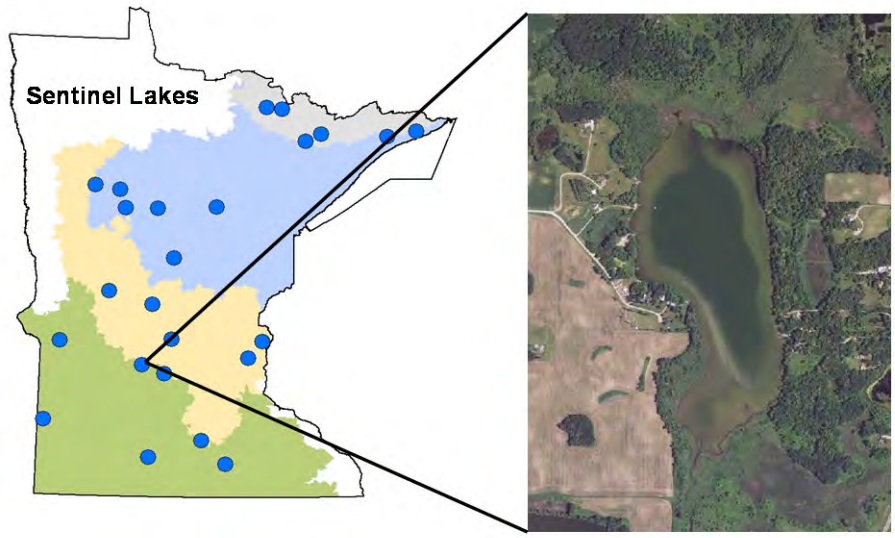
Sentinel Lake Assessment Report
Carrie Lake (34-0032)
Kandiyohi County, Minnesota



Minnesota Pollution Control Agency
Water Monitoring Section
Lakes and Streams Monitoring Unit
and
Minnesota Department of Natural Resources
Section of Fisheries
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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 2010). 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 typically do not stratify and are well mixed throughout most of the summer. "Cold Water" lakes are defined as lakes that harbor cisco, lake whitefish, or lake trout and are the focus of research funded by the Environmental Trust Fund (ETF). "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is funded by the ETF.

Carrie represents a lake of moderate depth in the Western Corn Belt Plains (WCBP) ecoregion. Carrie is 36.8 hectares (91 acres) in size and is located southwest of Atwater, Minnesota in Kandiyohi County, within the Minnesota River basin watershed. The lake has a maximum depth of 7.9 meters (26 feet) and a mean depth of 3.2 meters (10.4 feet). The lake is 23 percent littoral with one public access. The total contributing watershed for Carrie Lake is quite small at 1,637 hectares (4,044 acres). The watershed is predominantly cultivated; however, the near shore riparian area is mostly wooded and ringed with homes and cabins.

Carrie is a relatively deep lake for the WCBP ecoregion and is one of few southern Minnesota lakes that exhibit thermal stratification throughout the summer months. Carrie Lake is a small marl lake with low total phosphorus (TP) and chlorophyll-a (Chl-a). Its transparency is low relative to TP and Chl-a, which is presumably caused by very fine calcium carbonate particles suspended in the water. Marl deposits are quite evident on plants and substrates in the lake and the marl is readily re-suspended when sediments are disturbed. Curly-leaf pondweed is present at very low densities in the lake and it does not appear to have an influence on TP or Chl-a.

Based on recent water quality data (2008-2011), Carrie Lake is mildly eutrophic with TP, Chl-a, and Secchi values of: 23 micrograms per liter (µg/L), 6.7 µg/L, and 1.4 meters (4.6 feet) respectively. These values are better than the typical range for reference lakes in the WCBP ecoregion. Nuisance algal blooms (Chl-a >20 µg/L) have not been observed during sampling, but have been noted in the past; severe nuisance blooms (Chl-a > 30 µg/L) are uncommon. Secchi transparency data have been collected by a Citizen Lake Monitoring Program (CLMP) volunteer, Gene Lehmbecker. CLMP is essential to identifying long-term trends in water quality along with short-term variations in lake trophic status.

Pesticide samples were collected on four dates in 2009 and 2010 and analyzed at Minnesota Department of Agriculture. Detection frequency ranged from 25percent to 100 percent for the various detected compounds. The Carrie Lake watershed is highly cultivated and associated pesticide use is likely reflected in the pesticides detected. All pesticide detections in Carrie Lake are well below applicable water quality standards and benchmarks. The pesticide detections and concentration ranges in Carrie Lake are consistent with other lake sampling results of lakes located in highly cultivated areas in southern Minnesota.

Carrie Lake has a diverse fish community including at least 22 species. The primary game fish species in Carrie are walleye, northern pike, largemouth bass, black crappie, white crappie, and bluegill. Black or brown bullheads and common carp have been abundant historically; however, recently bullheads have

declined while carp have continued to be abundant in some years. Abundance of common carp in Carrie Lake probably is influenced by movement between Elizabeth and Carrie Lakes, and carp may contribute to turbidity by re-suspending sediment during their bottom-feeding activity.

Carrie Lake has a history of little or no submersed aquatic vegetation; however, a small amount of curly-leaf pondweed was discovered in Carrie Lake in 2010. In 2011, it was present at 14.5 percent of the points sampled in spring. In addition, sago pondweed was first reported in summer samples in 2010, and in 2011, its frequency of occurrence increased to 12.3 percent. Thus, we may be seeing the beginning of a trend toward more submersed aquatic plants in Carrie Lake.

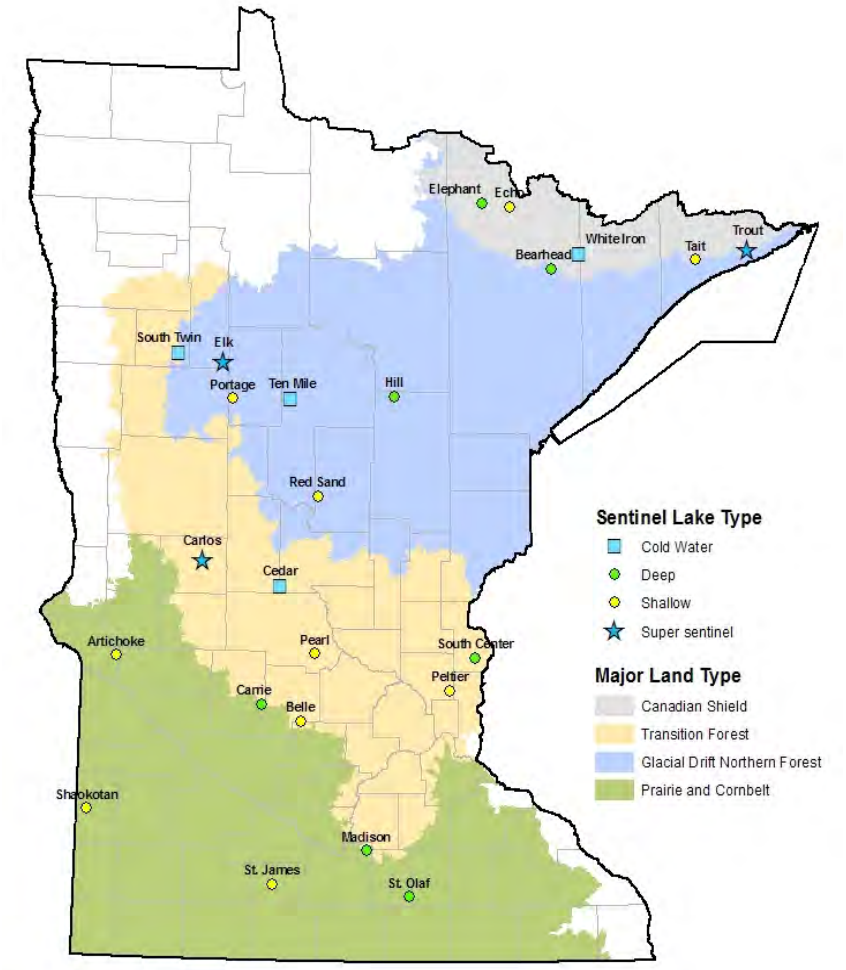


Figure 1. MDNR map of Sentinel Lakes and major land types

Introduction

This report provides a relatively comprehensive analysis of physical, water quality, and ecological characteristics of Carrie Lake in Kandiyohi County, Minnesota. This assessment was compiled based on MDNR surveys of the lake's fish and aquatic plant communities, MPCA, 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, 2009, 2010, and 2011 seasons, which is the primary source of data for the lake. Water quality data analyzed will include all available data in MPCA's EQUIS water quality database. 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).

Carrie is located in eastern Kandiyohi County and is near the transition from the(North Central Hardwood Forest (NCHF) and WCBP ecoregions. The lake is small, but relatively deep for a WCBP lake. The lake shoreline is developed with a ring of year-round and seasonal dwellings and much of the remainder of the watershed is in cultivated land use. It is highly used and is an important resource for this part of the State.

History

1950s	One resort on lake.
1979	Initial Fisheries survey. Immediate watershed use listed as 80 percent forest or woodland, 10 percent agricultural, 10 percent wetland. No resorts, eight homes or cottages (7/8 on east side), 13 boats. Light recreational use. Some bank erosion on east side where cattle crossed a ravine. Noted that bullheads migrated from adjacent Elizabeth Lake into Carrie Lake when winterkill conditions existed in Elizabeth Lake.
1980	Fisheries natural reproduction check.
1984	Fisheries population check. Noted algae blooms in summer probably caused by agricultural runoff.
1989	Fisheries population assessment. Noted unsubstantiated angler report of winterkill of crappie during 1989-1990.
1996	Fisheries re-survey.
2002	Fisheries population assessment.
2006	Fisheries re-survey. Watershed listed as 50 percent agricultural, five percent grassland, 20 percent marsh, five percent pasture, 20 percent forested; shoreline listed as 30 percent marsh, 55 percent forested, five percent agricultural, 10 percent residential. Ten homes or cottages and eight Recreational Vehicles on lots. Spawning habitat listed as excellent for common carp; good for largemouth bass, black bullhead, bluegill, northern pike, and black crappie; fair for yellow perch; and poor for walleye.
2008	Sampling for SLICE began.
2010	Curly-leaf pondweed documented for the first time in Carrie Lake, although it had been abundant in nearby Elizabeth and Ella Lakes during previous years.

Background

Lake morphometric and watershed characteristics

Carrie is a relatively deep lake for the WCBP ecoregion, where typical maximum depth is in the 3.0-4.5 meters (m; 10-15 foot) range. It has a surface area of 36.8 ha (91 acres), of which 23 percent is considered littoral (percent of lake <15 feet). Carrie is a deep lake based on its maximum depth of 7.9 m (26 feet) and percent littoral, which is less than 80 percent of the lake (Figure 2). Carrie Lake has a large watershed relative to its lake surface area (44:1); however, a large portion of the watershed flows to a diffuse wetland on the southern end of Carrie Lake and then flows into Lake Elizabeth. The proportion of water that enters Carrie Lake from the southern portion of the watershed is unclear and likely depends on water level. Significant groundwater contributions, which serve to maintain lake level, are likely in Carrie Lake given the geology of the surrounding area.

Table 1. Carrie Lake and watershed morphometric, characteristics

Lake Name	Lake ID	Lake Basin hectares (acres)	Littoral Area (%)	Total Watershed Area hectares (acres)	Watershed: Lake	Max. Depth meters (feet)	Mean Depth meters (feet)	Lake Volume acre-ft
Carrie	34-32	36.8 (91)	23	1,637 (4,044)	44:1	7.9 (26)	3.2 (10.4)	946.9

Carrie Lake's contributing watershed lies within the South Fork Crow River watershed. The lake's watershed drains through a wetland, south, into Lake Elizabeth. The contributing watershed has a total area of 1,637 hectares (4,044 acres) resulting in a watershed-to-lake area ratio of approximately 44:1 (Table 1). Watershed areas were estimated based on data from the University of Minnesota Remote and Geospatial Analysis Lab.

