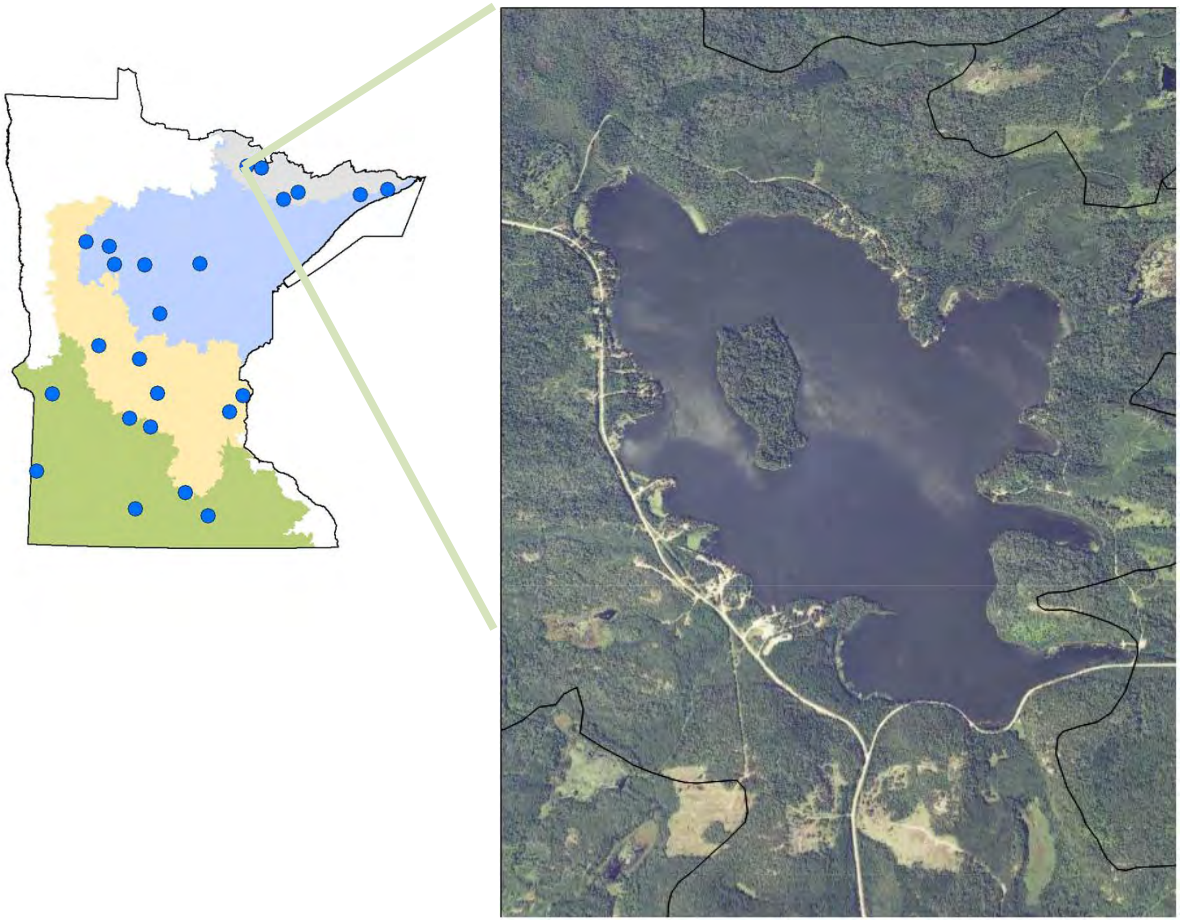
Sentinel Lake Assessment Report
Elephant Lake (69-0810)
Saint Louis County, Minnesota



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

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Minnesota Pollution Control Agency

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DEPARTMENT OF NATURAL RESOURCES

Minnesota Pollution Control Agency
520 Lafayette Road North
Saint Paul, MN 55155-4194
http://www.pca.state.mn.us
651-296-6300 or 800-657-3864 toll free
TTY 651-282-5332 or 800-657-3864 toll free
Available in alternative formats

Contributing Authors

Steve Heiskary & Jesse Anderson, MPCA
Ray Valley & Kevin Peterson, MDNR

Review & Editing

Lee Engel MPCA
Peter Jacobson MDNR

Sampling

Jesse Anderson, MPCA
Brent Flatten, Jacob Garcia, Superior National Forest
Tom Burri, Jeff Eibler, Kevin Peterson, and Kim Strand, MDNR
Peter Brown, CLMP volunteer

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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. "Shallow" lakes typically remain well mixed 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 Environment and Natural Resources Trust Fund (ENTF). "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is funded by the ENTF.

Elephant Lake is located in Saint Louis County within the Vermilion River watershed, part of the Rainy River basin. Elephant Lake is located northeast of Orr, MN, within the Kabetogama State Forest. The watershed is dominated by forested and wetland land use. There is some development and a limited road network along the shore of the lake, primarily on the west and north sides. It is a moderate-size lake at 300 ha (742 acres) with a maximum and mean depth of 9.1 m (30 ft) and 4.5 m (15 ft), respectively. With a fetch of almost 3 km (1.9 miles), the lake is subject to wind mixing.

Elephant Lake supports a relatively simple fish community composed of cool- and warm-water species. Walleye were introduced in 1932 through multiple initial stockings and established a self-sustaining (yet variable) population. The lake has not been stocked with walleye since 1996. Elephant Lake supports a relatively small northern pike population. Northern pike size has increased since experimental regulations were implemented in 2003 to protect large individuals. Warm water species such as black crappie, bluegill, and smallmouth bass have increased appreciably during recent decades and black crappie and smallmouth bass support viable sport fisheries. Current trends of increasing warm water species conform to expectations of outcomes of climate warming.

Since, most of Elephant Lake's watershed and shoreline is under public ownership and is forested; there is little direct threat to habitats through landscape and shoreline alteration. The greatest concern for continued viability of Elephant Lake's habitats and biologic communities are current and future non-native species invasions and continued climate warming. Rusty crayfish have been in the lake since at least 1991; however, their impact on aquatic plant communities is presumed to be low since the lake has abundant and diverse aquatic plants. Nevertheless, invasive species and climate change have the potential to alter Elephant Lake habitats and measures should be taken to prevent the introduction of non-native species. In addition, to continued vigilance of the protection of Elephant Lake's watershed and shoreline, Fisheries management that maintains a balance of predator and prey communities will go a long way in enhancing the resilience of Elephant Lake to unforeseen future changes.

Elephant Lake was sampled by MPCA staff from May through October of 2008 and 2009 and then on three occasions in 2010. Since there was minimal, previous data this will be the primary data used to characterize the lake. Epilimnetic dissolved oxygen (DO) concentrations exceeded five milligrams per liter throughout both years, a concentration needed to sustain a productive cool and warm water fishery. The lake remained well mixed until July when thermal stratification is evident. Once the lake is thermally stratified a distinct hypolimnion is formed and DO is rapidly depleted in the lower layer. Stratification is

somewhat ephemeral and will break up with a strong wind or cold front. Previous observations by MDNR fishery staff indicate the lake may not stratify every summer.

Total phosphorus (TP) concentrations did not change significantly between years, averaging 22 micrograms per liter (µg/L). Seasonal patterns in TP were somewhat variable among the three years and are related, in part, to periodic stratification and mixing that occurs over the summer season. When the lake is stratified bottom water TP increases because of internal P recycling. When the lake mixes this source of P is mixed with the surface waters and increases surface water concentrations. Algal biomass, as measured by chlorophyll-a (Chl-a), responds to changes in TP and small increases are noted, consistent with increased TP. Secchi transparency changes in direct response to changes in Chl-a. All three trophic state indicator summer-means: TP, Chl-a, and Secchi are well within the typical range for minimally impacted lakes in the NLF ecoregion.

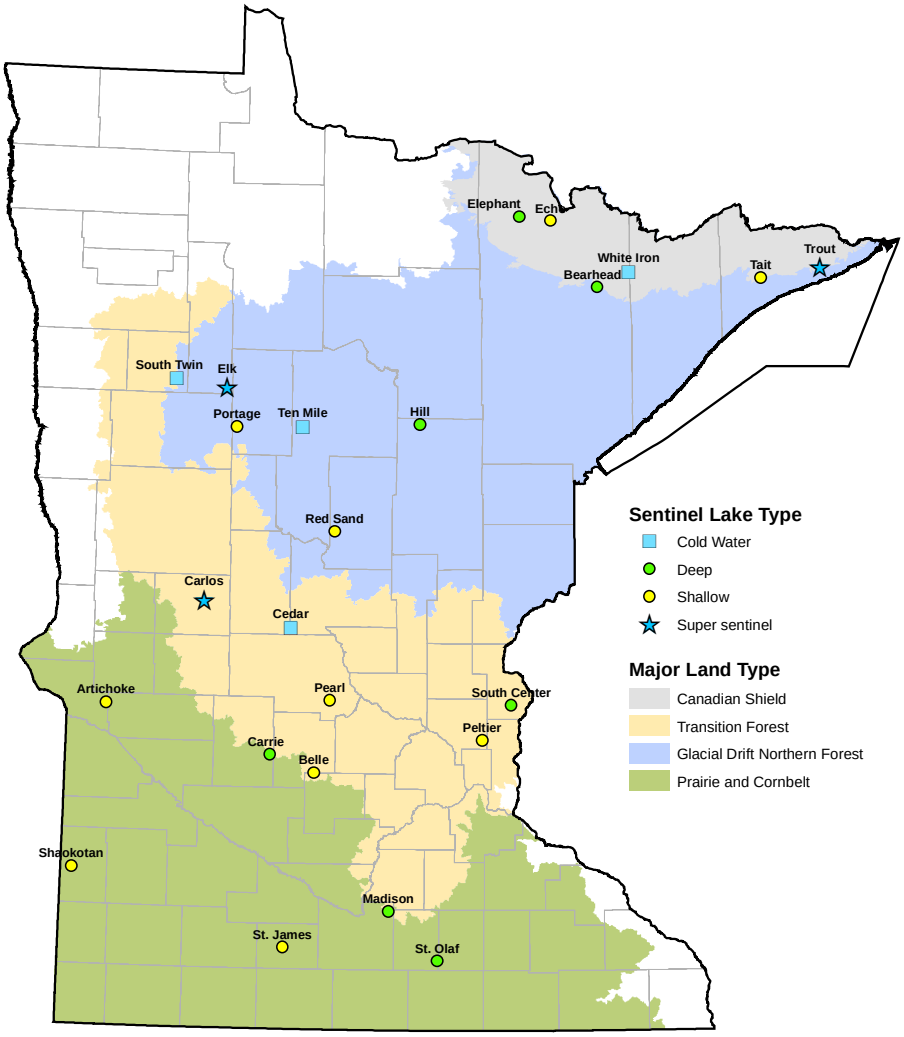
Elephant has a slight bog stain originating from incompletely dissolved organic matter from forest and wetland runoff. At high concentrations, "bog stain" may limit transparency; however at the modest concentrations observed in Elephant, its impact is minimal and transparency is highly correlated with algal productivity. The low alkalinity and ion concentrations indicate Elephant has very soft water. This is a function of the thin soils, exposed bedrock, and minimal amounts of carbonate in the soils and parent material. Collectively, these data indicate that Elephant has good water quality that is typical for a lake in this region of the state.

Various algal forms were evident from spring through fall; however, blue green algae were dominant in late summer in 2008 and 2009, which is common in mesotrophic lakes. Chlorophyll-a concentrations were low and nuisance levels of blue greens were not observed. Zooplankton density was highest in the spring, and slowly declined throughout the season. Zooplankton density and biomass in Elephant is near the level anticipated, based on its nutrient levels and the region where it is located. As zooplankton decline algae (Chl-a) often increases, and zooplankton may account for some of the observed seasonal trends in algal biomass and composition.

Two empirical water quality models, BATHTUB and MINLEAP, were run on Elephant Lake using data from 2008-2009, lake morphometry, and watershed information. MINLEAP predicts a TP loading rate of about 224 kilograms (kg) per year entering Elephant Lake from its small, forested watershed. The model predicts approximately 66 percent of the TP is retained in the lake, a reasonable estimate given the lake's small watershed, volume, and relatively long residence time (estimated at ~ 3-4 years). The BATHTUB model provides a further basis for estimating water and nutrient budgets for Elephant Lake using a combination of runoff and TP export coefficients based on land use in the watershed. The only human-induced loadings to account for were estimates of the P that may seep from on-site systems to the lake. This was estimated based on the number of cabins/homes around the lake, standard per-capita loading values (assumed seasonal usage), and on-site system and soil retention of 80 percent of the load that enters the systems. Based on model inputs relative contributions from the three source categories were as follows: watershed runoff ~ 55 percent, precipitation on the lake ~ 42 percent and on-site septic systems ~3 percent. It is important to note these are only estimates and are based on available data. These relative contributions seem realistic for a lake of this size, with a relatively small, forested watershed and very limited development.

Elephant Lake meets water quality standards for waters that support a cool and warm water fishery in Minnesota's Northern Lakes and Forests Ecoregion. In summary, water quality in Elephant is very good and relatively stable, which is reflective of the lake's setting and small forested watershed.

Figure 1 MDNR map of Sentinel lakes and major land types. “Deep” lakes stratify during the summer. “Shallow” lakes are defined here as those that mix continuously throughout the summer. “Cold Water” lakes are those 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 funded by the ENTF.



Introduction

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

Background

Lake morphometric and watershed characteristics

Elephant Lake is located in Saint Louis County within the Vermillion River watershed (Figure 2), part of the Rainy River basin. Elephant Lake is located northeast of Orr, MN. The majority of the watershed is within state, county, and federal forests.

Elephant Lake's morphometric characteristics are summarized in Table 1. Elephant is a moderate-sized lake covering 300 hectares (742 acres). The lake has a mean depth of ~4.5 meters (15 feet), a maximum depth of 9.1 meters (30 feet), and ~45 percent of the lake is considered littoral (portion 15 feet or less in depth). Lakes with a high percentage of littoral area and non-rocky substrates often have extensive rooted plant (macrophyte) beds and that appears to be the case in Elephant, which has extensive beds of native rooted plants.

Elephant has moderate depth with a deep spot of ~9 m in its southern basin, while much of the northwestern basin is less than 4.5 m deep (Figure 2). The lake often stratifies by mid-summer; however, with a fetch of almost 3 km it is subject to mixing under sustained windy periods. It has four small surface inlets and outlets via Elephant Creek to Bug Creek and the Vermillion River (Figure 4). Located within the Kabetogama State Forest, the lake is surrounded by primarily forested land interspersed with some smaller lakes and wetlands. A 2009 aerial image demonstrates the predominance of forested land use (Figure 4). Most of the developed portions of the lake are found on the west and north sides. A very limited road network is evident as well.

Elephant Lake has a relatively small lake to watershed ratio (5:1) and highly forested watershed that is typical for a northern Minnesota lake. Water residence time is estimated at 3-4 years, reflective of the lake's moderate depth and relatively small watershed.

Table 1 Elephant Lake and watershed morphometric characteristics

Lake Name	Lake ID	Lake Basin hectares (acres)	Littoral Area (percent)	Total Watershed Area hectares (acres)	Total Watershed: Lake	Max. Depth meters (feet)	Mean Depth meters (feet)	Lake Volume acre-ft
Elephant	69-0810	300 (742)	45	1,496 (3,695)	5:1	9.1 (30)	~4.5 (~15)	~11,130

Lake bathymetry based on original surveys in 1960

Figure 2 Elephant Lake bathymeric map. Primary sampling site in east bay over point of maximum depth.

