Sentinel Lake Assessment Report
White Iron Lake (69-0004)
Saint Louis County, Minnesota

Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit
&
Minnesota Department of Natural Resources
Section of Fisheries
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2008-09 Lake Assessment of White Iron Lake (69-0004) St. Louis County, Minnesota
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Executive Summary

The Minnesota Pollution Control Agency (MPCA) is working in partnership with the Minnesota Department of Natural Resources (MDNR) on the Sustaining Lakes in a Changing Environment (SLICE) Sentinel Lakes Program. The focus of this interdisciplinary effort is to improve understanding of how major drivers of change such as development, agriculture, climate change, and invasive species can affect lake habitats and fish populations, and to develop a long-term strategy to collect the necessary information to detect undesirable changes in Minnesota Lakes (Valley 2009). To increase our ability to predict the consequences of land cover and climate change on lake habitats, SLICE utilizes intensive lake monitoring strategies on a wide range of representative Minnesota lakes. This includes analyzing relevant land cover and land use, identifying climate stressors, and monitoring the effects on the lake's habitat and biological communities.

White Iron Lake is located in Saint Louis and Lake Counties within the Kawishiwi River watershed, part of the headwaters of the Rainy River basin. White Iron Lake is located approximately 5 miles east of Ely, Minnesota. White Iron is a relatively large lake, covering 1,319 hectares (3,238 acres). The lake has a mean depth of 5.7 meters (19 feet) and a maximum depth of 13 meters (43feet). The water column occasionally stratifies during periods of calm weather; however it is most often well mixed (polymictic). The hydrology of the Kawishiwi River watershed and White Iron Lake are relatively complex and are influenced by hydroelectric facilities downstream of White Iron Lake. White Iron receives flow from the South Branch of the Kawishiwi River, which drains approximately 75% of the entire Kawishiwi River watershed. White Iron Lake's watershed has its drainage point located on the northeast shore of the lake at Silver Rapids. White Iron's contributing watershed has a total area of over 592,000 acres (931 square miles), resulting in a short residence time of approximately 40 days. Land use within the White Iron Lake watershed is dominated by forest, wetlands, and open water. There has been little change in land use since 1969, primarily because most of the watershed is within the public lands of Superior National Forest and / or the Boundary Waters Canoe Area Wilderness.

Based on recent water quality data (2008-2009), White Iron Lake is considered to be mesotrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 21 micrograms per liter (µg/L), 4 µg/L, and 1.5 meters (5 feet) respectively. Secchi and chl-*a* are slightly low relative to TP. The lake's high color from bog stain reduces water transparency (hence lower Secchi) and to some degree may limit light for algal growth. This natural staining originates from tannin compounds drained from wetlands and forests within the watershed.

White Iron supports a diverse assemblage of cold, cool, and warm-water fish species and one rare species of special concern (Longear sunfish - *Lepomis megalotis*). As such, this lake is an important sentinel to monitor changes to thermal habitat and associated fish species in response to climate change. Because the lake does not routinely stratify (and thus form cold-water hypolimnetic refuge less sensitive to atmospheric temperature), the lake is extremely sensitive to changes in atmospheric temperature. Under most climate change scenarios, coldwater species in unstratified lakes are imperiled. In White Iron, we may expect large declines in burbot (*Lota lota*), cisco (*Coregonus artedi*), and lake whitefish (*Coregonus clupeaformis*) populations should ambient temperatures increase as a result of climate change.

Projections from a model suggest that the temperature at 3 milligrams of oxygen during the period of greatest oxythermal stress will increase to 21.7 °C after climate warming. That change in temperature would drop the Habitat Suitability Index for cisco from 57 to 33, suggesting that conditions for cisco in White Iron would be significantly poorer. Summer mortality events could become common; however, White Iron may be one of the few unstratified lakes in Minnesota that may be able to sustain a cisco population (albeit at lower and more variable abundances).

Because White Iron is a rocky, bog-stained lake, macrophytes are naturally sparse with approximately 9% of the area less than 4.5 meters (15 feet) having some degree of rooted aquatic plant growth. Nevertheless, these aquatic plants provide critical habitat for a number of fish species at some point in their life history. In particular, submerged and emergent vegetation is often cited as a limiting factor controlling northern pike recruitment in Canadian Shield lakes.

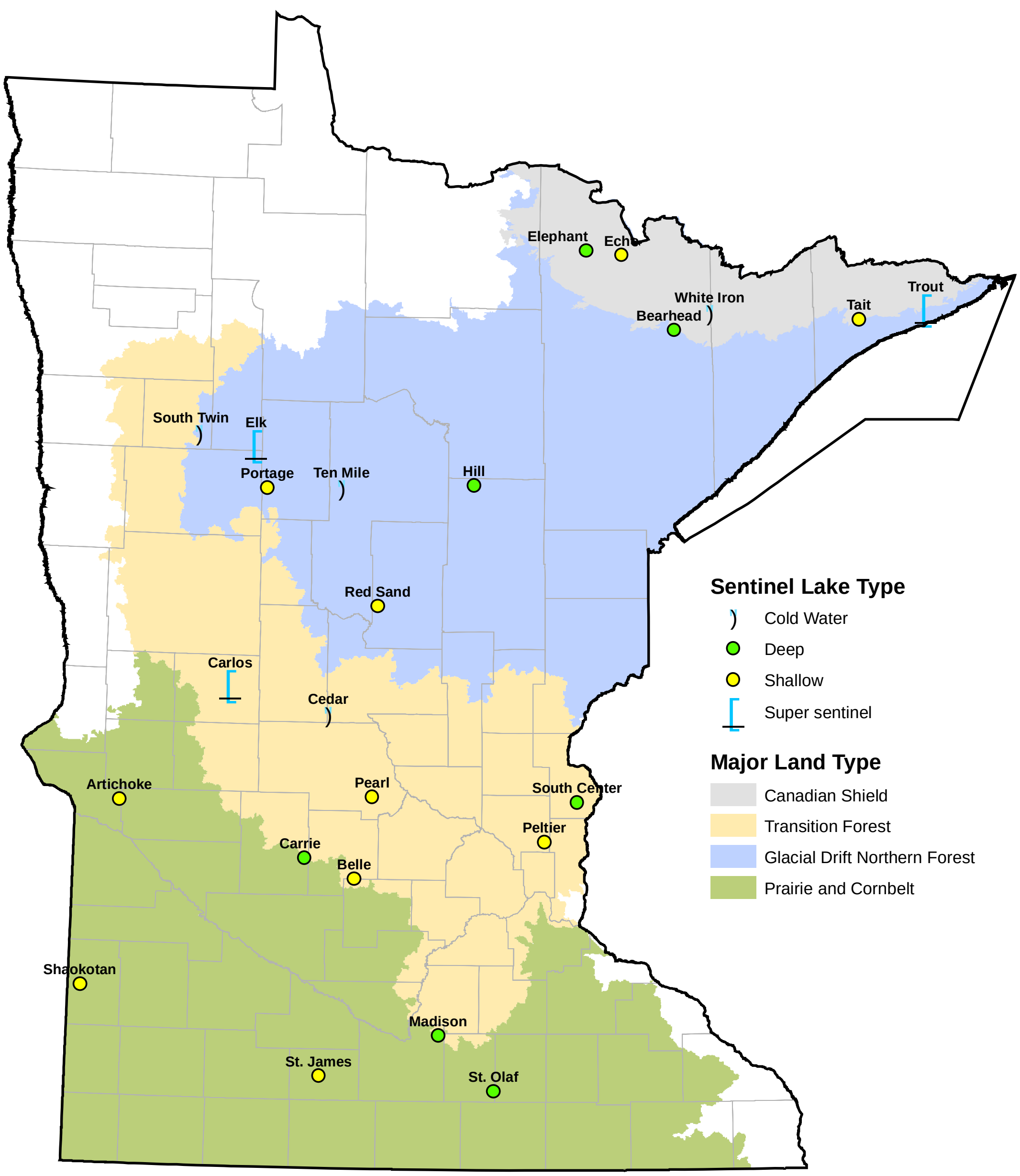
Aquatic plant communities varied little between 2008 and 2009. The most common plant species surveyed in 2008 and 2009 was water celery. Wild rice (*Zizania palustris*)), an important species for a variety of littoral fish and waterfowl, was found in several shallow areas of the lake.

Rusty crayfish, a large and aggressive crayfish species native to the Ohio River Valley, were captured by the U.S. Forest Service in crayfish traps in the summer of 2007 in Birch Lake, White Iron Lake, Farm Lake, and Garden Lake. Future surveys by the Superior National Forest and MDNR will be assessing the current status of rusty crayfish in White Iron Lake and the impacts on aquatic plants.

An ecoregion-based eutrophication model was used to predict in-lake TP based on White Iron Lake's size, depth, and watershed area using inputs from the Northern Lakes and Forests (NLF) ecoregion. The model predicted an in-lake TP of 21 µg/L, which is identical to the observed 21 µg/L. A separate subroutine within the model estimated "background" TP for the lake at 10 µg/L. The model predictions, along with the overall assessment of White Iron Lake's water quality data, clearly indicate the lake's water quality is meeting NLF nutrient criteria for a lake of its size in this portion of the State. MPCA data, along with data collected by White Iron Chain of Lakes Association volunteers and Minnesota Power, show stable concentrations of TP and chl-*a* in recent years, averaging about 20 and 5 µg/L respectively; with perhaps a slight decline in TP since the 1990's. A non-parametric statistical analysis of historical Secchi transparency data shows an overall improvement in transparency since 1994. The long-term mean is approximately 1.6 meters. Transparencies have declined slightly since 2004. Continued long-term monitoring is essential to determine if these trends are due to natural variability, climate change, water levels, reservoir operations, or other causes.

As a Sentinel lake, future monitoring will be frequent and cover a wide range of climate, watershed, water quality, habitat, and fish indicators. As a part of a grant funded by the Environmental Trust Fund in 2009-2012, the Science Museum of Minnesota will reconstruct historical water quality conditions in White Iron Lake with sediment cores. Furthermore, through a partnership with University of Minnesota-Duluth, MDNR will also evaluate hydroacoustic tools for assessing cisco populations and further researching cisco habitat needs and behavior. We will continue to monitor the status of cisco habitat in White Iron Lake and promote landuse policies that will minimize lake eutrophication.

Figure 1. MDNR map of Sentinel lakes and major land types. "Deep" lakes stratify during the summer. "Shallow" lakes are defined here as those that mix continuously throughout the summer. "Cold Water" lakes are those that either harbor cisco, lake whitefish, or lake trout and are the focus of research funded by the Environmental Trust Fund (ETF). "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is also funded by the ETF.



Introduction

This report provides a relatively comprehensive analysis of physical, water quality and ecological characteristics of White Iron Lake in Saint Louis and Lake Counties, Minnesota (MN). This assessment was compiled based on Minnesota Department of Natural Resources (MDNR) surveys of the lake's fish community, Superior National Forest surveys of the aquatic plant communities, Minnesota Pollution Control Agency (MPCA) and volunteer water quality monitoring, and analysis of various other sources of data for the lake. The water quality assessment focuses on data collected during the 2008 and 2009 seasons; however, historical data are used to provide perspective on variability and trends in water quality. Water quality data analyzed includes all available data in STORET, the national repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

1900 to 1917	Logging on Kawishiwi River. Dams are built to impound water for moving logs at 1) the site of the current Winton Hydroelectric dam at the outlet of Garden Lake, 2) the site of the current Birch Lake Hydroelectric reservoir dam, raising the water level about five feet, 3) the first narrows on the South Kawishiwi River below the point where the north and south forks divide. The purpose of the last dam was to divert flow to the North Kawishiwi River while logging was being done there. There are few remnants to this dam and no apparent restriction of flow remains. A dam is built at the head of Murphy Rapids on the North Kawishiwi to divert flow to the South Kawishiwi River while logging was being done there. Some of this dam still remains, restricting flow down the North Kawishiwi River.
1920's	1923 - Winton Hydroelectric facility is completed. The logging dam at the outlet of Garden Lake is rebuilt to its current configuration, resulting in a Garden Reservoir pool elevation about 1.5 feet (ft) lower than White Iron Lake, logging dams are rebuilt at the at the Birch Lake outlet, and on the North Kawishiwi River (Murphy Rapids) to divert and impound water. Additional dams are built at Gabbro Lake (a tributary to the South Kawishiwi River) to create an additional storage reservoir.
1940's	Gabbro Lake Dam operations are abandoned; dams are left in place to deteriorate.
1950's	Record floods on White Iron Lake (and other area lakes) in 1950. On May 17, the flow at the Winton Dam was 15,153 cubic feet per second (the normal flow for May is 2,500 cubic feet per second). White Iron Lake rose 8 ft. The west bridge approach at Silver Rapids was washed out. A 10 ft culvert was subsequently added to alleviate future flooding, a measure that helped little. Eventually a used, longer steel bridge was placed over the rapids, and the culvert and the rock and gravel added in 1927 were removed. The first fisheries lake survey was conducted in 1958. No bass were captured. Shoreline development included 96 cottages and six resorts.
1970's	Winton Hydroelectric Dam relicensing process. Many complaints are received about spring flooding on White Iron Lake with water level rises up to 6 ft. The MDNR is concerned that spring draw-downs of water of up to 3

	ft in the Garden Lake Reservoir to alleviate flooding in White Iron Lake during the spring snow melt are negatively affecting walleye reproduction by exposing their spawning areas. A proposal is made to remove the remnants of the old North Kawishiwi River Dam at Murphy Rapids and to rebuild part of the South Kawishiwi River Dam to divert flow to Garden Lake Reservoir via the North Kawishiwi River, thus bypassing Birch Lake and White Iron Lake and alleviating flooding in those lakes, and negating the need to draw-down Garden Reservoir. This proposal is opposed by the U.S. Forest Service on legal grounds. The present bridge at Silver Rapids was built. The channel was dredged of old debris and abutments.
1980's	Shoreline development included 135 homes and cottages and six resorts with 52 cabins based on a 1982 inventory. The first largemouth bass are captured in a fisheries investigation.
1990's	White Iron Chain of Lakes Association (WICOLA) is formed in 1993. Annual water testing begins. Lake Assessment Program Report, a cooperative study between WICOLA and the MPCA, is published in 1996. White Iron Lake added to impaired waters list for mercury in fish tissue in 1998.
2000's	Shoreline development includes 197 homes and cottages and four resorts with 42 cabins and 11 motel units based on 2001 inventory. MPCA and WICOLA initiate cooperative lake monitoring program in 2005.

Background

Lake Morphometric and Watershed Characteristics

White Iron Lake is located in Saint Louis and Lake Counties within the Kawishiwi River watershed (Figure 2), part of the headwaters of the Rainy River basin. White Iron Lake is located approximately 5 miles east of Ely, MN. Public accesses are located on the northwest and southwest shores. White Iron Lake is a moderately deep lake and the water column occasionally stratifies during periods of calm weather; however, it is most often well-mixed (polymictic).

The hydrology of the Kawishiwi River watershed is relatively complex and is influenced by hydroelectric facilities both upstream and downstream of White Iron Lake operated under Federal license by Minnesota Power (Figure 3). The Kawishiwi River originates in Lake County in the heart of the Boundary Waters Canoe Area Wilderness (BWCAW). It flows westerly through several large lakes, until it naturally splits into a North and South branch. The South Branch flows into Birch Lake Reservoir, immediately upstream of White Iron Lake. A dam at the outlet of Birch Lake controls lake levels on Birch Lake, and influences water levels in the South Kawishiwi River and White Iron Lake. The North Branch flows into the Garden Lake Reservoir (composed of Garden, Farm, South Farm, and Friday Lakes), immediately downstream of White Iron Lake (Figure 3). The branches converge in the Garden Lake Reservoir and the Kawishiwi River eventually flows into Fall Lake via the Winton hydroelectric dam at the confluence with Fall Lake. Minnesota Power is required to operate the Birch and Garden Lake reservoirs within elevation ranges (Figure 4) that balance hydropower generation, recreational uses, aesthetics, and the natural flow of water within the basin.

White Iron Lake's morphometric characteristics are summarized in Table 1. White Iron is a relatively large lake, covering 1,319 hectares (3,238 acres). The lake has a mean depth of 5.7meters (19 feet), maximum depth of 13 meters (43 feet), and 50 percent of the lake is considered littoral. Percent littoral area refers to that portion of the lake that is 4.6 meters (15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake. Lakes with a high percentage of littoral area and non-rocky substrates often have extensive rooted plant (macrophyte) beds. These plant beds are a natural part of the ecology of these lakes and are important to maintain and protect.

