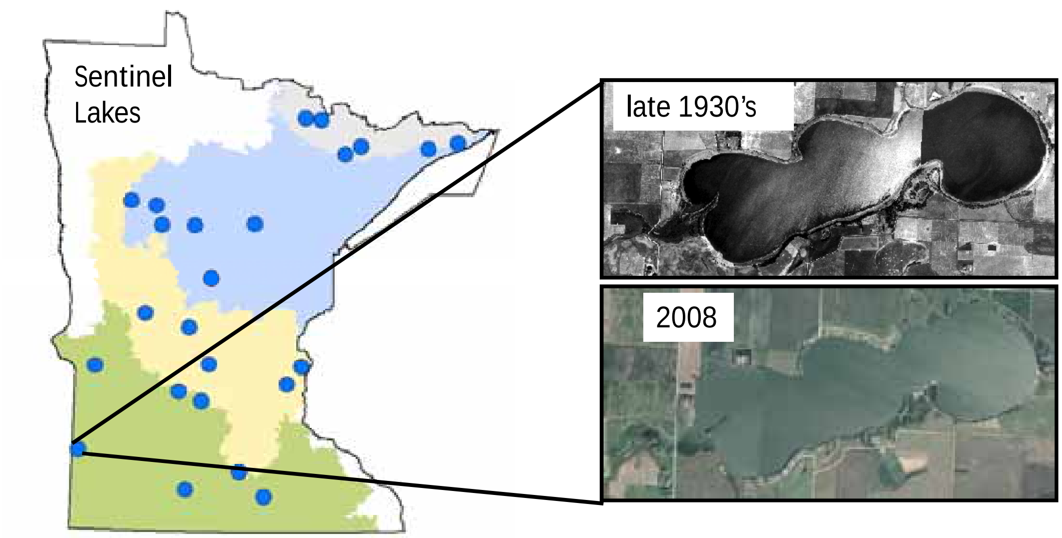
# 2008 Sentinel Lake Assessment Report Lake Shaokotan (41-0089)
# Lincoln County, Minnesota




Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit &
Minnesota Department of Natural Resources
Section of Fisheries
July 2009

Minnesota Pollution Control Agency

Minnesota Pollution Control Agency
520 Lafayette Road North
Saint Paul, MN 55155-4194
http://www.pca.state.mn.us
651-296-6300 or 800-657-3864 toll free
TTY 651-282-5332 or 800-657-3864 toll free
Available in alternative formats

## Contributing Authors

Lee Engel & Steve Heiskary, Minnesota Pollution Control Agency

Craig Soupir, Brian Schultz, & Ray Valley, Minnesota Department of Natural Resources

## Review

Mark Hanson & Kelly Daberkow, Minnesota Pollution Control Agency

## Editing

Dana Vanderbosch, Minnesota Pollution Control Agency

Peter Jacobson, Minnesota Department of Natural Resources

## Sampling

Lee Engel, Dereck Richter, and Nicole Gabriel, Minnesota Pollution Control Agency

Mark Hanson (CLMP Volunteer)

2008 Lake Assessment of Lake Shaokotan (41-0089) Lincoln, Minnesota

Minnesota Pollution Control Agency

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

*wq-2slice41-0089*

*The MPCA is reducing printing and mailing costs by using the Internet to distribute reports and information to wider audience. For additional information, see the Web site:*
*www.pca.state.mn.us/water/lakereport.html*

*This report was printed on recycled paper manufactured without the use of elemental chlorine (cover: 100% post-consumer; body: 100% post-consumer*

# Table of Contents

List of Tables ..... i

List of Figures ..... ii

Executive Summary ..... 1

Introduction ..... 3

History ..... 3

Background ..... 4
- Lake Morphometry and Watershed Characteristics ..... 5
- Lake Mixing and Stratification ..... 5
- Watershed Area and Land use ..... 6
- Precipitation and Climate ..... 8
- Water Level ..... 9

Macrophyte Assessment.... ..... 10

Fisheries Assessment.... ..... 17
- Species Assessment ..... 18

Water Quality Assessment.... ..... 21
- Methods ..... 21
- Results and Discussion ..... 21
- Summer-mean Water Quality Summary for Year ..... 22
- Trophic State Summary for Year ..... 24
- Trophic Status ..... 24
- Phytoplankton and Zooplankton ..... 25

Water Quality Trends and Diatom Reconstruction.... ..... 29

TMDL Summary ..... 30

303(d) Assessment and Goal Setting ..... 31

Conclusions and Recommendations ..... 32

References ..... 34

Appendices
- A Fisheries Data ..... 37
- B Water Quality Data ..... 42

# Table of Contents, continued

LIST OF TABLES


1. Lake morphometric characteristics ..... 5
2. Watershed and land use characteristics as compared to ecoregion reference lakes ..... 7
3. Frequency of aquatic plants in Lake Shaokotan point-intercept survey, August 2000 ..... 14
4. Percent frequency of occurrence of aquatic plant species sampled over the entire lake, during point-intercept surveys on 4 August 2008, at Shaokotan Lake, Lincoln County, MN (N=617) ..... 17
5. Fish species documented in past surveys in Lake Shaokotan. ..... 18
6. Lake Shaokotan summer-mean water quality as compared to ecoregion reference lake typical range ..... 23
7. 2008 Lake Shaokotan mean annual zooplankton biomass and densities ..... 27
8. Eutrophication standards by ecoregion and lake type ..... 32


LIST OF FIGURES


1. Sentinel lakes ecoregion representation ..... 2
2. Lake Shaokotan basin contour map ..... 5
3. Lake stratification ..... 6
4. Minnesota's seven ecoregions as mapped by U.S. EPA ..... 6
5. Lake Shaokotan watershed and land use. ..... 7
6. Minnesota water year precipitation and departure from normal ..... 8
7. Historic lake levels ..... 9
8. Annual precipitation, maximum, and minimum water levels ..... 10
9. Aquatic plant occurrence, Shaokotan point–intercept survey, September, 1949 ..... 11
10. Aquatic plant occurrence using transect method, August, 2000 ..... 12
11. Aquatic plant survey on Shaokotan, point-intercept survey, August, 2000 ..... 13
12. Emergent and submergent plants, point-intercept survey on Shaokotan, August 2002 ..... 15
13. Numbers of plant taxa present during the point intercept survey, August, 2008 ..... 16
14. Lake Shaokotan dissolved oxygen profiles ..... 22
15. Lake Shaokotan temperature profiles ..... 22
16. 2008 monthly total phosphorus, chlorophyll-a, and Secchi ..... 24
17. Secchi transparency site comparison ..... 24
18. Historic summer average total phosphorus, chlorophyll-a, and Secchi ..... 25
19. Lake Shaokotan trophic status index ..... 26
20. 2008 Lake Shaokotan phytoplankton community composition ..... 28
21. Monthly zooplankton densities and biomass ..... 29
22. Diatom reconstruction of historic phosphorus concentrations ..... 30
23. Shaokotan watershed phosphorous contribution model ..... 31

# 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 results of alterations to the landscape on lake habitats SLICE utilizes intensive lake monitoring strategies on a wide range of Minnesota lakes. This includes analyzing the relevant land cover and land use, identifying climate stressors, and monitoring the effects on the lake habitat and biological communities. The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). Lake Shaokotan was selected to represent a shallow, eutrophic lake in the prairie region of Minnesota.

Lake Shaokotan (or Shaokatan, as spelled locally) is a 994-acre lake in west central Lincoln County [note-in deference to MDNR Public Waters Inventory, we will use the Shaokotan spelling throughout the report]. There are two public accesses on the lake: a MDNR maintained access on the north side and a county park access on the southern shore of the lake. Lake Shaokotan is located within the Northern Glaciated Plains (NGP) ecoregion. It has a 100% littoral area with a maximum depth of about 3.4 meters (11 feet) and a mean depth of 2.4 meters (8.0 feet). The total contributing watershed for Lake Shaokotan is 8,817 acres.

Lake Shaokotan is typical of many NGP lakes given its broad shallow basin and its high algal productivity. The lake has a rich history of water quality studies that were generally initiated to support projects and improve management of the lake and watershed. Watershed restoration practices were implemented in the past to reduce phosphorus inputs to the lake. By reducing total phosphorus (TP), algal biomass (i.e., chlorophyll-a) typically decreases and water clarity increases. Reductions in the severity of algal blooms and improvements in transparency are of benefit to lake users as well as aquatic life. Increased water clarity promotes the growth of aquatic plants, which anchor sediments and provide habitat for a variety of fish species and waterfowl.

A Clean Water Partnership effort involving MPCA, MDNR and local groups and units of government was initiated in the early 1990's in an attempt to reverse excessive nutrient loading into Lake Shaokotan caused by agricultural practices in the watershed. Subsequently, an extensive data gathering effort began in 1991 to understand watershed nutrient loading and lake response dynamics. After completion of the monitoring efforts, a watershed restoration program was implemented. A 58% reduction in the phosphorus loading to the lake was achieved as a result of the watershed restoration project. By 1994, the decrease in nutrient loading into Lake Shaokotan eventually led to a cascading ecological shift in the dynamics of the lake, which included decreased algal blooms, improved water clarity, and increased vegetative growth. Since that time, there have been periodic increases in TP loading related to storm events, poor land and manure management practices in the watershed; however, while TP has increased, it still remains substantially lower than pre-1994 levels, and the frequency and intensity of blue-green algal blooms has remained at a lower level, as well.

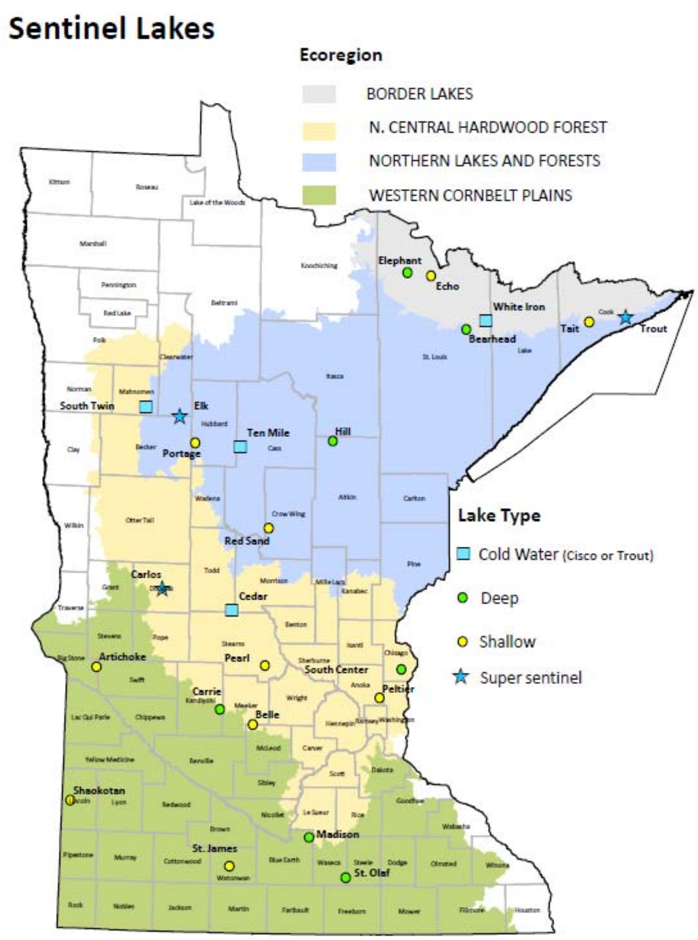
Nuisance algal blooms are common throughout the summer and modern-day TP in Lake Shaokotan remains much higher than pre-European settlement, as shown by diatom reconstruction from a sediment core taken from the bottom of the lake. Lakes whose nutrient concentrations exceed water quality standards and that do not support aquatic recreational use are termed 'impaired' and are placed on a list biennially. This list is formally termed the 303(d) list (referencing the section within the federal Clean Water Act that requires us to assess for condition); it is also commonly called the "Impaired Waters List". A lake placed on the Impaired Waters List is required to be intensively researched through a Total Maximum Daily Load (TMDL) study to determine the source and extent of the pollution problem. The study also requires the development of a restoration plan. In 2002, Lake Shaokotan was included on the 303(d) list that the MPCA submitted to the

United States Environmental Protection Agency.  A TMDL report has been drafted that is out for review will form the foundation and guidance for future improvements to the watershed and lake.

Perhaps due to reductions in winterkill (as a result of aeration and potentially climate change) and modest improvements in water quality, black bullhead populations have declined appreciably. Black bullhead declines have been favorable for other fish species in Shaokotan and many Minnesota anglers, but surprisingly have come at the chagrin of out-of-state anglers eager to harvest bullhead.  Shaokotan continues to support modest populations of stocked walleye.

Despite high algae concentrations, Shaokotan still can provide many recreational opportunities. The lake has a healthy fishery with desirable-sized walleye. There are several campsites located within the county park on the southern end of the lake. Bird watchers can see the many migratory birds that use Shaokotan as resting area during the spring and fall migrations.

**Figure 1. Sentinel lakes and ecoregion representation**



# Introduction

This report provides a relatively comprehensive analysis of physical water quality and ecological characteristics of Lake Shaokotan in Lincoln County. 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 other sources of data for the lake. The water quality assessment focuses on data collected during the 2008 season; however, historical data are used to provide perspective on variability and trends in water quality. Water quality data analyzed included all available data in STORET. 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

**Pre-settlement:**

Lake Shaokotan lies in a traditional prairie landscape of rolling hills and natural wetlands (i.e., prairie potholes). Prior to European settlement, deep-rooted prairie grasses buffered runoff from natural storm events and likely maintained clear water and abundant aquatic plants in Shaokotan. As European immigrants began to settle, till, ditch, and drain the watershed for agriculture, changes to the prairie pothole region occurred. Potholes were drained and waterways were connected to efficiently move water off of the landscape, carrying with it fertilizers and human and animal waste. The impaired condition of Shaokotan today is likely a legacy of these past practices.

**1930's**

The first known stocking in Shaokotan occurred between 1913 and 1933 when 6 cans of brook trout, 21 cans of "pike", 2,210,000 "pike" fry, 27 cans of crappie, and sunfish fingerlings were stocked. Shaokotan was dry in 1933 and 1934 due to drought conditions.

**1940's:**

The 'General Duck Lake Survey', the first known MDNR survey on Lake Shaokotan, was completed in September 1949. This survey included 56 sites equally spaced throughout the lake. Aquatic vegetation was encountered in only 8 sites (14.3%) and was comprised mostly of coontail, sago pondweed, lesser duckweed and star duckweed. Most aquatic vegetation was observed in the western reaches of the lake. Based on the results of this survey Lake Shaokotan was classified as a 'bullhead lake,' which was characterized as having severe algal blooms, high turbidity, low water transparency, and minimal vegetative growth.

**1950's:**

In 1953, the Shaokotan Sportsman's Club formed and reached seventy members by March of the following year.

In 1957, Marv's Resort, located on the southern shore of Lake Shaokotan, reported that on average between 500 and 600 guests per season were visiting the resort and about "90% of them want bullheads." (Thomsen 1957).

