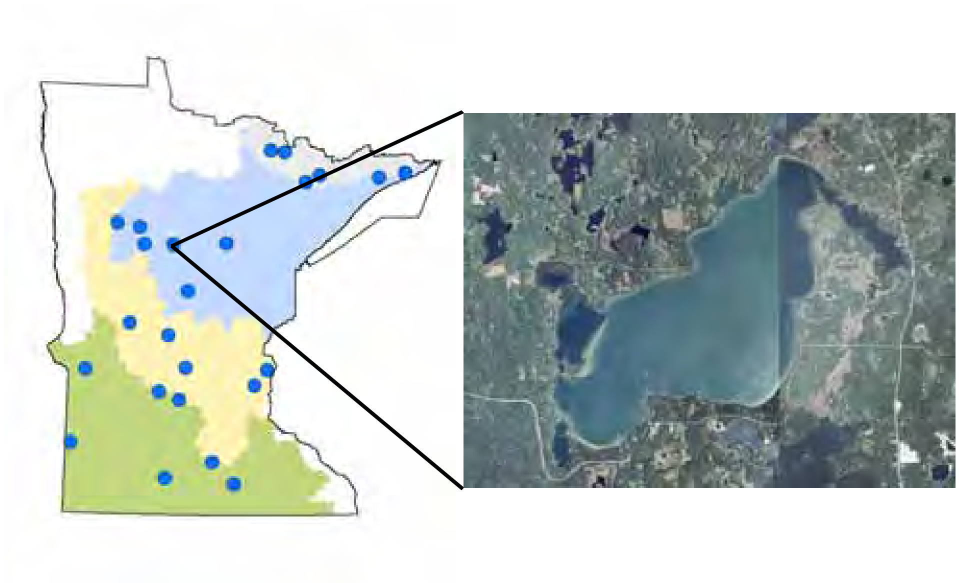
2010 Lake Assessment of Ten Mile Lake (11-0413) Cass County, Minnesota



Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit
and
Minnesota Department of Natural Resources
Section of Fisheries
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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 2008). 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.

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). The "Deep" lakes typically stratify during the summer months only. "Shallow" lakes are defined as mixing continuously throughout the summer. "Cold Water" lakes are defined as lakes that either harbor cisco (*Coregonus artedi*) or lake whitefish (*Coregonus clupeaformis*) and are the focus of research funded by the Environmental Trust Fund (ETF). Ten Mile Lake was selected to represent a deep mesotrophic lake in the Northern Lakes and Forests (NLF) ecoregion. Ten Mile Lake is a 2,042 hectare (5,072 acre) lake with a maximum depth of 63 meters (208 feet) and a mean depth of 16 meters (51 feet). Ten Mile Lake is located just north of Hackensack, Minnesota in Cass County, within the Leech Lake River major watershed. The lake is 26 percent littoral with one public access on the southwestern shore. The total contributing watershed for Ten Mile Lake is 10,031 hectares (24,828 acres).

Ten Mile Lake is a clear, deep lake that is well-mixed in the spring, but is stratified during the rest of the summer forming a distinct thermocline. Based on recent water quality assessment data (June-September of 2008 & 2009), Ten Mile Lake is considered to be mesotrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 11 micrograms per liter (µg/L), 2 µg/L, and 4.9 meters (16 feet) respectively. TP and chl-*a* are below the typical ranges (based on reference lakes) for the NLF ecoregion. No nuisance algal blooms were observed and transparency was typically high during the summer. As a result, Secchi transparency for Ten Mile Lake was deeper than the typical range for the NLF ecoregion.

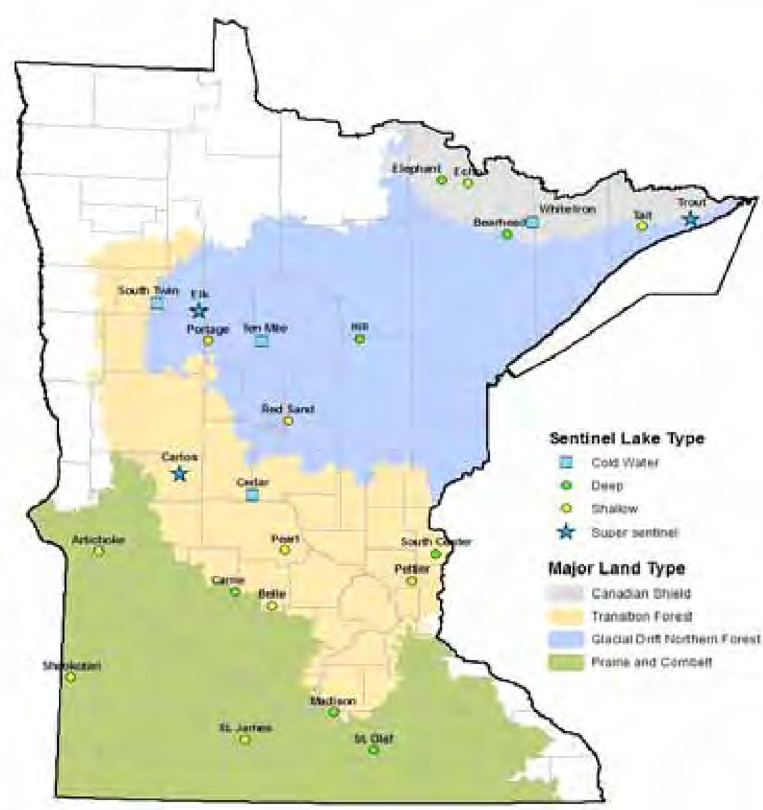
Ten Mile Lake has a rich history of water quality monitoring and reporting. In 1976, the Environmental Research Laboratories of FMC Corporation from Princeton, New Jersey, with the cooperation of Warren Gross (Former President of the Ten Mile Lake Association) completed a limnological survey of Ten Mile Lake. In 1991, the MPCA, in cooperation with Jim Schwartz of the Ten Mile Lake Association (TMLA) and the MDNR area fisheries office completed a Lake Assessment Program report to determine the lake's water quality and possible sources of nutrient input to the lake. This report was conducted at the request of the TMLA. Another collaborative study between TMLA and MPCA was conducted a few years later (Magner 1995). Additionally, the association has collected profile, transparency, and chemical data for several years. The association also maintains a long term Lake Management Plan with such goals as maintaining the water quality, sustaining and improving the watershed and related watershed development, and maintaining and improving the lakes fishery. Trophic status data collected through each of these studies indicate nutrient levels have consistently remained below the typical range expected for lakes within the NLF ecoregion. As a result, Secchi transparency has also remained deeper than the typical range of NLF lakes. Based on these data, Ten Mile Lake is fully supportive of aquatic recreational use and this will be acknowledged in the 305(b) and 303(d) assessments that MPCA conducts in support of the Clean Water Act and submits to the United States Environmental Protection Agency (EPA).

An ecoregion-based eutrophication model was used to predict in-lake TP based on Ten Mile Lake's size, depth, and watershed area using ecoregional inputs. The model predicted in-lake TP of 11 µg/L, which is close to the observed 2009 levels. A separate subroutine within the model estimated "background" TP for the lake at 14 µg/L. The model predictions, along with the overall assessment of Ten Mile Lake's water quality data, indicate the lake's water quality is quite good and falls within the expectations for a lake of this size in this portion of the State.

The aquatic plant community in Ten Mile Lake is very diverse with a total of 37 plant species found in a 2006 survey. Owing to exceptionally clear water, plants were found to a maximum depth of 29 feet and 63 percent of the sampled sites contained vegetation. Local species assemblages were also spatially diverse within the lake since most species were rarely sampled at > five percent frequency (Table 7). Nevertheless, muskgrass (*Chara* sp.), was by far the most common species and was widespread throughout the lake (Table 7). Muskgrass is critical habitat for several juvenile and non-game fish species and also is important for maintaining clear water.

The fish community in Ten Mile Lake is also exceptionally diverse with at least 13 species that are intolerant to pollution and three state-listed species of special concern (pugnose shiner (*Notropis anogenus*), longear sunfish (*Lepomis megalotis*), and least darter (*Etheostoma microperca*)). Ten Mile harbors two coldwater fish species: lake whitefish and dwarf cisco, the latter of which likely supports high quality populations of walleye and northern pike. Because of Ten Mile's deep depth and exceptional water quality, the lake should be resilient to modest climate warming. Maintaining this resilience will require continued low-impact watershed and shoreline land use practices that infiltrate runoff prior to entering the lake.

Figure 1. MDNR map of Sentinel lakes and major land types



Introduction

This report provides a relatively comprehensive analysis of physical, water quality and ecological characteristics of Ten Mile Lake in Cass County, Minnesota. This assessment was compiled based on MDNR surveys of the lake's fish and aquatic plant communities, 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 will include 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: (www.pca.state.mn.us/water/lakeprotection.html).

History

Provided by Bruce Carlson, Ten Mile Lake Association

The earliest history of Ten Mile Lake remains shrouded in mystery. One of the deepest lakes in the state, its origin has often been attributed to a glacial ice block. Its numerous underwater islands may be the result of the concentration of stones from waterfalls emanating from the melting glacial ice and/or uneven deposits of glacial till. Although Native Americans have lived in the area since about 1,000 AD, there is little evidence of significant settlement on what they called Devil Lake.

Ten Mile Lake was given its name in 1881 because it was ten miles down the governmental wagon road from the Leech Lake Agency toward Hackensack. In 1894, the Northern Minnesota Railroad built tracks along the wagon road, and the now-extinct town of Lothrop had arisen along the east side of the lake. Lothrop was a logging boom town that boasted three hotels, three stores, eight saloons, a house of ill-repute and the various shops, and equipment needed by the railroad. The main business of the railroad was transporting logs to logging companies in Brainerd. During the logging boom, pine logs were transported to the railroad by both land and water. Long Bay was used as a holding area for cut logs. Ten Mile Lake was a main water route, and according to scuba divers, submerged logs still litter the bottom of the lake in certain areas. Lothrop's place in the sun was short-lived. By 1900 loggers had cleared the area of commercially valuable timber, and they moved on. From that point, the village of Lothrop declined rapidly and became a ghost town by 1901.

Not long after the end of the logging boom, residents of Walker began to take the train to Lothrop in order to fish in Ten Mile Lake. A few private cabins were built on high ground. Some of the oldest were built in the Boone Point area. Construction materials were brought up by train and transported across the ice to sites on the lake opposite the train station. By the 1920's, at least seven resorts had sprung up around the lake. More followed in the 1930's. Angel Island, in particular, was a popular site, with both a resort and a restaurant.

By the 1930's, increasing numbers of cabins were built in certain areas around the lake. Many of the early cabin owners came from Iowa, and even today, there is a large presence of Hawkeyes on the lake, particularly at the north end - an area commonly called Iowa beach. After World War II, when both transportation and the economy improved, the pace of cabin-building increased. By 1948 there were 165 cabins, 16 resorts and 81 boats on the lake. The trend toward building cabins continued at a rapid pace until the early 1980's, when the rate of construction slowed, partially because of a limited number of construction sites. The increased number of private cabins was accompanied by a trend toward fewer resorts. In 2003 there were 506 cabins and only one resort and one trailer camp on the lake. The number of boats was estimated at 608 in 1983, the last time that lake survey crews made watercraft counts on the lake.

The early settlers and cabin owners on Ten Mile treated the lake as an inexhaustible resource and used the waters to dispose of garbage and animal wastes from farms. Outhouses were common around the lake. With these changes, the color of the water gradually changed from blue to what was described in the 1960's as a beautiful turquoise green. This was accompanied by decreases in water clarity and summer algae blooms. During the 1970's, the Ten Mile Lake Association (TMLA), which was founded in 1946, recognized that the color and decreasing water clarity were the result of excessive nutrients entering the lake, and it began a program to restore the quality of the water. A major part of the effort was focused on reducing the nutrients entering the lake from outhouses and faulty septic systems, which were by then the mode. Over the next decade, these efforts bore fruit, and the Secchi disk readings improved substantially. The water lost its greenish hue, and significant algae blooms diminished considerably. These changes for the better in water quality were not well received by all. Local walleye fishermen complained that because of the increased clarity of the water, it was increasingly difficult to catch walleyes during daytime hours. Ten Mile Lake is now considered a night-fishing lake for walleyes. The TMLA has continued its vigilance in reducing pollutants and currently has in place a program of monitoring septic systems on a rotating basis every three years.

Chronology provided by MDNR Fisheries

Late 19th and Early 20th Century: Logging was started in the 1880's. The town of Lothrop was located on Long Bay in 1886, but disappeared by 1910. Lake trout were stocked on three occasions, with little or no return to anglers.

40's – 60's: Lake association was started in 1946 and chartered in 1952. First documented stocking of northern pike (*Esox lucius*) and walleye (*Sander vitreus*) occurred.

70's : Rainbow trout stocking was done by TMLA. TMLA started to participate in Citizen Lake Monitoring Program with Secchi disk measurements, and DNR Division of Waters started to document water levels. Inquiries were made about restarting a lake trout (*Genus species*) stocking program, but it was decided not to stock. Yearly walleye stocking occurred with the help from several Lake Association Coop ponds

80's: Comprehensive lake management plan was written by the TMLA; Creel survey conducted in 1988; DNR Fisheries wrote its first fisheries management plan for Ten Mile Lake. The use of the TMLA Coop pond was discontinued because of poor production for several years. Lake Association conducted some water sampling to look for septic contamination and oxygen profiles. Theodore Halpern studies the lake's cisco (*Coregonus artedi*) population as part of his doctoral dissertation at the University of Minnesota.

90's: Two year creel survey was conducted in 1995 and 1996. Process was started to add a public access on Long Bay, which did not go forward. A mark-recapture estimate of the walleye population was made. Walleye fingerling stocking was changed to odd-years to monitor the success of natural reproduction. Coded-wire tagged walleye were used to measure stocking contribution. Twenty-inch maximum length limit for northern pike was implemented. MPCA conducted a lake assessment study in collaboration with TMLA in 1991(Hodgson and Heiskary 1991) and a later study in 1995 (Magner 1995).

00's: Another creel survey was conducted in 2005 and 2006. Northern pike regulation was converted to a 24- to 36-inch protected slot. "Beneath the surface" written by Bruce Carlson (Carlson 2007) and "Ten Mile History – 200 years" written by Tom Cox. Ten Mile Lake was included in Ecological Resources sensitive shoreline project.

Background

Lake Morphometric and Watershed Characteristics

Ten Mile Lake is located in Cass County within the Leech Lake River major watershed. Ten Mile Lake is approximately one mile northwest of Hackensack, Minnesota. A public access is located on the southwestern shore. Ten Mile Lake is a clear deep lake that mixes in the spring and fall and forms a distinct thermocline during the summer months. Groundwater likely accounts for 43-52 percent of the annual in-flow budget (Magner 1995)

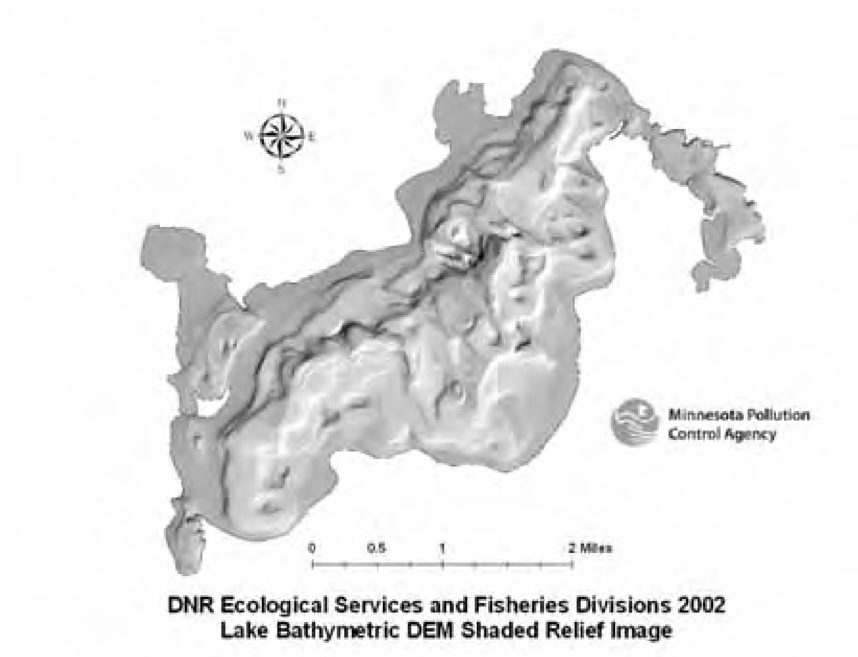
Ten Mile Lake's morphometric characteristics are summarized in Table 1. A three dimensional representation of the lake's depth contour is presented in Figure 2. Percent littoral area refers to that portion of the lake that is 4.5 meters (15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake. Lakes with a high percentage of littoral area 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. Because of its large surface area and great depth the percent littoral on Ten Mile is rather small; making it all the more important to protect the submergent and emergent vegetation in this zone.

Table 1. Ten Mile 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
Ten Mile	11-0413	2,039 (5,047)	26 %	10,031 (24,828)	5:1	63 208	16 (53)	250,101

Lake bathymetry based on MDNR 2006 acoustic survey.

Figure 2. Ten Mile Lake three dimensional depth contour



Ten Mile Lake's contributing watershed lies within the Leech Lake River major watershed. The lake's watershed pours out of one drainage point located on the southern tip of Long Bay. The contributing watershed has a total area of 10,031 hectares (24,828 acres) resulting in a watershed-to-lake area ratio of approximately 5:1, which is rather small as compared to many Minnesota lakes. Watershed areas were estimated based on data from MDNR Waters Delineations.

Ten Mile Lake soils are defined as medium-textured forest soils formed from loam and sandy loam calcareous buff-colored glacial till from the Nebish-Rockwood series. The area is undulating to hilly and the soils are light-colored and well drained. Common tree species are aspen and white birch (Arneman 1963). Ten Mile Lake was likely formed by glacial deposition within the till (Zumberge, 1952).

Lake Mixing and Stratification

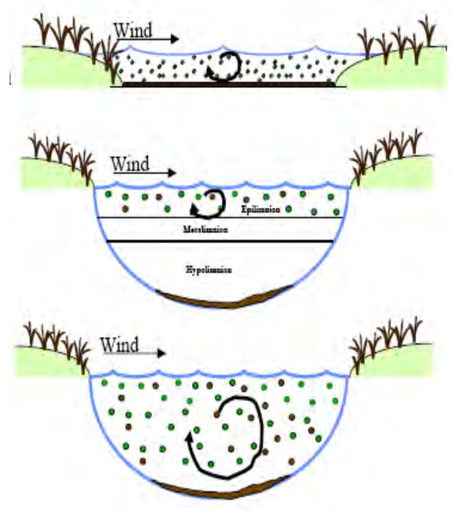
Lake depth and mixing has a significant influence on lake processes and water quality. *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of nine meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 3). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of six meters or less) in contrast, typically do not stratify and are often referred to as *polymictic*. Lakes, with moderate depths, may stratify intermittently during calm periods, but mix during heavy winds and during spring and fall. Measurement of temperature throughout the water column (surface to bottom) at selected intervals (e.g. every meter) can be used to determine whether the lake is well-mixed or stratified. The depth of the thermocline (zone of maximum change in temperature over the depth interval) can also be determined. In general, dimictic lakes have an upper, well-mixed layer (epilimnion) that is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. This low oxygen environments in the hypolimnion are conducive to total phosphorus (TP) being released from the lake sediments. During stratification, dense colder hypolimnion waters are separated from the nutrient hungry algae in the epilimnion. Intermittently (weakly) stratified polymictic lakes are mixed in high winds and during spring and fall. Mixing events allow for the nutrient rich sediments to be re-suspended and are available to algae.

Figure 3. Lake stratification

Polymictic Lake
Shallow, no layers,
mixes continuously
spring, summer & fall

Dimictic Lake
Deep, form layers,
mixes spring/fall

Intermittently Stratified
Moderately deep
mixes during high winds
spring, summer, & fall



Ecoregion and Land Use Characteristics

Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. 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. Ten Mile Lake is located within the Northern Lakes and Forests (NLF) ecoregion (Figure 4). NLF ecoregion values will be used for land use (Table 2) and summer-mean water quality comparisons (Table 9). Additionally, the NLF ecoregion-based values will be used for the model application.