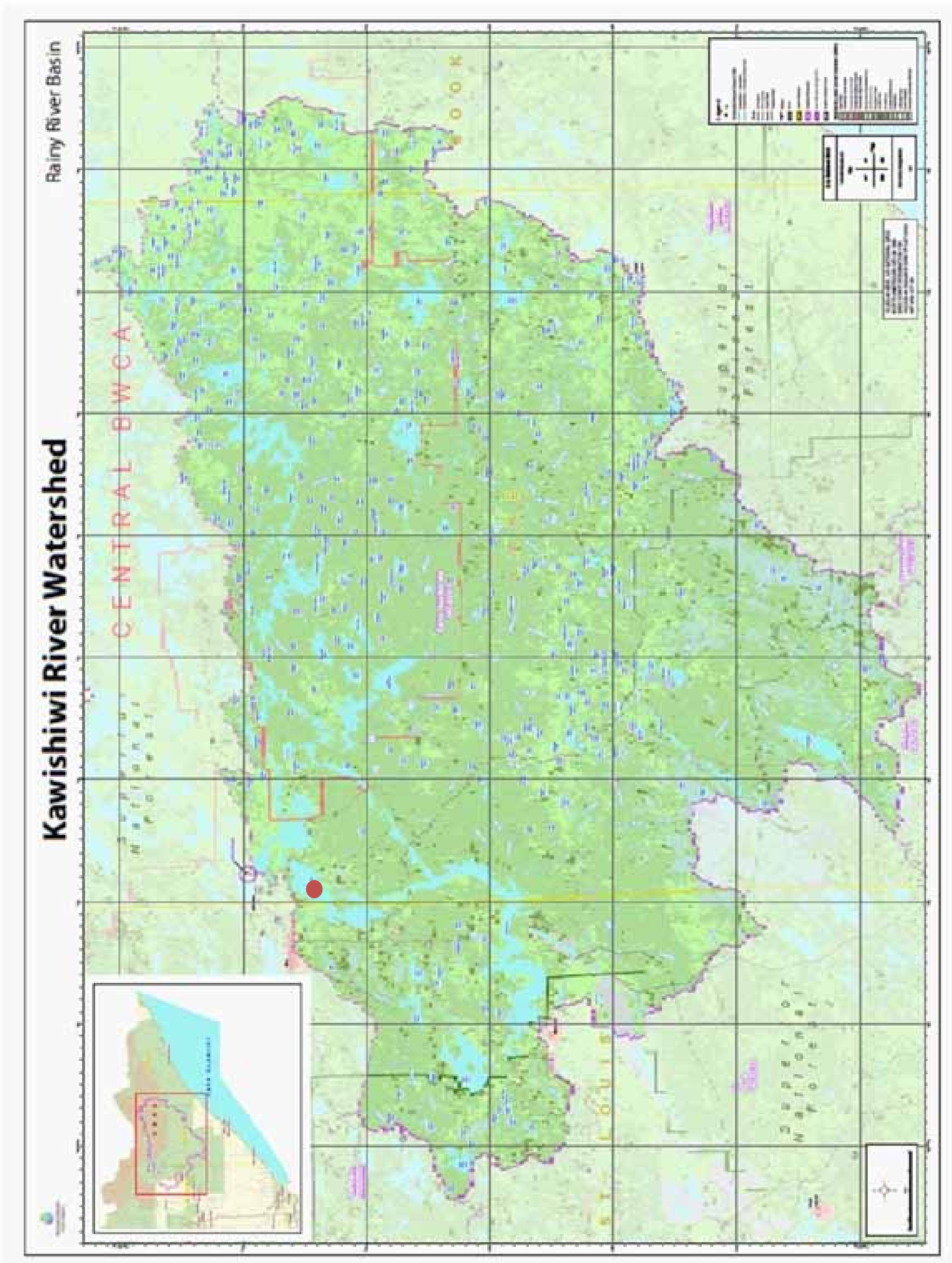


Figure 2. Kawishiwi River Watershed. White Iron Lake monitoring site # 202 indicated by red circle (Pete Knutson, MPCA)

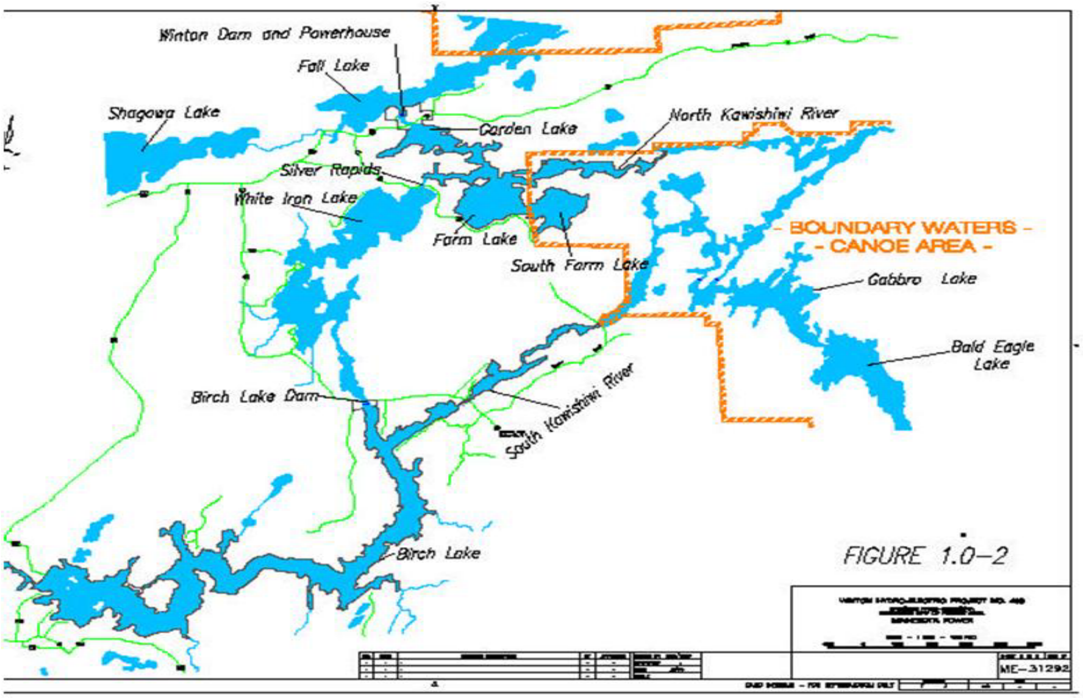


Figure 3. Close up Winton Hydroelectric project area, courtesy of Minnesota Power (ftp://ftp.mnpower.com/mp/winton/environment_draft.pdf)

Figure 4. White Iron and Garden Lake 2009 water level data and elevation ranges (courtesy of Minnesota Power)

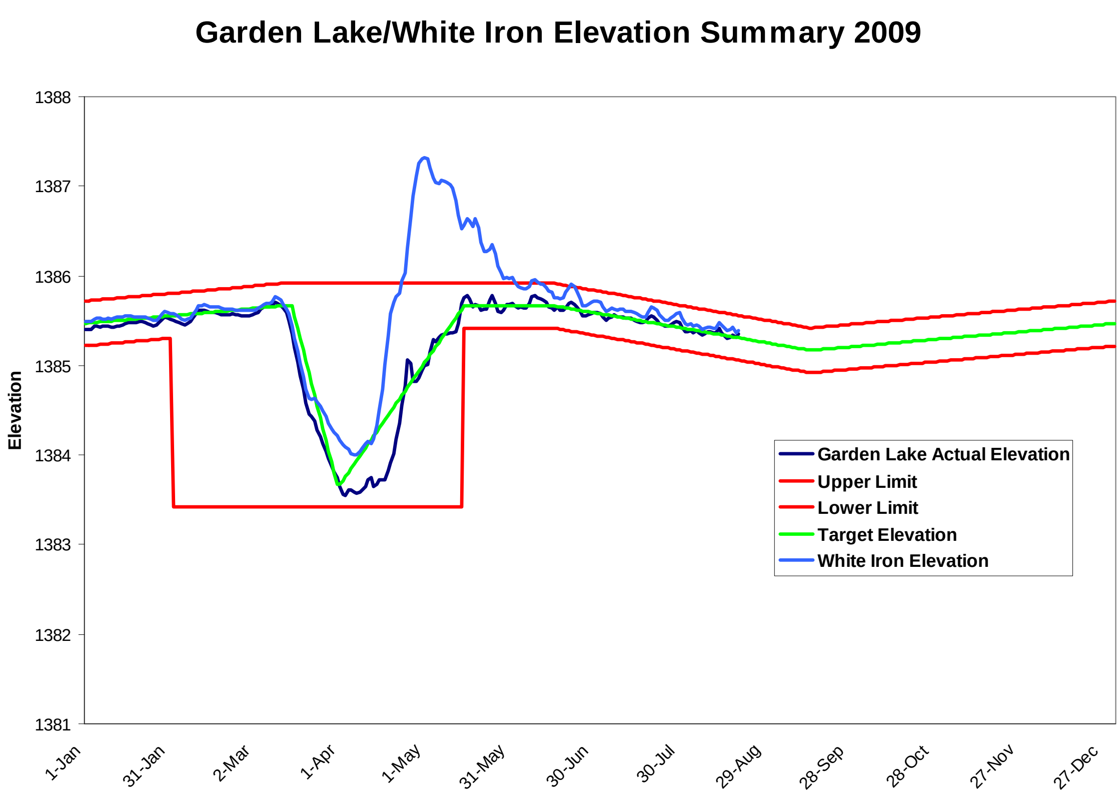


Table 1. White Iron Lake and watershed morphometric characteristics

Lake Name	Lake ID	Lake Basin hectares (acres)	Littoral Area (%)	Total Watershed Area hectares (acres)	Watershed: Lake	Max. Depth meters (feet)	Mean Depth meters (feet)	Lake Volume acre-ft
White Iron	69-0004	1319 (3238)	49.5	239,827 (592,626)	183:1	13(43)	5.7(19)	61,522

Lake bathymetry based on original survey in 1957

The White Iron Lake contributing watershed lies within the Kawishiwi River watershed. White Iron Lake receives flow from the S. Branch of the Kawishiwi River, which drains approximately 75% of the entire watershed. Major tributaries to the S. Branch include the Bear Island, Dunka, Stony, and Isabella River watersheds. White Iron Lake's watershed has its drainage point located on the northeast shore of the lake at Silver Rapids. White Iron's contributing watershed has a total area of over 592,000 acres (931 square miles) resulting in a very large watershed-to-lake area ratio of approximately 183:1. The lake's large watershed results in a short residence time, estimated at 40 days. This estimate was made from the authors' analysis of U.S. Geological Survey streamflow records from their gage located at the inlet to White Iron Lake. Watershed delineations are available at http://deli.dnr.state.mn.us/data_search.html "DNRwatersheds - DNR Level 08 – All Catchments"

Soils within the White Iron Lake watershed are primarily sand and gravel, however bedrock of the Canadian Shield is at or near the surface in much of the watershed; the southern portion of the watershed drains brown, noncalcareous till (Ericson et al. 1976). The White Iron basin is generally a bedrock basin formed after the retreat of the last ice age about 12,000 years ago.

Ecoregion and Land Use Characteristics

Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, potential natural vegetation and land use (Omernik 1987). Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. White Iron Lake lies within the Northern Lakes and Forest (NLF; Figure 5) ecoregion. NLF values will be used for land use (Table 2) and summer-mean water quality comparisons (Table 3- page 31). Additionally, the NLF ecoregion will be used for model applications. Omernik level III and IV ecoregions provided a basis for the "land type" delineations noted in Figure 1. This step was taken prior to selection of the sentinel lakes and provided a means to most closely characterize geomorphological differences in lake condition. In the NLF ecoregion this allowed for differentiation between the "Canadian Shield" lakes and "Glacial Drift Northern Forest" lakes.

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Land use within the White Iron Lake watershed is dominated by forest, wetlands, and open water. There has been little change in land use since 1969, primarily because most of the watershed is within the public lands of Superior National Forest and / or the BWCAW.

Figure 5. Minnesota ecoregions as mapped by United States Environmental Protection Agency

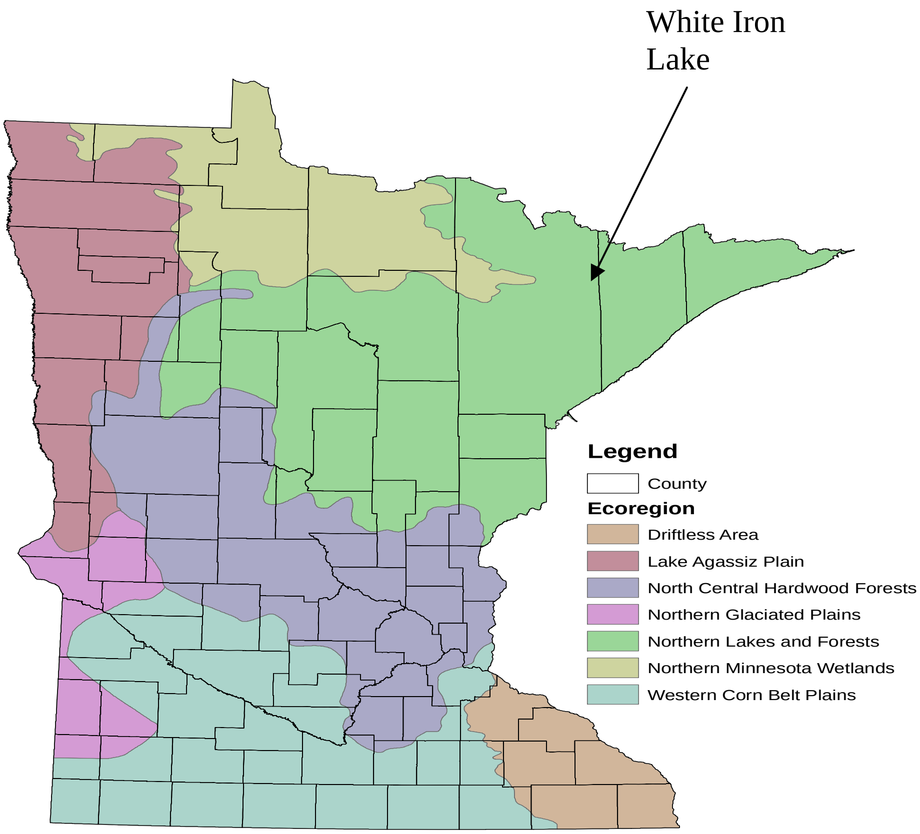


Table 2. White Iron Lake watershed ecoregion land use comparison. Typical (interquartile) range based on NLF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	White Iron (2001)[1]	NLF ecoregion	Applicable (1969)[2]	Applicable (1991)[3]
Developed	1	0 - 7	<1	<1
Cultivated (Ag)	<1	< 1	<1	<1
Pasture & Open	<1	0 - 6	<1	<1
Forest	83	54 - 81	91[4]	80
Water & Wetland	15	14 - 31	7[4]	19

[1]National Land Cover Database www.mrlc.gov/index.php
[2]Minnesota Land Management Information Center www.lmic.state.mn.us/chouse/metadata/luse69.html
[3]Minnesota Land Cover 1991-1992:MAP www.lmic.state.mn.us/chouse/land_use_DNRmap.html
[4] differences from 2001 data likely due to interpretations of forested wetlands, and do not reflect an actual change in land use within the watershed

Lake Level

The MDNR Division of Waters and Minnesota Power have been measuring water levels on White Iron Lake since the 1970's. During this period of record (1976 –2009), the lake has varied by about 7.3 feet (highest maximum daily elevation minus lowest minimum elevation; Figure 6). Since 1997, summer fluctuations typically have a range of about 1 foot, with peak elevation in June, which corresponds to conclusion of spring snowmelt runoff moving through the system (Figure 7). Historically, annual fluctuations were greater than those of recent decades (see History section) - likely in response to a combination of record flooding events and reservoir operations. The normal pool elevation for White Iron is 1386.44 feet (MN Power, 2001).

During low flow conditions, (i.e., less than 2,000 cubic feet per second - cfs - at the Winton gage) the elevation at the hydroelectric dam, Garden, Farm, South Farm and White Iron Lakes are an essentially flat pool elevation; above 2,000 cfs the levels in White Iron Lake begin to increase significantly as the flow (and water levels) increase due mainly to the constriction at the Silver Rapids Bridge; at a flow of 16,000 cfs there was a difference in elevation of 7.4 feet between White Iron Lake and the dam at Winton (Minnesota Power, 1998; 2001). The average annual water level fluctuation (i.e. drawdown) on Birch Lake (immediately upstream of White Iron) is 3.77 feet (MN Power, 2001). Levels are drawn down in the fall and winter for hydropower generation and to alleviate spring flooding on White Iron Lake.

The complete water level record may be obtained from Minnesota Power or the MDNR web site http://www.dnr.state.mn.us/lakefind/showlevel.html?id=69000400 . More detailed information on water level management throughout the Winton project area and Minnesota Power's history of hydropower generation in the watershed can be found in Minnesota Power (2001) and Minnesota Power (1998).

