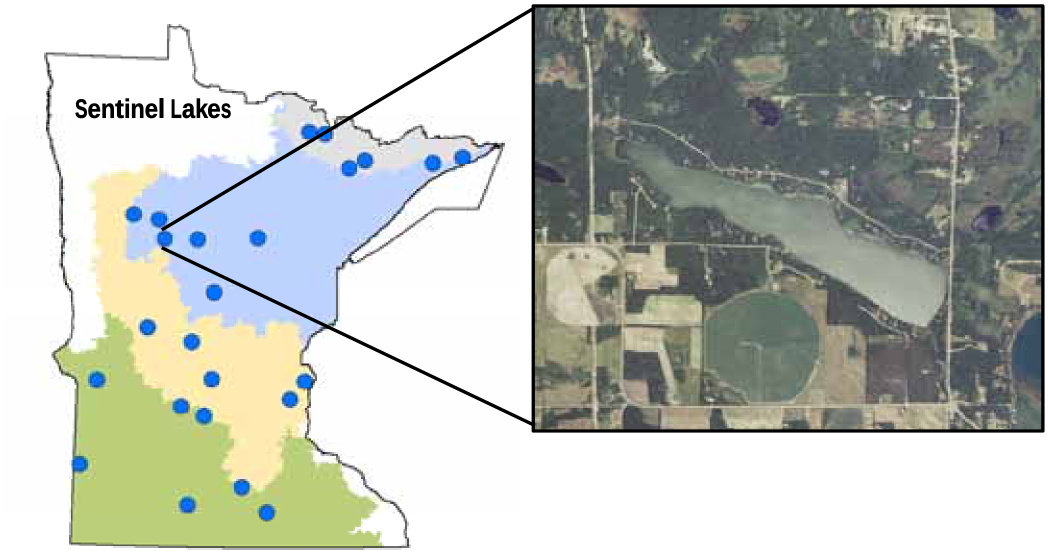
Sentinel Lake Assessment Report
Portage Lake (29-0250)
Hubbard County, Minnesota



Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit
&
Minnesota Department of Natural Resources
Section of Fisheries
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2008 Lake Assessment of Portage Lake (29-0250) Hubbard County, Minnesota
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Executive Summary

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

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). Portage Lake was selected to represent a shallow eutrophic lake in the Northern Lakes and Forest (NLF) ecoregion. Portage Lake is a 170 hectare (422 acre lake), located approximately 5 miles north of Park Rapids, Minnesota in west central Hubbard County, within the Crow Wing River watershed. The lake has a maximum depth of 5.2 meters (17 feet) and a mean depth of 2.3 meters (7.6 feet). The lake is 97% littoral with one public access on the southern shore of the lake. The total contributing watershed for Portage Lake is 1,210 hectares (2,995 acres). Portage Lake is located within the NLF ecoregion, but is very close to the transition to the North Central Hardwood Forests (NCHF) ecoregion.

Portage Lake is a relatively shallow lake that mixes during high winds and weakly stratifies during calm periods. Based on recent water quality data (2007-2008), Portage Lake is considered to be eutrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 60 micrograms per liter (µg/L), 21 µg/L, and 0.9 meters (3 feet) respectively. TP is particularly high and exceeds the typical ranges (based on reference lakes) for both the NLF and NCHF ecoregions. Nuisance algal blooms were common and transparency was typically low during much of the summer. Trophic status data collected by the lake association since 1997 suggest slight increases in nutrient levels and algal growth over time and in particular for the recent period from 2004-2008. As a result, Secchi transparency has declined slightly as well. Based on these data, Portage Lake was included on the 2006 303(d) (Impaired waters) list that Minnesota submitted to the United States Environmental Protection Agency (EPA). A Total Maximum Daily Load (TMDL) study is targeted to begin for Portage Lake in 2014. Once a lake is placed on the Impaired Waters List it is required to be intensively researched through a TMDL study to determine the source and extent of the pollution problem followed by the development of a restoration plan.

Portage Lake was reportedly a wild rice marsh before construction of a dam in 1937 raised water levels. Surveys in 2008 indicated that Portage Lake supports a fish community that is more diverse than other eutrophic lakes, but average when compared to mesotrophic lakes (the productivity class where Portage Lake might be under unimpaired conditions). Portage Lake is primarily managed for walleye (*Sander vitreus*) through supplemental stocking of fry and fingerlings. Portage Lake infrequently experiences partial winterkills due to low levels of dissolved oxygen in winter. Those events can dramatically affect species' abundance and subsequent growth and condition. Perhaps as a combined result of poor habitat conditions, insufficient forage, and/or over harvest, the size-structure of most game fish populations in the lake is poor. Yellow perch (*Perca flavescens*) have been particularly low in abundance while black and brown bullheads (*Ameiurus melas* and *Ameiurus nebulosus*) have increased in abundance in recent years. Presumably, this is providing an alternative, but lower quality, forage base than yellow perch.

In addition to eutrophication, Portage Lake has seen increasing cover and abundance of the non-native curly-leaf pondweed (*Potamogeton crispus*). Curly-leaf pondweed thrives in nutrient-rich conditions and at some unknown threshold of nutrient levels it can become a self-sustaining, internal driver of poor water quality conditions due to mid-summer senescence. Fortunately, muskgrass (*Chara* sp.) is abundant in the lake and appears to be increasing in cover and abundance. Muskgrass is a native bottom-growing plant that promotes clear water. In turn, clear water promotes growth of muskgrass. Muskgrass also provides critical habitat for sensitive non-game and juvenile game fish species.

An ecoregion-based eutrophication model was used to predict in-lake TP based on Portage Lake's size, depth, and watershed area using inputs from both ecoregions. Using inputs for both the NLF and NCHF ecoregions the model predicted a range in in-lake TP from 25 µg/L (NLF) to 44 µg/L (NCHF), which are both much lower than the observed 60 µg/L. A separate subroutine within the model estimated "background" TP for the lake at 30 µg/L. The model predictions, along with the overall assessment of Portage Lake's water quality data, clearly indicate the lake's water quality is much poorer than anticipated for a lake of this size in this portion of the State.

The TMDL diagnostic study and implementation plan will provide useful information for improving the water quality and ecology of Portage Lake. The study must consider the relative significance of internal sources (e.g. curly-leaf senescence and sediment phosphorus recycling) and external sources of nutrients so that effective implementation strategies can be developed. The presence of natural resilience mechanisms, such as muskgrass, increase the chances that comprehensive and coordinated watershed and lake restoration activities through a TMDL and Lake Vegetation Management Plan (LVMP) will be successful in restoring water quality and quality fish habitat conditions. Continued agency and citizen participation in lake monitoring will be critical to evaluate restoration practices outlined in the TMDL and LVMP.

Figure 1. Sentinel Lakes and ecoregional representation

Introduction

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

History

Provided by the Portage Lake Improvement Association
and Doug Kingsley (MDNR, Park Rapids Area Fisheries Supervisor)

Early 20th Century	Northern Pacific Railway owned a majority of the land surrounding Portage Lake. A variety of lumber companies owned and logged the land as well. The lake was used as a holding pond for logs at this time. Logs were skidded onto the ice during the winter where they remained until ice out. The logs were then sent down the Portage River to Fish Hook Lake and into the Fish Hook River to a saw mill on the east side of the river. The first recorded fish stocking occurred from 1912 to 1945.
1930's	Following the departure of the logging industry, Portage Lake was shallower and the river wider and deeper. The dam was built in 1937 by the Civilian Conservation Corp as a Works Progress Administration project to raise the lake's water level. Some shoreline agricultural use also occurred at this time.
1940's	Portage Lake was initially mapped in 1941. Residents and resorts received electricity and telephone service in 1947. Portage Lake was also opened to liberalized fishing in 1947-1948. Additionally, stop logs were placed in the dam to establish a reading of 1.3 meters (4.4 feet) at the headwater gauge. Three resorts existed on Portage Lake. Seaquist Resort, later known as Silver Birches, on the eastern shore; Jensen's Resort located on the northeastern shore; and Karlson's Portage Retreat on the northern shore. Seaquist and Jensen's remained in business until the 1970's, while Karlson's closed in 1954. In 1955, the property was sold and the new owner surveyed and platted the land into individual lots which were eventually sold.
1950's	In 1954-1956, construction and major resurfacing of Highway (Hwy) 71 took place. Stop logs were illegally placed in the dam in 1958 to raise the water level to 1.5 meters (5.0 feet). They were eventually removed to restore the water level to 1.3 meters (4.4 feet). Public complaints about low water led to securing flowage easements and restored water levels to 1.5 meters (5.0 feet) at the headwater gauge. The initial lake survey was conducted in 1959 for management purposes. Portage Lake was classified as a largemouth bass-panfish-walleye lake.
1960's	Dredging began in 1965 in the channel south east of Portage Lake. This created a continuous deep water channel along Hwy 71. The dredging was MDNR

	approved with the intention of creating walleye habitat. Instead, pan fish and bass prospered resulting in increased fishing traffic. These fishing conditions remained until a fish kill in 1985. The culvert on the east end under Hwy 71 is the outlet to the Portage River that flows into Fish Hook Lake. Portage Lake was also opened to liberalized fishing in 1965 and was re-mapped in 1969.
1970's	The Portage Lake Improvement Association was established in 1971. The goal was to create a social group that focused the attention of lake home owners on issues such as fish kills, beaver dams, road conditions, and recently curly leaf pondweed. Annual walleye fingerling, yearling, or adult stocking occurred from 1977 to 1980.
1980's	Beginning in 1982, walleye fingerling, yearling, or adult stocking occurred in even numbered years to 2004. Partial winterkills occurred in 1985-86 and 1988-1989 with winterkill assessments completed for each event. Portage Lake was once again opened to liberalized fishing in 1985-1986. In 1988, the first Fisheries Lake Management Plan was developed.
1990's	In 1997, the lake association joined Coalition of Lake Associations and began water monitoring for TP and chl-*a*. This monitoring has continued and is conducted by Marilyn Peterson, President of the association. Curly-leaf pondweed was first identified in the late 1990's, but was not documented. A partial winterkill occurred in 1995-1996.
2000's	In the spring of 2002, curly-leaf pondweed was first documented and became a significant lake concern as it impaired lake activities. Large mats of vegetation began forming, particularly around the eastern and southern shores. Beginning in May 2003, the lake association funded chemical treatment of curly-leaf pondweed. The treatment has helped make recreational activities possible, and thus far appears to have a relatively benign ecological effect. Chemical treatment is tentatively scheduled to continue to prevent mat growth. In 2005, the Portage Lake Association received grant funding and prepared a Healthy Lakes and Rivers Program Lake Management Plan. Portage Lake was included on the 2006 303(d) list that Minnesota submitted to the EPA. A TMDL study is targeted to begin for Portage Lake in 2014. A Lake Vegetation Management Plan (LVMP) was prepared in 2007.

Background

Lake Morphometric and Watershed Characteristics

Portage Lake is located in west-central Hubbard County within the Crow Wing River watershed. Portage Lake is approximately five miles north of Park Rapids, MN. A public access is located on the south central shore. Portage Lake is a relatively shallow lake that mixes during high winds and weakly stratifies during calm periods.

Portage Lake's morphometric characteristics are summarized in Table 1. Percent littoral area refers to that portion of the lake that is 4.6 meters (15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake. Lakes with a high percentage of littoral area 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.

Table 1. Portage Lake and watershed morphometric characteristics

Lake Name	Lake ID	Lake Basin	Littoral Area	Total Watershed Area	Watershed: Lake	Max. Depth	Mean Depth	Lake Volume
		Hectares (Acres)	%	Hectares (Acres)	Ratio	Meters (Feet)	Meters (Feet)	Acre-Ft.
Portage	29-0250	170 (422)	97	1,210 (2,995)	7:1	5.2 (17)	2.3 (7.5)	3,207

Lake bathymetry based on MDNR 2008 acoustic survey.

The Portage Lake contributing watershed lies within Crow Wing River major watershed. The lake's watershed has one drainage point located on the eastern shore of the lake. The contributing watershed has a total area of 1,210 hectares (2,995 acres) resulting in a watershed-to-lake area ratio of approximately 7:1. Watershed areas were estimated based on data from the University of Minnesota Remote and Geospatial Analysis Lab.

Portage Lake soils are defined as coarse- to medium-textured forest soils formed from glacial outwash from the Menahga-Marquette series. The area is level to rolling and the soils are light-colored and droughty. Agriculture is not typical to these soils and most areas are supportive of jack pine trees (Arneman 1963). Portage Lake was likely formed by glacial deposition within the outwash (Zumberge, 1952).

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. Portage Lake lies within the Northern Lakes and Forests ecoregion but near the transition to the NCHF ecoregion (Figure 2). NLF and North Central Hardwood Forest values will be used for land use (Table 2) and summer-mean water quality comparisons (Table 8). Additionally, both ecoregions will be used for the model application.

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Land use within the watershed is fairly typical for the NLF ecoregion with the exception of a higher percentage of agriculture and pasture use. Since Portage Lake lies near the NCHF and the NLF ecoregion transition, comparisons with both ecoregion are merited (Table 2). Pasture and open land use percentages for Portage Lake's watershed fall within the values typically associated with the NCHF ecoregion. Forest is the highest land use and falls within the typical range for the ecoregion (Figure 3 & Table 2). Based on Figure 3, the agricultural uses are located along or adjacent to the stream network that drains the western portion of the watershed.

