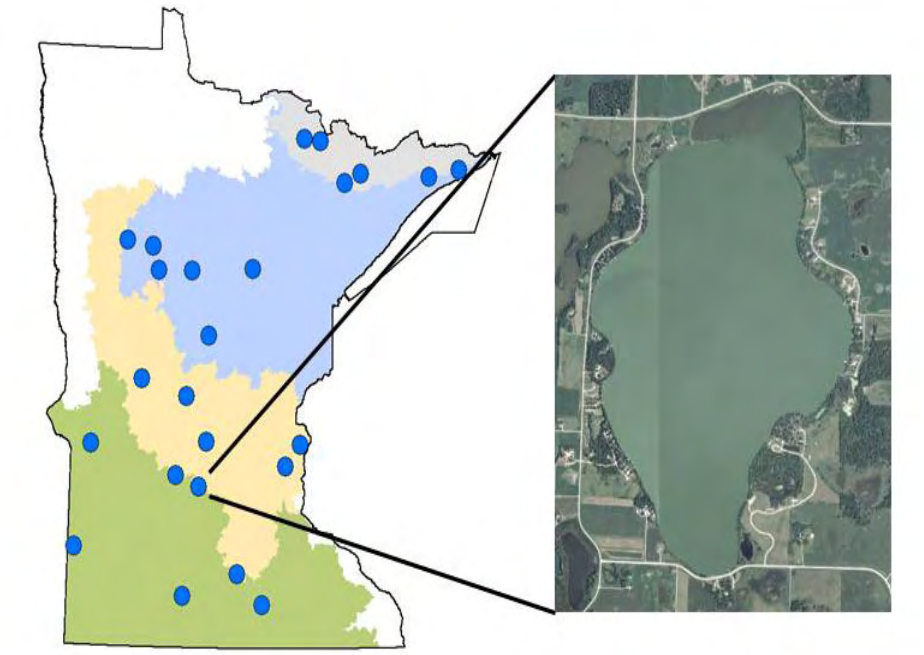
Sentinel Lake Assessment Report
Belle Lake (47-0049-01)
Meeker County, Minnesota



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

October 2011

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Executive Summary

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

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). The "deep" lakes typically stratify during the summer months only. "Shallow" lakes are defined as mixing continuously throughout the summer. "Cold water" lakes are defined as lakes that 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.

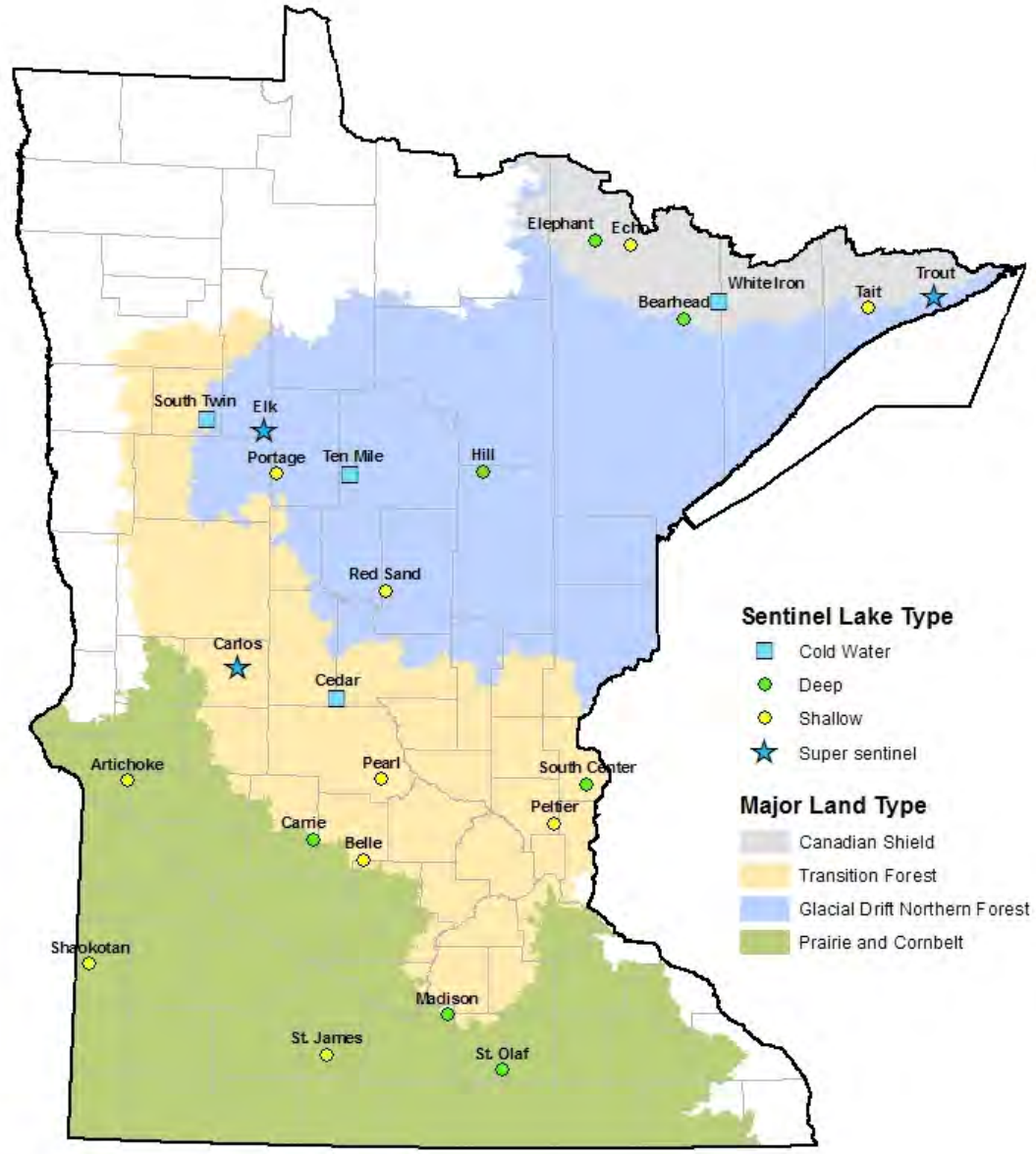
Belle Lake was selected to represent a shallow lake in the transition between North Central Hardwood Forests (NCHF) and Western Corn Belt Plains (WCBP) ecoregions. Belle Lake is a 349 hectare (863 acres) lake, located near Hutchinson, Minnesota in Meeker and McLeod counties, within the South Fork Crow River watershed. The lake has a maximum depth of 7.6 meters (25 feet) and a mean depth of 4.9 meters (16 feet). The lake is 44 percent littoral with two public accesses, one on the southeast shore and one on the east shore of the lake. The total contributing watershed for Belle Lake is 2,106 hectares (5,206 acres).

Belle Lake is a moderately deep lake that mixes continuously throughout the open water season. The lake has a large fetch and is susceptible to wind mixing. Based on recent water quality data (2008-2010), Belle Lake is considered to be eutrophic with total phosphorus (TP), chlorophyll-*a* (chl-*a*), and Secchi values of: 56 micrograms per liter (µg/L), 23.2 µg/L, and 1.0 meters (3.2 feet) respectively. TP is greater than the typical ranges (based on reference lakes) for NCHF ecoregion and better than the typical ranges for the WCBP ecoregion. Algal blooms were observed and transparency was typically low during much of the summer. Secchi data collected since the 1990s suggest declining water clarity over the past decade. Based on these data, Belle Lake, while not formally assessed, is exceeding the aquatic recreation use standards (i.e. not supporting recreation use).

Despite its high position in the watershed with light residential development and moderate crop cultivation, Belle Lake has been a common-carp infested turbid lake lacking aquatic plant growth since the first lake survey records in 1947. The cumulative effects of runoff from farm fields and potential septic sources coupled with the bottom-feeding activities of common carp have likely led to the impaired water quality conditions in the lake.

The consequence of poor water quality conditions has been a highly variable fish community that is less diverse than other similar lakes. Still, walleye populations are maintained through stocking and have consistently been above average compared with similar lakes. Due to the lack of aquatic plant cover, bluegill, pumpkinseed, and largemouth bass populations have historically been low. Habitat for northern pike is also marginal if not poor within Belle Lake, but access to marshy habitats downstream from Belle appears to have periodically supported some sizeable year classes. Throughout the surveyed history of Belle Lake, recruitment of yellow perch, black crappie, white sucker, black bullhead, and common carp has been variable. An ecoregion-based eutrophication model was used to predict in-lake TP based on Belle Lake's size, depth, and watershed area using inputs from the NCHF and WCBP ecoregions. The model predicted in-lake TP at 30 µg/L, which is significantly lower than the observed values. A separate subroutine within the model estimated "background" TP for the lake at 24 µg/L. The model predictions, along with the overall assessment of Belle Lake's water quality data, clearly indicate the lake's water quality is worse than anticipated for a lake of this size in this portion of the State.

Figure 1. Sentinel lakes and major land types



Introduction

This report provides a relatively comprehensive analysis of physical, water quality and ecological characteristics of Belle Lake in Meeker County, Minnesota (MN). This assessment was compiled based on Minnesota Department of Natural Resources (MDNR) surveys of the lake's fish and aquatic plant communities, Minnesota Pollution Control Agency (MPCA) and volunteer water quality monitoring, and analysis of various other sources of data for the lake. The water quality assessment focuses on data collected during the 2008-2010 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

1800's

An 1857 Public Land Survey map shows Belle Lake at an elevation similar to current levels, and possibly connecting through wetlands with Fallon Lake.

1900-1950

From 1908-1947 stocking consisted of northern pike, bass, sunfish, crappie, silver bass, sucker, minnow, and bullhead. Silver bass were likely not indigenous to Belle Lake.

Major wetland draining begins in the 1920's. After the major drought in the early 1930's, USDA aerial photos taken in 1938 show Belle Lake to be 10 to 15 feet lower, compared to existing levels, exposing as much as 50 percent of the lake bottom. Winterkills were reported in the 1930's, 1941 and again in 1948. Belle was closed to darkhouse spearing from 1944-1951 and closed to taking of minnows commercially from 1945-1951. The lake was closed to angling from 1944-1946. The lowest recorded water level was 1067.66' on 9/9/43. The initial MDNR lake survey report was in 1947. No resorts and nine homes were present at that time. The 1947 lake level was estimated to have risen 5-10' from the 1940 seining assessment. A slight overabundance of bullhead was noted, but Belle was considered a game fish lake and walleye management was recommended. The watershed was described as rolling moraine being moderately timbered with hardwood forest (oak-basswood). World War II ends in 1945 and industrial agriculture begins.

1950-1980

Winterkill was reported in 1953; along with a summerkill of bullhead caused by Argulus. In 1953, the MDNR acquired the access on east shore. In 1957, a full MDNR survey was done. The ecological classification was warm-water game fish. The watershed was estimated at 60 percent cultivated, 25percent grassland pasture, and 15 percent woodland. The number of cottages present was 14. The carp trap between Belle and Cedar Lake was noted as being present in 1957, and sometimes prevented movement of large fish between lakes, but never small fish.

Lake bathymetry was mapped in 1968 and updated in 1975. A summerkill of northern pike, sucker, crappie, sunfish, and perch was reported in 1970. A MDNR fisheries resurvey was completed in 1975. The immediate watershed was estimated at 80 percent agriculture, 15 percent cabins and homes, and five percent marsh. Carp barriers were now recorded as being present on inlets from the wetland, south of Erie Lake, and at the wetland between Stahl's and Belle lakes. The barriers were never 100 percent effective at preventing fish movement. The number of lake homes present increased to 24. Davis (1975) investigates the diets of walleye in Belle Lake and finds walleye preference for yellow perch, bullheads and crappie. Annual winter fish house counts began in 1977. Largemouth bass, northern pike, walleye, crappies, sunfish, and suckers were frequently stocked during the 1950 – 1980 time period.

1980's

A MDNR population assessment was completed in 1980. A MDNR resurvey was completed in 1983. The number of cottages present increased to 28. Curly-leaf pondweed was first sampled in 1983 and its abundance was rated as occasional. Belle was given an ecological classification of Centrarchid (i.e., bass/sunfish) and a management classification of Walleye-Centrarchid. The initial lake management plan was written in 1984 and updated in 1986 and 1989 with a shift in focus to primary management focused on walleye and secondarily on northern pike and bluegill. Northern pike were last stocked in 1984. Piepenberg County Park, in McLeod County, opened in 1984 and provided a second boat ramp for anglers and a fishing pier in 1987. A five year bluegill stocking program began in 1985, but objectives were not met. The last time that bluegill were stocked was 1989. A walleye was diagnosed as having Myofibrogranuloma in 1989.

1990's

The lake management plan was rewritten in 1991with primary management species changing to walleye and northern pike and secondary management species changing to black crappie, largemouth bass, and black bullhead. Revisions were completed in 1992, 1993, 1994, and in 1996 the secondary species was changed to black crappie. Black crappies were stocked in 1991 and 1992. Flathead catfish, 59 adults, were stocked to control the bullhead population in 1991, with inconclusive results. Largemouth bass were last stocked in 1991. The lake association formed between 1990 and 1992 and began monitoring water levels under the Division of Waters Lake Gage Program. Fish were tested for contaminants in 1992. A resurvey was conducted in 1993. The watershed was estimated to be 75 percent agriculture. A total of 36 homes were now present on the lake. The highest recorded water level of 1079.35' occurred on 7/3/93. A new walleye stocking regime (1,000 fry/littoral acre every other year) was initiated in 1993 that is still being followed in 2010. Annual fall electrofishing for young-of-the-year walleye was initiated in 1993 to document natural reproduction of walleye. The lake classification was changed to a class 24, in 1995. Deformed frogs were found in 1996 around Belle Lake with an investigation by the Minnesota Pollution Control Agency. The Piepenberg Kid's Fishing Pond was first stocked in 1994; given its own DOW number (47-0049-02) in 1998, and was typically stocked with bluegill, pumpkinseed sunfish, and black crappie. The lake management plan was rewritten in 1998 and 1999. A fishkill of bullhead occurred in 1999.