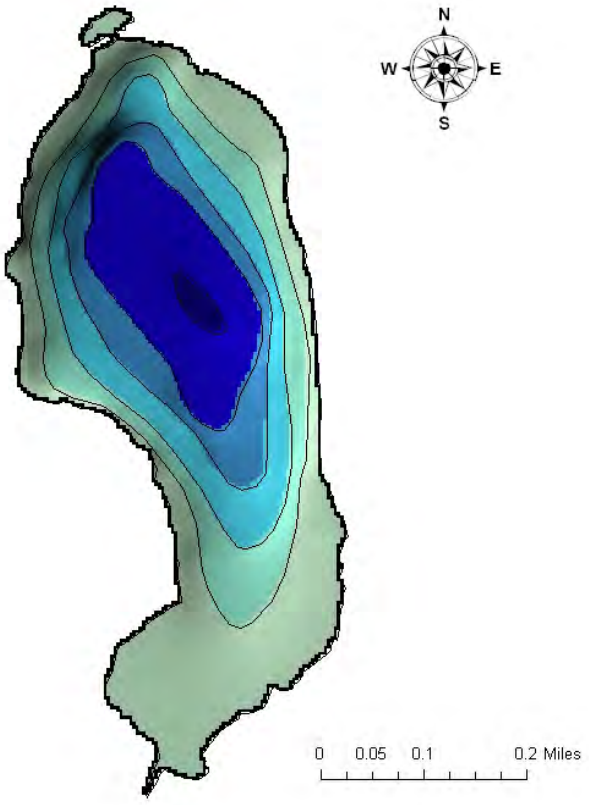


Figure 2. Carrie Lake bathymetric contour map as of 2009

Soils in the South Fork Crow River Watershed near Carrie Lake are composed of Central Iowa and Minnesota Till Prairies. "This area is called the "Des Moines Lobe" of the Wisconsin-age ice sheet that covered the north central United States about 12,000 years ago. Most of this area is nearly level to gently rolling till plain. This area is covered with glacial till, outwash, and glacial lake deposits. Recent alluvium consisting of clay, silt, sand, and gravel fill the bottoms of most of the major river valleys. Natural lakes dot this Major Land Resource Area (MLRA) and numerous bogs, swales and circular depressions indicate sites of previously ponded water. Much of the area is tile drained with extensive drainage ditches providing outlets for the tile drains. End moraines have a banded pattern across this area and are typically described as knob and kettle topography" (Natural Resources Conservation Service).

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) is a process by 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. Thus low oxygen environments in

the hypolimnion are conducive to TP being released from the lake sediments. During stratification, dense colder hypolimnion waters are separated from the nutrient-hungry algae in the epilimnion. Intermittently (weakly) stratified polymictic lakes are mixed in high winds and during spring and fall. Mixing events allow for the nutrient-rich sediments to be re-suspended and become available to algae.

Polymictic Lake
Shallow, no layers,
mixes continuously
spring, summer and fall

Dimictic Lake
Deep, form layers,
mixes spring/fall

Intermittently Stratified
Moderately deep
mixes during high winds
spring, summer, and fall

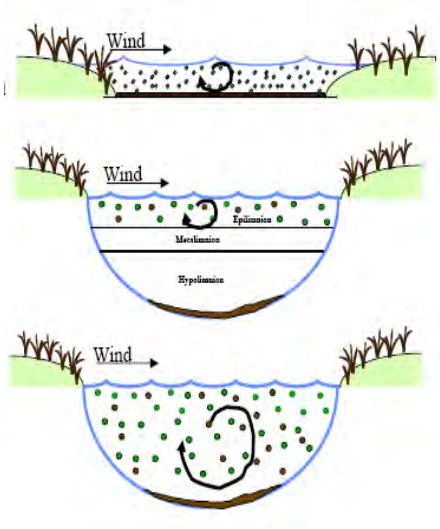


Figure 3. Lake Stratification

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. Carrie Lake lies within the WCBP ecoregion (Figure 4). WCBP ecoregion values are used for land use (Table 2) and summer-mean water quality comparisons (Table 6). Additionally, the WCBP ecoregion is used for the model application.

Since land use affects water quality, it has proven helpful to document the land use composition in the watershed of the lake. The Carrie Lake watershed is dominated by agriculture land use (Figure 5), which is typical for a WCBP lake (Table 2). Fortunately, cultivated lands do not extend all the way to the shoreline of the lake, in contrast to many WCBP lakes that may be completely ringed by cultivated lands. The riparian area of Carrie is characterized by numerous homes, a county park, and a patchwork of woods and open land. A 2007 MDNR lake management plan indicated near shore habitat was relatively stable based on lake surveys dating back to the1950s, but there were some concerns with shore land erosion at some locations.

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

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

Land Use	Carrie* 1969	Carrie* 1991	Carrie 2001	NGP Typical Land Use %
Developed	1	1	4	0-2
Cultivated (Ag)	74	66	65	60-82
Pasture & Open	12	12	10	5-15
Forest	6	14	14	0-1
Water & Wetland	7	7	7	8-26
Feedlots (#)	-	-	2	-

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

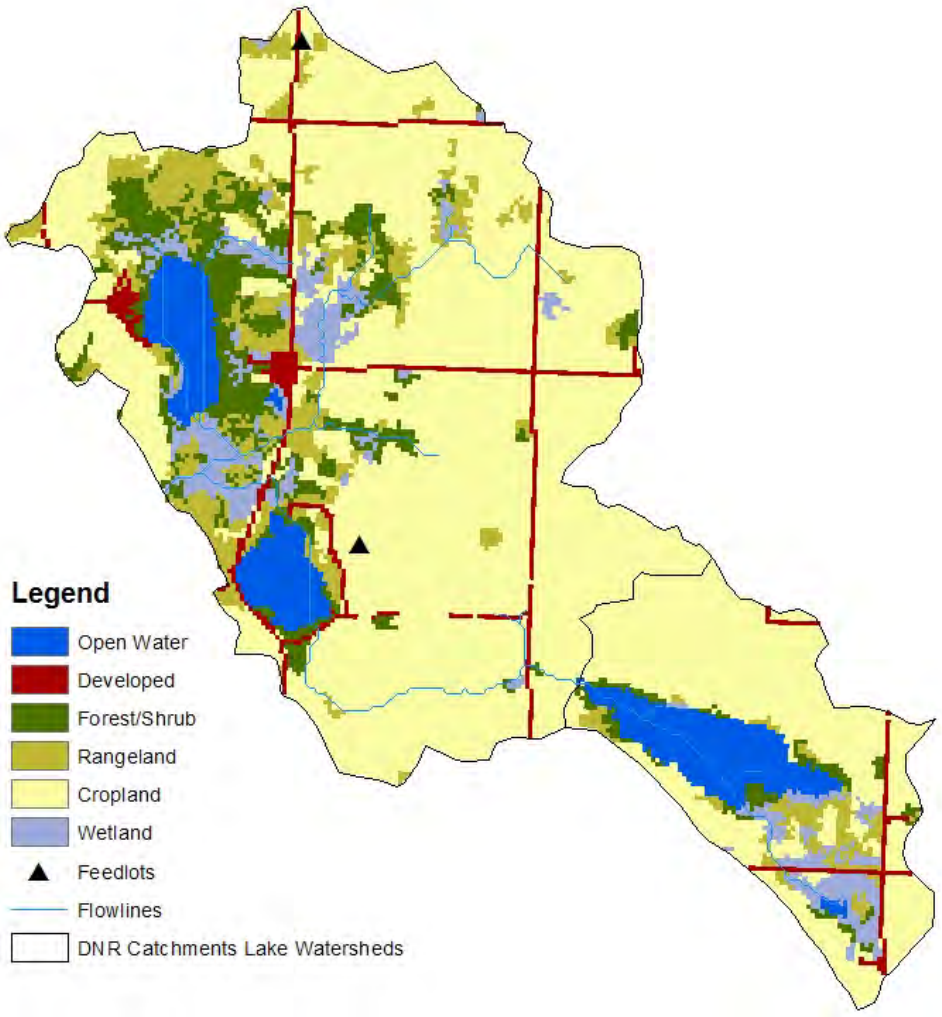


Figure 5. Carrie Lake Watershed and land use composition

Lake level and ice on/off

The MDNR Division of Waters has been measuring water levels on Carrie Lake since 1980, and regular measurements have been taken every year since. Two hundred forty-seven measurements have been taken through April 2012. The highest recorded lake elevation was 1127.66 feet recorded on September 19, 1991 and the lowest was 1124.52 feet recorded on June 21, 2006. The Ordinary High Water (OHW) level was established at 1126.9 feet. Water levels in Carrie Lake are relatively stable and most likely maintained by groundwater. Wet periods of record show the lake rising; however, when water levels are high, Carrie Lake flows to Elizabeth Lake through a diffuse wetland and stream channel. For the 2008-2010 periods, the lake level typically decreased during the summer months and increased during spring and fall (Figure 6). There is no long-term trend when the entire record is considered (Figure 7). The complete water level record may be obtained from the MDNR website at: http://www.dnr.state.mn.us/lakefind/showlevel.html?id=34003200.

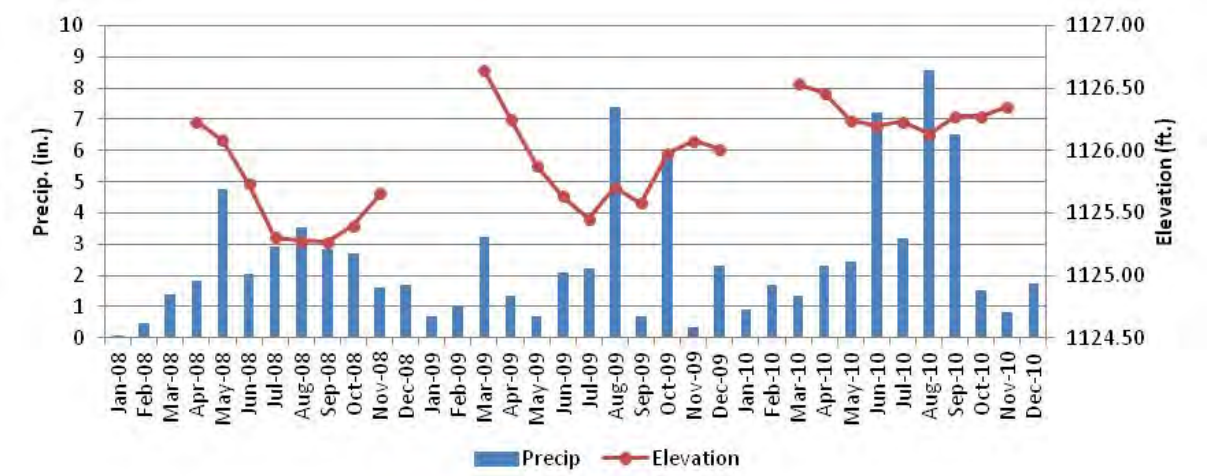


Figure 6. 2008-2010 lake level fluctuations and precipitation

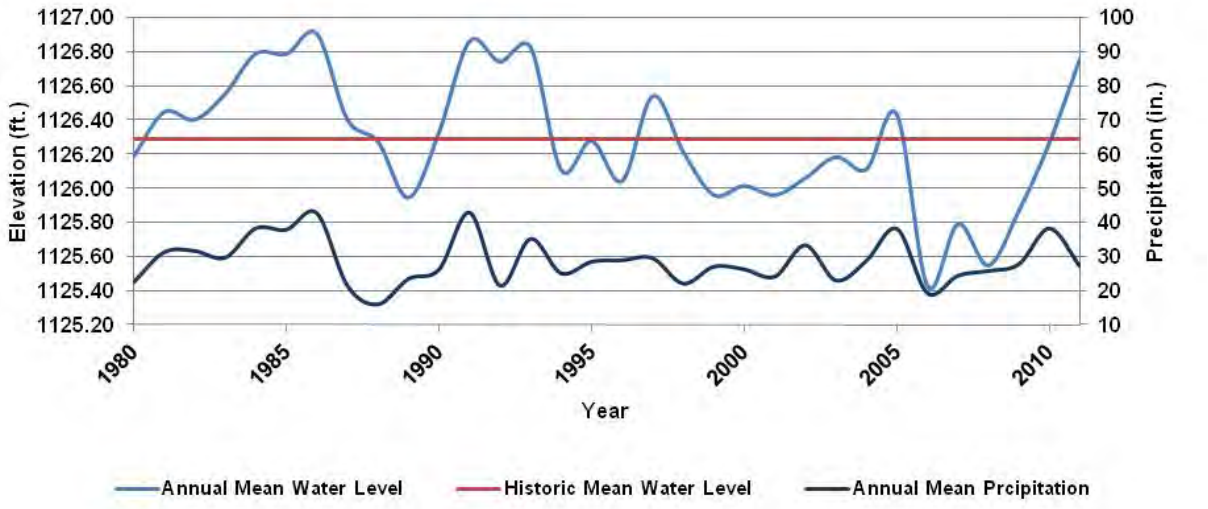


Figure 7. 1980-2011 annual mean lake level and precipitation

There has been increased interest in recording ice on and ice off dates as a part of climatological studies and the more recent interest in global climate warming. Some Minnesota lakes have very extensive records; however most do not. As a part of the Sentinel lakes effort this is something we are interested in compiling for all Sentinel lakes. Ice on and off dates have been recorded from 1994-2008 on Carrie Lake. Records for Carrie show that ice-on dates are between November 4th and December 18th and ice off dates are between March 8th and April 10th (Appendix A).