Figure 6. Maximum, average, and minimum White Iron lake elevations for the period January 1, 1976-December 31, 1999 (Minnesota Power, 2001)

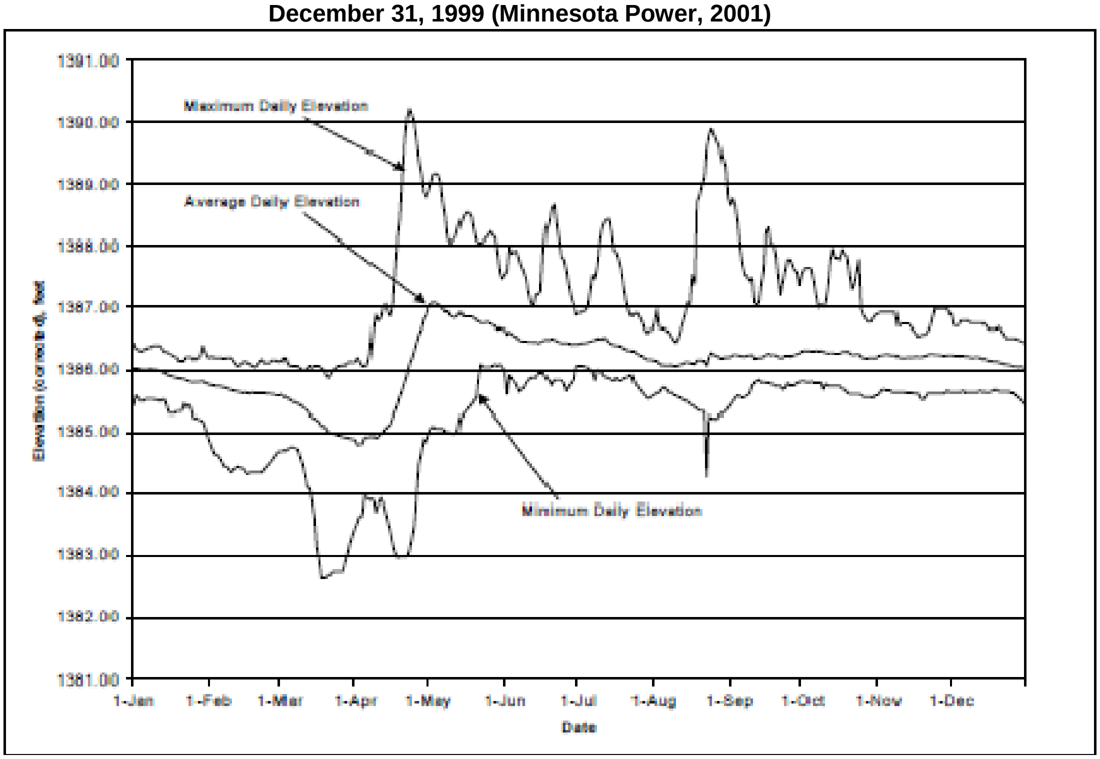
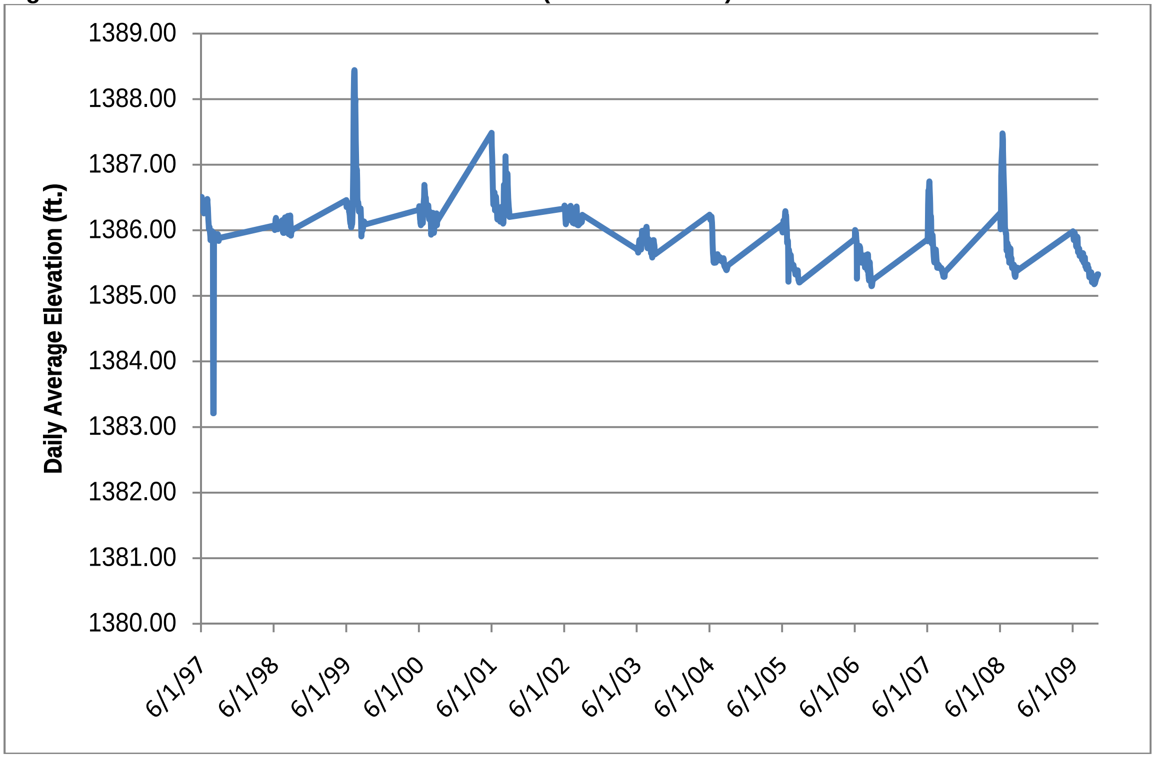


Figure 7. 1997-2009 White Iron Lake elevations (MN Power Data)



Precipitation and Climate Summary

Rain gage records from Winton show two 2.5 centimeter (cm; 1inch) plus rain events during the 2008 field season and one during 2009. (Figures 8 and 9). Large rain events will increase runoff into the lake and may influence in-lake water quality and lake levels. Precipitation records for the 2008 water year (October 2007 through September 2008) showed conditions were much wetter than average, with a large portion of the watershed 15.25-25.5 cm (6-10 inches) above normal (Figure 10). Drought conditions occurred during the late summer of 2007, with near record low flows on area streams. Heavy rains fell that fall, including 25.5 cm (10 inches) of rain at Winton in September, nearly triple the normal amount. Data from the Winton Dam climate station from 1970-2008 show that average annual precipitation is 73.1 cm (28.8 inches), and is slightly increasing (Figure 11).

Figure 8. 2008 monitoring season rainfall based on records for Winton, MN. State Climatology Office Data

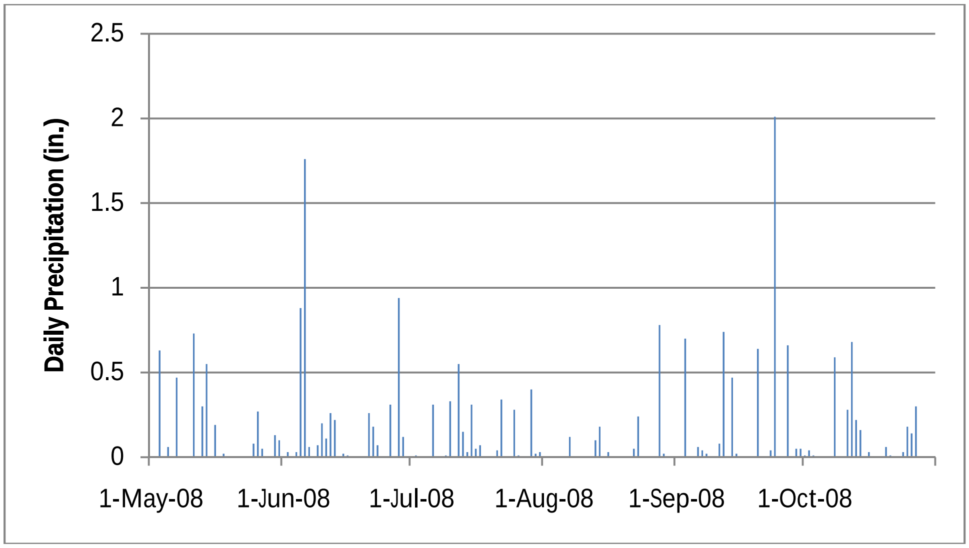


Figure 9. 2009 monitoring season rainfall based on records for Winton, MN. State Climatology Office Data

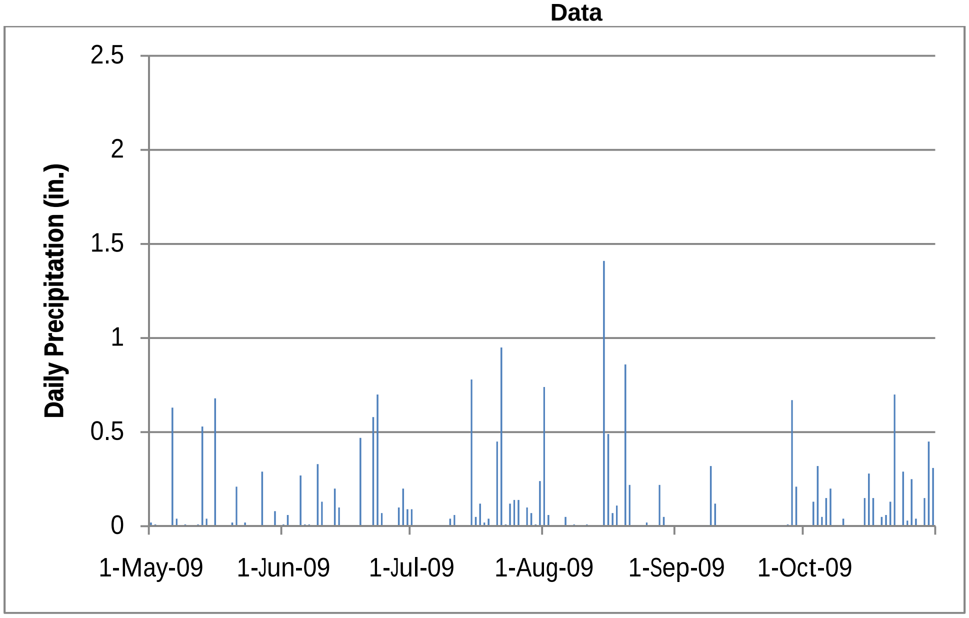
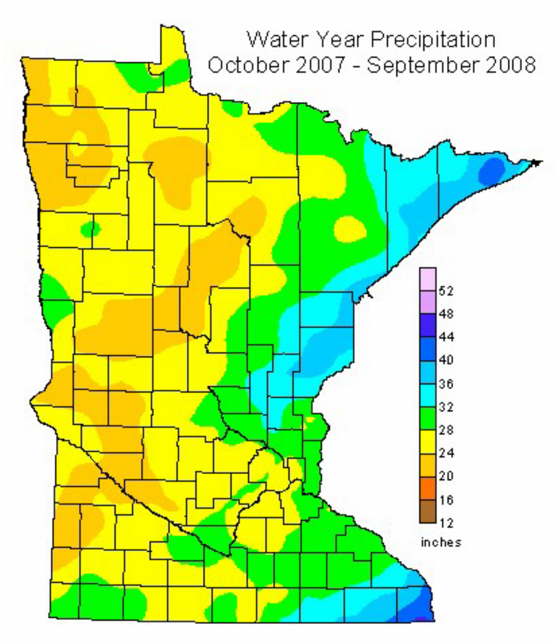


Figure 10. 2008 Minnesota water year precipitation and departure from normal (State Climatology Office data)



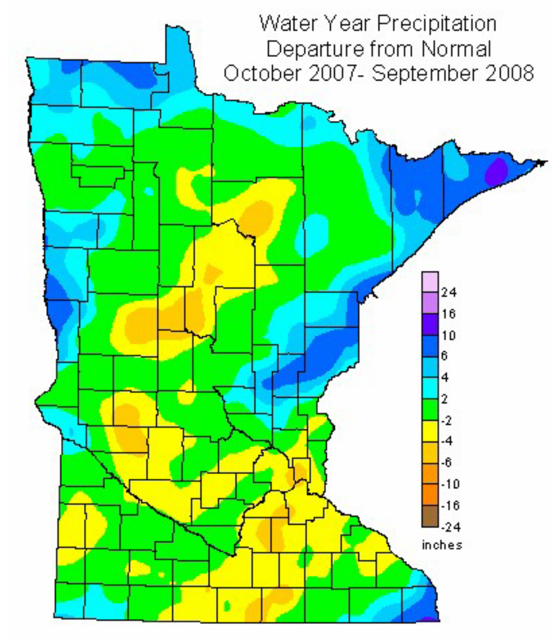
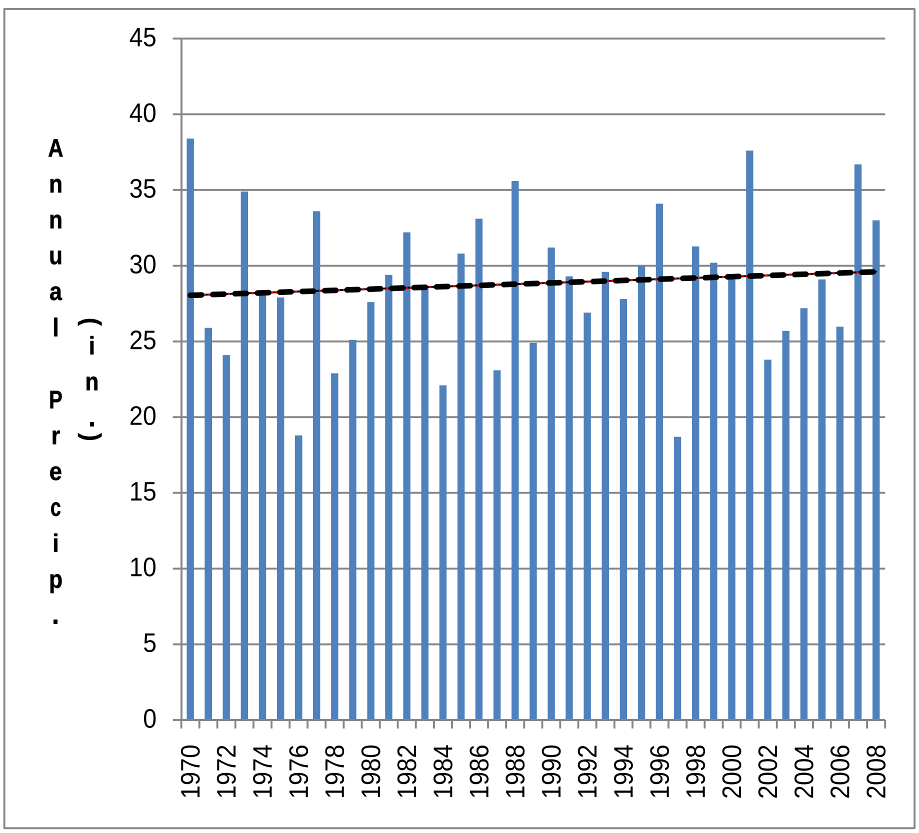


Figure 11. Historical annual precipitation trends based on records for Winton, MN, 1970-2008. Simple linear regression noted by black dashed line. State Climatology Office data



Flow into White Iron Lake in 2008 and 2009 was slightly above average, based on 8 years of United States Geological Survey (USGS) streamflow data (Figure 12.) Long-term USGS streamflow monitoring at the watershed outlet (Winton Dam) indicate no trend in annual mean streamflow over the entire period of record; however, the recent record (1970-2007) indicates a decline in flow over time (Figure 13). The causes of the divergence of precipitation and streamflow trends at Winton since 1970 needs further study.

Figure 12. 2008 and 2009 Kawishiwi River streamflow into White Iron Lake. USGS streamflow gage 05126210

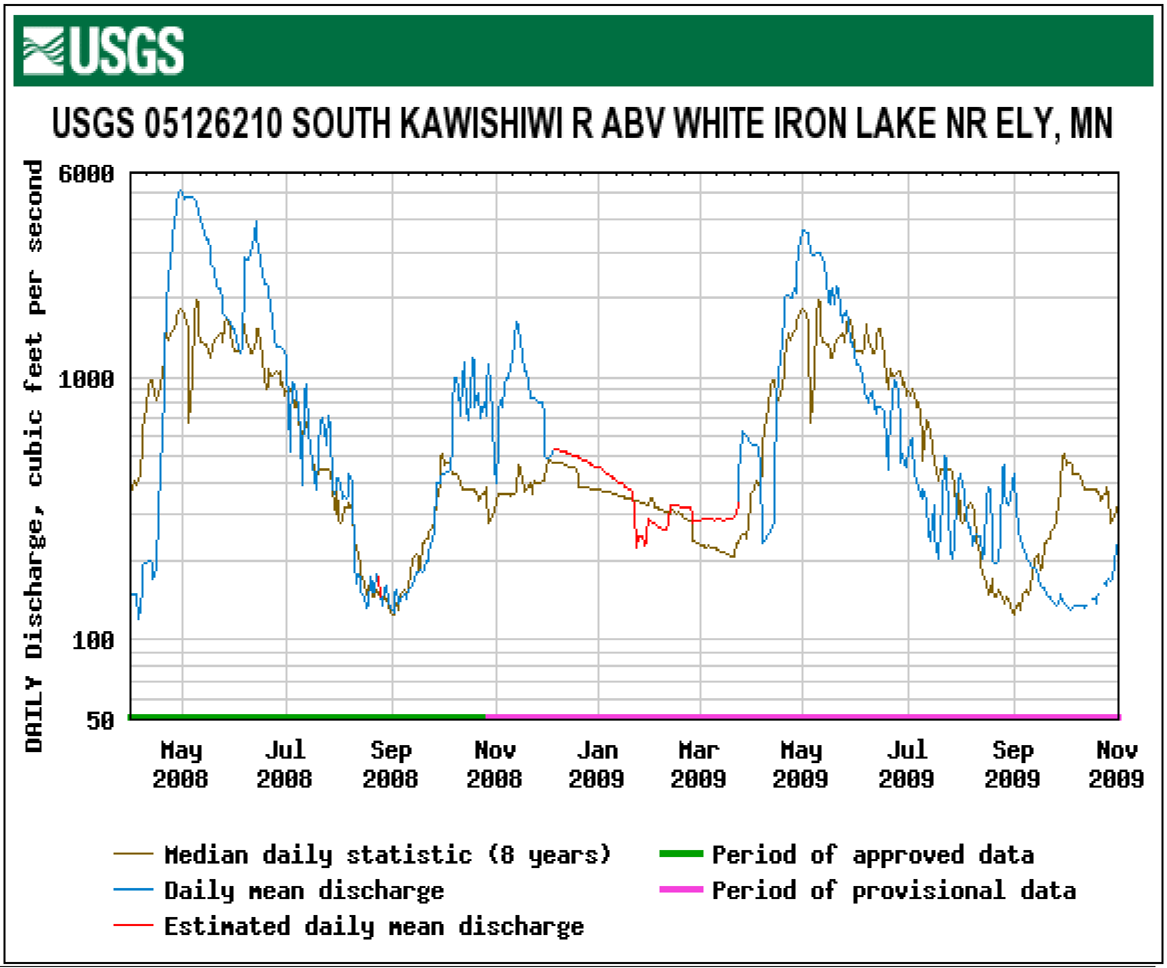
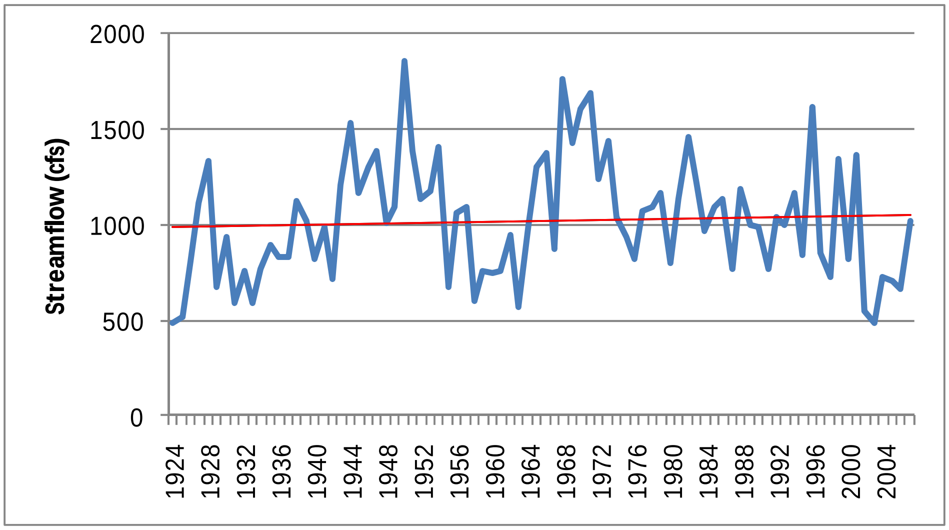
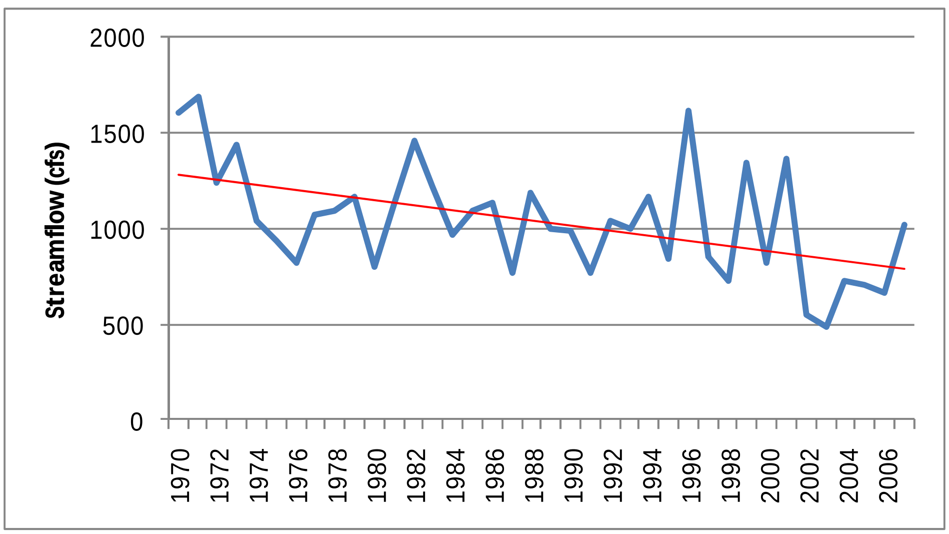


Figure 13. Annual mean discharge from 1924-2007 and 1970-2007 at the USGS / MN Power Kawishiwi River streamflow gage at Winton Dam. Simple linear regression trend line noted in red.





