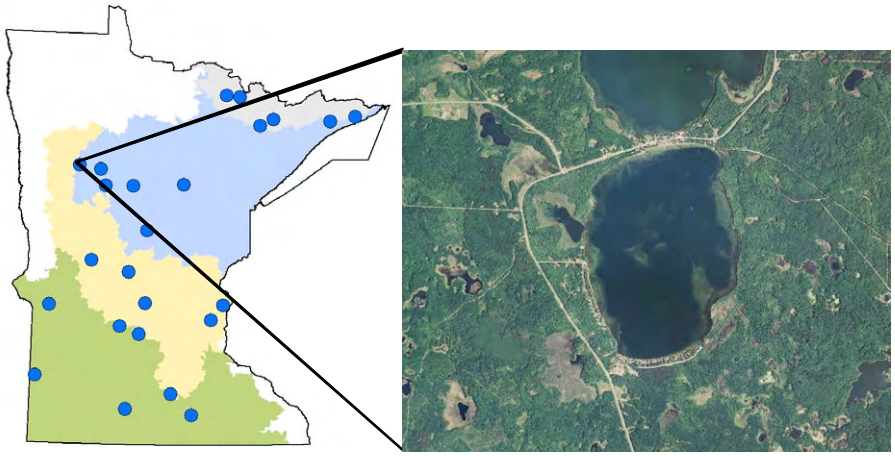
Sentinel Lake Assessment Report
South Twin Lake (44-0014)
Mahnomen County, Minnesota



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

April 2012

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Executive Summary

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

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 both harbor cisco, lake whitefish, or lake trout and are the focus of research funded by the Environment and Natural Resources Trust Fund (ENTF). "Super Sentinel" lakes also harbor cold-water fish populations and research on these lakes is also funded by the ENTF.

South Twin Lake was selected to represent a coldwater, mesotrophic lake in the Northern Lakes and Forests (NLF) ecoregion. South Twin Lake is a 452 hectare (1,118 acre lake) and is located south of Nay-tah-waush in Mahnomen County. It lies within the Wild Rice River major watershed. South Twin Lake has a maximum depth of 8.8 meters (29 feet) and a mean depth of 3.7 meters (12 feet). The lake is 47% littoral with one public access on the western shore. The total contributing watershed for South Twin Lake is 2,724 hectares (6,743 acres).

South Twin Lake is a shallow lake that fully mixes in the summer during periods of high winds and intermittently stratifies during calm periods. Based on recent water quality data (2008-2010), South Twin Lake is considered to be mesotrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 17 micrograms per liter (µg/L), 4 µg/L, and 3.2 meters (10.5 feet) respectively. TP levels for South Twin Lake were below the assessment standard for the NLF ecoregion. Chl-*a* levels were also below the assessment standard for the NLF ecoregion, with no observed nuisance algal blooms and normal transparency values for all three monitoring seasons.

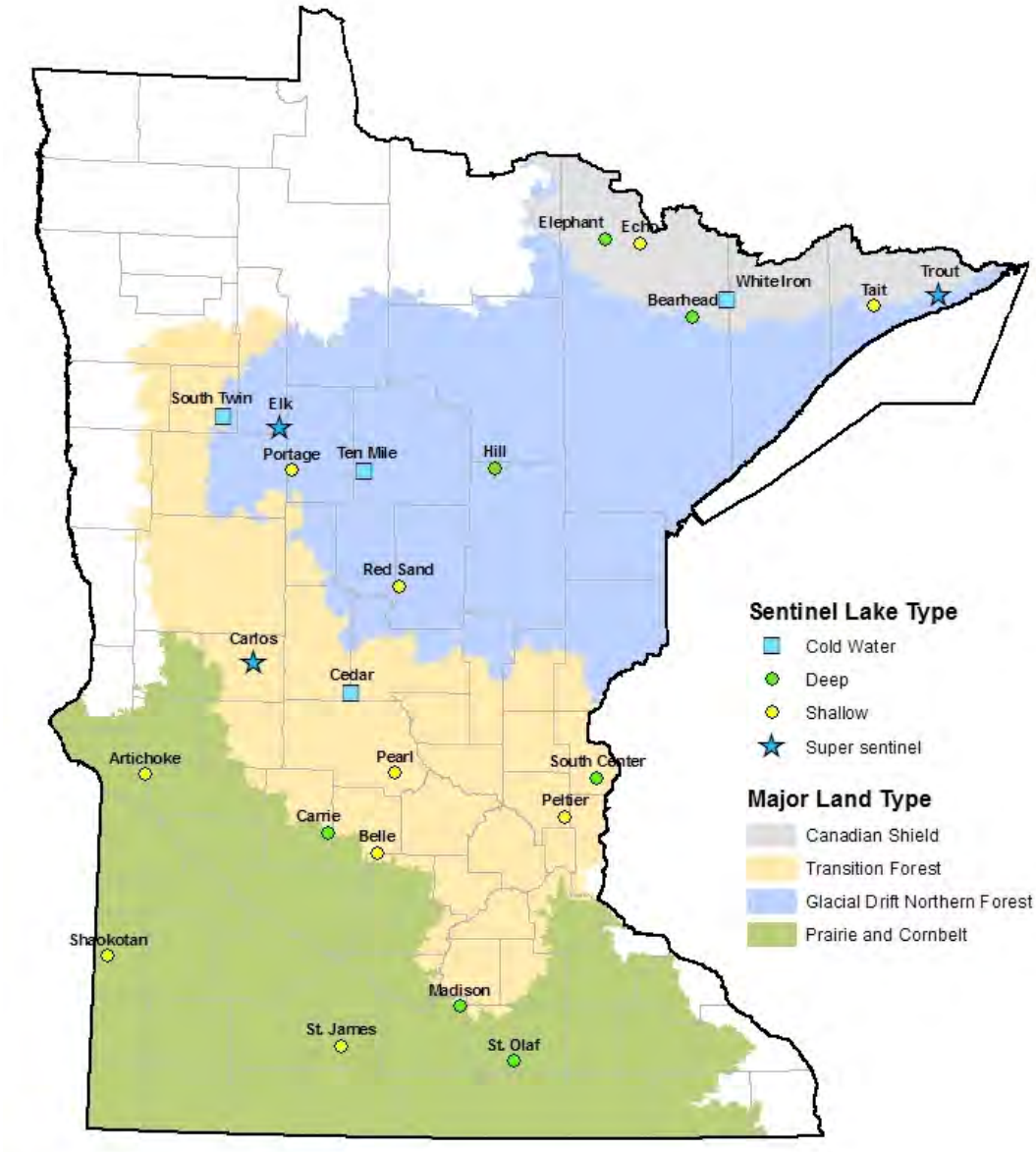
Secchi transparency was better than the assessment standard for NLF lakes. Secchi data, collected since 2005, suggest a slight improvement in the lakes transparency. South Twin Lake was determined to be fully supporting of recreational activities in the 2010 assessment cycle and was not placed on the 303(d) (or Impaired Waters) List.

An ecoregion-based eutrophication model was used to predict in-lake TP based on South Twin Lake's size, depth, and watershed area. Using inputs for the NLF ecoregion the model predicted in-lake TP for South Twin Lake to be 21 µg/L, which is fairly close to the observed 17 µg/L. A separate subroutine within the model estimated "background" TP for the lake at 26 µg/L. The model predictions, along with the overall assessment of South Twin Lake's water quality data, indicate the lake's water quality meets the expectations for a lake of this size in this portion of the state.

South Twin has a moderately diverse aquatic plant community with a high degree of patchiness. The diverse assortment of habitat patches supports a diverse fish community with several non-game fish species that are intolerant to high nutrients; however the densest patches of aquatic plants happen to be found in areas of greatest shoreline development, thus placing these habitats at risk if lakeshore owners choose to remove plants in front of their lakeshore to increase recreational access. Thus far, fortunately, lakeshore owners have been conservative with regards to their plant removal activities.

Long-term trends in game fish communities suggest the food-web may be out of balance with an overabundance of top predators (e.g., walleye (*Sander vitreus*), northern pike (*Esox lucius*), and largemouth bass (*Micropterus salmoides*)). As predators have increased over time, prey, particularly yellow perch (*Perca flavescens*) and cisco (tullibee) (*Coregonus artedi*) have declined. Continued declines in cisco are expected if waters continue to warm over the long-term. Fisheries management that reduces predator numbers and increases size structure could promote a recovery in yellow perch populations.

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 South Twin Lake in Mahnomen County, Minnesota (MN). This assessment was compiled based on Minnesota Department of Natural Resources (MDNR) surveys of the lake's fish and aquatic plant communities, Minnesota Pollution Control Agency (MPCA) and volunteer water quality monitoring, and analysis of various other sources of data for the lake. The water quality assessment focuses on data collected during the 2008-2010 monitoring seasons; however, some historical data was used to provide perspective on variability and trends in water quality. Water quality data analyzed will include all available data in EQuIS, the MPCA repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

1867: Treaty between the United States and the Mississippi Band of Ojibwe Indians. Natural resources within the White Earth Reservation are cooperatively managed by the MDNR and the White Earth Natural Resource Department. Status as a Tribal Government provides the White Earth Reservation with broad powers, ensuring various immunities for the Tribe and its individual members. Powers include those of self-governance granted by the Indian Reorganization Act. Immunities include the right to be free from State interference as well as other immunities afforded any other federal entity. All governmental powers of the White Earth Reservation are delegated through the Minnesota Chippewa Tribe's Constitution. Subsistence netting has occurred throughout South Twin's history but tribal members are not required to report catch.

1900 – 1920: According to Marschner's original land survey, South Twin's watershed was composed largely of mixed white and red pine. Pinehurst Resort, was established in 1918 and remains in operation today. The area was probably undeveloped, although little information is available on land use and characteristics of that time.

1920s: Fish stocking began in the 1920s. Records indicate that northern pike (*Esox lucius*), bass (*Micropteruss sp.*), crappies (*Pomoxis sp.*), and sunfish (*Lepomis sp.*) were stocked during 1920 and 1945. Accurate dates and stocking rates are not recorded.

1930s: The first mapping of South Twin's bathymetric contours occurred in 1937. Also in 1937, the outlet dam was constructed. The dam was a Works Progress Administration project built for lake level control and to provide employment opportunities. The dam had 2 stop log bays, with each being 5-feet wide. The elevation of the stop logs were 1,444.1 feet and the water level of the lake was 1,444.3 feet (Waters field report). Today, the ordinary high water mark is 1,445.3 feet. The dam was authorized to have 1.8-feet of stop logs in place, and was built with a concrete catwalk with a hand railing on the downstream side and around the perimeter of the abutments. The earthen slopes around the abutments and shoreline were paved with hand-placed fieldstone. The dike on the left side (facing downstream) of the spillway was 35-feet long and the dike on the right was 65-feet long.

1940s: South Twin was closed to darkhouse spearing from 1944 to 1951, and closed for Northern pike angling from 1944 to 1947. Between 1948 and 1949, there was "experimental" (presumed to mean commercial) fishing for bullheads (*Ameiurus sp.*), yellow perch (*Perca flavescens*), crappies, and sunfish. Bass spawning beds were posted for protection in 1944, and largemouth bass (*Micropterus salmoides*) were stocked in 1945 and 1946. Natural reproduction in 1949 resulted in a large year class of walleyes (*Sander vitreus*) that would become apparent in future assessments.

1950s: An initial fisheries survey was done in 1954. At that time, there were 30 homes surrounding South Twin. South Twin was open to experimental fishing for sunfish and "rough" fish from 1950 through 1953. Recommendations to stock walleye fingerlings was made in 1955, and it was proposed that northern pike be stocked from winter rescue operations to be used to control the large bluegill (*Lepomis macrochirus*) population. Commercial fishermen removed 1050 pounds of bullheads between 1956 and 1958, and 16 pounds of yellow perch in 1956-57. Species stocked during the 1950s include largemouth bass, northern pike, and walleye. Correspondence in the lake file indicates as many as five washouts of the dikes adjacent to the dam between 1951 and 1963. Repairs were made following each washout.

1960s: The outlet dam was significantly altered in 1965. The single pier, railings, and catwalk were removed, and an 11 foot concrete weir was poured to replace the stop logs. The abutments were cut back to prevent tampering with the lake level, and concrete was poured where the weir meets the abutments. The crest of the weir matched the level of a previous dam on the site. The earth fill in the abutments was sloped to match the slope of the cut abutments. The dam regularly plugged with debris and frequent clearing was necessary. Tampering resulted in the dikes of the lake washing out on two occasions. Northern pike and walleye were stocked throughout the 1960s at various rates. Commercial fishermen removed 2,697 pounds of bullheads between 1963 and 1964. Walleye natural reproduction checks were done in 1960 and 1965.

1970s: In 1974, a resurvey was completed on South Twin. At that time, there were 152 homes/cottages along the shore of South Twin. Bathymetric contours were remapped in 1976. The last recorded northern pike stocking occurred in 1978, while the last recorded bluegill stocking was in 1979. Walleyes were stocked every year except 1973. Anglers reported good rock bass (*Ambloplites rupestris*), northern pike, and walleye angling, although the walleyes were reportedly small in size. Large crappies were being caught, and bluegill fishing was described as fair.

1980s: A resurvey was completed in 1982, and population assessment in 1987. During the 1980's, walleyes were stocked at a rate of one pound per littoral acre, every other year. Natural reproduction of walleyes was very good during the early and mid 1980s. Largemouth bass were over 10 times state and local median levels during the 1980s. Bluegills were extremely abundant in 1989, but showed signs of a stunted population. Perch steadily declined through the 1980s.

1990s: A resurvey was completed in 1992. Poor results from alternate year fingerling stocking prompted change to biennial fry stocking at a rate of 1,000 fry per littoral acre in 1994. In 1997, a population assessment was conducted. Walleye catch rates did not positively reflect the 1994 stocking change and anglers had been complaining of poor fishing. As a result, a meeting with lake association officers was held, and an agreement was reached to begin stocking walleye fingerlings at an increased rate of 1.5 pounds per littoral acre, beginning in 1998. It was hoped that fingerling stocking would have a better chance of success at this higher rate than previously tried due to lower northern pike catch rates and higher yellow perch catch rates in 1998. Potential special regulations were investigated for bluegill and northern pike during the late 1990s. South Twin was also one of four lakes within the White Earth Reservation being considered for muskellunge (*Esox masquinongy*) management. Any regulation would require matching White Earth tribal regulations since even a small amount of non-compliance could negate the effects of the regulation. As such, plans for special regulations were abandoned.

2000s: A population assessment was completed in 2002. Catch rates for northern pike, walleye, yellow perch, cisco (tullibee) (*Coregonus artedi*), and yellow bullhead (*Ameiurus natalis*) were all relatively high. Many of the walleye sampled in 2002 were attributed to natural reproduction (non-stocking years). In 2004, the walleye stocking rate was changed to annual stocking of one pound of fingerlings per littoral acre due to new statewide stocking policies. A resurvey was completed in 2007. At that time, there were approximately 137 lake homes, two resorts, 84 seasonal campers along the shore of South Twin. Walleye catch rates declined from the historical high sampled in 2002. Annual special assessments started in 2008 as part of the SLICE program. Walleye stocking continues at the rates established in 2004, with one pound of fingerlings per littoral acre on an annual basis. This rate is based on statewide walleye stocking policy implemented in 2001 (i.e., Accelerated Walleye Program). The food-web appears to be out of balance with a high abundance of top predators and extremely low levels of perch and declining cisco populations.

Background

Lake Morphometric and Watershed Characteristics

South Twin Lake is located in Mahnomen County within the Wild Rice River watershed. South Twin Lake is just south of Nay-tah-waush, MN. A public access is located on the western shore. South Twin Lake is a shallow lake that remains mixed for most of the summer, but can start to stratify during calm conditions.

