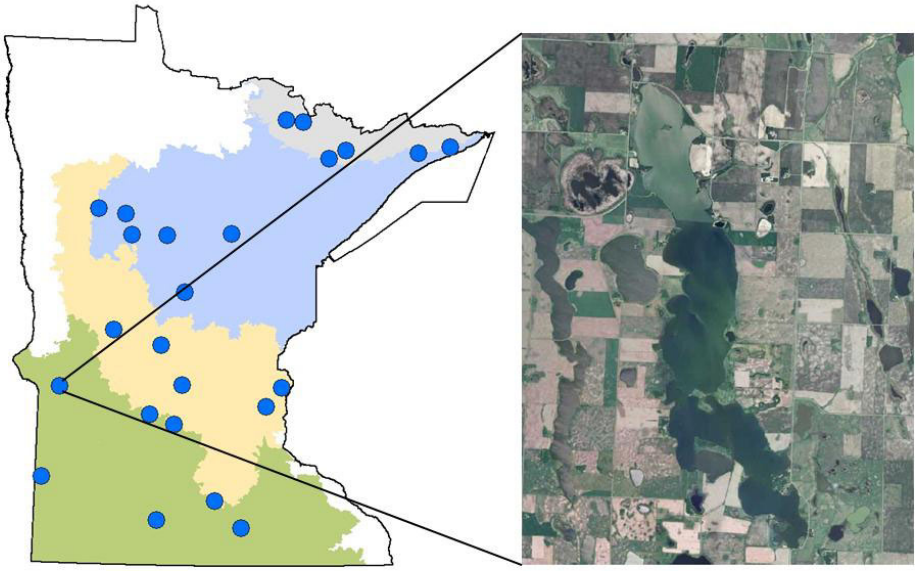
Sentinel Lake Assessment Report
Artichoke Lake (06-0002)
Big Stone County, Minnesota



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

April 2012

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2011 Lake Assessment of Artichoke Lake (06-0002) Big Stone County, Minnesota
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Executive Summary

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

The Sentinel Lakes Program has selected 24 lakes for long-term intensive lake monitoring (Figure 1). 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 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 also funded by the ETF.

Artichoke Lake is located in Big Stone County within the Pomme de Terre River watershed. The lake is located 15 miles east of Ortonville, Minnesota (MN). Artichoke Lake has a surface area of 795 hectare (1964 acres) and has a maximum depth of 4.7 meters (15.5 ft); however, its size and depth has fluctuated greatly since the 1940s. Artichoke Lake is a polymictic lake that mixes during wind events. The majority of the shoreline remains undeveloped. Two public accesses are located on Artichoke Lake. The lake supports recreational activities such as waterfowl hunting and fishing.

Historic trophic status data for Artichoke Lake indicates the lake has been fertile (eutrophic) for some time. The earliest total phosphorus (TP) samples were taken in 1985 and found to be 364 micrograms per liter (µg/L). Based on data from 2008-2009, summer-mean epilimnetic (TP) is typically between 150-325 µg/L and chlorophyll-a (Chl-*a*) is generally between 5-50 µg/L. Summer-mean Secchi has been variable, but is generally between 0.6-2.0 meters (m) in most summers. TP concentrations were found to exceed water quality standards for the Northern Glaciated Plains ecoregion (NGP); however, the response variables, Chl-*a* and Secchi did not exceed the corresponding standards in the most recent assessment. Hence, Artichoke Lake was not deemed impaired.

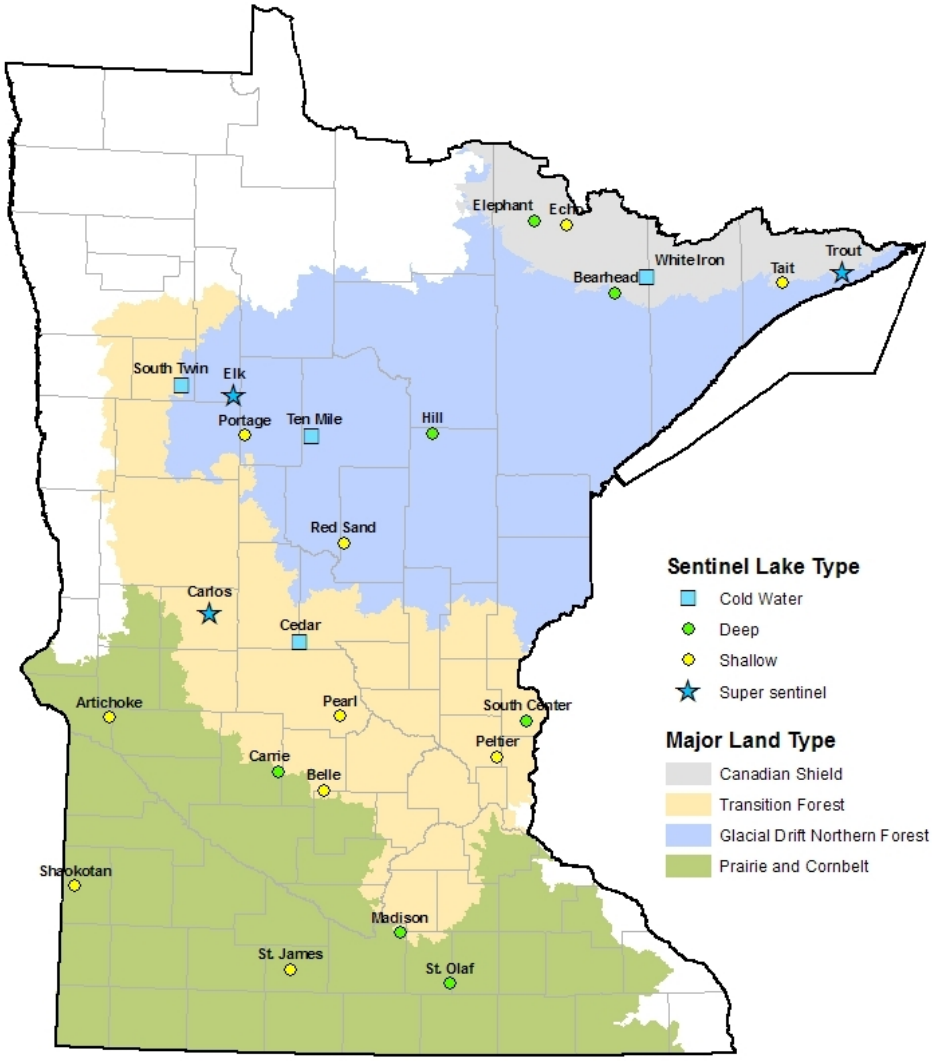
Like other highly fertile lakes in the glaciated plains of Minnesota, the fishery of Artichoke Lake can be characterized as boom-bust for several species. High rates of walleye stocking have successfully maintained walleye in the system at relatively high levels of abundance; however the walleye population remains in a precarious state due to highly variable and mostly poor habitat conditions, a constantly changing food-web, and slowly warming waters that stress this cool water fish. Perhaps due to similar reasons, size and abundance of northern pike, and abundance of yellow perch (both cool water species) have seen recent declines as well. Still, Artichoke supports high angling recreation for walleye and black crappie, especially during winter. Bottom-feeding fish (i.e., benthivores) and omnivores such as black bullhead, common carp, and fathead minnow have historically dominated the fish community of Artichoke Lake. Populations of black bullhead and common carp have declined in recent years, but fathead minnow populations remain high. Declines in benthivores are beneficial from a water quality standpoint; however, Artichoke's phosphorus levels remain excessively high due to land use impacts such as agricultural runoff and shoreline erosion.

Agricultural runoff and shoreline erosion impacts have not only impacted fish populations, but also presumably waterfowl use. In the early to mid 1900s, a local resident recalls abundant emergent and submersed vegetation and high use of diving ducks. Today, the lake is barren of aquatic plant growth,

and the lake is mostly a rest stop for migrating waterfowl rather than a destination. Significant reductions in external and internal nutrient loading will have to occur in order to see improvements in water quality, aquatic plants, and vegetation-dependent fish species such as bluegill, northern pike, and largemouth bass and waterfowl.

BATHTUB modeling was conducted for Artichoke Lake. Land use composition, number of animal units, and standard runoff and phosphorus (P) export values were used to estimate external loading to the lake. The modeling indicated that in-lake P was much higher than anticipated based on these estimated loads. A review of Artichoke's morphometry (large fetch and shallowness), combined with DO and temperature profiles, suggest that wind resuspension, inefficient sedimentation, and high temperature above the sediments may contribute to internal recycling and the higher than anticipated in-lake P; however, in the event that a Total Maximum Daily Load or watershed restoration strategy is developed for Artichoke, there is a need to more accurately measure water and nutrient loads from the watershed. Once accurate estimates of external loading are obtained, attention can be turned to understanding of the role of wind resuspension, internal recycling and sedimentation efficiency in Artichoke. For example, feedlots were noted as a possible source of excess P within Artichoke's watershed. Two feedlots are located very near the lake and two more are directly north of the lake adjacent to a wetland and tributary that drains to the lake. We do not know precisely where land spreading of manure occurs; however, if it is near any tributaries (ditches, creeks or streams) that drain to the lake, this is a possible source of excess nutrients to the lake. Bank sloughing was observed at various shoreline locations. This may also be a source of suspended sediment in Artichoke Lake. Both P cycling and sediment loads to the lake should be investigated further in future studies on the 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 Artichoke Lake in Big Stone, 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, 2009, and 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 STORET, the national repository for water quality data. Further detail on water quality and limnological concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

History

ca. early 1900's	Fill is laid across the outlet to create 260th Ave. which divides Swift and Big Stone County. Culverts are presumed insufficient to facilitate flow through the lake and the road acts as a quasi-dam. Elevated water levels likely caused steep-cut banks and significant bank erosion.
ca. 1936-38	According to historic aerial photos, Artichoke Lake is dry except for 122 acres in the south east basin (6% of its modern size of 1,970 acres). Photo evidence suggests the dry lake bed was cultivated for row crops and used for hay and pasture.
1949	First record of walleye stocking.
1951	Lake noted as a "freeze-out" lake.
1953	Abundant submersed vegetation noted in August fish natural reproduction surveys
1959	15-20-ft high steep cut banks and shoreline erosion noted in first game survey. Reported as mostly a resting area for migrating waterfowl.
1978-79	Partial winterkill.
1983	12-15 gallons of crayfish captured in summer gillnets; crayfish are much less numerous in subsequent surveys.
1984	Winter aeration system is installed to maintain sufficient dissolved oxygen (DO) for fish during winter.
1990	Non-native curly-leaf pondweed first documented and abundant in the northern part of the lake. Curly-leaf pondweed has since been noted as sparse in the lake.
1980's – 2000's	Periodic partial winter and summerkills. Kills of adult common carp throughout the year have been noteworthy in recent years.

Background

Lake Morphometric and Watershed Characteristics

Artichoke Lake is located in Big Stone County within the Pomme de Terre River Watershed. Artichoke Lake is approximately 15 miles east of Ortonville, MN. A public access is located on the south end and the northwest shore of the lake. Artichoke Lake is polymictic and has a maximum depth of 4.7m (15.5 ft).

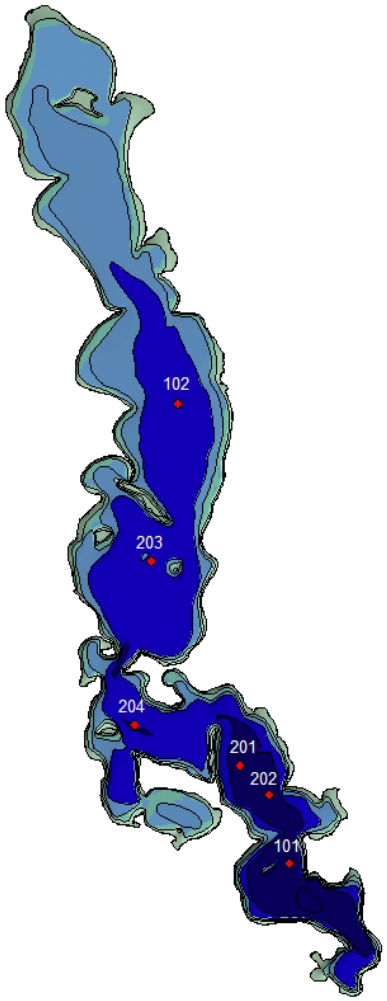
Artichoke Lake's morphometric characteristics are summarized in Table 1. A bathymetric contour map is for South Center Lake is shown in Figure 2. Artichoke Lake is slender in shape and runs north and south with many shallow bays and rocky points. Percent littoral area refers to that portion of the lake that is 4.6 meters (m; 15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake. Lakes with a high percentage of littoral area often have extensive rooted plant (macrophyte) beds. These plant beds are a natural part of the ecology of these lakes and are important to maintain and protect. Absence of aquatic plants is an issue if Artichoke Lake and is likely related to water quality.

Table 1. Artichoke 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
Artichoke	06-0002	795 (1964)	100	8,576 (21,193)	10:1	4.7 (15.5)	1.8 (5.9)	

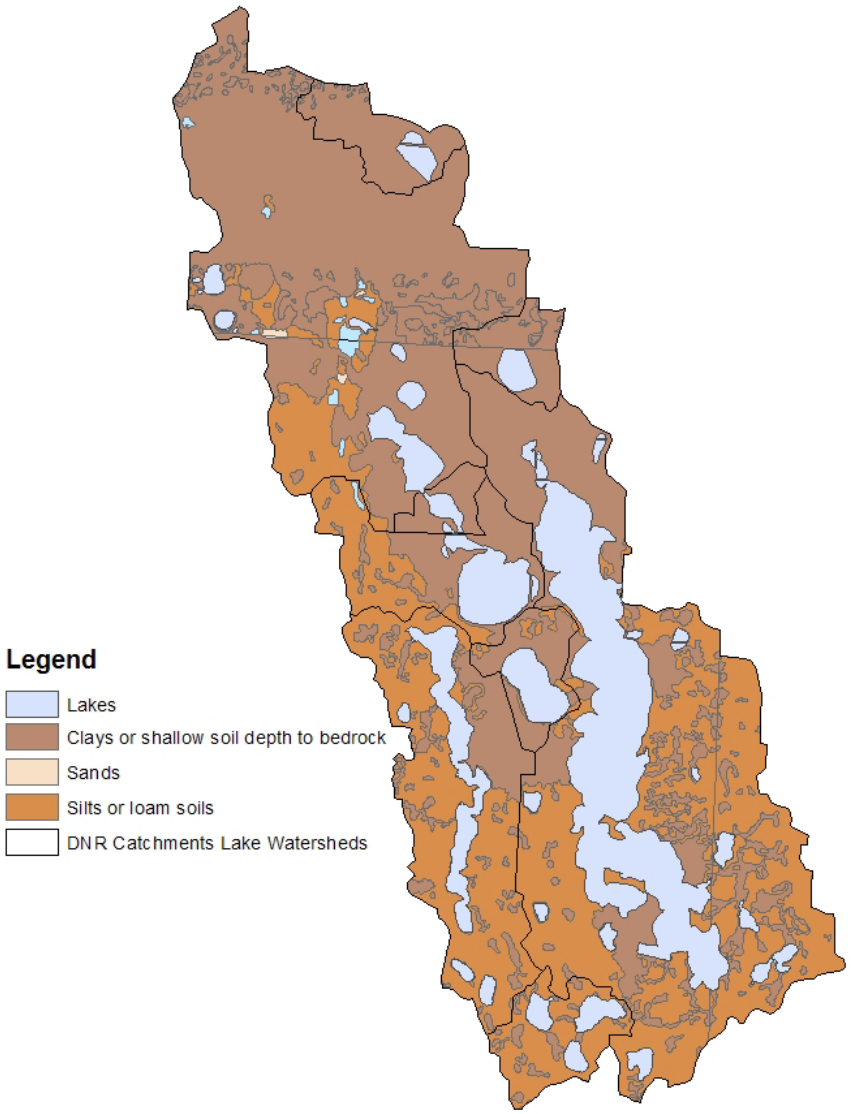
Artichoke Lake's contributing watershed lies within the Pomme de Terre River Watershed. The lake's watershed has one drainage point located on the eastern shore of the lake. The contributing watershed has a total area of 8,576 hectares (21,193 acres) resulting in a watershed-to-lake area ratio of approximately 10:1. Watershed areas were estimated by MDNR and include all upstream catchments that have the potential to contribute surface flow to the lake.

Figure 2. Artichoke Lake bathymetric contour and site map as of 2009.



Soils in the western portion of the Pomme de Terre River Watershed, near Artichoke Lake, are composed of Fergus Falls Till Plain. This outwash plain is nearly level to moderately sloping from (0-6%) and composed of poorly drained clayey and loamy soils (Figure 3). Slight to high water and wind erosion potentials exist across this section of the basin (NRCS).

