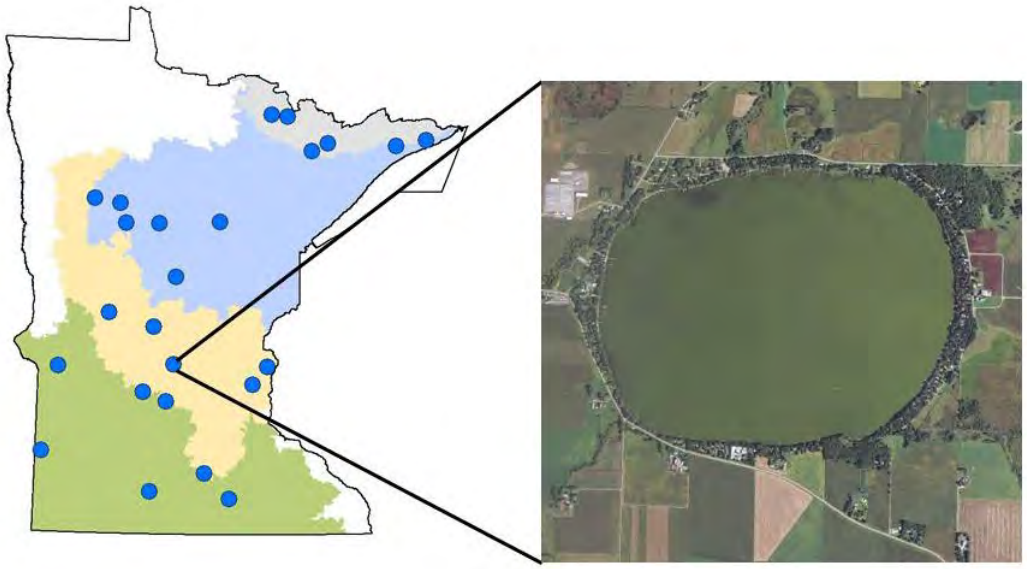
Sentinel Lake Assessment Report
Pearl Lake (73-0037)
Stearns County, Minnesota



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

October 2012

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Executive Summary

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

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). The "deep" lakes typically stratify during the summer months only. "Shallow" lakes are defined as mixing continuously throughout the summer. "Cold water" lakes are defined as lakes that either harbor cisco, lake whitefish, or lake trout or are the focus of research funded by the Environment and Natural Resource Trust Fund (ENRTF). "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is also funded by the ENRTF.

Pearl Lake was selected to represent a shallow lake in the North Central Hardwood Forests (NCHF) ecoregion. Pearl Lake is a 304 hectare (750 acres) lake, located near Rockville, Minnesota in Stearns County, within the Sauk River Watershed. The lake has a maximum depth of 5.5 meters (18 feet) and a mean depth of 3.0 meters (9.8 feet). The lake is 68 percent littoral with one public access on the north shore of the lake. The total contributing watershed for Pearl Lake is 7,380 hectares (18,237 acres).

Pearl Lake is a relatively shallow lake that mixes continuously throughout the open water season. Based on recent water quality data (2008-2010), Pearl Lake is considered to be eutrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 35 micrograms per liter (µg/L), 16.2 µg/L, and 1.95 meters (5.8 feet) respectively. TP is within the typical ranges (based on reference lakes) for NCHF ecoregion. Algal blooms were common and transparency was typically low during latter portions of the summer. By MPCA statute, for the purposes of lake eutrophication assessment, Pearl Lake is considered a deep lake and is held to the deep lake eutrophication standard. Based on data from 1998-2007, Pearl exceeded the lake eutrophication standard and was placed on the 2008 impaired waters list. Since then a draft Total Maximum Daily Load was completed and is awaiting U.S. Environmental Protection Agency (EPA) approval. Based on more recent data (2008-2009), Pearl Lake's TP and chl-*a* values meet the water quality standard and the lake may be eligible for removal from the TMDL list.

Pearl Lake has a fully developed shoreline and high crop cultivation in the contributing watershed. Pearl Lake has documented common carp populations, but it is unclear what the density of the population is. The cumulative effects of farm field runoff, feedlot runoff, and potential on-site system seepage, all contribute to the nutrient over-enrichment of the lake.

Pearl Lake has sustained a productive fishery and has a very high Index of Biotic Integrity (IBI) as compared to lakes of similar productivity. However, predator species, especially northern pike, are very abundant and presumably play a major role in the decline of yellow perch. Experimental fishing regulations are now in effect in an attempt to restore fish community balance.

It is critical to note that although IBIs are quite sensitive to changes in water quality conditions, there are significant time lags between when disturbances occur and they are detected in the IBI score. The finding of a high IBI score in Pearl in which TP has increased in recent years is cause for alarm. Given the possibility of negative impacts to the lake's fishery, there is some urgency to implement practices, which reduce nutrient loads in the lake. If nutrient loads do not decrease within the lake, we may expect

continuing and possibly worsening curly-leaf pondweed conditions, and the extirpation of the intolerant fish species. We will continue to monitor the fish community during regular intervals into the future.

Although aquatic plant removal by lakeshore owners constitutes a small fraction of the Pearl Lake's total vegetated area, most removal has occurred in near-shore areas. Near-shore vegetation is critical for spawning and nursery habitat for several juvenile and intolerant fish species (Valley et al. 2004). Efforts should be made to minimize the loss of aquatic vegetation from near shore areas.

An ecoregion-based eutrophication model was used to predict in-lake TP based on Pearl Lake's size, depth, and watershed area using inputs from the NCHF ecoregion. Based on analysis completed during the Pearl Lake TMDL development (Barr 2011), the MINLEAP modeling was run for both the total and contributing watersheds. The model predicted in-lake TP at 50 ±17 µg/L, which agrees with existing water chemistry data. A separate subroutine within the model estimated "background" TP for the lake at 27 µg/L. The model predictions, along with the overall assessment of Pearl Lake's water quality data, clearly indicate the lake's water quality has declined since the onset of modern development, but has the potential, given current inputs, to decline further.

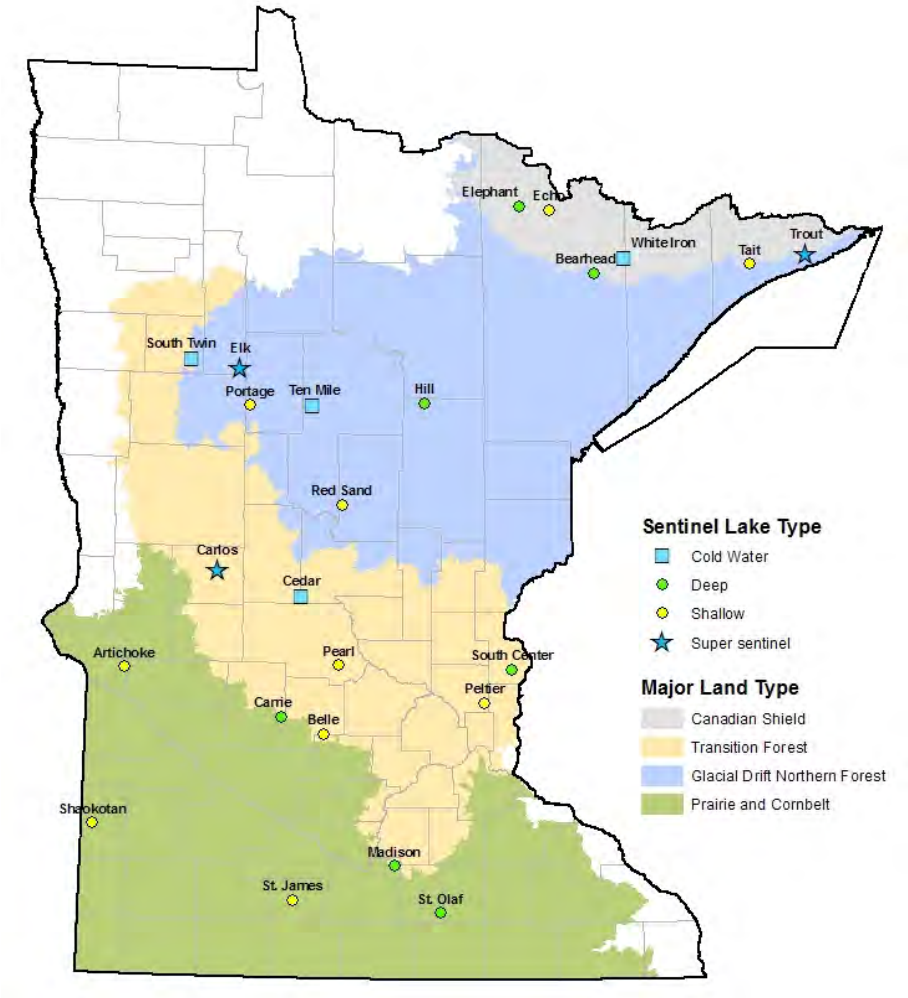


Figure 1. Sentinel Lakes and major land types

Introduction

This report provides a relatively comprehensive analysis of physical, water quality and ecological characteristics of Pearl Lake in Stearns 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 2008-2011 seasons; however, historical data are used to provide perspective on variability and trends in water quality. Water quality data analyzed will include all available data in EQuIS, the MPCA repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

Fisheries lake surveys were done in 1949, 1975, 1987, 1992, 1998, and 2008. Pearl Lake was surveyed as part of the statewide creel survey 1972-1974. A recreational use survey was made in1988 and winter creel survey in 1990-1991. Winter fish house counts were made annually1976-1993, 1998, and every third year thereafter. Lake Assessment Report, MPCA 1997. A draft vegetation management plan was completed in1996.

1908 The first fish stocking records for Pearl Lake.

1946 Areas are posted to protect spawning largemouth bass. The posting was discontinued in 1986 since the areas were not critical to largemouth spawning.

1949 The first fisheries lake survey noted that there were five resorts and 40 cottages on Pearl Lake. The catch of sunfish and bass was above the state average. (1998-151 homes/cabins).

1949 The first lake map was drawn based on fieldwork and sounding done this summer. The lake area was shown to be 728 acres. The maximum depth was 17 feet.

1950 Regular stocking of Pearl Lake with walleye fingerlings begins.

1959 The public access is acquired.

1969 The most current lake map was drawn based on fieldwork this summer. The lake area was 733 acres and the maximum depth was 17 feet.

1985 A spawning area for northern pike was developed by Vince Kunkel. Northern pike levels have been high such that there hasn't been a need to use the area. The current landowner is unwilling to allow use of the area.

1986 The public access was expanded and a new dam was constructed.

1988 A recreational use survey estimates that angling pressure is 43 hours per acre.

1987 The gill net catch of walleye was 25.0 /lift during the resurvey, the highest level recorded for Pearl Lake.

1991 A creel survey conducted during the winter of 1990-1991 estimated angling pressure to be 37 hours per acre.

1992 During the 10 years from 1983-1992 an average of 103 fish houses were placed on the lake each January for winter fishing.

1997 The MPCA completes its first lake assessment report for Pearl Lake. Nutrient loads were much lower in 1997, and years previous than 2008.

1998 The gill net catch of northern pike was 10.6/lift during the survey, making it the highest level recorded for Pearl Lake. Aquatic vegetation is mapped with GPS/GIS technology.

2001 Five riffles were constructed on Mill Creek, tributary to Pearl Lake, in order to improve walleye spawning habitat. Lake water quality is monitored by Stearns SWCD.

2006 While viewing the constructed riffles, it appeared that the stream had become more entrenched. Since riffle construction we have not had favorable spring run-off conditions to attract spawning fish and evaluate the work that has been done.

2007 Pearl Lake selected as a Sentinel lake in the SLICE program.

2009 A 17" minimum size limit for walleye and a 24"-36" protected slot limit for northern pike goes into effect. The regulation proposal was not without some controversy. The 2008, survey showed northern pike at a historic high; and walleye fingerling survival was jeopardized.

Background

Lake morphometric and watershed characteristics

Pearl Lake is in Stearns County within the Sauk River watershed. Pearl Lake is located near Kimball, Minnesota. One public access exists on Pearl Lake on the northern shore. Pearl Lake has relatively shallow depth (Figure 2).

Pearl 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 (Figure 3). 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.

Pearl Lake has two tributaries, Mill and Unnamed creeks, and one outlet, Mill Creek, draining the lake on the north side. The total watershed has an area of 7,380 hectares (18,237 acres) resulting in a watershed-to-lake area ratio of approximately 24:1. Barr reports a contributing watershed less than the larger, total watershed; both will be considered later in the report for modeling purposes (Barr 2011).

Soils in the Pearl Lake watershed consist of those in the Central Minnesota Sandy Outwash major land resource area. The major soils are Mollisols and Histosols. Water and wind erosion are known problems (USDA, 2006).