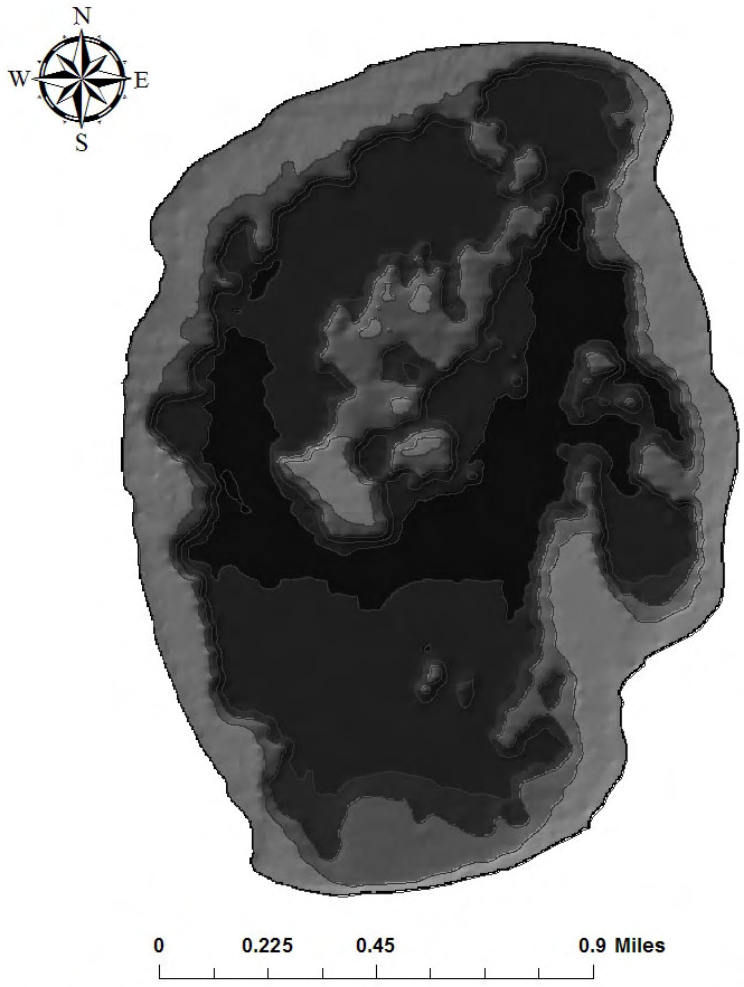
South Twin Lake's morphometric characteristics are summarized in Table 1. Also, a three dimensional representation of the lake's depth contour is presented in Figure 2. Percent littoral area refers to that portion of the lake that is 4.5 meters (15 feet) or less in depth, which often represents the depth 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. Roughly 47 percent of South Twin Lake is considered littoral.

Table 1. South Twin Lake and watershed morphometric characteristics

Lake Name	Lake ID	Lake Basin	Littoral Area	Total Watershed Area	Watershed: Lake	Max. Depth	Mean Depth
		Hectares (Acres)	%	Hectares (Acres)	Ratio	Meters (Feet)	Meters (Feet)
South Twin Lake	44-0014	452 (1,118)	47	2,724 (6,743)	6:1	8.8 (28.9)	3.7 (12.1)

Lake bathymetry based on MDNR 2008 acoustic survey.

Figure 2. South Twin Lake three dimensional depth contour map



MDNR Ecological Services & Fisheries Divisions 2008
Lake Bathymetric DEM Shaded Relief Image

The South Twin Lake contributing catchment watershed lies within the Wild Rice major watershed in the Red River basin. The contributing catchment watershed drains from the northern shore of South Twin Lake to North Twin Lake. The contributing watershed has a total area of 2,724 hectares (6,743 acres) resulting in a watershed-to-lake area ratio of approximately 6:1. Watershed catchment areas were estimated based on data from MDNR delineations.

South Twin Lake soils are defined as coarse- to medium-textured forest soils formed from glacial outwash from the Menahga-Marquette series. The area is level to rolling and the soils are light-colored and droughty. Agriculture is minimal and Jack pine is the most common tree species (Arneman 1963). South Twin Lake was likely formed as an ice block basin in either the glacial till or the outwash (Zumberge1952).

Lake Mixing and Stratification

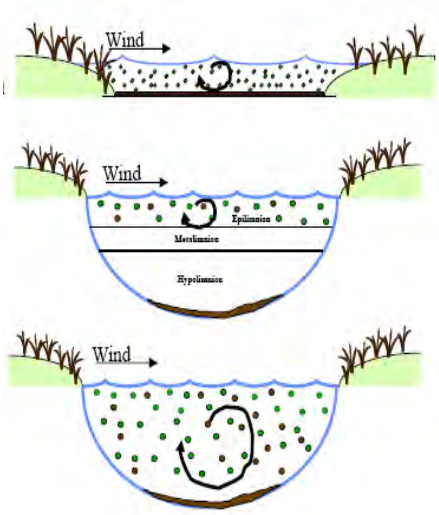
Lake depth and mixing has a significant influence on lake processes and water quality. *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 9 meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 3). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of five 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 environment in the hypolimnion are conducive to 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 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. South Twin Lake lies within the Northern Lakes and Forest (NLF) ecoregion (Figure 4) and was one of the reference lakes for this ecoregion. NLF ecoregion values will be used for land use (Table 2) and summer-mean water quality comparisons (Table 7). Additionally, the NLF ecoregion will be used for the model application.

Land use within the watershed is typical for the NLF ecoregion. When compared to historical records from 1969 and 1991, the land use for South Twin Lake's watershed shows little change with forest being the dominant land use (Figure 5 & Table 2).

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

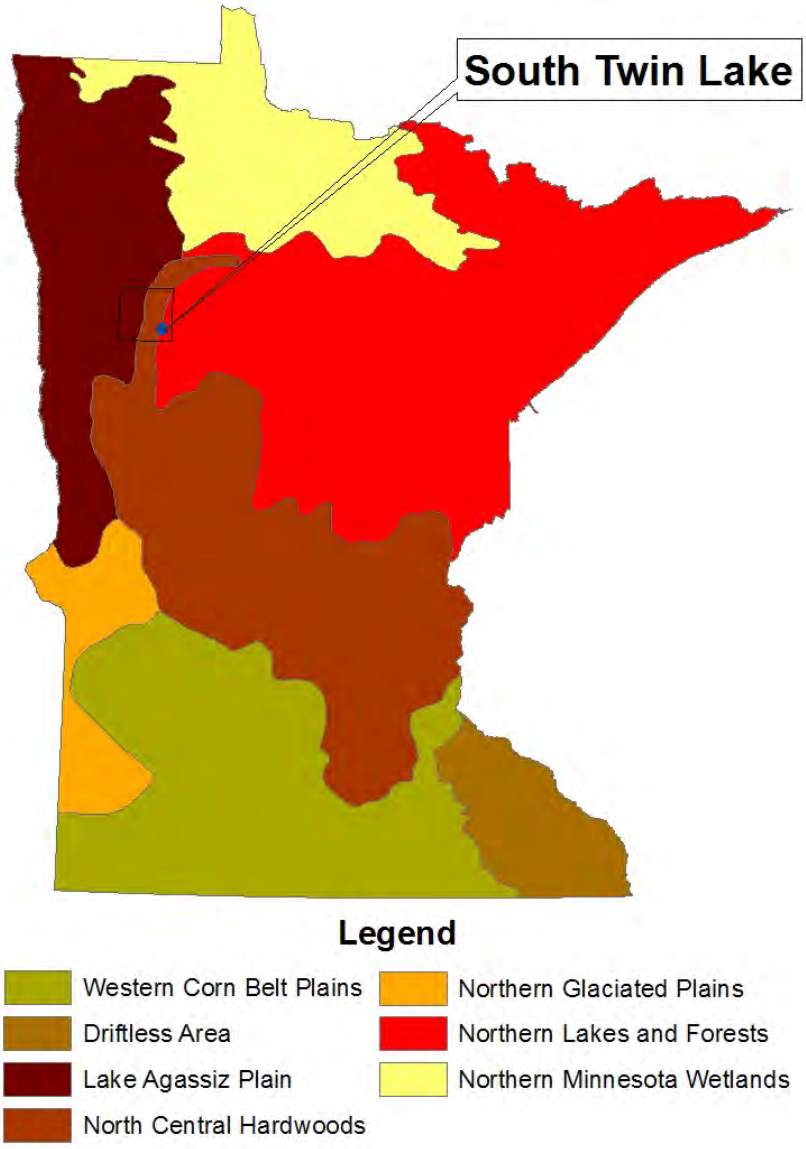
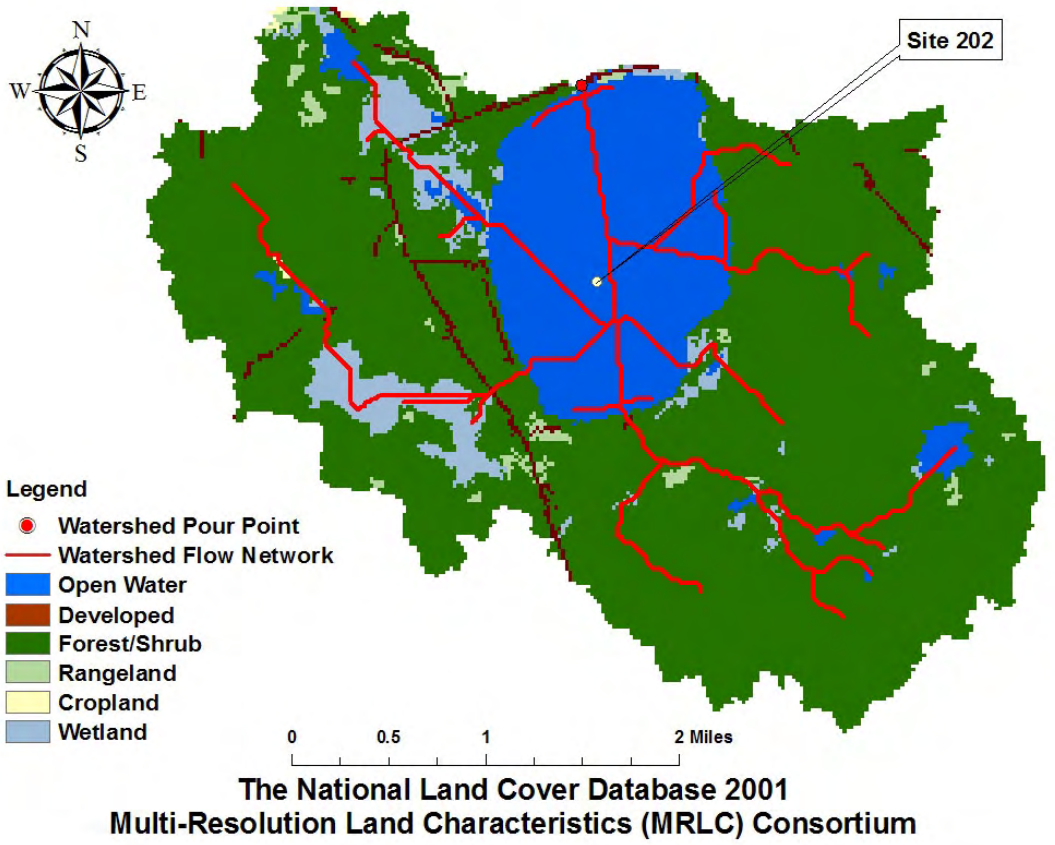


Table 2. South Twin Lake ecoregion land use comparison. Typical (interquartile) range based on NLF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	South Twin Lake (1969)[2]	South Twin Lake (1991)[3]	South Twin Lake (2001)[1]	NLF Ecoregion
Developed	4	1	1	0 - 7
Cultivated (Ag)	<1	<1	<1	<1
Pasture & Open	11	1	1	0 - 6
Forest	77	74	74	54 - 81
Water & Wetland	19	24	24	14 - 31

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

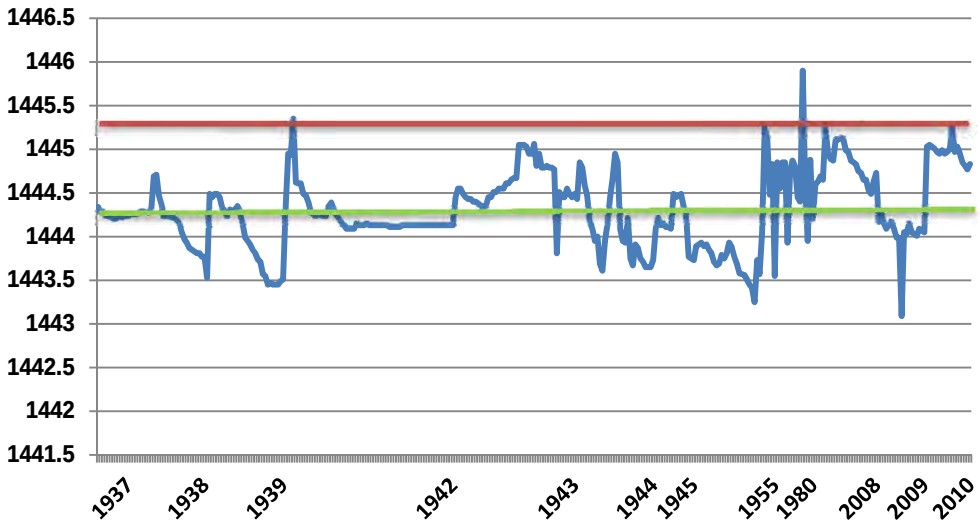
Figure 5. South Twin Lake water chemistry monitoring location, watershed area, and land use composition



Lake Level

The MDNR Division of Waters has been measuring water levels sporadically on South Twin Lake since 1937. During the period of record (1937 - 2010), the lake has varied by 2.65 feet, based on 345 readings. The highest and lowest recorded elevations are 1,445.9 feet on 06/23/1976 and 1,443.25 feet on 09/08/1946. The ordinary high water mark for South Twin Lake is 1,445.3 feet (red horizontal line within Figure 6). Based on recorded lake levels the lake has typically remained over 1.5 feet below the ordinary high water mark with a long term mean of 1,444.3 (green horizontal line within Figure 6). The complete water level record may be obtained from the MDNR web site at:
http://www.dnr.state.mn.us/lakefind/showlevel.html?id=44001400

Figure 6. South Twin Lake water level record. Ordinary high water mark represented by red horizontal line. Long term mean represented by green horizontal line.



Precipitation and Climate Summary

Rain gauge records from Itasca State Park which is 20 miles to the East of South Twin, show six one-inch plus rain events during summer 2010 (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 2010. Precipitation records for the 2010 water year (October 2009 through September 2010) indicated the South Twin Lake area received 6-10 inches above normal precipitation (Figure 8). Based on long-term records 2008 and 2010 had above normal precipitation, while 2009 was below normal (Figure 9). This had a distinct influence on lake level (Figure 6).

