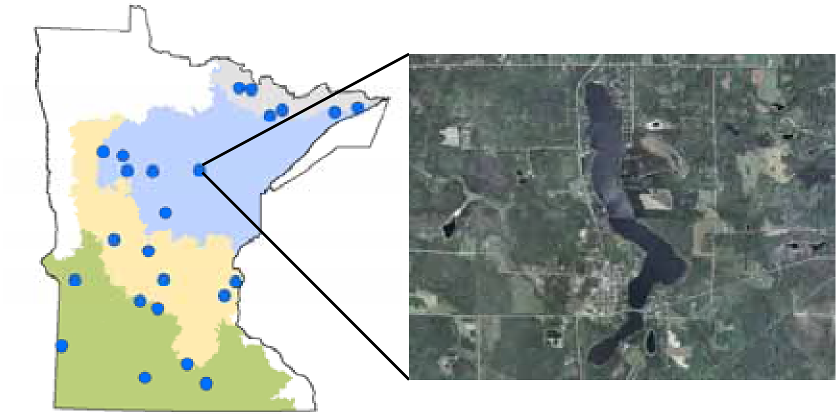
Sentinel Lake Assessment Report
Hill Lake (01-0142)
Aitkin County, Minnesota



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

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Executive Summary

The Minnesota Pollution Control Agency (MPCA) and the Minnesota Department of Natural Resources (MDNR) are working in partnership 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 either harbor cisco, lake whitefish, or lake trout or are the focus of research funded by the Environmental Trust Fund. "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is also funded by the Environmental Trust Fund.

Hill Lake was selected to represent a moderately deep, mesotrophic lake in the Northern Lakes and Forests (NLF) ecoregion. Hill Lake is a 315 hectare (780 acre lake), located within Hill City, Minnesota in Aitkin County, within the Mississippi River (Grand Rapids) major watershed. Hill Lake is divided into two basins by State Highway 210. The north basin (NB) is 265 hectares (656 acres) with a maximum depth of 14.6 meters (48 feet) and a mean depth of 7.4 meters (24.3 feet). The south basin (SB) is 50 hectares (124 acres) with a maximum depth of 7.3 meters (24 feet) and a mean depth of 2.8 meters (9.1 feet). The lake is 39 percent littoral with two public accesses. The total contributing watershed for the NB is 3,703 hectares (9,165 acres). The contributing watershed for the SB is much larger at 10,394 hectares (25,728 acres).

The NB of Hill Lake is moderately deep, mixes in the spring and fall, and is typically stratified from June through August. The SB of Hill Lake is shallow and continually mixes throughout the season, but will develop a weak thermocline under calm conditions. Based on recent water quality data (2008-2009), the NB of Hill Lake is considered to be mesotrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 22 micrograms per liter (µg/L), 5 µg/L, and 3.7 meters (12 feet) respectively. TP levels for the NB were within the typical ranges (based on reference lakes) for the NLF ecoregion. Chl-*a* levels were also within the typical range for the NLF ecoregion with no observed nuisance algal blooms and a high transparency during a majority of the summer. The SB of Hill Lake is considered to be eutrophic with TP, chl-*a*, and Secchi values of: 36 µg/L, 12 µg/L, and 2.3 meters (7.5 feet) respectively. TP and chl-*a* levels for the SB exceeded the typical ranges for the NLF ecoregion, with only minor algal blooms observed.

Secchi transparency was slightly better than the expected range for NLF lakes. Trophic status data collected in 1994 suggest decreases in nutrient levels and algal growth over time for the NB. As a result, Secchi transparency has improved. Once a lake has been placed on the 303(d) (or Impaired Waters) List, it is required to be intensively researched through a total Maximum Daily Load (TMDL) study to determine the source and extent of the pollution problem, followed by the development of a restoration plan. Hill Lake was placed on the 1998 Impaired Waters list for aquatic consumption related to mercury in fish tissue. A TMDL study began for Hill Lake in 1999 and is targeted for completion in 2011.

When recent data were compared with the data collected for the 1994 lake assessment report, there are indications that the water quality for the NB has improved. The NB was historically considered to be eutrophic. Improvement is seen within the SB as well; however, the SB is still considered to be eutrophic. The 1994 lake assessment report can be accessed at http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/lakes/lake-water-quality/lake-water-quality-assessment-reports.html?menuid=&missing=0&redirect=1.

An ecoregion-based eutrophication model was used to predict in-lake TP based on Hill Lake's size, depth, and watershed area. Using inputs for the NLF ecoregion the model predicted in-lake TP for the NB to be 21 µg/L, which is similar to the observed 22 µg/L. A separate subroutine within the model estimated "background" TP for the lake at 20 µg/L. Using the same relative inputs the model predicted in-lake TP for the SB to be 43 µg/L. This is not significantly different from the observed 36 µg/L. The model predictions, along with the overall assessment of Hill Lake's water quality data, indicate the lake's water quality within the NB meets the expectations for a lake of this size in this portion of the state while the SB does not.

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 Hill Lake in Aitkin, 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 and 2009 seasons. Minimal historical data are available and are used to provide some perspective on variability and trends in water quality. Water quality data analyzed included all available data in STORET, the national repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the *Guide to Lake Protection and Management*: http://www.pca.state.mn.us/water/lakeprotection.html.

History

Provided by the Paul Bauer, Hill Lake Association and Rick Bruesewitz, MDNR area fisheries supervisor

1869 - Hill Lake surveyed, surveyor notes clear, spring-fed lake and forested watershed.

1880 - Logging began in the watershed.

1900-1915 - Settlement established at head and south end of lake. Logging camps, earth skids, and saw mills were present along the shores of the lake. Most of the white pine is gone. Agriculture in the watershed increasing -- Morrison Brook area in particular. Much road building occurred, beginning of boom for Hill City.

1912-1945 - Intermittent stocking of walleye and one-time stockings of lake trout and largemouth bass.

1915-1920 - Continued settling and development. Cedar swamps logged. Large fires reported. Farms continue to increase.

1921 - Dam at mouth of Hill Lake built.

1927 - Timber is very hard to find, eventually leads to closure of Woodenware Company.

1930 - Drought causes Hill Lake to shrink.

1937 - New dam constructed.

1939 - Lake is high and channel to Pughole Lake is open.

1940 - 1949 - Notable increase in tourism helping local economy.

1950-1959 - Hill City population stable at about 300.

1953-1955 - High water and flooding reported.

1960-1969 - Extensive development along shoreland and in the immediate watershed of Hill Lake. Quadna Resort development is underway. Hill City constructs storm sewers that drain to Hill Lake. Blandin Paper Mill starts tree plantations on sites of former farms.

1974 and 1990 - Hill City and Hill Lake host the Governor's fishing opener.

1979 - Semi-annual stocking of walleye fry began and continues to this day.

1988 - Additional storm sewer construction.

1990s - Change in Quadna Mountain from resort to association with private cabin ownership. Recreational use of the lake presumed to decline as a result.

1994 - Lake assessment of Hill Lake.

1998 - Creel survey conducted on the Hill Lake.

Background

Lake morphometric and watershed characteristics

Hill Lake is located in Aitkin County within the Mississippi River (Grand Rapids) major watershed and has two distinct basins: a large and deep northern basin (NB) and a small and shallow south basin (SB) that serves as the outlet of the lake. Hill City, MN lies on the western shore of Hill Lake. A public access is located on the southwestern shore of the NB in Hill Lake Park and another lies on the eastern shore of the SB. The NB of Hill Lake is deep and well mixed in the spring and fall, with a deep thermocline forming during the summer months. The SB of Hill Lake is shallow and well mixed throughout the season, with a weak thermocline forming during calm periods.

Hill 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. The distinct differences in morphometry will influence water quality and plant growth in the two basins. The NB comprises 84 percent of the total lake by area and 94 percent by volume. About 21 percent of the NB is considered littoral; whereas about 84 percent of the SB is littoral.

Figure 2. Hill Lake three dimensional depth contour map

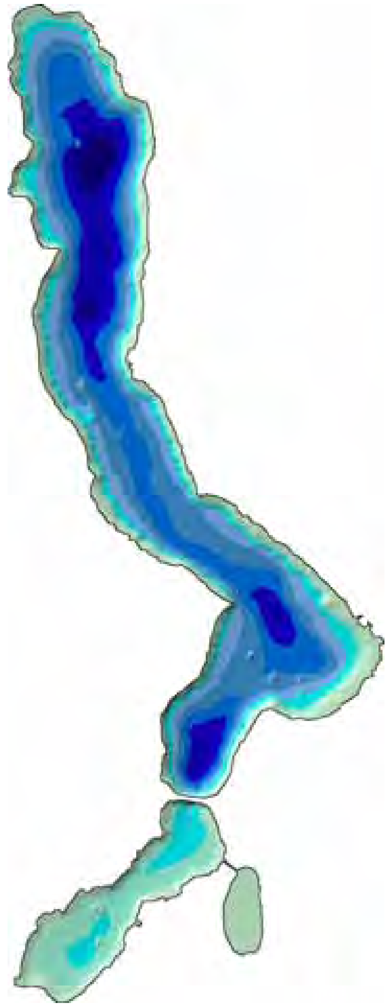


Table 1. Hill Lake and watershed morphometric characteristics

Lake Name	Lake ID	Lake Basin	Littoral Area	Total Watershed Area	Watershed: Lake	Maximum Depth	Mean Depth	Lake Volume (by basin)
		Hectares (Acres)	%	Hectares (Acres)	Ratio	Meters (Feet)	Meters (Feet)	Acre-Ft.
Hill Lake (NB)	01-0142-01	265 (656)	21	3,703 (9,165)	14:1	14.6 (48)	7.4 (24.3)	16,081
Hill Lake (SB)	01-0142-02	50 (124)	84	10,394 (25,728)	207:1	7.3 (24)	2.8 (9.1)	1,730

Lake bathymetry based on MDNR 2008 acoustic survey.

The Hill Lake contributing watershed lies within the Mississippi River (Grand Rapids) major watershed. Both basins drain from one outlet point located on the southwestern shore of the SB. The contributing watershed for the NB (3,703 hectares (9,165 acres)) is significantly smaller than the contributing watershed for the SB (10,394 hectares (25,728 acres)) resulting in watershed-to-lake area ratios of approximately 14:1 and 207:1, respectively. Watershed areas were estimated based on data from MDNR Waters Delineations.

Hill Lake soils are defined as fine-textured forest soils formed from weakly calcareous red clayey glacial till from the Hibbing-Zim series. The area is undulating to strongly hilly and the soils are light-colored. Hibbing soils are well- to moderately well-drained while Zim soils are somewhat poorly drained and occupy the more level areas. Common tree species are aspen, birch, and fir (Arneman 1963). Hill Lake was likely formed by glacial deposition within the till (Zumberge, 1952).

Lake mixing and stratification

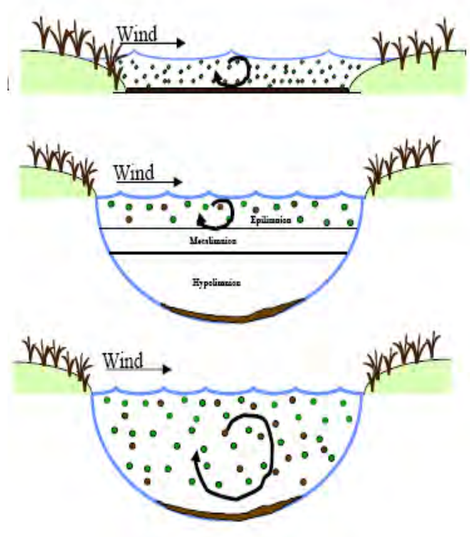
Lake depth and mixing has a significant influence on lake processes and water quality. *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 9 meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 3). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of 5 meters or less) in contrast, typically do not stratify and are often referred to as *polymictic*. Lakes, with moderate depths, may stratify intermittently during calm periods, but mix during heavy winds and during spring and fall. Measurement of temperature throughout the water column (surface to bottom) at selected intervals (e.g. every meter) can be used to determine whether the lake is well-mixed or stratified. The depth of the thermocline (zone of maximum change in temperature over the depth interval) can also be determined. In general, dimictic lakes have an upper, well-mixed layer (epilimnion) that is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. This low oxygen environments in the hypolimnion are conducive to 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. Hill Lake lies within the NLF ecoregion (Figure 4). NLF ecoregion values will be used for land use (Table 2) and summer-mean water quality comparisons (Table 8) as well as the model application (Table 12).

Land use within the watershed is very typical for the NLF ecoregion, with the exception of a slightly higher percentage of pasture and open land use. When compared to one another, the land uses for each of Hill Lake's basins is also similar with forest being the dominant usage (Figure 5 & Table 2). One exception is the small area that is open water for the SB's watershed. This is reflected in the watershed-to-lake ratio of 207:1 for the SB.

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

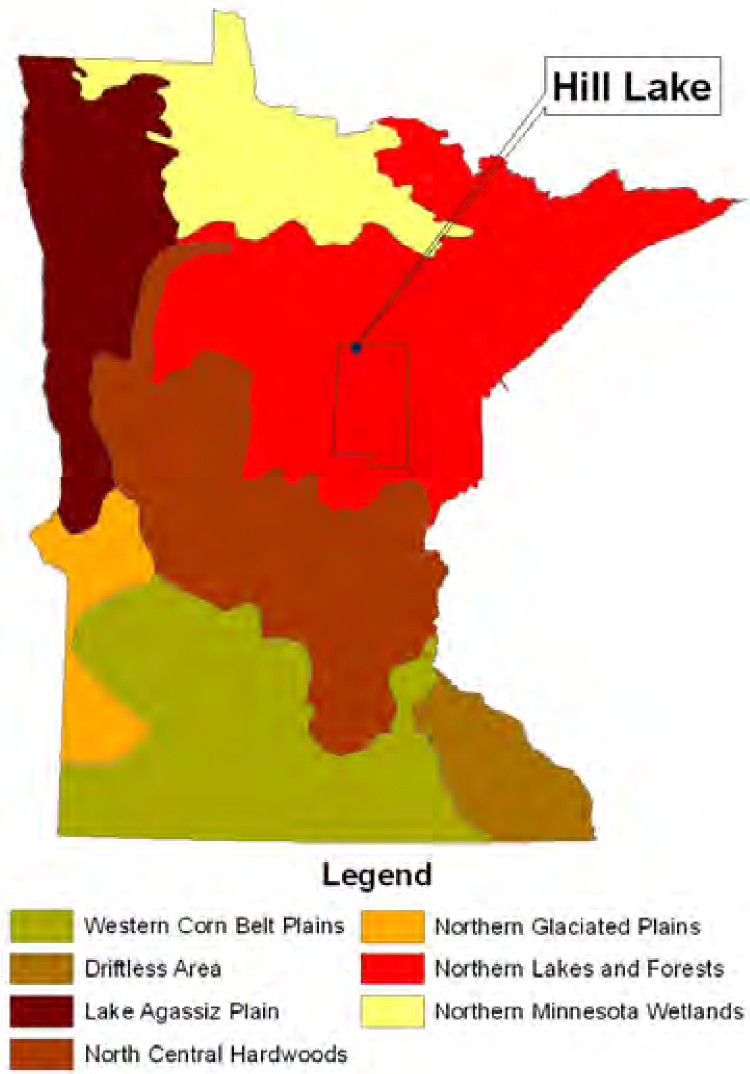
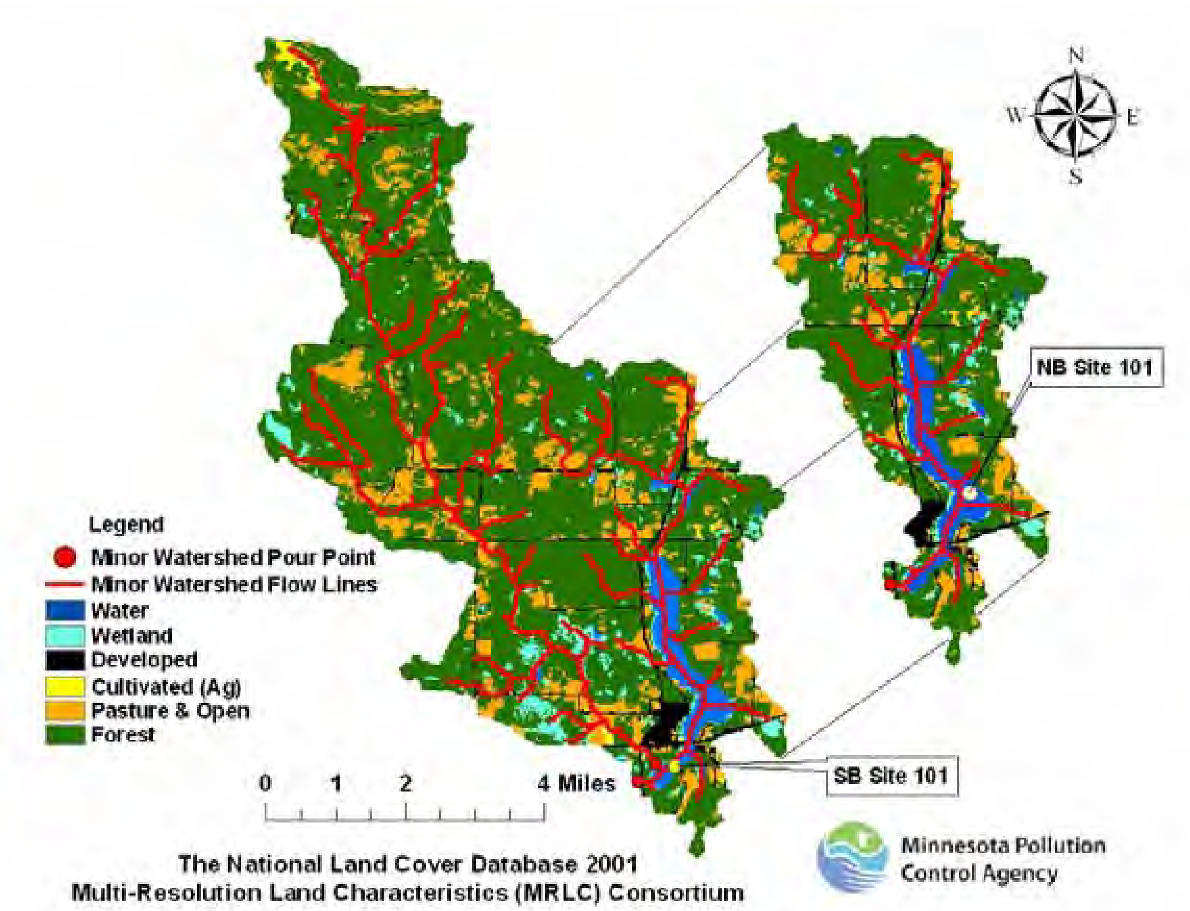