**1970's:**

The first documented commercial harvested was conducted in 1973. All commercial harvest from 1973 to present has targeted bullhead.

**1980's:**

The lake association and Shaokatan Sportsman Club were seeking technical assistance and funding from governmental agencies to improve water quality in the late 1980's.

**1990's:**

The MPCA initiated a detailed Clean Water Partnership Phase I diagnostic study in 1991. In-lake total phosphorus (TP) measurements ranged from 200 to 350 micrograms per liter (µg/L) from 1991 to 1992, indicative of excessive phosphorus loading. In spring 1993, restoration efforts guided by the Clean Water Partnership study began and continued through 1996 at a cost of roughly $450,000.

By 1994, significant reductions in in-lake P were realized with concentrations approaching the ecoregion-based P goal of 90 µg/L. Noticeable reductions in the frequency and severity of nuisance algal blooms were observed and the water transparency had increased with evidence suggesting expansion of the macrophyte population.

In 1998, Lake Shaokotan was included in a six lake study in southwestern Minnesota to compare the growth and survival of the Pike River and Little Cutfoot Sioux Lake strains of walleye.

A failure of a feedlot improvement project occurred during the years 1999 – 2000, which resulted in a "shock" loading of manure to Lake Shaokotan and a subsequent reversal of water quality improvements. Corrective measures were taken which included removal of manure from the site and re-routing of a tile-line to a shallow wetland adjacent to Lake Shaokotan.

**2000's:**

Shaokotan does not meet state standards for aquatic recreation and was placed on the 303d impaired waters list. The Yellow Medicine River Watershed District conducted monitoring in 2005 and prepared a Total Maximum Daily Load (TMDL) report to achieve state water quality standards for Lake Shaokotan which is currently in final draft form to be submitted to United States Environmental Protection Agency (USEPA) in late 2009.

Lake Shaokotan was selected as a Sentinel lake in the Sustaining Lakes in a Changing Environment (SLICE) cooperative long-term monitoring program, with initial sampling beginning in 2008.

**Winterkill events:**

Lake Shaokotan oxygen testing history since 1951 indicated potential winterkill or partial winterkill events (dissolved oxygen ≤ 1.0 milligrams per liter -mg/L) in the following years: 1960, 1969, 1975, 1976, 1978, 1979 and 1988. Lake Shaokotan has been opened to liberalized fishing seven times since 1951, most recently in 1978-79. An aeration system has been in use since 1981, with no significant winterkill occurrence since then.

**Other studies**

Bacigalupi, M. D., 2000. Growth and survival of two populations of stocked walleye and naturally spawned walleye in the same lakes. Master's Thesis. University of Minnesota.

# Background

## Lake Morphometry and Watershed Characteristics

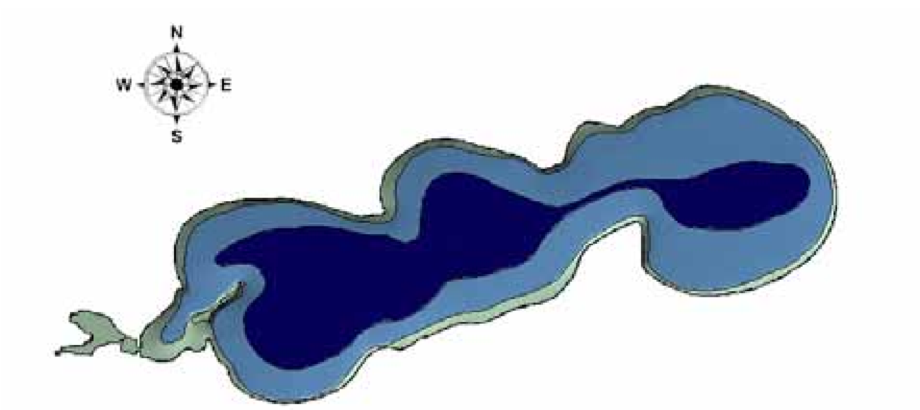
Lake Shaokotan is a shallow lake with a maximum depth of about 3 meters (m-10 ft) with simple basin characteristics (Table 1). Because of a long fetch, combined with its shallowness, wind mixing is common throughout the open water season.  (Figure 2).

**Table 1. Lake Shaokotan morphometric characteristics**

| Lake Name | Lake | Lake Basin Area | Littoral Area | | Total Watershed Area | Watershed: Lake | Max. Depth | Average Depth | Lake Volume |
|---|---|---|---|---|---|---|---|---|---|
| Name | ID | Acres[1] | Acres | % Littoral | Acres[2] | Ratio | Ft. | Ft. | Acre-Ft. |
| Shaokotan | 41-0089 | 994 | 994 | 100 | 9046 | 9:1 | 10-11 | 8 | 7,952 |

1MNDNR Lake Finder http://www.dnr.state.mn.us/lakefind/index.html

**Figure 2. Lake Shaokotan basin contour map**




## Lake Mixing and Stratification

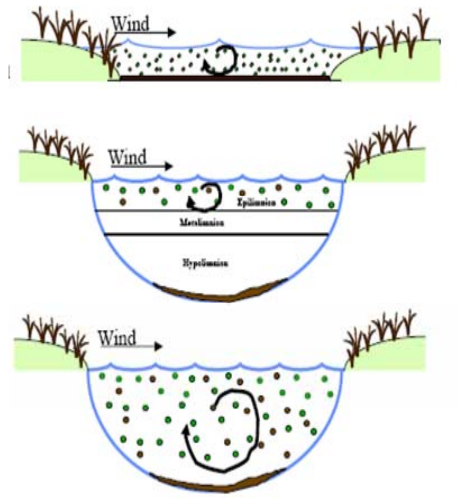
Lake depth and mixing has a significant influence on lake processes and water quality.  *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 30 feet (9.14m) or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 3).  These lakes fully mix or turn over twice per year; typically in spring and fall.  Shallow lakes (maximum depths of 20 feet (6.10m) or less) in contrast, typically do not stratify and are often referred to as *polymictic* (Figure 3).  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 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

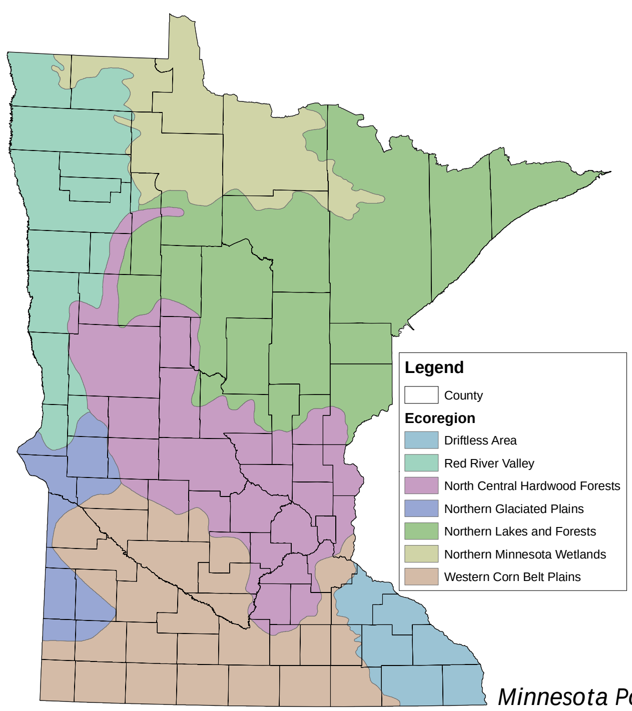
**Intermittently Stratified**
Moderately deep
Mixes during high winds
Spring, Summer, & Fall




## Watershed Area and Land Use

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation, and current land use (Figure 4). 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. Lake Shaokotan is located in the Northern Glaciated Plains (NGP) ecoregion.

**Figure 4. Minnesota's seven ecoregions as mapped by USEPA**



Characteristics of land use within each watershed have implications affecting water quality and productivity of lakes. Typical land use characteristics have been established for the NGP ecoregion (Table 2). Lake Shaokotan has typical NGP ecoregion land use characteristics. The landscape is dominated by agriculture primarily pasture, grasslands, and cultivated fields. From 1969 to 2001, a conversion from cultivated agriculture to pasture has been observed. The area is sparsely populated and has low density development. A land use watershed map is shown in Figure 5. Numerous studies have found large sources of phosphorus entering Shaokotan by overland flow and runoff.

**Figure 5. Lake Shaokotan watershed and land use**

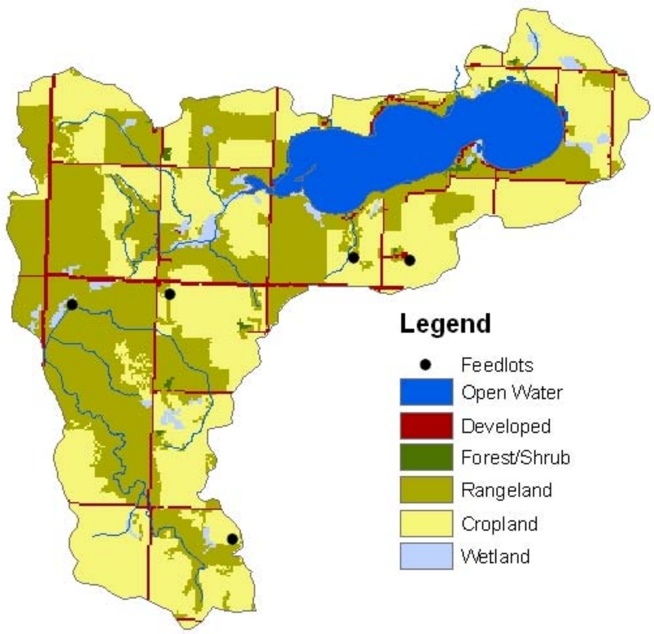



**Table 2.**

| Land Use | Shaokotan | Shaokotan | Shaokotan | NGP Typical Land Use % |
|---|---|---|---|---|

**Watershed and land use characteristics as compared to ecoregion reference lakes.**

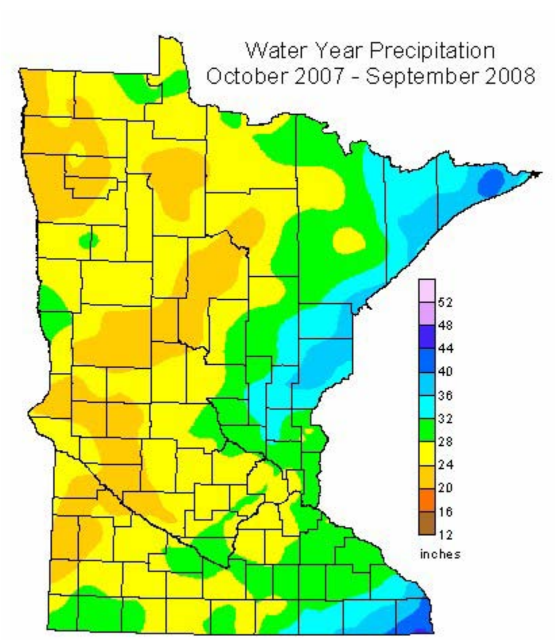
| | 1969 | 1991 | 2001 | |
|---|---|---|---|---|
| Developed | 1 | 1 | 5 | 0-2 |
| Cultivated (Ag) | 67 | 60 | 43 | 60-82 |
| Pasture & Open | 20 | 27 | 40 | 5-15 |
| Forest | 1 | 1 | - | 0-1 |
| Water & Wetland | 11 | 11 | 12 | 8-26 |
| Feedlots (#) | - | - | 5 | |

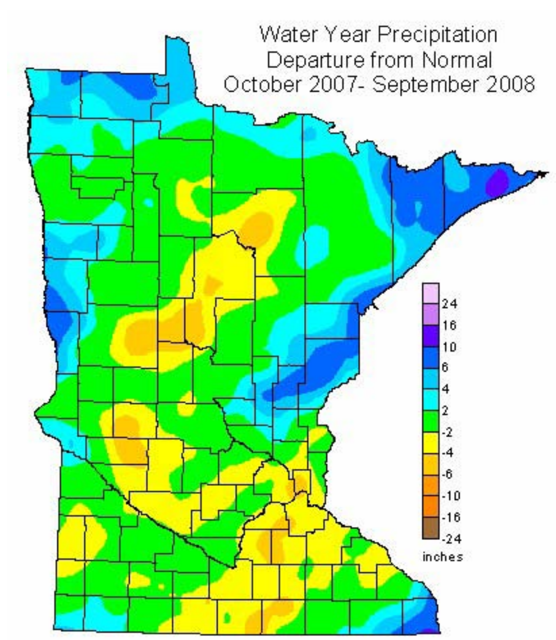
[1]National Land Cover Database www.mrlc.gov/index.php
[2]Minnesota Land Management Information Center www.lmic.state.mn.us/chouse/metadata/luse69.html
[3]Minnesota Land Cover 1991-1992:MAP www.lmic.state.mn.us/chouse/land_use_DNRmap.html

## Precipitation and Climate

Based on state climatology records, precipitation averages between 0.54 – 0.61 m (20 and 24 inches) annually in this part of the state (Figure 6). Recent years have been within this precipitation range. Typical evaporation and runoff values for lakes in the NGP ecoregion are 0.76 meters per year (m/yr) of evaporation and 0.05 m/yr of runoff. This implies that evaporation typically exceeds precipitation on the surface of the lake. Thus, unless watershed runoff or groundwater inputs are sufficient to maintain lake level, lake levels will decline over the summer open water period in most years. The 2008 water year precipitation was about 0.05-.1 m (2-4 inches) below normal for this part of the state (Figure 6).