Precipitation and climate summary

Large rain events increase runoff into the lake and may influence in-lake water quality and lake levels. This will be considered in the discussion of lake water quality for 2008-2011. Precipitation data for Carrie Lake were collected at the Willmar HWY Garage (218999) rain gauge station. Total Precipitation values were calculated for each month and fluctuations are shown throughout the record in Figure 8. Based on state climatology records, precipitation averages for the October 2008 to September 2009 water year were between 0.61–0.71 m (24 and 28 inches) annually at Carrie Lake (Figure 9). Precipitation in recent years has been significantly higher than this range, 0.15-0.25 m (6-10 inches) above normal (Figure 9). This corresponds to the increase in water level observed from 2008 -2010.

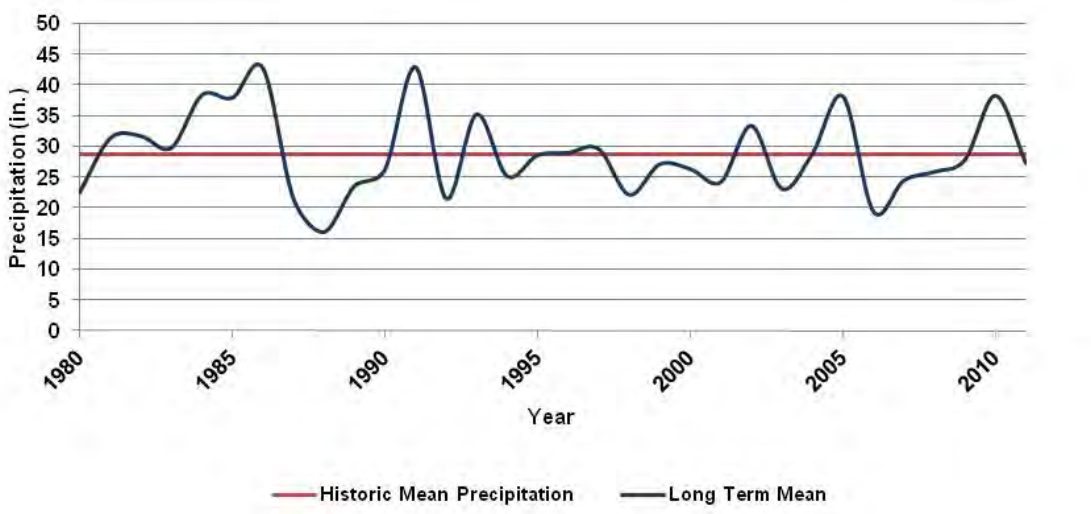


Figure 8. Precipitation annual values 1980-2011

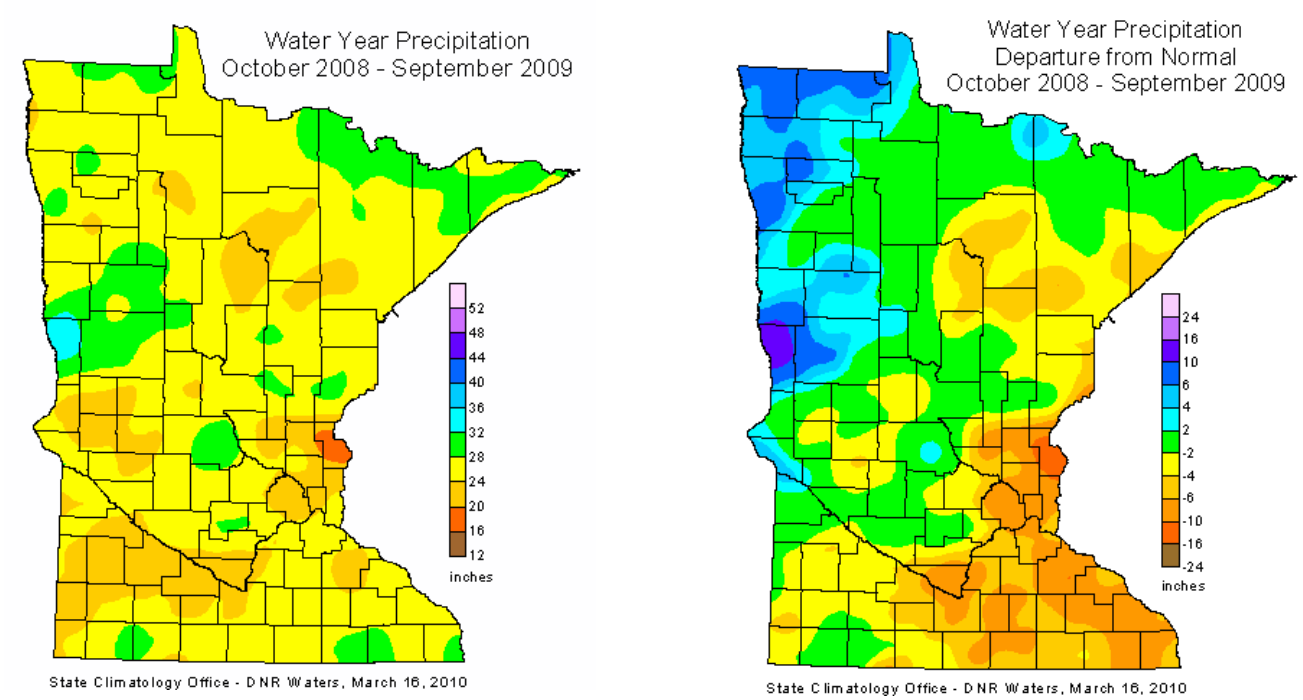


Figure 9. 2009 Minnesota water year precipitation and departure from normal

Prepared by State Climatology Office DNR waters values are in inches

Methods

Fisheries and aquatic plants

Frequencies of occurrence of aquatic plant species were assessed using the point-intercept method (Madsen 1999). This method entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately 1 m, then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80-m (0.7 points per littoral acre). Hydroacoustics were used to survey vegetation bio-volume (percent of water column occupied by vegetation) along 40-m transects using methods and equipment described by Valley et al. (2005). Local kriging with VESPER 1.6 was used to create 15-m raster grids of bio-volume (Walter et al. 2001; Minasny et al. 2002).

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

Water quality

Water quality data for Carrie Lake were collected May through October for 2008, 2009, 2010, and 2011 by MPCA staff. Lake surface samples were collected by MPCA staff with an integrated sampler; a poly vinyl 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 µm mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Hypolimnetic total phosphorous (TP) samples were collected with a Kemmerer sampler. Temperature and dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken. 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 laboratory of the Minnesota Department of Health using United States Environmental Protection Agency-approved methods (Table 3). 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.

Table 3. Laboratory methods and precision

Parameter and unit	Reporting limit	Method number	Precision: [1] mean difference	Difference as percent of observed
Total Phosphorus µg/L	3.0	EPA365.1	4.8	2.7 %
Total Kjeldahl N mg/L	0.1	EPA351.2	0.05	2.8 %
$NO_2 + NO_3$ mg/L	0.05	EPA353.2		
Total Suspended Solids mg/L	1.0	SM2540D	2.8	9.6 %
Total Suspended Volatile Solids mg/L	1.0	SM2540E	--	--
Alkalinity mg/L CaCO3	10	SM 2320 B	--	--
Chloride mg/L	1.0	EPA 325.2		
Color CU	5	EPA 110.2		
Chlorophyll-a µg/L		SM10200H	1.7	7.4 %
Pheophytin		SM10200H	--	--

Zooplankton

Zooplankton samples were collected monthly from ice-out (April/May) through October for 2008-2009. Samples were collected in May, July, and October in 2010-2011. 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 5-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 (number/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.

Carrie Lake is connected to a large shallow and productive lake (Elizabeth) via an outlet channel during moderate to high water level conditions. Fish movement frequently occurs between these two lakes during the spring months. Walleye and northern pike have been observed spawning in or near the outlet channel adjacent to the two lakes. Lake Elizabeth is generally stocked with walleye fry every other year. Carrie was recently stocked in 1995 (44 adult northern pike), 2004 (1,440 walleye yearlings), 2006 (97 walleye adults/yearlings), 2007 (125 walleye yearlings), 2008 (448 walleye yearlings), 2009 (8,496 walleye frylings) and 2011 (13,040 walleye frylings). The primary gamefish species managed in Carrie are walleye, largemouth bass, and black crappie. All fish species that have been reported from Carrie Lake are listed in Table 4. Relative Stock Densities (RSD) for common fish species in Carrie Lake are shown in the time series charts (Figure 10).

Historically, black bullhead catch rates often greatly exceeded the 75th percentile for the lake class, but catches have been low since 2008. Brown bullheads also have been reported in Carrie Lake, but in very low numbers except in 2002, when black bullheads were also very abundant. Due to the difficulty of accurately distinguishing black and brown bullheads in the field, there likely was some misidentification of black bullheads as brown bullheads and vice versa. The extremely high catch rates of black/brown bullheads in 2002 were due to recruitment of small fish, as indicated by the dramatic dip in RSD-8. Yellow bullheads are also present in Carrie Lake, but catch rates have been low for the lake class, and there is evidence of a declining trend after 1989.

Common carp catch rates also often greatly exceeded the 75th percentile for the lake class, and unlike bullheads, catch rates have not declined recently. In 2011, the trapnet catch rate was the highest on record, but this may be an anomaly because the gillnet catch rate was slightly below the long-term average, and no young carp (under 15 inches) have been captured in Carrie Lake since 1989. Some of the annual variability in catch rates may be due to movement of common carp between Carrie Lake and Elizabeth Lake (Bajer and Sorensen 2009).

Black crappie catch rates were much higher than typical for the lake class, and tended to increase in the 2000s. Back-calculated lengths at age were within the Spicer Area interquartile ranges for fish collected in 1996, 2002, and 2006, but fell below the 25th percentiles at age's ≥ 2 for fish collected in 2009. Quality-size (≥ 8 in) fish made up a large portion of the catch in 1979 and 1984, but smaller fish dominated the catch from 1989 through 2009. Size structure has improved since 2009: in 2011, RSD-8 was almost 40.

White crappies are also common in Carrie Lake, although the long-term average trapnet catch rate for white crappies is only 62 percent of the black crappie catch rate. Similar to other lakes with both crappie species, some fish counted as white crappies probably were hybrids with black crappies, and vice versa. White crappie lengths at age were within or below the Spicer Area interquartile ranges, and RSD-8 was usually below 20.

Bluegill catch rates were low in 1979, 1984, and 1989, and then increased dramatically due to recruitment of small fish in 1996. In the 2000s, catch rates have been toward the low end of the interquartile range for

the lake class. Growth rates were within or above the Spicer Area interquartile ranges in recent years. There has been a strong increasing trend in RSD-6 after 1996, and quality-size fish made up a substantial proportion of the catch during the last three years.

Largemouth bass were targeted with spring electrofishing beginning in 1996. Abundance of largemouth bass in Carrie Lake appears to be low: catch rates have fluctuated around the long-term mean of 18.5/h of on time, but the Spicer Area largemouth bass average catch rate is 46.6/h of on time. The 2009 year class composed 40 percent of the 2011 electrofishing catch. Values of RSD-12 were above 50 every year except 1996 and 2010. Largemouth bass lengths at age generally were within the Spicer Area interquartile ranges.

Northern pike gillnet catch rates showed an increasing trend after 1989, reaching levels above the 75 percent lake class quartile in 2002 and 2011. As catch rates have increased, the proportion of quality-size fish has tended to decrease, but RSD-21 still remained above 50 in 2011. The 2008 year class composed 41 percent of the catch in 2011. Northern pike lengths at age in Carrie generally were within the Spicer Area interquartile ranges.

