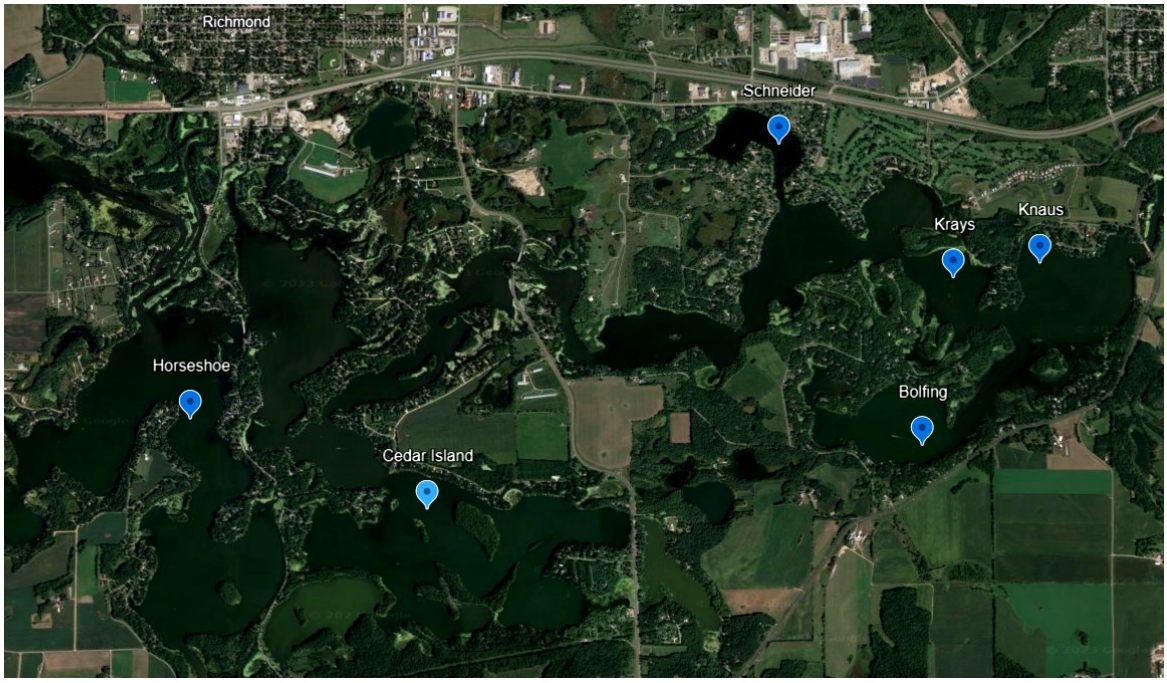
2024 SRWD Lake Monitoring Report

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

Sauk River Chain of Lakes Overview

One of the Sauk River Watershed District's (SRWD) most popular resources for habitat and aquatic recreation is the Sauk River Chain of Lakes (SRCL). This water quality monitoring summary provides the 2024 water quality sample results for six lakes within the Chain of Lakes and a review of past conditions at those sites. Lakes monitored in 2024 include: Horseshoe, Cedar Island, Schneider, Krays, Knaus, and Bolfing Lakes. Additional information regarding the Sauk River monitoring sites upstream (Richmond) and downstream (Cold Spring) of the lake system has also been included, along with flow measurements for the 2024 monitoring season.

The Sauk River Chain of Lakes Association, Inc. (SRCLA) has been actively monitoring and collecting water quality information in the chain since their 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.



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Sauk River Watershed District

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SRCL Water Quality Standards

The Sauk River Chain of Lakes is made up of 14 interconnected lakes. Some lakes are designated as shallow, some are deep, and some are considered flowage lakes of the Sauk River mainstem. The Sauk River enters the Chain of Lakes system near the city of Richmond, 95 miles south of the river's 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 2024, and in past years, have been distributed throughout the chain to incorporate shallow, deep, and flowage lakes. In 2024, the lakes monitored were: **Cedar Island** (non-flowage), **Horseshoe South** (non-flowage), **Bolfing** (non-flowage), **Knaus** (flowage), **Krays** (flowage), and **Schneider** (North Central Hardwood Forest Ecoregion 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 chlorophyll-A and total phosphorus, combined with Secchi disk depth readings. The more available nutrients in a waterbody, the more likely it 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:

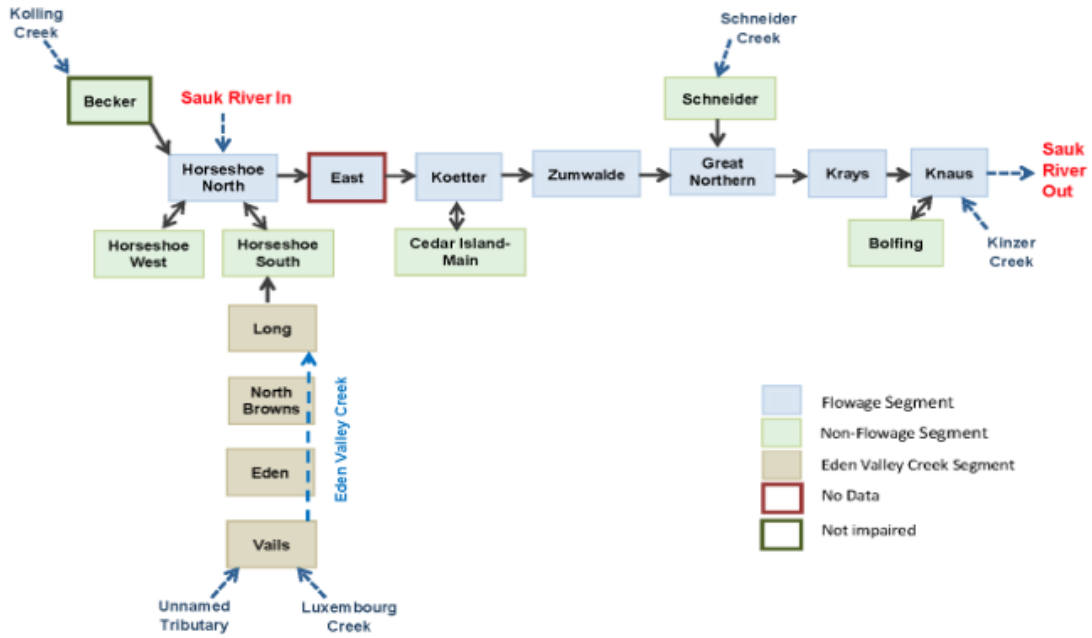
Oligotrophic: TSI 0 - 40, Clear water, good oxygen conditions, limited nutrients available, deep or shallow lake. From the Greek "oligos" meaning few, scanty.

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.

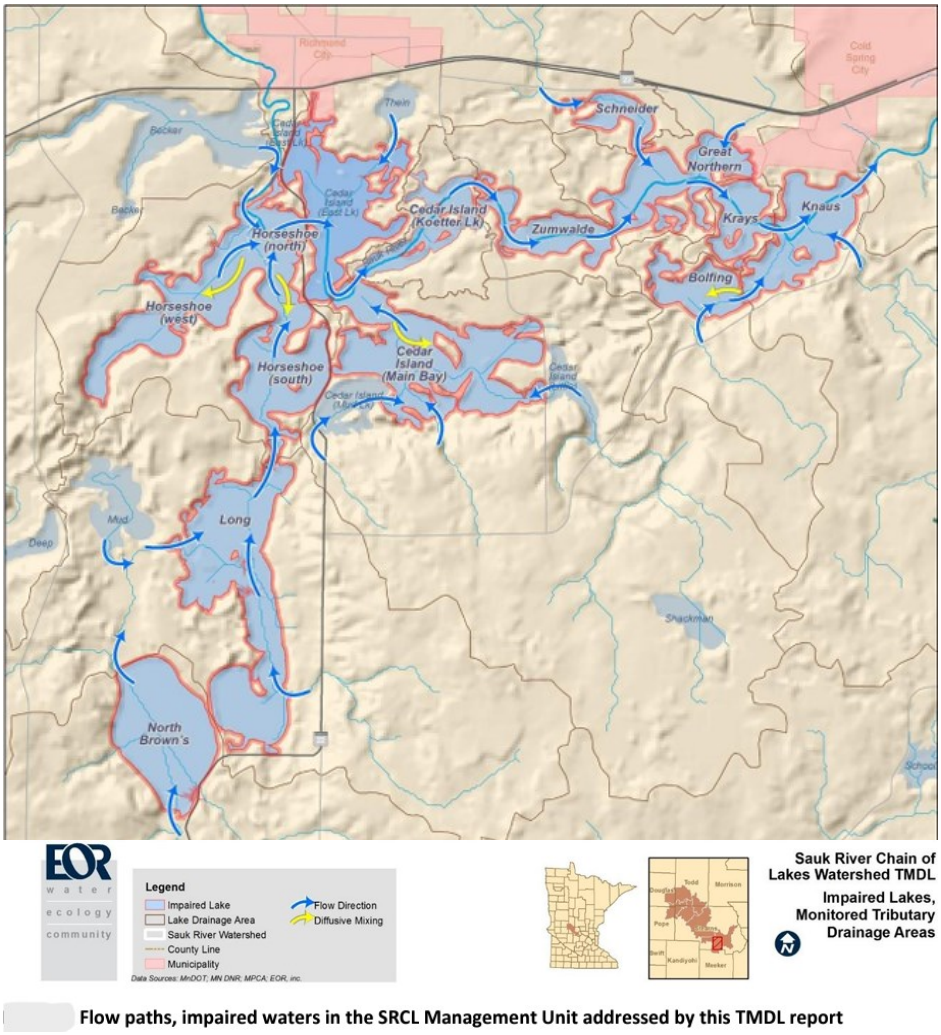
Hypereutrophic: TSI 70+, Dense plant growth, heavy algal blooms and scum possible, low oxygen conditions, fish kill possible. From the Greek "hyper" meaning over much.

For more details on the Carlson TSI, see page 29. The graphic below is the directional flow chart for the SRCL and Eden Valley Watershed Unit, and it calls out which lakes in the system are flowage lakes and which are not. The chart was taken from the MPCA TMDL Report.



River & Lake Sampling

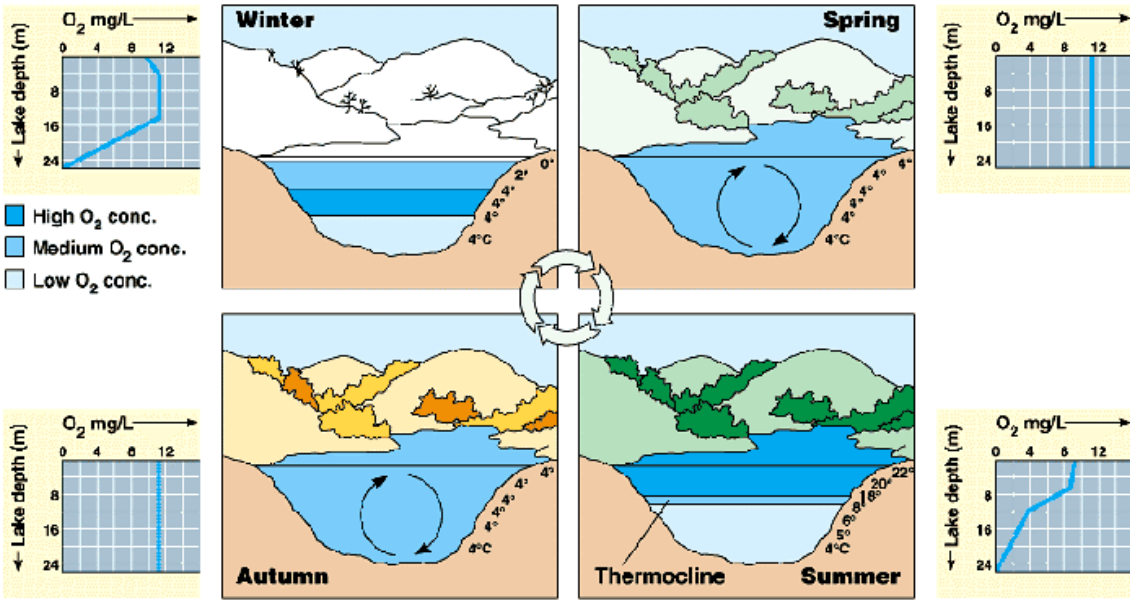
The Sauk River monitoring samples presented in this report are taken from the mainstem Sauk River near the city of Richmond and near the dam in Cold Spring. These samples are of the river's surface water only. The SRWD river sampling device, called a Van Dorn, is submerged to a maximum depth of 1-2 feet below the water surface for sample collection.



This differs from the lake sampling method, which occurred every-other week from May to October for a total of 9 sampling days in 2024. The SRWD monitors and samples 28 priority lakes within the entire watershed on a 5-year rotational basis. There are around 371 established lake basins in the watershed, and priority lakes are chosen based on their impairment status and connectivity to the Sauk River. All of the 28 SRWD priority lakes are listed as impaired, and continued data collection is important to track water quality trends and supporting TMDL development. The six lakes sampled in the chain are all listed as impaired for Aquatic Recreation: Nutrients/Eutrophication Biological Indicators.

Lake samples were collected by SRCLA volunteers and/or SRWD staff 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. The surface water quality parameters include total phosphorus (TP), ortho-phosphate (OP), chlorophyll-A (chl-A), and total Kjeldahl nitrogen (TKN). If a thermocline and/or oxycline layer was detected, an additional sample was also taken one meter off the lake bottom using a Kemmerer depth sampler. A thermocline is a zone in the water column at which temperature changes rapidly with warmer water near the surface and colder water near the bottom. An oxycline is similar, but involves a rapid change in dissolved oxygen with lower oxygen levels near the lake bottom. The bottom samples were analyzed for TP, OP, and TKN. Also at each sampling location, a multi-parameter probe was lowered into the water and collected dissolved oxygen (DO) and temperature readings at one-meter increments until the probe hit the bottom. This data was used to create water column profiles for each lake and assess the presence or absence of a thermocline/oxycline.

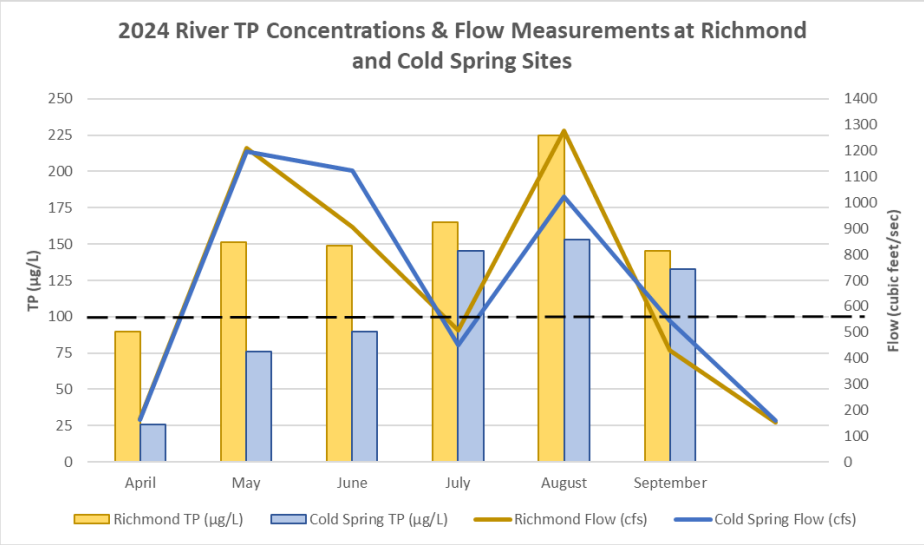
Lake Stratification & Water Quality



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 depth profile is taken from the lake surface to the lake bottom. 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 2 milligrams per liter), or even become "anoxic" (completely 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.

