dissolved phosphorus
NH4-N = ammonia-nitrogen
NO3-N = nitrate-nitrogen
NO2-N = nitrite-nitrogen
TSS = total suspended solids
TVS = total volatile solids
MPN = most probable number

Bone Lake Outlet

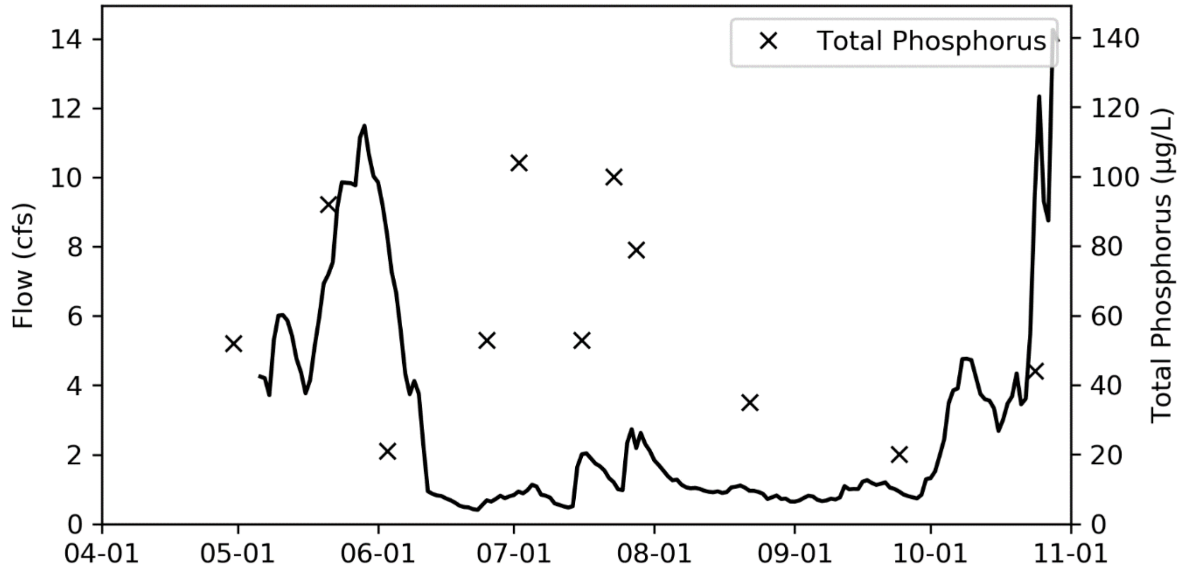


Figure 11. Daily flow and total phosphorus concentration by sample date at Bone Lake Outlet (2019)

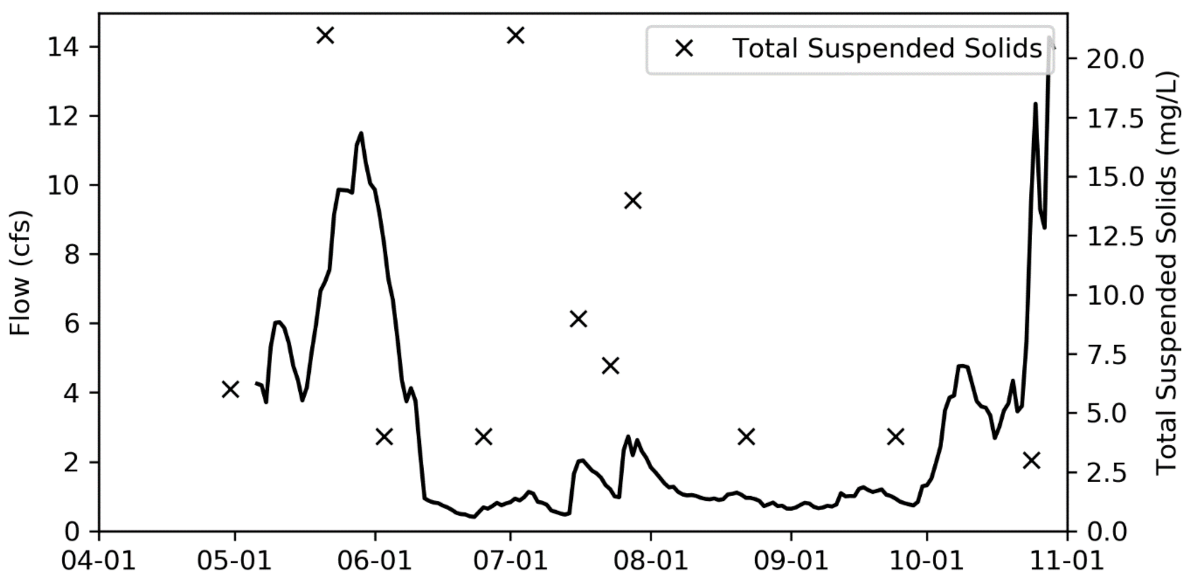


Figure 12. Daily flow and total suspended solids concentration by sample date at Bone Lake Outlet (2019)

Table 12. Bone Lake Outlet (S004-463) 2019 Stream Water Chemistry Sample Results

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

Date/Time	Collection	Temp. (deg. C)	D.O. (mg/L)	pH	Sp. Cond. (uS/cm)	TP (µg/L)	TDP (µg/L)	NH4-N (mg/L)	TKN (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TSS (mg/L)	TVS (mg/L)	*E. coli* (MPN/100mL)	Chloride (mg/L)
MN Class 2B Standards		< 20	< 5	6.5-9.5		< 100						> 30		< 126	< 230
3/27/19 15:45	Grab	3.6	6.32	7.33	251	**143**	50	0.38	1.4	0.14	<0.03	4	3		14.4
4/30/19 10:10	Grab	9.7	12.7	8.53	301	52	<20	~0.02	1	<0.20	<0.06	6	5	<1	14.9
5/21/19 11:49	Grab					92	<20	<0.02	1.4	<0.20	<0.06	21	13		13.1
6/3/19 9:40	Grab	18.4	9.07	8.25	267	~21	<20	~0.03	0.87	<0.20	<0.06	4	~2	5	15
6/25/19 9:20	Grab	**21.1**	5.25	8.06	303	53	~34	~0.05	0.85	<0.20	<0.06	4	3	8	20.1
7/3/19 7:00	Automated Composite					104	<20	0.1	1.5	<0.20	<0.06	21	13		15.3
7/17/19 10:59	Automated Composite					53	<20	<0.02	0.96	<0.20	<0.06	9	7		14.4
7/23/19 11:15	Grab	**25.5**	7.9	8.87	286	100	<20	<0.02	1	<0.20	<0.06	7	7	10	14.9
7/29/19 11:05	Automated Composite					79	<20	~0.04	1.4	<0.20	<0.06	14	11		14.4
8/22/19 11:16	Grab	**23.7**	7.68	8.59	283	~35	<20	<0.02	0.9	<0.20	<0.06	~4	~4	9	16.1
9/24/19 9:05	Grab	19.5	8.09	8.26	288	<20	<20	<0.02	0.86	<0.20	<0.06	~4	~4	30	15
10/24/19 8:46	Grab	8.7	8.19	8.07	249	~44	<20	0.24	1	<0.20	<0.06	3	~2	44	13.4

Temp. = temperature in degrees Celsius
D.O. = dissolved oxygen
Sp. Cond. = specific conductance
TP = total phosphorus
TDP = total dissolved phosphorus
NH4-N = ammonia-nitrogen
NO3-N = nitrate-nitrogen
NO2-N = nitrite-nitrogen
TSS = total suspended solids
TVS = total volatile solids
MPN = most probable number

Forest Lake Outlet

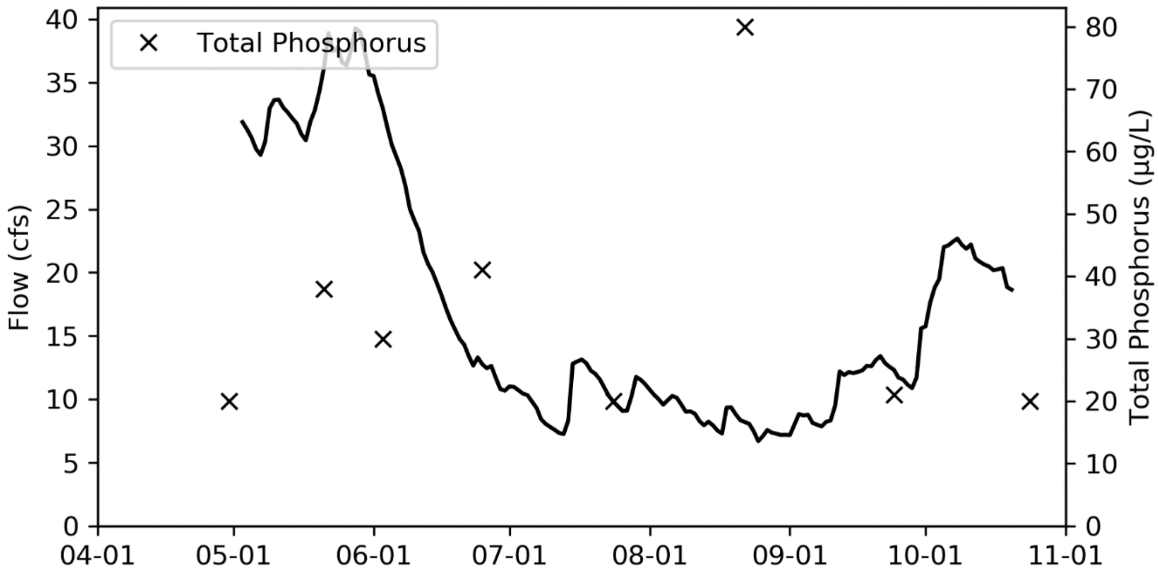


Figure 13. Daily flow and total phosphorus concentration by sample date at Forest Lake Outlet (2019)

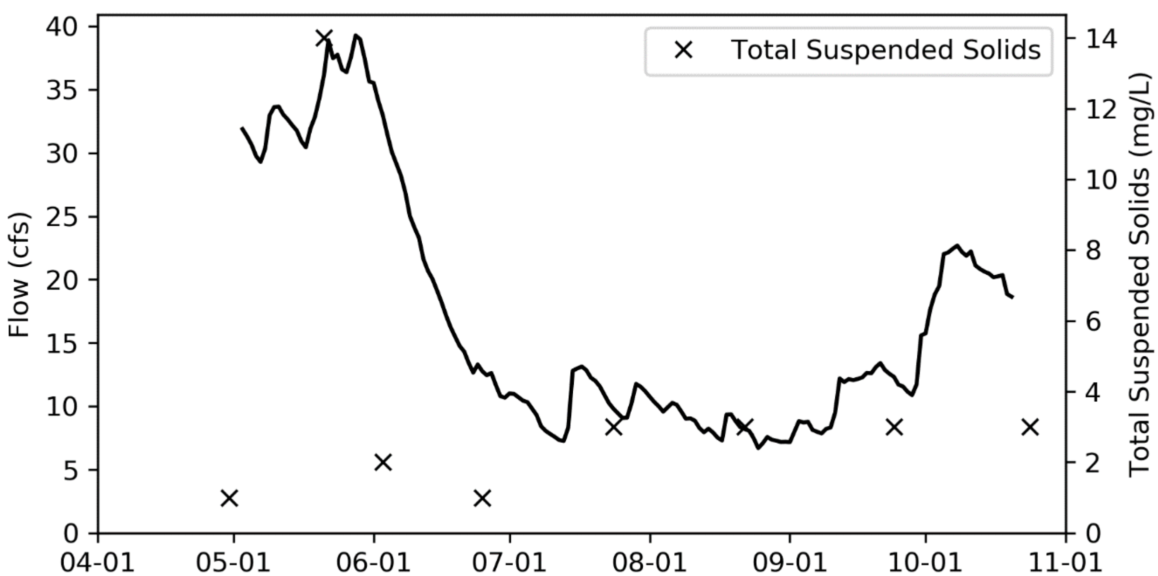


Figure 14. Daily flow and total suspended solids concentration by sample date at Forest Lake Outlet (2019)

