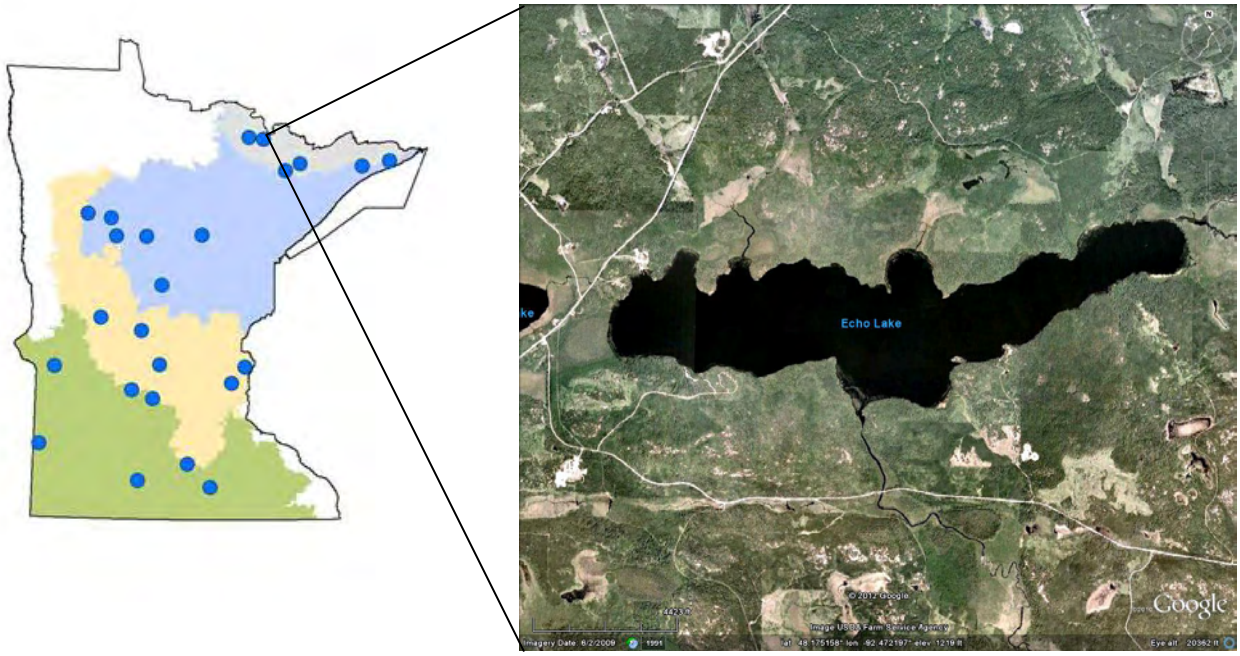
Sentinel Lake Assessment Report
Echo Lake (69-0615)
St. Louis County, Minnesota



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

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2008-11 Lake Assessment of Echo Lake (69-0615) St. Louis 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. "Shallow" lakes are defined as mixing continuously throughout the summer. "Cold Water" lakes are defined as lakes that harbor cisco, lake whitefish, or lake trout and are the focus of research funded by the Environmental Trust Fund (ETF). "Super sentinel" lakes also harbor cold-water fish populations and research on these lakes is funded by the ETF.

Echo Lake was selected to represent a shallow lake on the Canadian shield. It is a large but very shallow lake with a surface area of 461 hectares (ha) and a maximum depth of 3 meters (m). With a fetch of 5.9 kilometers (km), the lake is subjected to significant wind mixing and as a result, it is well mixed throughout most of the open water season. Echo Lake has a large forest and wetland dominated watershed, with a lake surface: watershed area of 27:1 that ultimately drains to Crane Lake. Because of the large watershed area and small volume, lake residence time is about 0.3 year, which implies the lake flushes about three times per year. Because the watershed lies in the Superior National Forest and Kabetogama State Forest there is very limited development on the lake.

Echo Lake is relatively nutrient-rich for a Shield Lake. Summer-mean total phosphorus (TP), chlorophyll-a (Chl-a), and Secchi averaged 44 µg/L, 7.3 µg/L, and 1.0 m over the 2008-2010 sampling. TP is high and Secchi is low as compared to Northern Lakes and Forests (NLF) ecoregion reference lakes. The Chl-a is within the typical range for the NLF. The lower than anticipated Chl-a and low Secchi can be attributed to the very high water coloration (112 platinum-cobalt units). This "bog stain" or coffee coloring arises from incompletely dissolved organic matter from the wetland and forest runoff that enters Echo. This dark coloration limits transparency and to some degree algal and plant productivity. In terms of trophic status the TP and Secchi values indicate eutrophic conditions, while Chl-a is in the mesotrophic range.

The initial fisheries survey of Echo Lake was done in 1960 and a re-survey was completed in 1988. Fish population assessments were done in 1972, 1976, 1980, 1983, 1986, 1987, 1991, 1996, 2001, 2006, and 2009. Though the precision of these surveys varied (e.g., prior to 1996 only three gill nets were used), they do allow for general comparison of fishery composition and status over time. Species found during the first survey included white sucker, shorthead redhorse, golden shiner, northern pike, yellow perch, walleye, johnny darter, pumpkinseed sunfish and rock bass. Although walleye still maintain a good population (higher than the third quartile for class 16 lakes) in Echo Lake, their numbers had previously been much higher. The two highest gill-net catch rates came from the 1960 and 1972 samplings. They were 38. 7 and 43.3, respectively. Gill nets were not used again until the 1988 survey due to concerns about the high catch rates, and when they were again implemented, only three were set. As stated, the trend from 1960 until the last gill netting survey from 2009 shows a general decline in the catch rates of

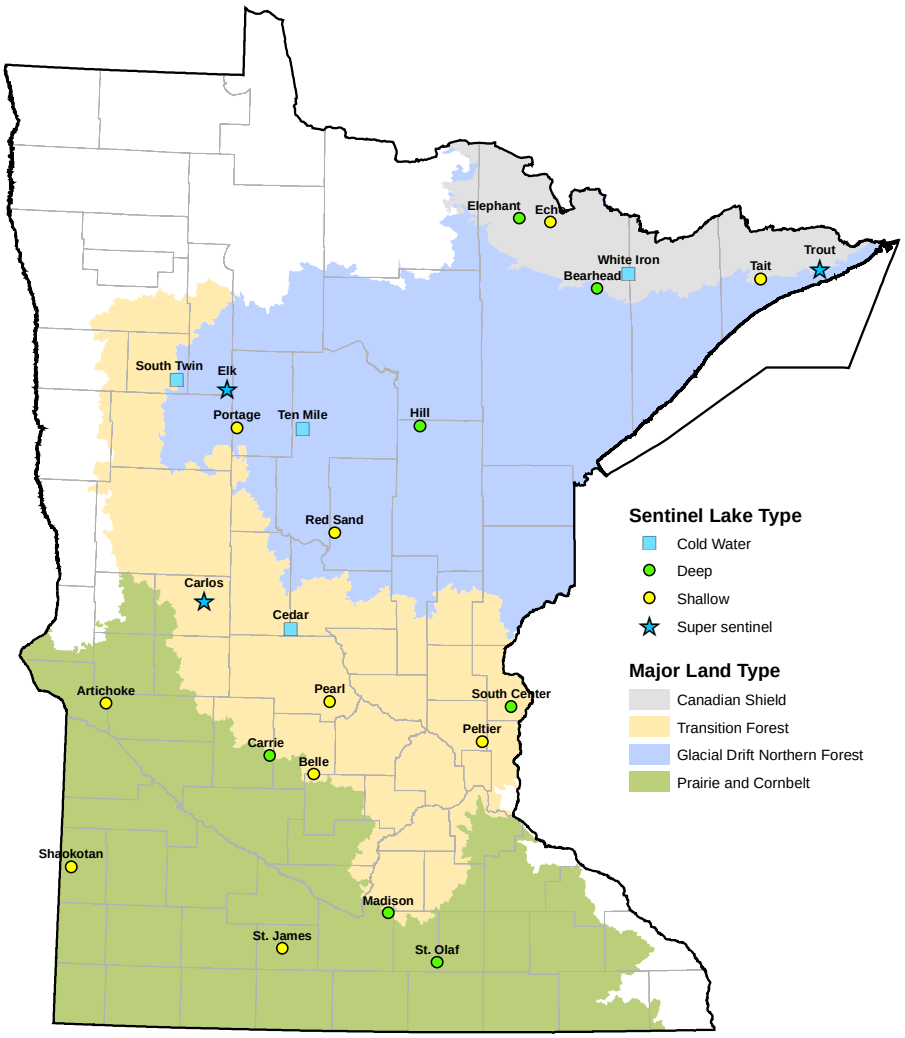
walleye. However, of all the gill net investigations, only the 2001 catch rate is below the third quartile for class 16 lakes.

Over the whole lake, submersed aquatic plants in Echo are relatively sparse (9 percent biovolume across the whole lake) and rarely grow deeper than 5 feet. The very low transparency, high coloration, and rocky substrates all serve to limit rooted plant growth. However, plants are relatively abundant and diverse nearshore. Survey crews recently sampled 4 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). An Index of Biotic Integrity developed by Beck et al. (2010) rates Echo Lake at 59-69 out of a possible 100. Some historic plant surveys from 1960 and 1988 note variable pondweed, yellow waterlilly, and wild rice as "common." While each of are still "found" in the lake, the current percent occurrence does not suggest they are common. These nearshore vegetated areas are critically important for northern pike, largemouth bass, and bluegill recruitment.