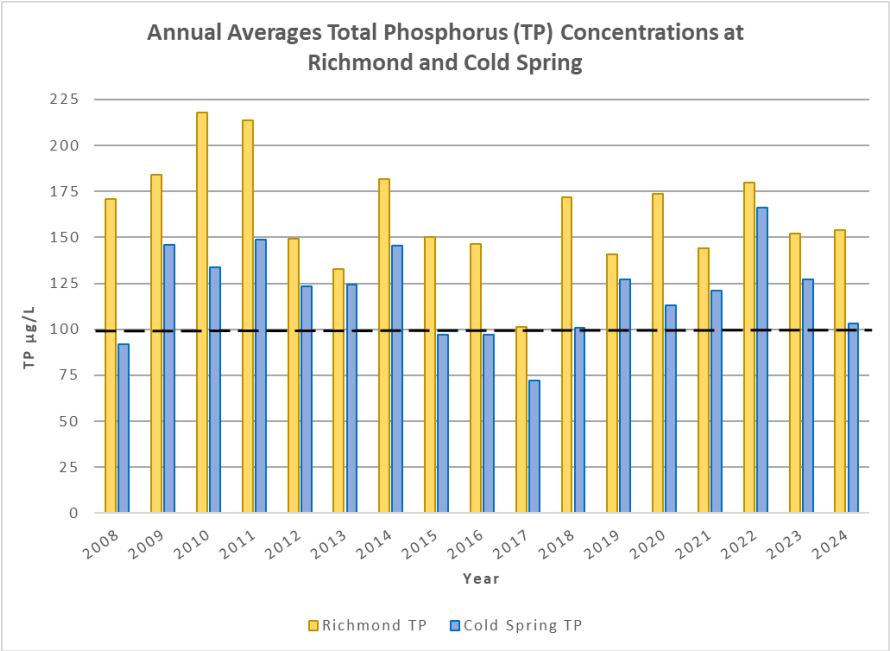
Hypoxic conditions in the lake also create hypoxic conditions in the lake bottom sediments. This lack of oxygen changes the chemical interaction of the sediment and water, leading to more dissolved phosphorus and nitrogen being released from the sediment to the bottom layer. Additionally, lake bottom-dwelling bacteria usually use oxygen to metabolize phosphorus and nitrogen into energy. Hypoxic lake bottom conditions change the bacteria's metabolism; they switch from aerobic respiration to anaerobic respiration, which can lead to the release of more phosphorus. The process of low-oxygen conditions leading to a release of sediment nutrients is known as ***internal lake nutrient loading***. Internal loading occurs naturally in many lakes, but it 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.

2024 Sauk River Phosphorus and Flows

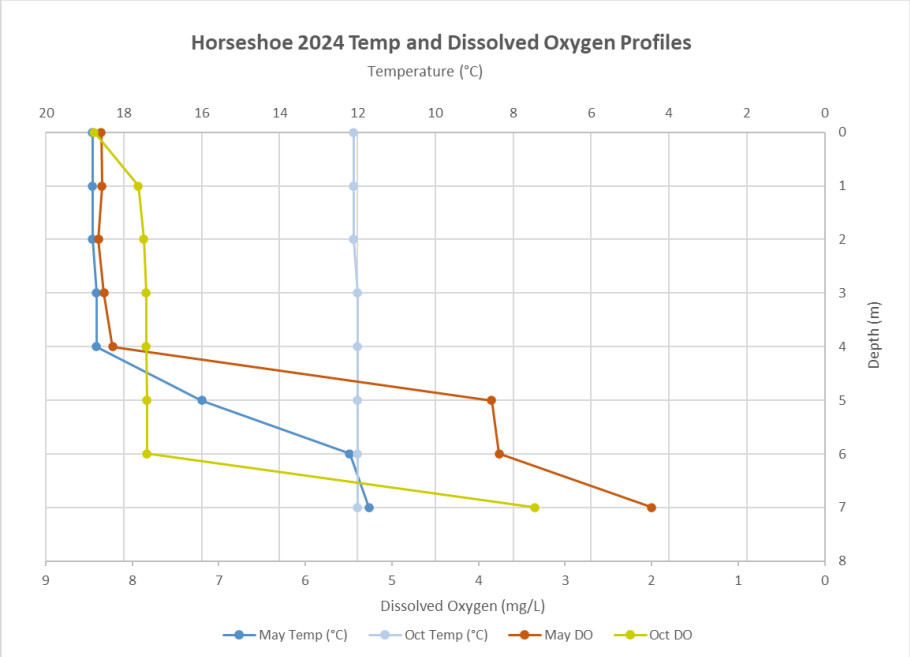


The SRWD maintains long-term monitoring sites upstream of the Chain of Lakes on County Road 111 near the city of Richmond and downstream of the chain on Red River Road near the Cold Spring Dam. River monitoring sites are visited regularly from March to October, and water quality (WQ) samples are taken twice a month. Flow (discharge) measurements are also taken by the SRWD monthly at each main-stem river site. The 2024 monitoring year saw both extremes of high flows and low flows. We started out the year in drought conditions, with flow measurements at both sites (graphed as a line on the right vertical axis) being around 165 cubic feet/second (cfs). The rains came, and there was a large jump for flows in May with cfs reaching above 1100 at both sites. More rain means more runoff entering the river, so there was a steady increase in total phosphorus (TP) levels as well. The monthly averages for both the Richmond and Cold Spring sites peaked in August. TP levels at the Richmond site are consistently higher than at Cold Spring because sediment and nutrients have a chance to settle out of the system once they enter the chain. The monthly averages for TP concentration at the Cold Spring site remained below the water quality (WQ) standard of **<100 µg/L** for April, May, and June. Richmond exceeded the standard for every month except for April. As flows came down in September, so did TP concentrations. To give some context for the high TP results, according to daily precipitation data from the St. Cloud Regional Airport, the monitoring season experienced accumulated precipitation that was **4.87 inches higher** than the accumulated daily normal for any given year. A wet year with big runoff events leads to higher levels of phosphorus in the system.

The bottom graph contains the annual average total phosphorus (TP) concentrations for the Richmond and Cold Spring sites since 2008. Both sites exceed the TP WQ standard the vast majority of the time. The annual average at Cold Spring this year was 103 µg/L, barely above the WQ standard. The high TP concentrations in the Sauk River upstream of the Chain of Lakes near Richmond will make it difficult to meet the WQ standard in the SRCL flowage lakes. Upstream water quality improvement projects are needed to reduce phosphorus loading to the Chain of Lakes system.

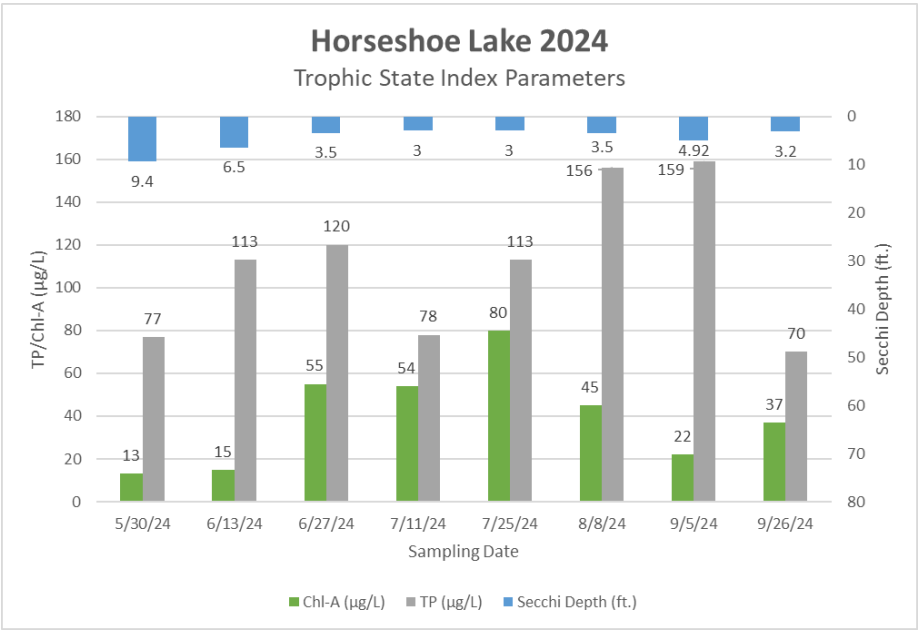


Horseshoe Lake Profiles and TSI Parameters

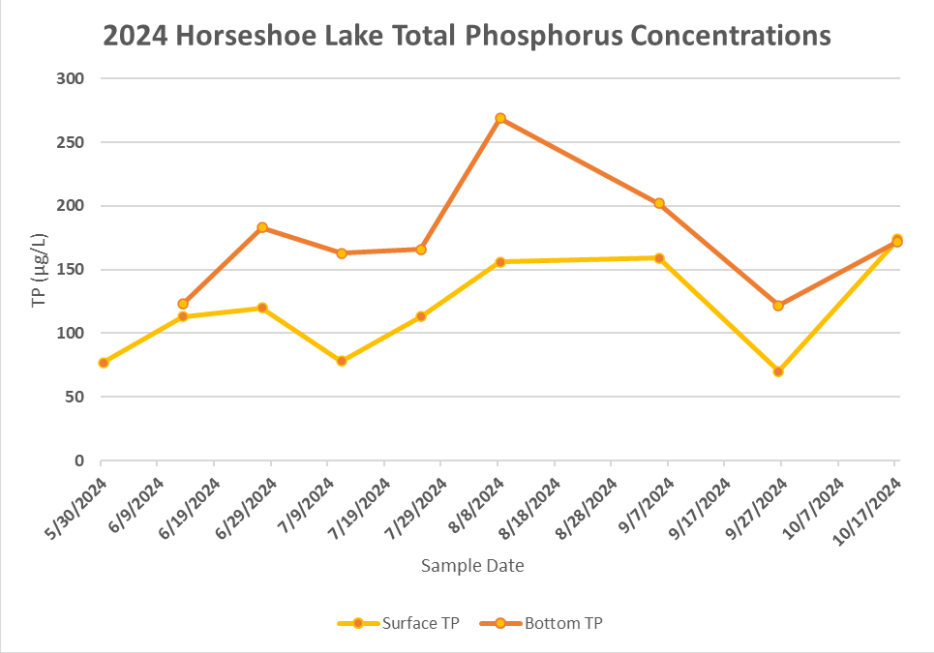


Horseshoe Lake is the first lake the Sauk River enters into the Chain of Lakes system. The temperature and dissolved oxygen profiles compiled to the right are from the first and last sampling dates in 2024. **Depth** is shown on the right vertical axis and increases from the top down, while **temperature** is read across the top horizontal axis and **dissolved oxygen** on the bottom horizontal axis. The temperature graph (blue lines) shows that the May water temperature went from around 19 °C (66 °F) near the surface down to 11.7 °C (53 °F) near the bottom. The oxygen concentration in May (orange line) for Horseshoe Lake shows a large drop in oxygen levels around 4 meters, with almost hypoxic conditions near the lake bottom being at 2 mg/L. This temperature and oxygen stratification remained around the 3-5 meter range throughout summer. The water temperature in October barely changed throughout the depth profile, staying consistently near 12 °C (54 °F). The oxygen concentration in October (yellow line) started at around 8 mg/L, but did see a sharp decrease at the last meter (3.4 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 with the water column mixing enough for the temperature throughout the profile to be uniform.

The below graph includes water quality parameters that are used to calculate a Carlson Trophic State Index (TSI) score. A breakdown of each lake's TSI score will be provided in the summary section for that lake type (non-flowage, flowage, or NCHF). This common classification method is used to evaluate the health of a waterbody based off of chlorophyll-A (chl-A) levels, total phosphorus (TP), and water clarity (measured by Secchi depth). The index is a scale from 0 -100, with a low score indicating better water quality. For more information on Carlson TSI, see page 29. Secchi depth is displayed from the top down and is read on the right vertical axis. Horseshoe exceeded the chl-A site-specific standard of <32 µg/L for all but 3 samples. The lake exceeded the TP WQ standard of <55 µg/L for each sample. For Secchi depth, it satisfied the WQ standard of >4.6 ft. for only 3 sampling visits.



Horseshoe Lake Total Phosphorus

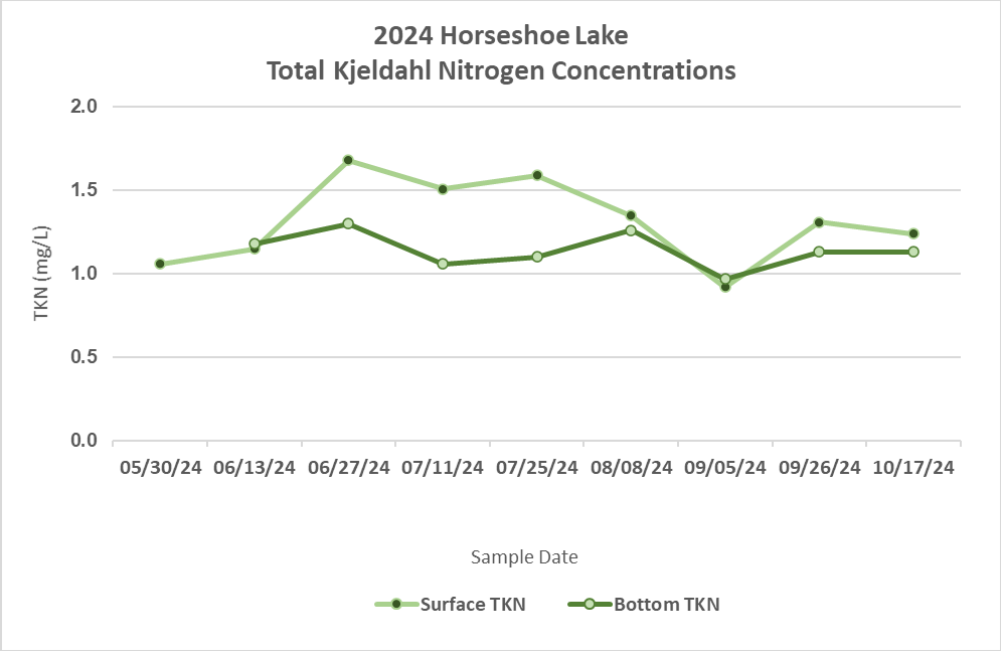


The graph above for TP shows that concentrations for surface and bottom started off fairly similar, but bottom phosphorus concentrations started to take off as summer progressed. Anoxic conditions throughout the warm months caused bacteria living near the bottom to release more phosphorus from breaking down sediments and settled organic matter. This indicates that internal nutrient loading is occurring. Surface concentrations (yellow line) peaked in August and September, and there was a large spike in August for the bottom sample coming in at 269 µg/L. By the sampling visit on 10/17, it is clear that Horseshoe had mixed and was no longer stratified; both the surface and bottom concentrations were ~170 µg/L, which is 3 times higher than the WQ standard of <55 µg/L for TP. The annual averages for phosphorus are also significantly higher than the other non-flowage lakes that were sampled (Cedar Island and Bolfing).

TP is a measure of all molecular forms of phosphorus, but ortho-phosphate (OP) measures only the inorganic form that is readily taken up by plants in bio-respiration. There is no WQ standard for OP because larger forms of phosphorus will eventually break down into OP and become bioavailable. **High levels of OP have been correlated with poor water quality conditions and eutrophication in lakes and rivers**. The ratio of OP to TP indicates how much of all forms of phosphorus in a lake is bioavailable for consumption at the time. On average, the ratio of OP to TP in 2024 for surface samples in Horseshoe was 39%. For bottom samples, the average ratio was 84%. The table below contains all sample results for 2024, including OP:TP ratios.