**Figure 6. 2008 Minnesota water year precipitation and departure from normal**
Prepared by State Climatology Office MDNR Waters
Values are in inches

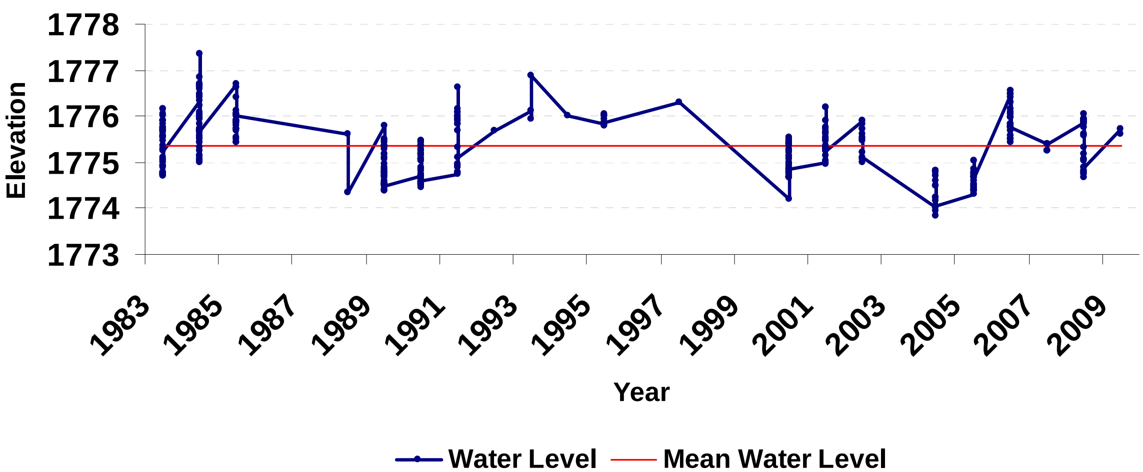


## Water Level

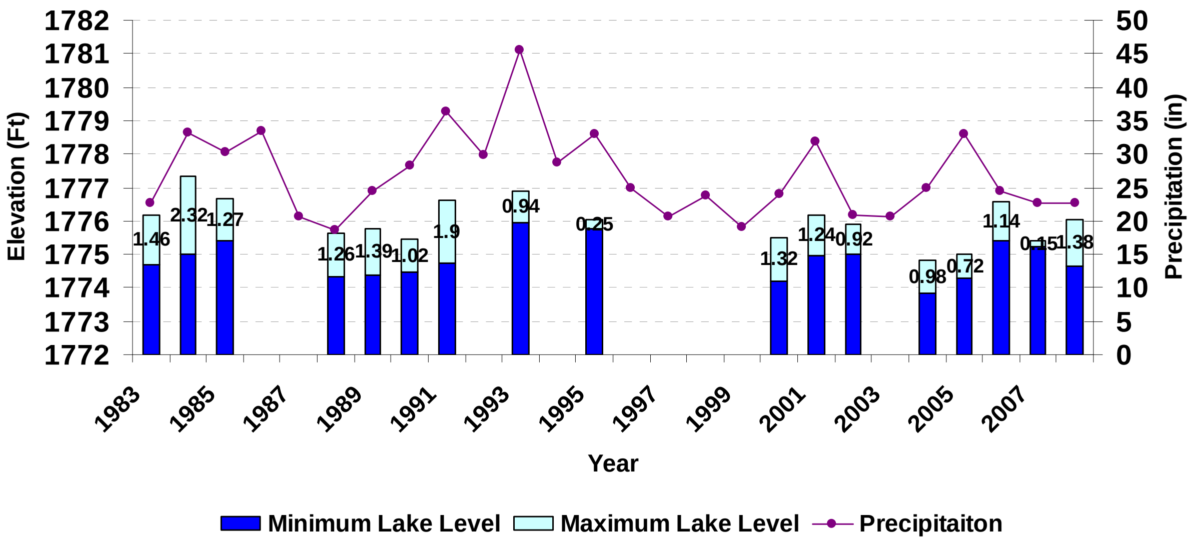
Lake Shaokotan has an extensive lake level record with 4,024 readings since 1983 that show large seasonal variations (Figure 7). Based on plat and easement records from the Lincoln County Courthouse, the ordinary high water level is 1776.5 feet, which was presumably established by MDNR (Mark Hanson, personal communication). The first lake level reading was taken in 1961 and again during a hydrographic survey in 1977. Regular lake level monitoring commenced in 1983. Interestingly, elevations recorded in 1961 and 1977 were far below the modern range of lake elevations of 1773.06 and 1773.72 feet, respectively. Over the period of record from 1983-2009, the lake level has fluctuated 4.27 feet and has a long-term average elevation level of 1775.34 feet. High evaporation rates and periodically intense runoff from the watershed likely explain much of the variation in lake level. Very low lake levels were noted during the 1988 drought and then again in 2000, 2004 and 2005. A peak in lake level was noted for 1993, which was characterized by very high precipitation and runoff (Figure 8). Work on the outlet structure may have influenced levels as well; however the authors and reviewers did not have a complete history on the structure (repairs and improvements).

**Figure 7. Historic lake levels datum: NGVD 8.8 m (29 feet)**




Analyzing lake level and precipitation data can be difficult since timing of lake level measurements may not always capture the maximum and minimum water levels each year. This can make it difficult to discern how much the lake level fluctuates and the precise reason for the fluctuation. Precipitation data were taken from a variety of weather stations near Lake Shaokotan because there were no weather stations within the Lake Shaokotan watershed. The majority of precipitation data was taken from the Tyler weather station which is approximately 21 kilometers (13 miles) from the lake. Based on a pairing of lake level and precipitation data on an annual basis, some patterns are evident (Figure 8). In general, minimum and maximum water levels show good correspondence to the amount of precipitation; however, short term fluctuations may occur due to magnitude and intensity of precipitation events along with evaporation rates during a given year.

**Figure 8. Annual precipitation, maximum, and minimum water levels**

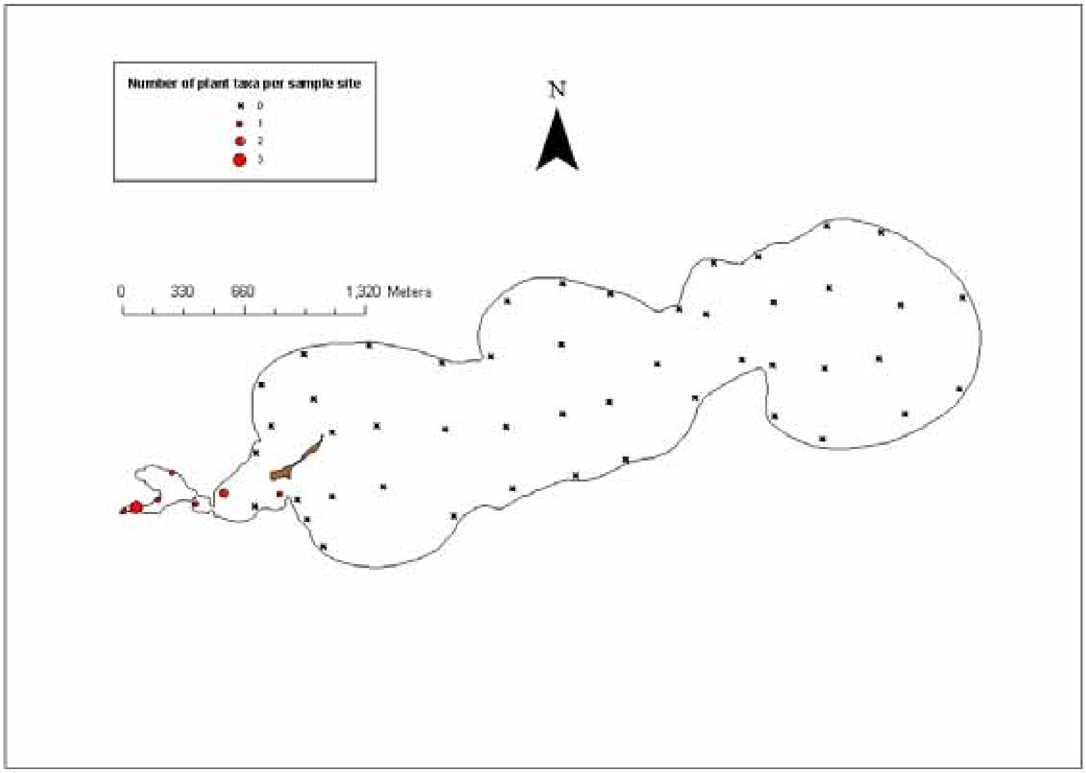



# Macrophyte Assessment

Shallow lakes often exhibit one of three "regimes" a stable clear-water regime with abundant aquatic plants, an unstable regime of fluctuating water quality and plant conditions, or a stable, turbid regime with little or no aquatic plant growth (Scheffer and Carpenter 2003, van Nes and Scheffer 2005). Absent human disturbances, natural resilience forces often keep the lake in a clear-state; however, as disturbances to the lake increase, the lake becomes unstable and increasingly drawn to the opposing turbid domain. Historical reconstructions of water quality with sediment cores in Shaokotan suggest total phosphorus was much lower (50 µg/L) than modern-day levels (Edlund and Kingston 2004). Furthermore, this study documented more diatom species associated with aquatic plants than present day levels, suggesting water clarity and aquatic plant growth was much higher prior to European settlement.

Since the first vegetation survey in 1949 up to 2008, Shaokotan seems to occupy a precarious state tending more towards a stable turbid regime than what was originally observed prior to cultivation by European settlers. The first vegetation survey ever recorded was from a "General Duck Survey" conducted in 1949 by the MDNR. The survey identified the location, species of vegetation, and depths observed at 56 equally distributed points. The only vegetation observed during the survey was on the far west end of the lake (Figure 9). The lack of vegetation observed throughout the rest of the lake was attributed to low water transparency from severe algal blooms and high turbidity. Compared to recent surveys, depths along the shoreline appeared deeper. Aquatic vegetation was encountered in only 8 sites (14.3%) and was comprised mostly of coontail, sago pondweed, lesser duckweed and star duckweed.

**Figure 9. Aquatic plant occurrence, Shaokotan point-intercept survey, September, 1949**




A re-survey was conducted in 2000 on Lake Shaokotan. Thirteen plant taxa were observed during the transect survey. Vegetation was observed on 28 of the 30 transects surveyed (Figure 10). The percent frequency (N=30 sample points) on a per species basis ranged from 3 (swamp milkweed, reed canary grass) to 67 percent (clasping-leaf pondweed). A point intercept survey was also conducted during the same time frame as the vegetation transect survey (Perleberg 2000). Survey points were spaced 200 meters apart. Vegetation was found in 11 of the 73 sites sampled (Figure 11). Ninety percent of all vegetation observed was in less than 1.5 m (5 feet) of water. Within the sampled area (shore to 2.7 m), 15% of the sites contained vegetation. The percent frequency (N=73 sample points) ranged from 1 (lesser and greater duckweed) to 7 percent (clasping-leaf pondweed; Table 3).