Table 2. Hill Lake (NB and SB) ecoregion land use comparison. Typical (interquartile) range based on NLF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	Hill Lake (1969)[2]	Hill Lake (1991)[3]	Hill Lake NB (2001)[1]	Hill Lake SB (2001)[1]	NLF Ecoregion
Developed	3	2	6	3	0 - 7
Cultivated (Ag)	5	2	<1	<1	<1
Pasture & Open	6	10	12	13	0 - 6
Forest	83	63	67	75	54 - 81
Water & Wetland	3	24	15	9	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

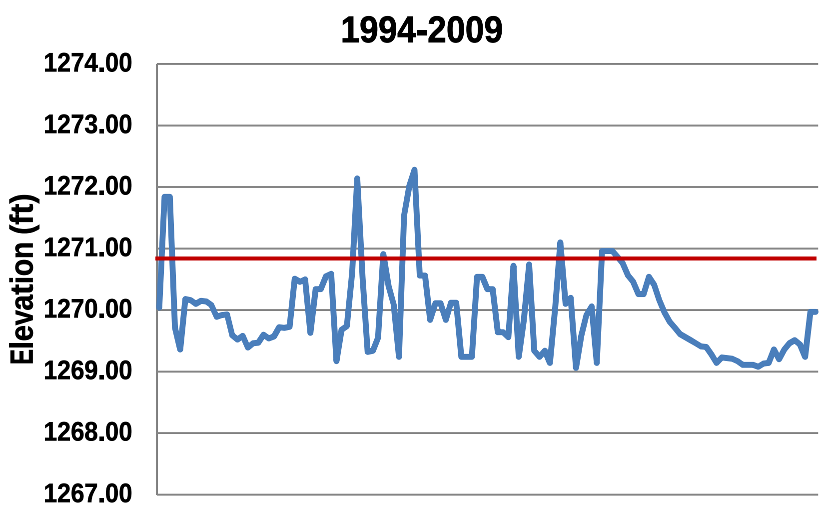
Figure 5. Hill Lake NB & SB sample locations, watershed areas, and land use composition

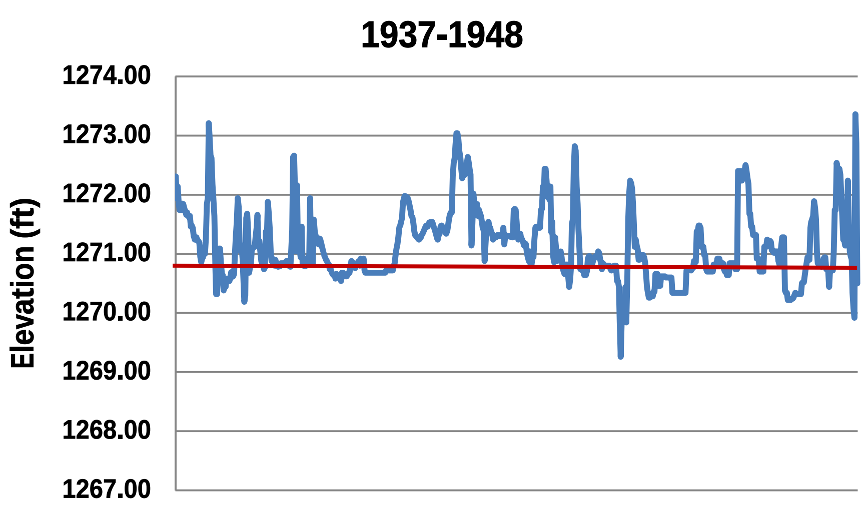


Lake level

The MDNR Division of Waters has been measuring water levels on Hill Lake since 1937. During the period of record (June 1937 – May 2009), the lake has varied by 4.55 feet, based on 886 readings. The highest and lowest recorded elevations are 1273.61 feet on 04/27/1982 and 1269.06 feet on 07/26/2006. The ordinary high water mark for Hill Lake is 1270.9 feet (red horizontal lines within Figure 6). Based on current lake levels from 1994 to 2009 the lake has typically remained below the ordinary high water mark. When two time periods from the historical water levels are compared (1937 to 1948 and 1994 to 2009), the current trend in water levels for Hill Lake are lower than what they were decades ago (Figure 6). Water level for Hill Lake is not being actively managed at this time. The complete water level record may be obtained from the MDNR web site at: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=29025000.

Figure 6. Hill Lake current and historical water level reports





Precipitation and climate summary

Rain gage records from Grand Rapids show two, one-inch plus rain events during summer 2009 (Figure 7). Large rain events will increase runoff into the lake and may influence in-lake water quality and lake levels. This will be considered in the discussion of lake water quality for 2009 that follows later in this report. Precipitation records for the 2009 water year (October 2008 through September 2009) showed that the Hill Lake area was 4 to 6 inches below normal (Figure 8). Historical precipitation records show that the average rainfall amounts for the summer months to be approximately 18 inches (Figure 9). The average precipitation during the summer months within the Grand Rapids area has been below the historical average since 2004.

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

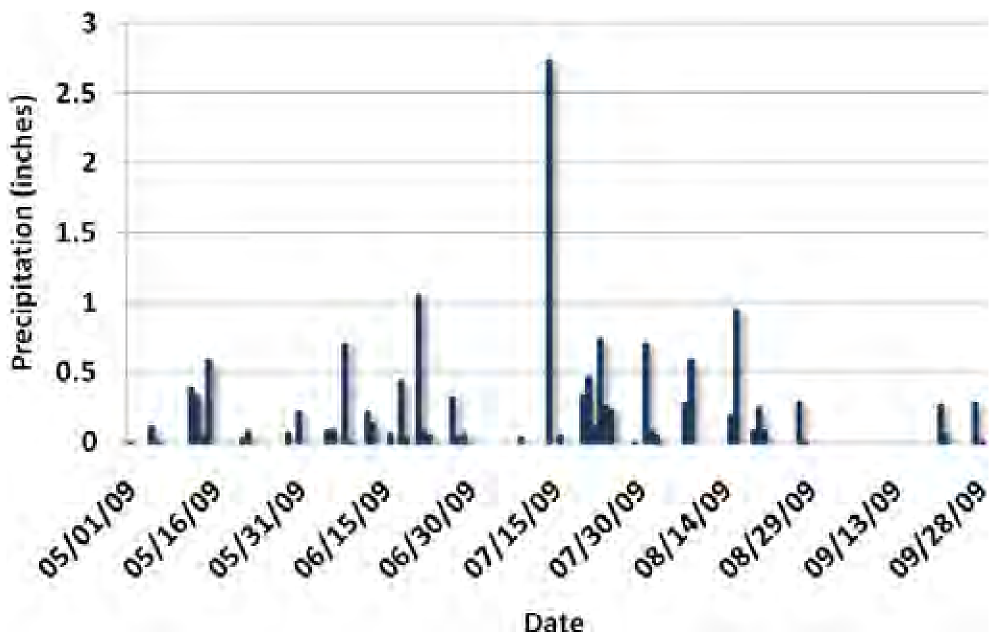
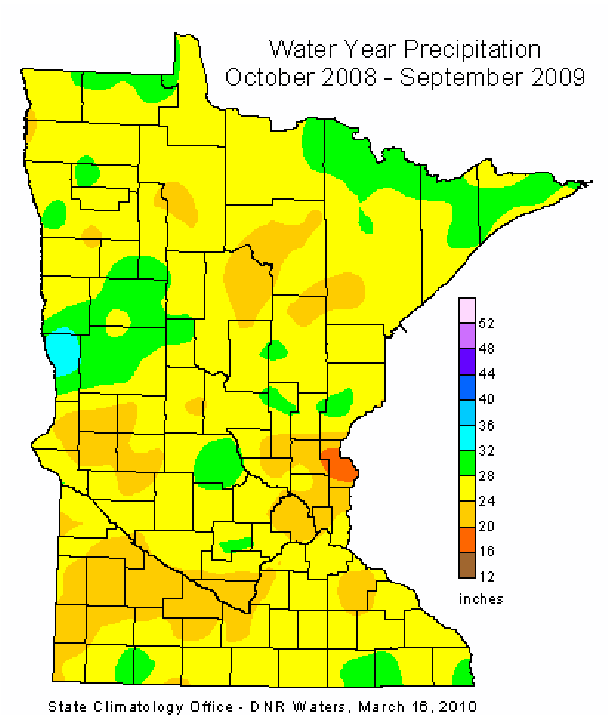


Figure 8. 2009 Minnesota water year precipitation and departure from normal

Prepared by State Climatology Office, MDNR
Values are in inches



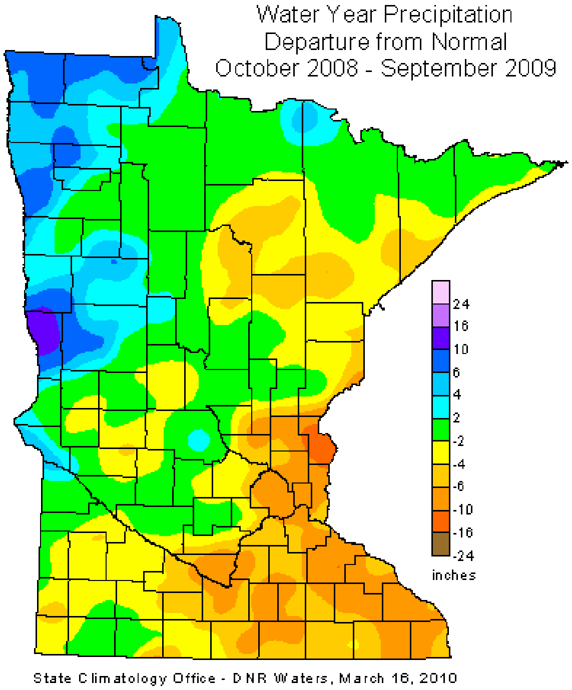
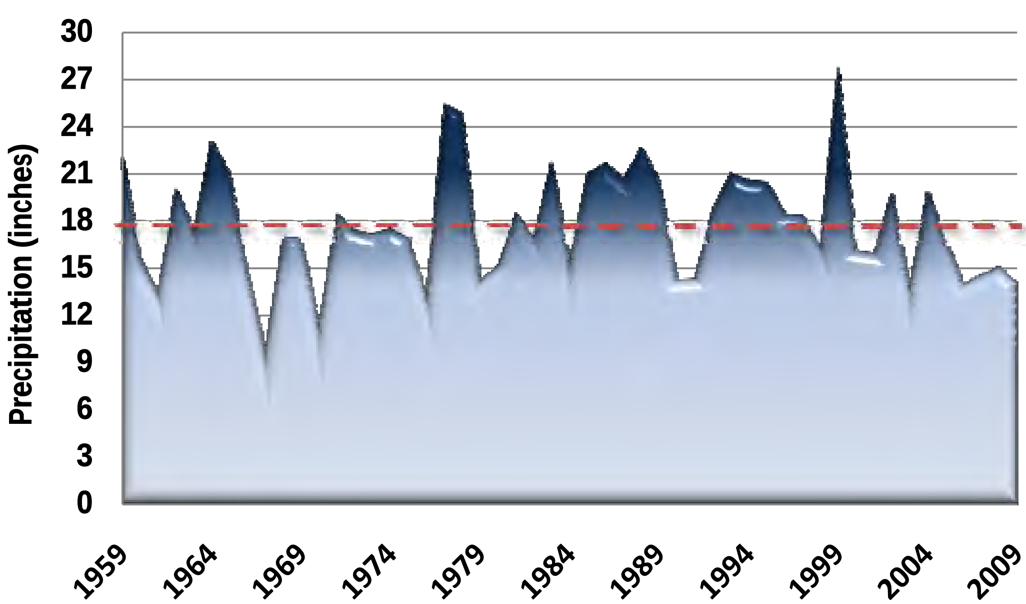


Figure 9. Historical water-year precipitation trends based on records for Grand Rapids, Minnesota. 50-year mean indicted by dashed line



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 1 meter (m), then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80-m (0.7 points per littoral acre). Hydroacoustics were used to survey vegetation biovolume (percent of water column occupied by vegetation) along 40-m 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 (1993; Manual of Instructions for Lake Survey). Fish community integrity (index of biotic integrity) surveys were also completed on each sentinel lake following methods described by Drake and Pereira (2002).

Water quality

Water quality data for the NB and SB of Hill Lake were collected monthly from May through October of 2008 and 2009 by MPCA staff. Bi-weekly dissolved oxygen (DO) and temperature profiles and Secchi disk measurements were collected by volunteers, Paul and Linda Bauer, in the NB. Surface water chemistry samples were collected by MPCA staff with an integrated sampler, a polyvinyl chloride (PVC) pipe 2 meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (cm) (1.24 inches). Zooplankton samples were collected with an 80 micrometer mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. In addition, hypolimnetic total phosphorous (TP) samples were collected approximately one meter from the lake bottom with a Kemmerer water sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples were collected at site 101 in the NB and site 101 in the SB (Figure 5). Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found at: http://www.pca.state.mn.us/publications/wq-s1-16.pdf.

Laboratory analysis was performed by the laboratory of the Minnesota Department of Health using U.S. Environmental Protection Agency-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride, metals, and chl-*a*. Phytoplankton samples were analyzed at the MPCA using a rapid assessment technique.

Zooplankton

Zooplankton samples were collected monthly from May through October 2008 & 2009. 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 percent reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 µg/L mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5-milliliter aliquot. A 5-milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted,

identified to the lowest taxonomic level possible (most to species level), and measured to the nearest .01 millimeter using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick 1994 in Hirsch 2009).

Results and Discussion

Fisheries assessment

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 were stored in a long-term fisheries survey database, which has proven valuable in qualifying and quantifying changes in environmental and fisheries characteristics over time.

Hill Lake's fish community is diverse compared with other lakes of similar productivity (Table 3) with an assortment of cool- and warm-water species. In 2008 and 2009, survey crews assessed the "biotic integrity" of the fish community in Hill 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 surveys from over 325 lakes across the state provide a good assessment of the range of conditions we might expect in lakes of differing productivity.

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

Common Name	Species Name	Trophic Guild	Thermal Guild[a]	Environmental Tolerance[b]	First Documented
Northern pike	*Esox lucius*	Predator	Cool	Neutral	1948
Northern redbelly dace	*Phoxinus eos*	Herbivore	Cool	Neutral	2008
Brook stickleback	*Culaea inconstans*	Insectivore	Cool	Neutral	2008
Blacknose dace[c]	*Rhinichthys atratus*	Omnivore	Cool	Neutral	1948
Creek chub[c]	*Semotilus atromaculatus*	Insectivore	Cool-warm	Tolerant	1948
Iowa darter	*Etheostoma exile*	Insectivore	Cool	Intolerant	1948
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	Tolerant	1948
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Cool-warm	Neutral	1948
Banded killifish	*Fundulus diaphanous*	Insectivore	Cool-warm	Intolerant	1948
Rock bass	*Ambloplites rupestris*	Predator	Cool-warm	Intolerant	1948
Black crappie	*Pomoxis nigromaculatus*	Predator	Cool-warm	Neutral	1948
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-warm	Neutral	1948
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1948
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1948
Bowfin	*Amia calva*	Predator	Warm	Neutral	1948
Common shiner	*Notropis cornutus*	Insectivore	Warm	Neutral	1970
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	Neutral	1948
Bigmouth buffalo[c]	*Ictiobus cyprinellus*	Insectivore	Warm	Neutral	1980
Blackchin shiner	*Notropis heterodon*	Insectivore	Warm	Intolerant	1948
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	Neutral	1948
Bluntnose minnow	*Pimephales notatus*	Omnivore	Warm	Neutral	1948
Fathead minnow	*Pimephales promelas*	Omnivore	Warm	Tolerant	2008
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	1948
Yellow bullhead	*Ameiurus natalis*	Omnivore	Warm	Neutral	1948
Hybrid sunfish	*Lepomis sp.*	Insectivore	Warm	Neutral	1990
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1948

Common Name	Species Name	Trophic Guild	Thermal Guild[a]	Environmental Tolerance[b]	First Documented
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1948
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1948
Least darter	*Etheostoma microperca*	Insectivore	Warm	Intolerant	2008
Shorthead redhorse	*Moxostoma macrolepidotum*	Insectivore	Warm	Warm	1980
Slender madtom[d]	*Noturus exilis*	Insectivore	Warm	Undetermined	1970[b]
Blacknose shiner	*Notropis heterolepis*	Insectivore	Warm	Intolerant	1948
Tadpole madtom	*Noturus gyrinus*	Insectivore	Warm	Neutral	1948

[a]Thermal guilds classified by Lyons et al. (2009)
[b]Environmental tolerance classified by Drake and Pereira (2002)
[c]Only year these species were noted in catch records.
[d]Only one observation present in historical records and identification is questionable

IBI surveys conducted in Hill Lake in 2008 and 2009 were close to the 90th percentile when compared with other lakes of similar productivity (score = 104 and 102 respectively). Specifically in Hill Lake, crews sampled six species intolerant to nutrient pollution including blacknose shiners (*Notropis heterolepis;* sampled in 2008 only), blackchin shiner (*Notropis heterodon*), banded killifish (*Fundulus diaphanus*), Iowa darter (*Etheostoma exile*), least darter (*Etheostoma microperca)* and rock bass (*Ambloplites rupestris*). The least darter is a state-listed species of greatest conservation need. These species have disappeared from many Twin City metropolitan lakes whose watersheds have been developed or hydrologically altered (Dodd 2009). Muskgrass appears to provide important habitat for several intolerant littoral fish species (Valley et al. 2010). In addition to nutrient reductions, protection of muskgrass beds will be important for protecting these species and fish community integrity in general.

