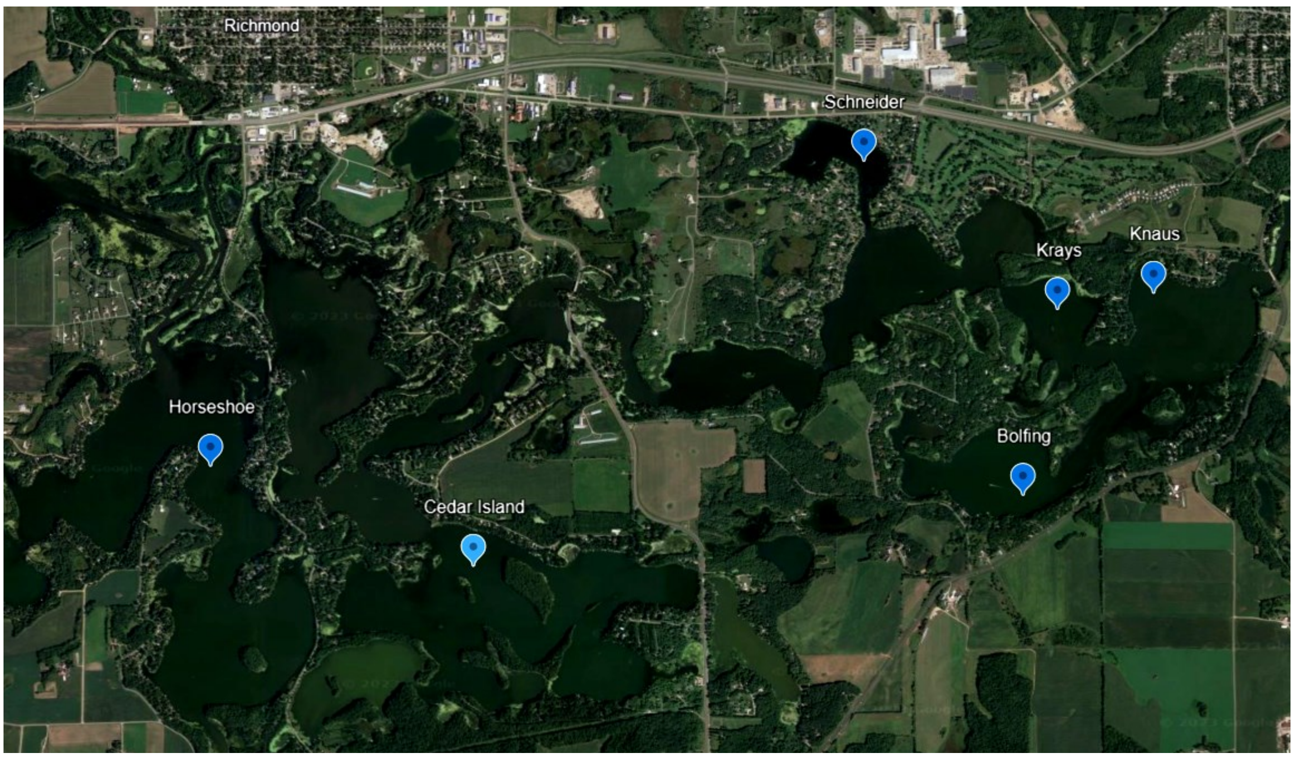
2023 SRCLA Monitoring Summary

Bolfing, Cedar Island, Horseshoe, Krays, Knaus, Schneider

Sauk River Chain of Lakes Overview

This monitoring summary provides 2023 water quality sample results for six lakes within the Sauk River Chain of Lakes and a review of past conditions at those sites. Lakes monitored in 2023 included: Horseshoe, Cedar Island, Schneider, Krays, Knaus, and Bolfing. Information regarding SRWD river monitoring sites upstream (Richmond) and downstream (Cold Spring) of the chain of lakes system has also been included, along with flow measurements and rainfall totals for the 2023 summer season.

The Sauk River Chain of Lakes Association, Inc. (SRCLA) has been actively monitoring and collecting water quality information in the chain since the associations establishment in 1982. The SRCLA was instrumental to the creation of the Sauk River Watershed District (SRWD) in 1986, and the organizations have worked together over the decades to plan and initiate water quality improvement projects in the region.



Select Content:

Sauk River Watershed District

Created January 2024

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Environmental Monitoring Manager

SRCL Water Quality Standards

The Sauk River Chain of Lakes is made up of 14 interconnected lakes. Some lakes are shallow, some are deep, and some are considered flowage lakes of the mainstem Sauk River. The Sauk River enters the chain of lakes system near the city of Richmond, 95 miles south of the rivers headwaters at Lake Osakis, and meanders for 7 river-miles through numerous lakes before flowing over the Cold Spring Dam.

Due to the unique hydrologic conditions in the SRCL, the Minnesota Pollution Control Agency (MPCA) has determined that some of the lakes require site-specific standards to protect the water quality and recreational resources in this river and lake system. Water quality standards (WQS) can be set for a pollutant at a statewide level, by ecoregion, or be site-specific. These standards are used to describe the desired conditions of a water body and to protect its designated uses. An ecoregion standard may be modified on a site-specific basis to account for unique characteristics such as: waterbody depth, temperature, hydrologic connectivity, drainage area, land use, regional geology, distance from ecoregion borders, and more. To assign representative WQS, many elements of the watershed ecosystem are taken into account.

The MPCA and the Sauk River Watershed District (SRWD) proposed site-specific standards for some of the Sauk River Chain of Lakes in 2012. The Environmental Protection Agency (EPA) reviewed and approved these standards in 2020. The proposal was created in response to several issues that arose during the development of the Total Maximum Daily Load (TMDL) study for the area.

The issues that prompted the MPCA and SRWD to propose site-specific standards include, but are not limited to:

1. The SRCL is a flowage/reservoir system, and the Minnesota Administrative Rules allow for the development of site-specific standards for reservoirs;
2. Lakes directly in the flowage of the river have very short water residence (generally it takes <7 days for water to flow through the chain), and their water quality is largely driven by the Sauk River; and
3. Several deep lake basins in the chain are influenced by their connection to river and lake flowage, and that influence can vary greatly from lake to lake. Site-specific water quality standards that are more representative of these waterbodies are needed to ensure recreational and aquatic life protection throughout the chain.

MPCA Water Quality Standards			
Lakes	**TP** (µg/L)	**Chl-a** (µg/L)	**Secchi Disk** (ft)
North Central Hardwood Forest (NCHF) General: Schneider	<40	<14	>4.6
Sauk River Chain of Lakes Site Specific Standards			
Non-Flowage Lakes: Cedar Island (main), Horseshoe, Bolfing	<55	<32	>4.6
Flowage Lakes: Krays, Knaus	<90	<45	>2.6
Rivers	**TP** (µg/L)	**TSS** (mg/L)	**Secchi Tube** (cm)
Central MN River Nutrient Region (RNR): Sauk River	100	30	>35

SRCL Water Quality Standards cont…

The table on page 2 contains the approved site-specific standards for total phosphorus (TP), chlorophyll-A (chl-a), and Secchi disk readings for the chain of lakes. The lakes monitored in 2023, and in past years, have been distributed throughout the chain to incorporate the various lake types. In 2023, the lakes monitored were: Cedar Island (non-flowage), Horseshoe South (non-flowage), Bolfing (non-flowage), Knaus (flowage), Krays (flowage), and Schneider (NCHF General).

The Carlson Trophic State Index (TSI) is used throughout this report to discuss annual water quality trends in each lake. The Carlson TSI is a classification system designed to rate water bodies using concentration measurements of both chlorophyll-A and total phosphorus, combined with Secchi disk depth readings. The more available nutrients, the more likely the waterbody is to have problems with algae and aquatic plant overgrowth. The index consists of a scale ranging from 0 - 100+ and is used as a predictor of poor water quality conditions. Under the Carlson TSI scale, the four main TSI classifications are:

Oligotrophic: TSI 0 - 40, Clear water, good oxygen conditions, limited nutrients available, deep or shallow lake. From the Greek "oligos" meaning few, scanty.

Mesotrophic: TSI 40 - 50, Moderately clear water but increased chance of low oxygen conditions in shallow lakes. From the Greek "meso" meaning middle, moderate.

Eutrophic: TSI 50 - 70, Moderately clear to cloudy water, with a high chance of low oxygen conditions in the summer, extensive plant growth, and potential algal scum. From the Greek "eu" meaning well, plenty.

Hypereutrophic: TSI 70+, Dense plant growth, heavy algal blooms and scum possible, low oxygen conditions, fish kill possible. From the Greek "hyper" meaning over much.

This photo provides an examples of Secchi disk visibility during the 4 different trophic states. Water clarity and visibility is noticeably reduced in eutrophic and hypertrophic conditions.