2000's

Between 2000 and 2003, the county park rip-rapped 400' of shoreline on Belle Lake to reduce erosion. The project went from the small lagoon on the east shore continuing south around the point. In 2003, the MDNR rip rapped from the beach to the north (meeting up with the County's project). The "No Molesting Fish" signs were removed from the outlet trap, so anglers could legally fish in the area. A lake shore owner illegally removed cattails in 2003 on the northeast shore, and restoration orders were written in 2003 and 2006. The lake management plan was rewritten in 2004, with the primary management species changing to walleye and black crappie and the secondary management species changing to northern pike. The metal grate fish trap at the outlet to Cedar was removed in 2006. The lake management plan was rewritten in 2007. A summerkill of carp was documented in 2008. Sustaining Lakes in a Changing Environment (SLICE) sampling begins with MDNR population assessments in 2008, 2009, and 2010. A resurvey was scheduled for 2011. Near shore Index of Biotic Integrity sampling was first conducted in 2008. A walleye was diagnosed as having Myofibrogranuloma in 2010. The current Belle Lake ordinary high water level was 1077.8'. Record high water levels observed in summer 2011.

Background

Lake Morphometric and watershed characteristics

Belle Lake is on the border of Meeker and McLeod counties within the South Fork Crow River watershed. Belle Lake is located near Hutchinson, MN. Two public accesses are located on Belle Lake, one on the east shore and one in the Piepenberg County Park on the southeast shore. Belle Lake has moderate depth; however it has a relatively long fetch (distance wind can travel unimpeded by land) that allows for significant wind mixing (Figure 2).

Belle 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.

The lake's watershed has one drainage point located on the northwest shore of the lake empting into Cedar Lake. The contributing watershed has a total area of 2,106 hectares (5,206 acres) resulting in a watershed-to-lake area ratio of approximately 5:1.

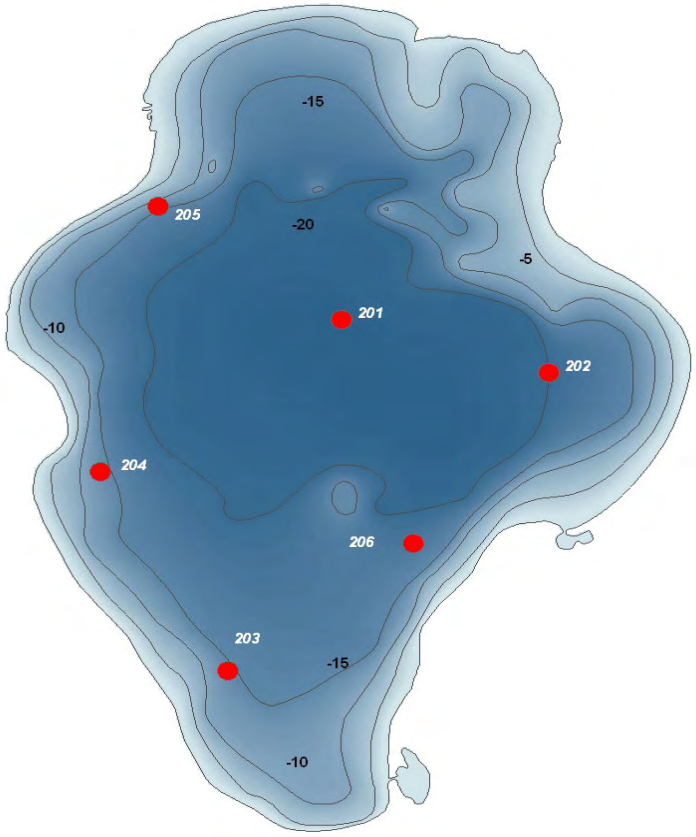
Soils in the Belle Lake watershed consist of those in the Central Iowa and Minnesota Till Prairies major land resource area. The major soil series are Lester-Storden-Muskego and Lester-Cordova-Canisteo, which are primarily loamy soils, underlain by glacial till, outwash, and glacial lake deposits. Agriculture dominates the land use in these soil types, and water erosion is a known problem (USDA, 2006).

Table 1. Belle Lake and watershed morphometric characteristics

Lake Name	Lake ID	[1]Lake Basin	[2]Lake Basin	Littoral Area	[3]Total Watershed Area	Watershed: Lake	[2]Max. Depth	[2]Mean Depth	Lake Volume
		Hectares (Acres)	Hectares (Acres)	%	Hectares (Acres)	Ratio	Meters (Feet)	Meters (Feet)	Acre-Ft.
Belle	47-0049-01	334 (826)	349 (863)	44	2,106 (5,206)	5 : 1	7.6 (25)	4.9 (16)	13,808

[1] Based on the Protected Waters Inventory, MDNR
[2] Based on the 2009 1:100,000 Lakes and Rivers Coverage, MDNR
[3]Based on the MDNR Catchments Lake Watersheds Layer

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



Lake mixing and stratification

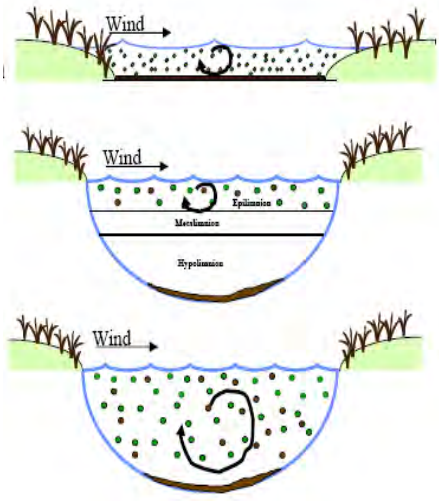
Lake depth and mixing has a significant influence on lake processes and water quality. *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of nine meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (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. This 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 are available to algae.

Figure 3. Lake stratification

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

Dimictic Lake
Deep, form layers,
Mixes Spring/Fall

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



Ecoregion and land use characteristics

Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Belle Lake lies within the North Central Hardwood Forests (NCHF) ecoregion, in the transition zone to the Western Corn Belt Plains (WCBP) ecoregion (Figure 4). NCHF and WCBP 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 (38 percent), which is distributed throughout the watershed. Water/wetland and forested land uses comprise approximately 29 percent and 24 percent of the watershed (Figure 5, Table 2), which is consistent with the NCHF ecoregion but would be a high percentage for the WCBP. The open water/wetland areas in the southern portion of the watershed likely retain a significant portion of the nutrient and sediment load from this portion of the watershed. Based on the watershed land use composition, Belle Lake is most appropriately associated with the NCHF ecoregion (Table 2).

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

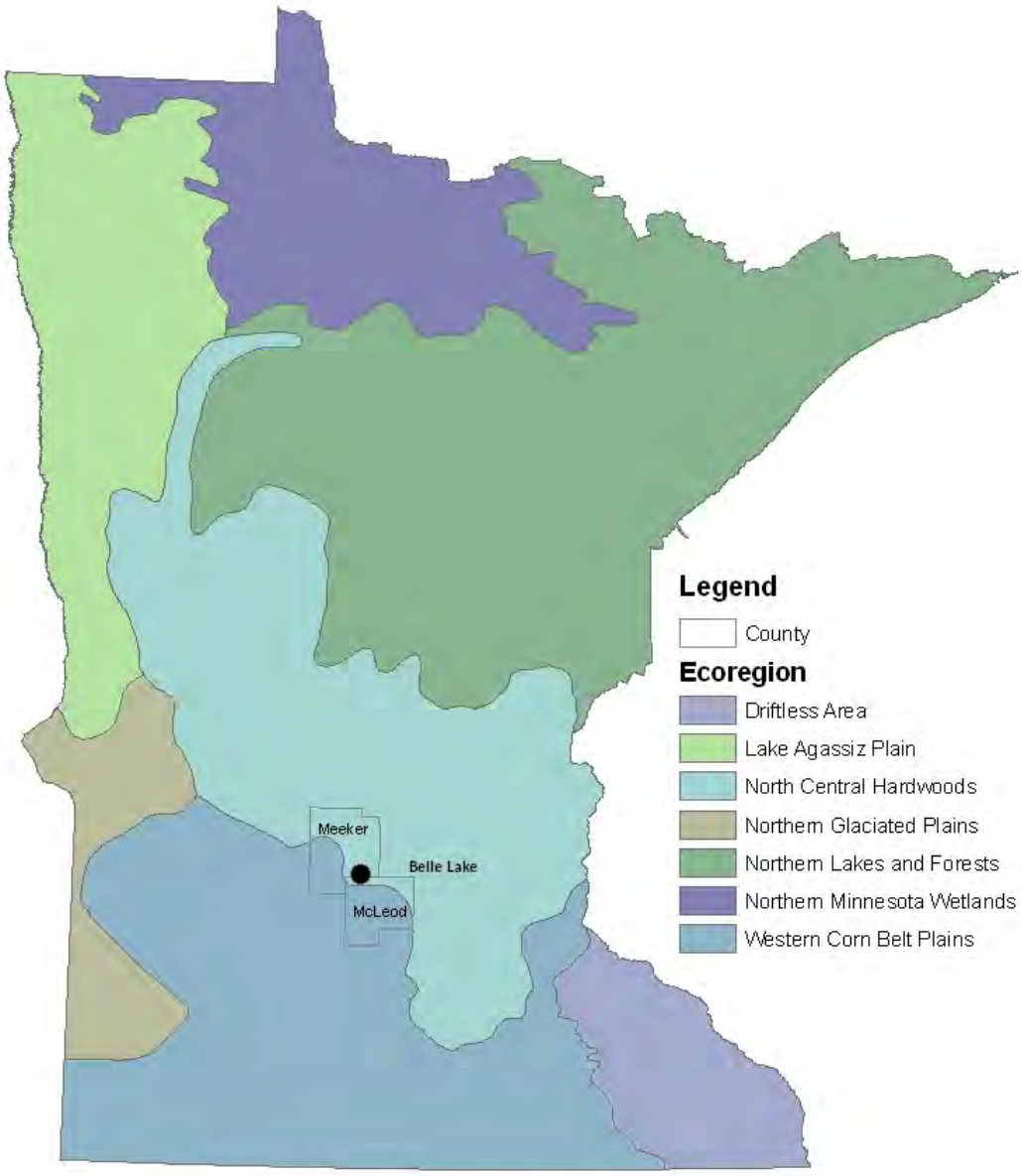


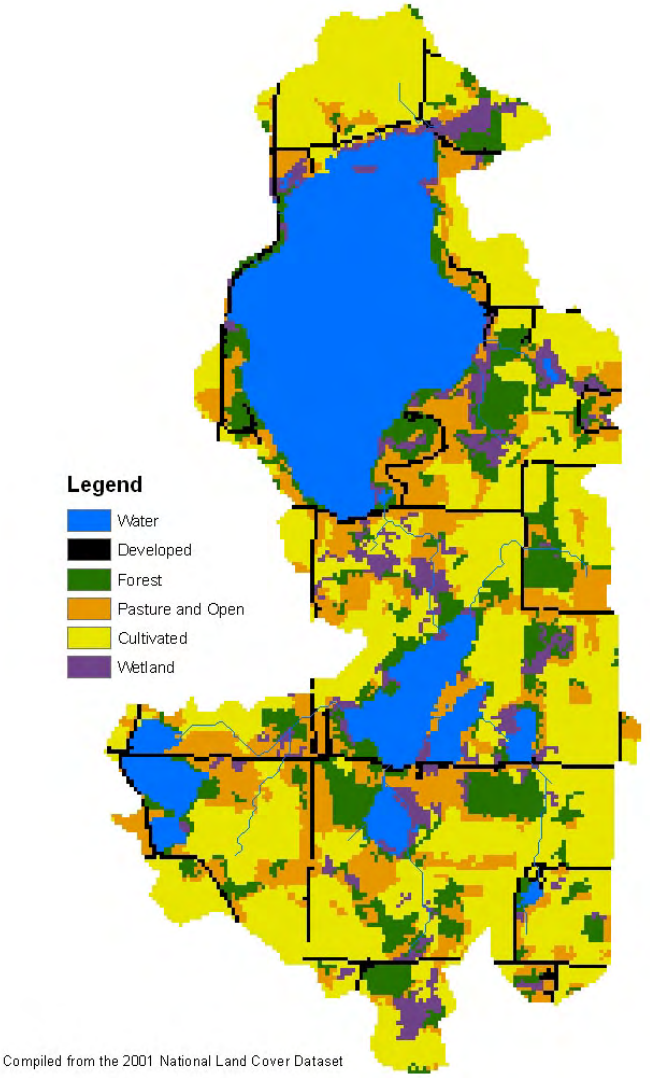
Table 2. Belle Lake ecoregion land use comparison

Typical (interquartile) range based on 35 NCHF and 12 WCBP ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	NCHF ecoregion	WCBP ecoregion	Belle $(1969)_2$	Belle $(1991)_3$	Belle $(2001)_1$
Developed	2 - 9	0-16	3	0	4.5
Cultivated (Ag)	22 - 50	42-75	46	44	38
Pasture & Open	11 - 25	0-7	12	9	16
Forest	6 – 25	0-15	17	24	23.5
Water & Wetland	14 - 30	3-26	22	23	29.5

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

Figure 5. Belle Lake watershed and land use composition



Lake level and ice on/off

The MDNR Division of Waters has been measuring water levels intermittently on Belle Lake since 1943. The long-term record is spotty until 1992, when a consistent record is available (multiple readings per year). During the period of record (1943 – 2010), the lake has varied by 3.6 m (11.69 feet), based on 607 readings. The highest and lowest recorded elevations up to 2010 were 1079.35 feet on 7/3/1993 and 1067.66 feet on 9/9/1943, respectively. The ordinary high water mark (OHW) for Belle Lake is 1077.8 feet (Figure 6). Lake levels increased in 2010 and were even higher in 2011, consistent with increased precipitation (Figure 7). The 1993 high water mark was broken on 6/3/2011when water levels reached 1079.69 ft. The pictures below, taken during a MDNR curly-leaf survey in June 2011, provide evidence of flooding and erosion at several locations on the lake (Figure 8). The complete water level record may be obtained from the MDNR website at: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=47004900.