Figure 7. Summer 2010 rainfall based on records for Itasca State Park

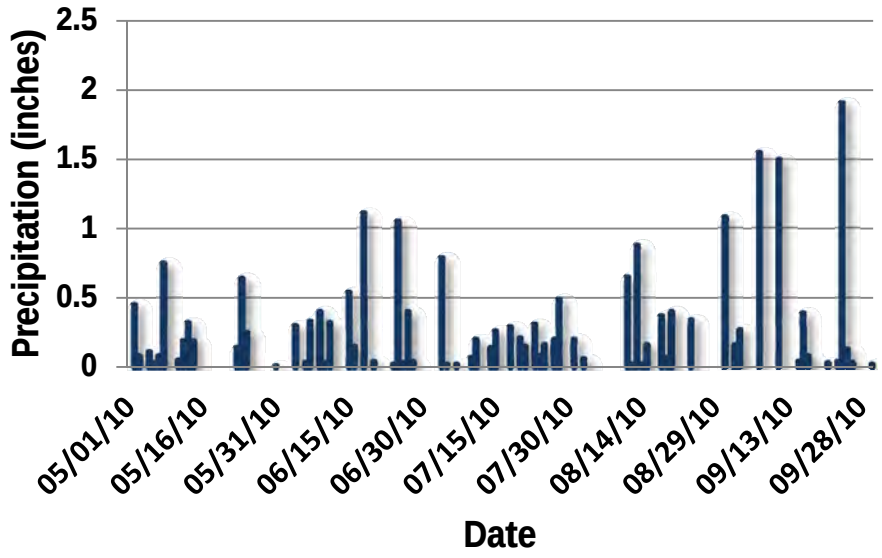


Figure 8. 2010 Minnesota water year precipitation and departure from normal

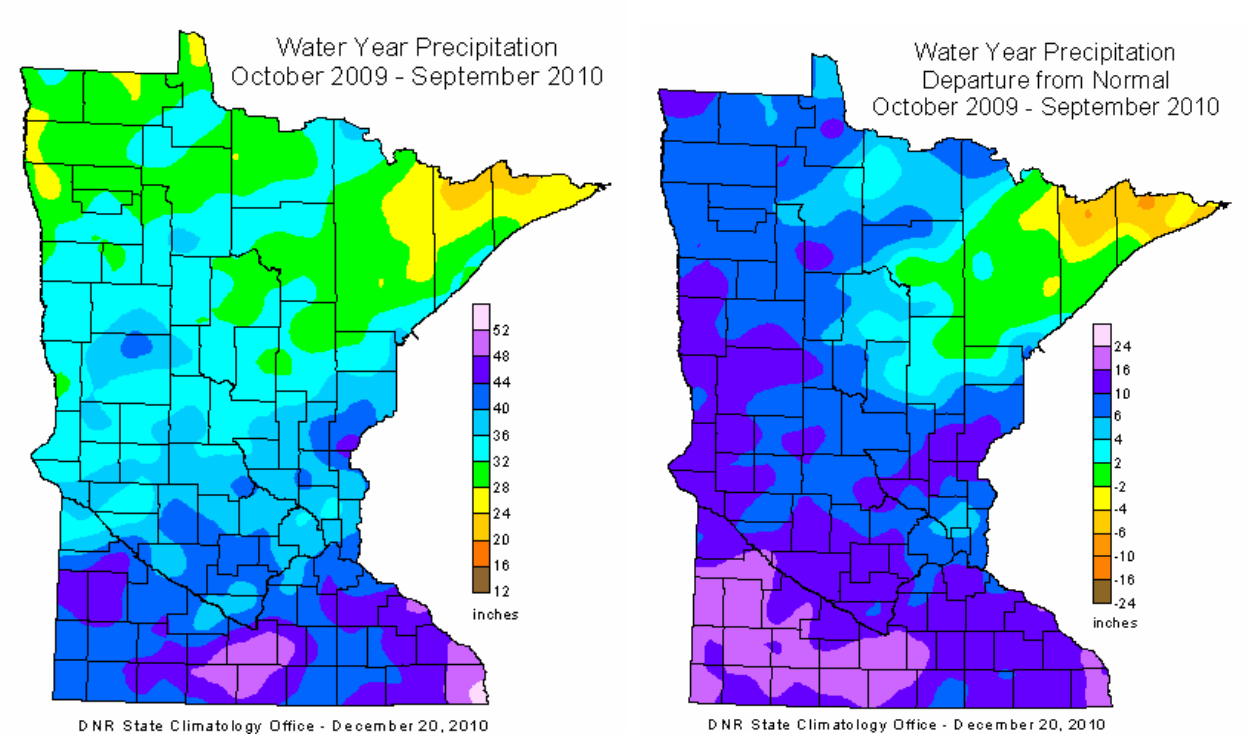
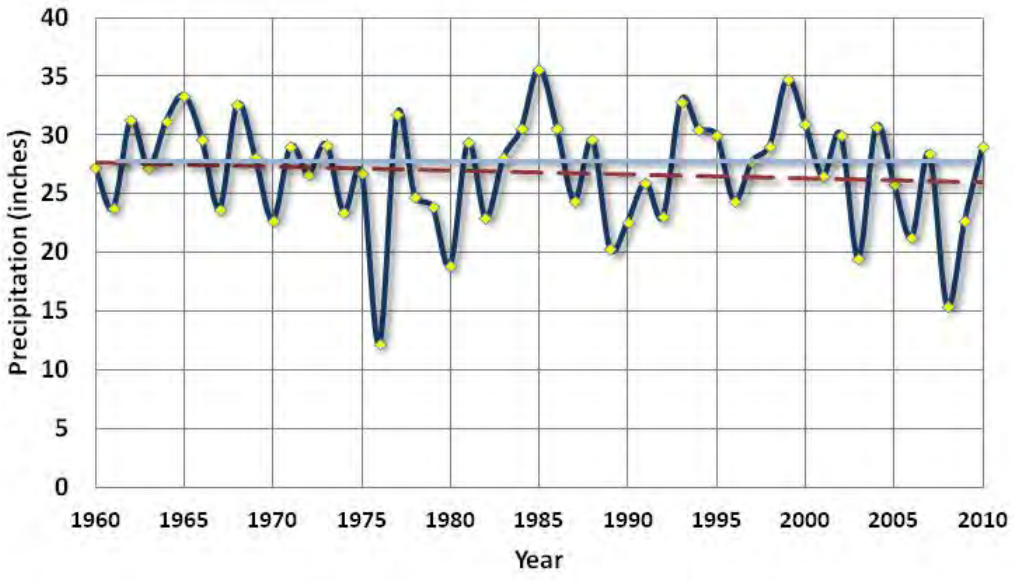


Figure 9. Historical summer precipitation trends based on records for Itasca State Park. Light blue line is long term mean and red dashed line represents simple linear regression.



Methods

Fisheries and Aquatic Plants

Frequency of occurrence of aquatic plant species were assessed using the point-intercept method (Madsen 1999). This method entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately one meter, then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80-meters (0.7 points per littoral acre). In summer 2008, hydro acoustics were used to survey vegetation biovolume (percent of water column occupied by vegetation) along 40-meter transects using methods and equipment described by Valley et al. (2005). Local kriging with VESPER 1.6 was used to create 15-m raster grids of biovolume (Walter et al. 2001; Minasny et al. 2002).

Most recent Fisheries surveys follow guidelines outlined by DNR Special Publication 147 (MDNR 1993). Fish community integrity (IBI) surveys were also completed on each sentinel lake following methods described by Drake and Pereira (2002).

Water Quality

Water quality data for South Twin Lake has been collected monthly from May through October since 2008 by MPCA staff. Several volunteers have also collected periodic dissolved oxygen (DO) and temperature profiles and Secchi disk measurements. Lake surface samples were collected by MPCA staff 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 micrometer (µm) mesh Wisconsin zooplankton net. Depth total phosphorous (TP) samples were collected with a Kemmerer sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples were collected at site 101 (Figure 5). Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf .

Laboratory analysis was performed by the Minnesota Department of Health Environmental Laboratory using United States Environmental Protection Agency (USEPA)-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride (Cl), 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 2008-2010. Two replicate vertical tows were taken at 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% reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 micrograms per liter (µg/L) mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5-milliliter aliquot. A 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 in Hirsch 2009).

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 within survey catch information 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 qualifying and quantifying changes in environmental and fisheries characteristics over time.

South Twin Lake's fish community is relatively diverse compared with other Minnesota lakes, but average for lakes of similar productivity (Table 3**.**). The lake has an assortment of cold-, cool-, and warm-water species. In 2008-2010, survey crews assessed the "biotic integrity" of the fish community in South Twin Lake (Drake and Pereira 2002). Indices of biotic integrity (IBI) have been used for decades across North America to assess status of aquatic communities and to classify biotic impairments (Angermeier and Karr 1994). Although formal criteria have yet to be developed for classifying biotic impairments in Minnesota lakes, IBI survey data from over 400 lakes across the state where fish IBI survey data are available provide a good assessment of the range of conditions we might expect in lakes of differing productivity.

IBI surveys conducted in South Twin Lake during 2008-2010 were within the normal range when compared with other lakes of similar productivity (score range = 102 - 119). Six species classified as intolerant to nutrient pollution were surveyed (Table 3). Several of these intolerant minnow species found in South Twin Lake have disappeared from many Twin City metropolitan lakes whose watersheds have been developed or hydrologically altered (Dodd 2009). High water clarity with dense muskgrass (*Chara* sp.) in lakes like South Twin is important for several intolerant fish species that inhabit shallow areas of lakes (Valley et al. 2010).

Table 3. Trophic position, thermal guild, and tolerance to nutrient pollution of all fish species historically sampled in South Twin Lake

Common name	Species name	Trophic guild	Thermal Guild[a]	Environmental tolerance[b]	First Documented
Cisco	*Coregonus artedi*	Zooplanktivore	Cold	Intolerant	1954
Northern red-belly dace	*Phoxinus eos*	Herbivore	Cold-cool	Neutral	2009
Iowa darter	*Etheostoma exile*	Insectivore	Cool	Intolerant	1987
Northern pike	*Esox lucius*	Predator	Cool	Neutral	1954
Central mudminnow	*Umbra limi*	Insectivore	Cool-warm	Neutral	2007
Creek chub	*Semotilus atromaculatus*	Insectivore	Cool-warm	Tolerant	2007
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-warm	Neutral	1974
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1954
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	Tolerant	1954
Rock bass	*Ambloplites rupestris*	Predator	Cool-warm	Intolerant	1954
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1954
Log perch	*Percina caprodes*	Insectivore	Warm	Neutral	1974
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Warm	Neutral	1954
Yellow bullhead	*Ameiurus natalis*	Omnivore	Warm	Neutral	1954
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	2007
Brook silverside	*Labidesthes sicculus*	Insectivore	Warm	Neutral	2010
Mimic shiner	*Notropis volucellus*	Insectivore	Warm	Intolerant	2010
Emerald shiner	*Notropis atherinoides*	Insectivore	Warm	Neutral	2008
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	Neutral	1954
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	Neutral	2007
Blackchin shiner	*Notropis heterodon*	Insectivore	Warm	Intolerant	2008

Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1954
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1954
Green sunfish	*Lepomis cyanellus*	Insectivore	Warm	Neutral	1982
Black crappie	*Pomoxis nigromaculatus*	Insectivore	Warm	Neutral	1954
Blacknose shiner	*Notropis heterolepis*	Insectivore	Warm	Intolerant	1992
Tadpole madtom	*Noturus gyrinus*	Insectivore	Warm	Neutral	2008
Bluntnose minnow	*Pimephales notatus*	Omnivore	Warm	Neutral	1954
Fathead minnow	*Pimephales promelas*	Omnivore	Warm	Tolerant	2009
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1954

[a]Thermal guilds classified by Lyons et al. (2009)
[b]Environmental tolerance classified by Drake and Pereira (2002)

Fish Management and Population Assessments

Northern Pike - Northern pike catch rates were 0.6 fish per gill net in 1974, and northern pike were stocked in 1978 (Figure 10). Following stocking, the population increased quickly and the catch rate was 10.6 in 1982. In 1987, the catch rate had decreased to 6.3, but the population rebounded in 1992 and the catch rate was 11.2. Following another drop in the catch rate in 1997, the population has been increasing to its current historic high of 17.5 northern pike per gill net. Through the population fluctuations, the size and abundance of large northern pike has decreased, and the population is dominated by smaller northern pike (Figure 11). Some large fish are present in the population, but 94% of the fish sampled in 2010 were smaller than 24 inches. Historically, the average percentage of the population over 24 inches is about 10%. Growth rates of northern pike are slower than the statewide average. South Twin has a history of producing northern pike over 30 inches, and special regulations were investigated in the late 1990s. Lack of agreement with the White Earth Reservation and the inability to enforce the regulation resulted in abandoning the proposal. There appears to be a strong inverse link between northern pike and yellow perch population abundance. Times of high northern pike populations coincide with low yellow perch populations. High populations of walleye are likely exacerbating the recent decline of yellow perch.

Walleye - Multiple stocking regimes have been attempted on South Twin, as reflected in the historical section. In addition the White Earth Tribe and a local sportsman club stock walleye with variable rates and accurate records are not always kept. Perhaps as a result, catch rates have varied dramatically since the initial survey in 1954 (Figure 10). Still, the catch rates have generally remained within the typical range for similar lakes in Minnesota, and the historical average for South Twin is 7.5 walleyes per gill net. Peaks in the population were in 1974 and 2002 with catch rates of 14.8 and 15.8, respectively. Catch rates were 3 fish per net throughout the 1990s. Following the peak of 2002, the population decreased steadily until 2009. The 2009 catch rate was 4.8. The population has increased once again, as the 2010 the catch rate was 10.8. Variable catch rates have resulted in the experimentation with multiple stocking regimes for South Twin by MDNR until 2001 when new statewide intensive stocking policies went into effect (i.e., the Accelerated Walleye Program) that established a consistent high rate of stocking. Despite the heavy stocking, South Twin has a history of producing some good natural year classes. Mean length of walleyes on South Twin is 15.9 inches. Walleye size has decreased since its peak in 1997 potentially due to high harvest (Figure 11). Recreational creel studies have not been completed, and the White Earth tribe does not require reporting of subsistence netting efforts. It is unlikely that the walleye population can remain at the current high level given declines in yellow perch and cisco. Thus, the mandate to intensively stock South Twin will be evaluated and a lower stocking rate in the future should be considered.

Bluegill - Bluegills were stocked in 1979. The historical average catch rate for bluegills in South Twin is 39.5 per trap net (Figure 10); however, net catches have been highly variable through time. This variability is most likely due to inefficiency of the survey gear rather than fluctuations in the populations. During the 1950s and 1970s, large bluegills were common, and a large number of bluegills over eight inches were produced (Figure 11). As the population fluctuated over time, the mean size decreased when catch rates increased. Historical mean length for bluegills in South Twin is 5.4 inches. Bluegills over eight inches have not been common since the 1970s. The current population is dominated by smaller fish, with a mean length of 4.7 inches. Growth rates are slower than the statewide average. With continued climate warming, bluegill populations are expected to increase.

Black Crappies – Like bluegill, black crappie (*Pomoxis nigromaculatus*) net catches have been highly variable over time presumably as a result of gear inefficiencies rather than large changes in the population. The historical mean length of black crappies in South Twin is 7.8 inches (Figure 12). At the population's peak in 1954, mean length was 9.6 inches. The population in the 1980s was relatively small, as mean length was 3.8 inches, and maximum length was 4.3 inches. As the population increased following the 1997 assessment, mean length has generally increased, and crappies over 10

inches were present in the population. Current mean length is 9.1 inches. Crappies are believed to be a commonly sought after species, particularly during spring and winter fishing seasons.

Yellow perch - The yellow perch population increased dramatically during the 1990s, reaching a historic high in 1997 (Figure 10). Following 1997, however, the population crashed and has not recovered. The catch rate of yellow perch in 2010 was 3.5, up slightly from the historic low of 0.5 documented in 2009. Northern pike abundance has been increasing since 1997, and likely is suppressing the yellow perch population. Peaks in walleye abundance throughout history have also likely played a part in the variable perch population. It is unlikely that the increased walleye and northern pike populations will be able to sustain themselves without any yellow perch forage.

Largemouth Bass - Catch rates for largemouth bass have generally been above the typical catch rates for similar lakes in Minnesota. Trap net data, despite the gear being poorly selective for the species, indicates the population may have peaked in the late 1980s, with a catch rate of 9.8 in 1987 (Figure 12). Following that peak, the population may have declined. The catch rate was 0.8 in 1992, and no bass were sampled in 1997. The population presumably increased between 1997 and 2002, and has hovered around the historical average catch rate of 2.8 fish per trap net since that time, which is above the third quartile for lakes in South Twin's lake class (quartiles reflect historic species catch rates within 43 Minnesota lake classes; Schupp 1993). Night time electrofishing, which is more selective for largemouth bass, has been conducted as part of SLICE monitoring since 2008. Electrofishing has sampled a wider range of lengths than trap netting, and the mean length of fish sampled has been larger than the bass sampled with trap nets (Figure 13). Mean length of bass sampled by electrofishing was 12.1 inches between 2008 and 2010, and 9.8 inches during the same time frame with trap nets.

Growth rates for largemouth bass seem to be slightly slower than the statewide average. Increased prominence of largemouth bass populations have been observed throughout northern Minnesota (Schneider 2010) and Canada (Sharma and Jackson 2008). Warmer water temperatures over the long-term due to climate change will likely favor higher prominence of this and other warm water species (e.g., sunfish) and declines in cold water species (e.g., cisco). Consequences of climate change on cool-water species in northern Minnesota (e.g., walleye, northern pike, and yellow perch) are more uncertain and likely to be complex. The structure of the predator community will likely dependent on interactions between cool- and warm-water species (Fayram et al. 2005) and the degree that climate change tips the balance in the favor of warm water species (Minns 2009).

Cisco - Cisco (also known as tullibee) have been steadily declining since a peak in 2002 (Figure 10). Recruitment of new year classes since 2007 appears low and most fish in the population are large adults, too big to be consumed by predators in the lake (Figure 14). The population is below the historical average for South Twin, yet still within normal rage for Lake Class 27. South Twin is on the border of the cisco range for unstratified lakes. Cisco in unstratified lakes is strongly affected by summer temperatures.

There is not a well-developed thermocline in the lake during the summer (Figure 15); however, partial stratification occurs during relatively calm periods in some years. Several of the measured profiles show relatively cooler water near the bottom of the lake, with some depletion of oxygen (e.g. the 8/3/10 profile). Other profiles exhibit near isothermal conditions, probably caused by recent high wind events that drive surface waters deep and mix the entire water column. Cisco habitat in unstratified lakes such as South Twin is completely dependent on summer temperatures. Water quality has little effect – there is no hypolimnion for nutrient-driven oxygen depletion to occur.