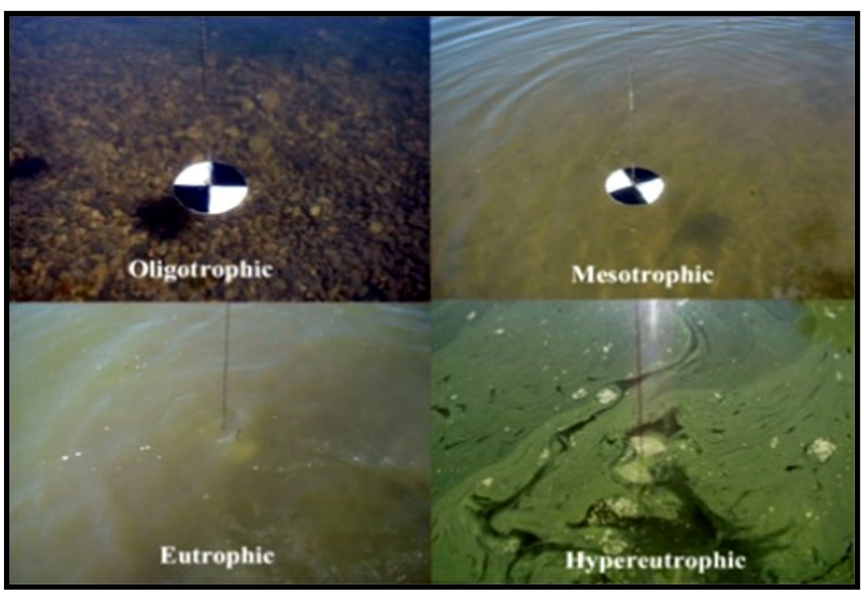
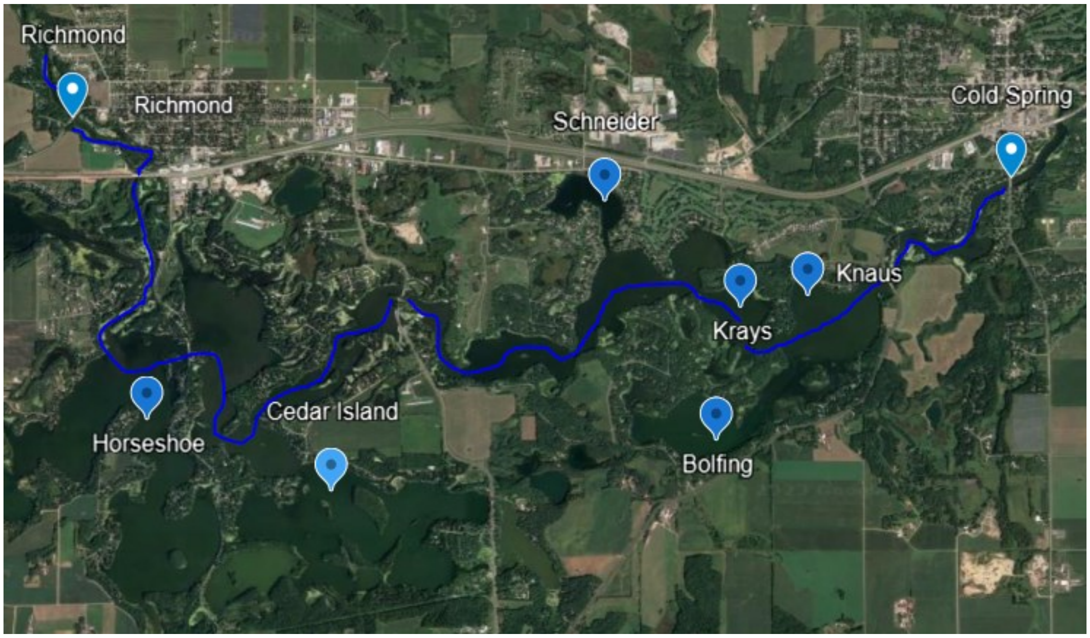


Photo Courtesy of the Minnesota Pollution Control Agency (MPCA)

River and Lake Sampling

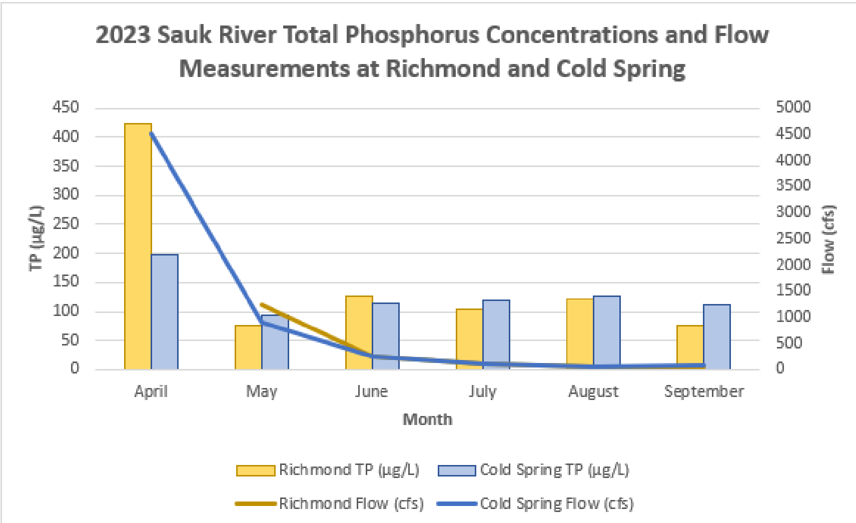


The Sauk River Chain of Lakes contains natural lakes, flowage lakes, and non-flowage lakes. The aerial map above shows the predominant flow path of the Sauk River as it moves through the chain (flowing from left to right). The river enters the chain just south of the city of Richmond at Horseshoe Lake and follows a circuitous path for 7 river-miles before flowing out over the Cold Spring Dam. The lakes within the chain on the main-stem river are considered flowage lakes, and water typically moves through in just 7 days. This is much quicker than water typically enters and leave a natural lake. Horseshoe, Cedar Island, and Bolfing Lakes are not considered to reside in flowage, but instead very slowly drain to the flowage zone. This has led to the development of different WQS for flowage vs. non-flowage lakes within the chain. Schneider Lake is considered to be a natural lake, and the general WQS for the North Central Hardwood Forest ecoregion applies. These standards can be seen in the table on page 2.

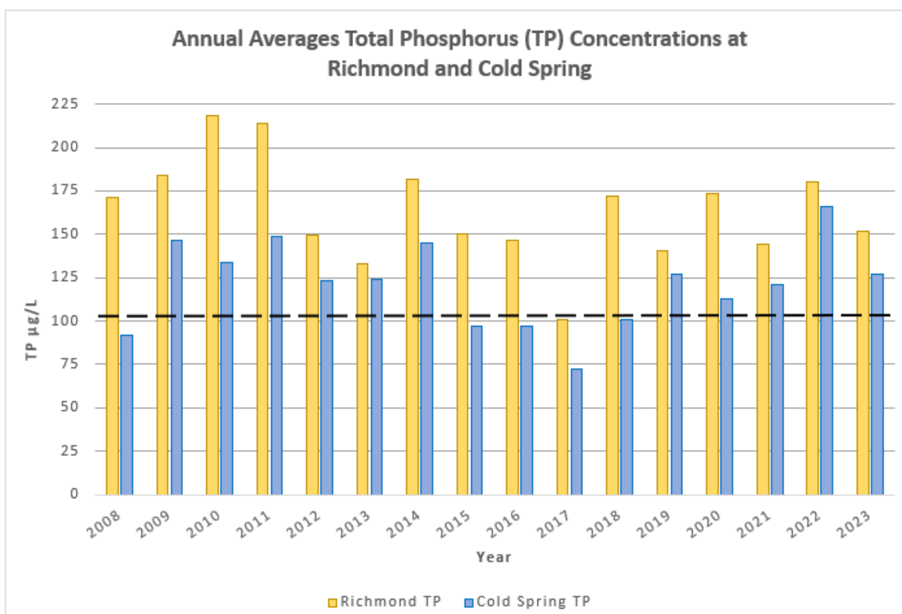
SRWD intern demonstrating the use of a lake surface integrated sampler.

The Sauk River monitoring samples presented in this report are taken from the mainstem Sauk River near the city of Richmond and near the Cold Spring Dam. These samples are of the river's surface water only. The SRWD river sampling device, called a Van Dorn, is submerged to a maximum depth of 1 - 2 feet below the water surface for sample collection. This differs from the lake surface sampling method. Lake samples were collected by SRCLA volunteer Gary Schnobrich with a 2-meter long pipe, called an integrated sampler, that is plunged vertically into the lake until just submerged. A stopper is then placed in the top of the submerged pipe, the pipe is quickly pulled from the water, and the water is released into a pitcher to allow for mixing before filling sample bottles. Taking a sample from the top 2 meters of the lake is done to capture water quality conditions in the upper region on the water column where sunlight penetrates the water.

2023 Sauk River Total Phosphorus



The SRWD maintains long-term monitoring sites upstream of the chain of lakes on County Road 111 near the city of Richmond, and downstream of the chain on Red River Road near the Cold Spring Dam. River monitoring sites are visited regularly from March to September, and water quality (WQ) samples are taken twice a month. The 2023 monitoring year was one of highs and lows, with ~6 feet of winter snowpack melting in just a few days in early April. This led to spring flooding and created high water conditions across the watershed. The high flows also brought high levels of total phosphorus, with samples exceeding the total phosphorus WQ standard of 100 µg/L at both Richmond and Cold Spring in April, June, July, and August (see the bar graph above for phosphorus levels, with the lines representing flow measurements). A flow measurement could not be taken in April at the Richmond site as the river was out of its banks, filling and flowing in a large and inaccessible side channel. By June, flow measurements upstream and downstream of the chain were essentially the same, indicating most tributaries to the chain of lakes system were not flowing by late June. According to the NOAA website, accumulated precipitation near Kimball, MN from April 1st to October 1st, 2023 was ~16 inches. This is 6.5 inches below the normal accumulated precipitation for the area of 22.5 inches.



The bottom graph contains the annual average total phosphorus concentrations for the Richmond and Cold Spring sites over the last 16 years. Both sites exceed the TP WQ standard the vast majority of the time. The high total phosphorus concentrations in the Sauk River upstream of the chain of lakes near Richmond will make it difficult to meet the WQ standard in the Sauk River Chain of Lakes flowage lakes. Upstream water quality improvement projects are needed to reduce phosphorus loading to the chain of lakes system.

Lake Stratification and Water Quality

The Sauk River Chain of Lakes Association, LLC purchased a YSI brand dissolved oxygen and temperature meter in 2023 and has started monitoring the chain for these parameters. At each SRCLA water quality sampling site, a temperature and dissolved oxygen (DO) depth profile is taken from the lake surface to the lake bottom in one meter increments. The temperature and dissolved oxygen concentrations give us clues about what is going on in the depths of the chain of lakes system. If the oxygen and/or temperature readings fall markedly as the meter descends into the lake, this is a sign the lake is undergoing stratification. Stratification most commonly occurs in deep (greater than 15 feet) lakes when the surface water warms in the spring and summer. Since cold water is more dense than warm water, the colder water settles to the lake bottom (hypolimnion) and the warmer water stays near the lake surface (epilimnion). If the water remains stratified as the summer progresses, the lake bottom's oxygen concentration can become depleted due to the decomposition of organic matter by bacteria using up all the oxygen. The bottom layer will stay oxygen-depleted throughout the season in deep lakes that lack enough wind energy to mix the water column. Lake oxygen concentrations can become "hypoxic," when the dissolved oxygen in the water drops below two milligrams per liter (mg/L), or even become "anoxic," totally devoid of oxygen. These conditions are strongly linked to lake eutrophication and can create a stressful, or even deadly environment for aquatic organisms who need oxygen to survive.