Table 1. Pearl Lake and watershed morphometric characteristics

Lake Name	Lake ID	[1]Lake Basin	Littoral Area	[2]Contributing Watershed Area	[3]Total Watershed Area	Watershed : Lake Ratio	[2]Max. Depth	[2]Mean Depth	Lake Volume
		Hectares (Acres)	%	Hectares (Acres)	Hectares (Acres)		Meters (Feet)	Meters (Feet)	Acre-Ft.
Pearl	73-0037	304 (750)	68	3,897 (9630)	7,380 (18,237)	24:1	5.5 (18.2)	3.0 (9.8)	7,399

[1] Based on the 1:24,000 National Hydrography Dataset
[2] Based on the Pearl Lake TMDL report (Barr, 2011)
[3]Based on the MDNR Catchments Lake Watersheds Layer

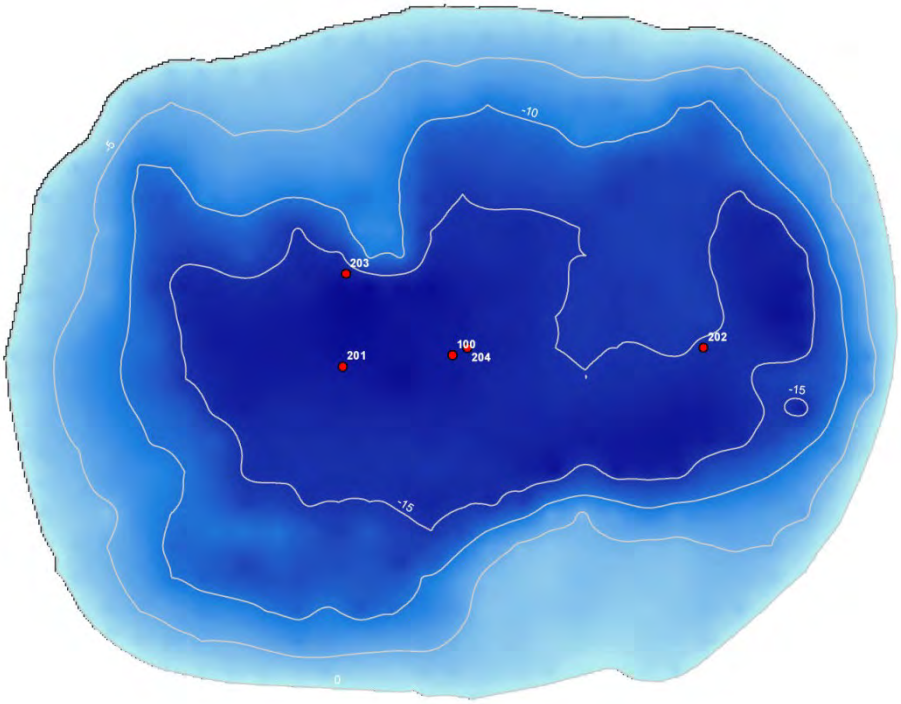


Figure 2. Pearl Lake monitoring sites and bathymetry (based on 2008 MDNR acoustic survey)

Lake mixing and stratification

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

Polymictic Lake
Shallow, no layers,
Mixes continuously
Spring, Summer & Fall

Dimictic Lake
Deep, form layers,
Mixes Spring/Fall

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

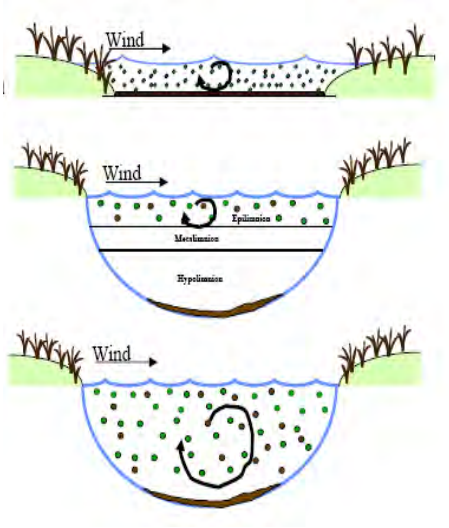


Figure 3. Lake stratification

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. Pearl Lake lies within the NCHF ecoregion (Figure 4). NCHF values will be used for land use (Table 2), summer-mean water quality comparisons (Table 5), and in 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 dominated by cultivated land use (53 percent) and pasture (21 percent), which is distributed throughout the watershed. Water/wetland, urban and forested land uses comprise approximately seven percent, six percent, and 13 percent of the watershed (Figure 5, Table 2), which are consistent with typical ranges found in the NCHF ecoregion.

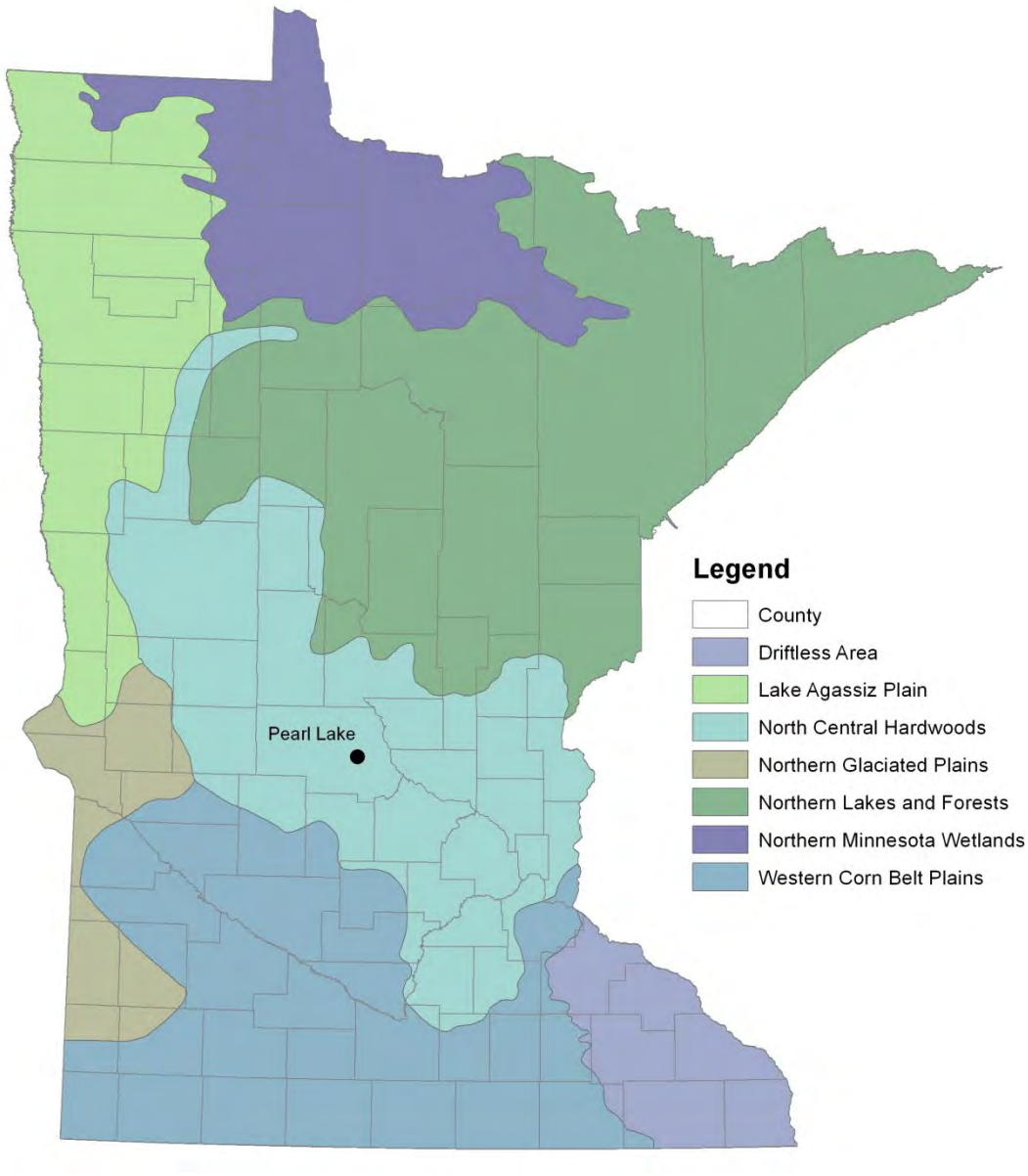
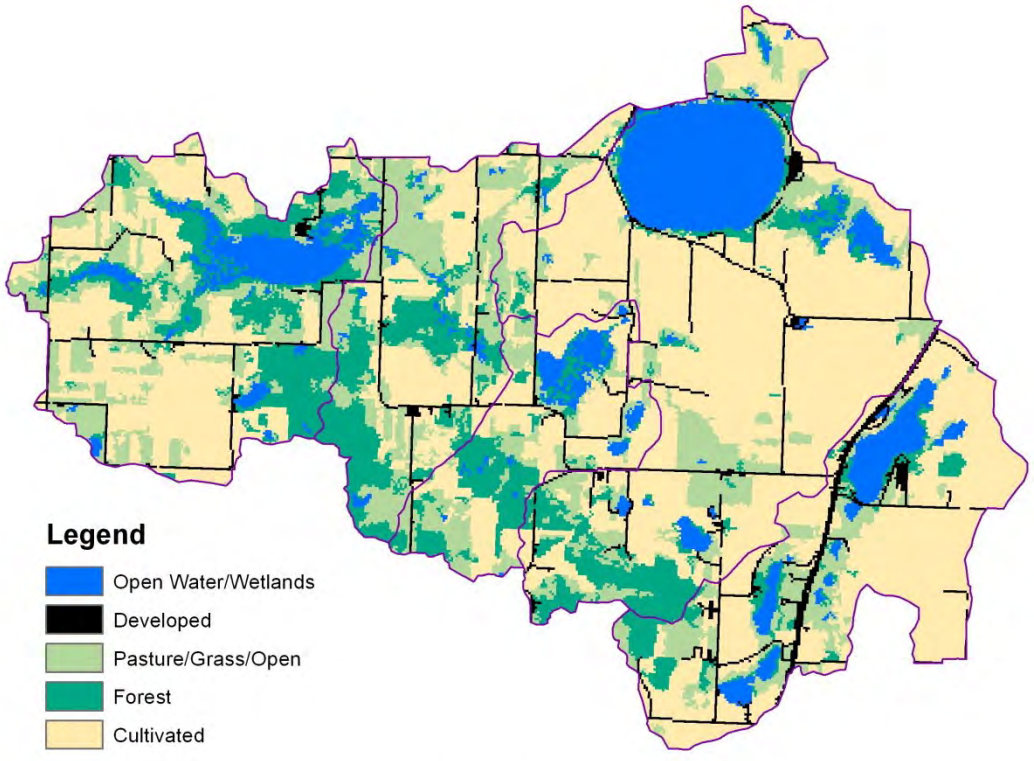


Figure 4. Minnesota ecoregions as mapped by United States Environmental Protection Agency

Table 2. Pearl Lake ecoregion land use comparison

Typical (interquartile) range based on 35 NCHF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005). 2006 National Land Cover Dataset used for determine land use percentages for the watershed.

Land Use	Pearl Lake Land Use %	NCHF Typical Land Use %
Developed	5	2 - 9
Cultivated (Ag)	49	22 - 50
Pasture & Open	20	11 - 25
Forest	15	6 - 25
Water & Wetland	11	14 - 30
Feedlots (#)	51	



Land Use complied from the 2006 National Land Cover Dataset.

Figure 5. Pearl lake watershed and land use composition

Lake level and ice on/off

The MDNR Division of Waters has been measuring water levels intermittently on Pearl Lake since 1981 (Figure 6). The historical range of the lake is 3.7 feet with the highest measured level at 1119 feet in June of 1983 and the lowest reading at 1115.3 feet in September of 1988. Very limited ice on/ice off data is available on Pearl Lake; a November 8, 2003 ice on date is the earliest information and ice out has been recorded regularly since 2009. The range of ice out dates is from as early as March 19 in 2012 and as late as April 15 in 2009.

Precipitation and climate summary

Rain gage records from Kimball, Minnesota show four, one-inch plus rain events during summer 2009, and six each in the summers of 2010 and 2011 (Figure 7). Large rain events may 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 Pearl Lake. Precipitation records for the 2008 and 2009 water years (October 2007 through September 2008 and October 2008 through September 2009, respectively) showed normal amounts of rainfall were received (Figure 8). Lake level can respond to these changes in precipitation; though there may be a lag in this response (Figure 7).

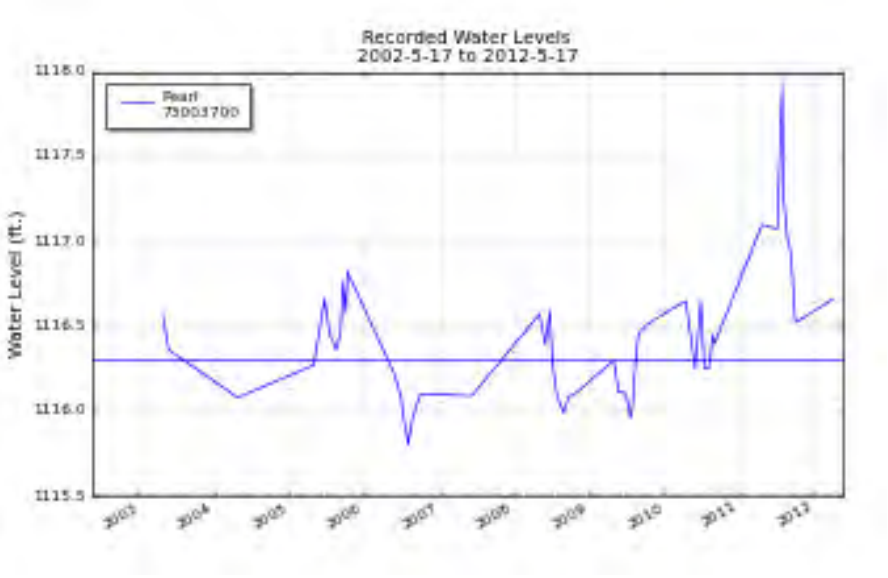


Figure 6. Historical Pearl Lake water levels
(flat line indicates ordinary high water mark)