Figure 3. Artichoke Lake watershed soil contour and site map.



Lake Mixing and Stratification

Lake depth and mixing has a significant influence on lake processes and water quality. *Thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 9 meters or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 4). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of 6 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

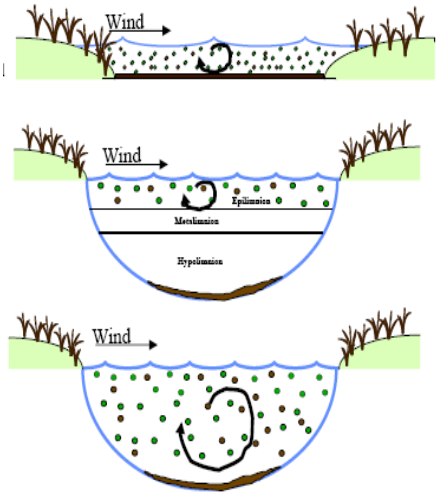
environment may allow for P release from the lake sediments. During stratification, dense colder hypolimnion waters are separated from the nutrient hungry algae in the epilimnion. Intermittently (weakly) stratified polymictic lakes are mixed in high winds and during spring and fall. Mixing events allow for nutrient rich sediments to be re-suspended, which increases TP in the surface waters where it is available for use by algae.

Figure 4. 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. Artichoke Lake lies within the Northern Glaciated Plains (NGP) ecoregion (Figure 5). NGP ecoregion values will be used for land use (Table 2) and summer-mean water quality comparisons (Table 9). Additionally, the NGP ecoregion values will be used for the model application.

Since land use affects water quality, it has proven helpful to divide Minnesota into regions where land use and water resources are similar. Land use within Artichoke Lake or the Pomme de Terre River watershed is primarily cropland and water/wetland (Figure 6). Land use percentages have been compared for 1969, 1991, and 2001(Table 2). 1969 and 1991 values group forest and wetland values together. Trends show a reduction in cultivated land use along with an increase in development and water/wetland. Although development is increasing, it remains a relatively small portion of the overall watershed. As for feedlots, no comparable data were available for the 1969 and 1991 timeframes so no conclusions can be drawn on trends among these three periods; however, seven feedlots were noted in 2011 as compared to four in 2001. Of the seven, two are located very near the lake and two more are directly north of the lake adjacent to a wetland and tributary that drains to the lake (Figure 6). It is not clear precisely where land spreading of manure occurs; however if it is near any tributaries (ditches, creeks or streams) that drain to the lake this is a possible source of excess nutrients to the lake.

Figure 5. Minnesota ecoregions as mapped by United States Environmental Protection Agency.

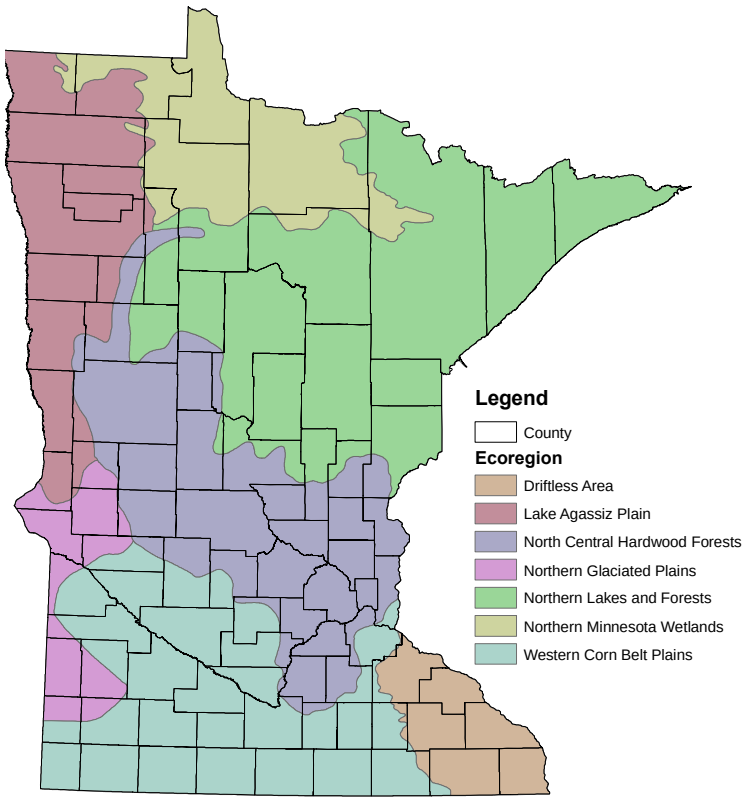
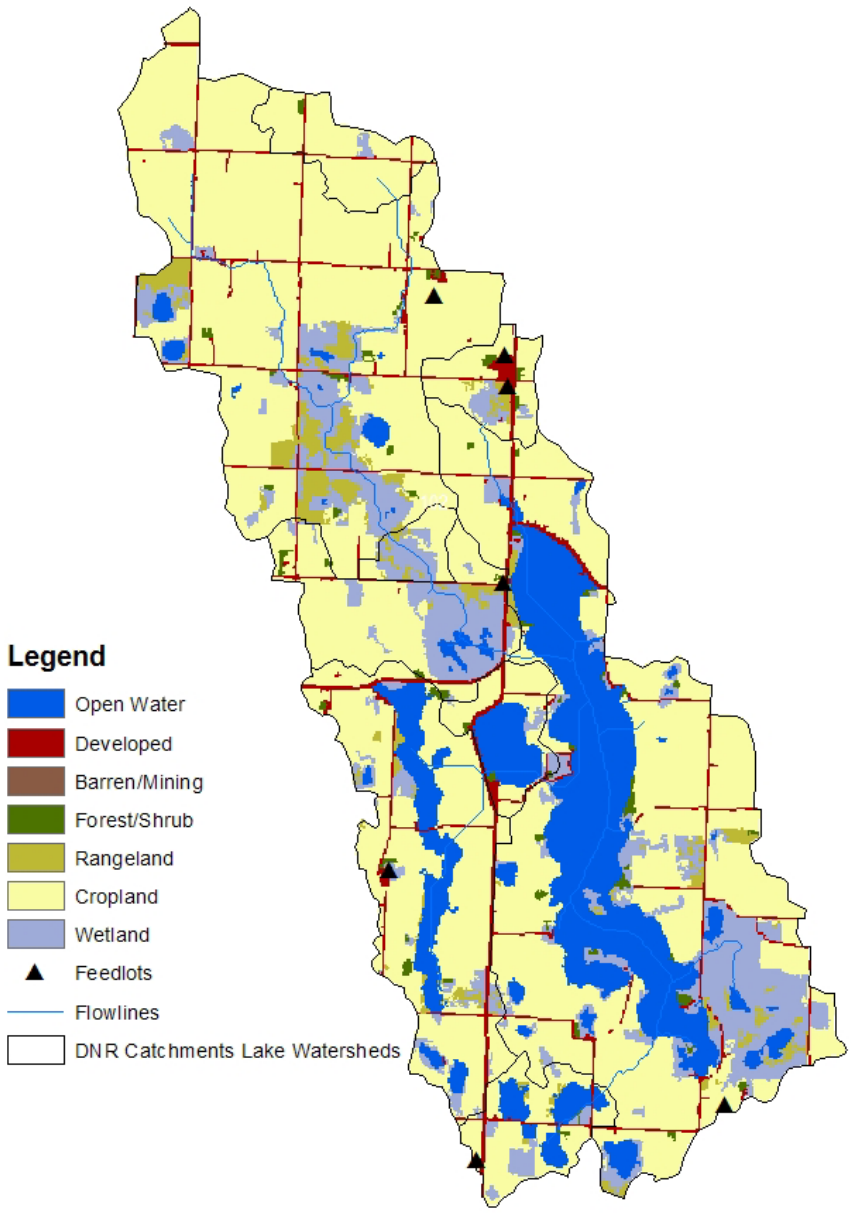


Table 2. Artichoke Lake ecoregion land use comparison. Typical (interquartile) range based on NGP ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use	Artichoke* 1969	Artichoke* 1991	Artichoke 2001	NGP Typical Land Use %
Developed	0	0	5	0-2
Cultivated (Ag)	73	70	63	60-82
Pasture & Open	12	13	3	5-15
Forest	4	7	1	0-1
Water & Wetland	12	11	28	8-26
Feedlots (#)	-	-	4	

[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 6. Artichoke Lake watershed and land use composition.



Lake Level and Ice On/Off

The MDNR Division of Waters has been measuring water levels on Artichoke Lake since 1957. During the period of record (1957 – 2011), the lake has varied by 1.52 m (5 ft.), based on 24 readings. Water level has been highly variable in Artichoke Lake. Aerial photographs from 1938-1940 show the lake basin as row crops, of which, only 49 hectares (120 acres) are open water (Figure 8). Construction of 260th Avenue across the outlet of Artichoke Lake in the early 1900s caused a change in hydrology. The lake outlet unintentionally acted as a control structure and when combined with above average precipitation in the 1990's (Figure 7) caused water levels to rise. As a result, Artichoke Lake's banks became highly eroded from wave activity and rising water levels. The complete water level record may be obtained from the MDNR web site at:
http://www.dnr.state.mn.us/lakefind/showlevel.html?id=06000200

One ice on and off record was recorded for Artichoke Lake, 11/27/07 ice on and 4/20/08 ice off.

Figure 7. 1957-2011 lake level fluctuations.

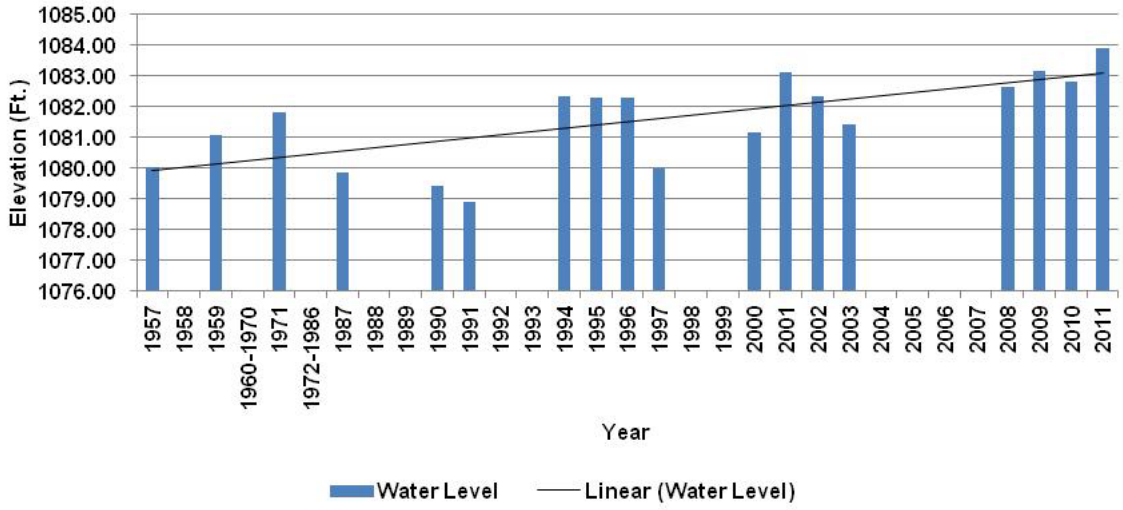
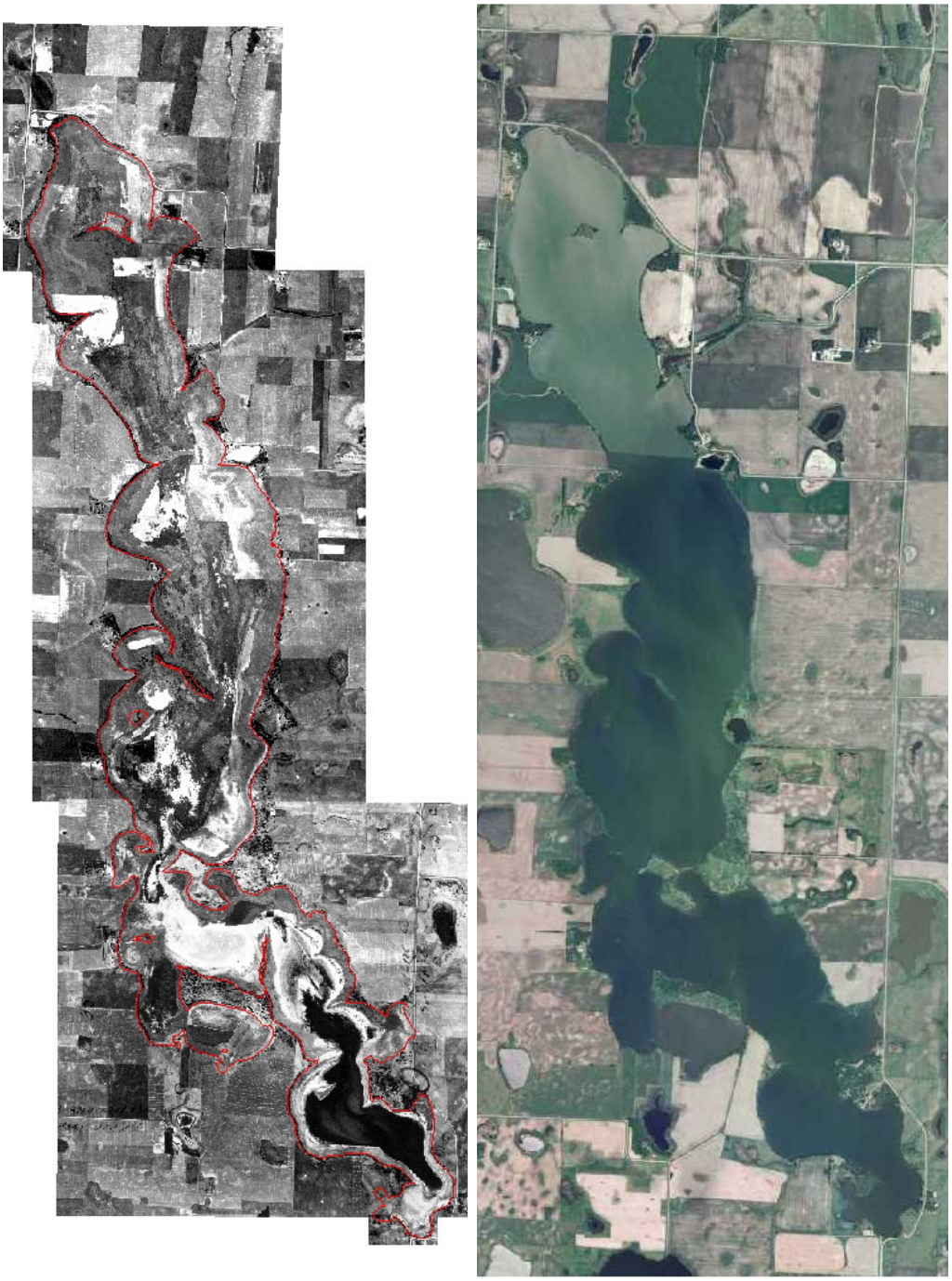


Figure 8. 1938-1940 and 2009 aerial photographs.



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, 2009, 2010, and 2011. Precipitation data were collected at the Artichoke Lake rain gauge station and are highly variable for the period of record (Figure 9). 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 Artichoke Lake (Figure 10). 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 -2011.

Figure 9. Precipitation annual values 1972-2010.