The profiles in Figure 15 were taken during the period of greatest oxythermal stress (July 13 through August 12 for unstratified lakes; see Jacobson et al. 2010). Profile data replotted as temperature vs. oxygen illustrate how close oxythermal habitat approached lethal conditions (Jacobson et al. 2008). These profile data indicate lethal conditions were present on 8/6/2008 and on 8/3/2010. Indeed, netting crews noticed some dead cisco on the lake during the week of 8/3/2010. Values of temperature at 3 mg O_2

interpolated from the profiles (a measure of coldwater oxythermal habitat; see Jacobson et al.2010) are presented in Table 4. The mean temperature at 3 mg O_2 of 21.6 degrees Celsius (°C) represents poor cisco habitat. On a scale of 0 to 100 (with 0 being worst and 100 best) calculated from Jacobson et al. (2010), South Twin Lake has a cisco Habitat Suitability Index of 3. The primary reason that the lake maintains a good population of cisco is because of cool summers. There are low Habitat Suitability Indices for lake whitefish (*Coregonus clupeaformis*) (8) and burbot (*Lota lota*) (13) and no habitat for lake trout (*Salvelinus namaycush)* (Habitat Suitability Index of 0).

Table 4. Temperatures at 3 milligrams of oxygen interpolated from the profiles taken by MPCA and MDNR during the period of greatest oxythermal stress (July 13 through August 12) from South Twin Lake

Date	Total Dissolved Oxygen
7/15/2008	21.2
7/16/2008	19.1
7/26/2008	22.0
8/1/2008	22.2
8/6/2008	23.0
7/15/2009	20.2
8/12/2009	19.8
7/29/2010	23.2
8/3/2010	23.5

Because of South Twin's dependence on summer water temperatures and no available coolwater hypolimnetic refuge, the lake is very susceptible to climate warming. South Twin Lake is interesting in that it is one of the most southern of the unstratified lakes that currently have cisco; however, summer mortality events will likely become more common and cisco may not persist in South Twin Lake in the future.

Figure 10. Historical catch per effort [No. per gillnet (GN) or trapnet (TN)] of major fish species in South Twin Lake. Twelve gillnets were set from 1993-2007. From 2008-2011, gillnet numbers were reduced to 4.

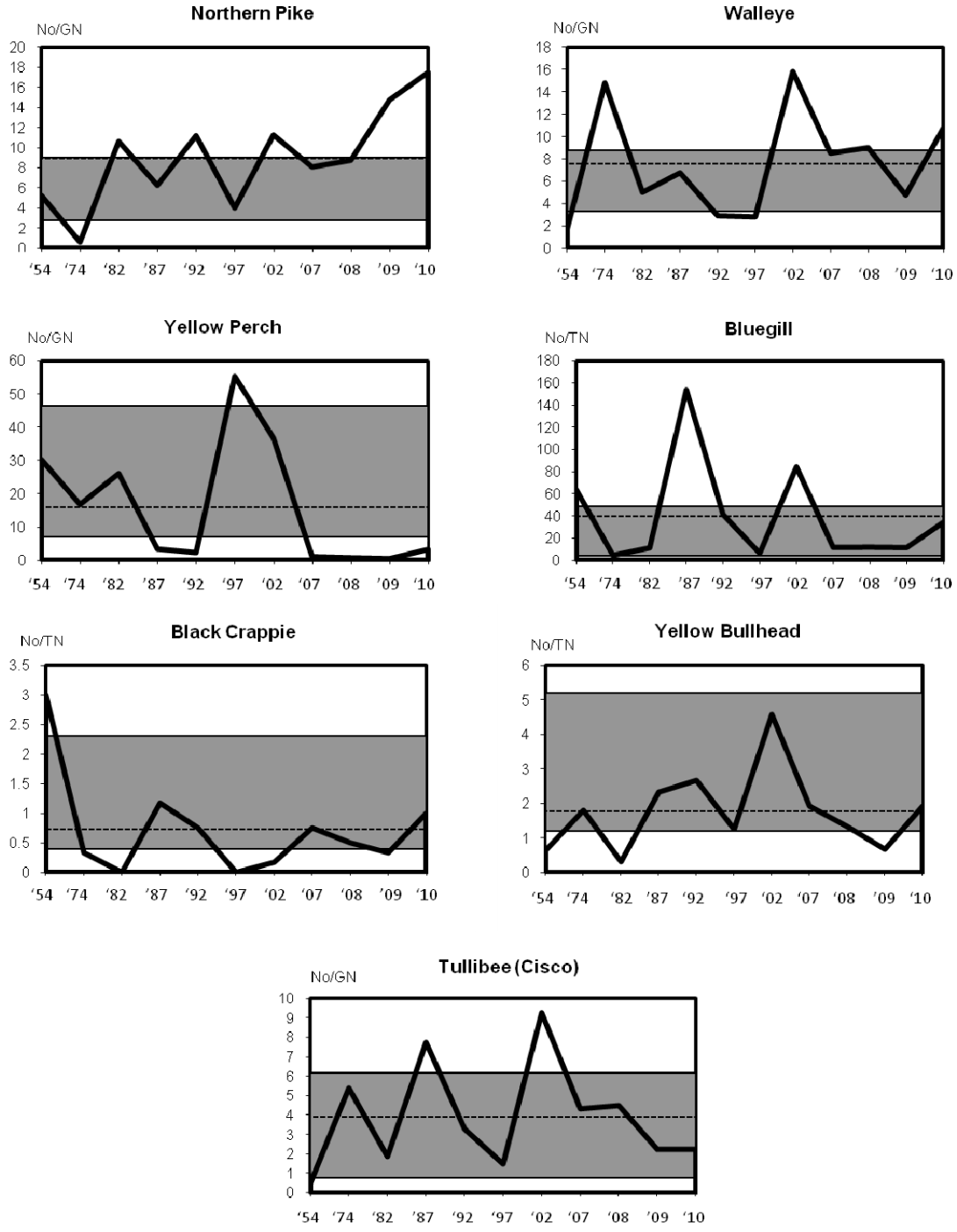


Figure 11. Historic size and Relative Stock Density (RSD – size in inches in parentheses) of northern pike, walleye, and bluegill in South Twin Lake. Gillnet (GN) numbers were reduced from 12 to 4 beginning in 2008.

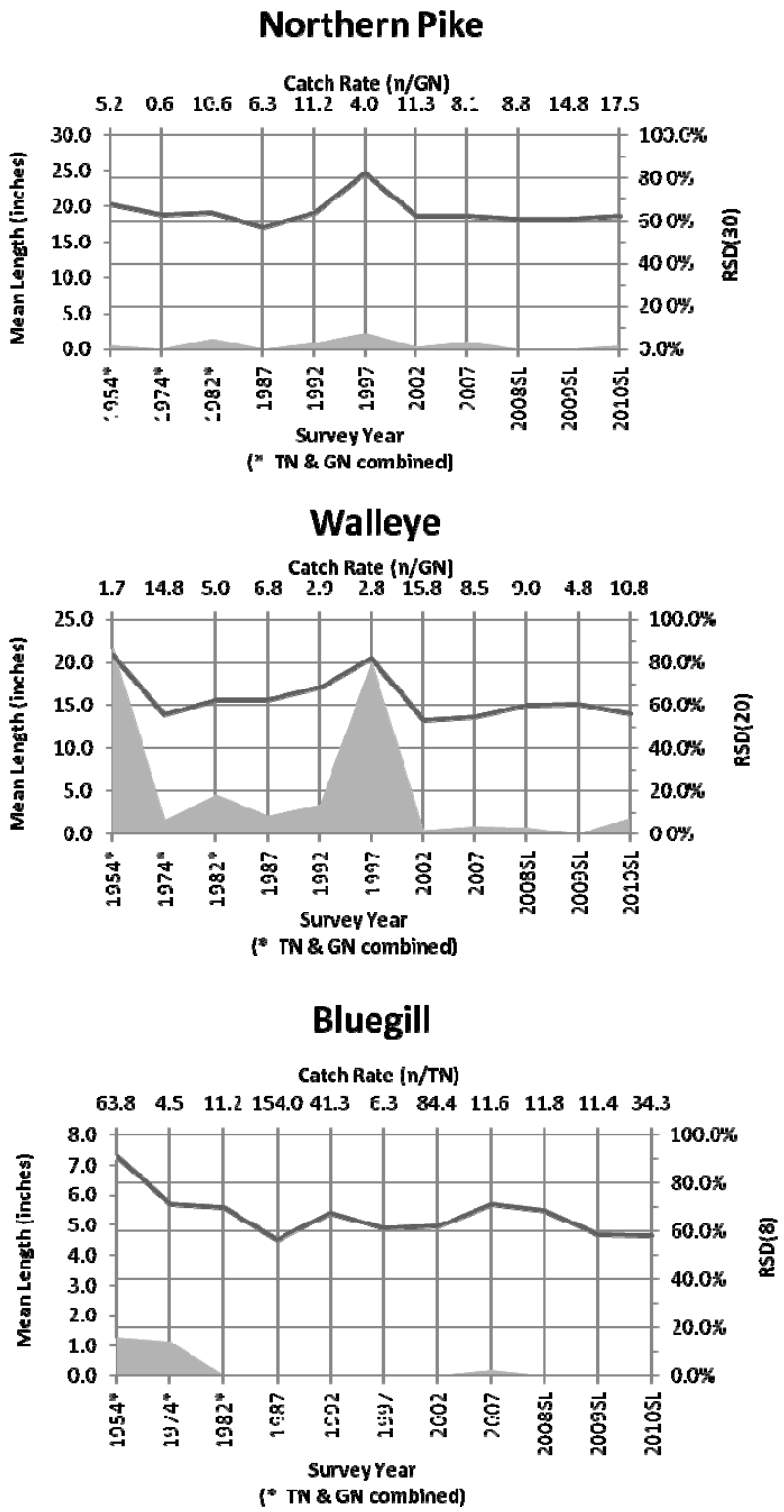
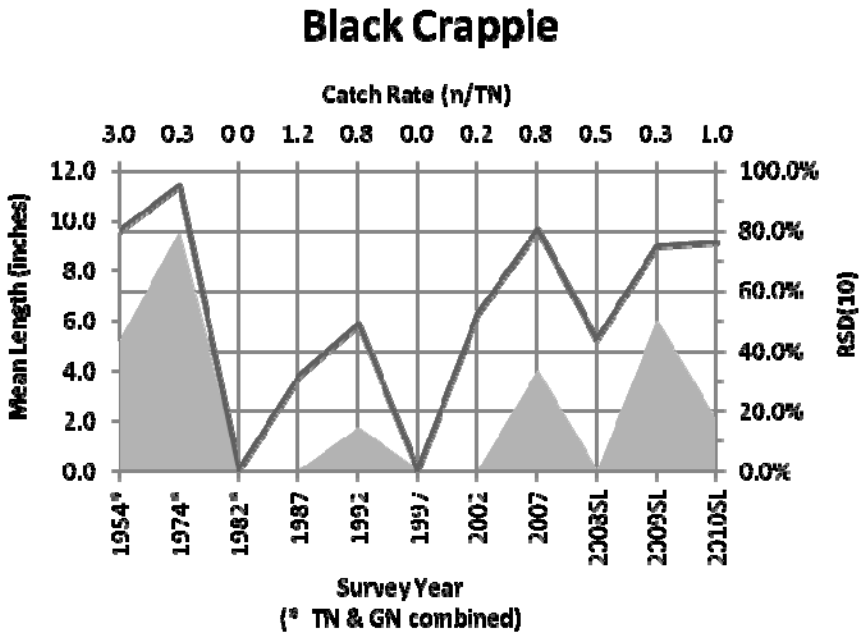


Figure 12. Historic size and Relative Stock Density (RSD – size in inches in parentheses) of black crappie and largemouth bass in South Twin Lake. Gillnet (GN) numbers were reduced from 12 to 4 beginning in 2008. RSD is a relative measure of the proportion of quality sized fish found in a survey.



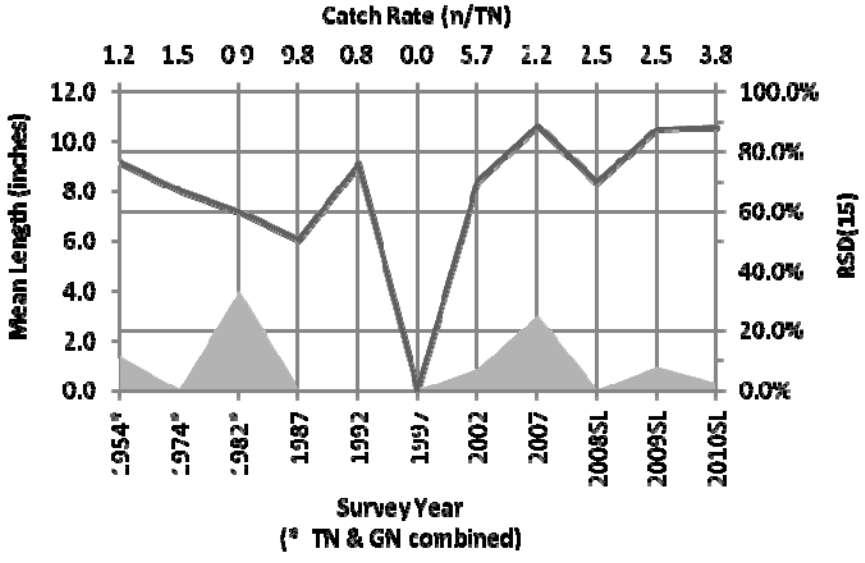


Figure 13. Number of largemouth bass (LMB) captured per hour of night electrofishing and No. of fish > 15 inches in South Twin Lake.

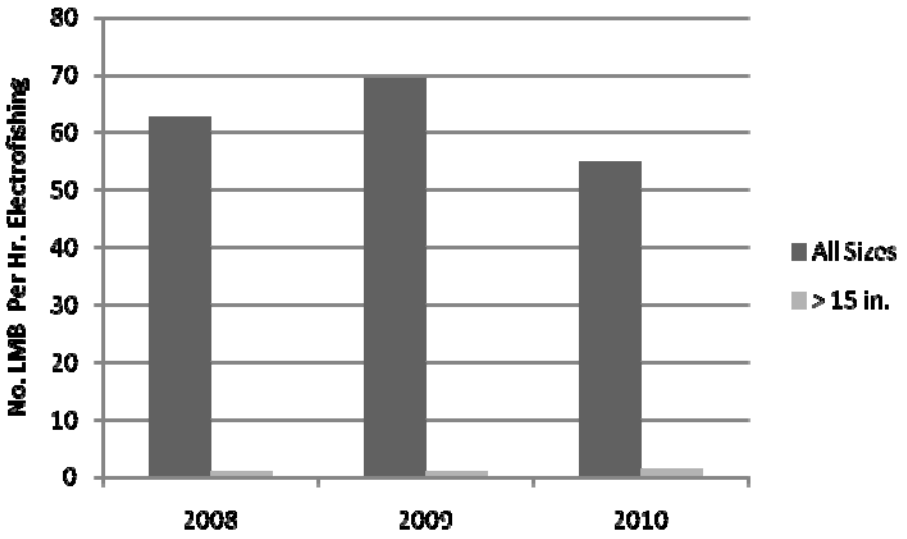


Figure 14. Relative frequency (% of catch) of different size classes of cisco in gillnets pooled between 1997 and 2010 in South Twin Lake. Twelve gillnets were used during 1997-2007, four gillnets were used in 2008-2010.