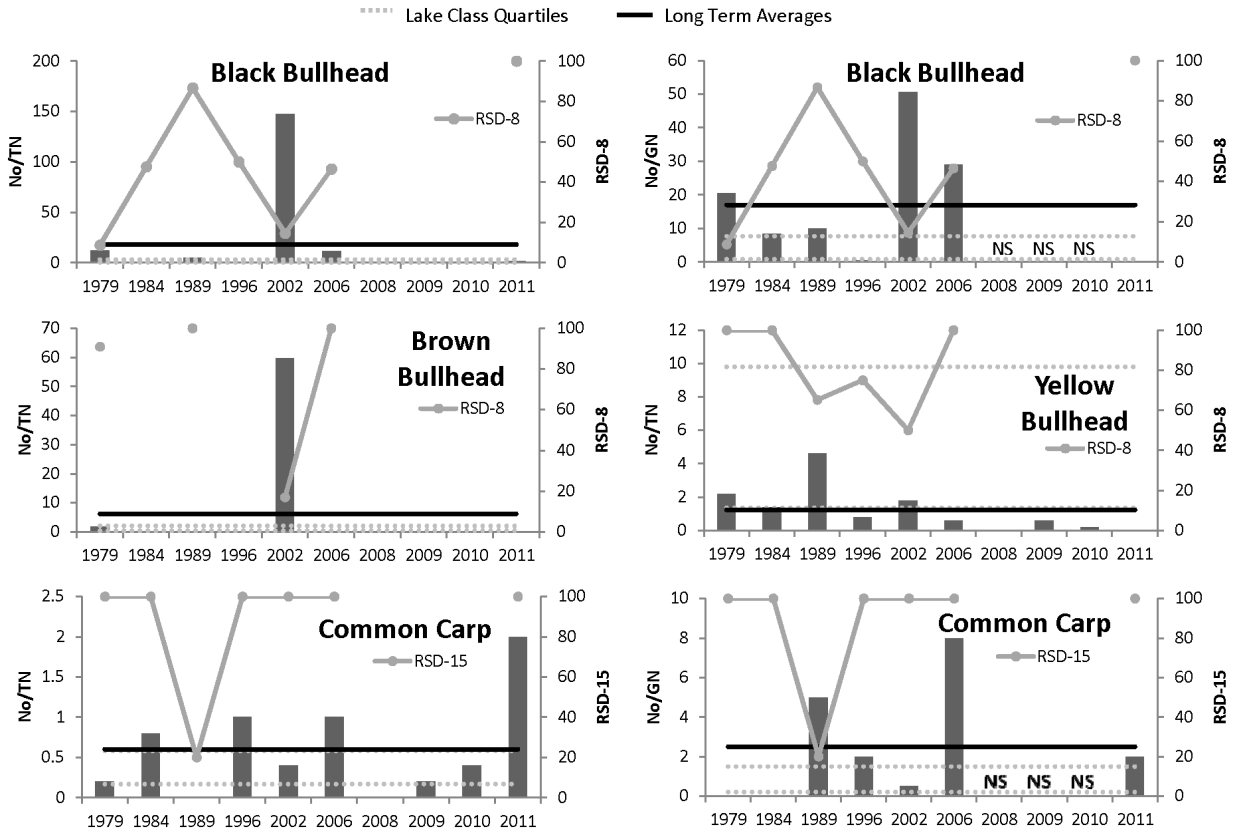
Walleye catch rates have been within the interquartile range for the lake class except in 1979 (high) and 1996 (low). In recent years, the RSD-15 has been 80-100, typical of a population with little or no natural reproduction. Lengths at age were generally above the 75th percentile for the Spicer Area. The 2008 and 2009 year classes composed, the majority of the 2011 gillnet catch. Abundant numbers of young of year (YOY) walleye (58.4/h; 6.6 in average lengths) were captured in the 2011 fall electrofishing survey. Approximately 97 percent of the YOY walleye were oxytetracycline (OTC) marked fish from a 2011 fryling stocking. There were no YOY walleye captured in the 2010 (non-stocked year) fall electrofishing survey. Abundant numbers of YOY walleye (50.3/h; 4.9 in average lengths) were captured in the 2009 fall electrofishing survey (fryling stocked year). Approximately 50 percent of the 2009 YOY walleye captured were OTC marked fish from the 2009 fryling stocking. The unmarked fish observed in the 2009 fall survey probably moved into Carrie from connected Lake Elizabeth (2009 fry-stocked). The walleye population present in Carrie had been primarily the result of fish movement from Elizabeth into Carrie during high water prior to 2009. Good walleye spawning habitat (wind-swept areas of rubble bars and points) is not present in Carrie.

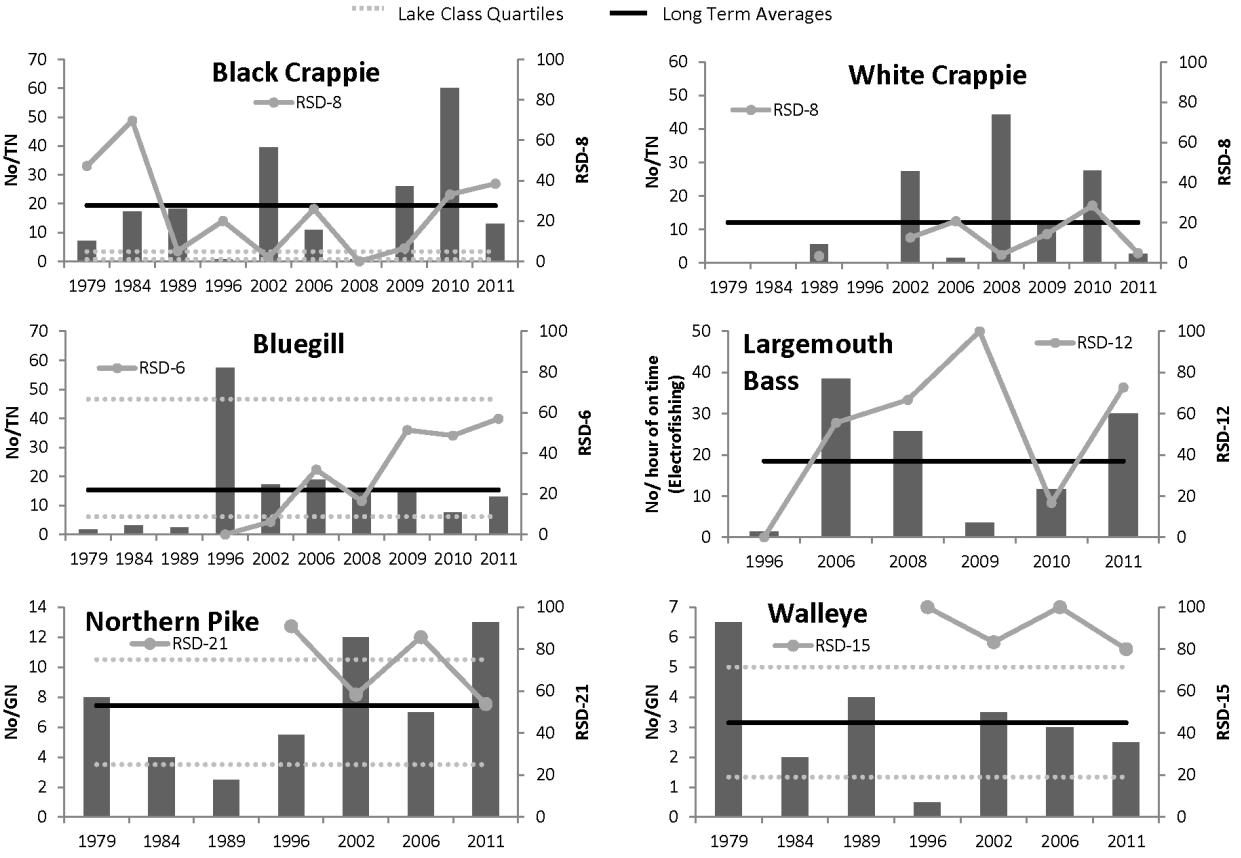
Yellow perch catch rates generally were within the lake class interquartile range. The catch rate of 34/gillnet in 2011, although not unusual for the lake class, was the highest on record for Carrie Lake. Average size of yellow perch has been small, with RSD-8 less than 12. The 2009 year class composed 47 percent of the 2011 catch. Yellow perch lengths at age were within the Spicer Area interquartile ranges.

White sucker catch rates generally were within lake class quartiles, with no apparent trend over time.

Table 4. Fish species captured during past fisheries surveys in Carrie Lake. Thermal guilds were classified by Lyons et al. (2009) and environmental tolerances were categorized by Drake and Pereira (2002)

Common name	Species name	Trophic guild	Thermal guild	Environmental tolerance[a]	First sampled
Northern pike	*Esox lucius*	Predator	Cool	Neutral	1979
Black crappie	*Pomoxis nigromaculatus*	Predator	Warm	Neutral	1979
White crappie	*Pomoxis annularis*	Predator	Warm	Neutral	1989
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1979
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1979
Channel catfish	*Ictalurus punctatus*	Predator	Warm	Neutral	2009
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	Tolerant	1984
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-warm	Neutral	1989
Iowa darter	*Etheostoma exile*	Insectivore	Warm	Neutral	2008
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1979
Bluntnose minnows	*Pimephales notatus*	Omnivore	Warm	Neutral	1989
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	1979
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Warm	Neutral	1979
Yellow bullhead	*Ameiurus natalis*	Omnivore	Warm	Neutral	1979
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1979
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1984
Green sunfish	*Lepomis cyanellus*	Insectivore	Warm	Neutral	1989
Orangespotted sunfish	*Lepomis humilis*	Insectivore	Warm	Neutral	2008
Hybrid sunfish	*Lepomis spp.*	Insectivore	Warm	Neutral	2008
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	Neutral	2009
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	Neutral	1996
Fathead minnow	*Pimephales promelas*	Omnivore	Warm	Neutral	2009
Common carp	*Cyprinus carpio*	Omnivore	Warm	Tolerant	1979


Lake Class Quartiles
Long Term Averages
Black Bullhead
RSD-8
No/TN
RSD-8
Black Bullhead
RSD-8
No/GN
RSD-8
NS NS NS
Brown Bullhead
RSD-8
No/TN
RSD-8
Yellow Bullhead
RSD-8
No/TN
RSD-8
Common Carp
RSD-15
No/TN
RSD-15
Common Carp
RSD-15
No/GN
RSD-15
NS NS NS
1979 1984 1989 1996 2002 2006 2008 2009 2010 2011


Lake Class Quartiles
Long Term Averages
Black Crappie
RSD-8
No/TN
RSD-8
White Crappie
RSD-8
No/TN
RSD-8
Bluegill
RSD-6
No/TN
RSD-6
Largemouth Bass
RSD-12
No/ hour of on time (Electrofishing)
RSD-12
Northern Pike
RSD-21
No/GN
RSD-21
Walleye
RSD-15
No/GN
RSD-15
1979 1984 1989 1996 2002 2006 2008 2009 2010 2011

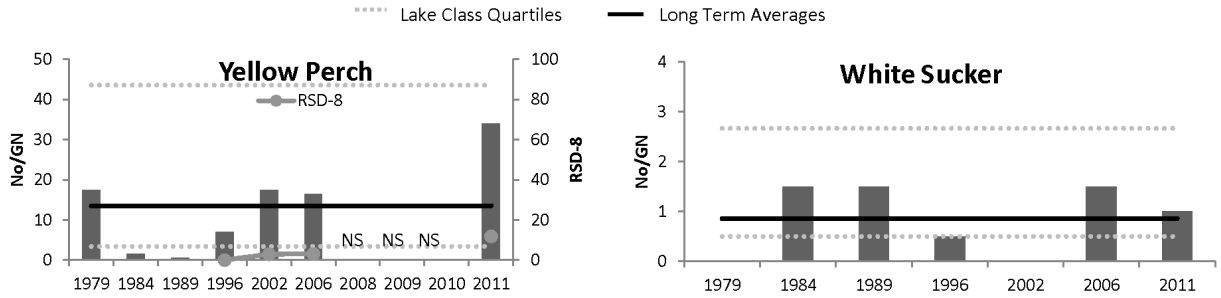


Figure 10. Time series of catch data for common fish species in Carrie Lake. TN=trapnet; GN=gillnet; NS=no sample; RSD-*x* = percentage of "stock-size" fish that are greater than or equal to *x* inches long

Aquatic plant assessment

Little or no submersed aquatic vegetation was observed in historical transect surveys (Table 5). Annual point-intercept surveys beginning in 2008 also revealed low frequencies of occurrence of submersed aquatic plants (Table 6). Historically high abundance of common carp and bullheads has probably contributed to the scarcity of submersed aquatic plants in Carrie Lake; however, a small amount of curly-leaf pondweed was discovered in Carrie Lake in 2010. In 2011, it was present at 14.5 percent of the points sampled in spring. In addition, sago pondweed was first reported in summer samples in 2010, and in 2011, its frequency of occurrence increased to 12.3 percent. Thus, we may be seeing the beginning of a trend toward more submersed aquatic plants in Carrie Lake. Interestingly, this coincides with an apparent decrease in abundance of bullheads, but not common carp.

Table 5. Common species observed during previous transect surveys. Species documented were either labeled as "common" at any transect or found at 10 percent of the transects is listed.

Date	Common Name	Species Name	Growth Form
7/13/79	Common cattail	*Typha latifolia*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	No submersed veg observed		
8/11/84	Common cattail	*Typha latifolia*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	No submersed veg observed		
7/17/96	Reed canary grass[a]	*Phalaris arundinacea*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	Common cattail	*Typha latifolia*	Emergent
	Yellow waterlily	*Nuphar sp.*	Floating-leaf

Table 6. Percent frequency of occurrence of aquatic plant species at depths £ 15 feet sampled during point-intercept surveys on 14 July 2008, 20 July 2009, 23 July 2010, and 25 July 2011 at Carrie Lake, Kandiyohi County, Minnesota.