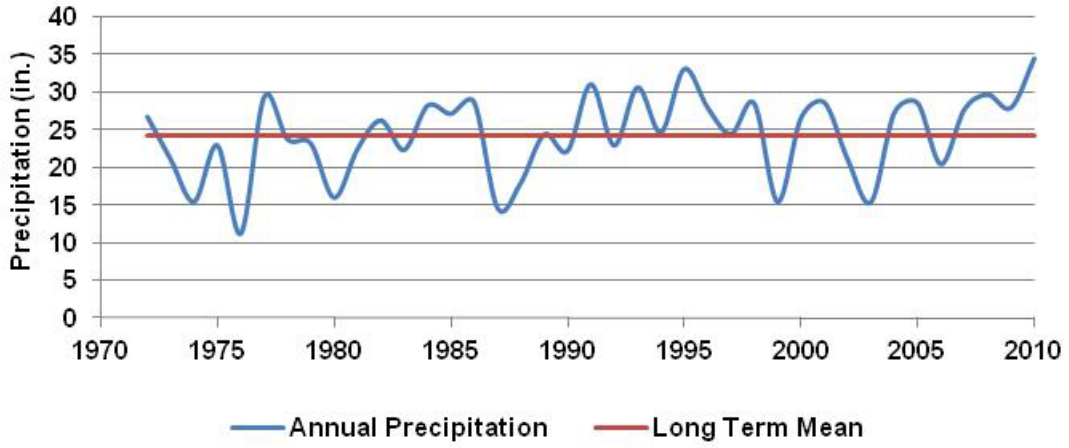
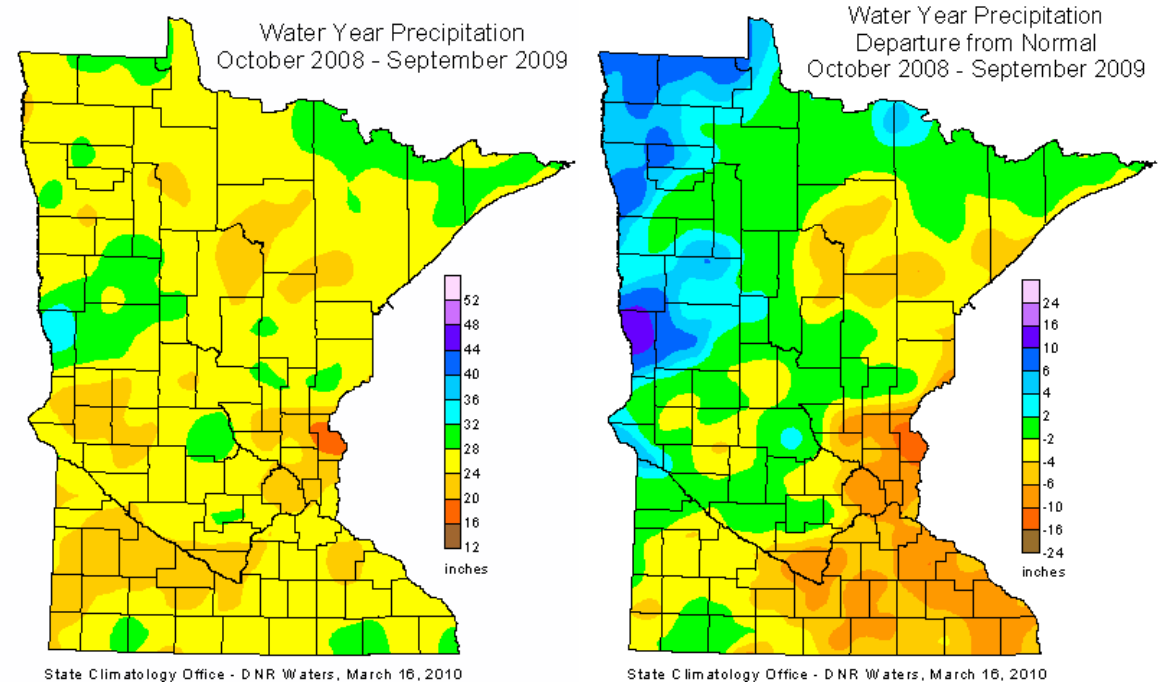


Figure 10. 2009 Minnesota Water Year Precipitation and Departure from Normal.
Prepared by State Climatology Office DNR Waters
Values are in inches



Methods

Fisheries and Aquatic Plants

Frequency of occurrence of aquatic plant species were assessed using the point-intercept method (Madsen 1999). This method entailed visiting sampling points on a grid within the vegetated zone of the lake, throwing a two-sided rake over one side of the boat at each point, raking the bottom approximately 1 m, then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 240-m (0.07 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 Artichoke 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 2 meters (6.6 feet) in length, with an inside diameter of 3.2 centimeters (1.24 inches). Zooplankton samples were collected with an 80 µm mesh Wisconsin zooplankton net. Phytoplankton (algae) samples were taken with an integrated sampler. Depth total phosphorous (TP) samples were collected with a Kemmerer sampler. Temperature and DO profiles and Secchi disk transparency measurements were also taken. Samples were collected at site 101 and 102 (Figure 3). 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 withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100% reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 µg/L mesh netting and rinsing specimens into a graduated beaker. Water was added to the beaker to a volume that provided at least 150 organisms per 5-milliliter aliquot. A 5-milliliter aliquot was withdrawn from each sample using a bulb pipette and transferred to a counting wheel. Specimens from each aliquot were counted, identified to the lowest taxonomic level possible (most to species level), and measured to the nearest .01 millimeter using a dissecting microscope and an image analysis system. Densities (#/liter), biomass (µg/L), percent composition by number and weight, mean length (millimeter), mean weight (µg) and total counts for each taxonomic group identified were calculated with the zooplankton counting program ZCOUNT (Charpentier and Jamnick 1994 in Hirsch 2009).

Results and Discussion

Fisheries Assessment

MDNR fisheries managers utilize netting survey information to assess the status of fish communities and measure the efficacy of management programs. Presence, absence, abundance, physical condition of captured fishes, and community relationships among fish species within survey catch information also provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). These data 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 (Table 4).

Artichoke Lake has been a popular summer and winter angling destination in west central Minnesota for many decades. Anglers have primarily fished for walleye, northern pike, crappie, bluegill, and bullhead. Early fish management activities include walleye stocking and natural reproduction checks as early as 1949. A 1959 Game Lake Survey reported that a resort was present on the lake. An initial lake survey was conducted in 1983 and the resort was no longer present, however 27 homes/cottages were noted. The vast majority of the shoreline presently remains undeveloped. Thirteen additional population assessment/surveys have been conducted since 1983. Primary species managed have been walleye, northern pike, and black crappie.

Artichoke Lake has a maximum depth of 4.7 m (15.5 ft) and it rarely stratifies due to frequent strong winds. Dense *Aphanizomenon* sp. algal blooms are common during summer months, and have been reported since 1949. Secchi disk readings during blooms have often been less than two feet. Localized fish kills were reported during decomposition of blooms in 1983 and 1998. Pelicans and cormorants were present in high numbers during the kill in 1998, which made evaluation difficult, as only fish too large for them to eat were found. The high nutrient content of the lake makes it susceptible to winterkill and a partial winterkill occurred in 1978-79. Save-A-Lake Aeration has operated an aeration system on the lake since 1984.

Some interesting changes have occurred in Artichoke's ecosystem. In 1959 sago pondweed (*Stuckenia pectinata*) was present over the majority of the northern third of the lake. By 1983 the abundance of submerged plants was quite low; however in the late 1980s curly-leaf pondweed (*Potamogeton crispus*) was extremely abundant in the northern third of the lake. However, since the mid 1990s curly-leaf pondweed has been rare. Crayfish were abundant in 1983 with 12-15 gallons caught per gill net; however their numbers have been very low in recent decades. During recent years common carp have been dying throughout the year from some unknown cause.

Due to its size and high nutrients, fish biomass in Artichoke is high, but diversity is low (Figure 12). Commercial winter harvest of fish in Artichoke Lake since 1950 is shown in Figure 11. Various species year classes over Artichoke's surveyed history spike, then crash, as is typical of nutrient-rich shallow lakes (Lathrop et al. 1992). According to commercial fishing records and past lake surveys, omnivorous and benthivorous species such as fathead minnows, common carp, and black bullhead have been abundant through history (Figure 12). These species not only tolerate high nutrients, but also increase internal nutrient loading through their spawning and feeding activities. Due primarily to high numbers of disturbance-tolerant species and no intolerant fish species, index of biotic integrity (IBI) scores in Artichoke Lake are among the lowest in Minnesota (ranging from 23-32 out of 160 in surveys conducted from 2007-11). Still, periodic large year classes of northern pike, stocked walleye, and black crappie provide a productive fishery.

Figure 11. Commercial winter harvest of fish in Artichoke Lake, Big Stone Co. since 1950.

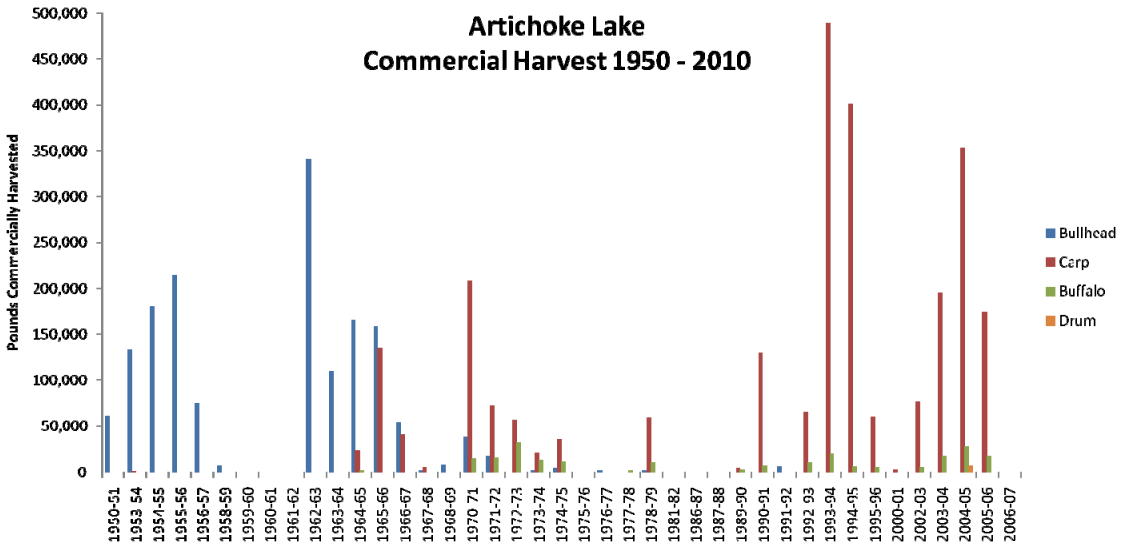


Table 4. Fish species captured during past fisheries surveys in Artichoke Lake, Big Stone. Co. Thermal guilds were classified by Lyons et al. (2009) and environmental tolerances were categorized by Drake and Pereira (2002).

Common name	Species name	Trophic guild	Thermal guild	Environmental tolerance	First documented
Fathead minnow	*Pimephales promelas*	Omnivore	Warm	Tolerant	1950
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1976
Orangespotted sunfish	*Lepomis humilis*	Insectivore	Warm	Neutral	1990
Brook stickleback	*Culaea inconstans*	Insectivore	Cool-warm	Neutral	1993
Spottail shiner	*Notropis hudsonius*	Insectivore	Warm	Neutral	2007
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1974
Black bullhead	*Ameiurus melas*	Omnivore	Warm	Tolerant	1950
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Warm	Neutral	1983
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	Tolerant	2010
Black crappie	*Pomoxis nigromaculatus*	Predator	Warm	Neutral	1983
White crappie	*Pomoxis annularis*	Predator	Warm	Neutral	2008
Largemouth bass	*Micropterus salmoides*	Predator	Warm	Neutral	1990
Northern pike	*Esox lucius*	Predator	Cool-warm	Neutral	1969
Common carp	*Cyprinus carpio*	Omnivore	Warm	Tolerant	1950
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1950
Buffalo	*Ictiobus spp.*	Insectivore	Warm	Neutral	1969
Freshwater drum	*Aplodinotus grunniens*	Omnivore	Warm	Neutral	2001

Fish species assessments

Bigmouth buffalo *(Ictiobus cyprinellus)*: Commercial fishing records indicate bigmouth buffalo have been present since at least 1966 and have been caught most years when commercial seining was conducted (Figure 11). Gill net catches have typically been low, and when catches have been high (2006, 2008-2010), the majority of the fish were young-of-the year (Figure 12). An extremely large year class of bigmouth buffalo was observed in 2010. Bigmouth buffalo young-of-year may be important forage for walleye, northern pike, bass, and crappie.

Black bullhead *(Ameiurus melas)*: The gill net catch of black bullhead has varied substantially (Figure 12). Historic commercial fishing records document high abundances of black bullhead in Artichoke Lake (11); however, no black bullhead were caught during the 1983 initial lake survey. High catches occurred during 1988 and 1990. The high catches were possibly due to low water level spawning conditions that favored them over other species during the late 1980s. Since 1993, the black bullhead catch has been relatively low. Bullheads were considerably more abundant historically possibly due to more frequent winterkill conditions and presumably, lower numbers of predators because the lake was not stocked as heavily. The recent decline in black bullheads mirrors a statewide decline in black bullhead populations potentially due to increasingly shorter winters and less winterkill (D.S. Staples, MDNR unpublished data; Fang and Stefan 2009). Lower black bullhead numbers is good from a water quality standpoint

Black Crappie (*Pomoxis nigromaculatus*): The trap net catch of black crappie has fluctuated considerably since 1983 (Figure 12). Strong year classes appear to occurr infrequently; however, ineffectiveness of summer trapnets for sampling black crappie complicate black crappies population inferences (McInerny and Cross 2006). Black crappie growth has been good with fish attaining 10 inches by age 3-4. Anglers generally experience better crappie fishing during the winter, and have reported catching fish in excess of 14 inches. Several thousand black crappie died from a columnaris bacterial infection in 2001.

Bluegill (*Lepomis macrochirus*): The trap net catch of bluegill has generally been quite low with the exception of 1988 and 1990 (12). Curly-leaf pondweed was very abundant in 1990 in the northern portion of Artichoke Lake and the resulting habitat would have favored bluegill recruitment. For reasons unknown curly-leaf pondweed has been scarce ever since and with the loss of vegetation cover, bluegill have remained scarce. Consequently, very limited bluegill angling has been noted during the past 15-20 years. If aquatic plants return to Artichoke Lake as a result of watershed restoration, bluegill populations should benefit.

Common carp *(Cyprinus carpio)*: Common carp have been present since at least the 1950s. Their introduction likely occurred by upstream migration from the Pomme de Terre River through Dry Wood Creek. Commercial harvest of them has been high at times and over 400,000 pounds of them were harvested during the winters of 1993-94 and 1994-95 (Figure 11). No commercial fishing of carp has occurred since 2006 due to low numbers. The carp gill net catches have fluctuated widely (Figure 12). Adjacent marshes have provided suitable carp spawning habitat during high water years and high recruitment may be linked to the presence of winterkill (Bajer and Sorensen 2010). Through their feeding and spawning activities common carp can destroy aquatic plants and increase internal nutrient loads, shallow lakes with high external nutrient loading favor greater carp abundance (Egertson and Downing 2004; Weber and Brown 2009; Kuhlanek et al. 2011; Weber and Brown 2011). Several hundred carp have been dying year-round during recent years. Samples were submitted for disease identification but results were inconclusive. With continued poor water quality and downstream recruitment sources, common carp will remain a problem in the lake.

Fathead minnows (*Pimephales promelas*): Fathead minnows have dominated seine catches since the first natural reproduction checks in 1950 and continuing through more recent fish IBI surveys. These

species (although native) are also known to produce low water transparencies by heavily preying on zooplankton that allows high densities of phytoplankton to occur. Fathead minnows are tolerant of low oxygen and turbidity and are usually one of the last species to succumb to winterkill (Becker 1983). Consequently, they are prolific species in shallow prairie lakes. Their prolific nature and omnivorous feeding habitats (detritus and invertebrates) lead to increased availability of phosphorus and nitrogen for algae growth, thus potentially exacerbating the harmful effects of nutrient loading from the watershed (Zimmer et al. 2006). Nevertheless, fathead minnows likely provide a valuable food source for predators, especially young year classes.

Freshwater drum (*Aplodontus grunniens*): Freshwater drum were first caught in 2001 when numerous young-of-year were observed during electrofishing. Adults migrated into the lake from the Pomme de Terre River during spring when Drywood Creek eroded a new channel around its dam. The dam had previously provided a substantial barrier to upstream fish migration. Freshwater drum have proliferated in Artichoke Lake and moderate to high gill net catches have been occurred since 2002 (12). Stomach analyses of game fish have revealed young-of-year drum are heavily utilized for forage, similar to what has been observed in Big Stone, Lac qui Parle, and Traverse Lakes. Surprisingly, Artichoke Lake has become a high quality destination for drum fishing.

Largemouth bass (*Micropterus salmoides*): Limited historical data exist regarding largemouth bass abundance. Recent electrofishing catches revealed a low to moderate population (Figure 12). Two electrofishing stations that contain bulrushes accounted for almost all the bass sampled. This habitat type has been quite limited in recent years. Some strong bass year classes have been observed as young-of-year failed to recruit to age 1, possibly due to winter mortality or predation by walleye and northern pike. Like bluegill, largemouth bass populations will benefit from future watershed restoration that successfully achieve clearer water and a return of emergent and submersed vegetation.