An ecoregion-base eutrophication model was used to predict in-lake TP based on Echo's size, depth, and watershed area using inputs from the NLF ecoregion. The model predicted an in-lake TP of 35 ±8µg/L, which not significantly different from the observed TP of 44 µg/L. Additional modeling estimated that about 92 percent of the P loading arose from watershed runoff and about 8 percent from atmospheric deposition on the surface of the lake. On-site septic systems from the two resorts on the lake were estimated to contribute <1 percent of the P load.

The trophic status measurements from 2008-2010 were compared to the lake eutrophication water quality standards for 2b lakes. This comparison indicates TP is greater than the 30 µg/L standard and Secchi is less than the 2.0 m standard. Chl-a, at 7.3 µg/L, complies with the 9.0 µg/L standard. Exceedance of the TP and Secchi standards would normally indicate that Echo would be considered impaired relative to the standard. However, given its large wetland and forest-dominated watershed, high water coloration, and model predictions it appears that this "exceedance" is the result of natural processes in the lake and watershed. This issue will be addressed when the Vermilion River watershed 303(d) "Impaired waters" assessment is conducted in 2015.

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 harbor cisco, lake whitefish, or lake trout and are the focus of research funded by the Environmental Trust Fund (ETF). “Super sentinel” lakes also harbor cold-water fish populations and research on these lakes is funded by the ETF.



Introduction

This report provides a relatively comprehensive analysis of physical, water quality, and ecological characteristics of Echo Lake in St. 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), US Geological Survey (USGS) and volunteer water quality monitoring, and analysis of various other sources of data for the lake. The water quality assessment focuses on data collected during the 2008-2010 seasons; however, historical data are used to provide perspective on variability and trends in water quality. Water quality data analyzed includes all available data in EQuiS, the state 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: (www.pca.state.mn.us/water/lakeprotection.html).

Background

Lake morphometric and watershed characteristics

Echo Lake is located in St. Louis County within the Vermilion River watershed (Figure 2), part of the Lake of the Woods basin. Echo Lake is near Buyck, MN and about 22 miles NE of Orr. It lies between Voyageurs National Park to the north and the BWCAW to the east. The watershed lies in the Superior National Forest and Kabetogama State Forest. The vast majority of the watershed is forest and we tland and the primary road network is the Echo Trail that runs near the west and south sides of the lake. Crane Lake Road runs to the NW of the lake but there is no road network along the north shore of the lake. The lake has very limited development with two small resorts: Timber Wolf Point and Trails End and a USFS campground on the south side of the lake.

Echo Lake is located in a bedrock basin and is surrounded by forested land (Figure 3). Quaternary geology includes thin, unconsolidated materials (gravel and boulders) over bedrock (Olcott et. al., 1978). The lake has a very large watershed, made up of forest, wetlands, and open water

Echo Lake's morphometric characteristics are summarized in Table 1. It is a large lake but extremely shallow and with its long fetch is quite subject to wind mixing. It is 100 percent littoral. Percent littoral refers to that portion of the lake that is 4.6 meters (15 feet) or less in depth, which often represents the depth to which rooted plants may grow in the lake). The lake has five inlets and one outlet (Echo River) that drains to the NE to Crane Lake and eventually to Hudson Bay.

Table 1. Echo Lake and watershed morphometric characteristics.

Lake name & ID	Lake basin hectares (acres)	Littoral area (%)	Total watershed area ha (acres)	Watershed: lake	Max. depth meters (feet)	Mean depth meters (feet)	Fetch km (mi)	Lake volume acre-ft.
Echo 69-0615	461 (1,139)	100%	12,521 (30,929)	27:1	3.0 (10)	1.8 (6)	5.9 (3.7)	6,834

Lake bathymetry based on original surveys in 1941

Figure 2. Echo Lake watershed and land use.

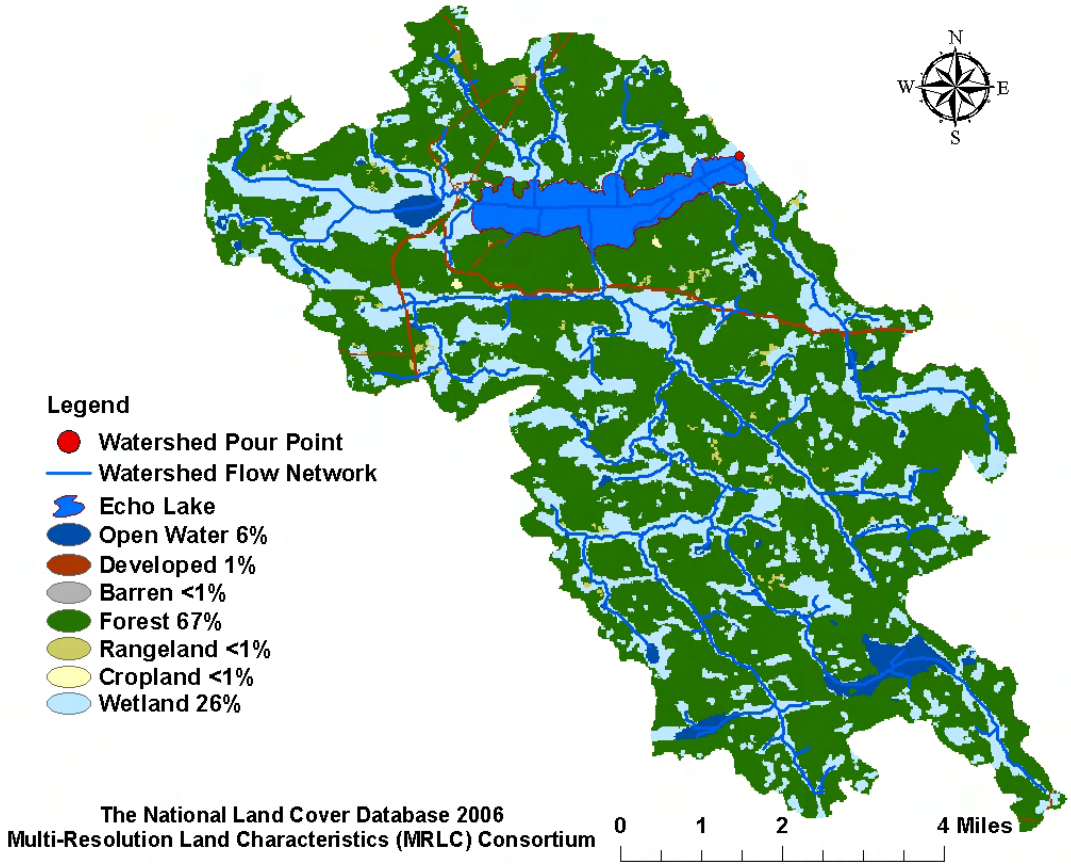
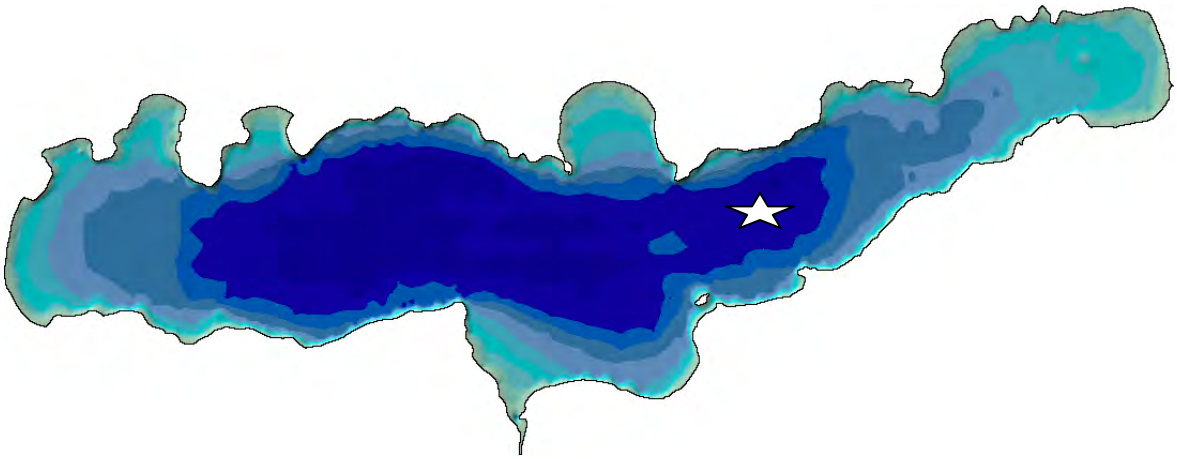


Figure 3. Echo Lake depth contours. Darkest color represents 10-foot contour. Sample site noted.



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. Echo Lake lies within the Northern Lakes and Forest (NLF; Figure 4) 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 most closely 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 Echo Lake watershed is nearly all forest, wetlands, and open water. There has been little change in land use since 1969 (Table 2), primarily because most of the watershed is within the public lands of Superior National Forest.

Figure 4. Aquatic ecoregions as mapped by Omernik. Echo Lake noted.