Table 13. Forest Lake Outlet (S004-466) 2019 Stream Water Chemistry Sample Results

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

Date/Time	Collection	Temp. (deg. C)	D.O. (mg/L)	pH	Sp. Cond. (uS/cm)	TP (µg/L)	TDP (µg/L)	NH4-N (mg/L)	TKN (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TSS (mg/L)	TVS (mg/L)	*E. coli* (MPN/100mL)	Chloride (mg/L)
MN Class 2B Standards		< 20	< 5	6.5-9.5		< 100						> 30		< 126	< 230
3/27/19 13:35	Grab	6.2	10.06	8.15	339	~36	<20	0.13	0.73	0.08	<0.03	~2	~2		30.3
4/30/19 8:30	Grab	9.5	10.6	8.52	362	<20	<20	~0.03	0.68	<0.20	<0.06	~1	~1	1	29.1
5/23/19 4:29	Automated Composite					~38	~20	~0.05	0.9	<0.20	<0.06	14	5		27.5
6/3/19 11:25	Grab	18.7	9.88	8.72	327	~30	<20	<0.02	0.65	<0.20	<0.06	~2	~1	7	29.3
6/25/19 11:10	Grab	**21.8**	10.1	8.99	336	~41	<20	<0.02	0.56	<0.20	<0.06	~1	~1	69	28
7/24/19 8:45	Grab	**23.5**	7.1			<20	<20	<0.02	0.59	<0.20	<0.06	3	~2	18	30.3
8/22/19 9:14	Grab	**21.3**	7.67	8.43	350	80	<20	~0.04	0.6	<0.20	<0.06	~3	~3	101	29.1
9/24/19 11:00	Grab	19.6	8.4	8.45	341	~21	<20	~0.04	0.68	0.36	<0.06	3	~2	102	28.9
10/24/19 11:25	Grab	8.5	10.22	8.31	356	<20	~26	0.07	0.68	<0.20	<0.06	3	~2	3	28

Temp. = temperature in degrees Celsius
D.O. = dissolved oxygen
Sp. Cond. = specific conductance
TP = total phosphorus
TDP = total dissolved phosphorus
NH4-N = ammonia-nitrogen
NO3-N = nitrate-nitrogen
NO2-N = nitrite-nitrogen
TSS = total suspended solids
TVS = total volatile solids
MPN = most probable number

Little Comfort Inlet (at Itasca Aveue)

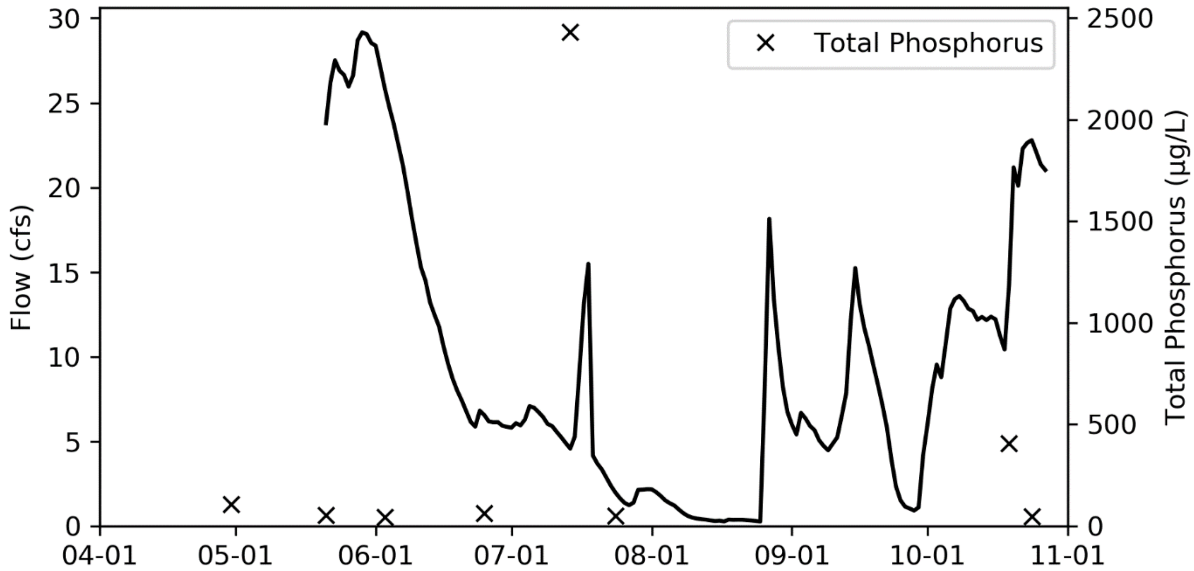


Figure 15. Daily flow and total phosphorus concentration by sample date at Little Comfort Inlet (at Itasca Avenue, 2019)

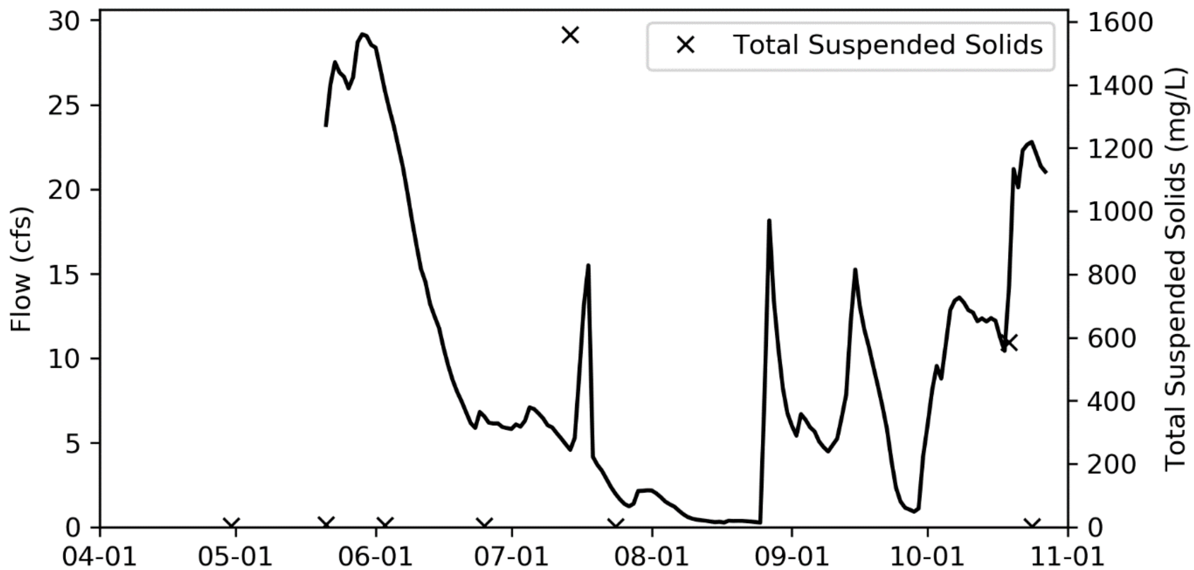


Figure 16. Daily flow and total suspended solids concentration by sample date at Little Comfort Inlet (at Itasca Avenue, 2019)

Table 14. Little Comfort Lake Inlet at Itasca Avenue (S001-232) 2019 Stream Water Chemistry Sample Results

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

Date/Time	Collection	Temp. (deg. C)	D.O. (mg/L)	pH	Sp. Cond. (uS/cm)	TP (µg/L)	TDP (µg/L)	NH4-N (mg/L)	TKN (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TSS (mg/L)	TVS (mg/L)	*E. coli* (MPN/100mL)	Chloride (mg/L)
MN Class 2B Standards		< 20	< 5	6.5-9.5		< 100						> 30		< 126	< 230
3/27/19 15:10	Grab	4.1	5.88	7.23	236	**180**	73	0.42	1.4	0.12	<0.03	14	~8		14.7
4/30/19 9:40	Grab	9	10.38	7.89	275	**107**	<20	~0.02	0.76	<0.20	<0.06	4	3	6	16.1
5/21/19 10:47	Grab					53	~35	<0.02	0.88	<0.20	<0.06	7	5		14.4
6/3/19 10:05	Grab	18.4	7.47	7.89	283	~44	<20	~0.02	0.88	<0.20	<0.06	6	4	29	15.2
6/25/19 9:40	Grab	19.4	6.28	7.87	344	64	~33	0.11	0.9	<0.20	<0.06	4	~2	**156**	15
7/15/19 23:43	Automated Composite					**2,430**	57	0.08	17	<0.20	<0.06	**1560**	722		9.3
7/24/19 10:10	Grab	**22**	**4.01**			~49	<20	0.12	0.95	<0.20	0.07	~2	~2	50	14.6
10/19/19 19:35	Automated Composite					**405**	~21	~0.05	4.3	0.34	<0.06	585	130		13.5
10/24/19 9:19	Grab	7.4	8.08	7.93	352	~47	<20	0.18	0.9	<0.20	<0.06	~2	~1	**517**	13.3

Temp. = temperature in degrees Celsius
D.O. = dissolved oxygen
Sp. Cond. = specific conductance
TP = total phosphorus
TDP = total dissolved phosphorus
NH4-N = ammonia-nitrogen
NO3-N = nitrate-nitrogen
NO2-N = nitrite-nitrogen
TSS = total suspended solids
TVS = total volatile solids
MPN = most probable number

Little Comfort Inlet (at Heath Ave)

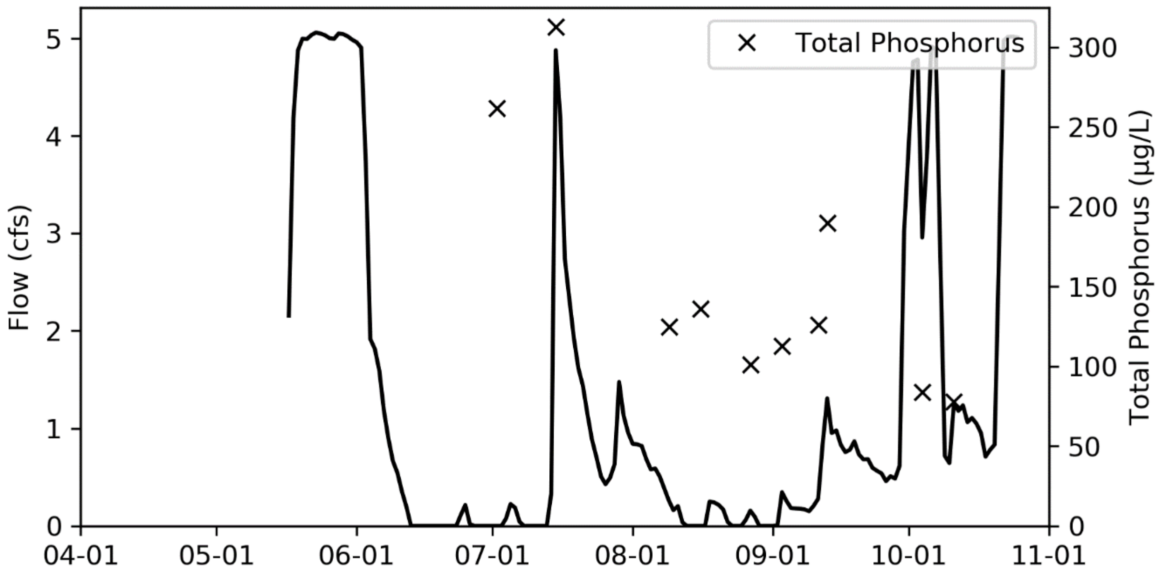


Figure 17. Daily flow and total phosphorus concentration by sample date at Little Comfort Inlet (at Heath Avenue, 2019)