Lake Name	Site ID	Sample Date	Surface Temp (°C)	Surface DO (mg/L)	Secchi Disk Depth (feet)	Surface Chl-a (µg/L)	Surface TP (µg/L)	Suface OP (µg/L)	% Surface OP:TP	Surface TKN (mg/L)	Bottom TKN (mg/L)	Bottom TP (µg/L)	Bottom OP (µg/L)	% Bottom OP:TP	Bottom Sample Depth (m)
Horseshoe	73-0157-00-211	5/30/24	18.8	8.4	9.4	13	77	26	*34*	1.06					
Horseshoe	73-0157-00-211	6/13/24	23	8.9	6.5	15	113	75	*66*	1.15	1.18	123	95	*77*	5.5
Horseshoe	73-0157-00-211	6/27/24	23.6	14.0	3.5	55	120	34	*28*	1.68	1.30	183	168	*92*	5.5
Horseshoe	73-0157-00-211	7/11/24	25.7	15.3	3.0	54	78	5	*6*	1.51	1.06	163	141	*87*	5
Horseshoe	73-0157-00-211	7/25/24	24.6	12.1	3.0	80	113	6	*5*	1.59	1.10	166	142	*86*	5
Horseshoe	73-0157-00-211	8/8/24	21.7	8.2	3.5	45	156	86	*55*	1.35	1.26	269	232	*86*	6
Horseshoe	73-0157-00-211	9/5/24	21.1	8.3	4.9	22	159	119	*75*	0.92	0.97	202	149	*74*	7
Horseshoe	73-0157-00-211	9/26/24	20.3	12.9	3.2	37	70	5	*7*	1.31	1.13	122	101	*83*	5.5
Horseshoe	73-0157-00-211	10/17/24	12.2	8.1	5.0	14	174	136	*78*	1.24	1.13	172	147	*85*	5.5
2024 Annual Averages			**21.2**	**10.7**	**4.7**	**37.2**	**117.8**	**54.7**	***39***	**1.31**	**1.14**	**175.0**	**146.9**	***84***	**5.6**

Horseshoe Lake Total Kjeldahl Nitrogen

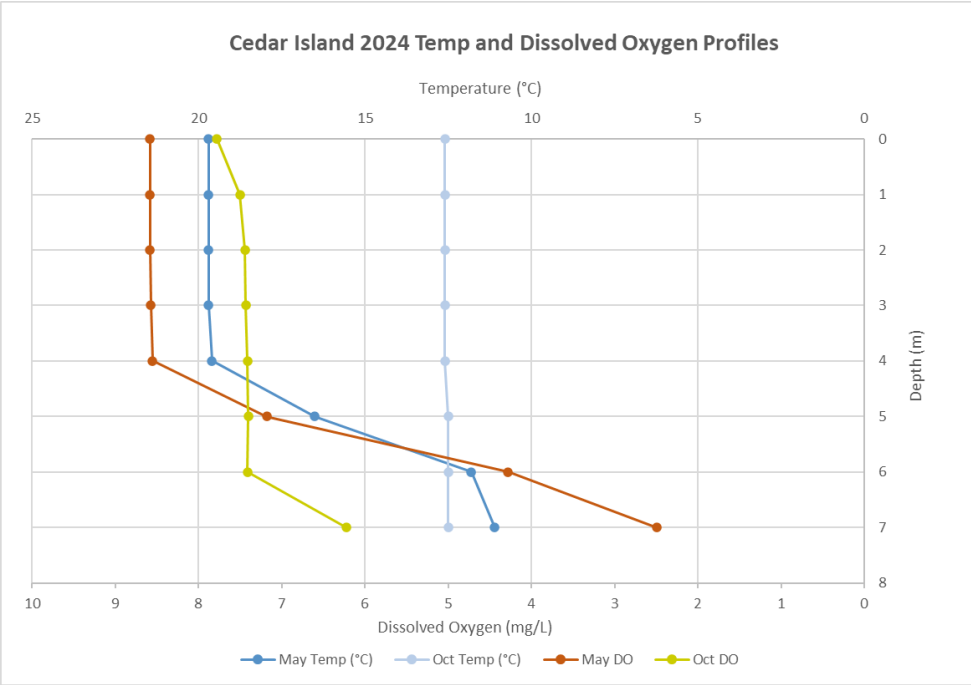


Nitrogen levels are also useful for evaluating lake eutrophication and is used as a secondary indicator of nutrient loading. Organic nitrogen is found in proteins, amino acids, urea, living and dead organisms (i.e., algae and bacteria), and decaying plant matter; soluble organic-N sources are from animal and bacterial waste. Ammonia (NH^4) is another source of organic N and is commonly found in septic system effluent and animal waste, as well as commercial fertilizer. Organic nitrogen is commonly assessed by sampling for total Kjeldahl nitrogen (TKN), which is a sum of both the organic nitrogen and ammonia in a sample. See page 28 for more information on TKN. High levels of TKN often indicate the presence of animal waste and can lead to abundant plant growth. This in turn can have adverse effects on lake ecosystems, aquatic plants, invertebrates, fish, and humans. Excessive plant growth can impact the types of plants and ecological communities found in a lake, as available oxygen is decreased during the decomposition of plant material. Unlike total phosphorus, TKN and other forms of nitrogen *do not* have a state WQ standard for surface waters, but there is an EPA drinking water standard of <10 mg/L for nitrates.

The graph above plots TKN concentrations at the surface and bottom of Horseshoe Lake. Surface water TKN (light green line) was almost always higher than bottom samples (dark green line), except for on 6/13 and 9/5. This is likely because Horseshoe receives a significant input from the Sauk River, and there were several rain events during the summer months that contributed runoff to the lake. The most common source of nitrogen compounds in lakes are fertilizers that contain nitrate. Even so, the surface and bottom samples stayed consistently close to each other with almost every sample falling between 1 and 1.7 mg/L. To put these numbers into context, the average TKN concentration for the NCHF ecoregion (which the Chain of Lakes falls into) is 0.6-1.2 mg/L, so these levels are not a concern.

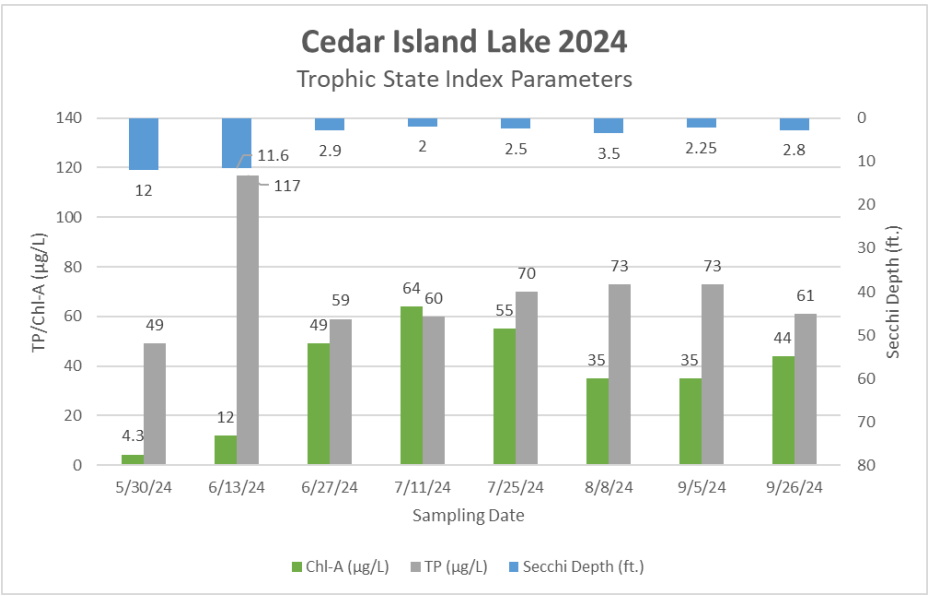
Horseshoe Lake on 10/17/24

Cedar Island Profiles and TSI Parameters

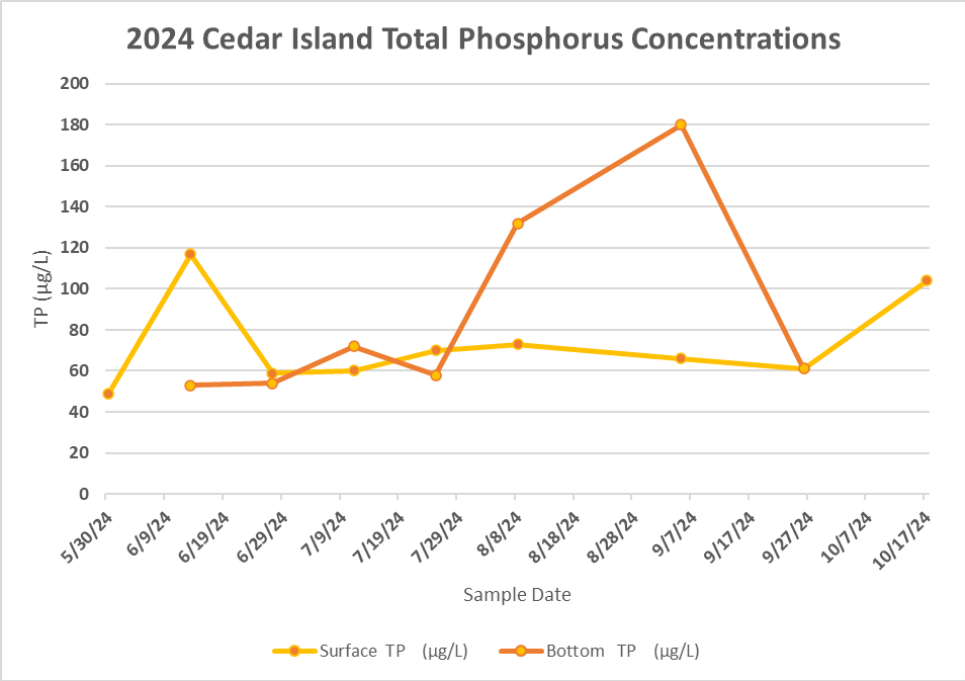


Cedar Island Lake is one of the larger lakes in the chain with 27 miles of shoreline and 77% of the lake being 15 feet deep or less. It is broken up into Cedar Island Main Bay, East Lake, and Koetter Lake, with the SRWD samples being taken from the Main Bay. The temperature and dissolved oxygen profiles compiled to the right are from the first and last sampling dates in 2024. The temperature graph shows that the May water temperature went from around 20 °C (67.5 °F) near the surface down to 11 °C (52 °F) near the bottom. The oxygen concentration in May (orange line) for Cedar Island shows a large drop in oxygen levels around 6 meters, with the bottom DO level being at 2.5 mg/L. This temperature and oxygen stratification remained around the 5-6 meter range throughout summer, but it became clear that the lake had started to mix by the end of September based on the temperature profile. The water temperature in October barely changed throughout the profile, staying consistently near 12.5 °C (54.5 °F). The oxygen concentration in October started at around 8 mg/L and only saw a slight decline at the last meter (6.2 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 water cooled, becoming more dense, and the lake turned over as the water column mixed.

The below graph includes water quality parameters that are used to calculate a Carlson Trophic State Index (TSI) score. This common classification method is used to evaluate the health of a waterbody based off of the three indicated parameters. The index is a scale from 0-100, with a low score indicating better water quality. Cedar Island exceeded the chl-A site-specific standard of <32 µg/L for all but 2 samples, but there was a decrease in August and beginning of September. Samples exceeded the TP WQ standard of <55 µg/L for all but one sample (May). For Secchi depth, it satisfied the WQ standard of >4.6 ft. for only 2 sampling visits.



Cedar Island Total Phosphorus

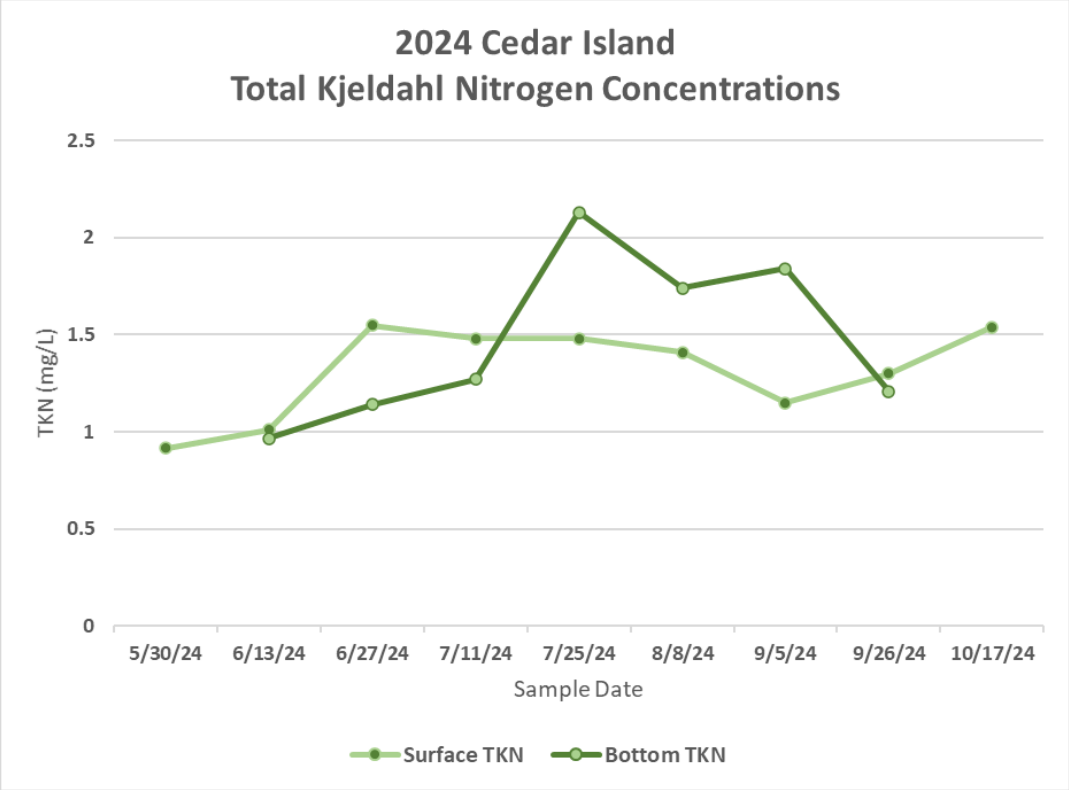


The graph above for TP shows a comparison between surface and bottom samples. There was no bottom sample taken in May, but it can be seen that surface TP came in higher than bottom TP for both samples in June. However, as summer and warmer temperatures progressed, bottom TP had two large spikes in August and September. Surface concentrations (yellow line) peaked in June, and there was one more slight increase in October on the last sampling day, reaching 104 µg/L. There was also no bottom sample taken in October since Horseshoe had already begun to turn over by the end of September, which is indicated by both TP results on 9/26 being at 61 µg/L. This is also likely why there was an increase in surface TP in October because the layers had begun mixing at that point, so some of the phosphorus near the bottom had moved closer to the top of the water column.

The ratio of OP to TP indicates how much all forms of phosphorus in a lake is bioavailable for consumption at the time. On average, the ratio of OP to TP in 2024 for surface samples in Cedar Island was 14%. For bottom samples, the average ratio was 51%. Compared to other lakes in the chain, these results indicate that Cedar Island may not be experiencing as significant internal loading. The table below contains all sample results for 2024, including OP:TP ratios.

