Crane Lake
Limnological Study

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Chapter 1. Introduction

Crane Lake is located in Forest County, Wisconsin. It is a 355-acre drainage lake (both inlet and outlet are present) with a maximum depth of 25feet. The Waterbody Identification Code (WBIC) is 388500. Crane Lake is classified as a mildly eutrophic lake. Characteristics of this type of lake often include: decreased water clarity, little dissolved oxygen near bottom, heavy algal blooms, high levels of plant growth and high in nutrients. All of these characteristics are manifest in Crane Lake and stakeholders there have the sense that conditions are moving toward an even more pronounced eutrophic status. As a result, the ***Pickerel/Crane Protection and Rehabilitation District*** engaged White Water Associates to conduct a specific limnological study on Crane Lake. This effort is part of a broader integrated undertaking on the lake that will address algae, aquatic plants, recreation and water quality. Questions of interest to this broader work at Crane Lake include:

1. Are human developments and/or activities effecting water and/or sediment chemistry?
2. Are upstream inputs having an effect on the chemistry of the water and/or sediment?
3. Is Crane Lake water quality compatible with human recreation/use?
4. Is the native plant community changing?
5. Is the Eurasian watermilfoil population size/distribution changing?
6. Is the Eurasian watermilfoil management effective?
7. Does Crane Lake experience nuisance algae blooms?
8. What algae species seem to be prevalent?
9. Are the algae effecting fish spawning habitat?
10. What environmental conditions are favorable to nuisance algae blooms in Crane Lake?

The Pickerel/Crane Lakes Adaptive Management Plan (Premo, et al. 2021) provided a comprehensive review of Crane Lake water quality in Appendix C2 and we urge stakeholders to review that document for historical context. The 2023 specific limnological study investigates characteristics of the lake that influence trophic status and we present that work in this report.

Chapter 2. Crane Lake watershed

The Crane Lake watershed is shown in Figure 1. It is 6.9square miles (17.9square kilometers) in surface area. It is in the Northern Lakes and Forests Ecoregion and the watershed is primarily forested. A small stream with origins in a forested wetland, and possible hydrological connection to St. Johns Lake, flows about one mile from its headwaters and enters Crane Lake along the north shore (lat/lon: 45.41713, -88.88964) after flowing under Doemel Lane (Figure 2). A public access to Crane Lake exists about one thousand feet west of the mouth of the creek (lat/lon: 45.41769, -88.89297). Although not shown on USGS topographical maps, aerial photos show two branches of small stream entering the channel between Crane Lake and Pickerel Lake from the north and east at a point about 300feet north of the road separating Crane and Pickerel Lakes (lat/lon: 45.401057, -88.883423). The channel that flows from Crane Lake to Pickerel Lake is about 0.4mile long and 200feet wide exits. It flows south under Pickerel Lake Road and into Pickerel Lake. This channel allows boat traffic between the two lakes.

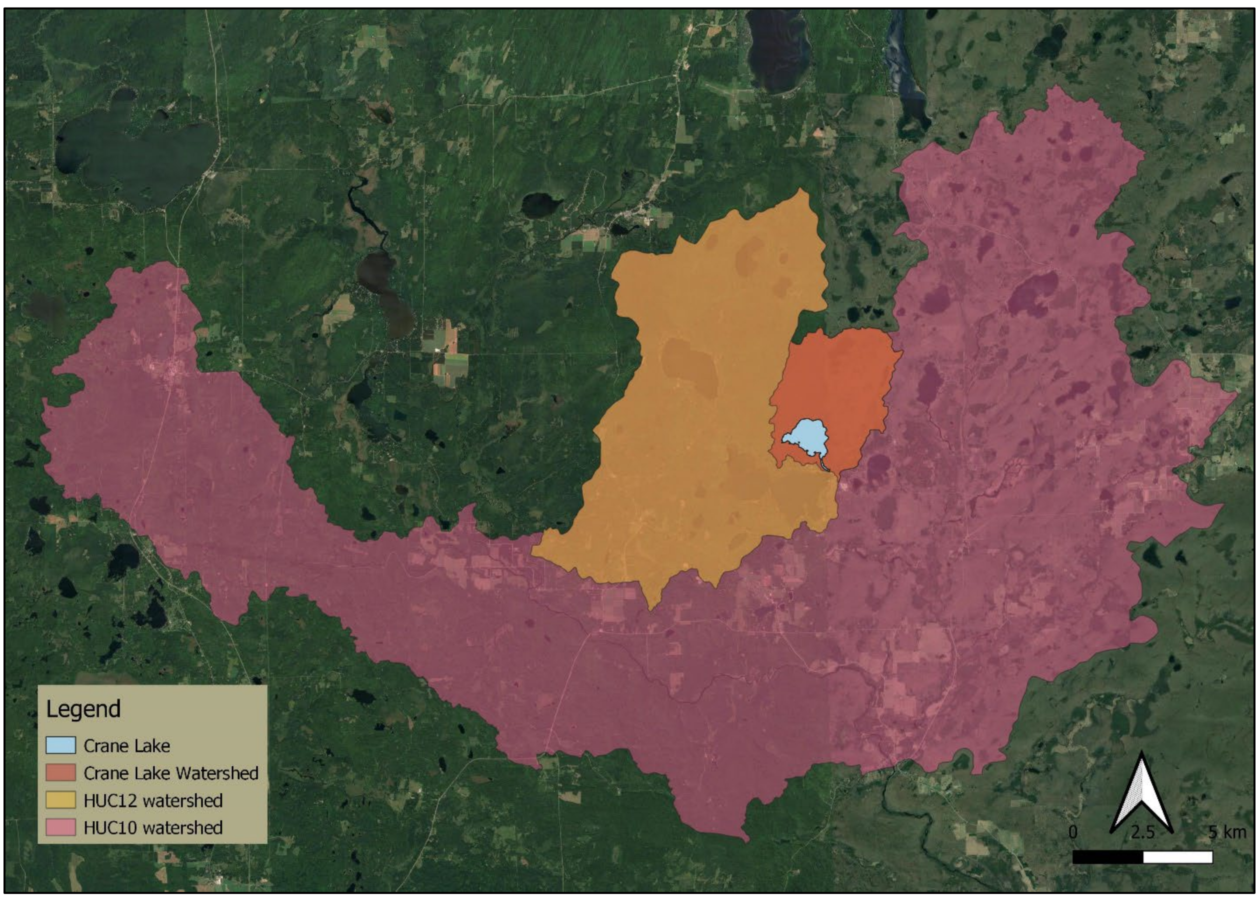

Figure 1. Crane Lake watershed.

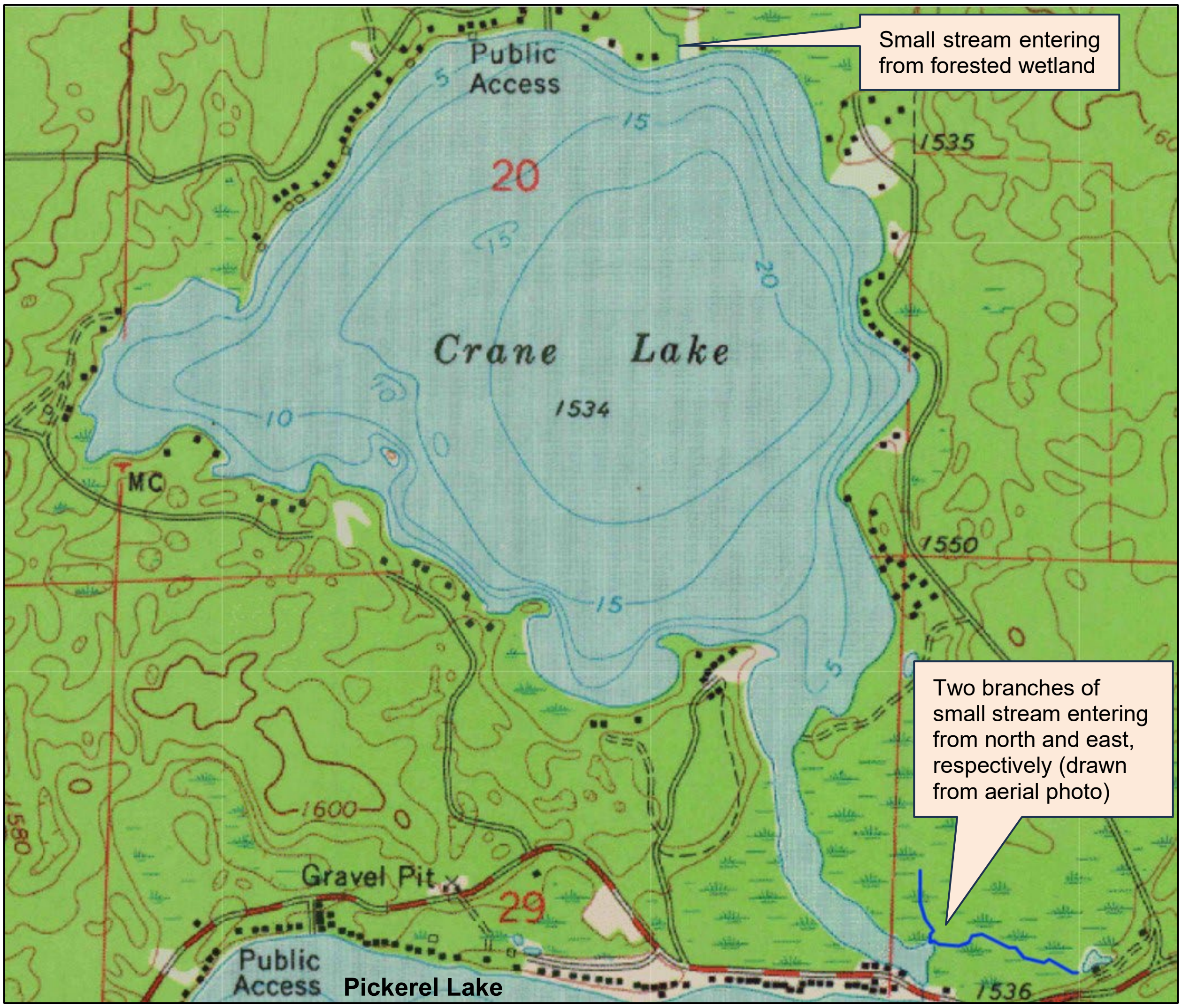

Figure 2. Crane Lake Topographical Map.

Chapter 3. Study methods

For the collection of field data and samples, this project integrated efforts by Crane Lake stakeholder volunteers and scientists from White Water Associates. Crane Lake volunteers collected data on water transparency, lake level, rainfall and stream discharge. A Crane Lake volunteer also collected rain event water samples. White Water Associates lake biologists measured temperature and dissolved oxygen profiles, carried out a conductivity study, and collected water and sediment samples. Water and sediment samples were analyzed at the White Water laboratory. Details on the field methods are described in this section.

Lake volunteer Mark Starich collected Crane Lake water transparency data using a standard Secchi disk. He took these measurements on 18 dates during spring, summer and fall of 2023.

Lake volunteer Gene Eben conducted lake level monitoring by obtaining measurements at the upstream end of the culvert at Pickerel Lake Road where the channel from Crane Lake enters Pickerel Lake. Mr. Eben measured water depth from the stream bottom to the water surface.