Northern pike (*Esox lucius*): Northern pike recruitment has been highly variable and gill net catches have varied considerably (Figure 12). There has been a positive correlation between northern pike reproduction and spring water levels in adjacent wetlands; however, many wetlands throughout the watershed that historically provided suitable spawning habitat have been drained. During the past ten years pike recruitment has been poor and the population has been supplemented by stocking winter-rescued adults (Table 5). Northern pike were moderately abundant in 2010 with 6 caught per gill net. Most pike were from the 2008 year class and probably came from stocking. Pike growth has been good with fish often exceeding 12 inches by age 1 and at times in the recent past, large fish were not uncommon (Figure 13); however in recent years, fish larger than 26 inches have rarely shown up in gillnets (Figure 13). Like bluegill and largemouth bass, northern pike populations will benefit from future clean water efforts that successfully achieve clearer water, restore adjacent wetlands, and facilitate the return of emergent and submersed vegetation.

Walleye *(Sander vitreus)*: Walleye is the primary species managed and most heavily sought by anglers. Although suitable spawning habitat exists, very limited walleye natural reproduction has occurred and the population has been primarily maintained by fry stocking. Heavy periphyton growth on existing spawning substrate may be limiting walleye egg survival. The current lake management plan calls for stocking 750 walleye fry per littoral acre (1.5 million) two of three years (Table 5). Supplemental stocking of fingerlings and yearlings has occurred when fry stocking wasn't adequate and abundant forage was present. Walleye gill net catches generally have been moderate to high and have exceeded the third quartile for class 41 lakes eight out of fourteen assessments (Figure 12). Twenty-four walleye were caught per gill net in 2010, second only to 43 per net in 1996. Walleye growth rates have been good and fish often have exceeded 12 inches by age 2. Historically Artichoke was known for high numbers of walleye over 20 inches; however the numbers of them have been lower in recent years (Figure 13).

Walleye exploit a range of forage in the lake presumably depending on their availability. Since the introduction of freshwater drum, walleye have utilized them as a food source; however, there is some evidence that freshwater drum compete with walleye for food at early life stages; so the net benefit of freshwater drum on walleye populations is uncertain. In fact following the negative patterns in Figure 12, there's more evidence to suggest freshwater drum may have negative effects on walleye than positive benefits. Still these interactions are clouded by changing stocking regimes, variable recruitment of young year classes, and steep declines in yellow perch (their preferred forage in most lakes). Climate change and warming water temperatures may also contribute to a long-term slide in peak production of this cool water fish (Gao and Stefan 1998). Still, average mid-summer (Jul. & Aug.) air temperatures show no long-term trends in nearby Morris MN, since climate records began in1891 (Minnesota Climate Working Group; unpublished data)

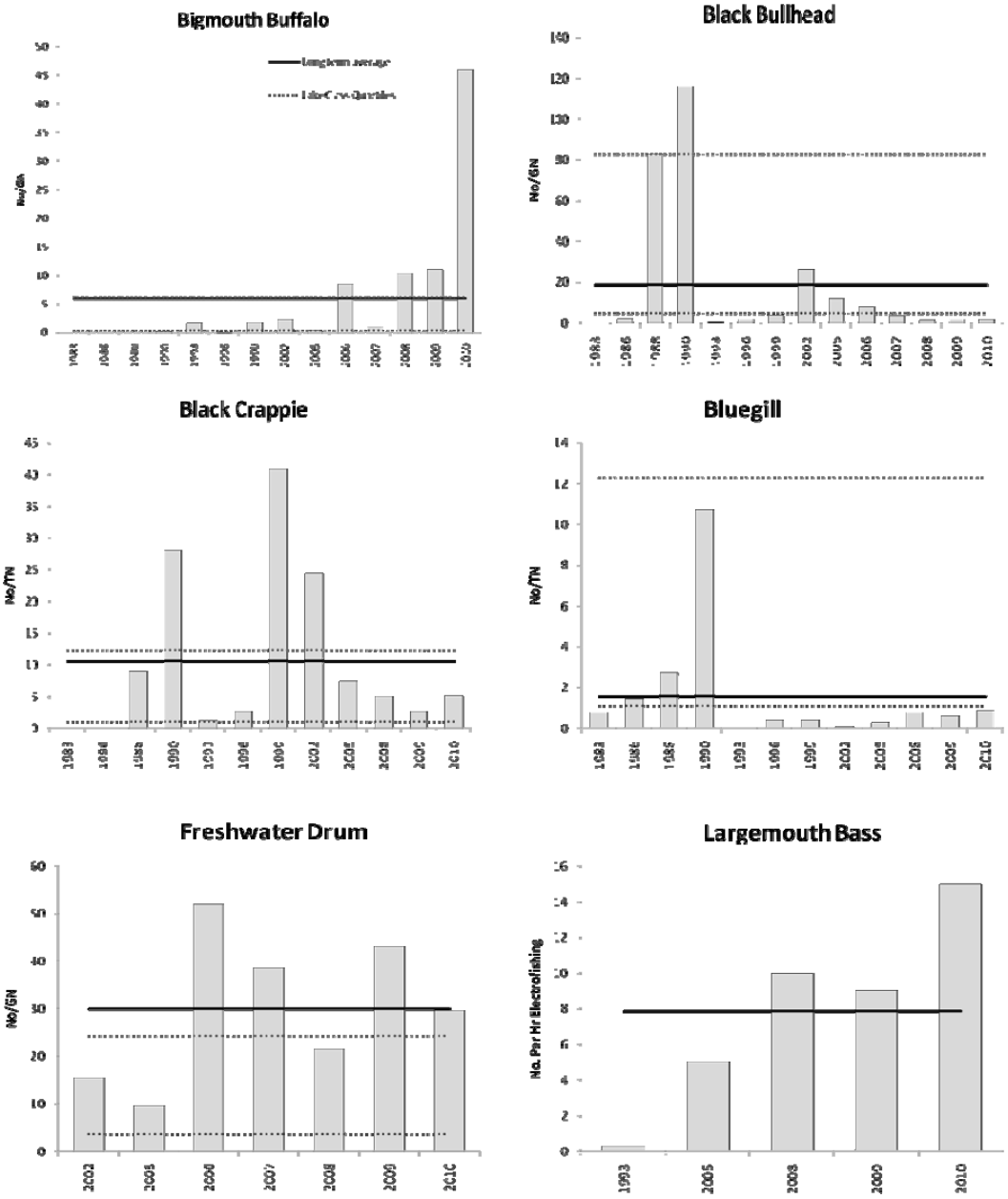
White sucker (*Catostomus commersonnii*): A very limited population of white suckers has been present. Only three adult white sucker have been sampled with gillnets and ¾ trap nets since 1993; one in 1988, 2002 and 2010. White sucker have not been an important component of the fish community for at least the last 30 years.

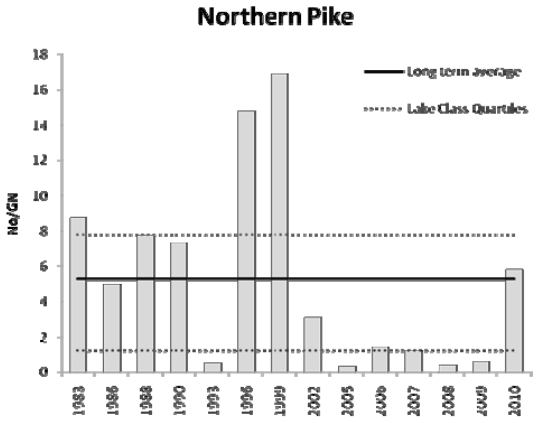
Yellow perch *(Perca flavescens)*: Yellow perch were abundant in the mid to late 1980s, since then gill net catches have been low (Figure 12). No obvious reason exists to explain the higher abundance, but it may be due to more suitable spawning/nursery conditions at that time. During this time, curly-leaf pondweed was abundant and is speculated to have benefitted yellow perch recruitment; however both curly-leaf pondweed and high yellow perch populations were short lived, yellow perch today rarely show up in gillnets. Sporadic yellow perch fluctuations have been observed in other class 41 lakes including Lac qui Parle and Traverse. Yellow perch have steeply declined statewide for reasons that need further investigation (D.S. Staples, MDNR Unpublished data).

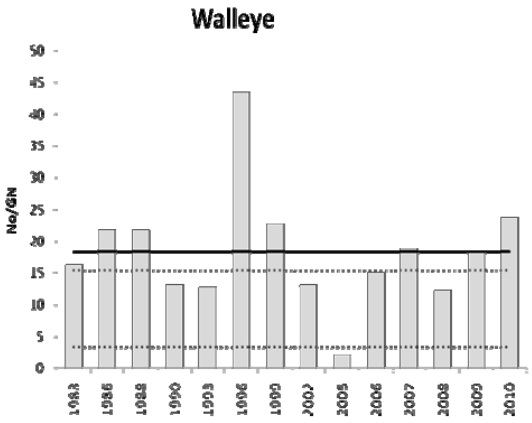
Table 5. Recent stocking history including size and number for fishes stocked into Artichoke Lake, 2001-2010.

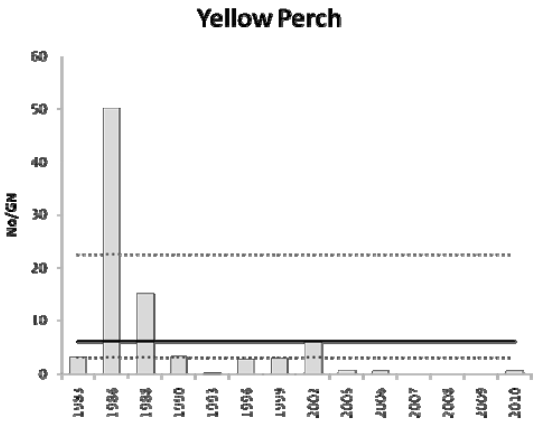
Year	Species	Size	Number	Pounds
2010	Northern Pike	adults	837	1,092.0
2009	Walleye	adults	961	769.0
	Walleye	fingerlings	468	130.0
	Walleye	fry	750,492	8.2
	Walleye	yearlings	9,077	1,901.0
2008	Northern Pike	adults	1,950	1,585.0
	Walleye	fry	751,732	6.1
	Walleye	fingerlings	572	36.0
2007	Northern Pike	adults	380	499.5
	Walleye	fry	712,385	6.5
2006	Northern Pike	adults	200	300.0
2004	Walleye	fry	840,320	7.8
2002	Walleye	fry	1,509,360	14.3
2001	Walleye	yearlings	534	326.0
	Walleye	fingerlings	58,502	2,240.5

Figure 12. Catches of major fish species in Artichoke Lake, Big Stone Co during past Fisheries surveys. GN = Gillnets, TN = trapnets. Dashed lines indicate the 1st and 3rd quartiles for class 41 lakes.




Northern Pike
Long term average
Lake Class Quartiles
No/GN


Walleye
No/GN


Yellow Perch
No/GN

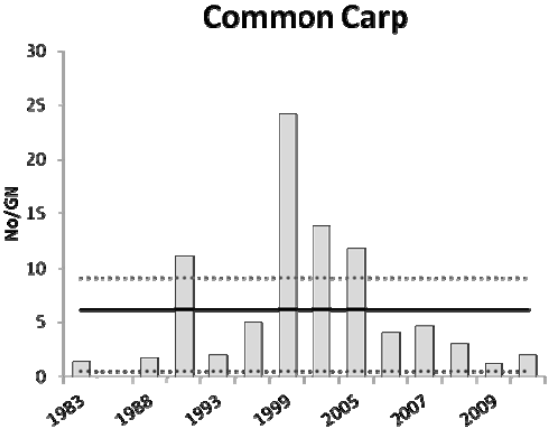
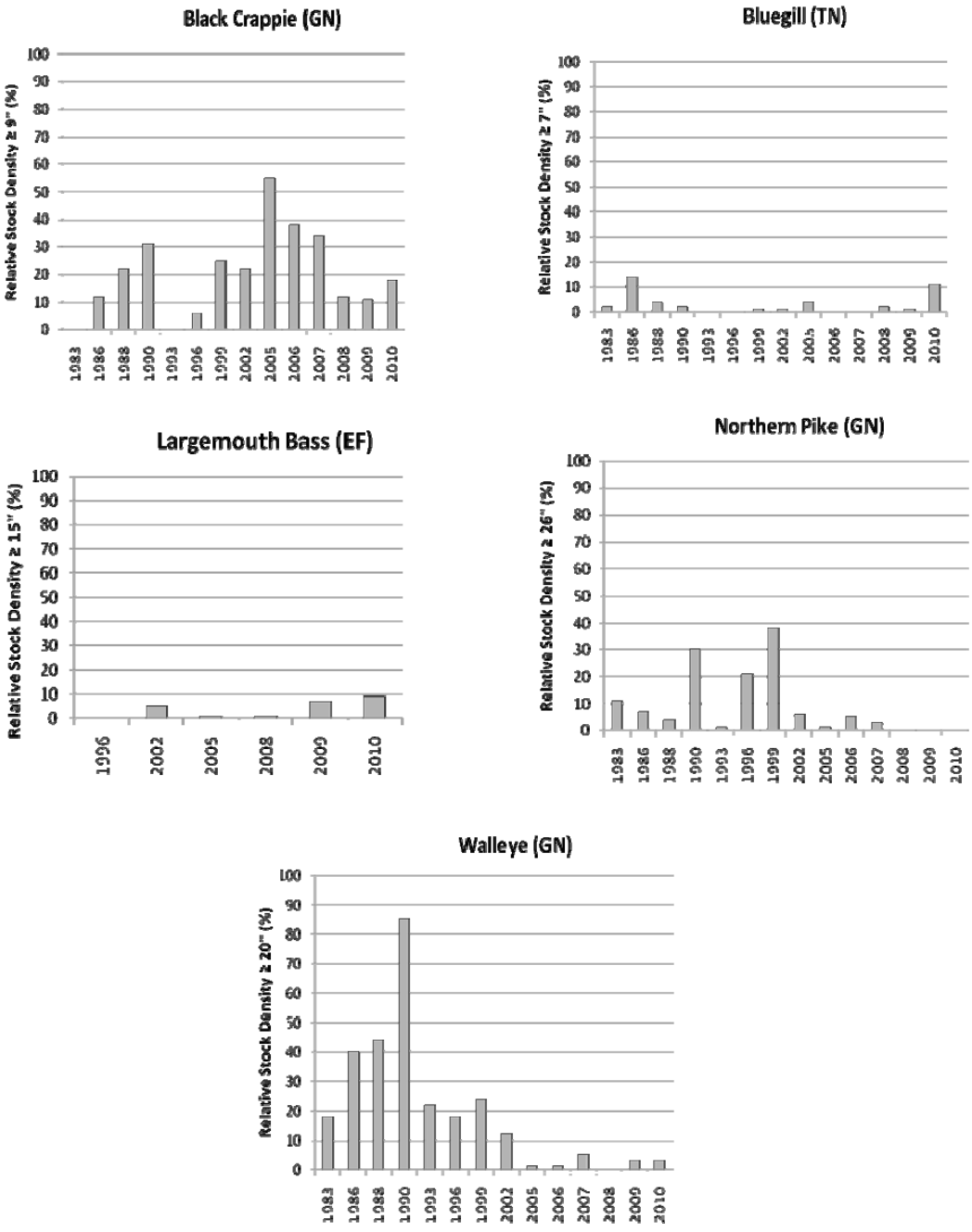

Common Carp
No/GN
1983
1988
1993
1999
2005
2007
2009

Figure 13. Relative Stock Density (Gablehouse 1984) of desirable sizes of major game fish species in Artichoke Lake, Big Stone Co expressed as a percentage. GN = index calculated for gillnet-caught fish; TN = trapnets; EF = electrofishing.



Aquatic Plant Assessment

Presumably due to historically high phosphorus concentrations and bank erosion, emergent and submersed aquatic plants have been rare throughout most of Artichoke's surveyed history, except for observations in 1953 of dense sago pondweed and dense curly-leaf pondweed in 1990 (Table 6). The frequencies of aquatic plant species in Artichoke Lake, during July sampling (2008-2010), are shown in Table 7. Today aquatic plants are rare and blue-green algae, Aphanizomenon, dominates the plant life in the lake.

Table 6. Commonly occurring aquatic plants during historical lake surveys prior to 2008.

Year	Common Name	Species Name	Growth Form
1953	*Abundant vegetation noted in fish natural reproduction check*		
1957	Sago pondweed	*Stuckenia pectinata*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
1983	Cattail	*Typha angustifolia*	Emergent
1990	Smartweed	Polygonum lapathifolium	Floating-leaf
	Chufa grass	*Cyperus esculentus*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	River bulrush	*Scirpus fluviatilis*	Emergent
	Curly-leaf pondweed[a]	*Potamogeton crispus*	Submersed
	Sago pondweed	*Stuckenia pectinata*	Submersed
1999	Filamentous Algae		
	Narrow-leaf cattail	*Typha angustifolia*	Emergent
	Reed canary grass	*Phalaris arundinacea*	Emergent
	Cane	*Phragmites australis*	Emergent
	River bulrush	*Scirpus fluviatilis*	Emergent
	Softstem bulrush	*Scirpus validus*	Emergent
	Curly-leaf pondweed[a]	*Potamogeton crispus*	Submersed

[a]Non-native

Table 7. Percent frequency of occurrence of aquatic plant species at depths ≤ 15 feet sampled during point-intercept surveys on 31 July 2008, 1 June 2009, and 26 July 2010 at Artichoke Lake, Big Stone County, MN.