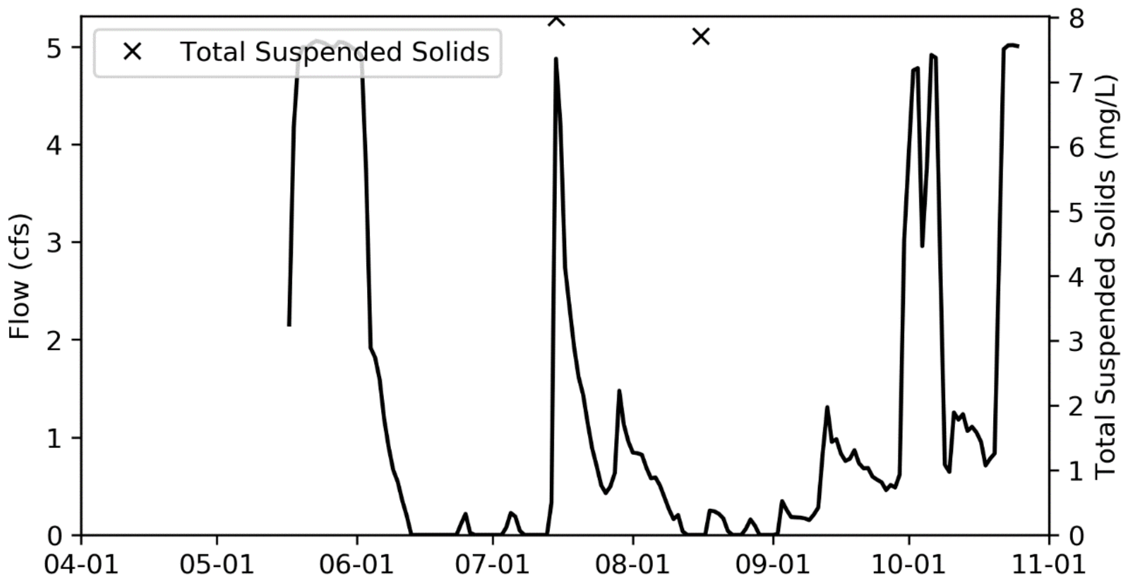


Figure 18. Daily flow and total suspended solids concentration by sample date at Little Comfort Inlet (at Heath Avenue, 2019)

Table 15. Little Comfort Lake Inlet at Heath Avenue (EOR) 2019 Stream Water Chemistry Sample Results

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

Sample Date	TSS (mg/L)	TP (µg/L)
MN Class 2B Standard	**< 30**	**< 100**
7/2/2019		**262**
7/15/2019	8	**313**
8/9/2019		**125**
8/16/2019	7.71	**136**
8/27/2019		101
9/3/2019		**113**
9/11/2019		**126**
9/13/2019		**190**
10/4/2019		84
10/11/2019		78

Sunrise River at Greenway Ave

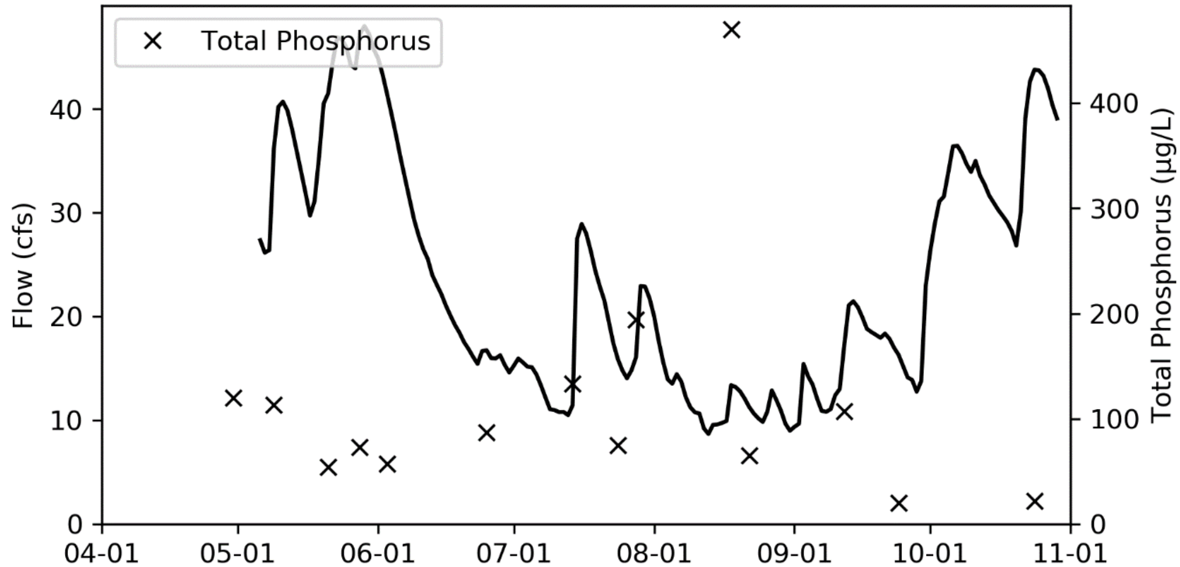


Figure 19. Daily flow and total phosphorus concentration by sample date at Sunrise River (at Greenway Avenue, 2019)

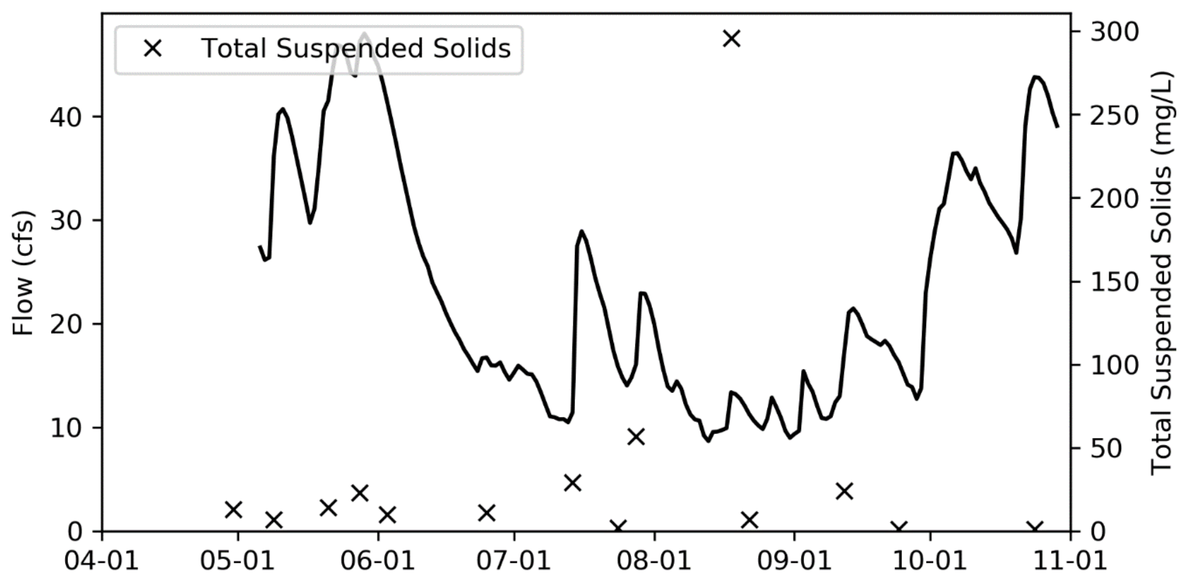


Figure 20. Daily flow and total suspended solids concentration by sample date at Sunrise River (at Greenway Avenue, 2019)

Table 16. Sunrise River at Greenway Avenue (S004-926) 2019 Stream Water Chemistry Sample Results

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

Date/Time	Collection	Temp. (deg. C)	D.O. (mg/L)	pH	Sp. Cond. (uS/cm)	TP (µg/L)	TDP (µg/L)	NH4-N (mg/L)	TKN (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TSS (mg/L)	TVS (mg/L)	*E. coli* (MPN/100mL)	Chloride (mg/L)
MN Class 2B Standards		< 20	< 5	6.5-9.5		< 100						> 30		< 126	< 230
3/27/19 14:00	Grab	5.9	9.8	7.84	411	85	50	0.27	1	0.12	<0.03	4	~2		56.8
4/30/19 8:45	Grab	8.8	8.94	7.86	450	**120**	<20	~0.05	1	<0.20	<0.06	13	5	6	49.9
5/9/19 10:51	Automated Composite					**113**	119	~0.02	1.2	0.26	<0.06	7	4		65.8
5/21/19 9:12	Grab					54	<20	~0.04	1	<0.20	<0.06	14	6		50.8
5/28/19 20:42	Automated Composite					73	<20	~0.02	1.1	<0.20	<0.06	23	8		42.5
6/3/19 11:10	Grab	17.6	7.37	7.94	385	57	<20	<0.02	0.88	<0.20	<0.06	10	4	36	43
6/25/19 10:50	Grab	**20.5**	5.82	7.97	437	87	~33	0.12	0.97	<0.20	<0.06	11	4	**129**	49.6
7/15/19 23:28	Automated Composite					**133**	60	0.1	1.7	<0.20	<0.06	29	10		43.4
7/24/19 9:00	Grab	**21.9**	**3.45**			75	~38	~0.03	0.87	<0.20	<0.06	~2	~2	65	45.3
7/30/19 8:57	Automated Composite					**194**	~44	~0.03	1.7	<0.20	<0.06	**57**	19		54
8/18/19 16:05	Automated Composite					47	~41	~0.02	4.7	<0.20	<0.06	**296**	84		53
8/22/19 9:36	Grab	**20.1**	**4.23**	7.8	407	65	<20	<0.02	0.77	<0.20	<0.06	7	~4	**249**	39.1
9/13/19 9:56	Automated Composite					**107**	53	0.14	1.3	<0.20	<0.06	24	10		60.2
9/24/19 10:40	Grab	18.3	6.9	7.95	414	<20	<20	~0.05	0.71	<0.20	<0.06	~1	~1	104	43.1
10/24/19 10:54	Grab	6.8	7.45	8.15	400	~22	~32	<0.02	0.8	<0.20	<0.06	~1	~1	50	39.9

Temp. = temperature in degrees Celsius
D.O. = dissolved oxygen
Sp. Cond. = specific conductance
TP = total phosphorus
TDP = total dissolved phosphorus
NH4-N = ammonia-nitrogen
NO3-N = nitrate-nitrogen
NO2-N = nitrite-nitrogen
TSS = total suspended solids
TVS = total volatile solids
MPN = most probable number

Sunrise River (at 256th St.)