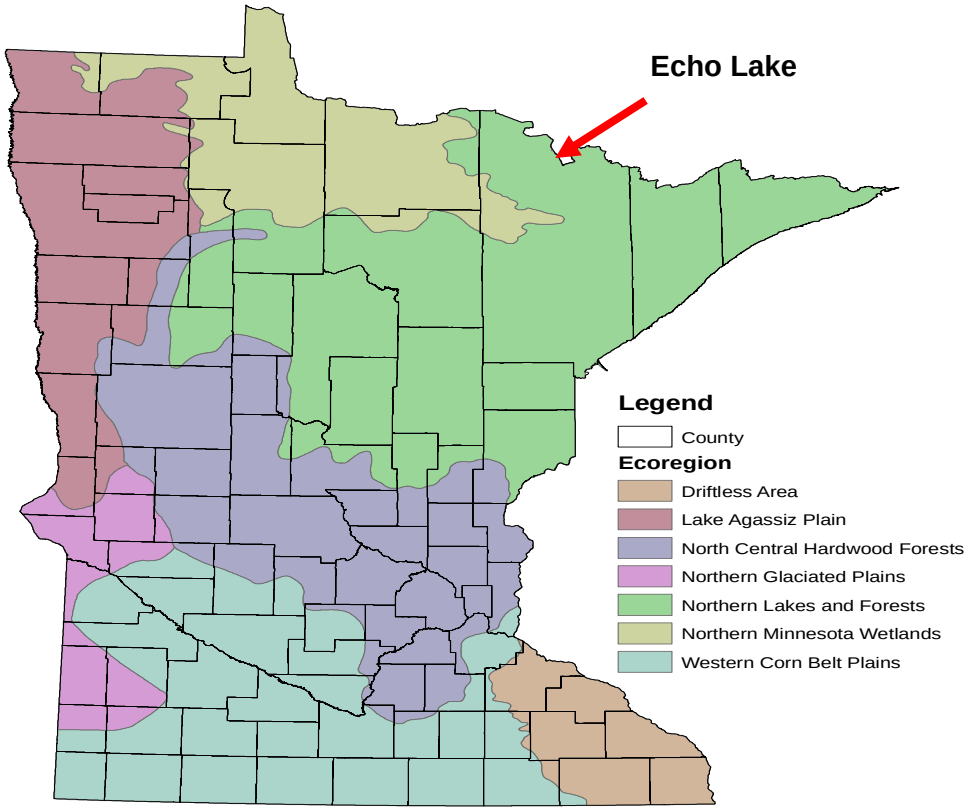


Table 2. Echo Lake watershed ecoregion land use comparison. Typical (interquartile) range based on NLF ecoregion reference lakes noted for comparison (Heiskary and Wilson 2005).

Land Use (%)	Echo (2001)[1]	NLF ecoregion
Developed	<1	0 - 7
Cultivated (Ag)	<1	< 1
Pasture & Open	1	0 - 6
Forest	67	54 - 81
Water & Wetland	32	14 - 31

[1]National Land Cover Database 2006 www.mrlc.gov/index.php

History

Some historical notes on Echo Lake were compiled from various sources including MDNR Fishery management plan and associated records, MPCA records, and historical accounts from the two resorts on the lake: Timber Wolf Point and Trails End

1915-1942 Various species of fish were stocked by MDNR

1960 Initial survey conducted by MDNR, surveys were repeated periodically up through 2001

1969 Last fish stocking of record

1969 Initial land clearance and development of what would become Timber Wolf Point Resort took place in this approximate timeframe

1981 MPCA conducted some initial sampling as a part of acid rain surveys

1992 MDNR conducts a water quality survey

2001 MPCA samples Echo as part of Crane and Little Vermilion Lake study

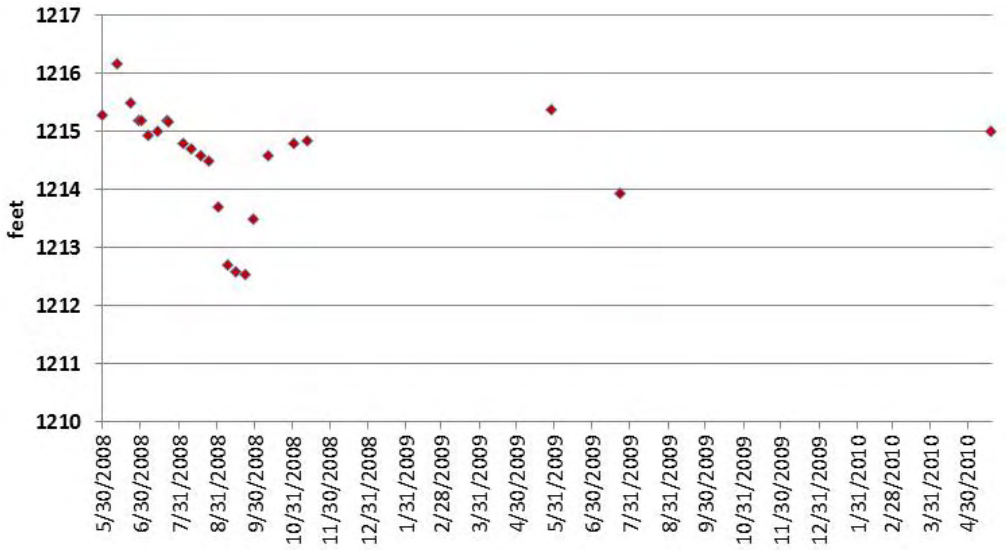
2008 Echo Lake included in Sentinel Lakes program and intensive sampling initiated

Lake level

The MDNR Division of Waters began lake level monitoring on Echo in 2008, with several instantaneous readings and a couple readings in 2009 and 2010 (Figure 5). During 2008, lake level averaged 1214.5 feet. Lake level was at its highest in early June coincident with a rainy period (Figure 6). As rain subsided in July and August lake level declined because of evaporation. Lake level increased in late September and October in response to fall rain events. The overall change in lake level (3.6 feet) from the peak of 1216.17 (June 11) to the minimum of 1212.54 (September 22) is rather significant given the overall shallowness of the lake.

A couple spot measurements were made in spring of 2009 and 2010 and those measurements were relatively similar to 2008. The most recent measurement was 1214.5 feet on June 1, 2011, which is slightly lower than for the corresponding date in 2008.

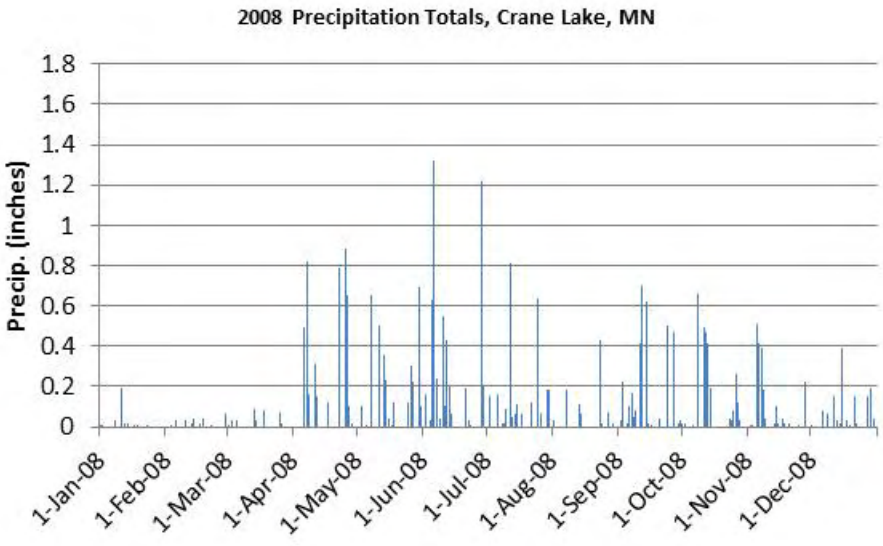
Figure 5. Echo Lake level elevations in 2008, 2009, and 2010. MDNR data with elevation in feet above MSL.



Precipitation and climate summary

Climate and precipitation records for the 2008-2010 field seasons varied somewhat. Rain gage records from Crane Lake (the closest long-term climate station to Echo Lake) show two 2.5 centimeter (cm; 1 inch) plus rain events during the 2008 field season and four during 2009 (Figure 6). Large rain events will increase runoff into the lake and may influence in-lake water quality and lake levels. Overall precipitation amounts were fairly similar in calendar years 2008 and 2009 with annual precipitation of 69 and 71 cm respectively and May to September values of 40 and 39 cm. Precipitation records for the 2008 water year (October 2007 through September 2008) showed conditions were slightly wetter than average, while 2009 was near normal (Figure 7).

Figure 6. 2008 and 2009 rainfall based on records for, Minnesota State Climatology Office Data.