Common Name	Species Name	Growth Form	Frequency (%) 2008	2009	2010
All rooted			3.7	4.6	1.6
Curly-leaf pondweed[a]	*Potamogeton crispus*	Submersed	2.5	1.6	0
Sago pondweed	*Stuckenia pectinata*	Submersed	1.2	0	0
Filamentous algae			3.7	8.5	92.1
Hardstem bulrush	*Scirpus acutus*	Emergent	0	1.6	
Narrow-leaf pondweed	*Potamogeton sp.*	Submersed	0	0.8	0.8
Cattail	*Typha spp.*	Emergent	0	0.8	
Greater duckweed	*Spirodela polyrhiza*	Floating	0	0	0.8
Bulrush	*Scirpus sp.*	Emergent	0	0	0.8
Max depth of veg growth (ft)[b]			7.0	10.0	3.3

[a]Non-native
[b]Depth of 95% of all plant occurrences

Curly-leaf pondweed

Curly-leaf pondweed is a non-native invasive submerged aquatic plant that is widespread throughout the southern part of the state. The exact date of introduction into Minnesota is unknown, but it is believed to have been present in Minnesota lakes since the early 1900s when carp were brought into the state. In nutrient-rich lakes curly-leaf pondweed grows most abundantly during early spring and senesces by mid-summer. When curly-leaf pondweed is abundant, mid-summer diebacks are thought to promote algae blooms which limit light penetration for native aquatic plants. Consequently, aquatic plant growth during mid- to late-summer is typically sparse in lakes where curly-leaf pondweed is abundant in spring; however, despite water quality conditions favorable for curly-leaf pondweed growth, the plant rarely grows abundantly in the lake.

Although it is a non-native species, curly-leaf pondweed is a desirable plant in disturbed agricultural lakes like Artichoke Lake because it can grow where native aquatic plants cannot and thus can provide important cover and food for native game fish and waterfowl (Nichols and Shaw 1986; Valley et al. 2004).

Summary of nearshore human impacts on aquatic plant communities

Only 25 dock structures along Artichoke's 20 mile shoreline were enumerated from aerial photos acquired from the Farm Service Administration in summer 2010. This, coupled with an absence of aquatic vegetation growth, suggests losses of aquatic plant cover by nearshore landowners is negligible and is the least of Artichoke's habitat problems. Legacy impacts (e.g., bank erosion, benthivorous fish, historic watershed nutrients and sediment) and continued high phosphorus inputs from farm fields and feedlots in the lake's watershed are of much greater significance to Artichoke's fish and wildlife habitats than aquatic plant removal by lakeshore owners.

Artichoke Lake Waterfowl Use

The MDNR's Section of Wildlife has been formally monitoring waterfowl use in Artichoke Lake during the fall migration season since 2003; however, historically the lake was an important fall staging area for diving ducks. According to life-long resident and Artichoke Lake property owner,

Charles Hanson, the lake filled up with "reeds and rushes" during the dry periods of the 1930s, when Artichoke was only a fraction of its current size. When the lake reflooded, waterfowl use was great and included redheads (*Aythya americana*), canvasbacks (*A. valisineria*), scaup (*A. affinis*), ring-necks (*A. collaris*) and mallards (*Anas platyrhynchos*). Mr. Hanson recalls his father shooting 20 canvasbacks on the lake in one fall in the early 1940s. The amount of bulrush began to gradually decline and most were gone by the late 1940s; however, the waterfowl use of the lake remained high. Sago pondweed was historically abundant but disappeared sometime after the 1950s when carp found their way into the lake and proliferated. It was still a popular duck hunting lake through the 1950-60s. As many as 12 duck hunting parties would access the lake from the Hanson farm on opening weekend of the duck hunting season. Diving ducks use was modest through the 1980s and into the 1990s according to Mr. Hanson and former local Area Wildlife Manager. A Harlequin duck (*Histrionicus histrionicus*) , a coastal duck and a very unusual species for this area, was shot on the lake in the late 1980's and it is now on display at the Big Stone County Museum in Ortonville. Today duck use of the lake has declined to almost nothing (Table 8), although a few people still hunt the south end of the lake. Fall duck use has dropped from very little to almost nothing in the last couple of years, as habitat has been poor in the lake since at least 2005. The lake still gets spring migratory waterfowl use, primarily mallards, Canada (*Branta canadensis*) and White-fronted (*Anser albifrons*) geese. These birds roost on the lake and feed in nearby fields.

Table 8. Peak fall duck counts for Artichoke Lake from weekly aerial waterfowl surveys flown from late September through freeze-up.

Year	Peak Count	Number of surveys
2003	550	6
2004	269	1
2005	No data	0
2006	648	6
2007	638	5
2008	350	5
2009	1	2
2010	14	6

Water Quality

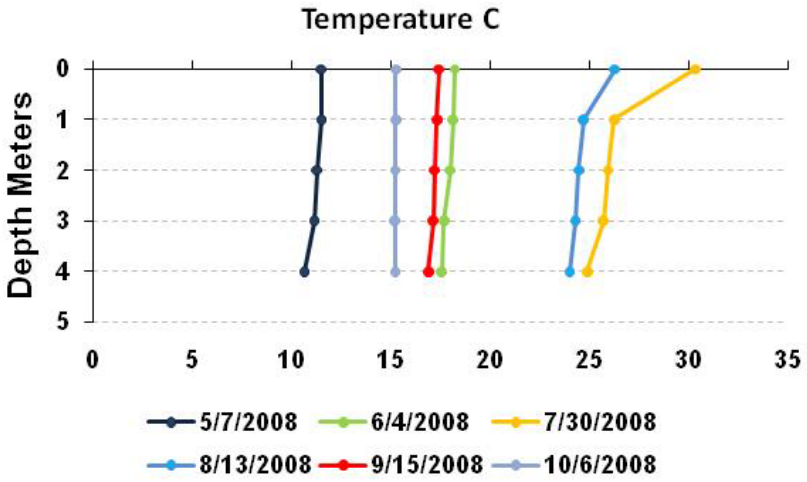
Standard summer mean water quality data for 2008-2010 are presented in Table 9, and raw data results are provided in Appendix A. In addition, major cations, anions, and total organic carbon were analyzed. Those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in Tables 9 and 10. 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 10 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a regional perspective.

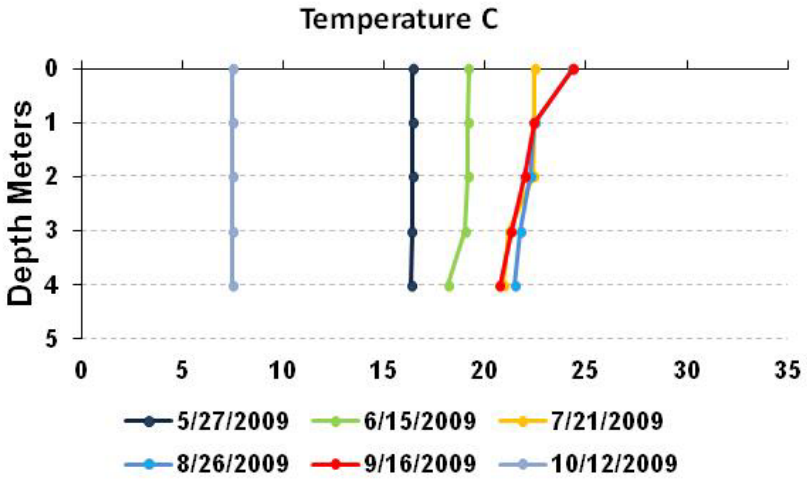
Dissolved Oxygen and Temperature profiles

Profiles were taken at one-meter intervals at site 101 and 102 in Artichoke Lake. A comparison of 2008, 2009, and 2010 dissolved oxygen and temperature profiles are found in Figures 14, 15, 16, and 17. Surface water temperatures were recorded every day by a temperature logger and are shown in Figure 18. Short periods of hot temperatures did increase the surface temperature, top meter, of the water column during mid-summer. Summer temperatures were higher on average in 2010.

Artichoke Lake is polymictic and does not stratify (Figures 14-15). This can be attributed to the lake's long fetch and shallow basin morphology. Even though frequent mixing occurred, DO dropped below 5 milligrams per liter (mg/L; threshold for class 2B waters, cool and warm-water fisheries not protected for drinking water) within the bottom meter during some years in mid to late summer. This may be a result of large amount of organic matter decomposing in the lower portion of the water column, in turn reducing DO concentrations. Thermal conditions in Artichoke Lake are dependent on air temperature. For the most part, the lake did not stratify during the summer months. Short periods of hot temperatures did increase the surface temperature, top meter, of the water column during mid-summer.

Figure 14. 2008, 2009, and 2010 seasonal temperature profiles at site 101 Artichoke Lake.





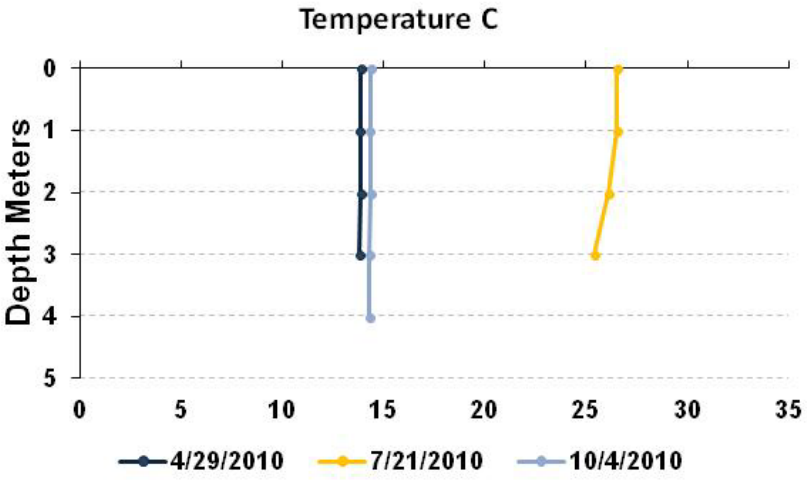


Figure 15. 2008, 2009, and 2010 seasonal temperature profiles at site 102 Artichoke Lake.

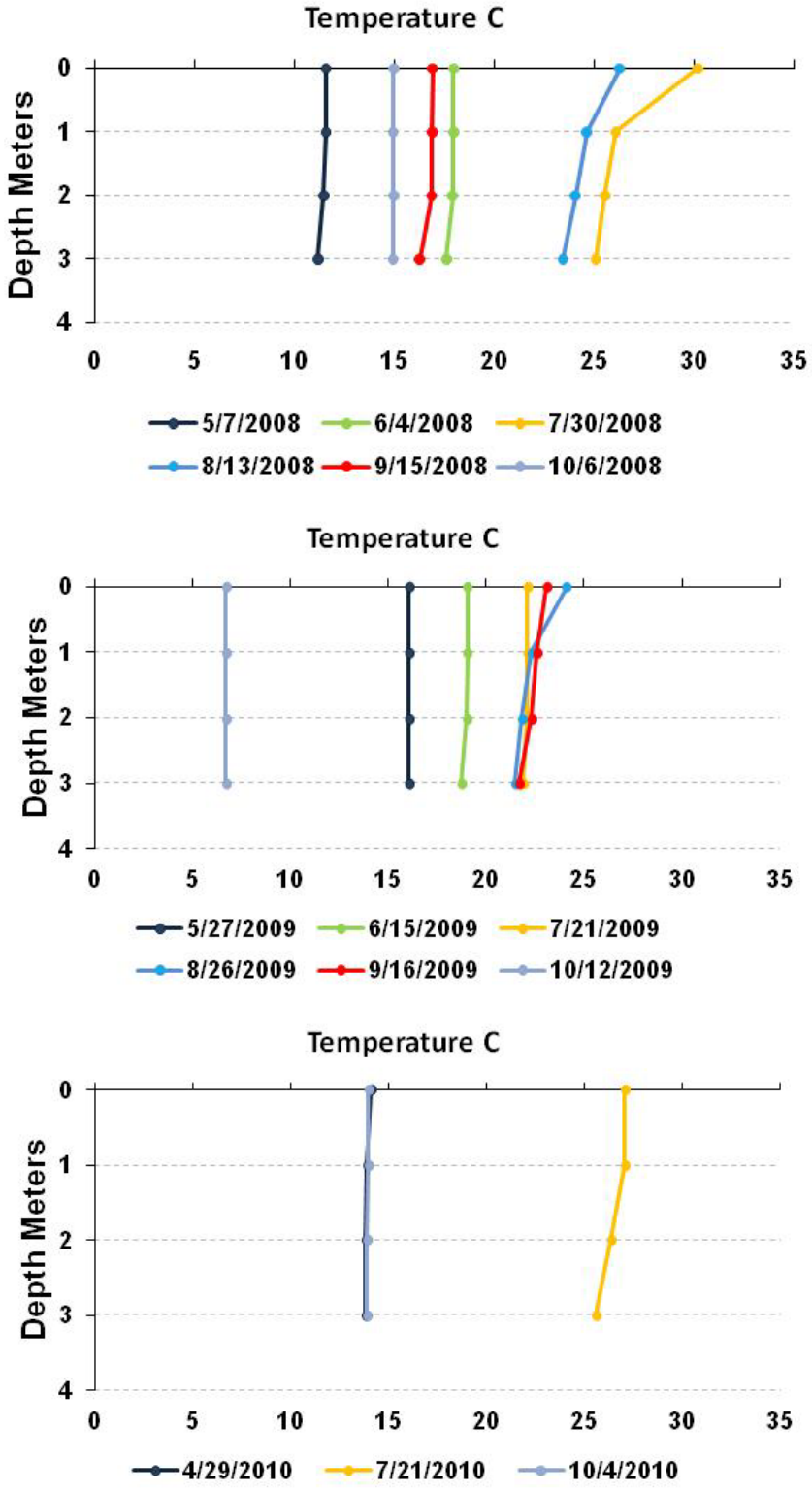


Figure 16. 2008, 2009, and 2010 dissolved oxygen profiles at site 101 Artichoke Lake.

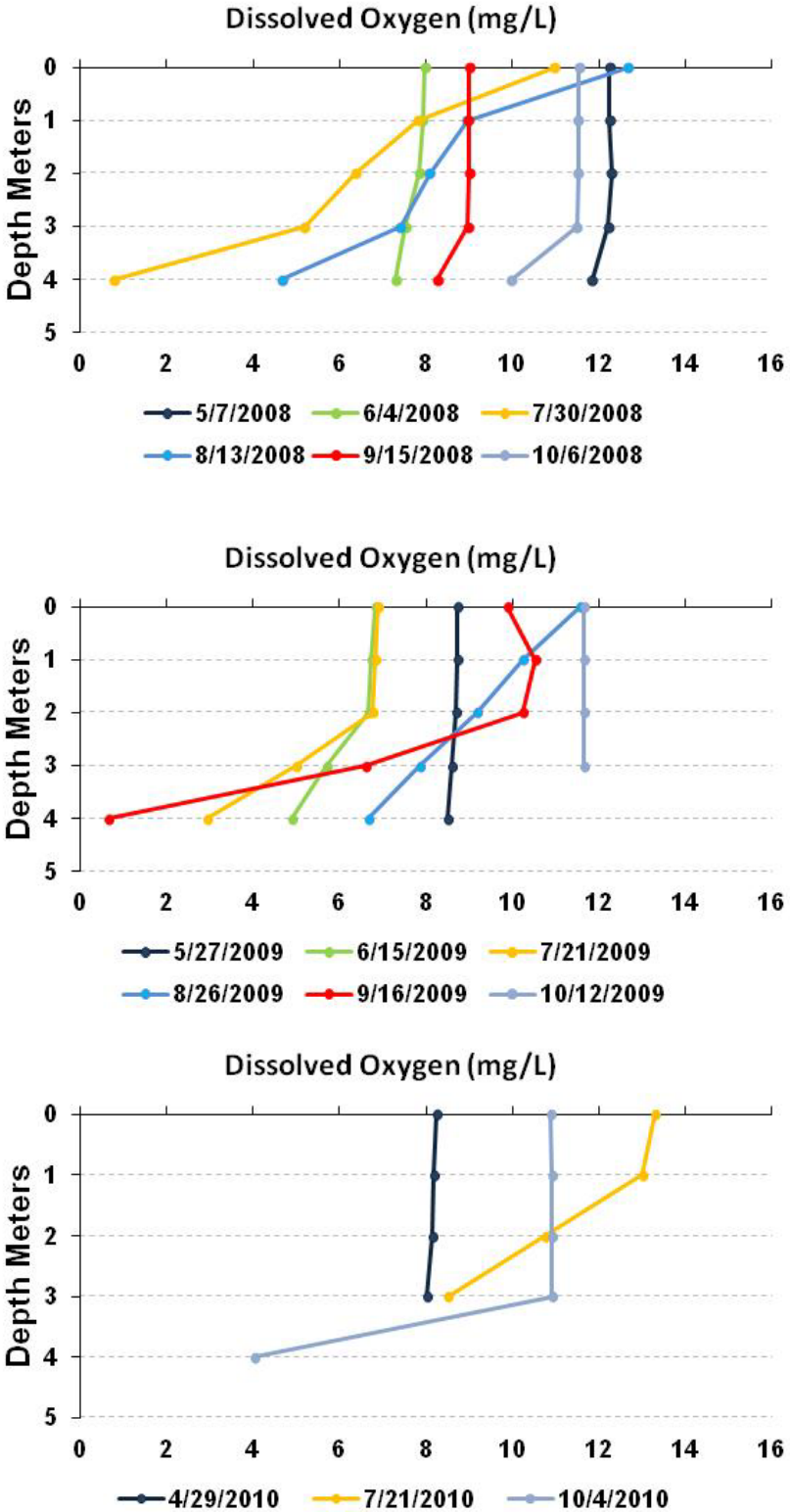


Figure 17. 2008, 2009, and 2010 dissolved oxygen profiles at site 101 Artichoke Lake.