Fish management

Hill Lake is a class 25 lake, with a long history of fish management activities, beginning with an initial stocking of walleye fry in 1912. It has been managed primarily for walleye with intermittent stockings of walleye (*Sander vitreus*) fry between 1912 and 1945, with fingerlings from 1950-1973, and again with fry in alternate years beginning in 1979. Other species stocked have included one-time stockings of lake trout (*Salvelinus namaycush*) and largemouth bass (*Micropterus salmoides*) (1912-1945), and nearly annual stockings of northern pike (*Esox lucius*) yearlings or adults between 1956 and 1983. The first fishery survey was conducted in 1948, and assessments have been conducted every five years since 1980. A special spring assessment was conducted in 1992 for bass using electrofishing, and has now been repeated in 2008 and 2009 as part of the SLICE sampling protocol. The additional SLICE sampling has also included spring trap net sampling for northern pike. Other management activities at Hill Lake have included the addition of a fishing pier, habitat improvement projects on two tributaries, Morrison Brook (a spring fed trout stream in most of upper reaches of watershed) and Greenfield Creek, habitat improvement in the in-lake area near highway 200, and an angler creel survey that was conducted in 1998. Hill Lake also generated statewide fishing attention when the Governor's fishing opener was hosted at the lake by Hill City in 1974 and 1990.

Population status

The gill net index (Figure 10) of walleye at Hill Lake has ranged from a low of about 4/net in 1948 (adjusted for current sampling methods and gear) to a high of 14/net in 1980, and is currently at about 8/net, which is well above the 75th percentile for this lake class, and is higher than most lakes in Aitkin County. Analysis of gill net catch at age data (Figure 11) indicated that natural reproduction was a significant component of walleye recruitment as recently as the mid-1970s. By the mid-1980s natural reproduction was only moderate, and by 1990 was minimally contributing to the population. The 2006 year class is the first in many years that suggests natural reproduction can be a significant component of recruitment. Walleye spawning areas in Morrison Brook and Greenfield Creek are priority locations for habitat protection in the area.

Growth rates for walleye at Hill Lake are currently average for the area, but may have increased slightly since the late 1980s (Figure 12). The increase may be slightly underestimated since the 1985 and 1990 surveys used a less reliable indicator of growth (scales) compared to otoliths (inner ear structures) to estimate ages of walleye. Ages of older fish are typically underestimated with scales, which would result in an overestimate of growth rate.

Overall walleye stock status was evaluated using the biological performance indicators (BPIs) method of Gangl and Periera (2003), which compares various measures of stock health with similar measures generated from other fisheries of known or presumed health. One of the requirements for the

evaluation is a measure of growth potential (growing degree days (GDD) of air temperature over 5 degrees Celsius). The average of the GDD at Mille Lacs and Leech Lakes was used as a surrogate for local GDD. Precision of the analysis can be improved with measures of GDD from closer weather stations. Overall, the BPIs suggested that overfishing of walleye may have occurred at Hill Lake (Table 4). Omega (L_{oo}/K, a measure of growth), length at age three, age at maturity, and gill net variability all suggested that overfishing may have occurred, while length at maturity and female spawner diversity did not. The overall conclusion of overharvest is at odds with a 1998 creel survey that observed less than 0.5 pounds/acre walleye yield. This may be due to other stressors/variables in the fishery that manifest similar symptoms (i.e. increases in growth rate, earlier maturation, etc.). In addition, some of the growth parameters make use of the GDD, which may not be as precise as necessary to account for these differences. One other alternative interpretation is that the one year snapshot of fishing pressure may not have been adequate to identify the entirety of the long term fishing history for the lake. Of the parameters that can be evaluated for each survey, female spawner diversity (an index of how many of each age of spawning females are in the population) appears to have been improving over the past 14 years (Figure 13), suggesting an increase in survival in this period. This trend is also evident in the length distributions for these time periods (Figure 14). It is feasible for there to have been considerable fishing effort in the 1970s and 1980s that resulted in a depressed population with symptoms of fast growth, earlier maturation, and increased variability in abundance, and now to have begun recovery. The 1948 assessment reported an angler harvest rate of 0.25 fish/hour in July, 1946. This is considerably higher than the 0.06 fish/hour observed in July of 1998. Although only 0.5 pounds/acre were harvested in 1998, one would expect considerably higher effort and harvest in a year with better catch rates.

Given the rather robust female spawning stock, the reasonably high gill net catch rates for walleye, and the protection given the tributary spawning streams, it is certainly feasible that natural reproduction will once again contribute significantly to the walleye population.

Netting indices for yellow perch indicate abundance of this species varies greatly and can attain very high densities (Figure 10), to the point that the 1948 assessment was implemented in order to "Investigate reports of an overabundant perch population." The propensity for high perch abundance is an advantage for walleye and northern pike, which prey heavily on this species. Abundance in 2009 appeared to be down somewhat (3.4/gill net), with most fish in the sample from one year class (2005). Growth rates for perch were normal for the area. In addition to providing forage for highly sought species such as walleye and northern pike, adult perch are believed to prey upon juvenile centrarchids to the point of reducing densities enough to improve growth rates of sunfish at early ages.

The gill net index of northern pike at Hill Lake has been relatively stable, typically averaging between about 2 and 5 fish per net (Figure 10), which is relatively low for this lake class. Growth rates (Figure 12) have been above average for the area, likely a result of the ample yellow perch (*Perca flavescens*) and white sucker (*Catostomus commersonii*) populations. Most of the spawning habitat for pike is in the south basin, which is the primary location sampled during ice-out trap netting in springs 2008 and 2009. Size distributions (Figure 15) from the spring trap net assessments indicated quality sized fish are attainable in Hill Lake (largest fish were over 96.5 cm (38 inches) in both years); however, the decrease in abundance of fish over 61 cm (24 inches) between 2008 and 2009 suggests angling may be limiting recruitment to the larger sizes. Although an angler yield of 1.7 pound/acre does not seem excessive, the year sampled (1998) may not have been representative of the typical pressure and harvest at Hill Lake. Also, although a large portion of the pike caught in 1998 were released (~70 percent), the same proportion of fish over 53.3 cm (21 inches) long that were caught by anglers were harvested, and none over 66 cm (26 inches) were reported to have been released. Certainly the Hill Lake northern pike population has the potential to provide quality angling experiences, but will require angler cooperation (releasing more medium and large sized fish), in order to succeed in accomplishing this more than just occasionally.

The gill net and electrofishing assessments appear to indicate that abundance of largemouth bass has increased in the last decade (Figure 10). Electrofishing catch rates of more than 69 per hour are very high for our area. These high catch rates may also be partly explained by the morphometry of the north basin, which drops off sharply along most shorelines, making spawning bass more susceptible to the gear than in other lakes with wide expanses of shallow water. Growth rates for bass appear to be above the local average (Figure 12), and have not changed in the last twenty years. In addition to the abundant perch population, there appears to be ample small panfish in the shoal areas to provide forage for bass. Age and length distributions of spring electrofishing samples in 2008 and 2009 indicated annual recruitment to the population between 1998 and 2008, with exceptionally strong year classes in 2002 and 2005. The expectation of warmer local climate will be to the advantage of largemouth bass young of year, which have difficulty surviving long winters in this area. Angler interest in bass at Hill Lake was minimal in the 1998 creel survey, when less than 1 percent of the anglers targeted bass. This may change, or may already have changed, as bass become more abundant and word of quality sized fish is disseminated in the local area (fish up to 55.9 cm (22 inches) were reported to have been caught in the 1998 creel, and fish over 45.7 cm (18 inches) were observed in each of the last two electrofishing assessments).

In general, centrarchid (panfish and bass) abundance has been increasing over the years (Figure 10). Specifically, bluegill sunfish (*Lepomis macrochirus*) and rock bass (*Ambloplites rupestris*) appear to have had higher recruitment in recent years, similar to largemouth bass. While bluegill densities are still well within the normal range for this lake class, rock bass are regularly indexed well above average. Abundance of black crappie (*Pomoxis nigromaculatus*) appears typical for this lake class, and varies greatly from one assessment period to the next. Pumpkinseed sunfish (*Lepomis gibbous*) abundance has remained near the lower quartile for this lake class. Unlike bluegill and rock bass, pumpkinseed and crappie populations appear to be stable. While growth rates (Figure 12) for black crappie have been above average and have not changed within the last 20 years, bluegill appear to have experienced a decrease in growth rates from what was once well above average to near average for the area. Pumpkinseed and rock bass also seem to have slowed growth rates in recent years, although there is yet no local average for comparison. These changes in the growth rates for centrarchids are expected with an increase in density, which appears to be real. Historical seining data indicate a clear increase in presence of young of year and adult centrarchids when compared to that of the 2008 and 2009 nearshore seining. While panfish have not been as important in the angler harvest as northern pike or walleye, about 16 percent of the anglers fishing Hill Lake in 1998 were seeking these species. Although angling harvest is very low based on the 1998 creel survey, the black crappie and bluegill fisheries are known locally to produce quality sized individual fish, and attract local effort in spring and fall.

Very little attention has been paid to white suckers in this area; however, they are forage for species such as northern pike and walleye. Interestingly, walleye and white sucker abundance as indexed in the assessment gill nets appeared to show similar patterns (Figure 10) and the correlation between the abundance of the two species was relatively high (Figure 16). Considering that white suckers and walleye spawn in similar habitats and their eggs and early fry stages are both bottom dwelling and later fry of both species live in the water column, it appears that whatever is affecting one species may also affect the other. Since we do not have good age data for white suckers, it is impossible to determine if the correlation is truly related to habitat/fry survival or only an autocorrelation related to netting conditions that may favor both species.

In general, Hill Lake is a rather diverse fish community with relatively healthy populations of desirable species. Although the walleye population may at one time have been over-exploited, it is apparently in the process of recovery and the current population level of this species is well above average for this lake class, with an age structure that should provide for a decent chance of natural reproduction. Largemouth bass are another species that appears to be becoming more abundant in Hill Lake, which is similar to trends observed in numerous lakes in this region of the state. Other

centrarchids also appear to be increasing in abundance, but this may be to a detriment of the good growth rates we've previously seen for bluegill. To maintain the quality fishery for most species, anglers should be encouraged to practice selective harvest in order to maximize their recreational experiences of catching quality sized fish of all species.

Table 4. Biological performance indicators for Hill Lake walleye population, Aitkin County, Minnesota. Thresholds were based on those used by Gangl and Periera (2003).

Parameter	Observed	Predicted	Difference	Threshold	Suggests Overfishing?
Omega (L_{oo}/K)	170	128	42	4	Yes
Mean length at age 3 (inches)	12.8	12.2	0.6	0.2	Yes
Mean age at maturity (years)	3.7	4.4	-0.7	-0.2	Yes
Mean length at maturity (inches)	16.7	15.9	0.8	-0.8	No
H (spawner diversity)	0.69			0.575	No
Coefficient of variation of gill net CUE for time series (CV)	0.38			0.36	Yes

Figure 10. Historical assessment catch rates, by year, for select species at Hill Lake, Aitkin County, Minnesota. Solid points refer to gill net CUEs (fish/net), left vertical axis; open circles refer to trap net CUEs (fish/trap), right vertical axis; and asterisk points on largemouth bass figure refer to electrofishing CUEs (fish/hour), right vertical axis. Black lines are quartiles of gillnet catches from other class 25 lakes.

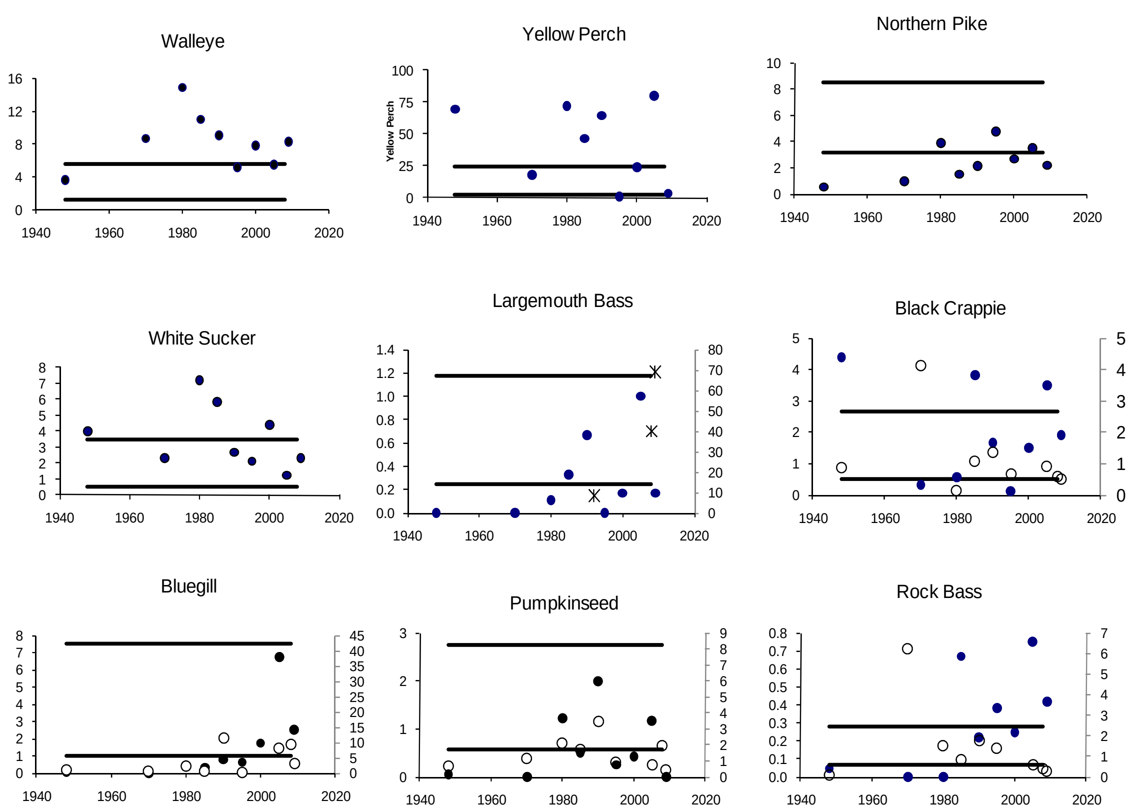


Figure 11. Walleye year class strength indices (Schupp's index) at Hill Lake, Aitkin County, Minnesota. Grey bars depict years stocked, and the number above the bar indicates the number of surveys used to estimate the year class strength.