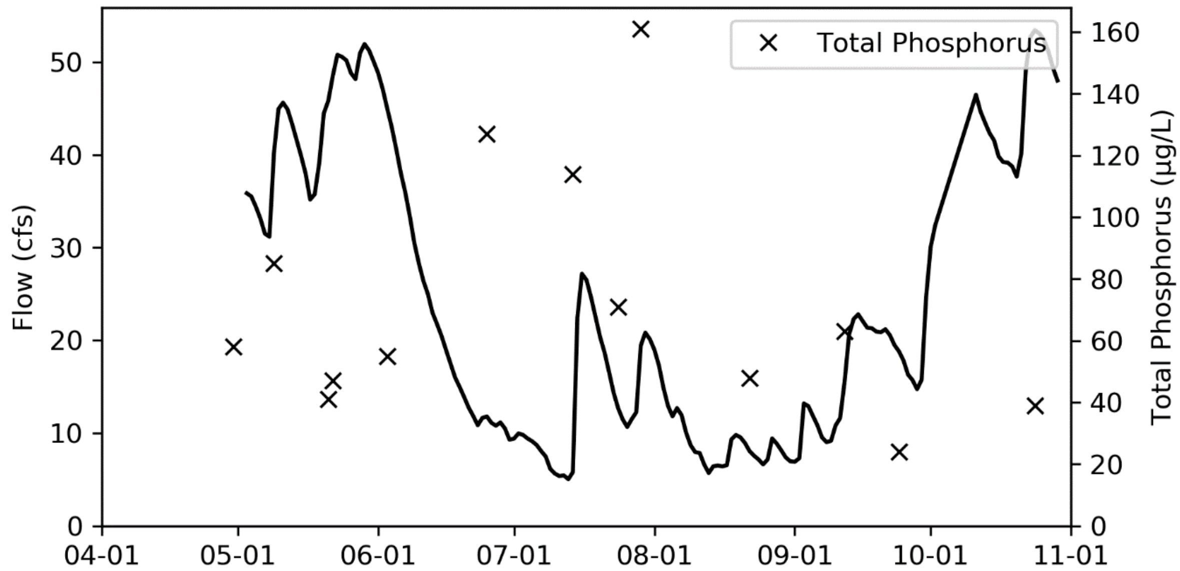


Figure 21. Daily flow and total phosphorus concentration by sample date at Sunrise River (at 256th St., 2019)

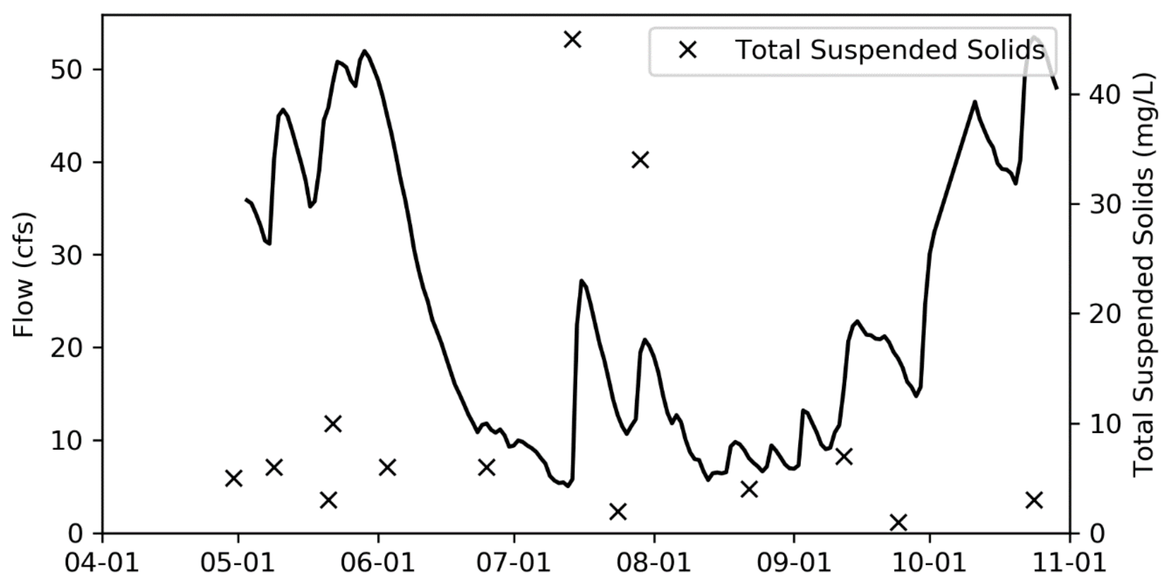


Figure 22. Daily flow and total suspended solids concentration by sample date at Sunrise River (at 256th St., 2019)

Table 17. Sunrise River at 256th St. (S005-161) 2019 Stream Water Chemistry Sample Results

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

Date/Time	Collection	Temp. (deg. C)	D.O. (mg/L)	pH	Sp. Cond. (uS/cm)	TP (µg/L)	TDP (µg/L)	NH4-N (mg/L)	TKN (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TSS (mg/L)	TVS (mg/L)	*E. coli* (MPN/100mL)	Chloride (mg/L)
MN Class 2B Standards		< 20	< 5	6.5-9.5		< 100						> 30		< 126	< 230
3/27/19 14:05	Grab	4.5	8.42	7.5	390	99	51	0.27	1.1	0.16	<0.03	3	3		56
4/30/19 8:55	Grab	8.1	7.27	7.6	437	58	<20	0.06	0.98	<0.20	<0.06	5	~2	17	47.2
5/9/19 16:27	Automated Composite					85	76	<0.02	0.99	0.22	<0.06	6	3		62.4
5/21/19 9:46	Grab					~41	<20	~0.04	0.91	<0.20	<0.06	3	~2		49.8
5/23/19 9:05	Automated Composite					~47	<20	~0.05	1.1	<0.20	<0.06	10	3		51.6
6/3/19 11:00	Grab	17.8	5.05	7.63	388	55	<20	<0.02	0.91	<0.20	<0.06	6	3	68	42.3
6/25/19 10:35	Grab	20.7	6.45	7.76	440	**127**	~35	0.13	1.7	<0.20	<0.06	6	3	**172**	48.8
7/16/19 0:26	Automated Composite					**114**	~36	0.07	1.4	<0.20	<0.06	**45**	18		39
7/24/19 9:15	Grab	**22.3**	**2.73**			71	~46	~0.05	0.91	<0.20	<0.06	~2	~1	41	44.4
7/30/19 9:18	Automated Composite					**161**	54	~0.03	1.4	<0.20	<0.06	34	13		55.7
8/22/19 9:53	Grab	20.2	**4.91**	7.67	413	~48	<20	~0.02	0.76	<0.20	<0.06	~4	~4	93	43.5
9/13/19 7:17	Automated Composite					63	~34	~0.03	0.98	<0.20	<0.06	7	3		57
9/24/19 10:20	Grab	18.1	5.3	7.7	420	~24	<20	~0.04	0.72	<0.20	<0.06	~1	~1	105	44.3
10/24/19 10:39	Grab	7.5	6.3	7.77	397	~39	<20	<0.02	0.74	<0.20	<0.06	3	~2	64	37.3

Temp. = temperature in degrees Celsius
D.O. = dissolved oxygen
Sp. Cond. = specific conductance
TP = total phosphorus
TDP = total dissolved phosphorus
NH4-N = ammonia-nitrogen
NO3-N = nitrate-nitrogen
NO2-N = nitrite-nitrogen
TSS = total suspended solids
TVS = total volatile solids
MPN = most probable number

Big Comfort Outlet

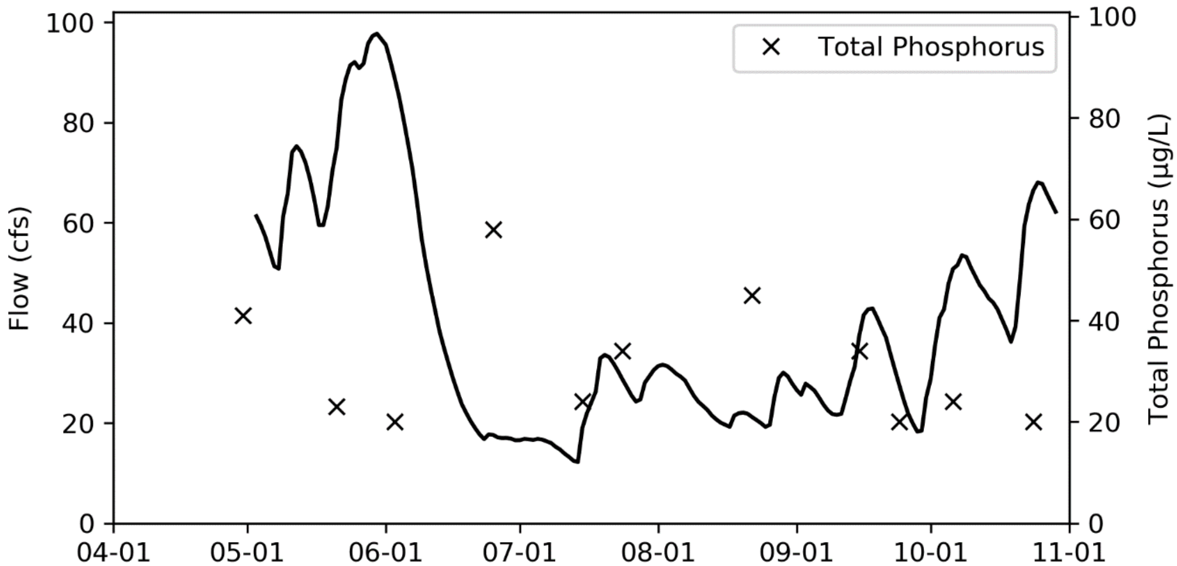


Figure 23. Daily flow and total phosphorus concentration by sample date at the Big Comfort Lake Outlet (2019)

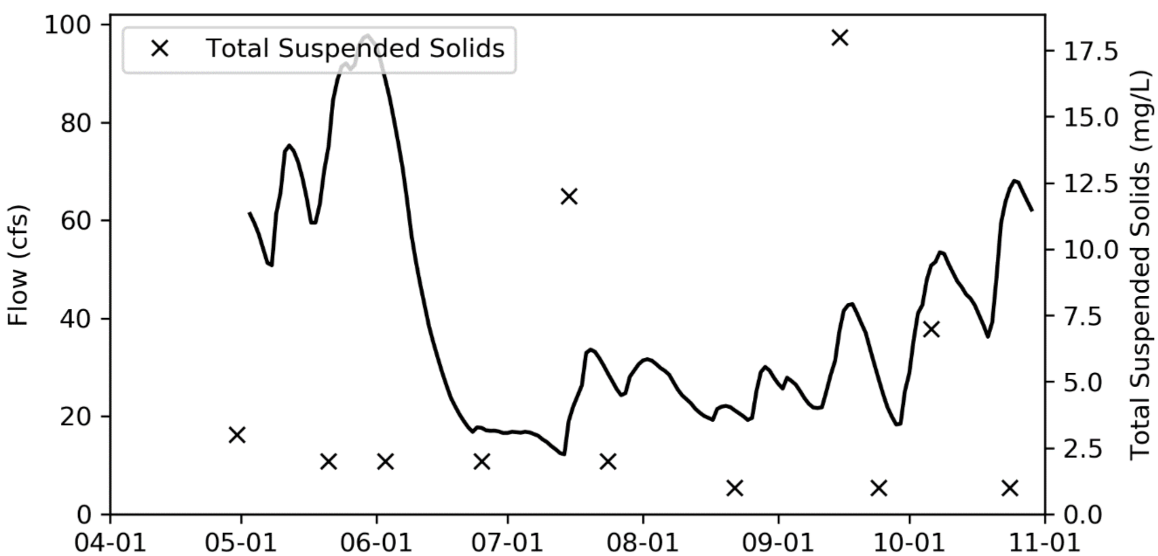


Figure 24. Daily flow and total suspended solids concentration by sample date at the Big Comfort Lake Outlet (2019)

Table 18. Big Comfort Outlet (S003-569) 2019 Stream Water Chemistry Sample Results