Hypoxic conditions in the lake also create hypoxic conditions in the lake bottom sediments. This lack of oxygen changes the chemical interaction of the sediment and water, leading to more dissolved phosphorus and nitrogen being released from the sediment into the bottom layer. Additionally, lake bottom dwelling bacteria use oxygen to metabolize phosphorus and nitrogen into energy. Hypoxic lake bottom conditions change the bacteria's metabolism to become less active. This reduces the amount of dissolved phosphorus and nitrogen the bacteria can digest from the water. The process of low oxygen conditions leading to a release of sediment nutrients and a reduction of nutrient-fixing bacteria is known as *internal lake nutrient loading*. Internal loading occurs naturally in many lakes, but can lead to a large input of nutrients in the fall/winter when lake water cools and the water column mixes. This can move legacy nutrients from the lake bottom into the upper water column, and potentially lead to noxious algae blooms and reduce water quality.

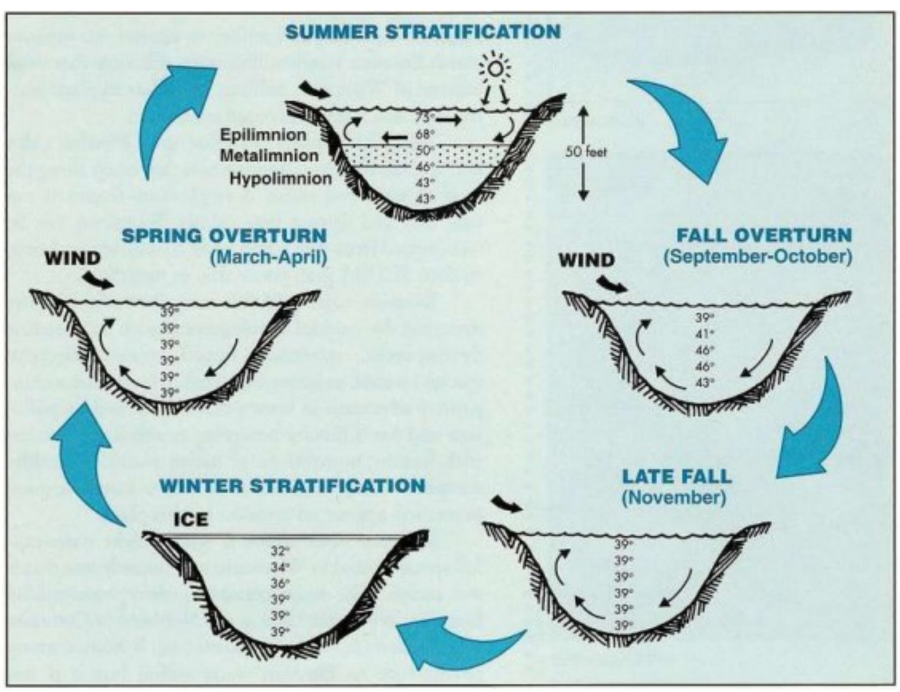
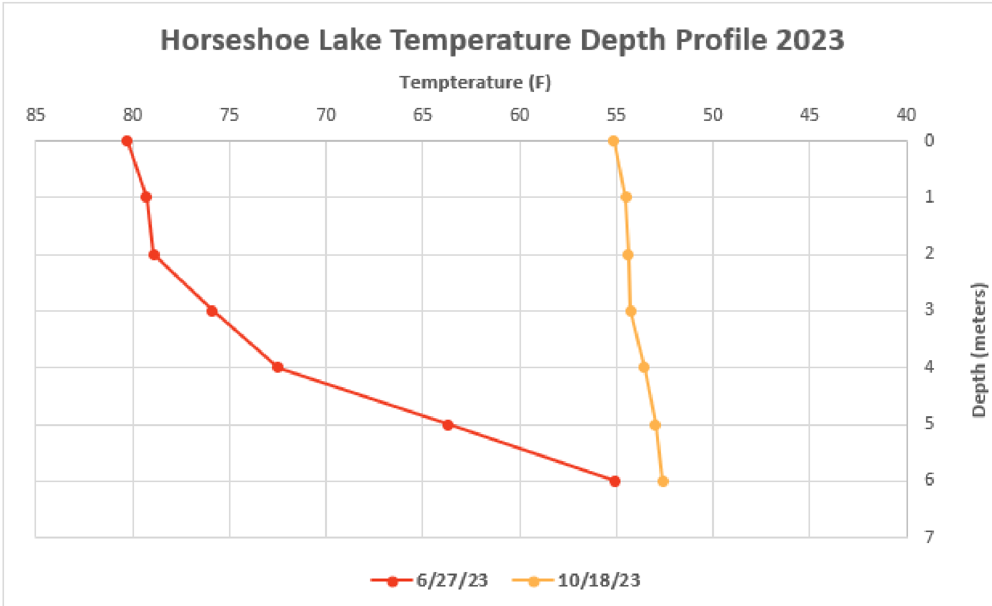


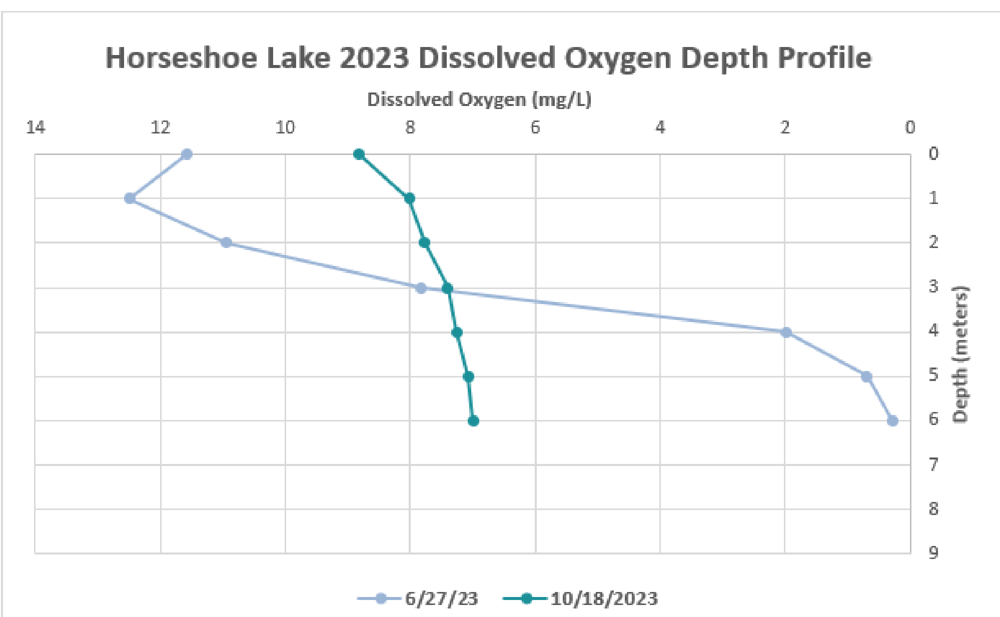
Photo sourced from the City of St Cloud 2020 Limnology Report, created by SHE.

Horseshoe Lake Depth Profiles - *Non-Flowage*

Horseshoe Lake is the first lake the Sauk River enters in the chain of lakes system. The temperature and dissolved oxygen profiles compiled here are both from sampling dates on June 27th and October 18th, 2023. The temperature and dissolved oxygen meter did not arrive until mid-June, so May 2023 depth data was not captured.

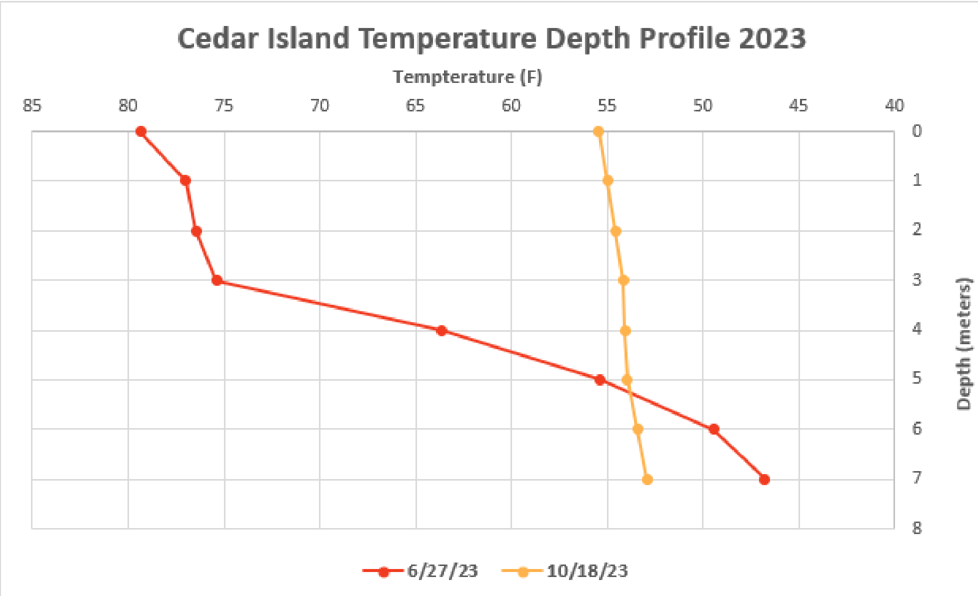


The temperature graph above shows that in June, the water temperature went from ~80°F near the surface down to 55°F near the bottom. The oxygen concentrations graph below for Horseshoe Lake shows a big reduction in oxygen levels around 3-4 meters depth on June 27th, with anoxic conditions near the lake bottom. This temperature and oxygen stratification stayed in place around 3-4 meters depth until mid-October. The water temperatures on October 18th vary just slightly throughout the depth profile, and the oxygen concentration near the lake bottom on October 18th was up to around 7 mg/L. This indicates that Horseshoe Lake stratified by temperature and became oxygen-depleted in the early summer months. As temperatures cooled in the fall, the surface water cooled, becoming more dense, and Horseshoe Lake turned over and the water column mixed. This occurred some time between 9/28 and 10/18.