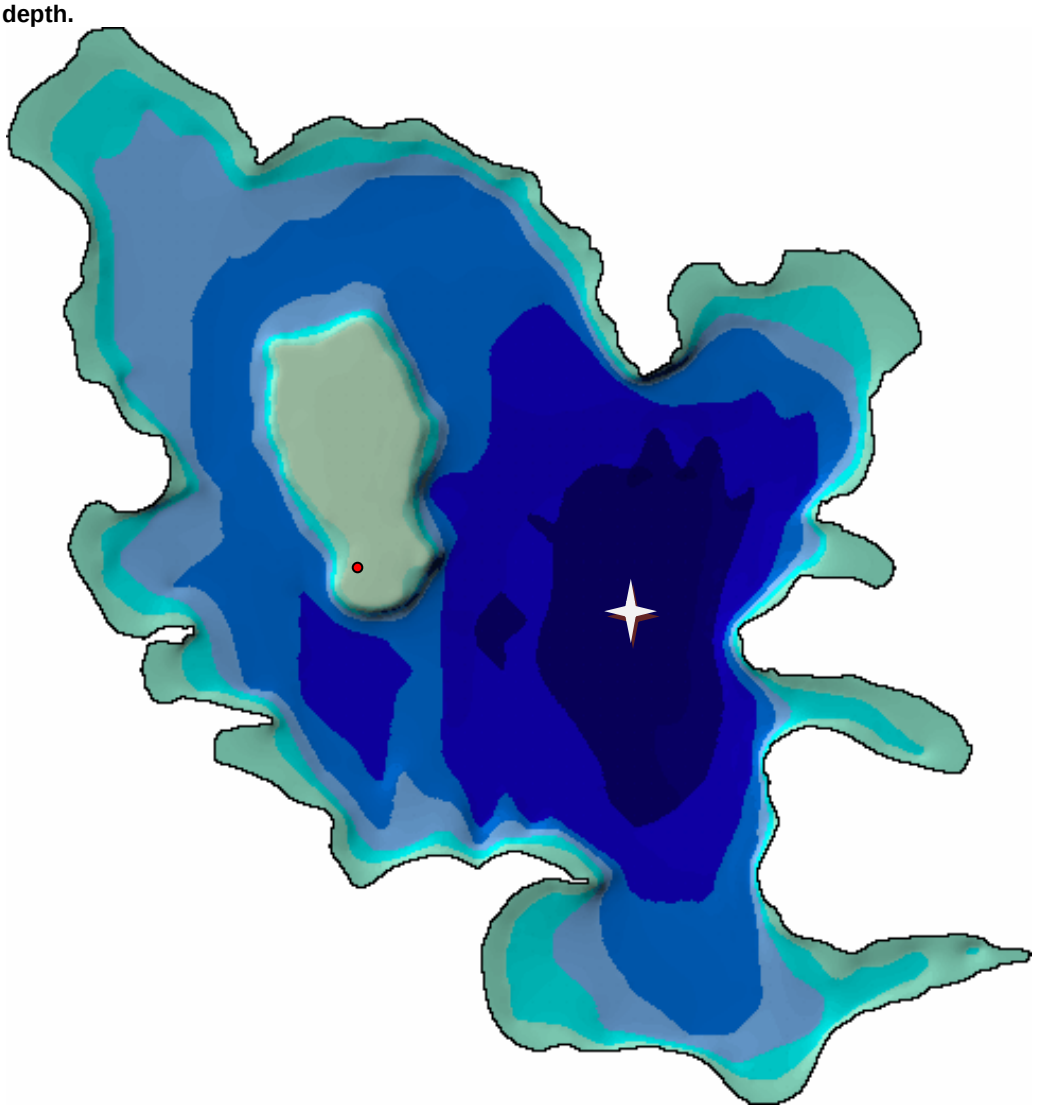
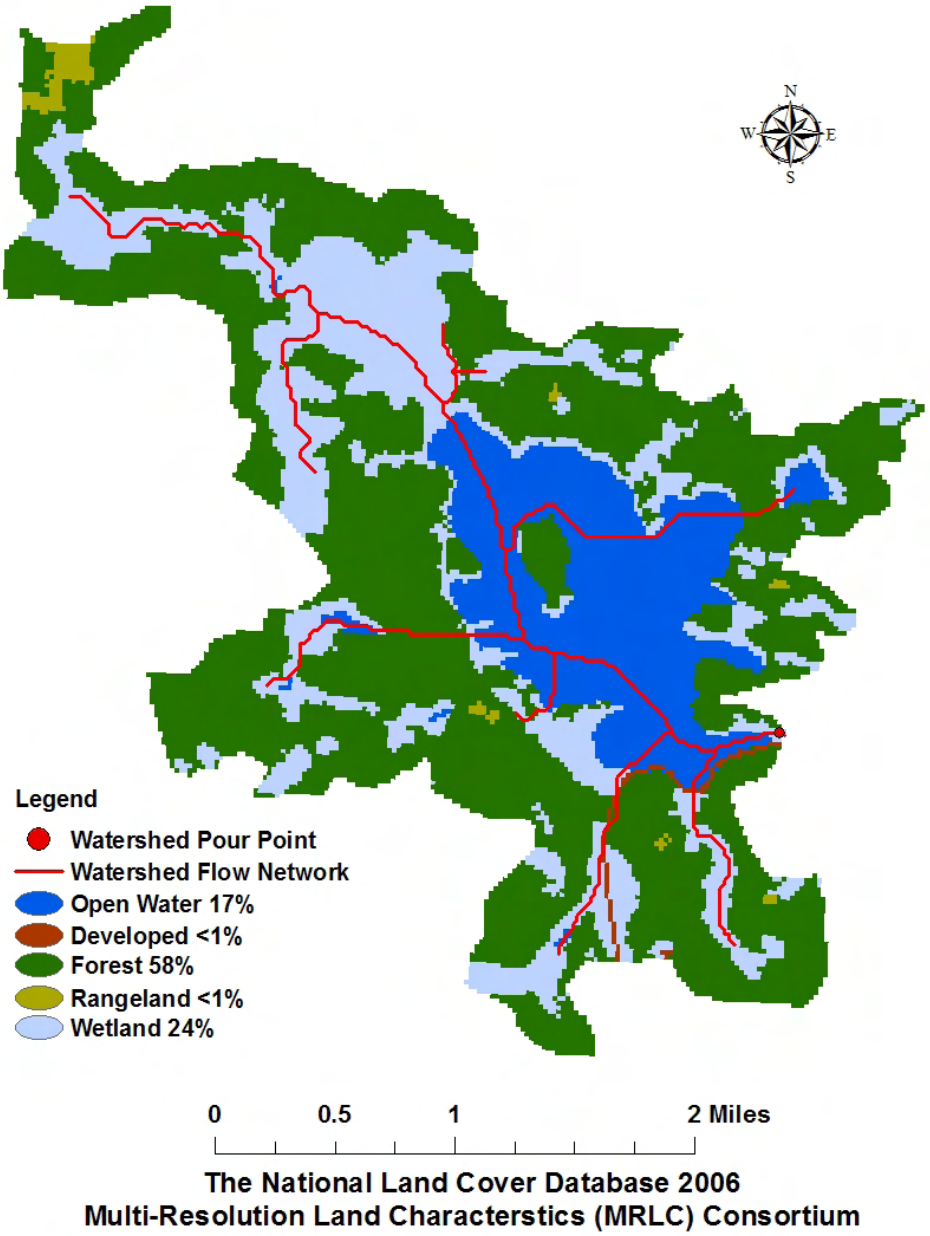
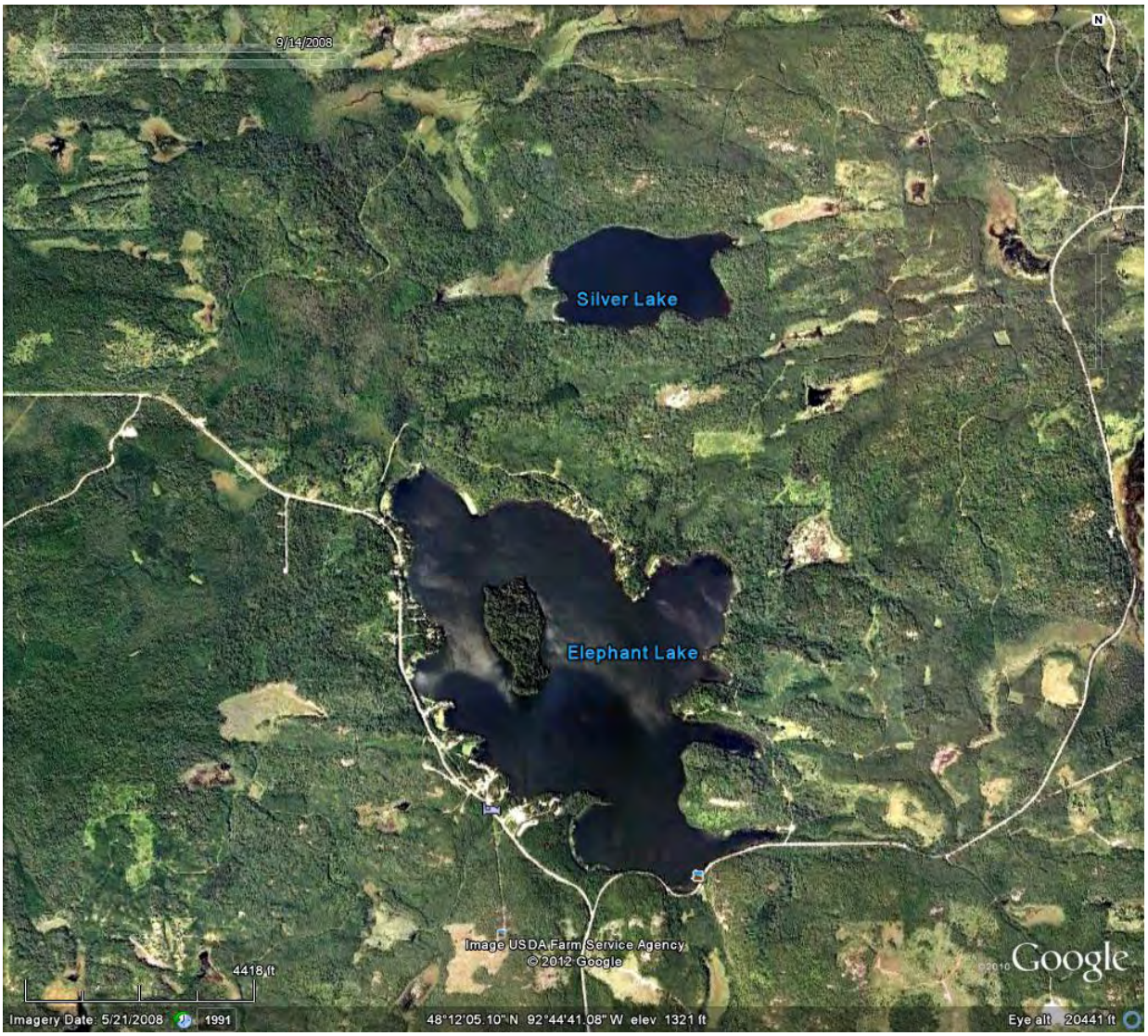


Figure 3 Elephant Lake watershed and landuse composition. Map land use percentages include lake.



Land use	Elephant Lake watershed land use percentage	NLF typical land use percentage
Developed	<1	0 – 7
Cultivated (Ag)	0	<1
Pasture & Open	<1	0 – 6
Forest	74	54 – 87
Water & Wetland	24	14 – 31

Figure 4 Aerial image of Elephant Lake based on September 14, 2008 photo. Lake outlets through southeast bay.

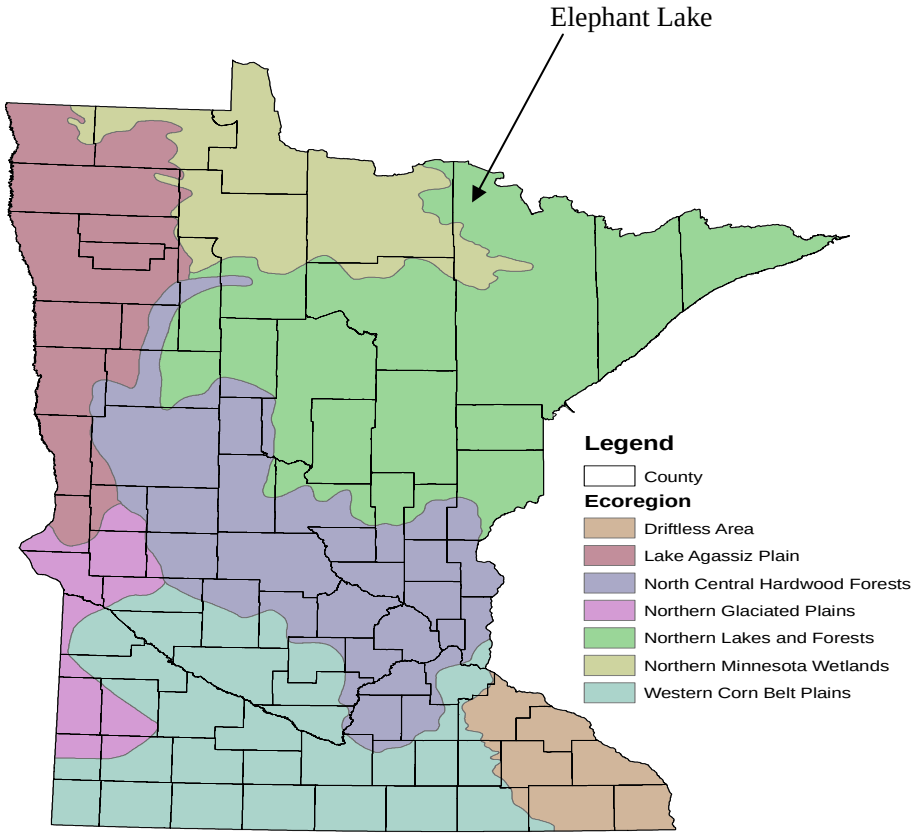


Ecoregion and land use characteristics

Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, potential natural vegetation, and land use (Omernik 1987). 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. Elephant Lake lies within the Northern Lakes and Forest (NLF; Figure 5) ecoregion. NLF values will be used for land use (Table 2) and summer-mean water quality comparisons. Additionally, the NLF ecoregion will be used for model applications. Omernik level III and IV ecoregions provided a basis for the "land type" delineations noted in Figure 1. This step was taken prior to selection of the Sentinel lakes and provided a means to characterize geomorphologic differences in lake condition. In the NLF ecoregion, this allowed for differentiation between the "Canadian Shield" lakes and "Glacial Drift Northern Forest" lakes.

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Land use within the Elephant Lake watershed is nearly all forest and open water.

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



History

There are minimal historical records for Elephant Lake in MDNR and MPCA files. Information from those files is summarized below. There are likely additional records available at county offices. The web site for the "Melgeorge Resort" does have some useful background information and a few notes from that web site are included here.

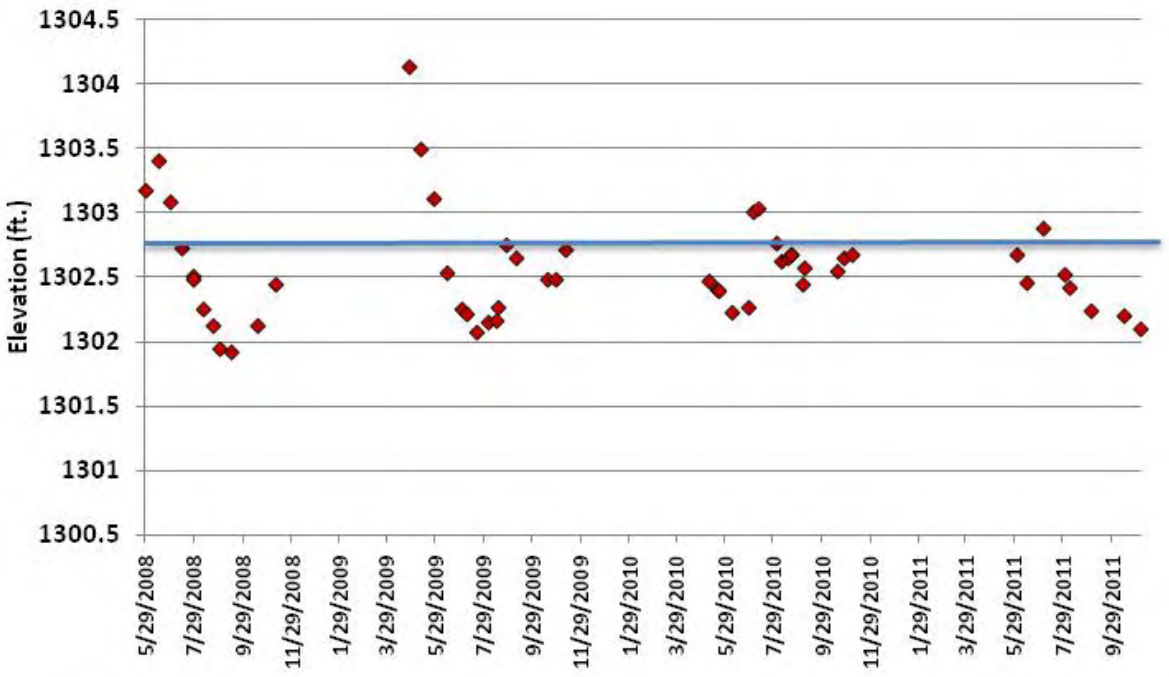
1932-1962 The earliest fisheries investigation on record for Elephant Lake in 1957. The author, H.R. Hanson, noted Elephant Lake was "Originally a northern pike and yellow perch lake – walleye were introduced in about 1932…" The initial introduction was followed by four periods of fingerling stocking from 1955 to 1961. By the first fisheries assessment in 1962, walleye were the dominant predator in the lake.

~1935 - present	Melgeorge Resort became established in the former logged-off wilderness area. The resort has undergone various changes and upgrades and is now comprised of ~13 cabins and a lodge.
1962	MDNR fisheries staff note 18 homes on the lake in a survey report.
1991	Invasive rusty crayfish *Orconectes rusticus* first documented in Fisheries trapnets
1993-1995	Secchi monitoring through CLMP initiated
2001	MDNR staff note 32 homes on the lake in a survey report.
2003	40-in minimum size limit on northern pike implemented as part of a statewide initiative to improve or maintain the size northern pike in Minnesota lakes. Regulation is due to expire on March 1, 2013.

Lake level

Elephant Lake has a rather short water level record with a single measure in 2002 and 53 records total. The MDNR Division of Waters initiated lake level monitoring on Elephant in 2008 as a part of the Sentinel Lakes program. The highest elevation of record is 1304.14 (April 26, 2009) and lowest of record is 1301.92 (September 15, 2008) for a total range of 2.22 feet. The Ordinary High Water level (OHW) is established at 1302.7. Based on this brief record, the OHW was exceeded in each of the years from 2008-2011(Figure 6). A distinct seasonal cycle in elevation is evident each year with high levels in the spring because of snowmelt and spring runoff, followed by declining levels as runoff from the watershed declines and evaporative losses increase. Late summer rain events in 2009 (Figure 8) served to increase lake levels.