Lake volunteer Brian King recorded rainfall (in inches) from a standard rain gauge for rain events in 2023.

Lake volunteer Brad Kupfer estimated discharge from the northernmost incoming stream and the channel between Crane and Pickerel Lakes using a "float method." For these estimates, he measured stream width at the established measuring site. At the same site, he recorded stream depth at three points across the stream. At each of the three points, Kupfer recorded the number of seconds required for a neutrally buoyant sphere to float for a distance of 4feet. Using this data, mean stream velocity was calculated in feet per second (fps). The mean depth (in decimal feet) and mean velocity (fps) were used with the stream width to calculate stream discharge in cubic feet per second (cfs). Mr. Kupfer also collected water samples at near shore locations after rain events. These samples were conveyed to White Water laboratory for testing. Mr. Kupfer also recorded notes of filamentous and planktonic algae blooms in Crane Lake during the 2023 field season.

White Water biologists collected surface water samples at the deep hole in Crane Lake. They also collected sediment samples at this location using a Ponar dredge and recorded dissolved oxygen and temperature profiles at the deep hole location.

White Water biologists carried out a conductivity study on Crane Lake in August 2023. Such studies are used to determine levels of substances dissolved in the water. A lake's natural conductivity is influenced by geology and soils in the watershed. Low conductivity is characteristic of high-quality, oligotrophic (low nutrient) lake waters (GVSU, 2014). High conductivity is observed in eutrophic lakes where plant nutrients (fertilizers) are abundant (GVSU, 2014). Very high values indicate possible pollution sites (GVSU, 2014). Lake conductivity studies are sometimes used to determine if there are faulty septic systems or other pollution sources present that could be a source of extra nutrients in a lake. The Crane Lake shoreline conductivity study compared levels found near the shoreline with those recorded at the center of the lake (deep hole). The mean value of the readings taken at center of the lake was used as a control value for comparing the near-shore conductivity values. White Water staff boated slowly around the edge of the lake recording data on conductivity, depth, and location. Over 300 conductivity readings were obtained at approximately 30-meter intervals. Water conductivity samples were analyzed using a HI98494 pH/EC/opdo meter (Hanna instruments).

Chapter 4. Crane Lake water quality findings

This chapter presents the Crane Lake water quality data from 2023 sampling events. The findings from samples collected at the Crane Lake Deep Hole are presented in Table 1. Table 2 contains nutrient data collected from incoming and outgoing streams and shoreline sites. The data are referenced in the various Parts of this Chapter along with historical data for context.

Table 1. Water quality data from 2023 sampling of Crane Lake Deep Hole.

Parameter	Units	Results by Sampling Date (2023)			
		June 6	July 5	July 7	Aug 4
Alkalinity	mg/L	130		130	120
Aluminum	mg/L			ND	
Chloride	mg/L	ND			
Chlorophyll a	mg/m^3	1.1		2.1	2.9
Dissolved Organic Carbon	mg/L			3.2	
Calcium	mg/L			27	
Hardness	mg/L			120	
Iron	ug/L			16	
Magnesium	mg/L			13	
Manganese	ug/L			14	
Potassium	mg/L			0.68	
Sodium	mg/L			2.0	
Sulfate	mg/L	7.6			
Nitrate/Nitrite N	mg/L	ND	ND	ND	ND
pH	pH units	8.5		8.6	8.7
Silica	mg/L			12	
Tot Kjeldahl Nit	mg/L	0.21		0.25	0.41
Total Phosphorus	mg/L	ND	ND	ND	0.010
Total Suspend Solids	mg/L			ND	
Turbidity	NTUs	ND		ND	2.5
Sediment Tot Phosphorus	mg/kg			1600	
Sediment Total Solids	%			3.7	

Table 2. Nutrient data (nitrite/nitrate and total phosphorus) from 2023 sampling of Crane Lake Incoming Stream, Outgoing Stream, and Shoreline Sites.

Sampling Site	Parameter	Units	Results by Sampling Date (2023)		
			May 8	July 5	Jul 28
Incoming stream	Nitrite/Nitrate	mg/L	ND	ND	ND
	Total Phosphorus	mg/L	0.030	0.020	0.033
Outgoing stream	Nitrite/Nitrate	mg/L	ND		
	Total Phosphorus	mg/L	0.021		
Holler SW	Nitrite/Nitrate	mg/L			ND
	Total Phosphorus	mg/L			0.039
Frankie SW	Nitrite/Nitrate	mg/L			ND
	Total Phosphorus	mg/L			ND
Koehl SW	Nitrite/Nitrate	mg/L			ND
	Total Phosphorus	mg/L			0.040
Lakeshore East	Nitrite/Nitrate	mg/L		ND	
	Total Phosphorus	mg/L		0.008	
Lakeshore Northeast	Nitrite/Nitrate	mg/L		ND	
	Total Phosphorus	mg/L		ND	
Lakeshore North	Nitrite/Nitrate	mg/L		ND	
	Total Phosphorus	mg/L		0.016	

Part 1. Temperature

The temperature of a lake at different depths influences physical, biological, and chemical processes of the lake. Lake water temperature influences decomposition, nutrient recycling, lake stratification, and dissolved oxygen (DO) concentration. Temperature can also affect the distribution of fish species throughout a lake. Figure 3 presents Crane Lake water temperature profiles collected in 2023. These profiles show an expected pattern in a stratified lake.

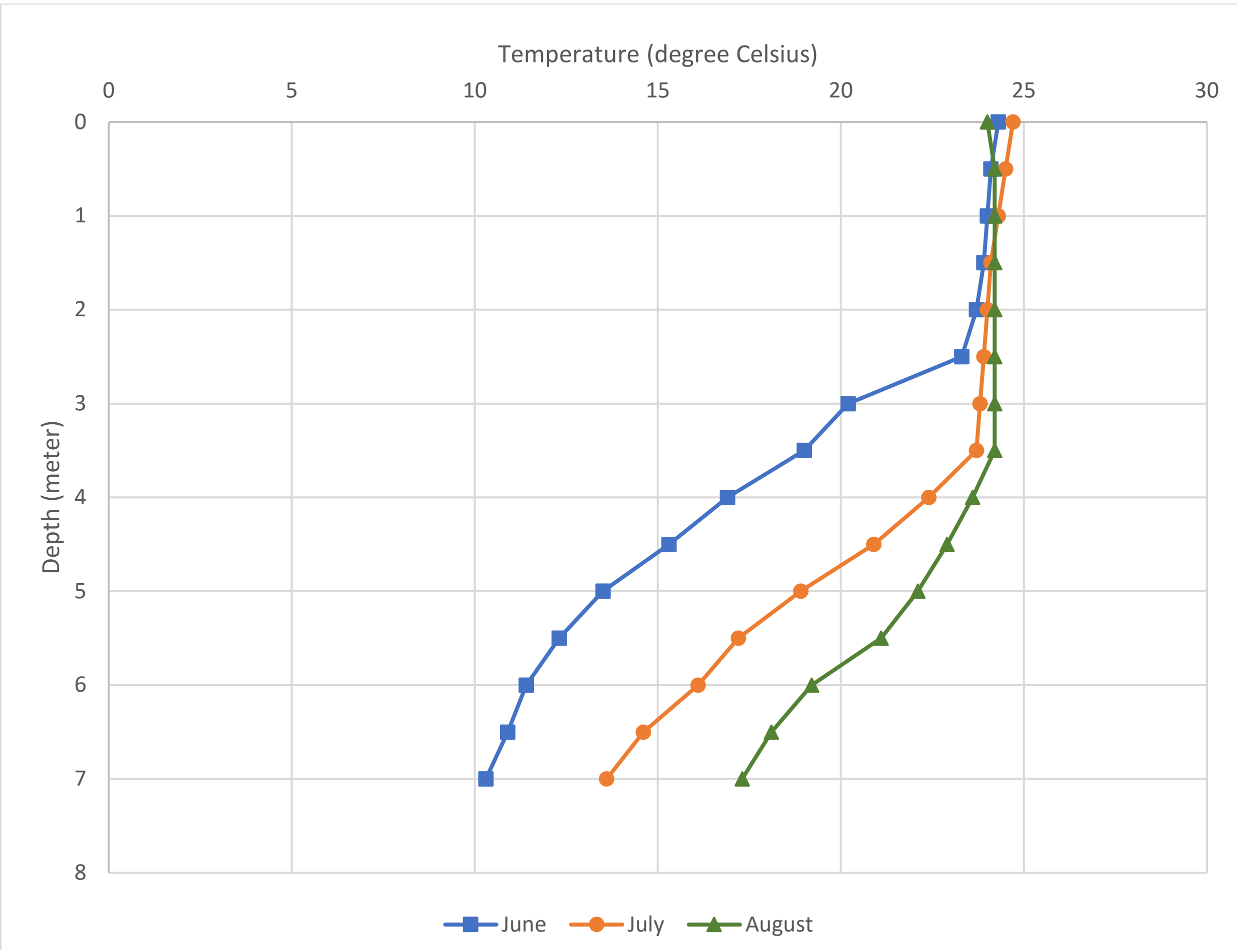

Figure 3. Crane Lake 2023 Temperature profiles.

Part 2. Dissolved Oxygen

The dissolved oxygen (DO) content of lake water is vital in determining presence of fish species and other aquatic organisms. Dissolved oxygen also influences chemical and physical conditions of a lake. The amount of dissolved oxygen is dependent on the water temperature, atmospheric pressure, and biological activity. Oxygen levels are increased by aquatic plant and algae photosynthesis, but reduced by respiration of plants, decomposer organisms, fish, and invertebrates. Crane Lake DO and percent saturation profiles measured in 2023 are displayed in Figure 4 and Figure 5. The Crane Lake dissolved oxygen and percent saturation profiles show an expected pattern in a stratified lake. It is often reported that 7mg/l is the oxygen concentration above which coldwater fish (trout) will thrive. A similar threshold for warmwater species is 5mg/l.