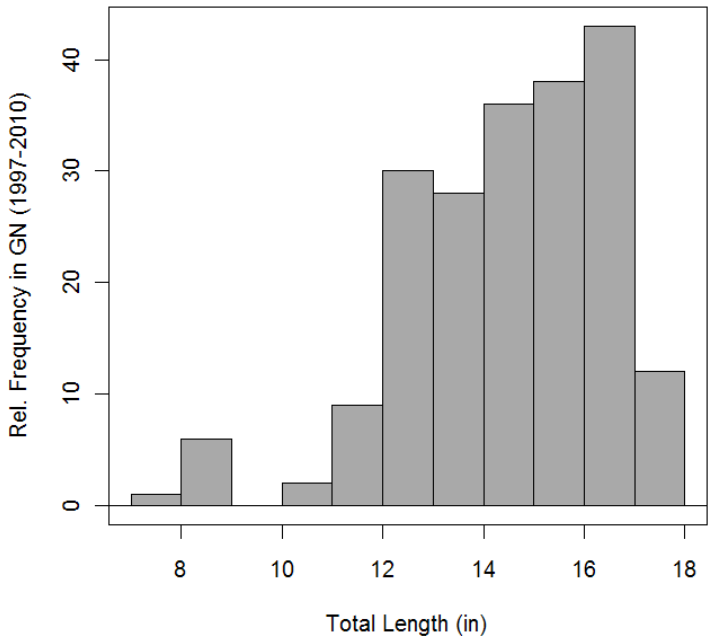
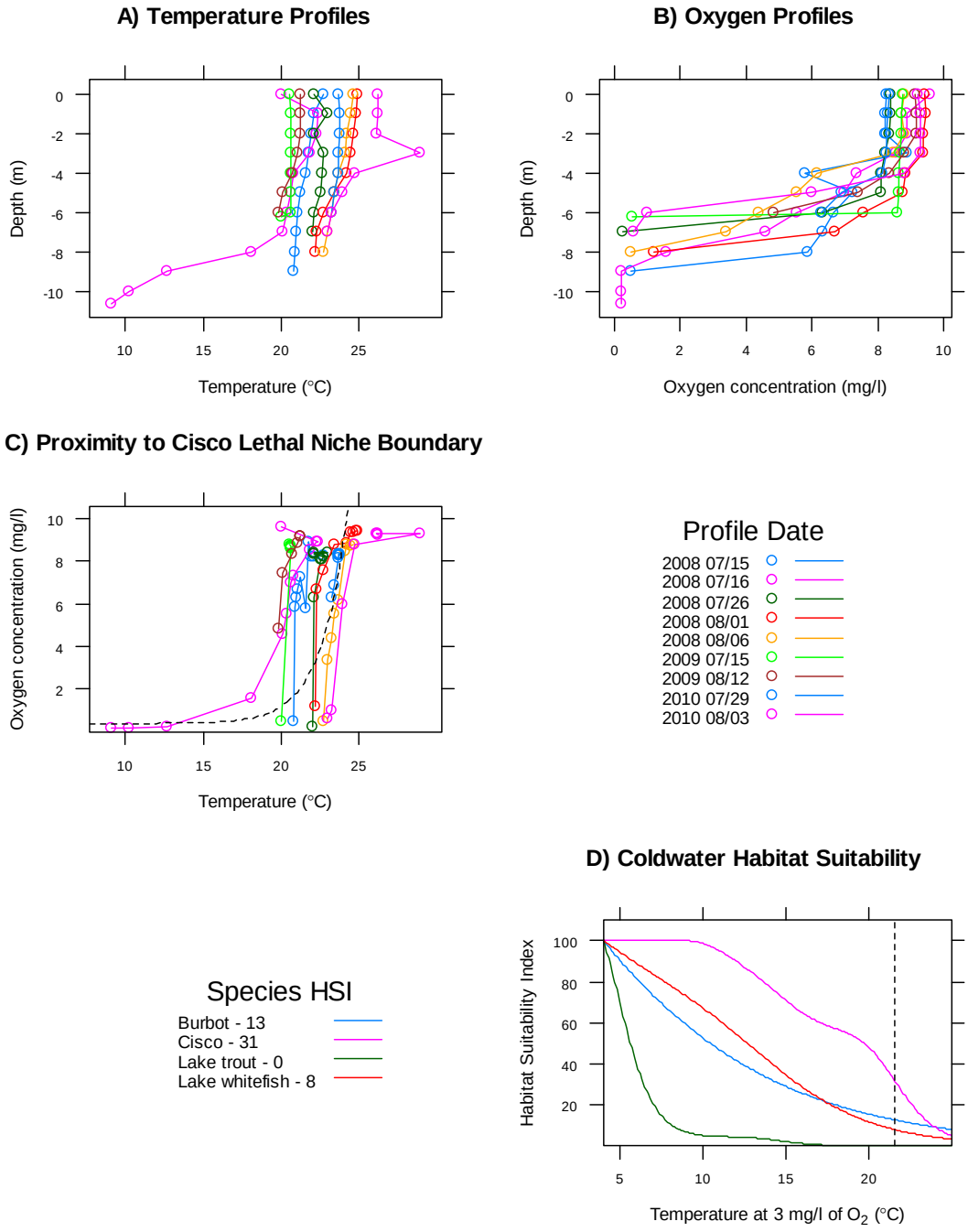


Figure 15. Cisco oxythermal habitat in South Twin Lake. A) and B) are profiles taken during the period of greatest oxythermal stress (July 13 through August 12). C) is the profile data replotted for comparison with lethal oxythermal conditions for cisco (dashed line). The dashed line in D) represents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



Aquatic Plant Assessment

Aquatic plants have been qualitatively assessed as part of most MDNR Fisheries surveys since 1974 (Table 5). In 2008-2010, detailed quantitative surveys of vegetation cover were conducted as part of the SLICE suite of lake surveys. In August 2008, hydroacoustic mapping of vegetation biovolume (percent of water column occupied by vegetation) was conducted.

Throughout its surveyed history, only emergent species hardstem bulrush (*Schoenoplectus acutus*) and submersed flat-stem pondweed (*Potamogeton zosteriformis*) have been noted as being prevalent (Table 5). Because historic plant surveys were rapid assessments with few transects, these findings only suggest that both species were prevalent and do not indicate the absence of species found more recently with more comprehensive surveys. Today, the aquatic plant community in South Twin is moderately diverse with 8-12 species occurring at frequencies greater than or equal to 10% in depths less than 4.5 meters (15 feet) (Table 6). Index of biotic integrity scores as described by Beck et al. (2010) were moderate compared with lakes similar to South Twin and ranged from 65-75 (out of 100). *Chara* sp. or muskgrass is common in the lake and abundant in spots, providing both water quality and fish habitat benefits (Valley et al. 2010).

Table 5. Common aquatic plant species sampled during past MDNR Fisheries lake surveys. Species were deemed common if they were either noted as "common" or "abundant" or if they were encountered greater than 10% of the sample stations or transects surveyed.

Date	Common Name	Species Name	Growth Form
8/12/1974	Hardstem bulrush	*Schoenoplectus acutus*	Emergent
	Flat-stem pondweed	*Potamogeton zosteriformis*	Emergent
7/12/1982	Hardstem bulrush	*Schoenoplectus acutus*	Emergent
	Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed
7/13/1992	Hardstem bulrush	*Schoenoplectus acutus*	Emergent
	White water lily	*Nymphaea odorata*	Floating leaf
	Coontail	*Ceratophyllum dermersum*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
	Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed
	Common bladderwort	*Utricularia vulgaris*	Submersed
7/17/2007	Hardstem bulrush	*Schoenoplectus acutus*	Emergent
	Arrowhead	*Sagittaria sp*	Emergent
	Naiad	*Najas sp.*	Submersed
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
	Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed
	Illinois pondweed	*Potamogeton illinoensis*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Filamentous algae		

Table 6. Percent frequency of occurrence of aquatic plant species at depths ≤ 15 feet sampled during point-intercept surveys on 30 July 2008, 17 August 2009, and 6 July 2010 at South Twin Lake

Common Name	Species Name	Growth Form	Frequency (%) 2008	2009	2010
All rooted plants			93.8	96.2	95.5
Muskgrass	*Chara sp.*	Submersed	76.4	79.2	75.8
Common bladderwort	*Utricularia vulgaris*	Submersed	39.7	39.6	31.1
Flatstem pondweed	*Potamogeton zosteriformis*	Submersed	24.7	25.4	21.3
Fries pondweed	*Potamogeton friesii*	Submersed	23.1	17.5	25.5
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	18.2	18.3	12.2
Naiad	*Najas sp.*	Submersed	17.9	1.9	1.3
Illinois pondweed	*Potamogeton illinoensis*	Submersed	13.9	15.8	7.7
Hardstem Bulrush	*Scirpus acutus*	Emergent	11.7	15.3	16.0
Leafy pondweed	*Potamogeton foliosus*	Submersed	10.1	11.5	3.2
Filamentous algae			9.2	1.9	5.0
Sago pondweed	*Stuckenia pectinata*	Submersed	8.7	11.2	7.7
Coontail	*Ceratophyllum demersum*	Submersed	8.4	13.1	13.3
White-stem pondweed	*Potamogeton praelongus*	Submersed	5.7	0.6	13.0
Canada waterweed	*Elodea canadensis*	Submersed	5.4	5.7	4.3
Variable-leaf pondweed	*Potamogeton gramineus*	Submersed	4.1	3.0	3.5
Wild Rice	*Zizania palustris*	Emergent	0.8	2.2	1.1
Floating-leaf pondweed	*Potamogeton natans*	Floating-leaf	0.5	0.3	0
Water moss			0.3	0.3	0.8
Yellow waterlily	*Nuphar sp.*	Floating-leaf	0.3	0.6	0.5
Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	0.3	0.3	0.3
Arum-leaved arrowhead	*Sagittaria cuneata*	Emergent	0.3	0.3	0
Southern naiad	*Najas guadalupensis*	Submersed	0	12.6	0.5
Bushy pondweed	*Najas flexilis*	Submersed	0	11.2	1.3
Arrowhead	*Sagittaria sp.*	Emergent	0	1.4	0.3
Stonewort	*Nitella sp.*	Submersed	0	1.4	0
Softstem bulrush	*Scirpus validus*	Emergent	0	1.1	0.3
Little yellow waterlily	*Nuphar microphyllum*	Floating-leaf		0.6	0
Spikerush	*Eleocharis sp.*	Emergent		0.6	0.5
Cattail	*Typha sp.*	Emergent		0.3	0.8
Narrow-leaved cattail	*Typha angustifolia*	Emergent		0.3	0

Lesser duckweed	*Lemna minor*	Free-floating		0.3	0
Sessile-fruited arrowhead	*Sagittaria rigida*	Emergent		0.3	0
Water stargrass	*Heteranthera dubia*	Submersed		0.3	0
White waterlily	*Nympaea sp.*	Floating-leaf		0.3	0.3
Sedge	*Carex sp.*	Emergent		0	0.3
Star duckweed	*Lemna trisulca*	Free-floating		0	0.3
Small pondweed	*Potamogeton pusillus*	Submersed		0	2.1
Narrow-leaf pondweed	*Potamogeton sp.*	Submersed		0	0.5
Greater duckweed	*Spirodella polyrhiza*	Free-floating		0	0.3
Max depth of veg growth (ft)[a]			15.5	15.3	18.0

[a]Depth of 95% of all plant occurrences

Overall vegetation is sparse in South Twin Lake save for three distinct areas near the northeast shore, north central reef, and south shore (Figure 16). In these areas, vegetation grows close to the surface and represents potential critical habitat areas for the lake's vegetation-dependent fish species such as northern pike, largemouth bass, bluegill, pumpkinseed (*Lepomis gibbosus*), blacknose shiner (*Notropis heterolepis*), blackchin shiner (*Notropis heterodon*), mimic shiner (*Notropis volucellus*), Iowa darter (*Etheostoma exile*), tadpole madtom (*Noturus gyrinus*), and central mudminnow (*Umbra limi*). It will be important to minimize disturbance to these vegetation beds for the conservation of these species.

In 2008 over the whole lake, plants covered approximately 28% of bottom areas (318 acres), with densest growth typically found at intermediate depths of 2.1 – 3.7 meters (7 – 12 feet) (Figure 17). On average, aquatic plants occupied only 4% of the water column over the whole lake plus or minus 4% (i.e., standard deviation of grid cell estimates; Figure 16).

Nearshore Development

Using 2010 aerial imagery acquired from the Farm Service Administration, 148 dock structured were enumerated. Given the South Twin's 8.2 kilometer (5.1 mile) long shoreline, this number seems insignificant until the location of these 148 structures is considered (Figure 18). In 2010, 48 docks were located along a 1,310 meter (4,300 foot) length of shoreline along the south shore (1 dock every 27 meters (89 feet)). The south shore is also where most of the critical aquatic vegetation occurs, thus for fishery habitat conservation, efforts by homeowners should be undertaken to minimize shoreline runoff and removal of nearshore emergent and submerged vegetation. Presently, lakeshore owners on the lake do not seek aquatic plant management permits to destroy more than what is allowed without a permit (232 square meters (2500 square feet) in front of their property). Allowed but unpermitted and permitted destruction of aquatic plants should remain minimal in the interests of aquatic habitat conservation.

Figure 16. Submersed aquatic plant biovolume (% of water column occupied by vegetation) of South Twin Lake. Collected using hydroacoustics described by Valley et al. (2005) during August 2008.

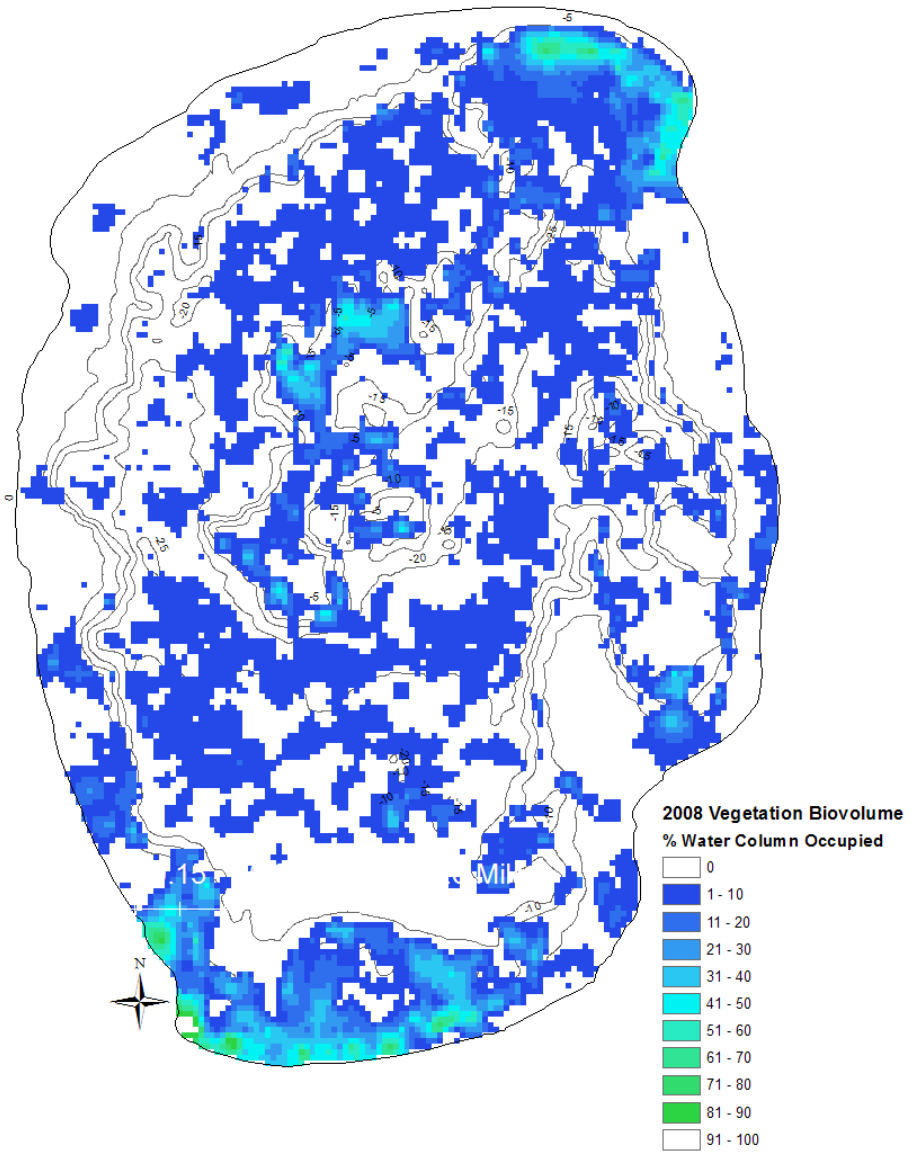


Figure 17. Vegetation biovolume (% of water column occupied by vegetation) as a function of water depth from hydroacoustic vegetation surveys in South Twin Lake in August 2008. A non-parametric regression smoother is plotted through the points (Valley et al. 2005).