Season	Common Name	Species Name	Growth Form	2008	2009	2010	2011
Spring[a]	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed	0[c]	0[c]	1.8[c]	14.5[c]
Summer	All rooted plants			26.7	30.0	35.7	45.6
	Hardstem bulrush	*Scirpus acutus*	Emergent	15	11.7	14.3	12.3
	Yellow waterlily	*Nuphar* sp.	Floating-leaf	8.3	5.0	7.1	5.3
	Cattail	*Typha* sp.	Emergent	6.7	18.3	16.1	19.3
	Water moss	*Drepanocladus* sp.		1.7	1.7	1.8	
	Swamp aster	*Boltonia asteroides*	Emergent		3.3		1.8
	Reed canary grass	*Phalaris arundinacea*	Emergent		3.3		3.5
	Muskgrass	*Chara* sp.	Submersed			5.4	7.0
	Filamentous algae					17.9	7.0
	Lesser duckweed	*Lemna* sp.	Free-floating			1.8	
	Cane	*Phragmites australis*	Emergent			5.4	1.8
	Sago pondweed	*Stuckenia pectinatus*	Submersed			1.8	12.3
	Arrowhead	*Sagittaria* sp.	Emergent			1.8	1.8
	Broad-leaf cattail	*Typha latifolia*	Emergent			5.4	
	Curly-leaf pondweed[b]	*Potamogeton crispus*	Submersed				7.0
	Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed				3.5
	Max depth of veg growth (ft)[d]			2.0	2.0	4.5	5.5

[a]Surveys targeting curly-leaf pondweed
[b]Non-native
[c]Surveyed on 4 June 2008, 1 June 2009, 22 June 2010, 23 June 2011
[d]Depth of 95 percent of all plant occurrences

Water quality

Standard summer-mean water quality data for 2008-2011 are presented in Table 7, and raw data results are provided in Appendix B. In addition, major cations, anions, and total organic carbon were analyzed (Table 7). Those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Table 8. The NLA was a statistically-based survey of the nation's lakes administered by the United States Environmental Protection Agency in 2007. The typical range provided in Table 8 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

Dissolved Oxygen temperature profiles

Profiles were taken at one-meter intervals at site 201 in Carrie Lake. Comparisons of 2008, 2009, and 2010 DO and temperature profiles are found in Figures 11, 12, 13, and 14. An isopleth was not created for 2009 profiles because of an insufficient number of profile readings.

Carrie Lake thermally stratified during most of the summer sampling season. This can be attributed to the lake's depth and basin morphology. As a result, Carrie Lake is dimictic and resistant to wind mixing events during periods of strong stratification. DO typically declined below five milligrams per liter (mg/L; necessary to support game fish) at four m in 2008 and 2009. Variations could be attributed to temperature and mixing fluctuations from year to year. Based on DO profiles for 2008 and 2009, hypoxic conditions (DO<2.0 mg/L) are common starting in June and persisting into September.

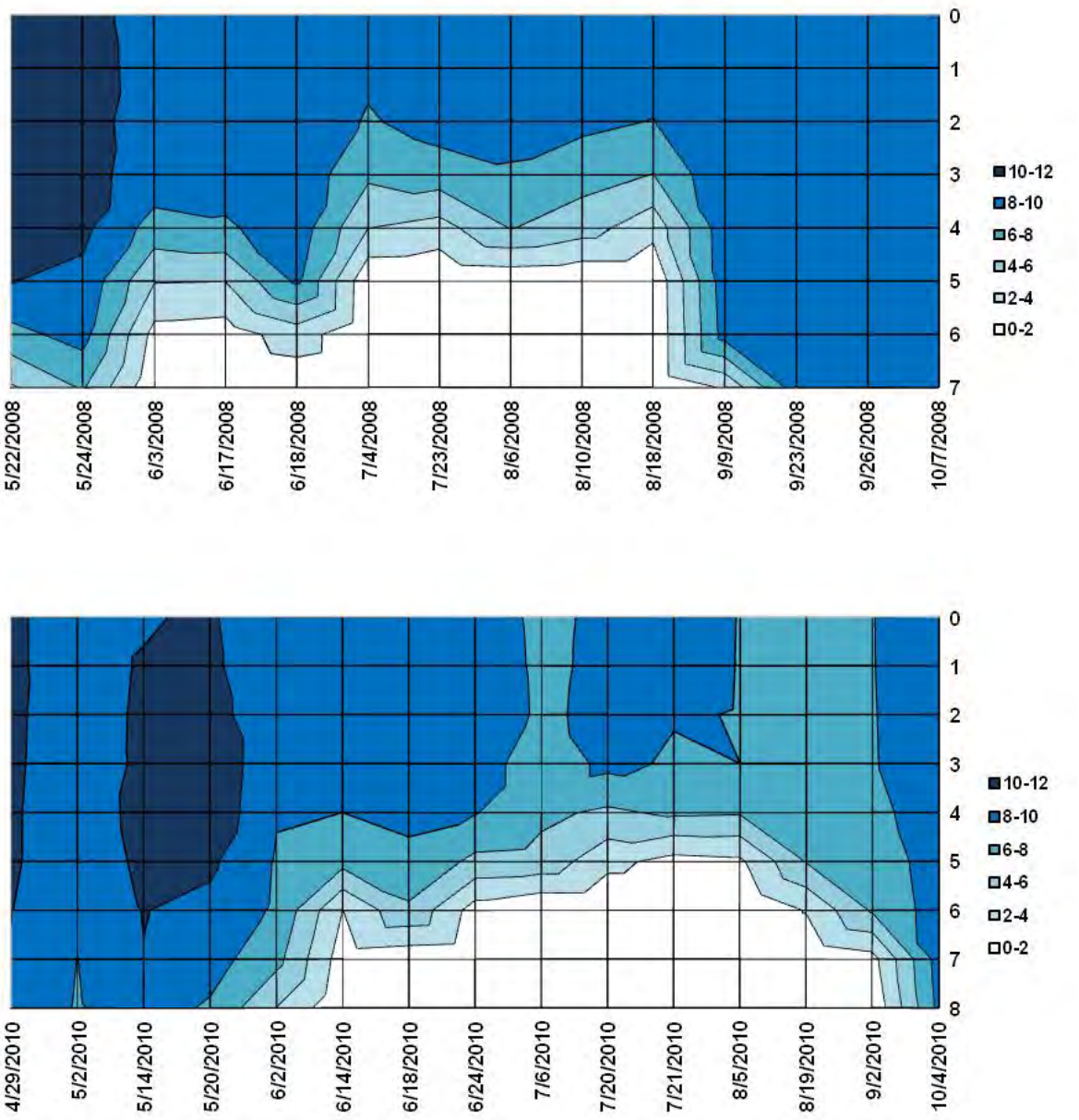


Figure 11. 2008and 2010 dissolved oxygen isopleth profiles site 201 Carrie Lake

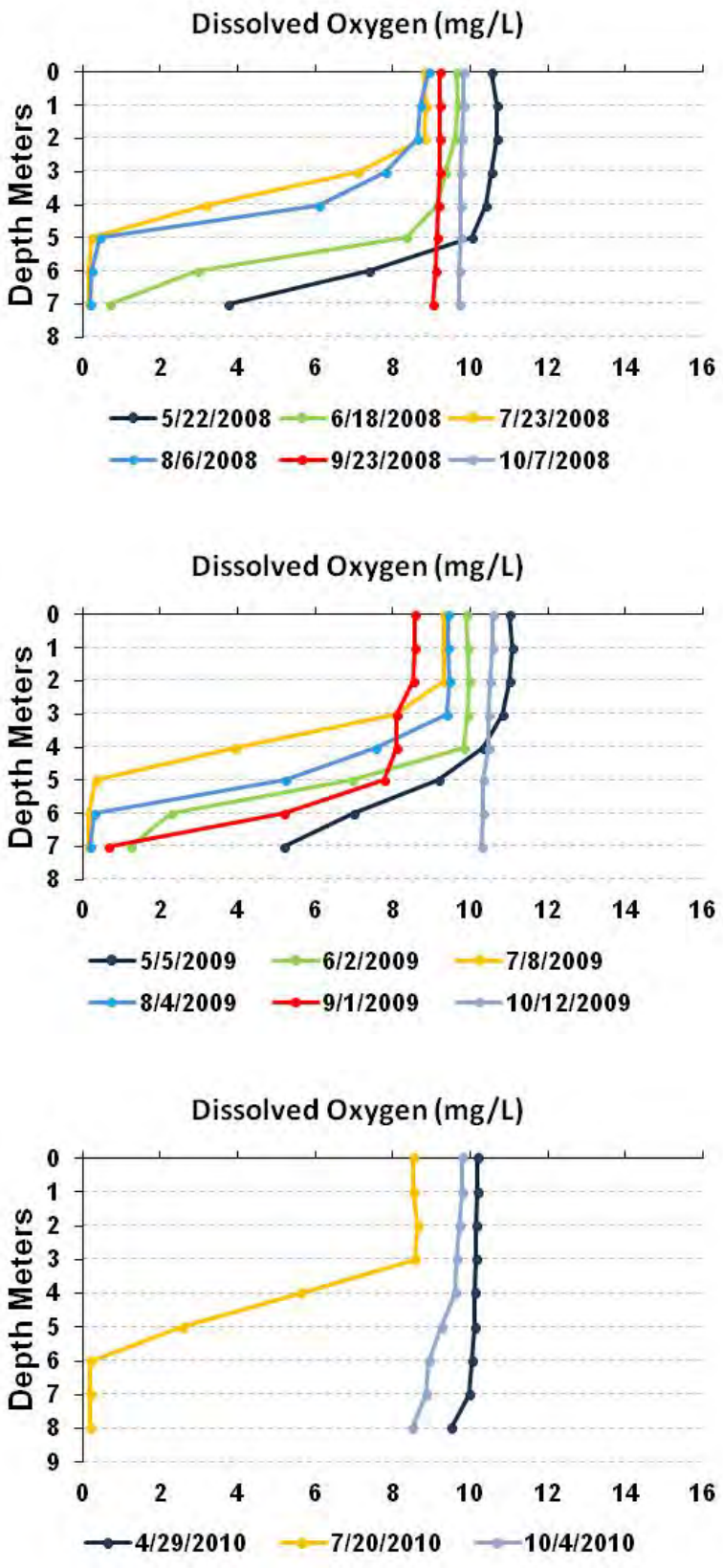


Figure 12. 2008, 2009, and 2010 dissolved oxygen profiles at site 201 Carrie Lake