Figure 2. Minnesota ecoregions as mapped by EPA

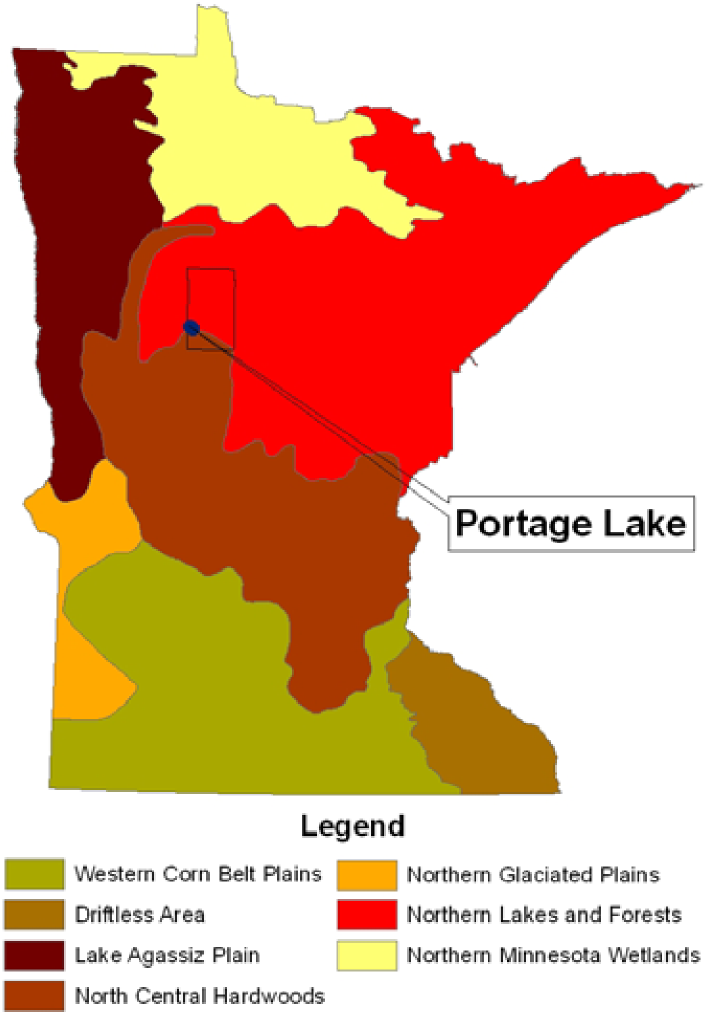
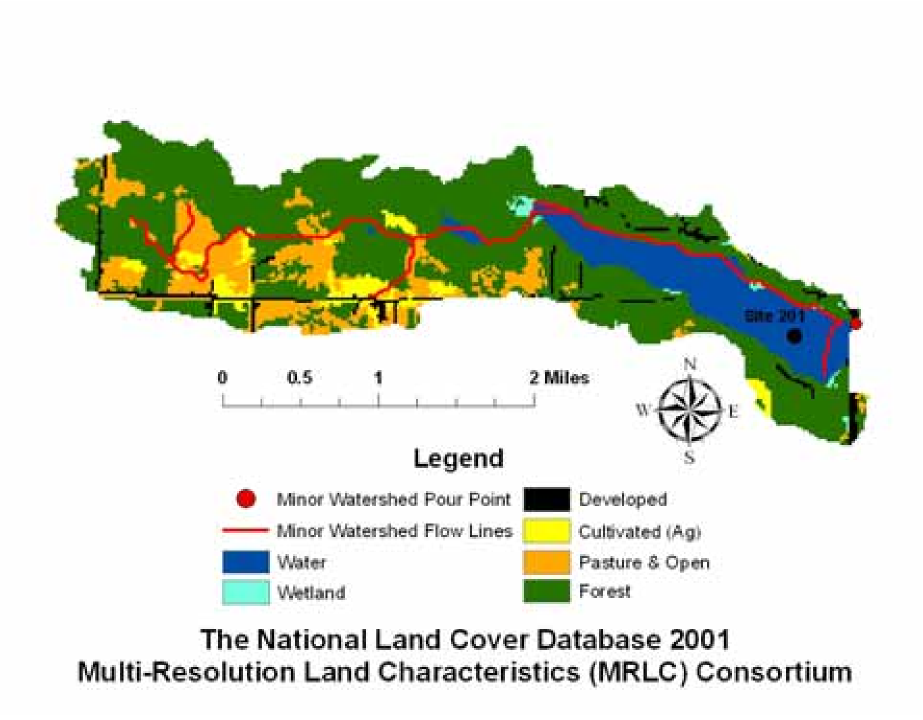


Table 2. Portage Lake ecoregion land use comparison. Typical (interquartile) range based on NLF and NCHF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	Portage (2001)[1]	NLF ecoregion	NCHF ecoregion	Portage (1969)[2]	Portage (1991)[3]
Developed	4	0 - 7	2-9	1	Data NA
Cultivated (Ag)	5	< 1	22-50	19	17
Pasture & Open	19	0 - 6	11-25	4	5
Forest	56	54 - 81	6-25	59	63
Water & Wetland	16	14 - 31	14-30	17	15

[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 3. Portage Lake watershed and land use composition

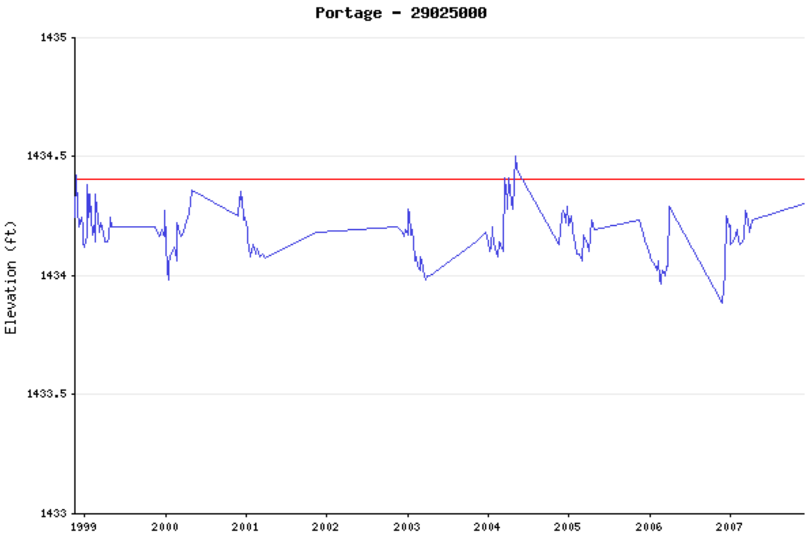


Lake Level and Ice On/Off

The MDNR Division of Waters has been measuring water levels on Portage Lake since 1958. During the period of record (1958 – 2008), the lake has varied by 2 feet, based on 240 readings, although only 6 readings were recorded between 1958 and 1996. Interestingly, both the lowest (1433.1) and the highest (1435.1 feet) occurred in these respective years. The ordinary high water (OHW) mark for Portage Lake is 1434.4 feet (Figure 4). Based on the recent record, the lake has remained below the OHW with the exception of brief excursions in 1999 and 2004. Portage Lake drains through a box culvert underneath Hwy 71 on the eastern shore. Additionally, a stop log dam is in place to the east of Hwy 71. Water level for Portage 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.

Ice-on records for Portage Lake, dating back to 1975, indicate that ice has typically formed by mid-November. October 31, 1993 is the earliest recorded ice-on date and November 29, 2001 is the latest ice-on date. The ice is historically off of Portage Lake by the third week in April. May 5, 1979 is the latest ice-off date while April 5, 2000 is the earliest ice-off date on record (Appendix C). Despite statewide and global trends of earlier ice-off dates (Johnson and Stefan 2006; Magnuson et al. 2000), based on this data record there is no distinct temporal trend in ice-on or ice-off dates for Portage Lake.

Figure 4. Portage Lake water level report



Precipitation and Climate Summary

Rain gage records from Park Rapids show two one-inch plus rain events during summer 2008 (Figure 5). Large rain events will increase runoff into the lake and may influence in-lake water quality and lake levels. This will be considered in the discussion of lake water quality for 2008. Precipitation records for the 2008 water year (October 2007 through September 2008) showed normal rain fall conditions for the Park Rapids area (Figure 6). Based on historical precipitation data (Figure 7), the Park Rapids area is showing a slight decline in summer precipitation since 1986.

Figure 5. Summer 2008 rainfall based on records for Park Rapids, MN

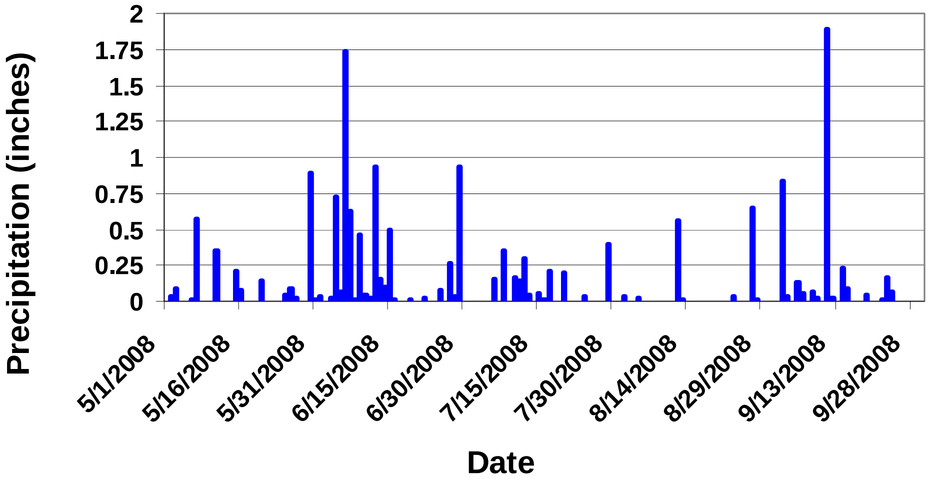


Figure 6. 2008 Minnesota Water Year Precipitation and Departure from Normal
Prepared by State Climatology Office MDNR Waters
Values are in inches

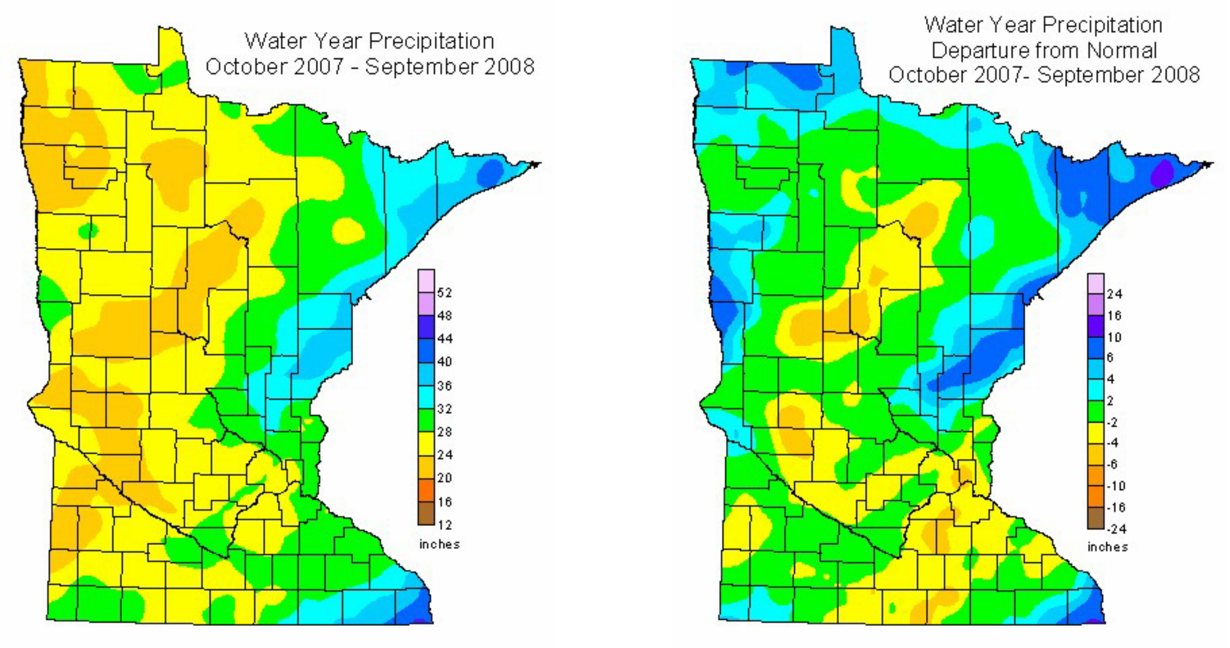
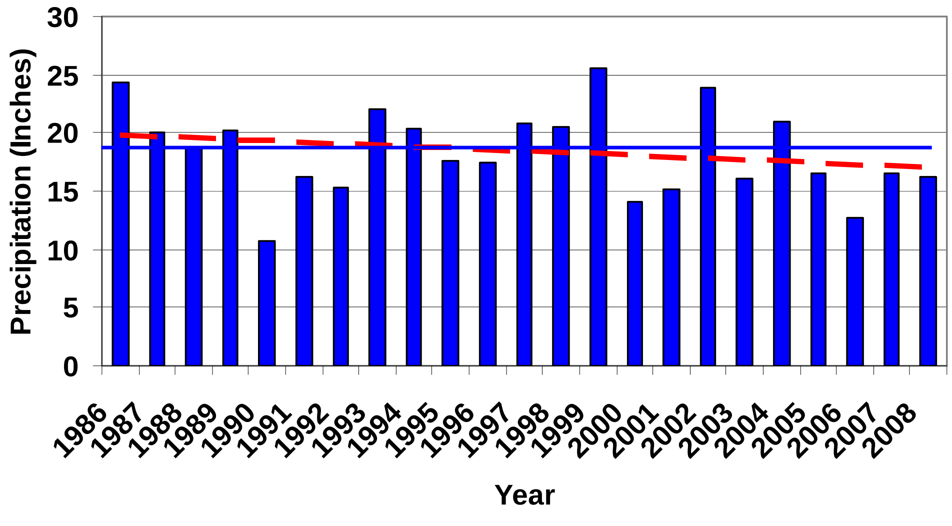


Figure 7. Historical summer precipitation trends based on records for Park Rapids, MN. Mean for period of record indicated by solid blue line and simple linear regression by red dashed line.



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 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 MDNR Special Publication 147 (1993; Manual of Instructions for Lake Survey). Fish community integrity surveys were also completed on each Sentinel lake following methods described by Drake and Pereira (2002).

Water Quality

Water quality data for Portage Lake were collected monthly from May through October 2008 by MPCA staff. Bi-weekly dissolved oxygen (DO) and temperature profiles and Secchi disk measurements were collected by a volunteer, Marilyn Peterson. Lake surface samples were collected by MPCA staff with an integrated sampler, a poly vinyl chloride (PVC) tube 2 meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (1.24 inches). Zooplankton samples were collected with an 80 µm mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth total phosphorous (TP) samples were collected with a Kemmerer sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples were collected at site 201 (Figure 3).