Methods

Fisheries and Aquatic Plants

Frequency of occurrence of aquatic plant species was assessed using the point-intercept method (Madsen 1999). This method entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately 1 meter (m), then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80-m (0.7 points per littoral acre).

Most recent fisheries surveys follow guidelines outlined by MDNR Special Publication 147 (1993; Manual of Instructions for Lake Survey). Nearshore non-game fish surveys were also completed on each Sentinel lake following methods described by Drake and Pereira (2002).

Water Quality

In 2008 and 2009 water quality data on White Iron Lake were collected by the MPCA, WICOLA and Minnesota Power. MPCA staff sampled White Iron monthly from May through October in 2008 and 2009, WICOLA sampled monthly May - September in 2008 and 2009, and MN Power collected samples in May, July, and September 2009 per a requirement in their hydropower license. WICOLA's monitoring is conducted under supervision from MPCA staff. Samples were collected at the lake's maximum depth, near the center of the lake's deeper northern basin (MPCA site id # 202). Lake surface samples were collected with an integrated sampler, a poly vinyl chloride (PVC) tube 2 meters (6.6 feet) in length, with an inside diameter of 3.2 cm (1.24 inches). Zooplankton samples were collected with an 80 micrometer (µm) mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth total phosphorous (TP) samples were collected with a Kemmerer sampler. Temperature and dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken by MPCA staff and WICOLA volunteers. Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf .

Laboratory analysis was performed by the laboratory of the Minnesota Department of Health, or RMB Laboratories (WICOLA) or ERA Labs (MN Power) using United States Environmental Protection Agency-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride, metals, and chlorophyll-*a* (chl-*a*). Phytoplankton samples were analyzed at the MPCA using a rapid assessment technique.

Zooplankton

Zooplankton samples were collected monthly from ice-out (May) through October 2008 and 2009. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 m of the bottom and withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100% reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 micrograms per liter (µg/L) mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5-milliliter aliquot. A 5-milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level), and measured to the nearest .01 millimeter using a dissecting microscope and an image analysis system.

Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick, 1994 in Hirsch, 2009).

Results and Discussion

Fisheries Assessment

White Iron supports a diverse assemblage of cold, cool, and warm-water fish species (Table 4) and one rare species of special concern (Longear sunfish). As such, this lake is an important sentinel to monitor changes to thermal habitat and associated fish species in response to climate change. Indeed, warm-water species such as sunfish and bass have become increasingly abundant in northeast Minnesota lakes since the 1970's (K. Schneider, University of Minnesota Dept. Fish, Wildlife, Cons. Biol. Unpublished Master's thesis data). Because the lake does not routinely stratify (and thus form cold-water hypolimnetic refuge less sensitive to atmospheric temperature), the lake is extremely sensitive to changes in atmospheric temperature. Under most climate change scenarios, coldwater species in unstratified lakes are imperiled. In White Iron, we may expect large declines in burbot, cisco, and lake whitefish populations (more information discussed below under species assessments).

Population Assessments

Three fisheries lake surveys and15 fish population assessments have been done on White Iron Lake, dating back to 1958. Gillnets (3 to 15 sets) were used during all 18 of these investigations. Trapnets (8-15 sets) were used during eight of these investigations. Most gillnetting was done in mid-to-late August, while most of the trapnetting was done in late June or early July. Shoreline seining was done during the lake surveys in 1958, 1982, and 2001. Shoreline seining or small mesh trapnetting for young-of-year walleye and yellow perch was done during 13 years from 1967 through 1984, but appeared to yield little useful information. Electrofishing was done in 1986 and 2008. See Figure 14 for a summary of standard gillnet and trapnet catches on White Iron Lake.

The median total catch of fish in the gillnets (all species combined) in all investigations on White Iron Lake of 35 fish/net (27 lb/net) is typical for Lake Class 7. This lake class is one of the more productive lake classes in northeast Minnesota, in terms of gillnet catches of fish. White Iron Lake has few panfish, and trapnet catches (median of 8 fish/net and 7 lb/net) have been correspondingly low.

Fish populations in White Iron Lake have been quite stable over time, and have been dominated by northern pike (*Esox lucius*) and walleye (*Sander vitreus*), followed by white sucker (*Catostomus commersonii*), cisco (*Coregonus artedi*), and yellow perch (*Perca flavescens*). Largemouth (*Micropterus salmoides)* and smallmouth bass (*Micropterus* dolomieu) are present, but are not abundant.

Table 4. Fish species sampled over time in White Iron Lake, feeding guild, thermal habitat preferences, and date first sampled.

Common name	Species name	Trophic guild	Thermal guild	First documented
Burbot	*Lota lota*	Predator	Cold	1958
Cisco (Tullibee)	*Coregonus artedi*	Planktivore	Cold	1958
Lake whitefish	*Coregonus clupeaformis*	Planktivore	Cold	1970
Mottled sculpin	*Cottus bairdii*	Insectivore	Cold	1986
Trout-perch	*Percopsis omiscomaycus*	Insectivore	Cold	1968
Iowa darter	*Etheostoma exile*	Insectivore	Cool	2008
Northern pike	*Esox lucius*	Predator	Cool	1958
Tiger muskellunge	*Esox masquinongy x Exox lucius*	Predator	Cool	2004
Black crappie	*Pomoxis nigromaculatus*	Predator	Cool-warm	1958
Central mudminnow	*Umbra limi*	Insectivore	Cool-warm	2008
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-warm	1958
Rock bass	*Ambloplites rupestris*	Insectivore	Cool-warm	1958
Walleye	*Sander vitreus*	Predator	Cool-warm	1958
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	1958
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	1958
Blacknose shiner	*Notropis heterolepis*	Insectivore	Unknown	1984
Log perch	*Percina caprodes*	Insectivore	Unknown	1958
Black bullhead	*Ameiurus melas*	Omnivore	Warm	2009
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	1958
Bluntnose minnow	*Pimephales notatus*[b]	Omnivore	Warm	2001
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	1968
Largemouth bass	*Micropterus salmoides*	Predator	Warm	1986
Longear sunfish[a]	*Lepomis megalotis*	Insectivore	Warm	2008
Pumpkinseed sunfish	*Micropterus gibbosus*	Insectivore	Warm	1986
Smallmouth bass	*Micropterus dolomieu*	Predator	Warm	1967
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	1986

Tadpole madtom	*Noturus gyrinus*	Insectivore	Warm	1984

[a]State listed species of greatest conservation need.

Northern pike
The median catch of northern pike over the long term of 2.4/gillnet was in the third quartile for this lake class. Pike sizes have averaged 53.3 cm (21 inches) in the gillnet catches, and pike over 101.5 cm (40 inches) have been caught in several investigations. Scales from pike in White Iron Lake were difficult to read, but it appeared that most pike captured in recent assessments were age four or younger. Growth of pike appeared to be somewhat faster than normal (at the third quartile) by area standards.

Walleye
The median catch of walleye over the long term of 7.7/gillnet was in the third quartile for this lake class. Walleye numbers have been very stable since 1988, but in earlier investigations walleye numbers ranged from 2/gillnet (1971) to 26/gillnet (1976, 1977). Walleye catches in 1976 and 1977 were unusually high in White Iron Lake and a number of other area lakes during 1976-1978. Walleye sizes over the long-term have averaged 32.75 cm (12.9 inches). Large walleye, up to 76.25 cm (30 inches), have been captured in many of the investigations on this lake. Most of the walleye captured by gillnets have been age four or younger. Recently, strong walleye year classes appear to have been produced in 1998, 1999, 2001, 2002, and 2006. Walleye growth has been slower than normal by area standards (in the first quartile for ages 1-4 and in the second quartile for ages 5-7).

Yellow perch
The median catch of yellow perch over the long term of 8.3/gillnet was in the fourth quartile for this lake class. Perch sizes have averaged 17.75 cm (7 inches), and the largest was 28 cm (11 inches). Perch scales have been difficult to read, but perch growth appeared to be normal by area standards.

Black crappie
Black crappie (*Pomoxis nigromaculatus*) numbers have been low in this lake, but some large crappie (up to 33 cm) - have been captured in fisheries investigations. Crappie growth was faster than normal by area standards.

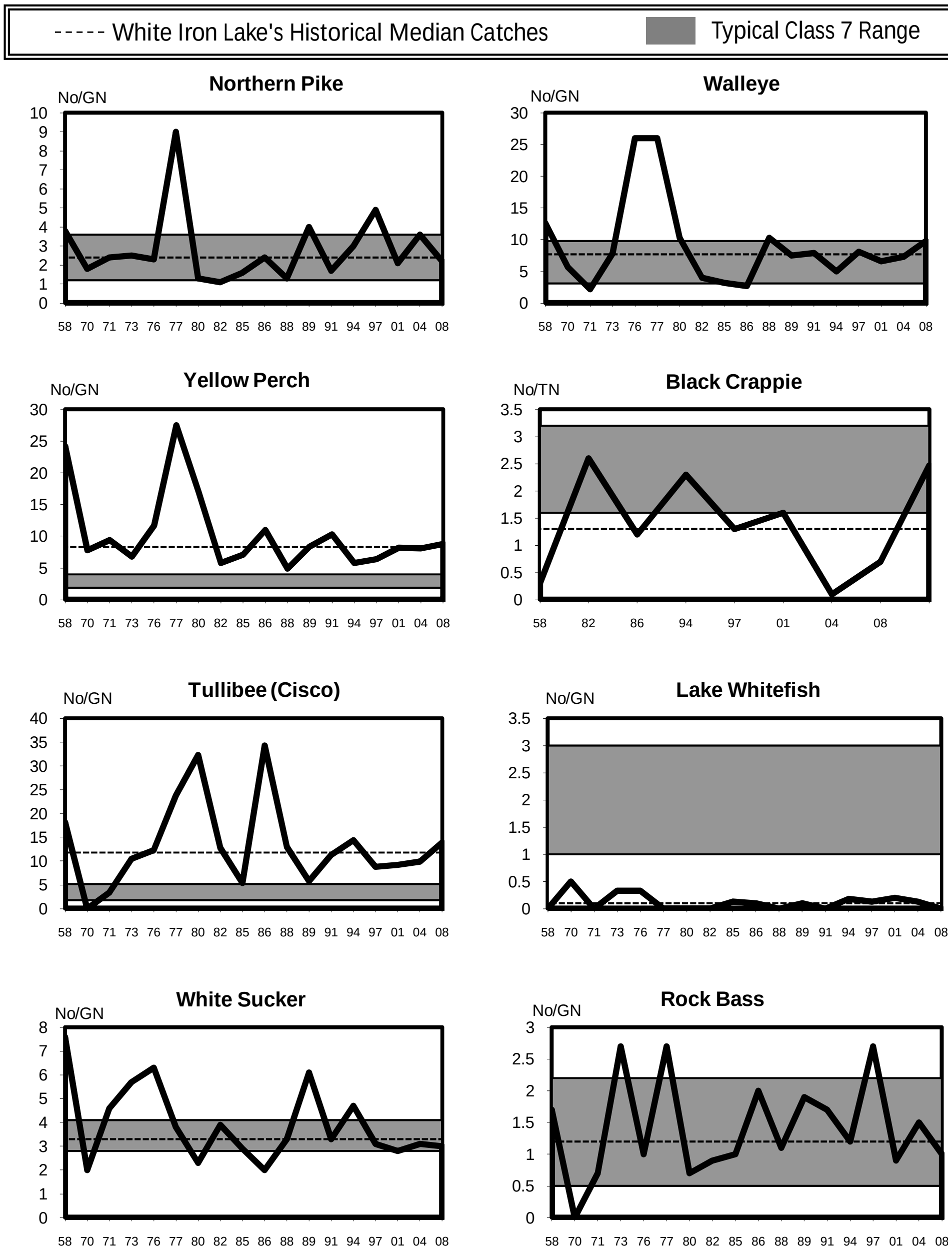
Smallmouth and largemouth bass
Smallmouth bass were first observed during seine surveys in 1967. Largemouth bass were first observed in the 1986 investigation. Bass are not highly vulnerable to standard nets, and adult abundance is likely underestimated by net catches. Therefore, their historical status in the lake is uncertain. Nevertheless, more recent electrofishing surveys (1986 and 2008) that better target adult bass than gillnets or trapnets suggest populations of both largemouth and smallmouth bass are small.

Tiger muskellunge
Two tiger muskellunge (*Esox masquinongy x Esox lucius*), 61-81.25 cm, were caught during the 2004 investigation, and one tiger muskie (91.50 cm) was caught during the 2008 investigation. Tiger muskie are a cross between muskellunge and northern pike, and were likely the offspring of native northern pike and muskie that were stocked in adjacent Farm Lake in 1974 (200 fingerlings) and in adjacent Birch Lake in 1969 (504 fingerlings) and 1981 (19 fingerlings). No pure strain muskies were caught in any fisheries investigation on this lake.

Lake Whitefish
Lake whitefish (*Coregonus clupeaformis*), a coldwater planktivore, have also been sampled in low numbers in the lake since 1970. White Iron Lake was open to whitefish netting in the past; however, netting by DNR crews and observations of private netting led to the conclusion that few whitefish

were present, few were caught, and many northern pike were taken. The lake was closed to whitefish netting in 1989.

Figure 14. Historical catch per unit effort by year of the major fish species present in White Iron Lake.



Cisco a critical, yet vulnerable forage species

The long-term median catch of cisco (11.8/gillnet) was in the third quartile for this lake class. Cisco are a schooling, pelagic coldwater fish species. Cisco catches have been correspondingly quite variable, ranging from 3/gillnet (1971) to 34/gillnet (1986), and likely underestimate cisco numbers in deeper water. Cisco sizes have averaged 9", and the largest was 43 cm (17 inches). Cisco are high quality forage for game fish and are critical components of northern Minnesota lake foodwebs. Unfortunately, cisco are highly vulnerable to eutrophication and climate change. Given their importance to lake foodwebs and sensitivity to climate change, graduate research by the University of Minnesota Duluth (Lead: Dr. Tom Hrabik) will explore alternative hydroacoustic and netting methods in Cedar Lake to understand population dynamics and habitat use of these species.