Lake Name	Site ID	Sample Date	Surface Temp (°C)	Surface DO (mg/L)	Secchi Disk Depth (feet)	Surface Chl-a (ug/L)	Surface TP (µg/L)	Suface OP (µg/L)	% Surface OP:TP	Surface TKN (mg/L)	Bottom TKN (mg/L)	Bottom TP (µg/L)	Bottom OP (µg/L)	% Bottom OP:TP	Bottom Sample Depth (m)
Cedar Island	73-0133-01-205	5/30/2024	19.7	8.6	12.0	4	49	5	*10*	0.916					
Cedar Island	73-0133-01-205	6/13/2024	23.1	10.3	11.6	12	117	5	*4*	1.01	0.965	53	29	*55*	7.0
Cedar Island	73-0133-01-205	6/27/2024	23.7	13.2	2.9	49	59	9	*15*	1.55	1.14	54	28	*52*	6.2
Cedar Island	73-0133-01-205	7/11/2024	27.8	15.1	2.0	64	60	5	*8*	1.48	1.27	72	44	*61*	6.7
Cedar Island	73-0133-01-205	7/25/2024	25.3	9.9	2.5	55	70	6	*9*	1.48	2.13	58	15	*26*	6.5
Cedar Island	73-0133-01-205	8/8/2024	22.7	5.9	3.5	35	73	8	*11*	1.41	1.74	132	109	*83*	8.0
Cedar Island	73-0133-01-205	9/5/2024	22.1	8.9	2.3	36	66	9	*14*	1.15	1.84	180	131	*73*	6.5
Cedar Island	73-0133-01-205	9/26/2024	21.2	9.9	2.8	44	61	5	*8*	1.3	1.21	61	5	*8*	6.6
Cedar Island	73-0133-01-205	10/17/2024	12.6	7.6	4.0	21	104	49	*47*	1.54					
2024 Annual Averages			**22.0**	**9.9**	**4.8**	**35.6**	**73.2**	**11.2**	***14.1***	**1.3**	**1.5**	**87.1**	**51.6**	***51.0***	**7.0**

Cedar Island Total Kjeldahl Nitrogen

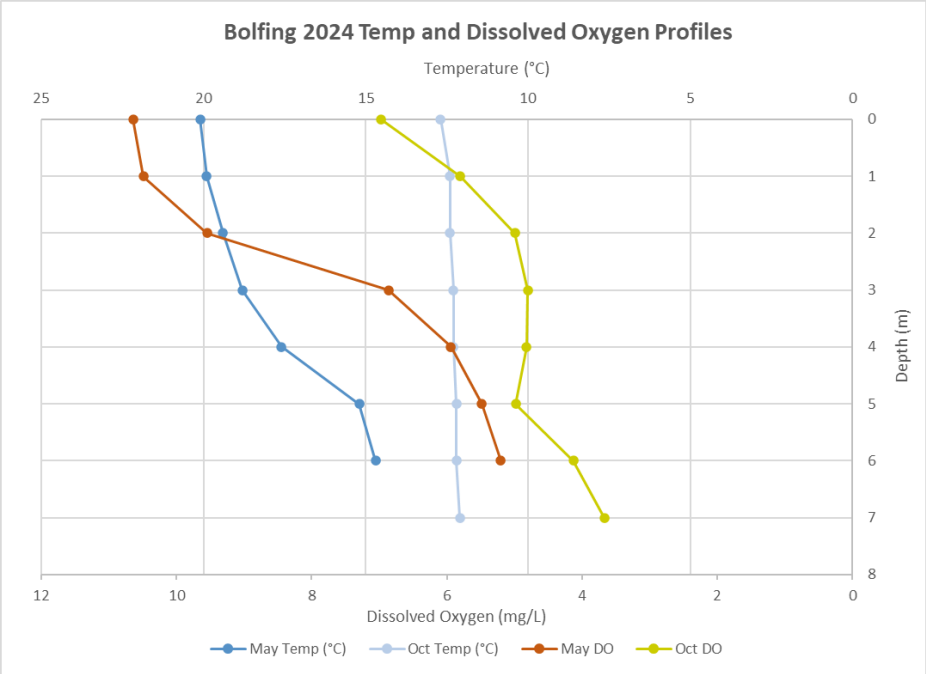


Organic nitrogen is commonly assessed by sampling for total Kjeldahl nitrogen (TKN), which is a sum of both the organic nitrogen and ammonia in a sample. Unlike total phosphorus, TKN and other forms of nitrogen *do not* have a state WQ standard for surface waters, but there is an EPA drinking water standard of <10 mg/L for nitrates.

The graph above plots TKN concentrations of surface and bottom samples from Cedar Island Lake. Surface water TKN started off the year higher than bottom TKN, but bottom concentrations continued to climb throughout the summer and surpassed surface concentrations The highest bottom sample result was 2.13 mg/L on 7/25. All surface samples remained below 1.6 mg/L and remained fairly consistent throughout the season. To put these numbers into context, the average TKN concentration for the NCHF ecoregion is 0.6-1.2 mg/L, so these levels are not unreasonable.

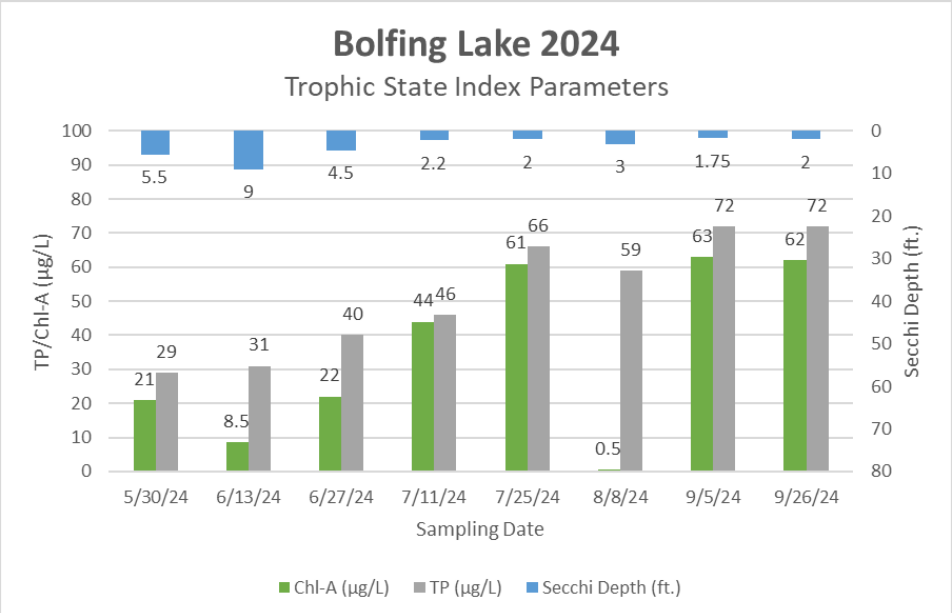
Cedar Island Lake on 10/17/24

Bolfing Lake Profiles and TSI Parameters



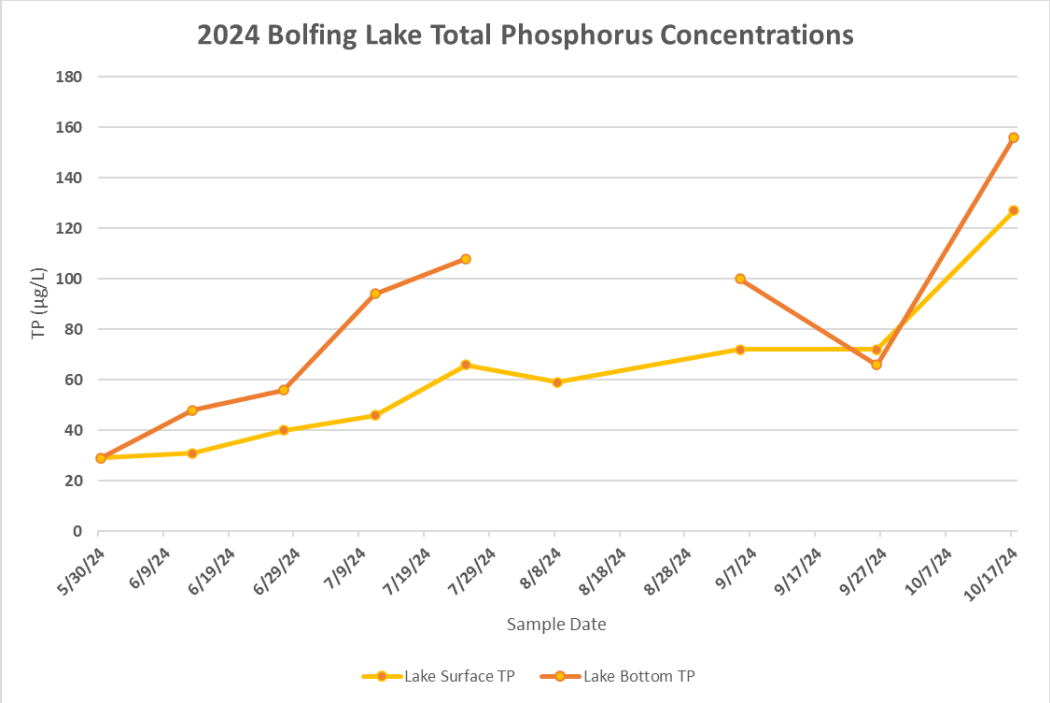
Bolfing Lake is just south of the SRCL flowage lakes Knaus and Krays Lakes. It slowly drains to the Sauk River flowage area at its outlet. The profiles compiled to the right are from the first and last sampling dates in 2024. The temperature graph shows that the May water temperature went from around 20 °C (67.5 °F) near the surface down to around 15 °C (59 °F), which is only a slight decrease. The oxygen concentration in May for Bolfing shows a large drop in oxygen levels at 3 meters, with the bottom DO level being at 5.2 mg/L, which is not at hypoxic levels. A more pronounced stratification became apparent in the summer months and progressed until the end of September. The water temperature in October was consistent throughout the profile, staying near 12 °C (53.6 °F). The oxygen concentration in October started at around 7 mg/L, wavered at around 5 mg/L, then dropped down to 3.7 mg/L. The lake stratified by temperature and became oxygen-depleted in the early summer months. As temperatures cooled in the fall, the surface water cooled, and the water column began mixing. The temperature profile became completely uniform by October, but there was still a slight oxycline.

The below graph includes water quality results that are used to calculate a Carlson Trophic State Index (TSI) score. Bolfing exceeded the chl-A site-specific standard of <32 µg/L for 4 samples, and a steady increase throughout the summer months is apparent. There was a notably low chl-A sample on 8/8 with a result of <1 µg/L, which is below the detection range of the lab analysis. Levels were also unusually high in September, which is when temperatures start to drop and lakes are not as productive.



For TP, samples exceeded the standard of <55 µg/L on 4 sampling days, all of them in the later months. For Secchi depth, it satisfied the WQ standard of >4.6 ft. for only two sampling visits early in the season.

Bolfing Lake Total Phosphorus

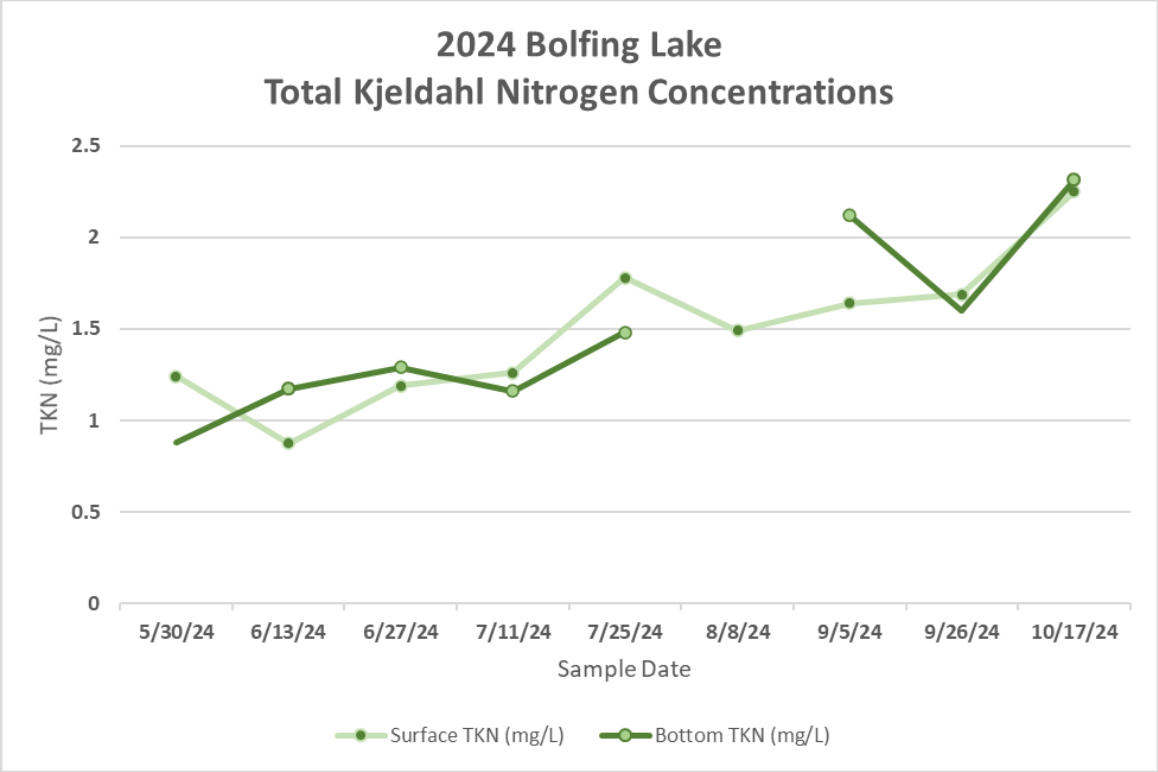


The graph above for TP shows a comparison between surface and bottom samples. Both samples had a result of 29 µg/L on 5/30, but bottom concentrations started to take off after that. There are no bottom sample results for 8/8 due to a handling error. Surface concentrations also increased throughout the year, peaking in October at 127 µg/L. The October bottom result was 156 µg/L, which is 2.8 times higher than the WQ standard. It appears that Bolfing had begun to mix by the end of September since the bottom concentration was lower than the surface concentration. The sharp increase at the end of the season implies that internal loading is occurring since the phosphorus had begun mixing into the surface water. Compared to the other non-flowage lakes sampled (Cedar Island and Horseshoe), the annual averages for phosphorus are notably lower in Bolfing.

The ratio of OP to TP indicates how much all forms of phosphorus in a lake is bioavailable for consumption at the time. On average, the ratio of OP to TP in 2024 for surface samples in Bolfing was 13.2%. For bottom samples, the average ratio was 44%. Compared to other lakes in the chain, these results indicate that Bolfing is not experiencing as significant internal loading. The table below contains all sample results for 2024, including OP:TP ratios.