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 watershed is typical for watersheds within the NLF ecoregion (Figure 5). Forest is the dominant land use while open water occupies a quarter of the total area resulting in a low watershed-to-lake ratio of 5:1.

Figure 4. Minnesota ecoregions as mapped by United States Environmental Protection Agency

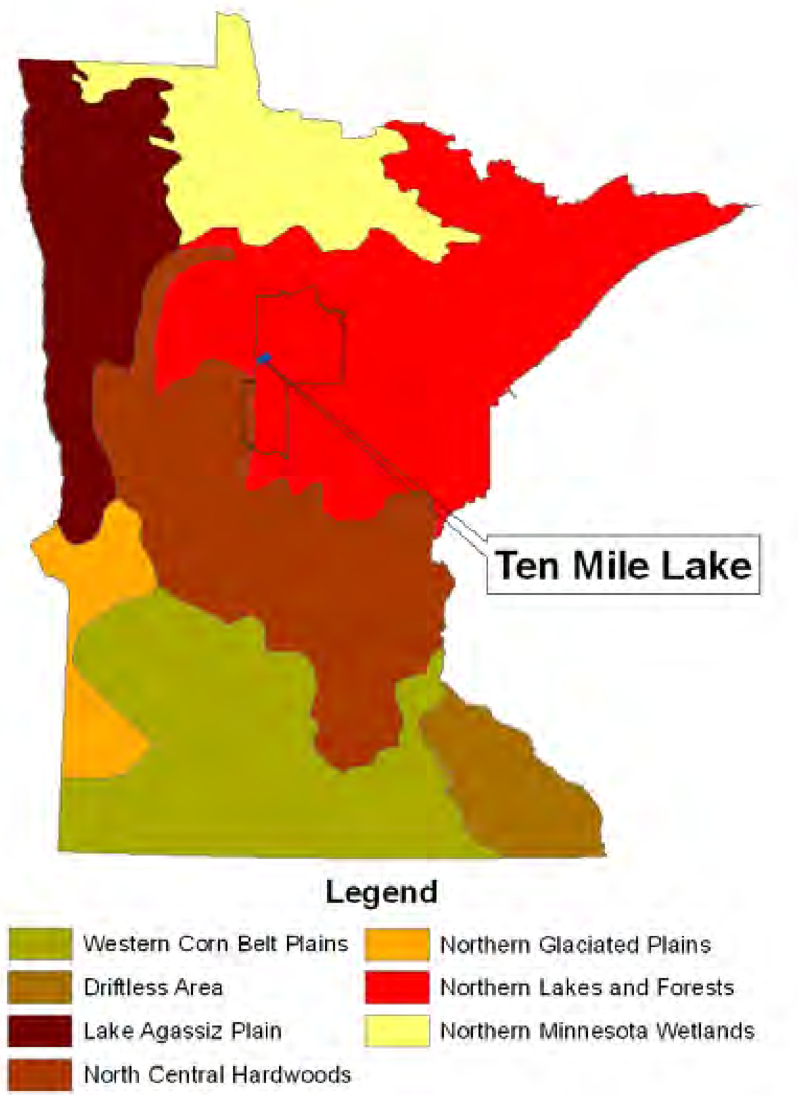
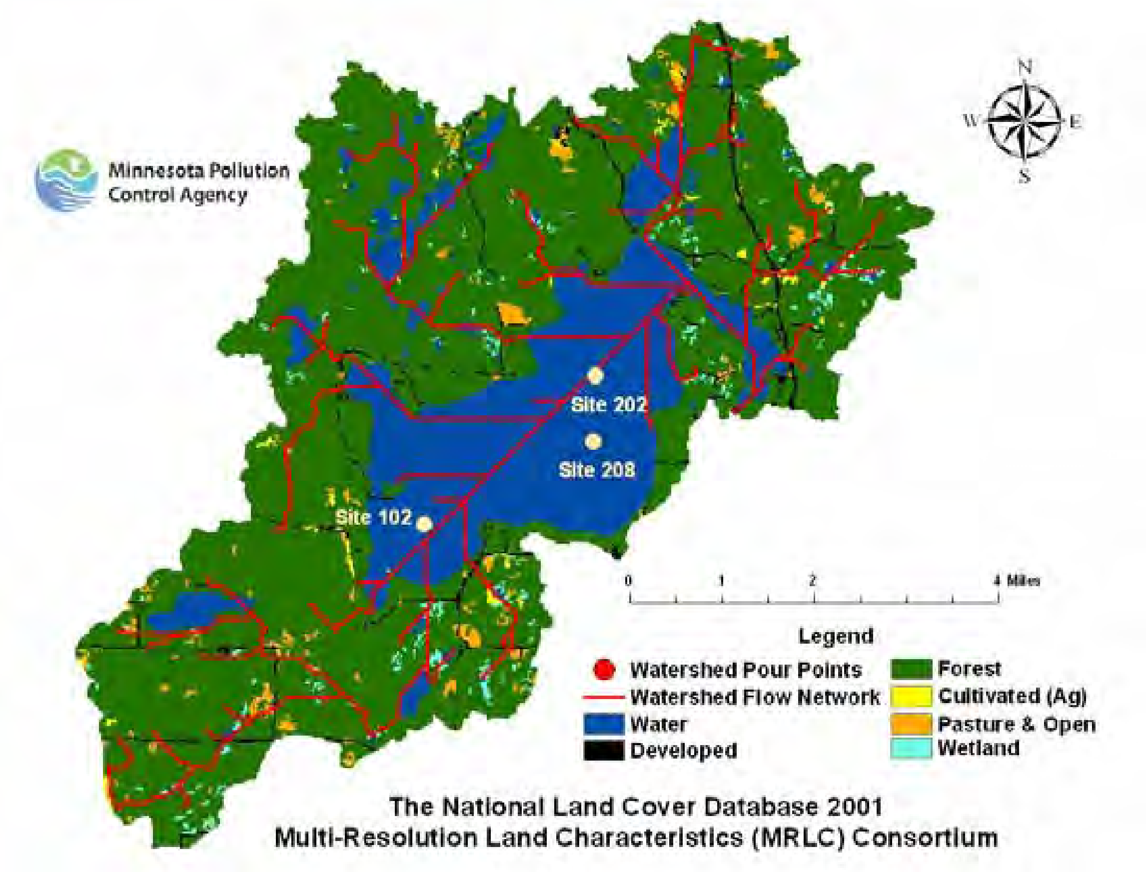


Table 2. Ten Mile Lake ecoregion land use comparison. Typical (interquartile) range based on Northern Lakes and Forest ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	Ten Mile Lake (2001)[1]	Ten Mile Lake (1991)[2]	Ten Mile Lake (1969)[3]	NLF Ecoregion
Developed	3	Data NA	6	0 - 7
Cultivated (Ag)	<1	2	<1	<1
Pasture & Open	2	2	5	0 - 6
Forest	70	66	65	54 - 81
Water & Wetland	25	29	23	14 - 31

[1]National Land Cover Database www.mrlc.gov/index.php
[2]Minnesota Land Cover 1991-1992:MAP www.lmic.state.mn.us/chouse/land_use_DNRmap.html
[3]Minnesota Land Management Information Center
www.lmic.state.mn.us/chouse/metadata/luse69.html

Figure 5. Ten Mile Lake watershed and land use composition

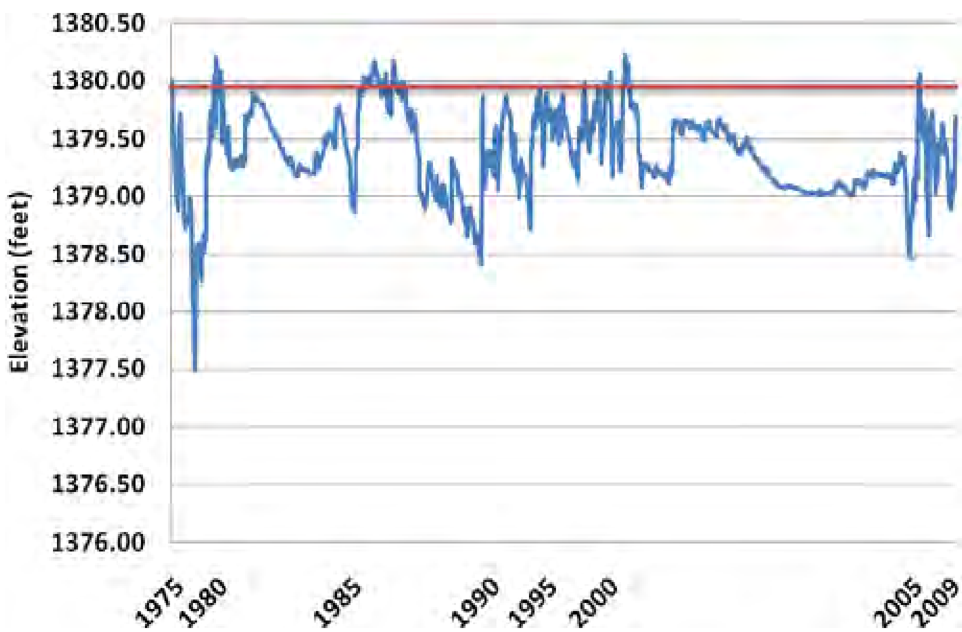


Lake Level and Ice On/Off

The MDNR Division of Waters has been measuring water levels on Ten Mile Lake since 1973. During the period of record (1973 – 2009), the lake has varied by 2.74 feet, based on 1,426 readings. The ordinary high water (OHW) mark (noted by the red line in the figure) for Ten Mile Lake is 1379.9 feet (Figure 6). Based on the recent record, the lake has remained below the OHW since July of 2005. Additionally, with the exception of spikes in water level in July of 2005, Ten Mile Lake has remained below the OHW for a nearly all of the past decade. The highest level on record is 1380.23 on June 14th, 2001 while the lowest level on record is 1377.49 on November 23rd, 1976. The droughts of 1976 and 1988 are also evident in the water level record.

Water level for Ten Mile Lake is not managed at this time; however, a dam is in place at the outlet of Birch Lake. Birch Lake is connected to Ten Mile Lake via the Boy River. Per Kirk English, MDNR Area Hydrologist, prior to 2005 several disputes existed between the residents of Ten Mile Lake and Birch Lake regarding the desired water level of Birch Lake and its impact on the resulting high water levels of Ten Mile Lake. A stop log dam was formerly in place at the Birch Lake outlet and was not regularly maintained. In 2005, after a hydrologic study, an improved dam was constructed that required no human intervention to control water levels. Since its construction there has been little public comment. The complete water level record may be obtained from the MDNR Web site at: www.dnr.state.mn.us/lakefind/showlevel.html?id=29025000.

Figure 6. Ten Mile Lake water level record



Ice-on records for Ten Mile Lake, dating back to 1988, indicate that ice typically forms within the first or second week of December. November 22, 1999 is the earliest recorded ice-on date and December 25, 1998 is the latest ice-on date. The ice is typically off of Ten Mile Lake by the last week in April. May 18, 1996 is the latest ice-off date while April 12, 1998 is the earliest ice-off date on record (Appendix A).

Precipitation and Climate Summary

Rain gauge records from Walker, Minnesota show two one-inch plus rain events during summer 2009 (Figure 7). Large rain events will increase runoff into the lake and may influence in-lake water quality and lake levels. This will be considered in the discussion of lake water quality for 2008 and 2009 as well as historical trends. Precipitation records for the 2009 water year (October 2008 through September 2009) showed that the Ten Mile Lake area received normal rainfall amounts.

Figure 7. Summer 2009 rainfall based on records for Walker, Minnesota

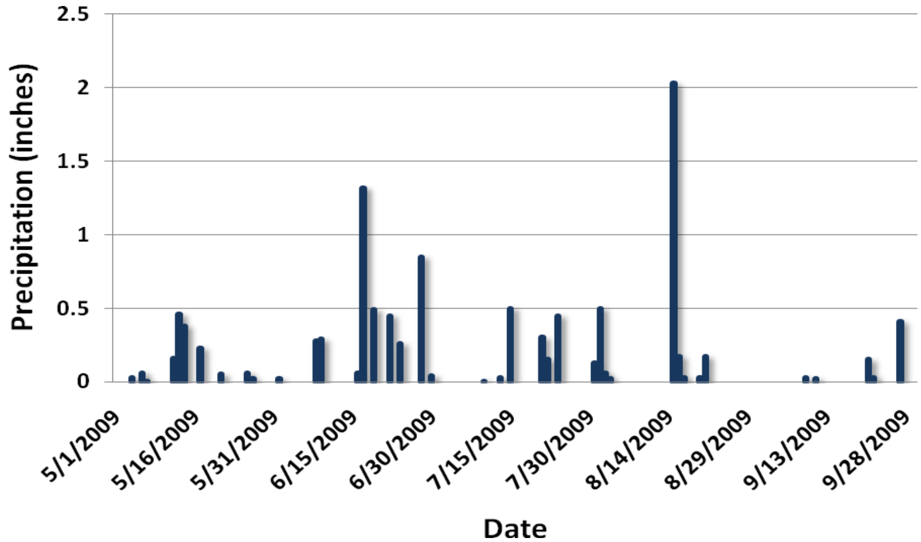
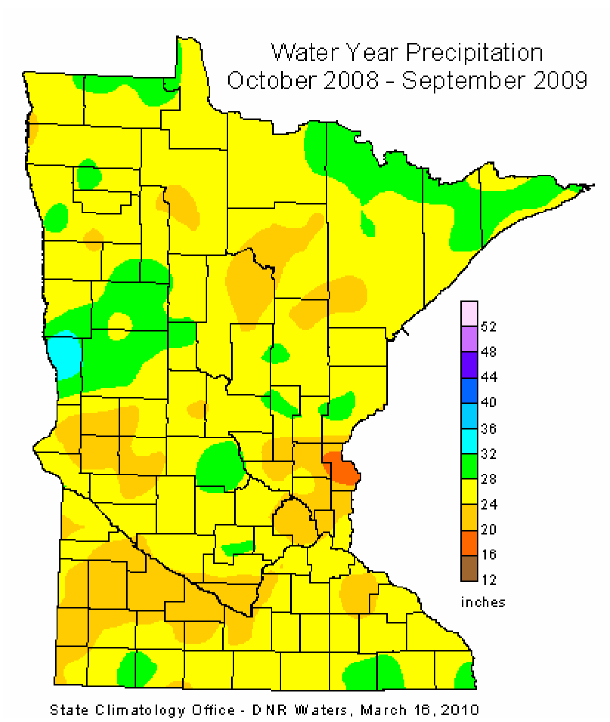


Figure 8. 2009 Minnesota Water Year Precipitation and Departure from Normal



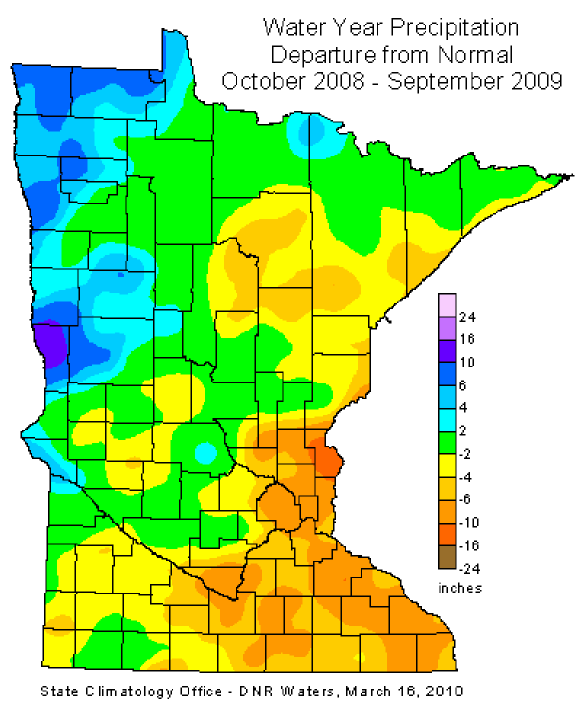
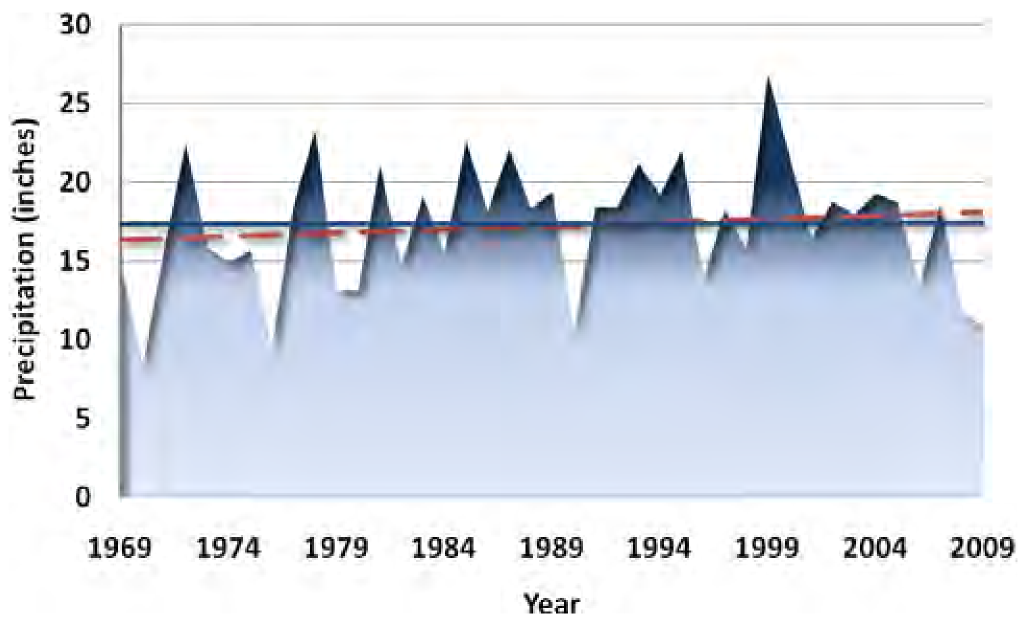


Figure 9. Historical summer precipitation trends based on records for Walker, Minnesota



Methods

Fisheries and Aquatic Plants

Frequency of occurrence of aquatic plant species was assessed by the MDNR Division of Ecological Resources (Perleberg 2007) using the point-intercept method (Madsen 1999). Most recent fisheries surveys follow guidelines outlined by MDNR Special Publication 147 (1993; Manual of Instructions for Lake Survey). Fish community integrity surveys were also completed on each Sentinel lake following methods described by Drake and Pereira (2002).

Water Quality

Water quality data for Ten Mile Lake were collected from May through October of 2008 and 2009 by MPCA staff. Bi-weekly dissolved oxygen (DO) and temperature profiles and Secchi disk measurements were collected at site 208 by a volunteer, Bruce Carlson (Figure 5). MPCA staff collected lake surface samples with an integrated sampler, a poly vinyl chloride (PVC) tube, two meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (1.24 inches). Zooplankton samples were collected with an 80 µm mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth TP samples were collected with a Kemmerer sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples and profile data were collected at sites 102 and 202 (Figure 5). Sampling procedures were utilized as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found at: www.pca.state.mn.us/publications/wq-s1-16.pdf.

Analysis was performed by the environmental laboratory of the Minnesota Department of Health 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 (April/May) through October 2009. Two replicate vertical tows were taken at sites 102 and 202 during each sampling event. The net was lowered to within 0.5 meter 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 percent reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 microgram 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 five-milliliter aliquot. A five-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).

Results and Discussion

Fisheries Assessment

MDNR fisheries managers utilize netting survey information to assess the status of fish communities and measure the efficacy of management programs. Presence, absence, abundance, physical condition of captured fishes, and community relationships among fish species also provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). These data are stored in a long-term fisheries survey database, which has proven valuable in quantifying changes in environmental and fisheries characteristics over time. Thirty-nine fish species have been documented during the various surveys conducted on Ten Mile Lake (Table 3), including four cold-water species sensitive to climate warming (burbot (*Lota lota*), mottled sculpin (*Cottus bairdi*), tullibee or cisco, and lake whitefish (*Coregonus clupeaformis*)).