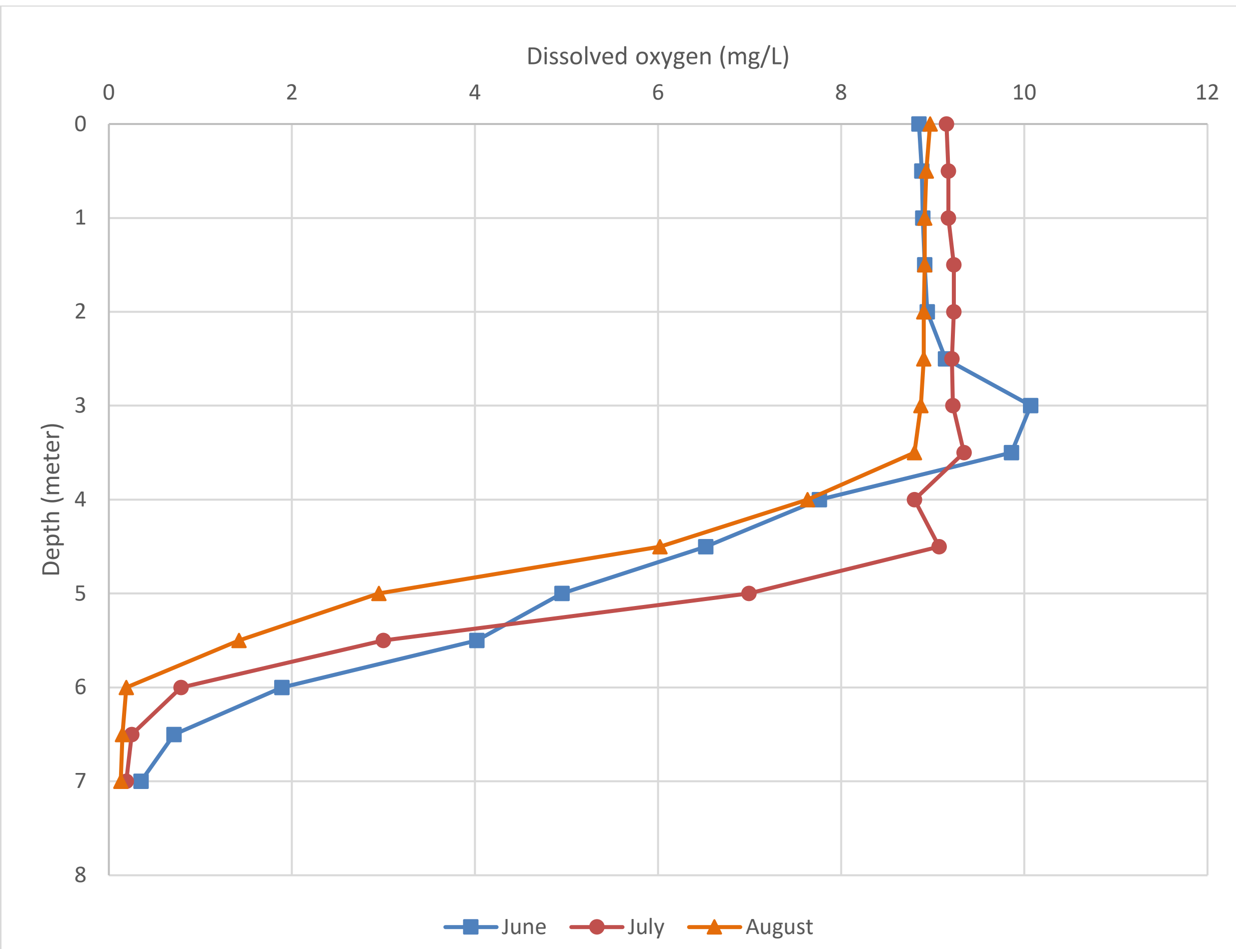

Figure 4. Crane Lake 2023 dissolved oxygen profiles.

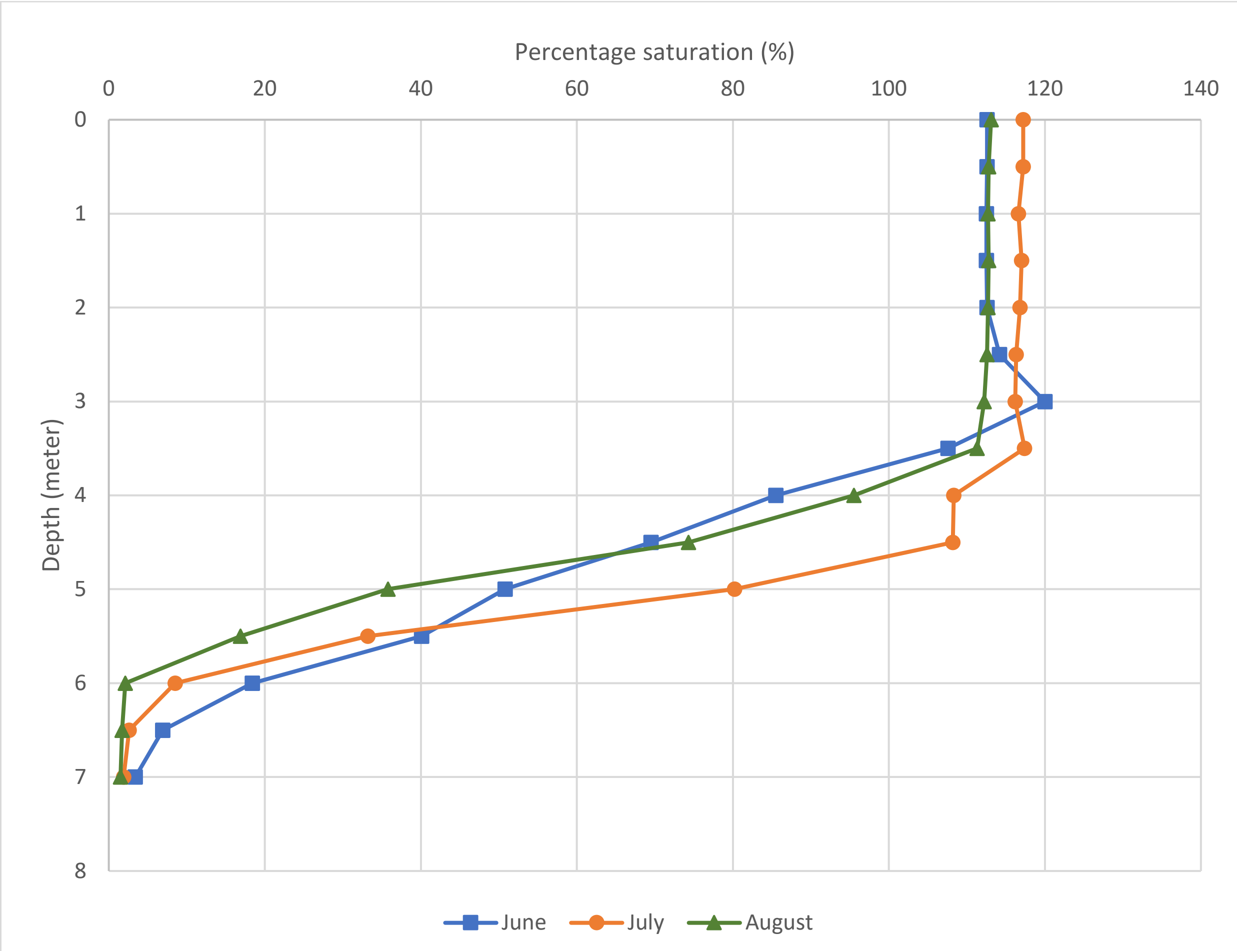

Figure 5. Crane Lake 2023 percentage saturation profiles.

Part 3. Water Clarity

Water clarity (sometimes referred to as transparency) has two main components: turbidity (suspended materials such as algae and silt) and true color (materials dissolved in the water) (Shaw et al., 2004). Water clarity gives an indication of the overall water quality in a lake. Water clarity is typically measured using a Secchi disk (black and white disk) that is lowered into the water column on a tether. The depth at which the disk disappears is noted and then the disk is slowly brought up to where it is just visible again and the depth noted. The mean of these two values is recorded as the Secchi depth.

Secchi transparency readings were taken by Crane Lake volunteer Mark Starich on nearly a weekly basis May through September, 2023. The values are reported in Table 3 and can be compared to historical data displayed in Figures 6, 7, and 8. The lower values likely represent times when planktonic algal blooms were reducing water transparency. When this happens, zooplankton populations boom and consume the algae and help increase transparency. The zooplankton are eaten by fish. The July and August average for these readings is 8.5feet. This value represents the best July-August mean water clarity on Crane Lake for the past 10 years and would be rated as “fair to good” (see Table 4).

Table 3. Crane Lake 2023 Secchi readings.

2023 Date	Secchi Depth (ft)	Water Appearance	Water Color
9-May	8	Clear	Brown
17-May	10.6	Clear	Clear
25-May	13	Clear	Clear
30-May	15	Clear	Brown
8-June	19	Clear	Brown
14-June	13	Clear (Cloudy)	Brown
20-June	16	Clear	Brown
29-June	14	Clear	Green
18-July	11	Clear	Green
25-July	13	Clear	Green
1-August	9	Clear	Green
8-August	8.6	Clear	Green
17-August	6.6	Clear	Green
21-August	6	Clear	Green
31-August	5	Clear	Green
5-September	4	Murky	Green
13-September	4	Murky	Green
20-September	4	Murky	Green

Figure 6 displays mean Secchi depths over the years (using July and August measurements). Crane Lake Secchi depth categorizes from “very good” to “poor” with respect to water clarity (Table 4). Figure 7 displays all Secchi depths recorded over the years and shows similar variation and fairly similar water transparency over the years when considering all months when Secchi was recorded. Finally, Figure 8 displays Secchi readings by date and illustrates the typical seasonal arc of water transparency.

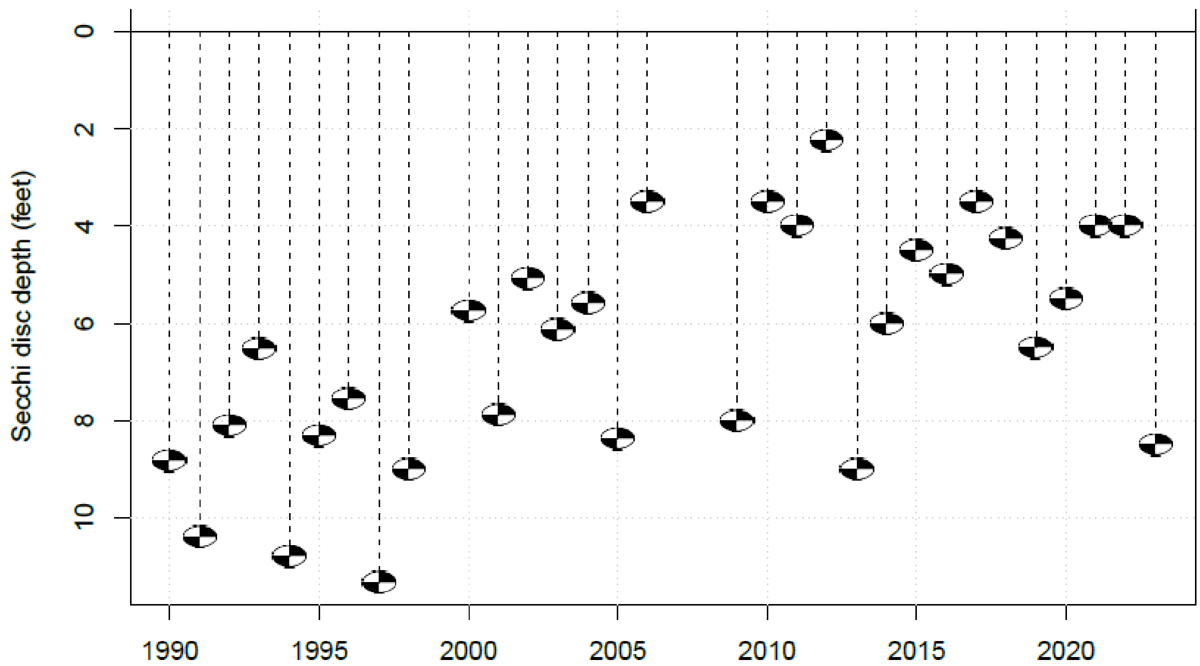

Figure 6. Crane Lake Secchi depth average, July and August only (WDNR, 2024).