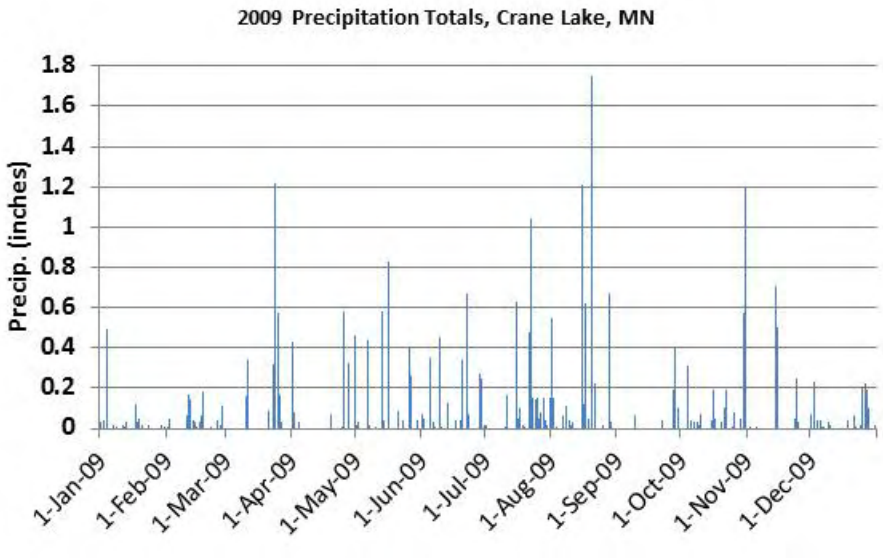
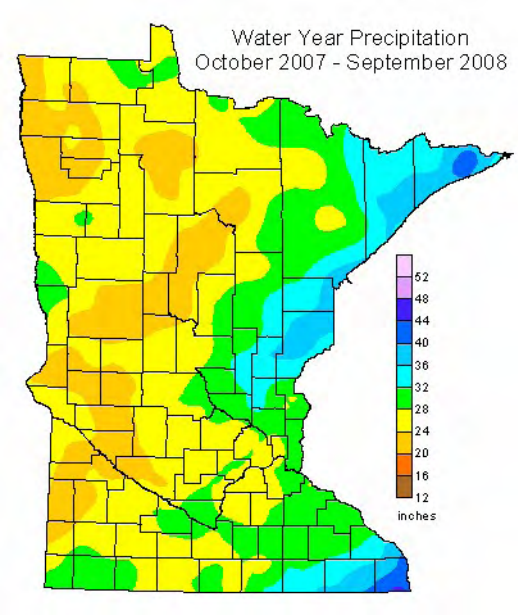
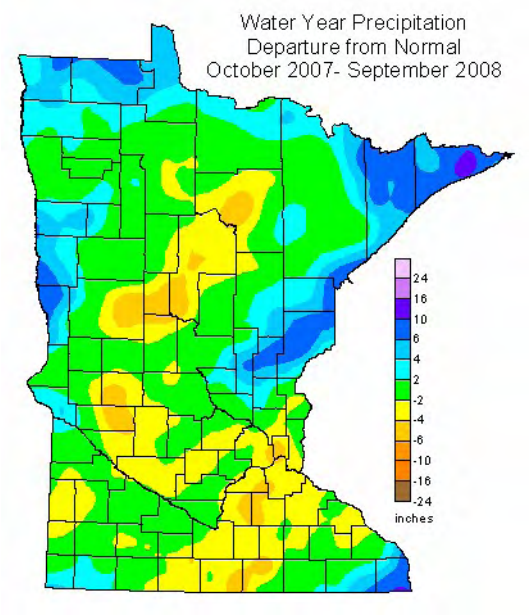
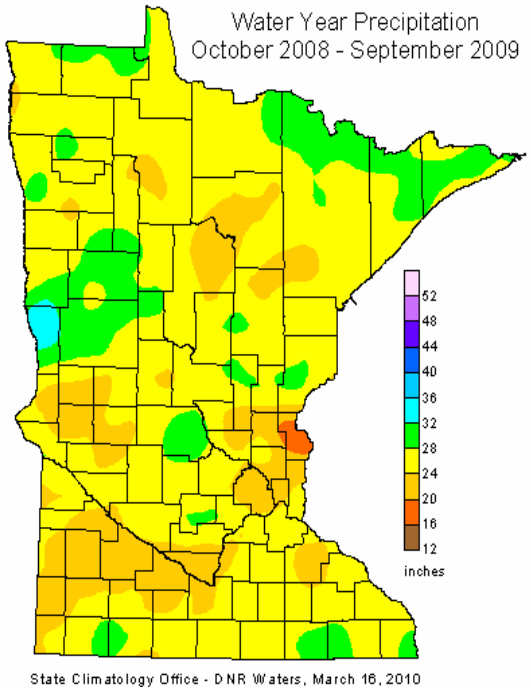
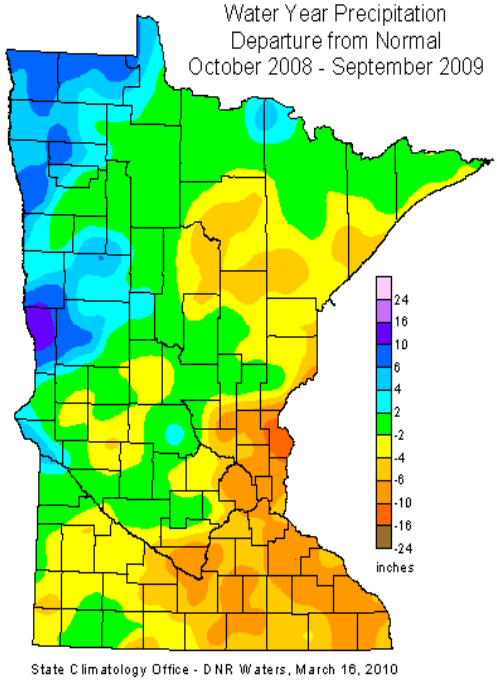


Figure 7. 2008-2009 Minnesota water year precipitation and departure from normal (State Climatology Office data).









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 one 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). Nearshore 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 Echo Lake were collected by the MPCA. MPCA staff sampled Echo monthly from May through October. Samples were collected at the lake's maximum depth, in the northeast portion of the lake (MPCA site # 101; Figure 2). MPCA lake surface samples were collected with an integrated sampler, a poly vinyl chloride (PVC) tube two meters (6.6 feet) in length, with an inside diameter of 3.2 cm (1.24 inches). Zooplankton samples were collected with an 80-micrometer (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 dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken by MPCA, MDNR, and USGS staff. Sampling procedures were employed as described in the MPCA Standard Operating Procedure for Lake Water Quality document, which can be found here: www.pca.state.mn.us/publications/wq-s1-16.pdf.

Laboratory analysis was performed by the laboratories of the Minnesota Department of Health, or USGS 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 withdrawn at a rate of approximately 0.5 meters per second. Contents were rinsed into sample bottles and preserved with 100 percent reagent alcohol. Analysis was conducted by MDNR personnel.

Each zooplankton sample was adjusted to a known volume by filtering through 80 micrograms per liter (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

The initial survey of Echo Lake was done in 1960 and a re-survey was completed in 1988. Fish population assessments were done in 1972, 1976, 1980, 1983, 1986, 1987, 1991, 1996, 2001, 2006, and 2009. Precision varied among the surveys (e.g., prior to 1996 used only three gill nets, however, data are useful for describing fishery composition and general trends. Species found during the first survey included white sucker, shorthead redhorse, golden shiner, northern pike, yellow perch, walleye, johnny darter, pumpkinseed sunfish and rock bass. Night electrofishing was initiated in 1991 and repeated in 1996, 2006, and 2008 through 2011 to better assess largemouth and smallmouth bass populations. In 1996 gill netting effort was increased to nine gill net sets to improve confidence in abundance estimates. Ice out trap netting targeting northern pike as well as general summer trap netting was initiated and conducted from 2008 to 2011 as part of the SLICE sampling project. SLICE sampling protocols on Echo Lake called for annual ice-out trap net sampling, spring electrofishing for bass, summer trap netting using standard ¾ inch nets, ¼ inch nets, and gill-net sampling at least once during the pilot study to sample the fish community.

Although walleye still maintain a good population (higher than the third quartile for class 16 lakes) in Echo Lake, their numbers had previously been much higher. The two highest gill-net catch rates (based on three gill nets in each year) came from the 1960 and 1972 samplings (Table 3, Figure 9). They were 38.7 and 43.3 respectively. Gill nets were not used again until the 1988 survey due to concerns about the high catch rates, and when they were again implemented, only three were set. As stated, the trend from 1960 until the last gill netting survey from 2009 shows a general decline in the catch rates of walleye. However, of all the gill net investigations, only the 2001 catch rate is below the third quartile for class 16 lakes (Figure 9).

Walleye abundance of 14.5 per gill net in 2009 was above the third quartile (13.73 fish/set) for Class 16 lakes, which implies a healthy population relative to other lakes in its class. The 2009 catch does represent a decline from levels reported prior to 1996 but up from the low point of 5.5 in 2001. Walleye lengths ranged from 4.0 to 23.5 inches with a mean of 12.0 inches. The mean weight was 0.81 pounds, which is just above the first quartile. Ten year-classes (ages 1-10) were present in the 2009 assessment with good distribution. Back calculated length at age-4 was 14.8 inches, which is just above the mean of 14.6 inches for walleye samples taken from the International Falls Management Area (IFMA) since 1989.

Walleye trap-net catches are not normally analyzed but because Echo has been grouped in as part of the SLICE project it has received four years of annual summer trap-net sampling. It also has more trap-net sampling years than the gill-net sets from 1960 making the gear worth looking at. When comparing a trend of the CPUE of the trap-nets to the CPUE of the gill-nets through the years, the period in which the walleye population seems to have decreased and has yet to recover from can easily be identified. When looking at the trap-net catches (Figure 9) it shows the CPUE rose and fell from 1960 to 1983 but after that point, the overall cyclic pattern stays much lower than what it was before 1983.

An electrofishing assessment was done on April 28, 1995 by the Fond du Lac Band of Lake Superior Chippewa. The objective was to obtain estimates of adult walleye abundance and age distribution and to calculate safe harvest levels. Surveys were planned to begin at ice-out and continue as long as pre-spawn walleye could be captured. Sampling on Echo Lake began five days after ice-out and found that most walleye had already spawned. Ninety four walleye were sampled and no population estimate was made.

Northern pike abundance has generally been above the Lake Class 16 median of 3.6 per gill-net with the exception of the initial survey in 1960. Though only three gill-net sets were made, the catch rate of 1.7 per net suggests lower abundance at that time. Northern pike abundance of 10.3 per gill-net set a new record high in 2006, but in 2009, the catch rates fell to 4.7, still above the median though (Figure 9). Lengths ranged

from 14.7 to 35.6 inches with a mean of 23.4 inches. The mean weight was 2.84 pounds, which did exceed the third quartile (2.50) of class 16 lakes. Six year classes (ages 2-9) were present in the 2009 assessment with the 2005 year class contributing nearly 46 percent of the total catch. Length at age-4 was 22.9 inches, which is just below the IFMA mean.

Ice-out trap net sampling for northern pike was done from 2008 to 2011 as part of the SLICE protocol. Over the four-year period CPUE values were 7.2, 8.3, 4.3, and 2.6 fish/lift respectively, with a mean of 5.6 fish/lift (Figure 9). Mean lengths were 21.7, 22.2, 21.4, and 19. 8 inches and mean weights were 2.26, 2.51, 2.42, and 2.26 pounds respectively. Maximum length values were 30.8, 34.3, 40.0, and 39.0 inches respectively.