In the future, it may be beneficial to deviate from the MPCA recommendation of taking samples from only May to September and take lake samples in October to assess nutrient loading after lake turnover. This event varies from year to year, but has been occurring later in more recent years.

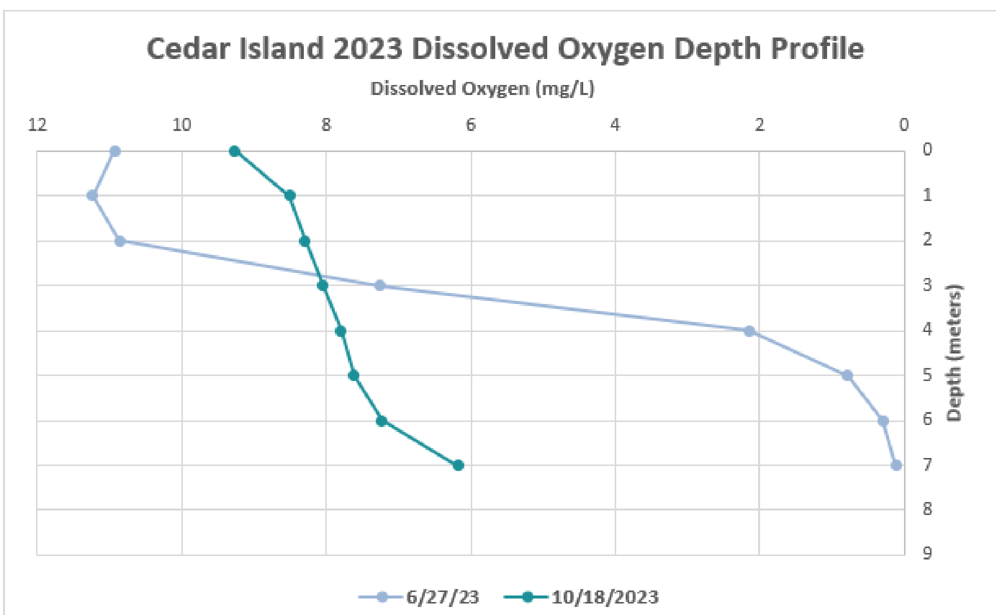
Cedar Island Depth Profiles - *Non-Flowage*



Cedar Island is one of the larger lakes in the chain, with 27 miles of shoreline and 76% of the lake being 15 feet deep or less. The temperature and dissolved oxygen profiles compiled here are both from sampling dates on June 27th and October 18th, 2023. The temperature and dissolved oxygen meter did not arrive until mid-June, so May 2023 depth data was not captured.

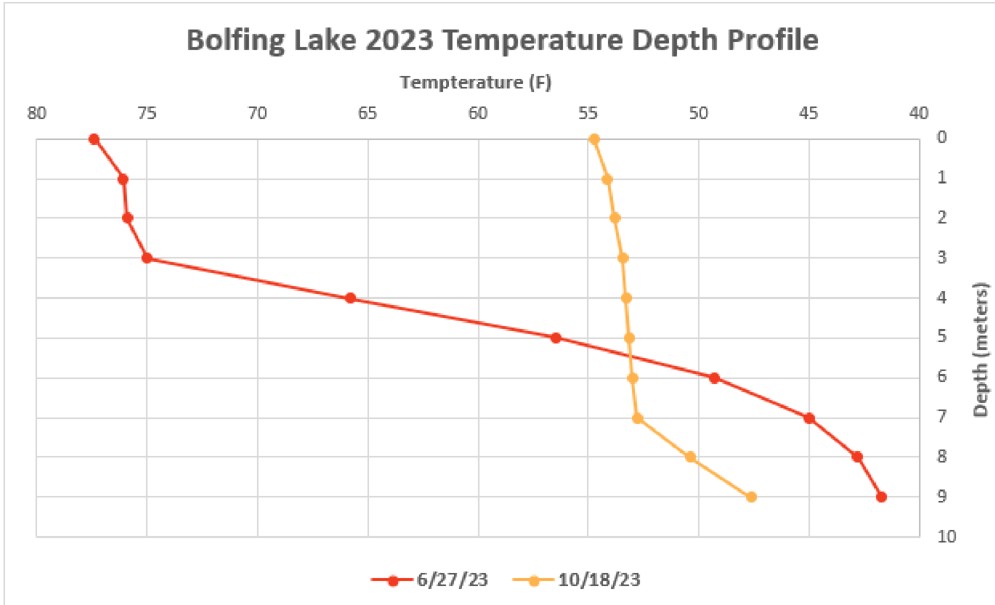
The temperature graph above shows that in June, the water temperature went from ~78°F near the surface down to ~52°F near the bottom. The oxygen concentrations graph below for Cedar Island shows a big reduction in oxygen levels around 2-4 meters depth on June 27th, with anoxic conditions near the lake bottom. This temperature and oxygen stratification was seen in the depth profile until mid-October. The depth temperature readings on October 18th vary only slightly throughout the profile, and the oxygen concentration near the bottom on October 18th was up to around 6 mg/L. This indicates that Cedar Island stratified by temperature and became oxygen-depleted in the early summer months. As temperatures cooled in the fall, the surface waters cooled, becoming more dense, and Cedar Island's water column turned over and mixed. This occurred some time between 9/28 and 10/18.

In the future, it may be beneficial to deviate from the MPCA recommendation of taking samples from only May to September and take lake samples in October to assess nutrient loading after lake turnover. Turnover varies from year to year, but has been occurring later as time goes on.

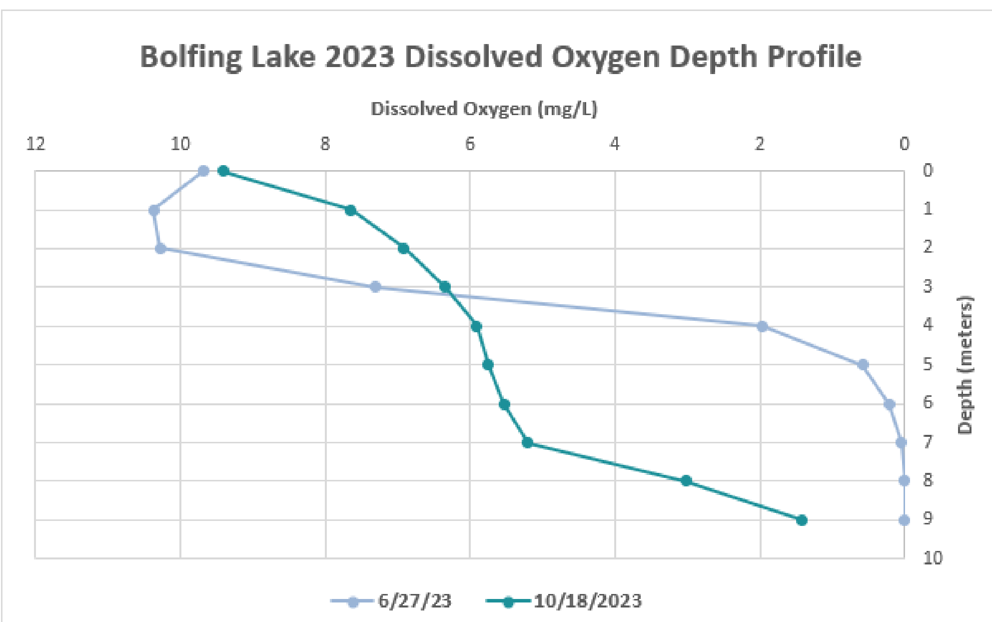


Bolfing Lake Depth Profiles - *Non-Flowage*

Bolfing Lake is just to the south of the SRCL flowage lakes Krays and Knaus and slowly drains towards the Sauk River flowage area as its lake outlet. The temperature and dissolved oxygen profiles compiled here are both from sampling dates on June 27th and October 18th, 2023. The temperature and dissolved oxygen meter did not arrive until mid-June, so May 2023 depth data was not captured .

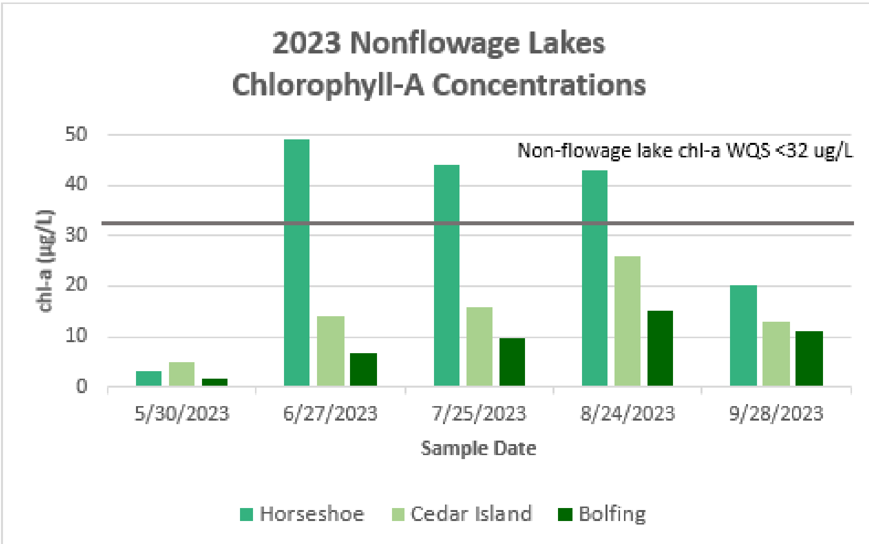


The temperature graph above shows that in June, the water temperature went from ~77°F near the surface down to ~42°F near the bottom. The oxygen concentrations graph below for Bolfing Lake shows a big reduction in oxygen levels around 2-5 meters depth on June 27th, with anoxic conditions near the lake bottom. This temperature and oxygen stratification remained in the Bolfing depth profiles until mid-October. Although the water temperature did not change much on October 18th, the water at the bottom was still colder and denser than the upper layer, so the lake was still stratified. The oxygen concentrations on October 18th had begun to rebound and come back up in the profile. This increase in oxygen indicates some mixing was occurring in Bolfing's water column, but the lake had not yet fully turned over.