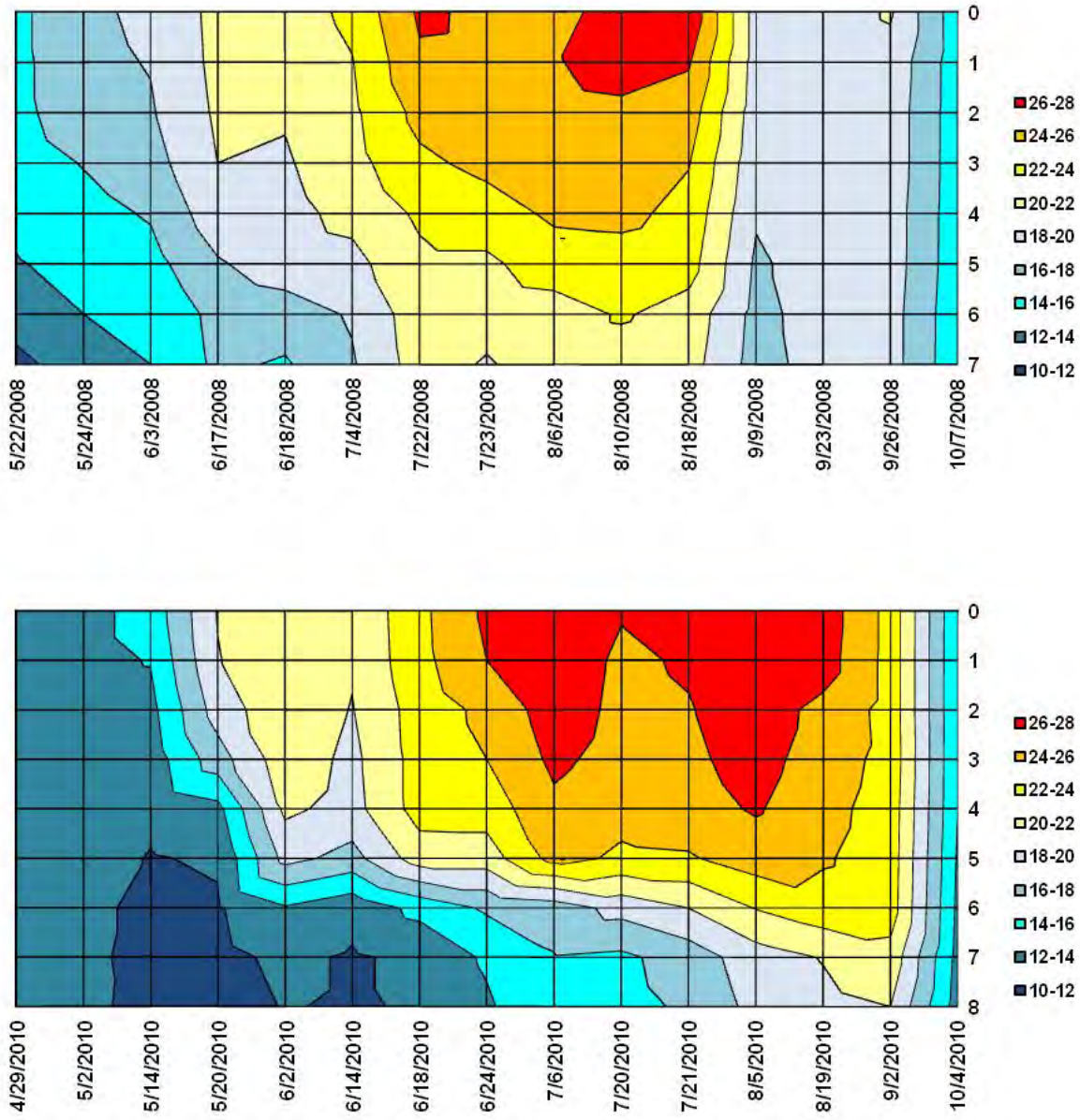


Figure 13. 2008 and 2010 temperature isopleth profiles site 201 Carrie Lake

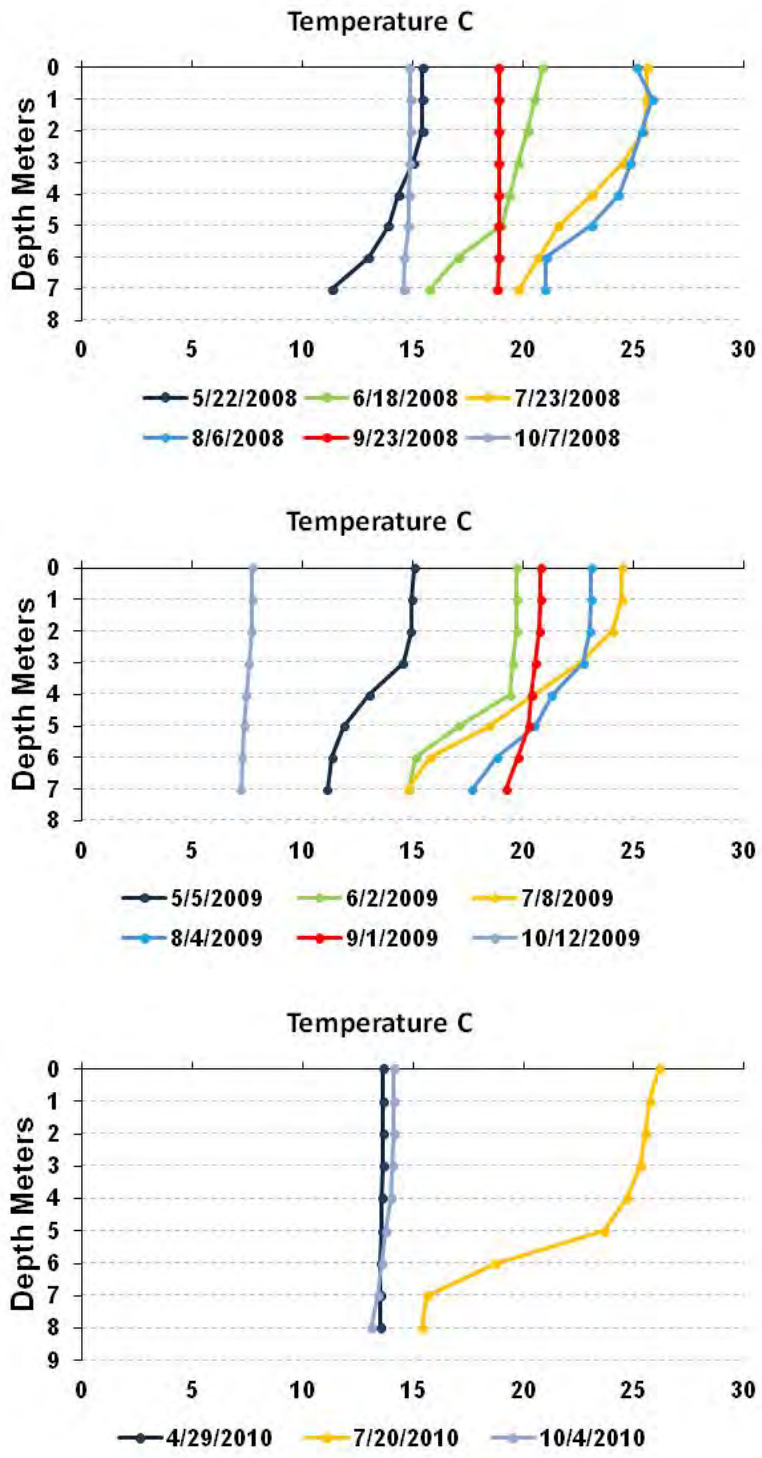


Figure 14. 2008, 2009, and 2010 seasonal temperature profiles at site 201 Carrie Lake

Total Phosphorus

TP is the limiting nutrient for algal growth in most freshwater lakes. Carrie Lake's surface TP was variable throughout 2008, 2009, 2010, and 2011 ranging from 12-39 µg/L at 201 (Figure 15). TP concentrations were generally higher in spring and fall then mid-summer concentrations for all four years. TP concentrations are reduced mid-summer as the lake stratifies and sedimentation of P occurs. Macrophytes also reduce P concentrations during the growing season; however, Carrie Lake has very few macrophyte beds so this effect is likely minor. Summer mean TP concentrations were between 23-25 µg/L during all four years sampled. TP concentrations were significantly lower than the typical WCBP ecoregion range of 65-150 µg/L.

Chlorophyll-*a*

Chl-*a*, a pigment found in algae, is used to estimate the amount of algal production in a lake. Carrie Lake appears to have limited algal production, which is likely a result of low concentrations of available P. In 2008, 2009, 2010, and 2011, Chl-*a* values for Carrie Lake ranged from 2.9-10.5 µg/L (Figure 15). The summer-mean range of Chl-*a* in reference lakes in the WCBP ecoregion is 30-80 µg/L. Summer-mean Chl-*a* for 2008, 2009, 2010 and 2011 are below the WCBP typical range.

Secchi disk transparency

Transparency is generally a function of the amount of algae in the water. Suspended sediments or color (due to dissolved organic material) may also reduce water transparency. Carrie Lake has very little algal production reducing its effect on transparency; however, during wind events suspension of total suspended solids (TSS) may decrease Secchi transparency. Carrie Lake's 2008 through 2011 mean Secchi ranged from 1.0 m (3.3ft) to 2.0 m (6.6ft) which is greater than the WCBP ecoregion range of 0.5 m (1.6 ft) to 1.0 m (3.3 ft) (Table 7).

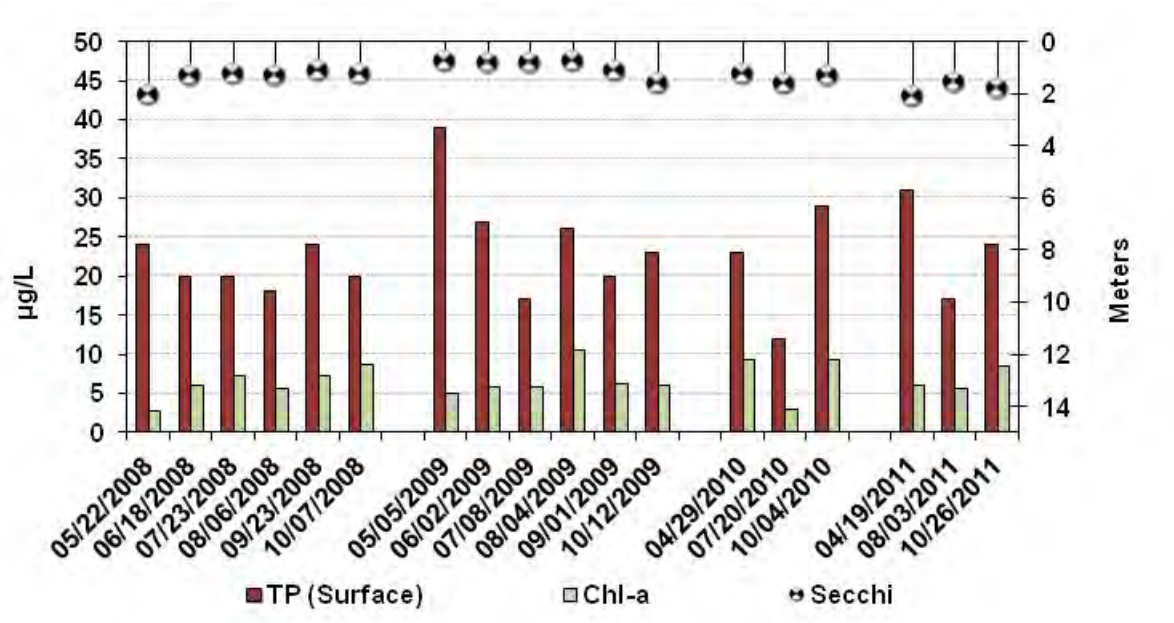


Figure 15. Carrie Lake trends 2008, 2009, 2010, and 2011 at site 201

Dissolved minerals and organic carbon

Dissolved minerals and organic carbon were measured in 2008, 2009, 2010, and 2011 as part of long-term monitoring of Carrie Lake and other Sentinel lakes. This includes some of the standard measures, such as TSS, alkalinity, conductivity, and color (Table 7), as well as major cations, anions, silica, iron and organic carbon (Table 8). While several of these parameters have "typical" ecoregion-based concentrations (e.g. Table 7); some do not. For parameters without ecoregion–based comparisons, data from the 2007 NLA study were used to provide perspective on reported concentrations (Table 8). Since NLA lakes were selected randomly, they provide a reasonable basis for describing typical ranges and distributions at a statewide level.

TSS values were slightly below the typical range of WCBP reference lakes during most years. 2009 had one sampling event with elevated TSS, which was likely caused by suspension of sediments by wave action or wind mixing. Most of the TSS can be attributed to organic suspended solids (TSS-TSIS), i.e. suspended algae. Water clarity in Carrie Lake is variable because of wind mixing, which keeps fine sediment particles in suspension.

The color value indicates water is clear, but has modest amounts of dissolved organic carbon (DOC) and accounts for the majority of total organic carbon (TOC), which is consistent with the statewide data. Lakes that receive a majority of their water inputs from forest and wetland runoff often have correspondingly higher color and TOC values because of incompletely dissolved organic matter (plants, leaves, and other organic material).

Alkalinity is higher than the typical range for WCBP lakes. Alkalinity values indicate hard waters that are common throughout lakes in this area (Table 7). Conductivity for Carrie Lake is within the WCP ecoregion range.

Table 7. Carrie Lake summer-mean water quality as compared to the ecoregion reference lake typical range

Parameter	2008	2009	2010	2011	WCBP
# of lakes					16
Total Phosphorus (µg/L)	21	25	21	24	65-150
Chlorophyll mean (µg/L)	6.3	6.6	7.1	6.7	30 – 80
Chlorophyll maximum (µg/L)	8.7	10.5	9.2	8.6	60 - 140
Secchi Disk (feet)	4.3	3.3	4.6	5.9	1.6 – 3.3
(meters)	1.3	1.0	1.4	1.8	(0.5 – 1.0)
Total Kjeldahl Nitrogen (mg/L)	0.8	1.0	0.9	0.9	1.3 - 2.7
Alkalinity (mg/L)	193	197	203	220	125 - 165
Color (Pt-Co Units)	5	8	20	13	15-25
pH (SU)	7.9	8.3	8.4	8.1	8.2 – 9.0
Chloride (mg/L)	11.7	11.4	10.6	10.4	13-22
Total Suspended Solids (mg/L)	6.5	18.2	6.9	4.7	7-18
Total Sus. Inorganic Solids (mg/L)	2.9	3.9	2.4	2.9	3-9
Conductivity (µmhos/cm)	459	487	453	473	300 - 650
TN:TP ratio	26:1	25:1	23:1	27:1	17:1 - 27:1

Most cation and anion concentrations were stable across sampling events and years (Table 8). Magnesium (Mg), sodium (Na), potassium (K) and chloride (Cl) are conservative ions and undergo only minor spatial and temporal changes (Wetzel 2001). Mg is required by algae to produce Chl-*a* and calcium (Ca) is used by rooted plants. Silica (Si), which is required by diatoms to form their "glass" shells, varied slightly from spring to fall. Calcium (Ca) and magnesium (Mg) are dominant cations and concentrations of both are well above the typical range of statewide data (Table 8). The other major cations sodium (Na) and potassium (K) are within the typical NLA range. Bicarbonate is the dominant anion, followed by chloride (Cl) and sulfate (SO_4). Chloride is within the typical range for WCBP reference lakes (Table 7); and statewide NLA data (Table 8). Sulfate is much higher than the relative range of NLA data. This is likely a reflection of the geology and soil of the area which tend to have higher sulfate concentrations. Average cation and anion balances (cation-anions expressed as a percent of cations) for 2008, 2009, 2010 and 2011 were within four percent, excluding the April 29, 2010, April 19, 2011, and October 26, 2011 sampling events (Table 8), which means that the dominant cations and anions were sampled.