Smallmouth bass young-of-year were first captured in seines in 1980. Electrofishing in 1991 sampled three smallmouth bass and one was captured in a gill net in 2001. The 2009-2011 electrofishing (6.8, 9.9 and 7.3 fish/one hour of on time) suggests that the smallmouth bass population has declined slightly from previously higher numbers recorded in 2006 (25.2) and 2008 (20.2) (Figure 8). Mean lengths ranged from 9. 7 to 13.6 inches and mean weights ranged from 0.66 to 1.56 pounds between 2006 and 2011. Age and growth data is only available for the 2006, 2008, and 2009 samples but the average growth at age-4 was 11.1 inches, which puts it near the 90th percentile for IFMA lakes. Largemouth bass were sampled by electrofishing in 2006, 2008, and 2009, however, no largemouth have been sampled in the two most recent surveys (2010 and 2011). The CPUE's for the three years that largemouth were caught are 1.6, 14.8 and 0.5 fish/one hour of on time respectively. These odd catch rates are quite perplexing, although may represent inherent variability of the gear. The three largemouth caught in the 2006 survey had a mean weight of 1.35 pounds/fish. The 25 fish caught in 2008 had a mean weight of 0.68 pounds/fish, while the one fish caught in 2009 had a weight of 4.85 pounds.

A single 3.5-inch black crappie was captured in a trap net in 1988, which was the first recorded observation of this species in Echo Lake. Black crappie abundance increased rapidly and has been above the median (2.4) for class 16 lakes in all-subsequent assessments, except in 2009 (Figure 9). Catch rates have been above the 75th percentile in 5 of the 9 samples that have been taken since crappie were first discovered in 1988. Growth is slightly above the median for crappie in the IFMA. Length at age-4 for all samples between 1991 and 2009 are generally between the median and third quartile when compared to area lakes. The 2009 trap-netting sample ranged from 2.1 to 11.8 inches with a mean length of 9 inches. Five year-classes were present and age ranged from 2 to 7 years.

The first bluegill was sampled in 1991, though their abundance has remained low. Of the eight samples taken since 1991, only one year (2008) had a CPUE (1.3 fish/lift) higher than the lake class 16 first quartile (0.93), all other samples have been at or below 0.5 fish/lift (Figure 9). The bluegill from the 2008 sample had a length range of 3.6 to 8.4 inches with a mean of 4.6 inches. Growth to age-4 was 5.3 inches, which is slightly below the median of 5.5 inches for bluegill in the IFMA. In this sample three year classes were represented ranging from age 2 to 6. However, 87 percent of the fish were from the age-2, 2006 year class.

Yellow perch have been sampled in gill-nets since the initial survey in 1960. The 1960 survey had by far the highest CPUE (36. 7 fish/net) of all the samples taken. Since 1988 the gill-net CPUE has generally hovered between the median (9.20) and the first quartile (4.71). The two outlying years were 1996, which had a CPUE of 9.5 fish/net, and 2006, which had a CPUE of 3.4 fish/net (Figure 9). Lengths from the 2009 assessment ranged from 5.0 to 10.4 inches with a mean of 6.7 inches. Length at age-4 was 6.4 inches, which is right at the median for IFMA lakes. Six year classes were represented with ages ranging from 2 to 9. Nearly 46 percent of the sample came from the age-4, year class.

A summary of the overall gill net, trap net and electro-fishing effort for Echo Lake is provided in Table 3. This summary allows for a direct comparison among years and shows how effort varied among the years.

Figure 8. Comparison of gill net, trap net & electro-fishing catches over time for select fish species for Echo Lake. Expressed as catch-per-unit effort.

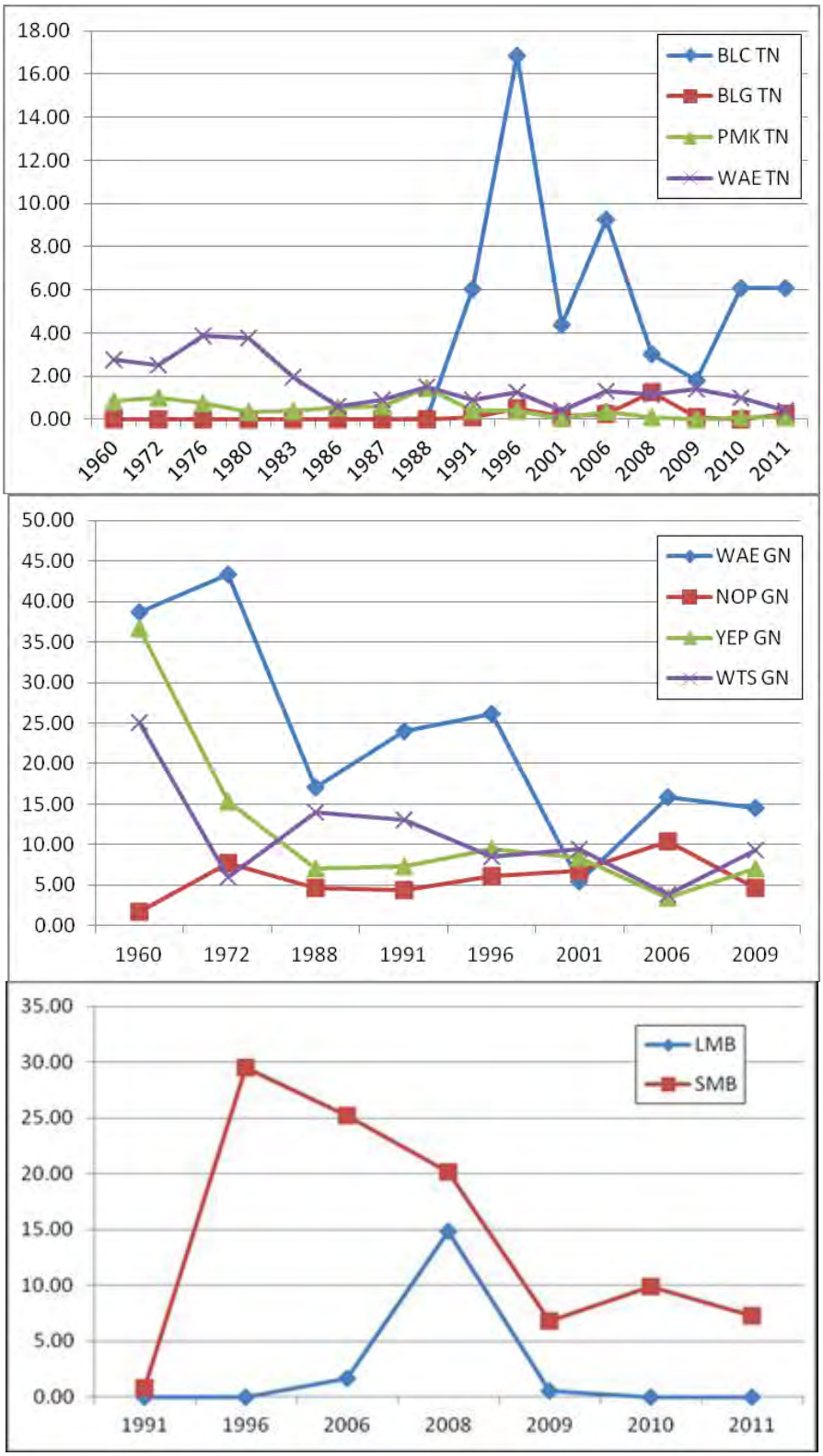
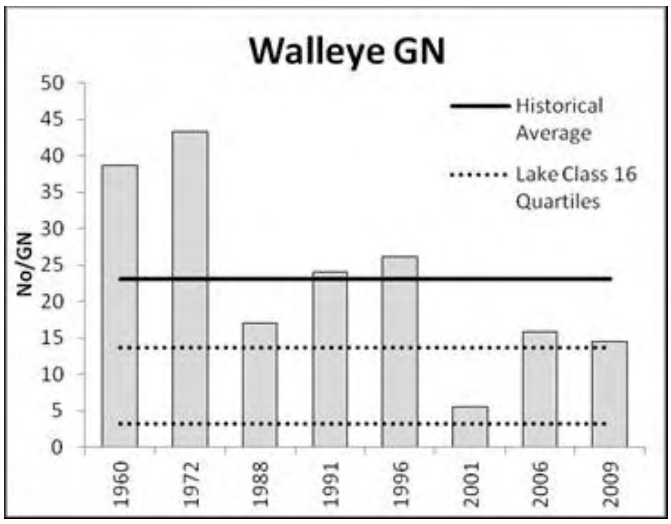
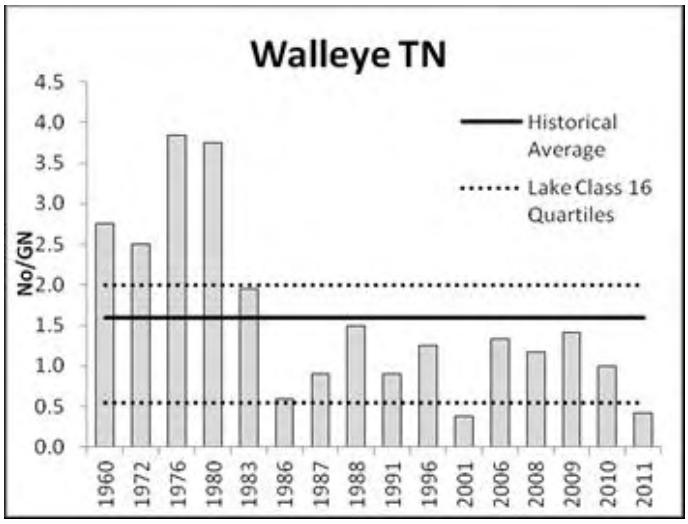
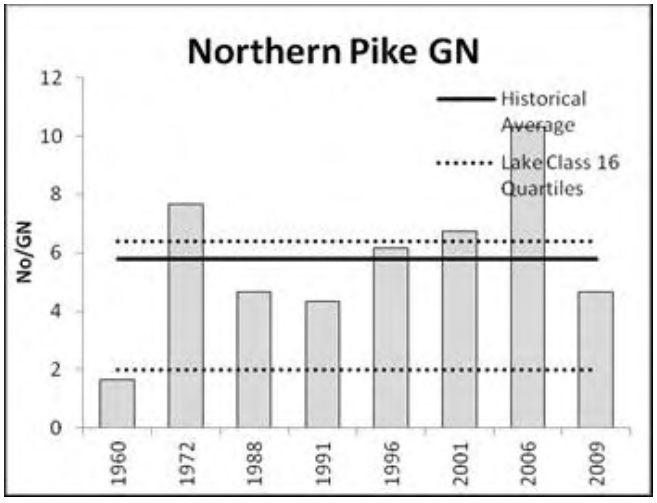
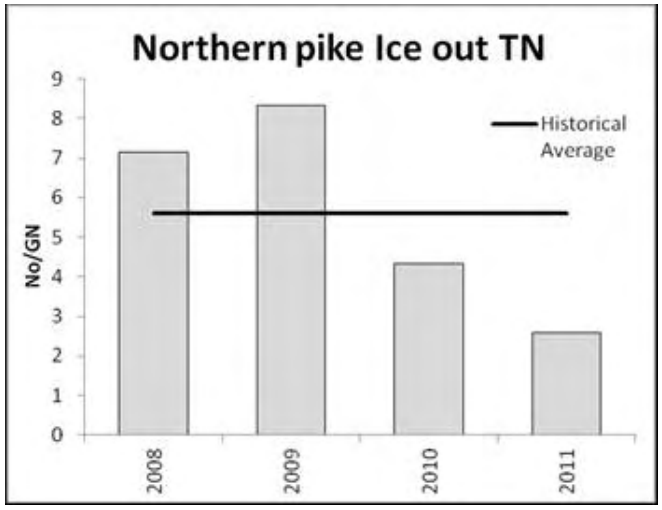