An index of biotic integrity (IBI) survey was conducted in Ten Mile Lake in 2008 and 2009, and the IBI score was exceptionally high in both years at 136 and 132 respectively. As part of the SLICE program, IBI surveys will be repeated in 2010 and 2011 to evaluate the natural year-to-year fluctuations in scores and to help managers understand biologically significant changes in scores; however, a variation of four points between surveys is likely not biologically significant.

A high IBI score usually indicates a diverse fish community with a high proportion species intolerant to disturbance and a low proportion of tolerant ones. MDNR crews sampled thirteen intolerant species and three state-listed species of special concern (pugnose shiner (*Notropis anogenus*), longear sunfish (*Lepomis megalotis*), and least darter (*Etheostoma microperca*)). In addition, crews sampled blacknose shiners (*Notropis heterolepis*), banded killifish (*Fundulus diaphanous*), blackchin shiner (*Notropis heterodon*) and Iowa darter (*Etheostoma exile*) which have disappeared from many Twin City metropolitan lakes whose watersheds have been extensively developed or hydrologically altered (Dodd 2009). Muskgrass (*Chara* sp.) appears to provide important habitat for several intolerant littoral fish species (Valley et al. 2010) and is abundant in Ten Mile Lake. In addition to keeping nutrient additions to the lake low, protection of muskgrass beds will be important for protecting these species and the fish community integrity in general.

Historical northern pike gill net catch rates ranged from 4.5 (1958) to 14.0 (2008) per lift and the current catch rate is 14.0 per lift (Figure 10). Historically, the catch rates have been in the upper 50th percentile range for this Lake Class. The current catch rate exceeded the long-range management goal for Ten Mile Lake (six to nine per lift) and was above the third quartile for Lake Class 22 lakes. The mean length and weight were 54.9 centimeters (cm) and one kilogram (kg) (21.6 inches and 2.17 pounds), and lengths ranged from 36.6 to 79.8 cm (14.4 to 31.4 inches). The Proportional Stock Density (PSD) and Relative Stock Density – Preferred (RSD-P; Gabelhouse 1984) values were 53 and 10, which were at or below the long-range management goals of 65 and 10 for Ten Mile Lake, but were consistent with the past several surveys (Table 4). A 50.8 cm (20-inch) maximum size limit was implemented in 1997 and converted to a 61 – 91.4 cm (24 - 36-inch) protected slot in 2008. Abundant populations of small northern pike follow a long-term statewide decline in the quality of northern pike populations. Overharvest of large individuals greater than 61 cm (24 inches) appears to explain much of this trend (MDNR Division of Fish and Wildlife 2008).

Historical walleye gill net catch rates ranged from 1.7 (1971) to 11.6 (1997) per lift and the long term average was above the 50th percentile for its lake class (Figure 10). The current walleye gill net catch rate was 5.1/lift, which was the lowest since 1983. This catch rate met the long-range management goal for Ten Mile Lake (five to eight) and was above the first quartile for its lake class. The mean length and weight were 47 cm and 1.1 kg (18.5 inches and 2.31 pounds), and lengths ranged from 27.7 to 68.1 cm (10.9 to 26.8 inches). A PSD of 76 and RSD-P of 28 were consistent with the past two surveys. Historically, the size distribution in terms of PSD and RSD-P has consisted of larger fish (Table 4). From 1971 to 1993, stocking contribution was difficult to assess because stocking occurred every year. In 1993, stocking was shifted to an every other year to assess natural reproduction. In 1998 and 2001, fingerlings were tagged to determine the stocking contribution, and it was found that 50 percent of the walleyes captured were from stocking (Vandergoot 2002; Shavlik 2003). Also, based on four recent creel surveys on Ten Mile Lake, the majority of the anglers on the lake are targeting walleye (Gran 1996, 1997; Shavlik 2006, 2007).

Historical bluegill (*Lepomis macrochirus*) trap net catch rates ranged from 4.6 (1983) to 127.0 (1988) per lift and the current catch rate is 22.5 per lift (Figure 10). Except for the historical high, all the other catch rates have been within the interquartile range for its lake class. This catch rate met the long-range management goal for Ten Mile Lake (15 to 30 per lift). The mean length and weight were 14.5 cm and 0.07 kg (5.7 inches and 0.15 pounds), and lengths ranged from 7.4 to 22.1 cm (2.9 to 8.7 inches). A PSD value of 48 and RSD-P of two were lower than the long-range management goals of 60 and five for Ten Mile Lake. The size distribution has appears to have shifted to a larger percentage of smaller fish over time (Table 4). Like northern pike, and small bluegill in Ten Mile follows a long-term statewide decline in quality sized bluegill. Overharvest of large individuals appears to explain much of this trend (Jacobson 2005).

Little emphasis has been placed on the black crappie (*Pomoxis nigromaculatus*) population on Ten Mile because our current sampling program does not sample them very well. However, anglers have been targeting them during the spring and they have been successful.

As part of this SLICE project, spring electrofishing will be conducted to sample the largemouth bass (*Micropterus salmoides*) population which might provide information about this population in Ten Mile Lake. Historically, little emphasis has been place on largemouth bass in Ten Mile Lake.

Smallmouth bass (*Micropterus dolomieui*) were first documented in 2003 and during the 2005 and 2006 creel survey, anglers were catching large size fish. As part of this SLICE project, some exploratory sampling is being done to look for some good locations to sample the smallmouth bass population. The smallmouth bass population in Ten Mile Lake is small, but several lakes downstream on the Boy River system have high numbers of this species. Smallmouth and largemouth bass populations are expanding northward due to climate change (Shuter et al. 2002; Casselman 2002). Consequently, these species may play a larger role in Ten Mile's food-web in decades to come.

Historical white sucker (*Catostomus commersonii*) gill net rates ranged from 0.8 (2006) to 4.8 (1988) per lift and the historical mean was near the first quartile for its lake class (Figure 10). The current gill net catch rate was 1.4 per lift. The lengths ranged from 17.5 to 52.8 cm (6.9 to 20.8 inches) and the mean length was 42.9 cm (16.9 inches).

Historical rock bass (*Ambloplites rupestris*) gill net catch rate have ranged from 6.14 (1958) to 22.40 (2008) per lift and the historical mean was above the third quartile for its lake class (Figure 10). The current gill net catch rate is 22.4 per lift, which is the historical high. The lengths ranged from 7.9 to 26.6 cm (3.1 to 10.47 inches) and the mean length was 19.3 cm (7.6 inches).

Lake whitefish, and tullibee (cisco) roam deep depths in the middle of lakes and thus are difficult to sample with standard fisheries sampling gear; however, special sampling conducted by University of Minnesota found Ten Mile Lake has a good population of cisco and lake whitefish (Halpern 1990). The cisco in Ten Mile rarely achieves large sizes so they provide good forage for top predators (i.e, walleye, and northern pike). Sampling by USGS Fisheries Biologist Larry Kallemeyn found that the age distribution of lake whitefish consisted of old fish (unpublished data). Further, detailed observations using Sonar graphs published by Carlson (2007) document some reverse vertical migrations by cisco or whitefish (i.e., moving deep at night rather than moving deep during the day). These observations suggest behavior and habitat use of cisco varies depending on characteristics of the lake and predator and prey communities. Given their importance to lake foodwebs, sensitivity to climate change, and difficulty to sample with traditional fisheries gears, graduate research by the University of Minnesota Duluth lead by Ph.D student Tyler Ahrenstorff (Dr. Tom Hrabik advising) will explore alternative hydroacoustic and netting methods to understand population dynamics and habitat use of cisco.

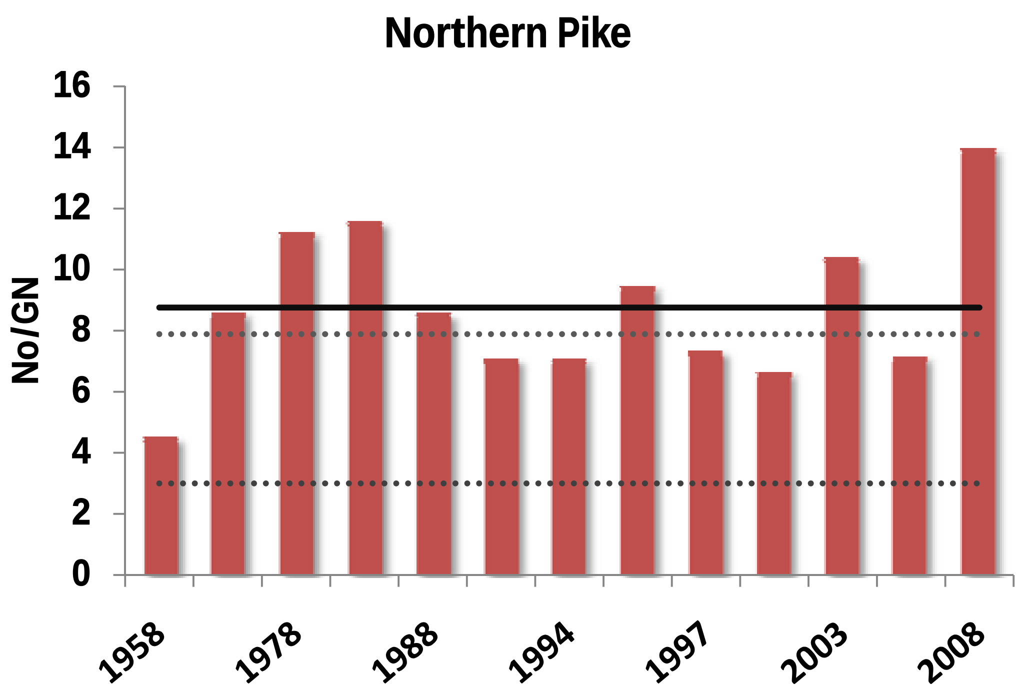
Table 3. Fish species historically sampled in Ten Mile Lake

Common name	Species name	Trophic guild	Thermal guild[a]	Environmental tolerance[b]	First documented
Burbot	*Lota lota*	Predator	Cold	Neutral	1944
Northern pike	*Esox lucius*	Predator	Cool	Neutral	1948
Black crappie	*Pomoxis nigromaculatus*	Predator	Cool-warm	Neutral	1948
Rock bass	*Ambloplites rupestris*	Predator	Cool-warm	Intolerant	1948
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1948
Bowfin	*Amia calva*	Predator	Warm	Neutral	1948
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1948
Smallmouth bass	*Micropterus dolomieui*	Predator	Warm	Intolerant	2003
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Cool-warm	Neutral	1948
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	Tolerant	1948
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	1948
Bluntnose minnow	*Pimephales notatus*	Omnivore	Warm	Neutral	1948
Fathead minnow	*Pimephales promelas*	Omnivore	Warm	Tolerant	1958
Yellow bullhead	*Ameiurus natalis*	Omnivore	Warm	Neutral	1958
Mottled sculpin	*Cottus bairdi*	Insectivore	Cold	Intolerant	2005
Brook stickleback	*Culaea inconstans*	Insectivore	Cool	Neutral	1948
Iowa darter	*Etheostoma exile*	Insectivore	Cool	Intolerant	1948
Banded killifish	*Fundulus diaphanous*	Insectivore	Cool-warm	Intolerant	1948
Central mudminnow	*Umbra limi*	Insectivore	Cool-warm	Neutral	2008
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-warm	Neutral	1948
Longnose dace	*Rhinichthys cataractae*	Insectivore	Cool-warm	Intolerant	1948
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1948

Blacknose shiner	*Notropis heterolepis*	Insectivore	Undetermined	Intolerant	1948
Log perch	*Percina caprodes*	Insectivore	Undetermined	Neutral	1958
Mimic shiner	*Notropis volucellus*	Insectivore	Undetermined	Intolerant	1948
Pugnose shiner[c]	*Notropis anogenus*	Insectivore	Undetermined	Intolerant	2006
Blackchin shiner	*Notropis heterodon*	Insectivore	Warm	Intolerant	1958
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1948
Common shiner	*Notropis cornutus*	Insectivore	Warm	Neutral	1948
Emerald shiner	*Notropis atherinoides*	Insectivore	Warm	Neutral	1997
Hybrid sunfish	*Lepomis sp.*	Insectivore	Warm	Neutral	1971
Least Darter[c]	*Etheostoma microperca*	Insectivore	Warm	Intolerant	2008
Longear sunfish[c]	*Lepomis megalotis*	Insectivore	Warm	Intolerant	2006
Northern redhorse (Shorthead redhorse)	*Moxostoma macrolepidotum*	Insectivore	Warm	Neutral	1948
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1948
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	Neutral	1948
Brassy minnow	*Hybognathus Hankinson*	Herbivore	Warm	Neutral	1948
Lake whitefish	*Coregonus clupeaformis*	Filter feeder	Cold	Intolerant	1948
Tullibee	*Coregonus artedi*	Filter feeder	Cold	Intolerant	1948

[a]Thermal guilds classified by Lyons et al. (2009)
[b] Environmental tolerance classified by Drake and Pereira (2002)
[c]State-listed species of special concern.

Figure 10. Catch per unit effort of the focal species in gillnets (GN) or trapnets (TN). Long-term lake average is plotted as a solid line and interquartile range is displayed as dotted lines for Schupp lake class 22 (Schupp 1992).



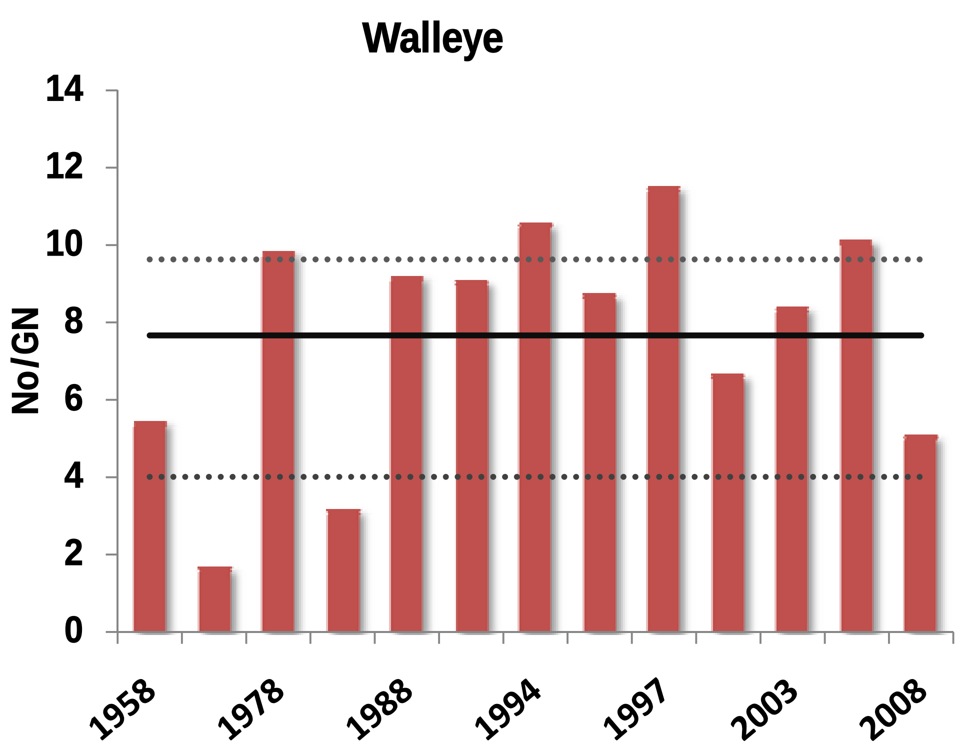
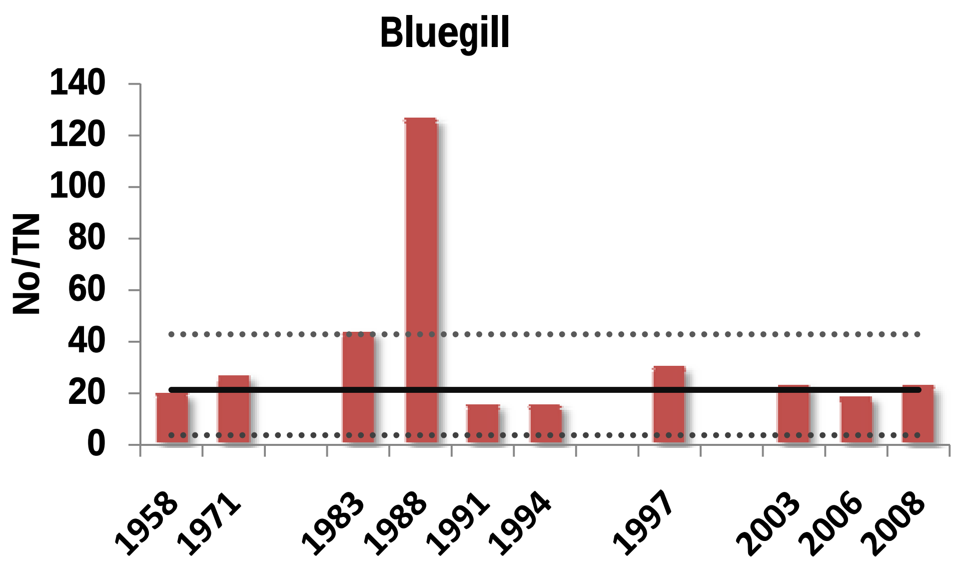
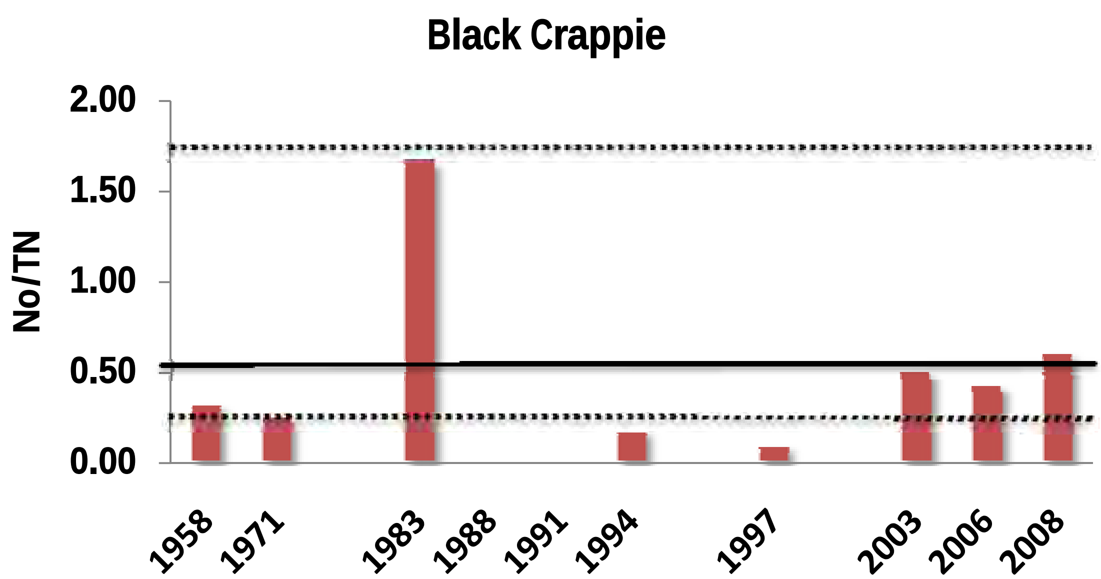


Figure 10. (Continued.)