**Figure. 10. Aquatic plant occurrence using transect method, August, 2000**

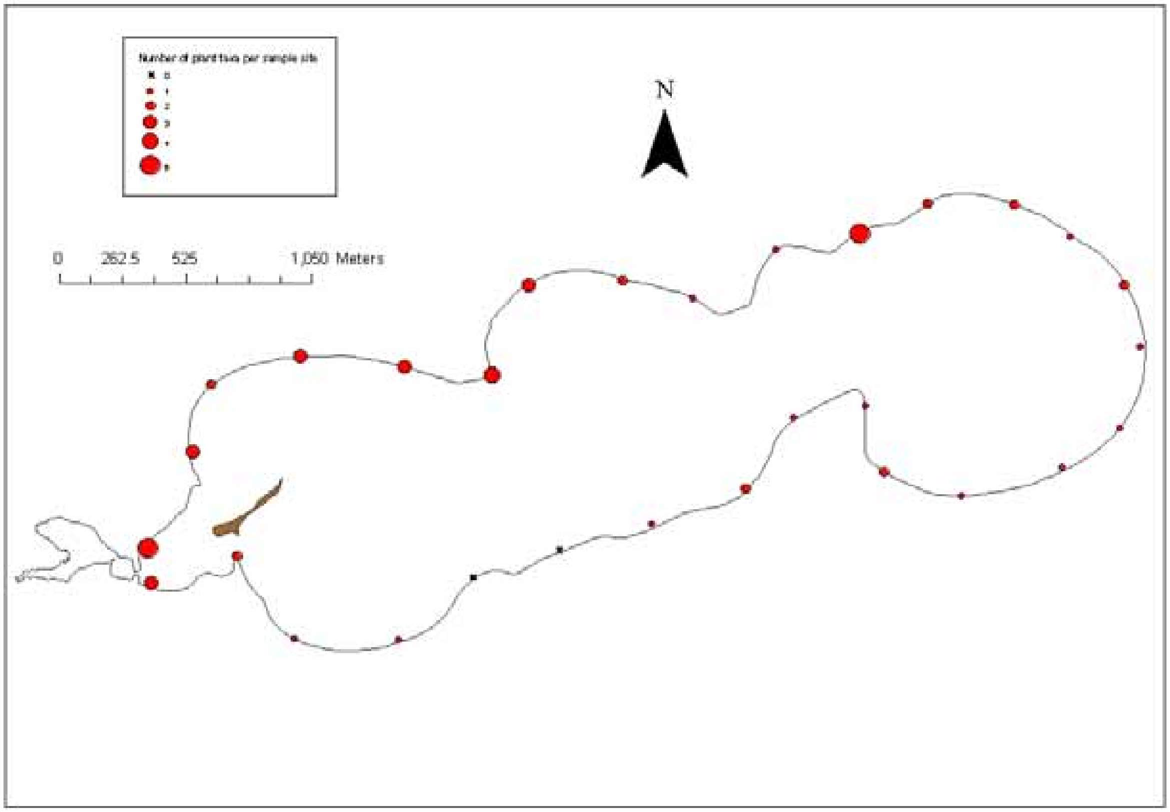


**Figure 11. Aquatic plant survey on Shaokotan, point-intercept survey, August, 2000**

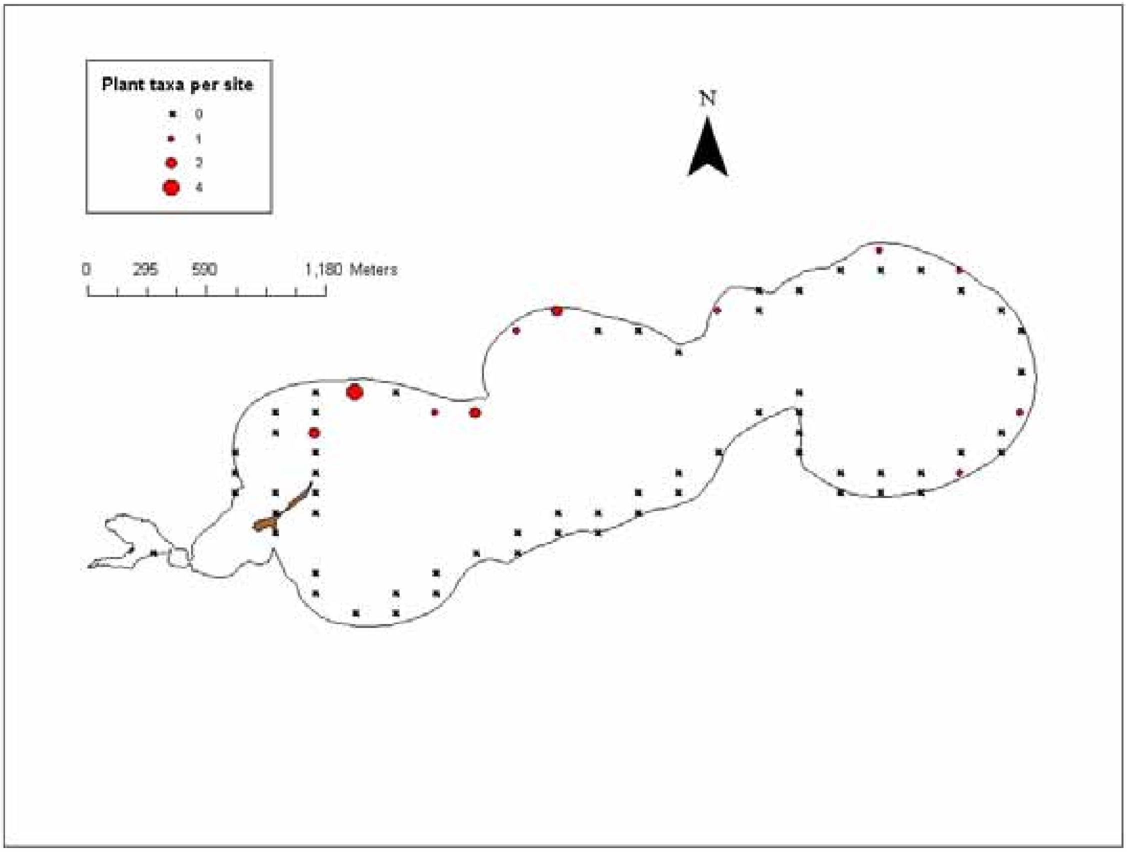


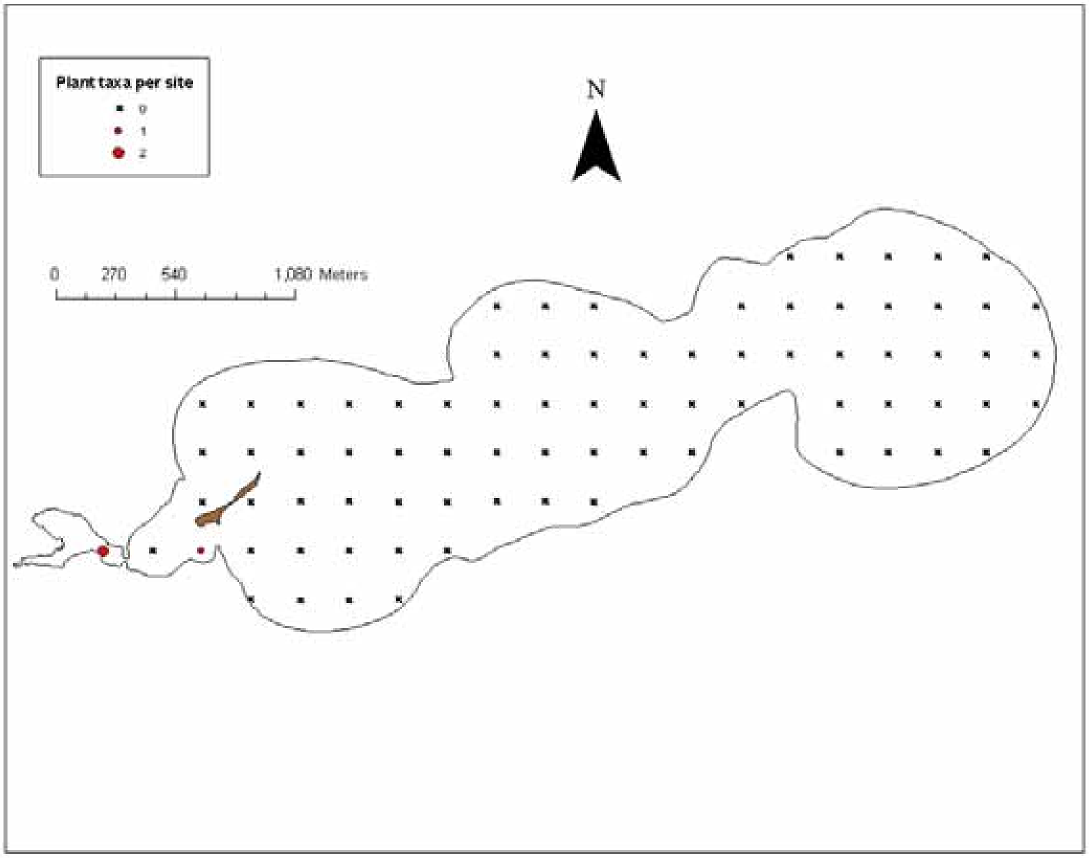
**Table 3. Frequency[1] of aquatic plants in Shaokotan Lake point-intercept survey, August 2000.**

| Common Name | Species Name | Growth Form | Frequency (%) |
|---|---|---|---|
| Sago pondweed | *Stuckenia pectinata* | Submersed | 5.0 |
| Clasping-leaf pondweed | *Potamogeton richardsonii* | Submersed | 7.0 |
| Coontail | *Ceratophyllum demersum* | Submersed | 3.0 |
| Leafy pondweed | *Potamogeton foliosus* | Submersed | 3.0 |
| Star duckweed | *Lemna trisulca* | Submersed | 3.0 |
| Lesser duckweed | *Lemna minor* | Submersed | 1.0 |
| Greater duckweed | *Spirodela polyhrhiza* | Submersed | 1.0 |

1. (Frequency is the percent of sample sites in which a plant taxon occurred within the shore to 2.7 m (9 feet) water depth.)

The MDNR Shallow Lakes Program conducted a Wildlife Lake Habitat Survey in August 2002. A point-intercept survey was conducted as part of the overall survey. Vegetation was found in 3 of 80 sites sampled (Figure 12). The percent frequency ranged from 1.3 (coontail, star duckweed) to 2.5 percent (sago pondweed). A failure of a feedlot improvement project occurred during the years 1999-2000 and resulted in a "shock" loading of manure to Lake Shaokotan and a subsequent reversal in water quality improvements that had been seen over the course of several years (addressed later in report).

**Figure 12. Emergent and submergent plants, point-intercept survey on Shaokotan, August 2002**




In 2008, a much more intensive point-intercept survey was conducted to better assess plant cover and potential plant indicators across all Sentinel lakes (N=617 target survey points across the whole lake). Because of the lack of vegetation in deeper water, only 388 sites were actually sampled (Figure 5). Plant cover overall was greater in 2008 than 2002 with rooted plants occupying 108 of the 617 sites (17.5%) with modest species richness and cover near inlet from the Yellow Medicine River. Two primary species of rooted vegetation observed during the 2008 point intercept survey were sago pondweed and clasping-leaf pondweed. The number of taxa at each sampling point vary throughout the lake (Figure 13). The percent frequency of occurrence was 11.5 and 9.7 percent respectively (Table 4). Ninety percent of all vegetation observed was in less than 1.3 m (4.4 feet). Point-intercept plant surveys will be repeated in 2009-2011 to assess short-term variability of vegetation parameters and to assess informative aquatic plant indicator metrics.

**Figure 13. Numbers of plant taxa present during the point-intercept survey, August, 2008.**

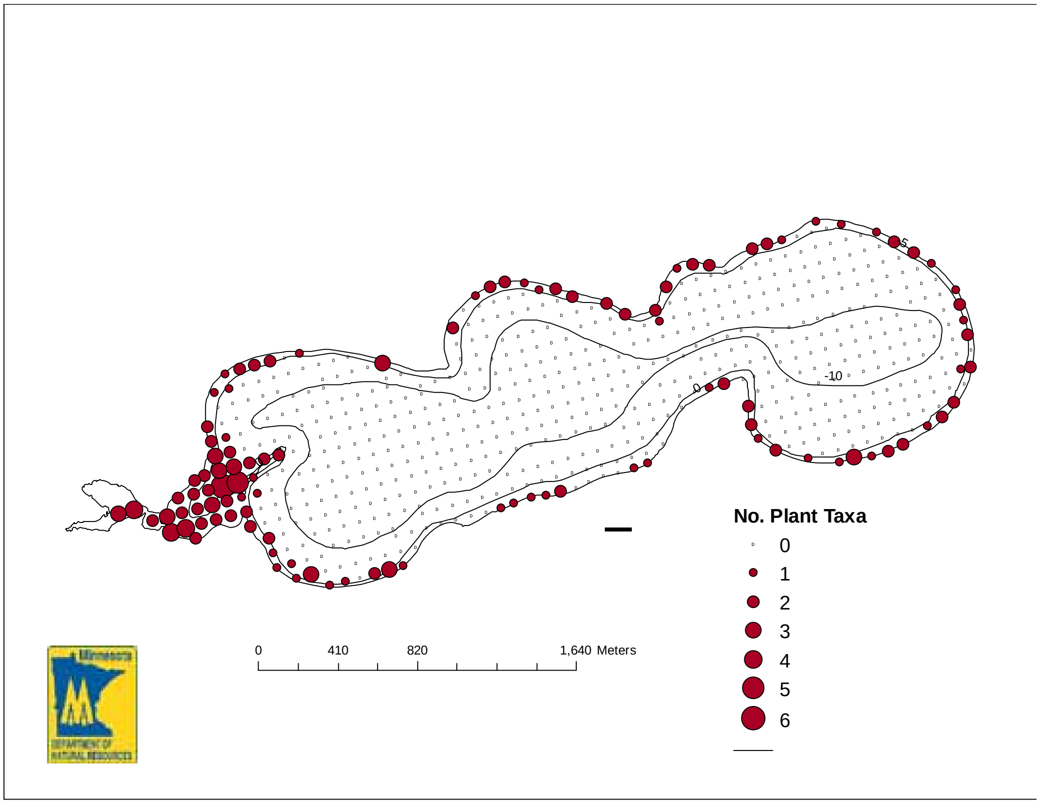


**Table 4. Percent frequency of occurrence of aquatic plant species sampled over the entire lake, during point-intercept surveys on 4 August 2008, at Shaokotan Lake, Lincoln County, MN (N=617).**[1]

| Common Name | Species Name | Growth Form | Frequency (%) |
|---|---|---|---|
| All rooted plants | | | 17.5 |
| Sago pondweed | *Stuckenia pectinata* | Submersed | 11.5 |
| Clasping-leaf pondweed | *Potamogeton richardsonii* | Submersed | 9.7 |
| Filamentous algae | | | 7.4 |
| Coontail | *Ceratophyllum demersum* | Submersed | 5.0 |
| Leafy pondweed | *Potamogeton foliosus* | Submersed | 2.4 |
| Star duckweed | *Lemna trisulca* | Submersed | 1.3 |
| Muskgrass | *Chara sp.* | Submersed | 1.1 |
| Northern watermilfoil | *Myriophyllum sibiricum* | Submersed | 0.5 |
| Canada waterweed | *Elodea canadensis* | Submersed | 0.2 |
| Sedge group | *Carex sp.* | Emergent | 0.2 |
| Flatstem pondweed | *Potamogeton zosteriformis* | Submersed | 0.2 |
| Greater duckweed | *Spirodela polyrhiza* | Free Floating | 0.2 |
| Cattail group | *Typha sp.* | Emergent | 0.2 |

1. Ninety percent of all plants sampled occurred in depths less than 1.3 m (4.4 feet).

*Permitted aquatic plant removal by lakeshore owners*
Because aquatic plant growth is currently so sparse, there have been no permits for removal of aquatic vegetation by property owners on Shaokotan Lake during recent years. Unfortunately, any future improvements to water clarity may result in increased aquatic plant growth and draw a negative response by lakeshore owners who see aquatic plants as a nuisance and an impediment to their recreation. As such, aquatic plant removal permits may become more common if water clarity in the lake improves. Indeed, given the feedbacks between aquatic plants and water quality this may retard gains in water clarity.

# Fisheries Assessment

For many years Lake Shaokotan was an important destination for bullhead anglers, especially those from out-of-state. Two resorts on the lake catered to bullhead anglers dating back to the 1950's, with occasional walleyes, perch and northern pike caught.

A Clean Water Partnership effort involving MPCA, MDNR and local groups and units of government was initiated in the early 1990's in an attempt to reverse excessive nutrient loading into Lake Shaokotan caused by agricultural practices in the watershed. Watershed restoration efforts led to a reduction in nutrient loading to Lake Shaokotan resulting in a cascading ecological shift in the dynamics of the lake, which included decreased algal blooms, improved water clarity, and increased vegetative growth. The improved water clarity, re-establishment of vegetation, and use of an aeration system on Lake Shaokotan led to better conditions for the establishment of a walleye population. In recent years, Lake Shaokotan has been primarily managed as a walleye fishery, with secondary management for northern pike and yellow perch.

The overall fish community of Shaokotan is depauperate compared with other, less nutrient-rich Minnesota lakes (Table 5). Shaokotan has a high abundance of disturbance-tolerant species such as fathead minnows, and in the recent past, black bullhead. Drake and Pereira (2002) developed a fish-based index of biotic integrity (IBI) for small Minnesota lakes. Indices of biotic integrity 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 surveys from over 250 lakes across the state provide a good assessment of the range of conditions we might expect in lakes of differing productivity. The fish IBI score in 2008 was 46, which is typical for highly productive, southwest Minnesota lakes.

**Table 5. Fish species documented in past surveys in Shaokotan Lake.**

| Common Name | Species Name | Trophic Guild | Environmental Tolerance[a] |
|---|---|---|---|
| Black crappie | *Pomoxis nigromaculatus* | Predator | Neutral |
| White crappie | *Pomoxis annularis* | Predator | Neutral |
| Northern pike | *Esox lucius* | Predator | Neutral |
| Walleye | *Sander vitreus* | Predator | Neutral |
| Black bullhead | *Ameiurus melas* | Omnivore | Tolerant |
| Carp | *Cyprinus carpio* | Omnivore | Tolerant |
| White sucker | *Catostomus commersonii* | Omnivore | Tolerant |
| Fathead minnow | *Pimephales promelas* | Omnivore | Tolerant |
| Brook stickleback | *Culaea inconstans* | Insectivore | Neutral |
| Bluegill sunfish | *Lepomis macrochirus* | Insectivore | Neutral |
| Pumpkinseed sunfish | *Lepomis gibbosus* | Insectivore | Neutral |
| Green sunfish | *Lepomis cyanellus* | Insectivore | Neutral |
| Johnny darter | *Etheostoma nigrum* | Insectivore | Neutral |
| Yellow perch | *Perca flavescens* | Insectivore | Neutral |
| Orange spotted sunfish | *Lepomis humilis* | Insectivore | Neutral |

## Species Assessments

A more detailed species-specific assessment follows. Corresponding data tables may be found in Appendix A.

**Common carp** *(Cyprinus carpio)***.** Common carp have been reported as early as 1949 and were considered a nuisance in early 1960. A letter dated January 22, 1960 requested the state to remove carp from the lake (Brown 1960). A severe winterkill during the winter of 1968-69 apparently wiped out the carp population according to a letter from Hjalmar O. Swenson (Supervisor for the Section of Fisheries) written to Senator Joe Josefson which stated “some perch and bullheads survived”). Nevertheless, today, carp are rarely observed in Shaokotan Lake and Mark Hanson (personal communication), a lake resident, notes he does not recall seeing one taken in the 15 years he has been on the lake. Bajer and Sorensen (2009) document that carp do not spawn successfully in lake systems that do not experience winterkill and where fish are present all year. Indeed, Shaokotan has not experienced winterkill in many years and few if any connected shallow wetlands exist along the length of the Yellow Medicine River that may support carp reproduction. The absence of carp (which suspend sediments through their activities) is one less obstacle in the way of restoring clear water conditions to Shaokotan Lake.