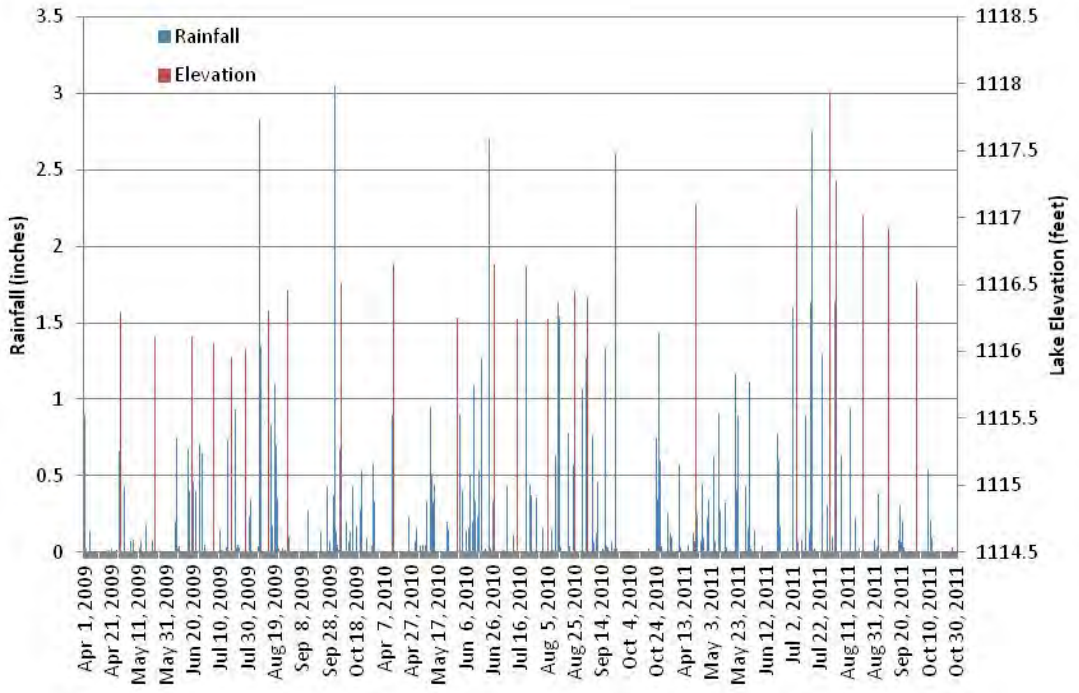


Figure 7. Summer (April to October) 2009-2011 rainfall based on records for Kimball, Minnesota and lake level

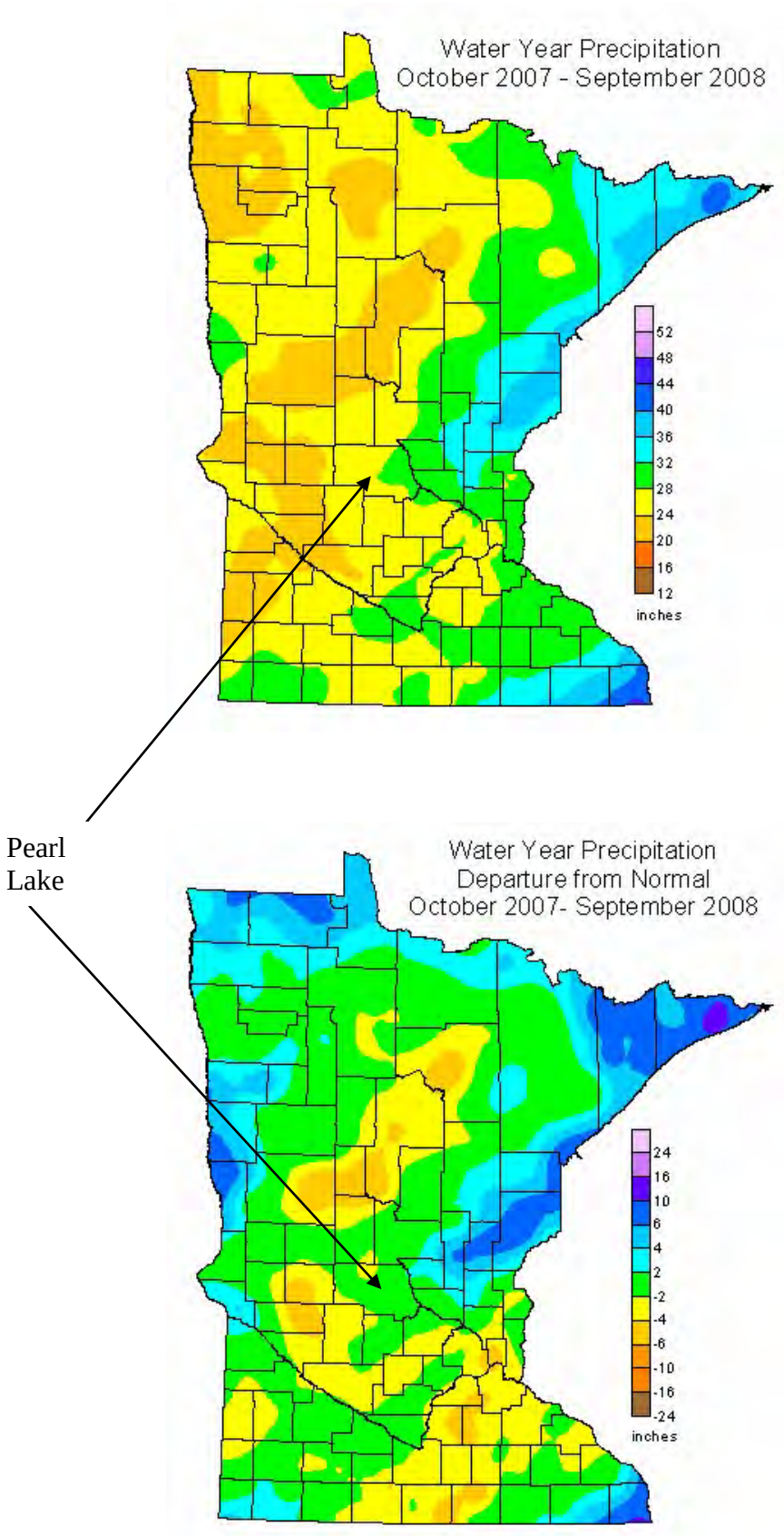


Figure 8. 2008 Minnesota water year precipitation and departure from normal

Prepared by State Climatology Office, MDNR; values are in inches

Methods

Fisheries and aquatic plants

Frequency of occurrence of aquatic plant species were assessed using the point-intercept method (Madsen 1999). This method entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately one mile, 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).

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 Pearl Lake were collected seasonally by MPCA staff from 2008, to 2011. Samples were collected by the Sauk River Watershed District during 2008 and 2009 during TMDL development. Lake surface samples were collected by MPCA staff with an integrated sampler, a polyvinyl chloride (PVC) tube two meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (1.24 inches). Zooplankton samples were collected with an 80 micrometer mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth TP samples were collected with a Kemmerer sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples were collected at site 203 (Figure 2). Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf .

MPCA collected samples were analyzed by 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.

Zooplankton

Zooplankton samples were collected seasonally. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 meter of the bottom and retrieved at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100 percent reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 µg/L mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per five milliliter aliquot. A five milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level), and measured to the nearest 0.01 millimeter using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick 1994 in Hirsch 2009).

Results and Discussion

Fisheries assessment

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

Fish community status and trends

Despite its elevated nutrient loads, Pearl Lake harbors many species of fish (Table 3). During the 1949 initial lake survey, MDNR Fisheries Research crews documented five fish species that were not sampled during 2008 surveys. Targeted searching of different habitats including the mouth of Mill Creek will be necessary in subsequent years to determine whether these species can be considered functionally extirpated or possibly misidentified in the 1949 survey.

Drake and Pereira (2002) developed a fish-based index 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.

IBI surveys conducted in Pearl Lake in 2008 were in the 90th percentile compared with other lakes of similar productivity (score = 96). MDNR crews sampled five species intolerant to high nutrient conditions and aquatic plant removal. A high IBI score usually indicates among other important community aspects, a community high in intolerant species and low in tolerant ones. Specifically in Pearl Lake, crews sampled blackchin shiners *Notropis heterodon*, blacknose shiners *Notropis heterolepis*, banded killifish *Fundulus diaphanus*, hornyhead chub *Nocomis biguttatus* and Iowa darter *Etheostoma exile.* These species have disappeared from many Twin Cities metropolitan lakes whose watersheds have been developed or hydrology altered (unpublished MDNR survey data).

Creel Surveys

Fishing pressure during the 1988 recreational use survey was estimated to be 43 hours per acre (moderate-heavy). Nearly all angling occurred from boats (98 percent). Non-fishing recreational use was 2.3 hours per acre. Harvest of northern pike, black crappie and bluegill was relatively high (Table 4). During the winters 1997-2008, an average of 86 houses were placed on the ice during the first week of January**.**

Table 3. Fish species sampled during the initial survey in 1949 and 2008. Thermal guilds were assessed by Lyons (2009). Environmental tolerances were assessed by Drake and Pereira (2002).

Common name	Species name	Trophic guild	Thermal guild	Environmental tolerance	Year first sampled
Black crappie	*Pomoxis nigromaculatus*	Predator	Warm	Neutral	1949
Bowfin	*Amia calva*	Predator	Warm	Neutral	2008
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1949
Northern pike	*Esox lucius*	Predator	Cool-Warm	Neutral	1949
Walleye	*Sander vitreus*	Predator	Cool-Warm	Neutral	1949
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	1949
Bluntnose minnow	*Pimephales notatus*[b]	Omnivore	Warm	Neutral	1949
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Warm	Neutral	2008
Common carp	*Cyprinus carpio*	Omnivore	Warm	Tolerant	Known to exist
White sucker	*Catostomus commersonii*	Omnivore	Cool-Warm	Tolerant	1949
Yellow bullhead	*Ameiurus natalis*	Omnivore	Warm	Neutral	1949
Banded killifish	*Fundulus diaphanus*	Insectivore	Cool-Warm	Intolerant	1949
Blackchin shiner	*Notropis heterodon*	Insectivore	Cool-Warm	Intolerant	2008
Blacknose shiner	*Notropis heterolepis*	Insectivore	Cool-Warm	Intolerant	1949
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1949
Brook stickleback	*Culaea inconstans*	Insectivore	Cool-Warm	Neutral	2008
Common shiner	*Notropis cornutus*	Insectivore	Warm	Neutral	1949
Creek chub	*Semotilus atromaculatus*	Insectivore	Cool-Warm	Tolerant	1949
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	Neutral	1949
Green sunfish	*Lepomis cyanellus*	Insectivore	Warm	Neutral	1949
Hornyhead chub	*Nocomis biguttatus*	Insectivore	Warm	Intolerant	2008
Iowa darter	*Etheostoma exile*	Insectivore	Warm	Intolerant	1949
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-Warm	Neutral	1949
Log perch	*Percina caprodes*	Insectivore	Warm	Neutral	1949
Mimic shiner	*Notropis volucellus*	Insectivore	Warm	Intolerant	1949
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1949
Least darter[b]	*Etheostoma microperca*	Insectivore	Warm	Intolerant	2009
Pugnose shiner[b]	*Notropis anogenus*	Insectivore	Unknown	Intolerant	2009
Tadpole madtom	*Notorus gyrinus*	Insectivore	Warm	Neutral	2009
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	Neutral	1949
Yellow perch	*Perca flavescens*	Insectivore	Cool-Warm	Neutral	1949

[a]Historically referenced as brassy shiner *Hybognathus notatus*

[b]State-listed species of greatest conservation need

Table 4. Results from the creel survey conducted during winter 1090-1991

Species	No. Harvested	Lbs. Harvested	Harvest. rate	Mean weight.
Walleye	47	217	.002	4.2
No. Pike (ang)	1,862	3,633	.068	2.5
No. Pike(spear)	417	1,393	.187	2.5
Black crappie	5,240	4,709	.192	0.3
Bluegill	16,014	1,801	.588	0.2

Walleye - Pearl Lake is primarily managed for walleye through fingerling stocking. Historically, the walleye catch has been high (Table 5, Figure 10). In 2011, the walleye catch was the lowest on record; however, it was still above average for lakes similar to Pearl Lake. Walleyes ranged in length from 7 - 26 inches and averaged 16 inches and 1.7 pounds. Growth was fast for both sexes. Both males and females reached 16 inches by age three. Thirty-three percent of the walleyes collected were longer than 17 inches and 22 percent were longer than 20 inches. Mill Creek was enhanced in 2002 by creating rock riffles for walleye spawning (Figure 9). Since then, low precipitation and spring run-off has prevented access of spawning walleye, and thus natural reproduction in Pearl is limited.



Figure 9. Mill Creek tributary modification area

Northern pike - The northern pike catch rate has increased substantially over time, and has been well above the lake class quartiles since 1992. In 2011, northern pike ranged in length from 14 - 36 inches and averaged 21 inches and 2.1 pounds. Growth of both male and female northern pike was average. Both males and females reached 24 inches in five-six years. Twenty-one percent of the northern pike sampled were 24 inches or larger and four percent were 30 inches or larger. High abundance of small northern pike follows a statewide trend of declining northern pike size (Table 5, Figure 10). Mechanisms behind this pattern are many; however, harvest of large individuals is chief among the suspected causes.

In order to improve the fishery, experimental fishing regulations began in 2009. The regulations are for three walleye per day with a 17 inch minimum size, and a protected slot limit of 24-36 inches for northern pike (daily bag of three, one over 36 inches).

Yellow perch - As the population of northern pike increased, the population of yellow perch declined and none have been taken in gill nets since 1992 (Table 5, Figure 10).

White sucker – The catch rate of white suckers in gillnets was very high in 1992 and 1998, but in 2008 and 2011 the catch per unit effort was within the lake class quartiles, similar to 1975 and 1981. Interestingly, the long-term trend in white sucker gillnet catch per unit effort is similar to that for walleye (Table 5, Figure 10).