Historic lake files detail an extensive history of hydrologic alterations to Belle Lake. Belle drains west to Cedar Lake, Harden Lake, Hoff Lake, ultimately outleting to the South Fork of the Crow River. Cedar Lake and Belle Lake, based on topographic maps, have the same outlet elevation. Depending on lake levels and runoff, water can flow from Cedar to Belle and vice versa. At high water levels, Belle may outlet to the north through Fallon Lake and ultimately the North Fork of the Crow River. Both Belle and Fallon sit at the top of the watershed, perched at the North and South Fork of the Crow River divide.

USDA aerial photos showed that in 1937, parts of Cedar Lake and Harden Lake were dry and Belle was very low. A ditch, between Harden Lake and Cedar Lake, was dredged in 1943 to divert water from Harden into Cedar and Belle, which had not yet filled following the drought. A connection enhancement (dredging) was made between Belle and Cedar around 1945, thus allowing easier movement of fish between the lakes. Fish are able to move from the South Fork of the Crow River to Belle when flows or water levels are adequate (spring runoff, heavy rainfall, etc.). The water level in the Belle/Cedar culvert, during the open water season, is usually deep enough for fish to move between the two lakes.

Ice-on records for Belle Lake are limited to the most recent ten years of sampling. The earliest ice on was recorded 11/21/2008 and the latest ice on was recorded 12/31/2004. Ice off was earliest in 2004, with the ice gone on 3/28/2004; 4/22/2008 was the latest ice off recorded.

Precipitation and climate summary

Rain gage records from Hutchinson, MN show four, one-inch plus rain events during summer 2008, four in the summer of 2009, and nine in the summer of 2010 (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 Belle 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 9). Lake level can respond to these changes in precipitation; though there may be a lag in this response (Figure 7). Changes in precipitation over time have a distinct affect on groundwater levels, which are very important in lake level regulation in lakes with small watershed: lake ratios like Belle Lake.

Figure 6. Historical Belle Lake water level (OHW in red

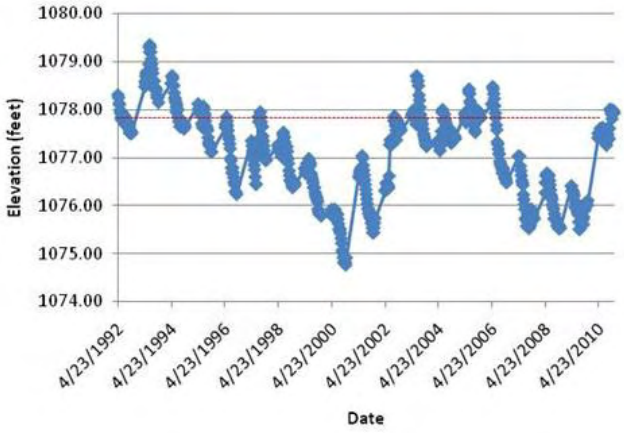


Figure 7. Summer (April to October) 2008-2010 rainfall based on records for Hutchinson, Minnesota and lake level

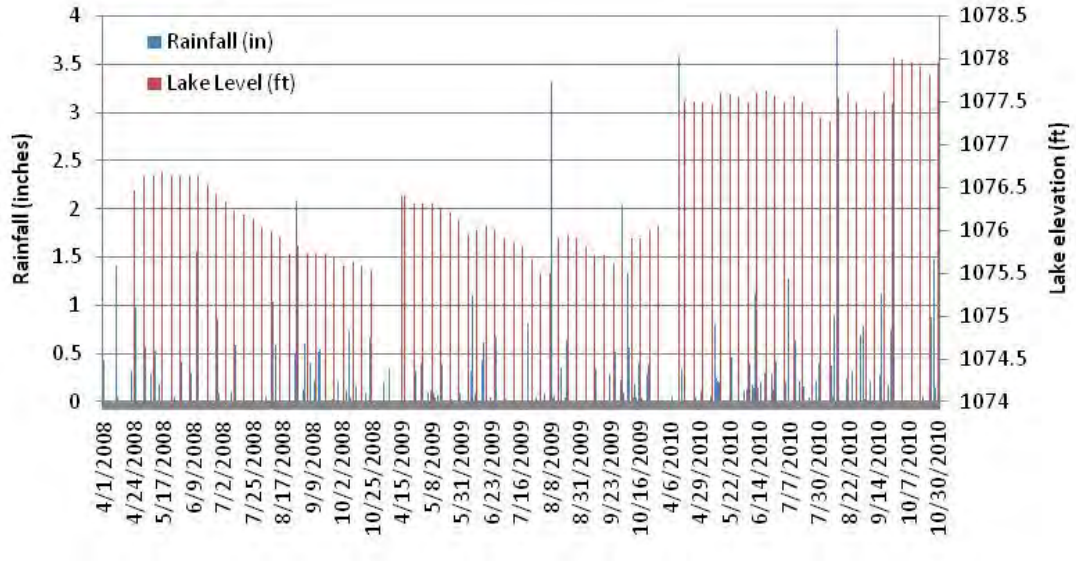
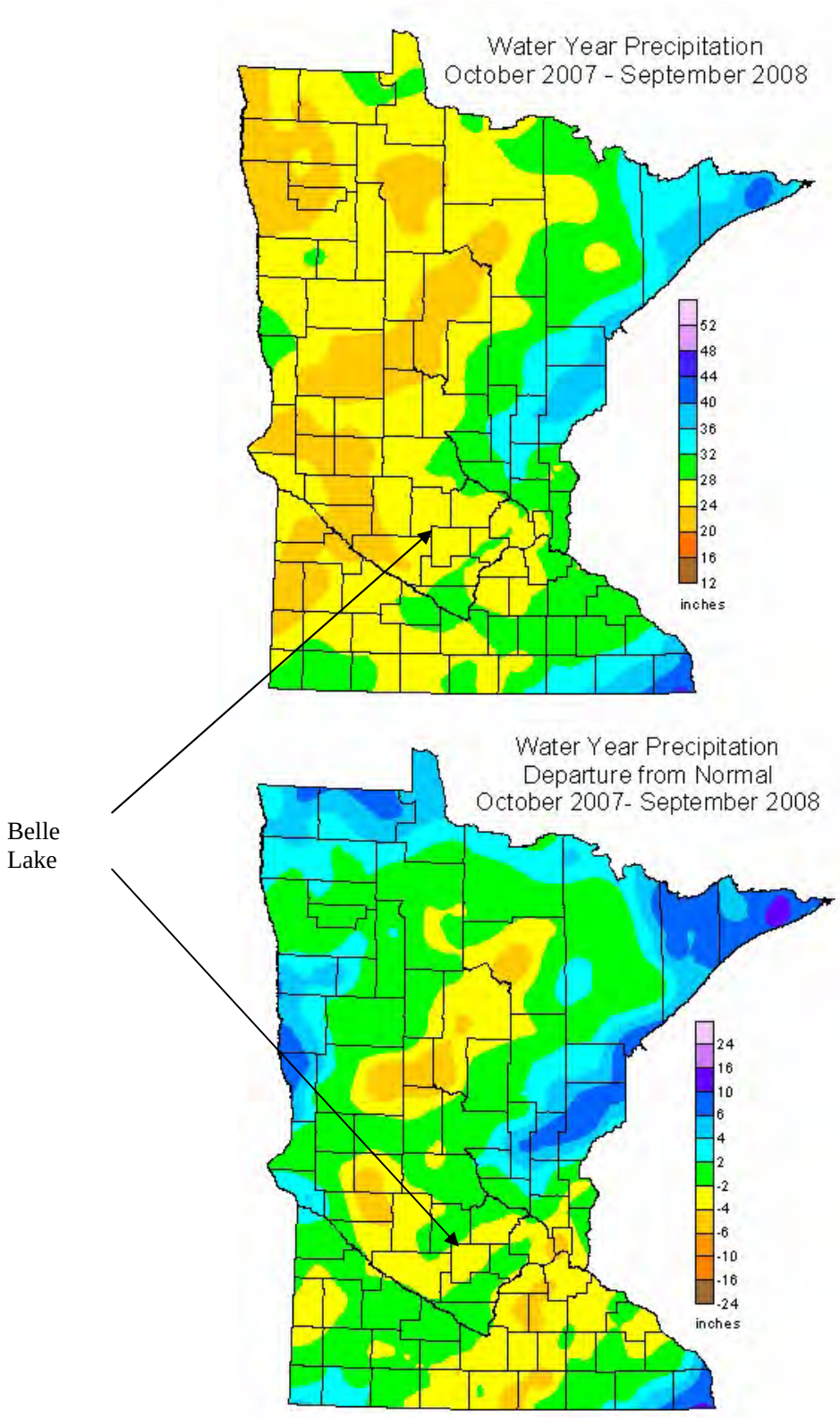


Figure 8. 2011 Photos of Belle Lake high water and erosion



Figure 9. 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 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).

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 Belle Lake were collected monthly by MPCA staff in 2008 and 2009 and seasonally in 2010. Bi-weekly dissolved oxygen (DO) and temperature profiles and Secchi disk measurements were collected by a volunteer. 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 201 (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 .

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

Zooplankton

Zooplankton samples were collected monthly from May to October 2008 and 2009 and seasonally in 2010. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 meter of the bottom and withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100 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).

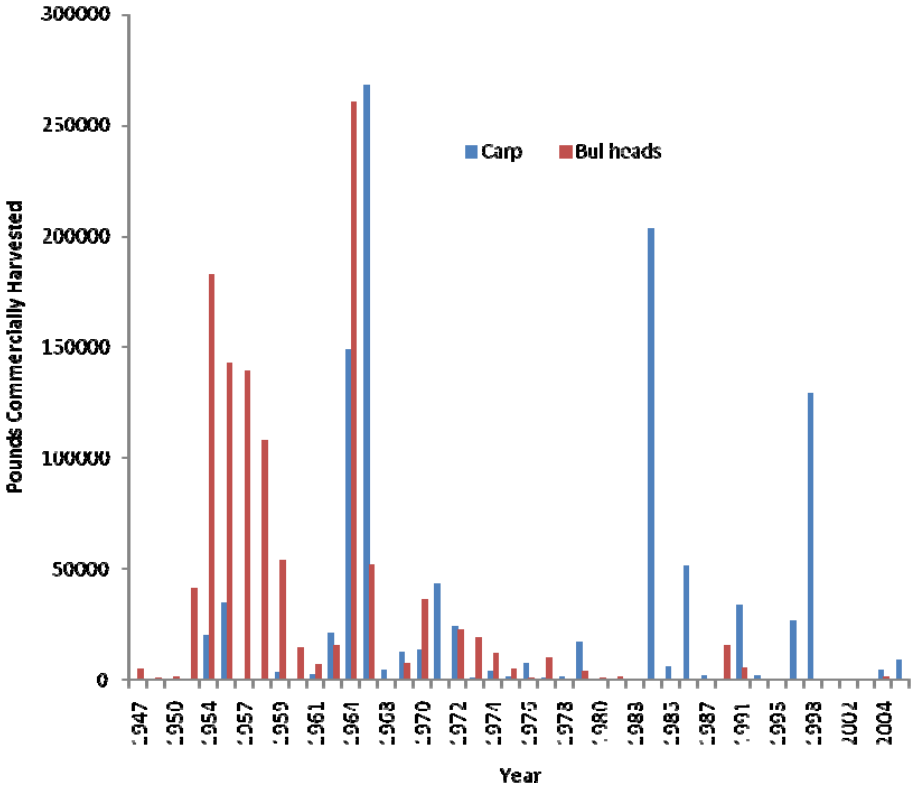
Results and Discussion

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

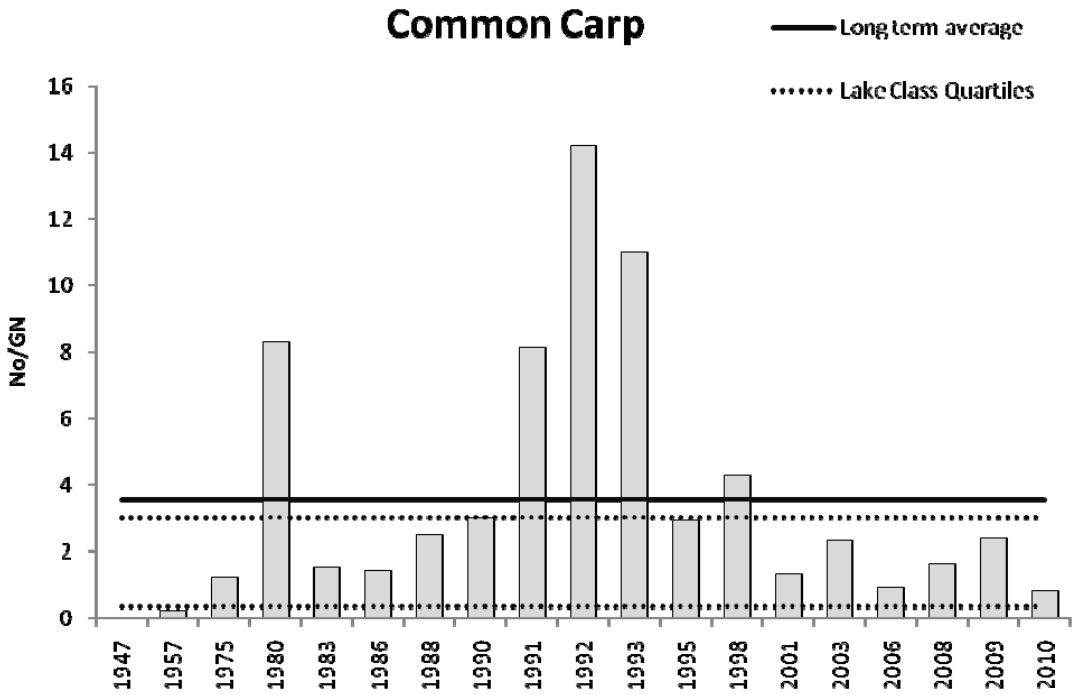
Belle Lake supports a periodic commercial fishery for bullheads and common carp (Figure 10). Over the history of the fishery over a million pounds of both species have been harvested. Commercial fishing activity on the lake has been low during the past decade.