Sampling procedures were employed as described in the MPCA 2009 Lake Monitoring Standard Operating Procedures (SOP). Laboratory analysis was performed by the laboratory of the Minnesota Department of Health using EPA-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. Further SOP details can be obtained from the MPCA website at: http://www.pca.state.mn.us/water/lake.html.

Zooplankton

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

Each zooplankton sample was adjusted to a known volume by filtering through 80 micrometer (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 (ml) aliquot. A 5 ml 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 (mm) using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (mm), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick 1994 in Hirsch 2009).

Results and Discussion

Fisheries Assessment

MDNR fisheries managers utilize netting survey information to assess the status of fish communities and measure the efficacy of management programs. Presence, absence, abundance, physical condition of captured fishes, and community relationships among fish species within survey catch information also provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). These data are stored in a long-term fisheries survey database, which has proven valuable in qualifying and quantifying changes in environmental and fisheries characteristics over time.

Portage Lake was reportedly a wild rice marsh before construction of a dam in 1937 raised water levels. Increased lake size and depth as a result of the dam presumably improved survival of many fish species and facilitated a fishery. High nutrient loads in the lake have negated many of the benefits the dam has provided for fish habitat. The lake was opened to liberalized fishing in 1948 and 1965 due to low oxygen levels, but there is no record of a fish kill in those years. The lake was also opened to liberalized fishing in 1986. Partial winterkills were documented on Portage Lake in 1985-86, 1988-89, and 1995-96. Those winterkills affected fish abundance and size structure and appeared to be detrimental to largemouth bass (*Micropterus salmoides)* and bluegill (*Lepomis macrochirus)* populations.

Portage Lake's fish community is more diverse than other eutrophic lakes (Table 3), but average when compared to mesotrophic lakes (the trophic state of typical northern Minnesota lakes). Drake and Pereira (2002) developed a fish-based index of biotic integrity (IBI) for small Minnesota lakes. Indices of biotic integrity have been used for decades across North America to assess status of aquatic communities and to classify biotic impairments (Angermeier and Karr 1994). Although formal criteria have yet to be developed for classifying biotic impairments in Minnesota lakes, IBI surveys from over 250 lakes across the state provide a good assessment of the range of conditions we might expect in lakes of differing productivity.

Table 3. Historical fisheries assessments results

Common name	Species name	Trophic guild	Environmental tolerance[a]	First Documented
Central mudminnow	*Umbra limi*	Insectivore	Neutral	2008
Northern pike	*Esox lucius*	Predator	Neutral	1959
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Neutral	1959
Blacknose shiner	*Notropis heterolepis*	Insectivore	Intolerant	2008
Mimic shiner	*Notropis volucellus*	Insectivore	Intolerant	2008
Bluntnose minnow	*Pimephales notatus*	Omnivore	Neutral	1959
White sucker	*Catostomus commersonii*	Omnivore	Tolerant	1959
Black bullhead	*Ameiurus melas*	Omnivore	Tolerant	1987
Yellow bullhead	*Ameiurus natalis*	Omnivore	Neutral	1959
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Neutral	1959
Banded killifish	*Fundulus diaphanous*	Insectivore	Intolerant	2008
Rock bass	*Ambloplites rupestris*	Predator	Intolerant	1959
Hybrid sunfish	*Lepomis sp.*	Insectivore	Neutral	1959
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Neutral	1959
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Neutral	1959
Largemouth bass	*Micropterus salmoides*	Predator	Neutral	1959
Black crappie	*Pomoxis nigromaculatus*	Predator	Neutral	1959
Iowa darter	*Etheostoma exile*	Insectivore	Intolerant	2008
Yellow perch	*Perca flavescens*	Insectivore	Neutral	1959
Walleye	*Sander vitreus*	Predator	Neutral	1959

IBI surveys conducted in Portage Lake in 2008 were close to the 90th percentile when compared with other lakes of similar productivity (score = 84). MDNR crews sampled four species intolerant to high nutrient conditions and aquatic plant removal. A high IBI score usually indicates, among other important aspects, a community high in intolerant species and low in tolerant ones. Specifically in Portage Lake, crews sampled blacknose shiners (*Notropis heterolepis*), banded killifish (*Fundulus diaphanous*), mimic shiner (*Notropis volucellus*) and Iowa darter (*Etheostoma exile*). 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. in revision). In addition to nutrient reductions, protection of muskgrass beds will be important for protecting these species and fish community integrity in general.

From 1912 to 1945 walleye, largemouth bass, northern pike (*Esox lucius)*, bluegill and pumpkinseed sunfish (*Lepomis gibbosus*), and black crappies (*Pomoxis nigromaculatus*) were all stocked in Portage Lake. Northern pike stocking continued until 1975, but was probably not necessary as natural reproduction has maintained adequate abundance. Shortly after walleye stockings were switched from fry to fingerlings in 1977, walleye abundance increased substantially. Walleye fry stockings were tried again from 2005 to present, but have not proved very successful. Fingerling stocking has now been supplemented instead of fry stocking.

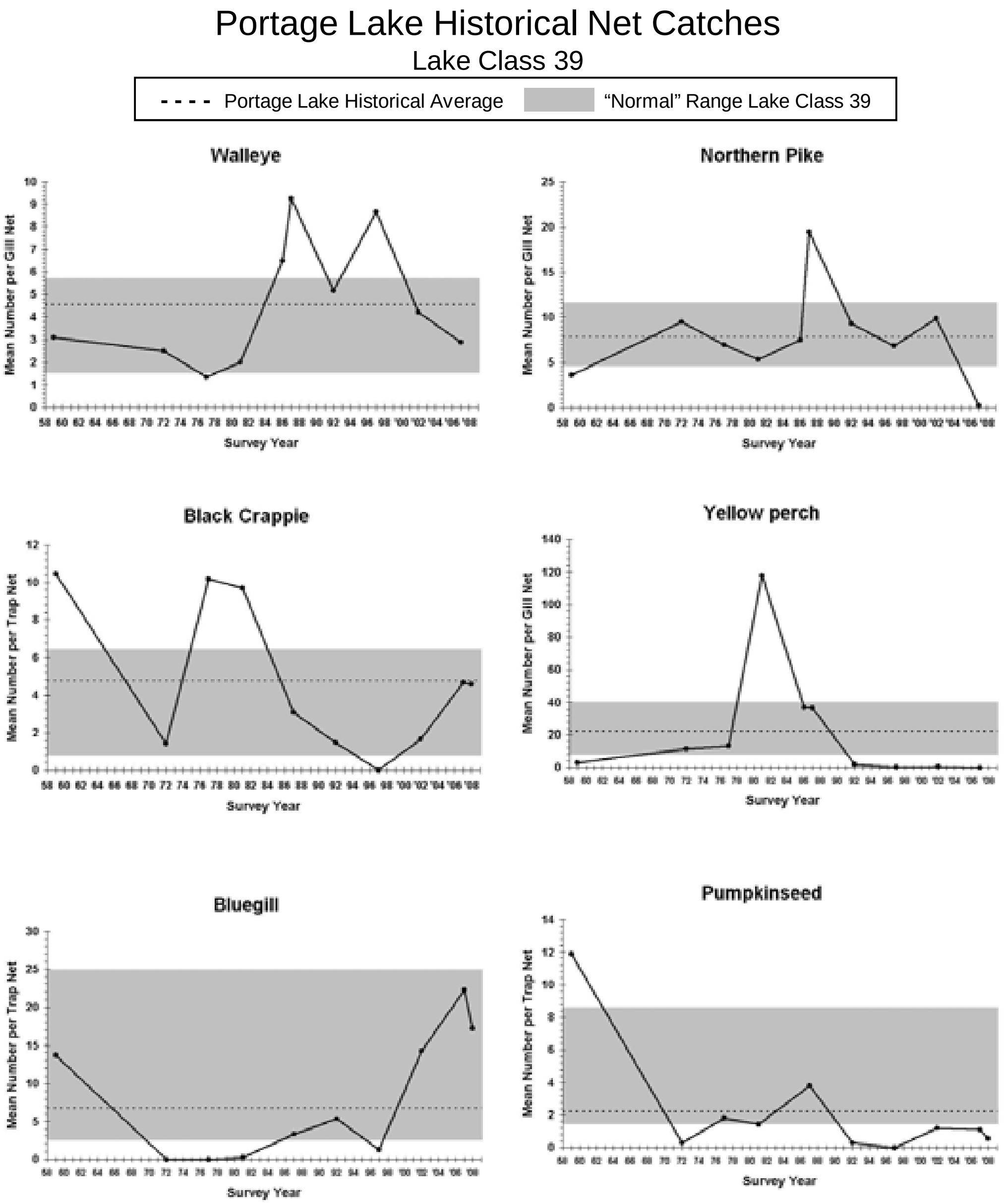
Increased fishing pressure and harvest in recent decades may be affecting abundance, size, and age structure of northern pike or other game fish populations. Anglers interested in the fishery of Portage Lake have specifically commented on the decline in abundance and size structure of crappies and bluegills. A liberalized bag limit of six northern pike was implemented for Portage Lake in 1988. The purpose of the regulation change was to reduce the abundance of small northern pike and increase growth rates of the remaining fish. No improvements in size structure or growth were observed, and the regulation was rescinded in 1994. The consensus was that anglers were not willing to harvest additional small northern pike.

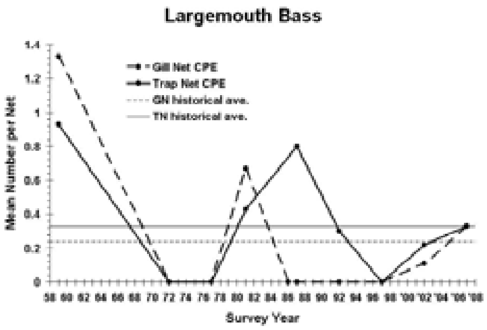
Two fisheries lake surveys and seven fish population assessments were conducted on Portage Lake between 1959 and 2007 (Figure 8). Gill nets and trap nets were used during all fisheries sampling, but gill net efforts were lower than desirable from the 1972 through 1997 sampling events, and trap net efforts were lower than desirable from the 1972 through 1981 sampling events. All samples were collected in early August.

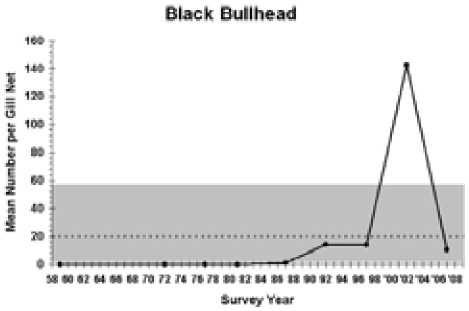
Average gill net catch rates of walleye in Portage Lake were near the low end of the interquartile or “normal” range for Lake Class 39 and below the long term average for Portage Lake from the 1959 through 1981 sampling events. Abundance increased and fluctuated near or above the high end of the interquartile range and above the Portage Lake long-term average from 1986 through 1997, then declined to within the normal range and below the long term average again in 2002 and 2007 samples. In the 1972 through 1981 sampling events, too few walleye were collected to estimate size structure indices. In other years, walleye population size structure indices have fluctuated widely. In 1959 and 1997, walleye sizes were quite good. In 1987, walleye sizes were small, possibly as a result of a partial winterkill in 1985-86. Walleye sizes in the 2007 assessment were the smallest ever observed for Portage Lake. In general, it appears that walleye fingerling stockings have contributed somewhat to the walleye population for Portage Lake. Mean gill net catch rates of year classes of walleye from years stocked with fingerlings appear to be somewhat higher (about 25%) than non-stocked years at the same age; however, sample sizes are small so conclusions about the effectiveness of stocking must be viewed cautiously. Evaluations of 2005-08 walleye fry stockings by fall electro fishing suggest that the fry stockings and/or natural reproduction have not been very successful.

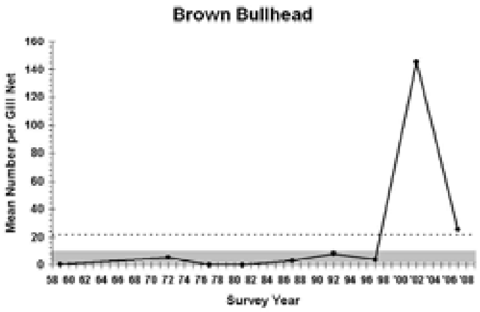
Average gill net catch rates of yellow perch for Portage Lake were below or near the low end of the interquartile range for similar lakes (Table 4) and below the long term average for Portage Lake from 1959 through 1977. Catches increased above the high end of the normal range and above the long-term average in 1981, then decreased to below the normal range and long-term average in 1992, and have remained extremely low since then. Sizes of perch have historically been small at Portage Lake. Low numbers and small size of yellow perch limit their value as a fishery for anglers; however, they are an important source of food for the lake’s predator fish species, particularly walleye and northern pike. It is important to maintain an adequate yellow perch population to provide forage for the lake’s predators

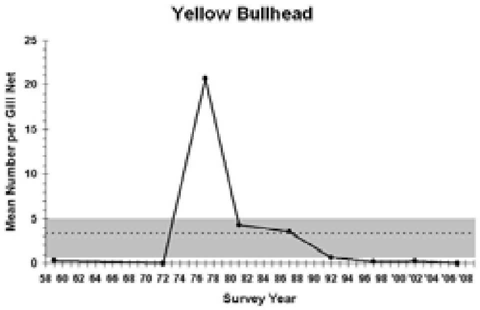
Figure 8. Historical net catches by species for Portage Lake and historical interquartile ranges for lake class 39

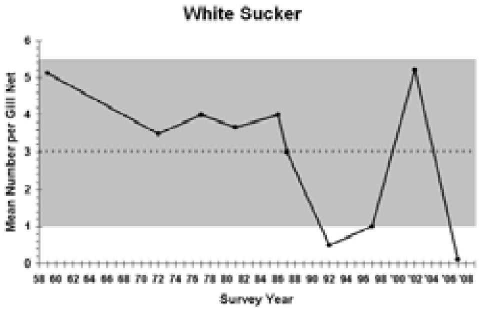



Largemouth Bass


Black Bullhead


Brown Bullhead


Yellow Bullhead


White Sucker

Average gill net catch rates of northern pike for Portage Lake were relatively stable. These rates were generally fluctuating within the range typically found in similar lakes (Table 4) and around the long-term average for Portage Lake in the 1959 through 2002 assessments. Northern pike catches declined drastically in the 2007 assessment to well below the normal range and the long-term average. Size structure indices of northern pike were fair in 1959, good in 1981, but declined through 1997 and have generally been low since then.