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

Date/Time	Collection	Temp. (deg. C)	D.O. (mg/L)	pH	Sp. Cond. (uS/cm)	TP (µg/L)	TDP (µg/L)	NH4-N (mg/L)	TKN (mg/L)	NO3-N (mg/L)	NO2-N (mg/L)	TSS (mg/L)	TVS (mg/L)	*E. coli* (MPN/100mL)	Chloride (mg/L)
MN Class 2B Standards		< 20	< 5	6.5-9.5		< 100						> 30		< 126	< 230
3/27/19 14:30	Grab	4.5	8.15	7.56	426	97	~48	0.28	1.1	0.19	<0.03	3	3		55.1
4/30/19 9:25	Grab	9.2	10.97	8.05	418	~41	<20	<0.02	0.88	<0.20	<0.06	3	3	8	41.2
5/21/19 10:15	Grab					~23	<20	<0.02	0.78	<0.20	<0.06	~2	~1		36.2
6/3/19 10:25	Grab	18.7	8.24	8.03	382	~20	<20	~0.02	0.8	<0.20	<0.06	~2	~1	18	37.1
6/25/19 10:00	Grab	20.1	**4.34**	7.82	412	58	~25	0.13	0.87	<0.20	<0.06	~2	~1	38	33.2
7/15/19 19:00	Automated Composite					~24	~42	~0.02	0.86	<0.20	<0.06	12	7		32.9
7/24/19 9:50	Grab	**23.6**	**4.15**			~34	<20	<0.02	0.91	<0.20	<0.06	~2	~2	26	35.5
8/22/19 10:36	Grab	**21.8**	**3.34**	7.77	434	~45	<20	~0.04	0.84	<0.20	<0.06	~1	~1	12	37
9/16/19 2:56	Automated Composite					~34	<20	<0.02	0.99	<0.20	<0.06	18	11		37
9/24/19 9:35	Grab	18.8	5.95	8.06	426	<20	<20	~0.05	0.74	<0.20	<0.06	~1	~1	4	37.4
10/7/19 23:47	Automated Composite					~24	~25	0.16	1	<0.20	<0.06	7	4		38
10/24/19 9:49	Grab	8.7	6.95	7.92	437	<20	~22	0.3	1	<0.20	<0.06	~1	~1	10	36.5

Temp. = temperature in degrees Celsius
D.O. = dissolved oxygen
Sp. Cond. = specific conductance
TP = total phosphorus
TDP = total dissolved phosphorus
NH4-N = ammonia-nitrogen
NO3-N = nitrate-nitrogen
NO2-N = nitrite-nitrogen
TSS = total suspended solids
TVS = total volatile solids
MPN = most probable number

APPENDIX C – 2019 LAKE WATER QUALITY DATA BY SAMPLE DATE

Table 19. 2019 lake water quality data by sample date

Lake Name	Date Time	Depth (m)	Secchi Depth (m)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Bone	5/2/2019 11:23	0	1.37	22	1	0.042
Bone	5/14/2019 11:26	0	2.13	8	0.87	0.024
Bone	5/28/2019 11:28	0	2.13	1	0.95	0.041
Bone	6/12/2019 10:08	0	2.13	9.8	0.76	0.024
Bone	6/27/2019 8:45	0	1.83	11	0.89	0.023
Bone	7/9/2019 10:07	0	1.52	15	0.92	0.028
Bone	7/23/2019 10:44	0	1.37	26	0.99	0.035
Bone	8/8/2019 10:53	0	0.91	40	1.3	0.03
Bone	8/21/2019 9:12	0	1.37	18	1.2	0.029
Bone	9/5/2019 8:55	0	1.37	26	1	0.03
Bone	9/16/2019 14:54	0	1.68	21	1.4	0.033
Bone	10/3/2019 10:49	0	1.37	18	1.3	0.033
Bone	10/14/2019 10:57	0	1.98	20	1.5	0.038
Comfort	5/2/2019 12:04	0	1.83	17	0.9	0.043
Comfort	5/14/2019 12:05	0	3.35	5	0.93	0.03
Comfort	5/28/2019 12:08	0	3.35	4.4	0.77	0.019
Comfort	6/13/2019 11:13	0	2.29	9.1	0.96	0.057
Comfort	6/27/2019 9:19	0	1.83	13	0.9	0.022
Comfort	7/11/2019 10:30	0	1.68	21	1.1	0.024
Comfort	7/11/2019 10:35	0		21	1.1	0.02
Comfort	7/23/2019 11:24	0	1.52	15	1	0.03
Comfort	8/8/2019 11:47	0	1.22	27	1.1	0.033
Comfort	8/20/2019 10:56	0	1.37	20	1.1	0.019
Comfort	9/3/2019 13:56	0	1.68	15	0.95	0.023
Comfort	9/17/2019 8:59	0	1.83	19	1	0.03
Comfort	10/3/2019 11:24	0	1.98	14	0.93	0.034

Lake Name	Date Time	Depth (m)	Secchi Depth (m)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Comfort	10/14/2019 11:31	0	1.52	6.6	1.4	0.053
Elwell	5/1/2019 9:35	0	1.07	9.1	0.69	0.054
Elwell	5/16/2019 8:50	0	1.98	4.3	0.56	0.027
Elwell	5/29/2019 13:55	0	1.68	1.8	0.5	0.026
Elwell	6/10/2019 9:58	0	1.52	2.2	0.5	0.03
Elwell	6/26/2019 11:51	0	1.14	1.9	0.62	0.029
Elwell	7/9/2019 10:49	0	0.3	5.7	0.74	0.037
Elwell	7/23/2019 14:01	0	0.46	4.1	0.64	0.039
Elwell	8/7/2019 9:26	0	0.15	51	1.2	0.11
Elwell	8/20/2019 13:14	0	0.61	13	0.76	0.048
Elwell	9/4/2019 11:52	0	0.76	11	0.75	0.044
Elwell	9/17/2019 12:30	0	0.61	8.8	0.74	0.043
Elwell	9/30/2019 10:51	0	0.61	9.1	0.71	0.056
Elwell	10/14/2019 13:41	0	1.52	2.4	0.52	0.024
Forest Lake (East Basin)	5/2/2019 14:09	0	1.98	7.9	0.68	0.027
Forest Lake (East Basin)	5/14/2019 14:13	0	4.57	1.7	0.5	0.012
Forest Lake (East Basin)	5/28/2019 14:37	0	3.96	2.7	0.59	0.017
Forest Lake (East Basin)	6/12/2019 11:05	0	4.42	3	0.6	0.026
Forest Lake (East Basin)	6/27/2019 9:56	0	3.66	4.7	0.65	0.028
Forest Lake (East Basin)	7/11/2019 11:11	0	2.74	8.8	0.79	0.031
Forest Lake (East Basin)	7/23/2019 13:50	0	1.83	13	0.67	0.028
Forest Lake (East Basin)	8/8/2019 14:14	0	1.37	29	0.9	0.028
Forest Lake (East Basin)	8/21/2019 9:48	0	1.37	34	0.9	0.039
Forest Lake (East Basin)	9/5/2019 9:51	0	1.22	24	0.86	0.047
Forest Lake (East Basin)	9/17/2019 9:49	0	1.22	25	0.89	0.043
Forest Lake (East Basin)	10/3/2019 12:41	0	2.59	11	0.72	0.034
Forest Lake (East Basin)	10/14/2019 13:34	0	6.1	2.2	0.75	0.036
Forest Lake (Middle Basin)	5/2/2019 14:25	0	2.9	5.4	0.68	0.016
Forest Lake (Middle Basin)	5/14/2019 14:28	0	3.96	1.4	0.57	0.021

Lake Name	Date Time	Depth (m)	Secchi Depth (m)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Forest Lake (Middle Basin)	5/28/2019 14:21	0	5.03	3.1	0.56	0.016
Forest Lake (Middle Basin)	6/12/2019 11:27	0	4.57	1.3	0.63	0.023
Forest Lake (Middle Basin)	6/27/2019 10:10	0	3.66	7.9	0.92	0.097
Forest Lake (Middle Basin)	7/11/2019 11:26	0	2.44	9.2	0.79	0.039
Forest Lake (Middle Basin)	7/23/2019 13:33	0	1.68	14	0.77	0.044
Forest Lake (Middle Basin)	8/8/2019 13:57	0	1.22	28	0.95	0.103
Forest Lake (Middle Basin)	8/21/2019 10:03	0	1.22	34	1.6	0.05
Forest Lake (Middle Basin)	9/5/2019 10:06	0	1.22	32	0.99	0.091
Forest Lake (Middle Basin)	9/17/2019 10:08	0	1.22	31	0.96	0.041
Forest Lake (Middle Basin)	10/3/2019 12:57	0	2.13	10	0.92	0.036
Forest Lake (Middle Basin)	10/14/2019 13:52	0	4.27	3.1	0.86	0.026
Forest Lake (West Basin)	5/2/2019 13:26	0	3.35	3	0.66	0.02
Forest Lake (West Basin)	5/14/2019 13:36	0	5.49	1.4	0.65	0.016
Forest Lake (West Basin)	5/28/2019 13:47	0	3.66	2.5	0.56	0.017
Forest Lake (West Basin)	6/12/2019 12:06	0	3.66	1.9	0.55	0.013
Forest Lake (West Basin)	7/11/2019 11:41	0	2.13	5.9	0.75	0.023
Forest Lake (West Basin)	7/23/2019 13:17	0	1.52	8.3	0.71	0.024
Forest Lake (West Basin)	8/8/2019 13:33	0	1.98	6.1	0.81	0.03
Forest Lake (West Basin)	8/21/2019 10:21	0	1.68	13	0.8	0.038
Forest Lake (West Basin)	9/5/2019 10:44	0	1.83	9	0.7	0.026
Forest Lake (West Basin)	9/17/2019 10:25	0	2.29	9.2	0.68	0.025
Forest Lake (West Basin)	10/3/2019 13:10	0	2.13	8.8	0.76	0.018
Forest Lake (West Basin)	10/14/2019 14:05	0	2.9	6.1	0.72	0.019
Fourth	5/2/2019 9:38	0	1.22	7.6	0.85	0.062
Fourth	5/16/2019 10:44	0	1.83	4.1	1.3	0.055
Fourth	5/30/2019 9:01	0	1.52	1.2	0.5	0.041
Fourth	6/10/2019 11:33	0	1.22	4	0.71	0.08
Fourth	6/26/2019 9:10	0	1.07	2.6	0.84	0.049
Fourth	7/10/2019 9:35	0	0.76	3.6	0.96	0.087

Lake Name	Date Time	Depth (m)	Secchi Depth (m)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Fourth	7/24/2019 8:42	0	0.15	14	0.95	0.203
Fourth	8/7/2019 11:09	0	0.46	3.9	0.79	0.031
Fourth	8/20/2019 11:43	0	0.76	15	0.85	0.06
Fourth	9/5/2019 10:02	0	0.46	13	0.94	0.057
Fourth	9/17/2019 13:55	0	0.61	170	1.5	0.14
Fourth	9/30/2019 13:34	0	0.76	36	1	0.08
Keewahtin	5/1/2019 8:53	0	3.66	2.5	0.52	0.014
Keewahtin	5/15/2019 11:47	0	5.79	3.2	0.41	0.015
Keewahtin	5/29/2019 11:52	0	5.94	1	0.42	0.017
Keewahtin	6/11/2019 10:46	0	5.18	1.2	0.46	0.036
Keewahtin	6/26/2019 12:21	0	2.9	2.8	0.45	0.009
Keewahtin	7/9/2019 10:19	0	3.2	3.4	0.56	0.015
Keewahtin	7/23/2019 13:24	0	3.66	1.9	0.49	0.013
Keewahtin	8/7/2019 8:44	0	3.35	2.3	0.5	0.015
Keewahtin	8/20/2019 14:40	0	3.81	2.8	0.52	0.016
Keewahtin	9/4/2019 13:39	0	4.27	5.3	0.44	0.003
Keewahtin	9/17/2019 11:44	0	2.74	4.5	0.48	0.011
Keewahtin	9/30/2019 10:23	0	3.05	4.7	0.5	0.02
Keewahtin	10/14/2019 11:15	0	3.96	4.2	0.47	0.009
Lendt	5/1/2019 11:24	0	1.52	1.9	0.44	0.014
Lendt	5/16/2019 11:08	0	1.52	1.2	0.42	0.011
Lendt	5/30/2019 9:26	0	1.6	1	0.42	0.012
Lendt	6/10/2019 12:08	0	1.37	1	0.44	0.009
Lendt	6/26/2019 9:33	0	1.52	2.4	0.56	0.014
Lendt	7/10/2019 9:12	0	1.37	2.6	0.55	0.017
Lendt	7/24/2019 9:12	0	1.37	1.9	0.54	0.018
Lendt	8/7/2019 11:35	0	1.07	2.4	0.56	0.02
Lendt	8/20/2019 11:22	0	1.22	2.1	0.55	0.017
Lendt	9/5/2019 9:43	0	1.37	3	0.49	0.016