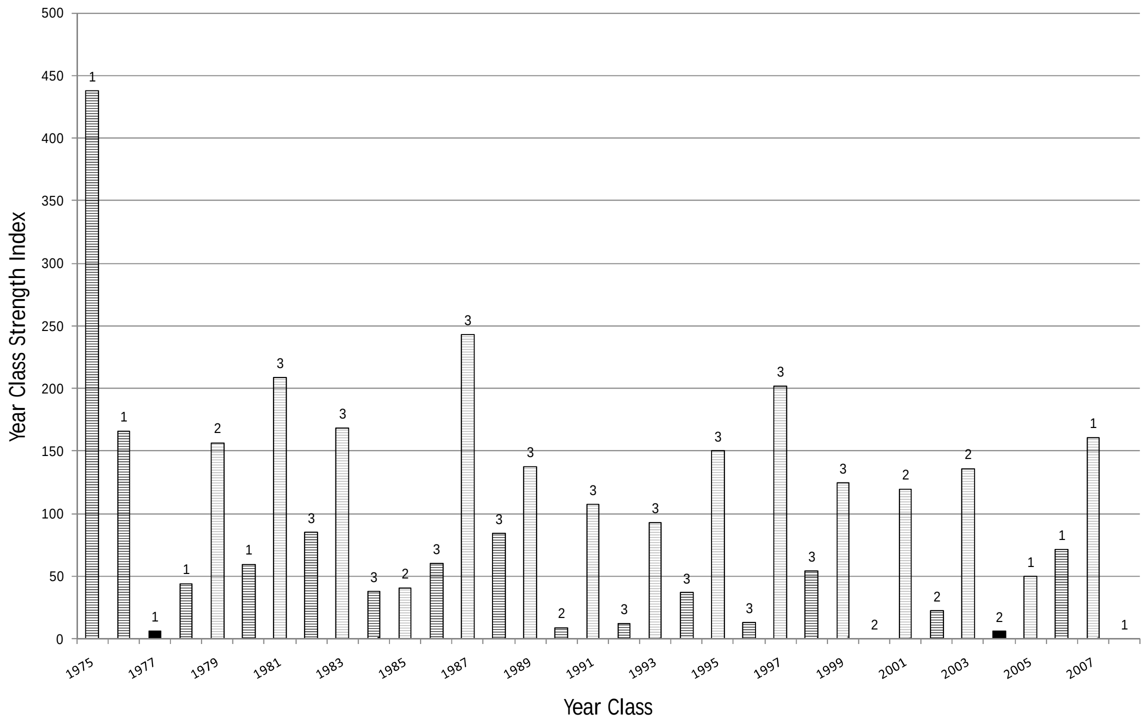


Figure 12. Growth rates of select species at Hill Lake, Aitkin County, Minnesota

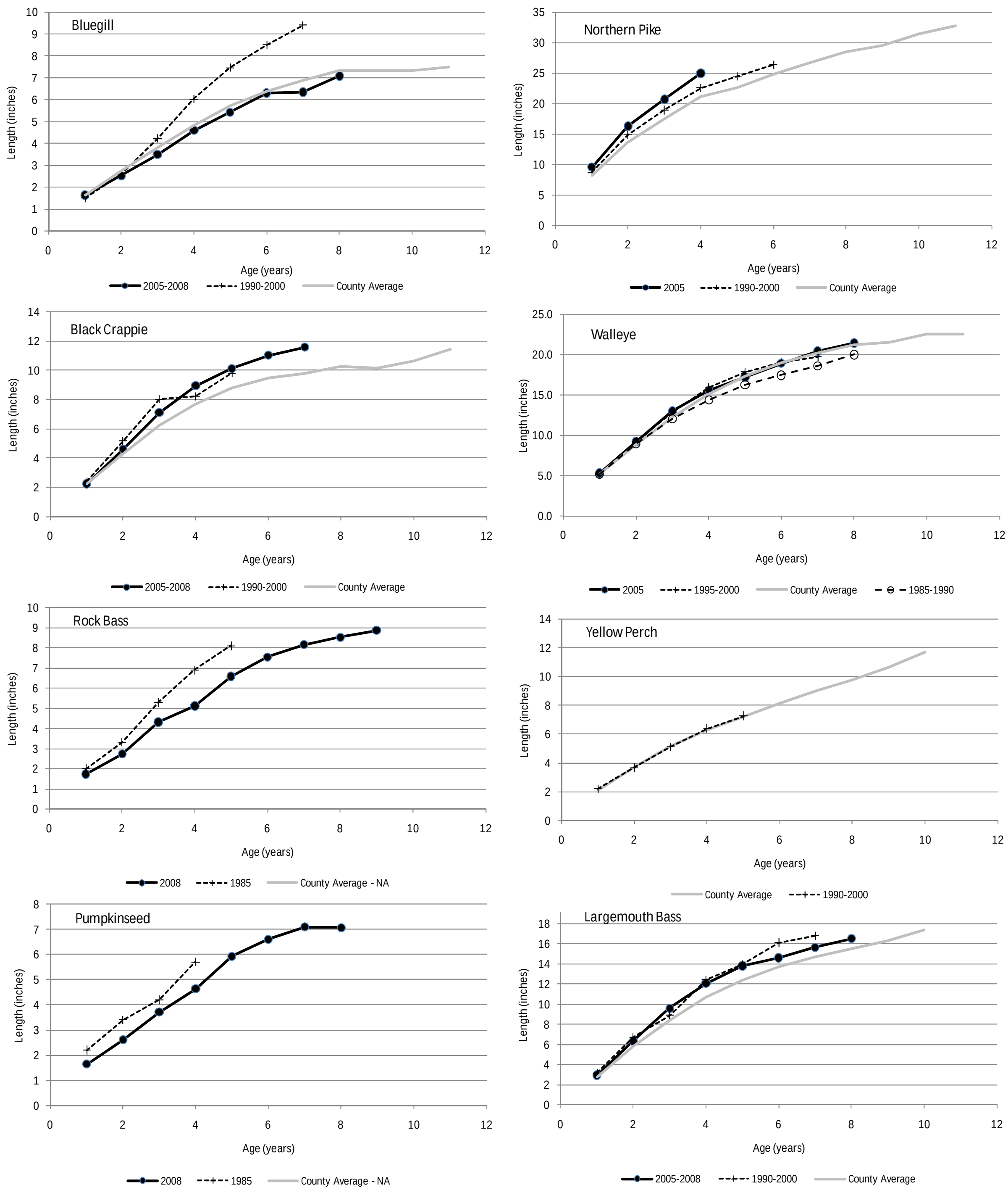


Figure 13. Female spawner diversity index (Shannon diversity index as used by Gangl and Periera 2003) of walleye from the gill net samples from 1990 to 2009 (excluding the 2005 survey for which no sex determination was made). The red horizontal line depicts a threshold determined by Gangl and Periera (2003), below which might suggest conditions of over-fishing.

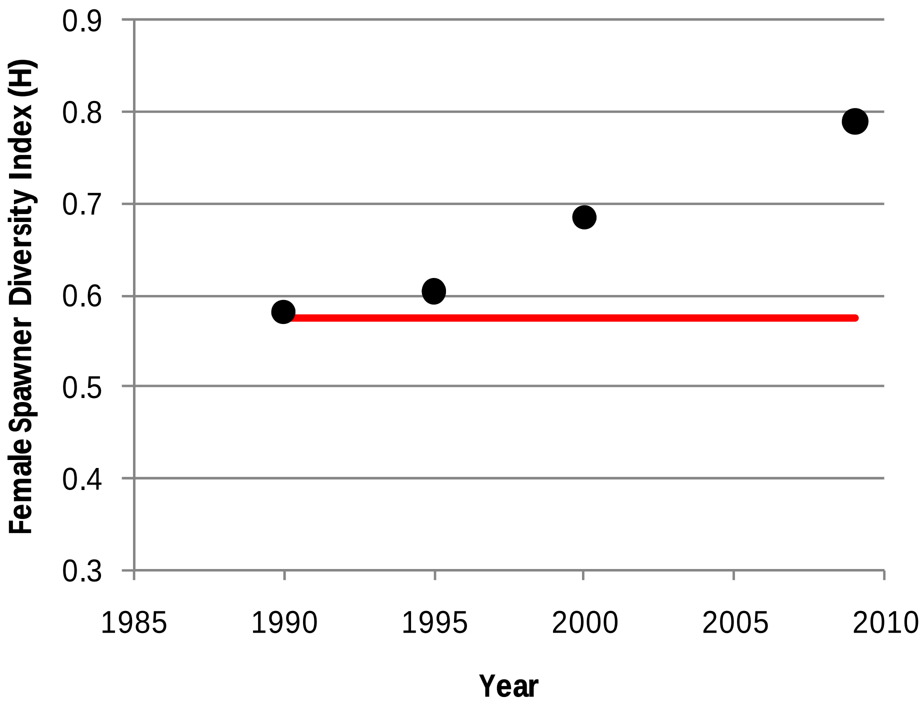


Figure 14. Length frequency distribution of walleye captured in assessment gill nets in three time periods at Hill Lake, Aitkin County, Minnesota

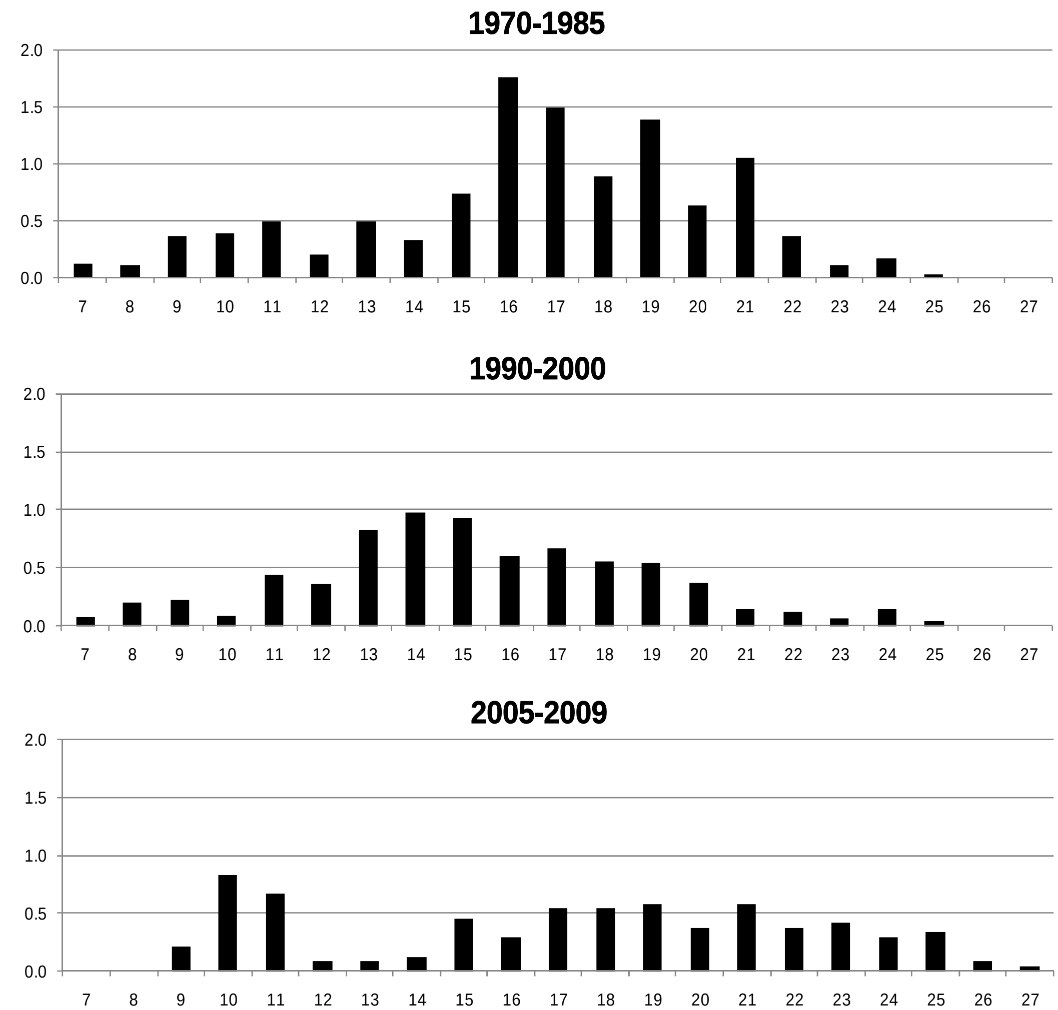


Figure 15. Northern pike length frequency distributions from samples collected during spring trap netting in 2008 and 2009

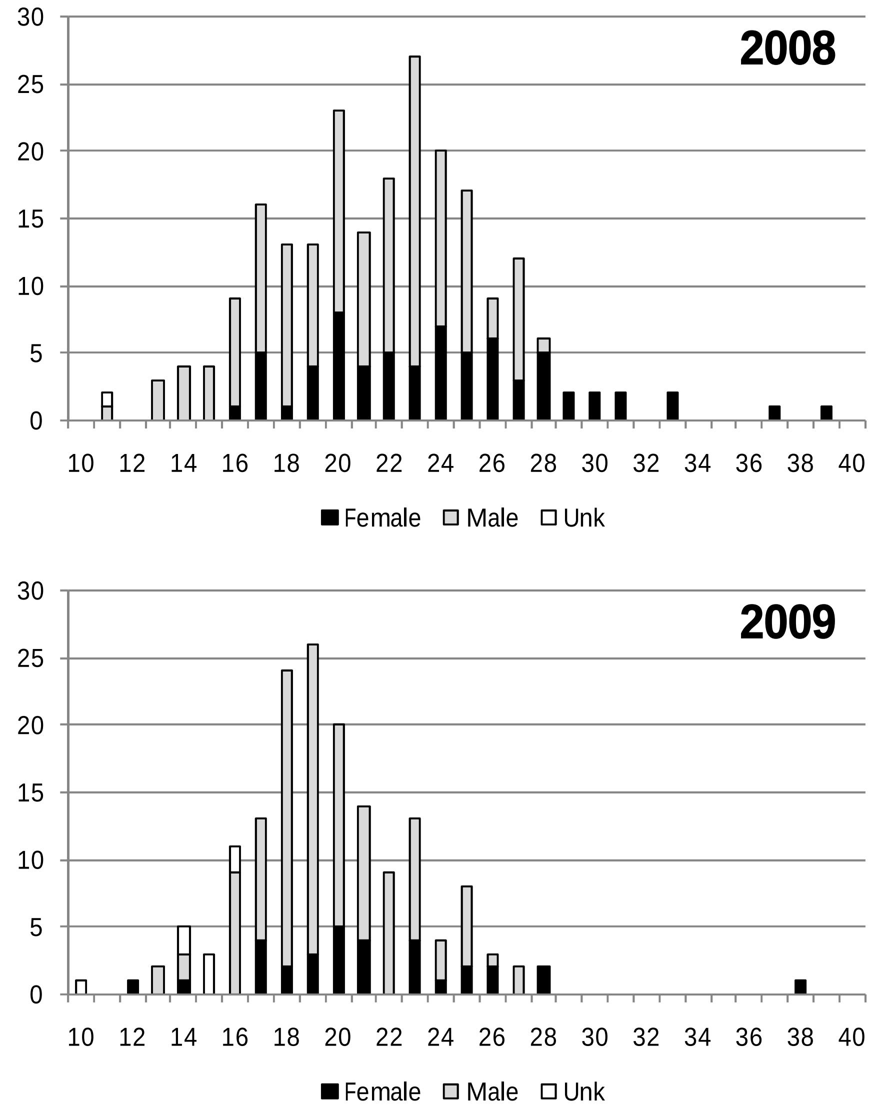
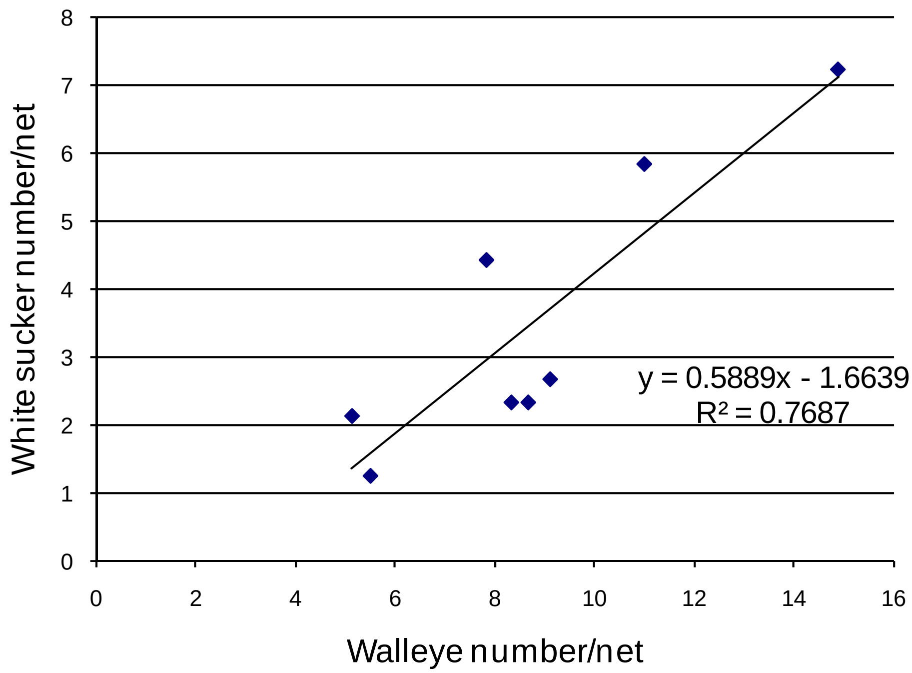


Figure 16. Apparent relation between abundance of walleye and white sucker at Hill Lake, Aitkin, County, Minnesota



Aquatic plant assessment

Aquatic plants have been qualitatively assessed as part of most MDNR Fisheries surveys since 1948 (Table 5). In September 1995, the Minnesota County Biological Survey compiled a list of aquatic plant species observed, including the relatively rare and commonly misidentified blunt-tipped sago pondweed (*Stuckenia filiformis*; Table 6). In 2008 and 2009, 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, emergent species bulrush (*Scirpus* spp.) and cattail (*Typha* spp.) have been prevalent (Table 5). With regards to submersed plant communities, species have varied in their frequency and detection by surveyors, but muskgrass (*Chara* sp.), coontail (*Ceratophyllum demersum*), sago pondweed (*Stuckenia pectinata*), and clasping-leaf pondweed (*Potamogeton richardsonii*) appear as common species across all historic surveys. The aquatic plant community in Hill Lake is modestly diverse with 13 – 14 species occurring at frequencies greater than or equal to 10 percent in depths less than 4.5 meters (15 feet) (Table 7). Despite modest differences in species frequency in 2008 and 2009, the overall integrity of the aquatic plant community remained similar between years. Additional surveys in 2010 and 2011 at Hill Lake and the other Sentinel lakes will allow for comparisons across repeated surveys, and will help researchers determine how much aquatic plants naturally vary from year to year and to separate natural ‘noise’ from a disturbance signal.