Largemouth bass - Historical status of largemouth bass in Pearl Lake is uncertain because bass are not vulnerable to traditional fisheries assessment nets. Only recently (1990s) has electrofishing, which can effectively survey bass populations, been employed to gage their status in Minnesota lakes. Catch per unit effort of largemouth bass has been increasing in Pearl Lake since 2008. In 2011, the catch rate of 87.3/hr on time was above the Montrose area night time average (67/ hr, on time). Largemouth bass ranged in length from 8.3 - 18.1 inches and averaged 13.0 inches. Growth of largemouth bass was average: they reached 12 inches in four years. Seventy-two percent of the largemouth bass sampled were 12 inches or larger and 27 percent were 15 inches or larger. Current fisheries research is focusing on developing length and size criteria for largemouth bass from which to gage status of populations in relation to other similar lakes (Table 5, Figure 10).

Bluegill - The bluegill catch was similar to previous surveys and within the range of expected values for similar lakes (Table 5, Figure 10). Bluegill ranged in length from 3-8 inches and averaged 6 inches. Growth of bluegill was slow: they reached 7 inches in six-seven years. Twenty-five percent of the bluegills were 7 inches or longer.

Black crappie - The black crappie catch rate has consistently been low, near the first quartile for the lake class (Table 5). In 2011, black crappies ranged in length from 5-11 inches and averaged 8 inches and 0.4 pounds. Growth of black crappies was fast, and they reached 8 inches in three years. Forty-six percent of the black crappies collected were 9 inches or larger.

Pumpkinseed – There is no obvious long-term trend in pumpkinseed catch rate (Table 5, Figure 10). In most years the catch rate was near the median for the lake class, but near the third quartile in 2010 and the first quartile in 1992 and 2011.

Yellow bullhead – The yellow bullhead catch rate was high in 1975; extremely high in 1981; slightly above the third quartile for the lake class in 1992; but generally within the lake class quartiles since 1992.

Table 5. Focal species captured during recent surveys and their size and abundance compared with other lakes in its lake class

Species	Stocked	Abundance	Size	Trend
Walleye*	Y	High	Large	Stable/high
Northern Pike*	N	High	Small	Increasing/high
Black Crappie	N	Low	Average	Stable/low
Largemouth bass	N	Average	Average	Increasing
Pumpkinseed	N	Average	Average	Stable
Bluegill	N	Average	Average-small	Stable
Yellow perch	N	Low	Small	Declining/low
White Sucker	N	Average	Large	Stable

*Primary species managed

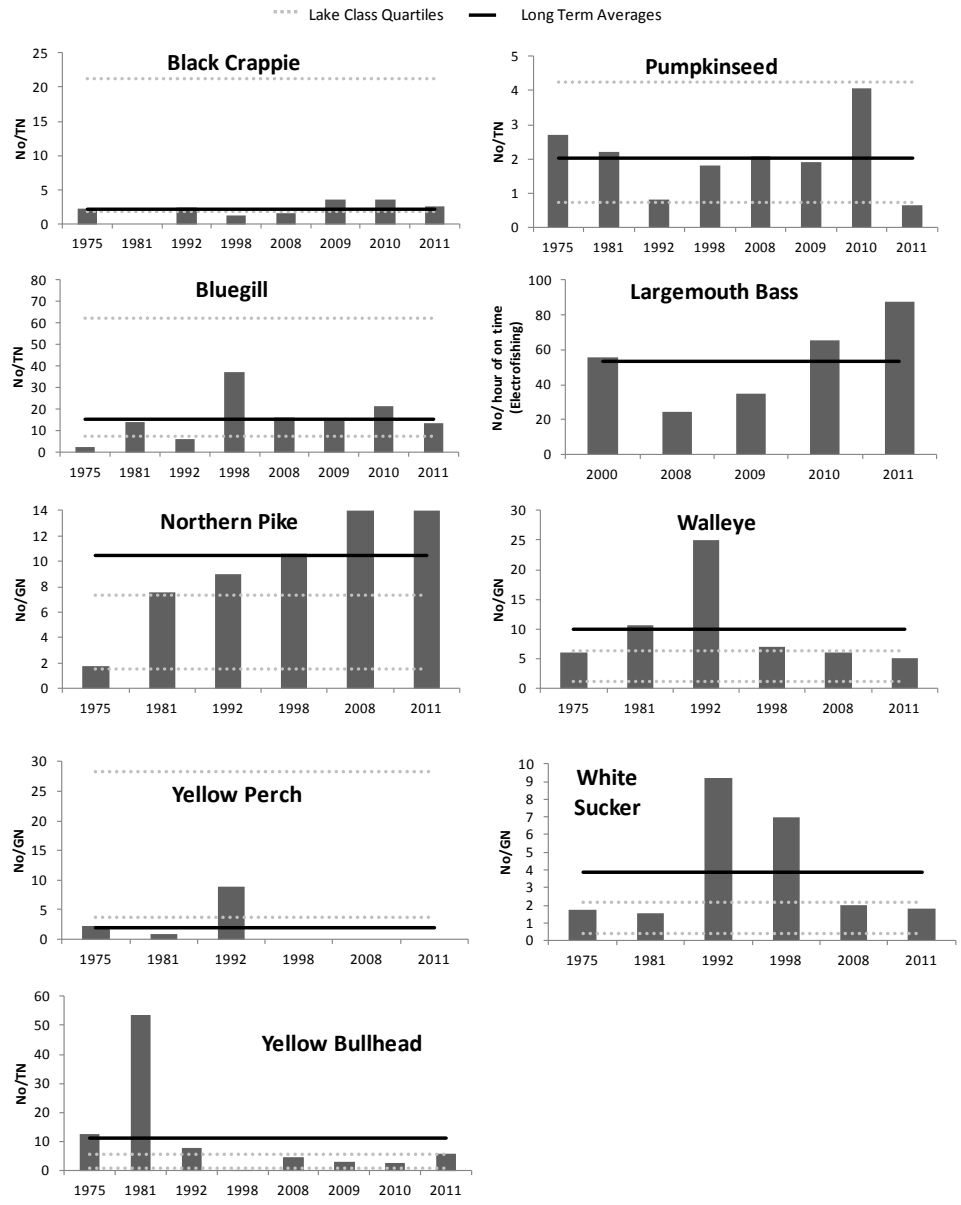


Figure 10. Historical net catches of major fish species vulnerable to gillnets and trapnets in Pearl Lake compared with lake averages and lake class 24 quartiles

Aquatic plant assessment

Aquatic plants – status and trends

Qualitative vegetation surveys were made at the time of most lake surveys. Beginning in 1998 GPS was used to quantify some aspects of the vegetation resource. Those mapping efforts include:
1998 - emergent and floating leaf vegetation; 2000, 2005, 2008-2011 – curly-leaf pondweed; and 2008-2011 – point-intercept surveys.

Figure 11 indicates that bulrush *Scirpus* sp. is in decline and cattails *Typha* sp. are occupying areas where bulrush was once found. Increased boating activities, removal by lakeshore owners, and increased nutrients are speculated causes of the bulrush decline.

The recent point-intercept surveys indicated that curly-leaf pondweed was by far the predominant species in spring, occurring at 43-50 percent of points sampled (Table 6). In summer, rooted plants occurred at 45-84 percent of points sampled. *Chara* was the predominant rooted plant sampled in summer (present at 37-63 percent of points), but many other species were present (Table 6).

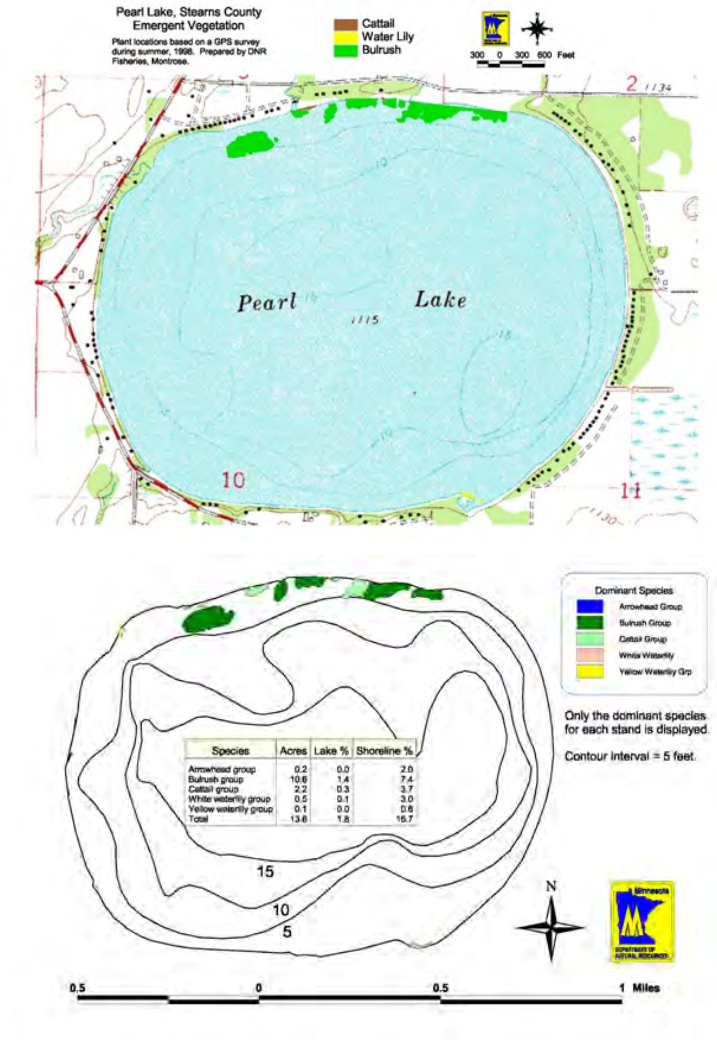


Figure 11. Emergent plant beds mapped with GPS in 1998 and 2008

Table 6. Percent frequency of occurrence of aquatic plant species at depths £ 15 feet sampled during point-intercept surveys on 12 August 2008, 2 September 2009, 23 August 2010, and 23 August 2011 at Pearl Lake, Stearns County, Minnesota

Season	Common Name	Species Name	Growth Form	Frequency (%) 2008	2009	2010	2011
Spring[a]	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	49.9[c]	42.5[c]	44.9[c]	43.8[c]
	Coontail	*Ceratophyllum demersum*	Submersed	6.5	3.3		
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	1.8	7.5		
Summer	All rooted plants			53.3	84.0	63.4	45.4
	Muskgrass	*Chara sp.*	Submersed	46.7	63.0	53.2	37.3
	Bushy pondweed	*Najas flexilis*	Submersed	10.0	9.2	7.2	3.6
	Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	9.4	22.4	4.7	1.9
	Coontail	*Ceratophyllum demersum*	Submersed	8.2	21.1	21.6	5.9
	Filamentous algae			8.2	10.8	1.2	0.8
	Sago pondweed	*Stuckenia pectinatus*	Submersed	5.4	5.4	4.5	10.6
	Wild celery	*Vallisneria americana*	Submersed	3.0	4.6	3.7	3.2
	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	2.8	5.4	1.0	0.4
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	2.8	3.0	3.0	2.5
	Illinois pondweed	*Potamogeton illinoensis*	Submersed	2.8	5.7	5.7	5.5
	Hardstem bulrush	*Scirpus acutus*	Emergent	1.8	3.2		
	White-stem pondweed	*Potamogeton praelongus*	Submersed	1.6	2.2	4.7	
	Narrow-leaf pondweed	*Potamogeton sp.*	Submersed	0.8	4.3		1.5
	Water stargrass	*Heteranthera dubia*	Submersed	0.8	0.8	1.0	
	White waterlily	*Nymphaea sp.*	Floating	0.6	0.3	0.2	0.6
	Canada waterweed	*Elodea canadensis*	Submersed	0.6	2.4	0.7	0.2
	Variable pondweed	*Potamogeton gramineus*	Submersed	0.4			
	Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed	0.4	1.9	2.0	1.9
	Lesser duckweed	*Lemna minor*	Free-floating	0.4	0.5		
	Large-leaf pondweed	*Potamogeton amplifolius*	Submersed	0.4		0.5	0.2
	Cattail	*Typha sp.*	Emergent	0.2	0.5	1.0	
	Floating-leaf pondweed	*Potamogeton natans*	Submersed	0.2			
	Arrowhead	*Sagittaria sp.*	Emergent	0.2	0.5	0.2	

	Stonewort	*Nitella sp.*	Submersed		7.3	1.2	1.0
	Fries' pondweed	*Potamogeton friesii*	Submersed		1.1	0.2	
	Star duckweed	*Lemna trisulca*	Submersed		0.3	0.2	0.2
	Smartweed	*Polygonum sp.*	Emergent		0.3		
	Greater duckweed	*Spirodela polyrhiza*	Free-floating		0.3		
	Naiad	*Najas sp.*	Submersed			0.2	
	Bulrush	*Scirpus sp.*	Emergent			2.5	2.1
	Sessile-fruited arrowhead	*Sagittaria rigida*	Emergent			0.2	
	Water horehound	*Lycopus americanus*	Emergent				0.2
	Common bladderwort	*Utricularia vulgaris*	Submersed				0.4
	Max depth of veg growth (ft)[d]			10	14	11.8	7.6

[a]Surveys targeting curly-leaf pondweed
[b]Non-native
[c]surveyed on 4 June 2008, 3 June 2009, 28 May 2010, 14 June 2011
[d]Depth of 95 percent of all plant occurrences

Curly-leaf pondweed *Potamogeton crispus* is a non-native invasive submerged aquatic plant that is widespread throughout the southern part of the state. The exact date of introduction into Minnesota is unknown, but it is believed to have been present in Minnesota lakes since the early 1900s when carp were brought into the state. Curly-leaf pondweed was first observed in Pearl Lake in 1987, but may have gone undetected for a long while previous to this date.