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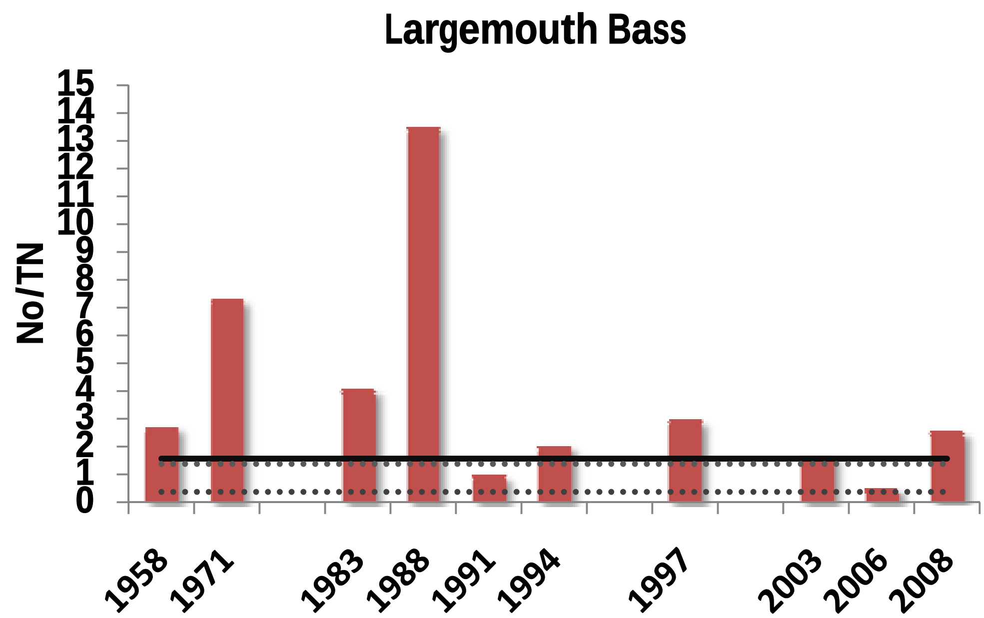

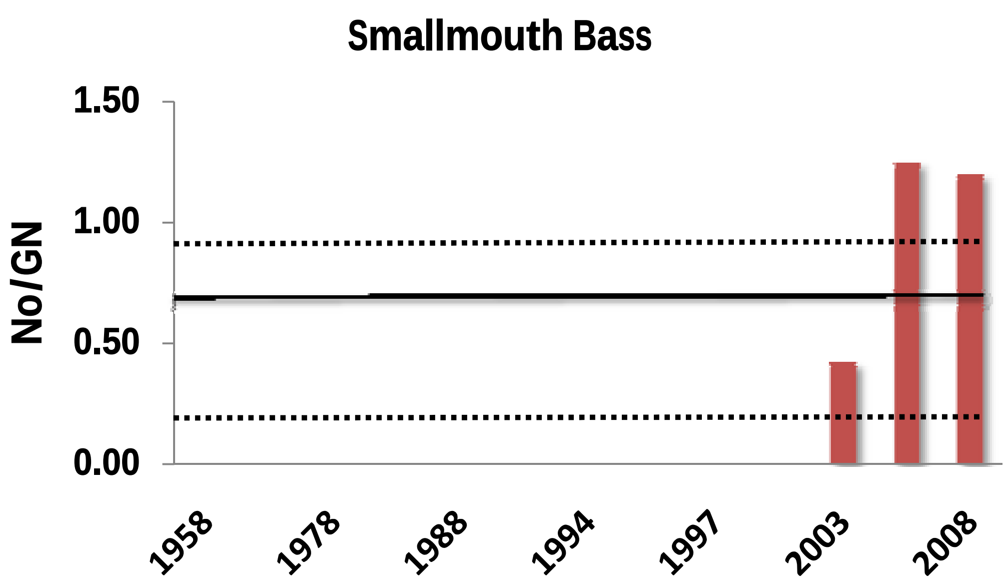

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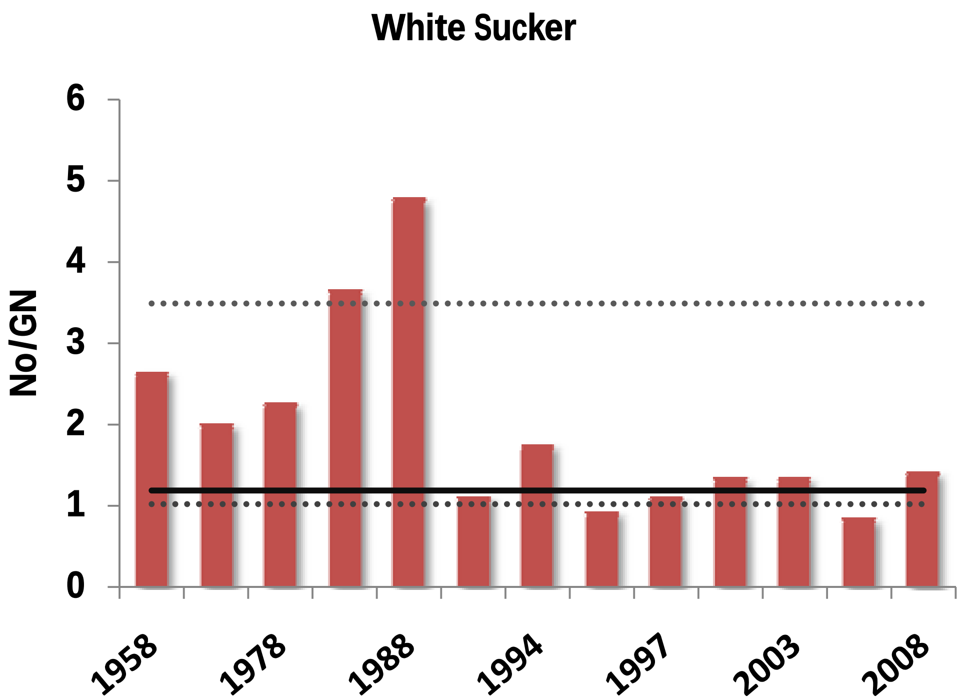


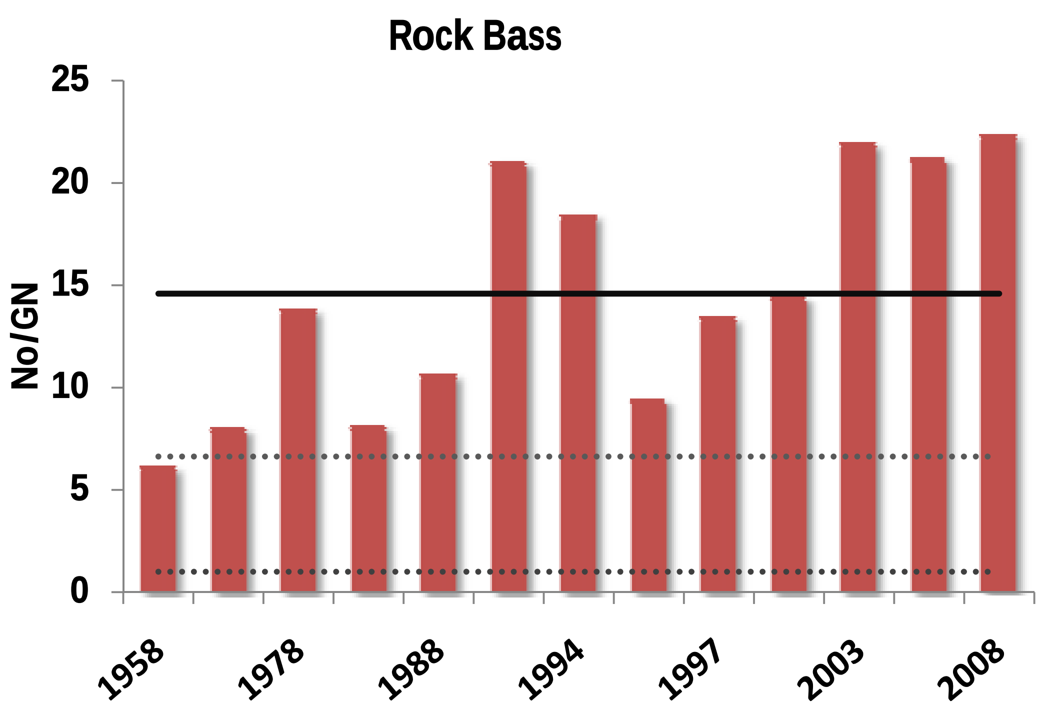


Table 4. Size distribution (Proprotional Stoch Density, Relative Stock Density Preferred, Memorable, and Trophy, Gabelhouse 1984) for several species

	1958	1971	1978	1983	1988	1991	1994	1995	1997	2000	2003	2006	2008
Walleye													
PSD	71	100	60	70	73	60	71	60	64	79	71	76	76
RSD-P	17	64	12	28	32	28	25	16	16	20	44	28	38
RSD-M	3	26		4	3	4	4	1	1		3	7	6
RSD-T													
Northern pike													
PSD	47	28	52	31	38	36	71	44	40	59	51	52	53
RSD-P	2	2	2	4	6	5	25	2	2	5	6	3	10
RSD-M				1			4			3			
RSD-T													
Black crappie													
PSD		100		39							88	91	88
RSD-P		50		19							50	55	13
RSD-M		33		3							13	9	4
RSD-T													
Smallmouth bass													
PSD											100	100	94
RSD-P											40	93	89
RSD-M												13	11
RSD-T													
Largemouth bass													
PSD	18	14	50	13	21	32	45	50	18	12	45	46	18
RSD-P	4	2	33	8	3		3		3	6	10	2	6
RSD-M													
RSD-T													
Bluegill													
PSD	33	75	76	71	22	59	67	54	90	14	43	48	48
RSD-P	1	4	16	3			3	2	1		3		2
RSD-M													
RSD-T													

Ten Mile Lake is a deep lake that strongly stratifies (Figure 11). Oxygen concentrations remain high through the metalimnion and well into the hypolimnion even during the period of greatest oxythermal stress (the period when water temperatures are highest at benchmark oxygen concentrations: July 28 through August 27 for stratified lakes). Pronounced metalimnetic oxygen maxima were usually present. Metalimnetic oxygen maxima occur when photic depth exceeds thermocline depth and photosynthesis allows oxygen concentrations to remain high in the cool waters of the metalimnion. Metalimnetic oxygen maxima are usually associated with lakes with good water quality (high Secchi depths).

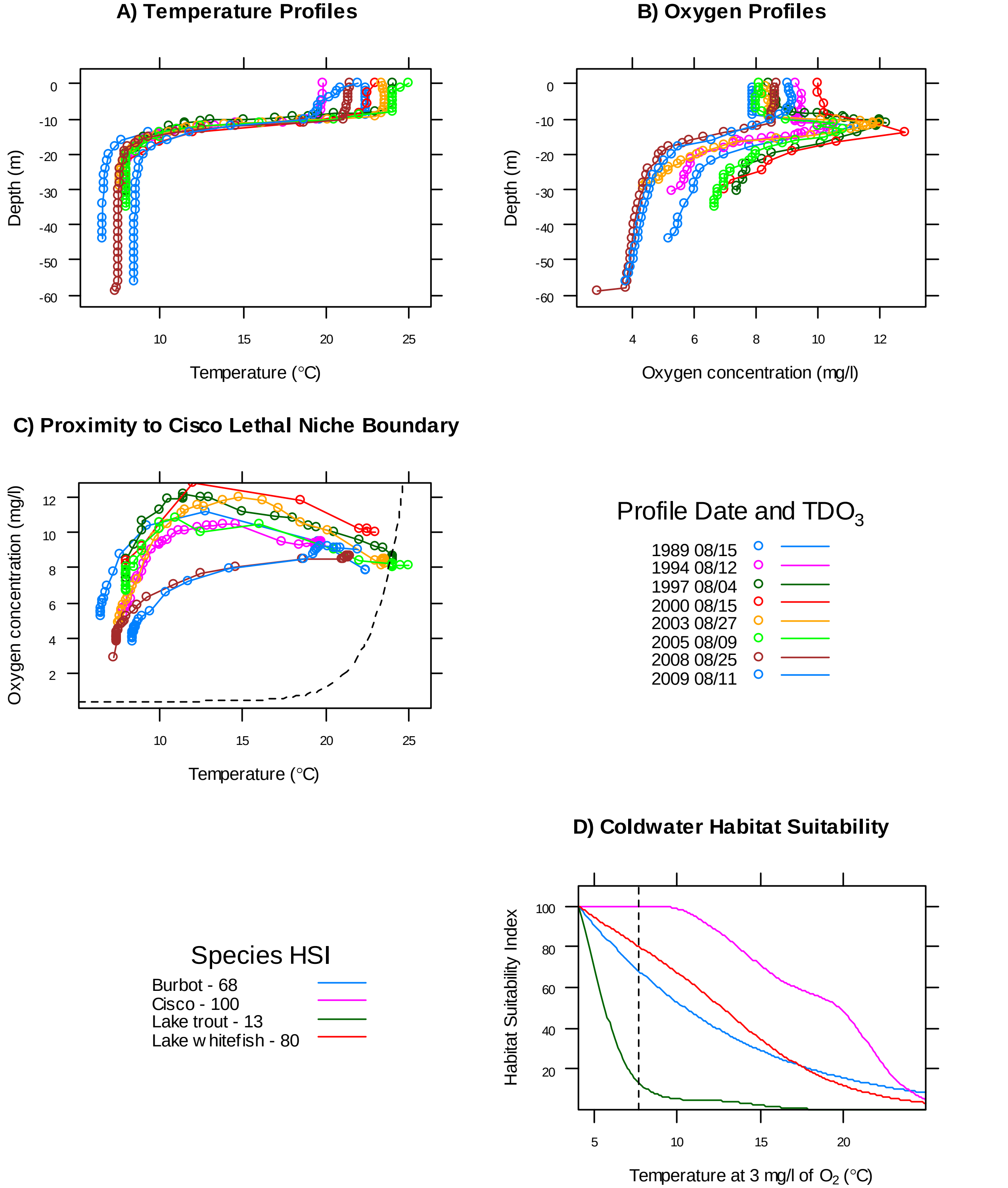
The benchmark measure of coldwater habitat, temperature at three milligrams (mg) oxygen (TDO_3; Jacobson et al. **-** accepted manuscript), suggest that coldwater resources in Ten Mile are excellent (Table 5). The mean TDO_3 was 7.7 °C during the period of greatest oxythermal stress. On a scale of 0 to 100, with 0 being worst and 100 best, Ten Mile Lake has a cisco Habitat Suitability Index of 100 and a lake whitefish Habitat Suitability Index of 80. Profile data replotted as temperature vs. oxygen illustrate how close oxythermal habitat approached lethal conditions (Jacobson et al. 2008). All profiles contained conditions where cisco could survive and were well away from the lethal niche boundary.

Ten Mile Lake has outstanding coldwater habitat because of its depth and excellent water quality. Maintaining that water quality will be critical for sustaining high quality coldwater habitat for cisco and lake whitefish in the lake.

Table 5. Temperatures at three mg O_2 interpolated from the profiles during the period of greatest oxythermal stress (July 28 through August 27).

Date	TDO_3
8/15/1989	6.5
8/12/1994	7.9
8/4/1997	8.0
8/15/2000	8.0
8/27/2003	7.6
8/9/2005	8.0
8/25/2008	7.3
8/11/2009	8.4
Mean	7.7

Figure 11. Cisco oxythermal habitat in Ten Mile Lake. A) and B) profiles taken during the period of greatest oxythermal stress (July 28 through August 27). C) profile data replotted for comparison with lethal oxythermal conditions for cisco (dashed line). Dashed line in D) represents coldwater habitat suitabilities in relation to entire gradient of HSIs in Minnesota.



Aquatic Plant Assessment

Aquatic plants have been assessed seven times over the last sixty years. For the 1948 and 1958 surveys, the reports have a listing of plant species with no abundance rating. Qualitative vegetation surveys were conducted in 1971, 1983, 1997, and 2003. MDNR Ecological Resources conducted quantitative, point-intercept surveys of aquatic vegetation in 2006 to assess the native aquatic plant community which incorporated some information about hardstem bulrush (*Scirpus acutus*) from the 2003 survey (Perleberg 2007). Across all historical surveys, the benthic macroalga *Chara* or muskgrass has been a major component of the plant community (Table 6).

The aquatic plant community in Ten Mile Lake is very diverse with a total of 37 plant species found in the 2006 survey (Perleberg 2007; Table 4; Fig. 12). Owing to exceptionally clear water, plants were found to a maximum depth of 8.8 meters (29 feet) and 63 percent of the sampled sites contained vegetation. Local species assemblages were also spatially diverse within the lake since most species were rarely sampled at > 5 percent frequency (Table 7; Figure 12). Nevertheless, muskgrass was by far the most common species and was widespread throughout the lake (Table 7; Figure 13). The depth zone of 3.4 – 6.1 meters (11 - 20 feet) contained the greatest number plant species and 75 percent of the sites contained vegetation (Table 7; Fig. 14).

Figure 12. Number of plant taxa sampled per site in Ten Mile Lake, June 2006 reproduced from Perleberg (2007).

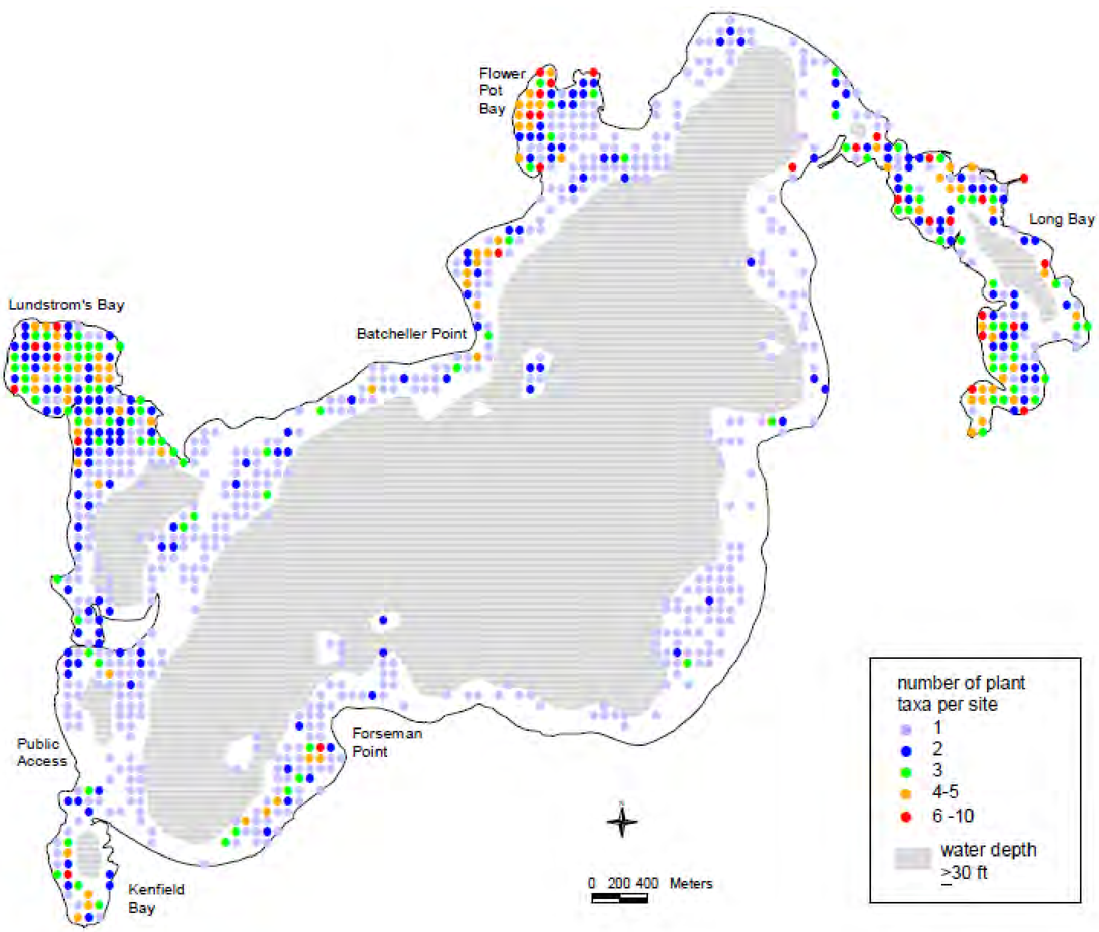


Figure 13. Distribution of large algae in Ten Mile Lake, June 2006 reproduced from Pereleberg (2007).