Figure 10. Commercial harvest of carp and bullheads in Belle Lake over time in Belle Lake, Meeker County



Common carp populations have fluctuated over time, with large peaks in 1980 and 1992 that were exceptionally high compared with other lakes in Belle's lake type (Figure 11). Carp are long-lived and typically produce large year classes infrequently depending whether they have access to spawning habitats free from other fish species that may prey upon their eggs (Bajer and Sorensen 2009). Carp can affect water quality and aquatic plants through their feeding and spawning activities (Lougheed et al. 1998). Thus these species indirectly impact lake species dependent on aquatic plants such as northern pike, bass, and bluegill (Egertson and Downing 2004). Turbid water and sparse summer aquatic plant growth in Belle Lake likely favors continued persistence of carp; in turn, persistent carp will favor continued poor water quality. See below for further discussion about carp dynamics in Belle Lake.

Figure 11. Common carp captured in gillnets during past fisheries surveys in Belle Lake, Meeker County



Surveys of fish community integrity were completed in 2008 – 2010 as described by Drake and Pereira (2002). In general, lakes with high integrity are species rich with balanced food webs and include species that are intolerant to turbidity. Community integrity generally declines as lake nutrient levels increase from moderate to high levels (Drake and Pereira 2005). Community integrity in Belle Lake ranged from low in 2008 (score of 32) to moderate in 2010 (score of 65) compared with other lakes of similar lake productivity. This large short-term variability is unusual and was related to variability in nearshore species assemblages and trapnet catches of bullhead and carp (R.D. Valley unpublished data). The source of this variability (e.g., sampling error vs. real community shifts) will be investigated.

Fish species assessments

Gabelhouse (1984) established a length-categorization system to assess fish stocks, the proportional stock density (PSD), which measures the proportion of fish at young stock size, and relative stock densities (RSD), which measure fish proportions at larger sizes grouped by size categories. Figure 12 provides a summary of historical catches of each major species documented in Belle Lake over its surveyed history.

The current Belle Lake management plan lists walleye and black crappie as primary management species, while northern pike are listed as secondary. Although a formal creel survey has never been done on Belle Lake, past lake surveys have mentioned good to excellent fishing for walleye and black crappie several times. It was not uncommon to have 50 to 100 ice fishing houses on the lake during the winter when the crappie was biting, as was the case during the 2010-2011 winters. Northern pike, largemouth bass, and bluegill were mentioned as occasionally providing modest catch rates in several reports. Nevertheless, the rarity of submersed vegetation has likely limited bluegill and largemouth bass populations at Belle Lake.

Winterkill has not been a direct factor at Belle Lake in recent years, with the last report of it occurring in 1953. More recently however in 2001, significant winterkills likely occurred in several connected lakes and wetlands including; Cedar, Hoff, Harden, French, Willie, Sioux and Greenleaf. Recent research suggests that winterkill may positively affect carp spawning success in spring (Bajer and Sorensen 2009). Records from lake files suggest winterkill was present in the chain in winters just preceding the large catches of carp in 1980 and 1991-1993 (Figure 11).

Walleye

Walleye have been a primary management species since the first lake management plan was written in 1984. The mean gill net (GN) catch rate from 1975 to 2010 for all assessments (n=17), under various stocking regimes, was 11.5/net. Catch rates have been quite variable ranging from 1.8 to 29.8/net (Figure 12). Approximately 94 percent of the catches were above the lake-class median and 65 percent were above the third quartile, indicating that Belle may not be a typical class 24 lake. Walleye size has been variable over time with mean relative stock density of fish over 20" (i.e., RSD-20") from 1993 to 2010 of 17. Gill net age frequency and fall electrofishing (FEF) data from the last 14 years showed that a strong year-class was produced every four years in Belle. Growth was variable from 1975 to 2010 depending on numerous factors including; walleye year-class strength, yellow perch abundance, environmental factors, and errors in estimations of age and growth. Natural reproduction was documented in alternate years (1993 to 2010) when walleye weren't stocked, and a strong natural year-class was produced in 1996. The latest stocking regime (1,000 fry/littoral acre every-other-year) was initiated in 1993 and walleye have been the only species stocked in the last 18 years.

Northern Pike

Northern pike were a primary management species for many years and are currently a secondary management species. Gill net catch rates from 1975 to 2010 (n=17) were variable, but generally low ranging from 0.0 to 9.1/net with a mean of 1.8 (Figure 12). Northern pike are generally large with mean weights for five-of-the-last-nine assessments being above the lake-class third quartile (3.5 lb). The mean proportion of the gill net catch, from 1990 to 2010 (n=12), that was 24 inches and 30 inches or longer was 44 and 13. If several low catches (1990 to 1993, n=4), following the drought of the late 1980's, were excluded then the means increase to 57 and 16, respectively. Prior to 2006, barriers/carp traps were possibly blocking northern pike from spawning migrations, thus limiting the population. In 2006, the carp trap/barrier at the outlet was removed. Gill net catch rates have remained low, with one exception in 2003. The 2003 catch rate of 9.1/net was due to an exceptionally strong 2001 year-class, but why recruitment was so successful that year is unknown. Age and growth data from the 1980's was unreliable and northern pike were not aged for many of the assessments in the 1990's. Northern pike were last stocked in 1984.

Yellow Perch

Yellow perch are likely an important forage item for many fish species at Belle Lake. Gill net catch rates from 1975 to 2010 (n=17) were variable ranging from 0.1 to 59.8/net with a mean of 15.2 (Figure 12). An increasing trend in catch rates for yellow perch was observed during the 2008 to 2010 time period. Higher perch catch rates (1993, 1995, 1998, and 2006) often matched up with years of higher walleye catch rates at Belle Lake. This runs contrary to statewide patterns of declines in yellow perch (D.S. Staples MN DNR, unpublished data). The mean RSD-10" scores, from 1993 to 2010 (n=10) were only 0.6 meaning that yellow perch rarely reach an acceptable size to satisfy anglers.

Black Crappie

Black crappie were added as a secondary management species in 1991 and elevated to primary in 2004. Gill net catch rates from 1975 to 2010 (n=17) were variable ranging from 0.0 to 20.3/net with a mean of 6.6. Trap net (TN) catch rates from 1975 to 2010 (n=15) were highly variable ranging from 0.0 to 85.2/net with a mean of 17.1 (Figure 12). Recruitment appeared to be sporadic at Belle Lake, with rarely more than one year-class being strong in an assessment. Black crappies have been small with mean gill net RSD-10" scores for 1998 to 2010 (n=6) of 0.4 and mean trap net RSD-10" scores from 1995 to 2010 of 4. Still, inefficiencies with summer trapnets for sampling black crappie affect black crappies population inferences (McInerny and Cross 2006) Anglers reported that fishing pressure was heavy during the winter of 2010-2011, with a substantial harvest of black crappie in the eight to nine inch range.

Bluegill
In 1989, bluegills were added to the lake management plan as a secondary management species and removed shortly thereafter (1991). Trap net catch rates from 1975 to 2010 (n=15) were generally low, ranging from 0.0 to 15.5/net with a mean of 5.4 (Figure 12). Catch rates were above the lake-class first quartile (7.5/net) only four times. Bluegill are generally few and small with a mean RSD-8" from 1998 to 2010 (n=4) of 6. Few bluegills were trap netted in 1975, 1980, and 1983, so bluegills were stocked annually from 1985 to 1989 in an effort to establish a bluegill fishery. Numbers increased in the early 1990's but a connection to Stahl's Lake, with potential for migration, made evaluation impossible. Finally, realizing that habitat was marginal due to the low abundance of submersed vegetation, the stocking of the bluegill was discontinued after 1989.

Pumpkinseed Sunfish
Pumpkinseed sunfish were first sampled in the 1947 initial survey and are relatively rare at Belle Lake (Figure 12). Trap net catch rates have only been above the lake-class first quartile (0.74) three times. Tracking similar patterns with bluegill recruitment, numbers peaked in the early to mid 1990's.

Black Bullhead
Gill net catch rates from 1975 to 2010 (n=17) were highly variable ranging from 0.0 to 217.2/net with a mean of 51.3 (Figure 12). Trap net catch rates (n=15) from 1975 to 2010 were highly variable ranging from 0.4 to 237.9/net with a mean of 62.5. Historically, rough fish removal crews and commercial fishermen removed high numbers of black bullhead from Belle Lake. Black bullhead catch rates have been low from 1998 through 2010, except for a moderate peak in 2003 (79.1/GN). From 1975 through 1995 at least one gear type (GN or TN) catch rate was above the lake-class third quartile, except for 1980. The decline in black bullhead in Belle Lake mirrors a statewide decline in black bullhead populations (D.S. Staples, MN DNR unpublished data). Possible mechanisms include more mild winters in the recent past decades that alleviated low oxygen conditions that are typically stressful for black bullhead competitors and predators (black bullhead are tolerant of low oxygen). For example, Davis (1975) documented that bullhead were a significant part of the walleye diet in Belle Lake and had some potential for the control of small bullhead.

White Sucker
Gill net catch rates (n=17) were variable ranging from 0.0 to 4.3/net with a mean of 1.5. Catch rates were within the lake-class interquartile range (0.4 to 2.17/net) 12 of 17 times. There was no obvious trend for the gill net catch rate data for Belle Lake white sucker (Figure 12).

Largemouth Bass
Largemouth bass were listed as a secondary management species in 1991 and were removed from that classification in 1996. Spring night-time electrofishing catch rates from 1993 to 2010 (n=7) were generally low ranging from 0.6 to 16.2/hr with a mean of 3.9. The last three assessments all sampled one largemouth bass (Figure 13). The higher 2004 catch rate was due to a strong 2002 year-class, accounting for 93 percent of the sample that year. Electrofishing in 2008 did not sample any fish from that 2002 year-class. Sampling protocols remained consistent between 2004 and 2008 and did not explain the missing year-class. Angler harvest and/or migration into connected lakes would be more likely explanations. Belle's lack of rooted submergent vegetation was probably not typical for most lake-class 24 lakes and likely explains the marginal largemouth bass population. Increasing submersed vegetation abundance would likely benefit largemouth bass and other vegetation dependent species like northern pike and bluegill, but may also reduce the abundance or catchability of other fish species anglers are accustomed to catching at Belle Lake such as walleye or black crappie. Largemouth bass were last stocked in 1991.

Common Carp
Trap net catch rates from 1975 to 2010 were variable ranging from 0.08 to 5.2/net with a mean of 1.9. Gill net catch rates from 1975 to 2010 (n=17) were highly variable ranging from 0.8 to 14.2/net with a mean of 3.8 (Figure 11). State fish crews and commercial fishermen harvested many carp from Belle Lake, over the last 60 years. A highly connected watershed makes management of this invasive species difficult. A substantial 2001 carp year-class was likely produced and showed up in the 2003, 2006, 2008, 2009, and 2010 assessments averaging 15" in length initially and 25" most recently (Figure 14). Hoff Lake also experienced winterkills in 2004, 2008, 2010, and likely 2011. Connected wetlands such as Harden Lake are even more likely than Hoff to experience severe winterkills. Following winterkills, these shallow wetlands would probably provide ideal spawning and rearing areas (few predators on eggs and fry) for carp (Bajer and Sorensen 2009).

Figure 12. Catches of select species from gillnets (GN) and trapnets (TN) from fisheries lake surveys in Belle Lake, Meeker County

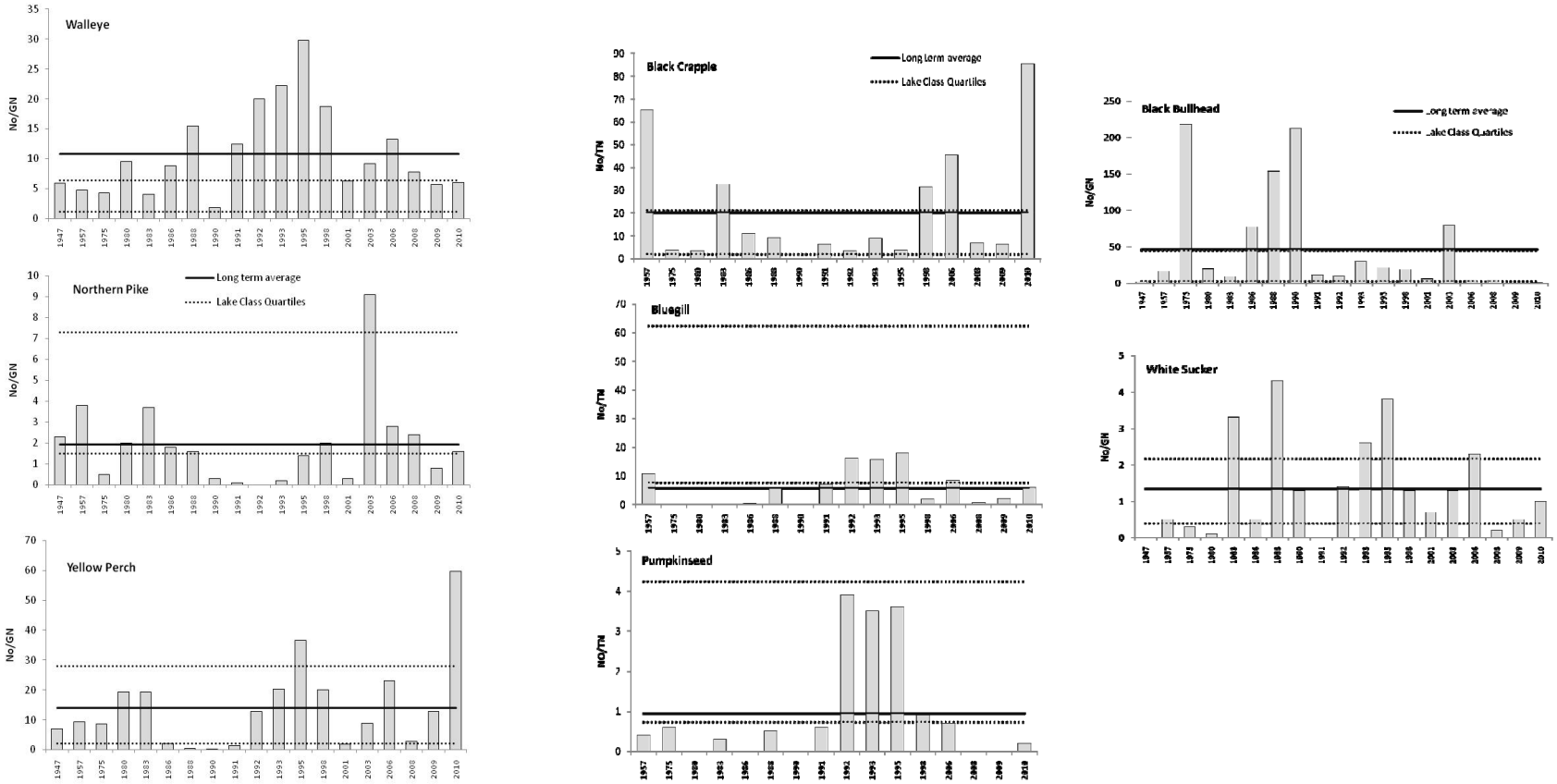


Figure 13. Electrofishing catch rates of largemouth bass in Belle Lake, Meeker County