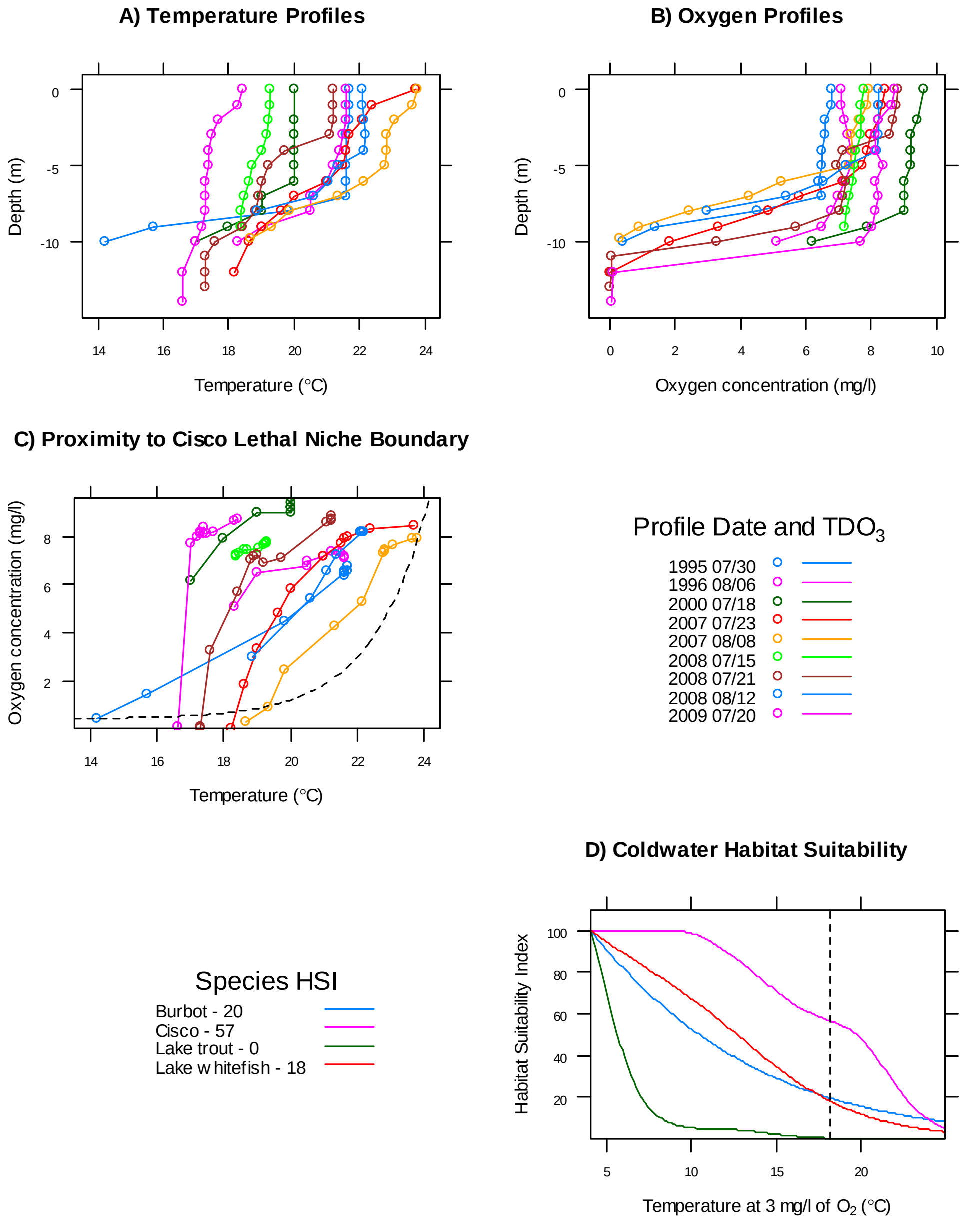
Oxythermal habitat, which is the physical property of water that provides a combination of suitable temperatures and adequate oxygen concentrations for fish (each species of fish has different oxythermal requirements) is an important consideration in fisheries management. Profiles (Figure 15) taken during the period of greatest oxythermal stress (July 13 through August 12 for unstratified lakes; Jacobson et al. - submitted manuscript) illustrate how close oxythermal habitat approached lethal conditions (Jacobson et al. 2008). All profiles contained depths where cisco could survive. Only the 8/8/07 profile came close to a lethal condition. Most summers appear to have suitable oxythermal habitat, well away from lethal conditions for cisco (which explains the robust population in the lake). Values of temperature at 3 milligrams oxygen (mg O_2) interpolated from the profiles (a measure of coldwater oxythermal habitat; see Jacobson et al. - submitted manuscript) are presented in Table 5. The mean temperature at 3 mg O_2 of 18.2 °C represents a moderate value for cisco habitat. On a scale of 0 to 100 (with 0 being worst and 100 best) calculated from Jacobson et al. (submitted manuscript), White Iron Lake has a cisco Habitat Suitability Index of 57. The primary reason that the lake maintains a good population of cisco is because of cool summers at the latitude of the lake. There are low Habitat Suitability Indices for lake whitefish (18) and burbot (20) and there is essentially no habitat for lake trout (Habitat Suitability Index of 0).

Because White Iron is well-mixed during most of the summer with no available coolwater refuge in a hypolimnion, the lake is susceptible to climate warming. Projections from the model presented in (Jacobson et al. - submitted manuscript), suggest that the temperature at 3 mg O_2 during the period of greatest oxythermal stress will increase to 21.7 °C after climate warming. That would drop the Habitat Suitability Index (HSI) for cisco from 57 to 33, suggesting that conditions for cisco in White Iron would be significantly poorer. Summer mortality events could become common (e.g. several of the profiles in Figure 15 could shift into lethal conditions); however, White Iron may be one of the few un-stratified lakes in Minnesota that may be able to sustain a cisco population (albeit at lower and more variable abundances).

Table 5. Temperatures at 3 mg O_2 interpolated from the profiles taken by MPCA and MDNR during the period of greatest oxythermal stress (July 13 through August 12) from White Iron Lake.

Date	Temperature (C) corresponding to a dissolved oxygen concentration of 3 mg/L
7/30/1995	17.8
8/6/1996	18.3
7/18/2000	17.0
7/23/2007	18.9
8/8/2007	20.3
7/15/2008	18.4
7/21/2008	17.6
8/21/2008	18.9
7/20/2009	16.8

Figure 15. Cisco oxythermal habitat in White Iron Lake. A) and B) are profiles taken during the period of greatest oxythermal stress (July 13 through August 12). C) is the profile data replotted for comparison with lethal oxythermal conditions for cisco (dashed line). The dashed line in D) represents current coldwater habitat suitability for White Iron Lake in relation to the entire gradient of HSIs in Minnesota.



Historical stocking activities

Since 1912, White Iron Lake was stocked with bass, largemouth bass, lake trout, rainbow trout, Loch Lomond (Scotland) strain brown trout, sucker, northern pike, and walleye. Muskie and northern pike were also stocked in adjacent lakes connected to White Iron Lake. Since 1945, walleye have been the only fish species stocked in White Iron Lake. It is uncertain what fish species were present prior to stocking, since the first fisheries survey was not done until 1958, but it is likely that white sucker, northern pike, and walleye were originally present.

Walleye - Small walleye fingerlings (200-1,680/lb) were stocked in 1954, 1960, 1963, 1966, and 1969 at the average rate of 0.05 lb/littoral acre (42 fingerlings/littoral acre) for each stocking. The walleye catch in the initial fisheries survey in 1958 and three subsequent fisheries investigations (1970, 1971, and 1973) averaged 7.1/gillnet (range: 2.2-12.6/gillnet). Limited walleye ageing during this period showed that strong and weak year classes occurred in both stocked years and in non-stocked years.

Walleye fry were stocked in 1973, 1975-76, 1978-80, 1982, and 1984 at the average rate of 916/littoral acre. Extraordinarily high walleye catches were made in 1976 (26.0/gillnet) and 1977 (also 26.0/gillnet), years in which high walleye catches were also made in other area lakes. No walleye were aged during these investigations to see if stocked years were stronger than non-stocked years, but analysis of the length frequency of the 1976 catch shows that 1 percent of the catch (one walleye) was one year old from the fry-stocked 1975 year class and perhaps 23 percent of the catch (26 walleye) were three years old from the fry-stocked 1973 year class. The remaining 76 percent of walleye were likely produced naturally.

Five subsequent investigations (1980, 1982, 1985, 1986, 1988) during this period of fry stocking had an average walleye catch of 4.0/gillnet (range: 2.7-10.3/gillnet), which was much lower than in 1976-77 and also lower than the average catch of 7.1/gillnet for the previous period of small fingerling stocking. Walleye fry stocking was discontinued after 1984 because ageing analysis showed that stocked years produced no more walleye than non-stocked years.

Seven investigations following the end of fry stocking (1989, 1991, 1994, 1997, 2001, 2004, 2008) captured an average of 7.5 walleye/gillnet (range: 5.0-9.8/gillnet). This is higher than the lake class median walleye catch of 6.2/gillnet.

In summary, walleye abundance in White Iron Lake prior to stocking is unknown. Walleye abundance during a period of light stockings of small fingerlings averaged 7.1/gillnet. Walleye abundance during a period of fry stocking initially was high (26.0 walleye/gillnet),at a time when many area lakes had high walleye gillnet catches, but then was low (average of 4.0/gillnet). Walleye abundance during the recent period of no stocking has been very stable, averaging 7.5/gillnet. The lake class median is 6.2/gillnet. There was generally poor correlation between individual walleye year-class strength and whether or not the lake was stocked that year. Walleye growth has been slower than normal, particularly for young fish. Walleye sizes in gillnet assessments have been very stable, averaging 32.75 cm (12.9 inches), and walleye up to 76.25 cm (30inches) have been caught.

Experimental regulations

Walleye - During public input meetings in 2002 on a proposed northern pike protected slot for the Farm, Garden, South Farm, White Iron Chain of Lakes, the public expressed interest in trying a special regulation on walleye on these lakes. Acknowledging that slow growth of walleye on these lakes would reduce chances for success of a regulation, a 43-66 cm (17-26 inches) protected slot on walleye was proposed. Public input meetings were held in September 2005 and the majority of comments received supported the proposed regulation.

A 43-66 cm protected slot limit for walleye with one walleye over 66 cm (26 inches) allowed in the daily and possession limit went into effect on March 1, 2006 for White Iron Lake and the adjacent Garden Reservoir Chain of Lakes. The slow growth of walleye in this system will make success and evaluation of this proposed regulation problematic for several reasons. First, walleye do not reach 43 cm (17 inches) in this system until they are over six years old, giving natural and fishing mortality many years to reduce walleye numbers prior to reaching the protected slot. Second, slow growth means that the size of protected walleye (over 43 cm) will not increase very fast. Hopefully, the presence of an abundant cisco population will provide a good forage base and somewhat better growth for older walleye within the protected slot.

The purpose of this regulation is to increase the number of walleye 43 cm (17 inches) and larger. The number of these large walleye in 2008 (2.6/gillnet) was higher than in any investigation from 1986 through 2004 (range: 0.40/gillnet to 2.27/gillnet). Compliance with the regulation is not known, and time will tell whether the increase in larger walleye observed in 2008 can be sustained or increased.

Northern pike - A special regulation (protected slot limit) to increase the size of northern pike in White Iron Lake (and the adjacent Garden Reservoir chain of lakes) was implemented starting with the 2003 open-water fishing season. Under this regulation, northern pike from 61-91.5 cm (24-36 inches) have to be immediately released, the bag limit is 3 fish, and only one pike over 91.5 cm (36 inches) is allowed in possession. Compliance with this regulation has not been measured and is not known.

Assuming that compliance with this regulation was high, that reasonable numbers of pike 61-91.5 cm were caught and released, that previously these fish would have been kept, and that few released pike died from being caught and released, numbers of pike 61 cm (24 inches) or larger should increase as a result of this regulation. Comparing the 2004 and 2008 northern pike gillnet catches to previous gillnet catches in 1994, 1997, and 2001, we find that the catches of pike 61 cm (24 inches) or larger in 2004 (1.3/gillnet) and 2008 (0.6/gillnet) were not consistently higher that the average pike catch in the three previous investigations of 0.7/gillnet (range: 0.6-0.9/gillnet).

As released pike in the protected slot continue to grow, the average size of pike 61 cm (24 inches) or larger should increase. Comparing the 2004 and 2008 gillnet catches to the three previous investigations mentioned above, we find that the average size of pike over 61 cm (24 inches) in 2004 (69.1 cm) and 2008 (85.1 cm) was larger than the average size in the previous investigations of 65.5 cm (range: 64.8-66.8 cm).

In summary, the larger average size of northern pike 61 cm (24 inches) and larger in 2004 and 2008 is consistent with expected results from the protected slot limit. The lack of higher numbers of pike 61 cm (24 inches) or larger is not consistent with the expected results. The recent implementation of this regulation and the variable success of natural reproduction of northern pike from year-to-year make conclusions based on two investigations speculative. Future investigations will give a better sense of the ultimate impact of this regulation.

Aquatic Plant Assessment

Because White Iron is a rocky, bog-stained lake, macrophytes are naturally sparse with only approximately 9% of the area less than 4.6 m (15 feet) having some degree of rooted aquatic plant growth in 2008 (Figure 16). Nevertheless, aquatic plant growth that is present may serve as critical habitat for a number of fish species at some point in their life history. In particular, submerged and emergent vegetation is often cited as a limiting factor controlling northern pike recruitment in Canadian Shield Lakes (Laine 1989; R. Pierce DNR Fisheries Research Biologist, personal communication).

Aquatic plant communities varied little between 2008 and 2009. The most common plant species surveyed in 2008 and 2009 was water celery (Table 6). Wild rice, an important species for a variety of littoral fish and waterfowl was found in several shallow areas of the lake (Figure 17).

Rusty crayfish

Rusty crayfish (*Orconectes rusticus*), a large and aggressive crayfish species native to the Ohio River Valley, were captured by the U.S. Forest Service in crayfish traps in the summer of 2007 in Birch Lake, White Iron Lake, Farm Lake, and Garden Lake. They were previously observed by MDNR fisheries crews in Birch Lake near the Kawishiwi River inlet, and they have been abundant in Fall Lake for over 20 years. Rusty crayfish often displace native crayfish species, destroy aquatic plants by clipping stems with their cheliped pinchers, and prey on the eggs of several fish species (Lodge and Lorman 1987, Claramunt et al. 2005). Future surveys by the Superior National Forest and MDNR will be assessing the current status of Rusty Crayfish in White Iron Lakes and the impacts on aquatic plants.

Figure 16. Cover of aquatic plants in September 2008 estimated from point-intercept sampling and indicator kriging interpolation.