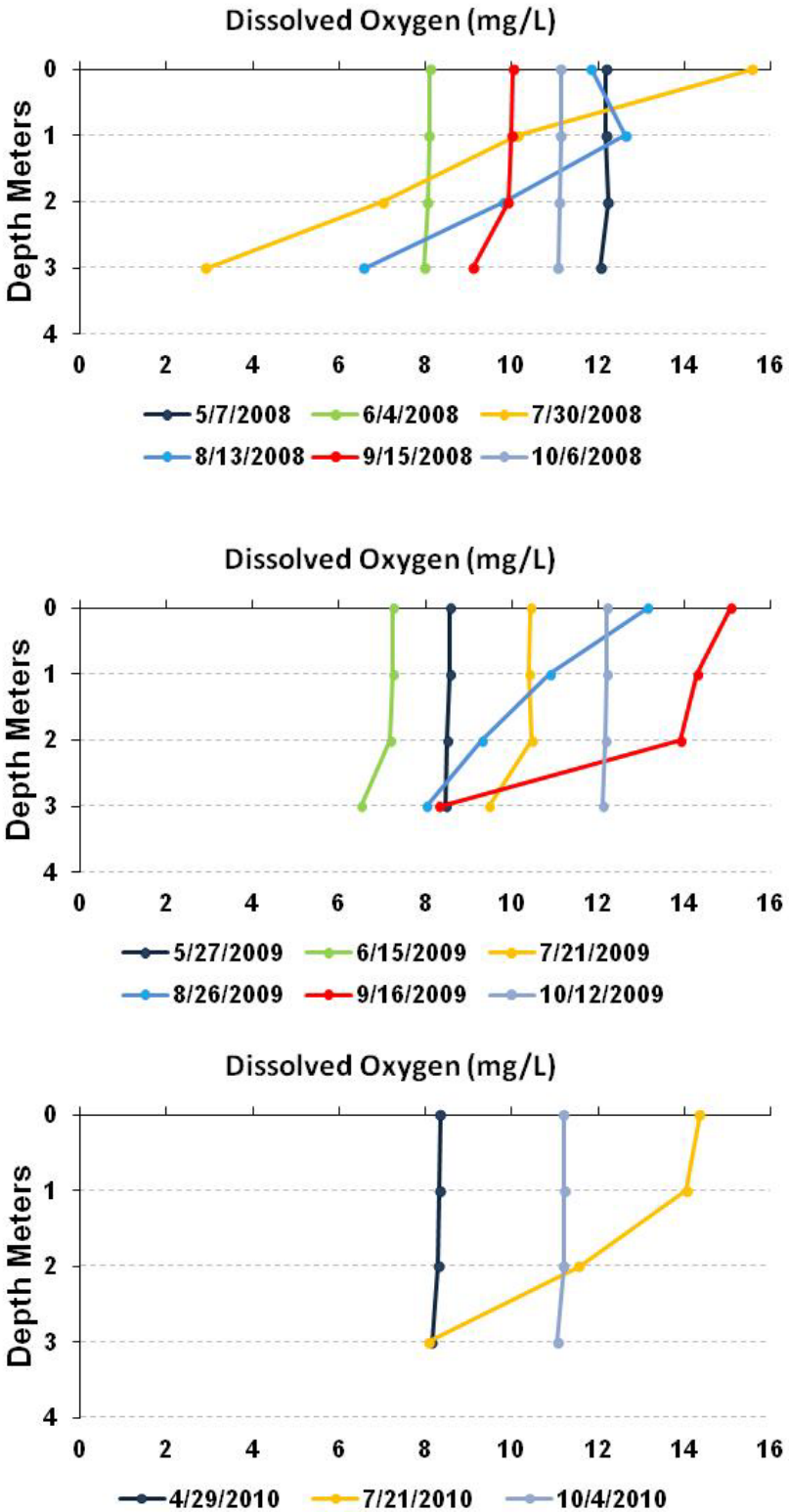
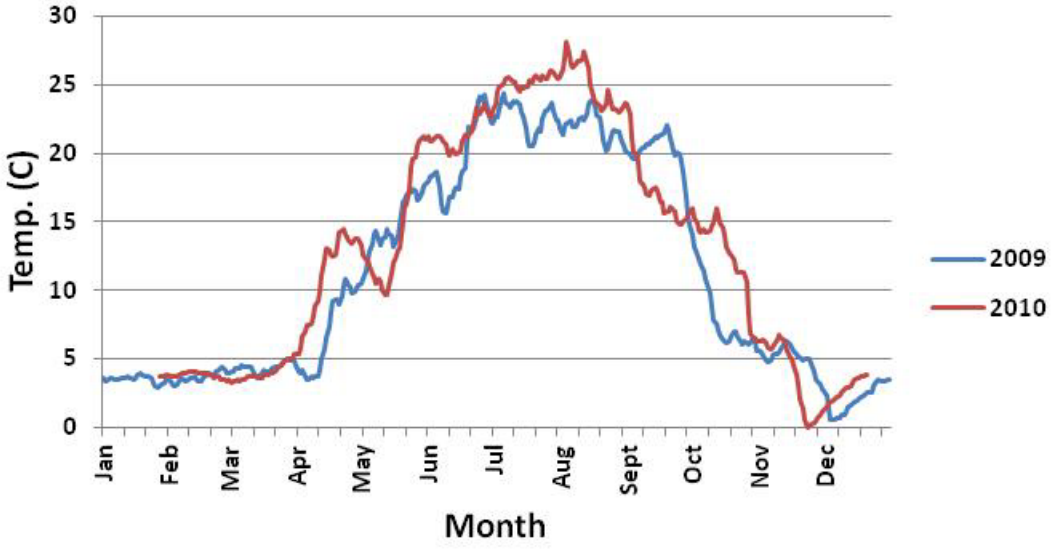


Figure 18. Surface water temperature daily averages for 2009 and 2010.



Total Phosphorus

TP is the limiting nutrient for algal growth in most freshwater lakes. Artichoke Lake's surface TP was highly variable throughout 2008, 2009, 2010, and 2011 ranging from 82-328 µg/L at 101 and 116-311 µg/L at 102 (Figures 19 and 20). At each site, an increase from June through July was noted. This increase coincides with rapid warming of the lake and curly-leaf pondweed die off. Since the amount of curly-leaf biomass is relatively low, as compared to the overall area of the lake, it seems likely that the mid-summer increase in TP may be related to temperature and/or wind-driven internal recycling rather than related to curly-leaf; however, this is but a guess without more detailed analysis. Some among year variability was noted, with July 2008 and 2009 TP being quite similar; whereas July 2010 was notably lower at both sites. Summer mean TP concentrations of 228 µg/L in 2008 and 225 µg/L in 2009 were significantly higher than the typical NGP ecoregion range of 122-160 µg/L. High variability in TP concentrations are a result of insufficient sedimentation of TP along with wind mixing events.

Chlorophyll-*a*

Chl-*a*, a pigment found in algae, is used to estimate the amount of algal production in a lake. In 2008, 2009, 2010, and 2011, Chl-*a* values for Artichoke Lake ranged from 1.9-112 µg/L. Peaks in algal production often occur in late summer when water temperatures are rather high. Since TP is extremely high and there is measureable soluble reactive P (Appendix), algae are not P-limited in Artichoke, Rather, the lower than expected Chl-*a* is likely due to other factor(s). Light limitation from resuspended organic and inorganic (e.g. clay) particles and continual mixing of algae out of the "photic" zone may be two such factors. The summer-mean range of Chl-*a* in reference lakes in the NGP ecoregion is 36-61 µg/L. Summer-mean Chl-*a* for 2008, 2009 and 2010 are within the NGP typical range. Nuisance algal blooms (>20 µg/L) occurred in each of the summers.

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. In Artichoke, algae and suspended sediments both contribute to the low transparency. Blue green algae's ability to move throughout the water column, may negate influences of light limitation in turbid water; however, total suspended solids (TSS) and the relative ratio among organic and inorganic solids in Artichoke Lake is within the typical range for NGP lakes. Artichoke Lake's 2008 through 2011 mean Secchi ranged from 0.7 m (2.3ft) to 1.4 m (4.6ft) which is within the NGP ecoregion range of 0.4 m (1.3ft) – 0.8 m (2.6 ft) (Table 9). The dominant blue green algae, *Aphanizomenon*, which floats in "rafts" on the surface of the water, had a minimal influence on Secchi transparency a Secchi disk can often be seen through the grass-like 'blades' of this large colonial algae species.

Figure 19. Artichoke Lake trends 2008, 2009, 2010, and 2011 at site 101.

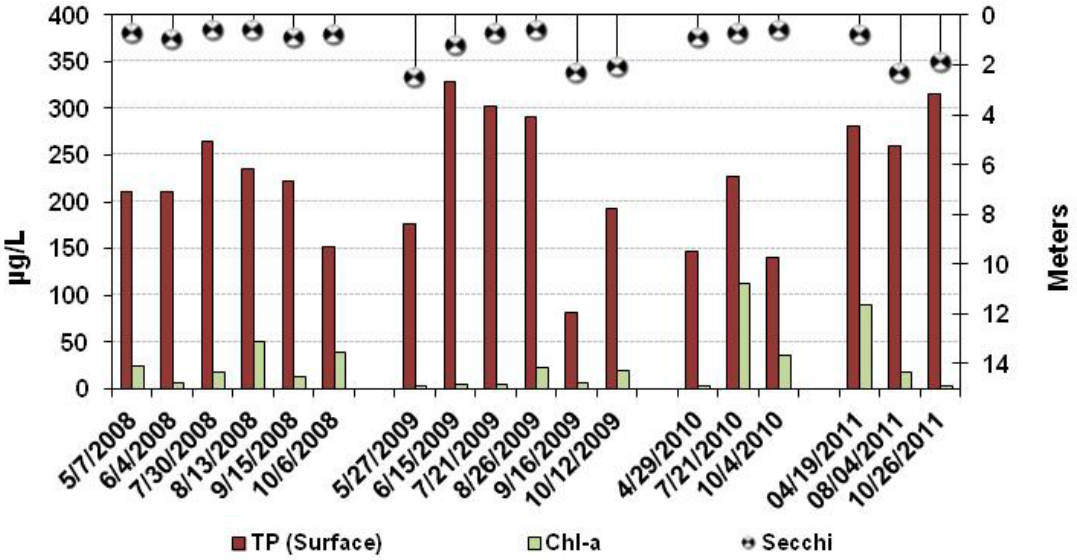
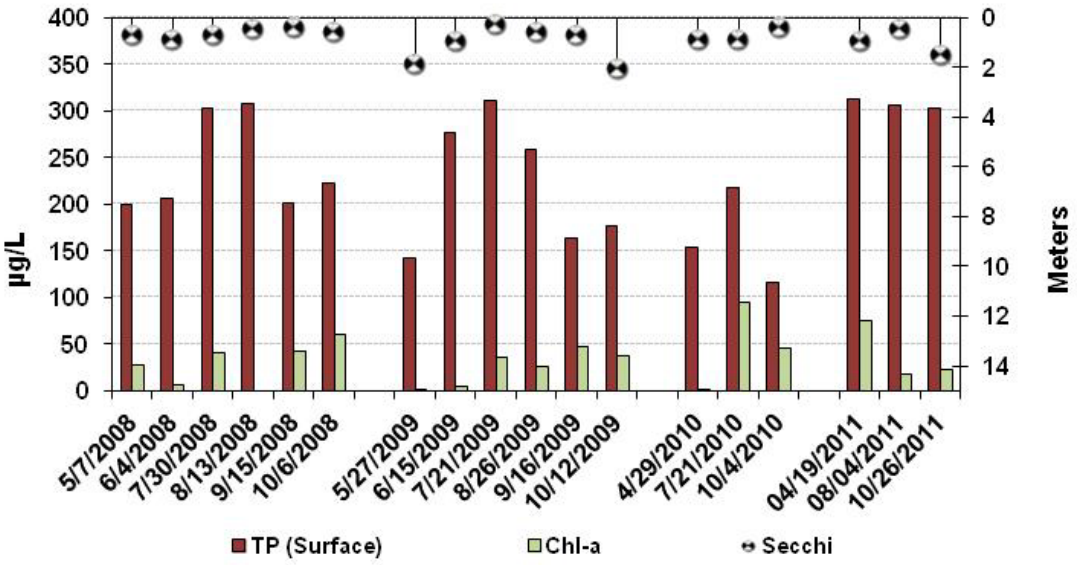


Figure 20. Artichoke Lake trends 2008, 2009, 2010, and 2011 at site 102.



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 Artichoke Lake and other Sentinel lakes. This includes some of the standard measures, such as TSS, alkalinity, conductivity and color (Table 9), as well as major cations, anions, silica, iron and organic carbon (Table 10). While several of these parameters have "typical" ecoregion-based concentrations (e.g. Table 9); some do not. For parameters without ecoregion–based comparisons, data from the 2007 NLA study were used to provide perspective on reported concentrations (Table 11). Since NLA lakes were selected randomly, they provide a reasonable basis for describing typical ranges and distributions at a state-wide level.

TSS values were within the typical range of NGP reference lakes. Most of the TSS can be attributed to organic suspended solids (TSS-TSIS), i.e. suspended algae. Water clarity in Artichoke Lake is highly variable because of routine 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 state-wide data. Lakes that receive a majority of their water inputs from forest and wetland runoff often have correspondingly higher color and TOC values as a result of incompletely dissolved organic matter (plants, leaves, and other organic material).

Alkalinity is higher than the typical range for NGP lakes. Alkalinity values indicate hard waters that are common throughout lakes in this area (Table 9). Conductivity for Artichoke Lake is within the NGP ecoregion range.

Table 9. Artichoke Lake summer-mean water quality as compared to the ecoregion reference lake typical range.

Parameter	2008	2009	2010	2011	NGP
# of lakes					13
Total Phosphorus (µg/L)	228	225	167	296	122 – 160
Chlorophyll mean (µg/L)	31.3	17.8	48.6	38.0	36 – 61
Chlorophyll maximum (µg/L)	49.5	28.5	103.5	89.4	66 - 88
Secchi Disk (feet)	2.3	4.6	2.6	4.3	1.3 – 2.6
(meters)	0.7	1.4	0.8	1.3	(0.4 – 0.8)
Total Kjeldahl Nitrogen (mg/L)	2.1	2.1	2.1	2.5	1.8 - 2.3
Alkalinity (mg/L)	300	300	293	283	160 - 260
Color (Pt-Co Units)	15	15	20	23	20-30
pH (SU)	8.4	8.8	9.0	8.3	8.3 - 8.6
Chloride (mg/L)	17	16	145	13	11-18
Total Suspended Solids (mg/L)	15.5	6.9	10.8	5.6	10-30
Total Sus. Inorganic Solids (mg/L)	5.6	2.5	5.1	3.5	5-15
Conductivity (µmhos/cm)	880	865	731	776	640 - 900
TN:TP ratio	11:1	11:1	8:1	12:1	13:1 - 17:1

Most cation and anion concentrations were stable across sampling events and years (Table 10). 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 state-wide data (Table 11). The other major cations sodium (Na) and potassium (K) are also higher than the typical NLA range. Bicarbonate is the dominant anion, followed by chloride (Cl) and sulfate (SO_4). Chloride is within the typical range for NGP reference lakes (Table 9); and statewide NLA data (Table 11). Sulfate is much higher than the relative range of NLA data. Average cation and anion balances (cation-anions expressed as a % of cations) for 2008, 2009, 2010 and 2011 were within 4%, excluding the 4/29/2010 sampling event (Table 11), which is within values exhibited by the NLA lakes.