**Fathead minnows** *(Pimephales promelas)***.** Although carp are not present in large numbers in the lake, fathead minnows are and dominated seine catches during 2008 fish IBI surveys. These species (although native) are also known to produce internal nutrient recycling problems similar to those observed with carp. Fathead minnows are tolerant of low oxygen and turbidity and are usually one of the last species to succumb to winterkill (Becker 1983). Consequently, they are prolific species in shallow prairie lakes. Their prolific nature and omnivorous feeding habitats (detritus and invertebrates) lead to increased availability of phosphorus and nitrogen for algae growth, thus potentially exacerbating the harmful effects of nutrient loading from the watershed (Zimmer et al. 2006). Nevertheless, fathead minnows likely provide a valuable food source for predators, especially young year classes.

**Black bullhead** *(Ameiurus melas)***.** Recruitment of black bullhead through the years has been highly variable (Appendix A Table 3). For example, the abundance of black bullhead based on frame net catch per unit effort (CPUE - number of fish per net) has ranged from 0.9 to 606.7 fish/net from 1954 to 2008. The black bullhead trap net CPUE of 0.8 in 2008 was the lowest relative abundance ever recorded in Lake Shaokotan, and was below the interquartile range of 1.3 to 78.1 for similar lakes. Boom-bust predator prey cycles are common in shallow prairie lakes. Like fathead minnows, black bullheads are tolerant of turbid water, low oxygen, and are omnivores. Bullheads also appear to be an important forage species for juvenile and adult walleye.

**Yellow perch** *(Perca flavescens)***.** Recruitment of yellow perch also appears highly variable (Appendix A Table 3). Yellow perch CPUE in gillnets has ranged from 0.7 to 147.7 between 1996 and 2008. In 2008, the yellow perch gill net CPUE was 38.7 and above the interquartile range of 3.0 to 22.5 for similar lakes. Lengths of yellow perch sampled in gill nets in 2008 indicated the population was balanced with perch ranging in length from 17-30 centimeters (6.6 to 11.7 inches), and with a mean length of 22 centimeters (8.6 inches - Appendix A Table 2). Yellow perch most likely provide the primary food for both walleye and northern pike in Lake Shaokotan.

**Walleye** *(Sander vitreus)***.** The Lake Shaokotan fisheries management plan calls for stocking walleye fry at 1,000 per littoral acre on a 2-1 rotation (2 consecutive years stocked followed by one year non-stocked; (Appendix A Table 1). This stocking protocol is intended to create consistent year-classes of walleye, while not allowing abundance to become so high that prey availability is reduced and walleye growth suffers. In 2008, the walleye gill net CPUEof 19.7 was above the interquartile range of 3.2 to 15.3, and surpassed the long-range goal of 15.0. The walleye gill net CPUE has generally stayed within the objective ranges historically ranging from 5.3 – 34.5 since 1954. Lengths of walleye sampled in gill nets in 2008 ranged from 20-60 centimeters (8.0 to 23.2 inches) with a mean length of 38.6 centimeters (15.2 inches). Six-year classes of walleye were sampled during the 2008 assessment, but the 2004 fry stocked year class comprised 68% of the walleye sampled. No walleye captured in 2008 were identified from a non-stocked year class, which implies that natural reproduction was not apparent since 1999, based on aging data.

As part of the sampling protocol for Sentinel lakes, fall electrofishing for young of the year walleye was conducted. Surprisingly, the electrofishing CPUE of 248.2 walleye/hr indicated good natural reproduction since walleye were not stocked in 2008. Typically, a CPUE of young-of-the-year walleye in fall night electrofishing that exceeds 75 – 100 fish/hr is thought to produce acceptable year classes in southwestern Minnesota lakes; however, the natural reproduction encountered in 2008 was not observed in Lake Shaokotan since the late 1990's when electrofishing was last conducted. The 2009 and 2010 population assessments will verify if this naturally reproduced year class survives through winter. The first winter is a critical recruitment bottleneck for many fish species. Lengths of young of year walleye sampled using electrofishing ranged from 12.1 to 29 centimeters (4.8 to 11.4 inches) with a mean length of 16.5 centimeters (6.5 inches).

Growth of walleye was very good in Lake Shaokotan with walleye achieving > 41 centimeters (16 inches) of length by age 2 during the 2004 and 2008 assessments (Appendix A Table 5). The stable walleye population in Lake Shaokotan based on consistent abundance, good growth and condition of walleye indicated that the current stocking protocol has been effective. Thus, over population followed by reduced prey availability likely has not been an issue on Lake Shaokotan. Despite boom-bust fluctuations in black bullhead and yellow perch, sufficient prey has been available (perhaps including other species such as fathead minnows). Furthermore, the consistently solid year-classes of walleye may have reduced overly abundant bullheads and fathead minnows, benefitting water clarity (Herwig et al. 2004).

**Northern pike** *(Esox lucius)***.** During the early 1960's, considerable effort was directed toward developing a northern pike spawning area on the south side of the lake at the site where the county park is now located. MDNR records don't offer any clues as to why this project never materialized. Shaokotan supports inconsistent northern pike recruitment. Several northern pike year-classes were present in 1996, and two year-classes were present in the 2000 and 2004 assessments. The northern pike gill net CPUE of 0.3 was below the interquartile range of 1.2 to 1.8 in 2008. The northern pike gill net CPUE has remained low and consistent through the years ranging from 0.0 to 0.7 from 1996 to 2008.

Northern pike have been stocked on two occasions (2004 and 2008) in Lake Shaokotan. Only one northern pike was sampled in gill nets in 2008. However, a larger number were sampled with trap nets. Lengths of northern pike sampled in trap nets in 2008 ranged from 15.5 to 90.9 centimeters (6.1 to 35.8 inches) with a mean length of 48 centimeters (18.9 inches), indicating a broad range of sizes in the population. Most of the northern pike captured during 2008 were from the 2008 fingerling stocking. The condition of northern pike was good with an overall relative weight (Wr) of 93 (Appendix A, Table 4), suggesting that food availability for northern pike was acceptable for providing good growth. Northern pike generally feed on yellow perch when available. Increased availability of yellow perch as food and vegetation growth in Lake Shaokotan will be necessary for northern pike to sustain a population.

A noteworthy observation was the number of northern pike observed darting around the electrical field during fall electrofishing, even swimming up onto the beach at times. This is a typical behavior by northern pike because they sense the electrical field during electrofishing, swim at the periphery of the electrical field, and are therefore difficult to capture using the sampling method; however, the presence of northern pike in both frame nets and the observation of northern pike during electrofishing may indicate that the abundance is higher than ascertained from gill netting data. This also may indicate the need to utilize spring trap netting to assess the northern pike population instead of summer gill netting. Staff from the MDNR office in Windom have hypothesized summer gill-netting results may not be indicative of actual northern pike abundance in southwestern Minnesota lakes possibly due to decreased movement of northern pike during warm summer months when water temperatures are high and algal blooms are abundant.

**Other species.** Species sampled in gill nets and trap nets in low abundance included bluegill, white sucker and green sunfish. Bluegill abundance could potentially increase if the water clarity in Lake Shaokotan continues to improve or aquatic vegetation maintains or increases in abundance.

**Assessment of the value of Shaokotan for wildlife.** There have been two wildlife lake surveys recorded for Lake Shaokotan (1949 and 2002). Habitat and water quality from a wildlife standpoint have been poor since 1949. Historical accounts of the lake from that time state the lake was not a good quality wildlife lake due to the lack of aquatic plants. In 1949, it was noted that the lake lacked food and cover for waterfowl and had little use as a breeding ground. It did, however, have moderate use during migration as a resting site. In 2002, conditions remained largely unchanged and impaired from a waterfowl habitat perspective. Nevertheless, broods of waterfowl typically congregate in a small area of the western bay of Shaokotan, perhaps due to modest cover of aquatic plants compared with the rest of the lake.

# Water Quality

## Methods

Water quality data was collected May through October during the 2008 sampling season. Lake samples were taken in a central location of the deepest part of the lake basin. General chemistry, metals, and chlorophyll-A surface samples were collected with an integrated sampler, which is a polyvinyl chloride tube 2 meters in length with an inside diameter of 3.2 centimeters. Phytoplankton (algae) samples were also taken with an integrated sampler and preserved with a Lugol's solution. Zooplankton samples were collected with a Wisconsin Plankton Tow. Lake profile data (temperature, depth, dissolved oxygen, conductivity, pH, Oxygen Reduction Potential (ORP)) were collected with a calibrated Hydrolab sonde. Secchi disk transparency was also collected during sampling events. Depth (hypolimnetic) samples were collected approximately one meter above the lake bottom with a Kemmerer sampler. Seasonal averages were calculated using June- September data.

Chl-a samples were filtered on the day of collection; filters were placed in Petri dishes and wrapped in foil. Samples were chilled on ice or frozen prior to shipment to the Minnesota Department of Health (MDH) for analysis.

A wide range of samples were collected and analyzed. TP and Chl-a were the primary focus analytes of interest. All data for this report were stored in STORET, USEPA's national water quality data bank. Water quality data used in this report can be found in Appendix B.

## Results and Discussion

**Dissolved Oxygen and Temperature Profiles.** Profiles were taken at one-meter intervals at site 101 (Latitude 44.405278, Longitude - 96.360611) in Lake Shaokotan. A comparison of May through September temperature and dissolved oxygen (DO) profiles is found in Figures 14 and 15. Lake Shaokotan does not thermally stratify during the summer sampling season. This can be attributed to the lakes shallow depth and simple basin morphology. As a result Lake Shaokotan is polymictic and able to mix during wind events. DO, typically does not drop below 5 mg/L (necessary to support game fish) throughout the water column during summer months. Based on DO, profiles for 2008 hypoxic conditions (DO<2.0 mg/L) are not common and this should minimize internal P recycling as a function of DO; however, warm temperatures near the bottom sediments can allow phosphorus to be released from the sediments. Based on 2008 data, near-bottom temperatures exceeded 20°C (a level that promotes internal recycling) from late June through late August (Figure 15). This potentially provides an additional source of nutrients that can promote algal growth.

.

**Figure 14. Lake Shaokotan dissolved oxygen (mg/L) profiles**

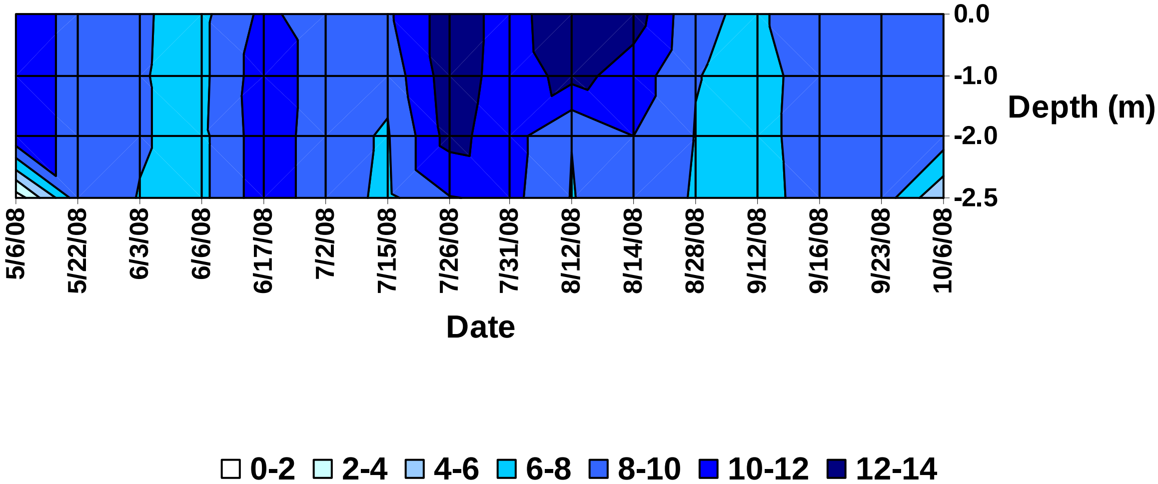
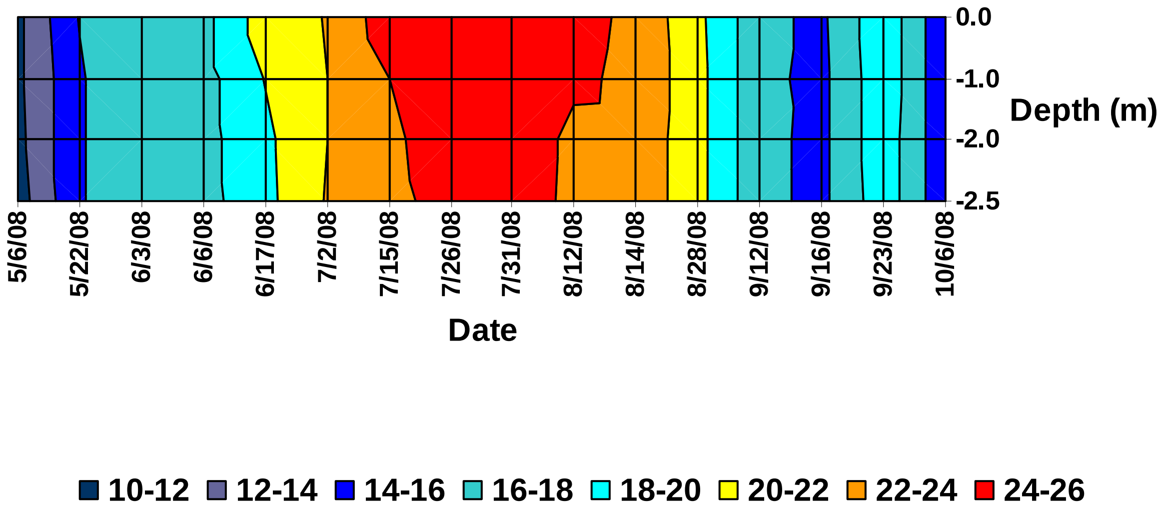



**Figure15. Lake Shaokotan temperature (°C) profiles**




**Total Phosphorus.** TP is the limiting nutrient for plant growth in most freshwater lakes. Lake Shaokotan's TP was variable throughout the 2008 open water period and ranged from 80-220 µg/L (Figure 16). In many shallow Minnesota lakes, it is common for TP to increase over the summer (as a result of several processes that promote internal recycling of P); however that was not the case for

Shaokotan. This could be attributed to wind mixing events which redistribute phosphorus throughout the water column periodically during the summer. It may also indicate that internal recycling of P may not be a major source of P in Shaokotan. The summer mean was 157 mg/L, which falls within the typical NGP ecoregion range of 122 – 160 ug/L.

**Chlorophyll-a.** Chl-a, a pigment found in algae, is used to estimate the amount of algal production in a lake. In 2008, Chl-a values for Lake Shaokotan were above the range of reference lakes in the NGP ecoregion. These values correspond with the high algae color observed for most of the summer and algal levels could be characterized as "severe nuisance blooms" for much of July through September. Chl-a and Secchi transparency show good correspondence throughout the summer in (Figure 16).