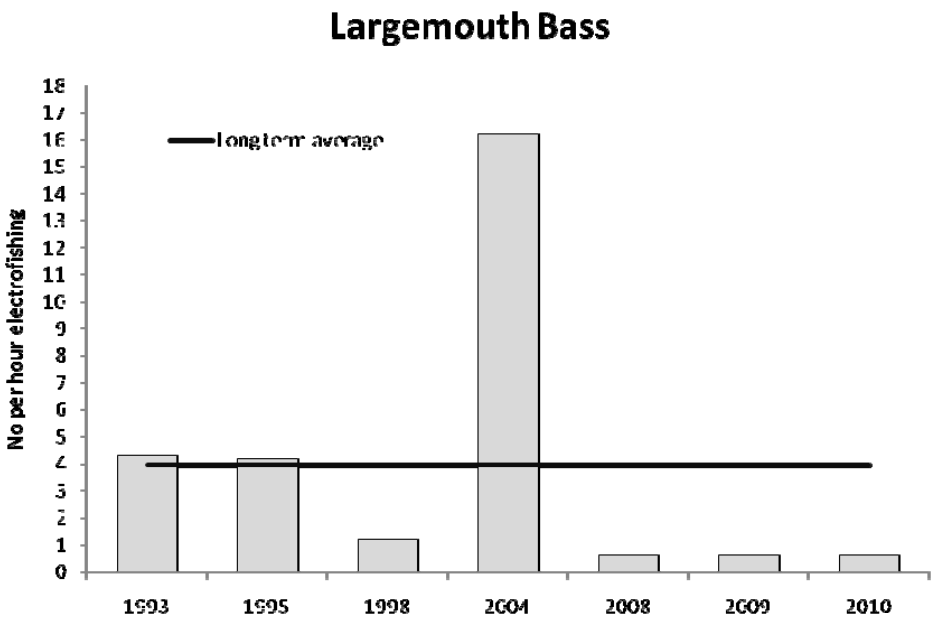
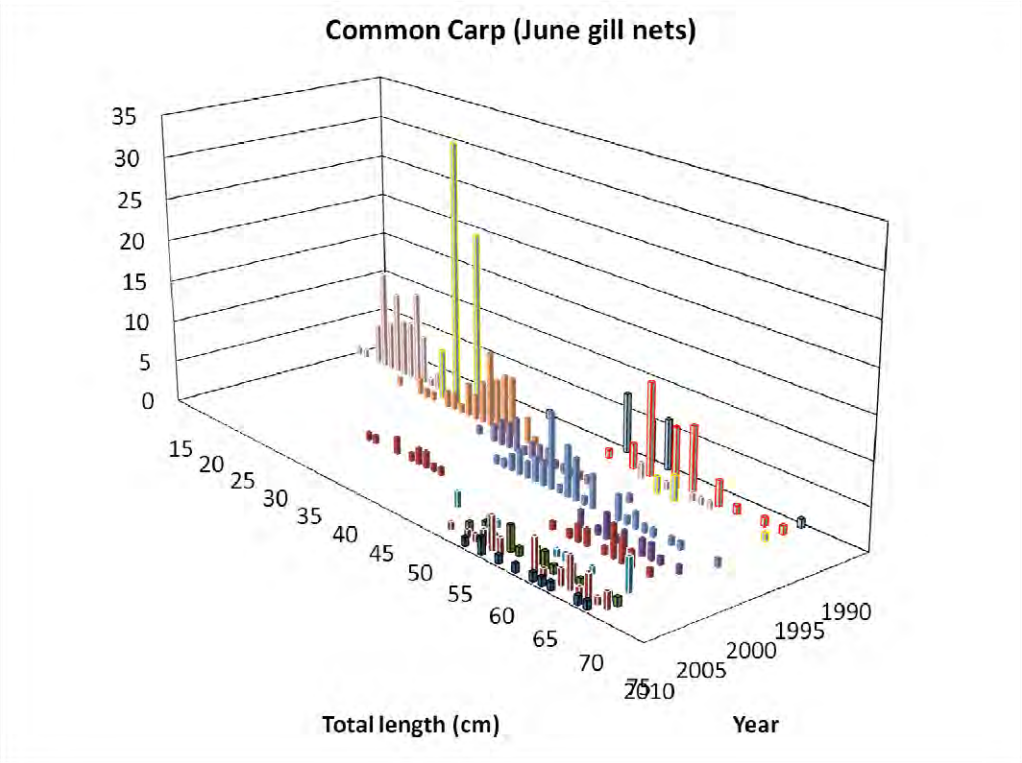


Figure 14. Catch rates of different size-classes of common carp captured in gillnets during Fisheries surveys in Belle Lake, Meeker County



Aquatic plant assessment

Emergent and submersed aquatic plants have been rare throughout the surveyed history of Belle Lake (Table 3). In fact, in the 1975 and 1983 surveys, no aquatic plant species were listed as more abundant than "occasional." More detailed plant surveys occurring after 2008 as part of sentinel lake monitoring still indicate scarce cover overall with the most common aquatic plant, Canada waterweed only occurring at eight percent of the of the surveyed sites (Table 4; Figure 15). Not surprisingly, plant IBI scores (as described by Beck et al. 2010) for Belle Lake are low (2008-10 range = 32-37 out of 100; MN DNR unpublished data).

Common carp are known to limit aquatic plant growth and cause turbid conditions and they have traditionally been abundant in Belle Lake. However, recently carp have become less common with the lowest catch in gillnets ever recorded in the lake in 2010 (Figure 11).

Table 3. Aquatic plant species from historic Fisheries lakes surveys listed as "common" at any sample location from Belle Lake, Meeker County

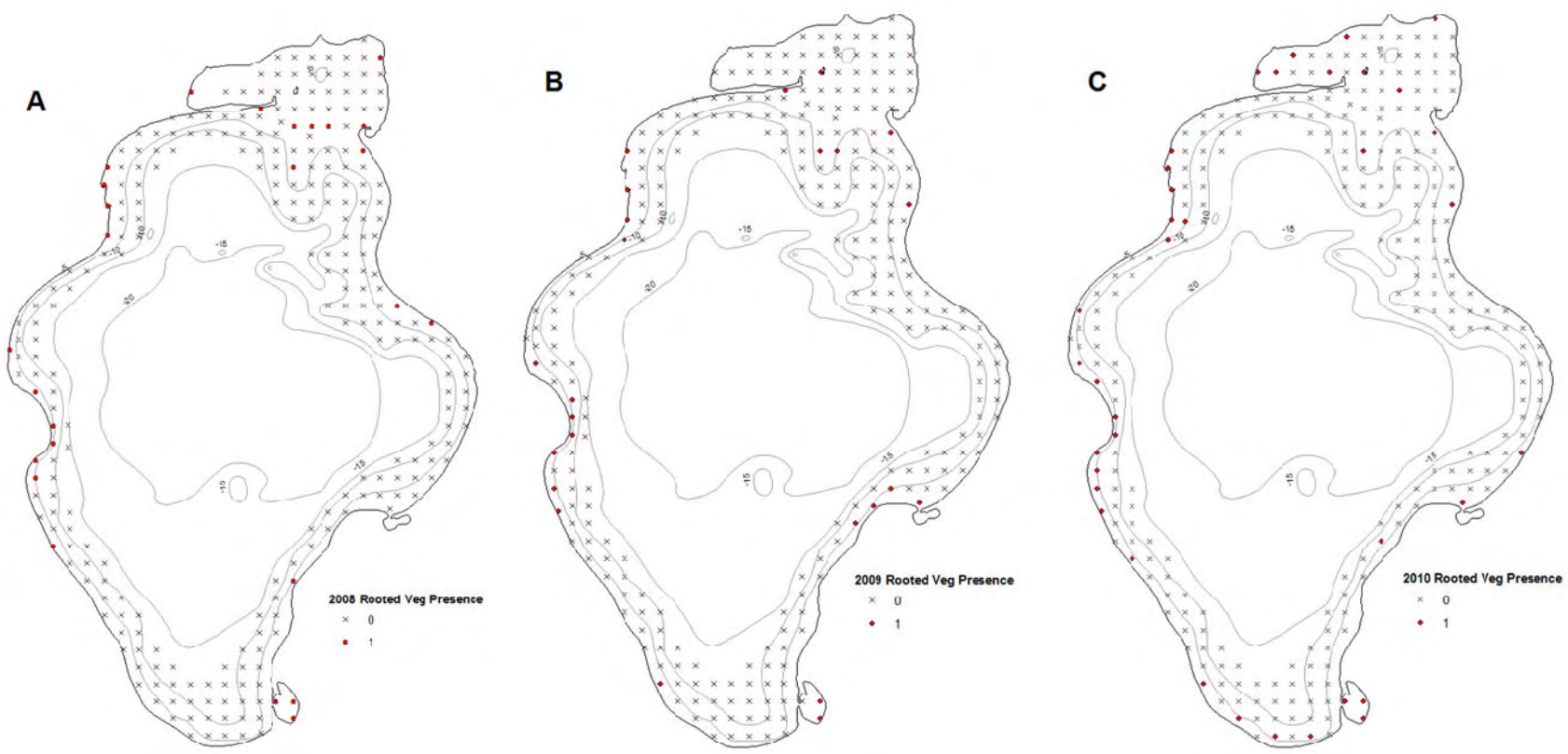
Survey Date	Common name	Species Name	Growth form
9/21/1947	Bulrush	*Scirpus* sp.	Emergent
	Sago pondweed	*Stuckenia pectinata*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
7/29/1957	Bushy pondweed	*Najas flexilis*	Submersed
	Floating-leaf pondweed	*Potamogeton natans*	Floating-leaf
	Coontail	*Ceratophyllum demersum*	Submersed
9/8/1975	No plants listed as common		
6/20/1983	No plants listed as common		
7/12/1993	Cane	*Phragmites australis*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	Narrow-leaved cattail	*Typha angustifolia*	Emergent
	Muskgrass	*Chara* sp.	Submersed
	Greater duckweed	*Spirodela polyrhiza*	Free-floating

Table 4. Percent frequency of occurrence of aquatic plant species at depths ≤ 15 feet sampled during point-intercept surveys on 7 August 2008, 17 August 2009, and 26 July 2010 at Belle Lake, Meeker County, Minnesota

Season	Common Name	Species Name	Growth Form	Frequency (%) 2008	2009	2010
Spring[a]	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	4.1[c]	0.7[c]	3.6[c]
Summer	All rooted plants			9.7	8.8	13.7
	Sago pondweed	*Potamogeton pectinatus*	Submersed	5.2	0.4	0.7
	Canada waterweed	*Elodea canadensis*	Submersed	2.6	0	8.1
	Narrow-leaf pondweed	*Potamogeton sp.*	Submersed	1.5	0	0.7
	Illinois pondweed	*Potamogeton illinoensis*	Submersed	1.1	0.8	0.4
	Filamentous algae			1.1	0.7	0.4
	Muskgrass	*Chara sp.*	Submersed	0.7	2.9	0.4
	Bushy pondweed	*Najas flexilis*	Submersed	0.7	0	0
	Hardstem bulrush	*Scirpus acutus*	Emergent	0.7	1.1	0
	Cattail	*Typha sp.*	Emergent	0.7	0.4	1.1
	Coontail	*Ceratophyllum demersum*	Submersed	0.4	0.4	4.4
	Lake sedge	*Carex lacustris*		0.4	0	0
	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	0.4	0	0
	Water stargrass	*Heteranthera dubia*	Submersed	0.4	0.7	0.4
	Burreed	*Sparganium sp.*	Emergent	0.4	0	0
	Arrowhead	*Sagittaria sp.*	Emergent	0.4	0.4	0.7
	Wild celery	*Vallisneria americana*	Submersed	0.4	0	0
	Small pondweed	*Potamogeton pusillus*	Submersed	0	1.8	0
	Lesser duckweed	*Lemna minor*	Free-floating	0	1.1	1.1
	Naiad group	*Najas sp.*	Submerged	0	0.8	0.4
	Spikerush	*Eleocharis sp.*	Emergent	0	0.4	0
	River bulrush	*Scirpus fluviatilus*	Emergent	0	0.4	0.7
	Water plantain	*Alisma sp.*	Emergent	0	0	0.4
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	0	0	0.4
	Giant burreed	*Sparganium eurycarpum*	Emergent	0	0	0.4
	Softstem bulrush	*Scirpus validus*	Emergent	0	0	0.7
	Willow	*Salix sp.*	Emergent	0	0	0.4
	Max depth of veg growth (ft)[d]			4.0	6.0	7.0

[a]Surveys targeting curly-leaf pondweed, [b]Non-native, [c]surveyed on 3 June 2008, 1 June 2009, 21 May 2010'[d]Depth of 95 percent of all plant occurrences

Figure 15. Presence/absence of rooted aquatic vegetation during surveys in summer 2008 (A), 2009 (B), and 2010 (C)



Curly-leaf pondweed

In 1983, the invasive curly-leaf pondweed was first noted in Belle Lake but has never been abundant in the lake. Curly-leaf pondweed is a non-native invasive submerged aquatic plant that is widespread throughout 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.

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

Curly-leaf pondweed cover was assessed during late May or early June in 2008-2010. Despite lake conditions that appear favorable for curly-leaf pondweed growth, the plant is rare in the lake and was never present at more than four percent of the sites in less than 15 ft deep (Table 4).