Table 10. Artichoke Lake cation, anion, and organic carbon measurements.

Date	mg/L	mg/L	mg/L	mg/L	µg/L	mg/L		mg/L	mg/L	mg/L	mg/L
	Ca	Mg	Na	K	Fe	Si		SO_4	Cl	TOC	DOC
5/7/2008	58.1	77.7	19.5	18.5	-	-		186.0	17.2	18.0	-
7/30/2008	60.1	72.9	22.0	19.0	-	-		191.0	17.4	16.0	-
10/6/2008	48.1	80.1	21.0	19.0	-	-		187.0	17.0	17.0	-
5/27/2009	55.4	72.1	19.7	17.0	80.1	2.7		162.0	16.1	17.0	16.0
7/21/2009	60.8	73.0	19.9	18.4	221.0	20.0		161.0	16.1	16.0	16.0
10/12/2009	48.4	74.1	20.0	18.0	26.9	5.3		163.0	17.1	16.0	15.0
4/29/2010	57.7	73.7	18.5	15.4	192.0	3.7		146.0	14.9	14.0	14.0
7/21/2010	56.8	68.8	17.4	15.0	14.0	14.3		154.0	14.9	15.0	14.1
10/4/2010	57.4	72.2	19.4	16.6	16.2	5.3		157.0	14.6	13.0	12.5
4/19/2011	61.6	68.6	16.5	12.0	14.0	14.2		150.0	13.4	13.0	11.6
8/4/2011	56.9	65.2	16.4	12.5	14.0	8.0		155.0	12.1	12.0	11.6
10/26/2011	66.4	75.1	19.3	13.9	14.0	24.4		170.0	13.0	13.0	12.3

Table 11. 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
5/7/2008	58.1	77.7	19.5	18.5	310.0	186.0	17.2	10.61	-10.55	0.29
7/30/2008	60.1	72.9	22.0	19.0	310.0	191.0	17.4	10.44	-10.66	-1.05
10/6/2008	48.1	80.1	21.0	19.0	280.0	187.0	17.0	10.39	-9.97	2.07
5/27/2009	55.4	72.1	19.7	17.0	300.0	162.0	16.1	9.99	-9.82	0.84
7/21/2009	60.8	73.0	19.9	18.4	310.0	161.0	16.1	10.38	-10.00	1.84
10/12/2009	48.4	74.1	20.0	18.0	290.0	163.0	17.1	9.84	-9.67	0.88
4/29/2010	57.7	73.7	18.5	15.4	290.0	146.0	14.9	10.14	-9.26	4.57
7/21/2010	56.8	68.8	17.4	15.0	290.0	154.0	14.9	9.64	-9.42	1.12
10/4/2010	57.4	72.2	19.4	16.6	300.0	157.0	14.6	10.07	-9.68	2.02
4/19/2011	61.6	68.6	16.5	12.0	290.0	150.0	13.4	9.74	-9.30	2.35
8/4/2011	56.9	65.2	16.4	12.5	260.0	155.0	12.1	9.24	-8.76	2.63
10/26/2011	66.4	75.1	19.3	13.9	300.0	170.0	13.0	10.69	-9.90	3.82
Average	57.3	72.8	19.1	16.3	294.2	165.2	15.3	10.1	-9.8	1.7
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			

Phytoplankton (algae)

Algal communities shift throughout the seasons in response to changes in nutrient supply, sunlight and temperature. The transitions in phytoplankton assemblage for Artichoke Lake in 2008 at sites 101 and 102 are depicted in Figures 21 and 22. Diatoms are generally most abundant in cool water, usually during spring and fall turn over. Though data for Artichoke Lake were not available for April this was likely the case. As water temperatures warm and minimal silica supplies decline (Table 10), diatom production slows and other forms become dominant. By mid-summer, blue-green algae thrive in high water temperatures and are able to out-compete other species of algae because of its larger size and ability to move vertically through the water column. Based on Figures 21 and 22, blue-greens became dominant in May and remained dominant through the fall sample collection in October. Yellow-browns and dinoflagelletes were present in low densities. Large blooms of blue-green algae (*Aphanizomenon*) are shown from Artichoke Lake in Figure 23.

Figure 21. 2008 Phytoplankton assemblage in Artichoke Lake at site 101.

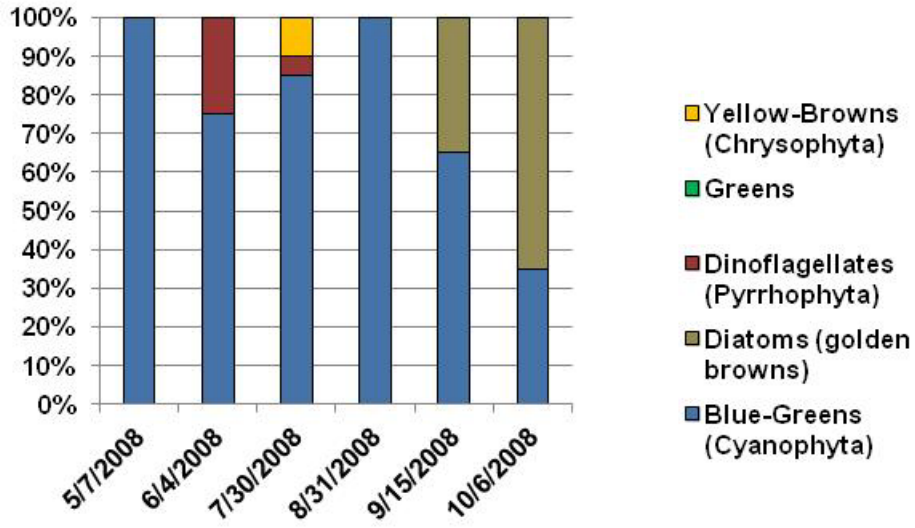


Figure 22. 2008 Phytoplankton assemblage in Artichoke Lake at site 102.

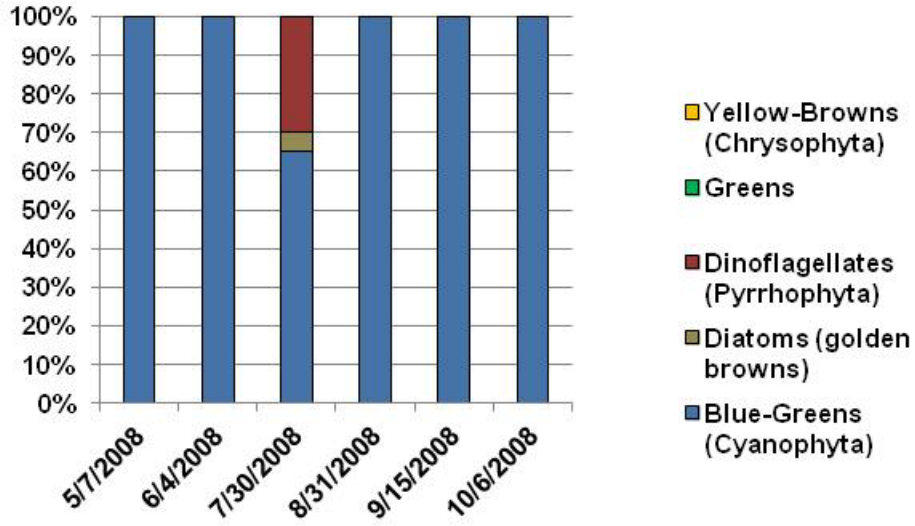
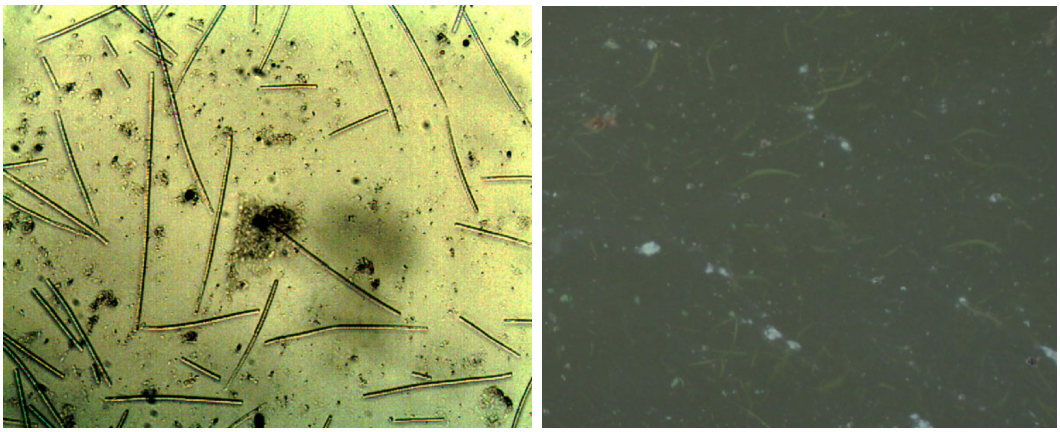


Figure 23. Phytoplankton found in Artichoke Lake, Blue Green *Aphanizomenon*.



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 Artichoke Lake.

Artichoke Lake had the highest mean annual density and second highest mean annual biomass of zooplankton of any of the NGP Sentinel lakes (Table 12). Total number of taxa for Artichoke Lake was average among the NGP 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. Artichoke Lake appears to have the highest zooplankton biomass and densities in May which then slowly decrease through June and July (Figure 24). Biomass and densities increase again from August through October.

Also, surprisingly, in summer 2010, Artichoke and Peltier Lake, the two most P-enriched shallow Sentinel lakes had the highest proportion of large daphnia (Figure 25). Large-bodied zooplankton are not typical of shallow, nutrient-rich lakes with high populations of zooplankton-eating fish. Future investigations will explore factors shaping zooplankton populations.

Table 12. Mean annual zooplankton densities (#/L), biomass (µg/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 (#/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 24. Mean monthly zooplankton densities (#/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).

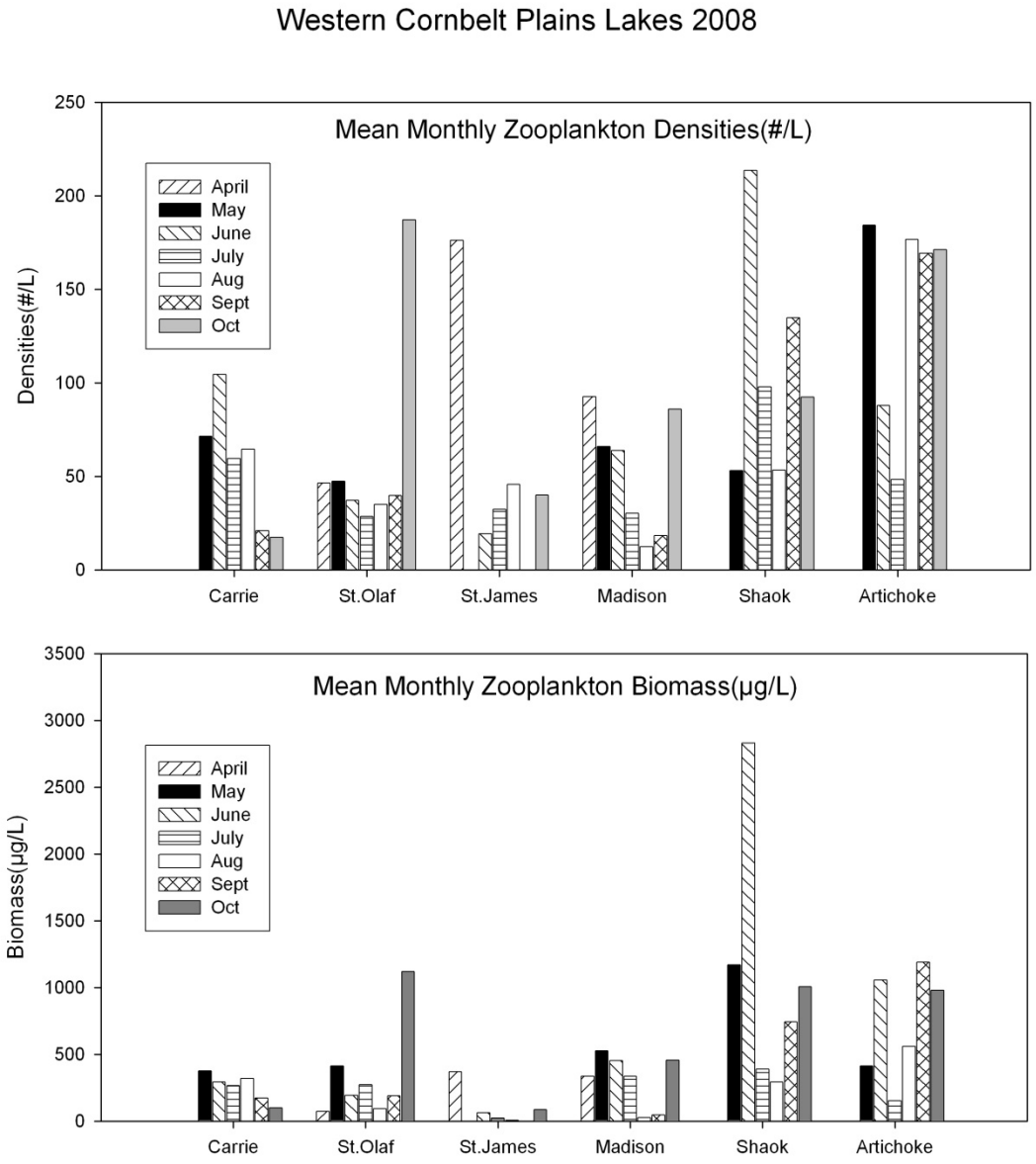
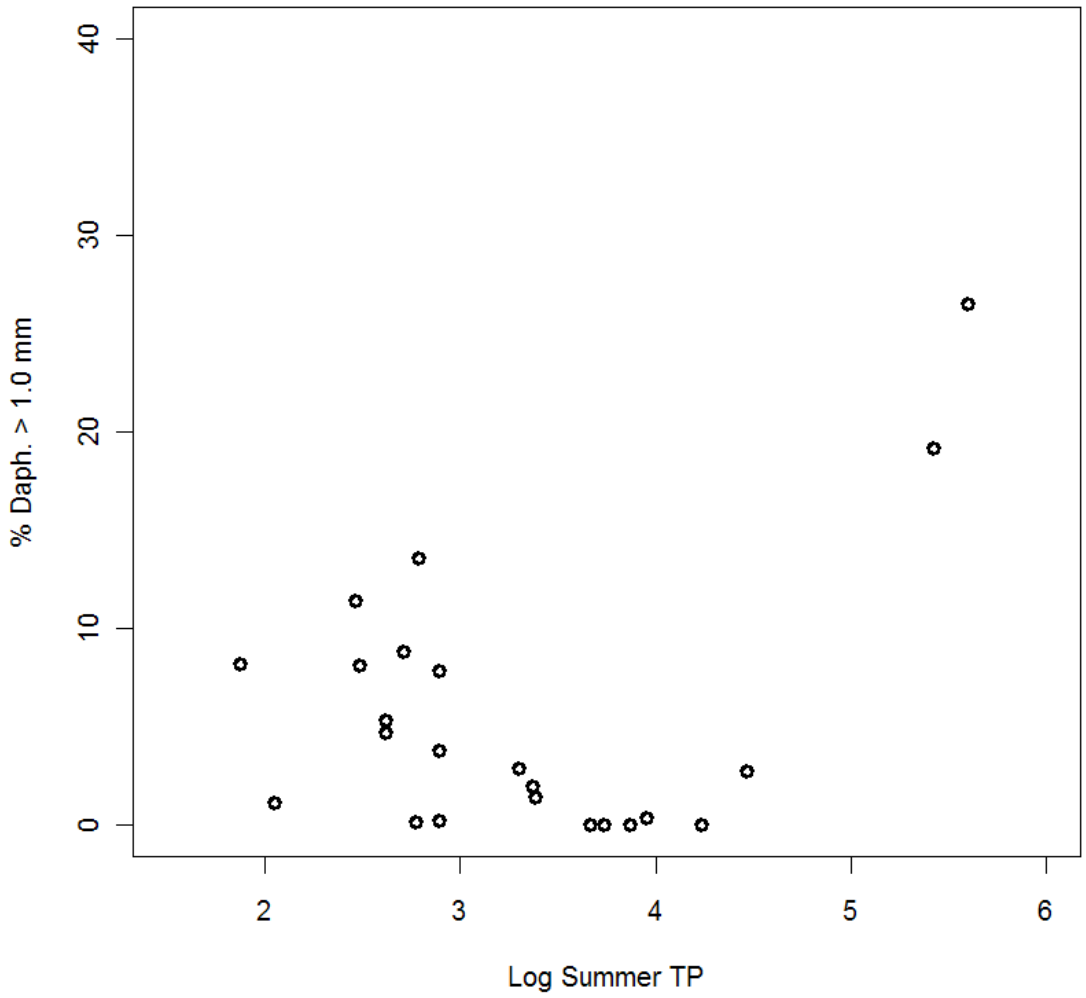


Figure 25. Percent composition of large-bodied *Daphnia* in summer 2010 zooplankton samples across the 24 sentinel lakes as a function of natural log-transformed total phosphorus.