**Secchi Disk Transparency.** Transparency is generally a function of the amount of algae in the water. Suspended sediments or color (due to dissolved organic material) may also reduce water transparency; however, total suspended solids (TSS) in Shaokotan is within the typical range for NGP lakes and its TSIS is rather low (Table 6) so it is unlikely total suspended inorganic solids (TSIS) limits transparency. Lake Shaokotan's 2008 mean Secchi was 0.8 m (2.6ft) and falls within typical NGP ecoregion range of 0.4 m – 0.8 m.

Secchi transparency readings were taken at multiple locations on Lake Shaokotan (Figure 17). No distinctions among station patterns are revealed by these data. The data do suggest that Secchi measures in 1989-1992 typically ranged from <0.5 m up to about 2.0 m. In contrast, the more recent measures range from about 0.5 m up to 3.0 m (Figure 17).

**Table 6. Lake Shaokotan summer-mean water quality as compared to ecoregion reference lake typical range**

| Parameter | Shaokotan 2008 | NGP |
|---|---|---|
| Number of reference lakes | | 13 |
| Total Phosphorus (µg/L) | 157 | 122-160 |
| Chlorophyll mean (µg/L) | 81 | 36-61 |
| Secchi Disk (feet) | | 1.3-2.6 |
| (meters) | 0.95 | (0.4-0.8) |
| Total Kjeldahl Nitrogen (mg/L) | 2.38 | 1.8-2.3 |
| Alkalinity (mg/L) | 160 | 160-260 |
| Color (Pt-Co U) | 12.5 | 20-30 |
| pH (SU) | 8.4 | 8.3-8.6 |
| Chloride (mg/L) | 10 | 11-18 |
| Total Suspended Solids (mg/L) | 15 | 10-30 |
| Total Suspended Inorganic Solids (mg/L) | 6.9 | 5-15 |
| Conductivity (umhos/cm) | 683 | 640-900 |
| TN:TP ratio | 15:1 | 13:1-17:1 |

| | |
|---|---|
| µg/L = micrograms per liter | Pt-Co-U = Platinum Cobalt Units |
| mg/L = milligrams per liter | SU = Standard Units |
| umhos/cm = micromhos per centimeter | |

**Figure 16. 2008 monthly total phosphorus, chlorophyll-a, and Secchi**

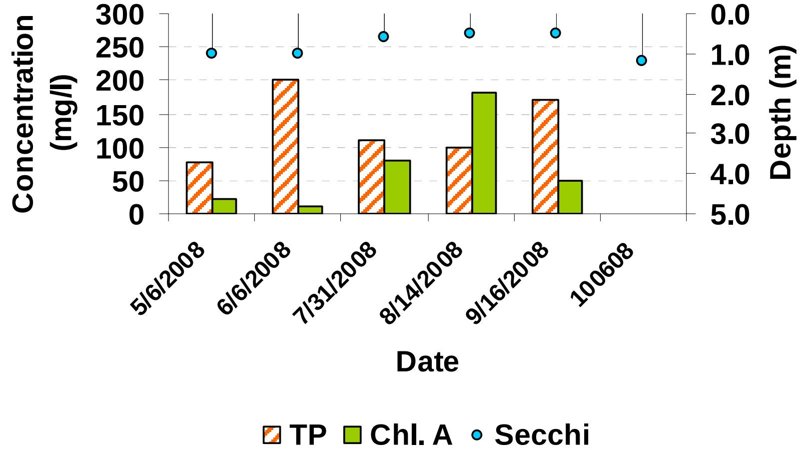
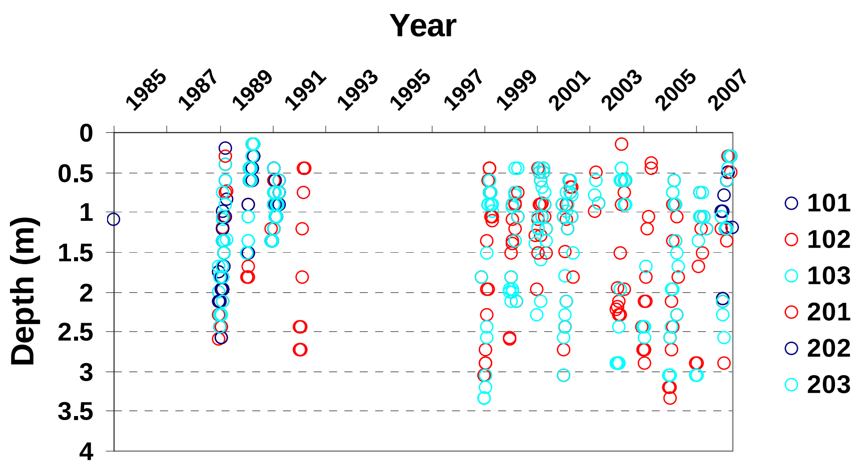



**Figure17. Secchi transparency site comparison**




## Trophic Status

The Carlson's Trophic State Index (TSI) (Carlson 1977), evaluates the trophic status of a lake by interpreting the relationship between TP, Chl-a, and Secchi disk transparency. TSI values are calculated as follows:

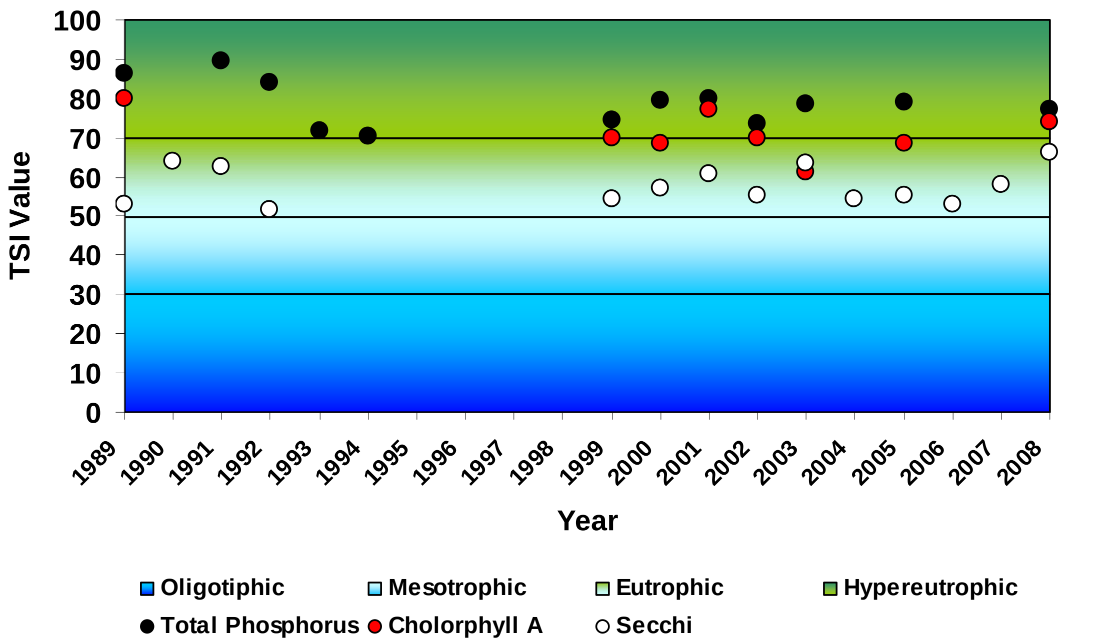
Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

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

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

TP and Chl-a units are in mg/L and Secchi measurements are 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. Oligotrophic lakes are typically cold, deep, clear, and less productive. In contrast, eutrophic lakes are shallow, warm, and highly productive. TSI values reflect a given lake's condition throughout this spectrum. TP and Chl-a show close correspondence and are indicative of hypereutrophic conditions (Figure 18). Secchi, in contrast, exhibits a lower TSI, which implies less eutrophic conditions. The deviation of Secchi TSI occurs over the majority of the record (Figure 18) and is most likely a result of dominance of the blue-green algal *Aphanizomenon* (Figure 19), which forms colonies or rafts at the surface of the water, allowing for deeper Secchi measurements.

**Figure 18. Lake Shaokotan trophic status index values. Based on summer-mean total phosphorus, chlorophyll-a, and Secchi**

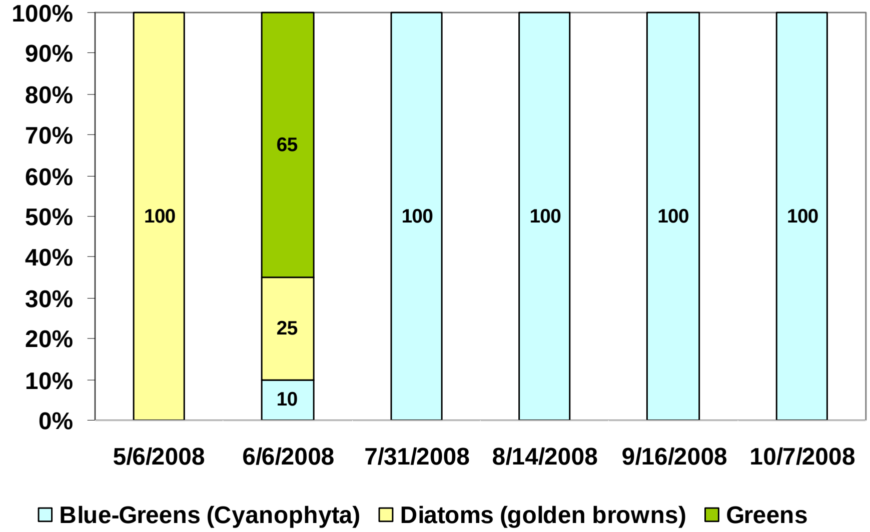


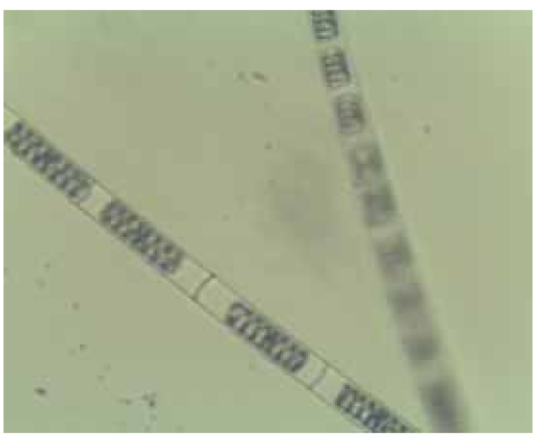

# Phytoplankton and Zooplankton

**Phytoplankton.** Algal communities shift throughout the seasons in response to changes in nutrient supply, sunlight and temperature. The transition for Lake Shaokotan in 2008 is depicted in Figure 19. Diatoms are most abundant in cool water conditions usually during spring and fall turn over (10-14°C based on Figure 15). As water temperatures warm and silica supplies decline, diatom production slows and green algae become more abundant. By mid-summer, blue-green algae are able to outcompete diatoms and green algae. Blue-green algae thrive in high water temperatures (~20-26°C based on Figure 15) and are able to outcompete other species of algae because of its larger size and ability to move vertically through the water column. Based on Figure 15, blue-greens became dominant in June and remained dominant through the fall sample collection in October, even though water temperatures had cooled to 14-16°C (Figure 15). *Aphanizomenon* and *Microcystis* are the two most common forms of blue-green algae found in Lake Shaokotan. *Aphanizomenon's* large size (forms colonies or rafts) may cause Secchi transparency to be greater than expected as compared to lakes not dominated by

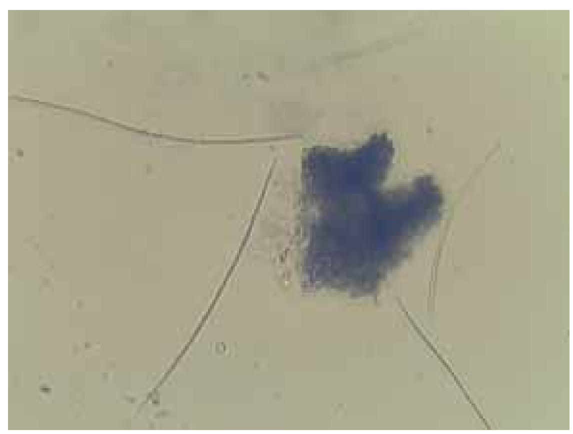
*Aphanizomenon* with the same Chl-a and TP concentrations. This was previously alluded to in our discussion of the observed pattern in Carlson TSI values (Figure 18).

**Figure 19. 2008 Lake Shaokotan phytoplankton community composition**



*Oedogoniales (Green)*



*Aphanizomenon* and *Microcystis (Blue-green)*

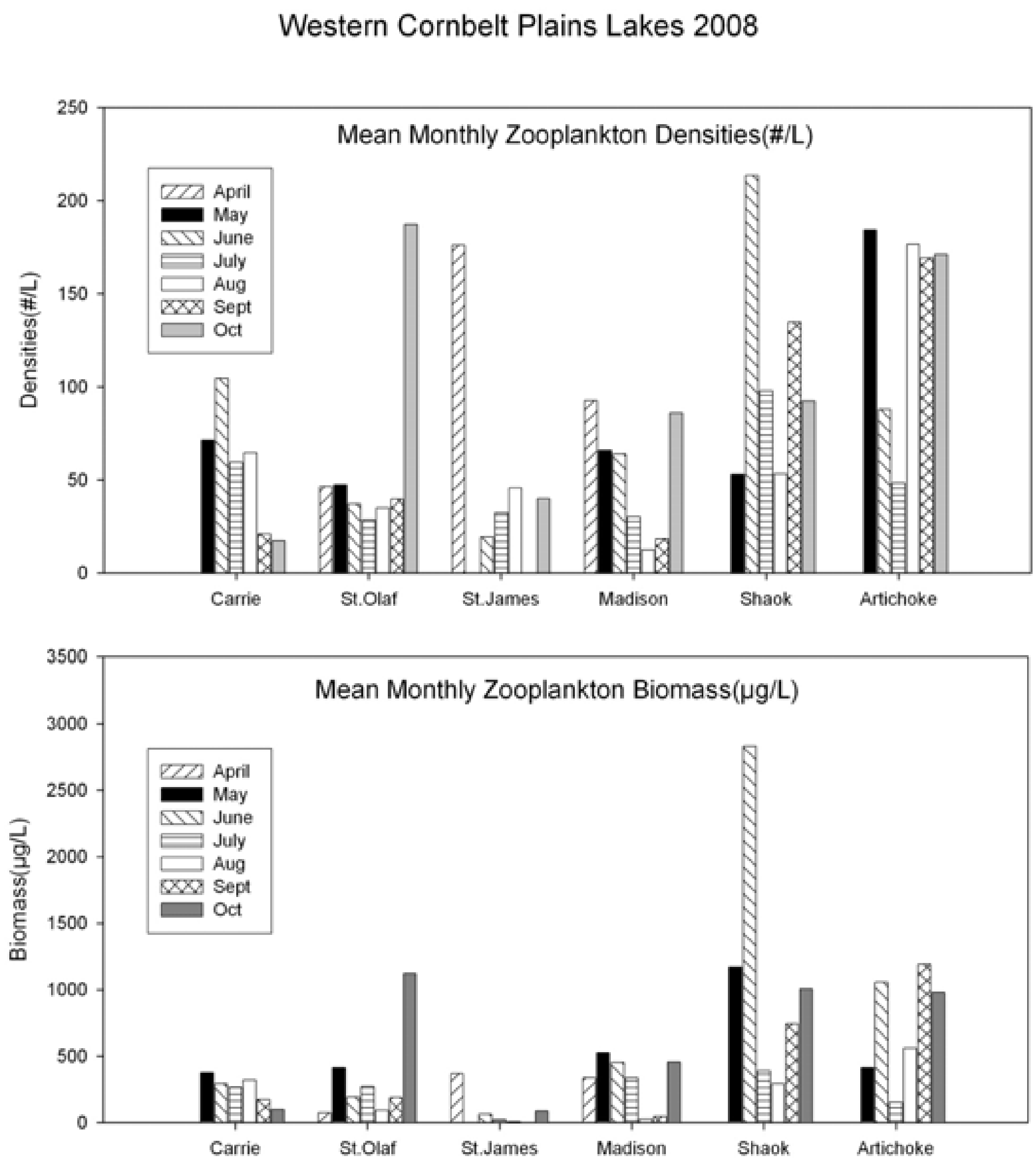
**Zooplankton.** Samples were analyzed by Jodie Hirsch, MDNR. A summary report was prepared that included information for all the Sentinel lakes (Hirsch 2009) and that report is the basis for the following comments on Lake Shaokotan.