Figure 6 Elephant Lake level elevations in 2008 and 2011. MDNR data.



Precipitation and climate summary

Climate and precipitation records for the 2008-2009 field seasons varied considerably. Rain gage records from Orr (a long-term climate station immediately southwest of Elephant Lake) show two 2.5 centimeter (cm; 1inch) plus rain events during the 2008 field season and four during 2009 (Figure 7, Figure 8). Large rain events will increase runoff into the lake and may influence in-lake water quality and lake levels. Precipitation records for the 2008 water year (October 2007 through September 2008) showed conditions were wetter than average near Elephant Lake (Figure 9). Precipitation for the 2009 and 2010 water years were near and slightly below normal, respectively. Ice in and out records for Elephant lake have also been monitored on Elephant lake since 2008 (Table 2). 2010 was a historic year for early ice out, and lakes in northeast Minnesota opened up 28 days earlier than the median ice-out date of April 30th (http://climate.umn.edu/lake_ice/).

Table 2 Elephant Lake ice-in and ice-out 2008-2011

Year	Ice In	Ice Out	Days of Ice Cover
2008	NA	5/6/2008	NA
2009	11/21/2008	4/26/2009	156
2010	12/5/2009	4/2/2010	118
2011	11/20/2010	4/24/2011	155

Figure 7 2008 monitoring season rainfall based on records for Orr, MN. State Climatology Office Data

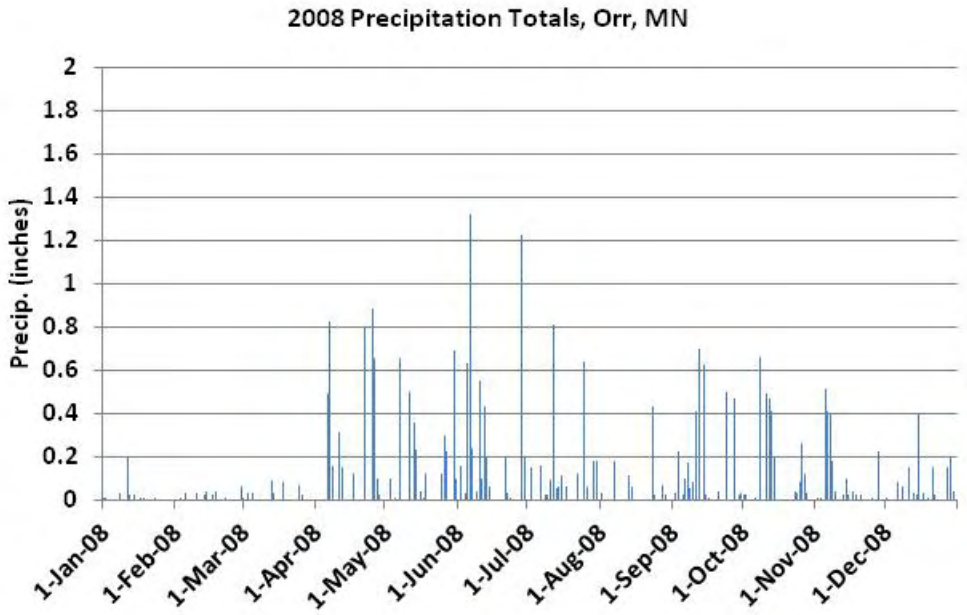


Figure 8 2009 monitoring season rainfall based on records for Orr, MN. State Climatology Office Data

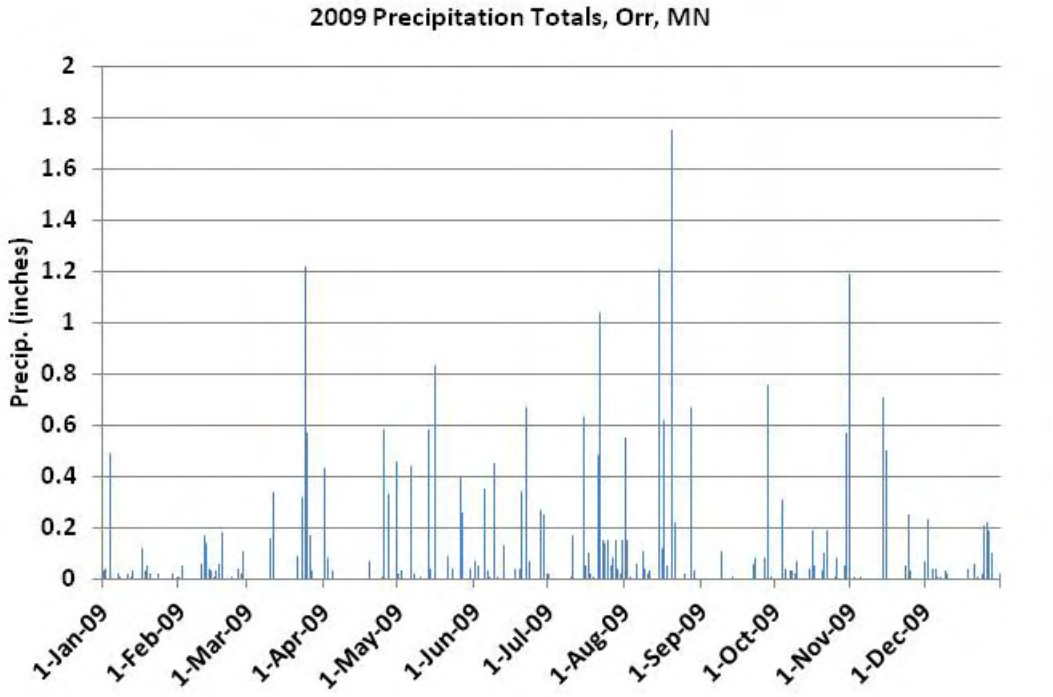
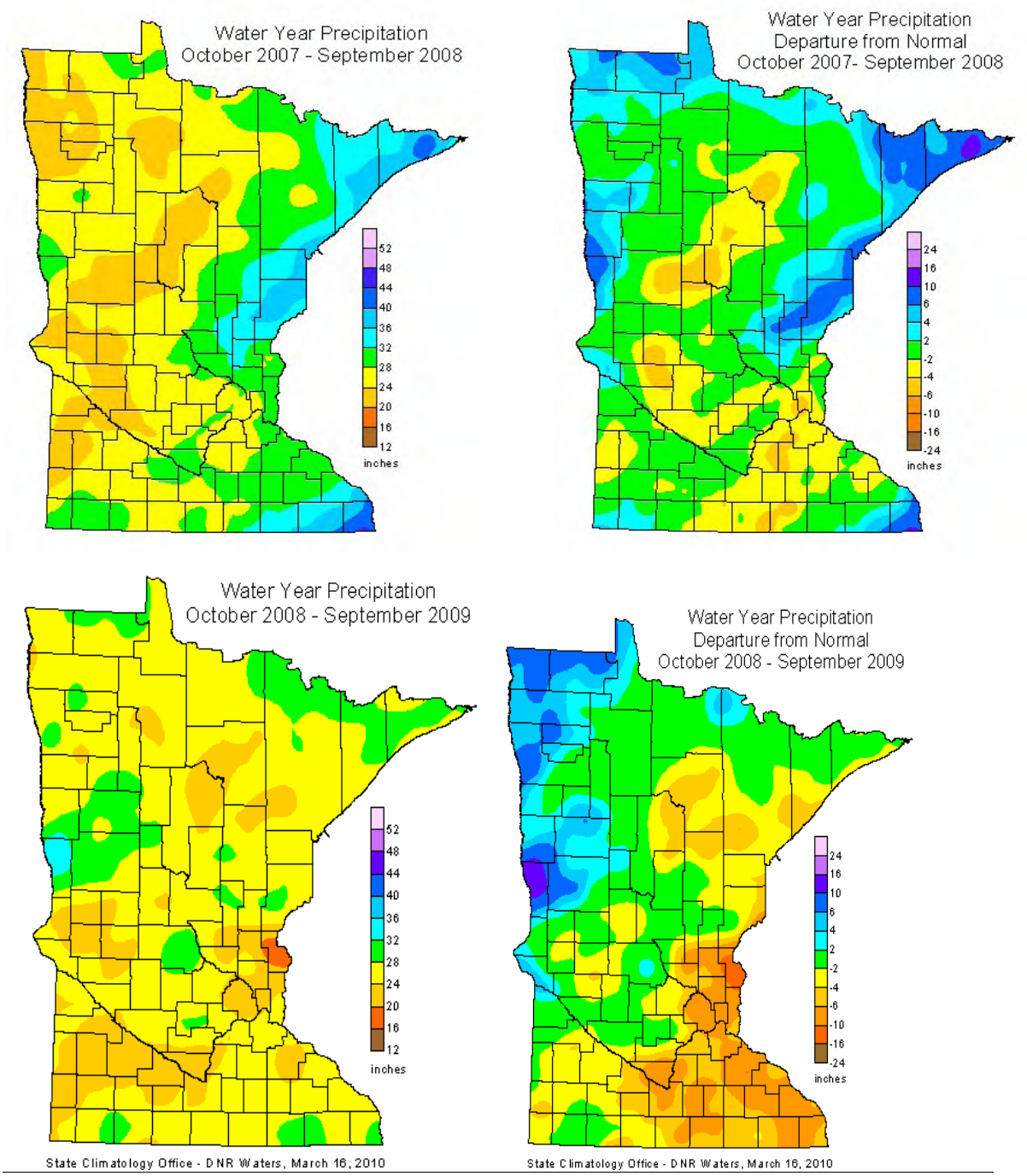


Figure 9 2008-2009 Minnesota water year precipitation and departure from normal (State Climatology Office data)



Methods

Fisheries and aquatic plants

Frequency of occurrence of aquatic plant species was 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 meter (m), then retrieving the rake and identifying all species present, and recording the depth. Survey points were spaced approximately 80-m (0.7 points per littoral acre).

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

Water quality

In 2008-2010 water quality data on Elephant Lake were collected by the MPCA. Staff sampled Elephant monthly from May through October in 2008-2009 and 'seasonally' – May, July, and October - in 2010. Samples were collected at the lake's maximum depth, in the southeast portion of the lake (MPCA site # 202). MPCA lake surface samples were collected with an integrated sampler, a poly vinyl chloride (PVC) tube 2 meters (6.6 feet) in length, with an inside diameter of 3.2 cm (1.24 inches). Zooplankton samples were collected with an 80 micron (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. Secchi measurements were also collected through the Citizens Lake-Monitoring Program. Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: http://www.pca.state.mn.us/publications/wq-s1-16.pdf .

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

Zooplankton

Zooplankton samples were collected monthly from ice-out (May) through October 2008-2010. Two replicate vertical tows were taken at each sampling event. The net was lowered to within 0.5 m 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 micron (µm) 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

DNR 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 provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). This data is stored in a long-term fisheries survey database, which has proven valuable in qualifying and quantifying changes in environmental and fisheries characteristics over time.

Fish Community Status and Trends
Elephant Lake supports a relatively simple fish community. The food-web is composed of a cool- and warm-water species such as walleye, northern pike, yellow perch, and white sucker (Table 3). Like many other Minnesota lakes, populations of all major species in Elephant Lake have fluctuated over time (Figure 10). Still, warm-water species such as black crappie, bluegill, and smallmouth bass have increased appreciably in recent decades. This mirrors statewide trends in these species and conforms to expectations of the outcomes of climate warming (Schneider 2010; MN DNR 2011).

Angler Effort and Harvest
When angling success is good on Elephant or, neighboring, Blackduck Lake, these lakes attract considerable fishing effort from communities located on Minnesota's Iron Range, approximately 50-60 miles south. Over-exploitation has been identified in the past, as a potential threat to the quality of the fishery and may be currently limiting recruitment of older walleye year classes in the lake.

Elephant Lake was included in a multi lake roving creel survey in 1993 and 1994. Angling pressure was estimated at 24.4 and 13.4 angler-hours per acre, respectively, during the open water-angling seasons. Forty-four percent of the anglers interviewed were non-residents. The remaining anglers were from Minnesota but lived more than 40 miles away from Elephant Lake. A significant number of anglers (35 percent) were not targeting any particular species. Those who expressed a preference were fishing for black crappie, walleye, and smallmouth bass (in order of preference). The harvest was comprised of black crappie, yellow perch, walleye, bluegill, and smallmouth bass. Black crappie dominated the angler's harvest in both numbers and pounds. Smallmouth bass provided the highest angling catch rate of any species, but 96 percent of those caught were released. Anglers tended to release very few of the black crappie or walleye they caught.

Individual species assessments

Walleye – Historical stocking has led to a self-sustaining walleye population in Elephant Lake and a past fisheries analysis demonstrated that more 'recent' stocking did little to contribute to walleye population status (2011 Elephant Lake Fisheries Management Plan). Consequently, stocking has not occurred in the lake since 1996 (Table 4).

Walleye catches since 1962 have been highly **variable** (Figure 10). Low catches occurred in 1974, 1984-86 and 1993. High gill net catches exceeding the Class 5 third quartile level of 9.7 per gill net occurred in eight of the fifteen years surveyed. This 'boom and bust' cycle appears to have frustrated fisheries managers and anglers in the past. Correspondence in Area Office files indicates dissatisfaction with Elephant Lake walleye fishing at times.

Still, concerns about poor walleye recruitment and high abundance of yellow perch were first recorded in the 1980 fish population assessment. A fish removal project targeting yellow perch was completed in 1983 and 1984 to "create a balanced predator-prey structure." A total of 11,077 pounds of yellow perch and 4,484 pounds of white sucker were removed from Elephant Lake. Yellow perch abundance declined temporarily, but rebounded by 1993. The 1988 lake survey report stated, "over-abundance of yellow perch from 1977 through 1986 appeared to be affecting walleye recruitment." In the recent decade,

yellow perch and white sucker have declined to levels more typical of other Lake Class 7 lakes (Figure 10).

Walleye abundance was high during the 2006 investigation and average size was large. The gill-net CPUE of 18.2/net exceeded the third quartile level (9.8/net) for Class 5 lakes and was the fourth highest catch on record. Walleye lengths ranged from 8.3 to 28.5 inches with a mean of 16.0 inches. The mean weight was 1.5 pounds. High abundance was supported primarily by one year-class, 2002. Age-4 walleye made up 65 percent of the catch. Eight other year-classes were present in the catch. Growth to age-4 exceeded the Area mean. Analysis of year-class abundance indicated that 12 of the last 33 cohorts were strong.

Similar to patterns observed in the past, walleye abundance declined to 6.1 per gill net in 2009. While still above the median level of 5.0, this represents a 66 percent decline in just three years. Only six year-classes were present in the sample, compared to twelve in the previous assessment. Total length ranged from 8.8 to 23.1 inches and the mean length was 14.2 inches. Mean total length at age-4 was 14.8 inches, similar to the International Falls Area average of 14.7 inches.

Northern pike - With but two exceptions, northern pike abundance has generally been below the median level of 3.2 per gill net (Figure 10). The initial survey (1962) reported a very low density of northern pike (0.5/net). Catch rates were high in 1983 and 1984 due to the presence of a very high number of small fish in the nets. By 1986, northern pike abundance returned to previous levels.

In 2006 northern pike abundance was relatively high again at 3.0 per gill net, approaching the median for Class 5 lakes. Lengths ranged from 17.0 to 33.2 inches with a mean of 25.7 inches. The mean weight, 4.21 pounds exceeded the third quartile level of 3.7 pounds. Growth rates to age-4 ranked at the 90th percentile for International Falls Area lakes.

The 2009 investigation found northern pike abundance was 1.3 per gill net, which was below the first quartile level of 1.8 per net. Six year-classes were present and age ranged from three to nine years. Total length in gill nets ranged from 18.4 to 31.3 inches. Mean total length at age-4 was nearly 2 inches greater than the Area mean, indicating fast growth. The mean weight was 4.6 pounds, again exceeding the third quartile level of 3.7 pounds.

Ice-out trap net sampling for northern pike was done in 2003 to collect baseline data in advance of the experimental regulation that was implemented that same year. One hundred and ten northern pike were captured during ice-out trap netting in 2003. The CPUE was 1.1/lift. Individual lengths ranged from 15.0 to 32.8 inches with a mean of 21.3 inches. Ice-out trap netting was repeated in 2008 and 2009. Seventy-five northern pike were sampled in 2008, for a catch rate of 1.9 per trap net. Lengths ranged from 9.8 to 34.6 inches, with a mean of 23.1 inches. The sample in 2009 again netted 75 northern pike, for a catch rate of 1.6 per trap net. Lengths of those sampled ranged from 11.9 to 35.3 inches and mean length was 23.6 inches. Ice-out trap netting results show the average size of northern pike has been steadily increasing since the 40 inch minimum size limit was implemented in 2003.

Black Crappie - Black crappie have been sampled in every investigation of Elephant Lake since the first one in 1962 (Figure 10). Ten of the fifteen assessments have reported abundance above the median level of 1.9 for Class 5 lakes. Black crappie abundance was above the third quartile level of 4.5 per trap net in three of the last four investigations. A record high catch of 11.8 per net was noted in 2001. Black crappie catches returned to historic levels in 2009; 2.9 per trap net. Black crappie grow fast and attain large sizes in Elephant Lake. Growth rates typically rank above the 90th percentile for International Falls Area lakes and a 14.4 inch fish was sampled in 2006. The 2009 sample ranged from 4.8 to 10.8 inches with a mean length of 8.0 inches. Four year-classes were present and age ranged from 2 to 5 years.