Factors limiting aquatic plant growth in Belle Lake should be explored. In particular, it remains unclear whether Belle Lake ever supported abundant aquatic plants or if plants have always been rare due to the sandy substrates that dominate the lake. Still given anecdotal evidence that suggests phosphorus levels are elevated since European colonization and introduction of carp, it is likely that aquatic plants are appreciably less abundant today than prior to these events.

Summary of near shore human impacts on aquatic plant communities

The cumulative effects of near shore alterations by lakeshore owners appears to be minimal in Belle Lake due to light lakeshore development and the rarity of aquatic plants. Approximately 49 dock structures were enumerated from aerial photos acquired from the Farm Service Administration in summer 2010 (1 dock for every 704 ft of shoreline). An aquatic plant management permit database maintained by MDNR indicated only one permit to harvest a small area of aquatic plants since electronic record keeping began in the early 1990's. Consequently, current aquatic plant removal activities probably have a very small impact on fish habitat in Belle Lake.

Water quality

Standard summer-mean water quality data for 2008-2010 are presented in Table 5; raw data results are provided in Appendix A. In addition, major cations, anions, and total organic carbon were analyzed on three sample dates, and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 6. The NLA was a statistically-based survey of the nations lakes administered by the United States Environmental Protection Agency in 2007. The typical range provided in Table 6 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Table 5. Belle Lake 2008-2010 summers mean (June to September) water quality

Typical range based on 35 NCHF and 12 WCBP ecoregion reference lakes (Heiskary and Wilson 2005) noted for comparison.

Parameter	Belle Lake	NCHF	WCBP
Total phosphorus (µg/L)	56	23 - 50	65 - 150
Chlorophyll mean (µg/L)	23.2	5 - 22	30 - 80
Chlorophyll max (µg/L)	50.5	7 - 37	60 - 140
Secchi disk (feet) **(meters)**	3.2 1.0	4.9 – 10.5 1.5 – 3.2	1.6 – 3.3 0.5 – 1.0
Total Kjeldahl Nitrogen (mg/L)	1.5	<0.6 – 1.2	1.3 – 2.7
Alkalinity (mg/L)	157	75 - 150	125 - 165
Color (Pt-Co Units)	6	10 - 20	15 - 25
pH (SU)	8.6	8.6 – 8.8	8.2 – 9.0
Chloride (mg/L)	14.6	4 - 10	13 - 22
Total suspended solids (mg/L)	15.6	2 - 6	7 - 18
Total suspended inorganic solids (mg/L)	9.6	1 - 2	3 - 9
Conductivity (µmhos/cm)	331	300 - 400	300 - 650
Total nitrogen : Total phosphorus ratio	27:1	25:1 - 35:1	17:1 – 27:1

Table 6. Belle 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
5/21/2008	30	20.9	5.1	5.9	160	4.1	13.3	3.59	-3.66	-0.94
7/23/2008	28.4	22.1	6	6.3	150	4.3	14	3.66	-3.48	2.46
10/7/2008	29.2	23.6	5.8	6.6	150	4	14.1	3.82	-3.48	4.68
5/5/2009	31.6	22.4	5.3	5.9	160	4.1	14.2	3.80	-3.68	1.61
7/8/2009	29.1	22.9	5.5	5.9	160	4.0	15.1	3.73	-3.71	0.27
10/12/2009	26.7	22.4	5.6	6.3	150	3.9	15.4	3.58	-3.51	0.95
4/29/2010	32.7	23.5	5.7	6.4	160	4.1	14.7	3.98	-3.70	3.64
7/26/2010	28.6	22.2	5.4	6	160	3.3	15	3.64	-3.69	-0.64
10/4/2010	29.5	22.5	5.7	6.4	150	3.3	14.9	3.74	-3.49	3.44
Average	30.0	22.5	5.6	6.2	155	3.9	14.5	3.75	-3.59	2.22
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 twice per month at site 201 (Figure 2). On a handful of dates, DO declined near the bottom of the lake (Figure 16). The lake was well mixed, from a temperature standpoint, on all sample dates from spring through fall (Figure 17). DO and temperature isopleths for 2008 demonstrate the dates and extent of time when DO was hypoxic near the bottom of the lake (Figure 16 and 17). This is significant as low DO and elevated temperatures can allow for release of phosphorus from the lake sediments. In 2008 hypoxic conditions were noted on July 23 and July 28 for short periods of time (Figure 16). While the lake was thermally well-mixed during this period surface and bottom temperatures were in excess of 20 ^{0}C, which can promote phosphorus release. These dates were also the only time that the DO dropped below the five mg/L necessary to support game fish and that was only below a depth of four to five meters. The 2009 data show several dates with very low DO just above the sediment (6/23/2009, 7/8/2009) and also indicate cooler water temperatures during the summer months in 2009 as compared to 2008 (Figure 17).

Total phosphorus (TP) concentrations in Belle Lake averaged 56 µg/L (Table 5). This is above the typical range for reference lakes in the NCHF ecoregion and below the range for the WCBP ecoregion. This average is just below the standard for NCHF shallow lakes. Generally, values were between 37 and 70 µg/L with the highest concentrations typically observed in the late summer or early fall (Figure 18). The pattern of stable to increasing TP from June through September is consistent with other polymictic lakes.

Hypolimnetic TP values ranged from a low of 9 µg/L to a high of 83 µg/L (Figure 19). Across the three years of available data hypolimnetic TP was similar to epilimnetic TP on most dates. One date with elevated hypolimnetic TP (July 23 2008) corresponded to a time period when DO was < 2.0 mg/L (Figure 16). Based on the profiles from 2008-2010 hypoxic DO in the bottom waters is uncommon but does occur periodically. 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. This "internal loading" of TP may contribute to the increase of TP across the season (Figure 19).

Nitrogen, measured as total Kjeldahl nitrogen (TKN), a primary nutrient required for algal and plant growth was on the low end of the typical range for WCBP lakes and just above the range for NCHF lakes (Table 5). Nitrate-N, which is readily used by algae and rooted plants was at or below detection on most sample dates (Appendix A). The TN:TP ratio is within than the typical range (Table 5).

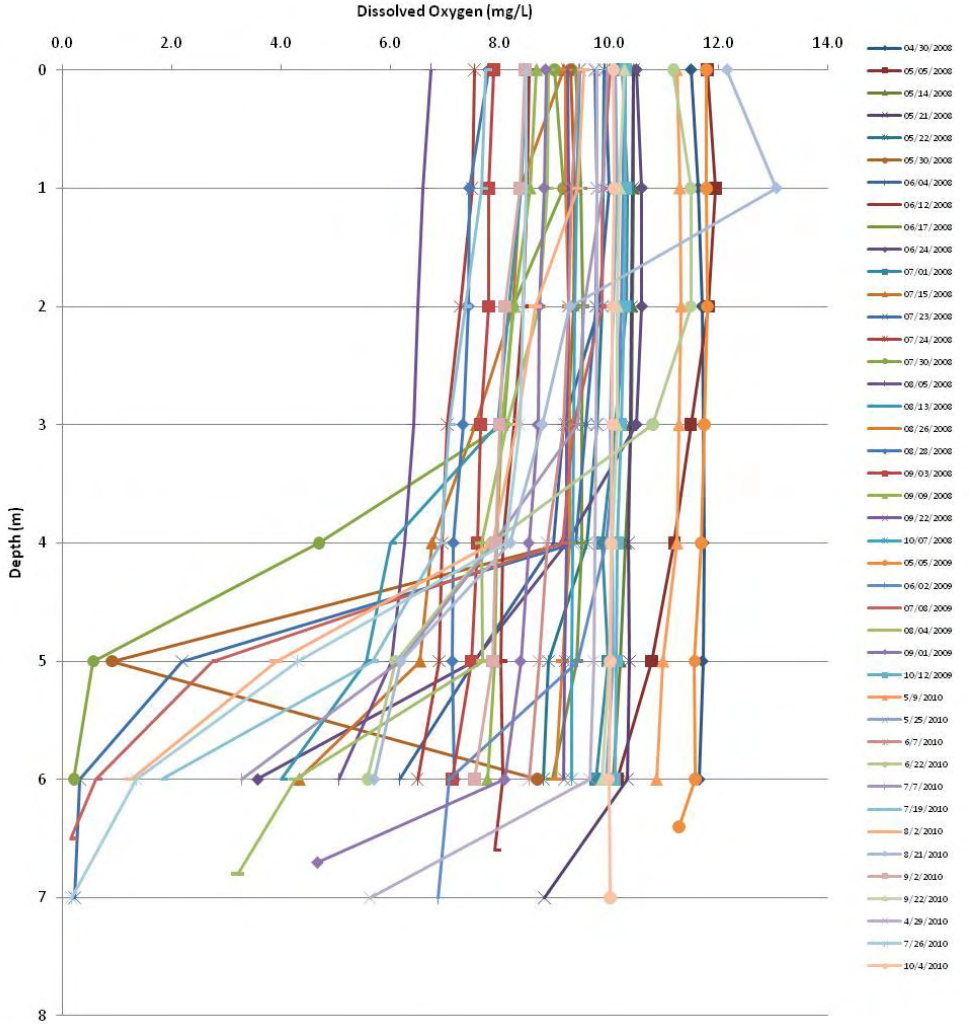
Chlorophyll-*a* (chl-*a*) concentrations provide an estimate of the amount of algal production in a lake. Chl-*a* concentrations averaged 23.2 µg/L, over the summers of 2008-2010 (Figure 18). Like TP, this is above the typical range for NCHF lakes and below the range for WCBP lakes (Table 5); however, in the case of chl-*a*, it does exceed the standard for NCHF shallow lakes. Chl-*a* concentrations increase across the season as the waters warm. With the exception of spring sample dates, nuisance algal blooms (chl-*a* > 20 ug/L) were present on most dates.

Chl-*a* was slightly higher in 2008 as compared to 2009 with averages of 22.5 µg/L and 17.0 µg/L respectively. In 2009 June through September chl-*a* generally remained below 20 µg/L and 2009 monthly measures were generally less than the corresponding monthly value for 2008 (Figure 18). Summer temperatures were a bit cooler in 2009 as compared to 2008 (Figure 17) and this may have had an influence on algal productivity.

Secchi disk transparency averaged 1.0 meters (3.2 feet) over 2008-2010. This is on the high end of the typical range of WCBP reference lakes and below the range for NCHF lakes. A Secchi of 1.0 m is right at the standard for shallow NCHF lakes. Transparency corresponded well to TP and chl-*a* concentrations; increases in those parameters resulting in a decline in transparency (Figure 18).

Figure 16. Belle Lake 2008-2010 dissolved oxygen (A) and 2008 isopleth (B)

A)



B)

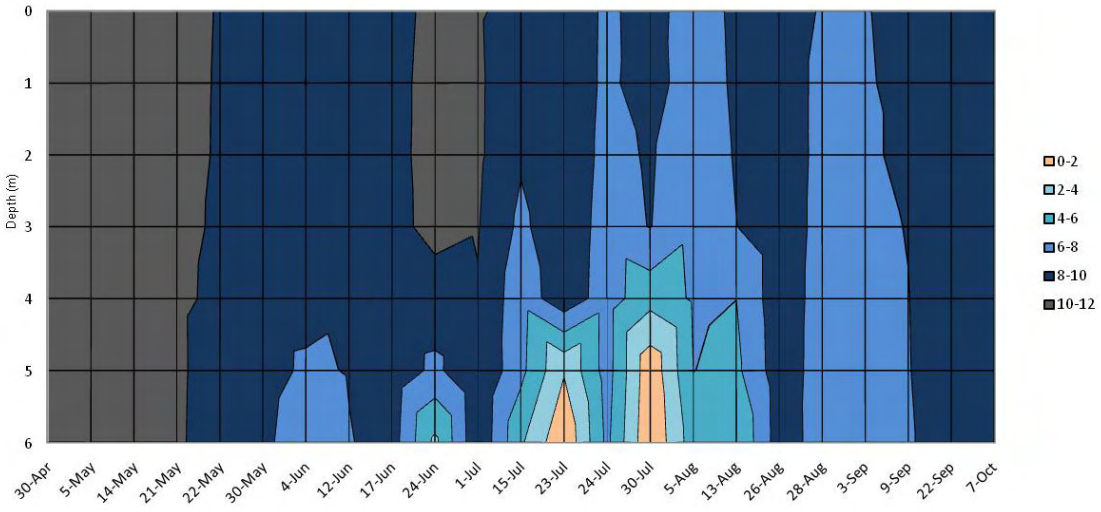
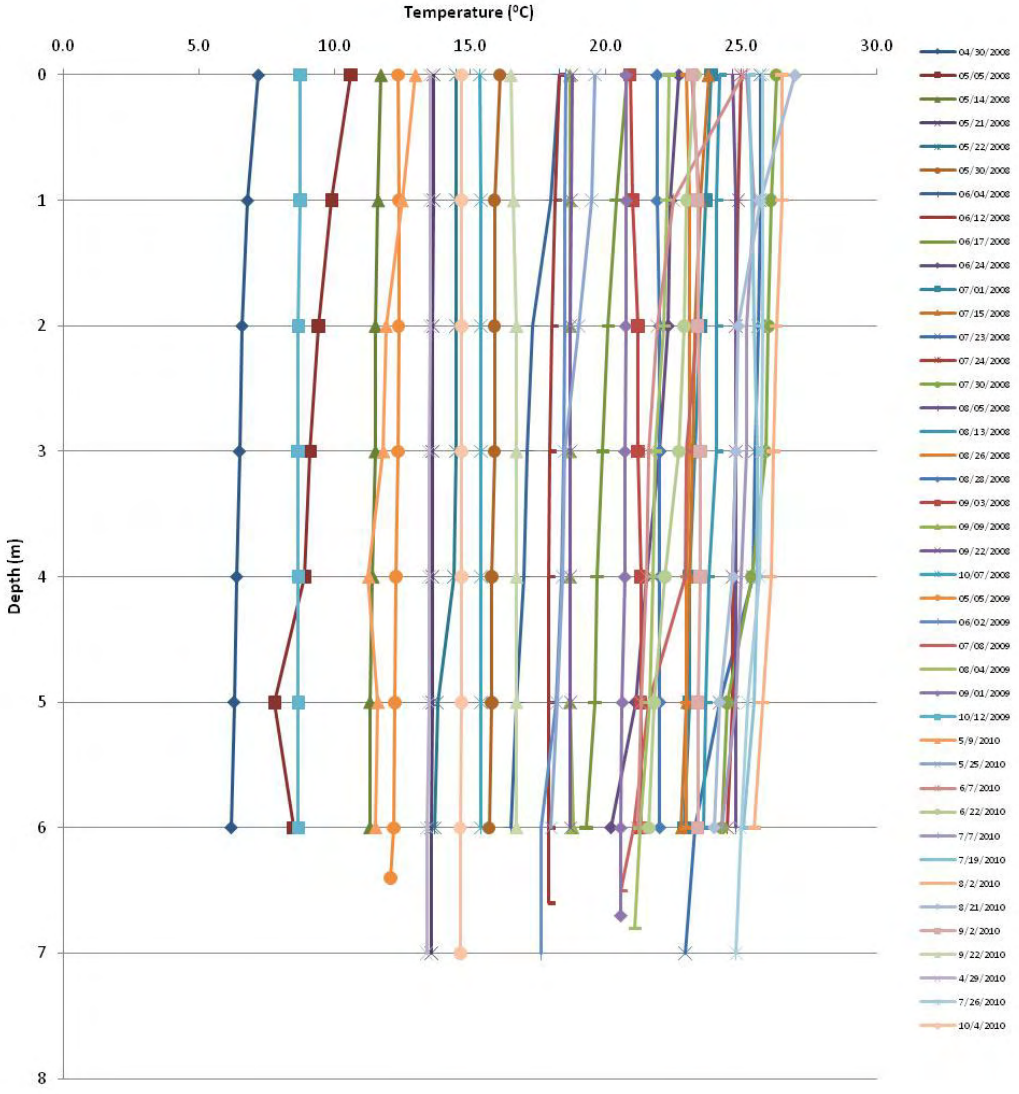