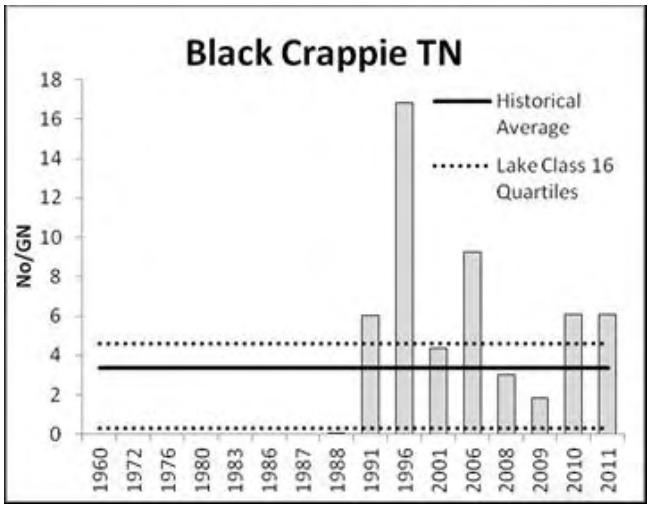
Figure 9. Fish netting trends as compared to historical average for Echo and Lake Class 16 interquartile range. GN=gill net and TN=trap net.











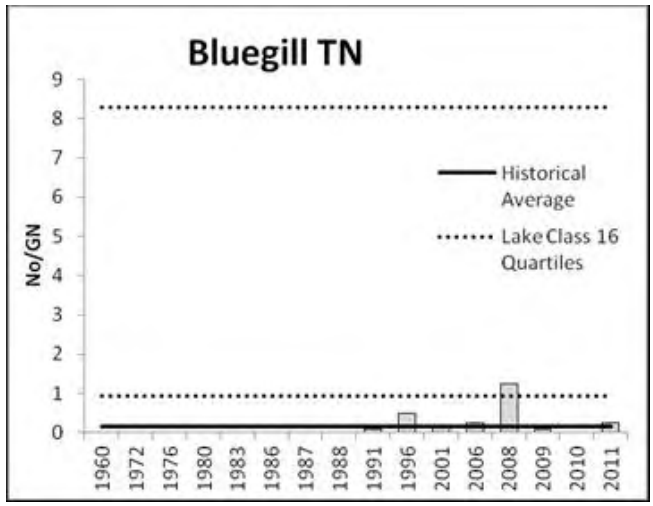


Figure 9. (continued)

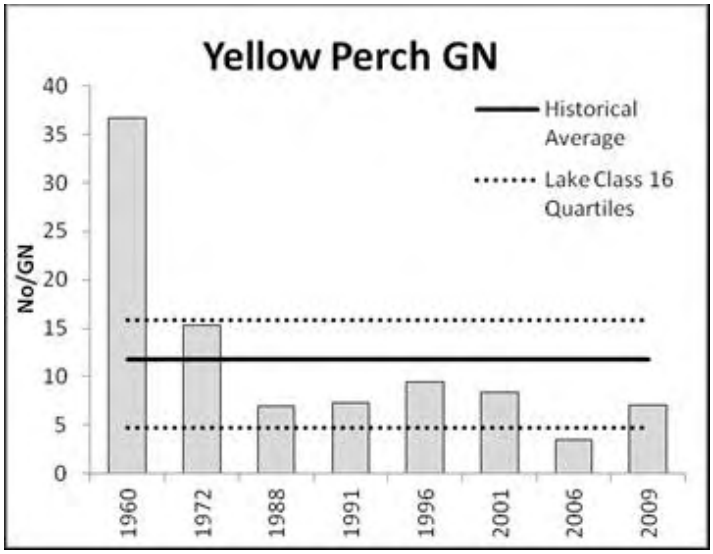


Table 3. Summary of a) trap-net, b) gill net, & c) electro-fishing CPUE by selected species, Echo Lake, 1960-2011.

a)

Year	Number Nets	Black Crappie	Bluegill	Pumpkinseed	Walleye
1960	20	0.0	0.0	0.9	2.8
1972	2	0.0	0.0	1.0	2.5
1976	20	0.0	0.0	0.8	3.9
1980	20	0.0	0.0	0.4	3.8
1983	20	0.0	0.0	0.4	2.0
1986	20	0.0	0.0	0.6	0.6
1987	21	0.0	0.0	0.6	0.9
1988	20	0.1	0.0	1.5	1.5
1991	20	6.1	0.1	0.4	0.9
1996	12	16.8	0.5	0.4	1.3
2001	16	4.4	0.0	0.1	0.4
2006	12	9.3	0.3	0.3	1.3
2008	12	3.0	1.3	0.1	1.2
2009	12	1.8	0.1	0.0	1.4
2010	12	6.1	0.0	0.1	1.0
2011	12	6.1	0.3	0.1	0.4

b)

Year	Number Nets	Walleye	Northern Pike	Yellow Perch	White Sucker
1960	3	38.7	1.7	36.7	25.0
1972	3	43.3	7.7	15.3	6.0
1988	3	17.0	4.7	7.0	14.0
1991	3	24.0	4.3	7.3	13.0
1996	6	26.2	6.2	9.5	58.5
2001	8	5.5	6.8	8.4	9.5
2006	9	15.9	10.3	3.4	3.9
2009	9	14.6	4.7	7.1	9.3

c)

Year	1991	1996	2006	2008	2009	2010	2011
Effort (hours)	3.84	1.73	1.83	1.68	1.91	1.93	2.06
Smallmouth Bass	0.78	29.50	25.17	20.19	6.80	9.85	7.27
Largemouth Bass	0.00	0.00	1.64	14.84	0.52	0.00	0.00

Aquatic plant assessment

Over the whole lake, submersed aquatic plants in Echo are relatively sparse (9 percent biovolume across the whole lake) and rarely grow deeper than 5 feet (Figure 10). The very low transparency, high coloration, and rocky substrates all serve to limit rooted plant growth. However, plants are relatively abundant and diverse nearshore (Figure 8, Figure 9). Survey crews recently sampled 4 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). An Index of Biotic Integrity developed by Beck et al. (2010) rates Echo Lake at 59-69 out of a possible 100. Some historic plant surveys from 1960 and 1988 note variable pondweed, yellow waterlilly, and wild rice as "common." (Table 4). While each of are still "found" in the lake, the current percent occurrence does not suggest that they are common (Table 5). These nearshore vegetated areas are critically important for northern pike, largemouth bass, and bluegill recruitment

Eighty-five percent of Echo Lake's shoreline is under public ownership (mostly the Superior National Forest). Currently two small resorts operate on the lake. Only four docks structures were identified from 2009 aerial photos. Thus, there is little threat of damage of aquatic plants by nearshore development and recreation activities.

Figure 10. Percent biovolume of aquatic vegetation in Echo Lake, St. Louis Co. in July 2008 mapped using hydroacoustics and kriging interpolation (Valley et al. 2005).