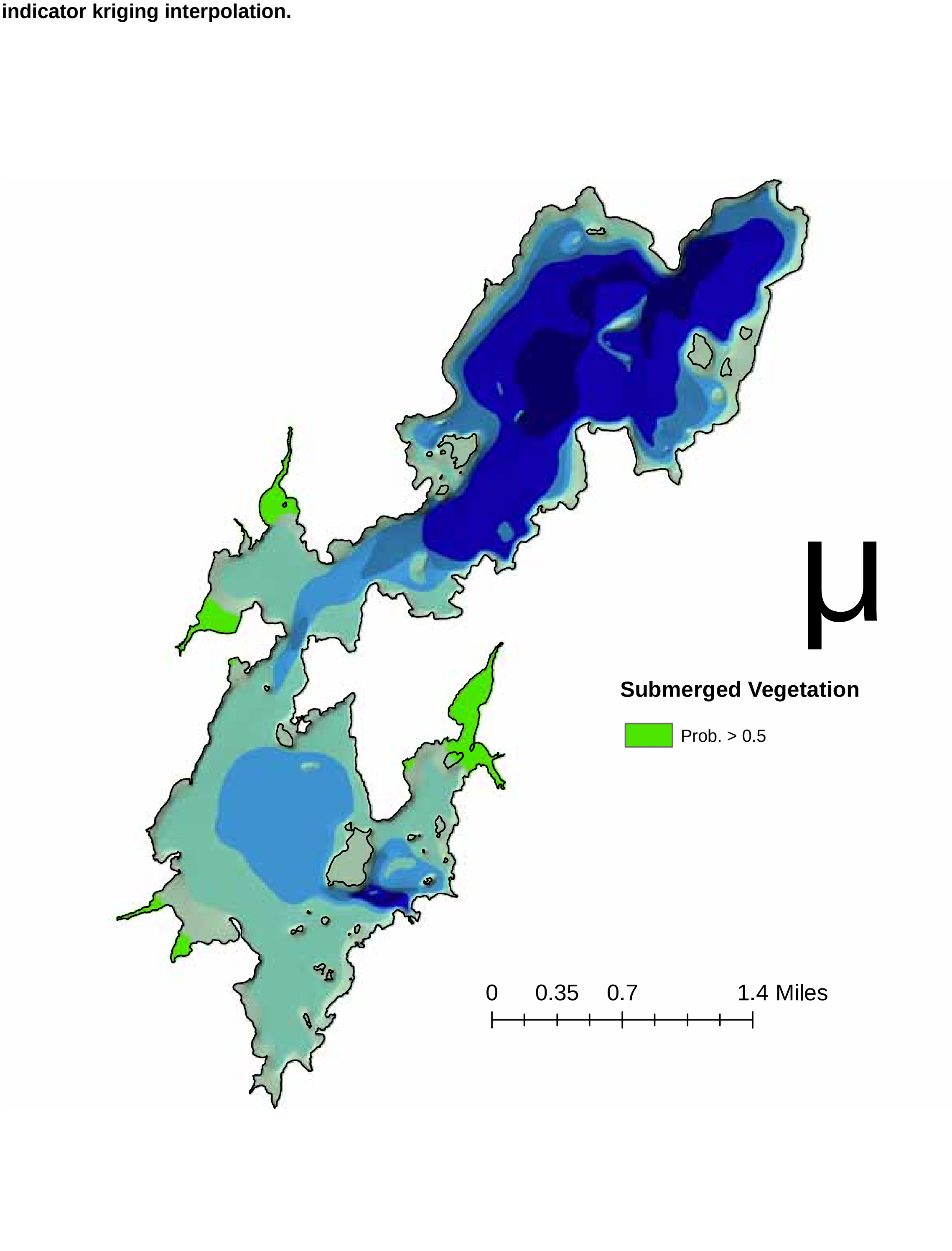


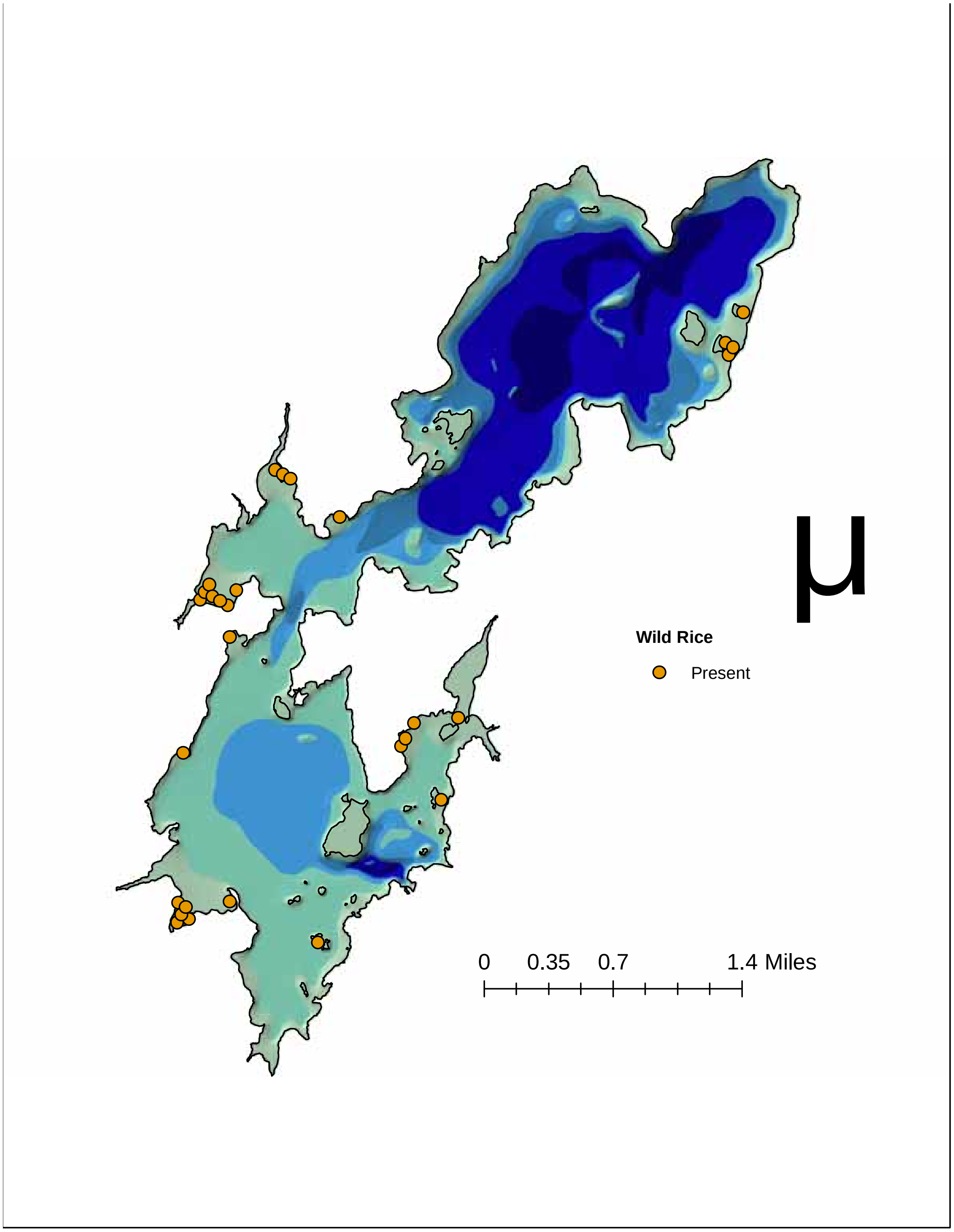
Table 6. Percent frequency of occurrence of aquatic plant species at over depths less than 15 ft sampled during point-intercept surveys on White Iron Lake during 2008 and 2009 .

Common name	Species name	Growth form	Frequency (%) 2008[a]	2009[b]
All Rooted Plants			16.9	18.1
Water celery	*Vallisneria americanus*	Submersed	10.7	9.9
Freshwater sponge			6.7	6.25
White waterlily	*Nymphaea sp.*	Floating-leaf	4.5	4.8
Coontail	*Ceratophyllum demersum*	Submersed	4.3	4.9
Burreed	*Sparganium sp.*	Emergent	3.9	2.7
Wild rice	*Zizania palustris*	Emergent	3.7	4.7
Bladderwort	*Utricularia sp.*	Submersed	1.8	1.5
Arrowhead	*Sagittaria spp.*	Emergent	1.8	0.1
Filamentous Algae			1.4	2.0
Yellow waterlily	*Nuphar sp.*	Floating-leaf	1.0	0.1
Common yellow waterlily	*Nuphar variegata*	Floating-leaf		0.4
Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	1.0	0.9
Muskgrass	*Chara sp.*	Submersed	0.9	1.3
Floating-leaf pondweed	*Potamogeton natans*	Floating-leaf	0.9	0.4
Water moss	*Drepanocladus sp.*		0.8	0.6
Hardstem bulrush	*Scirpus acutus*	Emergent	0.8	0.7
Watermilfoil	*Myriophyllum sp.*	Submersed	0.8	0
Water marigold	*Bidens beckii*	Submersed	0.6	0.4
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	0.4	0.4
Ribbon-leaf pondweed	*Potamogeton epihydrus*	Submersed	0.4	0.1
Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed	0.4	0.6
Softstem bulrush	*Scirpus validus*	Emergent	0.3	0.5
Quillwort	*Isoetes sp.*	Submersed	0.3	0
Pickerelweed	*Pontederia cordata*	Emergent	0.3	0.1
Stonewort	*Nitella sp.*	Submersed	0.1	0
Large-leaf pondweed	*Potamogeton amplifolius*	Submersed	0.1	0.2
Horsetail	*Equisetum sp.*	Emergent	0.1	0.1
Needlerush	*Eleocharis sp.*	Submersed	0.1	0
Canada waterweed	*Elodea canadensis*	Submersed	0.1	0
Sweet flag	*Acornus calamus*	Emergent	0	0.1
Naiad group	*Najas sp.*	Submersed	0	2.0
Robbins' pondweed	*Potamogeton robbinsii*	Submersed	0	0.1
Horsetail	*Equisetum sp.*	Emergent	0	0.1
Wild iris	*Iris sp.*	Emergent	0	0.1
Waterthread pondweed	*Potamogeton diversifolius*	Submersed	0	0.1
Leafy pondweed	*Potamogeton foliosus*	Submersed	0	1.7
Variable-leaf pondweed	*Potamogeton gramineus*	Submersed	0	0.2
Small pondweed	*Potamogeton pusillus*	Submersed	0	0.1

Floating-leaf burreed	*Sparganium sp.*	Submersed	0	0.2
Max depth of veg growth[c]			5.0ft	5.0ft

[a]Surveyed on 10 September 2008
[b]Surveyed on 10 August 2009
[c]Depth of 95% of all plant occurrences

Figure 17. Presence of wild rice surveyed during September 2008 in White Iron Lake.



Water Quality

Standard summer-mean water quality data for 2008 and 2009 are presented in Table 3, and raw data results are provided in Appendix A. In addition, major cations, anions, and total organic carbon were analyzed on three sample dates, and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 7. The NLA was a statistically-based survey of the nation's lakes administered by the United States Environmental Protection Agency in 2007. The typical range provided in Table 7 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a state-wide perspective.

Table 3. White Iron Lake 2008 and 2009 summer- mean water quality data. Typical range based on 32 NLF ecoregion reference lakes (Heiskary and Wilson 2008) noted for comparison. A value of half the detection limit was substituted for those values reported as less than the detection limit.

Parameter	White Iron Lake 2008 Site 202	White Iron Lake 2009 Site 202	NLF
Total phosphorus (µg/L)	23.7	18.7	14 - 27
Chlorophyll mean (µg/L)	4.3	4.3	4 - 10
Chlorophyll max (µg/L)	7.95	4.56	<15
Secchi disk (feet) (meters)	4.2 1.3	5.9 1.8	8 – 15 2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.63	0.53	<0.4 – 0.75
Alkalinity (mg/L)	12	15	40 - 140
Color (Pt-Co Units)	93	100	10 - 35
pH (SU)	6.39	6.17	7.2 – 8.3
Chloride (mg/L)	1.3	1.34	0.6 – 1.2
Total suspended solids (mg/L)	1.73	3.6	<1 - 2
Total suspended inorganic solids (mg/L)	0.94	1.2	<1 - 2
Conductivity (umhos/cm)	45	45	50 - 250
Total nitrogen: Total phosphorus ratio	26:1	28:1	25:1 - 35:1

Table 7. White Iron Lake cation, anion, and total organic carbon measurements. Typical (IQ) range derived from 64 NLA lakes sampled in 2007 is provided as a basis for comparison.

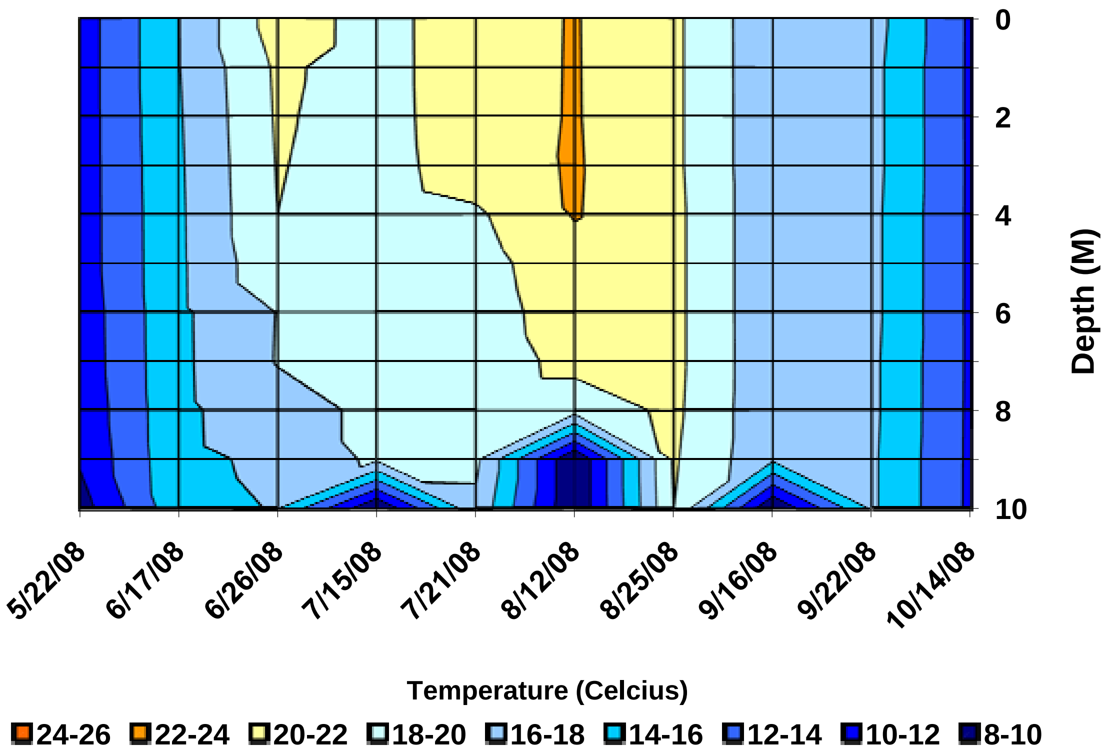
Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	SO_4 mg/L	Cl mg/L	TOC mg/L
2008 Average	11.3	10.2	0.25	1.72	3.4	1.3	14
2009 Average	11.9	11.0	0.32	1.69	3.7	1.3	13
NLA IQ range	19.1-33.7	6.7-26.9	0.9-4.8	2.2-9.0	2.2-14.1	1.5-18.4	7.3-14.2
	µeq/L						
2008 Average	562	839	6	74	70	36	
2009 Average	593	905	8	73	76	37	

Dissolved oxygen and temperature profiles

MPCA and WICOLA data were combined to produce biweekly DO and temperature profiles for 2008 and 2009, shown in Figures 18-19. White Iron was almost always well-mixed both years. Partial stratification occurred only once in 2009 (6/25) and 2008 (6/26), and temperatures only changed about 5 degrees Celsius in-total from the surface to the bottom. Maximum surface temperatures peaked at 22 degrees both years (August 2008 versus late June 2009). Overall, water temperatures averaged about 17 degrees each year, with 2008 having a warmer summer and cooler fall. Data from the 1996 MPCA Lake Assessment study (MPCA, 1996) showed that White Iron was stratified during the summer, with a thermocline between 5-10 m. During periods of warm, calm weather stratification can occur, but given the lake's very short residence time and large fetch, polymictic conditions are most likely to be observed.

Oxygen concentrations followed similar trends, tending to be consistent throughout the water column. Surface concentrations exceeded 7 milligrams per liter (mg/L) on all measurements, and concentrations only fell below 5 mg/L within 0-2 m of the lake bottom (Figure 19). More detailed dissolved oxygen data and modeling done by MDNR were included in the preceding section on cold water fisheries habitat.

Figure 18. 2008 and 2009 White Iron Lake temperature profiles



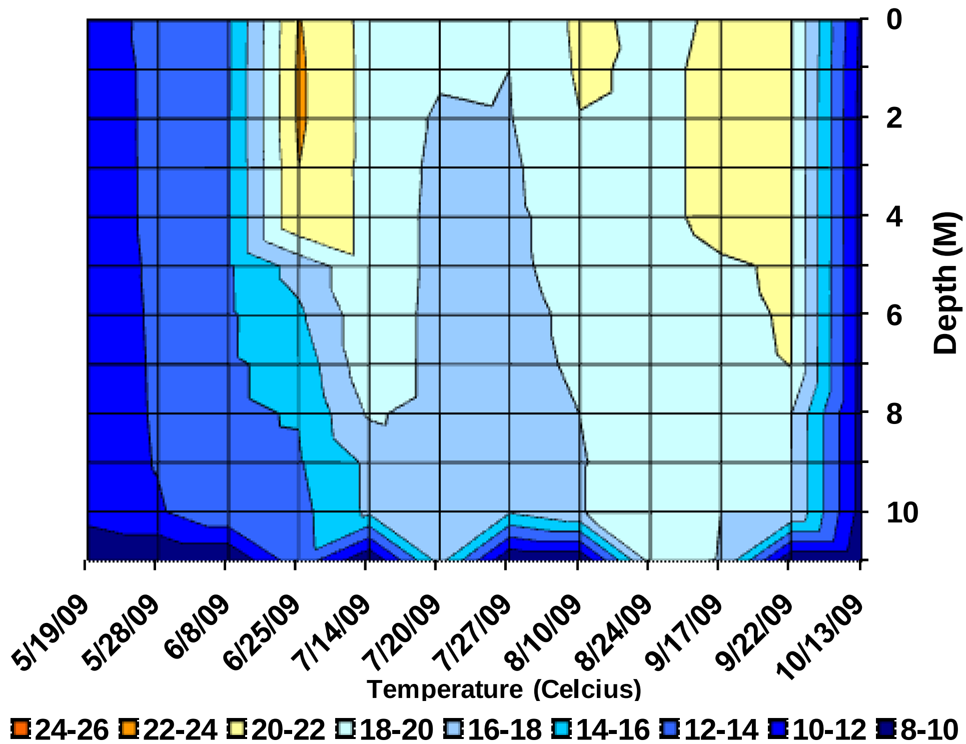
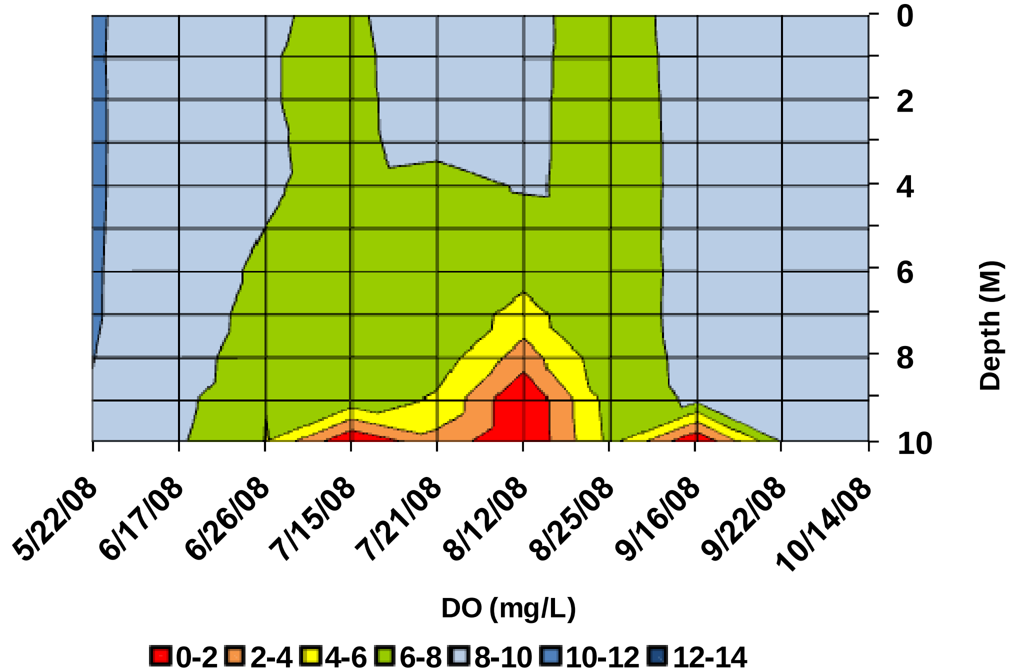
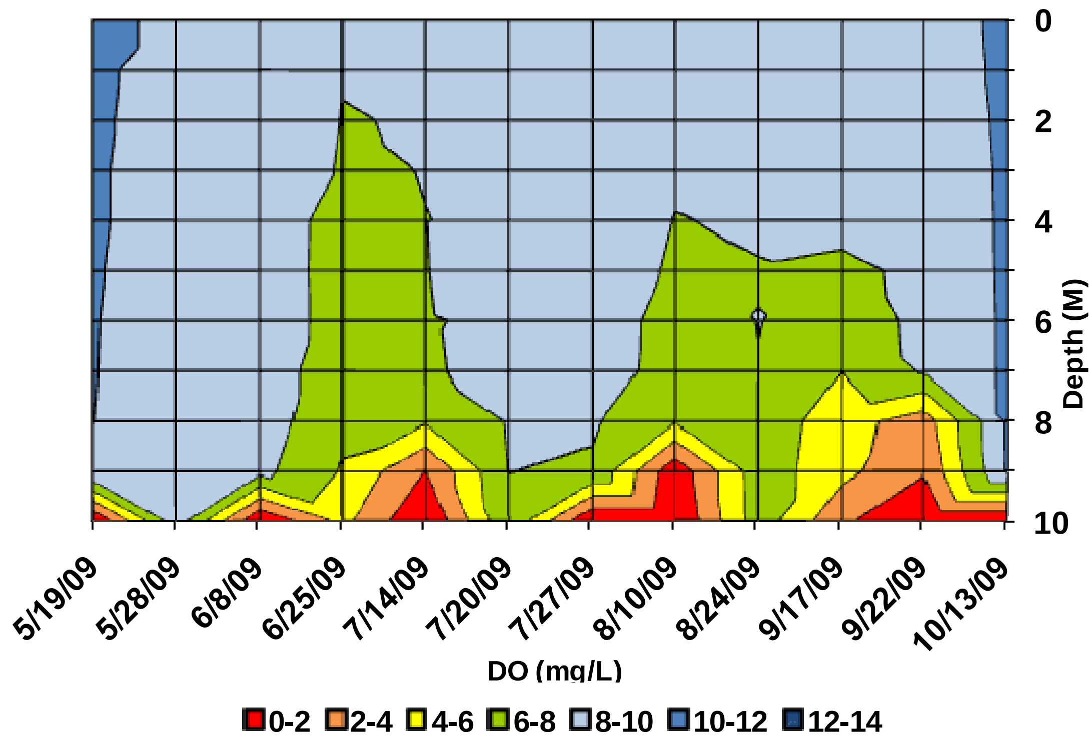


Figure 19. 2008 and 2009 White Iron Lake dissolved oxygen profiles





Total Phosphorus (TP) concentrations did not change significantly between years, averaging 23 µg/L in 2008 and 18 µg/L in 2009. Similarly, concentrations did not vary greatly about the annual mean on a monthly basis, only slightly increasing by the fall (Figures 20-21). Stable TP concentrations are likely due to the lake's large undeveloped forested watershed and rapid residence time. MPCA monitoring data on Birch lake (immediately upstream of White Iron Lake) averaged 24 µg/L from 2008-09. For most deep, oligotrophic to mesotrophic (low to moderate nutrient) lakes it is common to observe stable to slightly declining TP from May through September, accompanied by slight increases in chl-*a* and slight decreases in Secchi transparency. This is primarily the result of sedimentation of sediment-attached TP early in the summer along with algal uptake of P and sedimentation as algae grow and die over the summer. Near-bottom TP concentrations closely mirrored the surface values in White Iron. Epilimnetic TP data collected by WICOLA and MN Power in 2008-09 were very similar to MPCA data.