Trophic Status Trends

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

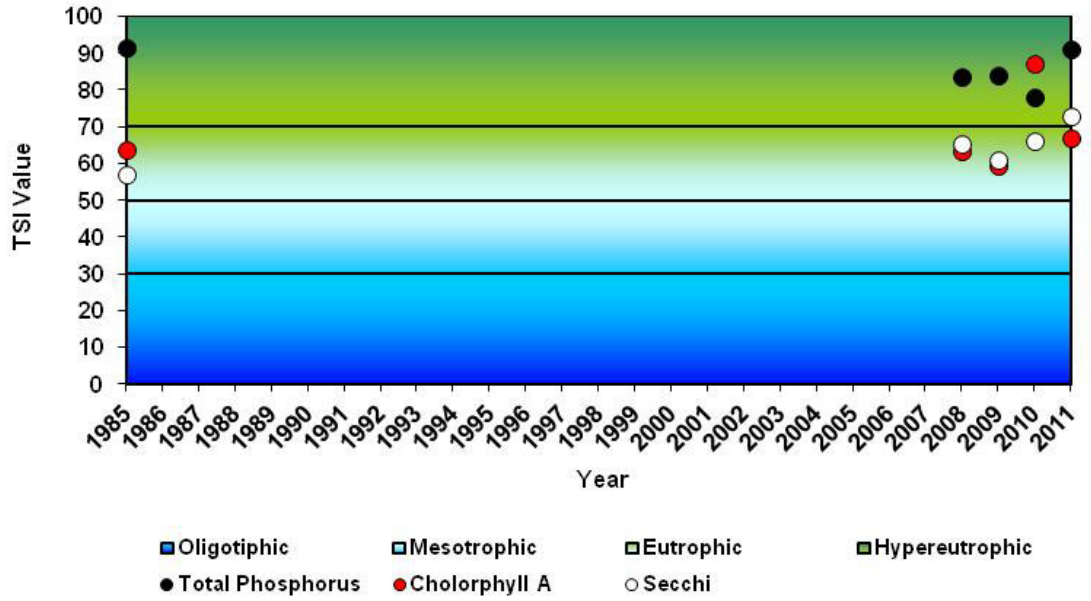
Chlorophyll-*a* TSI (TSIC) = 9.81 ln (Chl-*a*) + 30.6

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 provides a bases for assessing the relationship among TP, Chl-*a*, and Secchi (Figure 26). TSIP values are consistently higher than TSIS and are higher than TSIC in most summers (Figure 26). This suggests that based on TP, Artichoke has the potential to produce more algae and have much lower transparency than has been observed. In 2010, a summer sampling event, during a blue-green algae bloom, recorded a Chl-*a* value of 103.5 µg/L. This resulted in a higher summer-mean Chl-*a* ,and a much higher TSIC, as compared to previous summers. Based on an average TSI score of 72, Artichoke Lake would be characterized as hypereutrophic.

Figure 263. Artichoke Lake historic TSI values.



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 and 2009 water quality of Artichoke Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used along with BATHTUB, a US Army Corps of Engineers model for diagnosing lake and reservoir condition, to further examine watershed loading and sedimentation rates in Artichoke Lake. A comparison of MINLEAP predicted vs. observed values is presented in Table 13.

MINLEAP 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 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 Artichoke 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.

Artichoke Lake is located in the NGP ecoregion and the model was run using NGP ecoregion-based inputs. The observed TP values are much higher than predicted by MINLEAP. Observed Chl-*a* values were much lower than expected, given high concentrations of TP. Secchi transparency was greater than predicted, as well. It appears that the response variables, Chl-*a* and Secchi, do not correlate well with TP. This maybe a result of internal recycling from wind-mixed resuspension and/or much higher watershed P loading than estimated by MINLEAP.

Table 13. MINLEAP model results for Artichoke Lake.

Parameter	2008 Artichoke Observed	2009 Artichoke Observed	MINLEAP Predicted NGP Ecoregion
TP (µg/L)	228	225	159 (±69)
Chl-*a* (µg /L)	31.3	17.8	108.1 (±78.1)
Secchi (m)	0.7	1.4	0.5 (±0.2)
P loading rate (kg/yr)	-		6671
P retention (%)	-		0.92
P inflow conc. (µg/L)	-		2001
Water Load (m/yr)	-		0.42
Outflow volume (hm^3/yr)	-		3.33
Residence time (yrs)	-		4.3
Vighi & Chiaudani			40.2

BATHTUB Modeling

BATHTUB was used to further explore the dynamics of TP inputs and sedimentation in Artichoke Lake. The nutrient and water budget was estimated based on: a) landuse composition and standardized TP concentration and runoff values; b) estimate of number of head of animals in feedlots in the watershed and estimated P delivery, and c) region-based precipitation, evaporation and runoff. The animal unit P loading was estimated based on typical values from the literature and a "conservative" delivery rate of 10%, which implies that of all the P produced from animals in the watershed only 10% actually reaches the lake (i.e., 90% is retained in the watershed). A copy of model inputs is included in the Appendix.

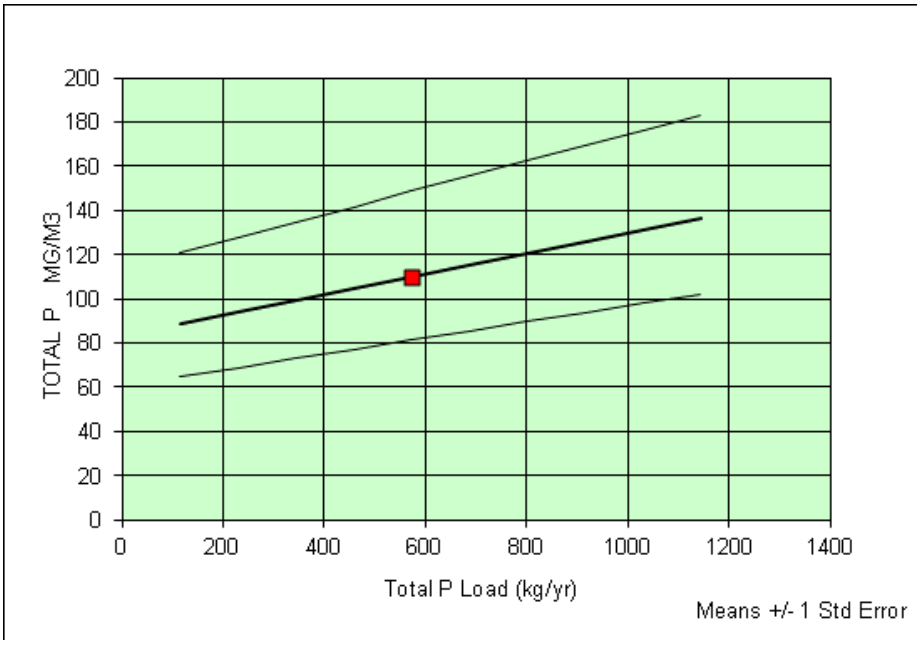
As with MINLEAP, BATHTUB (using three different P sedimentation models) underestimated in-lake TP (Table 14). Of the three, the 1st order decay showed the closest correspondence. In all cases, predicted Chl-*a* was much greater than observed, which further reinforces how low observed Chl-*a* is relative to in-

lake TP. Some very basic sensitivity analysis was conducted to determine the relative response of in-lake P to increased watershed loading and calibration of the sedimentation coefficient. Increasing the P loading from the "feedlot" component (i.e., animal unit loading) from the original estimate up to a value four times higher had a nominal affect on in-lake P (Figure 27); however, even with this large increase, in-lake P remained well below the 228 µg/L observed value. Next, the sedimentation coefficient was calibrated to allow predicted P to equal observed P and a calibration of 0.05 was needed to match observed. This implies that the sedimentation coefficient would need to be 95% lower than what would typically be expected for a lake of this size and depth. These results indicate that for the purposes of a TMDL or developing watershed restoration strategies, there is a need to more accurately measure loads from the watershed (including animal-generated P) and to improve our understanding of the role of wind resuspension, internal recycling and sedimentation efficiency in Artichoke before reliable model results can be obtained and an appropriate strategy is developed.

Table 14. Artichoke Lake comparison of observed and model-predicted values.

Lake	P sed. model	1st order	2nd order	Canfield-gen.	MINLEAP
Artichoke	**Observed**	**Predicted**			
TP µg/L	294	110	59	64	159
Chl-a µg/L	21	88	40	44	108

Figure 27. Artichoke Lake response to change in feedlot P loading; P load varied from 0.2 to 2.0.



303(d) Assessment and Goal Setting

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

Under Section 303(d) of the Clean Water Act, the state is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e., impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion. In addition, either the Chl-*a* concentration for the lake must exceed the standard or the Secchi data for the lake must be below the standard (Table 15). A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a water body is listed, an investigative TMDL study must be conducted to determine the sources and extent of pollution, and to establish pollutant reduction goals needed to restore the resource to meet the determined water quality standards for its ecoregion. In Minnesota, the MPCA is responsible for performing assessment activities, listing impaired waters, and ensuring that TMDL studies are carried out.

Artichoke Lake is highly eutrophic and is likely to be deemed impaired. Observed TP is much higher than NGP ecoregion reference lakes while, Chl-a is lower than predicted. Artichoke Lake is shallow, has a significant fetch, minimal rooted vegetation, and is very subject to wind mixing. This results in excessive physical resuspension of sediment and internal recycling; however, it is also possible that watershed loads are much higher than predicted by the modeling given the large number of animal units in the watershed and significant shoreline erosion. This can be explored in more detail in the development of a restoration plan for Artichoke Lake and its watershed. Artichoke Lake and associated data need to be looked at in more detail when restoration plans are developed. Continued data collection through the Sentinel lakes program on Artichoke Lake is useful in this regard.

Table 15. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). Artichoke Lake 2008 and 2009.

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
Artichoke Lake 2008	**228**	**31.3**	**0.7**
Artichoke Lake 2009	**225**	**17.8**	**1.4**

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Appendix A

Lake Surface Water Quality Data for Artichoke Lake for 2008, 2009, 2010, and 2010.

All water quality data can be accessed at: http://www.pca.state.mn.us/water/clmp/lkwqReadFull.cfm?lakeid=06-0002

Lake Name	Site ID	Sample Date	Alkalinity	Apparent color	Chl-*a*	Secchi	TP	Orthophosphate	Nitrate and Nitrite	TKN	TSS
			mg/L	PCU	µg/L	Meters	µg/L	µg/L	mg/L	mg/L	mg/L
Artichoke	101	05/07/2008	310	20	24.8	0.75	281			2.06	10
Artichoke	102	05/07/2008	310	20	27.2	0.75	146			2.01	8.4
Artichoke	101	06/04/2008			5.55	1	210		0.11	1.93	
Artichoke	102	06/04/2008			5.79	0.9	176				
Artichoke	101	07/30/2008	310	5	18.1	0.6	210			2.5	9.2
Artichoke	102	07/30/2008			40.6	0.7	328				
Artichoke	101	08/13/2008			50	0.6	302			2.02	
Artichoke	102	08/13/2008				0.5	227				
Artichoke	101	09/15/2008			11.9	0.9	265			1.92	
Artichoke	102	09/15/2008			42.5	0.4					
Artichoke	101	10/06/2008	280	20	39.2	0.8	236			2.03	28
Artichoke	102	10/06/2008			59.8	0.6	291				
Artichoke	101	05/27/2009	300	5	2.5	2.5	222	0	0.08	2.19	4.4
Artichoke	102	05/27/2009			2.04	1.9	82				
Artichoke	101	06/15/2009			4.58	1.2	141		0.07	2.17	
Artichoke	102	06/15/2009			5.16	1	151				
Artichoke	101	07/21/2009	310	20	4.75	0.7	193	93	0.11	2.19	12
Artichoke	102	07/21/2009			36	0.3	316				
Artichoke	101	08/26/2009			22.2	0.6	313		0.11	2.26	
Artichoke	102	08/26/2009			26.2	0.6	153				
Artichoke	101	09/16/2009			5.64	2.3	200			1.98	
Artichoke	102	09/16/2009			47.2	0.7	142				
Artichoke	101	10/12/2009	290	20	19.5	2.1	206	0		1.93	4.4

Artichoke	102	10/12/2009			37.4	2.1	277				
Artichoke	101	04/29/2010	290	20	1.92	0.9	311	0	0.05	1.68	8.8
Artichoke	102	04/29/2010			1.62	0.9	217				
Artichoke	101	07/21/2010	290	20	112	0.7	303	0	0.05	2.93	9.6
Artichoke	102	07/21/2010			95.1	0.9	307				
Artichoke	101	10/04/2010	300	20	35.8	0.6	307	0	0.05	1.69	14
Artichoke	102	10/04/2010			45.3	0.4	259				
Artichoke	101	04/19/2011	290	30	89.4	0.8	201	0	0.25	3.57	10
Artichoke	102	04/19/2011			75.7	1	163				
Artichoke	101	08/04/2011				2.3	116				
Artichoke	102	08/04/2011	260	20	18.55	0.5	223	0	0.05	1.96	2.8
Artichoke	101	10/26/2011	300	20	2.76	1.9	176	0	0.22	1.99	4
Artichoke	102	10/26/2011			23.5	1.5	302				

Appendix B

BATHTUB Model Inputs

Global Variables	Mean	CV		Model Options	Code	Description
Averaging Period (yrs)	1	0.0		Conservative Substance	0	NOT COMPUTED
Precipitation (m)	0.7	0.0		Phosphorus Balance	6	FIRST ORDER
Evaporation (m)	0.81	0.0		Nitrogen Balance	0	NOT COMPUTED
Storage Increase (m)	0	0.0		Chlorophyll-a	2	P, LIGHT, T
				Secchi Depth	1	VS. CHLA & TURBIDITY
Atmos. Loads (kg/km^2-yr)	**Mean**	**CV**		Dispersion	0	NONE
Conserv. Substance	0	0.00		Phosphorus Calibration	1	DECAY RATES
Total P	30	0.50		Nitrogen Calibration	1	DECAY RATES
Total N	1000	0.50		Error Analysis	1	MODEL & DATA
Ortho P	15	0.50		Availability Factors	0	IGNORE
Inorganic N	500	0.50		Mass-Balance Tables	1	USE ESTIMATED CONCS
				Output Destination	2	EXCEL WORKSHEET

Segment Morphometry											
			Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth	
Seg	Name		Segment	Group	km^2	m	km	Mean	CV	Mean	CV
1	Artichoke		2	1	8.5	1.8	5.48	1.8	0.12	3.7	0

Segment Observed Water Quality										
	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	5	0.1	248	0.35	2100	0.2	23.5	0.51	0.8	0.49
Segment Calibration Factors										
	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0

Tributary Data											
					Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)	
Trib	Trib Name		Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV
1	Artichoke Wshed		1	2	77.3	0	0	0	0	0	0

Tributary Non-Point Source Drainage Areas (km^2)							
			Land Use Category--->				
Trib	Trib Name		1	2	3	4	5
1	Artichoke Wshed		53.8	2.9	4	0.8	15.7
2	Artichoke feedlots		0	0	0	0	0

Non-Point Source Export Coefficients								
			Runoff (m/yr)		Conserv. Subs.		Total P (ppb)	
Categ	Land Use Name		Mean	CV	Mean	CV	Mean	CV
1	cultivated		0.1	0	0	0	200	0.25
2	pasture_grass		0.1	0	0	0	150	0
3	urban_developed		0.1	0	0	0	250	0
4	forest		0.1	0	0	0	30	0
5	wetland_water		0.05	0	0	0	30	0