Bluegill - Bluegill were first sampled in trapnets in Elephant Lake in 1977 (Figure 10). However, they were noted in seine surveys as early as the first Fisheries investigation in 1962. Bluegill did not become a regular component of the trap net catch until 1986. Bluegill abundance is on an increasing trend in

Elephant Lake and peaked in 2008 at 6.7 per trap net. Though abundance declined somewhat in 2009 to 4.5 per set, it was still between the first and second quartile levels of 3.2 to 7.9 per trap net. The total length of those sampled ranged from 4.8 to 7.4 inches with a mean length of 6.3 inches. Growth to age-4 was very slow and ranked at the 13th percentile for International Falls Area lakes.

Yellow Perch - Yellow perch abundance in Elephant Lake has exceeded the third quartile level of 14.1 per gill net for Class 5 lakes in all but two of the 15 previous investigations (Figure 10). The 2009 catch was the lowest ever at 7.8 per gill net. Four year-classes were present and age ranged from 3 to 7 years. Lengths ranged from 5.7 to 9.1 inches and yellow perch growth was above the International Falls Area average. Several assessments have produced yellow perch catches in excess of 100 per gill net, most recently in 1993.

Smallmouth bass - The first electrofishing assessment for smallmouth bass in 2001 yielded an "on-time" catch rate of 166 per hour, one of the highest ever recorded in the International Falls area. The 2006 electrofishing CPUE (322.4/hour) was nearly double the 2001 rate. Although bass up to 17.7 inches were captured, the vast majority of the catch in 2006 was less than 9 inches in length. Catch rates declined in the 2009 sample to 118/hour. Twelve year-classes were present and total length ranged from 3.0 to 18.5 inches. Smallmouth bass growth to age-4 was slightly below the International Falls Area average of 9.4 inches.

Table 3 Fish species captured during past fisheries surveys in Elephant 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	1962
Black crappie	*Pomoxis nigromaculatus*	Predator	Cool-warm	Neutral	1962
Walleye	*Sander vitreus*	Predator	Cool-warm	Neutral	1962
Smallmouth bass	*Micropterus dolomieu*	Predator	Warm	Intolerant	1962
White sucker	*Catostomus commersonii*	Omnivore	Cool-warm	Tolerant	1962
Iowa darter	*Etheostoma exile*	Insectivore	Cool	Intolerant	1962
Johnny darter	*Etheostoma nigrum*	Insectivore	Cool-warm	Neutral	1993
Yellow perch	*Perca flavescens*	Insectivore	Cool-warm	Neutral	1993
Hybrid sunfish	*Lepomis spp.*	Insectivore	Warm	Neutral	1962
Bluegill sunfish	*Lepomis macrochirus*	Insectivore	Warm	Neutral	1962
Blacknose shiner	*Notropis heterolepis*	Insectivore	Cool-warm	Intolerant	2008
Golden shiner	*Notemigonus crysoleucas*	Insectivore	Warm	Neutral	1991
Brown bullhead	*Ameiurus nebulosus*	Omnivore	Warm	Neutral	1984
Pumpkinseed sunfish	*Lepomis gibbosus*	Insectivore	Warm	Neutral	1971

Table 4 Elephant Lake fish stocking history based on known records.

Year	Species	Total No.	Life Stage
1943	Largemouth bass	510	Fingerling
1944	Largemouth bass	1,070	Fingerling
1945	Walleye	220,000	Fingerling
1955	Walleye	24,000	Fingerling
1957	Walleye	35,630	Fingerling
1960	Walleye	9,103	Fingerling
1961	Walleye	27,216	Fingerling
1967	Walleye	1,000,000	Fry
1968	Walleye	1,000,000	Fry
1969	Walleye	1,000,000	Fry
1977	Walleye	6,600	Fingerling
1981	Walleye	1,500,000	Fry
1982	Walleye	6,135	Fingerling
1984	Walleye	13,500	Fingerling
1989	Walleye	2,940	Fingerling
1994	Walleye	7,777	Fingerling
1996	Walleye	6,594	Fingerling

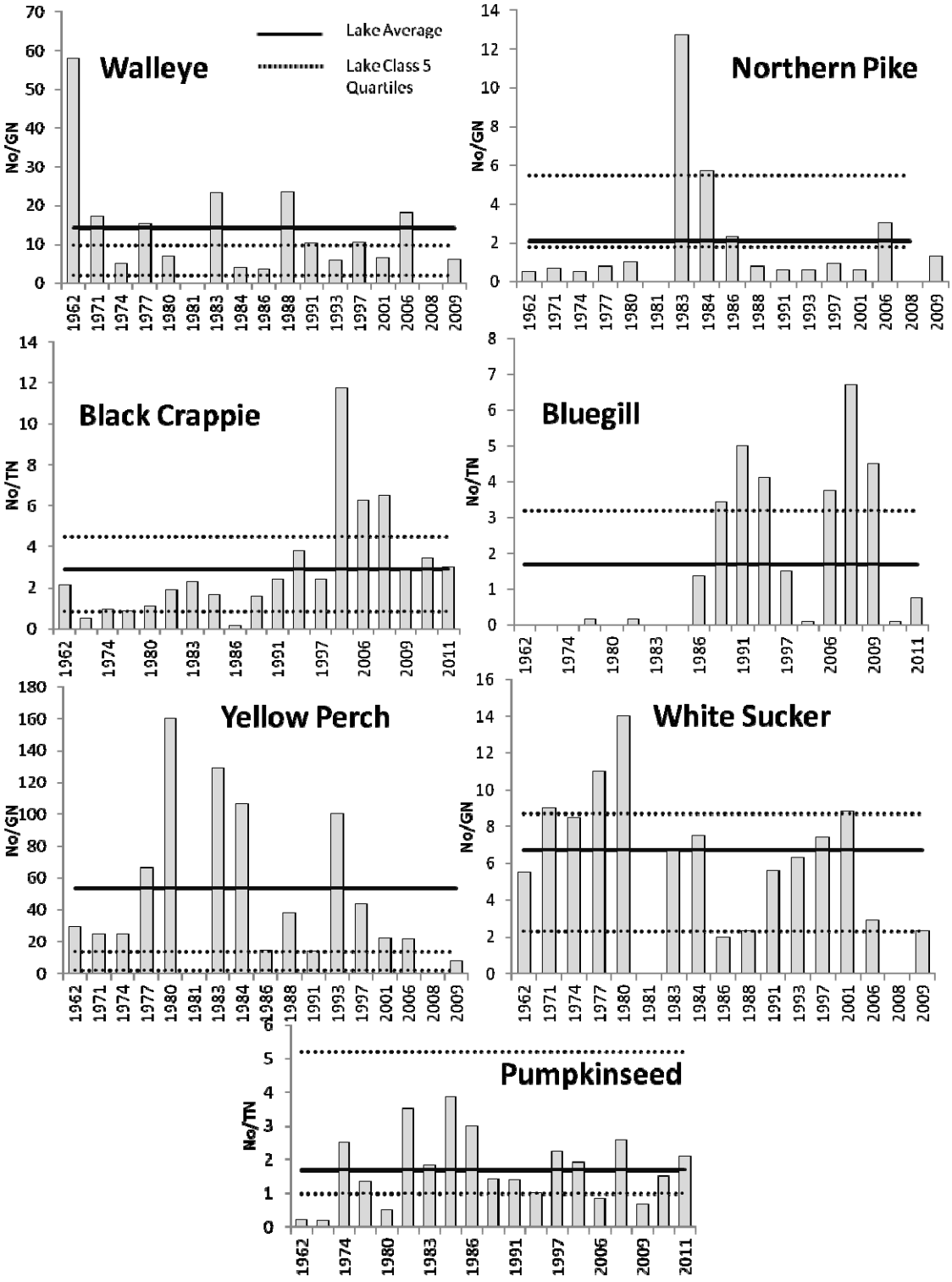


Figure 10 Historical catch per unit effort of the major fish species of Elephant Lake, St. Louis Co. For bluegill, the lower quartile is shown and the upper quartile of 21 fish per trapnet is not.

Aquatic plant assessment

Nearshore and submersed aquatic plants are moderately abundant and diverse in Elephant Lake (Table 5, Table 6, Figure 11, and Figure 12). Survey crews recently sampled four species identified as highly intolerant by Milburn et al. (2007) and one species listed by the State of Minnesota as species of special concern (Vasey's pondweed; Table 6). An Index of Biotic Integrity developed by Beck et al. (2010) rates Elephant Lake at 69-75 out of a possible 100.

Most of Elephant Lake's shoreline (85 percent) is under public ownership. Only 34 docks were identified from 2009 and 2010 aerial photos. Thus, there is little threat of damage of aquatic plants by nearshore development and recreation activities, especially if current lakeshore owners minimize removal of shoreline and nearshore vegetation. Efforts to minimize watershed, nearshore, and within lake disturbances by lake shore owners will be important to protect Elephant's aquatic plant community and fish habitat, and to enhance overall lake resilience.

Figure 11 Cover of aquatic vegetation in Elephant Lake, St. Louis Co. assessed via point-intercept vegetation surveys in August 2010 and mapped with indicator kriging. Areas of green represent where vegetation occurrence was highly likely.

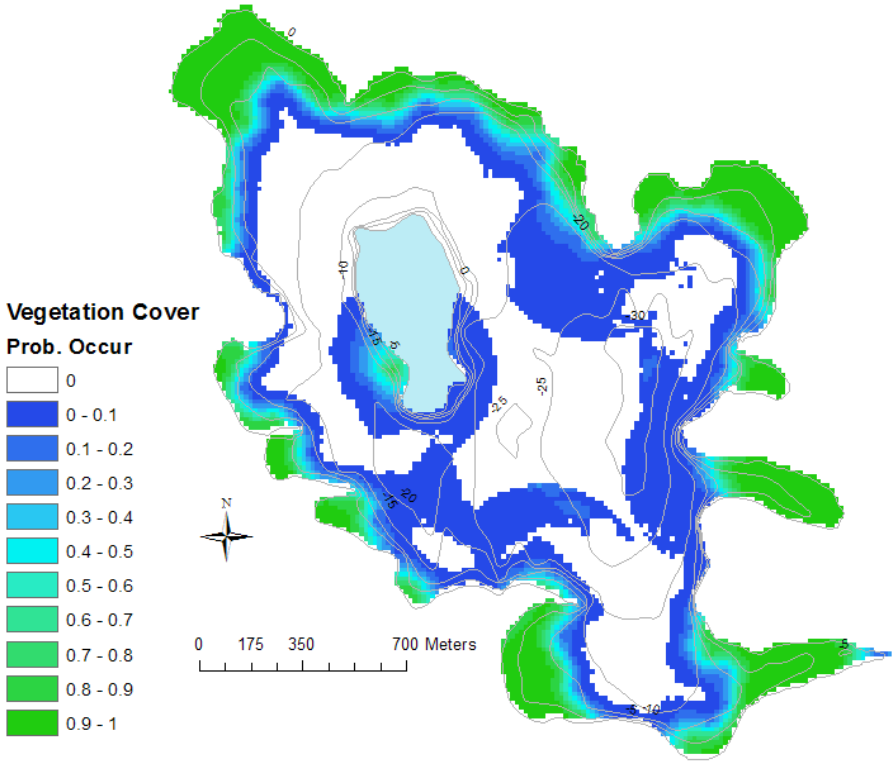


Figure 12 Number of aquatic plant species surveyed at each point during point intercept surveys in Aug 2011 on Elephant Lake, St. Louis Co.

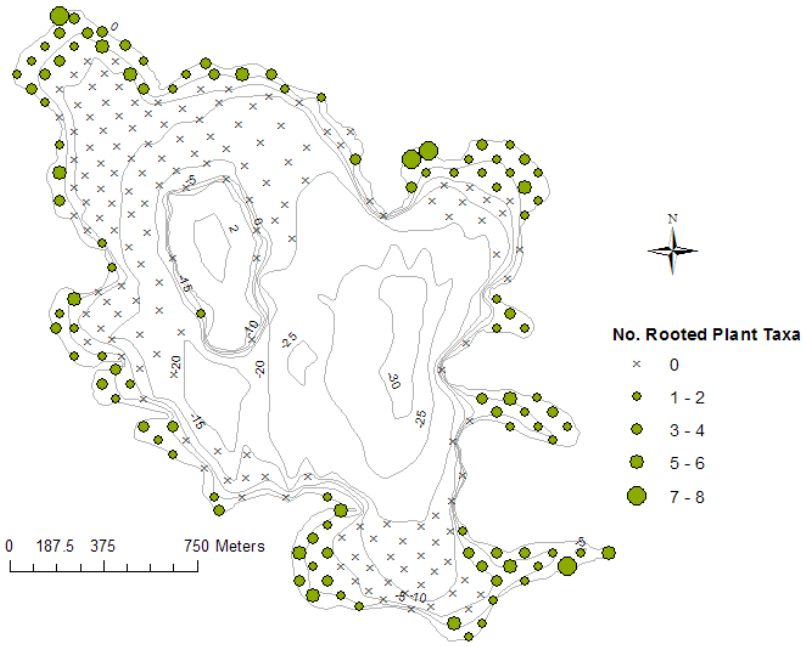


Table 5 Common species observed during previous transect surveys. Species documented were either labeled as "common" at any transect or found at ≥ 10percent of the transects. The aquatic plant surveys in 1961 and 1983 were rapid assessments of vegetative cover and likely missed many other common species.

Date	Common Name	Species Name	Growth Form
8/30/1961	Berchtold's pondweed	*Potamogeton berchtoldi*	Submersed
	Claspingleaf pondweed	*Potamogeton richardsonii*	Submersed
	Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
	Wild celery	*Vallisneria americana*	Submersed
8/03/1988	Spikerush	*Eleocharis sp.*	Emergent
	Bulrush	*Scirpus acutus*	Emergent
	Burreed	*Sparganium sp.*	Emergent
	Watermilfoil	*Myriophyllum sp.*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
8/10/2001	Horsetail	*Equisetum spp.*	Emergent
	Cane	*Phragmites australis*	Emergent
	Hardstem bulrush	*Scirpus acutus*	Emergent
	Arrowhead	*Sagittaria sp.*	Emergent
	Wool grass	*Scirpus cyperinus*	Emergent
	Giant burreed	*Sparganium eurycarpum*	Emergent
	Water Parsnip	*Sium suave*	Emergent
	Floating-leaf burreed	*Sparganium fluctuans*	Emergent
	Sessile-fruited Arrowhead	*Sagittaria rigida*	Emergent
	Broad-leaved cattail	*Typha latifolia*	Emergent
	Needlerush Group	*Eleocharis sp.*	Emergent
	Water Arum	*Calla palustris*	Emergent
	Sedge Group	*Carex sp.*	Emergent
	Spikerush Group	*Eleocharis sp.*	Submersed
	Pipewort	*Eriocaulon aquaticum*	Submersed
	Quillwort Group	*Isoetes sp.*	Submersed
	Muskgrass	*Chara sp.*	Submersed
	Coontail	*Ceratophyllum demersum*	Submersed
	Canada waterweed	*Elodea canadensis*	Submersed
	Water marigold	*Bidens beckii*	Submersed
	Stonewort group	*Nitella sp.*	Submersed
	Bushy pondweed	*Najas flexilis*	Submersed
	Large-leaf pondweed	*Potamogeton amplifolius*	Submersed
	Ribbon-leaf pondweed	*Potamogeton epihydrus*	Submersed
	Variable-leaf pondweed	*Potamogeton gramineus*	Submersed
	Blunt-leaf pondweed	*Potamogeton obtusifolius*	Submersed
	White-stem pondweed	*Potamogeton praelongus*	Submersed
	Claspingleaf pondweed	*Potamogeton richardsonii*	Submersed
	Coiled pondweed	*Potamogeton spirillus*	Submersed

Flatstem pondweed	*Potamogeton zosteriformis*	Submersed
Water celery	*Vallisneria americana*	Submersed
Common bladderwort	*Utricularia vulgaris*	Submersed
Watershield	*Brasenia schreberi*	Floating-leaf
White waterlily	*Nymphaea odorata*	Floating-leaf
Yellow waterlily	*Nuphar variegata*	Floating-leaf
Floating-leaf pondweed	*Potamogeton natans*	Floating-leaf
Water smartweed	*Polygonum amphibium*	Floating-leaf

Table 6 Percent frequency of occurrence of aquatic plant species at depths ≤ 15 feet sampled during point-intercept surveys on 26 August 2008, 5 August 2009, 4 August 2010, and 3 August 2011 at Elephant Lake, St. Louis Co.