Average trap net catch rates of black crappie for Portage Lake have fluctuated above, below and within the interquartile range for similar lakes (Table 4) and around the long-term average for Portage Lake, with no apparent trend of either increasing or decreasing over time. Too few black crappies were collected in most samples to accurately estimate population size structure indices. When they could be estimated, black crappie size indices generally increased from 1959 through 1992 then declined through 2008.

Largemouth bass have been collected with both gill nets and trap nets during the course of population assessments and lake surveys; however, these types of nets are not reliable for sampling bass. Catch rates with both types of nets have fluctuated widely. Catch rates using both nets were high in 1959, declined to zero in 1972 and 1977 samples, appeared to increase during the 1980s, declined to zero again in 1997, then increased somewhat in 2002 and 2007. Too few largemouth bass were collected in most samples to accurately estimate population size structure indices. Electro fishing was conducted for the first time in 2008 and catch rates of largemouth bass were somewhat low compared to other lakes within the Park Rapids area.

Bluegill trap net catch rates for Portage Lake were near the middle of the interquartile range for similar lakes (Table 4) and above the long-term average for Portage Lake in 1959, declined to near the low end or below the normal range and below the long-term average from 1972 through 1997, then increased to near the middle of the normal range and above the long-term average again in 2002 through 2008. Too few bluegill were collected in half the lake’s samples to accurately estimate population size structure indices. When they could be estimated, proportions of quality size (6 inch or larger) bluegill were lower than desirable in 1959, but have fluctuated around the top end of the desirable range since then. Proportions of preferred size (8 inches or larger) bluegill have been more stable, but generally low. No memorable sized (10 inches or larger) bluegill have ever been sampled in Portage Lake.

Average trap net catch rates of pumpkinseed for Portage Lake were above the interquartile range for similar lakes and the long-term average for Portage Lake in 1959, then declined and have fluctuated around the low end of the normal range and generally below the long-term average since 1972.

The various bullhead species have been a concern with lake residents and those interested in the lake. Gill and trap net catch rates of yellow bullhead (*Ameiurus natalis*) were quite high in 1977, but otherwise have been within or below the normal range for similar lakes (Table 4). On the other hand, catch rates of brown bullhead and black bullhead were quite low through the late 1980s, and then began to increase. In 2002, gill net catch rates of those two species were quite high, but declined again in 2007 and 2008 samples. Bullheads are tolerant of low DO and winterkill conditions. Partial winterkills often result in increased abundance of those species. Increased abundance of black bullheads, in particular, can be indicative of eutrophic or poorer water quality conditions.

Table 4. Recent survey focal species catch rates compared to similar lake classes

Species	Stocked	Abundance	Size	Trend
Walleye*	Y	Average	Small	Fluctuating
Yellow perch	N	Very low	Small	Stable/very low
Northern pike	N	Average	Small	Declining
Black crappie	N	Average	Average	Fluctuating
Largemouth bass	N	Average	Small	Fluctuating
Bluegill	N	Average	Small	Increasing
Pumpkinseed	N	Low	Small	Stable/low
Bullheads	N	Low	Average	Fluctuating

Aquatic Plant Assessment

Aquatic plants have been assessed periodically at Portage Lake over the last 20 years, with many surveys occurring during the last five years. Qualitative vegetation surveys were conducted during the 1987 and 1992 Fisheries Population Assessments, and the 2002 Fisheries Re-survey (Table 5). MDNR Ecological Resources conducted quantitative, point-intercept surveys of aquatic vegetation in August 2004 to assess the native aquatic plant community, and in May 2005 and May 2006 to assess the non-native, curly-leaf pondweed population (Table 6). The Minnesota County Biological Survey compiled a list of aquatic plant species observed at Portage Lake on June 20, 2006 (Table 7). Finally, quantitative, point-intercept and hydro acoustic surveys of vegetation biovolume (percent of water column occupied by vegetation) were also conducted in June and August 2008 to assess the aquatic plant community as part of the SLICE long-term monitoring project.

Submerged aquatic plants occur throughout Portage Lake to a depth of 3 meters (10 feet), but are most dense in water depths less than 1.8 meters (6 feet). During the 2004-06 vegetation surveys, the native plant community was dominated by coontail (*Ceratophyllum demersum*), a species tolerant of low light and high turbidity. Coontail was still abundant during the 2008 aquatic vegetation surveys, but abundance of muskgrass and northern watermilfoil (*Myriophyllum sibiricum*) had increased substantially. Conversely, Canada waterweed (*Elodea canadensis*) was relatively common during the 2004-06 surveys, but abundance decreased substantially during the 2008 survey. Ten other native submerged plant species were found during the surveys, but were generally restricted to water depths less than 3 meters. Across the whole lake in August 2008, plant beds occupied less than 15% of the water column; however, maps indicate that this 15% was patchy and strongly influenced by depth with the densest beds growing near the surface close to shore (Figure 9). Biovolume (percent of water column occupied by vegetation) was assessed with hydro acoustics and mapped using Kriging interpolation (see Valley et al. 2005) during August 2008. Growth was sparse past 1.8 meters, presumably due to low light penetration past this depth. In most hard water, mesotrophic lakes in northern Minnesota, aquatic plants typically cover bottom areas of at least 4.6 meters (15 feet).

Table 5. Common species sampled during past lake vegetation surveys

Date	Common Name	Species Name	Growth Form
8/19/1987	Wild rice	*Zizania aquatica*	Emergent
	Three-way sedge	*Dulichium arundinceum*	Emergent
	Muskgrass	*Chara sp.*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
	Sago pondweed	*Potamogeton pectinatus*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Illinois pondweed	*Potamogeton Illinoensis*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
8/17/1992	Wild rice	*Zizania aquatica*	Emergent
	Sedge	Carex sp.	Emergent
	Sago pondweed	*Potamogeton pectinatus*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Illinois pondweed	*Potamogeton Illinoensis*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
8/19/2002	Little yellow waterlily		Floating leaf
	Coontail	*Ceratophyllum demersum*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
	Illinois pondweed	*Potamogeton Illinoensis*	Submersed
	Sago pondweed	*Potamogeton pectinatus*	Submersed

Table 6. Frequency of common aquatic plants in 2004-2008 point intercept surveys

Frequency calculated for entire lake (shore to 16 feet depth).
Frequency = percent of 303 sample sites in which species occurred.

			Frequency				
Common Name	**Species Name**	**Growth Form**	**Aug 04**	**May 05**	**May 06**	**May 08**	**Jul 08**
Coontail	*Ceratophyllum demersum*	Submersed	40	24	17	30	39
Muskgrass	*Chara sp.*	Submersed	28	31	18	50	44
Curly-leaf pondweed[a]	*Potamogeton crispus*	Submersed	<1	7	13	20	2
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	2	1	2	34	23
Canada waterweed	*Elodea canadensis*	Submersed	15	10	9	<1	<1
Bushy pondweed	*Najas flexilis*	Submersed	8		6	1	10
Flatstem pondweed	*Potamogeton zosteriformis*	Submersed				5	10
Illinois pondweed	*Potamogeton Illinoensis*	Submersed	5			<1	8
Sago pondweed	*Potamogeton pectinatus*	Submersed	5	<1		<1	2
Water stargrass	*Zosterella dubia*	Submersed	2	1	1		

Water (wild) celery	*Vallisneria americana*	Submersed	2				5
Narrow leaf pondweed	*Potamogeton sp.*	Submersed	1		1	<1	
White water buttercup	*Ranunculus sp.*	Submersed	1	1	<1		<1
Bladderwort	*Utricularia sp.*	Submersed	<1		1	1	1
Whitestem pondweed	*Potamogeton praelongus*	Submersed	<1				
Star duckweed	*Lemna trisulca*	Free floating	2	5	6	19	12
Filamentous algae	*Not identified to genus*	Free floating				9	7
Water moss	*Not identified to genus*	Free floating	1		<1	7	6
Lesser duckweed	*Lemna minor*	Free floating	<1				1
Greater duckweed	*Spirodela polyrhiza*	Free floating	<1				<1
Watermeal	*Wolffia sp.*	Free floating	<1				
Yellow waterlily	*Nuphar sp.*	Floating leaf	5	3	3	4	14
Floating leaf pondweed	*Potamogeton natans*	Floating leaf	<1				1
Hybrid pink waterlily[a]	*Nymphaea sp.*	Floating leaf	p				<1
Water smartweed	*Polygonum amphibium*	Floating leaf	p				
Wild rice	*Zizania palustris*	Emergent	4			1	1
Hardstem bulrush	*Scirpus acutus*	Emergent	<1				<1
Cattail	*Typha sp.*	Emergent	p	p	p	<1	
Giant cane	*Phragmites australis*	Emergent	p	p	P		
Spikerush	*Eleocharis sp.*	Emergent	P				
Sedge	*Carex sp.*	Emergent	p			<1	
Marsh marigold	*Caltha palustris*	Emergent		p		<1	
Reed canary grass	*Phalaris arundinaceae*	Emergent	p	P			
Swamp milkweed	*Asclepias incarnate*	Emergent	P				
Joe-pye weed	*Eupatorium maculatum*	Emergent	P				
Water dock	*Rumex sp.*	Emergent	P				
Marsh skullcap	*Scutellaria galericulata*	Emergent	P				

[a] Invasive species

Table 7. Plant species observed at Portage Lake during 2006 MN County Biological Survey

Common Name	Species Name	Growth Form
Coontail	*Ceratophyllum demersum*	Submersed
Canadian waterweed	*Elodea canadensis*	Submersed
Water stargrass, Mud plantain	*Heteranthera dubia*	Submersed
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed
Bushy pondweed, Common naiad	*Najas flexilis*	Submersed
Curled pondweed[a]	*Potamogeton crispus*	Submersed
Fries' pondweed	*Potamogeton friesii*	Submersed
Illinois pondweed	*Potamogeton illinoensis*	Submersed
Straightleaved pondweed	*Potamogeton strictifolius*	Submersed
Common sago pondweed	*Stuckenia pectinata*	Submersed
Largesheath pondweed[b,c]	*Stuckenia vaginata*	Submersed
Greater bladderwort	*Utricularia vulgaris*	Submersed
Wild celery, Eel-grass	*Vallisneria americana*	Submersed
Turion-forming duckweed	*Lemna turionifera*	Free floating
Yellow water lily	*Nuphar variegata*	Floating leaf
Water smartweed	*Persicaria amphibia*	Floating leaf
Bald spikerush	*Eleocharis erythropoda*	Emergent
Arrowhead	*Sagittaria sp.*	Emergent
Soft stem bulrush	*Schoenoplectus tabernaemontani*	Emergent
Broad leaved cattail	*Typha latifolia*	Emergent
Bottlebrush sedge	*Carex comosa*	Emergent
Two stamened sedge	*Carex diandra*	Emergent
False cyperus sedge	*Carex pseudocyperus*	Emergent
Hummock sedge	*Carex stricta*	Emergent
Bulb bearing water hemlock	*Cicuta bulbifera*	Emergent
Jewelweed, Spotted touch-me-not	*Impatiens capensis*	Emergent
Blue flag	*Iris versicolor*	Emergent
Northern bugleweed	*Lycopus uniflorus*	Emergent
Tufted loosestrife	*Lysimachia thyrsiflora*	Emergent
Reed canary grass	*Phalaris arundinacea*	Emergent
Clearweed	*Pilea sp.*	Emergent
Dock; Sorrell	*Rumex sp.*	Emergent
Marsh skullcap	*Scutellaria galericulata*	Emergent

[a] Invasive species

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

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 1900's 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. For more information and resources on curly-leaf pondweed consult http://www.dnr.state.mn.us/aquatic_plants/submerged_plants/curlyleaf_pondweed.html.

Curly-leaf pondweed has been present in Portage Lake since at least the mid-1990s. In early summer 2002, it formed dense surface mats and in 2003 the lake association began efforts to control the plant through herbicide applications (see History for plant removal by lakeshore owners above). Curly-leaf pondweed occurred in seven percent of the aquatic vegetation survey sites in May 2005, in 13 percent of sites in May 2006, and in 20 percent of sites in May 2008. Those surveys suggest that abundance of curly-leaf pondweed was relatively low, but may have increased during this time period. In 2008, curly-leaf pondweed abundance was assessed with hydro acoustic technology during peak biomass in June. During 2008 surveys, most curly-leaf pondweed grew at depths of 1.8-3.7 meters (6-12 feet) with the largest, densest bed being found between 1.8-2.4 meters (6-8 feet) in the south east portion of the lake (Figure 10). Curly-leaf pondweed was much sparser throughout the rest of the lake and not common in shallow depths. After the curly-leaf senesced in mid-summer, plant biomass mostly disappeared from depths greater than 1.8 meters; although sparse plant fragments were common up to 3 meters (Figure 9).

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. Likely counterbalancing harmful water quality effects of curly-leaf pondweed is muskgrass, a benthic plant that is highly desirable from a fish habitat and water quality standpoint. Interestingly, areal cover (estimated from percent frequency) of muskgrass during past surveys was significantly higher in 2008 compared with 2004 (Figure 11). In 2004, muskgrass covered approximately 10% of Portage Lake. In 2008, cover of muskgrass increased to 26% of the lake's surface area. 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). Counterbalancing the positive reinforcing effects of muskgrass is the reinforcing negative effects of curly-leaf pondweed since curly-leaf pondweed promotes turbid water through its mid-summer senescence and nutrient-rich turbid water promotes more curly-leaf pondweed growth. The threshold of nutrient enrichment that favors one regime over another is currently unclear and is in need of further investigation. Given the high nutrient loads in Portage Lake and increasing cover of curly-leaf pondweed, Portage Lake exists in a precarious state and is at risk of losing muskgrass habitats and sliding further towards a resilient turbid water regime with continued excessive levels of nutrient loading.