Curly-leaf pondweed was mapped at the time of peak abundance in Pearl Lake in June 2008 and 2009. It was found growing at or near the surface (most common definition of "nuisance" conditions) on 170 acres or 23 percent of the lake's surface (Figure 12). This compares to 10 percent of the lake's surface in 2000 when it was first mapped; and 35 percent in 2005 (Figure 12). During the years 1998-2008, curly-leaf pondweed seemed to increase in abundance on most area lakes; however, patterns in curly-leaf pondweed surface-growth showed much more pronounced declines than plant frequency or cover (Table 7) from 2008 to 2010. Large declines in surface growth were apparent despite only moderately higher early winter snowfall compared with normal (Figure 13, Table 8). Surface growth covered 170, 5.7, and 3.8 acres respectively across all three years (Heiskary and Valley, 2012).

Curly-leaf pondweed thrives in nutrient-rich conditions and at some threshold of nutrients; it can become a self-sustaining internal driver of poor water quality conditions. In 2008, we estimated that curly-leaf pondweed covered 52 percent of Pearl's surface area, with most growth occurring at depths of five feet or greater (this percentage includes nuisance and non-nuisance conditions; Figure 14a). In 2009, curly-leaf pondweed covered a smaller percentage of the lake's area (Figure 14b). Likely counterbalancing harmful water quality effects of curly-leaf pondweed was *Chara* (Figure 15). *Chara* is a benthic plant that "locks" nutrients up into solid plant matter, rather than planktonic algae utilizing available nutrients. *Chara* also provided critical habitat structure for juvenile and non-game fish.

Besides offering quality physical habitat for fish, *Chara* is an important resilience mechanism in clear-water lakes that resists forces that push the lake towards an undesirable turbid-water regime. In other words, *Chara* promotes clear water, clear water promotes *Chara*. In contrast, curly-leaf pondweed promotes resilience of an undesirable turbid lake regime and resists forces that could push the lake back to a clear-water regime. In other words, curly-leaf pondweed promotes turbid water, turbid water promotes curly-leaf pondweed. The threshold of nutrient enrichment that favors one regime over another is currently unclear and in need have further investigation. Nevertheless, it is quite clear that Pearl Lake exists in a precarious state and is at risk of tipping towards a turbid water regime with continued levels of nutrient loading.

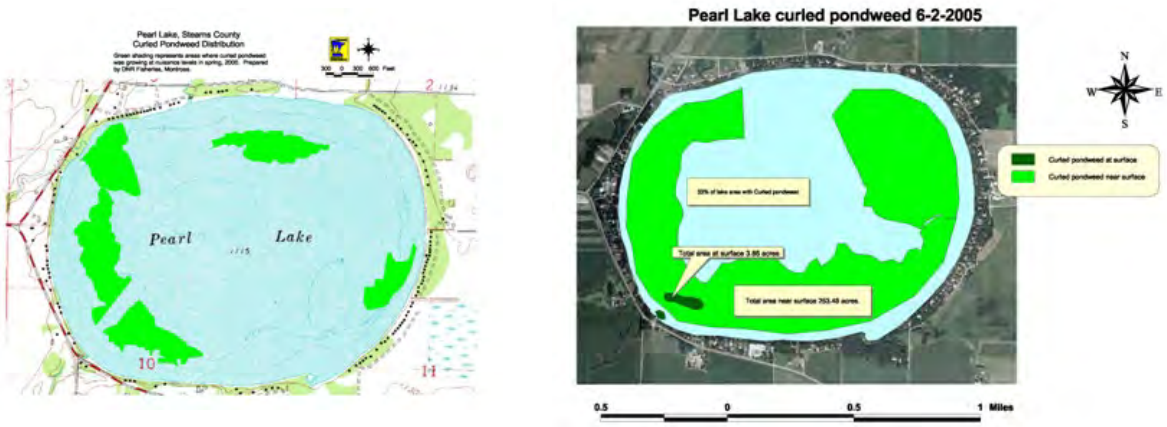


Figure 12. Changes in the cover of surface-growing curly-leaf pondweed: 2000 and 2005



Figure 13. Surface growth of curly-leaf pondweed mapped with GPS on Pearl Lake, Stearns County Minnesota in May 2008-2010

Table 7. Patterns of curly-leaf cover and surface growth in Pearl Lake, Stearns County Minnesota (Heiskary and Valley 2012)

Year	Frequency (% occurrence ≤ 15ft)	Estimated Cover (% of whole lake)	Measured surface growth (% of whole lake)
2008	49.9	51.8	22.60
2009	42.5	35.8	0.75
2010	41.1	44.7	0.50
2011	43.8	39.2	5.50

Table 8. Winter and spring conditions in sentinel lakes where changes in curly-leaf frequency were most pronounced (Heiskary and Valley 2012). Normals are from National Weather Service monthly totals averaged over the years of 1971-2000 from the climate station closest to each sentinel lake.

Lake	Year	Ice On	Ice Off	Days Ice	Dec - Jan Snowfall (in)	Dec - Jan Snow Normal (in)	Avg. Daily Spring Temp (°C)	Spring GDD (base 5 °C)
Pearl	2008	NA	NA	NA	15.3	19.7	10.1	280
	2009	12/11/2008	4/14/2009	123	23.5	19.7	10.6	418
	2010	12/5/2009	3/30/2010	116	23.5	19.7	12.8	532

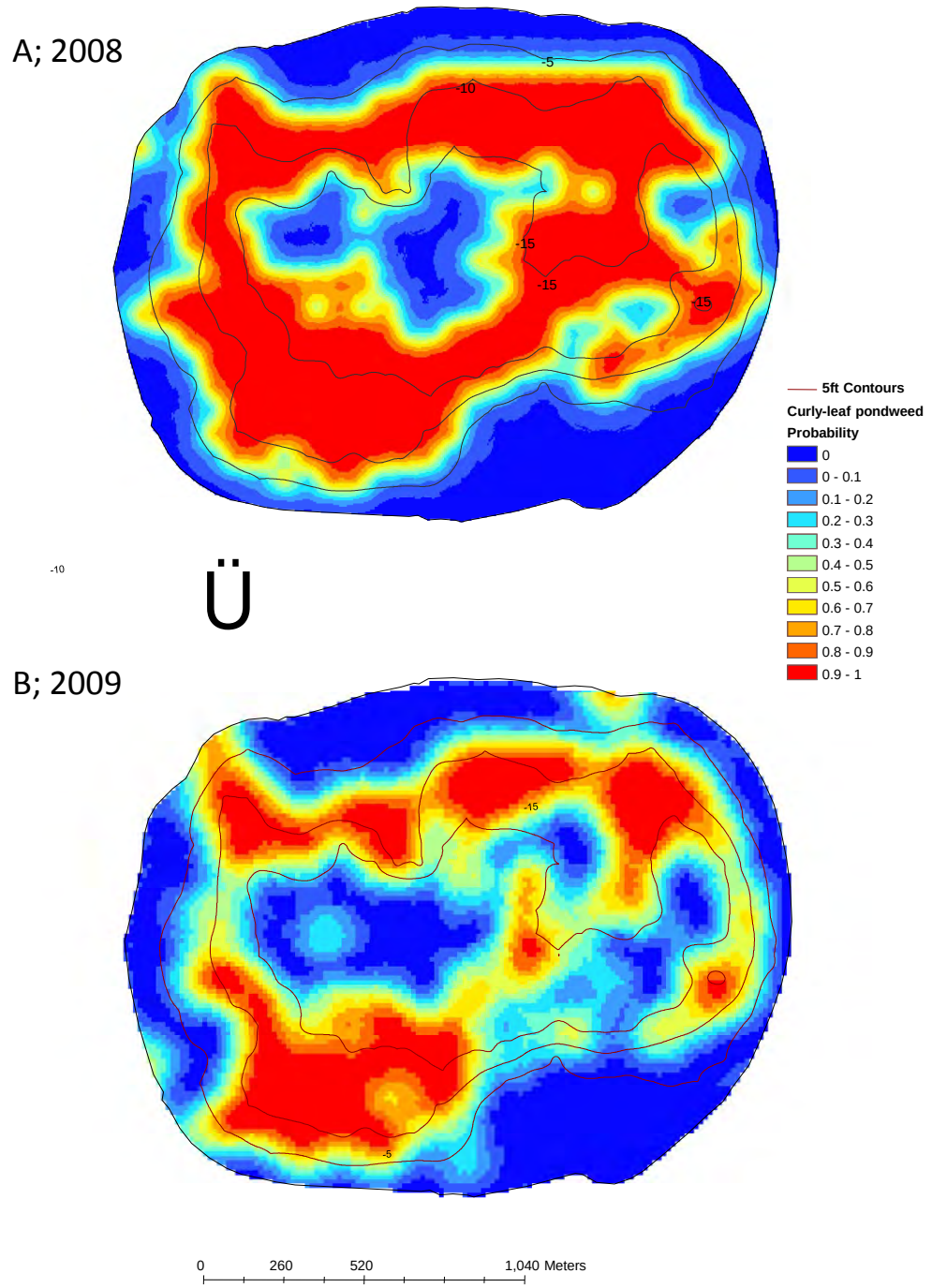


Figure 14. Maps of probability of occurrence of curly-leaf pondweed based on point-intercept surveys conducted in June 2008 and 2009. The grid was created using indicator kriging on presence/absence point data of curly-leaf pondweed. All grid cells with a probability of ≥ 0.75 were considered highly-likely that curly-leaf pondweed occurred in that location and were counted as "present"

Figure 15. Map of probability of occurrence of *Chara* based on point-intercept surveys conducted in June 2008.
The grid was created using indicator kriging on presence/absence point data of *Chara*. All grid cells with a probability of ≥ 0.75 were considered highly-likely that *Chara* occurred in that location and were counted as "present"

Aquatic plant removal by lakeshore owners:

Without a permit, lakeshore owners are allowed to remove 2,500 square feet of submersed aquatic plants immediately in front of their lakeshore property. Based on 2008 aerial photos, approximately 107 lakeshore properties were counted. This suggests that lakeshore owners could remove up to 6.1 acres of aquatic plants without a permit.

Since 1988 there have been 103 aquatic plant management (APM) permits issued for aquatic plant and algae control with 376 permitees. The vast majority (in area) of the aquatic plant control occurring on Pearl Lake has been herbicide treatments for nuisance aquatic plants. Most of these treatments are for areas less than 100 feet along the shore but more than 50 feet along the shoreline. Despite infrequent occurrence across most of the lake, sago pondweed *Stuckenia pectinata,* wild celery *Vallisneria Americana,* and bulrush *Scirpus sp.* were often listed as "nuisance" species on APM permit requests by lakeshore owners. Curly-leaf pondweed and Chara were other species listed as a nuisance to lakeshore owners. During past inspections, field crews observed these and many other native species co-occurring.

Acres treated spiked in 1993 with one permitee allowed 68 acres of treatment done by Lake Restoration (Figure 16). Pearl Lake has averaged 9 acres of plant control since 1993. There was no other information in APM records as to why this large treatment was allowed. The number of permitees has been declining since 1999, when 77 properties were treated. Since 2000, Pearl Lake has averaged 26 properties conducting chemical treatments (Figure 16). Since 1996, removal with automated unattended plant control devices (i.e., weedrollers) on the lake has been steady, averaging six devices operating yearly. In 2005, there was a high of nine weedrollers operating with several other years when only three weedrollers were permitted.

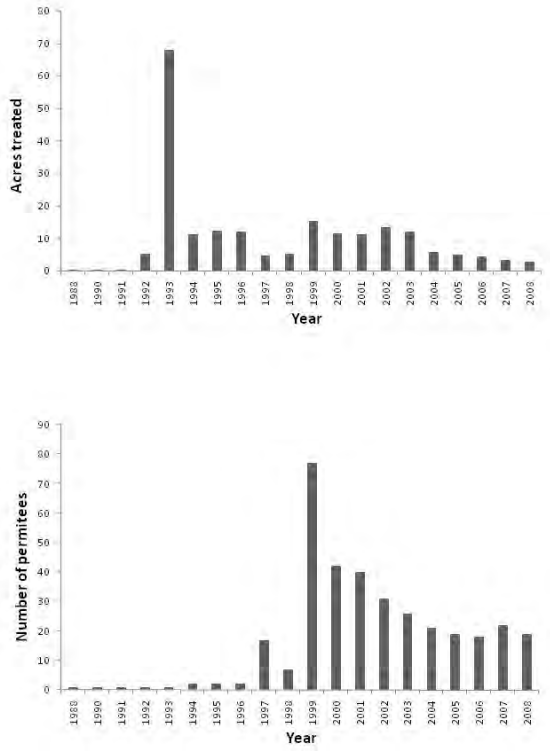


Figure 16. History of aquatic plant management (APM) permitting for chemical control of aquatic plants

Water quality

Standard summer-mean water quality data for 2008-2009 are presented in Table 9; raw data results are provided in Appendix A. In addition, major cations, anions, and total organic carbon were analyzed on three sample dates each year (2008-2011), and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 10**Error! Reference source not found.**. The NLA was a statistically-based survey of the nation's lakes administered by the EPA in 2007. The typical range provided in Table 10 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Table 9. Pearl Lake 2008-2009 summer mean (June to September) water quality
Typical range based on 35 NCHF ecoregion reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	Pearl Lake	NCHF
Total phosphorus (µg/L)	38	23 - 50
Chlorophyll mean (µg/L)	12.6	5 - 22
Chlorophyll max (µg/L)	26.8	7 - 37
Secchi disk (feet)	6.6	4.9 – 10.5
(meters)	2.0	1.5 – 3.2
Total Kjeldahl Nitrogen (mg/L)	0.9	<0.6 – 1.2
Alkalinity (mg/L)	135	75 - 150
Color (Pt-Co Units)	5	10 - 20
pH (SU)	8.8	8.6 – 8.8
Chloride (mg/L)	20	4 - 10
Total suspended solids (mg/L)	4.2	2 - 6
Total suspended inorganic solids (mg/L)	0.8	1 - 2
Conductivity (µmhos/cm)	362	300 - 400
Total nitrogen : Total phosphorus ratio	23.6:1	25:1 - 35:1