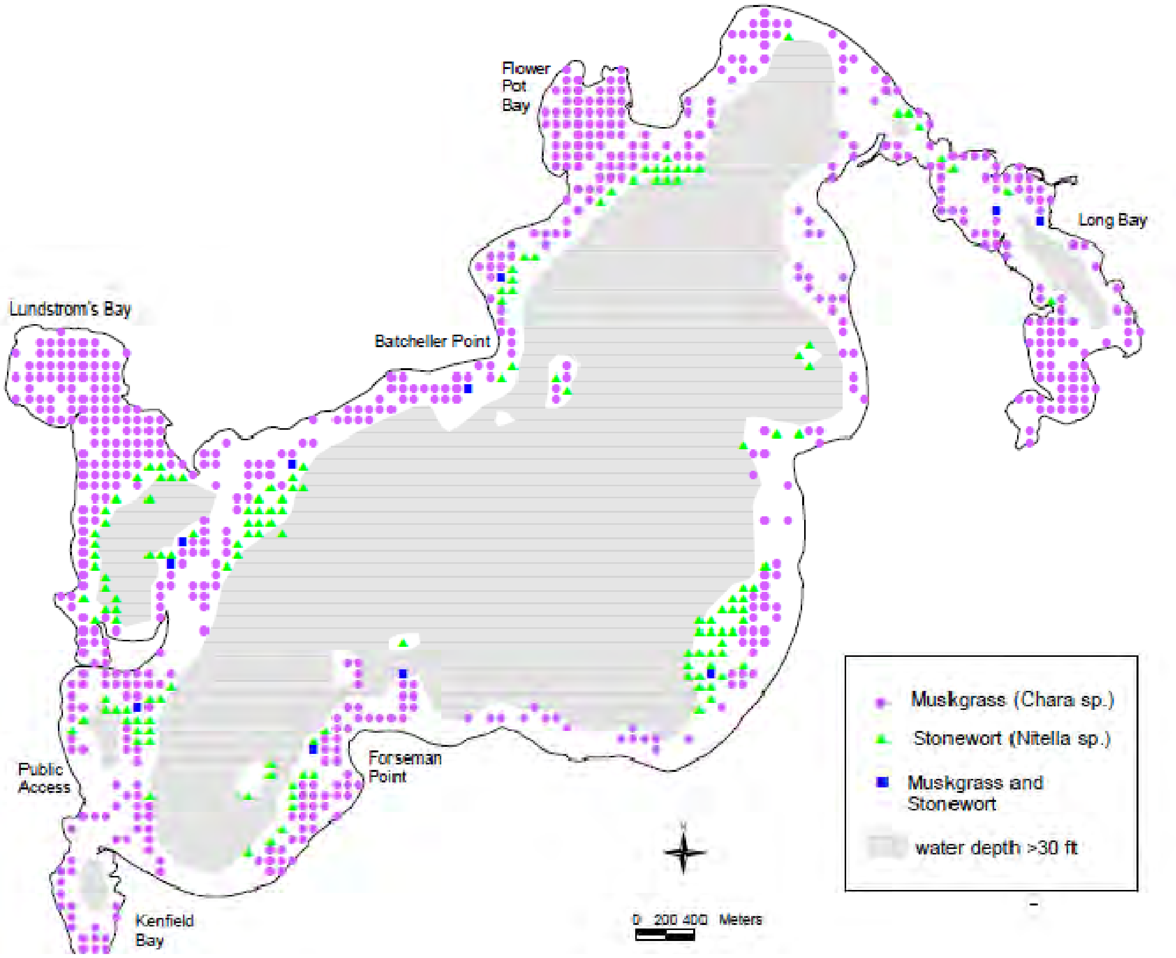


Figure 14. Plant abundance vs. water depth on Ten Mile Lake, 2006. Reproduced from Perleberg (2007).

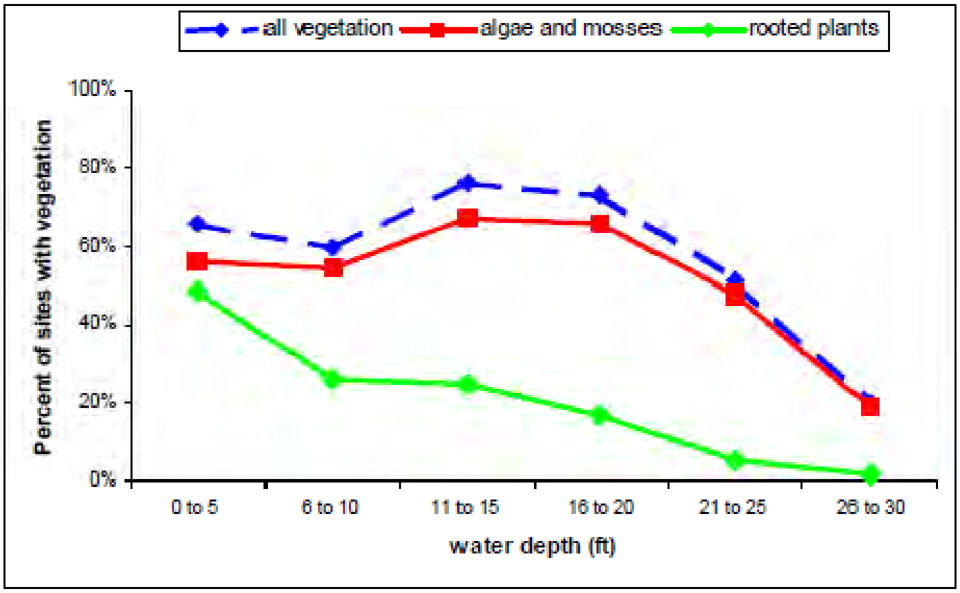


Table 6. Common species sampled during past vegetation surveys

Date	Common name	***Species name***	Growth form
1948 & 1958	Listed plants with no abundance rating		
1971 – abundant , common, or occasional species	Bushy pondweed	*Najas flexilis*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Floatingleaf pondweed	*Potamogeton natans*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Yellow water lily	*Nuphar variegate*	Submersed
1983 – abundant, common, or occasional species	Canada waterweed	*Elodea Canadensis*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
	Floatingleaf pondweed	*Potamogeton natans*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Yellow waterlily	*Nuphar variegate*	Submersed
1997 – Five most common	Bushy pondweed	*Najas flexilis*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Floatingleaf pondweed	*Potamogeton natans*	Submersed
	Grasses Group	*Gramineae*	Emergent
	Muskgrass	*Chara sp.*	Submersed
2003 – Five most common	Bushy pondweed	*Najas flexilis*	Submersed
	Claspingleaf pondweed	*Potamogeton richardsonii*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Grasses Group	*Gramineae*	Emergent
	Muskgrass	*Chara sp.*	Submersed

Table 7. Summary of point intercept method for aquatic plants in 2006 (N= 1465)

Common name	Scientific name	Growth form	Frequency of occurrence		
			Bays	Main basin	Lakewide
Muskgrass	*Chara sp.*	Submersed	67	37	45
Stonewort	*Nitella*	Submersed	2	14	11
Canada waterweed	*Elodea canadensis*	Submersed	15	3	7
Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed	15	3	6
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	12	3	6
Bushy pondweed	*Najas flexilis*	Submersed	14	<1	4
Narrow-leaf pondweed	*Potamogeton sp.*	Submersed	9	2	4
Robbins Pondweed	*Potamogeton robbinsii*	Submersed	10	1	4
White-stem pondweed	*Potamogeton praelongus*	Submersed	9	2	4
Coontail	*Ceratophyllum demersum*	Submersed	6	2	3
Variable pondweed	*Potamogeton gramineus*	Submersed	1	<1	2
Illinois pondweed	*Potamogeton illinoensis*	Submersed	4	1	1
Large-leaf pondweed	*Potamogeton amplifolius*	Submersed	4	<1	1
Watermoss	*Not identified to genus*	Submersed	2	<1	1
Bladderwort	*Utricularia sp.*	Submersed	<1	-	<1
Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	2	-	<1
Flat-leaved bladderwort	*Utricularia intermedia*	Submersed	1	-	<1
Fries pondweed	*Potamogeton freisii*	Submersed	1	<1	<1
Greater Bladderwort	*Utricularia vulgaris*	Submersed	2	-	<1
Quillwort	*Isoetes sp.*	Submersed	-	<1	<1
Sago pondweed	*Stuckenia pectinata*	Submersed	1	<1	<1
Water bulrush	*Scirpus subterminalis*	Submersed	1	-	<1
Water marigold	*Megaladonta beckii*	Submersed	1	<1	<1
Water stargrass	*Heteranthera dubia*	Submersed	1	<1	<1
White Water Buttercup	*Ranunculus spp.*	Submersed	1	-	<1

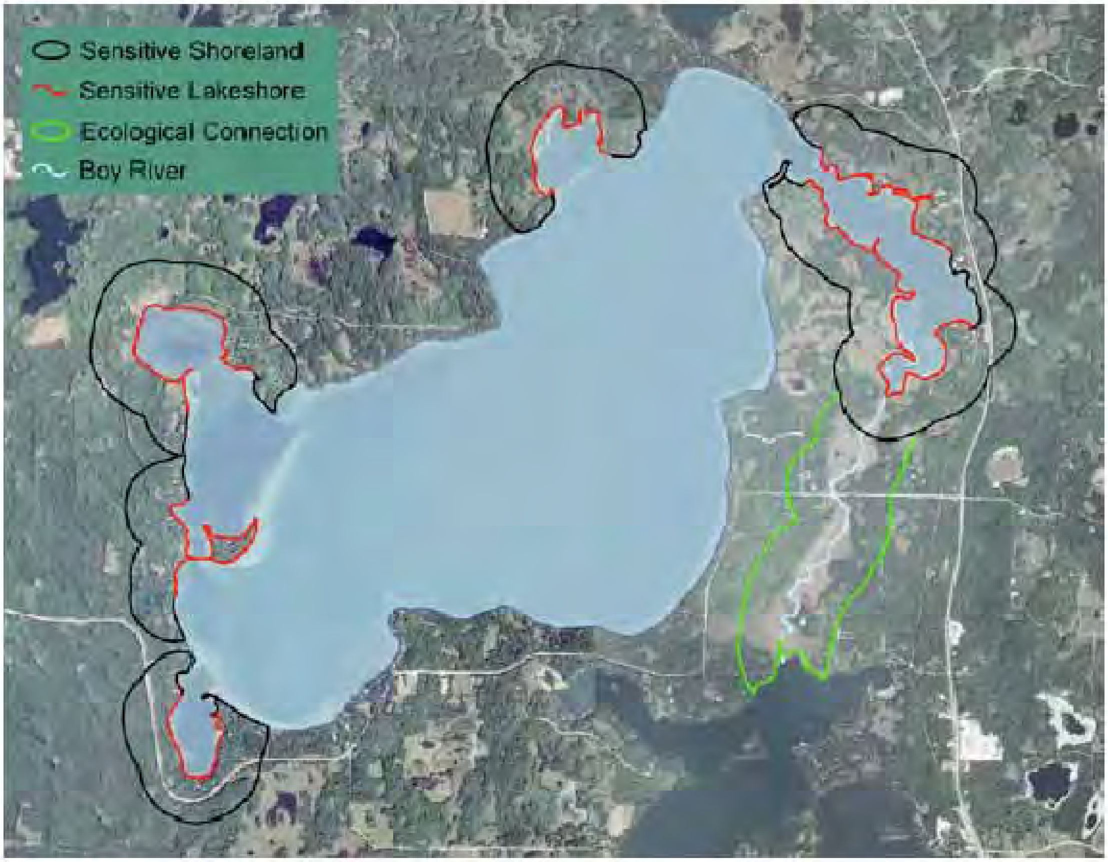
Wild Celery	*Vallisneria americana*	Submersed	<1	<1	<1
Greater Duckweed	*Spirodela polyrhiza*	Free Floating	<1	-	<1
Floating-leaf pondweed	*Potamogeton natans*	Floating	10	-	3
White water lily	*Nymphaea odorata*	Floating	7	-	2
Yellow water lily	*Nuphar variegata*	Floating	6	-	2
Watershield	*Brasenia schreberi*	Floating	2	-	1
Floating-leaf burreed	*Sparganium fluctuans*	Floating	<1	<1	<1
Bulrush	*Scirpus sp.*	Emergent	7	1	3
Wild rice	*Zizania palustris*	Emergent	3	-	1
Arrowhead	*Sagittaria sp.*	Emergent	<1	-	<1
Burreed	*Sparganium sp.*	Emergent	<1	-	<1
Spikerush	*Eleocharis sp.*	Emergent	<1	-	<1

Approximately 95 percent of Ten Mile's 40.3 kilometers (25 miles) of shoreline is in private ownership and much of that is developed with seasonal or permanent dwellings. Since 2001, 15 permits have been given out for aquatic plant removal (Table 8). The 15 permits covered 160 meters (525 feet) of shoreline. Although permitted destruction of aquatic plants is rather small, owners of lakeshore are allowed to remove up to 230 square meters (2,500 square feet) of submersed aquatic plants without a permit as described in Minnesota Rules chapter 6280. From 2008 aerial photos acquired through the US Farm Services Administration, approximately 422 dock structures were enumerated (one dock every 95.4 meters (313 ft) on a whole lake basis). Although most near shore development, as evidenced by docks, is along sandy shorelines of the main basin there is modest development in some of the shallow, densely vegetated bays. A sensitive shoreline assessment project found the shallow bays of Ten Mile Lake to be sites of high biodiversity and sensitivity to human impacts (Thompson and Perleleberg 2008; Figure 15). To conserve species and habitats in the lake, it will be important that near shore impacts from development and in-lake recreation (e.g., aquatic vegetation removal) be kept minimal, especially in shallow densely vegetated bays.

Table 8. Number of permit by year for Ten Mile Lake

Year	Number of Permits	Shoreline Feet	Total Acres
2001	1	15	0
2002	2	60	0.03
2003	-	-	-
2004	1	0	0
2005	4	110	0.13
2006	1	50	0.1
2007	1	50	0.1
2008	4	140	0.16
2009	2	100	0.24

Figure 15. Area of sensitive shoreline and shoreland on Ten Mile Lake



Water Quality

Standard summer-mean water quality data for 2009 are presented in Table 9, and raw data results are provided in Appendix B. Water quality data for 1991 is included for comparison. Worth noting, is that the values for 1991 and 2009 for TP, chl-*a*, and Secchi are identical. This indicates that the water quality for Ten Mile Lake has remained very good for the past 20 years. In addition, major cations, anions, and total organic carbon samples were collected in May, July, and October, and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 10. The NLA was a statistically-based survey of the nations lakes administered by the United States Environmental Protection Agency in 2007. The typical range provided in Table 10 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Table 9. Ten Mile Lake 1991 & 2009 summer mean water quality. Typical range based on NLF ecoregion reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	Ten Mile Lake 1991 Site 202	Ten Mile Lake 2009 Site 202	NLF
Total phosphorus (µg/L)	10	10	14 - 27
Chlorophyll mean (µg/L)	2	2	4 - 10
Chlorophyll max (µg/L)	3	3	<15
Secchi disk (feet)	16	16	8 – 15
(meters)	4.9	4.9	2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.4	0.4	<0.4 – 0.75
Alkalinity (mg/L)	118	115	40 - 140
Color (Pt-Co Units)	10	5	10 - 35
pH (SU)	8.5	8.4	7.2 – 8.3
Chloride (mg/L)	0.8	1.3	0.6 – 1.2
Total suspended solids (mg/L)	2	1	<1 - 2
Total suspended inorganic solids (mg/L)	1	1	<1 - 2
Conductivity (umhos/cm)	209	216	50 - 250
Total nitrogen:Total phosphorus ratio	27:1	27:1	25:1 - 35:1

Table 10. Annual mean values for cations, anions, and organic carbon. Interquartile range (referred to as typical range) based on 64 lakes included in the 2007 NLA study included for perspective.

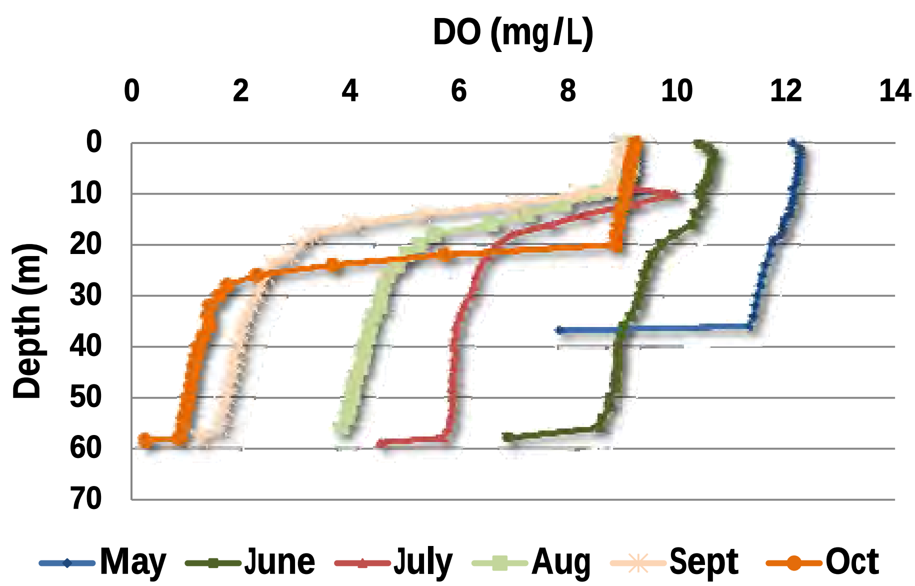
Parameter[1]	Ten Mile	Ten Mile	NLA IQ Range		Ion balance	µeq/L	µeq/L
	2008	**2009**	**2007**			**2008**	**2009**
Ca (mg/L)	24.1	25.1	19.1 - 33.7		cations	1205	1251
Mg (mg/L)	11.2	11.2	6.7 - 26.9			925	921
K (mg/L)	1.6	1.4	0.9 - 4.8			41	36
Na (mg/L)	3.1	3.0	2.2 - 9.0			135	131
Fe (µg/L)	-	20.1			**sum**	**2306**	**2338**
Si (mg/L)		7.3	3.1-13.5				
Alk (mg/L	118	115			anions	2427	2360
SO_4 (mg/L)	1.3	1.1	2.2 - 14.1			27	23
Cl (mg/L)	1.4	1.3	1.5 - 18.4			39	37
DOC (mg/L)					**sum**	**2427**	**2360**
TOC (mg/L)	3.3	3.4	7.3 - 14.2				

1. Cations and anions expressed as element (e.g. Ca as Ca); alkalinity expressed as $CaCO_3$

Dissolved Oxygen Profiles were taken monthly at sites 102 and 202 and biweekly at site 208 (Figures 16-18). For site 202 DO levels remained at or above five milligrams per liter (mg/L) in the epilimnion (upper, warmer layer) during the entire season. DO levels were above 5 mg/L in the hypolimnion (lower, cooler layer) in May, June, and July to a depth of 58 meters (190 feet). Beginning in August, the DO drops below five mg/L at 22 meters (72.2 feet) indicating oxygen demand from the decomposition of organic materials in the hypolimnetic water and bottom sediments and a lack of oxygen production. Low DO in the hypolimnion allows for phosphorus release from the sediments (Figure 20). As described in fisheries assessment the combination of adequate DO and cool water temperatures in deeper waters provides good habitat for cisco.

Temperature Profiles were also taken monthly at sites 102 and 202 and biweekly at site 208 (Figures 16-18). The lake was well-mixed in May and October with a distinct thermocline forming at approximately 10 meters in June, July, August, and September. The development of a thermocline between 10 and 15 meters was fairly consistent at all three locations indicating stratification from June through September throughout the lake. Surface temperatures at site 202 peaked at 22 degrees Celsius (°C) in August and water temperatures at the bottom varied from 6.8 °C in May to 8.8 °C in August. Additionally, when the July 2009 profile is compared with the July 2008 profile, the thermocline depth develops at approximately the same depth each year (Figure 19).