Lake Name	Date Time	Depth (m)	Secchi Depth (m)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Lendt	9/17/2019 13:38	0	1.37	13	0.52	0.018
Lendt	9/30/2019 13:16	0	1.52	13	0.56	0.029
Lendt	10/16/2019 10:24	0	1.68	3.2	0.43	0.019
Little Comfort	5/1/2019 14:07	0	1.22	17	0.84	0.05
Little Comfort	5/16/2019 12:07	0	1.52	5.2	0.78	0.04
Little Comfort	5/30/2019 10:27	0	2.29	1	0.8	0.056
Little Comfort	6/11/2019 11:45	0	1.68	15	0.95	0.074
Little Comfort	6/26/2019 14:51	0	1.37	13	0.94	0.037
Little Comfort	7/10/2019 10:33	0	1.68	19	0.96	0.041
Little Comfort	7/24/2019 10:40	0	0.61	30	1.2	0.076
Little Comfort	8/7/2019 13:48	0	1.07	35	1.4	0.113
Little Comfort	8/21/2019 11:45	0	1.45	36	1.2	0.039
Little Comfort	9/5/2019 10:31	0	1.68	27	1	0.029
Little Comfort	9/18/2019 9:25	0	1.37	41	1.1	0.039
Little Comfort	10/3/2019 9:11	0	1.98	13	0.88	0.035
Little Comfort	10/16/2019 11:17	0	1.22	5.3	1.4	0.103
Moody	5/1/2019 13:15	0	1.07	22	1.1	0.074
Moody	5/16/2019 10:05	0	2.13	2	0.92	0.059
Moody	5/30/2019 8:18	0	1.37	1	0.93	0.059
Moody	6/11/2019 10:03	0	0.46	60	1.6	0.075
Moody	6/26/2019 14:02	0	0.61	45	1.5	0.083
Moody	7/10/2019 9:57	0	0.53	63	1.8	0.067
Moody	7/24/2019 9:58	0	0.23	45	1.7	0.109
Moody	8/7/2019 13:00	0	0.46	19	1.6	0.064
Moody	8/21/2019 11:09	0	0.3	46	1.6	0.057
Moody	9/5/2019 8:52	0	1.22	22	1.5	0.037
Moody	9/17/2019 14:14	0	0.61	54	1.5	0.04
Moody	10/3/2019 8:27	0	0.76	23	1.4	0.039
Moody	10/16/2019 10:43	0	1.07	14	1.8	0.045

Lake Name	Date Time	Depth (m)	Secchi Depth (m)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Shields	5/1/2019 8:19	0	1.22	24	1.4	0.084
Shields	5/15/2019 11:18	0	2.13	8	1	0.049
Shields	5/29/2019 12:30	0	2.9	3.1	1.1	0.066
Shields	6/11/2019 11:14	0	1.68	25	1.3	0.102
Shields	6/26/2019 8:20	0	0.61	88	1.9	0.15
Shields	7/9/2019 9:47	0	0.46	52	2.3	0.212
Shields	7/23/2019 12:19	0	0.99	28	1.6	0.141
Shields	8/7/2019 8:12	0	0.15	62	1.6	0.138
Shields	8/20/2019 14:14	0	0.61	68	1.5	0.093
Shields	9/4/2019 13:12	0	0.61	73	1.6	0.082
Shields	9/17/2019 12:08	0	0.76	51	1.7	0.114
Shields	9/30/2019 9:56	0	0.91	22	1.8	0.116
Shields	10/14/2019 11:45	0	1.22	16	2.2	0.274
Third	5/1/2019 10:55	0	1.52	5.2	0.65	0.035
Third	5/16/2019 11:33	0	1.52	4.2	0.6	0.02
Third	5/30/2019 9:52	0	1.68	2.3	0.52	0.006
Third	6/10/2019 12:32	0	1.37	3	0.65	0.019
Third	6/26/2019 9:59	0	1.52	2.6	0.72	0.019
Third	7/10/2019 8:52	0	1.52	4.1	0.72	0.021
Third	7/24/2019 9:34	0	1.37	2.6	0.71	0.021
Third	8/7/2019 12:01	0	1.68	1.9	0.77	0.018
Third	8/20/2019 11:02	0	1.37	2.3	0.67	0.016
Third	9/5/2019 9:23	0	1.52	3.9	0.72	0.018
Third	9/17/2019 13:22	0	1.52	6	0.64	0.021
Third	9/30/2019 12:57	0	1.52	8.8	0.72	0.019
Third	10/16/2019 10:06	0	1.68	2.6	0.63	0.021
Twin (CLFLWD)	5/1/2019 10:14	0	1.98	3.3	0.48	0.018
Twin (CLFLWD)	5/16/2019 8:18	0	1.52	1.5	0.52	0.021
Twin (CLFLWD)	5/29/2019 14:28	0	2.13	1.6	0.45	0.014

Lake Name	Date Time	Depth (m)	Secchi Depth (m)	Chlorophyll-a (ug/L)	Total Kjeldahl Nitrogen (mg/L)	Total Phosphorus (mg/L)
Twin (CLFLWD)	6/10/2019 10:30	0	2.13	2.7	0.58	0.028
Twin (CLFLWD)	6/26/2019 11:12	0	1.14	3	0.67	0.026
Twin (CLFLWD)	7/9/2019 11:19	0	1.07	8.9	0.65	0.029
Twin (CLFLWD)	7/24/2019 8:18	0	0.76	12	0.69	0.036
Twin (CLFLWD)	8/7/2019 10:03	0	0.91	7.7	0.65	0.035
Twin (CLFLWD)	8/20/2019 13:44	0	1.07	5	0.61	0.02
Twin (CLFLWD)	9/4/2019 11:15	0	1.52	5.3	0.56	0.02
Twin (CLFLWD)	9/17/2019 12:54	0	1.37	2.3	0.46	0.028
Twin (CLFLWD)	9/30/2019 11:21	0	1.52	3.5		
Twin (CLFLWD)	10/14/2019 14:12	0	1.68	3.2	0.5	0.013

APPENDIX D – STREAM MONITORING METADATA

2019 Stream Rating Curves

Big Comfort Lake Outlet

- Rating Curve: y = 20.41320x^2 - 132.40264x + 220.20632
- The rating curve and stage are based on a permanent staff gage.
- A gradual shift was applied to the calculated discharge values to account for growth and decay of vegetation in the stream channel which affected discharge (6/13/19 14:45 – 10/29/19 10:00).
- The area velocity (A/V) sensor was installed 5/3/19 11:15 – 10/29/19 10:00.
- The A/V sensor is placed in the stream channel approximately 100 ft. upstream of Wyoming Trail, SW ¼ Sec. 22 T.33N. – R.21W.

Big Comfort Lake Inlet

- Rating Curve: y = 0.3417EXP(1.7331x)
- The rating curve and stage are based on the area-velocity (A/V) sensor depth in the box culvert.
- The A/V sensor was installed 5/6/19 11:30 – 10/29/19 9:30.
- A power failure and equipment malfunction occurred at the very end of the recorded dataset and no data was recorded after 10/7/19 10:45.
- The A/V sensor is placed in the upstream end of a 7 ft box culvert under West Comfort Drive, NW ¼ Sec. 27 T.33N. – R.21W.

Bone Lake North Inlet

- No continuous stage and discharge data were collected at this site in 2019. The area-velocity (A/V) sensor was installed on 5/6/19 9:21 and was damaged shortly thereafter. Data appear to indicate the A/V sensor was cut within 24 hours of installation, and no replacement sensor was purchased to continue monitoring for the year. Water quality grab samples were still collected throughout the year.
- Water quality monitoring site is located in the downstream end of a 3 ft round culvert under 238th Street North, NW ¼, NE ¼ Sec. 05 T.32N. – R.20W.

Bone Lake Outlet

- An area velocity relationship was used to calculate discharge.
- Stage is based on the area-velocity (A/V) sensor depth in a 2.2ft diameter round pipe.
- The A/V sensor was installed 5/6/19 10:30 – 10/29/19 10:45.
- A power failure occurred and no data was recorded during the following time period:
  - 10/25/19 3:00 – 10/25/19 8:15
- The A/V sensor is placed on the downstream invert of a 2.2 ft round pipe at the lake outlet under Lofton Avenue, NW ¼ Sec. 05 T.32N. – R.20W.

Forest Lake Outlet

- Shifts in stage occurred due to blockage of downstream culvert at Hwy 8 and the following rating curves were used to calculate discharge during the noted time periods:
  - $y = 2.4592(x-0.70)^2 - 29.366(x-0.70) + 57.028$
    - 5/3/19 9:30 – 8/12/19 7:00, 8/17/19 13:00 – 8/19/19 7:15
  - $y = 2.4592x^2 - 29.366x + 57.028$
    - 8/12/19 7:45 – 8/17/19 12:00, 8/19/19 8:00 – 10/20/19 14:30
- A gradual shift was applied to the calculated discharge values to account for the gradual change in stage and flow caused by the Hwy 8 culvert blockage (5/3/19 9:30 – 7/14/19 21:45).
- The rating curves and stage are based on a permanent staff gage.
- The area-velocity (A/V) sensor was installed 5/3/19 9:30 – 10/20/19 21:15.
- Stage data indicates that the blockage in the Hwy 8 culvert was removed 8/12/19 7:00, was reinstalled 8/17/19 12:30, and then removed again 8/19/19 7:30.
- Power failures occurred and no data was recorded during the following time periods:
  - 10/18/19 3:45 – 10/18/19 10:00
  - 10/18/19 20:30 – 10/19/19 11:30
  - 10/19/19 14:45 – 10/20/19 11:00
- The A/V sensor is placed in the stream channel approximately 25 ft. downstream of North Shore Drive, NW ¼ Sec. 4 T.32N. – R.21W.

Little Comfort Lake Inlet

- Discharge was affected by Little Comfort Lake backing-up into the site and by vegetation in the channel. The following rating curves were used to calculate discharge during the noted time periods:
  - $y = 2.5779x^2 + 4.5625x - 15.088$
    - 5/21/19 11:00 – 7/14/19 21:30, 8/26/19 14:00 – 9/25/19 2:15, 9/30/19 0:00 – 10/27/19 0:30
  - $y = 2.5779x^2 + 0.9535x - 17.018$
    - 7/15/19 0:00 – 7/18/19 19:30
  - $y = 0.0022x^{7.186}$
    - 7/18/19 19:45 – 8/26/19 13:45
  - $y = 0.1026x^{4.6597}$
    - 9/25/19 2:30 – 9/29/19 23:45
- The rating curves and stage are based on a permanent staff gage.
- The area-velocity (A/V) sensor was installed 5/21/19 11:00 – 10/27/19 0:30.
- A power failure occurred at the very end of the recorded dataset.
- The A/V sensor is placed in the stream channel approximately 15 ft. upstream of Itasca Avenue, SE ¼ Sec. 27 T.33N. – R.21W.

Greenway Avenue

- Rating Curve: $y = 3.41236(x^2) + 0.46019x - 3.66282$
- The rating curve and stage are based on a permanent staff gage.
- The area-velocity (A/V) sensor was installed 5/6/19 11:45 – 10/29/19 10:45.
- The A/V sensor is placed in the stream channel approximately 10 ft downstream of Greenway Ave, NW ¼ Sec. 33 T.33N. – R.21W.