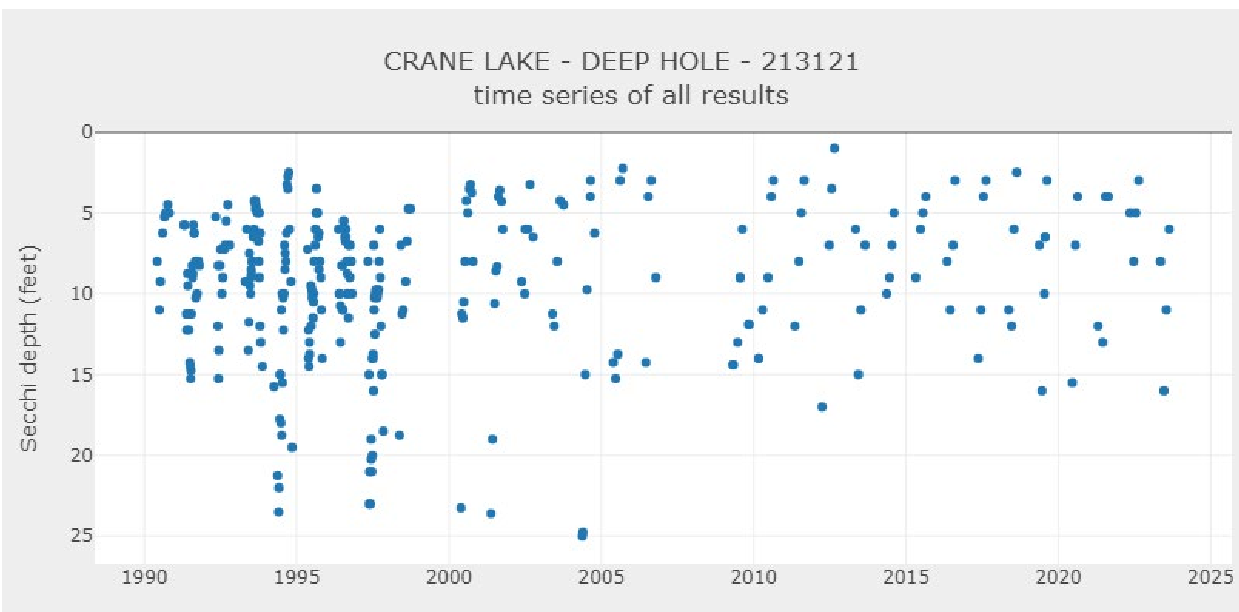

Figure 7. Crane Lake Secchi depth over the years (WDNR, 2024).

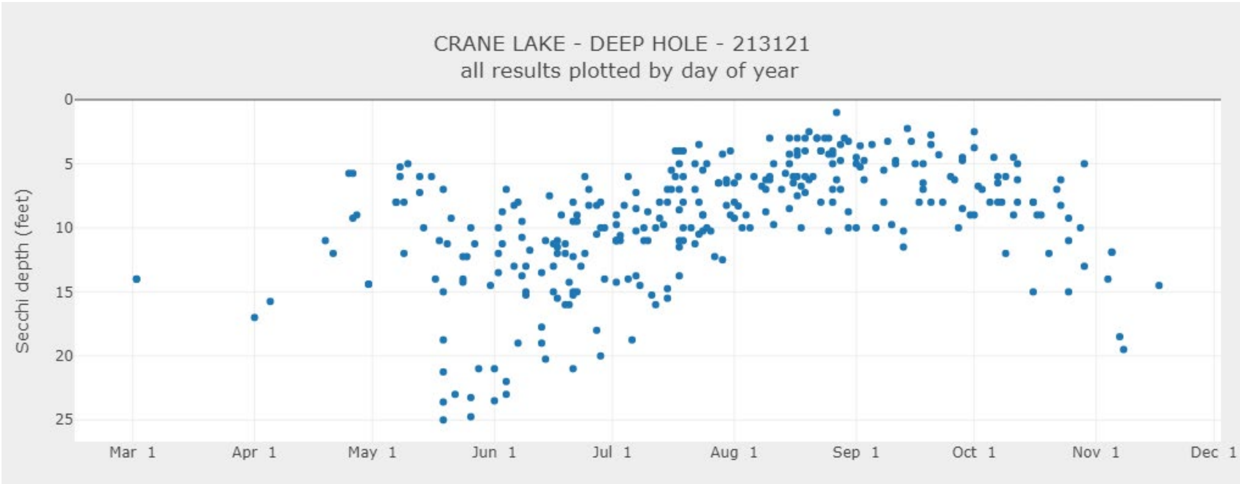

Figure 8. Crane Lake Secchi depth by day of years (data from 1990 to 2023) (WDNR, 2024).

Table 4. Water clarity index (Shaw et al. 2004).

Water clarity	Secchi depth (ft.)
Very poor	3
Poor	5
Fair	7
Good	10
Very good	20
Excellent	32

Part 4. Water Level and Incoming and Outgoing Waters

Water levels between April and October 2023 were monitored by Crane Lake volunteer Gene Eben and presented in Table 5. The highest lake level recorded in 2023 was at the end of April and consistently went down to the lowest level at the end of August when it was 9.5inches lower than the April reading. By the end of October, the lake level had increased to just 1.25inches less than the end of April reading.

Table 5. Crane Lake 2023 water depth at upstream end of Pickerel Lake Rd culvert.

Sampling Time	Water Depth (inches from stream bottom to water surface)	Net change (difference in inches from April value)
End of April	39.5	
End of May	32.25	-7.25
End of June	32	-7.50
End of July	31	-8.50
End of August	30	-9.50
End of September	31.5	-8.25
End of October	38.25	-1.25

Crane Lake is a "drainage lake." In other words, it has both incoming and outgoing streams. Crane Lake volunteer Brad Kupfer measured the discharge of incoming and outgoing streams in May and October of 2023. Those findings are presented in Table 6. Because this is a limited data set and there is uncertain influence of wind driven water currents on the outgoing stream flow, we are unable to draw conclusions from this data. Assuming that the incoming stream discharge measurement is less impacted by wind, we used it to calculate residence time in Crane Lake as 55 to 103 days (0.15 to 0.3-year) depending on whether the May or October discharge is used in the calculation. This is a somewhat less than the 0.80-year residence time estimated by the WiLMS model (see Chapter 5, Discussion), but in the same ballpark especially given that these measurements come from a time of year when the incoming stream tends to have higher flow.

Table 6. Discharges (cfs) for Crane Lake incoming and outgoing streams in 2023.

2023 Date	Location	Discharge in cubic feet per second (cfs)
8-May	Incoming stream	19.2
8-May	Outgoing stream	123.0
October	Incoming stream	35.9
October	Outgoing stream	Unable to measure (wind was pushing water upstream into culvert from Pickerel Lake)

Part 5. User Perceptions

The Wisconsin Citizen Lake Monitoring Network (CLMN) records perceptions of the water, based on the physical appearance and the recreational suitability. These perceptions can be compared to water quality parameters to see how the lake user would experience the lake at that time. For most lakes when the Secchi depth decreases, the rating of the lake's physical appearance also decreases. Figure 9 provides historical user perception data for Crane Lake. In 2023, the observers documented very minor aesthetic problems.

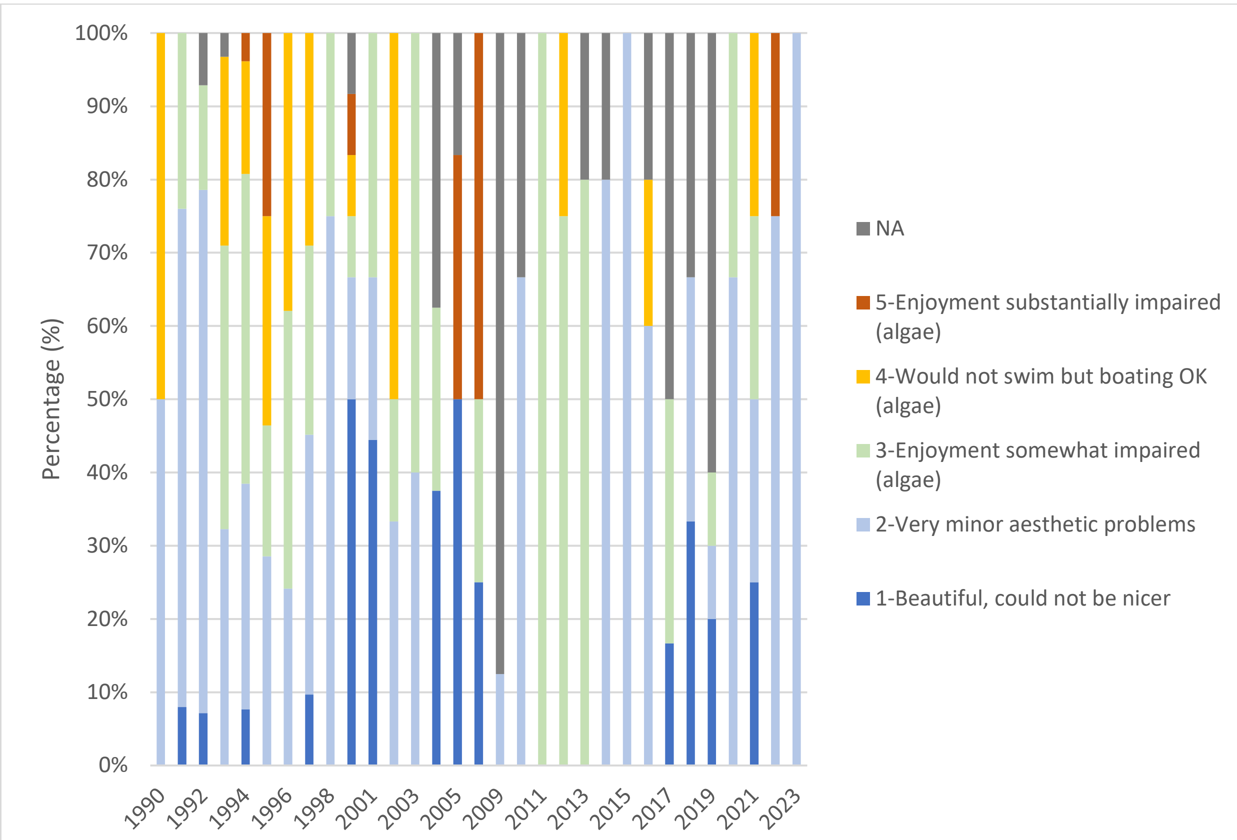

Figure 9. Crane Lake aesthetic value (CLMN 1990-2023).

Part 6. Chlorophyll *a*

Chlorophyll *a* is the photosynthetic pigment that conveys a green color to plants and algae. Chlorophyll *a* in lake water is an indicator of the abundance of planktonic algae. Chlorophyll *a* concentrations greater than 10µg/l are perceived as a mild algae bloom, while concentrations greater than 20µg/l are perceived as a nuisance. Over the last 20 years there have been only 3 years when Crane Lake chlorophyll *a* concentrations were less than 10µg/l and there were twelve years when the centration averaged above 20µg/l (Figure 10). It should be noted, however, that no clear upward or downward trend is evident from this record. The 2023 Crane Lake chlorophyll *a* data collected as part of this study is presented in Table 1. The values for June, July, and August were relatively low.