Lake Shaokotan had the second highest mean annual density and the highest mean annual biomass of zooplankton of any of the NGP lakes and was among the highest overall for all 24 Sentinel lakes (Table 7); however, the total number of taxa was on the low end among these 24 lakes. Hirsch (2009) found that, in general, as lake productivity increased (e.g. TP or Chl-a), the relative abundance (biomass) of zooplankton increased, as well, for all 24 Sentinel lakes. Shaokotan appears to have the highest zooplankton biomass and densities in June when green algae, zooplanktons primary food source, is prevalent (Figure 20). As the phytoplankton community switches to primarily blue-greens, zooplankton abundance decreases drastically (Figure 19).

**Table 7. 2008 Lake Shaokotan mean annual zooplankton biomass and densities**

| Sentinel Lakes Zooplankton 2008 | Mean Annual Densities (#/L) | Mean Annual Biomass (µg/L) | Total# Taxa |
|---|---|---|---|
| **Western Corn Belt 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 |

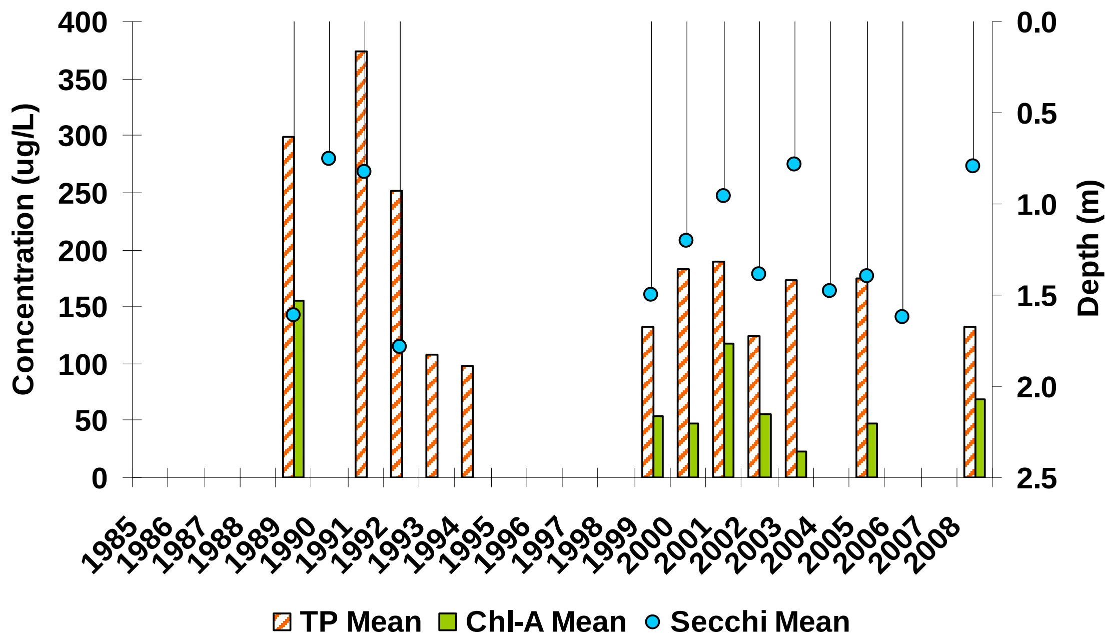
**Figure 20. Monthly zooplankton densities and biomass**



# Water Quality Trends and Diatom Reconstruction

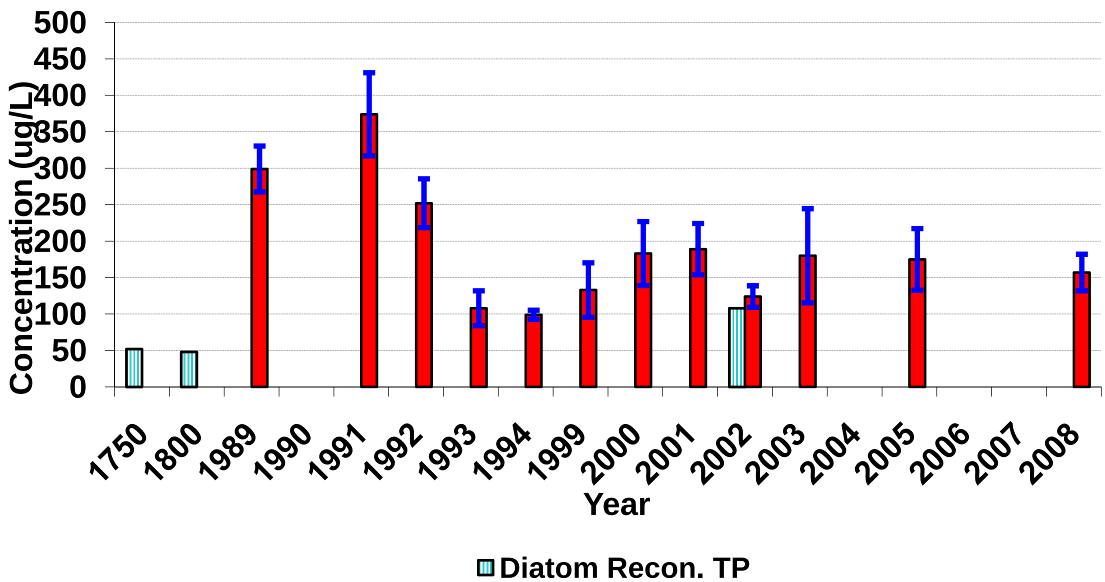
Shaokotan has a fairly rich data set for assessing trends in water quality. A combination of volunteer, MPCA and Clean Water Partnership(CWP)/TMDL project monitoring provide a basis for evaluating changes in TP, Chl-a and Secchi from 1989-2009 (Figure 21). Prior to 1994, the lake was extremely eutrophic with TP >250 µg/L, Chl-a >100 µg/L, and Secchi of 1.5 m or less. Large reductions in TP occur after 1994 as a result of a CWP phosphorous reduction program, which was implemented from 1991-1996. Phosphorus has increased slightly since 1994, but has not reached the excessive levels prior to 1993. A failure of a feedlot improvement project occurred during the years 1999 – 2000, which resulted in a release of manure to Shaokotan and a subsequent reversal in water quality improvements as marked by increased algae and a reduction in the extent of macrophytes.

**Figure 21. Historic summer average total phosphorus, chlorophyll-a, and Secchi**




Diatom sediment records can be used to predict historical phosphorus concentrations. The silicate structure of a diatom is resistant to decomposition and becomes trapped in the sediments when the diatom dies. There are many different species of diatoms and the environmental requirements of the various species are well known. As phosphorus concentrations change over time, species shifts are seen. Different species of diatoms outcompete each other at certain phosphorus concentrations. By identifying the dominant species of diatoms in a specific slice from a dated sediment core, an estimation of phosphorus concentration at that time is possible. In Shaokotan, core samples were taken at depths representing 1750, 1800, and 2002. According to the diatom record prior to the 1800's, phosphorus levels were significantly lower than today – on the order of 50 µg/L (Figure 22). When combined with the observed modern-day record, this provides a sense as to the dramatic changes that have occurred over time. The very close correspondence between the observed data and the diatom-reconstructed P provide a good indication that the diatom-reconstructed TP provides a good representation of historic TP for Shaokotan.

**Figure 22. Comparison of diatom reconstructed TP from sediment cores with observed summer-mean total phosphorus. Adapted from Heiskary et al. (2004)**

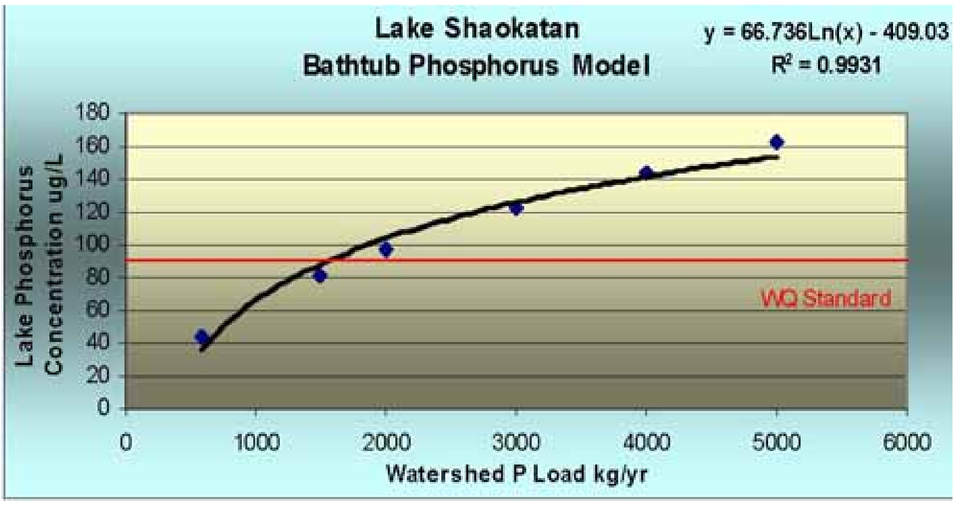



# TMDL Summary

Lake Shaokotan was included on Minnesota's 303(d) "Impaired Waters List" in 2002. The Lake Shaokotan Excess Nutrients TMDL began in 2004. The local sponsor of this project is the Yellow Medicine River Watershed District. The watershed district collected water samples, obtained global information systems (GIS) data and publicized the project from 2005-2006. Schuler Environmental Engineering was hired to develop the TMDL. The TMDL report was written based on water quality standards for shallow lakes within the NGP ecoregion.

A mass balance approach was used in assessing the watershed loading patterns and the lake response in terms of TP concentration. The P model is based on the watershed assessment developed during the 1991-92 CWP project and repeated in 1996 and 2001. Watershed P loads and lake response were calculated in each of these studies, providing a good record of data (Figure 23). The target watershed phosphorus load is 1,537 kilograms per year or 4.2 kg/day, corresponding to a resulting lake concentration of 80 µg/L phosphorus, a 67 percent reduction. For more information on the TMDL assessment, please see http://www.pca.state.mn.us/water/tmdl/project-lakeshaokatan.html

**Figure 23.Lake Shaokotan BATHTUB phosphorus model demonstrates relationships between watershed phosphorus loading and in lake phosphorus concentration**




# Assessment and Goal Setting

Eutrophication standards are now in place for assessing aquatic recreation use support for lakes in Minnesota (Table 8). For lakes in the NGP ecoregion, standards were developed for both deep and shallow lakes. Shallow lakes, by definition, are those with a "maximum depth of 15 feet or less, or with a littoral area of 80% or more". NGP lakes not fitting this description would use the deep lake standard. Lake Shaokotan is considered a shallow lake for purposes of assessing aquatic recreation use support, which determines whether the lake meets the eutrophication-based water quality standards. When compared to standards in Table 8, the TP and Chl-a values for Lake Shaokotan are in excess of standards. As a result, Lake Shaokotan was included on the Impaired Waters List. For Lake Shaokotan, there is a need to substantially reduce P loading to the lake – including both external and internal sources. Since the problems with excessive internal loading is typically a response to excessive external loads, it is important to address the remaining significant external sources prior to turning attention to internal sources. If external sources can be adequately controlled, internal sources may decline over time; however, this is somewhat dependant on flushing, which does not occur on a regular basis for Shaokotan. Overall, based on diatom-reconstructed, P and successful best management projects to date that have resulted in reduced P loading and improved in-lake water quality. The water quality standard of 90 µg/L is a realistic target for the lake and achieving it will result in improved water quality.

**Table 8. Eutrophication sandards by ecoregion and lake type**

| Ecoregion | TP | Chl-a | Secchi |
|---|---|---|---|
| | µg/L | µg/L | 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 |
| | | | |
| **Lake Shaokotan 2008** | **157** | **81** | **.95** |
| **Lake Shaokotan Long Term (1989-2008)** | **187** | **71** | **1.2** |

# Conclusions and Recommendations

Lake Shaokotan presents many challenges for water quality and fisheries management. It has a long history of concerns including excessive nutrient input from the watershed, internal recycling of nutrients, and lack of aquatic plant habitats to sustain naturally reproducing game fish populations and waterfowl. A sediment diatom-reconstruction study conducted in 2004 indicates it is much more productive today than it was prior to European colonization. Excessive amount of P have been deposited in Shaokotan as a result of runoff and feedlots. As a result, TP levels exceed water quality standards and nuisance algae blooms are common. A TMDL study is currently diagnosing management options which will likely include further reductions in P loading. Adding to the problem, Lake Shaokotan has a highly variable water level that fluctuates throughout the year depending on the amount and intensity of precipitation. Fluctuating water conditions cause nutrients within the lake to become concentrated during low water levels and increase the severity of algal blooms.

Shaokotan has a relatively simple basin with gravel substrate and shallow waters that promoting frequent mixing. This makes Shaokotan extremely efficient at utilizing the P within the lake. This means that the greatest gains in water quality must come from land management within the watershed.

Despite poor water quality, walleye growth rates are high; however, stocking will be necessary to provide a recreational fishery as long as habitats cannot support sufficient natural reproduction of fish populations.

Shaokotan is a productive shallow lake, typical of other shallow lakes in southwest Minnesota. The recreation value of Shaokotan and other lakes in this region is precarious and will hinge on lower-impact alternative agricultural/feedlot practices that reduce sediment and nutrient loading. Temporary improvements in water quality shortly following the clean water partnership in the late 1990's demonstrates resilience forces may pull the current turbid lake regime closer to a clear-water domain if external nutrient loads can be reduced. Clearer water and greater plant cover will benefit a great range of fish and wildlife species.

Given its involvement as a Sentinel lake in the SLICE program, Lake Shaokotan will be the site of intensive monitoring of many aspects of water quality, aquatic plants, and fish for many years to come. The benefits of this monitoring will result in better understanding of the basic structure and function of Lake Shaokotan ecosystem and quicker detection of threats to the lake and fishery.