		Growth Form	Frequency (percent)			
Common Name	**Species Name**		**2008**	**2009**	**2010**	**2011**
All rooted plants			25.8	42.6	60.0	48.4
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	18.3	10.9	19.5	11.6
Robbins' pondweed	*Potamogeton robbinsii*	Submersed	8.1	18.5	22.6	20.0
Hardstem bulrush	*Scirpus acutus*	Emergent	7.7	4.2	5.6	1.3
Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	6.9	6.0	13.3	6.2
Flat-stem pondweed	*Potamogeton zosteriformis*	Submersed	4.5	13.2	21.0	13.8
Water celery	*Vallisneria americanus*	Submersed	3.7	7.6	7.2	5.3
Canada waterweed	*Elodea canadensis*	Submersed	2.4	5.3	26.7	10.2
Filamentous Algae			2.2	6.0	0.5	3.1
Coontail[b]	*Ceratophyllum demersum*	Submersed	1.7	6.0	9.2	1.8
Variable-leaf pondweed	*Potamogeton gramineus*	Submersed	1.6	5.3	0	7.1
White waterlily	*Nymphaea sp.*	Floating-leaf	1.6	0	0.5	3.6
Muskgrass	*Chara sp.*	Submersed	1.6	9.0	12.3	7.6
Yellow waterlily	*Nuphar sp.*	Floating-leaf	1.4	0	5.6	4.9
Large-leaf pondweed	*Potamogeton amplifolius*	Submersed	1.3	2.6	5.6	2.7
Burreed	*Sparganium sp.*	Emergent	1.3	0.8	1.5	0
Three-square bulrush	*Scirpus americanus*	Emergent	1.3	0	0	0
Leafy pondweed	*Potamogeton foliosus*	Submersed	1.3	0	0.5	0.9
Naiad	*Najas sp.*	Submersed	1.2	2.3	8.2	2.7
Horsetail	*Equisetum sp.*	Emergent	0.8	0.8	0.5	0.9
Bladderwort	*Utricularia sp.*	Submersed	0.4	1.1	0	0
Watershield	*Brasenia shreberi*	Floating-leaf	0.3	1.5	1.0	2.2
Water marigold[a]	*Bidens beckii*	Submersed	0.3	3.8	13.3	4.4
Floating-leaf pondweed	*Potamogeton natans*	Floating-leaf	0.3	0	1.0	0
Stonewort	*Nitella sp.*	Submersed	0.3	0	0	0
Ribbon-leaf pondweed[a]	*Potamogeton epihydrus*	Submersed	0.1	0.8	5.6	0.4
Small pondweed	*Potamogeton pusillus*	Submersed	0.1	0.4	7.2	0.9
Softstem bulrush	*Scirpus validus*	Emergent	0	11.3	15.4	13.3
White waterlily	*Nymphaea odorata*	Floating-leaf	0	5.7	6.2	0.4
Yellow waterlily	*Nuphar variegata*	Floating-leaf	0	1.5	0	0
Freshwater sponge			0	1.1	0.5	0
Cane	*Phragmites australis*	Emergent	0	0.4	0	0
Vasey's pondweed[a,c]	*Potamogeton vaseyi*	Submersed	0	0.4	0	2.7
White water buttercup	*Ranunculus longirostris*	Submersed	0	0.4	0	0
Arrowhead	*Sagittaria sp.*	Emergent	0	0.4	0	1.8
Illinois pondweed	*Potamogeton illinoensis*	Submersed	0	0	0.5	0
Sago pondweed	*Stuckenia pectinatus*	Submersed	0	0	2.0	0.9
Common bladderwort	*Utricularia vulgaris*	Submersed	0	0	2.6	3.1
Waterweed	*Elodea sp.*	Submersed	0	0	0	0.4
Spikerush	*Eleocharis sp.*	Emergent	0	0	0	0.4

Quillwort[a]	*Isoetes sp.*	Submersed	0	0	0	0.4
Star duckweed	*Lemna trisulca*	Free-floating	0	0	0	0.4
White-stem pondweed	*Potamogeton praelongus*	Submersed	0	0	0	4.0
Max depth of veg growth (ft)[d]			8.2	7.7	9.4	6.8

[a]intolerant to turbidity (Conservatism values > 7) as described by Milburn et al. (2007) and Beck et al. (2010).
[b]Species tolerant to turbidity (Conservatism values > 7) as described by Milburn et al. (2007) and Beck et al. (2010).
[c]Species State listed as a species of Special Concern.
[d]Depth of 95percent of all plant occurrences

Water quality

Two complete years of spring through fall data are available for 2008 and 2009, while 2010 had only three seasonal collections: spring, mid-summer, and fall. Summer-mean water quality data for 2008 and 2009 are summarized in Table 7 and raw data results are provided in Appendix A. In addition, major cations, anions, total organic carbon (TOC), and dissolved organic carbon (DOC) were summarized based on available summer data. Typical ranges, as derived from the National Lakes Assessment (NLA) database for Minnesota are provided for comparison. 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 is based on 64 Minnesota lakes that were included in that NLA study and is intended to provide a state-wide perspective.

Table 7 Elephant Lake 2008-2009 summer- mean water quality data. Typical range based on 32 NLF ecoregion reference lakes (Heiskary and Wilson 2008) noted for comparison.

Parameter	Elephant Lake 2008-2010	NLF
Total phosphorus (µg/L)	22 ±2	14 - 27
Chlorophyll mean (µg/L)	5.1 ±0.8	4 - 10
Chlorophyll max (µg/L)	10.1	<15
Secchi disk (feet) (meters)	10.2 ±0.3 (3.1±0.1)	8 – 15 2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.653	<0.4 – 0.75
Alkalinity (mg/L)	39	40 - 140
Color (Pt-Co Units)	36	10 - 35
pH (SU)		7.2 – 8.3
Chloride (mg/L)	1.2	0.6 – 1.2
Total suspended solids (mg/L)	2.2	<1 - 2
Total suspended inorganic solids (mg/L)	0.9	<1 - 2
Conductivity (umhos/cm)	80	50 - 250
Total nitrogen: Total phosphorus ratio	30:1	25:1 - 35:1

Table 8 Elephant Lake cation, anion, and organic carbon measurements. Typical (IQ) range derived from 64 NLA lakes sampled in 2007 is provided as a basis for comparison. A value of half the detection limit was substituted for those values reported as less than the detection limit.

Date	Ca mg/L	Mg mg/L	K mg/L	Na mg/L	HCO_3 mg/L	SO_4 mg/L	Cl mg/L	TOC mg/L	DOC mg/L
2008-2010 Average	10.6	4.0	1.2	1.3	40	2.8	1.1	9.0	8.5
NLA IQ range	19.1-33.7	6.7-26.9	0.9 - 4.8	2.2 - 9.0		2.2-14.1	1.5-18.4	7.3-14.2	
	µeq/L								
2009-2010 Average	530	328	30	60	810	62	30		

Continuous temperature and dissolved oxygen and temperature profiles

Continuous surface water temperature was measured by a remote recording device from 2008-2011. Some among year differences are evident from this detailed data set. Spring temperatures in 2008, 2009, and 2011 were rather similar, while 2010 exhibited very rapid warming (Figure 13). Temperatures remained warm through spring 2010 but by June, temperature was in the range of the other three years.

Peak summer temperature occurred in 2011 with measurements above 25 C. Temperature declines rapidly by late September in all four years.

Profile data from 2008 provide a basis for examining seasonal patterns in dissolved oxygen (DO) and temperature for Elephant Lake (Figure 14). As anticipated, the lake was isothermal on the initial visit on May 13, 2008, and DO was relatively consistent from top to bottom. A rapid warming occurred over the next two weeks and surface temperatures increased to 13 C and some slight thermal stratification was evident (Figure 14). This subtle stratification was sufficient to allow for DO stratification as well. The thermal stratification was short-lived and subsequent profiles indicated well-mixed conditions until late July; however, DO was often reduced at the lower depths so the mixing was not adequate to replenish bottom water DO.

Distinct thermal stratification was again evident from the end of July through mid-August with a distinct thermocline at 4-5 m. Consistent with this stratification the hypolimnion became anoxic (Figure 14). Mixing was again underway in late August. As stratification broke down DO was replenished in the hypolimnion. On all dates epilimnetic DO remained well above the 5 mg/L water quality standard for DO.

Based on the 2008 profiles Elephant Lake stratifies intermittently. This is consistent with the observation by Eibler (2008), in the DNR Fisheries lake management plan for Elephant Lake, where he states that the lake does not stratify every summer. A comparison of mid-summer profiles for 2008, 2009, and 2010 (Figure 15) serves to reinforce this. Based on these 3 mid-July profiles the lake was well mixed in 2008 and 2009 but stratified in 2010. In 2008 and 2009 DO was relatively constant from surface to bottom. In 2010, a distinct thermocline was evident and the hypolimnion was anoxic. This periodic stratification and mixing can have distinct impacts for the fishery and for phosphorus recycling within the lake.

Figure 13 Elephant Lake continuous temperature measurement. Maximum daily temperature displayed.

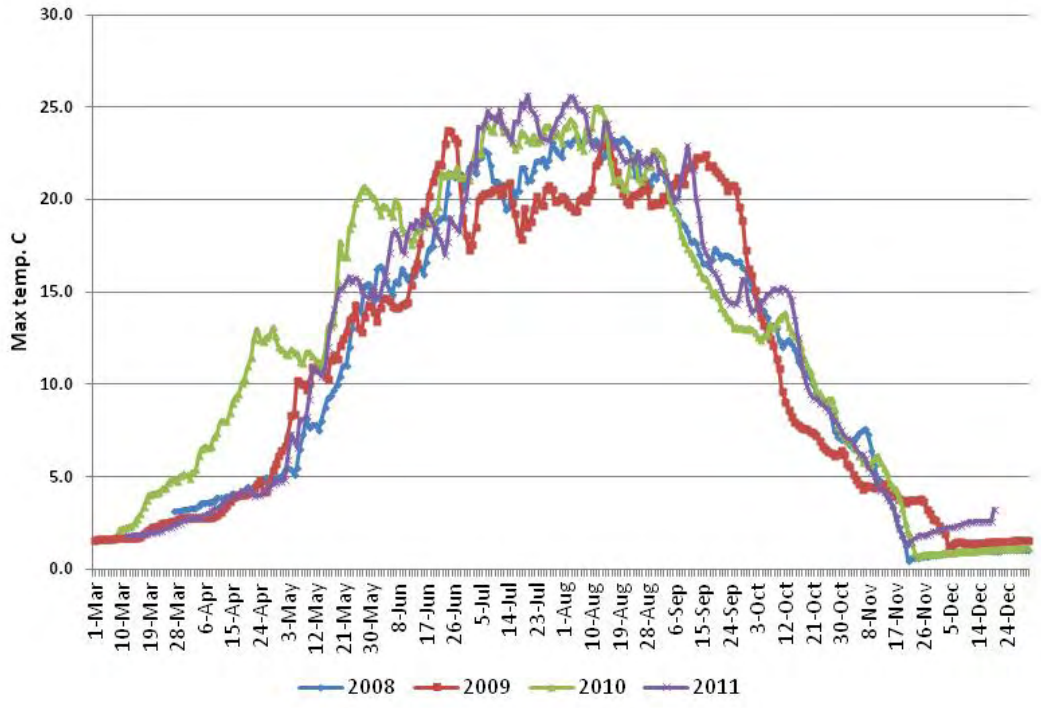


Figure 14 Elephant Lake temperature and dissolved oxygen (DO) profiles for 2008

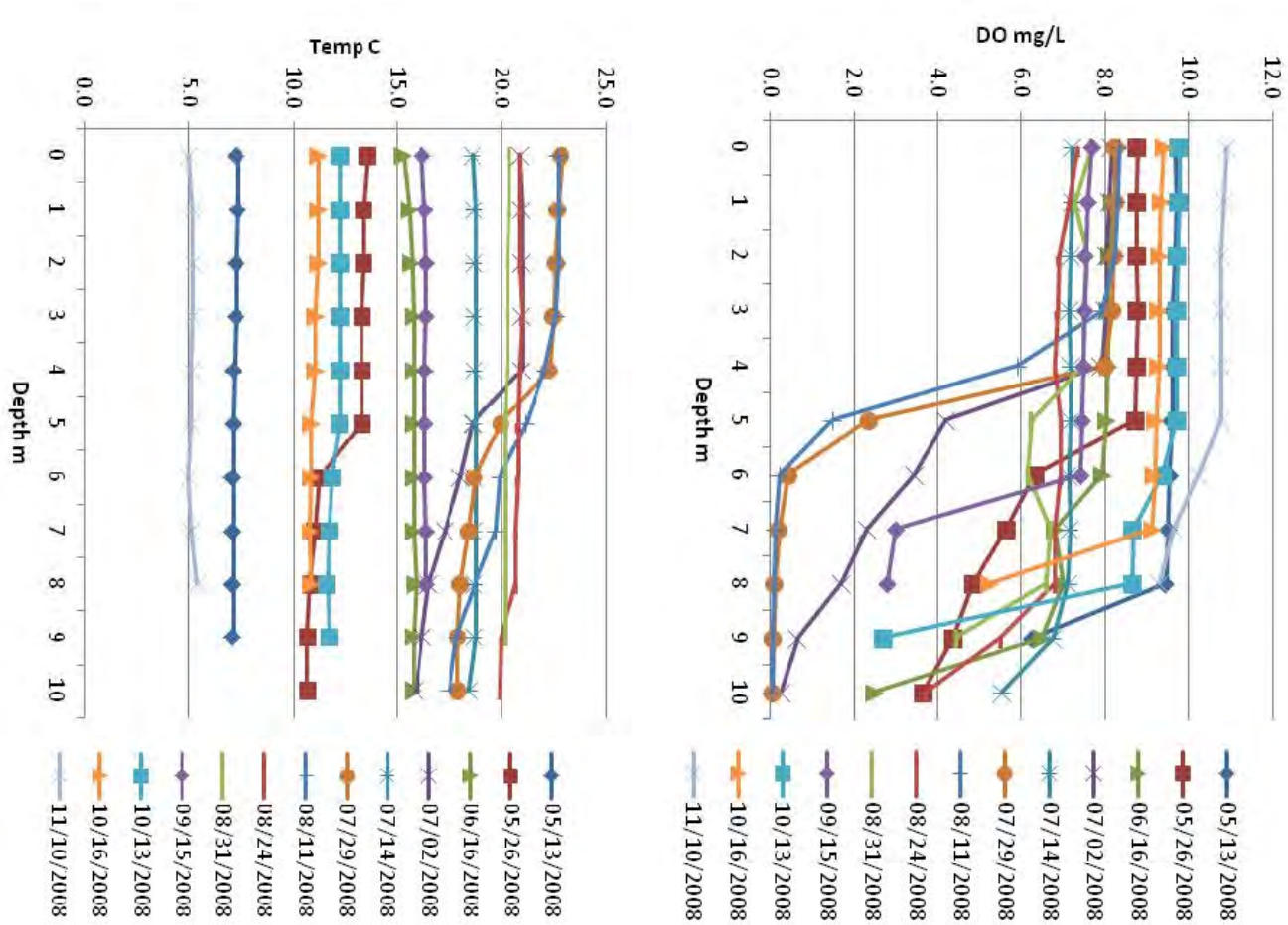
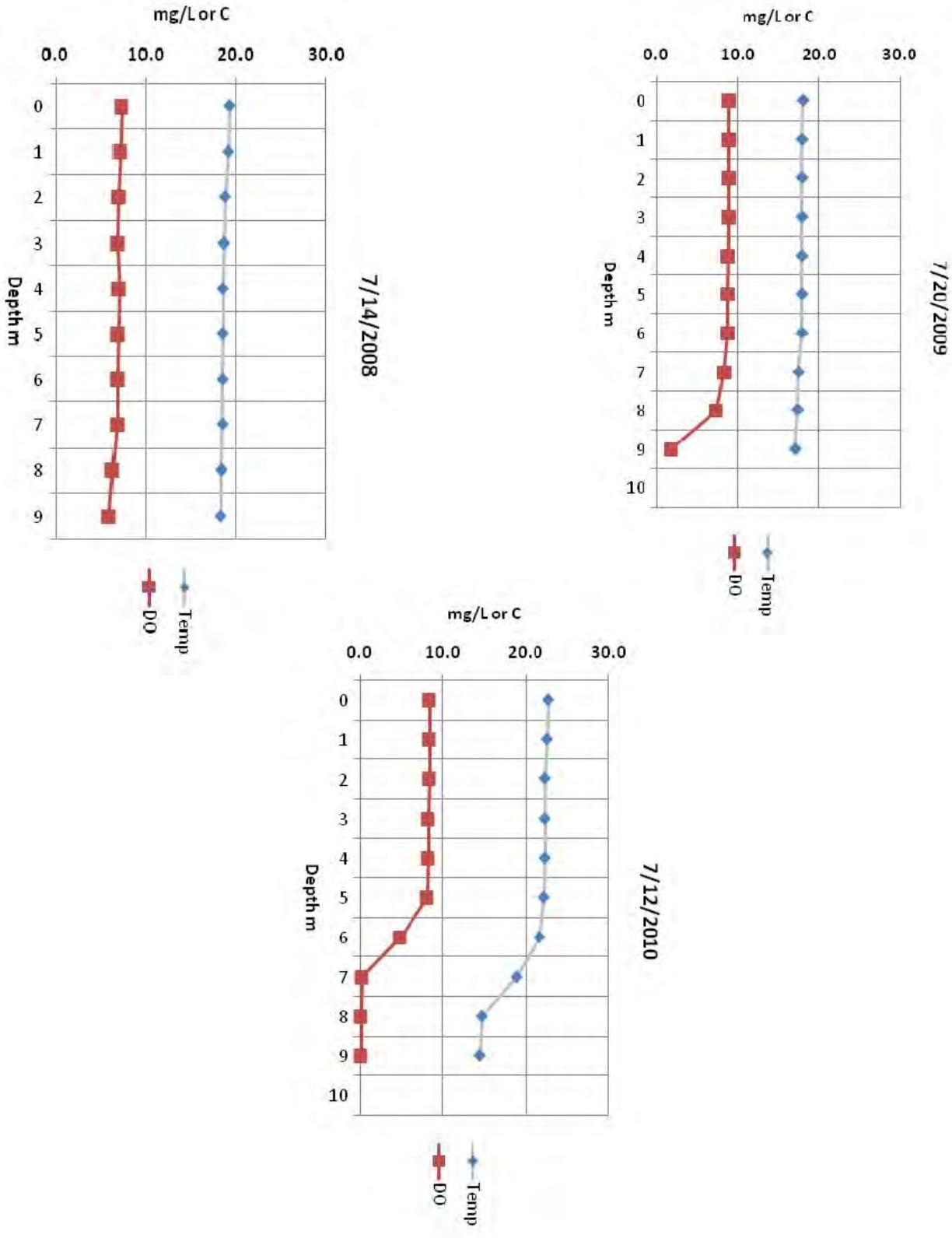


Figure 15 Comparison of mid-summer temperature profiles for 2008, 2009, and 2010



Total phosphorus (TP) concentrations were slightly higher in 2008 (25 ±1.2 µg/L) as compared to 2009 (17 ±1.8 µg/L). In 2008, TP remained relatively constant at 25 µg/L from May-August and then declined slightly in September and October (Figure 16). In 2009, TP was low in spring, increased and remained stable from July through September, and increased again with fall mixing in October. Intermittent stratification and mixing may have some influence on this cycle. In 2008, epilimnetic and hypolimnetic TP was similar when the lake was well mixed and there was measurable DO in the bottom waters (Figure 17). However, when the lake was stratified and the hypolimnion was anoxic (August 11, 2008 and July 20, 2010) hypolimnetic TP increased. Because the hypolimnetic volume is relatively small and stratification is relatively short-lived the periodic mixing, most likely does not have a large impact on the phosphorus budget for the lake. Overall, TP values in Elephant Lake indicate mesotrophic conditions.