Figure 9. Portage Lake biovolume from August 2008 survey

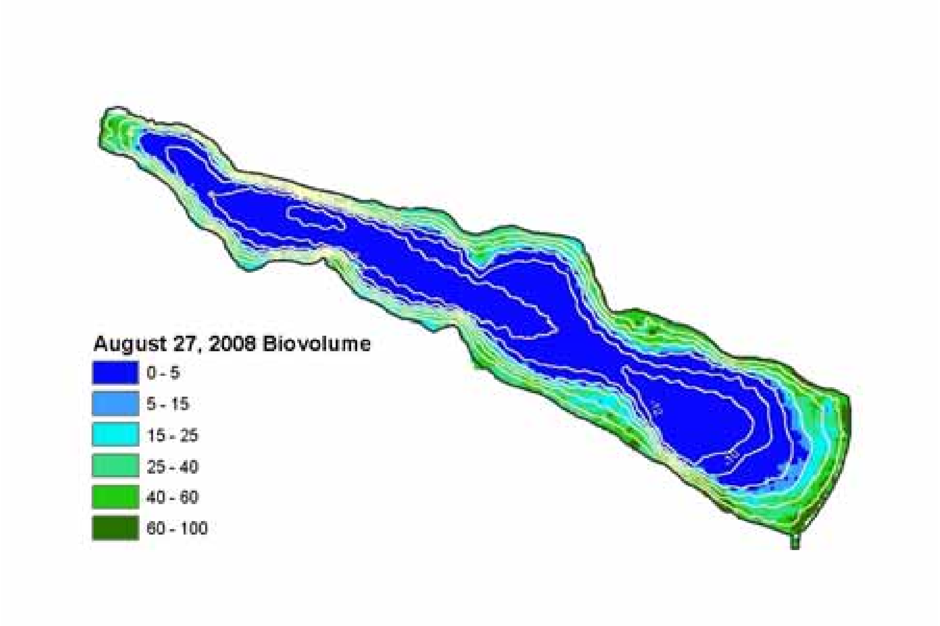


Figure 10. Curly-leaf pondweed bed locations in Portage Lake

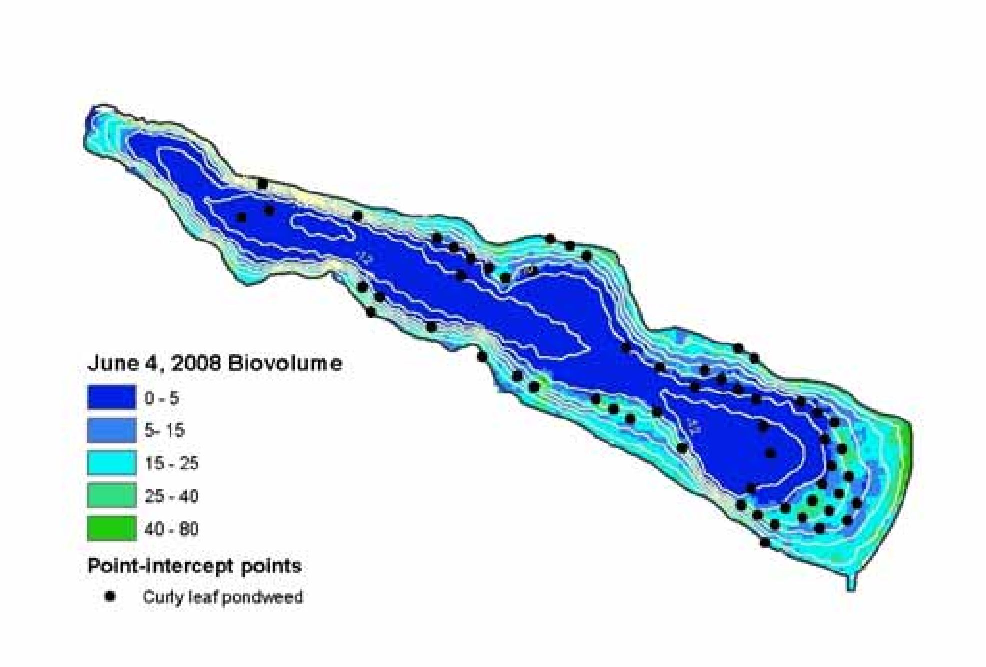
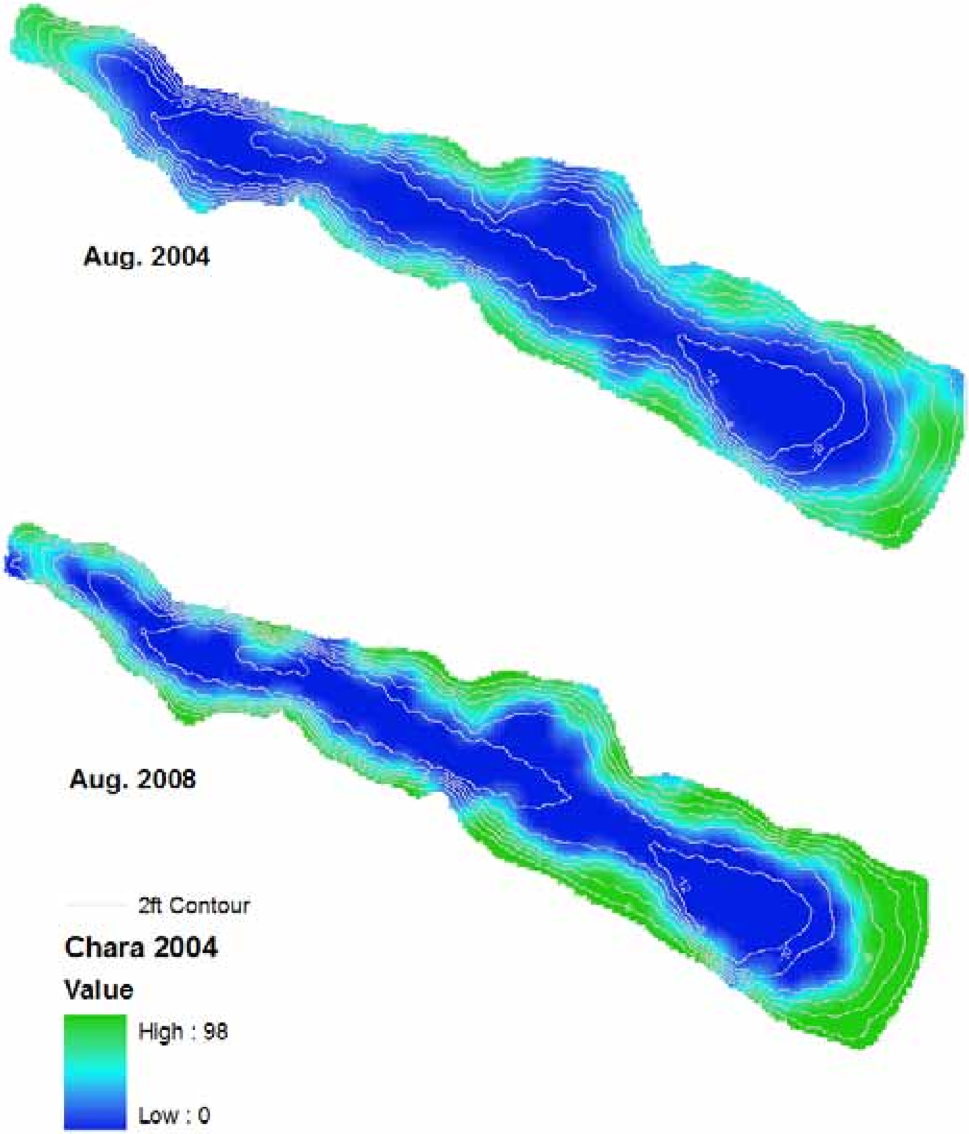


Figure 11. Probability of occurrence of muskgrass based on 2004 and 2008 survey points using indicator kriging (van Horssen et al. 1999).



Another non-native plant, hybrid pink waterlily (*Nymphaea sp.*) has been documented in Portage Lake (Table 6). This plant was likely purchased as a water garden plant and illegally placed into the lake. It has since spread to numerous areas around the lakeshore. Although it has an attractive flower, this exotic plant should not be planted in or near Minnesota lakes because it has the potential to crowd out native plant species.

Approximately 70 docks were enumerated from aerial photos acquired from the Farm Service Administration in summer 2008. By rule, lakeshore owners are allowed to remove a 2500 square foot area of submersed aquatic plants without a permit. If we assumed that all who owned a dock also removed 2500 square feet of aquatic plants, then the lakeshore owners have the option to remove up to 4 acres of aquatic plants without a permit. The actual amount of plant removal is probably less.

In addition to allowing un-permitted removal since 2003, approximately 20-55 acres of curly-leaf pondweed and native vegetation has been treated with herbicides (5 – 13% of the lake area less than 4.6 meters deep). Anecdotally, it appears aquatic plant removal and herbicide treatments have had a relatively benign effect on habitat conditions up to this point. Evidence of consistently poor water clarity in years before and after the treatments and lack of growth of native species in areas of the lake dominated by curly-leaf pondweed suggest few positive ecological effects of the treatments so far. Yet, the lack of evidence of declining water clarity in years after treatments and a lack of evidence of harm towards native plant species suggest few negative ecological effects of treatments. Presumably, treatments have produced mostly temporary recreational benefits by reducing surface mats of curly-leaf pondweed during peak growth in June.

Fisheries personnel worked with the Portage Lake Association to prepare a LVMP in 2007 that describes how aquatic vegetation management proposals will be reviewed and permitted. Specific goals of the LVMP are: Reduce interference with recreational use of Portage Lake by reducing density and coverage of curly-leaf pondweed; attempt to reduce peaks in concentrations of phosphorus and associated algal blooms; attempt to maintain abundance of native submersed aquatic plants in order to reduce risk of curly-leaf pondweed spreading or infesting areas where native vegetation has been removed or disturbed; protect high quality communities of native aquatic plants. Operational plans call for annual curly-leaf pondweed treatment early in the season when there is active growth but before turions form and before most native plants are actively growing. High quality, native aquatic plants will be identified and protected. Any new permits for treatment of native vegetation on individual properties will be limited to only that necessary to allow reasonable use. That plan should be periodically reviewed and revised.

Water Quality

Standard summer-mean water quality data for 2008 are presented in Table 8, and raw data results are provided in Appendix B. In addition, major cations, anions, and total organic carbon were analyzed on three sample dates and those values and typical interquartile ranges as derived from the National Lakes Assessment (NLA) program database for Minnesota are summarized in Table 9. NLA was a statistically based survey of the nations lakes administered by the EPA. Typical range is based on 64 Minnesota lakes sampled in the 2007 NLA study and is included to provide additional perspective.

Table 8. Portage Lake 2008 summer mean water quality. Typical range based on NLF and NCHF reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	Portage Site 201	NLF	NCHF
Total Phosphorus (µg/L)	60	14 - 27	23 - 50
Chlorophyll-*a* mean (µg/L)	21	4 - 10	5 - 22
Chlorophyll-*a* max (µg/L)	38	<15	7 - 37
Secchi Disk (feet) (meters)	3.0 0.9	8 – 15 2.4 – 4.6	4.9 – 10.5 1.5 – 3.2
Total Kjeldahl Nitrogen (mg/L)	1.1	<0.4 – 0.75	<0.60 – 1.2
Alkalinity (mg/L)	155	40 - 140	75 - 150
Color (Pt-Co Units)	5	10 - 35	10 - 20
pH (SU)	8.5	7.2 – 8.3	8.6 – 8.8
Chloride (mg/L)	6.8	0.6 – 1.2	4 - 10
Total Suspended Solids (mg/L)	11	<1 - 2	2- 6
Total Suspended Inorganic Solids (mg/L)	4	<1 - 2	1 - 2
Conductivity (umhos/cm)	274	50 - 250	300 - 400
TN:TP ratio	18:1	25:1 - 35:1	25:1-35:1

Table 9. Portage Lake cation, anion, and total organic carbon measurements. NLA typical range provided as a basis for comparison.

	mg/L						
Date	**Ca**	**Mg**	**K**	**Na**	**SO4**	**Cl**	**TOC**
5/20/2008	96	71	1.2	4	5.2		4.9
7/15/2008	73	79	1	4.1	4.1		4.8
10/8/2008	71	78	1.1	3.8	4.3		5.6
Average	80	76	1.1	4	4.5	6.8	5.1
NLA	19.1-33.7	6.7-26.9	0.9-4.8	2.2-9.0	2.2-14.1	1.5-18.4	7.3-14.2
IQ range (mg/L)							
	ueq/L						
5/20/2008	4790	5843	31	174	107		
7/15/2008	3643	6502	26	178	85		
10/8/2008	3543	6419	28	165	90		
Average	3992	6255	28	173	94	762	
	Ca	**Mg**	**K**	**Na**	**SO4**	**Cl**	**TOC**

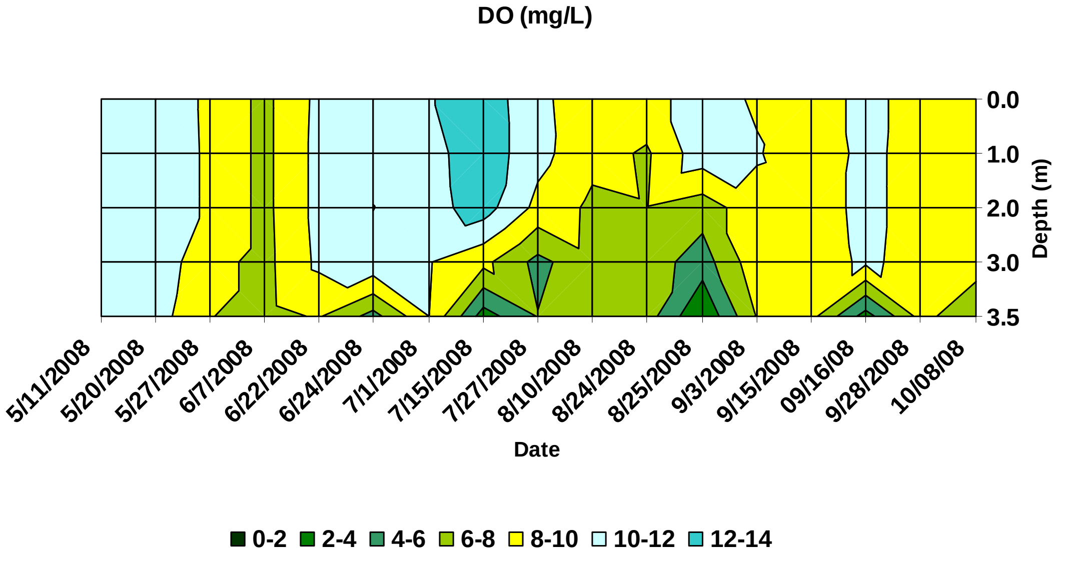
Dissolved Oxygen and Temperature profiles were taken bi-weekly at site 201 (Figure 3). The lake was well-mixed in the spring and fall and a weak thermocline was evident in June, July, and August. Surface temperatures peaked at 24C in July and bottom water temperatures remained consistent at 20C for June, July and August (Figure 12). DO levels remained at or above 5 mg/L (milligrams per liter) at the surface in all months; however low DO is evident when a thermocline was present in June, July and August (Figure 12). This time period is marked by increased algal productivity as well. Excessive algal growth contributes to supersaturation of DO in the surface waters (e.g. June and July); however algal decomposition and respiration contribute to low DO in the bottom waters. The 2008 data does not show any distinct midsummer mixing events. Portage Lake is likely subject to intermittent mixing with strong winds and/or the passage of cold fronts.