Table 8. Charge balance and seasonal values for cations, anions, and organic carbon. Interquartile range (referred to as typical range) based on 64 lakes included in the 2007 NLA study included for perspective.

Date	Ca 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
5/22/2008	60.1	29.1	3.2	3.3	210	45.8	11.0	5.6	-5.5	1.4
7/23/2008	48.1	29.1	3.9	3.3	190	48.7	11.8	5.1	-5.1	-0.9
10/7/2008	48.1	31.6	3.3	3.4	180	45.6	12.2	5.2	-4.9	3.4
5/5/2009	61.7	29.2	3.0	3.2	210	43.5	10.8	5.7	-5.4	2.6
7/8/2009	49.3	31.3	3.3	3.0	190	46.4	11.8	5.3	-5.1	1.6
10/12/2009	46.4	30.3	3.3	3.3	190	43.9	11.7	5.0	-5.0	0.0
4/29/2010	67.7	31.2	3.4	3.2	210	41.0	10.9	6.2	-5.4	7.1
7/20/2010	56.4	30.0	3.3	2.8	200	38.0	10.6	5.5	-5.1	3.9
10/4/2010	53.8	29.9	3.3	3.0	200	34.7	10.3	5.4	-5.0	3.4
4/19/2011	76.0	29.9	3.1	2.7	240	34.4	10.5	6.5	-5.8	5.3
8/3/2011	52.9	27.5	3.2	2.7	200	26.9	9.7	5.1	-4.8	2.8
10/26/2011	62.6	32.8	3.6	3.0	220	30.6	10.9	6.1	-5.3	6.3
Average	56.9	30.2	3.3	3.1	203	40.0	11.0	5.5	-5.2	3.1
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			

Carrie is a "marl" lake and whitish deposits of calcium carbonate marl are evident in the water and coating plants and lake sediments. Significant input from springs rich in carbonates is often the source of this. Marl lakes are often unproductive; however, summer-time depletion of DO is often evident, as is the case with Carrie. The resuspension of the fine calcium carbonate particles (~limestone) reduces light transparency and contributes to the low algal and plant productivity. Zooplankton populations are often sparse as well. The precipitation of calcium carbonate can bind with phosphorus making it unavailable for algae and plant growth. More detailed information on marl lakes may be found in Wetzel (2001).

Phytoplankton (algae)

Carrie is a "marl" lake and whitish deposits of calcium carbonate marl are evident in the water and coating plants and lake sediments. Significant input from springs rich in carbonates is often the source of this. Marl lakes are often unproductive; however, summer-time depletion of DO is often evident, as is the case with Carrie. The resuspension of the fine calcium carbonate particles (~limestone) reduces light transparency and contributes to the low algal and plant productivity. Zooplankton populations are often sparse as well. The precipitation of calcium carbonate can bind with phosphorus making it unavailable for algae and plant growth. More detailed information on marl lakes may be found in Wetzel (2001).

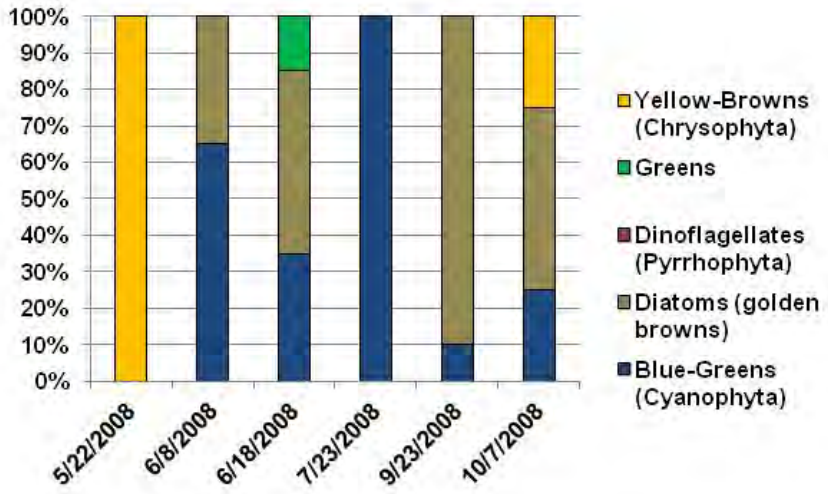


Figure 16. 2008 Phytoplankton assemblage in Carrie Lake at site 201

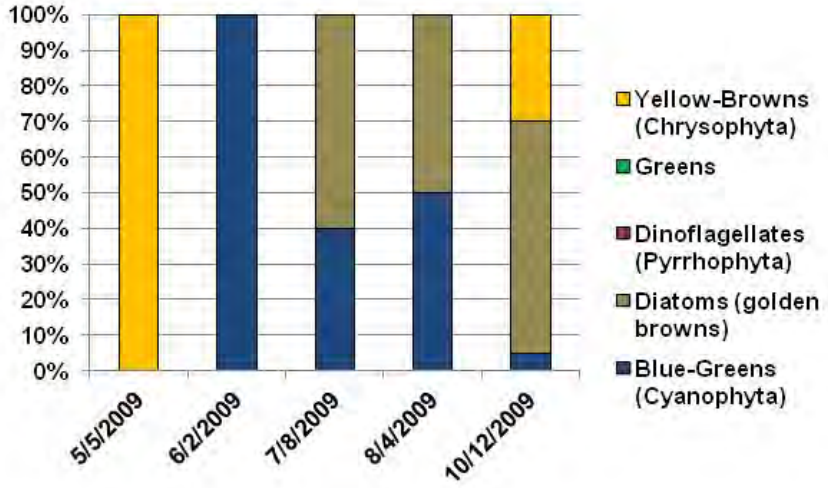


Figure 17. 2009 Phytoplankton assemblage in Carrie Lake at site 201

Zooplankton

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

Carrie Lake had the lowest mean annual density and mean annual biomass of zooplankton of any of the WCBP Sentinel lakes (Table 9). This may be a function of the influence of marl deposits on the overall productivity of the lake. Total number of taxa for Carrie Lake was average among the WCBP lakes. Hirsch (2009) found that as lake productivity increased (e.g. TP or Chl-*a*), relative abundance (biomass per volume of water column) of zooplankton increased in all 24 Sentinel lakes. Carrie Lake appears to have the highest zooplankton biomass and densities in May and June which then slowly decrease through summer and fall (Figure 18).

Table 9. Mean annual zooplankton densities (number/L), biomass (ug/L) and total number of taxa for each of the Sentinel Lakes sampled in 2008. Lakes are arranged by ecoregion (Sentinel Lake groupings).

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

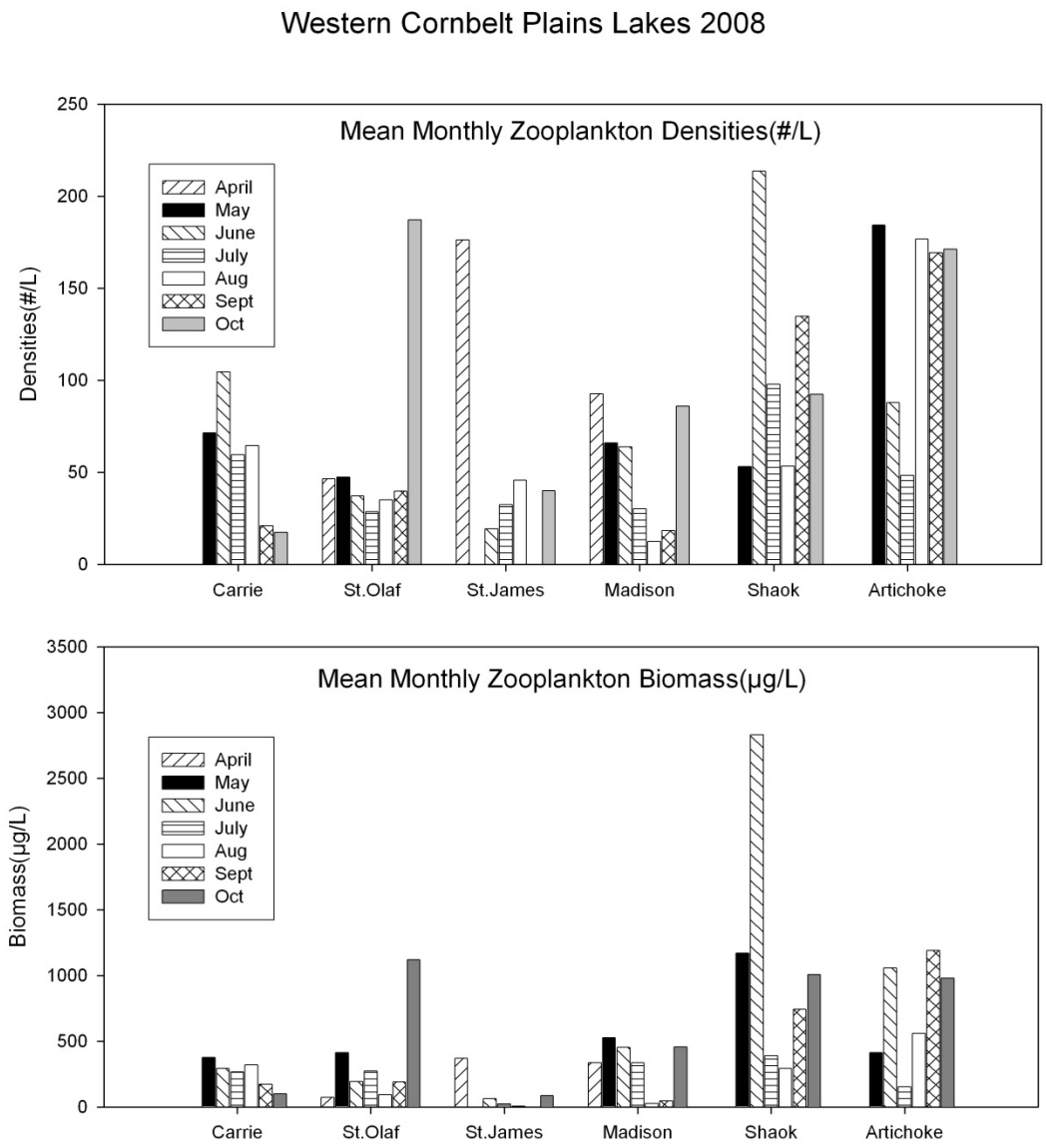


Figure 18. Mean monthly zooplankton densities (number/L) and biomass (µg/L) in the sentinel lakes of the Western Cornbelt-Plains ecoregion, 2008. (Lakes are arranged on graph from left to right, with increasing total phosphorous levels).

Trophic State Index

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

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

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

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

TP and Chl-*a* are measured in µg/L and 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 provide a basis for assessing the relationship among TP, Chl-*a*, and Secchi (Figure 19). TSIS values are consistently higher than TSIP and TSIC in most summers (Figure 19). This suggests water transparency is likely being affected by suspended sediment instead of algae on Carrie Lake. TSIP and TSIC correlate well; low concentrations of P likely limit Chl-a production. Based on an average TSI score of 49, Carrie Lake would be characterized as borderline mesotrophic to eutrophic.

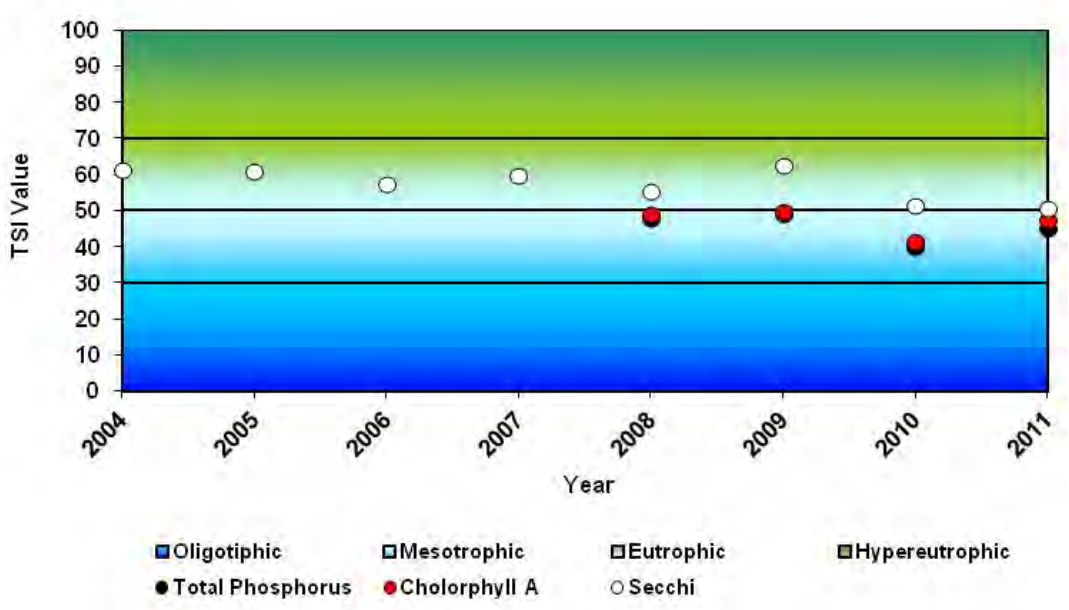


Figure 19. Carrie Lake historic TSI values

Modeling

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 input concentrations of TP, Chl-*a*, and Secchi. Predictions are made from Chl-*a* based on a regression equation of TP and Secchi based on a regression equation based on Chl-*a*. For analysis of Carrie Lake, MINLEAP was applied as a basis for comparing the observed (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.