Chlorophyll-*a* (chl-*a*) concentrations provide an estimate of the amount of algal production in a lake. During 2008-09, chl-*a* concentrations ranged from 2.2 µg/L to 7.9 µg/L, with an average of 4 µg/L (Figures 20-21). Concentrations greater than 20 µg/L will typically be perceived as a nuisance bloom in northern Minnesota lakes (Heiskary and Walker, 1988). Nuisance blooms were not observed on White Iron either year and during most sampling events algae levels in the epilimnion were sparse. Algal growth is limited to some degree by the lake's high color (i.e. bog stain). This natural staining originates from tannin compounds (i.e., incompletely dissolved organic matter) that arises from wetland and forest runoff within the watershed. Color averaged about 95 platinum-cobalt units in White Iron both years, nearly 3 times higher than the typical NLF ecoregion range based on the reference lakes (Table 3). In general, high color is common in many watersheds in the NLF ecoregion and should be viewed as the direct result of natural processes in these wetland and forest-dominated watersheds.

Secchi disk transparency averaged 1.2 and 1.7 m in 2008 and 2009, respectfully. These values are below the NLF ecoregion range. Secchi transparency is lower than expected because of the lake's high color, and is not related to excess TP or chl-*a* from watershed sources. Similar to trends observed in TP and chl-*a*, transparency did not change substantially throughout the season -- values were about 1.5 m each month for both years (Figures 20-21).

Additional water quality parameters were measured, as part of the long-term monitoring of White Iron and other Sentinel lakes. This includes some of the standard MPCA lake monitoring measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 3), as well as major cations, anions, and total organic carbon (Table 7). While several of these parameters have "typical" ecoregion-based concentrations, some do not. For parameters without ecoregion–based comparisons, data from the 2007 NLA study were used to provide perspective on reported concentrations. Since the NLA lakes were selected randomly, they provide a reasonable basis for describing typical ranges and distributions at the statewide level.

For the conventional lake monitoring parameters listed in Table 3, as discussed previously, only Secchi transparency and color were outside the NLF range. The low alkalinity and conductivity concentrations indicate soft water, typical of other area lakes. Total organic carbon (TOC) averaged 13.5 mg/L in White Iron, near the 75th percentile based on the NLA lakes. Much of the TOC in water is due to incompletely dissolved organic material. Lakes with high amounts of forest and wetlands in their watershed often have correspondingly higher color and TOC values.

Figure 20. White Iron Lake 2008 total phosphorus, chlorophyll-*a* and Secchi depth

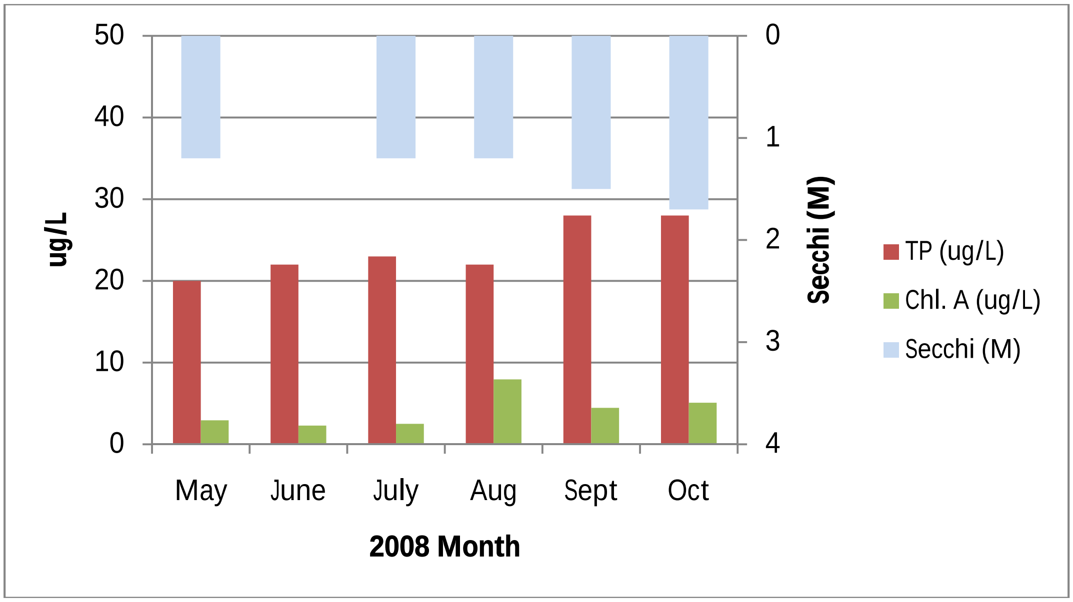
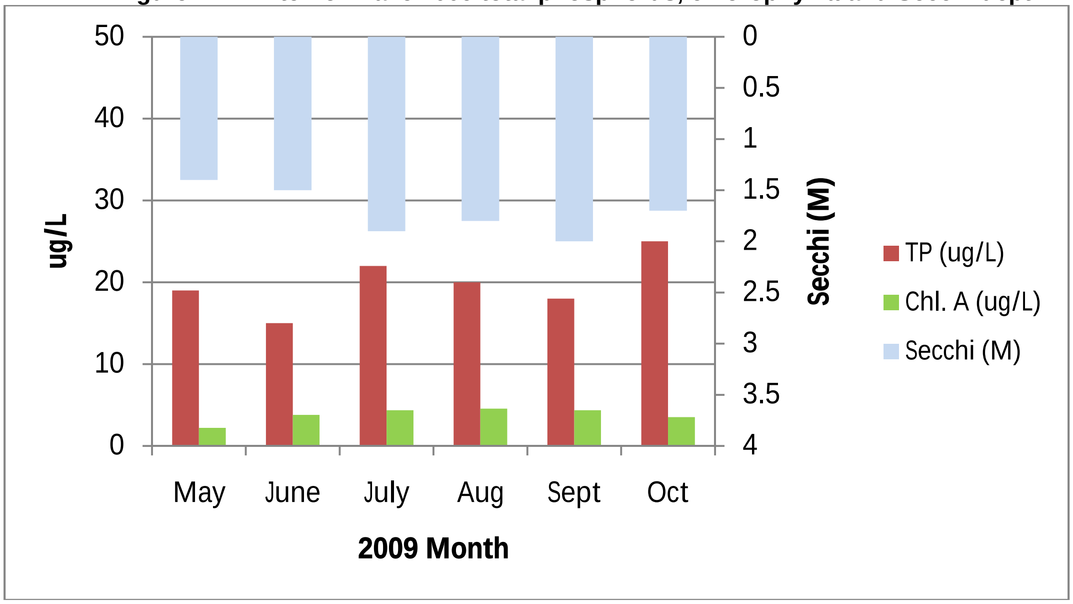


Figure 21. White Iron Lake 2009 total phosphorus, chlorophyll-*a* and Secchi depth



Phytoplankton (algae) for White Iron Lake are presented in terms of algal type (Figures 22 and 23). In May, dinoflagellates and diatoms were the dominant forms. Diatoms, which often prefer cooler water are often dominant in the spring and early summer. Blue-green algae remained dominant throughout the summer and fall of 2008, with the dominant genera being *Anabaena* and *Aphanizomenon*. Since chl-*a* was quite low, they may not have been perceived as nuisance blooms; however, they do float at the surface and would be visible to the casual observer.

A seasonal transition in algal types from diatoms to green to blue-green algae is rather typical for mesotrophic and eutrophic lakes in Minnesota. In White Iron Lake, blue-greens dominated in late summer and fall coinciding with warmer water temperatures in 2008; however, in 2009 diatoms and blue-greens were about equal in abundance from August – October. The cause for this difference may be related to cooler water temperatures in mid-summer 2009.

Figure 22. Algal composition for White Iron Lake in 2008

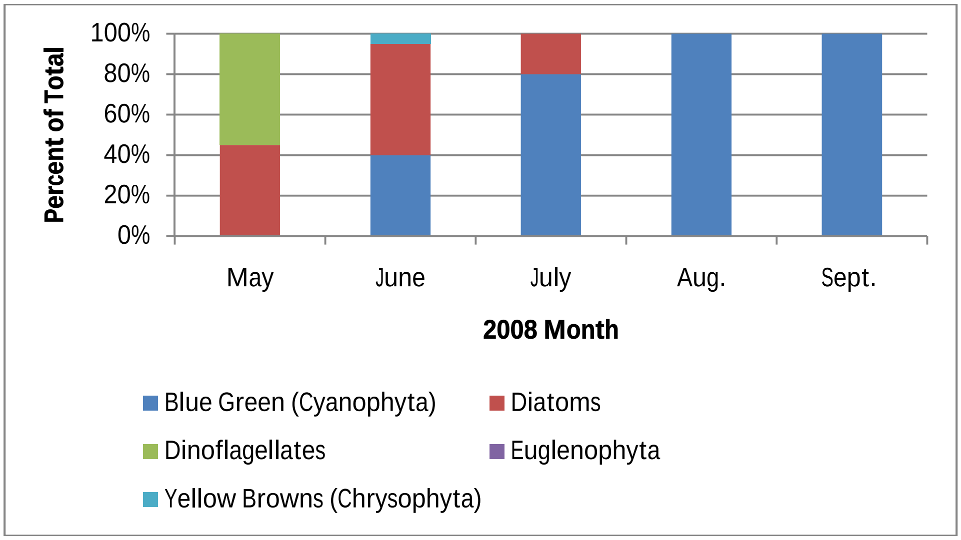
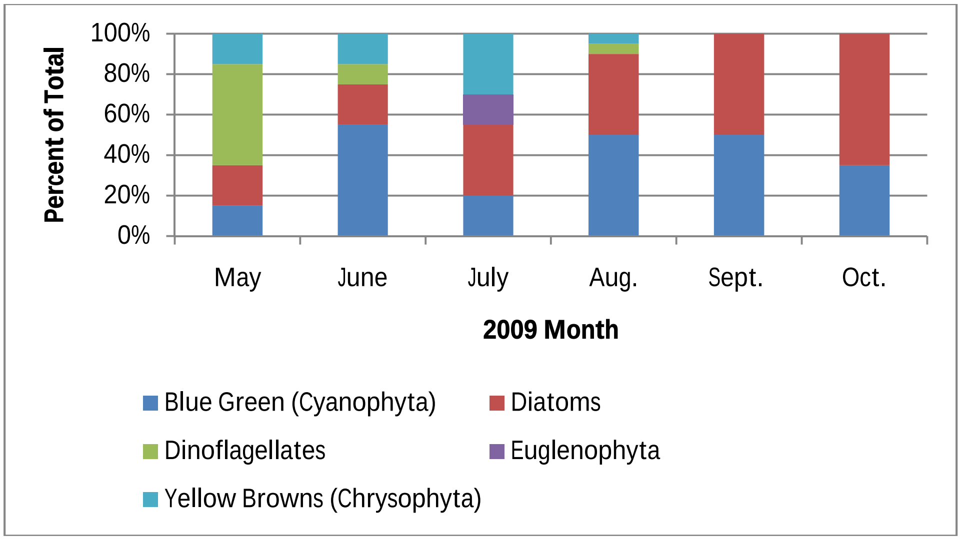


Figure 23. Algal composition for White Iron Lake in 2009



Zooplankton

Zooplankton samples were analyzed by Jodie Hirsch at the MDNR. A summary report was prepared that included information for all the Sentinel lakes and that report is the basis for the following comments on White Iron Lake (Hirsch 2009). Mean annual zooplankton densities for 2008 in White Iron were about average when compared to the five other Border region Sentinel Lakes (Table 8). Hirsch (2009) found that, in general, as lake productivity increased (e.g. TP or chl-*a*) the relative abundance (biomass) of zooplankton increased as well. This appears to be the case for White Iron and the other NLF lakes (Figure 24). Echo is the most productive Sentinel lake in the Border region and had the highest zooplankton density, while White Iron was intermediate (in terms of trophic state) for this group of lakes and exhibited moderate amounts of zooplankton (Figure 24; Table 8). Densities tended to be highest in mid-summer and lower in the spring and fall (Figure 24).

Figure 24 Mean monthly zooplankton densities and biomass for Border Sentinel lakes

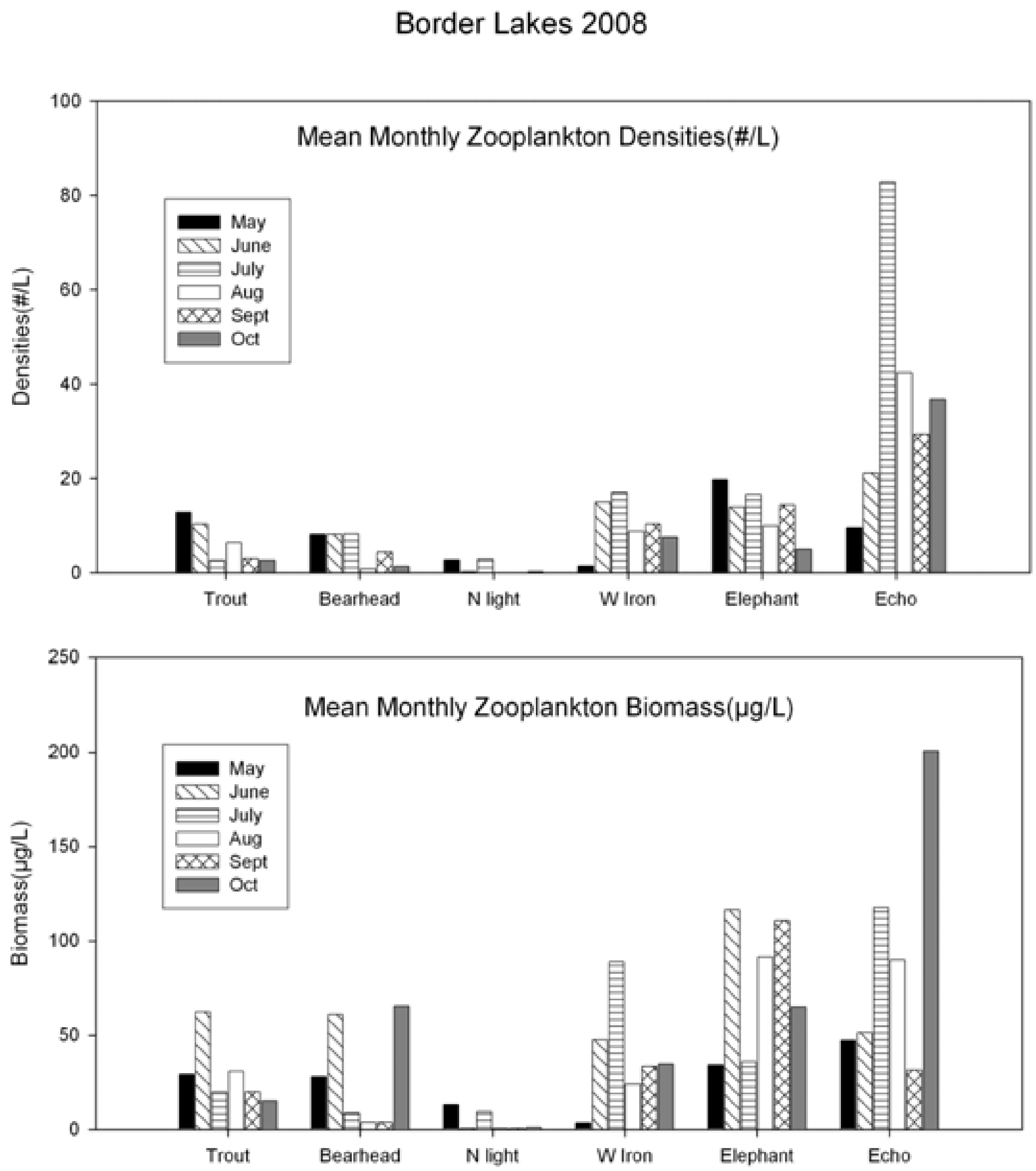


Table 8. White Iron Lake 2008 zooplankton data

Sentinel lakes zooplankton 2008	Mean Annual densities (#/L)	Mean Annual biomass (µg/L)	Total# taxa
Western Cornbelt Plains (WCBP & NGP)			
Artichoke	139.64	724.05	12
Shaokotan	107.55	1070.97	11
St. James	62.73	108.56	10
St.Olaf	60.23	336.20	15
Carrie	56.41	254.21	13
Madison	52.78	310.93	14
North Central Hardwood Forest (NCHF)			
Peltier	78.75	1098.39	12
Pearl	59.68	221.13	14
Belle	57.67	340.06	12
South Center	24.72	123.71	18
Carlos	19.66	73.49	16
Cedar	11.31	41.85	11
Northern Lakes and Forests (NLF)			
Portage	100.10	277.38	10
Red Sand	79.31	127.96	18
South Twin	25.83	54.93	12
Hill	17.73	147.29	11
Elk	16.95	47.10	12
Ten Mile	14.94	44.89	14
Border Lakes (NLF)			
Echo	37.03	89.68	12
Elephant	13.26	75.50	12
White Iron	10.00	38.64	14
Trout	6.28	29.52	13
Bearhead	5.15	38.37	14
Northern Light	1.03	4.16	13

Trophic State Index

One way to evaluate the trophic status of a lake and to interpret the relationship between TP, chl-*a*, and Secchi disk transparency is Carlson's Trophic State Index (TSI) (Carlson 1977). TSI values are calculated as follows:

Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

Chlorophyll-*a* TSI (TSIC) = 9.81 ln (chl-*a*) + 30.6

Secchi disk TSI (TSIS) = 60 – 14.41 ln (SD)

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a basis for assessing the relationship among TP, chl-*a*, and Secchi (Figure 25). In general, the phosphorus and chlorophyll TSI values for White Iron Lake are in fairly close correspondence with each other (though chl-*a* is slightly low relative to TP); however Secchi over-estimates trophic status because of the lake's high color. The TSI values are shown based on MPCA data for 2008 and 2009 (Figure 25). Based on an average TSI score of 48 White Iron Lake would be characterized as mesotrophic.