Total Phosphorus concentrations at site 201 averaged 60 micrograms per liter (µg/L) (Figure 13). These averages were well above the typical range of concentrations for NLF reference lakes as well as the typical NCHF range (Table 8). TP concentrations increased over the summer and peaked in October at 97 µg/L. Depth TP concentrations closely mirrored the surface values (Figure 13). This may have been the result of relatively high DO near the sediments (Figure 12), which would have minimized the amount of oxygen (redox)-related TP being released from the sediments. Also, the relatively weak thermocline would have allowed mixing to occur between the upper and lower waters.

Both external (watershed) and internal (sediments, plants, and fish) sources can contribute to elevated TP in lakes. The pattern of increasing TP from June through August in Portage Lake is consistent with other shallow lakes in Minnesota. While there was some significant precipitation in late May and early June, most of July and August was quite dry (Figure 5). Runoff from precipitation is often a significant source of nutrient input to a lake. Since the pastured and agricultural lands to the west of the lake are located along drainage networks (tributaries) that flow to the lake (Figure 2), it is quite likely event-based (storm runoff) may have elevated TP; however, this may not explain the mid- to late-summer increase in TP. This increase is often due to internal recycling of nutrients from the bottom sediments. This coincides with increasing water temperatures (typically 20 degrees Celsius and above) and/or aquatic vegetation senescence.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During summer 2008, chl-*a* concentrations at site 201 ranged from 5 µg/L to 38 µg/L, with an average of 21 µg/L (Figure 13). Concentrations greater than 20 µg/L will typically be perceived as a nuisance (Heiskary and Walker, 1988). As such, algae blooms were present during each sampling event with swimming being impaired from July through September. With the exception of May, chl-*a* concentrations for Portage Lake were all above the range of average values expected for NLF lakes and near the higher end of the typical range for NCHF lakes (Table 8).

Figure 12. Portage Lake 2008 dissolved oxygen and temperature profiles



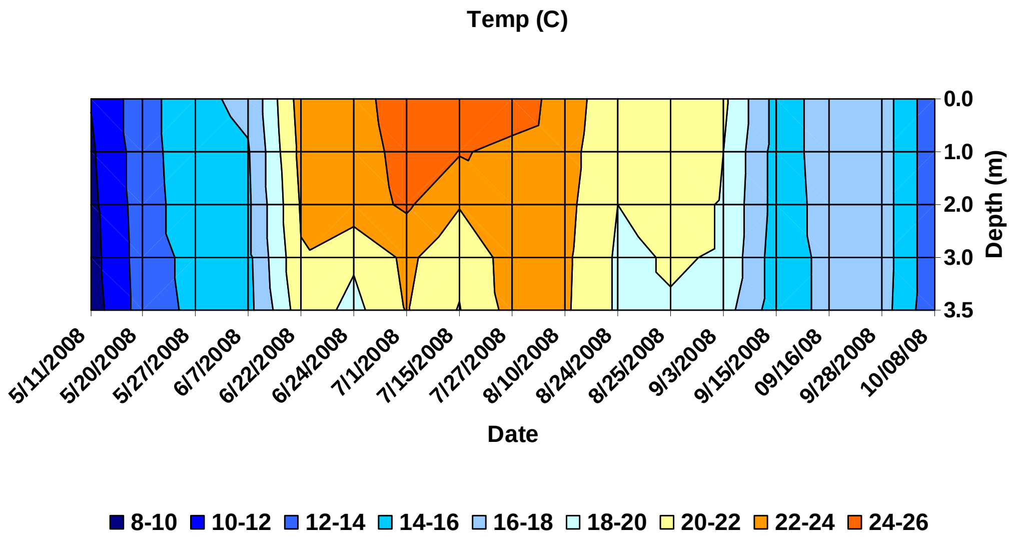
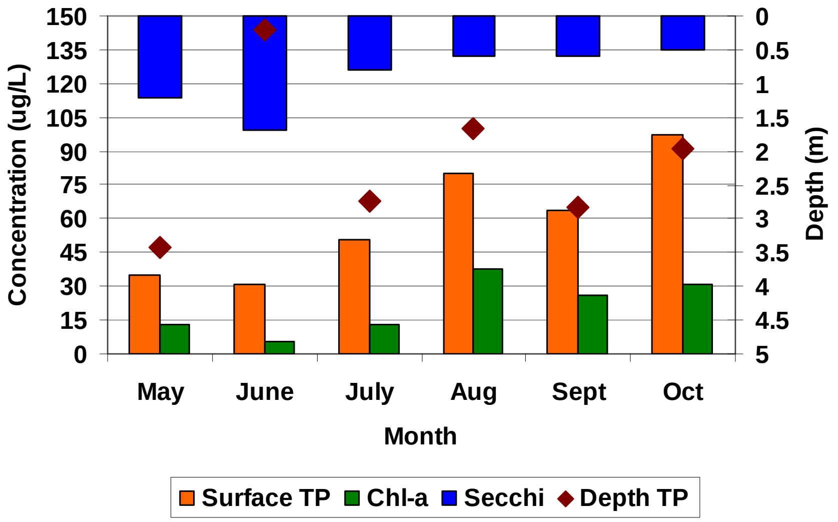


Figure 13. Portage Lake 2008 TP (surface & depth), chl-*a* concentrations, & Secchi depth



Secchi disk transparency on Portage Lake averaged 0.9 meters (3 feet) at site 201 during the summer of 2008 (Table 8). The average Secchi depth is significantly below the typical range of values for both the NLF and NCHF ecoregions. The change in the transparency of Portage Lake during each sampling event closely mirrored the changes in nutrient availability (TP) and algal production (chl-*a*). The Secchi disk transparency reached a low of 0.5 meters (1.6 feet) in October. Based on 2008 Secchi values, transparency remained below one meter for a majority of the summer.

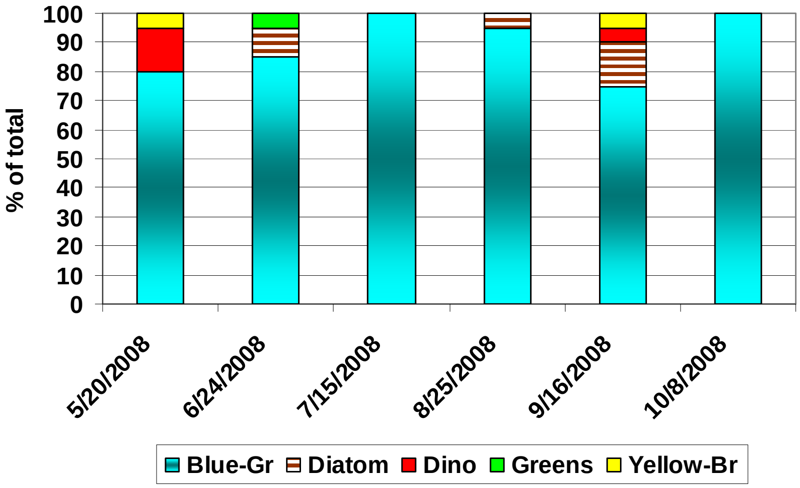
Additional water quality parameters were measured in 2008, as part of the long-term monitoring of Portage and other Sentinel lakes. This includes some of the standard MPCA lake monitoring measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 8), as well as major cations, anions, and total organic carbon (Table 9). While several of these parameters have "typical" ecoregion-based concentrations; some do not. For parameters without ecoregion–based comparisons, data from the 2007 NLA study were used to provide perspective on reported concentrations. Since the NLA lakes were selected randomly, they provide a reasonable basis for describing typical ranges and distributions at the statewide level.

TSS is rather high as compared to reference lakes for each ecoregion and most of the TSS can be attributed to organic suspended solids (TSS-TSIS) (i.e., suspended algae). Alkalinity and conductivity are in the typical range for NLF and NCHF lakes and are indicative of moderately hard water. The low color value indicates the water is clear and has minimal amount of dissolved organic carbon. As such, the total organic carbon (TOC) is rather low, as well. Much of the TOC in water is due to incompletely dissolved organic material. Lakes with high amounts of forest and wetlands in their watershed often have correspondingly higher color and TOC values. Calcium (Ca) and magnesium (Mg) are the dominant cations and concentrations of the two are quite similar; however, on a microequivalent basis, Mg is the dominant cation. Both parameters are above the typical range. The other two major cations – sodium (Na) and potassium (K) are well within the typical range. Bicarbonate is the dominant cation, followed by chloride (Cl) and sulfate (SO_4). Cl is above the typical range for NLF and NCHF reference lakes; however, it is well within the typical range based on NLA data. Elevated Cl is most often attributed to application of road salt on roads in the watershed. While Cl is high relative to the reference lakes, it is much lower than what we see in lakes of the more urbanized Twin Cities Metro area. SO_4 is rather low but well within the typical range based on NLA data.

Phytoplankton (algae) for Portage Lake is presented in terms of algal type (Figure 14). In May, the blue-green *Microcystis* were the dominant genera. The early dominance of blue-greens was not anticipated, as more commonly diatoms (cooler water forms) are often dominant in the spring and early summer. Blue-greens remained dominant throughout the summer with several genera being represented: June - *Microcystis* and *Merismopedia*; July – *Microcystis* and *Anabaena*; August – *Microcystis*, *Anabaena*, and *Oscillatoria*; September – *Anabaena, Microcystis,* and *Aphanizomenon*; October – *Microcystis*. Other algal forms that were notable in 2008 included: centric diatoms in June and September and the yellow –brown alga *Dinobryon* in May and September. As such, blooms that developed were dominated by floating blue-green algae that accumulates near the surface of the water often causing beds of scum.

A seasonal transition in algal types from diatoms to greens to blue-green is rather typical for mesotrophic and eutrophic lakes in Minnesota. In Portage Lake, however, blue-greens dominated throughout the summer. Based on chl-*a* concentrations (Figure 13), nuisance blue-green blooms were present in July through October. Elevated TP (Figure 13) and warm temperatures (Figure 12) help explain the dominance of blue-greens in July through September; however, May and October temperatures were rather cool (below the preferred range for blue-greens) and the dominance of blue-greens were not anticipated.

Figure 14. Algal composition for Portage Lake in 2008



Zooplankton

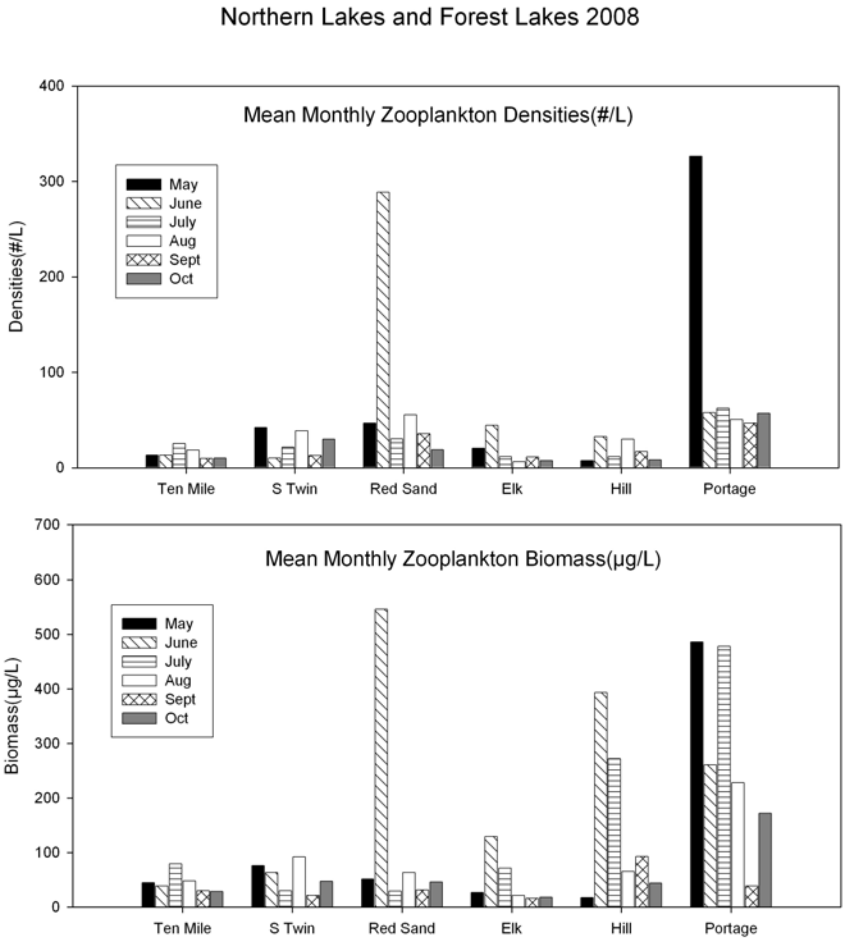
Zooplankton samples were analyzed by Jodie Hirsch at the MDNR. A summary report was prepared that included information for all the Sentinel Lakes and that report (Hirsch 2009) is the basis for the following comments on Portage Lake.

Portage Lake had the highest mean annual density and mean annual biomass of zooplankton of any of the NLF lakes and was among the highest overall for all 24 Sentinel Lakes (Table 10); however, total number of taxa was on the low end based on these 24 lakes. Hirsch (2009) found that, in general, as lake productivity increased (e.g. TP or chl-*a*) the relative abundance (biomass) of zooplankton increased as well. This appears to be the case for Portage and the other NLF lakes (Figure 15). Portage also differs from the other NLF lakes in that its biomass remains relatively high from May through July; whereas biomass drops off for most of the lakes following the spring pulse in May.