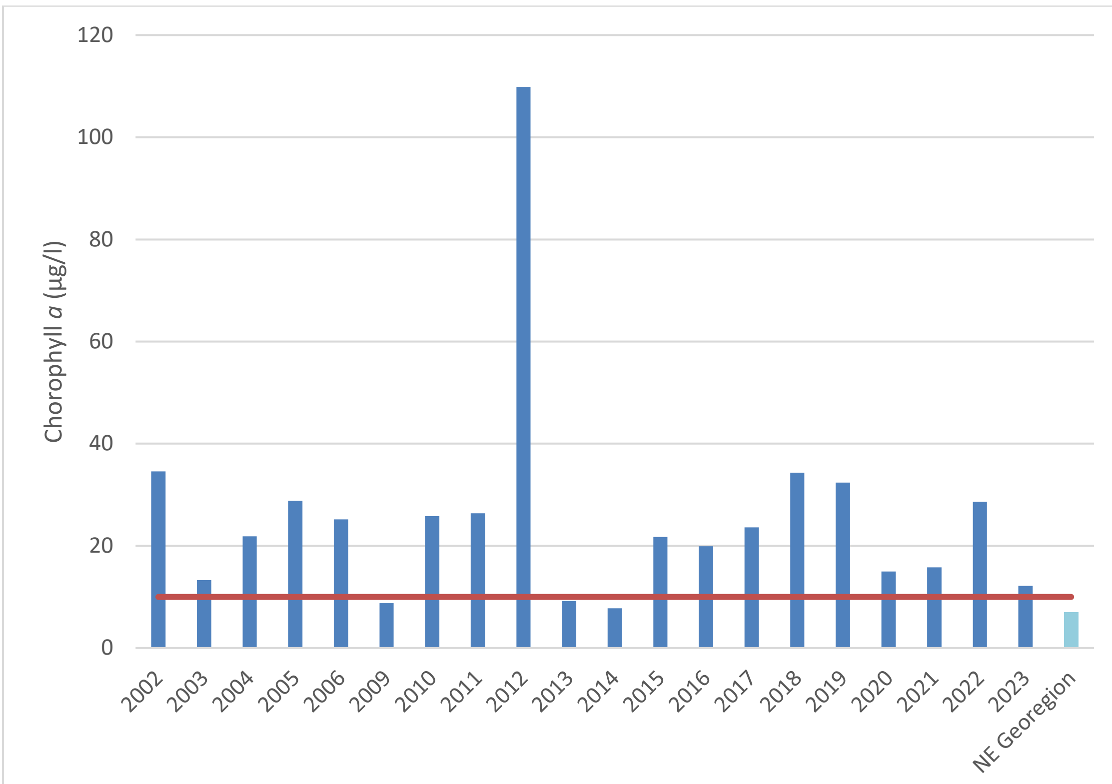

Figure 10. Crane Lake chlorophyll a (Average July 15 – September 15) (WDNR, 2024)
(Note: the mean value for the northeast Wisconsin georegion is displayed on far right of the histogram).

Part 7. Phosphorus

In more than 80% of Wisconsin's lakes, phosphorus is the key nutrient affecting algae and plant growth. If phosphorus levels are high, excessive aquatic plant growth can occur. Phosphorus originates from a variety of sources, many of which are related to human activities. Major sources include human and animal wastes, soil erosion, detergents, septic systems and runoff from farmland or lawns (Shaw et al., 2004). Phosphorus provokes complex reactions in lakes. An analysis of phosphorus often includes both soluble reactive phosphorus and total phosphorus. Soluble reactive phosphorus dissolves in the water and directly influences plant growth (Shaw et al., 2004). Its concentration varies in most lakes over short periods of time as plants take it up and release it. Total phosphorus is considered a better indicator of a lake's nutrient status than soluble reactive phosphorus because its levels remain more stable (Shaw et al., 2004). Total phosphorus includes soluble phosphorus and the phosphorus in plant and animal fragments suspended in lake water. A concentration of total phosphorus below 20µg/l for lakes typically prevents nuisance algal blooms (Shaw et al., 2004). As with the Crane Lake chlorophyll a history, average total phosphorus concentrations to not show dramatic trends since 2000. In fact, recent years show somewhat lower values (Figure 11). The 2023 Crane Lake total phosphorus data at the deep hole location are presented in Table 1 and values were below the 20µg/l threshold. These values are below average for natural Wisconsin Lakes (see Figure 12). Total phosphorus measured at the incoming stream location (Table 2) were higher than the lake values, but not dramatically so. Total phosphorus samples taken at the Holler SW and Koehl SW sites after a rain event did show somewhat elevated total phosphorus concentrations (39 and 40µg/l, respectively). Total phosphorus was also measured in a sediment sample from the deep hole location. This value was 1600mg/kg. Very little data is published on total phosphorus concentration for Wisconsin Lakes. We found one reference for the northeast U.S. where sediment values in lake sediments ranged from about 800 to 2,800 mg/kg (Ostrofsky, 2012). We are currently investigating other data sources to provide better context for the Crane Lake value. Severe weather events and global climate change will likely influence the release of phosphorus from the sediment.

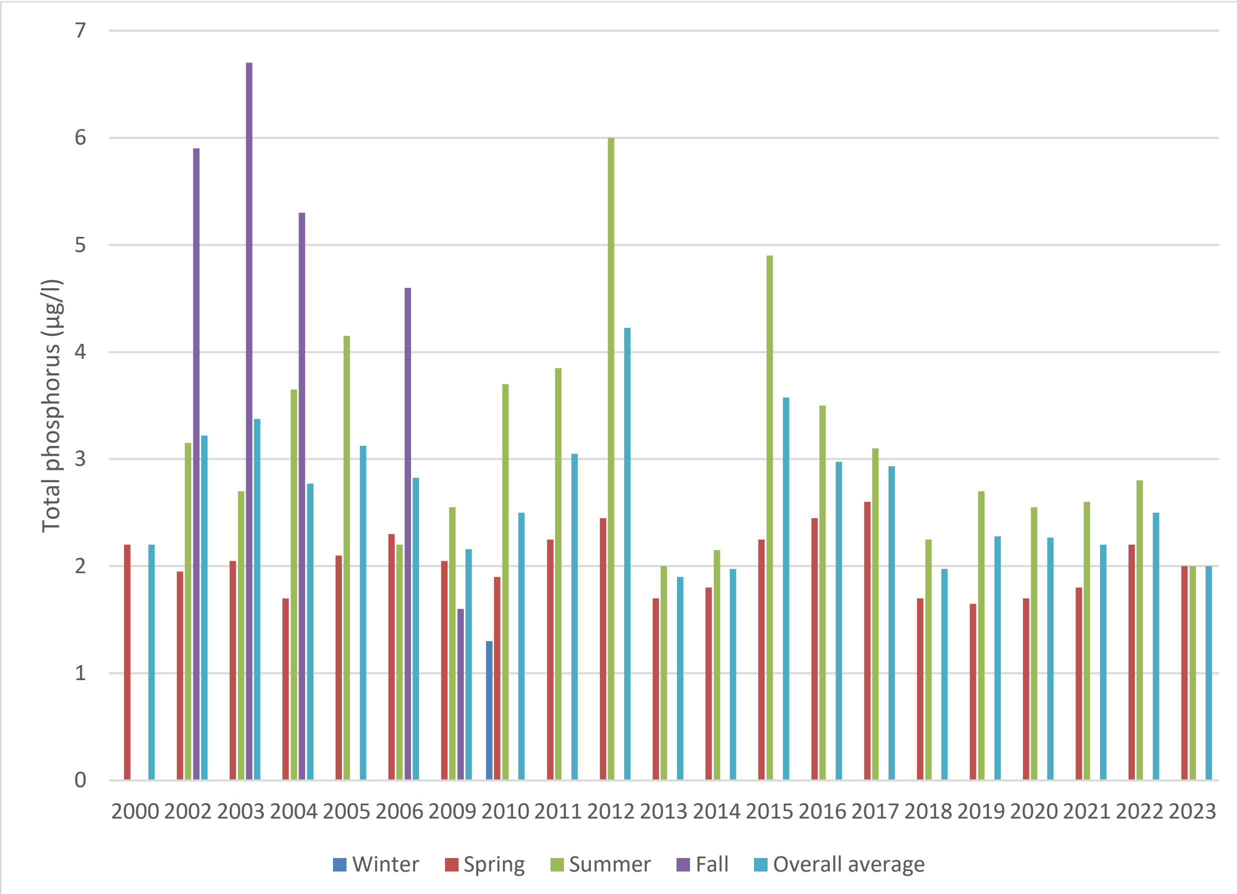

Figure 11. Crane Lake total phosphorus averages.

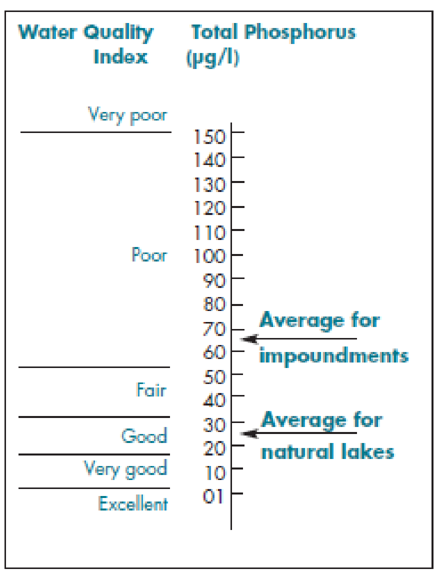

Figure 12. Total phosphorus concentration for Wisconsin's natural lakes and impoundments (Shaw et al., 2004).

Part 8. Trophic State

Trophic state is another indicator of water quality (Carlson, 1977). Lakes are typically divided into three categories based on trophic state: oligotrophic, mesotrophic, and eutrophic. These categories reflect a lake's nutrient, chlorophyl a and water clarity (Shaw et al., 2004). Common characteristics used to make the determination of the trophic state of lakes are: total phosphorus (important for algae growth), chlorophyll *a* concentration (a measure of the algae present), and Secchi disk readings (an indicator of water clarity) (Shaw et al., 2004) (Table 7).

Table 7. Example trophic classification of Wisconsin Lakes based on chlorophyll a, water clarity measurements, and total phosphorus values (Shaw et a., 2004).

Trophic Class	Total Phosphorus (µg/L)	Chlorophyll *a* µg/L	Secchi Disk (ft.)
Oligotrophic	3	2	12
	10	5	8
Mesotrophic	18	8	6
	27	10	6
Eutrophic	30	11	5
	50	15	4

Figure 13 presents a 33-year record of the calculated trophic state for Crane Lake. Trophic state determinations are based on total phosphorus, chlorophyll *a* and water clarity began about 2003. Since that time, although the lake consistently would be placed in eutrophic status, there is no upward trend in the data. In fact, there may be a slight downward trend (as was reflected by the total phosphorus and chlorophyll *a* data).