TSI < 30 Classical Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.

TSI 30 - 40 Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

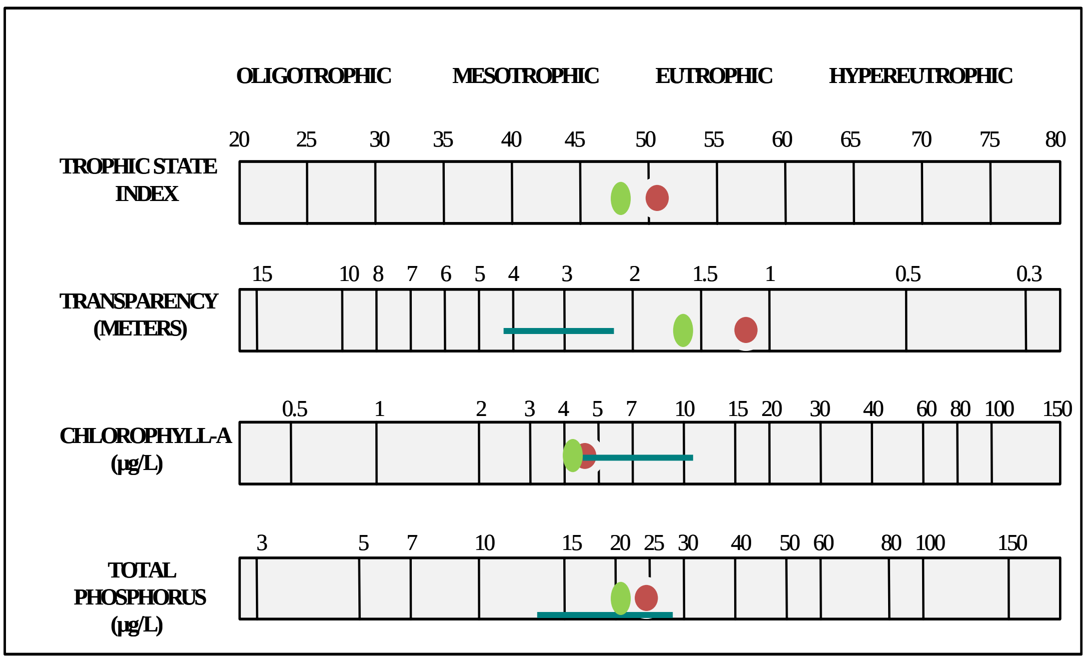
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 - 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 - 70 Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.

TSI 70 - 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.

TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



After Moore, l. and K. Thornton, [Ed.]1988. Lake and Reservoir Restoration Guidance Manual. USEPA>EPA 440/5-88-002.

NLF Ecoregion Range W. Iron Lake 2008 W. Iron Lake 2009

Figure 25. White Iron Lake TSI values for 2008 and 2009 MPCA sentinel lake monitoring data

Trophic Status Trends

One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in STORET. A review of data in STORET indicates there is a large amount of data for White Iron Lake to describe annual variability and to statistically assess trends. These data come from MPCA, WICOLA, and MN Power. In general, for trend assessment we seek a minimum of eight years of consistent data. Based on yearly TSI averages calculated for 1995 through 2009, White Iron Lake has historically been classified as mesotrophic (Figure 26). Only Secchi disk monitoring was conducted in the middle of the long-term record (late 1990's to 2004), and these data inflate the TSI calculations because transparencies in White Iron Lake are heavily influenced (i.e. lowered) by natural bog staining. Secchi derived TSI values have averaged about 55, with some annual variability. Intensive water quality monitoring (TP and chl-*a* sampling) occurred in 1995-96, and from 2005-2009 (WICOLA, MPCA, and MN Power data). These data show stable concentrations of TP and chl-*a* in White Iron (Figure 27). Annual average TP and chl-*a* concentrations are consistently near 20 and 5 µg/L respectively, and standard errors are low. These data point to stable water quality over the last few years, with perhaps a slight decline in TP since the 1990's.

A non-parametric statistical analysis of historical Secchi transparency data show an overall improvement in transparency since 1994 (Figure 28). The Secchi dataset on White Iron is very strong with 20 - 40+ measurements taken annually. WICOLA volunteers should be commended for their volunteer monitoring efforts. The long-term mean is approximately 1.6 m. Transparencies have declined slightly since 2004 (Figure 28); however, this may simply be part of a "cycle" within the lake, as Secchi appears to increase for several years (1999-2004) followed by subtle declines (2004-2009). Continued long-term monitoring is essential to determine if these trends are due to natural variability, climate change, water levels, reservoir operations, or other causes.

Figure 26. White Iron Lake trophic status trend

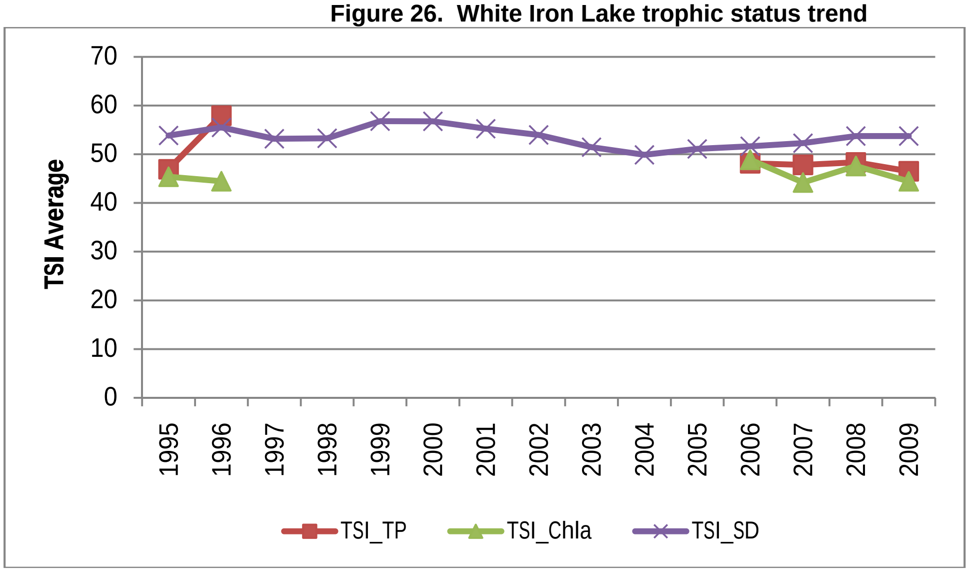


Figure 27. White Iron Lake long-term summer-mean total phosphorus and chlorophyll-*a*. Standard error of the mean noted for each year.

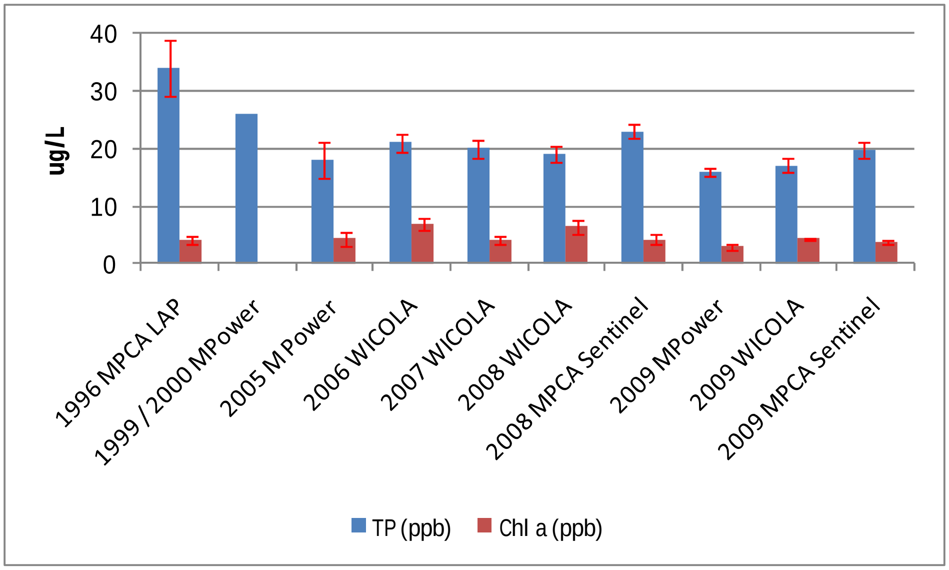
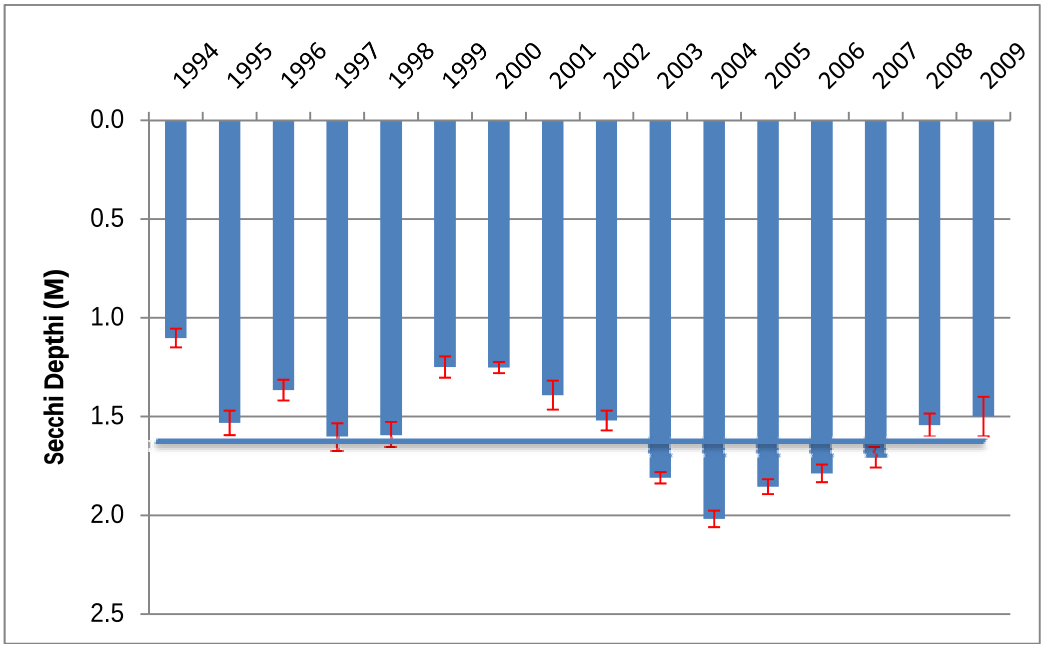


Figure 28. White Iron Lake long-term summer-mean Secchi disk depth. Long-term mean noted as blue line.



Modeling

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water that enters the lake. To analyze the 2008-09 water quality of White Iron Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. A comparison of MINLEAP predicted vs. observed values is presented in Table 9.

MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). The model predicts in-lake TP from these inputs. Chl-*a* and Secchi predictions are derived from Minnesota-based regression equations. For analysis of White Iron Lake, MINLEAP was applied as a basis for comparing the observed (2008-09 average) TP, chl-*a*, and Secchi values with those predicted by the model based on the lake size and depth and the area of the watershed. MINLEAP was not designed to model lakes and reservoirs with very large watersheds, such as White Iron; however, the results are still presented here for informational purposes.

White Iron Lake is located in the NLF ecoregion and the model was run using NLF-based inputs. To improve model predictions, inflow TP concentration was set at 25 µg/L (the 2008-09 average concentration of samples collected on Birch Lake by the MPCA). The observed and predicted TP and chl-*a* values for White Iron Lake are nearly identical. Observed Secchi values are lower than predicted, but not statistically different, due to the bog-stained waters, which the MINLEAP model does not account for. MINLEAP predicts a P loading rate of about 14,000 kilograms per year entering White Iron Lake from the S. Kawishiwi River watershed. An additional subroutine in the MINLEAP model estimates the "background" TP for the lake based on its alkalinity and mean depth and a regression equation developed by Vighi and Chiaudani (1985). For White Iron Lake, this value is estimated to be 10 µg/L.

Table 9. MINLEAP model results for White Iron Lake

Parameter	2008 / 2009 White Iron Lake Observed	MINLEAP Predicted NLF Ecoregion
TP (µg/L)	21	21
Chl-*a* (µg /L)	4.2	5.5
Secchi (m)	1.5	2.8
P loading rate (kg/yr)	-	14,061
P retention (%)	-	18
P inflow conc. (µg/L)	-	25
Water Load (m/yr)	-	42.45
Outflow volume (hm^3/yr)	-	556.3
Residence time (yrs)	0.11	0.1
Vighi & Chiaudani		10.4

303(d) Assessment and Goal Setting

The federal Clean Water Act requires states to adopt water quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming. The standards are set on a wide range of pollutants, including bacteria, nutrients, turbidity and mercury. A water body is "impaired" if it fails to meet one or more water quality standards.

Under Section 303(d) of the Clean Water Act, Minnesota is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e., impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion. In addition, either the chl-*a* concentration for the lake must exceed the standard or the Secchi data for the lake must be below the standard. A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a water body is listed, an investigative Total Maximum Daily Load (TMDL) study must be conducted to determine the sources and extent of pollution, and to establish pollutant reduction goals needed to restore the resource to meet the determined water quality standards for its ecoregion. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL studies in Minnesota.

White Iron Lake was assessed relative to the NLF Class 2B ecoregion standards (Table 10). The 2008, 2009, and long-term summer TP mean for White Iron Lake are well below this value. Likewise, chl-*a* is below the standard for the NLF ecoregion. Based on these results, White Iron Lake is meeting eutrophication criteria for NLF 2B waters (i.e. those waters that support a cool and warm water fishery). The Secchi standard in White Iron is not being met, but this is due to natural bog staining, as discussed previously, and is not in response to elevated chl-a concentrations. White Iron Lake is listed as impaired for mercury in fish tissue. That impairment was addressed through a statewide mercury TMDL. This TMDL is available here:
http://www.pca.state.mn.us/water/tmdl/tmdl-mercuryplan.html

Table 10. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). White Iron Lake 2008 and 2009 summer means; long-term means provided for comparison.

Ecoregion	**TP µg/L**	**Chl-*a* µg/L**	**Secchi meters**
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2b)	< 40	< 14	> 1.4
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	< 60	< 20	> 1.0
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7
White Iron Lake 2008	**24**	**4.3**	**1.3**
White Iron Lake 2009	**19**	**4.3**	**1.8**
White Iron Lake Long-term mean	**23**	**4.8**	**1.6**

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Appendix A

Lake Surface Water Quality Data for White Iron Lake for 2008-2009 (MPCA Data)

All water quality data can be accessed at: http://www.pca.state.mn.us/data/eda ; blank cells = no data

Lake Name	Lake ID	Sample Date	Site ID	Secchi	TP	Chl-a	Alkalinity	Chloride	TKN	Color, Apparent	TSS
				Meters	µg/L	µg/L	mg/L	mg/L	mg/L	PCU	mg/L
White Iron	69-0004	5/12/08	202	1.2	20	2.94	<10	1.0	0.63	80	2.8
White Iron	69-0004	6/17/08	202		22	2.29	11	1.4	0.66	82	2.0
White Iron	69-0004	7/15/08	202	0.9	23	2.51	12	1.4	0.58	100	2.0
White Iron	69-0004	8/12/08	202	1.2	22	7.95	15	1.2	0.71	100	1.2
White Iron	69-0004	9/16/08	202	1.2	28	4.47			0.58		
White Iron	69-0004	10/14/08	202	1.5	28	5.08	17	1.36	0.6	100	1.2
White Iron	69-0004	5/19/09	202	1.4	19	2.21	14	1.3	0.72	100	1.6
White Iron	69-0004	6/8/09	202	1.5	15	3.8			0.4		
White Iron	69-0004	7/14/09	202	1.9	22	4.36	15	1.15	0.58	100	5.2
White Iron	69-0004	8/10/09	202	1.8	20	4.56			0.62		
White Iron	69-0004	9/22/09	202	2.0	18	4.37			0.53		
White Iron	69-0004	10/13/09	202	1.7	25	3.52	17	1.58	0.65	80	4