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 15. Mean monthly zooplankton densities and biomass for NLF Sentinel lakes



Trophic State Index (TSI)

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

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

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

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

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, chl-*a*, and Secchi (Figure 16). 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 62 Portage Lake would be characterized as eutrophic.

Trophic Status Trends

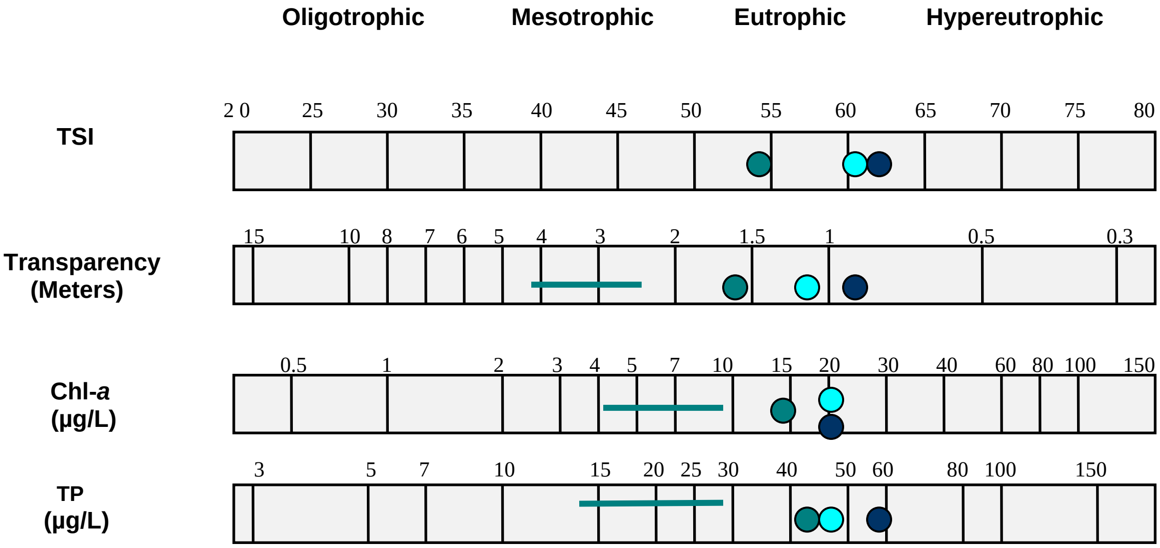
One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on MPCA, Citizen Lake Monitoring Program, or other available data in STORET. A review of data in STORET indicates there is a fair amount of data for Portage Lake to describe annual variability and to statistically assess trends. In general, for trend assessment we seek a minimum of eight years of consistent data. Based on yearly TSI averages calculated for 1997 through 2008, Portage Lake has historically been classified as eutrophic and exhibits a mild increase in TSI, as well, over this period (Figure 17).

Individual summer-mean TP, chl-*a* and Secchi data can provide further insight into trends and variability (Figure 18). The long-term average TP for Portage Lake is 56 ±7 µg/L. The standard error, expressed as a percent of the long-term mean, represents the coefficient of variation (CV) of the mean. For Portage Lake the CV equals 13 percent, which is fairly typical for Minnesota lakes. Since 2004, four of five years have been greater than the long-term mean and suggest a weak trend of increasing TP. This is consistent with the overall trend. Chl-*a* values are also elevated with a long-term mean of 24 ±5 µg/L. The CV for chl-*a* is 21 percent of the mean. The recent four of five years have been greater than the long-term mean (Figure 18). Secchi disk transparency has been consistently low with a long-term mean of 1.2 ± 0.1 m (Figure 19). The CV is 8 percent of the mean, which suggests minimal variability, but is within the typical range for Minnesota lakes. Secchi disk values since 2004 have been less than the long-term mean. As with TP and chl-*a*, the Secchi disk values indicate eutrophic conditions.

Precipitation data provides some insight as to whether a particular year was "wet" or "dry" and may provide some insight into processes (sources) that may be influencing observed trends. Based on precipitation records from 1986 to 2008, mean annual precipitation measured within Park Rapids is nearly 18 inches with a weak decline in precipitation over the period (Figure 7). With the exception of 2004, the past five years have had below average precipitation and elevated TP and chl-*a*. In contrast, 1999 and 2002, years with above average precipitation (Figure 7), exhibited below average TP and chl-*a* (Figure 18). While this analysis is far from conclusive it does suggest that precipitation and climate-related factors (runoff, evaporation, etc.) may play a role in the trophic status and trends for Portage Lake.

Figure 16. Carlson's Trophic State Index for Portage Lake
R.E. Carlson

TSI < 30	Classical Oligotrophy: Clear water, oxygen throughout the year in the Hypolimnion, salmonid fisheries in deep lakes.
TSI 30 – 40	Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
TSI 40 – 50	Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
TSI 50 – 60	Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.
TSI 60 – 70	Dominance of blue-green algae, algal scum probable, extensive Macrophyte problems.
TSI 70 – 80	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
TSI > 80	Algal scum, summer fish kills, few macrophytes, dominance of rough fish.



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

NLF Ecoregion Range: ▬ Portage 1997: ● Portage 2002: ● Portage 2008: ●

Figure 17. Portage Lake trophic status trend

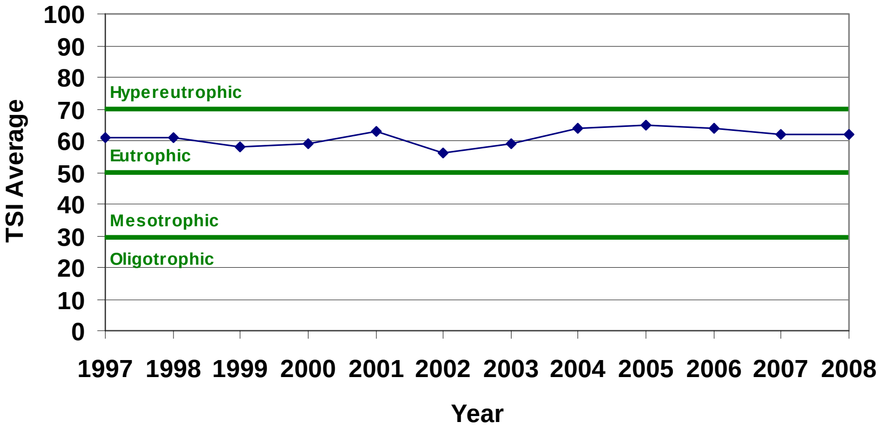


Figure 18. Portage Lake long-term summer-mean TP (orange line) and chl-*a* (green line). Standard error of the mean noted for each year.

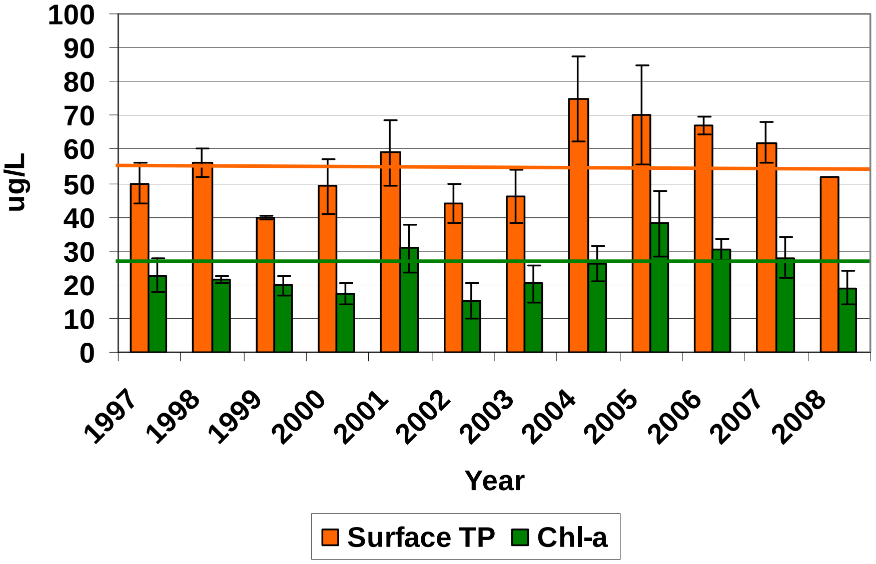
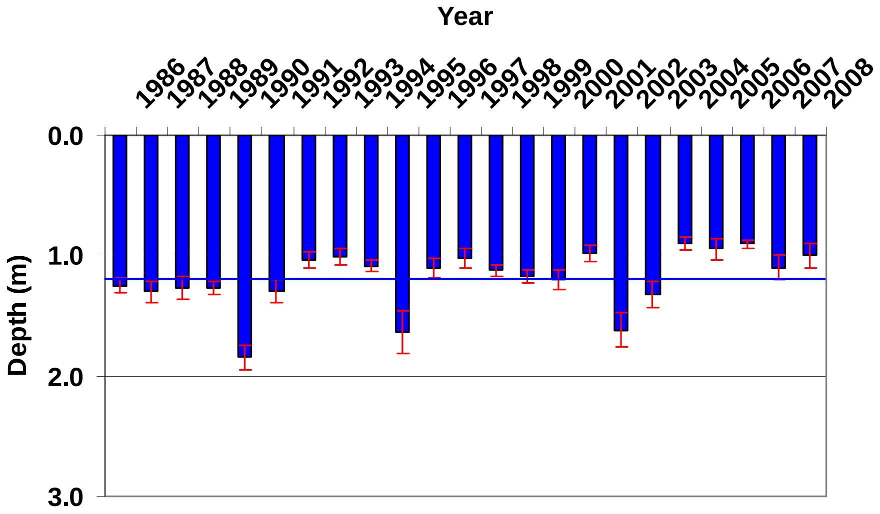


Figure 19. Portage Lake long-term summer-mean Secchi disk depth.

Long-term mean noted by solid blue line.



Sediment Core-based Trend Assessment

A sediment core was collected from Portage Lake in 2008 as a part of a MPCA study to determine pre-European TP, temporal changes in TP and sediment accumulation rates for several shallow TMDL-listed lakes in northern Minnesota (Tim James, MPCA, personal communication). This study was conducted in cooperation with the Science Museum of Minnesota. A complete assessment of the data from this study was not yet published as of the writing of this Sentinel Lake report; however, some preliminary data on sediment accumulation rates were available and that will be summarized here.

Sediment accumulation rates are proportional to the net delivery of sediment (organic and inorganic) from the watershed and in-lake production (algae and plants) to the lake (Heiskary and Swain 2002). The actual rate of sediment accumulation at the core site is a product of the watershed area, land use and soil characteristics, in-lake diagenesis and cycling, combined with the area and depth of the lake. Areal accumulation rates are typically expressed in terms of kilograms per meter squared per year or grams per centimeter squared per year.

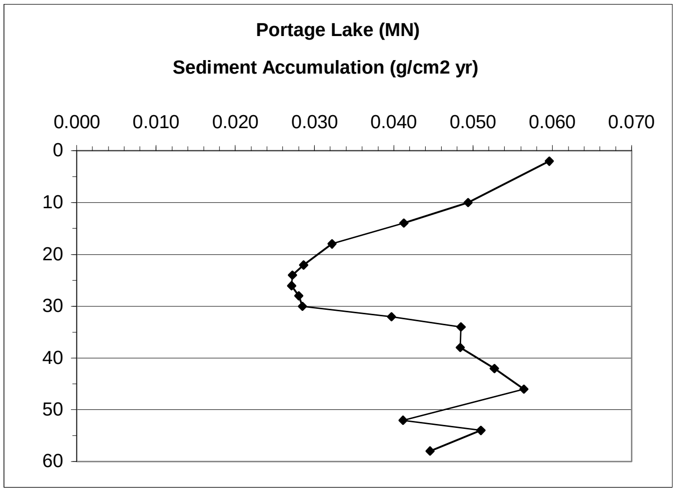
Sediment accumulation rates were high in Portage Lakes prior to the installation of the dam in 1937. This was likely a reflection of the extensive logging and land clearance that occurred in the early 20th century and the use of the river and lake to transport logs. With the installation of the dam and cessation of the logging, sediment accumulation rates stabilized at about 0.028 g cm^2yr from 1940-1960 (Figure 20a&b). Sediment accumulation rates then doubled over the subsequent 40-45 years. One caveat that must be considered in the interpretation of pre- and post-damming sedimentation rates is that the patterns and locations of sediment accumulation in Portage Lake may have changed in response to the rise in water level at the time of damming.

The relative sources of sediment changed over time as well (Figure 20c). In the pre-dam era sediment composition was ~70-80% calcium carbonate ($CaCO_3$), 15-20% organic, and 5-10% inorganic. For the period from damming to present day the composition had shifted to ~55% $CaCO_3$, 30% organic, and 15% inorganic. This suggests that a greater proportion of the sediment in the post-damming period could be attributed to soil erosion (inorganic) in the watershed and organic matter (essentially algae) and less to carbonate deposition.

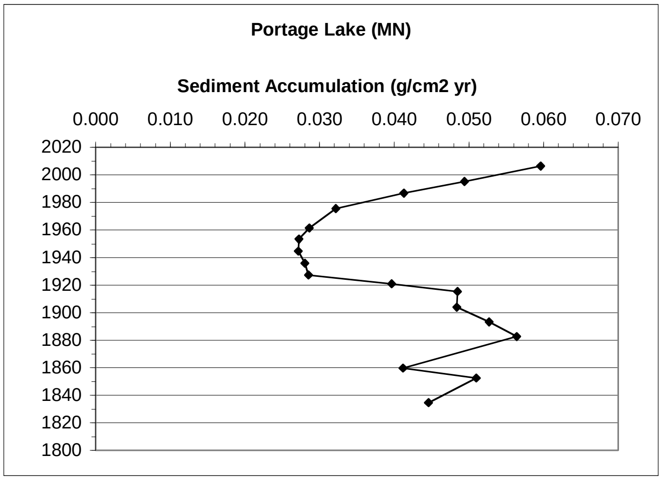
Analysis of sub-fossil diatom communities to reconstruct the ecological and nutrient history of Portage Lake could not be completed because of diatom dissolution (Edlund and Ramstack 2009). Analysis of biogenic silica (a measure of the quantity of diatoms preserved in the sediments) in the Portage Lake core showed the steep drop in biogenic silica from the top of the core to sediments deposited in circa 1950 (Figure 20d). Microscopic analysis of Portage Lake sediments confirmed diatom dissolution. Diatoms quickly disappeared in the top 15 centimeters cm (6 inches) of sediment core and their condition was indicative of dissolution. Dissolution of diatoms in Portage Lake is likely because of the high carbonate content of the sediments; diatoms readily dissolve in high pH water. Other factors that may contribute to dissolution include lake hydrology and groundwater flow. In studies of over 200 lakes in Minnesota (M. Edlund, Science Museum of Minnesota, pers. comm.), only a handful have problems with diatom dissolution. Others include 8th Crow Wing (Hubbard Co.), Decker Lake (Itasca Co.), Lake Itasca (Clearwater Co.), and Diamond Lake (Hennepin Co.).