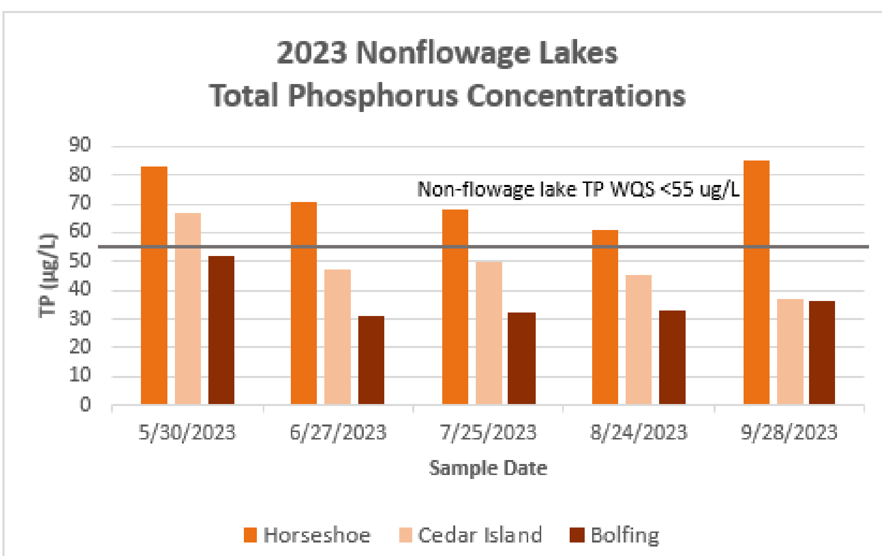


Lake turnover varies from year-to-year and from lake-to-lake, but has been occurring later in the fall as time goes on. It may be beneficial to deviate from the MPCA recommendation of taking samples from only May to September and take lake samples in October to assess nutrient loading after lake turnover.

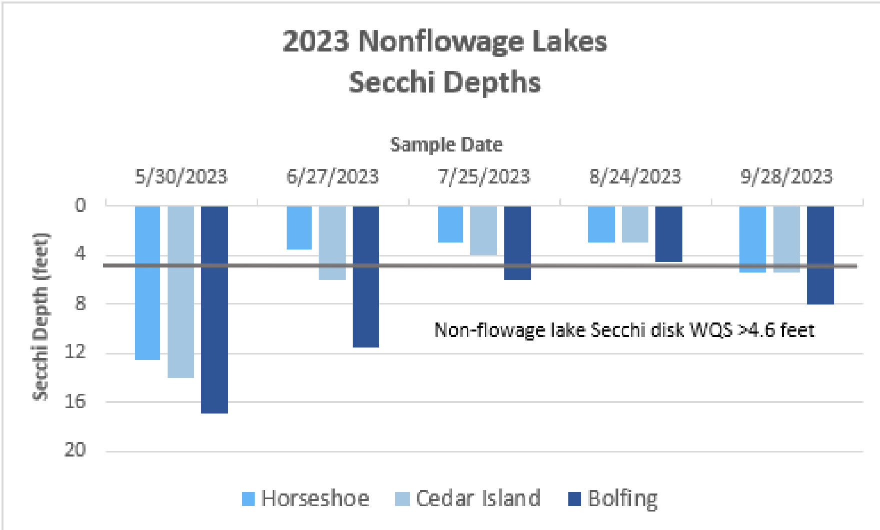
2023 Non-Flowage Lakes WQ - *Horseshoe, Cedar Island, Bolfing*



The site-specific water quality standards for the non-flowage lakes in the chain are balanced between the water quality standards for the Sauk River and the standards for lakes in the North Central Hardwood Forest Ecoregion. This is due to the increased connectivity of these non-flowage lakes with the Sauk River, which is much different than a traditional lake outlet. The graph above contains Horseshoe Lake's chlorophyll-A sample results, which exceeded the water quality standard of 32 µg/L in June, July, and August. Cedar Island and Bolfing had no chl-a WQ exceedances in 2023. The graph below shows that all of Horseshoe Lake's total phosphorus samples taken in 2023 were above the water quality standard of 55 µg/L, while Cedar Island only exceeded the standard once in May. Bolfing Lake was below the total phosphorus standard at all sample dates. It should be noted that Horseshoe Lake is the first lake the Sauk River enters in the chain, with Cedar Island coming later, and Bolfing Lake near the end of the chain. A pattern is apparent in the monthly data showing a reduction in phosphorus and chlorophyll concentrations the further into the chain the water travels.



2023 Non-Flowage Lakes WQ cont...



2023 Secchi disk depth measurements started out great in May, with good depth visibility at all three non-flowage lakes. Horseshoe Lake began to have poor Secchi visibility in June, followed by Cedar Island in July. Bolfing Lake, for the most part, was able to meet Secchi disk water quality standards throughout the season.

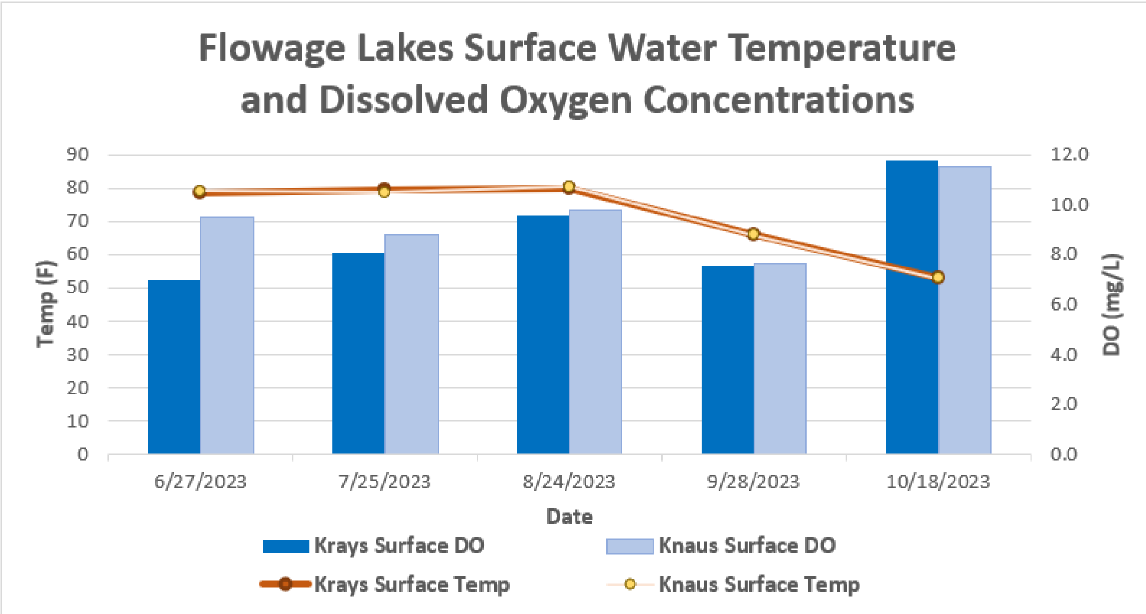
2023 Non-Flowage Lakes Summary

Month	Horseshoe TSI	Cedar Island TSI	Bolfing TSI
May	50	50	44
June	64	56	48
July	65	59	53
Aug	64	61	56
Sept	60	55	52

Using the 2023 non-flowage lakes' sample results for total phosphorus, chlorophyll-A, and Secchi disk depth readings, the Carlson trophic state index (TSI) was applied. The Carlson TSI is used to indicate how much aquatic plant and animal life a waterbody can sustain and the likelihood of observing poor water quality conditions due to the interplay between these three parameters. Horseshoe, Cedar Island, and Bolfing Lakes are all considered to be in the eutrophic range, which is a TSI value between 50 to 70. Sampling on Bolfing Lake had not occurred for some time, so only data from 2009 and 2023 is available for Bolfing. Applying the site-specific standards for non-flowage lakes (see page 2) to the Carlson TSI, we find that a TSI value of 61 and below is appropriate for non-flowage lakes. The 2023 annual average for Horseshoe sits just at a TSI of 61, and Cedar Island and Bolfing are both below the standard with a TSI of 56 and 51, respectively. Comparing 2009 to 2023, we can see the annual average Carlson TSI values have come down over the last 14 years in all three lakes.

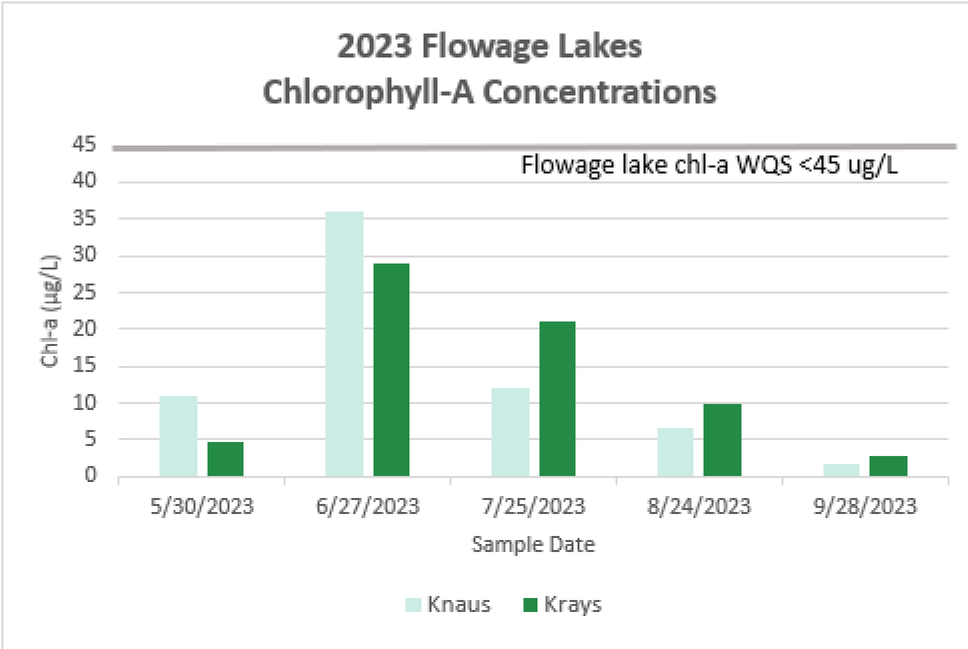
Year	Horseshoe TSI	Cedar Island TSI	Bolfing TSI
2009	66	66	68
2010	67	63	-
2011	67	68	-
2012	-	-	-
2013	-	-	-
2014	69	65	-
2015	63	63	-
2016	63	57	-
2017	60	54	-
2018	64	54	-
2019	65	59	-
2020	65	61	-
2021	63	59	-
2022	60	54	-
2023	61	56	51