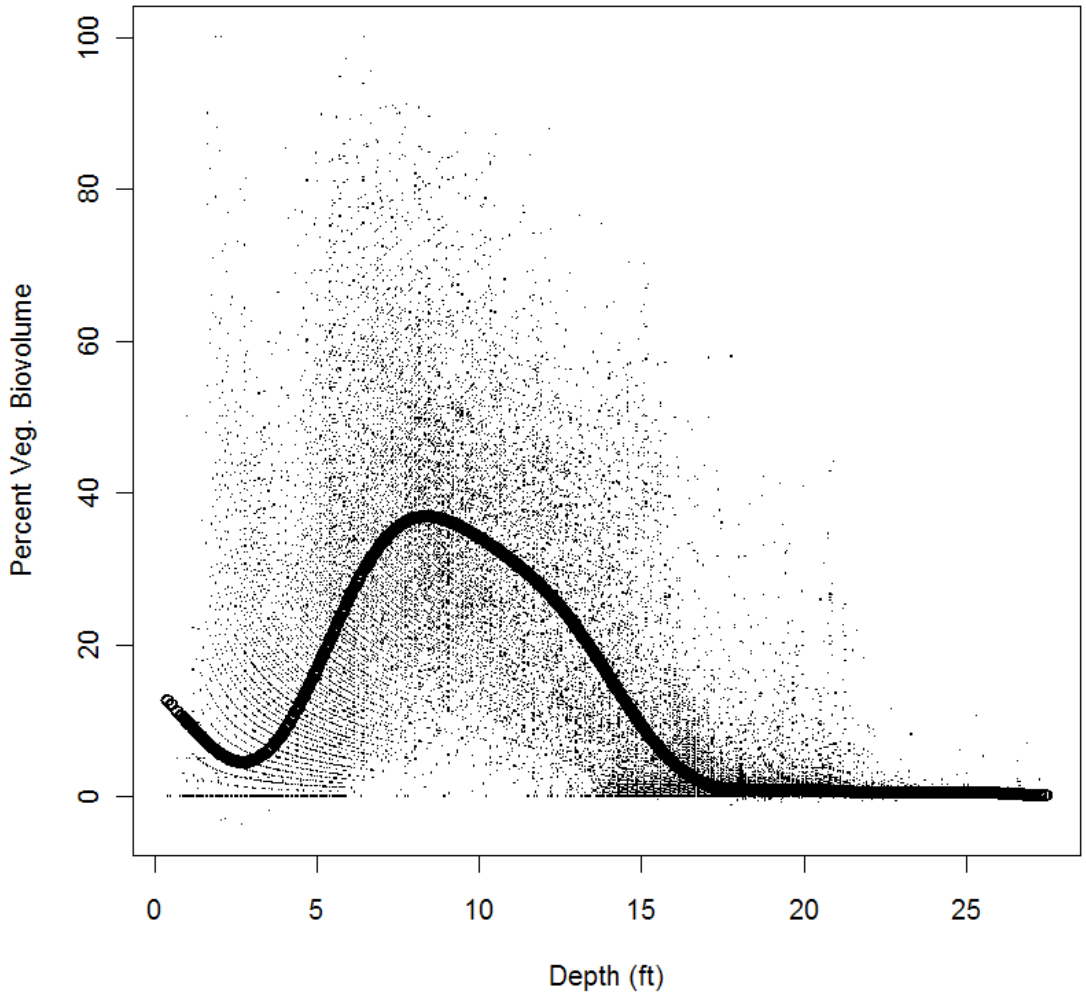
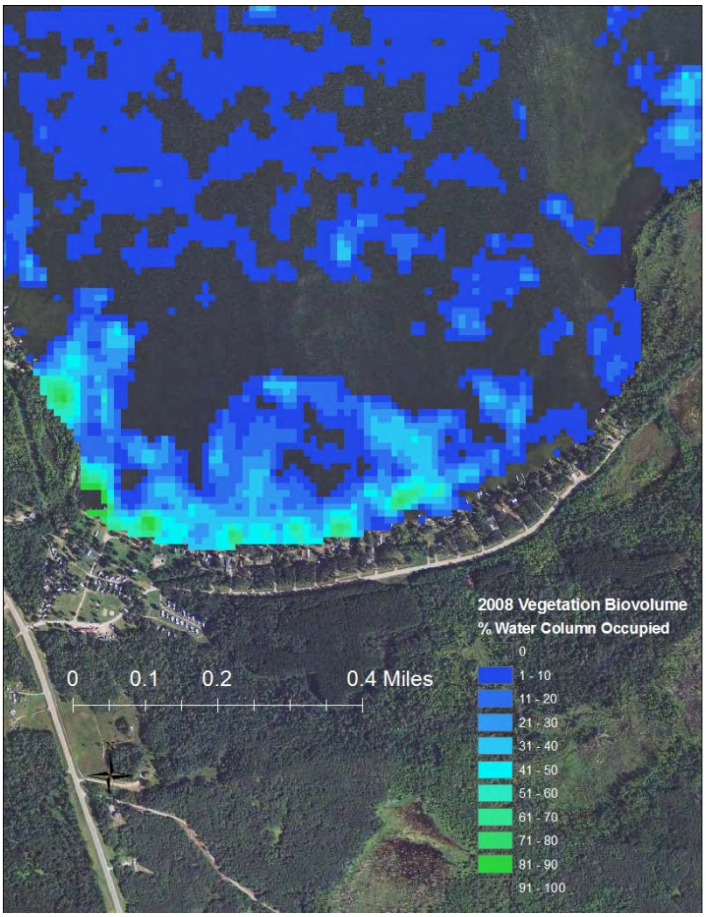


Figure 18. Primary location of lakeshore development on South Twin Lake overlain with submersed vegetation abundance.



Water Quality

Standard summer-mean water quality data for 2008 - 2010 are presented in Table 7, and raw data results are provided in the Appendix. In addition, major cations, anions, and total organic carbon 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 8. The NLA was a statistically-based survey of the nations lakes administered by the USEPA in 2007. The typical range provided in Table 8 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Table 7. South Twin Lake 2008-2010 summer mean water quality. Typical range based on NLF ecoregion reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	South Twin Lake 2008	South Twin Lake 2009	South Twin Lake 2010	NLF
Total phosphorus (µg/L)	17	16	16	14 - 27
Chlorophyll mean (µg/L)	4.7	4.6	4.9	4 - 10
Chlorophyll max (µg/L)	7.8	8	7.1	<15
Secchi disk (feet) (meters)	9.2 2.8	10.2 3.1	9.5 2.9	8 – 15 2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.6	0.5	0.5	<0.4 – 0.75
Alkalinity (mg/L)	170	160	160	40 - 140
Color (Pt-Co Units)	5	5	5	10 - 35
pH (SU)	8.5	8.6	8.8	7.2 – 8.3
Chloride (mg/L)	3.1	3.0	2.9	0.6 – 1.2
Total suspended solids (mg/L)	2.8	2.6	1.9	<1 - 2
Total suspended inorganic solids (mg/L)	1.5	0.8	0.2	<1 - 2
Conductivity (umhos/cm)	292	302	280	50 - 250
Total nitrogen: Total phosphorus ratio	35:1	31:1	31:1	25:1 - 35:1

Table 8. 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]	South Twin	South Twin	South Twin	NLA Interquartile Range		Ion balance	µeq/L	µeq/L
	2008	2009	2010	2007			2009	2010
Ca (mg/L)		30	31	19.1 – 33.7		cations	1,497	1,547
Mg (mg/L)		21	21	6.7 – 26.9			1,727	1,727
K (mg/L)	2	2	2	0.9 – 4.8			51	51
Na (mg/L)	5	4	5	2.2 – 9.0			174	218
Fe (µg/L)		35	14			**sum**	**3,449**	**3,543**
Si (mg/L)		13	12	3.1 – 13.5				
Alk (mg/L	167	163	162			anions	3,260	3,240
SO_4 (mg/L)	1	1	1	2.2 – 14.1			21	21
Cl (mg/L)	3	3	3	1.5 – 18.4			85	85
DOC (mg/L)						**sum**	**3,366**	**3,346**
TOC (mg/L)	6	6	5	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 site 202 (Figure 19). DO levels remain above 5 milligrams per liter (mg/L) from the surface to the bottom of South Twin Lake from July through October of 2010. DO levels fell below 5 mg/L between 5 and 6 meters (16.4 – 19.7 feet) near the sediment-water interface in May and June.

Temperature Profiles were also taken monthly at site 202 (Figure 19) and a temperature logger deployed two-meter below the surface has recorded temperatures at 30-minute intervals year-round since 2008. Temperature profiles indicated that South Twin Lake remained mixed during the entire 2010 monitoring season with no distinct thermocline forming. Surface temperatures at site 102 peaked at 24°C in July and water temperatures at the bottom fluctuated from a high of 23°C in July to a low of 13°C in September. Surface water temperatures got as warm as 26°C on 9 August 2010 but daily summer water temperatures averaged 20.1 to 20.8°C over the three years. Ice-free periods (i.e., the lake "growing" season) ranged from 199 days in 2008 to 235 days in 2010.

A comparison was made between July 2008, 2009, and 2010 profiles (Figure 20). South Twin Lake has consistently remained well-mixed during the summer months of all three monitoring seasons (Figure 20). The 2010 profile shows that the water temperature was nearly two degrees warmer, from surface to bottom, than the 2009 profile. The DO profiles, in contrast, were almost identical between the two time periods.

Figure 19. South Twin Lake 2010 dissolved oxygen and temperature profiles

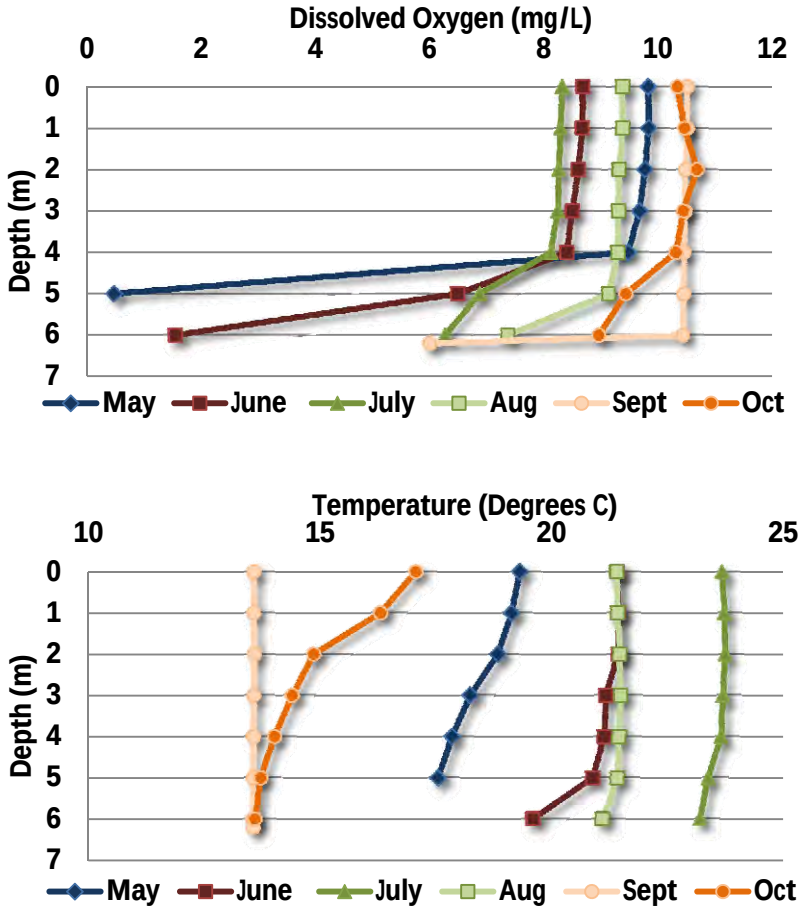
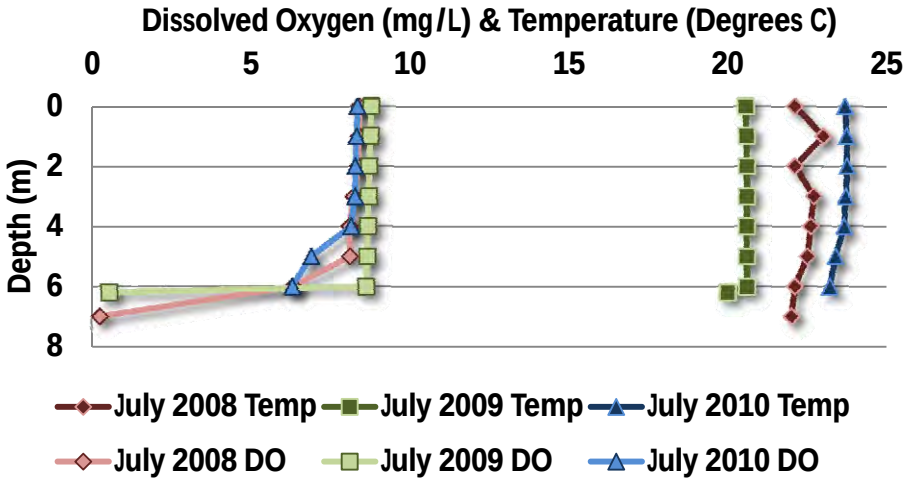


Figure 20. South Twin Lake July 2008, 2009, & 2010 dissolved oxygen & temperature profile comparison



Total Phosphorus concentrations for South Twin Lake (site 202) averaged 16 µg/L in 2010 (Table 7). This average was within the typical range of concentrations for NLF reference lakes. TP concentrations peaked at 21µg/L in May and declined in June (Figure 21). TP increased slightly in August but again declined through October. TP concentrations collected near the lake sediment were similar to those at the surface during all monitoring events with the exception of June of 2008 and 2010 (Figure 22). This coincided with anoxic conditions near the bottom (Figure 19) in May and June of 2010. The low levels of phosphorous near the lake bottom are a good indication that internal phosphorous recycling in South Twin Lake is minimal as compared to more eutrophic lakes. The three-year average for South Twin Lake surface TP was 17µg/L and there was no significant difference among years.

Both external (watershed) and internal (sediments, plants, and fish) sources can contribute to TP levels in lakes. TP in South Twin Lake remained relatively stable throughout each of the three summers monitored. Moderate precipitation occurred in mid-June through mid-July and more significant rain events in mid-August through September (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 smaller lakes and wetlands it is likely that much of the phosphorus from overland runoff is trapped in the various lakes and wetlands (Figure 5).

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During summer 2010, chl-*a* concentrations for South Twin Lake (site 202) ranged from 3 µg/L to 7 µg/L (Figure 21), with an average of 4 µg/L (Table 7). This is also the average for all three years of sampling (2008 - 2010). Chl-*a* concentrations from each sampling event within those three years were just within the typical 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 during the monitoring events.

Secchi disk transparency on South Twin Lake averaged 2.9 meters (9.5 feet) at site 202 during the summer of 2010 (Table 7). The average Secchi depth is within the typical range of values for the NLF ecoregion. The change in the transparency of South Twin 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 2.7 meters (8.9 feet) in August and a high of 5.1 meters (16.7 feet) in May (Figure 21).

Figure 21. South Twin Lake 2010 total phosphorus (surface), chlorophyll-*a* concentrations, & Secchi depth

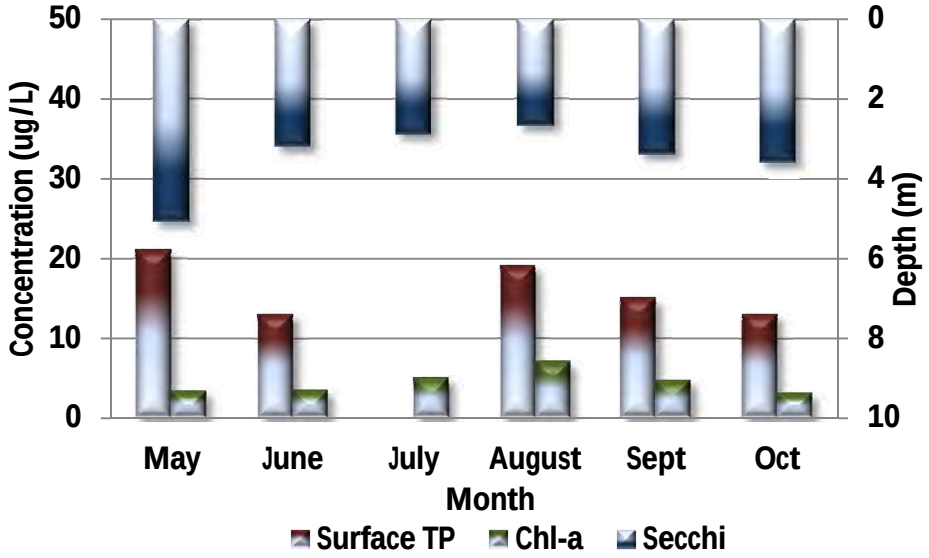
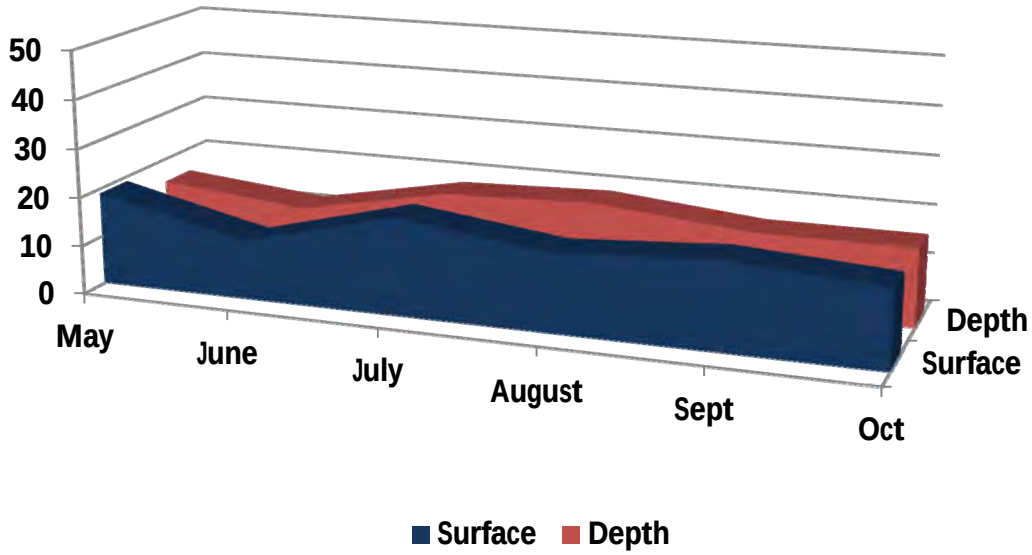


Figure 22. South Twin Lake 2009 surface and depth total phosphorus comparison



Dissolved minerals and organic carbon were measured in 2009 and 2010 as part of the long-term monitoring of South Twin Lake and other Sentinel lakes. This includes some of the standard lake assessment measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 7) as well as major cations, anions, silica, iron and organic carbon (Table 8). 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 8). Since the NLA lakes were selected randomly they provide a reasonable basis for describing typical ranges and distributions at the state-wide level.