Lake Name	Site ID	Sample Date	Surface Temp (°C)	Surface DO (mg/L)	Secchi Disk Depth (feet)	Surface Chl-a (ug/L)	Surface TP (µg/L)	Suface OP (µg/L)	% Surface OP:TP	Surface TKN (mg/L)	Bottom TKN (mg/L)	Bottom TP (µg/L)	Bottom OP (µg/L)	% Bottom OP:TP	Bottom Sample Depth (m)
Bolfing Lake	73-0088-00-203	5/30/2024	20.1	10.6	5.5	21	29	5	*17*	1.24	0.88	29	5	*17.24*	4
Bolfing Lake	73-0088-00-203	6/13/2024	23.1	10.2	9.0	9	31	5	*16*	0.88	1.17	48	9	*18.75*	6
Bolfing Lake	73-0088-00-203	6/27/2024	24.2	13.7	4.5	22	40	5	*13*	1.19	1.29	56	27	*48.21*	6
Bolfing Lake	73-0088-00-203	7/11/2024	26.6	14.1	2.2	44	46	8	*17*	1.26	1.16	94	74	*78.72*	6
Bolfing Lake	73-0088-00-203	7/25/2024	25.3	8.9	2.0	61	66	9	*14*	1.78	1.48	108	78	*72.22*	6
Bolfing Lake	73-0088-00-203	8/8/2024	22.8	6.4	3.0	0.5	59	7	*12*	1.49					
Bolfing Lake	73-0088-00-203	9/5/2024	22.1	8.4	1.8	63	72	8	*11*	1.64	2.12	100	48	*48.00*	6
Bolfing Lake	73-0088-00-203	9/26/2024	20.1	9.8	2.0	62	72	7	*10*	1.69	1.60	66	7	*10.61*	6
Bolfing Lake	73-0088-00-203	10/17/2024	12.7	7.0	2.5	50	127	12	*9*	2.25	2.31	156	35	*22.44*	6
2024 Annual Averages			**21.9**	**9.9**	**3.6**	**36.9**	**60.2**	**7.3**	***13.2***	**1.5**	**1.50**	**81**	**35**	***44***	**5.7**

Bolfing Lake Total Kjeldahl Nitrogen

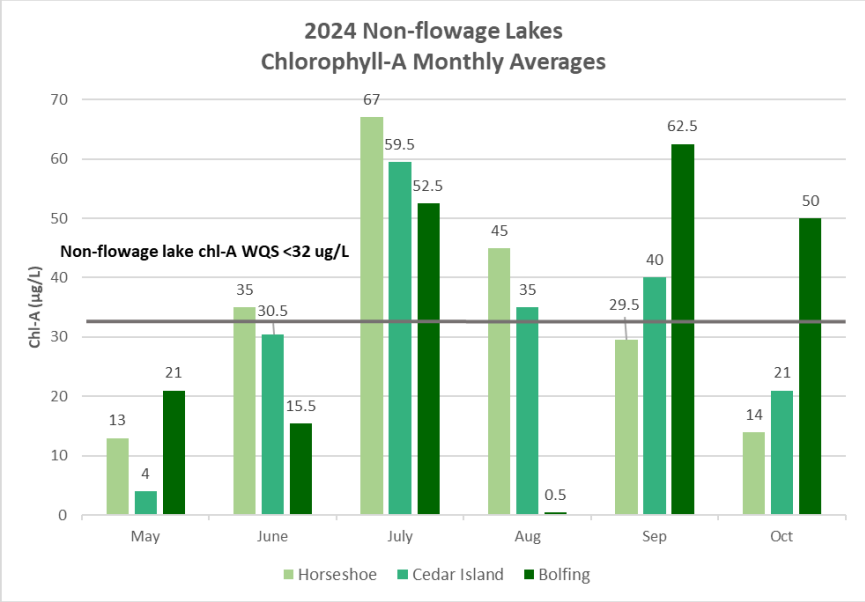


Organic nitrogen is commonly assessed by sampling for total Kjeldahl nitrogen (TKN), which is a sum of both the organic nitrogen and ammonia in a sample. Unlike total phosphorus, TKN and other forms of nitrogen *do not* have a state WQ standard for surface waters, but there is an EPA drinking water standard of <10 mg/L for nitrates.

The graph above shows TKN concentrations for surface and bottom samples from Bolfing Lake. Surface water TKN started off the year higher than bottom TKN, but both results remained fairly close throughout the season and saw a steady increase. The most notable difference was on 9/5 when bottom TKN was at 2.12 mg/L, and surface TKN was 1.64 mg/L. Surface and bottom results peaked in October, with the bottom concentration being at 2.31 mg/L. To put these numbers into context, the average TKN concentration for the NCHF ecoregion is 0.6-1.2 mg/L, so these levels are not unreasonable. However, the annual average TKN for Bolfing is slightly higher than those for Cedar Island and Horseshoe Lakes.

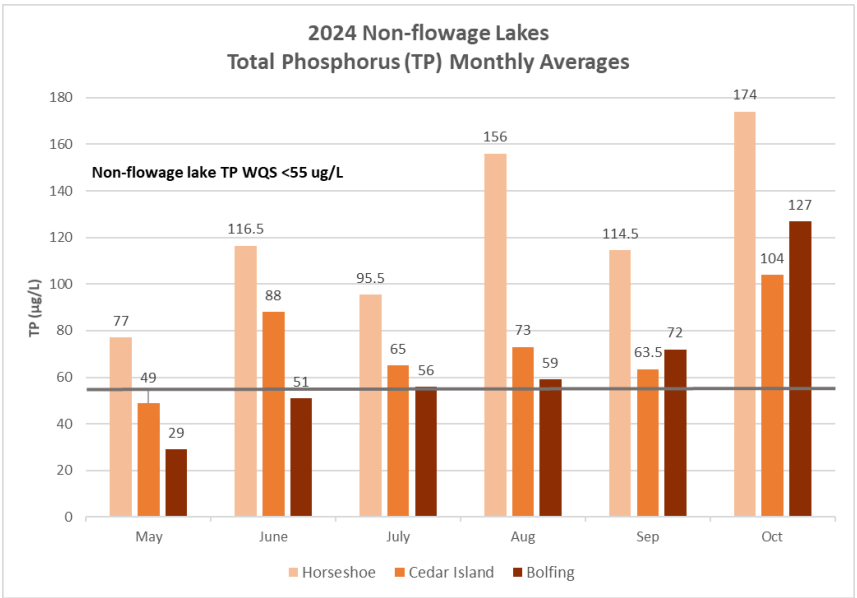
Bolfing Lake on 5/30/24

Non-Flowage Lakes Monthly Averages

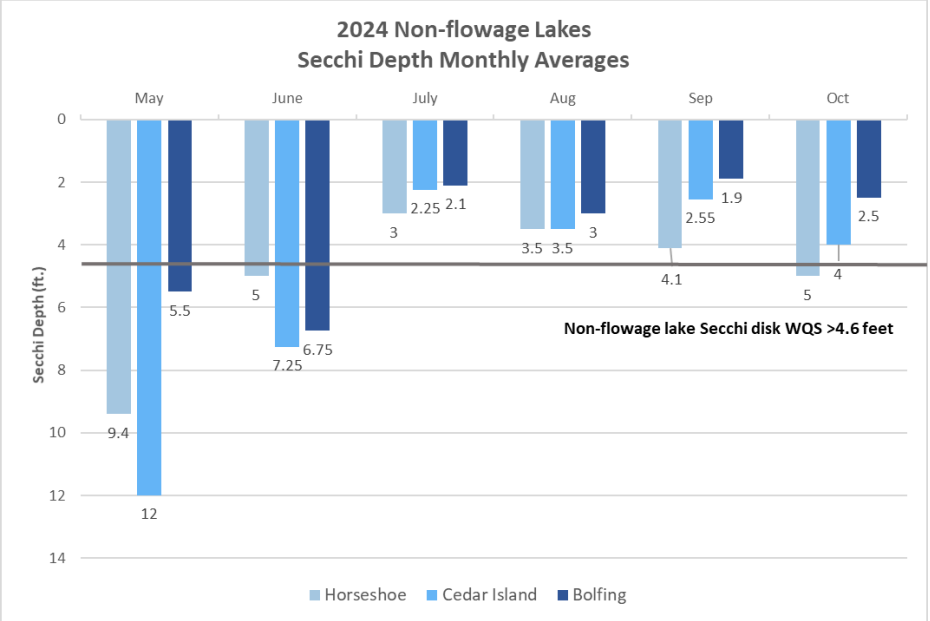


The site-specific water quality standards for the non-flowage lakes in the chain are balanced between the water quality standards for the Sauk River and for lakes in the North Central Hardwood Forest (NCHF) Ecoregion. This is due to the increased connectivity of these non-flowage lakes with the Sauk River, which is much different than a traditional lake outlet. These next graphs show a comparison of monthly averages for chlorophyll-A, TP, and Secchi depth. Chl-A averages are shown in the left graph, which saw many exceedances. **Horseshoe Lake** (the first bar in the bar graphs) chl-A levels peaked in July and began to drop after that. The overall annual average for Horseshoe was **37.2 µg/L**, slightly higher than the WQ standard of <32 µg/L. **Cedar Island Lake** also peaked in July, but otherwise saw fairly low results the rest of the months. The overall annual average was **35.6 µg/L**, slightly higher than the WQ standard. **Bolfing Lake**, the lake furthest east, greatly fluctuated throughout the year. There was a significant jump from August to September, where the chl-A levels peaked. This also coincides with the Secchi disk reading, which had its lowest reading in September. This may have to do with above-average temperatures experienced in fall of 2024. The overall annual average for Bolfing was **36.9 µg/L**. For chl-A in general, we likely saw higher results due to a mild winter, early ice-out, and above-average rainfall amounts during the summer months. These circumstances allow for more aquatic vegetative and algal growth, which was experienced all across the state.

As for TP, this graph is more consistent with what would be expected for the breakdown of the non-flowage lakes considering Horseshoe is the first lake that the Sauk River enters into the chain. By the time flow has reached Bolfing Lake, the nutrients that entered the system have had more of a chance to settle out. The TP averages for **Horseshoe** exceeded the WQ standard of <55 µg/L for each month, peaking in October. The overall annual average was **117.8 µg/L**. **Cedar Island** started off in May below the WQ standard, but remained above it for the rest of the season. TP levels were relatively consistent throughout the summer months until increasing once again in October. The overall annual average was **73.2 µg/L**. Lastly, **Bolfing** was below Cedar Island until September and October, when it peaked on the last sampling day. The overall annual average was **60.2 µg/L**, the lowest of the three non-flowage lakes.



Non-Flowage Lakes Monthly Averages Cont.



Secchi disk depth measurements in 2024 started off well above the WQ standard of 4.6 ft., which is encouraging since a higher value means better water clarity. The Secchi depth averages were above the standard for May and June, but clarity worsened throughout the warmer months, then saw a slight improvement in October. The annual average for **Horseshoe Lake was 4.7 feet**, just meeting the WQ standard. Horseshoe also had better clarity than the other lakes for 3 months out of the sampling season, which is notable considering the other lakes are further along in the chain. The annual average for **Cedar Island was 4.8 feet**, only slightly better than Horseshoe. Lastly, **Bolfing** had an annual average of **3.6 feet** for Secchi, which does not fulfill the WQ standard and is the lowest annual average out of all six lakes. Its clarity was consistently worse than that of Cedar Island, which is likely because it is a smaller lake. The maximum depth of Cedar Island is 75 ft. and has an area of 986 acres, while Bolfing has a maximum depth of 36 ft. and an area of 109 acres.

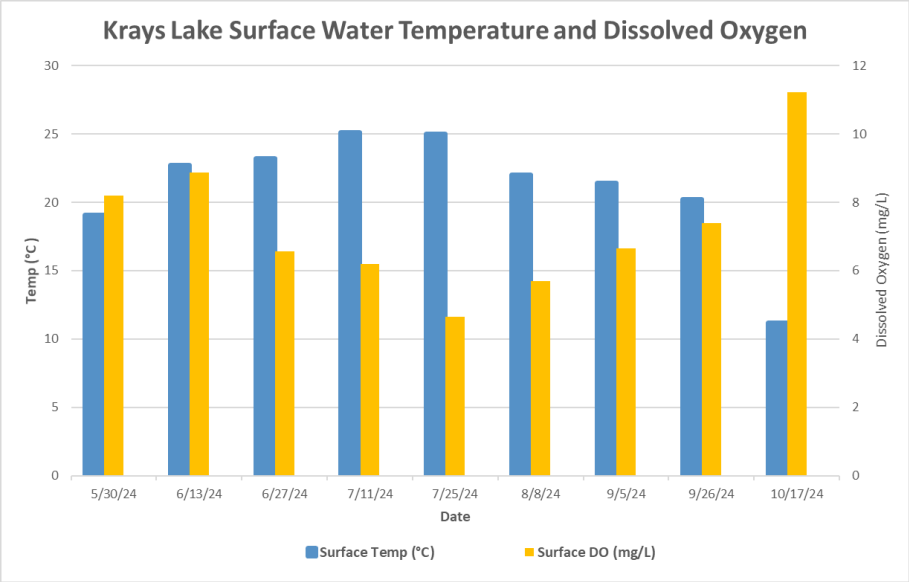
2024 Non-Flowage Lakes Summary

Looking at the overall Carlson TSI scores for 2024 and comparing those to past years will paint a picture of changing conditions for these three lakes. The Carlson TSI indicates how much aquatic plant and animal life a waterbody can sustain and the likelihood of observing poor water quality due to the interplay of the 3 applied parameters. All three non-flowage lakes fall into the *eutrophic* category, which is a TSI score between 50 and 70. Sampling on Bolfing Lake had not occurred for some time, so only data from 2009, 2023, and 2024 is available. Applying the site-specific standards for non-flowage lakes to the Carlson TSI, we find that a TSI value of **61 and below** is appropriate for these lakes. All three lakes saw an increase from last year's values. Bolfing had the lowest score at 60, but that is a jump from 2023's score. More long-term data is needed to determine a trend. Cedar Island is next with a score of 62, but this is not the highest score that has been seen for this lake. Horseshoe ended up with a score of 64, which is higher than last year, but is also not the highest score ever seen for this lake.

One should keep in mind the uncommon conditions experienced in 2024, most notably the mild winter and high rainfall amounts. In general, the TSI scores are staying relatively consistent and are still lower than historic levels.

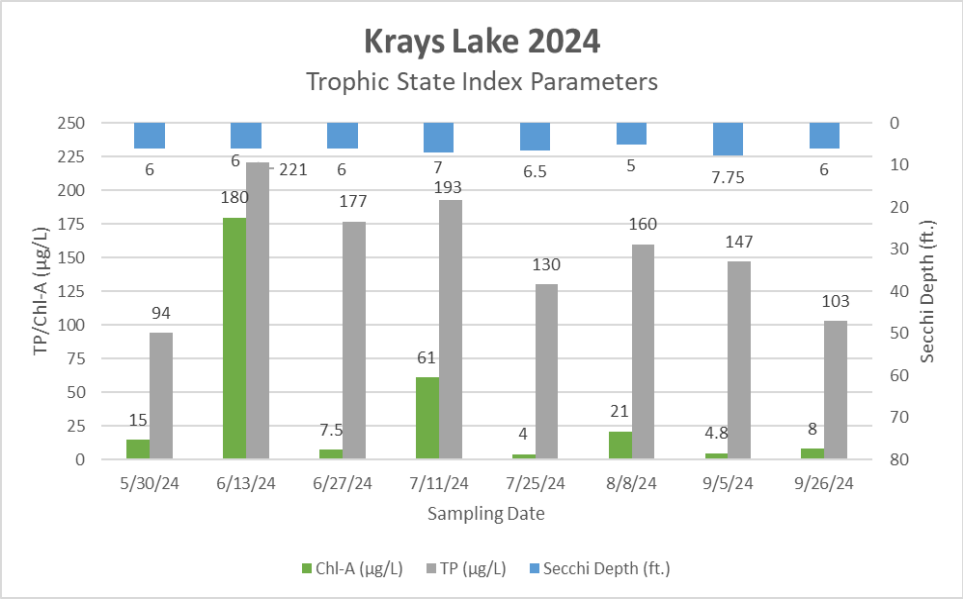
Year	Horseshoe TSI	Cedar Isl TSI	Bolfing TSI
2009	66	66	68
2010	67	63	-
2011	67	68	-
2012	-	-	-
2013	-	-	-
2014	69	65	-
2015	63	63	-
2016	63	57	-
2017	60	54	-
2018	64	54	-
2019	65	59	-
2020	65	61	-
2021	63	59	-
2022	60	54	-
2023	61	56	51
2024	**64**	**62**	**60**

Krays Lake Temp/DO & TSI Parameters

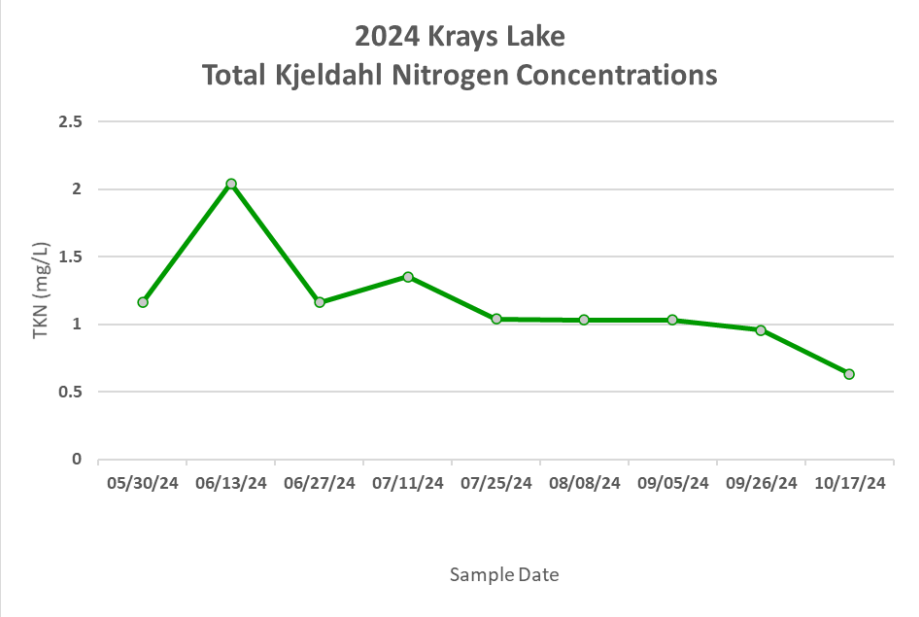


Krays Lake is considered a flowage lake in the chain and has different site-specific standards for those unique conditions. It is much more shallow, with a mean depth of only 7 feet. These shallow and flowage conditions do not allow for Krays to stratify, so water temperature and dissolved oxygen are mostly consistent throughout the profile. This is why the temperature and DO graph to the right only shows surface results. Temperature, which is graphed on the left vertical axis, fluctuated slightly throughout the year, peaked on 7/11 at 25.1 °C (77 °F), and dropped down to 11 °C (52 °F) in October. DO followed a typical pattern of starting off higher in May and June, then made an inverted bell curve and shot back up in October, reaching 11.2 mg/L. Higher dissolved oxygen levels are often observed in the cooler months since colder water can retain more dissolved oxygen than warm water. Since Krays is a shallow flowage lake, the water residency time is only 7 days, so it stays fairly well mixed and oxygenated throughout the season.