Krays and Knaus Lake Depth Profiles—*Flowage*

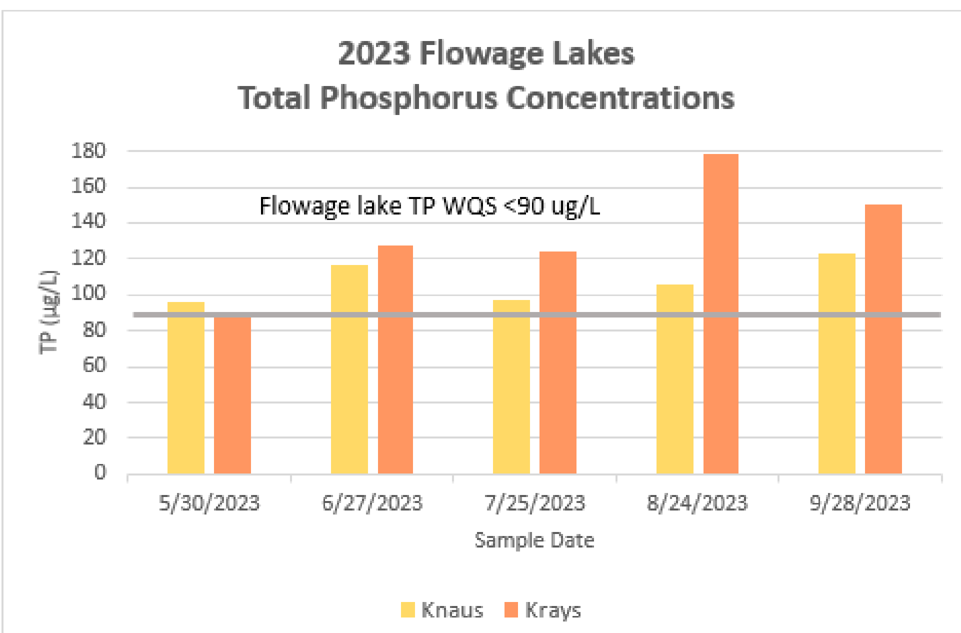


Krays and Knaus Lakes are Sauk River flowage lakes, and they have their own site-specific standards due to this unique flow condition. These lakes are very shallow, with the water quality sampling locations averaging just 7 feet. These shallow conditions do not allow for the lakes to stratify, and water temperature and dissolved oxygen concentrations are comparable throughout the profile. The graph above contains the surface water temperatures (graphed lines with axis labels on the left side of the graph) and dissolved oxygen concentrations (graphed bars with the axis labels on the right side of the graph) for both Krays and Knaus Lakes in 2023. Both lakes' temperature and oxygen concentrations were essentially equivalent throughout the season. The shallow nature of these lakes, along with a quick water residency time of just 7 days as the Sauk River flows through, keep the lakes well mixed and oxygenated throughout the season.

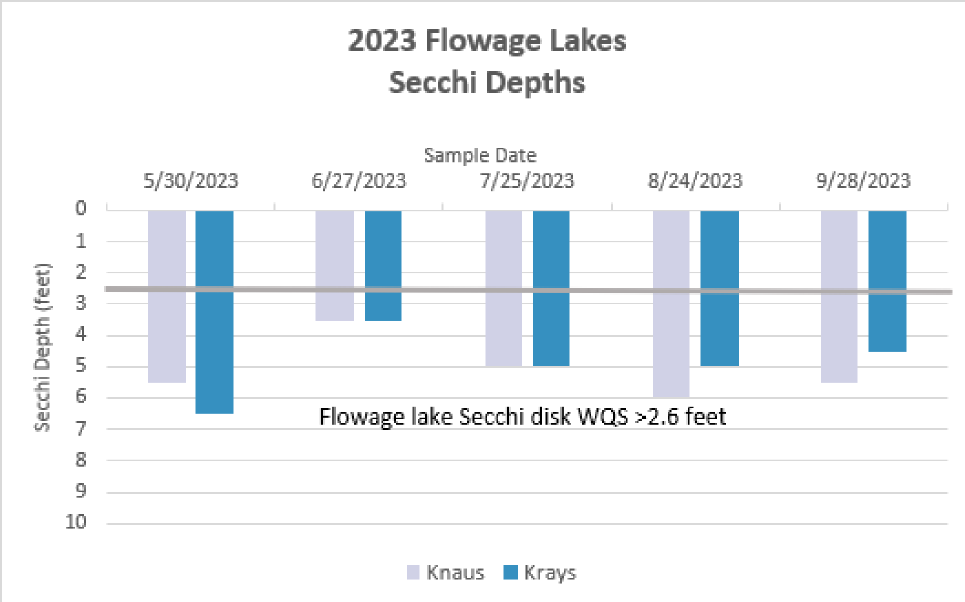
2023 Flowage Lakes WQ - *Krays, Knaus*



Water quality standards for the flowage lakes in the Sauk River Chain of lakes are closer to the water quality standards for the Sauk River. This is because the quality of the water that passes through these lakes is greatly influenced by the existing water quality in the Sauk River. All chlorophyll-A samples from Knaus and Krays Lakes in 2023 were below the water quality standard of 45 µg/L. All total phosphorus samples taken in 2023 exceeded the water quality standard of 90 µg/L for both lakes. It appears that Knaus Lake's total phosphorus levels are consistently below levels in Krays. This is likely due to Knaus Lake being further along the flowage lakes, giving nutrients more time to settle out or be metabolized by aquatic organisms.



2023 Flowage Lakes Cont…



All Secchi disk depth measurements were greater than the site-specific water quality standard of at least 2.6 feet for flowage lakes.

2023 Flowage Lakes Summary

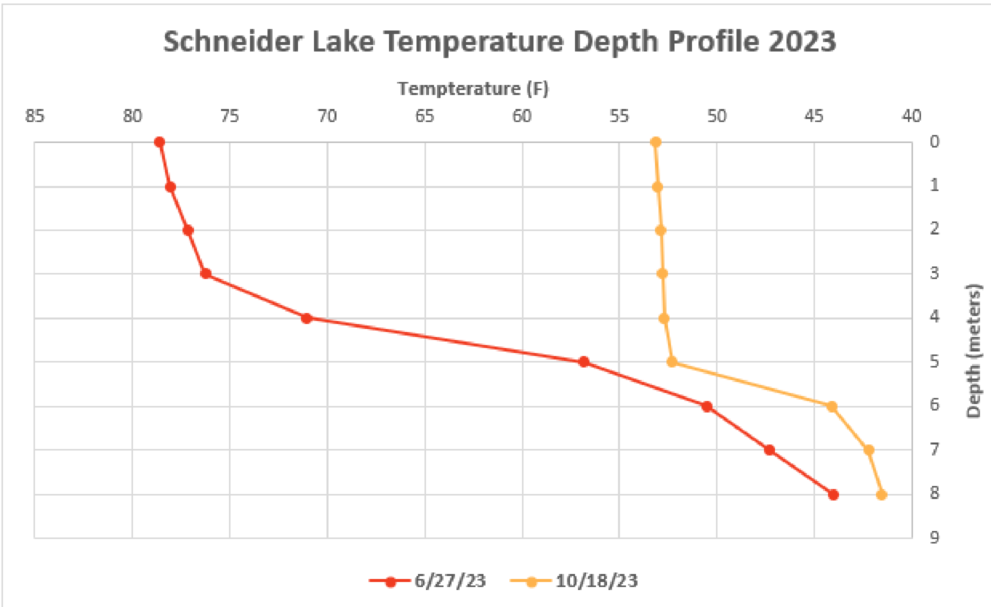
Month	Krays TSI	Knaus TSI
May	59	55
June	66	66
July	60	63
August	57	62
September	54	57

Using the 2023 flowage lakes' sample results for total phosphorus, chlorophyll-A, and Secchi disk depth observations, the Carlson trophic state index (TSI) calculations were applied. Both Krays and Knaus Lakes were in the eutrophic range in 2023, which is a TSI value of 50 to 70. The annual average Carlson TSI values in 2023 were the lowest average TSI for both lakes going back to 2009. Both Krays and Knaus Lakes are generally shallow, with an average depth of ~7 feet. The water in both lakes was approximately the same temperature and oxygen concentration throughout the year, and the water was well mixed from the top to the bottom of the water column. This indicates that Krays and Knaus Lakes generally do not stratify and do not contribute much internal loading of nutrients, as they do not experience hypoxic conditions.

Year	Krays TSI	Knaus TSI
2009	72	-
2010	69	69
2011	70	70
2012	70	71
2013	69	69
2014	-	-
2015	69	70
2016	68	65
2017	65	64
2018	66	64
2019	68	67
2020	68	67
2021	69	68
2022	63	64
2023	62	60

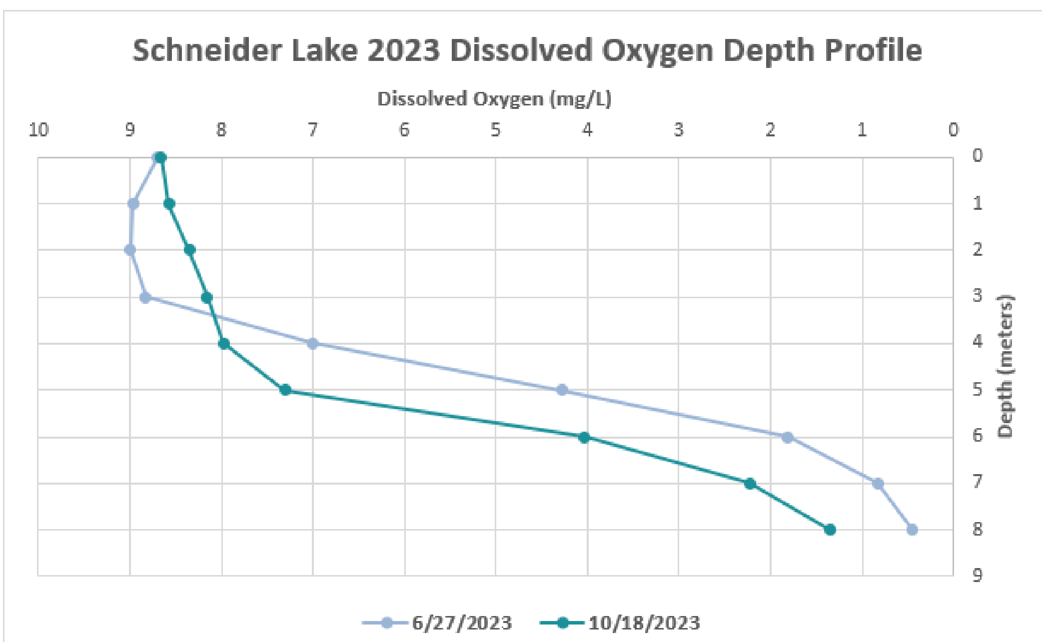
Applying the site-specific standards for flowage lakes (see page 2) to the Carlson TSI, we find that a TSI value of 67 and below is appropriate for flowage lakes. In the past, Krays and Knaus Lakes have had annual average TSIs (or TSI values) above 67, but 2022 and 2023 have both been below this value. Hopefully this trend continues, and nutrient reductions and increasing Secchi disk visibility will continue to show an improving trend in annual average Carson TSIs.