Figure 16. Ten Mile Lake Site 202 2009 dissolved oxygen & temperature profiles



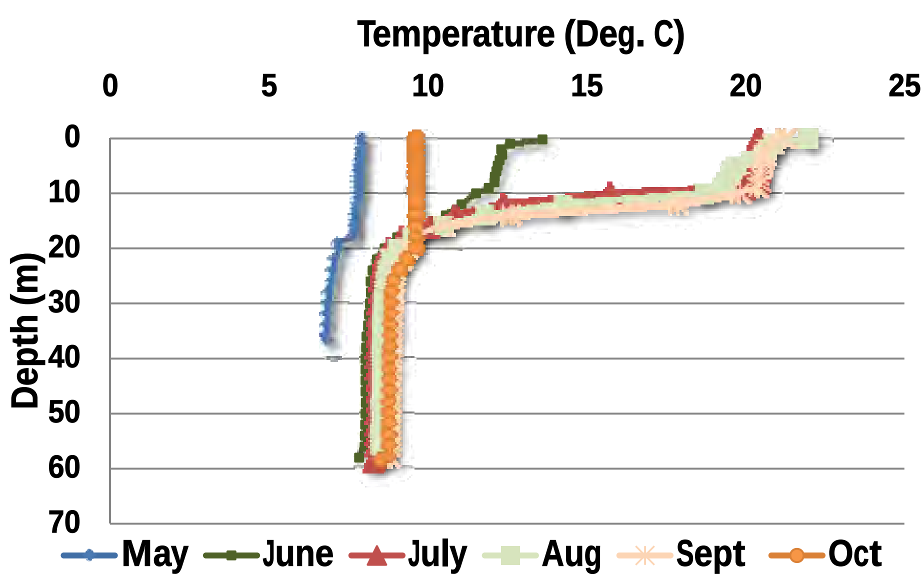
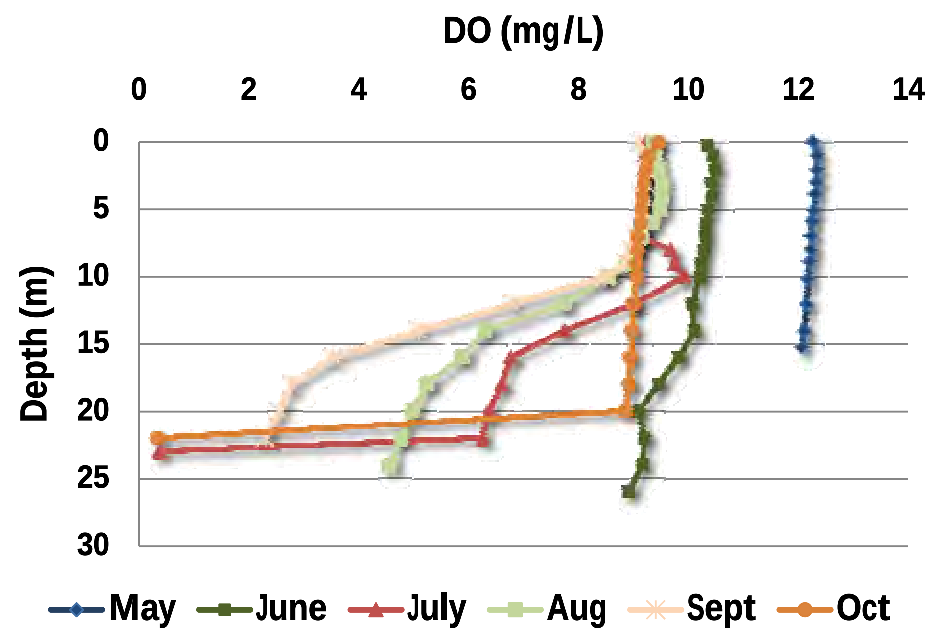


Figure 17. Ten Mile Lake Site 102 2009 dissolved oxygen & temperature profiles



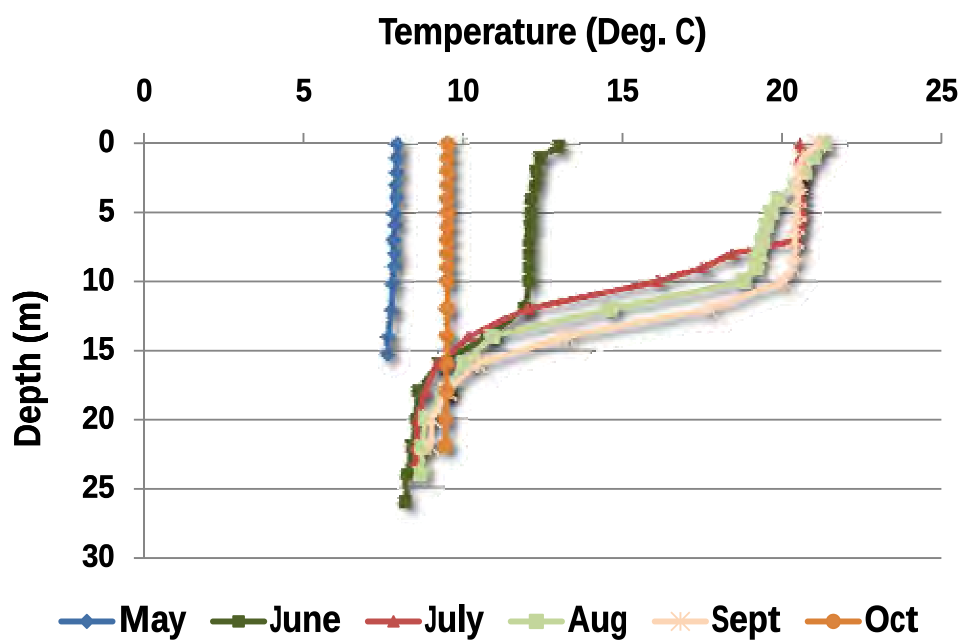
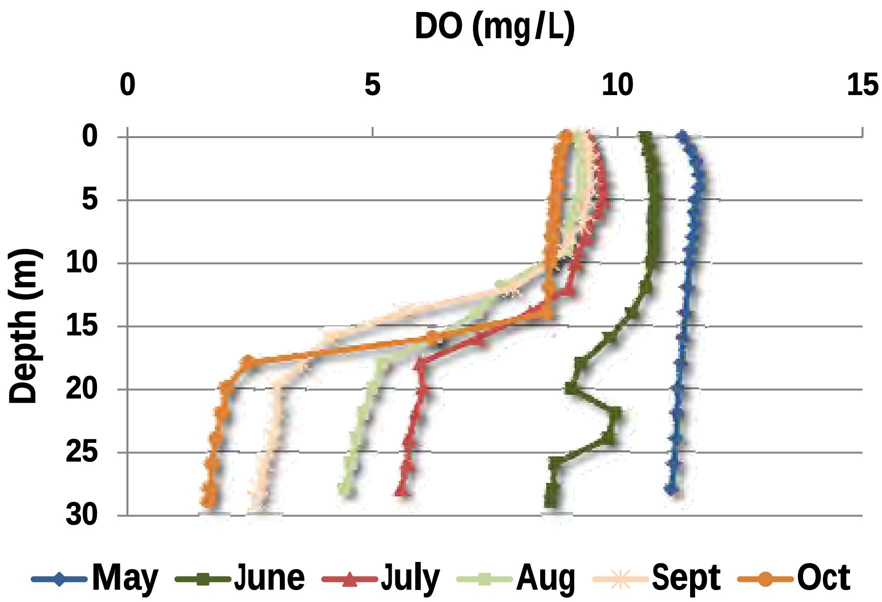


Figure 18. Ten Mile Lake Site 208 2009 dissolved oxygen & temperature profiles



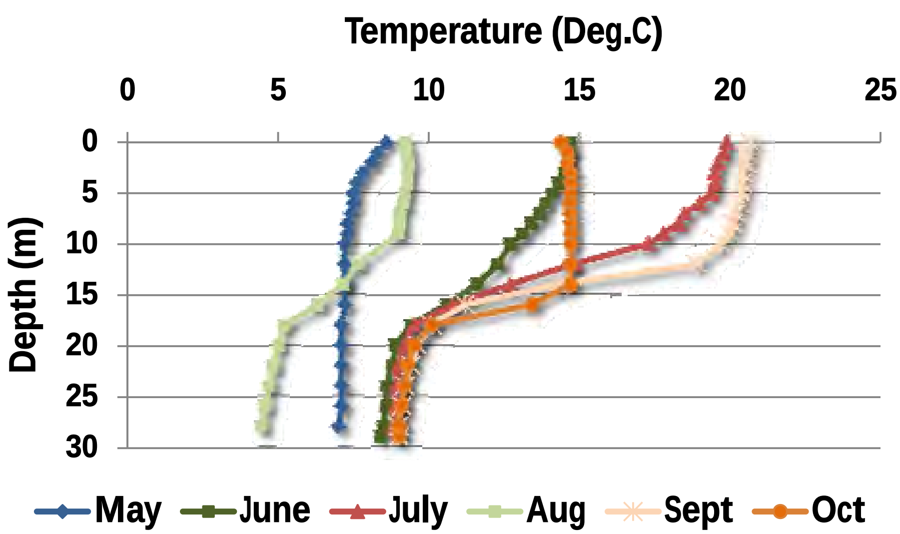
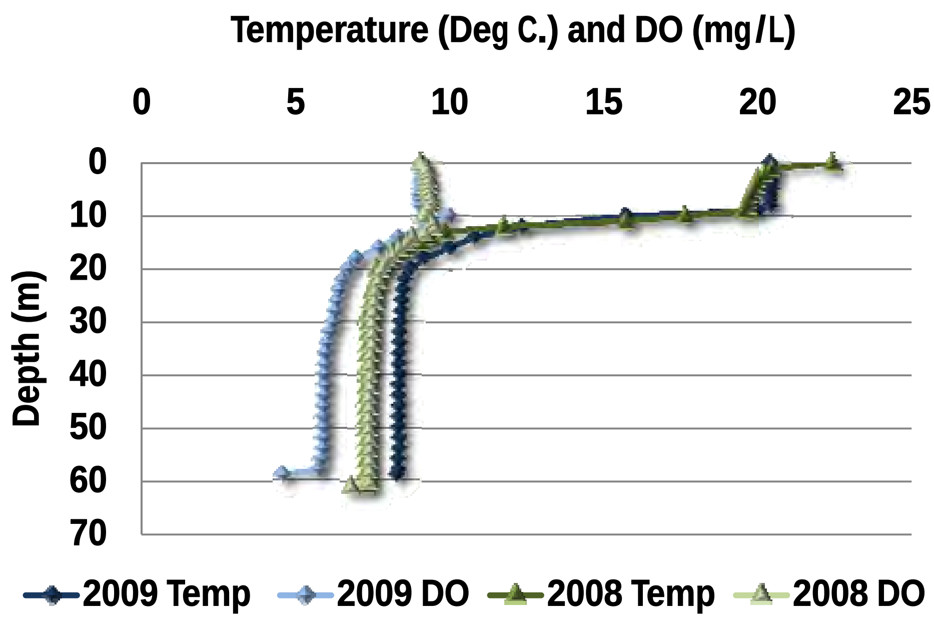


Figure 19. Ten Mile Lake July 2008 & 2009 dissolved oxygen & temperature profile comparison



Total Phosphorus concentrations for Ten Mile Lake (sites 102 and 202) averaged 10 µg/Lin 2009 (Figures 20 & 21). These averages were below the typical range of concentrations for NLF reference lakes (Table 9). TP concentrations declined slightly in June upon completion of spring turnover and in response to a spring diatom bloom. TP was fairly stable over the summer but increased to 14 µg/L in October during fall turnover. TP concentrations collected near the lake sediment at site 202 were similar to those at the surface with the exception of a spike of 35 µg/L in September (Figure 22) that coincides with anoxic conditions near the bottom (Figure 16). This indicates very minimal amounts of TP are being released from the sediments. This is in contrast to more eutrophic stratified lakes where large amounts of TP are released from the bottom sediments. The two year average for both sites is 11 µg/L.

Both external (watershed) and internal (sediments, plants, and fish) sources can contribute to TP levels in lakes. TP in Ten Mile is rather stable across the summer. While there was some moderate precipitation in mid-June and mid-August a majority of the summer was quite dry (Figure 7). Runoff from precipitation can be a significant source of nutrient input to a lake; however, since a majority of the land use within the drainage network surrounding the lake is forested with several other lakes and wetlands combined with the Ten Mile Lake's large area it is likely that that watershed inputs were rather minimal during the summer (Figure 5).

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During summer 2009, chl-*a* concentrations for Ten Mile Lake (sites 102 and 202) ranged from 1 µg/L to 3 µg/L (Figuers 20 & 21), with an average of 2 µg/L (Table 9). This is also the average for both years of sampling (2008 & 2009). Chl-*a* concentrations from each sampling event were below the expected range of 4-10 µg/L for the NLF ecoregion. Concentrations greater than 20 µg/L will typically be perceived as a nuisance (Heiskary and Walker, 1988). As such, no nuisance algal blooms were observed in 2008 or 2009.

Secchi disk transparency on Ten Mile Lake averaged 4.9 meters (16 feet) at site 202 during the summer of 2009 (Table 9). The average Secchi depth is deeper than the typical range of values for the NLF ecoregion. The change in the transparency of Ten Mile Lake during each sampling event closely mirrored the changes in nutrient availability (TP) and algal production (chl-*a*). The Secchi disk transparency reached a low of four meters (13.1 feet) in July and a high of 6.5 meters (21.3 feet) in August.

Figure 20. Ten Mile Lake site 202 2009 total phosphorus, chlorophyll-*a*, & Secchi depth

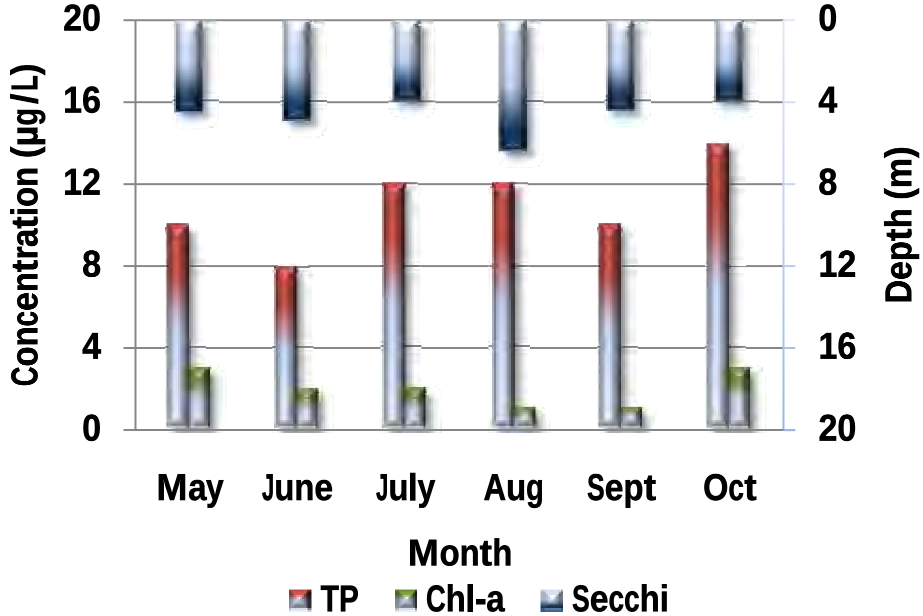


Figure 21. Ten Mile Lake site 102 2009 total phosphorus, chlorophyll-*a*, & Secchi depth

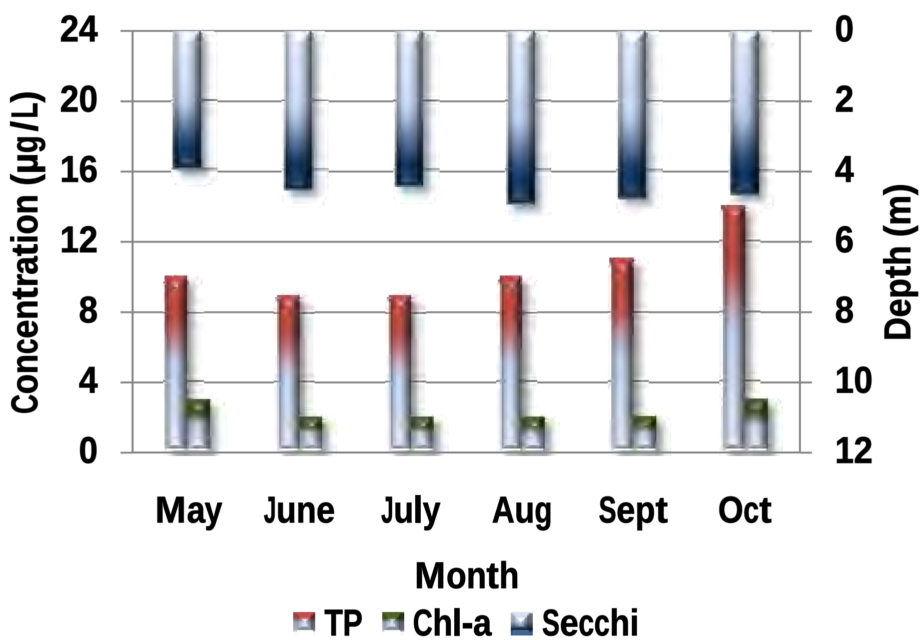
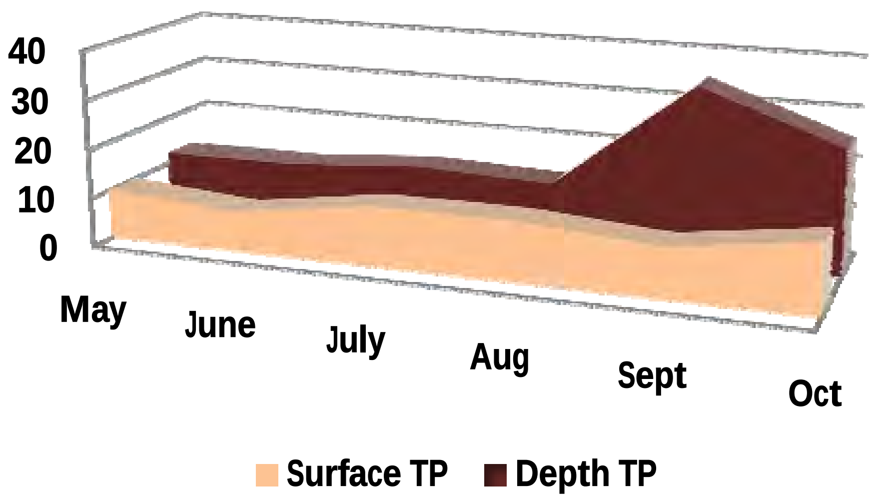


Figure 22. Ten Mile Lake 2009 surface and depth total phosphorus comparison



Dissolved minerals and organic carbon were measured in 2008 and 2009 as part of the long-term monitoring of Ten Mile and other Sentinel lakes. This includes some of the standard lake assessment measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 9) as well as major cations, anions, silica, iron and organic carbon (Appendix C). While several of these parameters have “typical” ecoregion-based concentrations (e.g. Table 9); some do not. For parameters without ecoregion–based comparisons data from the 2007 NLA study were used to provide perspective on reported concentrations (Table 10). Since the NLA lakes were selected randomly they provide a reasonable basis for describing typical ranges and distributions at the state-wide level.

TSS is low as compared to NLF reference lakes and most of the TSS can be attributed to organic SS (TSS-TSIS), i.e. suspended algae. The low color value indicates the water is clear and has minimal amount of dissolved organic carbon (DOC). As such, total organic carbon (TOC) is rather low and the majority of the TOC is in the DOC form, which is consistent with the state-wide data. Lakes that receive a majority of their water inputs from forest and wetland runoff often have correspondingly higher color and TOC values as a result of incompletely dissolved organic matter (plants, leaves, and other organic material).

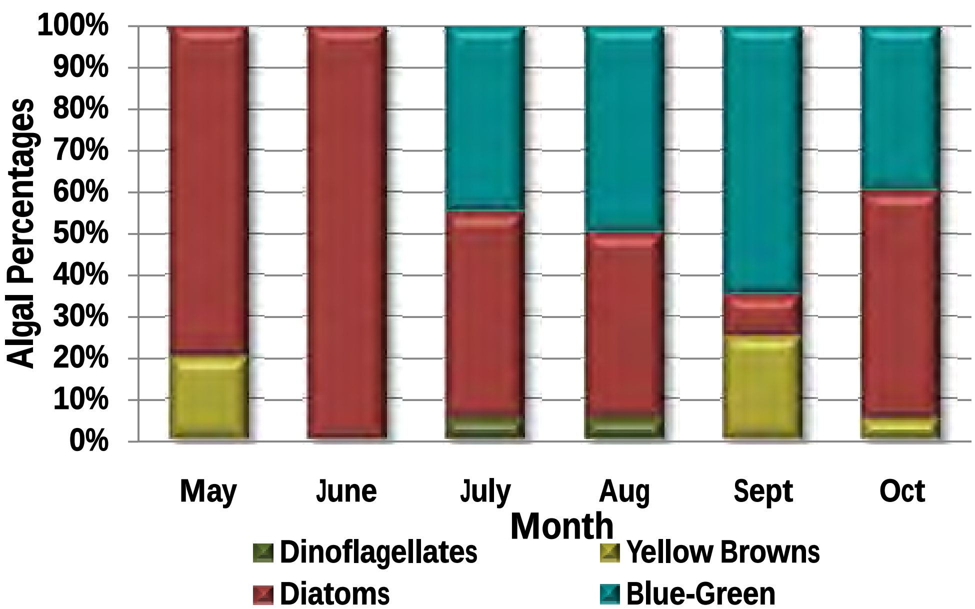
Alkalinity and conductivity are in the typical range for NLF lakes and are indicative of hard water (Table 9). Most cation and anion concentrations were quite stable across sample events and years (Table10), which is consistent with the literature. Magnesium (Mg), sodium (Na), potassium (K) and chloride (Cl) are noted to be relatively conservative and undergo only minor spatial and temporal change (Wetzel 2001). Mg is required by algae to produce chlorophyll-*a*, and calcium (Ca) is used by rooted plants. Silica (Si), which is required by diatoms to form their “glass” shells, varied slightly from spring to fall. The slight decline in fall may be caused by a fall diatom bloom.