256th Street

- Rating Curve: y = 2.42235(x^2) - 24.20858x + 46.75168
- The rating curve and stage are based on a permanent staff gage.
- The area-velocity (A/V) sensor was installed 5/3/19 10:15 – 10/29/19 10:45.
- The A/V sensor was damaged and no data was recorded during the following time period:
  - 10/2/19 7:30 – 10/11/19 9:00
- The A/V sensor is placed in the stream channel approximately 25 ft. upstream of 256th Street, SW ¼ Sec. 28 T.33N. – R.21W.

Historic Stream Monitoring Methods

While stream monitoring has been taking place on CLFLWD streams since 2004 it should be noted that the sampling technique has changed at nearly every site. When monitoring began the automated composite sampling technique was used at most sites. This involves multiple water samples collected at various flow points by an automated device, typically during storm events. Composite samples generally capture more of the rising limb and peak of a storm event when most nutrient loading is likely to occur. Between the years of 2005 and 2009 the sampling technique changed at several sites to grab samples, which are manually collected discrete water samples. The limitation of manual grab samples is the timing of the sample collection; it is very easy to miss the rising limb or peak of a storm event. Grab samples capture data at just one point in time during the storm event whereas a composite sample collects many samples during different points in the storm event. Stream loads based on grab samples likely underestimate individual event loads by not capturing the first flush of pollutants during the rising limb of the storm event (Figure 25).

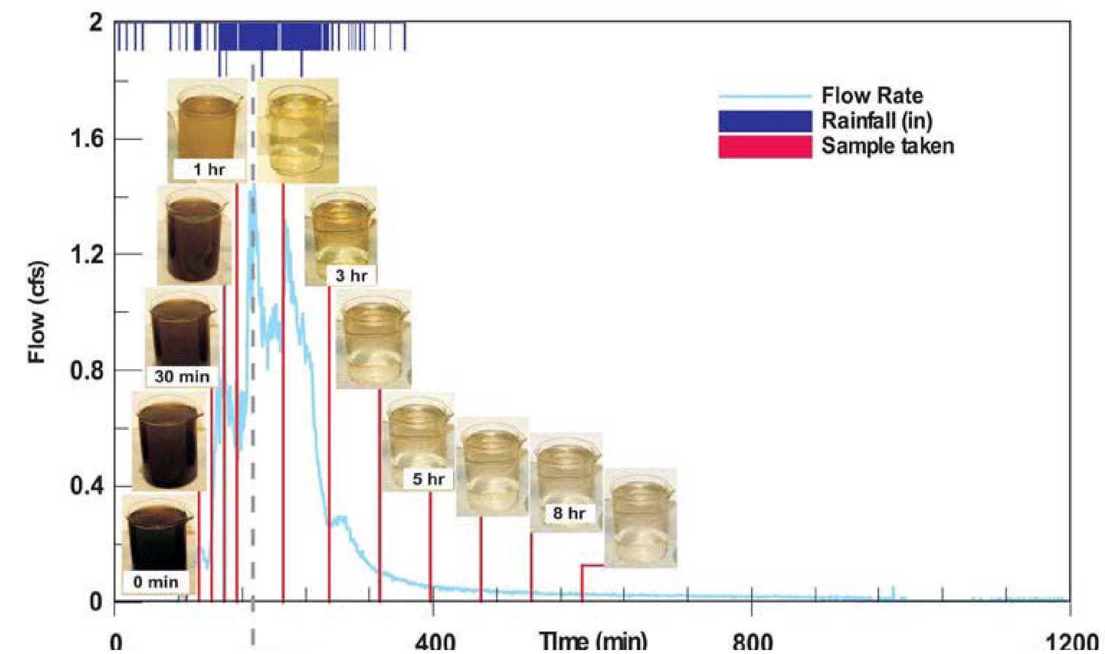


Figure 25. Stream turbidity during the rising (flows increasing) and falling (flows decreasing) limb of a storm event (Source: Pat Baskfield, MPCA Mankato Office)

The 2012 monitoring season brought a slight change in sampling technique for all monitored sites yet again. Grab sampling was still the technique used; however, the samples were collected using the automated sampler versus a manual grab. The reasoning was that the timing of the grab sample would be more accurate when automatically collected, during the rising limb or at the peak of the storm event. In 2013 it was decided to return to collecting automated storm composite samples in order to achieve more accurate loading calculations from sites where samples are collected. Composite sampling has continued since 2013.

These changes were instituted at the direction of the District Engineer to meet budgetary concerns of the CLFLWD Board of Managers while using scientifically accepted methods of stream load monitoring at that time; the CLFLWD is supportive of using the best available techniques when possible. Bone Lake Outlet, Forest Lake Outlet, and Comfort Lake Outlet sites have each utilized three different sampling techniques. All three sites started with the automated composite sampling technique, then switched to manual grab samples, and finally switched to using in-lake TP concentrations to estimate load, with the exception of Comfort Lake Outlet which has utilized automated composite sampling since 2013.

At Bone Lake Outlet automated composite sampling was used from 2003-2005 and switched to manual grab samples in 2006. Monitoring was discontinued at this site from 2007 through 2012. Monitoring resumed in 2013 using in-lake TP concentrations collected in Bone Lake to estimate load, this method was used through 2014 and 2015. The monitoring method reverted back to automated composite sampling in 2016.

Composite sampling was used at Forest Lake Outlet from 2003-2005 and switched to manual grab samples in 2006. Sampling ceased at the site in 2007 and all TP loads from 2007-2015 had been estimated using in-lake sample concentrations collected in the West Basin of Forest Lake. Monitoring resumed in 2016 using automated composite sampling.

Composite sampling was used at Comfort Lake Outlet from 2003-2005 and switched to manual grab samples in 2006. Grab samples were also collected in 2008 by the U.S Army Corps of Engineers. In-lake TP concentrations were used to estimate load for the 2009 and 2010 monitoring seasons. In 2011, manual grab samples were again collected at this site and in 2012 automated grab samples were collected. Since 2013, automated storm composite samples have been collected.

As with grab samples, using in-lake TP concentrations may lead to artificially low loading numbers. This is due to the difference in sampling technique and location (in-lake versus in-stream). More accurate loading numbers can be estimated by collecting samples at the monitoring site. The changes in sampling techniques must be taken into consideration when comparing loading numbers.

APPENDIX E – HISTORIC STREAM ANNUAL MONITORING DATA

Stream Monitoring Technique

Table 20 Stream Monitoring Technique by Stream Monitoring Site, 2004-2019

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	⌘	Bone Lake North Inlet		C	G				G	G	AG	C	C	C	C	C	C	
		Bone Lake South Inlet		C	C													
💧	⌘	Bone Lake Outlet	C	C	G							L	L	L	C	C	C	C
		Sunrise R Trib @ Manning Tr					G	G										
		Sunrise R Trib @ July Avenue					G	G										
	⌘	Little Comfort Lake Inlet	C	C	C	G	G	G	G	G	AG	C	C	C	C	C	C	C
		FL44 Subwatershed Drainage						G										
💧		Shields Lake Outlet		C	C													
💧	⌘	Forest Lake Outlet	C	C	G	L	L	L	L	G	L	L		L	C	C	C	C
		Bixby Park						G	G	G	AG							
		County Line Ditch				C	C	G	G	G	AG							
		Heims Lake Drainage									AG	C	CC					
		Greenway Avenue					C			G	AG	C					C	C
		256th Street															C	C
	⌘	Comfort Lake Inlet	C	C	C	G	G	G	G	G	AG	C	C	C	C	C	C	C
💧	⌘	Comfort Lake Outlet	C	C	G		L	L	L	G	AG	L	L	L	C	C	C	C

💧 = Lake outlet monitoring site

⌘ = Long-term monitoring site

C = automated composite water quality sample, G = grab sample, AG = automated grab sample, L = in-lake concentration

Stream Flow

Table 21. Total Annual Flow by Stream Monitoring Site, 2004-2019 (in ac-ft)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	⌘	Bone Lake North Inlet		323	221				126	1,051	279	372	1,134	948	1,091	698	457	
		Bone Lake South Inlet		528	363													
💧	⌘	Bone Lake Outlet	1,522	600	539							1,858	2,491	2,764	4,356	1,730	769	1,104
		Sunrise R Trib @ Manning Tr					1,451	258										
		Sunrise R Trib @ July Avenue					1,858	623										
	⌘	Little Comfort Lake Inlet	3,955	3,421	3,029	3,977	8,268	2,324	2,370	3,403	1,175	1,379	3,047	2,662	3,022	3,215	721	3,012
		FL44 Subwatershed Drainage												395				
💧		Shields Lake Otlet		634	408													
💧	⌘	Forest Lake Outlet	5,351	4,310	2,120	2,960	3,656	716	3,063	18,744	3,561	7,157		7,693	5,891	7,699	10,764	5,777
		Bixby Park						507	484	705	1,151							
		County Line Ditch				3,860	3,841	1,634	4,183	8,642	3,632							
		Heims Lake Drainage									130	221	743					
		Greenway Avenue					5,315			10,157	6,027	7,498					11,103	8,209
		256^{th} Street															10,616	8,050
	⌘	Comfort Lake Inlet	9,694	6,527	3,762	5,671	6,527	2,469	5,026	11,709	8,095	8,154	9,725	11,241	11,082	11,939	11,036	6,075
💧	⌘	Comfort Lake Outlet	15,473	4,634	4,208		5,841	1,401	5,514	19,894	7,656	9,779	19,683	11,765	11,007	12,613	15,450	14,191

💧 = Lake outlet monitoring site

⌘ = Long-term monitoring site

Runoff Depth

Table 22. Total Annual Flow by Stream Monitoring Site, 2004-2019 (as inches of runoff depth over the drainage area)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	⌘	Bone Lake North Inlet		1.6	1.1				0.6	5.1	1.4	1.8	5.5	4.6	5.3	3.4	2.2	
		Bone Lake South Inlet		8.3	5.7													
💧	⌘	Bone Lake Outlet	3.3	1.3	1.2							4.1	5.4	6.0	9.5	3.8	1.7	2.2
		Sunrise R Trib @ Manning Tr					2.4	0.4										
		Sunrise R Trib @ July Avenue					2.8	0.9										
	⌘	Little Comfort Lake Inlet	4.5	3.9	3.5	4.5	9.4	2.7	2.7	3.9	1.3	1.6	3.5	3.0	3.4	3.7	0.8	3.4
		FL44 Subwatershed Drainage												6.0				
💧		Shields Lake Outlet		9.2	5.9													
💧	⌘	Forest Lake Outlet	7.4	5.9	2.9	4.1	5.0	1.0	4.2	25.8	4.9	9.9		10.6	8.1	10.6	14.8	8.0
		Bixby Park						8.1	7.8	11.3	18.5							
		County Line Ditch				4.7	4.7	2.0	5.1	10.6	4.4							
		Heims Lake Drainage									2.3	4.0	13.4					
		Greenway Avenue					5.9			11.2	6.7	8.3					12.3	7.8
		256th Street															n/a	7.3
	⌘	Comfort Lake Inlet	8.5	5.7	3.3	5.0	5.7	2.2	4.4	10.2	7.1	7.1	8.5	9.8	9.7	10.4	9.6	5.4
💧	⌘	Comfort Lake Outlet	7.6	2.3	2.1		2.9	0.7	2.7	9.7	3.7	4.8	9.6	5.7	5.4	6.2	7.5	6.9