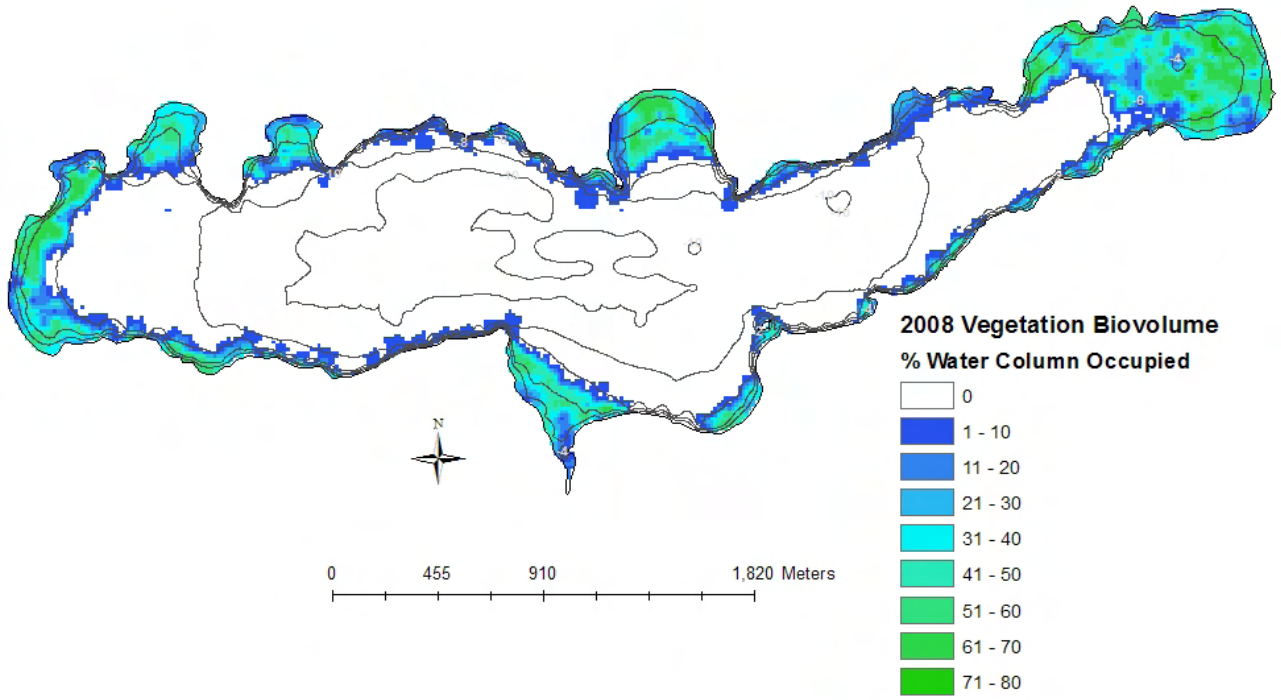


Figure 11. Number of aquatic plant species surveyed at each point during point intercept surveys in July 2011 on Echo Lake, St. Louis Co.

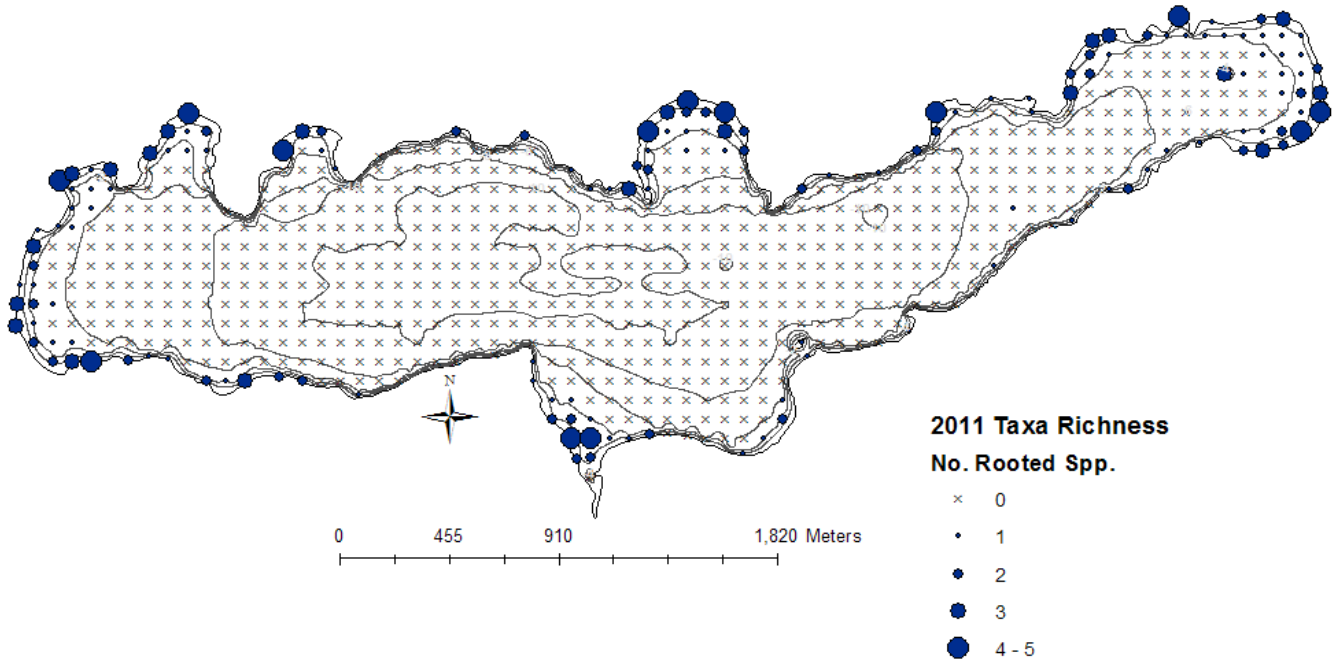


Table 4. Common species observed during previous transect surveys. Species documented were either labeled as "common" at any transect or found at ≥ 10% of the transects. The aquatic plant surveys in 1960 and 1988 were rapid assessments of vegetative cover and likely missed many other common species.

Date	Common Name	Species Name	Growth Form
7/24/1960	Variable pondweed	*Potamogeton gramineus*	Submersed
	Yellow waterlily	*Nuphar spp.*	Submersed
8/25/1988	Wild Rice	*Zizania aquatica*	Emergent
	No submersed spp. listed as common		

Table 5. Percent frequency of occurrence of aquatic plant species at depths of 15 feet or less sampled during point-intercept surveys on Echo Lake on 21 July 2008, 3 August 2009, 15 July 2010, and 1 July 2011.

Common Name	Species Name	Growth Form	Frequency (%) 2008	2009	2010	2011
All rooted plants			25.8	26.3	24.4	20.0
Water celery	*Vallisneria americanus*	Submersed	18.3	20.0	18.0	14.8
Wild rice	*Zizania palustris*	Emergent	8.1[a]	6.7	4.6	4.0
Stonewort	*Nitella sp.*	Submersed	7.7[b]	0[b]	0[b]	0[b]
Filamentous Algae			6.9	7.0	1.6	3.0
Bladderwort	*Utricularia sp.*	Submersed	4.5	4.3	1.2	0
Small pondweed	*Potamogeton pusillus*	Submersed	3.7	3.7	0.4	0
Coontail[c]	*Ceratophyllum demersum*	Submersed	2.4	3.0	4.7	0.1
Floating-leaf burreed	*Sparganium sp.*	Emergent	2.2[a]	0	0	0
Yellow waterlily	*Nuphar sp.*	Floating-leaf	1.7	0	1.7	1.6
Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	1.6	1.3	1.4	0.3
Southern naiad	*Najas guadalupensis*	Submersed	1.6	0	0	0
White waterlily	*Nymphaea sp.*	Floating-leaf	1.6	0	1.4	0
Arrowhead	*Sagittaria sp.*	Emergent	1.4	1.3	0.6	0.1
Watershield	*Brasenia shreberi*	Floating-leaf	1.3	1.3	2.1	1.4
Water marigold[d]	*Bidens beckii*	Submersed	1.3	2.4	2.2	1.8
Softstem bulrush	*Scirpus validus*	Emergent	1.3	0.8	1.0	1.2
Vasey's pondweed[e]	*Potamogeton vaseyii*	Submersed	1.3	1.4	0.1	0.1
Water moss	*Drepanocladus sp.*		1.2	3.8	1.2	0.1
Horsetail	*Equisetum sp.*	Emergent	0.8	0.5	0.8	0.9
Hardstem bulrush	*Scirpus acutus*	Emergent	0.4	0.4	0.6	0
White-stem pondweed	*Potamogeton praelongus*	Submersed	0.3	0	0	0.1
Quillwort[d]	*Isoetes sp.*	Submersed	0.3	0.5	0	0.6
Ribbon-leaf pondweed[d]	*Potamogeton epihydrus*	Submersed	0.3	0.1	0	0
Pickerelweed	*Pontederia cordata*	Emergent	0.3	0.1	0.4	0.4
Variable pondweed	*Potamogeton gramineus*	Submersed	0.1	0.4	0	0
Small-leaved watermilfoil[d]	*Myriophyllum farwellii*	Submersed	0.1	0	0	0
Freshwater sponge			0.1	1.0	0	0.1
Greater duckweed	*Spirodela polyrhiza*	Free-floating	0.1	0	0	0
Blunt-leaf pondweed	*Potamogeton obtusifolius*	Submersed	0.1	0	0	0
Floating-leaf pondweed	*Potamogeton natans*	Submersed	0.1	0	0.3	0
Burreed	*Sparganium sp.*	Emergent	0	4.5	2.5	1.7
Muskgrass	*Chara sp.*	Submersed	0[b]	4.2[b]	3.2[b]	2.0[b]
Naiad	*Najas sp.*	Submerged	0	3.8	1.7	0.4

Common Name	Species Name	Growth Form	Frequency (%) 2008	2009	2010	2011
Common white waterlily	*Nymphaea odorata*	Floating-leaf	0	2.8	1.0	3.3
Common yellow waterlily	*Nuphar variegata*	Floating-leaf	0	2.0	0.4	0
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed	0	0.7	0	0
Flat-stem pondweed	*Potamogeton zosteriformis*	Submerged	0	0.5	0.1	0.1
Leafy pondweed	*Potamogeton foliosus*	Submersed	0	0.3	3.5	0.3
Sweetgale	*Myrica gale*	Emergent	0	0	0.1	0
River bulrush	*Scirpus fluviatilis*	Emergent	0	0	0.1	0
Common bladderwort	*Utricularia vulgaris*	Submersed	0	0	2.5	1.6
Max depth of veg growth (ft)[f]			6.2	5.0	6.0	4.0

[a]In 2008, floating burreed stems may have been confused with wild rice.
[b]Stonewort was likely mis-identified as muskgrass in 2009-2011 surveys
[c]Species tolerant to turbidity (Conservatism values < 3) as described by Milburn et al. (2007) and Beck et al. (2010).
[d]Species intolerant to turbidity (Conservatism values > 7) as described by Milburn et al. (2007) and Beck et al. (2010).
[e]Species State listed as a species of Special Concern.
[f]Depth of 95% of all plant occurrences

Table 6. Percent frequency of occurrence of aquatic plant species at depths 15 feet or less sampled during point-intercept surveys on Echo Lake on 21 July 2008 and 3 August 2009.