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

Date	Common Name	Species Name	Growth Form
7/25/1948	Arrowhead	*Sagittaria sp.*	Emergent
	Bulrush	*Scirpus sp.*	Emergent
	Cattail	*Typha sp.*	Emergent
	Spikerush	*Eleocharis*	Emergent
	Bushy pondweed	*Najas flexilis*	Submersed
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Sago pondweed	*Stuckenia pectinatus*	Submersed
	Wild celery	*Vallisneria americana*	Submersed
6/17/1970	Broad-leaved cattail	*Typha latifolia*	Emergent
	Softstem bulrush	*Scirpus validus*	Emergent
	Spikerush	*Eleocharis palustris*	Emergent
	Swamp Horsetail	*Equisetum fluviatile*	Emergent
	Floating-leaf pondweed	*Potamogeton natans*	Floating leaf
	Yellow waterlily	*Nuphar variegatum*	Floating leaf
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
8/4/1980	Arrowhead	*Sagittaria sp.*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	Sedge	*Carex sp.*	Emergent
	Softstem bulrush	*Scirpus validus*	Emergent
	Swamp Horsetail	*Equisetum fluviatile*	Emergent
	Floating-leaf pondweed	*Potamogeton natans*	Floating leaf
	White waterlily	*Nymphaea sp.*	Floating leaf
	Yellow waterlily	*Nuphar variegatum*	Floating leaf
	Bushy pondweed	*Najas flexilis*	Submersed
	Coontail	*Ceratophyllum dermersum*	Submersed
	Curly-leaf pondweed[a]	*Potamogeton crispus*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Sago pondweed	*Potamogeton pectinatus*	Submersed
7/30/1990	Broad-leaved cattail	*Typha latifolia*	Emergent
	Greenfruited burred	*Sparganium chlorocarpa*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	Narrow-leaved cattail	*Typha angustifolia*	Emergent
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed
	Coontail	*Ceratophyllum dermersum*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed

Date	Common Name	Species Name	Growth Form
	Muskgrass	*Chara sp.*	Submersed
	Narrow-leaf pondweed	*Potamogeton spp.*	Submersed
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed
	Sago pondweed	*Potamogeton pectinatus*	Submersed
	White-stem pondweed	*Potamogeton praelongus*	Submersed
	Wild celery	*Vallisneria americana*	Submersed
7/25/2005	Arrowhead	*Sagittaria sp.*	Emergent
	Broad-leaved cattail	*Typha latifolia*	Emergent
	Giant burred	*Sparganium eurycarpum*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	Swamp Horsetail	*Equisetum fluviatile*	Emergent
	Star Duckweed	*Lemna trisulca*	Free-floating
	Bushy pondweed	*Najas flexilis*	Submersed
	Canada waterweed	*Elodea canadensis*	Submersed
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed
	Coontail	*Ceratophyllum dermersum*	Submersed
	Curly-leaf pondweed[a]	*Potamogeton crispus*	Submersed
	Flat-leaf bladderwort	*Utricularia intermedia*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Illinois pondweed	*Potamogeton illinoensis*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed
	Sago pondweed	*Potamogeton pectinatus*	Submersed
	Straight-leaf pondweed	*Potamogeton strictifolius*	Submersed
	Water marigold	*Bidens beckii*	Submersed
	Wild celery	*Vallisneria americana*	Submersed

[a]non-native invasive species

Table 6. Plant species observed on September 25, 1995, along the west shore of Hill Lake by the Minnesota County Biological Survey

Common Name	Species Name	Growth Form
Coontail	*Ceratophyllum demersum*	Submersed
Watermilfoil	*Myriophyllum sp.*	Submersed
Bushy pondweed, Common naiad	*Najas flexilis*	Submersed
Illinois pondweed	*Potamogeton illinoensis*	Submersed
Claspingleaf pondweed	*Potamogeton richardsoni*	Submersed
Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
Common sago pondweed[a]	*Stuckenia pectinata*	Submersed
Blunt-tipped sago pondweed[a]	*Stuckenia filiformis*	Submersed
Wild celery, Eel-grass	*Vallisneria americana*	Submersed
Turion-forming duckweed	*Lemna turionifera*	Free floating
Yellow water lily	*Nuphar variegata*	Floating leaf
White water lily	*Nymphaea odorata* ssp. *tuberosa*	Floating leaf
Water smartweed	*Persicaria amphibia*	Floating leaf
Hard-stem bulrush	*Schoenoplectus acutus* var. *acutus*	Emergent
Soft stem bulrush	*Schoenoplectus tabernaemontani*	Emergent
Burreed	*Sparganium sp.*	Emergent
Narrow-leaved cattail	*Typha angustifolia*	Emergent
Broad-leaved cattail	*Typha latifolia*	Emergent

[a]Occurrence recorded in Natural Heritage Rare Features Database and specimen deposited at University of Minnesota Herbarium

Table 7. Percent frequency of occurrence of aquatic plant species at depths ≤ 15 feet sampled during point-intercept surveys on Hill Lake

Season	Basin	Common Name	Species Name	Growth Form	Frequency (%) 2008	2009
Spring[a]	N & S	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	2.0[d]	10.4[e]
Summer	North	All rooted			91.0	96.4
		Coontail	*Ceratophyllum demersum*	Submersed	43.0	10.8
		Chara	*Chara sp.*	Submersed	41.0	59.0
		Fries' pondweed	*Potamogeton friesii*	Submersed	40.0	33.7
		Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed	32.0	15.7
		Water celery	*Vallisneria americanus*	Submersed	23.0	0
		Hardstem bulrush	*Scirpus acutus*	Emergent	19.0	33.7
		Variable pondweed	*Potamogeton gramineus*	Submersed	18.0	21.7
		Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	15.0	9.6
		Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	14.0	19.3
		Cattail	*Typha spp.*	Emergent	14.0	34.9
		Filamentous Algae			13.0	31.3
		Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	12.0	24.1
		Sago pondweed	*Stuckenia pectinata*	Submersed	12.0	1.2
		Bushy pondweed	*Najas flexilis*	Submersed	11.0	0
		Yellow waterlily	*Nuphar sp.*	Floating-leaf	8.0	13.3
		Star duckweed	*Lemna trisulca*	Free-floating	7.0	3.6
		White waterlily	*Nymphaea sp.*	Floating-leaf	6.0	2.4
		Water moss	*Drepanocladus sp.*		4.0	0
		White-stem pondweed	*Potamogeton praelongus*	Submersed	3.0	1.2
		Horsetail	*Equisetum sp.*	Emergent	2.0	4.8
		Water marigold	*Bidens beckii*	Submersed	2.0	0
		Broad-leaved arrowhead	*Sagittaria latifolia*	Emergent	1.0	0
		Arum-leaved arrowhead	*Sagittaria cuneata*	Emergent	1.0	0
		Common bladderwort	*Utricularia vulgaris*	Submersed	1.0	0
		Floating-leaf pondweed	*Potamogeton natans*	Floating-leaf	0	4.8
		Arrowhead group	*Sagittaria sp.*	Emergent	0	1.2
		Illinois pondweed	*Potamogeton illinoensis*	Submersed	0	3.6
		Large-leaf pondweed	*Potamogeton amplifolius*	Submersed	0	1.2
		Narrow-leaf pondweed	*Potamogeton spp.*	Submerged		2.4
		Spikerush	*Eleocharis sp.*	Emergent	0	2.4
		Max depth of veg growth (ft) a			15	11.5

Season	Basin	Common Name	Species Name	Growth Form	Frequency (%) 2008	2009
	South	All rooted			55.0	69.5
		Coontail	*Ceratophyllum demersum*	Submersed	55.0	52.5
		Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed	35.0	32.2
		Star duckweed	*Lemna trisulca*	Free-floating	25.0	49.1
		Yellow waterlily	*Nuphar sp.*	Floating-leaf	25.0	52.5
		Water celery	*Vallisneria americanus*	Submersed	23.0	1.7
		White waterlily	*Nymphaea sp.*	Floating-leaf	20.0	42.4
		Filamentous Algae			10.0	40.7
		Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	10.0	8.5
		Water moss	*Drepanocladus sp.*		8.3	
		Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	8.3	11.9
		Fries' pondweed	*Potamogeton friesii*	Submersed	8.3	20.3
		Common bladderwort	*Utricularia vulgaris*	Submersed	8.3	0
		Horsetail	*Equisetum sp.*	Emergent	6.7	10.2
		Water marigold	*Bidens beckii*	Submersed	5.0	0
		Sago pondweed	*Stuckenia pectinata*	Submersed	5.0	1.7
		Hardstem bulrush	*Scirpus acutus*	Emergent	5.0	16.9
		Cattail	*Typha spp.*	Emergent	5.0	37.2
		Chara	*Chara sp.*	Submersed	3.3	11.9
		Floating-leaf pondweed	*Potamogeton natans*	Submersed	3.3	1.7
		Variable pondweed	*Potamogeton gramineus*	Submersed	1.7	0
		Pickerelweed	*Pontederia cordata*	Emergent	1.7	0
		White-stem pondweed	*Potamogeton praelongus*	Submersed	1.7	8.5
		Small pondweed	*Potamogeton pusillus*	Submersed	1.7	0
		Burreed	*Sparganium sp.*	Emergent	1.7	3.4
		Bladderwort group	*Utricularia sp.*	Submersed	0	1.7
		Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	0	32.2
		Max depth of veg growth (ft)[c]			11.3	9.0

[a]Surveys targeting curly-leaf pondweed
[b]Non-native
[c]Depth of 95% of all plant occurrences
[d]surveyed on 19 May 2008
[e]surveyed on 2 June 2009

Patterns of vegetation cover and abundance

A narrow band of modestly dense aquatic plants rimmed both basins of Hill Lake in 2008 (Figure 17), however the depth that vegetation grows in the more turbid south basin was a few feet shallower than the north basin. In 2008, plants covered approximately 30 percent of bottom areas in the north basin and 66 percent of the south basin. When we factor in the third dimension of depth to gain inference into vegetation abundance, we saw that on average, aquatic plants occupied 23 percent of the water column in depths less than 6 meters in the north basin and 10 percent over the entire area of the south basin (Figure 17). Pooling data across both basins, submersed vegetation was relatively sparse near shore, but modestly dense at 2-m, then falling off rapidly at deeper depths (Figure 18). Aquatic plant growth in the northern basin is fairly typical of other northern, mesotrophic lakes; however, the aquatic plant growth is relatively sparse in the more productive southern basin.

Figure 17. Percent of water column occupied by vegetation (biovolume) in Hill Lake in summer 2008. Data were collected using hydroacoustics and mapped using kriging interpolation (methods described by Valley et al. 2005).

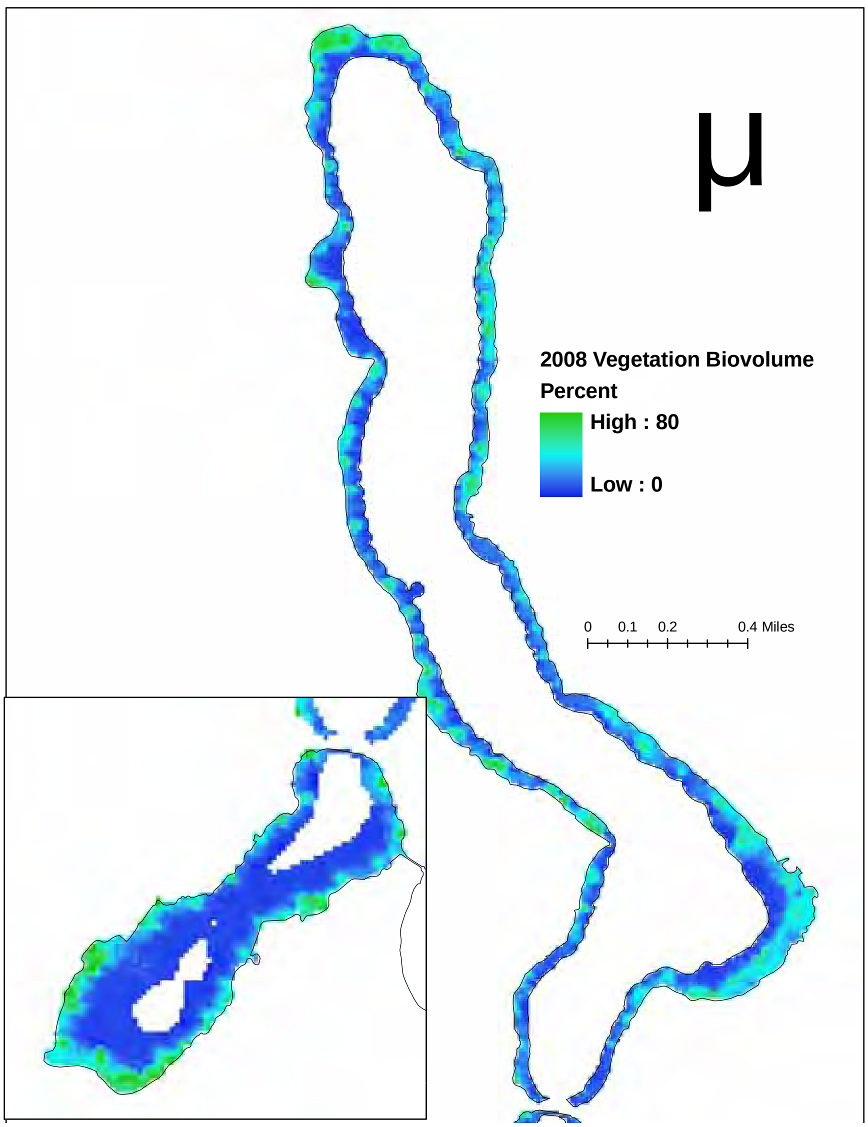
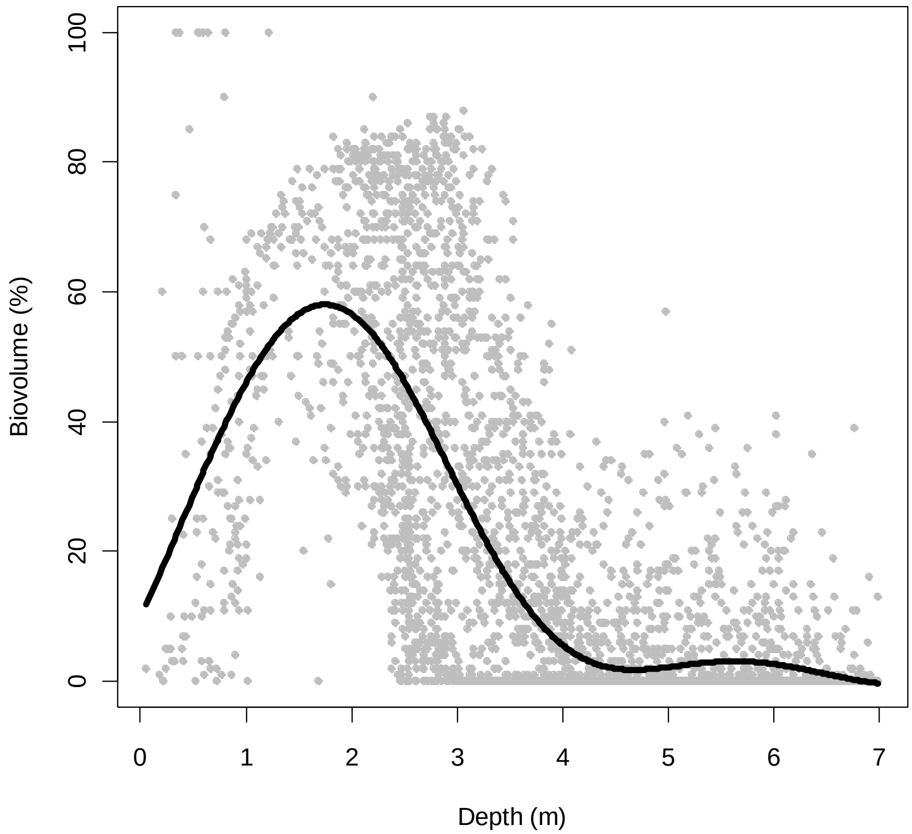


Figure 18. Percent of water column occupied by vegetation (biovolume) as a function of depth. A non-parametric regression smoother was used to model this relationship (see methods described by Valley et al. 2005).



In 1980, curly-leaf pondweed (*Potamogeton crispus*) was first noted and has been a common species observed ever since. Curly-leaf pondweed is a non-native invasive submerged aquatic plant that is widespread throughout the southern part of the state. The exact date of introduction into Minnesota is unknown, but it is believed to have been present in Minnesota lakes since the early 1900s when carp were brought into the state. Curly-leaf pondweed grows most abundantly during early spring and senesces by mid-summer. When curly-leaf pondweed is abundant, mid-summer diebacks often promote algae blooms, which limit light penetration for native aquatic plants.

Curly-leaf pondweed thrives in nutrient-rich conditions and at some threshold of nutrient levels (exact quantity unknown), can become a self-sustaining internal driver of poor water quality conditions. These self-perpetuating conditions of curly-leaf booms followed by large summer die-offs and algae blooms are most common in eutrophic to hypereutrophic lakes in the southern half of the state. In northern mesotrophic lakes with abundant native aquatic plants, curly-leaf pondweed is less abundant and typically is integrated with other aquatic plants. Because the plant needs to photosynthesize during winter, curly-leaf pondweed is sensitive to long periods of snow and ice cover on lakes. Reduced snow and ice cover due to climate change may favor increases in this plants abundance in infested lakes and latitudinal range of viability.
Indeed, surveys in 2008 and 2009 indicated a relatively low frequency of curly-leaf pondweed (Table 7)

The macroalgae muskgrass, acts as a resilience mechanism against a shift to a curly-leaf pondweed 'regime' in Hill Lake. In 2009, muskgrass was the most common species sampled in Hill Lake (Table 7). Muskgrass is a benthic plant that is highly desirable from a fish habitat and water quality standpoint. Besides offering quality physical habitat for fish, muskgrass is an important plant for maintaining clear water. In turn, clear water promotes muskgrass (Kufel and Kufel 2002; Ibelings et al. 2007). To best prevent a shift to a curly-leaf pondweed regime and protect fish habitat, muskgrass beds should be protected along with reductions to external phosphorus loading.

Approximately 114 dock structures were enumerated from aerial photos acquired from the Farm Service Administration in summer 2008 (one dock for every 505 ft of shoreline across both basins). By rule, lakeshore owners are allowed to remove a 232 square meter (2500 square foot) area of submersed aquatic plants without a permit. If we assumed that all who owned a dock also removed 232 square meters (2500 square feet) of aquatic plants, then the lakeshore owners have the option to remove up to 2.6 hectares (6.5 acres) of aquatic plants (1.5 prcent of the area of vegetation growth) without a permit. The actual amount of plant removal is probably less since many near-shore areas are naturally sparsely vegetated. Although this figure is probably not biologically significant from a fish habitat standpoint, the cumulative effects of vegetation removal has been detrimental to fish habitat in more developed areas of Minnesota. It will be important that aquatic plant removal remains minimal over time.