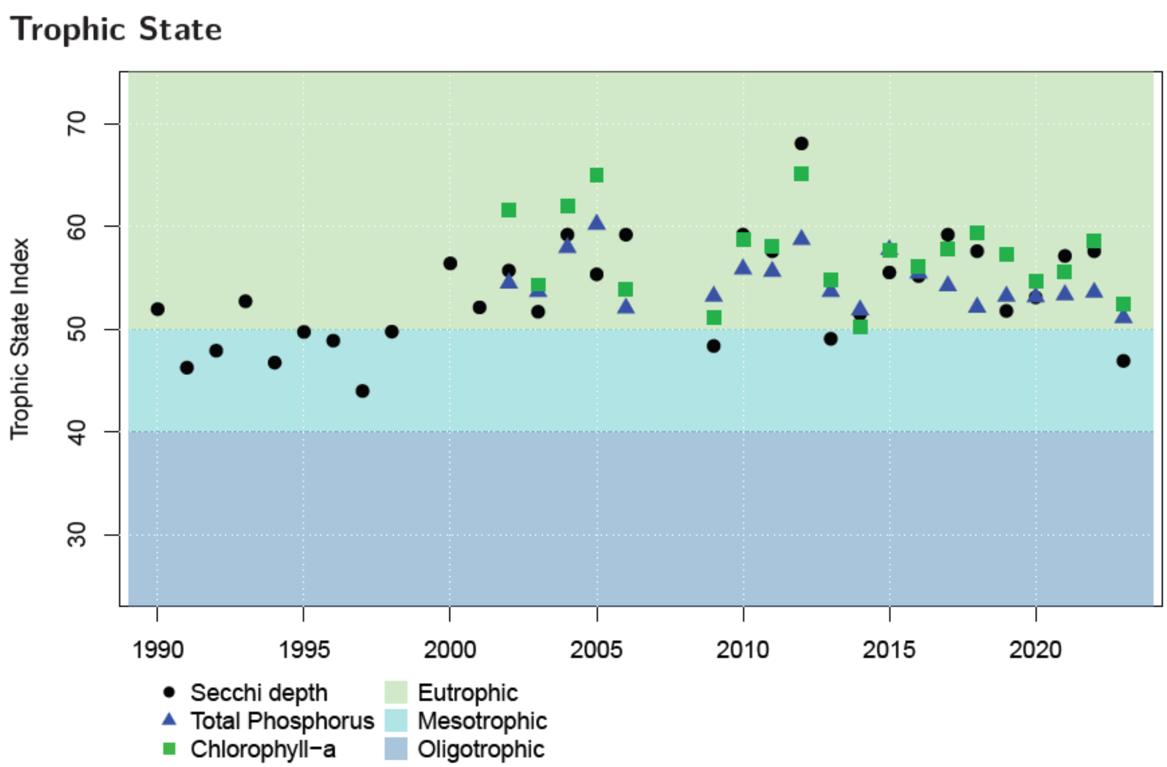

Figure 13. Crane Lake Trophic State Index (1990-2023) (WDNR, 2024).

Part 9. Nitrogen

Nitrogen is second only to phosphorus as an important nutrient for aquatic plant and algae growth (Shaw et al., 2004). Human activities on the landscape greatly influence the amount of nitrogen in a lake. Nitrogen may come from lawn fertilizer, septic systems near the lake, or from agricultural activities in the watershed. Nitrogen may enter a lake from surface runoff or groundwater sources. It is a major component of all organic (plant and animal) matter.

Nitrogen exists in lakes in several forms. Decomposing organic matter releases ammonia. In water, ammonia is often present as ammonium with proportions between the two related to pH and temperature. When oxygen is present, ammonia is converted to nitrate and nitrite by nitrifying bacteria. All inorganic forms of nitrogen (ammonia, nitrate/nitrite) can be used by aquatic plants and algae (Shaw et al., 2004). If these inorganic forms of nitrogen exceed 0.3mg/l (as N) in spring, there is sufficient nitrogen to support summer algae blooms (Shaw et al., 2004). Elevated concentrations of ammonia, nitrate, and nitrite, derived from human activities, can stimulate or enhance the development, maintenance and proliferation of primary producers (phytoplankton, benthic algae, macrophytes), contributing to the widespread phenomenon of the cultural (human-made) eutrophication of aquatic ecosystems (Camargo et al., 2007). The nutrient enrichment can cause important ecological effects on aquatic communities, since the overproduction of organic matter, and its subsequent decomposition, usually lead to low dissolved oxygen concentrations in bottom waters, and sediments of eutrophic and hypereutrophic aquatic ecosystems with low turnover rates (Camargo et al., 2007). Nitrite/Nitrate concentrations in Crane Lake 2023 water samples were all very low.

Part 10. Conductivity

Conductivity is a measure of the ability of water to conduct an electric current. Conductivity is reported in micromhos per centimeter **(**µmhos/cm) and is directly related to the total dissolved inorganic chemicals in the water. Usually, values are approximately two times the water hardness, unless the water is receiving high concentrations of human-induced contaminants (Shaw et al., 2004). Crane Lake conductivity was sampled in June, July and August (see Table 8) with the mean value of those readings being 235.8µmhos/cm). This value is 2.0 times the water hardness of Crane Lake indicating little human-induced contaminants are entering the lake.

Table 8. Crane Lake 2023 Conductivity monitoring.

	Conductivity (µmhos/cm)
June	243.3
July	242.1
August	222.0

White Water Associates scientists did a shallow water conductivity study on Crane Lake in August 2023. Conductivity studies are used to determine a lake's levels of dissolved substances. A lake's natural conductivity is influenced by the geology and soils in the watershed, but areas of high conductivity can be indicators of pollution or faulty septic systems. There was a total of 309 sample points around Crane Lake's shoreline. Several conductivity readings were taken in the center of the lake to develop a "control mean value." The conductivity readings from near the shoreline were obtained from shallow water (mean depth of just over 2feet) and did not show much variation. About half of the samples were taken in from of residences. The results are displayed in Figure 14. No areas of noteworthy high conductivity are evident from this study.

Elevated conductivity readings are typically due to human activity such as road salting, faulty septic systems, and agricultural runoff. The following are things riparian landowners can do to minimize the potential for increasing conductivity:

1. Limit soil disturbance and bedrock exposure on your property.
2. Create vegetative buffers to filter and reduce of storm water runoff from your property.
3. Replace a conventional beach to a natural beach.
4. Pump your septic system tank once every one to three years.
5. Replace or upgrade a failing leach field immediately.
6. Consider alternatives to road salt use near the lake and its tributaries.

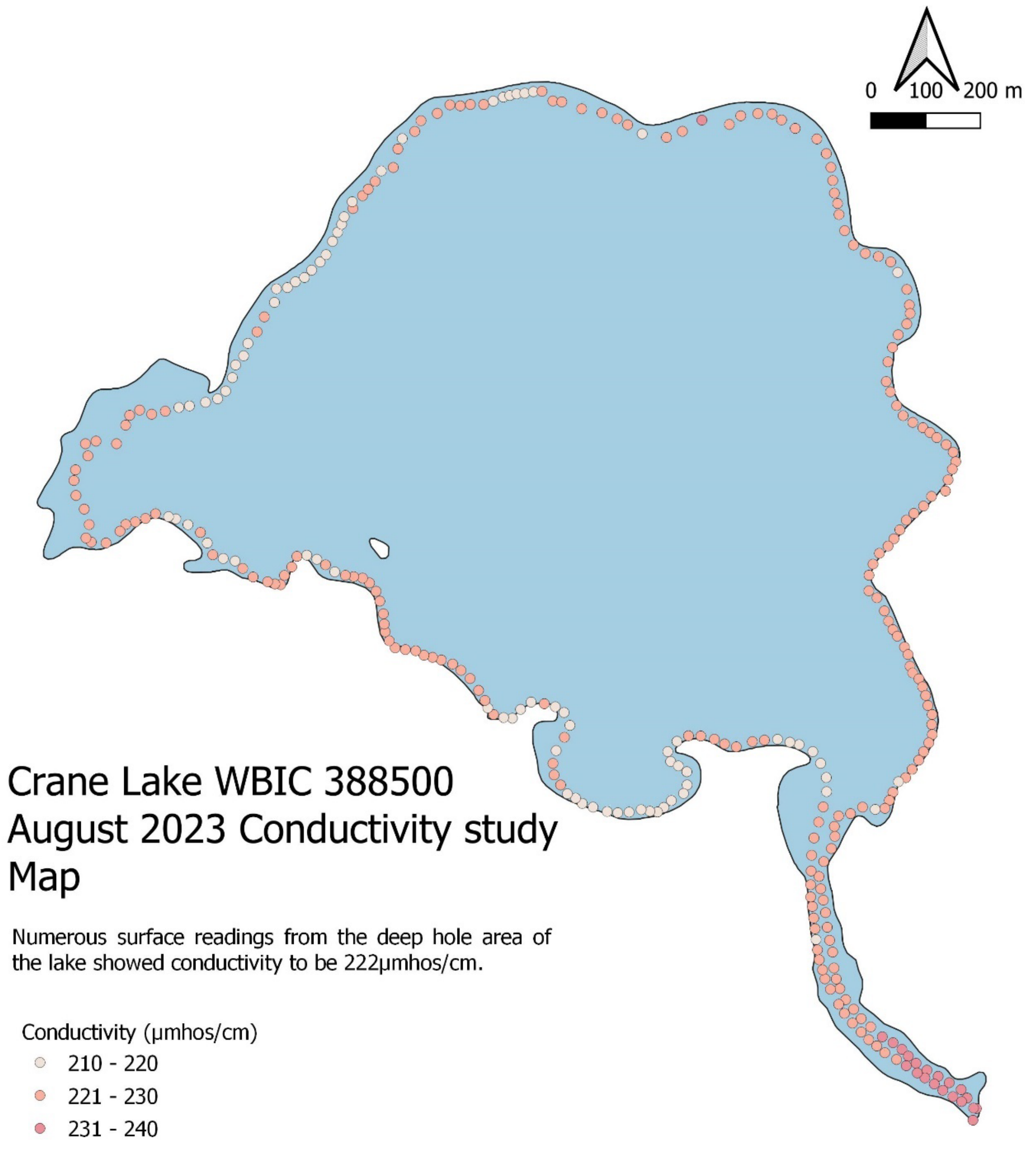

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Figure 14. Crane Lake 2023 Conductivity study

Part 11. pH

The acidity level of lake water regulates the solubility of many minerals. A pH level of 7 is considered neutral. The pH level in Wisconsin lakes ranges from 4.5 in acidic bog lakes to 8.4 in hard water, marl lakes (Shaw et al., 2004). Natural rainfall in Wisconsin averages a pH of 5.6. Some minerals become available under low pH (especially aluminum, zinc, and mercury) and can inhibit fish reproduction and/or survival. Mercury and aluminum are not only toxic to many kinds of wildlife, but also to humans. The pH scale is logarithmic, so every 1.0 unit change in pH increases the acidity tenfold. Water with a pH of 6 is 10 times more acidic than water with pH of 7. A lake's pH level is important for the release of potentially harmful substances and affects plant growth, fish reproduction and survival. A lake with neutral or slightly alkaline pH is a good lake for fish and plant survival. Crane Lake pH is consistently between 8 and 9 (Table 9).