Carrie Lake is located in the WCBP ecoregion and the model was run using WCBP ecoregion-based inputs. The observed TP values are much lower than predicted by MINLEAP (Table 10). Observed Chl-*values* were also much lower than predicted. Secchi transparency was greater than predicted, as well. MINLEAP likely overestimates Carrie Lake's TP and Chl-*a* concentrations because of the large watershed size. Most years the watershed may not receive loading from the southern portion and a proportion of the P load may pass through a diffuse wetland and into Lake Elizabeth. MINLEAP does not account for groundwater which likely has a significant influence on water quality. Carrie Lake would need to be modeled with a more complex model in order to better correlate observed and predicted water quality values.

Table 10. MINLEAP model results for Carrie Lake

Parameter	2008 Carrie Observed	2009 Carrie Observed	MINLEAP Predicted WCP Ecoregion
TP (µg/L)	21	25	181 (±61)
Chl-*a* (µg /L)	6.3	6.6	131 (±79.6)
Secchi (m)	1.3	1.0	0.4 (±0.2)
P loading rate (kg/yr)	-		1224
P retention (%)	-		0.68
P inflow conc. (µg/L)	-		569
Water Load (m/yr)	-		5.84
Outflow volume (hm^3/yr)	-		2.15
Residence time (yrs)	-		0.5
Vighi and Chiaudani			29.3

Pesticide Analysis

The Minnesota Department of Agriculture (MDA) analyzed water samples for several pesticides and their degradation products in 2009 through 2011. The analyses conducted were similar to those included in the 2007 National Lakes Assessment (NLA); however, there have been some changes in analytic methodology and detection limits since that time resulting in additional analytes and lowered method reporting limits. The analytes list is included in the appendix of this report. The majority of the analytes were reported from the laboratory as non-detect (ND). Pesticides or their degradation products with detected concentrations are presented in Table 11. Samples were collected on June 2, 2009, October 12, 2009, July 20, 2010, and August 3, 2011.

Table 11. Carrie Lake pesticide and degradation products concentrations

Analyte	Detections	Samples	% Detection	Minimum (ng/L)	Maximum (ng/L)
2,4-D	1	2	50%	nd	24.6
Acetochlor	2	4	50%	nd	P (<50)
Acetochlor ESA	2	4	50%	nd	116
Acetochlor OXA	1	4	25%	nd	41
Alachlor ESA	4	4	100%	347	640
Atrazine	3	4	75%	nd	P (<50)
Desethylatrazine	4	4	100%	P (<50)	60
Dimethenamid ESA	2	4	50%	nd	70
Hydroxyatrazine	2	2	100%	8.44	9.11
Metolachlor	2	4	50%	nd	P (<70)
Metolachlor ESA	4	4	100%	367	790

The Carrie Lake watershed is highly cultivated, and the associated pesticide use is likely reflected in Table 11. Detection frequency ranges from 25 percent to 100 percent for the various detected compounds. The detection frequency and measured concentration of pesticide degradate products tended to be higher than their associated parent pesticide for several compounds. With this said all pesticide detections in Carrie Lake are well below applicable water quality standards and benchmarks. The pesticide detections and concentration ranges in Carrie Lake are consistent with other lake sampling results of lakes located in highly cultivated areas in Minnesota. Additional information about pesticide monitoring in Minnesota lakes, including the NLA report and MDA's annual monitoring reports, can be found at: http://www.mda.state.mn.us/monitoring.

303 (d) Assessment and Goal Setting

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

Under Section 303(d) of the Clean Water Act, the state is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e., impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion (Table 12). In addition, either the Chl-*a* concentration for the lake must exceed the standard or the Secchi data for the lake must be below the standard. A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a water body is listed, an investigative Total Maximum Daily Load (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. In Minnesota, the MPCA is responsible for performing assessment activities, listing impaired waters, and ensuring that TMDL studies are carried out.

Carrie Lake is unique for the WCBP ecoregion. The lake is deep enough to thermally stratify and its marl deposits are quite uncommon for lakes in the WCBP ecoregion. Marl lakes typically have higher concentrations of Ca, which may suspend in the water column giving the lake a milky appearance at times. Overall, water chemistry is exceptional for the WCBP. TP and Chl-*a* are well below the concentrations observed in the WCBP reference lakes. Very little algal production allows for relatively (as compared to typical WCBP lakes) clear water throughout the summer.

Carrie Lakes needs to be protected in order to maintain its good water quality. Even though the shoreline looks to be in good condition the watershed is primarily agriculture. This said, it is important to limit P loading from within in the watershed to maintain good water quality. Since Carrie is connected to Lake Elizabeth, it is also a concern that the abundance of common carp remains low in order to allow for macrophyte beds to be established. Curly-leaf pondweed is also a concern in regards to water quality and needs to be documented.

Table 12. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). Carrie Lake 2008 and 2009.

Ecoregion	TP	Chl-*a*	Secchi
	µg/L	µg/L	meters
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
NCHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
NCHF – Aquatic Rec. Use (Class 2B)	< 40	< 14	> 1.4
NCHF – Aquatic Rec. Use (Class 2B) Shallow lakes	< 60	< 20	> 1.0
WCBP & NGP – Aquatic Rec. Use (Class 2B)	**< 65**	**< 22**	**> 0.9**
WCBP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7
Carrie Lake 2008	**21**	**6.3**	**1.3**
Carrie Lake 2009	**25**	**6.6**	**1.0**

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Appendix A

Ice-on and ice-off records for Carrie Lake

Lake Name	Lake ID	Ice On Date	Ice Off Date
Carrie	34-0032	11/25/1994	
Carrie	34-0032		4/1/1998
Carrie	34-0032	12/18/1998	4/10/1999
Carrie	34-0032	11/28/1999	3/8/2000
Carrie	34-0032	11/28/2000	4/19/2001
Carrie	34-0032	12/2/2001	4/14/2002
Carrie	34-0032	12/2/2002	4/2/2003
Carrie	34-0032	11/4/2003	3/27/2004
Carrie	34-0032	12/11/2004	4/5/2005
Carrie	34-0032	11/30/2006	4/1/2007
Carrie	34-0032	11/23/2007	4/21/2008
Carrie	34-0032	11/18/2008	4/8/2009

Appendix B

2011 Minnesota Department of Agriculture Laboratory Pesticide list

GC-MS	
Analyte	MRL (□g/)
Acetochlor	0.05
Alachlor	0.05
Atrazine	0.05
Boscalid	0.3
Chlorothalonil	0.12
Chlorpyrifos	0.04
Clomazone	0.1
Cyanazine	0.2
Cyfluthrin	0.5
Deisopropylatrazine	0.2
Desethylatrazine	0.05
Diazinon	0.12
Dimethenamid	0.05
Dimethoate	0.22
Disulfoton	0.15
EPTC	0.23
Esfenvalerate	0.2
Ethalfluralin	0.15
Fonofos	0.1
Lambda Cyhalothrin	0.2
Malathion	0.09
Metolachlor	0.07
Metribuzin	0.1
Metribuzin DA	1
Metribuzin DADK	1
Metribuzin DK	1
Myclobutanil	0.2
Oxadiazon	0.05
Parathion-methyl	0.12
Pendimethalin	0.08
Phorate	0.12
Prometon	0.1
Propachlor	0.1
Propazine	0.1
Propiconazole	0.2
Pyraclostrobin	0.23
Simazine	0.1
Tebuconazole	0.2
Tebuprimiphos	0.1
Terbufos	0.19
Tetraconazole	0.15
Triallate	0.1
Trifluralin	0.17
zeta-Cypermethrin	0.5

LC-MS/MS	
Analyte	MRL (ng/L)
2,4,5-T	50
2,4,5-TP	50
2,4-D	8.3
2,4-DB	13.3
Acetamiprid	25
Acetochlor ESA	30
Acetochlor OXA	33.3
Alachlor ESA	41.6
Alachlor OXA	33.3
Aldicarb sulfone	15
Aldicarb sulfoxide	50
Azoxystrobin	10
Bensulfuron-methyl	16.7
Bentazon	0.8
Bromacil	20
Carbaryl	25
Carbofuran	13.3
Chlorantraniliprole	50
Chlorimuron-ethyl	20
Clopyralid	41.6
Clothianidin	25
DEDI Atrazine	50
Dicamba	50
Dichlorprop	50
Difenoconazole	25
Dimethenamid ESA	6.7
Dimethenamid OXA	10
Disulfoton Sulfone	20
Diuron	13.3
Flufenacet OXA	8.3
Flumetsulam	50
Halosulfuron-	30
Hexazinone	10
Hydroxyatrazine	6.7
Imazamethabenz	10

LC-MS/MS (continued)	
Analyte	MRL (ng/L)
Imazamethabenz-	5
Imazamox	13.3
Imazapic	10
Imazapyr	8.3
Imazaquin	16.7
Imazethapyr	6.7
Imidacloprid	20
Isoxaflutole	40
Isoxaflutole DKN	50
Linuron	20
MCPA	5
MCPB	10
MCPP	50
Mesotrione	50
Metalaxyl	8.3
Metolachlor ESA	10
Metolachlor OXA	10
Metsulfuron-methyl	23.3
Neburon	10
Nicosulfuron	26.6
Norflurazon	20
Picloram	41.6
Prometryn	3.3
Propachlor ESA	30
Propachlor OXA	10
Propoxur	10
Saflufenacil	15
Siduron	6.7
Sulfometuron-methyl	8.3
Tembotrione	50
Thiamethoxam	25
Thifensulfuron-methyl	16.7
Thiobencarb	8.3
Triasulfuron	23.3
Triclopyr	50

Appendix C

Lake surface water quality data for Carrie Lake for 2008–2001

All water quality data can be accessed at: http://www.pca.state.mn.us/data/eda/STresults.cfm?stID=29-0250&stOR=MNPCA1

Lake Name	Lake ID	Sample Date	Site ID	Secchi	TP	Chl-*a*	Alkalinity	Chloride	TKN	Color, Apparent	TSS
				Meters	µg/L	µg/L	mg/L	mg/L	mg/L	PCU	mg/L
Carrie	34-0032	05/22/2008	201	2	24	2.84	210	11.0	0.82	5	2.8
Carrie	34-0032	06/18/2008	201	1.3	20	6.03			0.84		
Carrie	34-0032	07/23/2008	201	1.2	20	7.2	190	11.8	0.74	5	7.8
Carrie	34-0032	08/06/2008	201	1.25	18	5.58			0.65		
Carrie	34-0032	09/23/2008	201	1.1	24	7.24			1.01		
Carrie	34-0032	10/07/2008	201	1.2	20	8.69	180	12.2	0.96	5	8.8
Carrie	34-0032	05/05/2009	201	0.7	39	4.98	210	10.8	1.05	10	14.0
Carrie	34-0032	06/02/2009	201	0.8	27	5.82			0.92		
Carrie	34-0032	07/08/2009	201	0.8	17	5.75	190	11.8	0.98	5	35.0
Carrie	34-0032	08/04/2009	201	0.7	26	10.5			0.87		
Carrie	34-0032	09/01/2009	201	1.1	20	6.21			0.95		
Carrie	34-0032	10/12/2009	201	1.6	23	6.1	190	11.7	1.02	10	5.6
Carrie	34-0032	04/29/2010	201	1.2	23	9.22	210	10.9	0.87	20	9.2
Carrie	34-0032	07/20/2010	201	1.6	12	3.01	200	10.6	0.84		3.6
Carrie	34-0032	10/04/2010	201	1.3	29	9.22	200	10.3	1.11	20	8.0
Carrie	34-0032	04/19/2011	201	2.1	31	5.97	240	10.5	0.88	10	3.6
Carrie	34-0032	08/03/2011	201	1.5	17	5.58	200	9.73	0.93	20	5.6
Carrie	34-0032	10/26/2011	201	1.8	24	8.56	220	10.9	1.03	10	4.8