Water quality

Standard summer-mean water quality data for 2009 are presented in Table 8, and raw data results are provided in Appendix A. In addition, major cations, anions, and total organic carbon were analyzed for the May, July, and October sample dates; these values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 9. The NLA was a statistically-based survey of the nations lakes administered by the U.S. Environmental Protection Agency in 2007. The typical range provided in Table 9 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Table 8. Hill Lake 2009 summer mean water quality. Typical range based on NLF ecoregion reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	Hill Lake (NB) Site 101	Hill Lake (SB) Site 101	NLF
Total phosphorus (µg/L)	22	36	14 - 27
Chlorophyll mean (µg/L)	5	12	4 - 10
Chlorophyll max (µg/L)	8	59	<15
Secchi disk (feet) (meters)	12 (3.7)	7.5 (2.3)	8 – 15 2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.6	-	<0.4 – 0.75
Alkalinity (mg/L)	150	-	40 - 140
Color (Pt-Co Units)	17	-	10 - 35
pH (SU)	8.4	8.3	7.2 – 8.3
Chloride (mg/L)	6.7	-	0.6 – 1.2
Total suspended solids (mg/L)	4.6	-	<1 - 2
Total suspended inorganic solids (mg/L)	2.4	-	<1 - 2
Conductivity (umhos/cm)	315	313	50 - 250
Total nitrogen: Total phosphorus ratio	27:1	-	25:1 - 35:1

Table 9. 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.

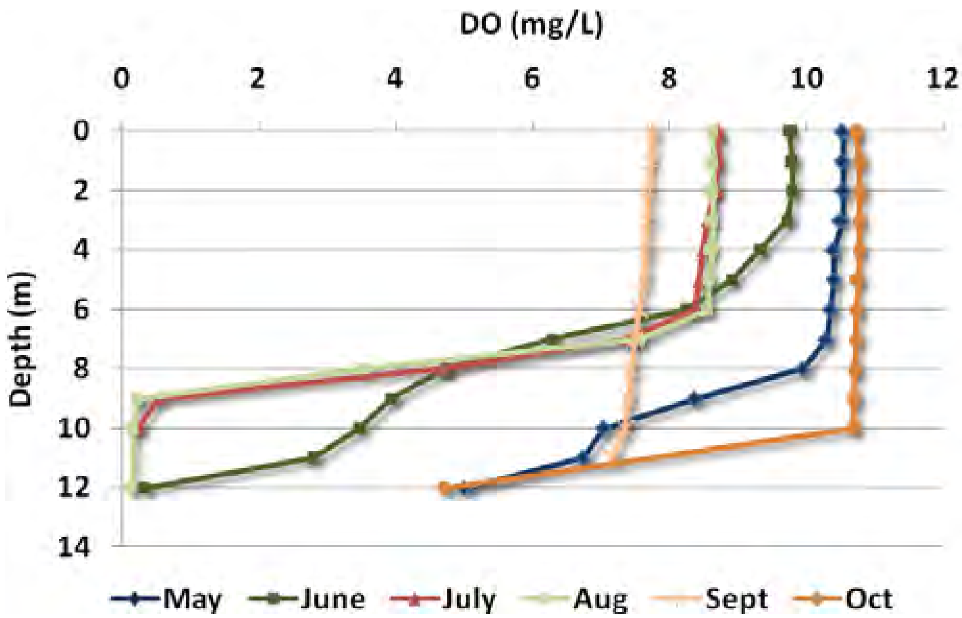
Parameter[1]	Hill (NB)	Hill (NB)	NLA IQ Range		Ion balance	µeq/L	µeq/L
	2008	**2009**	**2007**			**2008**	**2009**
Ca (mg/L)	41	42	19.1 - 33.7		cations	5090	2106
Mg (mg/L)	14	14	6.7 - 26.9			4607	1119
K (mg/L)	1.9	1.9	0.9 - 4.8			49	49
Na (mg/L)	6.7	6.6	2.2 - 9.0			291	287
Fe (µg/L)		16.6			**sum**		**3561**
Si (mg/L)		26.7	3.1-13.5				
Alk (mg/L	150	150			anions	3000	3060
SO_4 (mg/L)	9.4	9.6	2.2 - 14.1			196	200
Cl (mg/L)	6.4	6.7	1.5 - 18.4			181	189
DOC (mg/L)					**sum**		**3449**
TOC (mg/L)	7.2	7.1	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 biweekly at site 101 of the NB and monthly at site 101 of the SB (Figures 19 & 20). For the NB, DO levels remain at or above 5 mg/L (milligrams per liter) in the epilimnion (upper, warmer layer) during the entire season. DO levels remained above 5 mg/L in the hypolimnion (lower, cooler layer) in June, July, and August to a depth of 8 meters (26 feet) before eventually becoming hypoxic at approximately 10 meters (32.8 feet). The drop in hypolimnetic DO in August is the result of an increase in oxygen demand for the decomposition of organic materials and the lack of re-aeration because of a stable thermocline. DO levels increased to levels above 5 mg/L during the spring and fall turnovers. DO levels in the SB remained above 5 mg/L to the bottom most of the season with the exception of the summer months.

Temperature profiles were also taken biweekly at site 101 of the NB and monthly at site 101 of the SB (Figures 19 & 20). The NB was well-mixed in the fall with a weak thermocline forming at approximately 3 to 4 meters in June. A more distinct thermocline was visible at 8 meters (26 feet) in May, July, and August. The SB remained well mixed at every sampling event with the exception of June when a weak thermocline developed. Additionally, when the July 2009 profile is compared to the July 2008 profile the thermocline formed at nearly the same depth for the NB (Figure 21). Epilimnetic waters were much warmer in 2008 as well the NB. Water temperatures for the SB were also much higher in 2008 than in 2009 (Figure 22).

Figure 19. Hill Lake (NB) 2009 dissolved oxygen and temperature profiles



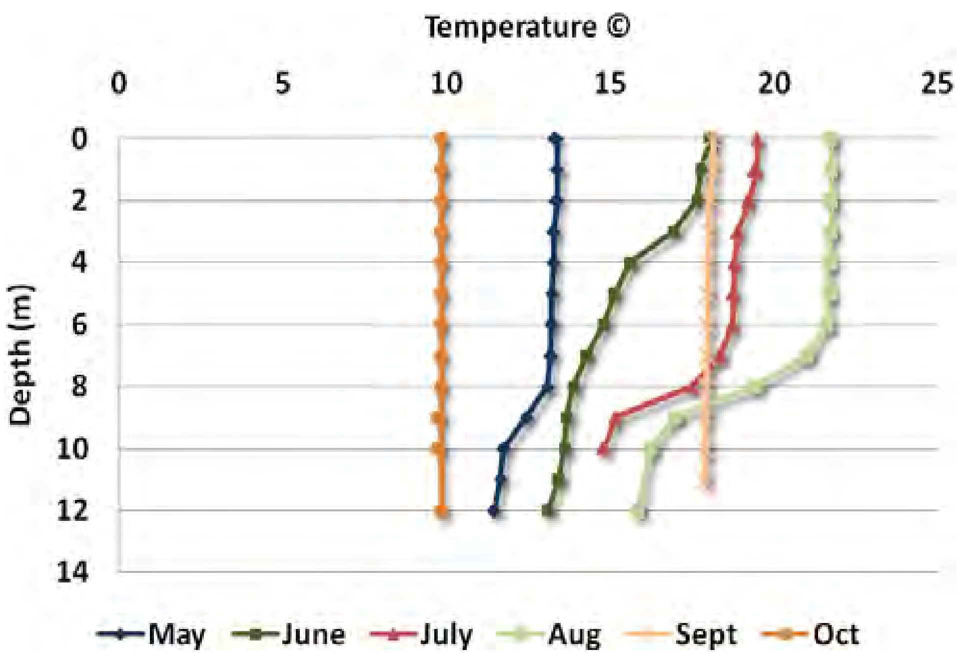
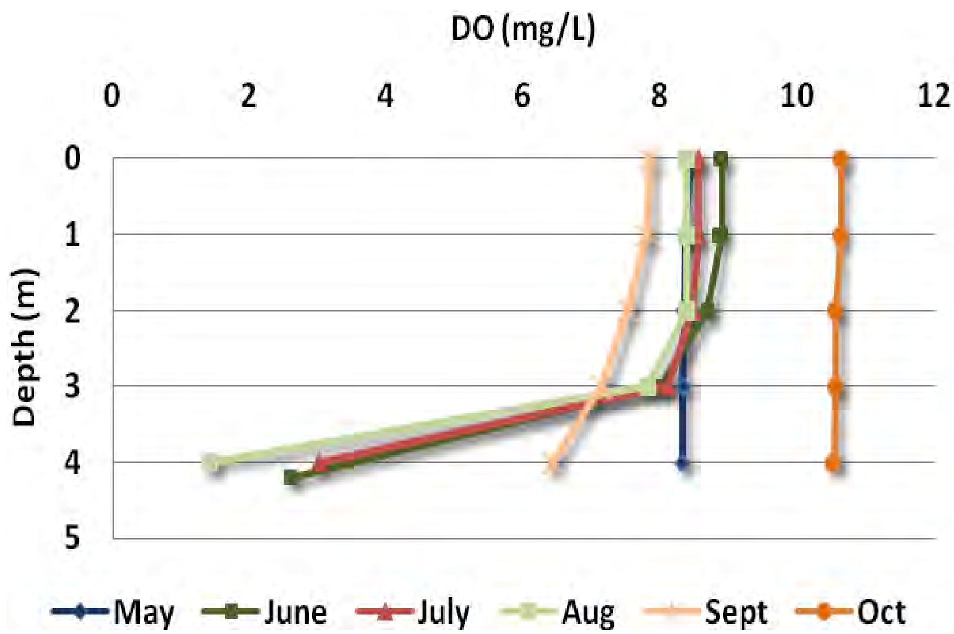


Figure 20. Hill Lake (SB) 2009 dissolved oxygen and temperature profiles



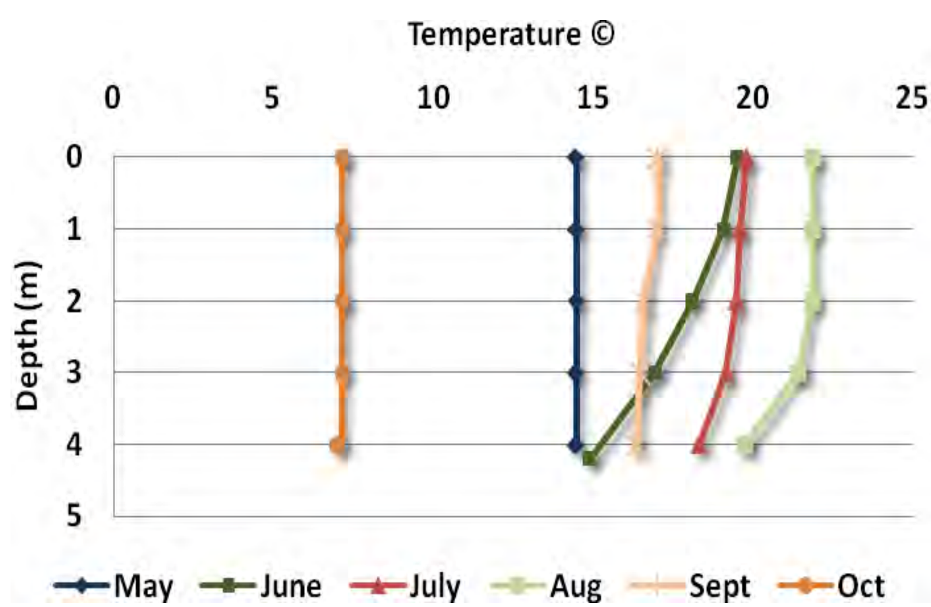


Figure 21. Hill Lake (NB) July 2008 & 2009 dissolved oxygen & temperature profile comparison

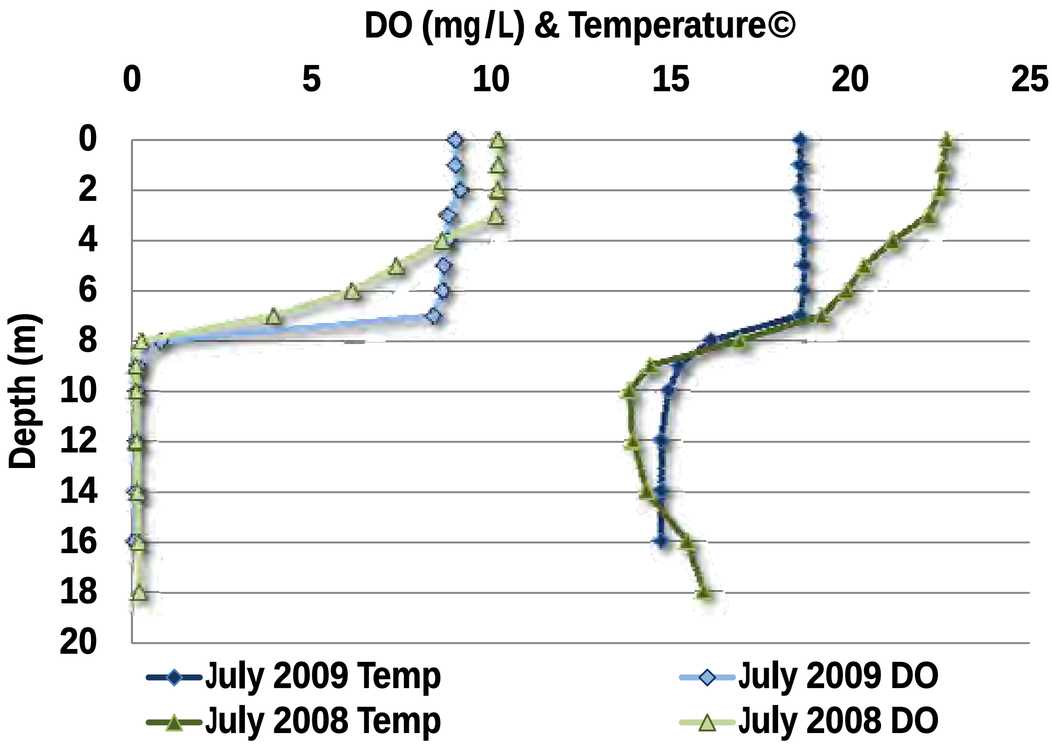
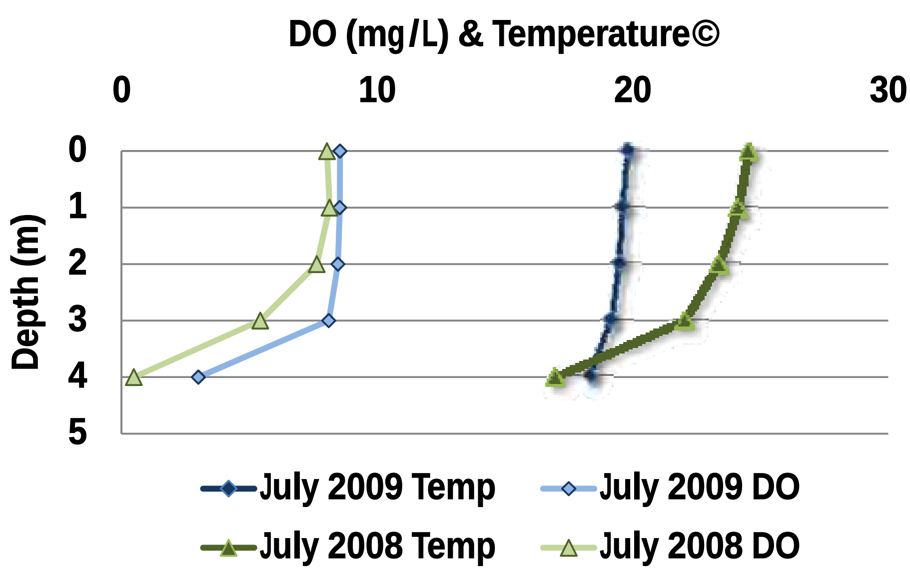


Figure 22. Hill Lake (SB) July 2008 & 2009 dissolved oxygen & temperature profile comparison



Total Phosphorus concentrations for Hill Lake averaged 22 micrograms per liter (µg/L) for the NB and 36 µg/L for the SB in 2009 (Table 8). The average for the NB was within the typical range of concentrations for NLF reference lakes while the average for the SB was above the typical range. TP concentrations remained relatively the same from May through July and then dropped in August before spiking at 32 µg/L in September (Figure 23). TP concentrations near the lake bottom in the NB were high throughout most of the season, spiking at 183 µg/L in August (Figure 25). This coincides with the sharp drop in DO near the sediment layer as TP is likely being released upward into the water column under anoxic conditions (Figure 19).

Both external (watershed) and internal (sediments, plants, and fish) sources can contribute to TP levels in lakes. The pattern of increasing TP over the course of the summer in the SB is consistent with other shallow Minnesota lakes. The difference in average TP values between the NB and SB is largely attributed to the differing size and depth of the basins and the watershed areas. The total contributing area for the SB is nearly three times the size of that which contributes to the NB (Table 2) and it is quite likely the SB receives higher levels of nutrients and water loading than does the NB from its smaller watershed. Moderate precipitation from mid June through mid-August contributed somewhat to summer nutrient loading; however, a majority of the summer was dry (Figure 7). Finally, internal recycling of nutrients from the bottom sediments will also contribute to the amount of TP suspended in the lake. Elevated TP levels coincided with decreasing DO levels within the hypolimnion as oxygen consumption due to decomposition increased.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During summer 2009, chl-*a* concentrations for Hill Lake NB ranged from 1 µg/L to 8 µg/L, with an average of 5 µg/L (Figure 23). Chl-*a* concentrations for the SB ranged from 3 µg/L to 26 µg/L with an average of 12 µg/L (Figure 24). The average was within the expected range of 4-10 µg/L for the NLF ecoregion for the NB. As such, no algae blooms were observed in 2009 (Table 8). Chl-*a* concentrations for the SB peaked at 26 µg/L in September coinciding with a TP spike of 59 µg/L.