Table 10. Pearl Lake cation and anion balance

Date	Ca[1] mg/L	Mg mg/L	Na mg/L	K mg/L	Alk mg/L	SO_4 mg/L	Cl mg/L	Sum Cations	Sum Anions	% Charge Balance
5/6/2008	48.0	24.0	5.4	3.3	180	29.2	19.5	4.69	-4.76	-0.70
7/15/2008	28.8	24	6.1	3.1	140	23.3	19.8	3.76	-3.84	-1.12
10/7/2008	29.6	26.7	6.7	3.4	140	20.6	20.5	4.05	-3.80	3.15
7/29/2009	26.4	25.7	6.2	3.6	130	20.4	20	3.79	-3.59	2.81
10/5/2009	29.5	25.1	6.0	3.6	140	18.3	20.6	3.89	-3.76	1.71
4/29/2010	48.6	25.8	6.0	3.7	170	21.2	19.5	4.90	-4.36	5.54
7/27/2010	29.0	24.1	5.5	3.3	150	16.3	19.6	3.75	-3.89	-1.78
10/20/2010	29.7	18.9	4.7	2.5	170	16.5	19.4	3.31	-4.29	-12.94
4/18/2011	61.7	23.8	4.9	2.9	210	21.1	17.5	5.29	-5.13	1.54
8/3/2011	39.3	21.5	4.7	2.8	160	11.3	15.4	4.01	-3.87	1.77
10/26/2011	43.7	25.8	5.8	3.0	170	17.6	18.0	4.23	-4.27	-0.54
Average	37.7	24.1	5.6	3.2	160	19.6	19.1			
NLA IQ range (mg/L)	19.1 – 33.7	6.7 – 26.9	2.2 – 9.0	0.9 – 4.8		2.2 – 14.0	1.5 – 18.4			

Dissolved oxygen and temperature profiles were taken a minimum of monthly at site 203 (Figure 17 and 18). The lake was well mixed, from a temperature standpoint, on all sample dates from spring through fall (Figure 18). Based on the profiles from 2008-2009, hypoxic Dissolved Oxygen (DO) in the bottom waters is uncommon but does occur periodically (Figure 17). These occasional periods of low DO and high water temperatures above the sediments (>20 ^{0}C) both can allow for release of phosphorus from the sediments that feeds phosphorus loads to the lake (Figure 20).

Continuous temperature loggers provide an additional means for measuring the change in surface water temperature on many of the sentinel lakes. Temperature data from 2008-2010 indicate mean surface temperature in Pearl was quite consistent for 2008 and 2009; however, mean temperature was warmer in 2010–primarily because of the warm spring temperatures (Table 11). This pattern was noted in other sentinel lakes, as well. Rapid warming can influence growth, turion production, and senescence of curly-leaf (Heiskary and Valley 2012).

Total phosphorus concentrations in Pearl Lake averaged 38 µg/L for 2008 and 2009. This is within the range of typical lakes in the NCHF Ecoregion. Concentrations increase across the season with concentrations typically doubling from spring to fall. This is typical of shallow lakes in Minnesota that experience internal loading.

Pearl has the second highest amount of curly-leaf of any of the Sentinel lakes (Heiskary and Valley, 2012). Based on intensive monitoring during 2008 and 2009, Pearl exhibited a seasonal increase in TP (Figure 19) that is quite consistent with other shallow lakes (Heiskary and Valley, 2012).Curly-leaf senescence contributes to mid-summer increases in P; however the degree of increase is moderated, to some degree, by the density of summer native vegetation (Kufel and Kufel 2002).

For example, in 2008 curly-leaf density was high in Pearl, St. James, and Portage Lakes; each of these lakes is of moderate eutrophication and has a high density of native vegetation. Each lake exhibited midsummer increased P, though the magnitude of increase varied. In contrast, as curly-leaf density declined in 2009, the magnitude of the midsummer spike in phosphorus was lessened. Summer native vegetation varied somewhat inversely to curly-leaf density. Maintaining native vegetation is critical to this class of lake to help ensure curly-leaf does not become the dominant form of vegetation. This will also reduce the risk of the lake shifting to an algal dominated state (Heiskary and Valley 2012).

Nitrogen, measured as total Kjeldahl nitrogen (TKN), a primary nutrient required for algal and plant growth was within the range for NCHF lakes (Table 9). Nitrate-N, which is readily used by algae and rooted plants was at or below detection on most sample dates (Appendix A).

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. Chl-*a* concentrations averaged 12.6 µg/L, over the summers of 2008-2009 (Figure 19). Like TP, this is the typical range for NCHF lakes (Table 9); and just below the criteria for the lake eutrophication standard. Chl-*a* concentrations increase across the season as the waters warm. With the exception of elevated chl-a concentrations in 2010 and 2011, nuisance algal blooms (chl-*a* > 20 µg/L) were not present on most dates. Temperatures were slightly higher in 2010 and 2011 than in 2008 and 2009. Chlorophyll-*a* may have been more prolific as a result of the higher temperatures in the more recent years of the study.

Secchi disk transparency averaged 2.0 meters (6.6 feet) over 2008-2009. This is within the typical range for NCHF lakes and meeting the criteria for the lake eutrophication standard. Transparency corresponded well to TP and chl-*a* concentrations; increases in those parameters resulting in a decline in transparency (Figure 19).

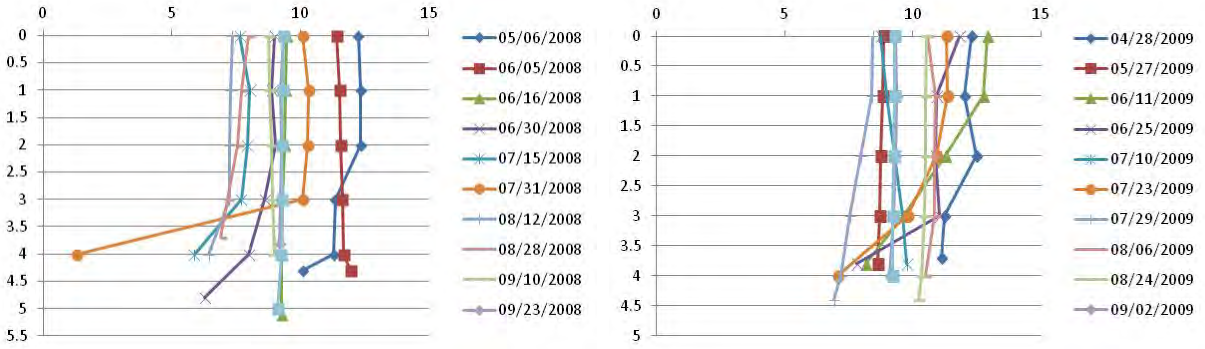


Figure 17. Pearl Lake 2008-2009 dissolved oxygen

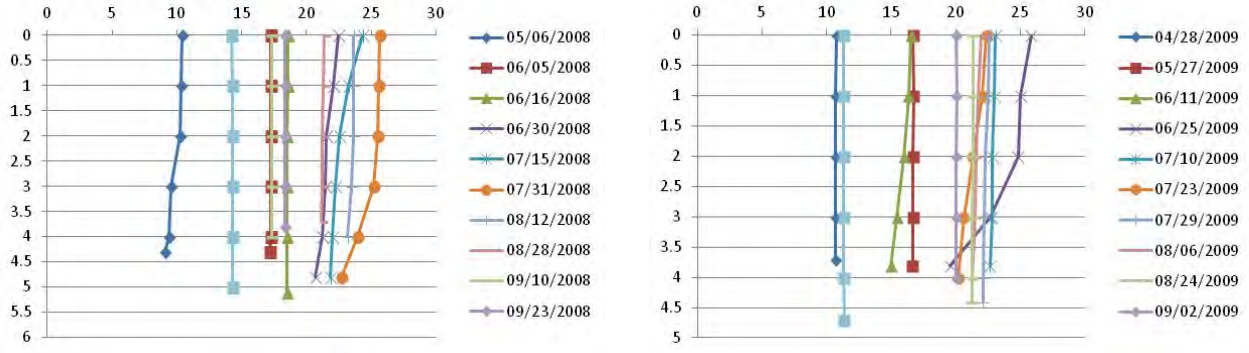


Figure 18. Pearl lake 2008-2009 temperature

Table 11. Average daily surface water temperatures based on logger data for 2008, 2009 and 2010. Includes open water mean, spring mean (Temp of all days ≥ 5 °C up to May 31st) and summer mean (June 1st – Sep. 30th) for lakes with available data. Lakes grouped by land type to allow for comparison

Land Type	Lake	2008 Mean Temp	2008 Mean spring	2008 Mean sum.	2009 Mean Temp	2009 Mean spring	2009 Mean sum.	2010 Mean Temp	2010 Mean spring	2010 Mean sum.
Transition	Belle	17.3	10.6	22.0	15.6	11.3	21.6	17.6	12.8	22.5
	Carlos	16.7	9.0	20.5	NA	NA	NA	NA	NA	NA
	Cedar	17.4	11.0	21.6	16.0	10.9	21.6	17.1	11.9	22.2
	Pearl	**16.7**	**10.1**	**21.6**	**15.1**	**10.6**	**21.4**	**17.1**	**13.3**	**22.3**
	Peltier	18.1	12.7	22.4	16.7	14.0	22.0	NA	NA	NA
	Mean	**17.2**	**10.7**	**21.5**	**15.9**	**11.9**	**21.7**	**17.1**	**12.6**	**22.3**
Prairie	Carrie	NA	11.4	16.9	15.6	11.5	21.7	17.9	13.3	23.0
	Artichoke	NA	NA	21.9	16.1	12.6	21.1	17.2	12.3	22.2
	Madison	NA	NA	NA	16.1	11.8	22.0	18.3	13.5	23.2
	St. James	NA	NA	NA	15.8	13.0	20.9	NA	NA	NA
	St. Olaf	NA	NA	NA	16.7	13.2	22.1	18.5	13.9	23.6
	Mean	**NA**	**NA**	**NA**	**16.0**	**12.2**	**21.6**	**17.9**	**13.2**	**22.9**

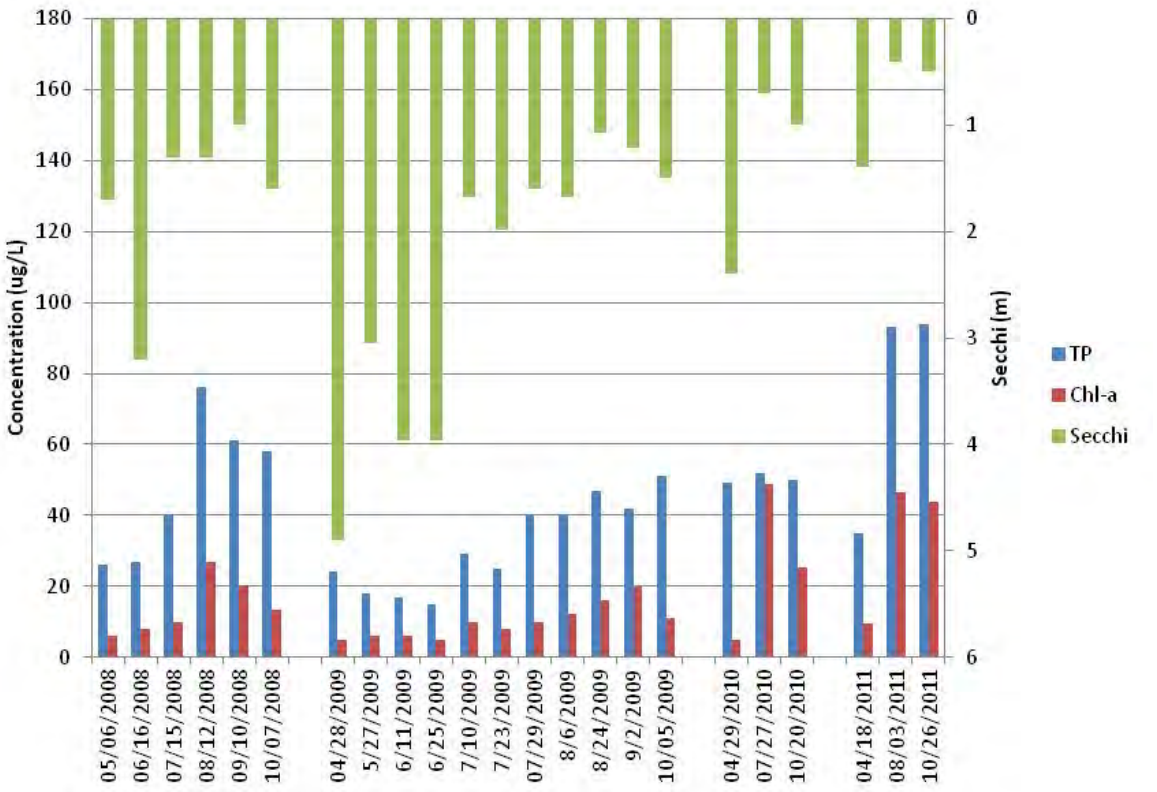


Figure 19. Pearl Lake 2008-2010 paired total phosphorus, chlorophyll-*a* concentrations, & Secchi depth