The graph below for TSI parameters is the same setup as the other lakes, but the WQ standards differ and are closer to those for the Sauk River. For chl-A, Krays only exceeded the standard of **<45 µg/L** twice, notably reaching 180 µg/L on 6/13. The TP standard for flowage lakes is **<90 µg/L**, so each 2024 sample exceeded this standard. The average TP concentration for the year was 146 µg/L. Secchi depth was mostly consistent throughout the season and remained above the WQ standard of **>2.6 feet** on each sampling day.



Krays Lake Total Kjeldahl Nitrogen



This graph shows the TKN concentrations for only surface samples since no bottom samples were taken on Krays. This is because the lake does not stratify, so a bottom sample would be nearly identical to the surface sample. Nitrogen levels remained consistently low, but there was a slight spike on 6/13 that reached 2.04 mg/L. TKN even dropped in October with a result of 0.63 mg/L. The average TKN concentration for the NCHF ecoregion is 0.6-1.2 mg/L, so these levels are satisfactory, especially considering this is a flowage lake that is a part of a chain of lakes system.

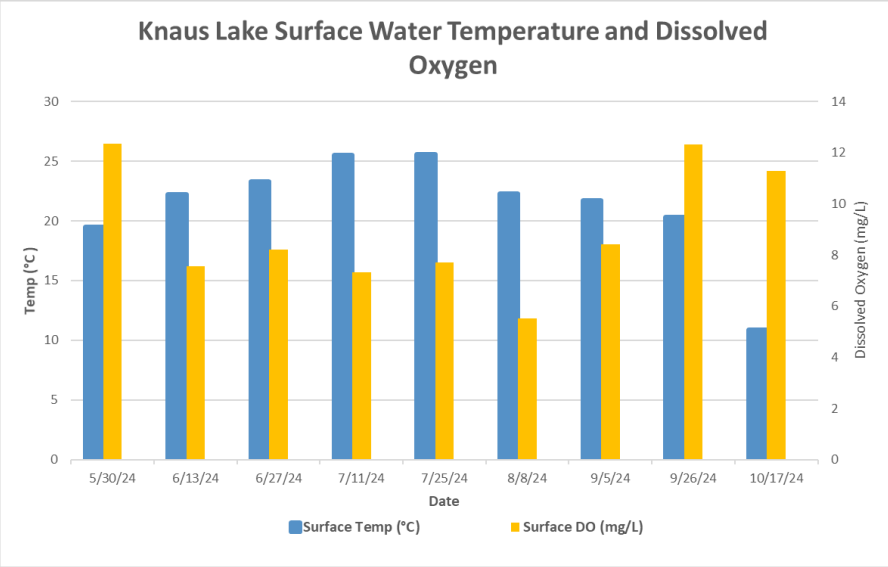
The below table shows the results of each parameter for each sampling day. The OP:TP average ratio for the year is around 70%, meaning there is a slightly high proportion of ortho-phosphate that is bioavailable.

Lake Name	Site ID	Sample Date	Surface Temp (°C)	Surface DO (mg/L)	Secchi Disk Depth (feet)	Suface Chl-a (ug/L)	Surface TP (µg/L)	Suface OP (µg/L)	% Surface OP:TP	Surface TKN (mg/L)
Krays Lake	73-0087-00-201	5/30/2024	19.1	8.2	6.0	15	94	54	*57*	1.16
Krays Lake	73-0087-00-201	6/13/2024	22.7	8.9	6.0	180	221	57	*26*	2.04
Krays Lake	73-0087-00-201	6/27/2024	23.2	6.6	6.0	8	177	150	*85*	1.16
Krays Lake	73-0087-00-201	7/11/2024	25.1	6.2	7.0	61	193	120	*62*	1.35
Krays Lake	73-0087-00-201	7/25/2024	25	4.7	6.5	4	130	105	*81*	1.04
Krays Lake	73-0087-00-201	8/8/2024	22	5.7	5.0	21	160	110	*69*	1.03
Krays Lake	73-0087-00-201	9/5/2024	21.4	6.7	7.8	5	147	115	*78*	1.03
Krays Lake	73-0087-00-201	9/26/2024	20.2	7.4	6.0	8	103	86	*83*	0.96
Krays Lake	73-0087-00-201	10/17/2024	11.2	11.2	6.0	4	91	78	*86*	0.63
2024 Annual Averages			**21.1**	**7.3**	**6.3**	**33.9**	**146.2**	**97.2**	***69.7***	**1.2**

Krays Lake on 7/25/24

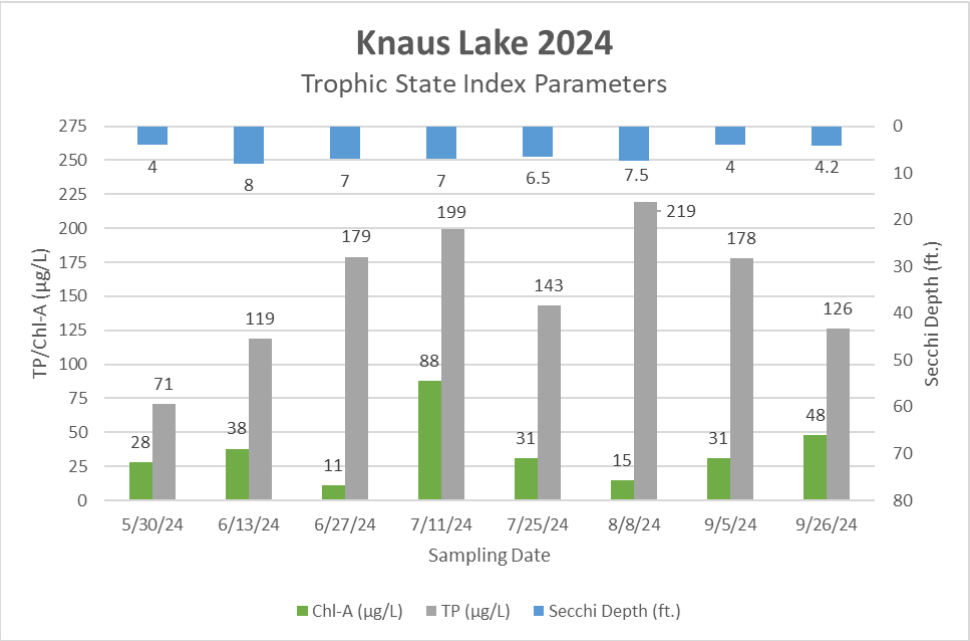
9/5/24

Knaus Lake Temp/DO & TSI Parameters

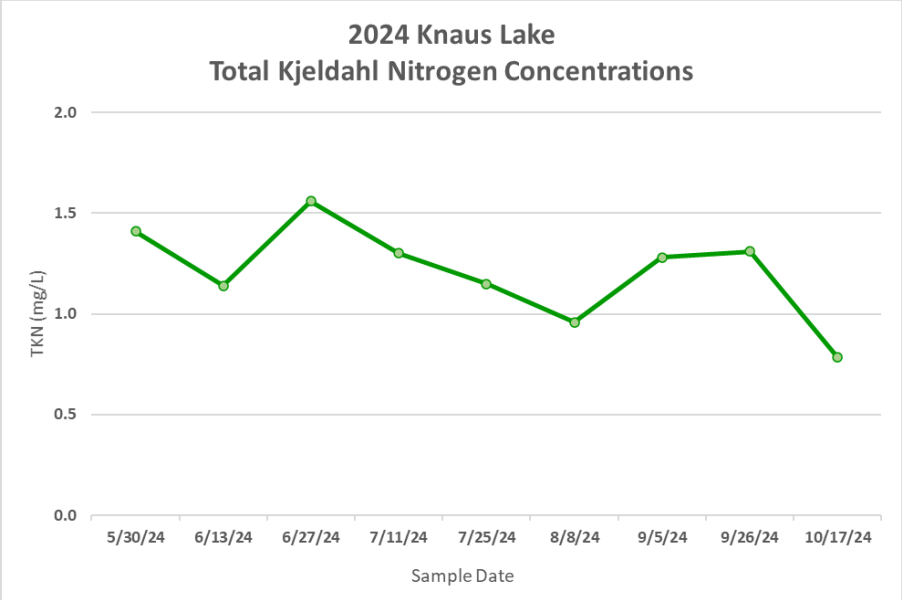


Knaus Lake, which is connected to and lies east of Krays, is considered a flowage lake in the chain and has different site-specific standards for those unique conditions. It is particularly shallow, with a mean depth of only 6.4 feet. These shallow and flowage conditions do not allow for Knaus to stratify, so water temperature and dissolved oxygen are mostly consistent throughout the profile. Temperature, which is graphed on the left vertical axis, is almost identical to the results for Krays. It peaked on 7/25 at 25.6 °C (78 °F), and dropped down to 11 °C (52 °F) in October. DO levels started off high in May and dropped down in the summer months. DO shot back up in September, reaching 12.3 mg/L. Higher dissolved oxygen levels are often observed in the cooler months since colder water can retain more dissolved oxygen than warm water. Since Knaus is a shallow flowage lake, the water residency time is only 7 days, so it stays fairly well mixed and oxygenated throughout the season.

The graph below for TSI parameters is the same setup as the other lakes, but the WQ standards differ and are closer to those for the Sauk River. Knaus exceeded the chl-A standard of **<45 µg/L** only twice. It is notable that one of those times was on 9/26, which is later in the year and when lakes are not as productive. The TP standard for flowage lakes is **<90 µg/L**, so samples exceeded this on each occasion except for in May. The average TP concentration for the year was 146.7 µg/L. Secchi depth fluctuated slightly, and the lake interestingly experienced the lowest clarity in May and September. However, Krays did satisfy the WQ standard of **>2.6 feet** on each sampling day.



Knaus Lake Total Kjeldahl Nitrogen



No bottom samples were taken on Knaus, so only surface data is displayed here. This is because the lake does not stratify, so a bottom sample would be nearly identical to the surface sample. Nitrogen levels remained consistently low and never exceeded 1.6 mg/L. TKN even dropped in October with a result of 0.79 mg/L. The average TKN concentration for the NCHF ecoregion is 0.6-1.2 mg/L, so these levels are satisfactory, especially considering this is a flowage lake that is a part of a chain of lakes system.

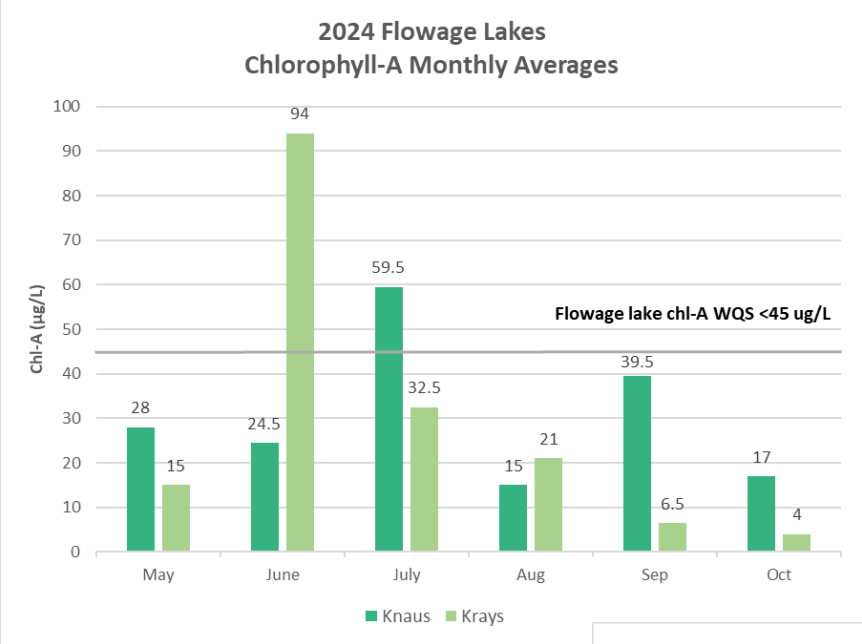
The below table shows the results of each parameter for each sampling day. The OP:TP average ratio for the year is 52.7%, meaning there is a slightly high proportion of ortho-phosphate that is bioavailable.