💧 = Lake outlet monitoring site

⌘ = Long-term monitoring site

Total Phosphorus Load

Table 23. Total Phosphorus Load by Stream Monitoring Site, 2004-2019 (in lb/yr)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	⌘	Bone Lake North Inlet		226	315				53	519	207	349	917	553	398	220	188	
		Bone Lake South Inlet		231	229													
💧	⌘	Bone Lake Outlet	339	97	49							194	271	283	652	140	53	150
		Sunrise R Trib @ Manning Tr					508	104										
		Sunrise R Trib @ July Avenue					431	151										
	⌘	Little Comfort Lake Inlet	1,283	1,023	1,551	676	1,127	418	331	481	230	330	354	543	430	504	191	1,712
		FL44 Subwatershed Drainage												85				
💧		Shields Lake Outlet		420	332													
💧	⌘	Forest Lake Outlet	1,235	457	173	253	341	43	221	1,828	411	706		701	630	321	749	559
		Bixby Park						179	158	285	973							
		County Line Ditch				1,212	650	85	811	1,792	930							
		Heims Lake Drainage									330	495	374					
		Greenway Avenue					1,505			3,722	6,370	2,071					2,386	2,011
		256^{th} Street															1,978	1,357
	⌘	Comfort Lake Inlet	1,963	1,119	1,887	997	1,153	547	1,278	2,876	1,914	1,519	2,006	2,880	2,176	1,525	2,135	1,464
💧	⌘	Comfort Lake Outlet	2,065	670	563		291	134	450	1,146	924	2,129	2,099	1,160	1,124	1,068	1,308	1,007

💧 = Lake outlet monitoring site

⌘ = Long-term monitoring site

Total Suspended Solids Load

Table 24. Total Suspended Solids Load by Stream Monitoring Site, 2004-2019 (in lb/yr)

Type		Station	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
	⌘	Bone Lake North Inlet		24,817	5,225				2,588	9,390	17,310	14,512	32,910	16,499	10,536	5,399	5,790	
		Bone Lake South Inlet		41,383	14,324													
💧	⌘	Bone Lake Outlet	35,283	38,776	3,158										78,053	46,748	8,792	24,256
		Sunrise R Trib @ Manning Tr					7,421	3,718										
		Sunrise R Trib @ July Avenue					14,137	9,112										
	⌘	Little Comfort Lake Inlet	1,220,397	697,890	643,540	43,113	94,344	34,444	18,146	29,758	37,392	50,187	42,545	120,755	50,151	75,358	49,337	
		FL44 Subwatershed Drainage												2,545				
💧		Shields Lake Outlet		79,186	8,620													
💧	⌘	Forest Lake Outlet	167,553	83,383	24,263										123,495	82,877	137,361	94,221
		Bixby Park						9,317	9,737	22,316	1,152,008							
		County Line Ditch				109,981	144,481	5,403	69,760	193,402	609,889							
		Heims Lake Drainage									51,715	24,224	106,692					
		Greenway Avenue					696,004			218,922	7,183,660	129,646					386,865	564,552
		256th Street															207,178	166,304
	⌘	Comfort Lake Inlet	403,759	125,039	175,089	63,755	196,267	21,691	60,721	215,478	150,817	99,754	253,252	145,235	305,188	202,161	202,493	204,767
💧	⌘	Comfort Lake Outlet	566,195	251,622	60,519		62,469			267,379	175,609	147,718	468,449	81,704	156,594	145,543	330,075	158,157

💧 = Lake outlet monitoring site

⌘ = Long-term monitoring site

APPENDIX F – HISTORIC LAKE GROWING SEASON AVERAGE ANNUAL WATER QUALITY

Total Phosphorus

Table 25. In-Lake Growing Season (June through September) Average Phosphorus Concentration, 1989-2019 (in µg/L)

Lake	#	In-Lake Growing Season (June through September) Average Phosphorus Concentration (µg/L) (in order left to right from most recent to oldest)																													
		2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989
Bone*	25	27	22	30	39	39	55	34	34	32	37	33	39	41	57	59	60	82	58	39		50	34	36		21		58				46
Birch	5		122	72										60	118	131																
Comfort*	22	26	32	31	34	31	43	25	47	32	28	27	26	19	49	29	40	48	41	29	44		43				37					
Elwell	1	48																														
Forest (West)	25	20	37	25	40	37	37	37	38	35	31	26	37	37	38	40	33	36	33	29	36	47	29	29	36			37				
Forest (Middle)	11	51	35	34	41	35	31	30	49	33					38				24													
Forest (East)	11	32	36	46	44	28	28	25	39	42					40				26													
Forest (All Basins)	25	*34*	*36*	*35*	*42*	*33*	*32*	*31*	*42*	*37*	*31*	*26*	*37*	*37*	*39*	*40*	*33*	*36*	*28*	*29*	*36*	*47*	*29*	*29*	*36*			*37*				
Fourth Lake	3	87				63	127																									
Heims	3					33	52					37																				
Keewahtin	22	15		14	18	18	13	14	18	23	14	13	15	14		19	20	17	19	19	19	24	13		23			11				
Lendt	3	18				11	18																									
Little Comfort*	16	58	50	43	68	88	58	62	58	46	28	19	28	47	73								56				51					
Moody*	13	60	92	86	104	122	113	87	155	128	81			168	158	168																
Nielsen	2		87	102																												
Sea	4			45	54							122	48																			
Second**	2	23											54																			
School*	6		53	51								47		53	66	97																
Shields*	25	128	180	191	194	349	299	162	195					206	234	201	229	381	259	245	179	286	220	188	184	209	145	190	90	100		
Third Lake	4	19				17	30						14																			
Twin Lake	1	28																														

**= Impaired, in the 2010 Six Lakes TMDL Study; **= Impaired, in the 2014 Sunrise River Watershed TMDL Study*

Lake names in bold have District Goals

Chlorophyll-*a*

Table 26. In-Lake Growing Season (June through September) Average Chlorophyll-a Concentration, 1989-2019 (in µg/L)

Lake	#	In-Lake Growing Season (June through September) Average Chlorophyll-a Concentration (µg/L) (in order left to right from most recent to oldest)																														
		2019	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989
Bone*	**19**	20	10	20	25	30	21	20	15	6	16		18		20	23	38	48	42	34		34	20	16		7		38				28
Birch	**5**		25	11										21	15	44																
Comfort*	**19**	16	14	12	18	20	16	14	22	16	20	12	9		12	16	17	25	26	19	25		14				16					
Elwell	**1**	12																														
Forest (West)	**19**	8	13	8	20	19	14	15	21	18	21	11	10		19	25	10	17	16	19	12	20	18	14	15			18				
Forest (Middle)	**12**	20	15	13	19	21	12	14	19	50					19				15													
Forest (East)	**12**	17	22	23	24	19	14	14	12	27					20				16													
Forest (All Basins)	**19**	*15*	*17*	*15*	*21*	*20*	*14*	*14*	*17*	*32*					*19*				*15*													
Fourth Lake	**3**	29				13	18																									
Heims	**2**					9						16																				
Keewahtin	**17**	3		3	5	4		4	3	3	2	3	3			3	3	4	3	5	4	6	4		3			4				
Lendt	**3**	5				3	1																									
Little Comfort*	**14**	25	26	26	43	28		24	17	11	14	8	10		24								18				32					
Moody*	**13**	41	75	44	46	59		32	82	87	71			80	44	60																
Nielsen	**2**		78	80																												
Sea	**4**			7	14							46	48																			
Second**	**2**	8											16																			
School*	**6**		50	31								29		40	28	48																
Shields*	**15**	52	67	64	57	77		39	31					45	59	61	48	46	49	25	26	49	40	8	9	18	23	25				
Third Lake	**3**	4				4							1																			
Twin Lake	**1**	6																														

**= Impaired, in the 2010 Six Lakes TMDL Study; **= Impaired, in the 2014 Sunrise River Watershed TMDL Study*

Lake names in bold have District Goals

Secchi Depth

Table 27. In-Lake Growing Season (June through September) Average Secchi Depth Transparency, 2000-2019 (in feet)

Lake	Number of years	n-Lake Growing Season (June through September) Average Secchi Depth (ft), 2000-2019 (in order left to right from most recent to oldest)																			
		2019	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**	**2011**	**2010**	**2009**	**2008**	**2007**	**2006**	**2005**	**2004**	**2003**	**2002**	**2001**	**2000**
Bone*	**30**	4.9	6.5	5.8	4.2	3.9	4.1	3.9	3.7	5.2	4.9		5.1	3.7	5.9	5.2	4.1	3.1	3.2	4.1	
Birch	**5**		3.5	5.0										5.6	5.1	3.9					
Comfort*	**28**	5.3	7.7	5.8	5.5	5.5	4.2	5.7	4.3	5.4	4.4	6.8	4.8	5.6	6.6	6.3	6.0	4.2	4.1	6.2	4.9
Elwell	**1**	2.2																			
Forest (West)	**31**	7.1	4.9	6.2	4.3	4.7	4.0	4.3	3.4	6.0	5.2	5.5	4.9	3.4	5.1	5.4	6.2	4.3	5.5	5.0	4.5
Forest (Middle)	**11**	7.0	7.7	8.2	5.7	6.4	6.2	5.7	5.2	5.3					5.5				6.3		
Forest (East)	**11**	7.9	6.4	8.1	5.7	7.8	5.5	6.6	7.0	4.0					5.5				6.3		
Forest (All Basins)	**31**	7.3	6.3	7.5	5.2	*6.3*	*5.2*	*5.5*	*5.2*	*5.1*	*5.2*	*5.5*	*4.9*	*3.4*	*5.4*	*5.4*	*6.2*	*4.3*	*6.0*	*5.0*	*4.5*
Fourth Lake	**3**	2.3				1.7	2.3														
Heims	**3**					2.8	3.8					1.7									
Keewahtin	**33**	13.4		14.2	13.7	13.9	17.7	14.4	15.0	13.9	17.0	15.5	14.7	15.3	16.1	15.5	16.7	14.0	15.3	13.8	14.2
Lendt	**3**	4.4				3.8	5.9														
Little Comfort*	**16**	4.5	4.3	3.6	3.7	4.3	5.9	5.2	4.7	5.5	5.8	6.6	5.8	4.5	4.8						
Moody*	**13**	2.4	1.8	1.9	2.7	2.1	2.7	3.7	2.4	2.6	2.6			2.2	2.7	2.3					
Nielsen	**2**		1.0	1.0																	
Sea	**4**			4.2	4.8							2.1	3.9								
Second**	**3**	8.7											5.8		4.8						
School*	**6**		2.5	2.8								0.2		4.3	4.0	3.8					
Shields*	**11**	2.5	1.9	2.2	2.7	1.9	3.4	4.1	4.6					3.4	2.7	2.3					
Third Lake	**3**	4.2				3.8							7.1								

**= Impaired, in the 2010 Six Lakes TMDL Study; **= Impaired, in the 2014 Sunrise River Watershed TMDL Study*

Lake names in bold have District Goals

Table 28. In-Lake Growing Season (June through September) Average Secchi Depth Transparency, 1986-1999 (in feet)

Lake	n-Lake Growing Season (June through September) Average Secchi Depth (ft), 1986-1999 (in order left to right from most recent to oldest)													
	1999	**1998**	**1997**	**1996**	**1995**	**1994**	**1993**	**1992**	**1991**	**1990**	**1989**	**1988**	**1987**	**1986**
Bone*	3.5	5.0	4.9	4.4	3.5	4.2	3.7			4.2	4.3	3.5	5.3	3.4
Birch														
Comfort*	4.5	4.1	6.3		4.3	6.3					9.3	7.9	8.4	
Elwell														
Forest (West)	3.9	4.6	5.1	4.9	5.3	4.8	5.2				6.9	5.7	5.3	5.6
Forest (Middle)														
Forest (East)														
Forest (All Basins)	*3.9*	*4.6*	*5.1*	*4.9*	*5.3*	*4.8*	*5.2*				*6.9*	*5.7*	*5.3*	*5.6*
Fourth Lake														
Heims														
Keewahtin	13.3	13.9	12.6	14.4	14.6	14.9	16.0	15.8	15.9	12.4	13.6	14.8	14.3	10.6
Lendt														
Little Comfort*		3.2				5.9								
Moody*														
Nielsen														
Sea														
Second**														
School*														
Shields*														
Third Lake														