TSS values for 2008 and 2009 were slightly above the range of expected values for NLF reference lakes before falling within the expected range in 2010 (Table 7). On average, most of the TSS can be attributed to suspended organic matter (i.e. algae); however in 2008 inorganic suspended solids (sediments) were slightly elevated. The total suspended inorganic solids have decreased since 2008 with 2010 having the lowest amounts. The low color value (Table 7) indicates the water is clear. As such, total organic carbon (TOC) was below the NLA IQ range of values (Table 7). 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). The relatively small watershed to lake ratio combined with a minimal wetland presence likely contributes to the clear conditions. Alkalinity and conductivity are above the typical range for NLF lakes and are indicative of hard water (Table 7). Cation and anion concentrations remained stable across sample events and years (Table 8).

Calcium (Ca) and magnesium (Mg) are the dominant cations and concentrations of both were within the typical range of the state-wide data for both 2009 and 2010 (Table 9). The other two major cations, sodium (Na) and potassium (K), were also within the typical range. Cl is slightly above the typical range for NLF reference lakes (Table 9); however it is low relative to state-wide NLA data (Table 8). Sulfate results were below the detection limits of the analyzing lab equipment for a majority of the sampling events and were reported as a non-detect.

Table 9. South Twin Lake cation, anion, and total organic carbon measurements

Date	Ca[1]	Mg	Na	K	Alk	Cl	TOC	Si
	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
5/21/2008	-	-	5	2	170	3	6	-
7/16/2008	-	-	5	2	170	3	6	-
10/8/2008	-	-	4	2	160	3	6	-
5/20/2009	34	21	4	2	170	3	6	13
7/15/2009	29	20	4	2	160	3	6	12
10/20/2009	28	21	5	2	160	3	6	15
5/27/2010	35	21	5	2	170	3	5	9
7/29/2010	28	20	4	2	160	3	5	12
10/11/2010	29	21	5	2	160	3	6	14
Average	31	21	4.5	2	165	3	5.7	12.5
NLA IQ range (mg/L)	19.1-33.7	6.7-26.9	2.2-9.0	0.9-4.8		1.5-18.4	7.3-14.2	3.1-13.5
µeq/L	1,522	1,727	196	51	3,250	85		

NLA typical range provided as a basis for comparison. [1]Microequivalents (µeq/L) based on average value. Ion concentrations expressed as element (e.g. Ca as Ca)

Zooplankton

Zooplankton samples were analyzed by Jodie Hirsch and Gary Montz at the MDNR Division of Ecological Resources. A summary report was prepared that included information for all the Sentinel lakes sampled in 2008 (Hirsch 2009). Results from 2009 and 2010 were charted by MPCA staff and will be included in the discussion below.

Mean annual density and mean annual biomass for South Twin Lake were moderately ranked among NLF lakes (excluding NLF border lakes) with 2010 having a higher density than 2008 and 2009 (Figures 23 & 24). Hirsch (2009) determined that, in general, as the amount of TP and chl-*a* increases (i.e. trophic state) so too does the relative abundance (biomass) of zooplankton. This appears to be the case for South Twin Lake and the other NLF lakes (Figure 21 & 24). Cladoceran density levels remained higher than daphnia levels with the later declining as the 2010 season progressed (Figure 25). Similar to other NLF lakes biomass peaked in spring and declined as the season progressed (Figure 26).

The zooplankton community over the three year period of record was dominated by copepods. Average cladoceran amounts did appear to make up half of the overall community during the summer of 2010 and did exceed the copepod population in June. Similar to the low variability of South Twin Lake nutrient availability, overall cladoceran and copepod populations have maintained a relatively consistent population level (Figure 27).

Figure 23. Mean annual zooplankton densities for Northern Lakes and Forests Sentinel lakes

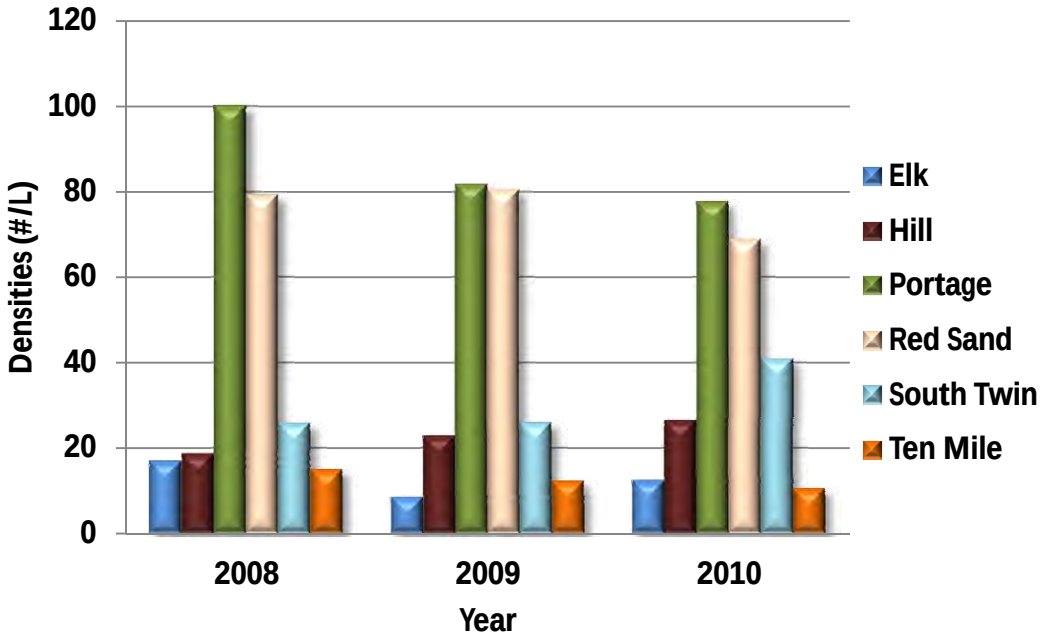


Figure 24. Mean annual zooplankton biomass for Northern Lakes and Forests Sentinel lakes

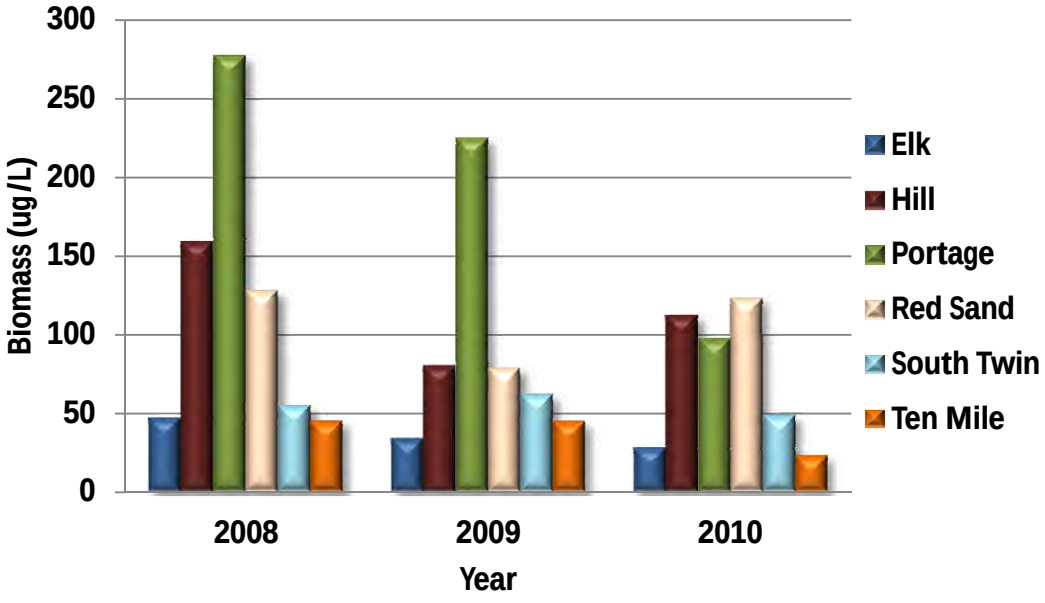


Figure 25. Mean monthly 2010 zooplankton densities for South Twin Lake

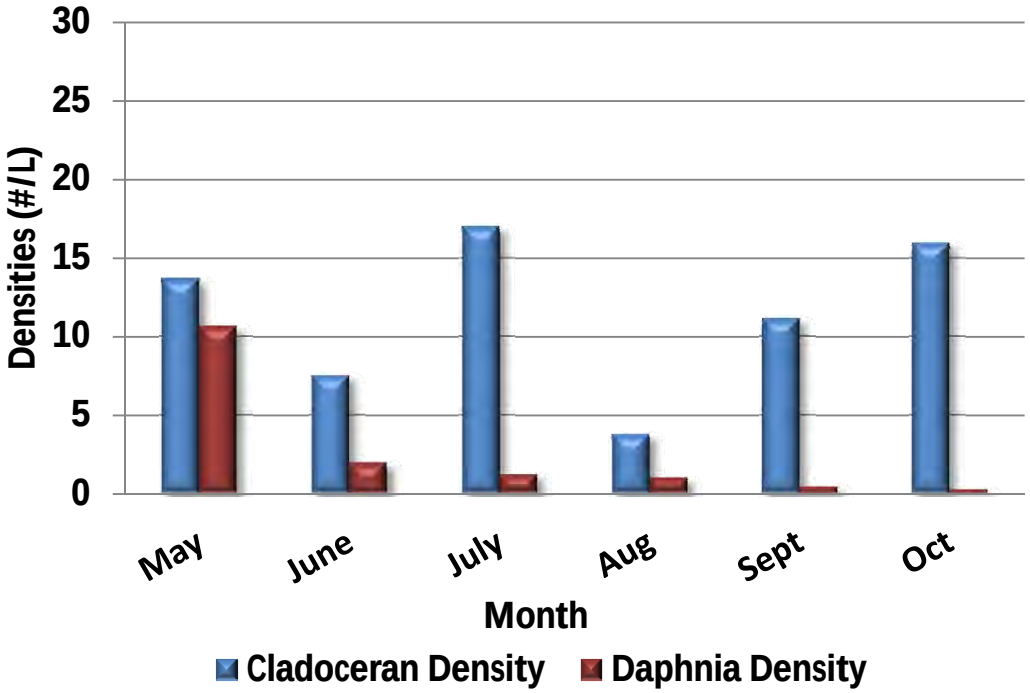


Figure 26. Mean monthly 2010 zooplankton biomass for South Twin Lake

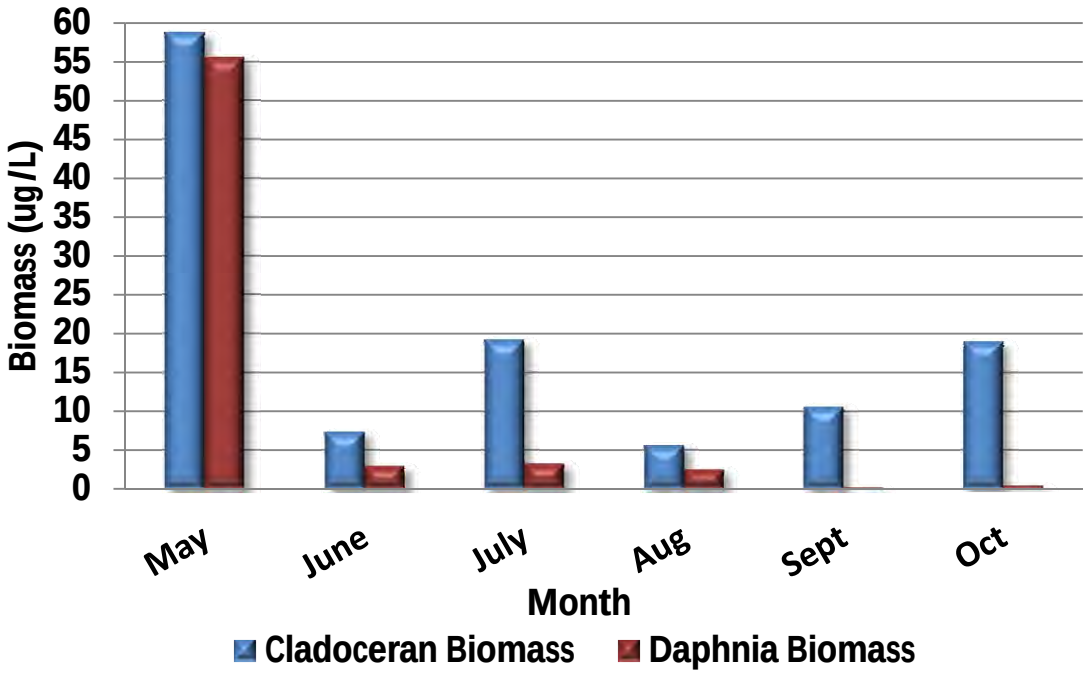
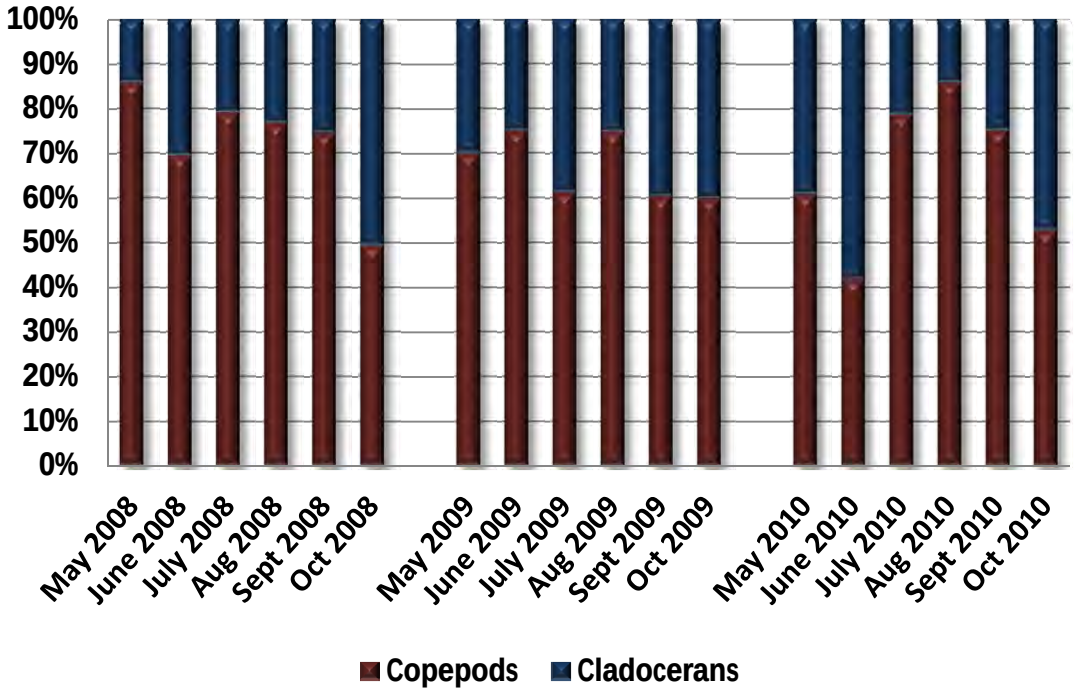


Figure 27. Percent composition by organism count



Trophic State Index

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

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

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

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

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a basis for assessing the relationship among TP, chl-*a*, and Secchi (Figure 31). In general, the TSI values are in fairly close correspondence with each other. Based on an average TSI score of 45 in 2010 South Twin Lake would be characterized as mesotrophic. When compared with the TSI score (and corresponding values) from 2008 and 2009, South Twin 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 EQuIS A review of data in EQuIS indicates there is a poor amount of data for South Twin 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. Based on yearly TSI averages calculated for 2008 through 2010, South Twin Lake can be classified as mesotrophic (Figure 31).