Figure 17. Belle Lake 2008-2010 temperature (A) and isopleth for 2008 (B)

A)



B)

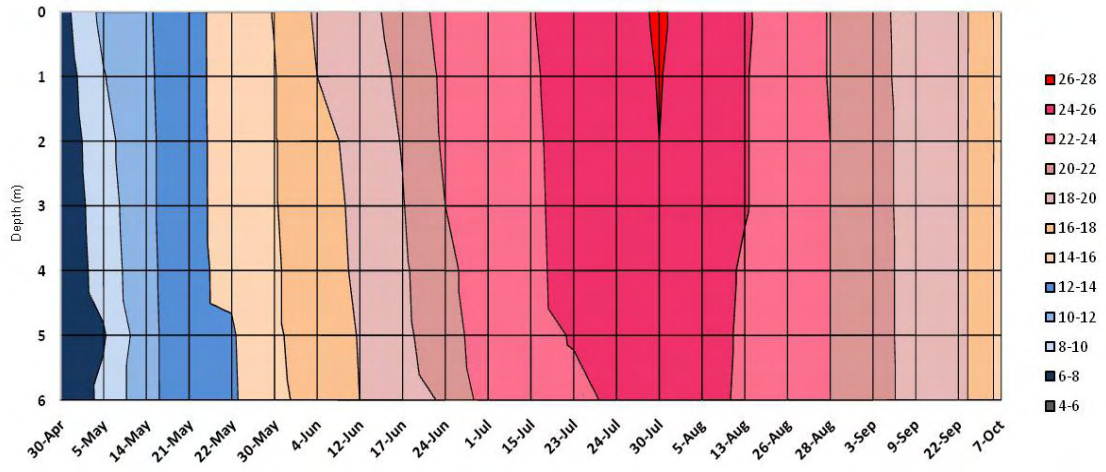


Figure 18. Belle Lake 2008-2010 paired total phosphorus, chlorophyll-*a* concentrations, and Secchi depth

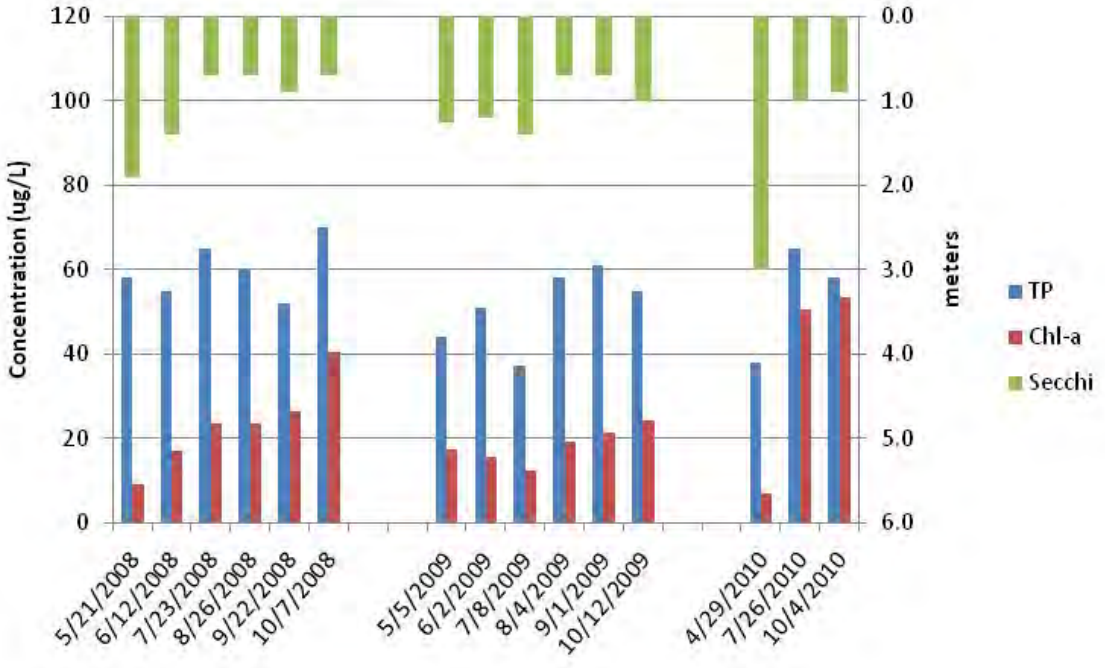
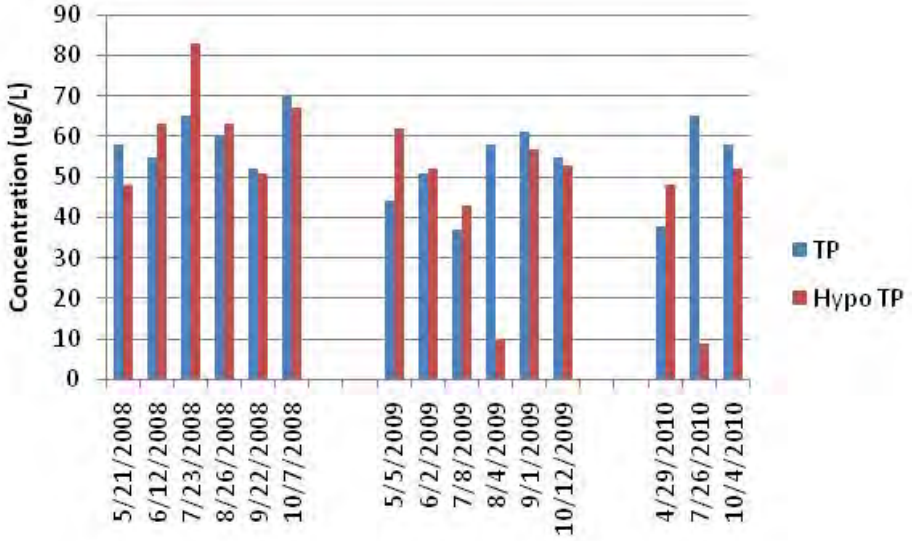


Figure 19. Belle Lake paired hypolimnetic and epilimnetic total phosphorus observations



Dissolved minerals and organic carbon were measured as part of the long-term monitoring of Belle and other Sentinel lakes. This includes some of the standard measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 5) as well as major cations, anions, and organic carbon (Table 6). While several of these parameters have "typical" ecoregion-based concentrations (e.g. Table 5); some do not. For parameters without ecoregion–based comparisons, data from the 2007 National Lakes Assessment (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).

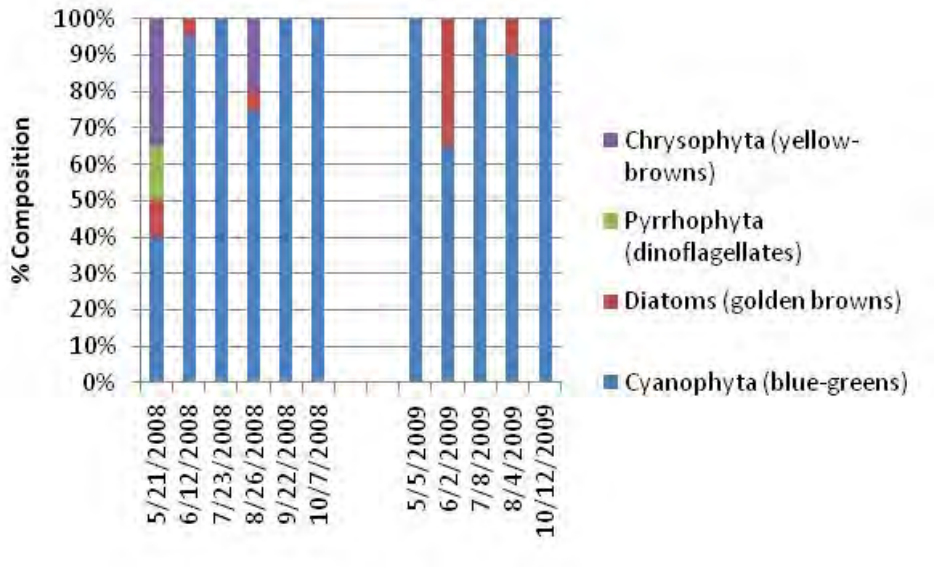
TSS is quite high and is on the high end of typical range for WCBP reference lakes (Table 5) and just over half of the TSS can be attributed organic solids (decomposing algal matter). The low color value (Table 5) indicates the water is clear and has minimal amount of total organic carbon. Lakes that 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 is above the typical range for NCHF lakes and within the range for WCBP lakes and conductivity is on the low end of the typical range for both ecoregions (Table 5). Calcium (Ca) and magnesium (Mg) are the dominant cations and both are within the typical range of the state-wide data (Table 6). The other two major cations – sodium (Na) and potassium (K) are within the typical range and above the typical range, respectively. 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 5). 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 ± two 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 2008-2010 (Table 6), 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) remained relatively constant during 2008 and 2009 on Belle Lake. Typically a transition from diatoms dominating the composition in the spring to blue-greens in the summer occurs. Blue-greens dominated all dates, with diatoms, dinoflagellates, and yellow-browns making up smaller portions of the population on a number of sampling dates (Figure 20). With the exception of May 2008, blue-greens never made up less than 65 percent of the composition, and on six dates comprised the entire algal community sampled.

Figure 20. Algal composition for Belle Lake in 2008 and 2009



Zooplankton

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

Belle Lake had one of the lower number of taxa (12) observed in the 2008 season; density and biomass of zooplankton was moderate compared to other lakes in the NCHF ecoregion (Table 7). The May sample had the highest density and biomass 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 Belle Lake and the other NCHF lakes (Figure 21).

Table 7. 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 21. Mean monthly zooplankton densities and biomass for North Central Hardwood Forest Ecoregion Sentinel Lakes in 2008

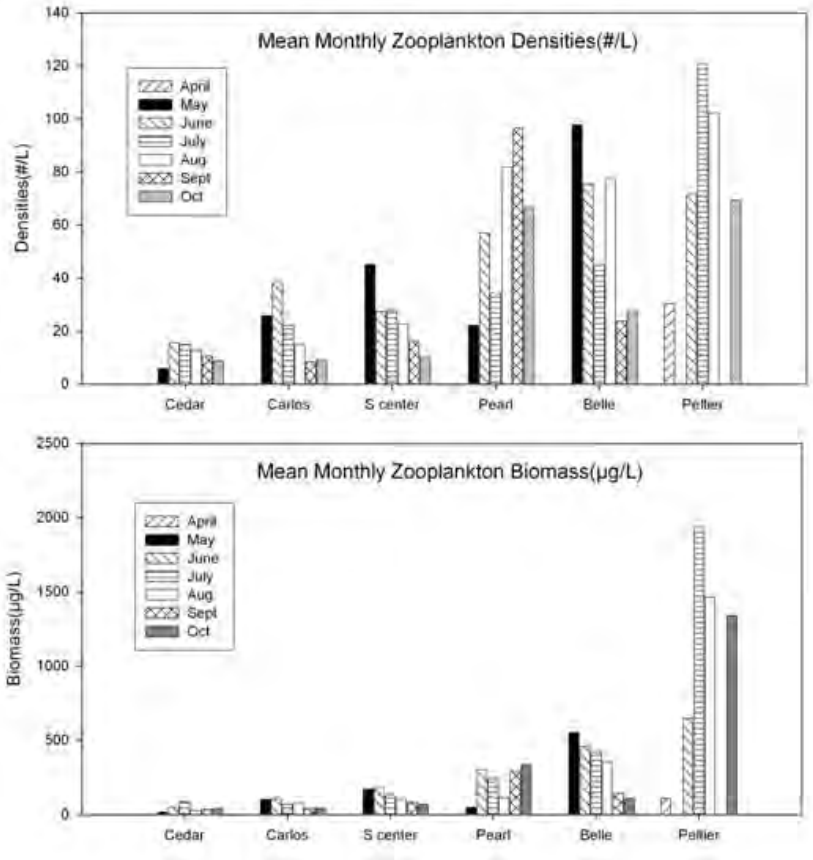


Figure 22. Mean monthly zooplankton density (#/L)