Figure 20. Portage Lake sediment accumulation assessment: a) sediment accumulation rates by core depth in cm; b) sediment accumulation rates by core date; c) loss on ignition and relative composition of sediment by core depth in cm; and d) evidence for diatom dissolution by core date. Note that dam was installed in 1937. Figures drawn from Edlund and Ramstack (2009).

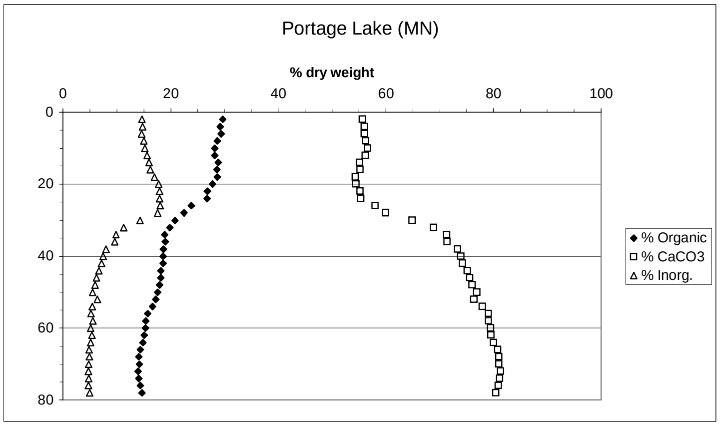
a)



b)



c)



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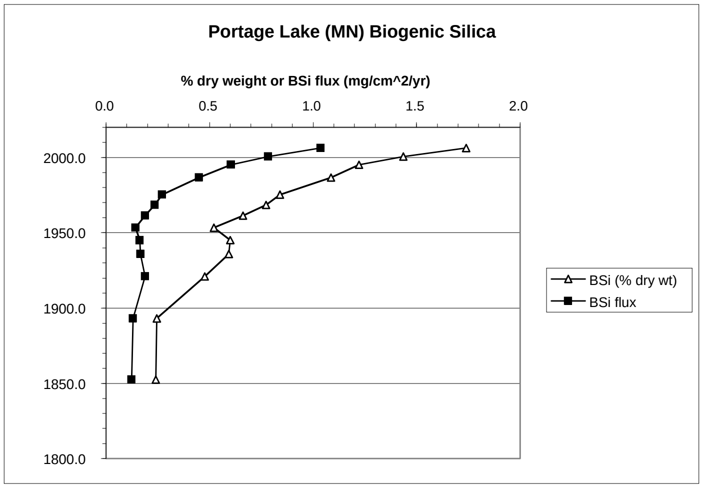

Modeling

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow or amount of water that enters the lake. To analyze the 2008 water quality of Portage 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 11.

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 Portage Lake, MINLEAP was applied as a basis for comparing the observed (2008) 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.

Portage Lake is located in the NLF ecoregion and the model was run using NLF ecoregion-based inputs. Since it's near the NCHF/NLF ecoregion transition a model run with NCHF inputs was also conducted to provide additional perspective.

The observed TP, chl-*a*, and Secchi values for Portage Lake are significantly different from both the NLF and NCHF predicted values. In simple terms, this means that the observed TP is not consistent with what is expected for a lake of its size, depth, and watershed area in either the NLF or the NCHF ecoregion. Model results, based on inputs from both ecoregions, bracket the predicted TP loading at 150-252 kilograms per year (kg/yr). Given that the observed TP is higher than the predicted values for each ecoregion, the actual TP loading is likely higher than the predicted results. The areal water load to the lake ranges between 0.8-1.8 meters per year (m/yr) and the estimated water residence time is on the order of 1.5-2.8 years. 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 Portage Lake this value is estimated at 30 µg/L, which is equal to the NLF nutrient criteria (Table 11).

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 two ecoregions a reasonable estimate of the anticipated nutrient and water loading to Portage Lake can be made. Based on the results in Table 11 it is quite likely that the actual nutrient loading to Portage is much higher than these regionally calibrated values. It is also likely that the excess nutrient loading may come from a combination of excess phosphorous contribution from the watershed (given the high percent of cultivated and pasture land use) as well as internal recycling processes within the lake. In-lake TP is well above the 30 µg/L nutrient criteria for lakes in the NLF ecoregion for recreational use (Table 12). 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 11. MINLEAP model results for Portage Lake

Parameter	2008 Portage Observed	MINLEAP Predicted NLF	MINLEAP Predicted NCHF
TP (µg/L)	60	25	44
Chl-*a* (µg /L)	21	7.3	16.7
Secchi (m)	0.9	2.4	1.5
P loading rate (kg/yr)	-	150	252
P retention (%)	-	56	75
P inflow conc. (µg/L)	-	57	177
Water Load (m/yr)	-	1.8	0.8
Outflow volume (hm^3/yr)	-	2.6	1.4
Residence time (yrs)	-	1.5	2.8
Vighi & Chiaudani		30	30

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.

Portage Lake was assessed relative to the NLF ecoregion standards (Table 12). Both the 2008 and long-term mean for Portage Lake are well above this value. Likewise, chl-*a* is above the standard for the NLF ecoregion. Based on these results, Portage Lake was included on the 2006 303(d) Impaired Waters List that Minnesota submitted to the U.S. EPA. The TMDL process for Portage Lake is targeted to begin in 2014. The TMDL study will gather additional data that will allow for development of an accurate nutrient and water budget for the lake and ultimately be used to develop load allocations needed to allow the lake to meet water quality standards. This Sentinel lake report, and additional monitoring conducted prior to 2014, should prove useful in development of the TMDL. Portage Lake was also listed as impaired for mercury in fish tissue. That impairment was addressed through a statewide mercury TMDL.

Table 12. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). Portage Lake 2008 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
Portage Lake 2008	**60**	**21**	**0.9**
Portage Lake Long-term mean	**56**	**24**	**1.2**

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Appendix A

Glossary

Acid Rain: Rain with a higher than normal acid range (low pH). Caused when polluted air mixes with cloud moisture; can cause lakes to be devoid of fish.

Algal Bloom: An unusual or excessive abundance of algae.

Alkalinity: Capacity of a lake to neutralize acid.

Bioaccumulation: Build-up of toxic substances in fish flesh. Toxic effects may be passed on to humans eating the fish.

Biomanipulation: Adjusting the fish species composition in a lake as a restoration technique.

Dimictic: Lakes which thermally stratify and mix (turnover) once in spring and fall.

Ecoregion: Areas of relative homogeneity. EPA ecoregions have been defined for Minnesota based on land use, soils, landform, and potential natural vegetation.

Ecosystem: A community of interaction among animals, plants, and microorganisms, and the physical and chemical environment in which they live.

Epilimnion: Most lakes form three distinct layers of water during summertime weather. The epilimnion is the upper layer and is characterized by warmer and lighter water.

Eutrophication: The aging process by which lakes are fertilized with nutrients. *Natural eutrophication* will very gradually change the character of a lake. *Cultural eutrophication* is the accelerated aging of a lake as a result of human activities.

Eutrophic Lake: A nutrient-rich lake – usually shallow, “green” and with limited oxygen in the bottom layer of water.

Fall Turnover: Cooling surface waters, activated by wind action, sink to mix with lower levels of water. As in spring turnover, all water is now at the same temperature.

Hypolimnion: The bottom layer of lake water during the summer months. The water in the hypolimnion is denser and much colder than the water in the upper two layers.

Lake Management: A process that involves study, assessment of problems, and decisions on how to maintain a lake as a thriving ecosystem.

Lake Restoration: Actions directed toward improving the quality of a lake.

Lake Stewardship: An attitude that recognizes the vulnerability of lakes and the need for citizens, both individually and collectively, to assume responsibility for their care.

Limnetic Community: The area of open water in a lake providing the habitat for phytoplankton, zooplankton and fish.

Littoral Community: The shallow areas around a lake’s shoreline, dominated by aquatic plants. The plants produce oxygen and provide food and shelter for animal life.

Mesotrophic Lake: Midway in nutrient levels between the eutrophic and oligotrophic lakes

Meromictic: A lake that does not mix completely

Nonpoint Source: Polluted runoff – nutrients and pollution sources not discharged from a single point: e.g. runoff from agricultural fields or feedlots.

Oligotrophic Lake: A relatively nutrient- poor lake, it is clear and deep with bottom waters high in dissolved oxygen.

pH Scale: A measure of acidity.

Photosynthesis: The process by which green plants produce oxygen from sunlight, water and carbon dioxide.

Phytoplankton: Algae – the base of the lake's food chain, it also produces oxygen.

Point Sources: Specific sources of nutrient or polluted discharge to a lake: e.g. Stormwater outlets.

Polymictic: A lake that does not thermally stratify in the summer. Lake tends to mix periodically throughout summer via wind and wave action.

Profundal Community: The area below the limnetic zone where light does not penetrate. This area roughly corresponds to the hypolimnion layer of water and is home to organisms that break down or consume organic matter.

Respiration: Oxygen consumption

Secchi Disk: A device measuring the depth of light penetration in water.

Sedimentation: The addition of soils to lakes, a part of the natural aging process, makes lakes shallower. The process can be greatly accelerated by human activities.

Spring Turnover: After ice melts in spring, warming surface water sinks to mix with deeper water. At this time of year, all water is the same temperature.

Thermocline: During summertime, the middle layer of lake water. Lying below the epilimnion, this water rapidly loses warmth.

Watershed storage area The percentage of a drainage area labeled lacustrine (lakes) and palustrine (wetlands) on U.S. Fish and Wildlife Service National Wetlands Inventory Data.

Zooplankton: The animal portion of the living particles in water that freely float in open water, eat bacteria, algae, detritus and sometimes other zooplankton and are in turn eaten by planktivorous fish.

Appendix B

Portage Lake Surface Water Data for 2008. All water quality data may 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
Portage	29-0250	5/11/2008	201	1.7							
Portage	29-0250	5/18/2008	201	1.4	49	16					
Portage	29-0250	5/20/2008	201	1.2	47	13	170	6.81	0.72	5	5.6
Portage	29-0250	5/27/2008	201	1.2							
Portage	29-0250	6/7/2008	201	1.2							
Portage	29-0250	6/15/2008	201	1.2	61	21					
Portage	29-0250	6/22/2008	201	1.2							
Portage	29-0250	6/24/2008	201	1.7	144	5					
Portage	29-0250	7/1/2008	201	1.1							
Portage	29-0250	7/6/2008	201	1.1							
Portage	29-0250	7/15/2008	201	0.9	68	13	140	6.79	1.16	5	16
Portage	29-0250	7/20/2008	201	1.1	37	20					
Portage	29-0250	7/27/2008	201	0.9							
Portage	29-0250	8/4/2008	201	0.8							
Portage	29-0250	8/9/2008	201	0.8							
Portage	29-0250	8/10/2008	201	0.6							
Portage	29-0250	8/17/2008	201	0.8	56	27					
Portage	29-0250	8/19/2008	201	0.8							

Portage	29-0250	8/24/2008	201	0.61							
Portage	29-0250	8/25/2008	201	0.6	128	38			1.62		
Portage	29-0250	9/3/2008	201	0.6							
Portage	29-0250	9/9/2008	201	0.6							
Portage	29-0250	9/15/2008	201	0.8	65	45					
Portage	29-0250	9/16/2008	201	0.6	65	26			0.97		
Portage	29-0250	9/20/2008	201	0.7							
Portage	29-0250	9/24/2008	201	0.6							
Portage	29-0250	9/28/2008	201	0.6							
Portage	29-0250	10/8/2008	201	0.5	97	31	140	7.11	0.87	5	19

Appendix C Ice-on and ice-off records for Portage Lake

Lake Name	Lake ID	Ice Off Date	Ice On Date
Portage	29-0250	05/05/75	11/22/75
Portage	29-0250	04/12/76	11/07/76
Portage	29-0250	04/17/77	11/12/77
Portage	29-0250	04/27/78	11/15/78
Portage	29-0250	05/05/79	11/09/79
Portage	29-0250	04/20/80	11/18/80
Portage	29-0250	04/06/81	11/21/81
Portage	29-0250	04/25/82	11/13/82
Portage	29-0250	04/20/83	11/22/83
Portage	29-0250	04/16/84	11/02/84
Portage	29-0250	04/21/85	11/11/85
Portage	29-0250	04/12/86	11/10/86
Portage	29-0250	04/10/87	11/21/87

Portage	29-0250	04/16/88	11/18/88
Portage	29-0250	04/25/89	11/12/89
Portage	29-0250	04/22/90	11/24/90
Portage	29-0250	04/10/91	11/03/91
Portage	29-0250	04/06/92	11/14/92
Portage	29-0250	04/18/93	10/31/93
Portage	29-0250	04/18/94	11/23/94
Portage	29-0250	04/21/95	11/04/95
Portage	29-0250	05/03/96	11/11/96
Portage	29-0250	04/23/97	11/12/97
Portage	29-0250	04/08/98	11/12/98
Portage	29-0250	04/14/99	11/28/99
Portage	29-0250	04/05/00	11/21/00
Portage	29-0250	04/25/01	11/29/01
Portage	29-0250	04/16/02	11/13/02
Portage	29-0250	04/15/03	11/06/03
Portage	29-0250	04/15/04	11/24/04
Portage	29-0250	05/03/06	11/11/06
Portage	29-0250	04/21/07	11/22/07
Portage	29-0250	05/03/08	11/18/08
Portage	29-0250	04/22/09	