# References


Angermeier P.L. and J.R. Karr 1994, Biological integrity versus biological diversity as policy directives: protecting biotic resources. Bioscience, 44: 690-697.

American Society of Agricultural Engineers ASAE D384.1, February, 2003, Manure Production and Characteristics

Bacigalupi, M. D., 2000. Growth and survival of two populations of stocked walleye and naturally spawned walleye in the same lakes. Master's Thesis. University of Minnesota.

Bajer, P. G., and P. W. Sorensen. 2009. Recruitment and abundance of an invasive fish, the common carp, is driven by its propensity to invade and reproduce in basins that experience winter-time hypoxia in interconnected lakes. Biological Invasions TBD.

Brown A. 1960. Letter correspondence to the Minnesota Conservation Department regarding the removal of carp Lake Shaokotan.

Carlson, R. E. 1977. A trophic state index for lakes. Limnology and Oceanography 22: 361-369.

Drake, M. T., and D. L. Pereira. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. North American Journal of Fisheries Management 22:1105-1123.

Edlund, M., and J. Kingston. 2004. Expanding a sediment diatom reconstruction model to eutrophic southern Minnesota lakes. Minnesota Pollution Control Agency, St. Paul.

Heiskary, S. A., E.B. Swain, and M.B. Edlund. 2004. Reconstructing historical water quality in Minnesota lakes from fossil diatoms. Environmental Bulletin. Number 4. MPCA, St. Paul MN

Herwig, B.R., M.A. Hanson, J.R. Reed, B.G. Parsons, A.J. Pothoff, M.C. Ward, K.D. Zimmer, M.G. Butler, D.W. Willis, and V.A. Snook. 2004. Walleye stocking as a tool to suppress fathead minnows in semipermanent and permanent wetlands in the Prairie Pothole Region of Minnesota. Minnesota Department of Natural Resources Special Publication No. 159.

Lake Finder. Minnesota Department of Natural Resources. 07 Apr. 2009 <http://www.dnr.state.mn.us/lakefind/index.html>.

MPCA October, 2002, Regional Total Maximum Daily Load Evaluation of Phosphorus Bacteria Impairments in the Lower Mississippi River Watershed in Minnesota.

Minnesota Pollution Control Agency, October 2002, "Regional Total Maximum Daily Load Evaluation of Phosphorus Bacteria Impairments In the Lower Mississippi River Watershed in Minnesota."

Perleberg, D. 2000. Aquatic Vegetation Survey of Shaokotan Lake (DOW #41-0089-00) Lincoln County, Minnesota. Minnesota Department of Natural Resources. Unpublished report.August 8, 2000

Scheffer, M., and S. R. Carpenter. 2003. Catastrophic regime shifts in ecosystems: linking theory to observation. Trends in Ecology and Evolution 18(12):648-656.

Schuler Environmental Engineering, David J Schuler. "Lake Shaokotan PhosphorusTotal Maximum Daily Load Report (Draft)." *Prepared for the Yellow Medicine Watershed District* (2009).

Swenson, H. 1969. Letter correspondence to Senator Joe Josefson regarding a winterkill event during the winter of 1968-69.

Thomsen. M. 1957. Letter correspondence to the Minnesota Conservation Department regarding poor bullhead fishing.

USEPA January 2001, "Protocol for Developing Pathogen TMDLS" , 1ST edition, 841-R-00-002.

University of Minnesota Department of Soil, Water, and Climate, June 30, 2002, Generic Environmental Impact Statement.

van Nes, E. H., and M. Scheffer. 2005. Implications of spatial heterogeneity for catastrophic regime shifts in ecosystems. Ecology 86(7):1797-1807.

Water Year Precipitation Departure from Normal, October 2007 – September 2008. Map. State Climatology Office, Minnesota Department of Natural Resources. 2009

Zimmer, K. D., B. R. Herwig, and L. M. Laurich. 2006. Nutrient excretion by fish in wetland ecosystems and its potential to support algal production. Limnology and Oceanography 51(1):197-207.

# Appendix A

## Fisheries Data for Lake Shaokotan

**Table 1. Stocking history including size and number for fishes stocked into Shaokotan Lake, 1988 – 2008.**

| Year | Species | Size | Number |
|---|---|---|---|
| 2008 | Northern pike | fingerling | 2,216 |
| 2007 | Walleye | fry | 994,816 |
| 2006 | Walleye | fry | 995,648 |
| 2004 | Northern pike | fingerling | 6,645 |
| | Walleye | fry | 986,148 |
| 2002 | Walleye | fry | 727,587 |
| 2000 | Walleye | fry | 741,000 |
| 1998 | Walleye | fry | 995,000 |
| 1995 | Walleye | fry | 740,480 |
| 1994 | Walleye | fry | 750,000 |
| 1992 | Walleye | fry | 721,000 |
| 1991 | Walleye | fry | 746,300 |
| 1989 | Walleye | fry | 745,720 |
| 1988 | Walleye | fry | 803,907 |

**Table 2. Sample size (n; stock length), stock density indices (proportional size structure; PSS) for quality (Q), preferred (P), memorable (M), and trophy (T) length categories and mean relative weight (Wr; where n 3) of various fish species captured in experimental gill net sets, frame net sets, seining, or night electrofishing in Shaokotan Lake during 2008.**

| Gear | | Proportional Size Structure | | | | Relative Weight | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | n | $PSS_Q$ | $PSS_P$ | $PSS_M$ | $PSS_T$ | S-Q | Q-P | P-M | M-T | T | Overall |
| **Gill nets** | | | | | | | | | | | |
| Black bullhead | 4 | 25 | 0 | 0 | 0 | 101 | --- | --- | --- | --- | 105 |
| Northern pike | 1 | 0 | 0 | 0 | 0 | --- | --- | --- | --- | --- | --- |
| Walleye | 41 | 88 | 17 | 0 | 0 | 95 | 90 | 89 | --- | --- | 91 |
| Yellow perch | 115 | 70 | 29 | 2 | 0 | 106 | 108 | 108 | --- | --- | 107 |
| **Frame nets** | | | | | | | | | | | |
| Black bullhead | 10 | 70 | 70 | 0 | 0 | 106 | 100 | --- | --- | --- | 102 |
| Northern pike | 11 | 27 | 0 | 0 | 0 | 97 | --- | --- | --- | --- | 94 |
| Walleye | 23 | 87 | 35 | 0 | 0 | 90 | 87 | 82 | --- | --- | 87 |
| Yellow perch | 7 | 71 | 29 | 0 | 0 | --- | 104 | --- | --- | --- | 106 |
| **Electrofishing[1]** | | | | | | | | | | | |
| Walleye | 364 | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |

[1] Fall electrofishing.
[2] All gears combined.

**Table 3. Historic mean catch rate (CPUE; Catch/net or Catch/h electrofishing) for various fish species captured in experimental gill net sets, frame net sets, or electrofishing in Shaokotan Lake, 1954 - 2008.**

| Species | 1954 | 1957 | 1967 | 1983 | 1988 | 1992 | 1996 | 2000 | 2004 | 2008 | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Gill nets** | | | | | | | | | | | |
| Black bullhead | 44.8 | 19.0 | 5.3 | 192.5 | 316.3 | 23.3 | 115.0 | 225.0 | 287.0 | 1.7 | 123.0 |
| Black crappie | 0.0 | 0.0 | 0.7 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| Common carp | 0.1 | 0.0 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 |
| Northern pike | 0.2 | 0.0 | 3.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.7 | 0.7 | 0.3 | 0.5 |
| Orangespotted sunfish | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | <0.1 |
| Walleye | 18.5 | 9.3 | 15.3 | 34.5 | 12.0 | 5.3 | 13.8 | 10.3 | 6.0 | 19.7 | 14.5 |
| White sucker | 0.5 | 0.3 | 0.0 | 0.0 | 0.3 | 0.0 | 1.0 | 1.7 | 0.3 | 0.0 | 0.4 |
| Yellow perch | 190.8 | 531.7 | 108.7 | 2.0 | 8.0 | 0.0 | 24.0 | 147.7 | 0.7 | 38.7 | 105.2 |
| **Frame nets** | | | | | | | | | | | |
| Black bullhead | 22.5 | 9.3 | 10.9 | 606.7 | 454.9 | 16.4 | 29.5 | 362.3 | 97.3 | 0.9 | 161.1 |
| Black crappie | 0.0 | 0.9 | 10.5 | 0.4 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 1.2 |
| Bluegill | 1.8 | 0.0 | 0.0 | 2.7 | 0.1 | 0.1 | 0.3 | 0.1 | 0.2 | 0.1 | 0.5 |
| Common carp | 0.1 | 5.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.6 |
| Green sunfish | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | <0.1 |
| Northern pike | 0.3 | 0.1 | 1.9 | 0.6 | 0.1 | 0.4 | 1.0 | 0.4 | 0.3 | 0.6 | 0.6 |
| Orangespotted sunfish | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | <0.1 |
| Pumpkinseed | 0.9 | 0.1 | 0.0 | 3.3 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.4 |
| Walleye | 1.8 | 7.2 | 1.1 | 1.6 | 2.3 | 2.3 | 4.2 | 8.0 | 5.7 | 2.6 | 3.7 |
| White sucker | 1.3 | 1.5 | 1.5 | 0.0 | 0.0 | 0.2 | 0.5 | 0.2 | 0.4 | 0.4 | 0.6 |
| Yellow perch | 17.0 | 17.1 | 3.6 | 0.1 | 0.3 | 0.1 | 1.4 | 2.6 | 0.7 | 0.6 | 4.4 |
| **Fall Electrofishing[1]** | | | | | | | | | | | |
| WAE | --- | --- | --- | --- | --- | --- | 74.4 | --- | --- | 242.6 | 279.8 |

**Table 4. Mean catch rate (CPUE; Catch/net), stock density indices (proportional size structure; PSS) for quality (Q) and preferred (P) length categories, and relative weight (Wr) for primary management species captured in experimental gill net sets, frame net sets, or electrofishing in Shaokotan Lake, 1954 - 2008.**

| Gear | Survey Year | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | 1954 | 1957 | 1967 | 1983 | 1988 | 1992 | 1996 | 2000 | 2004 | 2008 | Mean | Objective |
| **Frame nets** | | | | | | | | | | | | |
| Black bullhead | | | | | | | | | | | | |
| CPUE | 22.5 | 9.3 | 10.9 | 606.7 | 454.9 | 16.4 | 29.5 | 362.3 | 97.3 | 0.9 | 161.1 | 4.6 – 83.0 |
| $PSS_Q$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | 70 | 70 | --- |
| $PSS_P$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | 70 | 70 | --- |
| Wr | --- | --- | --- | --- | --- | --- | --- | --- | --- | 105 | 105 | ≥ 80 |
| **Gill nets** | | | | | | | | | | | | |
| Northern pike | | | | | | | | | | | | |
| CPUE | 0.2 | 0.0 | 3.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.7 | 0.7 | 0.3 | 0.5 | 1.2 – 1.8 |
| $PSS_Q$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0 | 30 – 50 |
| $PSS_P$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 0 | 5 – 10 |
| Wr | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | ≥ 80 |
| Walleye | | | | | | | | | | | | |
| CPUE | 18.5 | 9.3 | 15.3 | 34.5 | 12.0 | 5.3 | 13.8 | 10.3 | 6.0 | 19.7 | 14.5 | ≥ 15 |
| $PSS_Q$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 88 | 30 – 50 |
| $PSS_P$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 17 | 5 – 10 |
| Wr | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 91 | ≥ 80 |
| Yellow perch | | | | | | | | | | | | |
| CPUE | 190.8 | 531.7 | 108.7 | 2.0 | 8.0 | 0.0 | 24.0 | 147.7 | 0.7 | 38.7 | 105.2 | 3.0 – 22.5 |
| $PSS_Q$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 70 | --- |
| $PSS_P$ | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 29 | --- |
| *Wr* | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | 106 | ≥ 80 |

**Table 5. Weighted mean length at capture (inches) for walleye captured in experimental gill net sets in Shaokotan Lake, 1996 – 2008. Note: sampling was conducted at approximately the same time during each year allowing comparisons among years to monitor growth trends.**

| | | Age | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | N | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 2008 | 36 | --- | 11.1 | 16.2 | --- | 19.2 | --- | --- | 23.2 | 18.0 | 19.5 |
| 2004 | 25 | --- | 12.8 | 17.1 | --- | 20.2 | --- | 22.4 | --- | --- | --- |
| 2000 | 35 | --- | 9.8 | 10.6 | 11.4 | 20.2 | 20.5 | 23.0 | 23.4 | --- | --- |
| 1996 | 49 | --- | 10.2 | 13.8 | --- | 19.4 | 19.8 | --- | --- | --- | --- |

# Appendix B

## Lake Surface Water Quality Data for Lake Shaokotan for 2008

All water quality data may be accessed at:

http://www.pca.state.mn.us/data/eda/STresults.cfm?stID=41-0089&stOR=MNPCA1

| Lake Name | Lake ID | Sample Date | Site ID | Secchi | TP | Chl-a | Alkalinity | Cholride | TKN | Color | TSS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Meters | µg/L | µg/L | mg/L | mg/L | mg/L | PCU | mg/L |
| Shaokotan | 41-0089 | 5/6/2008 | 101 | 1 | 0.08 | 22.8 | 170 | 9.78 | 1.47 | 20 | 18 |
| Shaokotan | 41-0089 | 6/6/2008 | 101 | 1 | 0.202 | 10.7 | | | 1.83 | | |
| Shaokotan | 41-0089 | 6/17/2008 | 101 | 0.79 | | | | | | | |
| Shaokotan | 41-0089 | 7/2/2008 | 101 | 1.22 | | | | | | | |
| Shaokotan | 41-0089 | 7/15/2008 | 101 | 1.2 | | | | | | | |
| Shaokotan | 41-0089 | 7/26/2008 | 101 | 0.6 | | | | | | | |
| Shaokotan | 41-0089 | 7/31/2008 | 101 | 0.6 | 0.11 | 81 | 150 | 10.8 | 3.16 | 5 | 12 |
| Shaokotan | 41-0089 | 8/12/2008 | 101 | 0.5 | | | | | | | |
| Shaokotan | 41-0089 | 8/14/2008 | 101 | 0.5 | 0.146 | 182 | | | 2.87 | | |
| Shaokotan | 41-0089 | 8/28/2008 | 101 | 0.3 | | | | | | | |
| Shaokotan | 41-0089 | 9/12/2008 | 101 | 0.3 | | | | | | | |
| Shaokotan | 41-0089 | 9/16/2008 | 101 | | 0.172 | 50.4 | | | 2.74 | | |
| Shaokotan | 41-0089 | 9/23/2008 | 101 | 0.3 | | | | | | | |
| Shaokotan | 41-0089 | 10/6/2008 | 101 | 1.2 | | | | | | | |
| Shaokotan | 41-0089 | 10/7/2008 | 101 | | 0.114 | 40.4 | 170 | 11.1 | 2.39 | 10 | 10 |