Table 9. Crane Lake 2023 pH monitoring.

	pH
June	8.56
July	8.43
August	8.65

Part 12. Alkalinity

Alkalinity levels in a lake are affected by the soil minerals, bedrock type in the watershed, and frequency of contact between lake water and these materials (Shaw et al., 2004). Alkalinity is water's capacity to resist acidic changes in pH, essentially alkalinity is water's ability to neutralize acid. Alkalinity is important in a lake to buffer the effects of acidification from the atmosphere. Acid rain has long been a problem with lakes that have low alkalinity levels and high potential sources of acid deposition. Alkalinity in Crane Lake (see Table 1) is highly protective of pH change and is considered "non-sensitive" to acid rain (Table 10).

Table 10. Sensitivity of lakes to acid rain (Shaw et al., 2004).

Sensitivity to acid rain	**Alkalinity value (mg/l or ppm CaCO3)**
High	0-2
Moderate	2-10
Low	10-25
Non-sensitive	>25

Part 13. Hardness

Hardness levels in a lake are affected by the soil minerals, bedrock type, and frequency of contact between lake water and these materials (Shaw et al., 2004). One method of evaluating hardness is to test for calcium carbonate ($CaCO_3$). Crane Lake hardness was 120mg/l of $CaCO_3$ (Table 1). This level categorizes Crane Lake water as "moderately hard" (Table 11).

Table 11. Categorization of hardness by mg/l of calcium carbonate ($CaCO_3$) (Shaw et al., 2004).

Level of hardness	Total hardness as mg/l $CaCo_3$
Soft	0-60
Moderately hard	61-120
Hard	121-180
Very hard	>180

Part 14. E. coli monitoring

E. coli is a species of coliform bacteria that is monitored at beaches. White Water field staff collected water samples in Crane Lake to analyze for *E. coli* (see Figure 15 for sampling locations). All of the results are low. For context, swimming beach *E. coli* levels should be below 200MPN/100ml and the highest Crane Lake value was 12. The *E. coli* that is present in Crane Lake could be from water-associated warm-blooded animals (birds and mammals).

Table 12. Crane Lake 2023 E. coli monitoring.

Sample ID	Result (MPN/100ml)
June 6 - E. Coli Site 1	3
June 6 - E. Coli Site 2	1
June 6 - E. Coli Site 3	29
June 6 - E. Coli Site 4	1
July 7 - E. Coli Site 1	1.0
July 7 - E. Coli Site 2	ND
July 7 - E. Coli Site 3	ND
July 7 - E. Coli Site 4	2.0
August 4 - E. Coli Site 1	8
August 4- E. Coli Site 2	11
August 4- E. Coli Site 3	12
August 4- E. Coli Site 4	ND

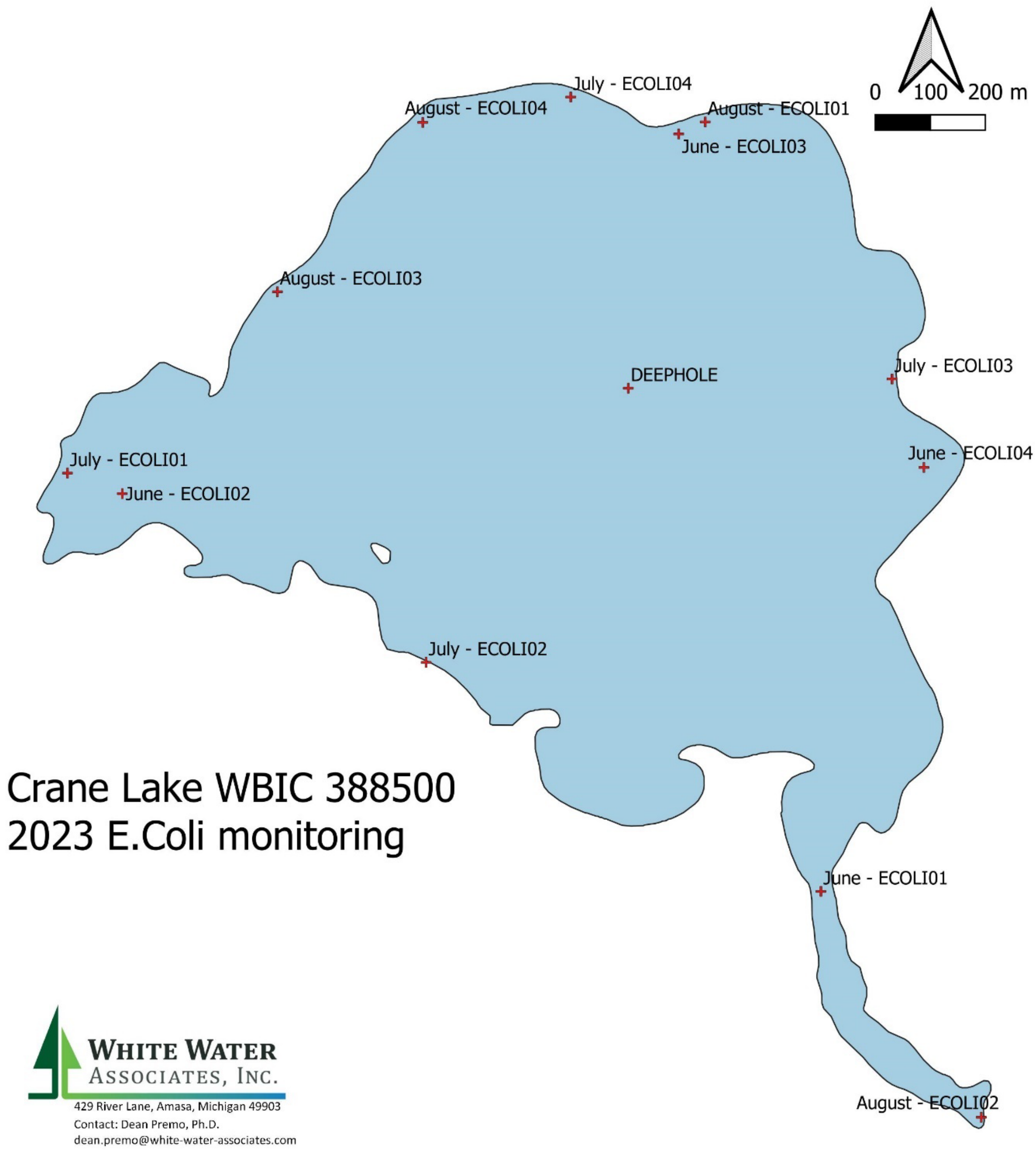

Figure 15. Crane Lake 2023 E.Coli monitoring sampling locations.

Part 15. Crane Lake modeling (WiLMS)

Freshwater algae and rooted aquatic plants (macrophytes) require a number of nutrients in order to grow. Two of these nutrients, phosphorus and nitrogen, are often present in small amounts and limit algae and macrophyte growth. In fact, phosphorus is the nutrient that most often limits the growth of aquatic plants in freshwater systems and, when present in high concentrations, is most often responsible for algal blooms, rampant growth of rooted plants, and lake eutrophication. This is the reason that phosphorus is such a focus when it comes to concerns of lake water quality.

The water (hydraulic) budget of a lake is closely associated with the phosphorus budget (both illustrated in Figure 16). The graphics show in general terms the overall movement of water and phosphorus into and out of a lake ecosystem.

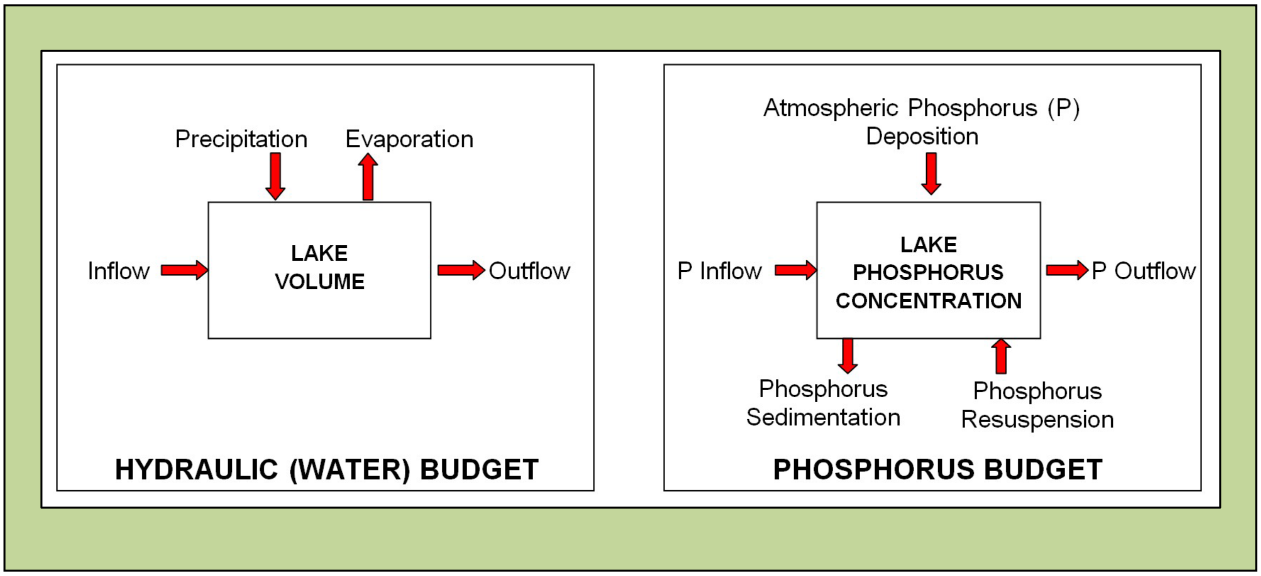

Figure 16. Hydraulic (water) and phosphorus budgets in lakes.

Several interrelated factors are at play when it comes to the water quality of a lake. These include water source, watershed size, retention time, watershed cover types, and internal loading. Because each lake and its watershed have unique characteristics and interactions, no two lakes behave in exactly the same way. Nevertheless, being familiar with these factors and how they interrelate is helpful for lake planning and stewardship.

The sources of water for a lake strongly influence the lake's water quality because the water carries with it nutrients such as phosphorus. The four water sources include precipitation, runoff from the surrounding land, upwelling groundwater, and inflow from a stream. The relative importance of each of these sources depends on several things. For example, some lakes have no incoming stream, so these lakes depend on precipitation, runoff, and groundwater. A lake with a small drainage basin (watershed) receives relatively less water as runoff. Water can leave a lake through an outflow, evaporation, and groundwater seeping back into the aquifer (water table).

Water source is the factor that lake scientists use to classify lakes into four categories (Shaw et al., 2004). A "seepage lake" is fed by precipitation, limited runoff, and groundwater and has no inlet or outlet. A "groundwater drainage lake" is fed by groundwater, precipitation, and limited runoff and has a stream outlet. A "drainage lake" is fed by one or more streams, groundwater, precipitation, and runoff and has a stream outlet. Finally, an "impoundment" is a manmade lake formed by damming a stream and is also drained by a stream. When water comes into a lake from its various sources, it also carries other materials to the lake. Some of these are dissolved in the water (like phosphorus, nitrogen, and calcium). Some of the materials are suspended in the water (like silt and small bits of detritus). Precipitation (rain and snow) also carries with it dissolved and suspended materials to the lake (acid precipitation and dust are examples).