Lake Name	Site ID	Date	Surface Temp (°C)	Surface DO (mg/L)	Secchi Disk Depth (feet)	Chl-a (ug/L)	Surface TP (µg/L)	Suface OP (µg/L)	% Surface OP:TP	Surface TKN (mg/L)
Knaus Lake	73-0086-00-205	5/30/2024	19.5	12.3	4.0	28	71	9	*13*	1.41
Knaus Lake	73-0086-00-205	6/13/2024	22.2	7.6	8.0	38	119	56	*47*	1.14
Knaus Lake	73-0086-00-205	6/27/2024	23.3	8.2	7.0	11	179	148	*83*	1.56
Knaus Lake	73-0086-00-205	7/11/2024	25.5	7.3	7.0	88	199	104	*52*	1.30
Knaus Lake	73-0086-00-205	7/25/2024	25.6	7.7	6.5	31	143	97	*68*	1.15
Knaus Lake	73-0086-00-205	8/8/2024	22.3	5.5	7.5	15	219	115	*53*	0.96
Knaus Lake	73-0086-00-205	9/5/2024	21.7	8.4	4.0	31	178	109	*61*	1.28
Knaus Lake	73-0086-00-205	9/26/2024	20.3	12.3	4.2	48	126	52	*41*	1.31
Knaus Lake	73-0086-00-205	10/17/2024	10.9	11.3	7.0	17	86	49	*57*	0.79
2024 Annual Averages			**21.3**	**9.0**	**6.1**	**34.1**	**146.7**	**82.1**	***52.7***	**1.2**

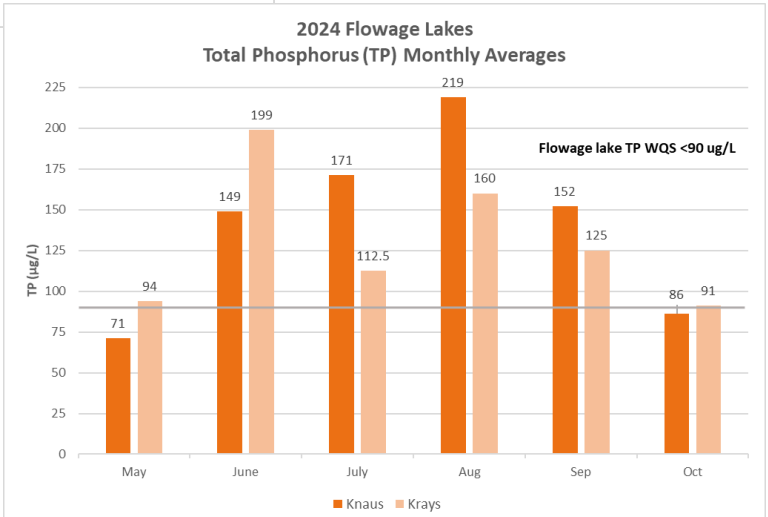
Knaus Lake on 6/13/24

Knaus Lake on 7/11/24

Flowage Lakes Monthly Averages

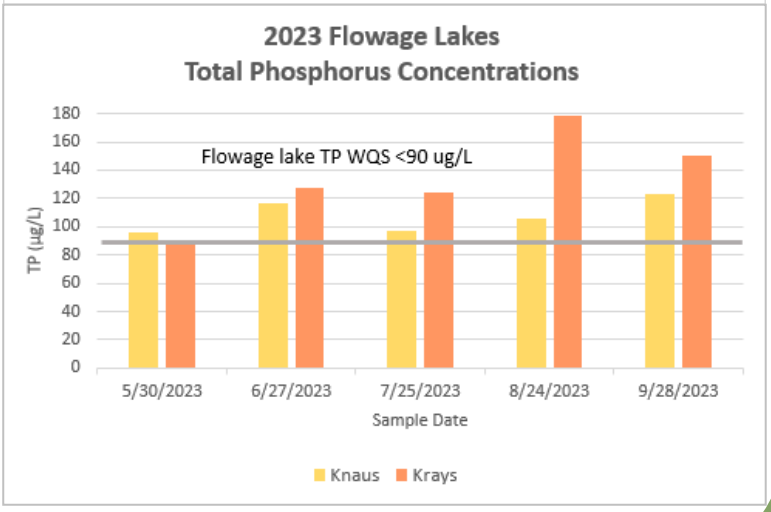


The following graphs compare monthly averages of Carlson TSI parameters for each flowage lake sampled. Chl-A averages, shown to the left, did not have many exceedances. June was the highest average for Krays, and July was the highest for Knaus. The flowage lakes saw far less exceedances than the non-flowage lakes. The overall chl-A annual average for Knaus was **34.1 µg/L**, and the average for Krays was **33.9 µg/L**.



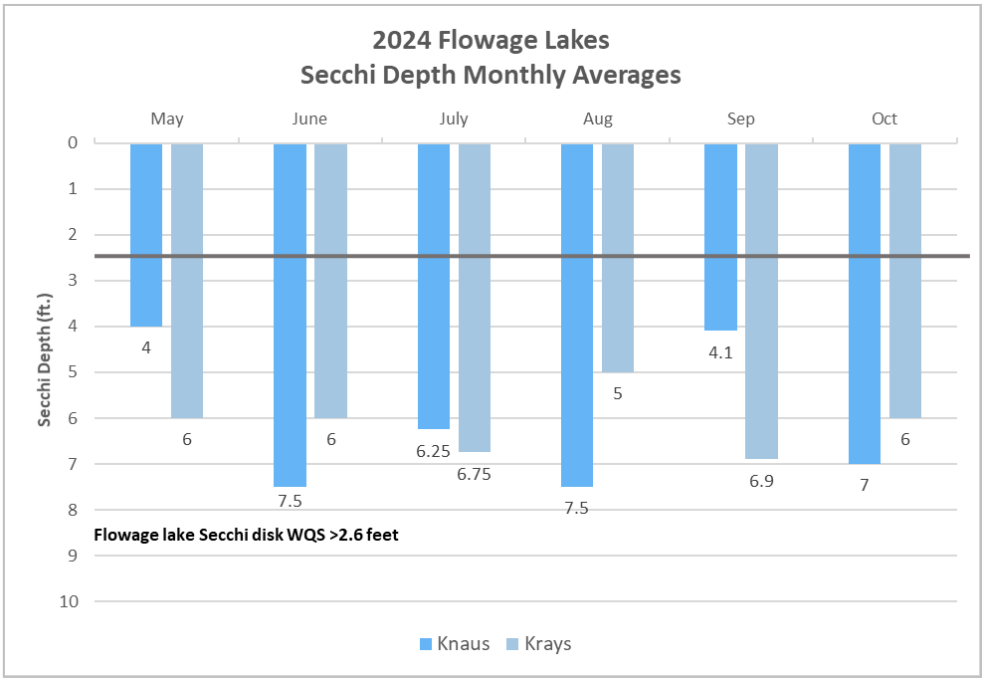
The next graph plots monthly TP averages for flowage lakes. Samples from Krays exceeded the WQ standard for each month, reaching the highest in June. Average sample results from Knaus stayed below the standard for May and October, but did reach 219 µg/L in August. There does not appear to be a pattern for either chl-A or TP indicating that one lake has consistently higher levels than the other. However, Knaus did have a slightly higher annual average for TP at 146.7 µg/L.

Included below for comparison are the TP results from the 2023 season. Those results were also regularly above the WQ standard.



Flowage Lakes Monthly Averages Cont.

Both flowage lakes had average Secchi disk depths that were higher than the standard for each month. In fact, Krays would also be satisfying the Secchi depth WQ standard for non-flowage lakes (>4.6 feet), and Knaus nearly meets that standard for each month. The overall annual average Secchi depth for Knaus was **6.1 feet**, and it was **6.3 feet** for Krays.



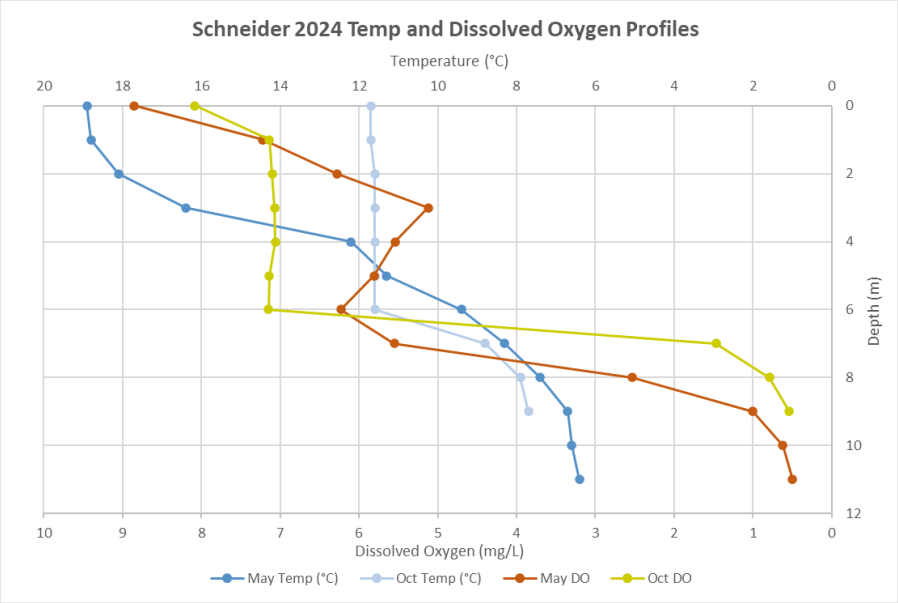
2024 Flowage Lakes Summary

Looking at the overall Carlson TSI scores for 2024 and comparing those to past years will paint a picture of changing conditions for these two lakes. Both flowage lakes fall into the *eutrophic* category, which is a TSI score between 50 and 70. Applying the site-specific standards for flowage lakes to the Carlson TSI, we find that a TSI value of **67 and below** is appropriate for these lakes. Both TSI scores came out to be below that standard. Krays received a score of 62, which is the same as the 2023 score. That is the lowest value for that lake going back to 2009. Knaus did see an increase from last year, receiving a score of 64. That is still lower than values that have been recorded in the past. It appears there is a slight trend towards improving water quality conditions for these lakes, even with the mild winter and increased vegetation that was experienced in 2024 (see pictures on pp. 19 & 21).

In general, the results for chl-A, Secchi disk depth, and TKN are not concerning for these lakes at this time. More concerning are the high TP levels that were consistently above the WQ standard. High TP levels were also observed in 2023, so this is not an emerging phenomenon but an ongoing one.

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
2024	**62**	**64**

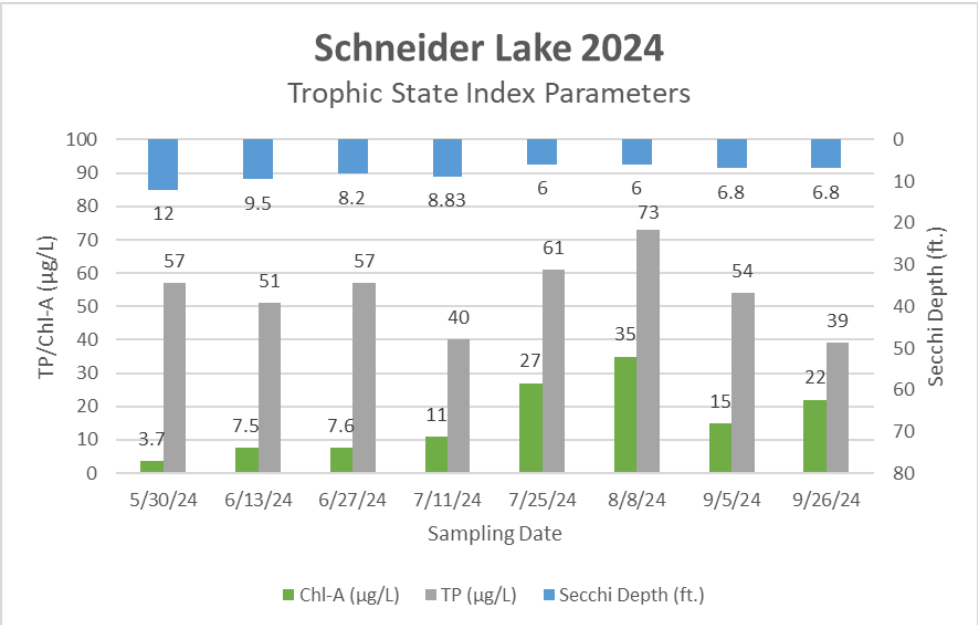
Schneider Lake Profiles and TSI Parameters



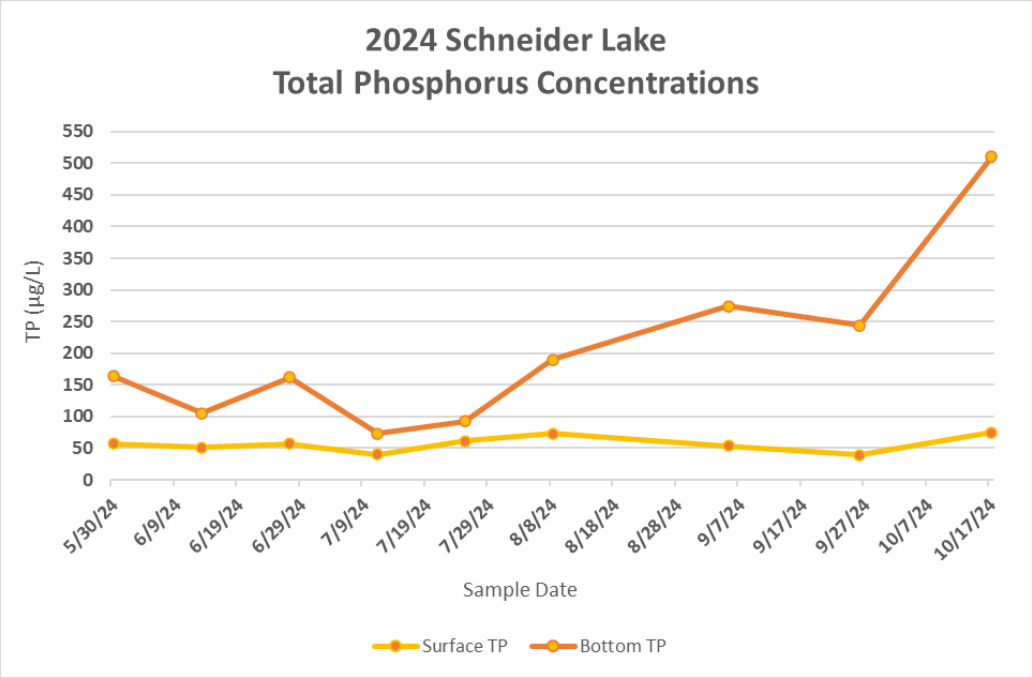
Schneider Lake is situated just north of the SRCL flowage lakes and is considered a natural lake because of its small, singular outlet into Great Northern Lake. It has a maximum depth of 52 feet and a mean depth of 19 feet.

The temperature profile (blue lines) shows that the May water temperature started at around 19 °C (66 °F), dropped significantly at 3 meters, then ended at 6.4 °C (43.5 °F). The lake remained stratified throughout the rest of the season, even in October. The temperature in October was steady until 7 meters, then eventually dropped down to 7.7 °C (46 °F). Dissolved oxygen followed a similar pattern. Schneider had a clear oxycline in both May and October, with the lowest depth having a DO concentration of around 0.5 mg/L for both months. This means the lake was nearly oxygen-depleted towards the bottom for most of the year.

The graph below for TSI parameters is the same setup as the other lakes, but the WQ standards follow those for the NCHF ecoregion since Schneider is removed from the flowage system of the river. For chl-A, Schneider exceeded the standard of **<14 µg/L** four times, all in the later months. It peaked on 8/8 at 35 µg/L. The overall average for chl-A was 15.3 µg/L, which is only slightly above the WQ standard. The TP standard for NCHF lakes is **<40 µg/L**, which was met or fell below the standard for only 2 sampling days. TP levels peaked on 8/8 at 73 µg/L. Secchi depth remained above the WQ standard of **>4.6 feet** on each sampling day. The overall average for Secchi depth was 8 feet for 2024.



Schneider Lake Total Phosphorus

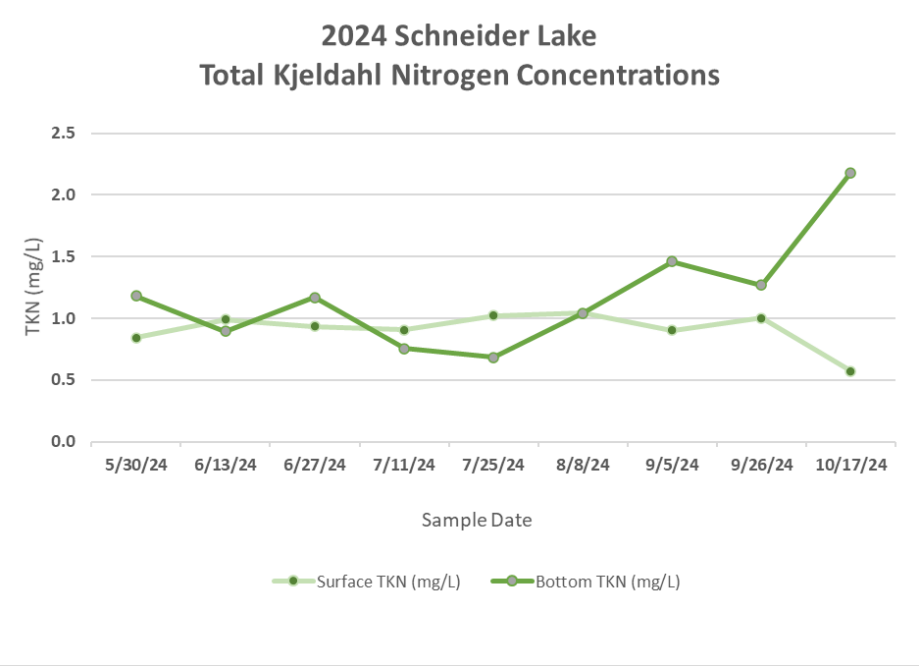


The graph above for TP shows a comparison between surface and bottom samples. Each bottom sample concentration was higher in TP than the surface sample, with a large increase at the bottom in October (510 µg/L). Results at the surface remained relatively consistent throughout the year. The overall average surface TP result for the year was **56.3 µg/L**, which is higher than the standard of <40 µg/L. High TP concentrations at the bottom, especially at the end of the year, indicate that dissolved oxygen conditions were anoxic, which led to bacteria releasing more phosphorus while breaking down sediment and settled debris. This graph also reflects that the lake was still stratified on 10/17 since bottom TP concentrations were much higher than surface concentrations.