2023 Schneider Lake Depth Profiles - *NCHF*



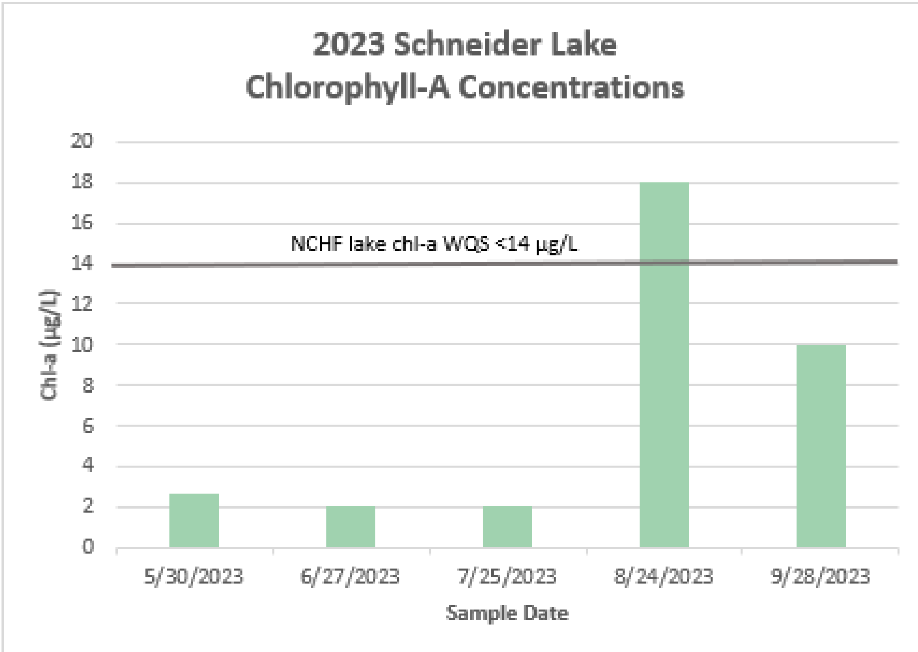
Schneider Lake is just north of the SRCL flowage lakes and is considered a natural lake due to its small, singular outlet to the chain of lakes. The temperature and dissolved oxygen profiles compiled here are both from sampling dates on June 27th and October 18th, 2023. The temperature and dissolved oxygen meter did not arrive until mid-June, so May 2023 depth data was not captured.

The temperature graph above shows that in June, the water temperature went from ~77°F near the surface down to ~44°F near the bottom. The oxygen concentration graph below for Schneider Lake shows a big reduction in oxygen levels around 3-6 meters depth on June 27th, with anoxic conditions near the lake bottom. The water column remained stratified by temperature and oxygen concentration when the last depth profile was taken in mid-October. Although the water temperature on October 18th did not swing widely, the water at the lake bottom was still colder and denser than the upper layer. The oxygen concentrations near the lake bottom on October 18th were still hypoxic, and oxygen conditions had not yet improved much. Schneider lake had not yet turned over by the end of the 2023 season.

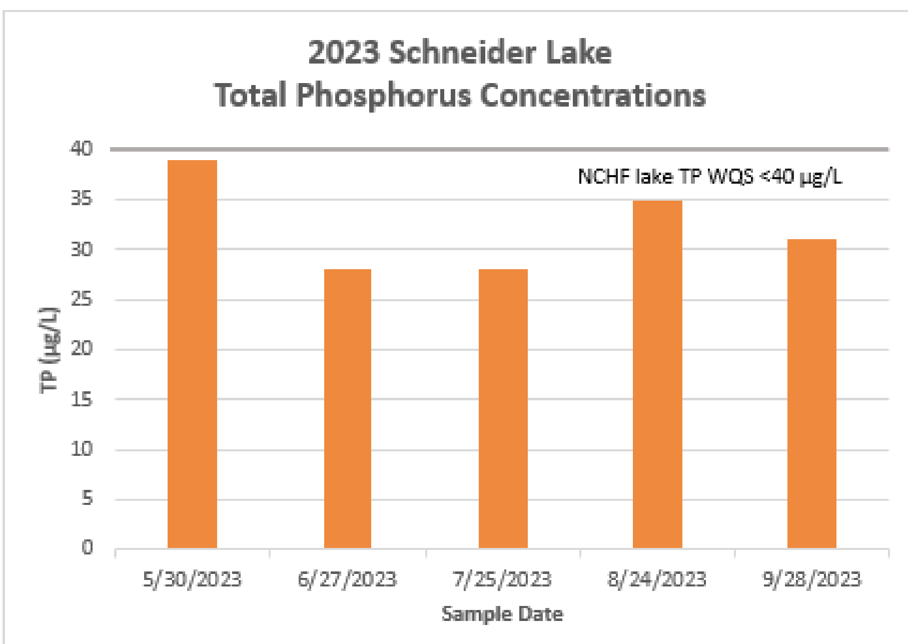


Lake turnover varies from year-to-year and from lake-to-lake, but has been occurring later in the fall as time goes on. It may be beneficial to deviate from the MPCA recommendation of taking samples from only May to September and take lake samples in October to further assess late season conditions.

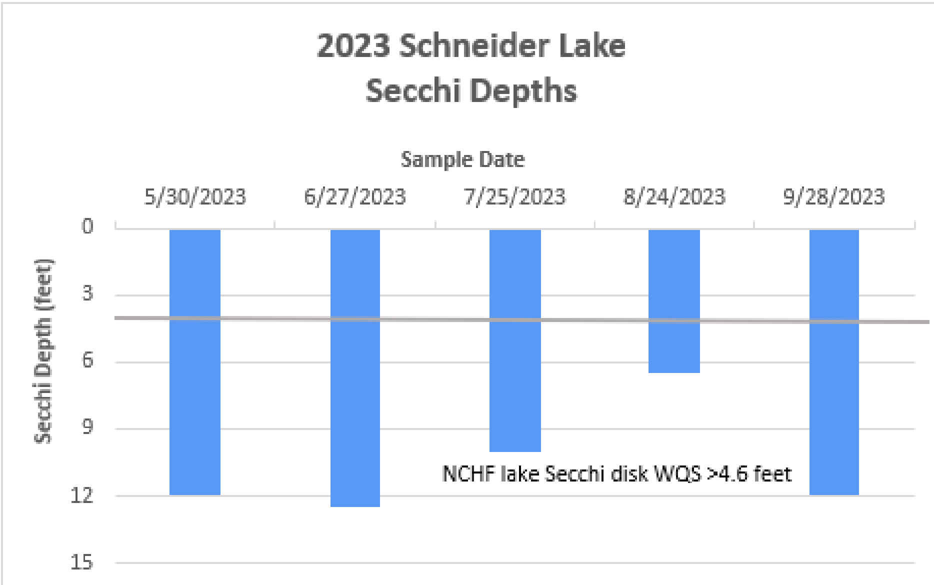
2023 Schneider Lake WQ - *NCHF*



Schneider Lake is considered a natural lake by the MPCA and follows the North Central Hardwood Forest ecoregion water quality standards (see page 2). Looking at the graph above, despite there being low levels of chlorophyll-A early in the summer, there was one exceedance of the WQ standard in August before dipping back below the standard in September. The total phosphorus samples taken from Schneider Lake in 2023 were all below the water quality standard of 40 µg/L and remained generally stable throughout the season.



2023 Schneider Lake WQ cont…



All Secchi disk depth measurements from Schneider Lake in 2023 were greater than the water quality standard of at least 4.6 feet.

2023 Schneider Lake Summary

Month	Schneider TSI
May	44
June	48
July	53
Aug	56
Sept	52

Using the 2023 Schneider Lake sample results for total phosphorus, chlorophyll-A, and Secchi disk depth observations, the Carlson trophic state index (TSI) was applied for each month. In 2023 Schneider Lake's TSIs ranged from mesotrophic, a TSI 40 - 50, to eutrophic, a TSI 50 - 70. The annual average Carlson TSI value for 2023 was 49. Schneider Lake stratified by water temperature and dissolved oxygen concentration in early summer and remained stratified at the last depth profile in October. The oxygen concentrations near the lake bottom in October were still hypoxic, and Schneider lake had not yet turned over by the end of the 2023 season.

Applying the site-specific standards for natural lakes (see page 2) to the Carlson TSI, we find that a TSI value of 56 and below is appropriate for natural lakes in the North Central Hardwood Forest (NCHF) ecoregion. Many of the annual average TSI values for Schneider Lake since 2009 have been at or near a TSI of 56, but in 2022 and 2023 the annual average has fallen below a TSI of 50. Hopefully this trend continues, and nutrient reductions and increasing depth visibility will continue to improve.