The size of a lake's watershed (drainage basin - DB) relative to the lake's surface area (LA) is important in determining the amount of nutrients and other materials that come into the lake (Shaw et al., 2004). This ratio of drainage basin area (DB) to lake area (LA) is a measure of how important the watershed is as the lake's source of water, nutrients (like phosphorus), and other materials. A higher DB/LA ratio means the watershed is relatively more important and runoff contributes more water and nutrients to the lake. With their small watersheds, seepage lakes receive fewer nutrients from runoff than drainage lakes and tend to be higher in water quality.

Another important concept in a lake's water and nutrient "budget" (that is, inputs and outputs) is "retention time" (also called "water residence time"), the average length of time that water stays in the lake. This is determined by a lake's size (volume), water sources, and watershed size. For some lakes and impoundments, retention time can be quite short (days or weeks). In other lakes, retention time can be as long as decades or centuries. Retention time also indicates how long nutrients stay in the lake. In short retention time lakes, nutrients are flushed through the system rather quickly. In long retention time lakes, nutrients stay around a longer time and can move into the sediments where they become a long-term part of the lake's chemistry.

The type of land cover (for example, forest, grassland, row crops, or human development) is also an important variable in determining amounts and kinds of materials (like nutrients and sediment) that are carried off the land and into the water. This is especially important close to the lake (the riparian area), but the entire watershed is a contributor and we often map the cover types and measure their acreages to give us some idea of how at risk the lake might be to receiving unwanted materials. Certain kinds of agriculture (tilled row crops) and urban areas (with their impervious surfaces) have a tendency to give up sediments and nutrients to runoff. In contrast, native vegetation (forests, wetlands, and grasslands), tend to slow runoff of water and nutrients, allowing the soil to absorb them. When excessive nutrients and sediment reach a lake they can cause increased growth of aquatic plants, algal blooms, and reduced water clarity.

The DB/LA (drainage basin/lake area) ratio interacts in an interesting way with drainage basin cover type related to nutrient runoff to a lake. For lakes where the ratio is relatively high (greater than 15:1), the role of drainage basin size in delivering water and nutrients to the lake tends to dominate the role of cover type. In small ratio lakes, the kind of cover type on the watershed has greater influence than watershed size. For these small DB/LA ratio lakes, maintaining or restoring good quality native cover type in the watershed will likely have a positive influence on the lake.

Internal loading refers to phosphorus (and other nutrients) that are present in the lake bottom sediment. Some of the phosphorus in a lake ecosystem continually falls to the bottom and becomes part of the sediment layer and is generally unavailable for plants. Under conditions of low dissolved oxygen, however, this phosphorus can go back into the water column and be taken up by algae and macrophytes. The amount of phosphorus contained in the sediment can be quite high, resulting from centuries of deposition. The phenomenon of internal loading can therefore make available a large amount of phosphorus to the algae and plants of the lake and typically happens at spring and fall overturn periods. Even if sources of phosphorus outside of the lake are reduced, the internal loading can still enrich the lake and cause eutrophic conditions.

Because it is often challenging to work out how these several factors interact to influence the water quality of a specific lake, the Wisconsin Department of Natural Resources developed the "Wisconsin Lake Modeling Suite" (WiLMS) as a lake water quality planning tool (WDNR, 2003). WiLMS is a computer program into which the user enters information about the lake (e.g., surface area, depth, and nutrient measures) and the watershed (e.g., acreage and cover type). The model also has information about average rainfall, aerial deposition of materials, and cover type characteristics that it uses to help predict nutrient (phosphorus) loading scenarios to the lake.

A WiLMs analysis for Crane Lake and its watershed was presented in the ***Pickerel and Crane Lakes Comprehensive Management Plan*** (Onterra 2012). Since watershed cover types have changed little since that time, the analysis is still valid and appropriate to the discussion of Crane Lake water quality. We summarize the 2012 analysis and its significance in this section.

The 355-acre Crane Lake has a watershed of 4,686 acres and a drainage basin/lake area ratio of about 13 to 1. This is a moderately high ratio and about at the level where the watershed starts to have more influence than simple cover type composition over the water quality of the lake. The lake volume is 3,922 acre-feet and the mean lake depth is 11.5 feet. The WiLMS model calculates the annual runoff volume as 1,743.3 acre-feet and the annual difference between precipitation and evaporation (precipitation minus evaporation) as 5.3 inches. The hydraulic loading for Crane Lake is 4893.9 acre-feet per year and the areal water load is 14.4 feet per year. The WiLMS model calculates the annual lake flushing rate as 1.25 times per year and the water residence time (retention time) as 0.80 year.

The cover types in the Crane Lake watershed are shown in Figure 17 with their respective acreages. The largest category is forest at 3764 acres or 80% of the watershed. Wetland is represented by 491 acres (11% of the watershed). The lake surface is 341 acres (7%) and pasture/grass cover type is 90 acres (2%).

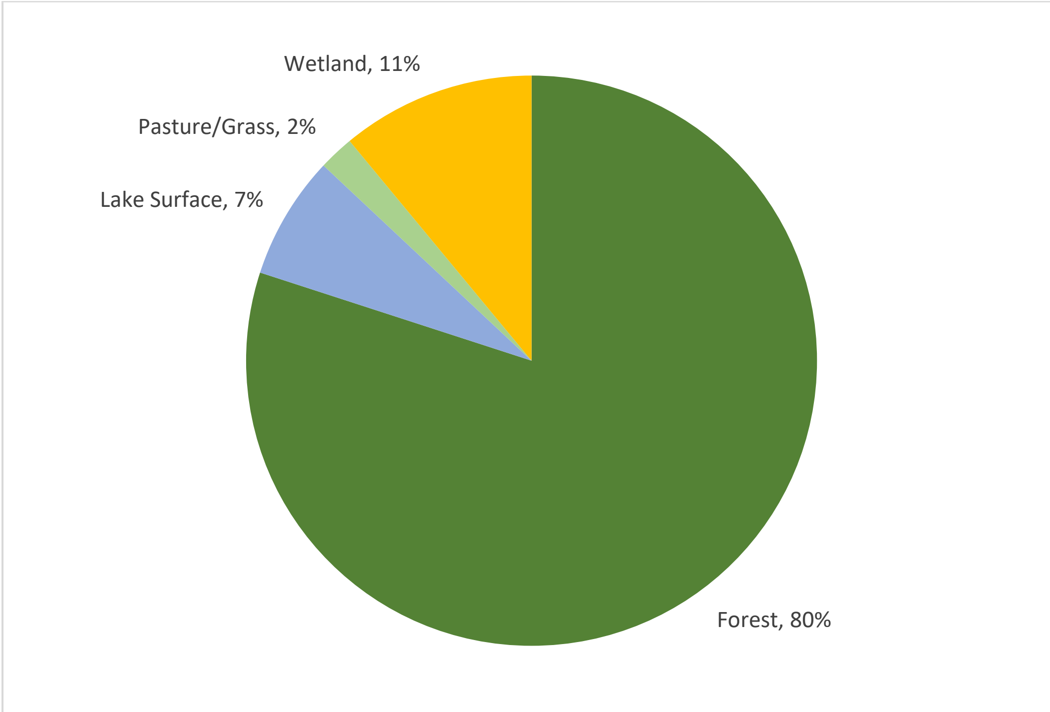

Figure 17. Crane Lake watershed land cover types

Table 13 presents output from the WiLMS model for non-point source phosphorus input to Crane Lake. No point-source data is available for Crane Lake. The WiLMS model indicated that 210kg (462pounds) of phosphorus are most likely delivered to the lake each year from watershed runoff and from direct deposition onto the lake surface (via precipitation and airborne particles). The WiLMS model predicts that most of the phosphorus delivered to Crane Lake comes from forest cover type, the most prevalent cover type in the watershed, but nearly 20% enters the lake through direct deposition on to the lake surface through dust and other particles. Wetlands contribute less than 10% of the phosphorus entering the lake. The 2012 ***Pickerel and Crane Lakes Comprehensive Management Plan*** emphasized that although forests and wetlands have a significant contribution of phosphorus to the lake, this is because of the large amount of the watershed lands they comprise. These cover types are protective of the lake and if they were converted to more developed land, the phosphorus load to Crane Lake would be much greater.

Table 13. WiLMS estimated non-point source phosphorus loading based on watershed land use type and acres for Crane Lake in 2012.

Land Use	Land Use Acres	Loading (kg/ha-year)				Loading kg/year		
		Low	Most Likely	High	Loading %	Low	Most Likely	High
Row Crop Ag.	0.0	0.50	1.00	3.00	0.0	0	0	0
Mixed Agricultural	0.0	0.30	0.80	1.40	0.0	0	0	0
Pasture/Grass	90	0.10	0.30	0.50	5.2	4	11	18
High Density Urban (1/8 acre)	0.00	1.00	1.50	2.00	0.0	0	0	0
Mid Density Urban (1/4 acre)	0.00	0.30	0.50	0.80	0.0	0	0	0
Rural Residential (>1/3 acre lot)	0.0	0.05	0.10	0.25	0.0	0	1	2
Wetlands	491	0.10	0.10	0.10	9.5	20	20	20
Forest	3764	0.05	0.09	0.18	65.5	76	137	274
Open Space/Park	0.0	0.1	0.30	0.50	0.0	0	0	0
Lake Surface	341.0	0.10	0.30	1.0	19.8	14	41	138
Totals					100	114	210	452

The 2012 ***Pickerel and Crane Lakes Comprehensive Management Plan*** also states that Crane Lake is moderately well flushed which may result in removal of part of the phosphorus load before it can be used by plants and algae or otherwise accumulate. The significant flushing rate is due in part to groundwater entering the lake.

Chapter 5. Discussion

Our 2023 investigation of Crane Lake generally reflects a lake that is stable or gradually improving with respect to water quality. Although still in the eutrophic category, the water clarity, chlorophyll *a* and phosphorus levels seem to be improving. There will always be a source of phosphorus from the sediments, but since the retention coefficient is less than one, more phosphorus is being released downstream then is accumulating. Because the residence time in the lake is less than one year, it means the lake is flushing at a reasonable rate and sending some phosphorus downstream before it can be taken up by plants and algae.

Despite this reasonably good water quality news, the fact remains that the planktonic and filamentous algae are prolific and represent a subject of concern for lake users. We will proceed with our investigation of Crane Lake in 2024 by focusing on the algae. Knowing what forms are present and abundant may inform us more about what is causing the algal blooms. Warmer water (caused by climate change) is also conducive to this algae growth and may be at play in Crane Lake. Although this factor is at a global scale, it makes it all the more important to endeavor to reduce nutrient load to the lake on a local basis.

There are indications from the samples taken during rainstorm events that important sources of phosphorus to the lake water are from near shore riparian areas. The two most likely sources are septic and runoff from lawns. We strongly recommend that riparian dwellers minimize or avoid use of lawn fertilizers in order to protect the water quality. Another important and easily accomplished remedy is to foster naturally vegetated buffers between lawns and other human disturbance. Minimizing the surface area of lawns will also be very protective of lake water quality. The added benefit to reduced lawn area and a natural riparian area is increased natural habitat for native plants and animals and contribution of large woody material to the lake as aquatic habitat structure.

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