The ratio of OP to TP indicates how much all forms of phosphorus in a lake is bioavailable for consumption at the time. On average, the ratio of OP to TP in 2024 for surface samples in Schneider was 41%. For bottom samples, the average ratio was 79%. These results indicate that Schneider is experiencing internal loading. The table below contains all sample results for 2024, including OP:TP ratios.

Lake Name	Site ID	Sample Date	Surface Temp (°C)	Surface DO (mg/L)	Secchi Disk Depth (feet)	Surface Chl-a (ug/L)	Surface TP (µg/L)	Suface OP (µg/L)	% Surface OP:TP	Surface TKN (mg/L)	Bottom TKN (mg/L)	Bottom TP (µg/L)	Bottom OP (µg/L)	% Bottom OP:TP	Bottom Sample Depth (m)
Schneider Lake	73-0082-00-202	5/30/24	18.9	8.9	12.0	4	57	17	*30*	0.84	1.18	164	13.9	*8*	10
Schneider Lake	73-0082-00-202	6/13/24	23	9.8	9.5	8	51	22	*43*	0.99	0.89	105	89	*85*	8
Schneider Lake	73-0082-00-202	6/27/24	23.4	8.6	8.2	8	57	28	*49*	0.93	1.17	162	149	*92*	8
Schneider Lake	73-0082-00-202	7/11/24	24.6	8.9	8.8	11	40	18	*45*	0.91	0.75	73	62	*85*	6
Schneider Lake	73-0082-00-202	7/25/24	24.1	9.8	6.0	27	61	19	*31*	1.02	0.69	93	73	*78*	6
Schneider Lake	73-0082-00-202	8/8/24	20	5.6	6.0	35	73	33	*45*	1.04	1.04	190	168	*88*	9
Schneider Lake	73-0082-00-202	9/5/24	21.2	8.9	6.8	15	54	22	*41*	0.90	1.46	274	241	*88*	8
Schneider Lake	73-0082-00-202	9/26/24	19.7	10.7	6.8	22	39	6	*15*	1.00	1.27	244	230	*94*	8
Schneider Lake	73-0082-00-202	10/17/24	11.7	7.5	7.5	9	75	52	*69*	0.57	2.18	510	470	*92*	7
2024 Annual Averages			**20.7**	**8.7**	**8.0**	**15.3**	**56.3**	**24.1**	***41.0***	**0.91**	**1.18**	**201.7**	**166.2**	***79***	**7.8**

Schneider Lake Total Kjeldahl Nitrogen



Organic nitrogen is assessed by sampling for total Kjeldahl nitrogen (TKN), which is a sum of both the organic nitrogen and ammonia in a sample. Unlike total phosphorus, TKN and other forms of nitrogen *do not* have a state WQ standard for surface waters, but there is an EPA drinking water standard of <10 mg/L for nitrates.

The graph above shows TKN concentrations for surface and bottom samples from Schneider Lake. Bottom TKN was slightly higher than bottom TKN on the first sampling day, and concentrations at the surface barely fluctuated throughout the year. Bottom concentrations peaked in October with a result of 2.18 mg/L. To give these numbers more context, the average TKN concentration for the NCHF ecoregion is 0.6-1.2 mg/L, so these levels are not a concern. The average surface TKN concentration for the monitoring year was **0.91 mg/L**.

2024 Schneider Lake Summary

Using the Carlson TSI scoring system, we can assess the water quality of the Schneider Lake for 2024 and compare that to past years. Schneider does fall into the eutrophic category, which is a TSI score between 50 and 70. Applying the state standards for natural lakes to the Carlson TSI, we find that a TSI value of **56 and below** is appropriate. Schneider falls just below this for 2024 with a TSI score of **55**. That is an increase from 2023, but it is still lower than the 2009 result. There is not an increasing trend in TSI scores at this time.

The temperature and DO profiles demonstrate that the lake was stratified for the duration of the monitoring season. The 2024 results for Secchi disk depth and TKN are not a concern. More concerning are the elevated concentrations of chl-A and TP that were consistently above the WQ standard. It is also important to remember that vegetation and algae had an early start in the year, and there was a reduced amount of ice coverage during the winter.

Year	Schneider TSI
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
2024	**55**

SRCL 2024 Summary

The 2024 monitoring year was one of highs and lows. We were coming out of a drought year and a winter that was not really a winter at all. This was followed by a wet summer and high levels of aquatic vegetation. In fact, many of the sampling locations were choked out by weeds, so samples sometimes had to be taken as close to the actual sampling site as possible.

Considering the Carlson TSI scores overall, Schneider experienced the best water quality in 2024 with a score of 55. Each lake's TSI score increased from 2023 except for Krays, which remained the same. Each lake also falls within the *eutrophic* category, often indicated by somewhat cloudy water and reduced oxygen conditions as summer progresses, along with a presence of algal scum. Knaus (flowage) and Horseshoe (non-flowage) had the highest TSI scores at 64, much of that being attributed to high TP levels. Knaus had notably high TP concentrations with an annual average at 146.7 µg/L. Those lakes are greatly affected by the water quality conditions in the Sauk River, which is likely why they are consistently higher in TP levels. Each of the non-flowage lakes also experienced slightly high concentrations for chl-A, though not as concerning as the phosphorus levels. Secchi disk depths were particularly satisfactory on Krays, Knaus, and Schneider Lakes, consistently staying above the WQ standard according to their specific lake type. For TKN concentrations in general, there were no highly concerning results for any of the six lakes. The highest result out of all the samples was a bottom result of 2.31 mg/L from Bolfing. Even so, this is well below the EPA drinking water standard of <10 mg/L. Bolfing also experienced high levels of chl-A and low clarity in the later months, which could be because it is a smaller lake and there were abnormally high temperatures during the fall months. More years of data are needed to determine a trend, but the lake still had the second lowest TSI score overall.

The SRCL is a unique lake system with unique conditions. It also thankfully has an active Lake Association that is devoted to monitoring and protecting the health of the chain. Continued monitoring in and around this lake system will help identify water quality changes and emerging issues to inform the actions of local governments and citizens on how to preserve and protect this invaluable resource. The SRWD appreciates the time and dedication of the Sauk River Chain of Lakes Association and looks forward to continuing working alongside them to achieve fishable and swimmable water in our watershed.

Year	Horseshoe TSI	Cedar Isl 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
2024	**64**	**62**	**60**	**62**	**64**	**55**

Water Quality Monitoring Parameters

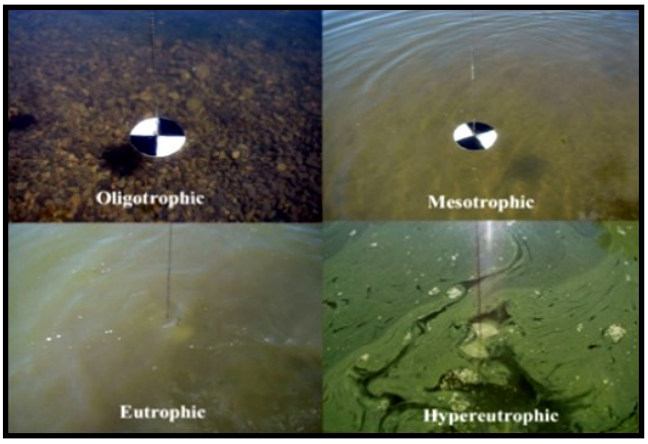
Chlorophyll-A (chl-A): Chlorophyll-A is a measure of the amount of algae growing in a waterbody and can be used as an indicator of water quality. It is a comparable analysis to TSS in streams. As water warms, algae begins to grow, and the amount of growth is dependent on the amount of nutrients in the 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 <14 µg/L.

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 >4.6 feet (1.4 meters).

Total Kjeldahl Nitrogen (TKN): A method for measuring organic nitrogen plus ammonia in a water sample. Nitrate and ammonia are the major forms of dissolved inorganic nitrogen and are the only forms that are available for algal and plant uptake. High levels of TKN often indicate the presence of animal waste and can lead to abundant plant growth. This in turn can have adverse effects on lake ecosystems, aquatic plants, invertebrates, fish, and humans. Excessive plant growth can impact the types of plants and ecological communities found in a lake, as available oxygen is decreased during the decomposition of plant material. TKN and other forms of nitrogen do not have a state WQ standard for surface waters, but there is an EPA drinking water standard of <10 mg/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 ortho-phosphorus, 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 <100 µg/L. The TP level for lakes in the chain varies depending on depth and connectivity to the river.

Common Terms



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.

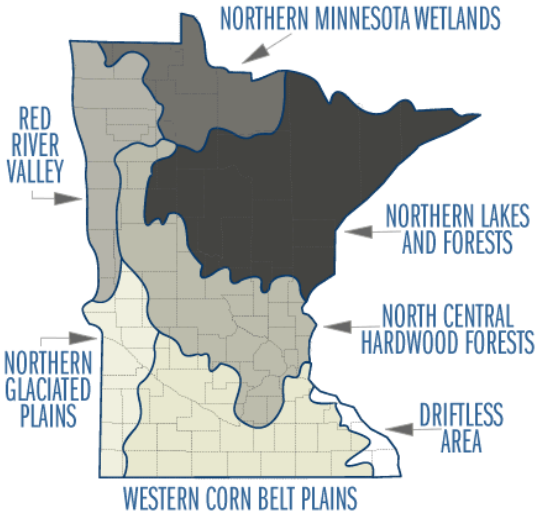
Eutrophic: TSI 50 - 70, Moderately clear to cloudy water, with a high chance of low oxygen conditions in the summer, extensive plant growth, and potential algal scum. From the Greek "eu" meaning well, plenty.

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.

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.

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 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.

Common Terms Cont.



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.

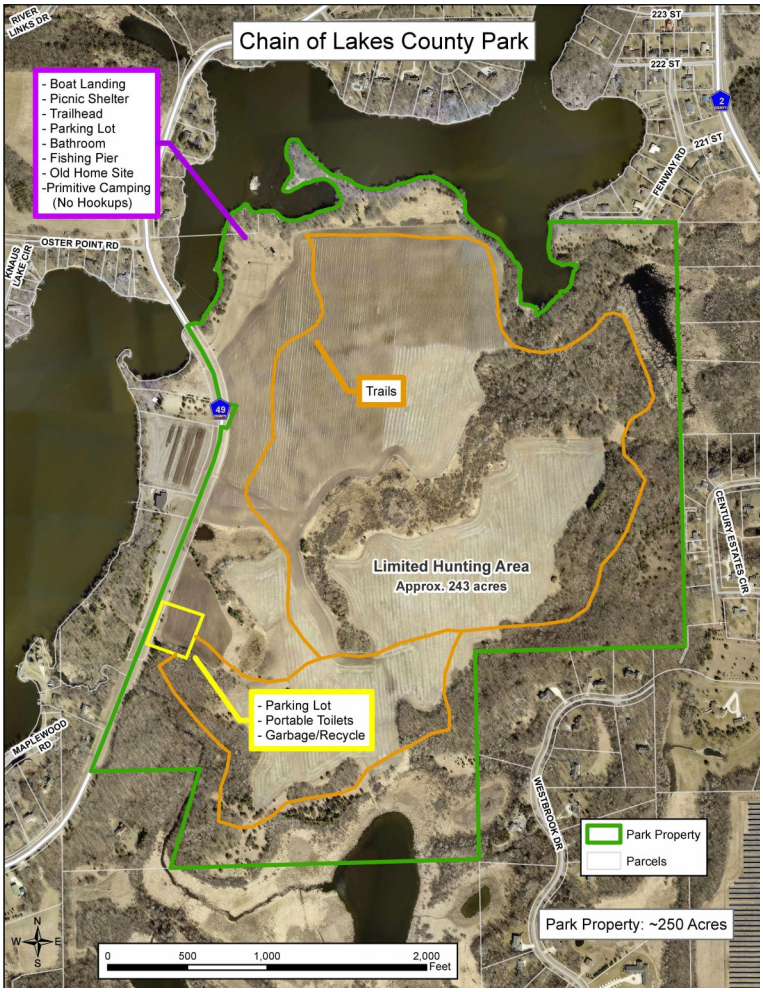
Point Source and Nonpoint Source: These terms are used when referring to how a pollutant enters a waterbody. Point sources are single and identifiable locations, such as the end of a pipe, and are regulated by state and federal agencies. Nonpoint sources can be rain and snow runoff, which accumulate 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.

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 (WQ) 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.

Stratification: The formation of distinct layers in a waterbody due to differing temperatures and densities. Warm water is less dense than cool water, so cool water sinks below warmer water. As summer progresses, the light-penetrated surface waters of a lake become warmer than the deeper water, and the water column stratifies by temperature and density. Stratification is a barrier to water column mixing, which moves oxygen, heat, and nutrients throughout the waterbody. Stratification commonly leads to dissolved oxygen depletion in the bottom layer of a lake.

Ongoing Projects



Stearns County gained a new county park in 2024, and it was named the Chain of Lakes Park. It is about 250 acres in size and is situated right on the Chain of Lakes near Cold Spring. West of the park is CR 49, which runs right along Knaus Lake. The county park also includes a half-mile stretch of river frontage on the north side, which is right on the outlet of the chain. It contains rolling hills, an old-growth oak forest, Kinzer Creek (which is a designated trout stream), and a heron rookery. Multiple organizations were involved in acquiring the property, including the SRWD, Pheasants Forever, and Dakota Ringnecks. The project received state grant money from the Lessard Sams Outdoor Heritage Fund (OHF) and used about $333,000 in unused COVID-19 relief funds from the county. The OHF grant requires the county to allow hunting in the park, so it will be the first in Stearns County to allow small game and archery deer hunting for the public.

Plans are in place to restore wetlands and the native prairie, which were previously being farmed. This will help protect and improve the water quality of the Sauk River and Kinzer Creek, which outlets into Knaus Lake. It will also provide critical habitat. Seven acres will be set aside for a picnic area, fishing pier, bathrooms, and primitive camping.

Another recent development for the Sauk River Chain of Lakes is the consideration to replace the Cold Spring Dam with a rock arch rapids (RAR) structure. This means that boulders would be placed across the waterway in a series of "steps" as the river gradually descends over the course of several hundred feet, while still maintaining stable water levels in the upstream lakes. Rock arch rapids help restore channel function and act like a staircase for fish to move upstream and downstream. This design would be more safe than a dam structure and could invite more recreation for fishing, walking on, and kayaking across the rapids. Along with this would also come water quality benefits for the system.

The MN Department of Natural Resources (DNR) is working with the Stearns Conservation District, who gave a presentation to the Cold Spring City Council at their December meeting and asked for a letter of support to conduct a feasibility study to remove the dam. The Council voted 4 to 1 to approve the letter supporting the survey. The state has provided funding for dozens of these projects in recent years as aging dams are increasingly failing and posing more of a liability. For more information, see the "Cold Spring City Council Meeting Notes for Dam Discussion" document on the SRCL website.

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