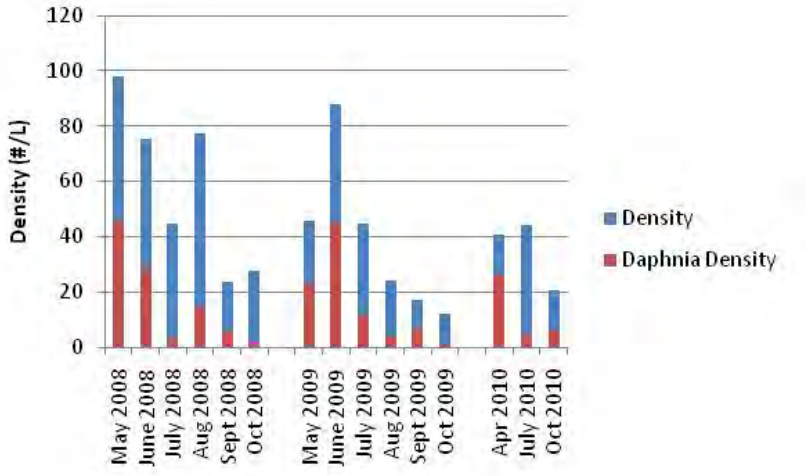
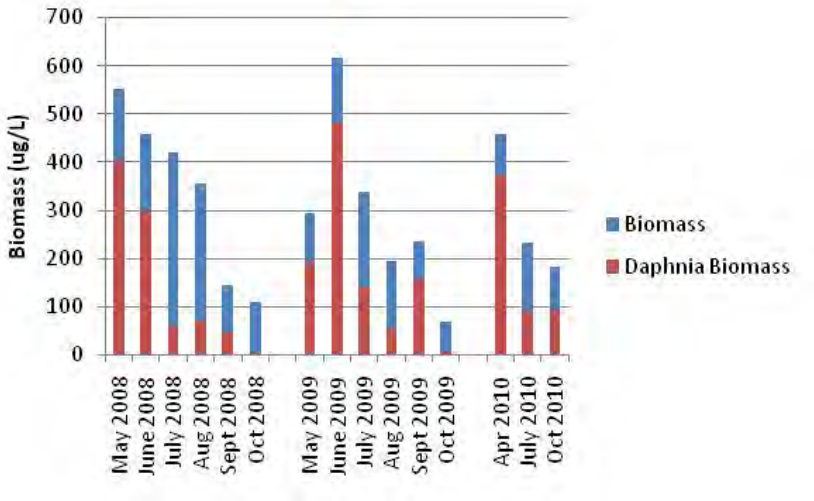


Figure 23. Mean monthly zooplankton biomass (ug/L)



Zooplankton density is typically highest in the spring for Belle Lake and declines across the season (Figure 22). Zooplankton densities vary greatly across the season, with densities approaching 100 organisms per liter in the spring and dropping as low as 11 organisms per liter in the fall. Daphnia collected were often less than half of the total density in number, but large in size, making up a significant portion of the biomass measured on many dates (Figure 23).

Trophic State Index

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

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

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

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

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, chl-*a*, and Secchi (Figure 24). 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, Belle Lake would be characterized as eutrophic.

Figure 24. Carlson's Trophic State Index for Belle Lake

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.

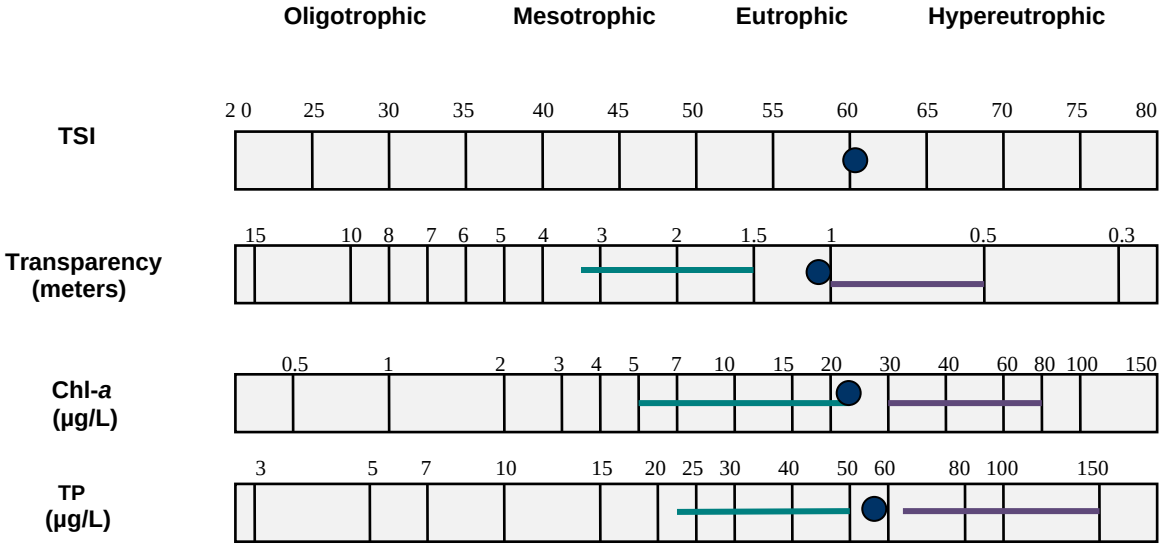
TSI 40 – 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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.

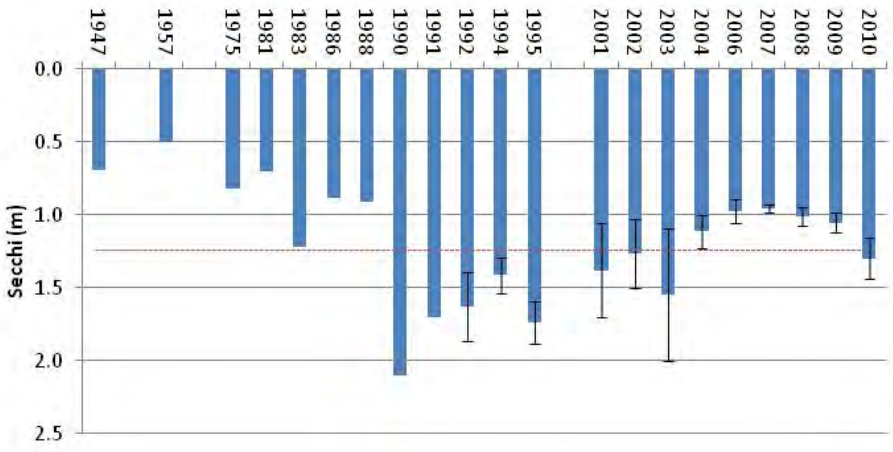
NCHF Ecoregion Range: 2008-2010
WCBP Ecoregion Range:

Trophic Status Trends

One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in STORET. A review of data in STORET indicates there is a good amount of data for Belle Lake to describe annual variability and to statistically assess trends for Secchi transparency (Figure 24). 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.

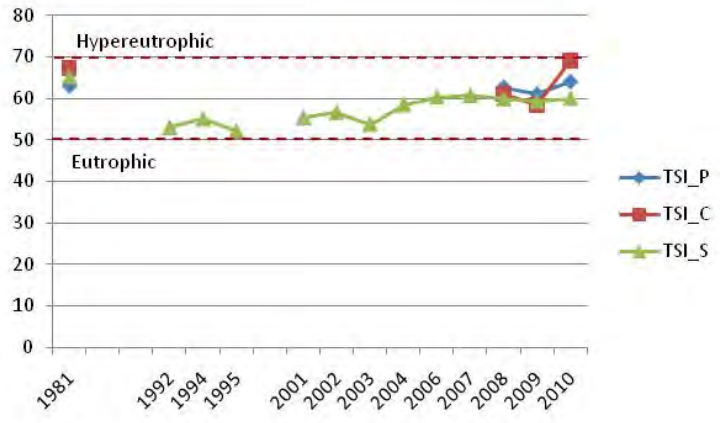
In general, for trend assessment, a minimum of eight years of consistent data is required. During the most recent trend analysis completed using Citizen Lake Monitoring Program Secchi data, it is estimated that water clarity is declining by 0.3 meter per decade (estimated range of 0.1 to 0.5 meter decline 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 25. Belle Lake long-term summer-mean Secchi disk depth



A single data point from 1981 is available for comparison of TP and chl-*a* concentrations (Figure 26). 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, Belle Lake has historically been classified as eutrophic and over the recent decade is trending toward hypereutrophic conditions (Figure 26).

Figure 26. Belle 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 Belle 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 8.

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 Belle Lake, MINLEAP was applied as a basis for comparing the observed summer (2008-2010) TP, chl-*a*, and Secchi values with those predicted by the model based on the lake size and depth and the area of the watershed.

Belle Lake is located in the NCHF ecoregion, near the boundary with the WCBP ecoregion; the model was run using both NCHF and WCBP ecoregion-based inputs. The observed TP, chl-*a*, and Secchi values for Belle Lake are significantly worse than expected based on the NCHF prediction but are relatively close to the WCBP predicted values. This implies P inflow concentrations may be closer to the WCBP rather than the NCHF estimate. Estimated water residence time is on the order of six-seven years (Table 8). The estimate of "background" TP (Vighi & Chiaudani) is less than half of the modern-day TP concentration for Belle Lake (Table 8), which further indicates Belle Lake is more nutrient-rich than anticipated for a lake of its size and depth in the NCHF ecoregion.

Table 8 MINLEAP model results for Cedar Lake

Parameter	2008-2010 Belle Lake Observed	MINLEAP Predicted NCHF Ecoregion	MINLEAP Predicted WCBP Ecoregion
TP (µg/L)	56	30	60
Chl-*a* (µg /L)	23.2	10	26
Secchi (m)	1.0	2	1
P loading rate (kg/yr)	-	443	1,407
P retention (%)	-	84	89
P inflow conc. (µg/L)	-	183	564
Water Load (m/yr)	-	0.69	0.71
Outflow volume (hm^3/yr)	-	2.42	2.49
Residence time (yrs)	-	7.1	6.9
Vighi & Chiaudani	-	24	24

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 ten year cycle, immediately following a two year intensive monitoring effort. Belle Lake is scheduled to be assessed 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.

Belle Lake, with a maximum depth of 7.6 meters and 44 percent littoral area would be held to the NCHF Aquatic Recreation Use (Class 2B) standards for deep lakes. While the lake is near the boundary with the WCBP ecoregion, a closer review of the watershed land use composition justifies the use of the NCHF standards. Belle Lake, while not formally assessed, is not meeting aquatic recreation use standards (Table 9). Measures should be taken to reduce nonpoint source runoff to the lake. Internal recycling of TP may be an important consideration as well in Belle Lake.

Table 9 Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005)

Belle Lake 2008-2010 and long-term means provided for comparison. Applicable standard in bold

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
Belle Lake 2008-2010	56	23.2	1.0

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Appendix A

Lake Surface Water Quality Data for Belle Lake for 2008-2010.

All water quality data can be accessed at: http://www.pca.state.mn.us/data/eda/STresults.cfm?stID=47-0049-01&stOR=MNPCA1.

Lake Name	Lake ID	Sample Date	Site ID	Secchi	TP	Chl-*a*	Alkalinity	Chloride	TKN	N02+NO3	Color, Apparent	TSS
				Meters	µg/L	µg/L	mg/L	mg/L	mg/L	mg/L	PCU	mg/L
Belle	47-0049-01	5/21/2008	201	1.9	58	9.21	160	13.3	1.7	0.18	5	4.8
Belle	47-0049-01	6/12/2008	201	1.4	55	16.9			1.71	0.15		
Belle	47-0049-01	7/23/2008	201	0.7	65	23.5	150	14	1.5	<0.05	5	12
Belle	47-0049-01	7/23/08 FR	201		61	25.3	150	14	1.5	<0.05	5	12
Belle	47-0049-01	8/26/2008	201	0.7	60	23.3			1.64	<0.05		
Belle	47-0049-01	9/22/2008	201	0.9	52	26.4			1.44	<0.05		
Belle	47-0049-01	10/7/2008	201	0.7	70	40.3	150	14.1	1.63	<0.05	10	11
Belle	47-0049-01	5/5/2009	201	1.25	44	17.4	160	14.2	1.49	0.17	10	9.6
Belle	47-0049-01	6/2/2009	201	1.2	51	15.5			1.47	<0.05		
Belle	47-0049-01	7/8/2009	201	1.4	37	12.4	160	14.8	1.47	<0.05	5	25
Belle	47-0049-01	7/8/2009 FR	201					15.3				
Belle	47-0049-01	8/4/2009	201	0.7	58	19			1.5	<0.05		
Belle	47-0049-01	9/1/2009	201	0.7	61	21.2			1.23	<0.05		
Belle	47-0049-01	10/12/2009	201	1	55	24.2	150	15.4	1.5	<0.05	10	7.6
Belle	47-0049-01	4/29/2010	201	3	38	6.96	160	14.7	1.34	0.15	20	5.6
Belle	47-0049-01	7/26/2010	201	1	65	50.5	160	15	1.78	<0.05	10	10
Belle	47-0049-01	7/26/2010 FR	201					15				
Belle	47-0049-01	10/4/2010	201	0.9	58	53.5	150	14.9	1.73	<0.05	10	9.6

Appendix B

Zooplankton Data 2008 – 2010

	Density	Biomass	Daphnia Density	Daphnia Biomass
Belle Lake	#/L	ug/L	#/L	ug/L
May-08	97.7	550.7	45.7	403.7
Jun-08	75.3	458.8	28.63	298
Jul-08	44.7	420.9	3.5	60.2
Aug-08	77.1	356.4	14.8	70.5
Sep-08	23.6	144.2	5.5	49.2
Oct-08	27.5	109.3	1.8	5.3
May-09	45.7	295.1	23.1	193
Jun-09	87.9	617.15	45.2	481.5
Jul-09	44.6	338.1	11.4	142
Aug-09	23.9	196.2	4.1	53.2
Sep-09	17.3	234.7	7.2	156.2
Oct-09	11.9	67.6	1.3	10.7
Apr-10	40.7	459.4	26.3	373
Jul-10	44	232.7	4.6	91.5
Oct-10	20.8	182.9	6	95.7