Chlorophyll-*a* (Chl-a) concentrations provide an estimate of the amount of algal production in a lake. Summer-mean Chl-a in 2008 (5.3 ±0.8) was slightly higher than 2009 (3.8 ±13 µg/L). Both years exhibited a subtle increase in Chl-a from May through September (Figure 16). Concentrations greater than 10 µg/L will typically be perceived as a mild algal bloom in northern Minnesota lakes (Heiskary and Walker 1988). Only two sample events exceeded 10 µg/L and both of these were in October. Nuisance-level blooms were not observed on Elephant from 2008-2010, and during most sampling events algae levels in the epilimnion were sparse.

Secchi disk transparency averaged 3.0 m and 3.1 m, respectively in 2008 and 2009. Transparency was quite stable in 2008 and a bit more variable in 2009. In general, Secchi declined as algal biomass (Chl-a) increased (Figure 16). Elephant has a slight bog stain (36 Platinum-Cobalt units) originating from forest and wetlands within the watershed, which (when elevated) can influence transparency. However, color values in Elephant are moderate and have minimal impact on transparency.

CLMP and MPCA Secchi measurements for 2007-2010 were combined to allow for a more comprehensive record of transparency (Figure 18). These data reveal elevated transparency measures in the spring and fall and further re-affirm the rather stable mid-summer transparency in 2008 and 2009. In contrast, 2010 exhibited a distinct decline in transparency from spring through summer, followed by an increase in September and October. July 2010 Chl-a was higher than July 2008 and 2009 measurements. The 2010 data suggest mild blooms may occur in some years and Secchi transparency will decline in response to the blooms. This further reinforces that long-term Secchi measurement will be a valuable means for tracking the trophic status of Elephant Lake over time.

Figure 16 Elephant Lake 2008-10 total phosphorus, chlorophyll-*a* and Secchi depth

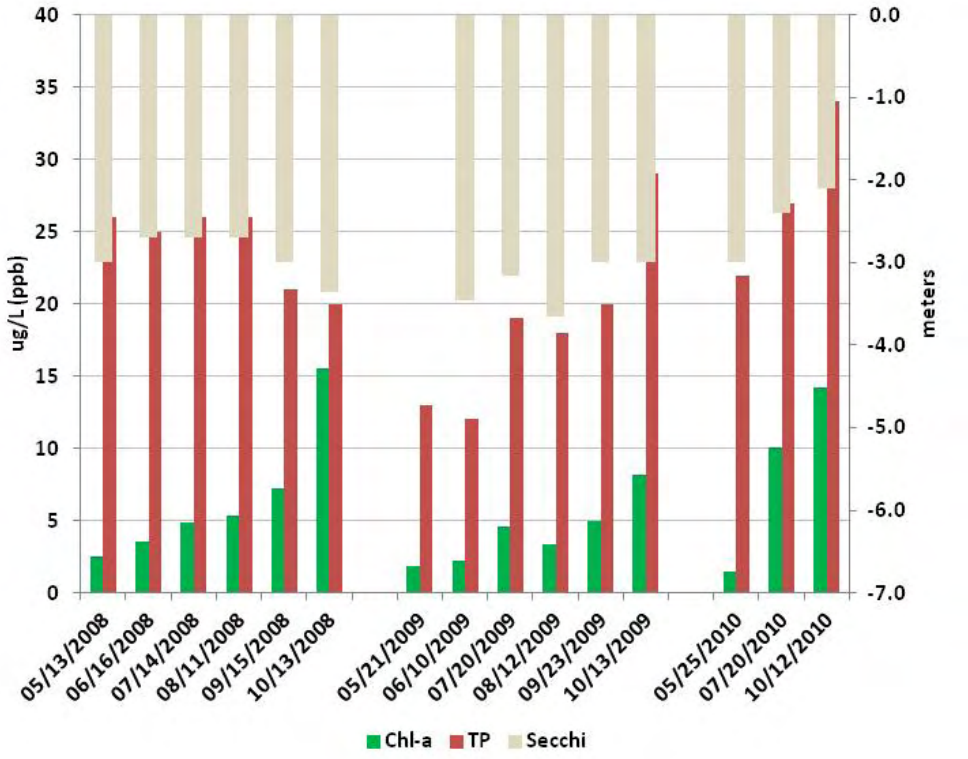


Figure 17 Comparison of epilimnetic and hypolimnetic TP

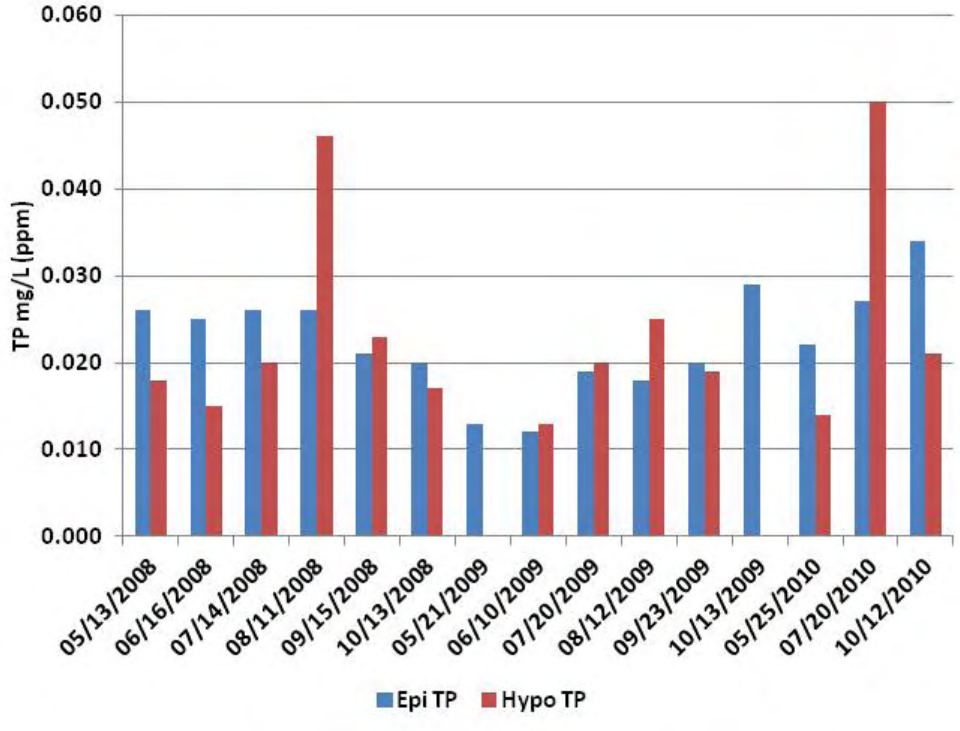
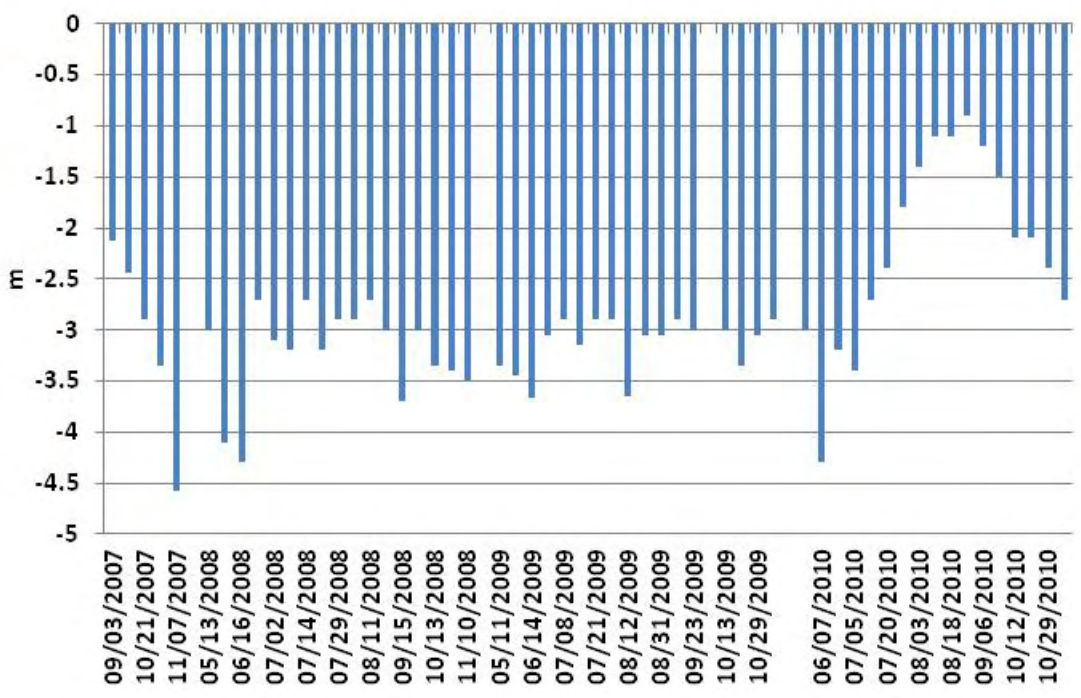


Figure 18 Secchi transparency readings from 2008-2010



Dissolved minerals and organic carbon were measured in 2008, 2009, and 2010 as part of the long-term monitoring of Elephant and other Sentinel lakes. This includes some of the standard LAP measures of total suspended solids (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 (Table 7), some do not. For parameters without ecoregion–based comparative data from the 2007 National Lakes Assessment (NLA) study were used to provide perspective on reported concentrations (Table 8). Since the NLA lakes were randomly, selected they provide a reasonable basis for describing typical ranges and distributions at the statewide level.

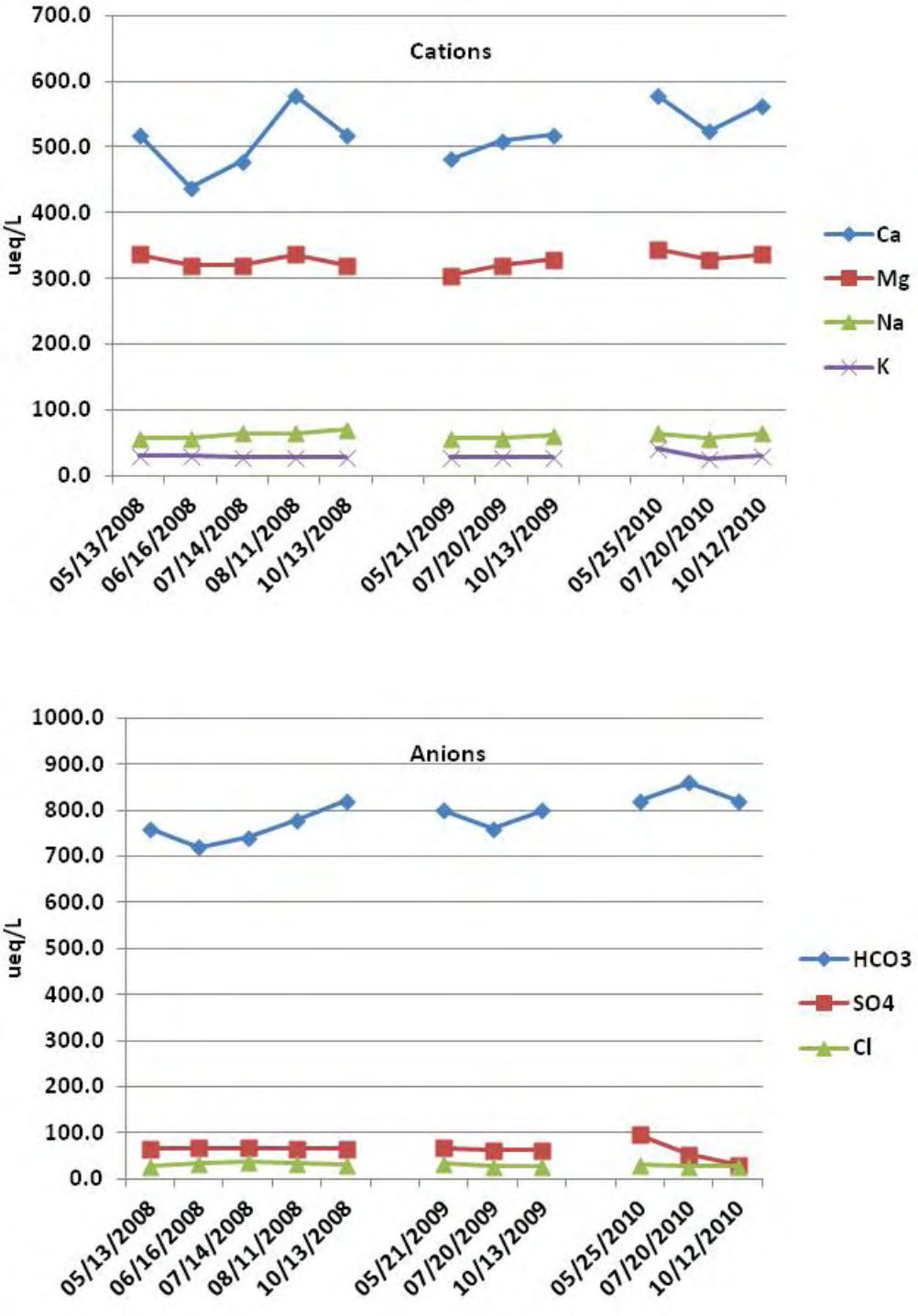
TSS is low as compared to NLF reference lakes (Table 7) and most of the TSS can be attributed to organic SS (TSS-TSIS), i.e. suspended algae. The moderate color value (Table 7) indicates the water has some coloration and moderate amount of dissolved organic carbon (DOC). Total organic carbon (TOC) is within the typical range, based on the NLA data and the majority of the TOC is in the DOC form, which is consistent with the statewide data (Table 8). 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 and conductivity are in the typical range for NLF lakes and are indicative of soft water (Table 7). Most cation and anion concentrations were quite stable across sample events and years (Figure 19), which is consistent with the literature. Mg, Na, K, and Cl are noted to be relatively conservative and undergo only minor spatial and temporal change (Wetzel 2001). Mg is required by algae to produce chlorophyll-a and Ca is used by rooted plants. Silica (Si), which is required by diatoms to form their "glass" shells, varied slightly from spring to fall. A slight decline in fall may be caused by a fall diatom bloom.

Calcium (Ca) and magnesium (Mg) are the dominant cations and concentrations of both are below the typical range of the statewide data. The other two major cations – sodium (Na) and potassium (K) are well within the typical range as well. Bicarbonate is the dominant cation, followed by sulfate (SO4) and chloride (Cl). Chloride is within the typical range for NLF reference lakes (Table 7); however, it is low relative to statewide NLA data (Table 8). Elevated Cl is most often attributed to application of road salt

on roads in the watershed. Of all the ions, Ca and HCO_3 are the most variable seasonally and this is likely the result of rooted plant growth, photosynthesis, and senescence.

Figure 19 Elephant Lake cation and anion values for 2008-2010



Pesticide data

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 lower method-reporting limits. The majority of analytes were listed as non-detects (ND). Pesticides or their degradation products with detected concentrations are presented in Table 9. Samples were collected on June 10, 2009, October 13, 2009, July 20, 2010, and August 2, 2011.

Table 9 Pesticides or their degradation products detected in Elephant Lake. P=present.