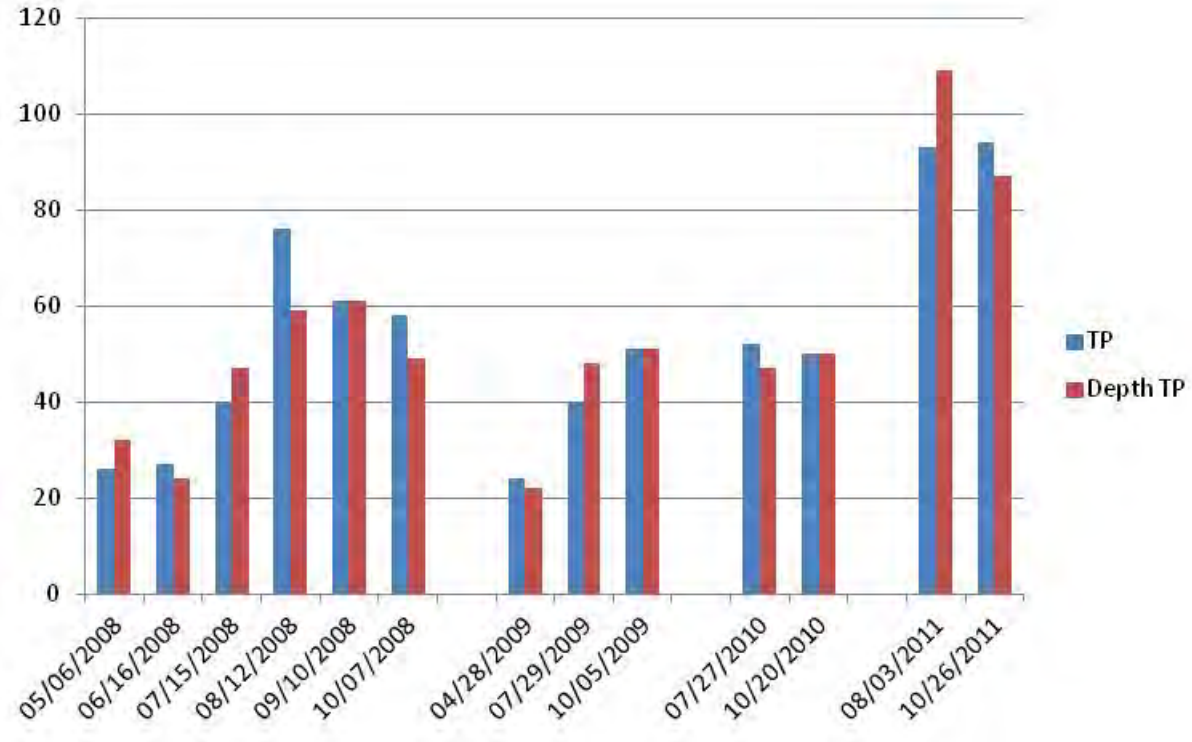


Figure 20. Pearl Lake paired hypolimnetic and epilimnetic total phosphorus observations

Dissolved minerals and organic carbon were measured as part of the long-term monitoring of Pearl and other Sentinel lakes. This includes some of the standard measures of total suspended solids (TSS), alkalinity, conductivity, and color (Table 9) as well as major cations, anions, and organic carbon (Table 10). While several of these parameters have "typical" ecoregion-based concentrations (e.g. Table 9); some do not. For parameters without ecoregion–based comparisons, data from the 2007 NLA study were used to provide perspective on reported concentrations (Table 6). Since the NLA lakes were selected randomly they provide a reasonable basis for describing typical ranges and distributions at the state-wide level (Heiskary and Lindon 2010).

TSS is within the typical range for reference lakes (Table 9) and only about one-fifth of the TSS can be attributed to organic solids (decomposing algal matter). The low color value (Table 9) indicates the water is clear and has minimal amount of total organic carbon. Lakes that receive a majority of their water inputs from forest and wetland runoff often have correspondingly higher color and TOC values as a result of incompletely dissolved organic matter (plants, leaves, and other organic material).

Alkalinity and conductivity are within the typical range for NCHF lakes (Table 9). Calcium (Ca) and magnesium (Mg) are the dominant cations; Ca exceeds the statewide data range and Mg is on the high end of the range (Table 10). The other two major cations – sodium (Na) and potassium (K) are within the typical range. Bicarbonate (alkalinity expressed as $CaCO_3$) is the dominant anion, followed by chloride (Cl) and sulfate (SO_4). Chloride is on the high end of the typical range for NCHF reference lakes (Table 9). Elevated Cl is most often attributed to application of salt on roads in the watershed, though leaching from septic systems is a potential source as well.

On most dates, the balance was less than ± 2 percent, indicating that suite of parameters was adequately representing the dominant anions and cations in the basin. Cation and anion concentrations were quite stable across sample events in 2008-2011 (Table 10), which is consistent with the literature. Mg, Na, K and Cl are noted to be relatively conservative and undergo only minor spatial and temporal change (Wetzel 2001). Mg is required by algae to produce chl-*a*. Ca and alkalinity exhibited somewhat similar patterns with peak concentrations in spring followed by a summer decline, which is a function of plant and algal primary productivity.

Phytoplankton (algae) transitioned from diatoms dominating the composition in the spring to blue-greens in the summer of 2008. Partial seasonal data is available from 2009 and 2010. Blue-greens dominated on many dates, with diatoms, dinoflagellates, and yellow-browns making up smaller portions of the population on a number of sampling dates (Figure 21).

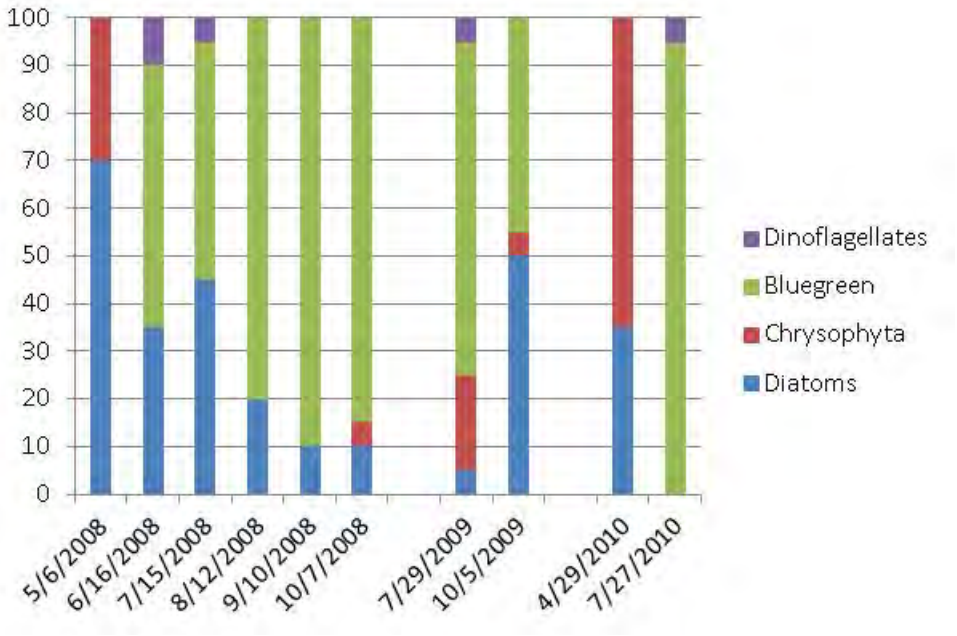


Figure 21. Algal compositions for Pearl Lake in 2008, 2009, and 2010

Zooplankton

Zooplankton samples were analyzed by Jodie Hirsch at the MDNR. A summary report was prepared that included information for all the Sentinel lakes sampled in 2008 (Hirsch 2009). Additional data from more recent years in the study were included in this report.

Pearl Lake had 14 taxa observed in the 2008 season; density and biomass of zooplankton was moderate compared to other lakes in the NCHF ecoregion (Table 12). The September sample had the highest density and biomass for the lake was relatively constant for summer 2008. Hirsch (2009) found that, in general, as lake productivity increased (e.g. TP or chl-*a*) the relative abundance and biomass of zooplankton increased as well. This appears to be the case for Pearl Lake and the other NCHF lakes (Figure 22)**.**

Table 12. 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 Corn Belt Plains			
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			
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
Sentinel Lakes Zooplankton 2008	**Mean Annual Densities (#/L)**	**Mean Annual Biomass (µg/L)**	**Total# Taxa**
Northern Lakes and Forests			
Portage Lake	100.10	277.38	10
Cedar	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

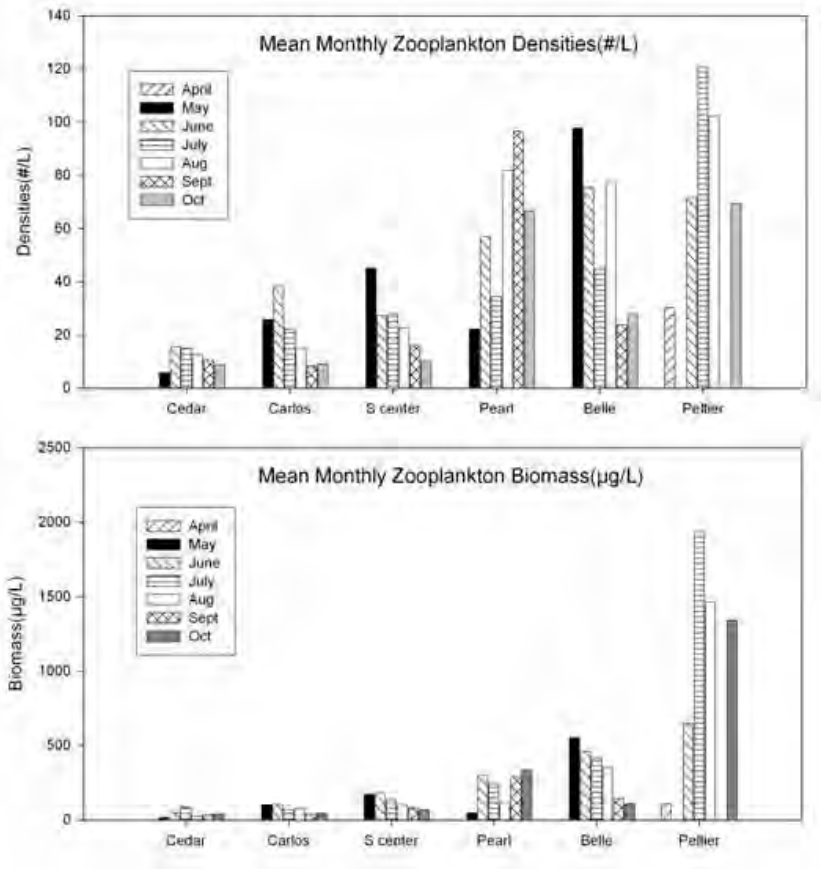


Figure 22. Mean monthly zooplankton densities and biomass for North Central Hardwood Forest Ecoregion Sentinel lakes in 2008

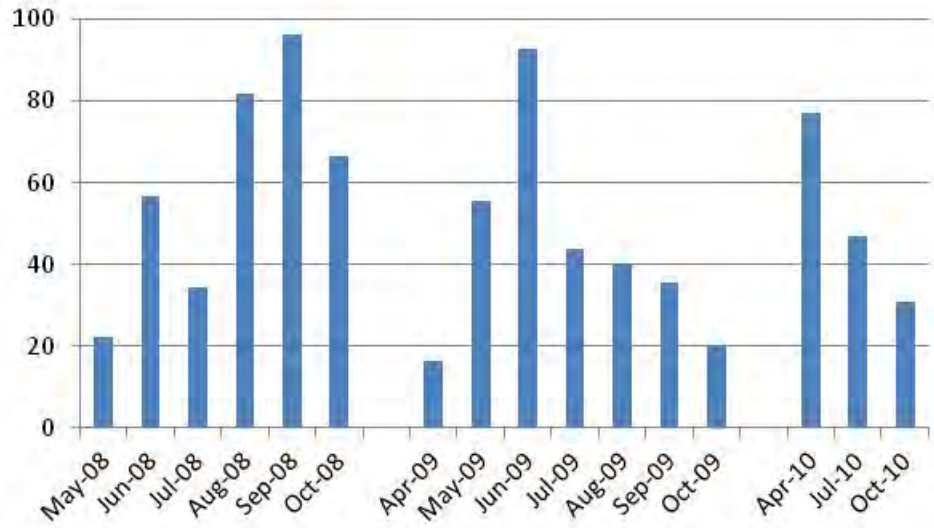


Figure 23. Mean monthly zooplankton density (#/L)

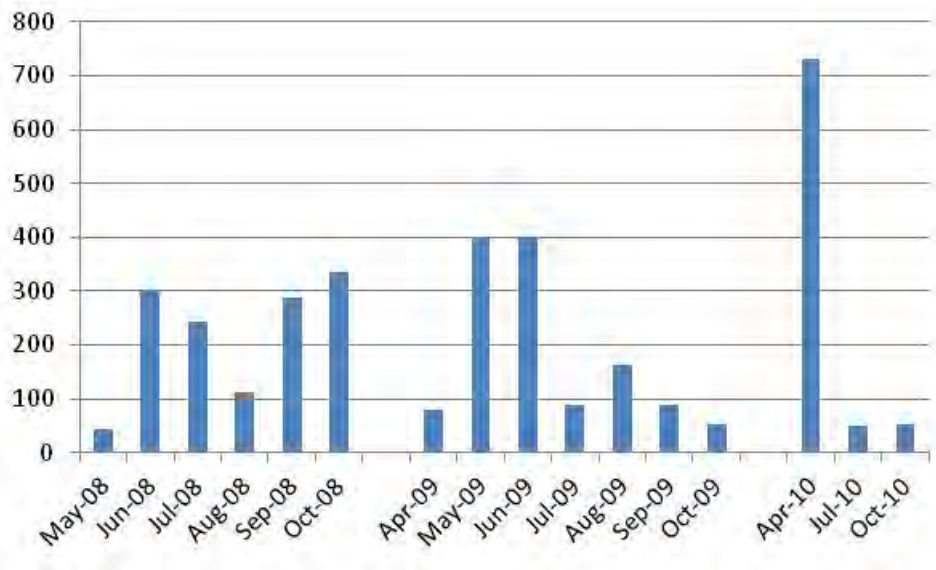


Figure 24. Mean monthly zooplankton biomass (ug/L)

Zooplankton density is typically highest in the spring for Pearl Lake and declines across the season, with the exception of the 2008 season (Figure 23). Zooplankton densities vary greatly across the season, with densities approaching 100 organisms per liter in the spring and dropping as low as 20 organisms per liter in the fall. Biomass varied from a low of 50 ug/L to a high of 400 ug/L (Figure 24).