Year	Schneider CTSI
2009	58
2010	55
2011	53
2012	56
2013	58
2014	-
2015	54
2016	56
2017	51
2018	54
2019	52
2020	56
2021	56
2022	48
2023	49

SRCL 2023 Summary

The Carlson TSI results for all lakes sampled in 2023 are compiled below. Schneider Lake had the best overall water quality of the sampled lakes in 2023. Schneider's annual average TSI is considered mesotrophic, indicating moderately clear water and intermediate oxygen conditions. All the other SRCL lakes fell into the eutrophic category, indicating somewhat cloudy water and reduced oxygen conditions as the summer progressed along with algal scum. Flowage lakes Knaus and Krays, along with non-flowage Horseshoe Lake, had the highest levels of total phosphorus and the highest Carlson TSIs of the SRCL lakes. These three lakes are highly affected by the Sauk River's water quality conditions, which is likely why these lakes trend higher for total phosphorus in general. Looking at the annual average TSI scores for each lake in 2009 vs. 2023, we can see a decrease in the TSI values, indicating improving water quality over this time period. Although each year's environmental conditions are highly variable, we are moving in the right direction.

Continued monitoring in and around the Sauk River Chain of Lakes will help identify water quality changes and emerging issues and guide the actions of government and citizen scientists to help preserve and protect the invaluable resources found in the chain. The SRWD appreciates the time and efforts of the Sauk River Chain of Lake Association, Inc. and looks forward to continuing our similar missions in pursuing fishable and swimmable water in the region.

Year	Horseshoe TSI	Cedar TSI	Bolfing TSI	Krays TSI	Knaus TSI	Schneider TSI
2009	66	66	68	72	-	58
2010	67	63	-	69	69	55
2011	67	68	-	70	70	53
2012	-	-	-	70	71	56
2013	-	-	-	69	69	58
2014	69	65	-	-	-	-
2015	63	63	-	69	70	54
2016	63	57	-	68	65	56
2017	60	54	-	65	64	51
2018	64	54	-	66	64	54
2019	65	59	-	68	67	52
2020	65	61	-	68	67	56
2021	63	59	-	69	68	56
2022	60	54	-	63	64	48
2023	61	56	51	62	60	49

Water Quality Monitoring Parameters

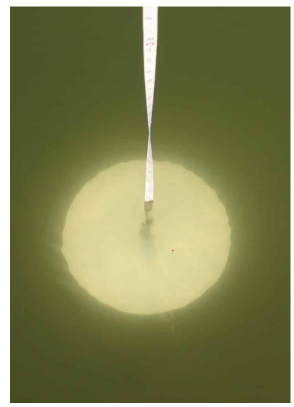
Chlorophyll-A (chl-a) - Chlorophyll -A is a measure of the amount of algae growing in a waterbody and can be used as an indicator of water quality. It is a comparable analysis to TSS in streams. As water warms, algae begins to grow, and the amount of growth is dependent on the amount of nutrients in the water body. Although algae is a natural part of freshwater ecosystems, too much algae can result in decreased levels of oxygen in the waterbody and cause aesthetic problems, such as green scum and bad odors. Some algae naturally produce toxins as well, which can be a public health concern in high concentrations. Waterbodies that receive septic systems discharges and agricultural and urban runoff may have high concentrations of chl-a in response to the excess nutrients. The general water quality standard for chl-a in lakes within the north central hardwood forest (NCHF) ecoregion is less than 14 µg/L.

Total Phosphorus (TP) - Total phosphorus is a measure of both the organic and inorganic forms of phosphorus. Organic phosphorus is not commonly found in suspension in the water column and is not as chemically available as food. Inorganic phosphorus, referred to as orthophosphorus, is commonly dissolved in water and is readily available to plants and animals. Phosphorus is an essential nutrient for growth, but is only necessary in small concentrations to sustain life. Phosphorus can also be found in the water column and embedded in water bottom materials. Most rivers and lakes have elevated phosphorus, with point source contributions from wastewater and industrial releases, and nonpoint source contributions from agricultural fertilizers and contaminated groundwater. Minnesota is broken up into ecoregions to account for the variability in landscape, land use, and weather across the state, and each ecoregion has unique water quality standards. The Central River Nutrient Region standard for total phosphorus in the Sauk River is less than 100 µg/L. The total phosphorus level for lakes in the chain varies depending on depth and connectivity to the river.

Secchi Disk - Water clarity is measured using a Secchi disk (also known as a transparency disk) that is lowered into the water until it can no longer be seen, and the depth of visibility is noted. Secchi disk readings are used to assess water visibility and quality. The general water quality standard for lake Secchi disk readings in the north central hardwood forest (NCHF) ecoregion is greater than 4.6 feet (1.4 meters).

Common Terms

Eutrophication - The term comes from the Greek *eutrophos*, meaning "well-nourished." Eutrophication occurs when an excess of nutrients that are usually environmentally limited enter a river or lake system and contribute to excessive plant and algae growth. Eutrophication can have quite negative impacts on aquatic communities' health. The excessive plant growth can clog up boat motors, outcompete native plants, and change the animals that are able to survive in the waterbody. When the excessive plant growth dies back and decomposes, microbes in the water break down the plant material and use up the majority of the available oxygen in the waterbody. This creates low oxygen (anoxic) conditions and will stress and even kill aquatic animals. Additionally, water clarity and recreational suitability are greatly reduced in eutrophic conditions, and physical contact with or ingestion of the water could result in indigestion or even death.



Carlson's Trophic State Index (TSI) - The Carlson Trophic State Index (TSI) is a classification system designed to rate water bodies using concentration measurements of both chlorophyll-A and total phosphorus, combined with Secchi disk readings. This rating indicates how much aquatic life, both plants and animals, a waterbody can sustain, and can be applied across all lake types and ecoregions uniformly. The higher the rating, the more likely it is that poor water quality will be observed. The word *trophic* is Greek, meaning nourishment or food. Under the TSI scale, waterbodies may be defined as:

Oligotrophic: TSI 0 - 40, Clear water, good oxygen conditions, limited nutrients available, deep or shallow lake. From the Greek "oligos" meaning few, scanty.

Mesotrophic: TSI 40 - 50, Moderately clear water but increased chance of low oxygen conditions in shallow lakes. From the Greek "meso" meaning middle, moderate.

Eutrophic: TSI 50 - 70, Moderately clear to cloudy water, with a high chance of low oxygen conditions in the summer, extensive plant growth, and potential algal scum. From the Greek "eu" meaning well, plenty.

Hypereutrophic: TSI 70+, Dense plant growth, heavy algal blooms and scum possible, low oxygen conditions, fish kill possible. From the Greek "hyper" meaning over much.

Flowage Lakes - A flowage lake is a lake that forms upstream of a dam and can be used synonymously with reservoir lake. Water in flowage lakes acts like a very slow river, as the water keeps flowing downstream, but is slowed down markedly by the dam structure. A *non-flowage* lake is a lake that was formed without the effects of downstream damming. Water enters non-flowage lakes and resides there significantly longer than in flowage lakes.

Common Terms and Concepts Cont…

Ecoregion - A region defined by distinctive geography, plant and animal communities, land uses, soil profiles, and sun and moisture patterns. Ecoregions are used by the Environmental Protection Agency (EPA) and Minnesota Pollution Control Agency (MPCA) to characterize regional differences in the state and their effects on water quality. The Minnesota ecoregion the Sauk River watershed resides in is the North Central Hardwood Forest (NCHF). The NCHF ecoregion is a transitional zone between the predominantly forested northern lakes region and the corn belt plains in Southern Minnesota. In addition to the ecoregion classification, lakes are further classified as shallow or deep, depending on the maximum and average lake depths. The size and depth of a lake influences characteristics such as water clarity, water temperature, and aquatic plant growth.

River Nutrient Region - The EPA and MPCA did not develop nationwide or even statewide water quality criteria for surface waters, but instead developed guidelines for each unique ecoregion. Each ecoregion has been studied to identify reference conditions for that area. Reference conditions are used to reflect what a pristine or minimally impacted stream condition would be, and what the normal range of conditions are in that ecosystem. The MPCA has further researched and developed river nutrient criteria for each of Minnesota's ecoregions. This is the basis for creating water quality standards appropriate to each ecoregion's background conditions. See page 2 for the specific standards for our parameters of interest.

A raindrop falling into Lake Itasca in Minnesota will travel the length of the Mississippi and arrive at the Gulf of Mexico about ninety days later.

Point Source and Nonpoint Source - These terms are used when referring to how a pollutant enters a waterbody. Point sources are single and identifiable locations, such as the end of a pipe, and are regulated by state and federal agencies. Nonpoint sources are can be rain and snow runoff, which accumulate pollutants as water drains. Places like parking lots, farmland, construction sites, and eroding streambanks are considered nonpoint sources of pollution and are harder to track, control and regulate.

Sauk River Chain Of Lakes Challenges

Due to the unique nature of the chain, conditions outside the immediate Subwatershed have a large effect on the chain. The SRCL's largest challenges when it comes to meeting water quality standards are:

1) Upstream river conditions bring high levels of total phosphorus and other nutrients to the chain system. Upstream water quality improvement projects are needed.

2)Tributaries to the lake chain system have not been sampled since 2009, and data collected at that time shows very high levels of TP in the spring, March in particular. Additional comparative samples will be necessary to assess if lake tributaries are heavily affecting individual lake conditions, as well as the chain as a whole.

The SRCLA has begun to identify if lakes in the chain are undergoing temperature stratification. In 2024 the SRWD will be active in the chain performing intensive monitoring on select lakes. This intensive monitoring will be done with SRWD time, equipment, and resources, so the SRCLA has the opportunity to focus their monitoring efforts elsewhere in the chain in 2024. The Sauk River Watershed District looks forward to working with the Sauk River Chain of Lakes Association, Inc. to build a more complete picture of water quality in the chain.

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Please Note:
The data and recommendations included in this report are based on the 2023 monitoring season. Stream and lake samples were collected by Gary Schnobrich, SRCLA's water quality volunteer, and all data was reviewed by the Sauk River Watershed District. This report is not a complete picture of all conditions, but built to assess specific measurements of water quality.

Contact Allison Lightfoot, Environmental Monitoring Manager with the Sauk River Watershed District, with any questions or concerns regarding the information presented in this report.

All aerial photos taken from Google Earth, and all water quality standard information and state statistics were gathered from Minnesota Pollution Control Agency (MPCA) documents accessed Dec. 2023.