Analyte	Detections	Samples	percent Detection	Minimum (ng/L)	Maximum (ng/L)
2,4-D	1	2	50%	nd	18.8
Atrazine	1	4	25%	nd	P (<50)
Dimethenamid ESA	2	4	50%	nd	70
MCPA	1	2	50%	nd	6.5
Metolachlor ESA	1	4	25%	nd	70

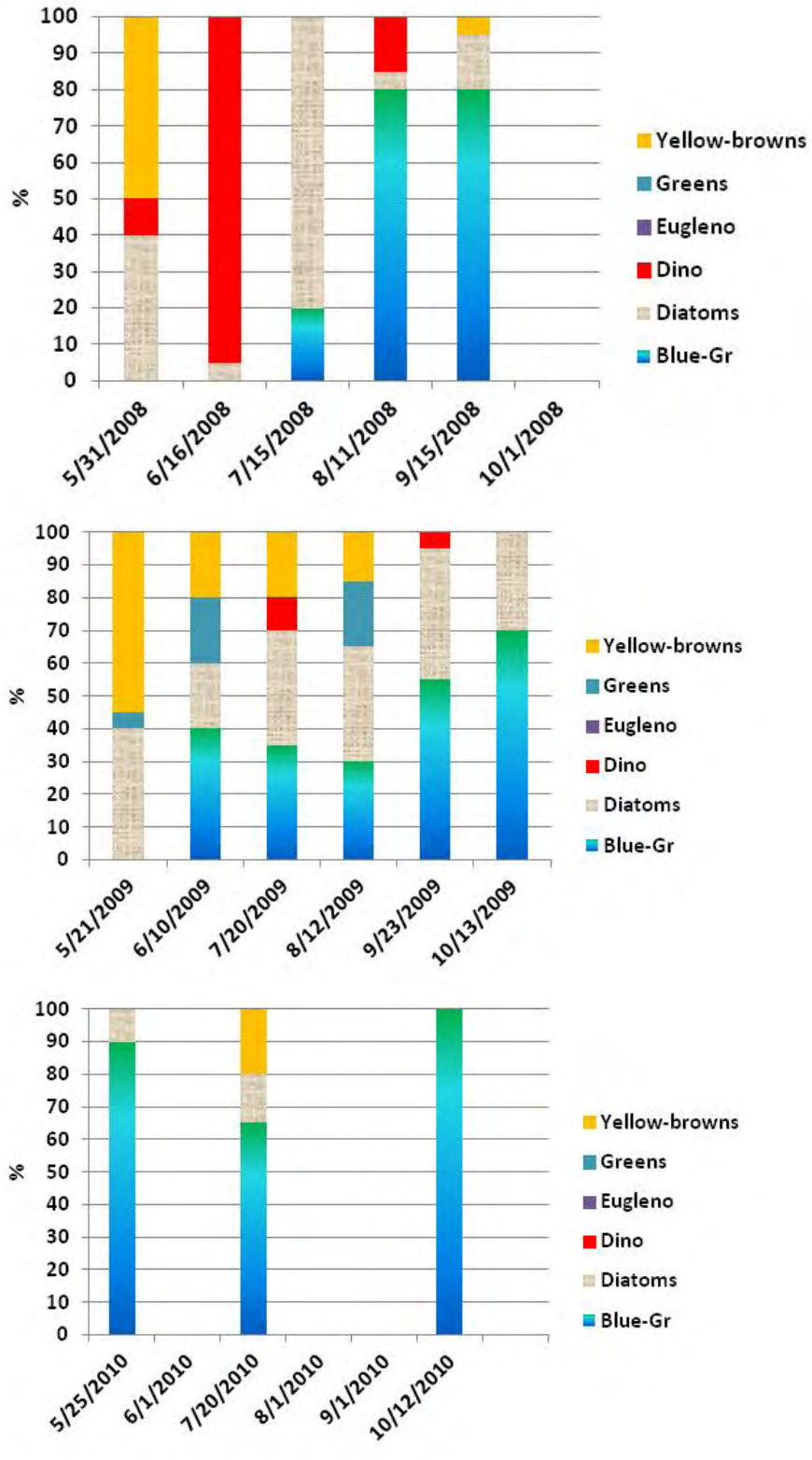
The Elephant lake watershed does not contain any cultivated land. Atmospheric deposition is suspected as the primary transport mechanism of pesticides in non-agricultural areas. Detection frequency ranges from 25 percent to 50 percent for the various detected compounds. Five pesticide compounds were detected in Elephant Lake. With this said all pesticide detections in Elephant Lake are well below applicable water quality standards and benchmarks. The pesticide detections and concentration ranges in Elephant Lake are consistent with other lake sampling results of lakes located in northern 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 .

Phytoplankton (algae) data for Elephant Lake in 2008, 2009, and 2010 are presented in terms of algal type (Figure 20). Algal composition was variable among sample dates and years. However, across all dates and samples blue-greens, diatoms, and yellow-brown algae were the most common forms. A "typical" seasonal transition in algal forms often includes diatoms in the spring, transitioning to greens in early summer and then to blue-green dominance in mid to late summer. Diatoms often grow abundantly in the spring following ice-out and turnover when temperatures are cool and there is abundant phosphorus and silica (which is required for their "glass-like" shells). As the water warms diatoms dieback and settle to the bottom of the lake, allowing other algal forms to prosper.

Of the three sample years, 2009 had what might be considered a somewhat "typical" transition. This is in contrast to 2008, which was dominated by diatoms and dinoflagellates, and 2010, which was dominated by blue-green algae on all three sample dates (Figure 20). While blue-greens were dominant on several dates in all three years the actual biomass (Chl-a concentration) was rather low (Figure 16). Thus, in most instances the algae would not have appeared as nuisance blooms. This is borne out, based on the Chl-a concentrations and the "user perceptions' as recorded by the samplers. The October 12, 2010 date was one of the few with Chl-a > 10 µg/L, a level often perceived as a "mild bloom." The blue-green bloom on that date was dominated by Microcystis and the sampler rated physical appearance as "medium algae."

Figure 20 Algal composition for Elephant Lake in 2008, 2009 and 2010



Zooplankton

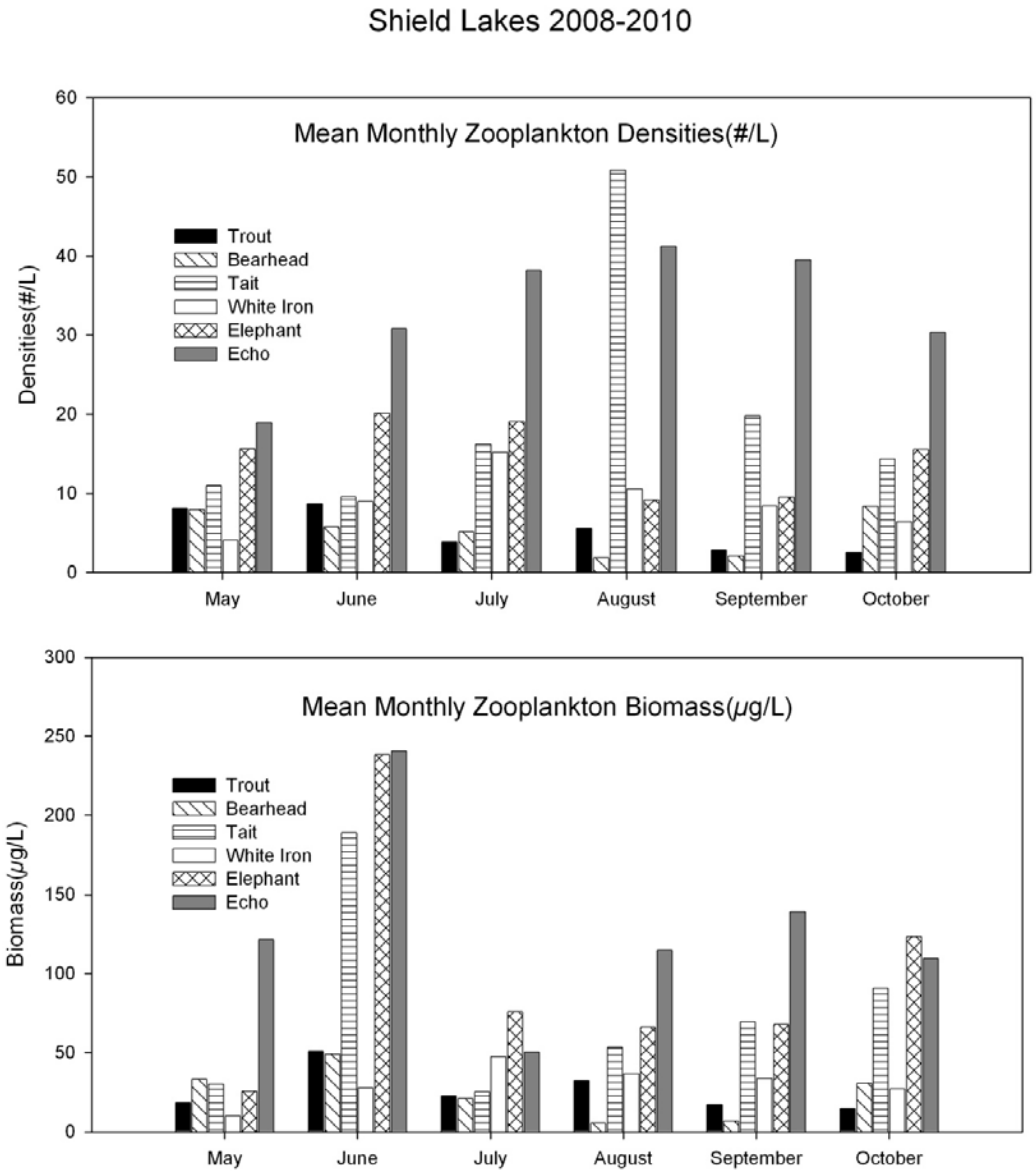
Zooplankton samples were analyzed by Jodie Hirsch at the MDNR. A summary report was prepared that included information for all the Sentinel lakes and that report is the basis for the following comments on Elephant Lake (Hirsch 2011). Mean 2008-2010 zooplankton densities in Elephant were higher than four other Border region sentinel lakes (Table 10). Hirsch (2009) found that, in general, as lake productivity increased (e.g. TP or Chl-a) the relative abundance (biomass) of zooplankton increased as well. This appears to be the case for Elephant, as its mean density and biomass was similar to other lakes of similar trophic status.

Mean monthly zooplankton density was rather consistent from May through July and then declined somewhat in August and September, and increased slightly in October (Figure 21). Mean monthly biomass peaked in June, declined rapidly in July, and increased slightly in October. This pattern was similar to what was observed in Echo and Tait Lakes. Fish predation, in particular bluegill, pumpkin seed and black crappie, is a likely cause of the seasonal decline in zooplankton density and biomass.

Table 10 Mean summer total phosphorus (µg/liter), mean annual zooplankton densities (number individuals/liter) and biomass (µg/liter) for the 24 sentinel lakes, 2008-2010. Lakes arranged by landtype and TP.

Sentinel Lakes Zooplankton	Lake Type	Mean Summer TP (2000-2009)	Mean Annual Densities (2008-2010)	Mean Annual Biomass (2008-2010)
Prairie				
Artichoke	shallow	248	87.97	636.49
Shaokotan	shallow	167	129.46	1588.75
Madison	deep	78	52.59	245.04
St. James	shallow	52	75.94	134.52
St. Olaf	deep	37	68.23	287.02
Carrie	deep	22	51.89	196.58
Transition				
Peltier	shallow	266	62.21	657.47
Belle	shallow	55	43.80	307.74
South Center	deep	51	21.26	98.81
Pearl	shallow	40	52.31	229.52
Carlos	deep-ciscoe	16	14.60	55.21
Cedar	deep-ciscoe	13	14.08	49.27
Forest				
Portage	shallow	56	86.51	199.91
Hill (south)	deep	37	32.27	154.08
Red Sand	shallow	24	76.23	109.95
Hill (north)	deep	23	14.38	86.23
Elk	deep-ciscoe	17	12.67	36.42
South Twin	deep-ciscoe	17	30.90	55.22
Ten Mile	deep-ciscoe	12	12.58	37.56
Shield				
Echo	shallow	43	33.01	126.18
Elephant	deep	21	15.95	94.96
White Iron	deep-ciscoe	21	9.34	31.45
Tait	shallow	16	17.04	61.46
Bearhead	deep	14	5.53	23.36
Trout	deep-ciscoe	7	5.02	26.00

Figure 21 Mean monthly zooplankton densities (#/liter) and biomass (*µ*g/liter) in the sentinel lakes of the shield landtype 2008-2010. (Lakes are listed by increasing phosphorus 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 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 22). In general, the phosphorus, chlorophyll, and Secchi TSI values for Elephant Lake are in close correspondence with each other. The TSI values are shown based on MPCA data for 2008-2010 (Figure 22). Based on an average TSI score of 46 Elephant Lake would be characterized as mesotrophic. These values also affirm that continued Secchi monitoring via CLMP should provide a good basis for assessing trends in trophic status for Elephant Lake.

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

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

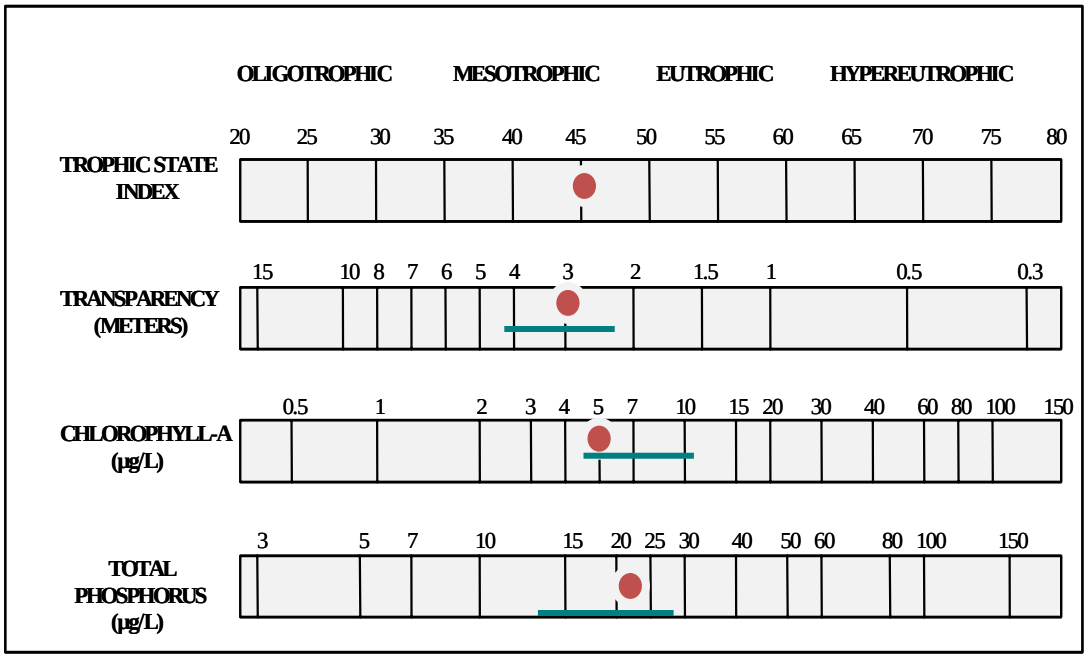
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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

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

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

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



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

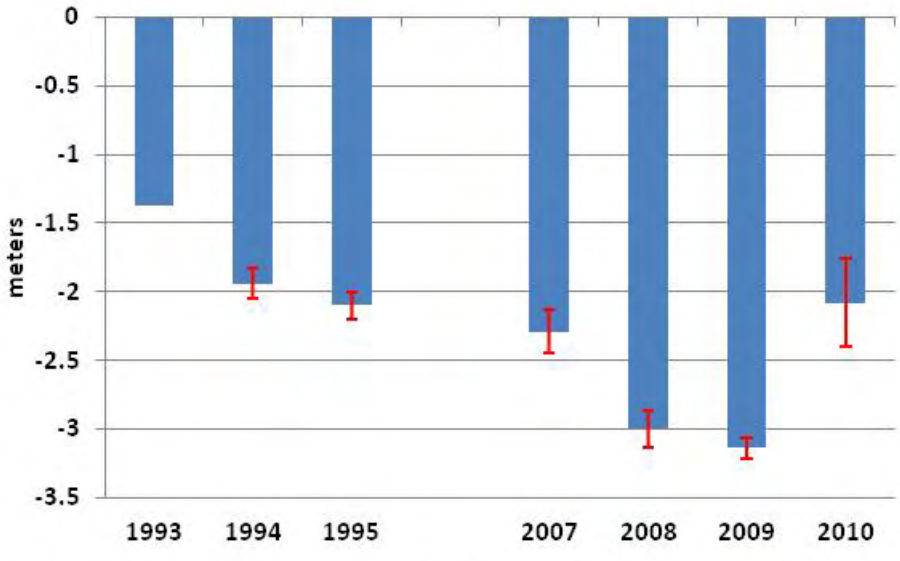
NLF Ecoregion Range — Elephant Lake 2008-2010

Figure 22 Elephant Lake TSI values from 2008-2010 MPCA Sentinel Lake monitoring data

Trophic status trends

One aspect of lake monitoring is to assess trends in the condition of the lake, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in STORET. A review of STORET data indicates that historical data are very sparse on Elephant. The majority of the available data was gathered through the Sentinel monitoring effort. In addition, there are some Secchi measurements gathered through CLMP. Current data are insufficient for trend analysis; however, the data are useful for characterizing year-to-year variability. Based on the recent measurements summer-mean Secchi averages about 2.5 m with a standard error of ~0.2 m. A simple comparison with the values from 1993-1995 with the 2007-2010 indicate present-day Secchi is equal to or better than the measurements from the earlier time-period. However, given the few measurements in some of the years and the few years of data this should not be deemed a "trend." Continued monitoring through CLMP, combined with future Sentinel monitoring will be critical to assessing trends over time in Elephant Lake.