Secchi disk transparency on Hill Lake averaged 3.7 meters (12 feet) for the NB and 2.3 meters (7.5 feet) for the SB during the summer of 2009 (Table 8). The average Secchi depth for the NB falls within the typical range of values for the NLF ecoregion. The average Secchi depth for the SB is just above the typical range. The change in the transparency within both basins of Hill Lake during each sampling event closely mirrored the changes in nutrient availability (TP) and algal production (chl-*a*). For the NB the Secchi disk transparency reached a low of 2.5 meters (8.2 feet) in September and October and a high of 5 meters (16.4 feet) in August.

Figure 23. Hill Lake (NB) 2009 total phosphorus, chlorophyll-*a* concentrations, & Secchi depth

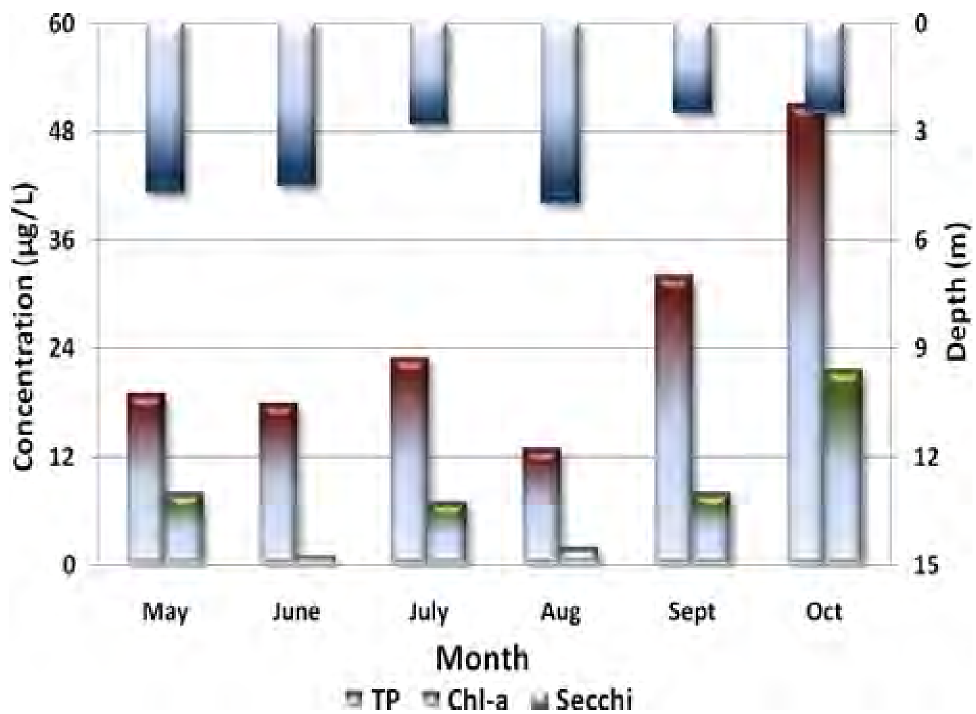


Figure 24. Hill Lake (SB) 2009 total phosphorus, chlorophyll-*a* concentrations, & Secchi depth

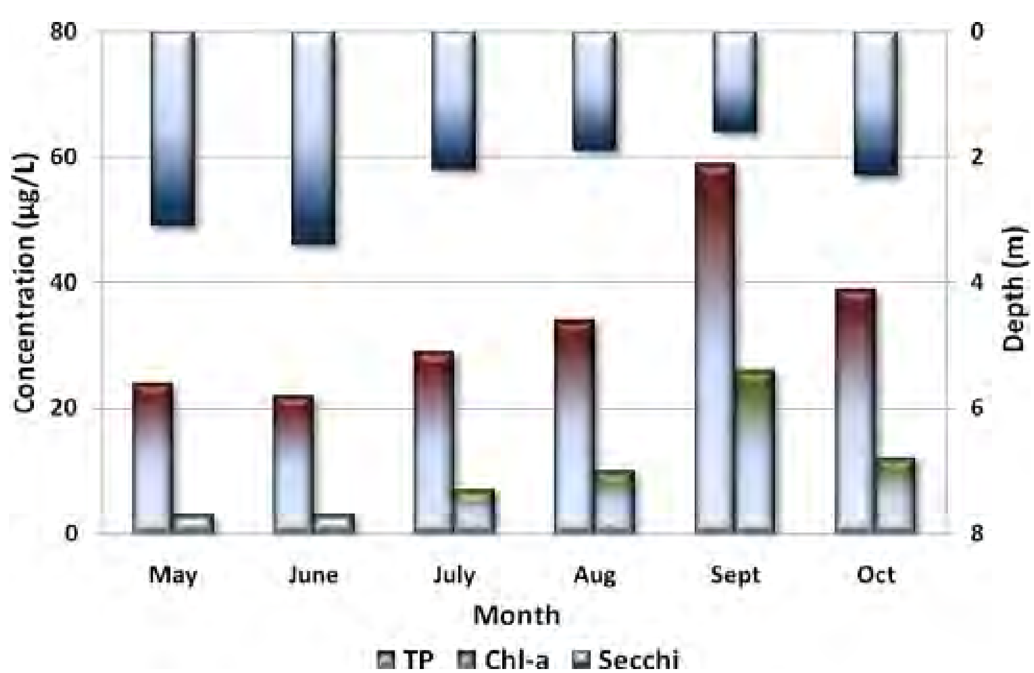
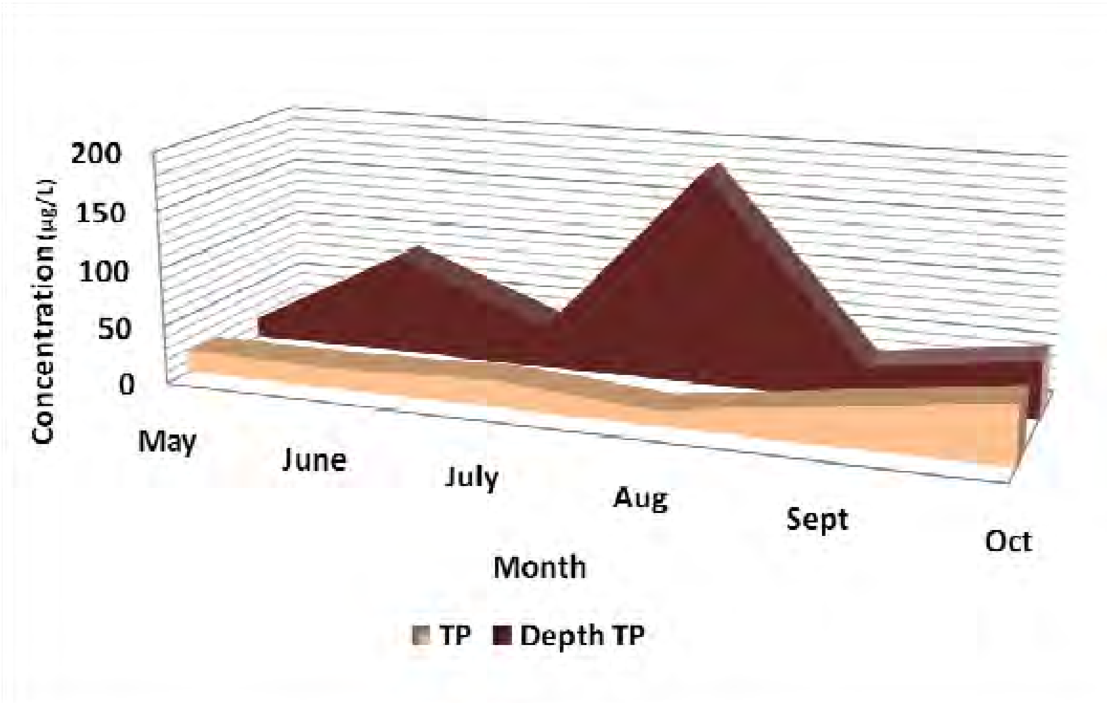


Figure 25. Hill Lake (NB) 2009 surface and depth total phosphorus comparison



Dissolved minerals and organic carbon were measured in 2008 and 2009 as part of the long-term monitoring of the NB of Hill Lake and other Sentinel lakes. This included some of the standard lake assessment measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 8) as well as major cations, anions, silica, iron and organic carbon (Table 9). While several of these parameters have "typical" ecoregion-based concentrations (e.g. Table 8), some do not. For parameters without ecoregion–based comparisons data from the 2007 NLA study were used to provide perspective on reported concentrations (Table 9). Since the NLA lakes were selected randomly they provide a reasonable basis for describing typical ranges and distributions at the state-wide level.

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

Alkalinity and conductivity are above the typical range for NLF lakes and are indicative of hard water (Table 8). Most cation and anion concentrations were quite stable across sample events and years (Table 9), which is consistent with the literature. Magnesium (Mg,) sodium (Na), potassium (K) and chloride (Cl) are noted to be relatively conservative and undergo only minor spatial and temporal change (Wetzel 2001). Mg is required by algae to produce chl-*a* and calcium (Ca) is used by rooted plants. Silica (Si), which is required by diatoms to form their "glass" shells, varied slightly from spring to fall. The slight decline in fall may be caused by a fall diatom bloom.

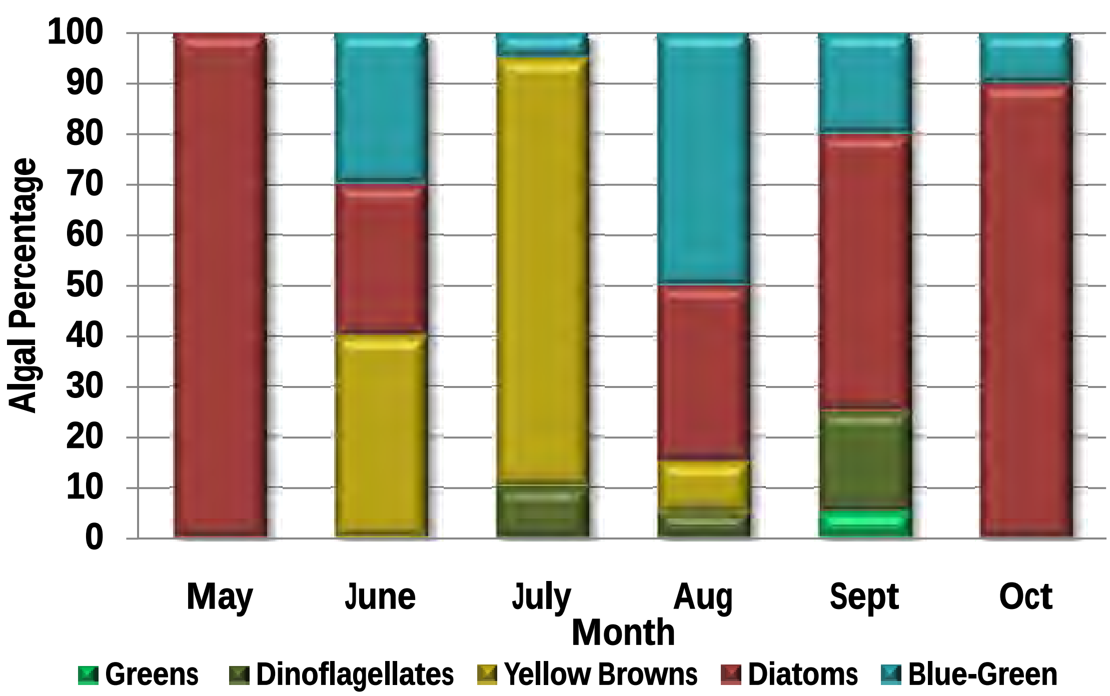
Ca and Mg were the dominant cations and concentrations of both exceeded the typical range of the state-wide data for 2009 (Table 9). The other two major cations, Na and K, were within the typical

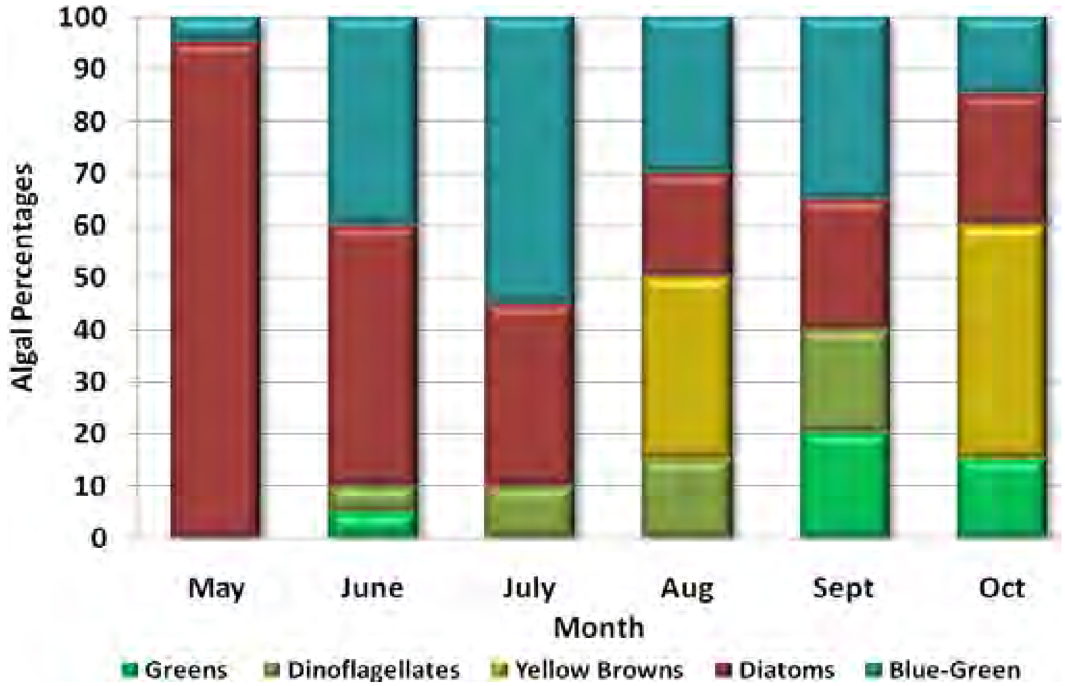
range. Bicarbonate is the dominant cation, followed by Cl and sulfate (SO_4). Chloride values were well above the typical range for NLF reference lakes (Table 8); however it was within the typical range relative to state-wide NLA data. Elevated Cl is most often attributed to application of road salt on roads within the watershed. Sulfate is within the typical range relative to the NLA data. The average cation and anion balances (cation-anions expressed as a % of cations) for 2008 and 2009 were within 5 percent and 1 percent, which is well within values exhibited by the NLA lakes.

Phytoplankton (algae) for the NB and SB of Hill Lake are presented in terms of algal type (Figure 26). For both basins, diatoms were the dominant genera for much of the season with the exception of July in the NB. This early abundance of diatoms is anticipated as they are often dominant in the spring and early summer. Diatoms remained present throughout the season with several genera being represented including *Asterionella*, *Centric*, *Fragelaria*, *Pennate*, and *Tabellaria*. Additionally, blue-greens increased in abundance as the summer progressed and dinoflagellates were identified from June through August. *Anabaena* was the dominant blue-green while *Dinobryon* was the most common yellow-brown algae identified in the spring and fall. No algal blooms were observed at either of the two sites monitored in 2008 or 2009.

Distinct differences can be seen between the NB and SB algal types and abundances. The abundance of yellow-brown algae from June through August is much higher for the NB than for the SB. Diatoms were the most abundant types in both basins but their abundance was much greater in October in the NB while the SB displayed a greater variety with yellow-brown being the dominant algae type. Finally, the SB displayed a greater variety of algal types throughout the season than the NB.

Figure 26. Algal composition for the NB and SB of Hill Lake in 2009





Zooplankton

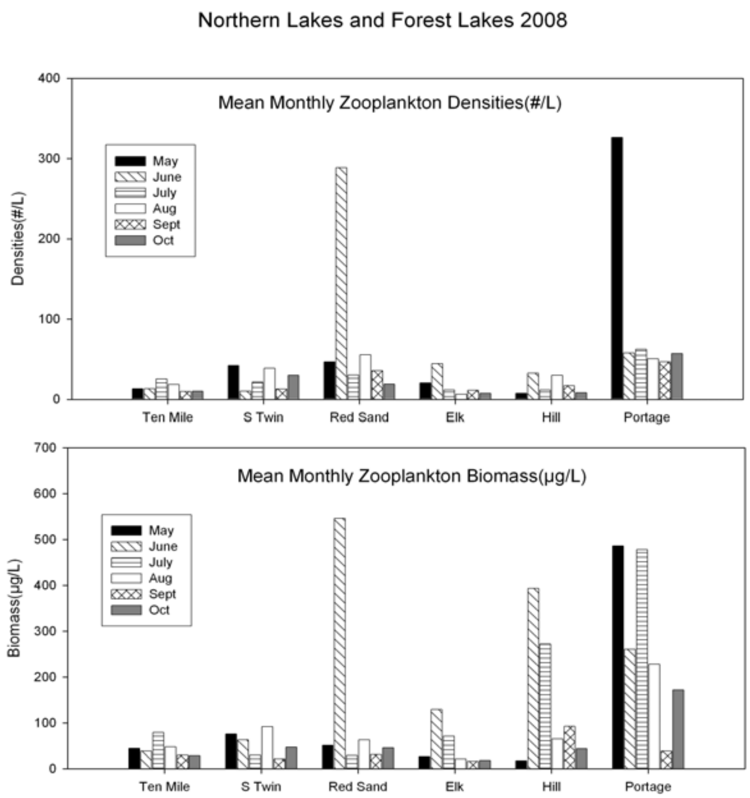
Zooplankton samples were analyzed by Jodie Hirsch at the MDNR. A summary report was prepared that included information for all the Sentinel Lakes and that report (Hirsch 2009) is the basis for the following comments on Hill Lake.