Individual summer-mean TP and chl-*a* data provide further insight into trends and variability. The three year average TP for South Twin Lake is 17 ± 1.5 µg/L. Standard error, expressed as a percent of the long-term mean, represents the coefficient of variation (CV) of the mean. or South Twin Lake, the CV equals nine percent, which is fairly typical for oligo-mesotrophic Minnesota lakes. Chl-*a* values are also low with a three year mean of 4.3 ± 0.6 µg/L and a CV of 13 percent of the mean. Secchi disk transparency has been fairly high with a long-term mean of 3.2 ± 0.3 m (Figure 28). The CV is eight percent of the mean, which suggests minimal variability and is a typical value for lakes that do not exhibit a long-term trend. Secchi disk values for 2009 and 2010 have been greater than the long-term mean indicating a recent increase in water clarity. As with TP and chl-*a*, the Secchi disk values indicate mesotrophic conditions.

Precipitation plays an important role in watershed runoff and lake level. As such, historical precipitation records (Figure 7) may help explain observed variation in transparency. Based on precipitation records from 1960 to 2010, mean annual precipitation is 26.9 inches, with a slight decrease over the period of record (Figure 9). 2008 was very dry with a measurement of 15.5 inches, 2009 precipitation increased to 22.8 inches (below the long-term average), and 2010 was considerably higher at 29.1 inches, placing it above the long-term mean. Secchi was slightly higher in 2009 and 2010 as compared to 2008, a year with very low precipitation (Figure 29). The lone historic summer-mean Secchi from 1976 also occurred in a dry summer (Figure 29). Based on this rather limited comparison (six years of Secchi readings), it appears that transparency may be higher in years with higher rainfall. (Figure 29); however, more years of Secchi data will be required to more fully characterize this relationship and required to generate more accurate year-to-year variability.

A comparison of 2008-2010 Secchi transparency data with 2008-2010 lake level data provides further insight into potential relationships among lake clarity, precipitation and lake level (Figure 30). Secchi declined in 2008 coincident with low precipitation and declining lake levels (Figure 30). Lake level continued to decline in 2009 as a direct result of reduced precipitation and runoff in 2008 and Secchi was at its lowest in July 2009. As precipitation increased flushing amounts for of South Twin Lake and lake levels increased through 2009 and into 2010 Secchi increased as well. Again, a longer Secchi record will allow for an improved understanding of how and whether precipitation and lake level may influence lake transparency.

Figure 28. South Twin Lake long-term summer-mean Secchi disk depth. Long-term mean noted by dashed blue line.

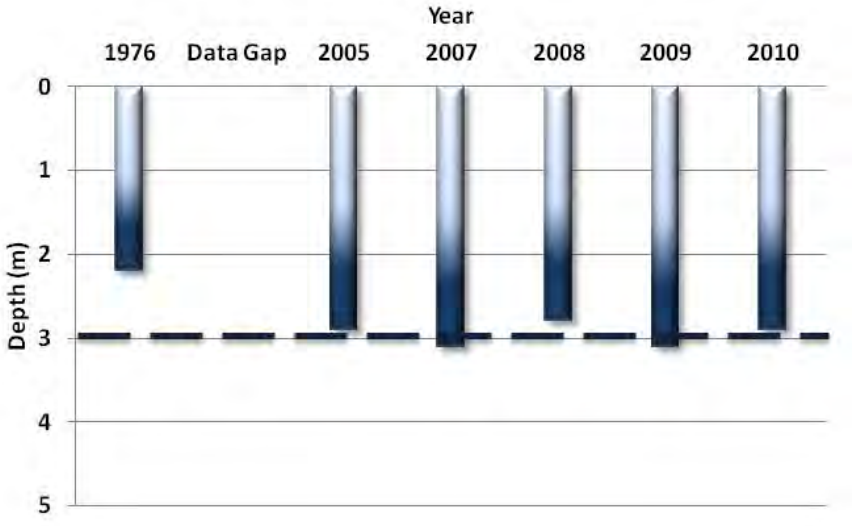


Figure 29. South Twin Lake historical Secchi transparency and precipitation comparison

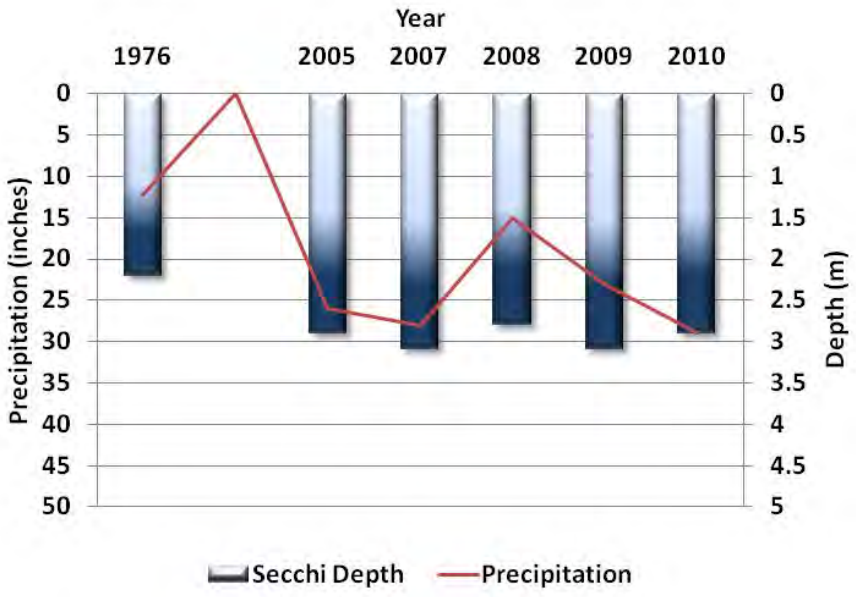


Figure 30. South Twin Lake Secchi transparency and lake level comparison

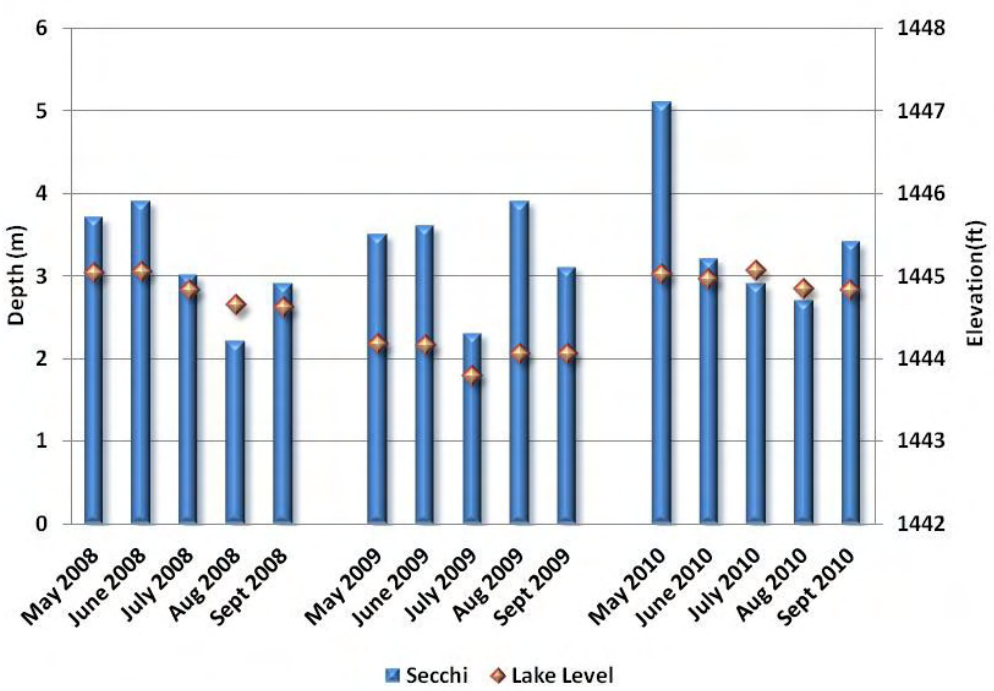


Figure 31. Carlson's Trophic State Index for South Twin Lake
R.E. Carlson

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.

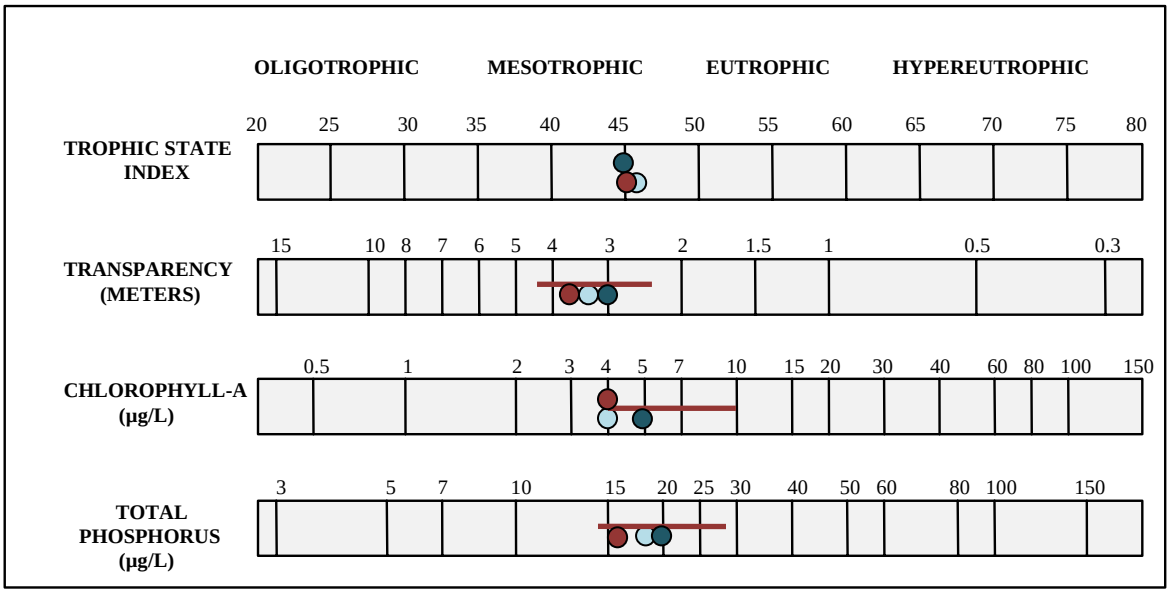
TSI 40 – 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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.



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

NLF Range: South Twin 2008: South Twin 2009: South Twin 2010:

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 2010 water quality of South Twin Lake, the Minnesota Lake Eutrophication Analysis Procedures (MNLEAP) model (Wilson and Walker, 1989) was used. A comparison of predicted vs. observed values is presented in Table 10.

MNLEAP 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 South Twin Lake, MNLEAP was applied as a basis for comparing the observed (2010) 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.

South Twin 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 South Twin Lake are relatively 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 394 kilograms per year (kg/yr) is reasonable, but is likely an overestimate given that the observed TP is lower than predicted and it is quite likely upstream lakes and ponds trap much of the nutrients that enter them. The areal water load to the lake is estimated at 1.5 meters per year (m/yr) and estimated water residence time is on the order of 2-3 years; however, it is important to note that this estimate only considers watershed runoff and precipitation on the lake and does not account for potential groundwater inputs for South Twin Lake. An additional subroutine in the MNLEAP 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 South Twin Lake this value is estimated at 26 µg/L. This is within the NLF nutrient criteria and further suggests the current water quality of the lake is close to or better than expected based on its size, watershed area and location in the state (Table 10).

Table 10. Minnesota Lake Eutrophication Analysis Procedures model results for South Twin Lake

Parameter	2010 South Twin Lake Observed	MNLEAP Predicted NLF Ecoregion
TP (µg/L)	16	21
Chl-*a* (µg /L)	4	6
Secchi (m)	3.5	2.8
P loading rate (kg/yr)	-	394
P retention (%)	-	63
P inflow conc. (µg/L)	-	57
Water Load (m/yr)	-	1.5
Outflow volume (hm^3/yr)	-	6.9
Residence time (yrs)	-	2.4
Vighi & Chiaudani		26

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 as impaired, 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. In Minnesota, the MPCA is responsible for performing assessment activities, listing impaired waters, and ensuring that TMDL studies are carried out.

South Twin Lake was assessed based on NLF ecoregion standards (Table 11). Both the 2010 and long-term mean for South Twin Lake have remained below 30 µg/L. Likewise, chl-*a* and Secchi are in full compliance with the NLF ecoregion standard. Based on these results, South Twin Lake was assessed as fully supportive of aquatic recreational use based on 305(b) and 303(d) assessment standards that the MPCA conducts in support of the Clean Water Act. These assessments are submitted to USEPA on a biennial basis. Efforts should be made to ensure the protection of the surrounding watershed and the preservation of South Twin Lake's high water quality.

Table 11. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). South Twin Lake 2010 and three year 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
South Twin Lake 2010	**16**	**4**	**3.5**
South Twin Lake three year mean	**17**	**4**	**3.2**

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Appendix

Lake Surface Water Quality Data for South Twin Lake for 2008-2010.

All water quality data can be accessed at: http://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
South Twin	44-0014	5/21/2008	202	3.7	15	3	170	3	0.5	5	1
South Twin	44-0014	5/27/2008	202	3.4					0.5		2
South Twin	44-0014	6/2/2008	202	3.7							
South Twin	44-0014	6/10/2008	202	3.5							
South Twin	44-0014	6/17/2008	202	3.4							
South Twin	44-0014	6/24/2008	202	3.7	17	3					
South Twin	44-0014	6/26/2008	202	3.4					0.5		1
South Twin	44-0014	7/7/2008	202	2.9							
South Twin	44-0014	7/15/2008	202	2.7							
South Twin	44-0014	7/16/2008	202	3	20	4	170	3	0.5	5	1.6
South Twin	44-0014	7/23/2008	202	2.1					0.7		11
South Twin	44-0014	7/26/2008	202	2.4							
South Twin	44-0014	8/1/2008	202	2.3							
South Twin	44-0014	8/6/2008	202	2.3							
South Twin	44-0014	8/14/2008	202	2.4							
South Twin	44-0014	8/24/2008	202	2.2							
South Twin	44-0014	8/26/2008	202	2	22	9			0.7		1
South Twin	44-0014	9/2/2008	202	2.9							
South Twin	44-0014	9/14/2008	202	2.4							
South Twin	44-0014	9/17/2008	202	2.9	20	5			0.6		
South Twin	44-0014	9/29/2008	202	3.1					0.5		1
South Twin	44-0014	10/8/2008	202	2.3	18	4	160	3	0.4	5	3.6

South Twin	44-0014	5/20/2009	202	3.5	19	3	170	3	0.4	5	2.6
South Twin	44-0014	5/21/2009	202	4					0.5		2
South Twin	44-0014	6/10/2009	202	3.6	12	2			0.5		
South Twin	44-0014	6/25/2009	202	3.7					0.6		5
South Twin	44-0014	7/15/2009	202	2.3	20	5	160	3	0.6	5	2.8
South Twin	44-0014	7/23/2009	202	2.4					0.5		1
South Twin	44-0014	8/12/2009	202	3.9	16	4			0.6		
South Twin	44-0014	8/20/2009	202	3.4					0.5		3
South Twin	44-0014	9/24/2009	202	3.1	18	6			0.6		2
South Twin	44-0014	10/19/2009	202	3	16	4	160	3	0.6	10	2
South Twin	44-0014	5/27/2010	202	5.1	21	3	170	3	0.4	10	1.2
South Twin	44-0014	6/15/2010	202	3.2							
South Twin	44-0014	6/30/2010	202	3.2	13	3	160	3	0.7	5	1.6
South Twin	44-0014	7/6/2010	202	3.5							
South Twin	44-0014	7/8/2010	202	2.3							
South Twin	44-0014	7/29/2010	202	2.9			160	3	0.6	5	1.6
South Twin	44-0014	8/3/2010	202	2.3							
South Twin	44-0014	8/10/2010	202	2.9							
South Twin	44-0014	8/15/2010	202	2.4							
South Twin	44-0014	8/26/2010	202	2.7	19	7	160	3	0.6	5	2.8
South Twin	44-0014	9/28/2010	202	3.4	15	5	160	3	0.4	10	2.4
South Twin	44-0014	10/11/2010	202	3.6	13	3	160	3	0.6	5	2