Ca and Mg are the dominant cations and concentrations of both are within the typical range of the state-wide data (Table 10). The other two major cations, Na and K, are well within the typical range as well. Bicarbonate is the dominant cation, followed by Cl and sulfate (SO_4). Chloride is near the typical range for NLF reference lakes (Table 9); however it is low relative to state-wide NLA data. Elevated Cl is most often attributed to application of road salt on roads in the watershed. Sulfate is low relative to the NLA data. The average cation and anion balances (cation-anions expressed as a percent of cations) for 2008 and 2009 were within five percent and one percent, which is well within values exhibited by the NLA lakes.

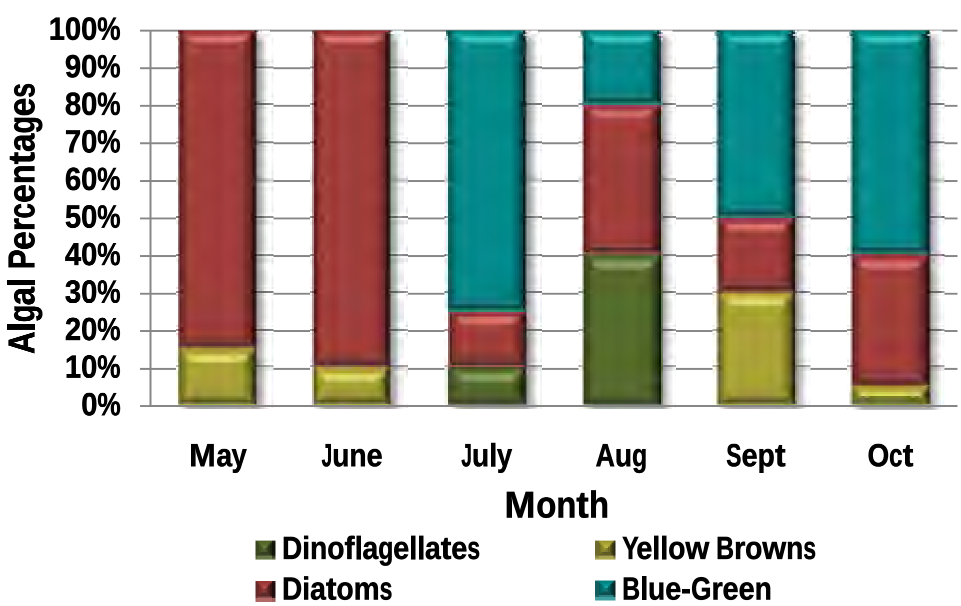
Phytoplankton (algae) for Ten Mile Lake is presented in terms of algal type (Figure 23). In May and June, the diatoms were the dominant genera. This early abundance of diatoms is anticipated as they are often dominant in the spring and early summer. Diatoms remained present throughout the season with several genera being represented including *Asterionella*, *Centric*, *Fragelaria*, *Pennate*, and *Tabellaria*. Additionally, blue-greens increased in abundance as the summer progressed and dinoflagellates were identified in July and August. *Anabaena* was the dominent blue-green while *Dinobryon* was the most common yellow-brown algae identified in the spring and fall. No algal blooms were observed at either of the two sites monitored in 2008 or 2009.

Figure 23. Ten Mile Lake 2009 algal composition for sites 102 and 202

Site 102



Site 202



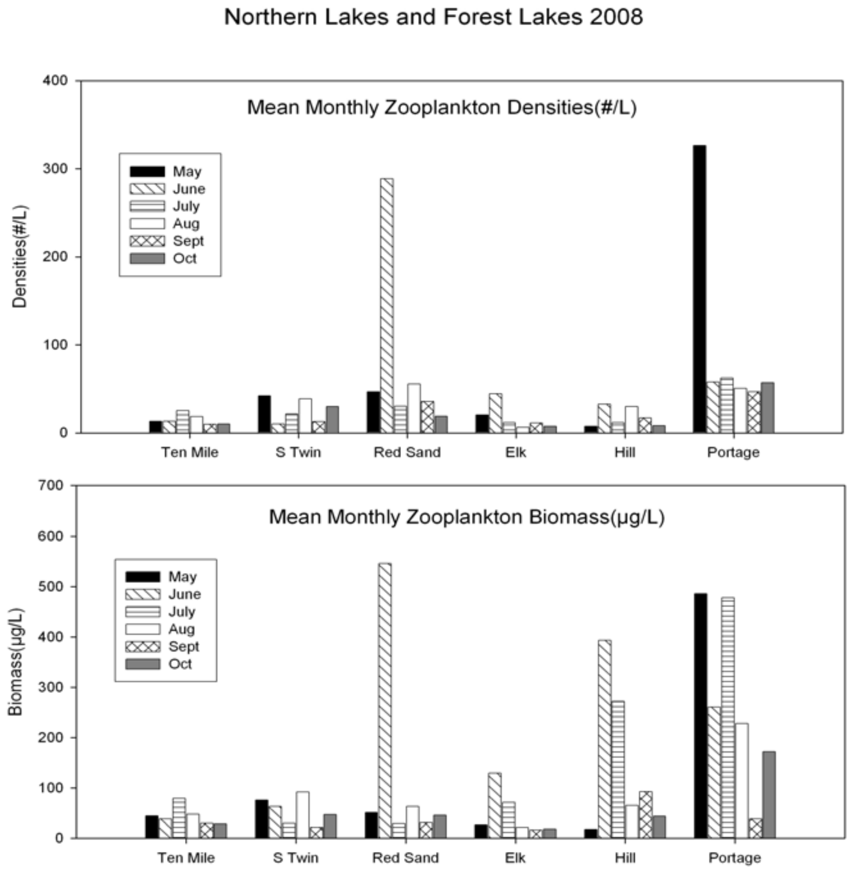
Zooplankton mean annual density and mean annual biomass for Ten Mile Lake was at the bottom of the list of the NLF (excluding NLF border lakes) within the Sentinel Lakes program (Table 11); however, total taxa was average amongst the NLF lakes. Hirsch (2009) determined that, in general, as the amount of TP and chl-*a* increases so too does the relative abundance (biomass) of zooplankton. This appears to be the case for Ten Mile Lake and the other NLF lakes (Figure 24). Unlike other NLF lakes that peaked in biomass in the spring and declined as the summer progressed, Ten Mile Lake peaked in July and had a low biomass throughout the rest season (Figure 24).

Table 11. Mean annual zooplankton densities, biomass, and total number of taxa for each Sentinel lake

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

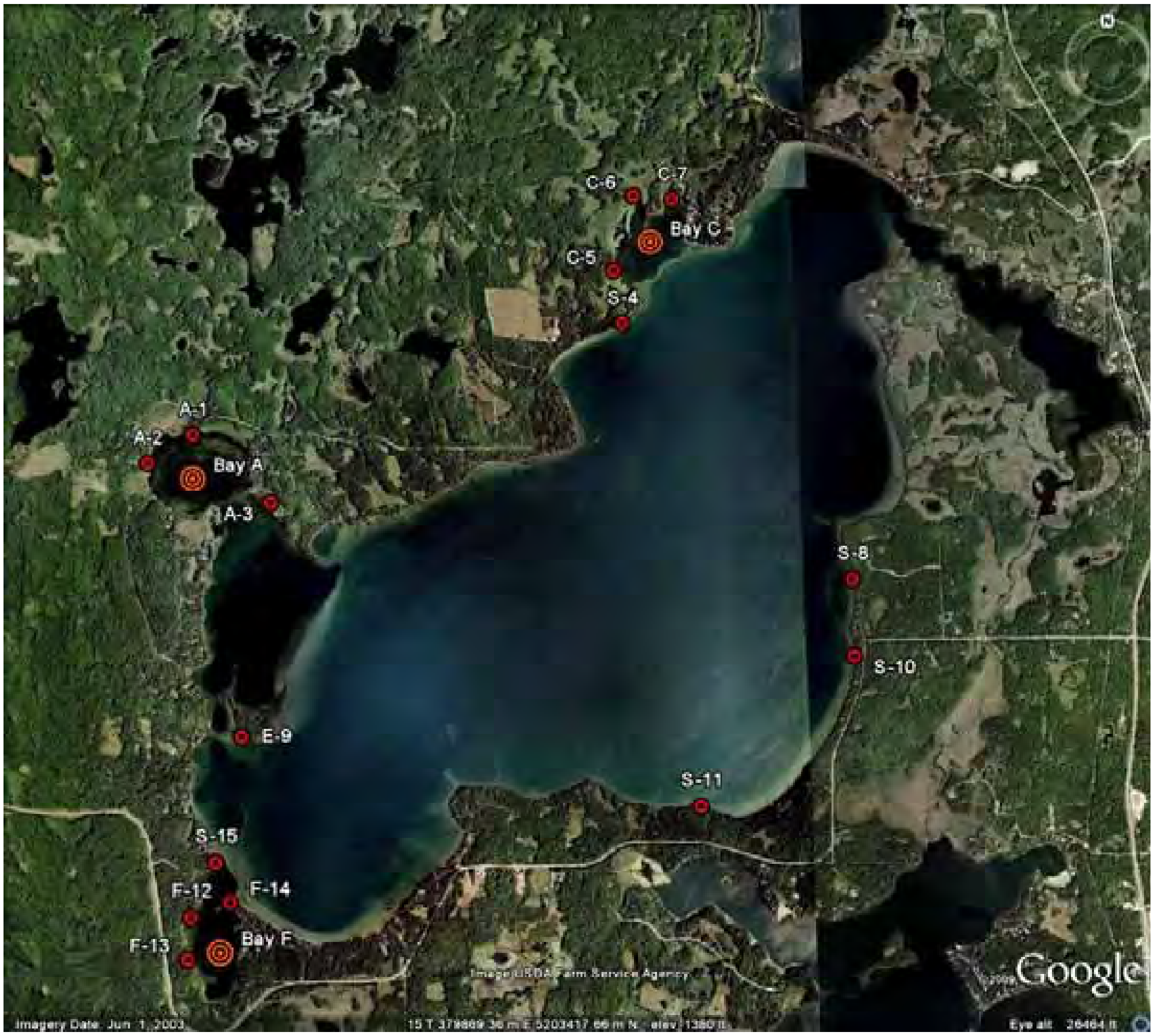
Samples analyzed by Jodie Hirsch and Gary Montz at the MDNR Division of Ecological Resources

Figure 24. Mean monthly zooplankton densities and biomass for NLF ecoregion Sentinel lakes



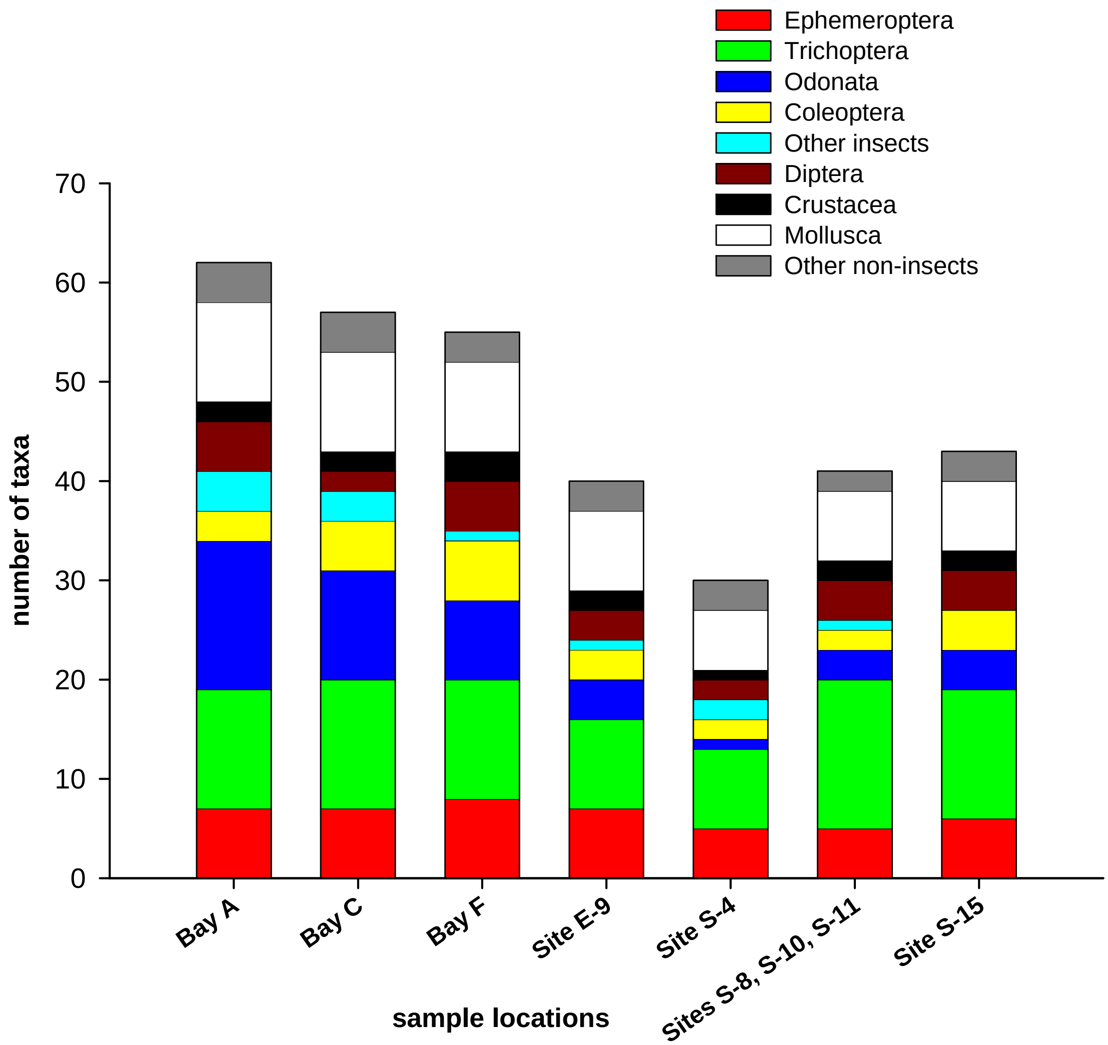
Macroinvertebrates: A total of 80 insect taxa (predominantly genera) were identified from the samples, as well as 20 non-insect taxa, mainly Gastropoda. This insect total would have been higher if the Chironomidae were identified to genus level. Additionally, Hirudinea were not identified to lower taxonomic levels, due to distortion and color/patterning loss due to preservation. Many of the invertebrates collected can be commonly found in lakes in the state. Numbers of taxa collected ranged from over 60 in bay A to approximately 30 at S-4 (Figure 25). While numbers of taxa varied, all sites showed relatively diverse invertebrate assemblages.

Figure 25. Sampling locations for aquatic invertebrate samples from Ten Mile Lake, 25–26 July 2006



Invertebrate assemblages in proposed sensitive sites (bays A, C, F and site E-9) were compared with those collected from developed shore sites (S-4, 8, 10, 11, and 15) to assess if this community could help in field determination of "sensitive shores". More Odonata taxa were collected in the bay sites than the developed shorelines (Figure 26). Additionally, more Coleoptera taxa were collected in the bay sites – however, this difference was not as noticeable as the Odonata. It also appears that the total number of distinct taxa was higher in bay sites than other shore sites, including E-9; however, these differences could be explained by the habitats in the respective sites. The proposed sensitive shore areas were in small, protected bays, and the habitat was abundant submerged aquatic macrophytes with soft sediments and some woody debris. The developed sites were on more exposed main lake shore areas, and likely subject to potentially heavy wave action. Substrate at these sites was commonly rock, cobble, gravel with scattered patches of woody debris, with vegetation sparse or lacking. Thus, the habitat differences likely account for the higher diversity of Odonata and Coleoptera. The lack of similar habitats between developed shore and proposed sensitive shore areas prevents any conclusions in using the invertebrate assemblages to help determine "sensitive shores" in Ten Mile Lake. Finally, while private property abounded along some of the areas (8, 10, 11, 15) much of this property was set back from the immediately shoreline, with trees and other vegetation often found directly adjacent to the shore. This may have negated any potential negative impacts of development on the shallow invertebrate community.

Fig. 26. Numbers of aquatic invertebrate taxa by sampling location from Ten Mile Lake near shore invertebrate samples collected 25 – 26 July 2006. (“Bay” = composites of sample sites within the bays)



Some taxa were only collected from one of the habitats. For example, the mayfly *Caenis* sp. and the caddisfly (*Leptocerus* sp.) were only collected from the bay sites. *Caenis* sp. is one of the most common mayflies in the littoral and sublittoral areas of lakes, and is able to tolerate low dissolved oxygen better than most mayflies. *Leptocerus* sp. is reported common among macrophytes in lentic habitats. In contrast, the mayfly (*Ephemera* sp.) and the caddisfly (*Helicopsyche* sp.) were only collected from the developed shores with coarser substrate. Ephemera mayflies are reported to burrow in sand and gravel of streams, while *Helicopsyche* sp. commonly attach to rocks in clean streams, but are also reported from windswept shores of clean lakes. Similarly, the elmid beetle (*Stenelmis* sp.) was only collected from the sand/gravel and rock dominated substrates, and has been reported from margins of clean lakes as well as in streams. This taxa was absent in the bay sites, while the *Coleoptera Haliplus* sp. and *Peltodytes* sp., commonly collected in vegetated areas, were more abundant. This suggests that the invertebrate community in Ten Mile Lake may have two somewhat distinct assemblages – one that is common in vegetation in lakes, while the other contains taxa which are more common in sand and gravel in lotic waters, but are also reported from windswept shores of larger and cleaner lakes.

Of particular interest is *Acella haldemani*, which was collected in very low numbers from both bay A and C (Figure 27). This slender, spire-shaped small snail has the common name of spindle *Lymnaea*. It is listed on the Species of Greatest Conservation Need list in Minnesota DNR "Tomorrow's Habitat for the Wild and Rare", as well as being similarly listed in other Great Lake States (for example, Michigan and Illinois). Additionally, Michigan lists this species as "Special Concern" on their state list. Distribution records for this snail are very limited. *Acella haldemani* has been collected from a handful of other lakes sampled for lake benthic work in central Minnesota, and was reported from the St. Croix River by the National Park Service in a recent snail survey. The Michigan wildlife action plan suggests that it may be vulnerable to excess nutrients, and copper sulfate treatments for swimmers itch should be avoided in areas where this snail has been collected. While this snail has not been listed in Minnesota, it may be well to avoid excessive disturbance in the bays until further state status and distribution has been better documented.

Figure 27. *Acella haldemani*

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 bases for assessing the relationship among TP, chl-*a,* and Secchi (Figure 28). In general, the TSI values are in fairly close correspondence with each other. The TSI values also correspond with observations for 2009. Based on an average TSI score of 38 Ten Mile Lake is characterized as mesotrophic. When compared with the TSI score (and corresponding values) from 1991, Ten Mile Lake has maintained the characteristics of a mesotrophic lake.