Figure 23 Elephant Lake summer-mean Secchi. Standard error of mean noted



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 2008-10 water quality of Elephant Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker 1989) was used.

MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is routinely used as a screening tool for estimating lake conditions with minimal input data and is described in more detail in Wilson and Walker (1989). The model predicts in-lake TP from these inputs. Chl-a and Secchi predictions are derived from Minnesota-based regression equations. For analysis of Elephant Lake, MINLEAP was applied as a basis for comparing the observed (2008-10 average) 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.

The BATHTUB model (Walker 2004) provides a further basis for estimating water and nutrient budgets for Elephant Lake using a combination of runoff and P export coefficients based on land use in the watershed and data from similar watersheds in this ecoregion. The number of residences (~32 cabins) and the sole resort (~13 cabins) were used as a basis to estimate potential on-site inputs into the lake. For purposes of this modeling, standard per capita estimates of P loading to septic systems were used (based on seasonal usage). Since we had no details on the status of septic systems around the lake a conservative value of 80 percent retention was used, which implies that the system and soils retain 80 percent of the P loaded to them. If systems are up-to-code and properly maintained this should be a reasonable estimate.

Elephant Lake is located in the NLF ecoregion and the MINLEAP model was run using NLF-based inputs. The observed and predicted TP values for Elephant Lake were not significantly different (Table 11). Observed Chl-a and Secchi were consistent with the predicted values. An additional subroutine in the MINLEAP model estimates the “background” TP for the lake based on its alkalinity and mean depth and a regression equation developed by Vighi and Chiaudani (1985). For Elephant Lake, the estimated value is 15 µg/L, which is slightly lower than the observed concentration (Table 11). Overall, these results indicate that Elephant’s trophic status is quite similar to that expected based on its size, depth, size of watershed, and ecoregion it is located in.

MINLEAP predicts a P loading rate of about 224 kilograms per year entering Elephant Lake from its watershed and atmospheric deposition on the lake surface. The model predicts approximately 67 percent of the TP will be retained in the lake, a reasonable estimate given the lake’s small watershed, volume, and relatively long residence time (estimated at ~3-4 years).

BATHTUB predicted in-lake P at 18 µg/L, which is not significantly different from the observed P (Table 12). Predicted Chl-a and Secchi were comparable to observed. Estimates of watershed, atmospheric (deposition on surface of the lake), and on-site P loading were used to estimate in-lake P. This allowed for estimates of the relative contribution for each source category as follows: watershed ~55 percent, atmospheric ~42 percent and on-site septic systems ~3 percent. These are estimates only and were based on the limited information that was available. More refined estimates would require measurement of runoff from the watershed, more accurate estimate of precipitation on the lake, and more detailed information on the actual number, usage, and maintenance of on-site systems around the lake. The BATHTUB framework, as used in this current effort is included in the Appendix and could be modified in the future should more accurate estimates be required.

Table 11 MINLEAP model results for Elephant Lake

Parameter	2008- 2010 Elephant Lake Observed	MINLEAP Predicted NLF Ecoregion
TP (µg/L)	22 ±2	19 ±6
Chl-*a* (µg /L)	5.1 ±0.8	4.9 ±3.0
Secchi (m)	3.1 ±0.1	3.0 ±1.0
P loading rate (kg/yr)	-	224
P retention (percent)	-	67
P inflow conc. (µg/L)	-	58
Water Load (m/yr)	-	1.28
Outflow volume (hm^3/yr)	-	3.83
Residence time (yrs)		3.5
Vighi & Chiaudani P (µg/L)		15.4

Table 12 BATHTUB model results for Elephant Lake

Parameter	2008- 2010 Elephant Lake Observed	BATHTUB Predicted
TP (µg/L)	22 ±2	18
Chl-*a* (µg /L)	5.1 ±0.8	6.0
Secchi (m)	3.1 ±0.1	2.9
P loading rate (kg/yr)	-	216
P retention (percent)	-	66
P inflow conc. (µg/L)	-	36
Water Load (m/yr)	-	
Outflow volume (hm^3/yr)	-	4.0
Residence time (yrs)		3.4

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, Minnesota is required to asses all waters of the state to determine if they meet water quality standards. Waters that do not meet standards (i.e., impaired waters) are added to the 303(d) list and updated every even-numbered year. In order for a lake to be considered impaired for aquatic recreation use, the average TP concentration must exceed the water quality standard for its ecoregion. In addition, either the Chl-a concentration for the lake must exceed the standard or the Secchi data for the lake must be below the standard. A minimum of eight samples collected over two or more years are needed to conduct the assessment. There are numerous other water quality standards, which are used to 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. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL studies in Minnesota.

Elephant Lake was assessed relative to the NLF Class 2B ecoregion standards (Table 13). The 2008, 2009, 2010, and long-term summer-mean TP, chlorophyll-a and Secchi for Elephant Lake fully meet the water quality standards (Table 13). Based on these results, Elephant Lake is meeting eutrophication standards for NLF ecoregion 2B waters (i.e. those waters that support a cool and warm water fishery).

Table 13. Eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005). Elephant Lake 2008-2010 summer means; long-term means provided for comparison.

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
Elephant Lake long-term mean	**22**	**5.1**	**3.1**

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Appendix

Lake Water Quality Data for Elephant Lake for 2008-2010

All water quality data can be accessed at: http://www.pca.state.mn.us/data/eda ; blank cells = no data

Date	Time	Dep m	TP mg/L	O-P	Chla ug/L	Pheo	Secchi m	TKN mg/L	NO3	NH4-N
11/07/2007	08:30	0					4.6			
05/13/2008	09:30	0	0.026		2.55	2.26	3.0	0.47	0.12	
05/13/2008	09:30	9	0.018							
05/26/2008	14:00	0					4.1			
06/16/2008	10:00	0					4.3			
06/16/2008	12:45	0	0.025		3.52	0.76	2.7	0.55	0.08	
06/16/2008	12:45	1								
06/16/2008	12:45	2								
06/16/2008	12:45	3								
06/16/2008	12:45	4								
06/16/2008	12:45	5								
06/16/2008	12:45	6								
06/16/2008	12:45	7								
06/16/2008	12:45	8								
06/16/2008	12:45	8	0.015							
07/02/2008	16:30	0					3.1			
07/14/2008	09:00	0					3.2			
07/14/2008	12:00	0	0.026		4.87	1.28	2.7	0.51	< 0.05	
07/14/2008	12:00	8	0.020							
07/14/2008	21:00	0					3.2			
07/29/2008	10:00	0					2.9			
08/11/2008	11:30	0					2.9			
08/11/2008	11:33	0	0.026		5.34	1.07	2.7	0.67	< 0.05	
08/11/2008	11:33	7	0.046							
08/24/2008	13:00	0					3.0			
09/15/2008	10:15	0					3.7			
09/15/2008	11:00	0	0.021		7.25	1.56	3.0	0.59	< 0.05	
09/15/2008	11:00	8	0.023							
10/13/2008	11:00	0	0.020		15.5	0.73	3.4	0.66	< 0.05	
10/13/2008	11:00	8	0.017							
10/16/2008	17:00	0					3.4			
11/10/2008	14:00	0					3.5			
05/11/2009	21:00	0					3.4			
05/21/2009	13:29	0	0.013	< 0.005	1.87	0.44		0.43	< 0.05	< 0.05
06/10/2009	09:00	0	0.012		2.19	0.56	3.5	0.57	< 0.05	
06/10/2009	09:00	8	0.013							
06/14/2009	10:00	0					3.7			
07/02/2009	17:00	0					3.1			
07/08/2009	20:00	0					2.9			
07/20/2009	12:00	0	0.019	< 0.005	4.57	0.76	3.2	0.59	< 0.05	< 0.05
07/20/2009	12:00	7.5	0.020							

07/20/2009	12:00	8											
07/20/2009	12:00	8.4											
07/21/2009	13:00	0					2.9						
08/04/2009	11:00	0					2.9						
08/12/2009	09:00	0	0.018		3.34	0.51	3.7	0.56	< 0.05				
08/12/2009	09:00	8	0.025										
08/12/2009	09:00	8.7											
08/18/2009	13:00	0					3.1						
08/31/2009	10:00	0					3.1						
09/08/2009	14:00	0					2.9						
09/23/2009	10:00	0	0.020		4.97	0.96	3.0	0.99	< 0.05				
09/23/2009	10:00	8	0.019										
10/13/2009	09:15	0	0.029	< 0.005	8.22	0.97	3.0	0.64	< 0.05	< 0.05			
10/18/2009	11:00	0					3.4						
10/29/2009	12:00	0					3.1						
11/11/2009	12:00	0					2.9						
05/25/2010	11:45	0	0.022	< 0.005	1.52	< 0.42	3.0	0.41	< 0.05	< 0.05			
05/25/2010	11:45	8	0.014										
06/07/2010	09:00	0					4.3						
06/28/2010	10:00	0					3.2						
07/05/2010	08:00	0					3.4						
07/12/2010	15:00	0					2.7						
07/20/2010	12:00	0	0.027	< 0.005	10.1	1.64	2.4	0.85	< 0.05	< 0.05			
07/20/2010	12:00	8	0.050										
07/27/2010	09:00	0					1.8						
08/03/2010	08:00	0					1.4						
08/09/2010	08:00	0					1.1						
08/18/2010	08:30	0					1.1						
08/22/2010	10:00	0					0.9						
09/06/2010	10:00	0					1.2						
09/08/2010	08:00	0					1.5						
10/12/2010	12:45	0	0.034	< 0.005	14.2	2.2	2.1	0.98	< 0.05	< 0.05			
10/12/2010	12:45	8	0.021										
10/19/2010	10:00	0					2.1						
10/29/2010	09:00	0					2.4						
11/09/2010	08:00	0					2.7						

Date	Ca[1]	Mg	Na	K	DOC	TOC	Color	Alk	Cl	SO4	Fe-dis	Fe-T	TSS	TVS
09/03/2007	mg/L						PCU	mg/L						
05/13/2008													1.2	1.2
06/16/2008	22	16	1.30	1.2		8.3	40	36	1.21	3.16			< 1.0	< 1.0
07/14/2008	24	16	1.50	1.1		8.5	30	37	1.27	3.20			2	1.2
08/11/2008	29	17	1.50	1.1		8.4	30	39	1.15	3.08			1.6	1.2
10/13/2008	26	16	1.60	1.1		7.9	5	41	1.12	3.05			2	1.6
06/10/2009	9.65	3.72	1.28	0.97	8.9	9.0	40	36	1.22	3.17		64.1	< 1.0	< 1.0
07/20/2009	10.2	3.94	1.34	1.06	8.4	8.6	40	38	< 1.00	2.96		78.2	3.2	1.6
10/18/2009	10.4	3.96	1.37	1.06	8.8	9.5	30	40	1.01	3.03		113	4	2.8
05/25/2010	11.6	4.19	1.51	1.59	8.2	8.8	30	41	1.12	2.69	43.2		2	
07/20/2010	10.5	3.95	1.27	1.02	10.5	11.0	40	43	< 1	2.62	31.0		2	
10/12/2010	11.3	4.11	1.50	1.15	10.7	11.0	40	41	1.01	2.31	19.4		6.8	

1 Note reporting units for Ca and Mg changed between 2008 and 2009 as follows: 2008 Ca as $CaCO_3$ & 2009 Ca as Ca.

BATHTUB Inputs and Model Output

Global Variables	Mean	CV
Averaging Period (yrs)	1	0.0
Precipitation (m)	0.75	0.2
Evaporation (m)	0.66	0.3
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr	Mean	CV
Conserv. Substance	0	0.00
Total P	30	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	8	CANF & BACH, LAKES
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	5	P, JONES & BACHMAN
Secchi Depth	1	VS. CHLA & TURBIDITY
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

Seg	Name	Outflow Segment	Group	Area km^2	Depth m	Length km	Mixed Depth (m) Mean	CV	Hypol Depth Mean	CV	Non-Algal Turb (m^{-1}) Mean	CV	Internal L Conserv. Mean
1	Main Basin	0	1	3	4.5	2	4.2	0.12	0	0	0.2	0.2	0

Segment Observed Water Quality

Seg	Conserv Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Chl-a (ppb) Mean	CV	Secchi (m) Mean	CV	Organic N (ppb) Mean	CV	TP - Ortho P (ppb) Mean	CV
1	0	0	22	0.2	500	0	5.1	0.2	3.1	0.15	0	0	0	0

Segment Calibration Factors

Seg	Dispersion Rate Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Chl-a (ppb) Mean	CV	Secchi (m) Mean	CV	Organic N (ppb) Mean	CV	TP - Ortho P (ppb) Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

Trib	Trib Name	Segment	Type	Dr Area km^2	Flow (hm^3/yr) Mean	CV	Conserv. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (p Mean	CV
1	Elephant wshed	1	2	14.96	0	0	0	0	30	0.2	0	0	0	
2	On-site	1	1	0	0.001	0	0	0	7000	0	0	0	0	

Tributary Non-Point Source Drainage Areas (km^2)

Trib	Trib Name	Land Use Category---> 1	2	3	4	5	6	7	8
1	Elephant wshed	14.7	0.2	0	0	0	0	0	0
2	On-site	0	0	0	0	0	0	0	0

Non-Point Source Export Coefficients

Categ	Land Use Name	Runoff (m/yr) Mean	CV	Conserv. Subs. Mean	CV	Total P (ppb) Mean	CV	Total N (ppb) Mean	CV	Ortho P (ppb) Mean	CV	Inorganic N (ppb) Mean	CV
1	wetlands / forest	0.25	0	0	0	30	0	0	0	0	0	0	0
2	open/developed	0.3	0	0	0	150	0	0	0	0	0	0	0
3	landuse3	0	0	0	0	0	0	0	0	0	0	0	0
4	landuse4	0	0	0	0	0	0	0	0	0	0	0	0
5		0	0	0	0	0	0	0	0	0	0	0	0
6		0	0	0	0	0	0	0	0	0	0	0	0
7		0	0	0	0	0	0	0	0	0	0	0	0
8		0	0	0	0	0	0	0	0	0	0	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.000	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	1.000	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Segment Mass Balance Based Upon Predicted Concentrations

Component:		TOTAL P		Segment:	1	Main Basin	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	% Total	kg/yr	% Total	mg/m^3
1	2	Elephant wshed	3.7	62.4	119.3	55.1	32
2	1	On-site	0.0	0.0	7.0	3.2	7000
PRECIPITATION			2.3	37.6	90.0	41.6	40
TRIBUTARY INFLOW			0.0	0.0	7.0	3.2	7000
NONPOINT INFLOW			3.7	62.4	119.3	55.1	32
***TOTAL INFLOW			6.0	100.0	216.3	100.0	36
ADVECTIVE OUTFLOW			4.0	66.9t	73.4	34.0	18
***TOTAL OUTFLOW			4.0	66.9	73.4	34.0	18
***EVAPORATION			2.0	33.1	0.0	0.0	
***RETENTION			0.0	0.0	142.8	66.0	

Hyd. Residence Time =	3.3699	yrs
Overflow Rate =	1.3	m/yr
Mean Depth =	4.5	m

Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment:	1	Main Basin				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	18.3	0.33	14.3%	22.0	0.20	19.4%
TOTAL N MG/M3	500.0		13.9%	500.0		13.9%
C.NUTRIENT MG/M3	15.5	0.24	14.9%	17.6	0.11	18.8%
CHL-A MG/M3	5.7	0.55	25.5%	5.1	0.20	21.4%
SECCHI M	2.9	0.27	90.5%	3.1	0.15	91.7%
ORGANIC N MG/M3	301.1	0.26	18.7%			
TP-ORTHO-P MG/M3	10.7	0.54	13.9%			
ANTILOG PC-1	60.3	0.63	14.2%	48.7	0.23	10.9%
ANTILOG PC-2	9.8	0.24	78.9%	9.8	0.18	79.0%
(N - 150) / P	19.1	0.34	56.8%	15.9	0.19	46.1%
INORGANIC N / P	26.1	0.59	44.8%			
TURBIDITY 1/M	0.2	0.20	10.3%	0.2	0.20	10.3%
ZMIX * TURBIDITY	0.8	0.23	4.4%	0.8	0.23	4.4%
ZMIX / SECCHI	1.4	0.30	1.9%	1.4	0.19	1.5%
CHL-A * SECCHI	16.6	0.36	75.4%	15.8	0.25	73.2%
CHL-A / TOTAL P	0.3	0.30	76.2%	0.2	0.28	60.4%
FREQ(CHL-a>10) percent	11.0	1.51	25.5%	8.1	0.61	21.4%
FREQ(CHL-a>20) percent	0.9	2.34	25.5%	0.6	0.96	21.4%

FREQ(CHL-a>30) percent	0.1	2.86	25.%	0.1	1.18	21.4%
FREQ(CHL-a>40) percent	0.0	3.23	25.5%	0.0	1.34	21.4%
FREQ(CHL-a>50) percent	0.0	3.52	25.5%	0.0	1.47	21.4%
FREQ(CHL-a>60) percent	0.0	3.76	25.5%	0.0	1.58	21.4%
CARLSON TSI-P	46.1	0.10	14.3%	48.7	0.06	19.4%
CARLSON TSI-CHLA	47.6	0.11	25.5%	46.6	0.04	21.4%
CARLSON TSI-SEC	44.5	0.09	9.5%	43.7	0.05	8.3%