The mean annual density for Hill Lake was near the bottom of the list of the NLF within the Sentinel Lakes program with a low amount of total taxa as well (Table 10). However, the mean annual biomass was relatively high amongst the NLF lakes. Hirsch (2009) determined that, in general, as the amount of TP and chl-*a* increases so too does the relative abundance (biomass) of zooplankton. Hill Lake displayed a similar pattern with most of the other NLF lakes by peaking in biomass in the spring and declining as the summer progresses (Figure 27).

Table 10. Mean annual zooplankton densities, biomass, and total number of taxa for each Sentinel lake.

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

Figure 27. Mean monthly zooplankton densities and biomass for NLF ecoregion Sentinel lakes



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 measured in µg/L and transparency using a Secchi disk measured 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 29). In general, the TSI values are in fairly close correspondence with each other. The TSI values also correspond with observations for 2008. Based on an average TSI score of 45 the NB of Hill Lake would be characterized as mesotrophic. The SB of Hill Lake, with a TSI score of 53, would be characterized as eutrophic.

Trophic Status Trends

One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in STORET. A review of data in STORET indicates there is a poor amount of data for Hill 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. The water quality for the NB of Hill Lake has improved from being classified as eutrophic in 1994 to the current classification of mesotrophic.

Individual summer-mean TP, chl-*a* and Secchi data can provide further insight into trends and variability (Table 11). Based on data collected for the 1994 LAP and the current data used for this report the long-term average TP for the NB of Hill Lake is 25 µg/L ± 2 µg/L. When compared to the 1994 results, recent years have been less than the long-term mean and indicate a distinct trend of decreasing TP. Chl-*a* values have a long-term mean of 8 µg/L ± 2 µg/L. When compared to the 1994 results, recent years have been less than the long-term mean and indicate a trend of decreasing chl-*a* within the NB of Hill Lake. Secchi disk transparency has also improved since 1994 with a long-term mean of 3.3 meters ± 0.2 meters. Secchi disk values for 2008 and 2009 have been greater than the long-term mean indicating an improvement in water clarity. As with TP and chl-*a*, the Secchi disk values indicate mesotrophic conditions.

Based on data collected for the 1994 LAP and the current data the long-term average TP for the SB of Hill Lake is 36 µg/L ± 1 µg/L. When compared to the 1994 results, recent years have shown little improvement. Chl-*a* values have a long-term mean of 12 µg/L ± 2 µg/L. When compared to the 1994 results, recent years have been slightly less than the long-term mean but still indicate a trend of excessive chl-*a* within the SB of Hill Lake. Secchi disk transparency has slightly improved since 1994 with a long-term mean of 2.2 meters ± 0.2 meters (Figure 28). Secchi disk values for 2008 and 2009 have been greater than the long-term mean indicating a slight improvement in water clarity.

Table 11. Hill Lake NB and SB trophic status trends and standard errors

	TP	Standard Error	Chl-a	Standard Error	Secchi	Standard Error
	ug/L		ug/L		meters	
1994	29		11		2.8	
2008	24		7		3.5	
2009	22		5		3.7	
NB Average	25	2	8	2	3.3	0.2
1994	37		15		1.9	
2008	37		11		2.4	
2009	36		10		2.4	
SB Average	37	1	12	2	2.2	0.2

Historical precipitation records, collected at the nearest station in Grand Rapids, MN, may provide some insight into potential nutrient sources influencing observed trends. Based on precipitation records from 1989 to 2009, mean annual precipitation is over 17 inches and has shown a decrease over the period of record (Figure 9). The summer months of both 2008 and 2009 were significantly drier with measurements of 15.08 inches and 13.98 inches. This below average precipitation coincided with the recent, slightly lower, TP and chl-*a* levels. When compared to the summer months of 1994 with above average

precipitation measurements of 20.6 inches, TP and chl-*a* levels were slightly elevated. This suggests that the trophic status trends of both the NB and SB of Hill Lake may be influenced by precipitation and runoff, which could yield higher P loading.

Figure 28. Hill Lake (NB) long-term summer-mean Secchi disk depth. Long-term mean noted by dashed line.

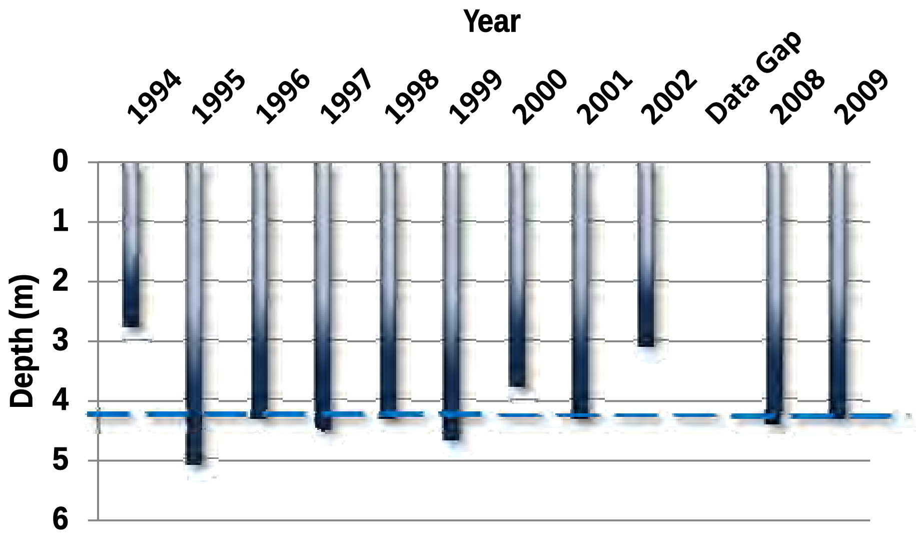
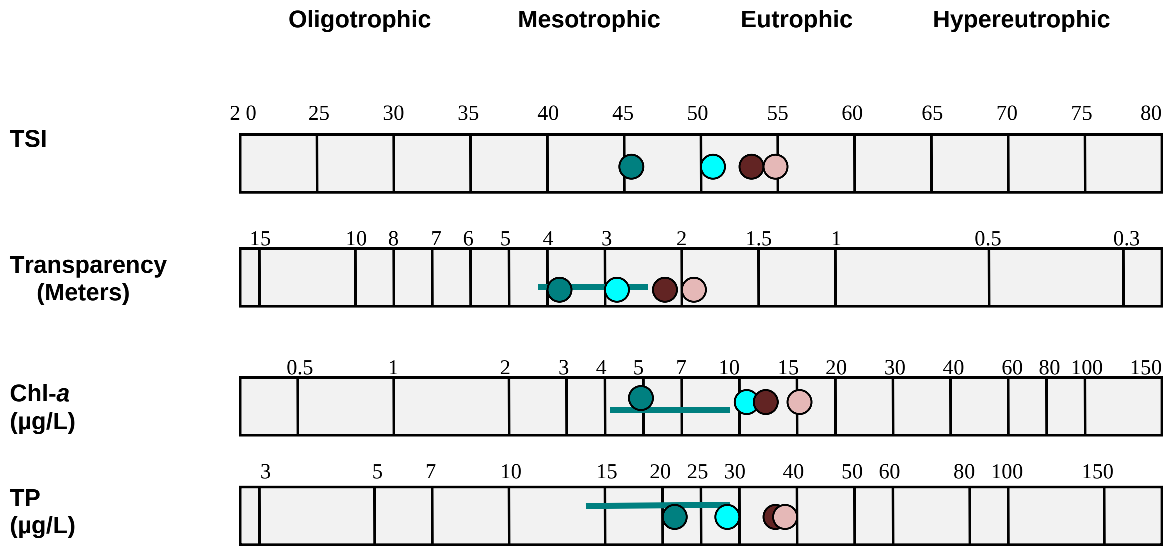


Figure 29. Carlson's Trophic State Index for Hill Lake
R.E. Carlson

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 scums probable, extensive Macrophyte problems.
TSI 70 – 80	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



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

NLF Ecoregion Range: Hill Lake NB 1994 Hill Lake NB 2009
Hill Lake SB 1994 Hill Lake SB 2009

Modeling

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water that enters the lake. To analyze the 2009 water quality of Hill Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. A comparison of MINLEAP predicted vs. observed values is presented in Table 12.

MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). The model predicts in-lake TP from these inputs and subsequently predicts chl-*a* based on a regression equation of TP and Secchi based on a regression equation based on chl-*a*. For analysis of both the NB and SB of Hill Lake, MINLEAP was applied as a basis for comparing the observed (2009) TP, chl-*a*, and Secchi values with those predicted by the model based on the lake size and depth and the area of the watershed.

Hill 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 the NB of Hill Lake were similar to the NLF predicted values with notably better water clarity. This indicates 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 483 kilograms per year (kg/yr) for the NB. This result is likely a good estimate given that the observed TP matches the predicted values. The areal water load to the NB is estimated at 3 meters per year (m/yr) and estimated water residence time is approximately 2.2 years; however, it is important to note that this

estimate only considers watershed runoff and precipitation on the lake and does not account for groundwater inputs that are likely quite significant in lakes like Hill. An additional subroutine in the MINLEAP model estimates the "background" TP for the lake based on its alkalinity and mean depth and a regression equation developed by Vighi and Chiaudani (1985). For the NB this value is estimated at 20 µg/L, which is within the NLF nutrient criteria (Table 13).

The observed TP, chl-a, and Secchi values for the SB of Hill Lake were also relatively similar to the predicted values. The model predicted TP loading at 1,251 kg/yr for the SB. In determining TP loading the model does not take into account the 61 percent retention occurring within the NB. Once the retention amount is calibrated into the model the loading for the SB is predicted to be 964 kg/yr. The areal water load to the SB is estimated at 48 meters per year (m/yr) and estimated water residence time is approximately 0.1 years. The model does not take into account the sedimentation of phosphorous that occurs in the NB; hence the predicted phosphorous loading is likely lower than what is reported here. Lower phosphorous loading would result in a slightly lower predicted phosphorous for the SB. For the SB the "background" TP is estimated at 28 µg/L, which is within the NLF nutrient criteria

The MINLEAP model does not indicate the actual source of nutrient loading to the lake; however, by using typical stream TP concentrations, runoff, precipitation and evaporation for the NLF ecoregion a reasonable estimate of the anticipated nutrient and water loading to Hill Lake can be made. The model estimates are derived from typical nutrient runoff concentrations from a forest and wetland-dominated watershed, combined with that contributed directly on the surface of the lake via wet and dry deposition. Rechow-Simpson modeling done as a part of the lake assessment study in 1994 estimated relative contributions as follows: precipitation contributes ~10 percent of the phosphorous loading to the lake watershed runoff contributes ~84 percent and ~6 percent is potentially from septic systems around the lake. Actual measurement of inflow phosphorous concentrations and flow would be required to develop a more accurate nutrient budget for the lake and an improved understanding of significant loading sources.

Table 12. MINLEAP model results for Hill Lake (NB & SB)

Parameter	2009 NB Hill Lake Observed	MINLEAP Predicted NLF Ecoregion	2009 SB Hill Lake Observed	MINLEAP Predicted NLF Ecoregion	*MINLEAP SB Adjusted
TP (µg/L)	22	21	36	43	34
Chl-*a* (µg /L)	5	6	12	16	11
Secchi (m)	3.7	2.8	2.3	1.5	1.9
P loading rate (kg/yr)	-	483	-	1,251	964
P retention (%)	-	61	-	18	16
P inflow conc. (µg/L)	-	54	-	52	40
Water Load (m/yr)	-	3	-	48	48
Outflow volume (hm^3/yr)	-	9	-	24	24
Residence time (yrs)	-	2.2	-	0.1	0.1
Vighi & Chiaudani	-	20	-	28	28

*Value adjusted to compensate for 61% retention by the NB.

303(d) Assessment and Goal Setting

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

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

Hill Lake was assessed based on NLF ecoregional standards (Table 13). Both the 2009 and long-term mean TP for the NB of Hill Lake have remained below 30 µg/L. Likewise, chl-*a* and Secchi are in full compliance with the NLF ecoregion standard. The SB of Hill Lake has not been in compliance with a mean TP above 30 µg/L and a mean chl-*a* value above 9 µg/L. Despite the TP and chl-*a* exceedence the water clarity of the SB has been greater than 2 meters. The Mississippi (Grand Rapids) watershed is due to begin its assessment in 2014 and waters listed as impaired will be included on the 2016 305(b) and 303(d) assessments that MPCA conducts in support of the Clean Water Act. Based on these results, the NB of Hill Lake will likely be assessed as fully supportive of aquatic recreational use while the SB may be listed as impaired for excessive nutrients. These assessments are submitted to the U.S. Environmental Protection Agency on a biennial basis. Additional data is anticipated to be collected as part of the Sentinel Lakes Program that may result in a change in the impairment status.

Table 13. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). Hill Lake (NB & SB) 2009 and long-term means provided for comparison.

Ecoregion	TP µg/L	Chl-*a* µg/L	Secchi meters
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2b)	< 40	< 14	> 1.4
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	*< 60*	*< 20*	*> 1.0*
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7
Hill Lake (NB) 2009	22	5	3.7
Hill Lake (SB) 2009	35	12	2.3
Hill Lake (NB) Long Term Mean	27	9	3.3
Hill Lake (SB) Long Term Mean	36	12	2.2

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Appendix A

Surface water quality data for Hill Lake (NB & SB)

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
Hill Lake (NB)	01-0142-01	5/31/1994	101	3.5	45	4	160	4.6	0.5	20	1
Hill Lake (NB)	01-0142-01	6/21/1994	101	3.4	24	4	130	4.8	0.6	20	2.4
Hill Lake (NB)	01-0142-01	7/19/1994	101	3	21	8	150	4.6	0.5	20	2.8
Hill Lake (NB)	01-0142-01	8/23/1994	101	2	29	12	150	4.7	0.6		2.8
Hill Lake (NB)	01-0142-01	9/13/1994	101	2	28	26	150	4.7		20	3.4
Hill Lake (NB)	01-0142-01	5/8/2008	101	2.2	25	8	150	6.6	0.5	20	2
Hill Lake (NB)	01-0142-01	6/2/2008	101	3.7	21	8			0.5		
Hill Lake (NB)	01-0142-01	7/7/2008	101	4.3	18	2	150	6.4	0.7	5	1.2
Hill Lake (NB)	01-0142-01	8/4/2008	101	3.8	28	4					
Hill Lake (NB)	01-0142-01	9/11/2008	101	2	26	13			0.6		
Hill Lake (NB)	01-0142-01	10/8/2008	101	3.4	40	7	150	6.3	0.5	5	2.2
Hill Lake (NB)	01-0142-01	5/27/2009	101	4.7	19	8	150	6.7	0.8	20	4.4
Hill Lake (NB)	01-0142-01	6/17/2009	101	4.5	18	1			0.3		
Hill Lake (NB)	01-0142-01	7/21/2009	101	2.8	23	7	150	6.4	0.5	20	0
Hill Lake (NB)	01-0142-01	8/18/2009	101	5	13	2			0.5		
Hill Lake (NB)	01-0142-01	9/29/2009	101	2.5	32	8			0.6		
Hill Lake (NB)	01-0142-01	10/19/2009	101	2.5	51	22	160	7	0.7	10	4.8
Hill Lake (SB)	01-0142-02	5/31/1994	101	3	18	3	140	3.7	0.7	40	1.8
Hill Lake (SB)	01-0142-02	6/21/1994	101	1.8	33	8	130	3.2	0.8	40	2
Hill Lake (SB)	01-0142-02	7/19/1994	101	1.8	45	15	140	3.3	0.8	40	2.6

Appendix A, continued

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
Hill Lake (SB)	01-0142-02	8/23/1994	101	1.9	43	15					
Hill Lake (SB)	01-0142-02	9/13/1994	101	1	46	33	160	3.7		30	5.2
Hill Lake (SB)	01-0142-02	5/8/2008	101	2	37	12					
Hill Lake (SB)	01-0142-02	6/2/2008	101	1.9	25	9					
Hill Lake (SB)	01-0142-02	7/7/2008	101	4	19	3					
Hill Lake (SB)	01-0142-02	8/4/2008	101	2.6	44	8					
Hill Lake (SB)	01-0142-02	9/11/2008	101	1.6	58	23					
Hill Lake (SB)	01-0142-02	10/8/2008	101	1.8	40	12					
Hill Lake (SB)	01-0142-02	5/27/2009	101	3.1	24	3					
Hill Lake (SB)	01-0142-02	6/17/2009	101	3.4	22	3					
Hill Lake (SB)	01-0142-02	7/21/2009	101	2.2	29	7					
Hill Lake (SB)	01-0142-02	8/18/2009	101	1.9	34	10					
Hill Lake (SB)	01-0142-02	9/29/2009	101	1.6	59	26					
Hill Lake (SB)	01-0142-02	10/19/2009	101	2.3	39	12					

Appendix B

Hill Lake (NB) cation, anion, and organic carbon results

Date	mg/L	mg/L	mg/L	mg/L	µg/L	mg/L	mg/L	mg/L	mg/L
	Ca	Mg	Na	K	Fe	Si	SO_4	Cl	TOC
5/8/2008	97	53	5.9	1.9			9.99	6.64	7.8
7/7/2008	100	57	6.9	1.9			9.87	6.36	7
10/8/2008	110	57	7.3	1.9			8.48	6.34	6.7
5/27/2009	42.5	13.3	6.55	1.93	14.4	11	10	6.7	7.9
7/21/2009	42.2	13.7	6.52	1.82	14.1	11	9.84	6.39	6.5
10/19/2009	42	13.8	6.71	1.92	21.2	14	8.95	7.02	6.8