Trophic State Index

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

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

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

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

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of 10 units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a basis for assessing the relationship among TP, chl-*a*, and Secchi (Figure 25). In general, the TSI values are in fairly close correspondence with each other. The TSI values also correspond with observations for 2008-2010. Based on an average TSI score of 61, Pearl Lake would be characterized as eutrophic.

TSI < 30 Classical Oligotrophy: Clear water, oxygen throughout the year in the Hypolimnion, salmonid fisheries in deep lakes.

TSI 30 – 40 Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

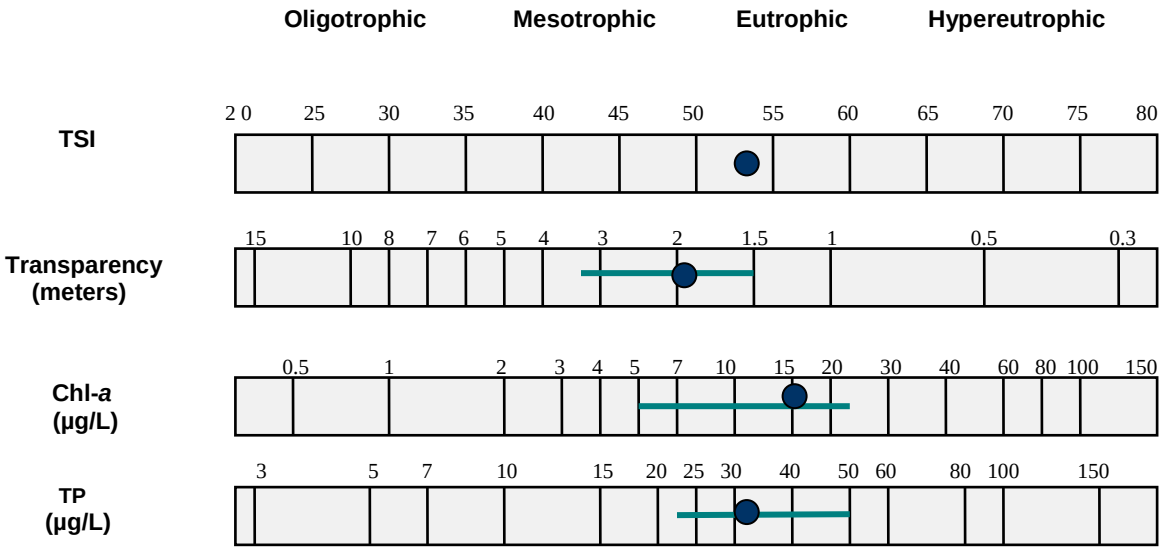
TSI 40 – 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 – 60 Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 – 70 Dominance of blue-green algae, algal scums probable, extensive Macrophyte problems.

TSI 70 – 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.

TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



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

NCHF Ecoregion Range: 2008-2010

Figure 25. Carlson's Trophic State Index for Pearl Lake

Trophic Status Trends

One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in EQuIS. A review of data in EQuIS indicates there is a good amount of data for Pearl Lake to describe annual variability and to statistically assess trends for Secchi transparency (Figure 26). The water chemistry dataset is much less robust; prior to the start of monthly sampling in 2008, the most recent water chemistry was a single sample collected in June 1981.

In general, for trend assessment, a minimum of eight years of consistent data is required. During the most recent trend analysis completed using Citizen Lake Monitoring Program Secchi data, it is estimated that water clarity is declining by 0.3 meter per decade (estimated range of 0.1 to 0.5 meter decline per decade). Based on Figure 25, the annual Secchi average has been less than the long-term mean for much of the recent decade.

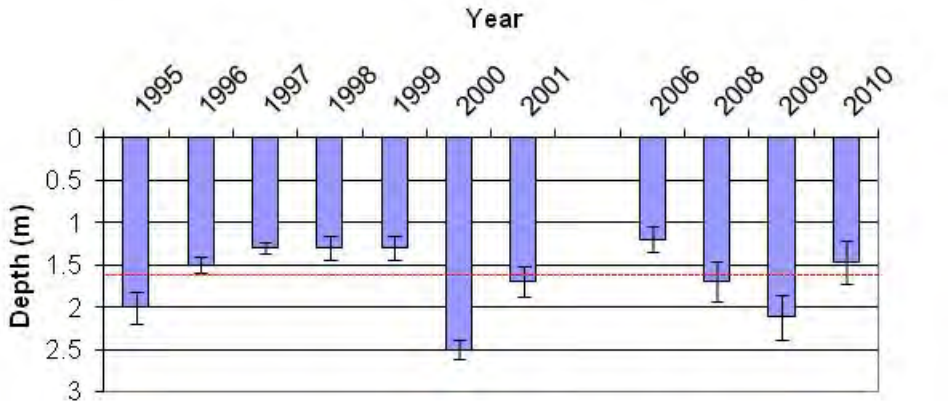


Figure 26. Pearl Lake long-term summer-mean Secchi disk depth
Long-term mean noted by dashed red line

A single data point from 1981 is available for comparison of TP and chl-*a* concentrations (Figure 27). It indicates that conditions in 1981 were similar to those in 2010; with elevated TP and chl-*a*. Based on yearly TSI averages calculated for 1985 through 2010, Pearl Lake has historically been classified as eutrophic and over the recent decade is trending toward hypereutrophic conditions (Figure 27).

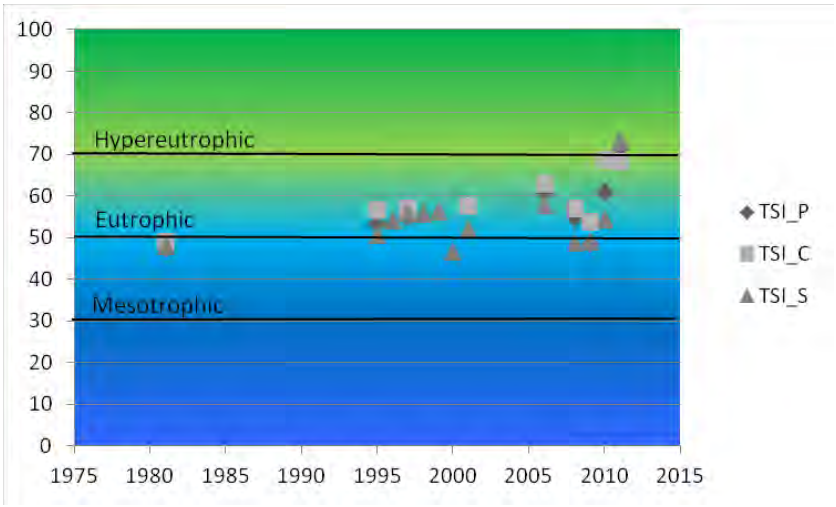


Figure 27. Pearl Lake trophic status trend

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 2008-2010 water quality of Pearl 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 13.

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 Pearl Lake, MINLEAP was applied as a basis for comparing the observed summer (2008-2009) TP, chl-*a*, and Secchi values with those predicted by the model based on the lake size and depth and the area of the watershed. As noted earlier in the report, during the development of the Pearl Lake TMDL, it was determined that a contributing watershed was smaller than the total watershed for the lake; both will be presented in Table 13 and the discussion below.

Pearl Lake is located in the NCHF ecoregion and the model was run with NCHF ecoregion-based inputs. Estimated water residence time is on the order of one to two years (Table 13), based on the volume of the lake, and estimated runoff, precipitation, and evaporation. The observed TP and chl-*a* values, when considering model error, are not significantly different from model-predicted values (Table 13).

The estimate of "background" TP (Vighi and Chiaudani) is approximately three-quarters of the modern-day TP concentration for Pearl Lake (Table 13). These results indicate that while Pearl Lake's observed TP is somewhat lower than MINLEAP-predicted, it has increased relative to the estimated background concentration. In addition, MINLEAP suggests the lake has the potential for significant increases in chl-*a* and declines in transparency if watershed phosphorus loading continue to increase.

Table 13. MINLEAP model results for Pearl Lake

Parameter	2008-2010 Pearl Lake Observed	MINLEAP Predicted NCHF Ecoregion Total Watershed	MINLEAP Predicted NCHF Ecoregion Contributing Watershed[1]
TP (µg/L)	38	60 ± 19	50 ± 17
Chl-*a* (µg /L)	13	26 ± 15	19.8 ± 12.1
Secchi (m)	2	1.1 ± 0.4	1.3 ± 0.5
P loading rate (kg/yr)		1,115	841
P retention (%)		61	69
P inflow conc. (µg/L)		156	162
Water Load (m/yr)		3.2	1.71
Outflow volume (hm^3/yr)		9.72	5.19
Residence time (yrs)		0.9	1.8
Vighi and Chiaudani		27	26.6

[1]As defined by the Pearl Lake TMDL (Barr 2011)

As part of the Pearl Lake TMDL, a finite difference model was used to predict the concentration of phosphorus in the water column (Pilgrim et al., 2007). It appears that the internal loading rate varies annually, with a marked increase after curly-leaf die-off in 2008 and a more constant level of internal loading in 2009 when the curly-leaf population was significantly lower (Barr 2011).

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 waterbody 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. Assessments against water quality standards are completed annually. The agency follows a rotating watershed approach, so that each watershed is assessed one year in a 10-year cycle, immediately following a two year intensive monitoring effort. Pearl Lake is scheduled to be assessed next in early 2014.

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 waterbody 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.

Pearl Lake, with a maximum depth of 5.5 meters and 68 percent littoral area would be held to the NCHF Aquatic Recreation Use (Class 2B) standard for deep lakes. Pearl Lake was formally assessed on the 2008 Impaired Waters List as not meeting aquatic recreation use standards (Table 14). At the time of the 2008 assessment, the lake was just exceeding the standard. This, combined with a six-year decline in Secchi, and a notable increase in phosphorus and chlorophyll-a in 2006, resulted in Pearl being added to the 2008 impaired waters list. Since that listing and the TMDL development, phosphorus and chlorophyll-*a* values are slightly better than the standard and the lake may be reviewed for removal from the list, should improve conditions continue. Given that Pearl is very close to the eutrophication standards, its water quality should benefit from even small reductions in phosphorus loading-in contrast to a lake that greatly exceeds the standards and requires large reductions before water quality improvements are realized.

Table 14. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005)
Pearl Lake listing data and 2008-2009 means provided for comparison. Applicable standard in bold.

Ecoregion	TP	Chl-*a*	Secchi
	µg/L	µg/L	meters
NCHF – Aquatic Rec. Use (Class 2b)	**< 40**	**< 14**	**> 1.4**
Pearl Lake 1998-2007	43	19.9	1.6
Pearl Lake 2008-2009	38	13.0	2.0

Analysis conducted through the TMDL development indicated that measures should be taken to reduce nonpoint source runoff to the lake and address internal recycling of TP. A special note was made in the TMDL regarding the role curly-leaf pondweed die-off is playing in the increase of internal loading (Barr, 2011). Since that report, additional analysis by Heiskary and Valley indicate that the internal loading may be less driven by the die-off than previously thought (Heiskary and Valley, 2012). It will be important to reduce watershed inputs of phosphorus and to consider how to best control or reduce the internal loading in Pearl Lake. Whether efforts should be targeted towards curly-leaf management or directly to the sediment to achieve the maximum reduction has yet to be determined.

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Appendix A

Lake Surface Water Quality Data for Pearl Lake for 2008-2011.
All water quality data can be accessed at: http://cf.pca.state.mn.us/water/watershedweb/datasearch/waterUnit.cfm?wid=73-0037-00.

Lake Name	Lake Site	Sample Date	Alkalinity	Color, Apparent	Chloride	Chl-a	Secchi	NO2+NO3	TKN	TP	TSS
			mg/L	PCU	mg/L	ug/L	meters	mg/L	mg/L	ug/L	mg/L
PEARL	73-0037-00-203	05/06/2008	180	10	19.5	5.92	1.7	0.35	0.61	26	2.8
PEARL	73-0037-00-203	06/16/2008				7.88	3.2	< 0.05	0.66	27	
PEARL	73-0037-00-203	07/15/2008	140	5	19.8	9.81	1.3	< 0.05	0.74	40	4.8
PEARL	73-0037-00-203	08/12/2008				26.8	1.3	< 0.05	1.07	76	
PEARL	73-0037-00-203	09/10/2008				20.3	1	< 0.05	1.11	61	
PEARL	73-0037-00-203	10/07/2008	140	10	20.5	13.5	1.6	< 0.05	0.79	58	4.4
PEARL	73-0037-00-203	04/28/2009				5	4.9			24	
PEARL	73-0037-00-203	07/29/2009	130	5	20	9.7	1.6	< 0.05	0.8	40	3.6
PEARL	73-0037-00-203	10/05/2009	140	10	20.6	10.9	1.5	0.06	1.08	51	6.2
PEARL	73-0037-00-203	07/27/2010	150	10	19.6	48.7	0.7	< 0.05	1.79	52	12
PEARL	73-0037-00-203	10/20/2010	170	10	19.4	25.1	1	0.2	1.22	50	11
PEARL	73-0037-00-203	08/03/2011	160	20	15.4	46.4	0.4	< 0.05	1.31	93	16
PEARL	73-0037-00-203	10/26/2011	170	20	18	43.8	0.5	< 0.05	1.22	94	22