Trophic Status Trends

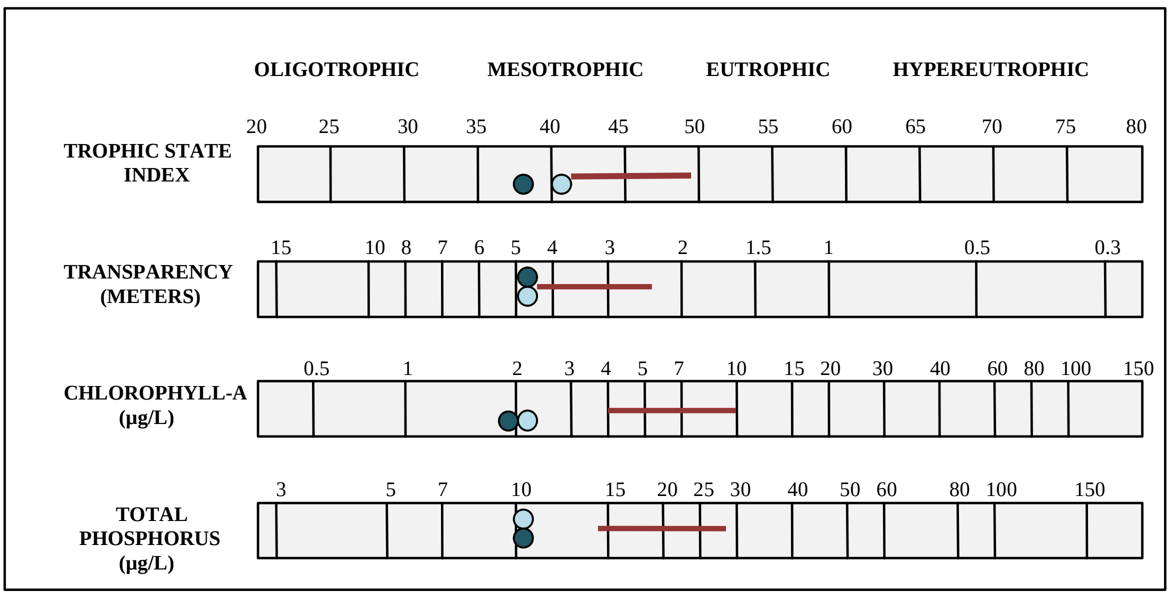
One aspect of lake monitoring is to assess trends in the condition of the lakes. This analysis is based on data gathered through the MPCA's Citizen Lake Monitoring Program or data collected by local groups and then stored in STORET. A review of data in STORET indicates there is a fair amount of data for Ten Mile Lake to describe annual variability and to statistically assess trends. In general, for trend assessment we seek a minimum of eight years of consistent data. Intermittent gaps in the data are present for site 202 on Ten Mile Lake. Based on yearly TSI averages calculated for 1989 through 2009, Ten Mile Lake has historically been classified as mesotrophic (Figure 29).

Individual summer-mean TP, chl-*a* and Secchi data provide further insight into trends and variability (Figure 29). The long-term average TP for Ten Mile Lake is 14 ± 5 µg/L. Standard error, expressed as a percent of the long-term mean, and represents the coefficient of variation (CV) of the mean. For Ten Mile Lake, the CV equals 36 percent, which is fairly typical for oligo-mesotrophic Minnesota lakes. Since 1989, only three of fifteen years have been greater than the long-term mean and there is a distinct trend of decreasing TP in recent years. Chl-*a* values are also low with a long-term mean of 1.6 ± 0.5 µg/L and a CV of 31 percent of the mean. Since 1989, six of fifteen years have been greater than the long-term mean (Figure 30). Secchi disk transparency has been consistently high with a long-term mean of 6.2 ± 0.8 m (Figure 31). The CV is 13 percent of the mean, which suggests minimal variability, which is typical for lakes that do exhibit a long-term trend. Secchi disk values for 2008 and 2009 have been less than the long-term mean indicating a recent reduction in water clarity. As with TP and chl-*a*, the Secchi disk values indicate mesotrophic conditions.

Historical precipitation records, collected in Walker, Minnesota, may provide some insight into potential nutrient sources influencing observed trends. Based on precipitation records from 1969 to 2009, mean annual precipitation is over 17 inches and showing a slight increase over the period of record (Figure 9). Mean for period of record indicated by solid blue line and simple linear regression by red dashed line. The summer months of both 2008 and 2009 were significantly drier with measurements of 11.72 inches and 10.74 inches. This below average precipitation coincided with below average TP and chl-*a* levels (Figure 30). When compared to the summer months of 1999 and 2000, with above average precipitation measurements of 26.75 and 21.61, TP and chl-*a* levels were still below average. This is an indication that TP within the water column for Ten Mile Lake remains very stable due to the lakes large size and volume despite fluctuations in precipitation amounts.

Figure 28. Carlson's Trophic State Index for
Ten Mile Lake R.E. Carlson

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 scum 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 scum, summer fish kills, few macrophytes, dominance of rough fish.



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

NLF Ecoregion Range: Ten Mile 1991: ○ Ten Mile 2009: ●

Figure 29. Ten Mile Lake trophic status trend

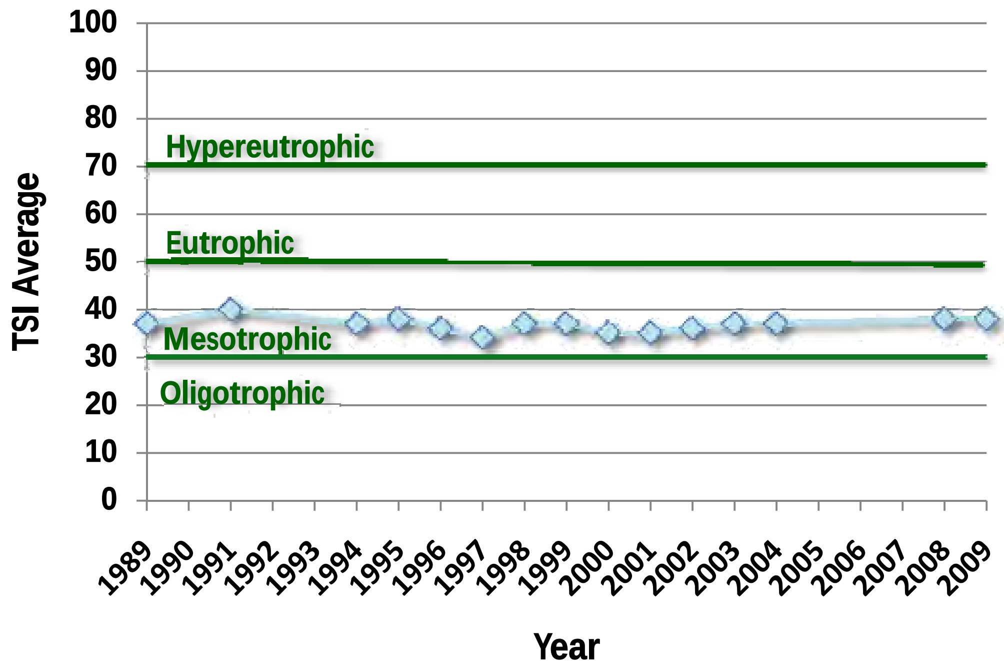


Figure 30. Ten Mile Lake long-term summer-mean total phosphorus (red line) and chlorophyll-*a* (green line)

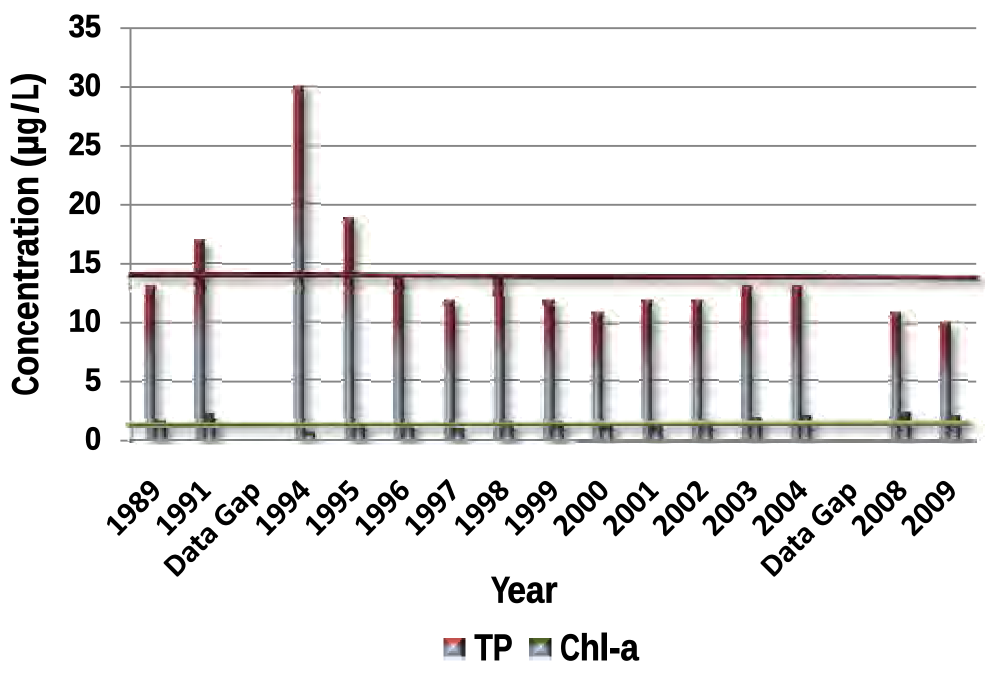
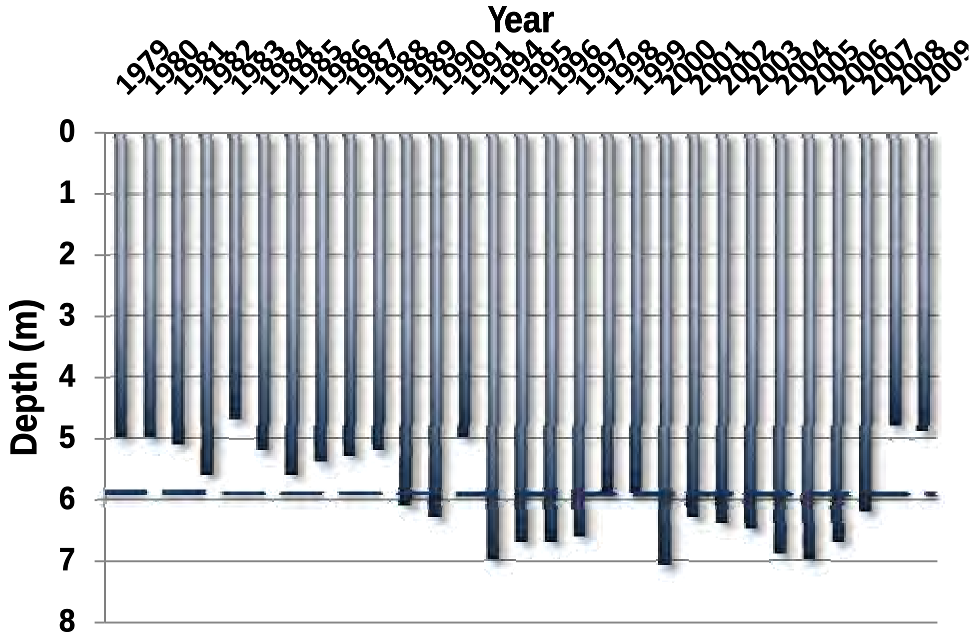


Figure 31. Ten Mile Lake long-term summer-mean Secchi disk depth. Long-term mean noted by dashed blue line.



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 2009 water quality of Ten Mile Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. A comparison of the MINLEAP predicted vs. observed values is presented in Table 12.

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 and subsequently predicts chl-*a* based on a regression equation of TP and Secchi based on a regression equation based on chl-*a*. For analysis of Ten Mile Lake, MINLEAP was applied as a basis for comparing the observed (2009) 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.

Ten Mile Lake is located in the NLF ecoregion and the model was run using NLF ecoregion-based inputs. The observed TP, chl-*a*, and Secchi values for Ten Mile Lake are very similar to the predicted values. This simply means that the observed TP is consistent with what is expected for a lake of its size, depth, and watershed area in the NLF ecoregion. The model predicted TP loading at 1,506 kilograms per year (kg/yr). This result is likely a good estimate given that the observed TP matches the predicted values. The areal water load to the lake is estimated at 1.8 meters per year (m/yr) and estimated water residence time is on the order of 12-13 years. However, it is important to note that this estimate only considers watershed runoff and precipitation on the lake and does not account for groundwater inputs that are likely quite significant in lakes like Ten Mile. 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 Ten Mile Lake this value is estimated at 14 µg/L, which is less than the NLF nutrient criteria (Table 13).

The MINLEAP model does not indicate the actual source of nutrient loading to the lake; however, based on its watershed to lake area ratio, land use composition, and the morphology of Ten Mile Lake it is probable that the model provides a reasonable estimate of the nutrient loading rate to Ten Mile Lake (Table 12). The model estimates are derived from typical runoff nutrient concentrations from a forest and wetland-dominated watershed, combined with that contributed directly on the surface of the lake via wet and dry deposition. Rechow-Simpson modeling done as a part of the lake assessment study in 1991 estimated relative contributions as follows: precipitation contributes 48 percent of the phosphorous loading to the lake while the variety of land uses contributes 44 percent and nine percent is potentially from septic systems around the lake. Actual measurement of inflow phosphorous concentrations and flow would be required to develop a more accurate nutrient budget for the lake and an improved understanding of significant loading sources.

Table 12. Minnesota Lake Eutrophication Analysis Procedures model results for Ten Mile Lake

Parameter	2009 Ten Mile Lake observed	MINLEAP predicted NLF ecoregion
TP (µg/L)	10	11
Chl-*a* (µg /L)	2	2.3
Secchi (m)	4.9	4.7
P loading rate (kg/yr)	-	1,506
P retention (%)	-	81
P inflow conc. (µg/L)	-	59
Water Load (m/yr)	-	1.3
Outflow volume (hm^3/yr)	-	25.7
Residence time (yrs)	-	12.7
Vighi & Chiaudani		14

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, the state 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 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.

Ten Mile Lake was assessed based on NLF ecoregional standards (Table 13). Both the 2009 and long-term mean for Ten Mile Lake have remained below 30 µg/L. Likewise, chl-*a* and Secchi are in full compliance with the NLF ecoregion standard. While the 2009 levels are below the standards for aquatic recreational use they are also below the NLF values required for lake trout (Class 2A waters). Based on these results, Ten Mile Lake was assessed as fully supportive of aquatic recreational use. as a part of the 305(b) and 303(d) assessments that MPCA conducts in support of the Clean Water Act. These assessments are submitted to USEPA on a biennial basis. Because of its exceptionally good water quality, Ten Mile is a good candidate for protection and every effort should be made to ensure long term maintenance of its high water quality.

Table 13. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). Ten Mile Lake 2009 and 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
Ten Mile Lake 2009	**10**	**2**	**4.9**
Ten Mile Lake long-term mean	**14**	**1.6**	**6.2**

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Appendix A

Ice-on and Ice-off Records for Ten Mile Lake

Lake Name	Lake ID	Ice Off Date	Ice On Date
Ten Mile	11-0413	4/30/1988	12/9/1988
Ten Mile	11-0413	5/4/1989	12/3/1989
Ten Mile	11-0413	4/26/1990	12/18/1990
Ten Mile	11-0413	4/26/1991	11/26/1991
Ten Mile	11-0413	4/21/1992	12/7/1992
Ten Mile	11-0413	4/24/1993	12/11/1993
Ten Mile	11-0413	4/22/1994	12/12/1994
Ten Mile	11-0413	5/3/1995	11/29/1995
Ten Mile	11-0413	5/18/1996	11/27/1996
Ten Mile	11-0413	4/28/1997	12/24/1997
Ten Mile	11-0413	4/12/1998	12/25/1998
Ten Mile	11-0413	4/24/1999	11/22/1999
Ten Mile	11-0413	4/18/2000	12/11/2000
Ten Mile	11-0413	4/29/2001	12/20/2001
Ten Mile	11-0413	4/24/2002	12/4/2002
Ten Mile	11-0413	4/24/2003	12/10/2003
Ten Mile	11-0413	4/25/2004	12/19/2004
Ten Mile	11-0413	4/16/2005	12/18/2005
Ten Mile	11-0413	4/19/2006	12/23/2006
Ten Mile	11-0413	4/27/2007	Data Missing
Ten Mile	11-0413	4/28/2008	12/17/2008
Ten Mile	11-0413	4/30/2009	

Appendix B

Lake Surface Water Quality Data for Ten Mile Lake for 2008 and 2009

All water quality data can be accessed at: www.pca.state.mn.us/data/eda/STresults.cfm?stID=29-0250&stOR=MNPCA1

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
Ten Mile	11-0413	5/21/2008	102	4.2	11	3					
Ten Mile	11-0413	5/21/2008	202	5	13	4	110	1.25	0.42	5	0
Ten Mile	11-0413	5/22/2008	208	4.6							
Ten Mile	11-0413	5/27/2008	208	4.4							
Ten Mile	11-0413	6/4/2008	208	4.9							
Ten Mile	11-0413	6/23/2008	102	5.7	9	1					
Ten Mile	11-0413	6/23/2008	202	6.3	12	1					
Ten Mile	11-0413	6/26/2008	208	5.8							
Ten Mile	11-0413	7/3/2008	208	6							
Ten Mile	11-0413	7/9/2008	208	5.3							
Ten Mile	11-0413	7/15/2008	208	5.8							
Ten Mile	11-0413	7/15/2008	102	4.3	9	1					
Ten Mile	11-0413	7/15/2008	202	5.8	15	1	110	1.52	0.43	5	0
Ten Mile	11-0413	7/23/2008	208	5.5							
Ten Mile	11-0413	7/30/2008	208	5.3							
Ten Mile	11-0413	8/6/2008	208	6.2							
Ten Mile	11-0413	8/13/2008	208	6.4							
Ten Mile	11-0413	8/24/2008	208	5.6							
Ten Mile	11-0413	8/25/2008	102	4.7	10	2					
Ten Mile	11-0413	8/25/2008	202	4.5	12	2			0.45		
Ten Mile	11-0413	8/30/2008	208	5.5							
Ten Mile	11-0413	9/4/2008	208	5.5							
Ten Mile	11-0413	9/9/2008	208	5.6							
Ten Mile	11-0413	9/16/2008	102	4.6	11	3					

Ten Mile	11-0413	9/16/2008	202	4.5	14	2					
Ten Mile	11-0413	10/7/2008	102	4.4	14	3					
Ten Mile	11-0413	10/7/2008	202	4	18	3	110	1.36	0.3	10	0
Ten Mile	11-0413	5/19/2009	102	4	10	4	110	1.44			
Ten Mile	11-0413	5/19/2009	202	4.6	12	3			0.33	5	0
Ten Mile	11-0413	6/9/2009	102	4.6	9	2					
Ten Mile	11-0413	6/9/2009	202	5	12	2			0.36		
Ten Mile	11-0413	7/14/2009	102	4.5	9	2					
Ten Mile	11-0413	7/14/2009	202	4	14	2	120	1.26	0.43	5	1.6
Ten Mile	11-0413	8/11/2009	102	5	10	2					
Ten Mile	11-0413	8/11/2009	202	6.5	13	1			0.43		
Ten Mile	11-0413	9/23/2009	102	4.8	11	2					
Ten Mile	11-0413	9/23/2009	202	4.5	10	1			0.38		
Ten Mile	11-0413	10/20/2009	102	4.7	14	3					
Ten Mile	11-0413	10/20/2009	202	4	14	3	110	1.29	0.39	5	1.2

Appendix C

Ten Mile Lake cation, anion, and organic carbon results

Date	mg/L	mg/L	mg/L	mg/L	µg/L	mg/L		mg/L	mg/L	mg/L	mg/L
	Ca	Mg	Na	K	Fe	Si		SO_4	Cl	TOC	DOC
5/21/2008	24.0	10.9	3.1	1.7				1.1	1.3	2.8	
7/15/2008	24.4	11.4	3.2	1.5				1.4	1.5	3.5	
10/7/2008	24.0	11.4	2.9	1.5				1.4	1.4	3.6	
5/19/2009	25.6	11.2	3.0	1.4	14.9	8.2		1.2	1.4	3.3	3.0
7/14/2009	24.7	11.0	3.0	1.4	20.6	7.3		1.1	1.3	3.6	3.4
10/20/2009	24.9	11.4	3.1	1.5	26.5	6.3		1.1	1.3	3.2	3.3