Common Name	Species Name	Growth Form	Frequency (%) 2008	2009
All rooted plants			25.8	26.3
Water celery	*Vallisneria americanus*	Submersed	18.3	20.0
Wild rice[a]	*Zizania palustris*	Emergent	8.1	6.7
Stonewort	*Nitella sp.*	Submersed	7.7	
Filamentous Algae			6.9	7.0
Bladderwort	*Utricularia sp.*	Submersed	4.5	4.3
Small pondweed	*Potamogeton pusillus*	Submersed	3.7	3.7
Coontail	*Ceratophyllum demersum*	Submersed	2.4	3.0
Floating-leaf burreed[a]	*Sparganium sp.*	Emergent	2.2	
Yellow waterlily	*Nuphar sp.*	Floating-leaf	1.7	
Clasping-leaf pondweed	*Potamogeton richardsonii*	Submersed	1.6	1.3
Southern naiad	*Najas guadalupensis*	Submersed	1.6	
White waterlily	*Nymphaea sp.*	Floating-leaf	1.6	
Arrowhead	*Sagittaria spp.*	Emergent	1.4	1.3
Watershield	*Brasenia shreberi*	Floating-leaf	1.3	1.3
Water marigold	*Bidens beckii*	Submersed	1.3	2.4
Softstem bulrush	*Scirpus validus*	Emergent	1.3	0.8
Vasey's pondweed	*Potamogeton vaseyii*	Submersed	1.3	1.4
Water moss	*Drepanocladus sp.*		1.2	3.8
Horsetail	*Equisetum sp.*	Emergent	0.8	0.5
Hardstem bulrush	*Scirpus acutus*	Emergent	0.4	0.4
White-stem pondweed	*Potamogeton praelongus*	Submersed	0.3	
Quillwort	*Isoetes sp.*	Submersed	0.3	0.5
Ribbon-leaf pondweed	*Potamogeton epihydrus*	Submersed	0.3	0.1
Pickerelweed	*Pontederia cordata*	Emergent	0.3	0.1
Variable pondweed	*Potamogeton gramineus*	Submersed	0.1	0.4
Small-leaved watermilfoil	*Myriophyllum farwellii*	Submersed	0.1	
Freshwater sponge			0.1	1.0
Greater duckweed	*Spirodela polyrhiza*	Free-floating	0.1	

Common Name	Species Name	Growth Form	Frequency (%) 2008	2009
Blunt-leaf pondweed	*Potamogeton obtusifolius*	Submersed	0.1	
Floating-leaf pondweed	*Potamogeton natans*	Submersed	0.1	
Burreed	*Sparganium sp.*	Emergent		4.5
Muskgrass	*Chara sp.*	Submersed		4.2
Naiad	*Najas sp.*	Submerged		3.8
Common white waterlily	*Nymphaea odorata*	Floating-leaf		2.8
Common yellow waterlily	*Nuphar variegata*	Floating-leaf		2.0
Northern watermilfoil	*Myriophyllum sibiricum*	Submersed		0.7
Flat-stem pondweed	*Potamogeton zosteriformis*	Submerged		0.5
Leafy pondweed	*Potamogeton foliosus*	Submersed		0.3
Max depth of veg growth (ft)[b]			6.2	5.0

[a]Early in the 2008 survey, floating burreed stems may have been confused for wild rice. Consequently, wild rice frequency may be overestimated and burreed underestimated.
[b]Depth of 95% of all plant occurrences

Water quality

Summer-mean water quality was summarized based on sample collections from 2008-2010 (Table 13). Individual sample results are provided in the Appendix. In addition, major cations, anions, and total organic carbon (TOC) were analyzed and those values and typical ranges as derived from the National Lakes Assessment (NLA) database for Minnesota are summarized in. 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. Echo 2008-2009 summer- mean water quality data. Typical range based on 32 NLF ecoregion reference lakes (Heiskary and Wilson 2008) noted for comparison.

Parameter	Echo Lake 2008-2010	NLF
Total phosphorus (µg/L)	44	14 - 27
Chlorophyll mean (µg/L)	7.3	4 - 10
Chlorophyll max (µg/L)	26.0	<15
Secchi disk (feet)	3.3	8 – 15
(meters)	1.0	2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.91	<0.4 – 0.75
Alkalinity (mg/L)	15	40 - 140
Color (Pt-Co Units)	112	10 - 35
pH (SU)	6.5	7.2 – 8.3
Chloride (mg/L)	1.0	0.6 – 1.2
Total suspended solids (mg/L)	5.5	<1 - 2
Total suspended inorganic solids (mg/L)	2.0	<1 - 2
Conductivity (µmhos/cm)	40	50 - 250
Total nitrogen: Total phosphorus ratio	21:1	25:1 - 35:1

Table 8. Echo 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	5.7	2.4	0.7	1.8	15	1.7	1.0	15.9	
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								
2008-2010 Average	234	161	1	16	296	20	30		

Dissolved oxygen and temperature profiles

Because of its shallowness and long fetch Echo Lake was well mixed on most sample dates. Profile data from 2008 show isothermal conditions on all sample dates (Figure 8). Dissolved oxygen (DO) likewise was consistent from top to bottom and concentrations typically ranged from 8-10 mg/L. Temperature peaked in August at 24 C.

A comparison of summer profile data from 2008-2010 suggests well-mixed conditions may be the norm for Echo Lake. Summer 2010 was warmer as compared to 2008 and 2009 (Figure 9). July DO was lower in 2010 as compared to 2008 and 2009, with values at or below 5 mg/L, which is the water quality standard.

Continuous temperature recorders provided additional data for 2008 and 2009 (Figure 10). Based on these records, 2008 and 2009 were similar, though peak temperatures were attained earlier in 2009, and warmer temperatures were sustained longer into the fall. The overall summer (June-September) average was 19.9 C in both years.

Figure 12. Echo Lake dissolved oxygen (DO) and temperature profiles for 2008.

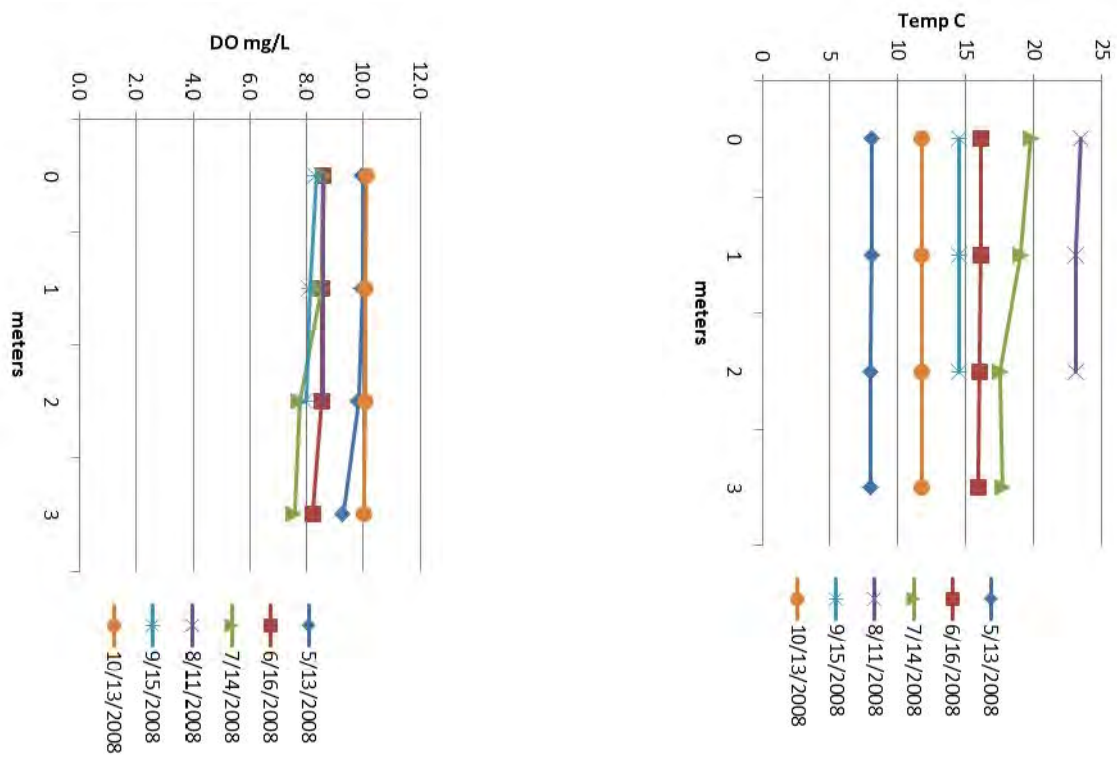


Figure 13. Comparison of July 2008-2010 DO and temperature profiles.

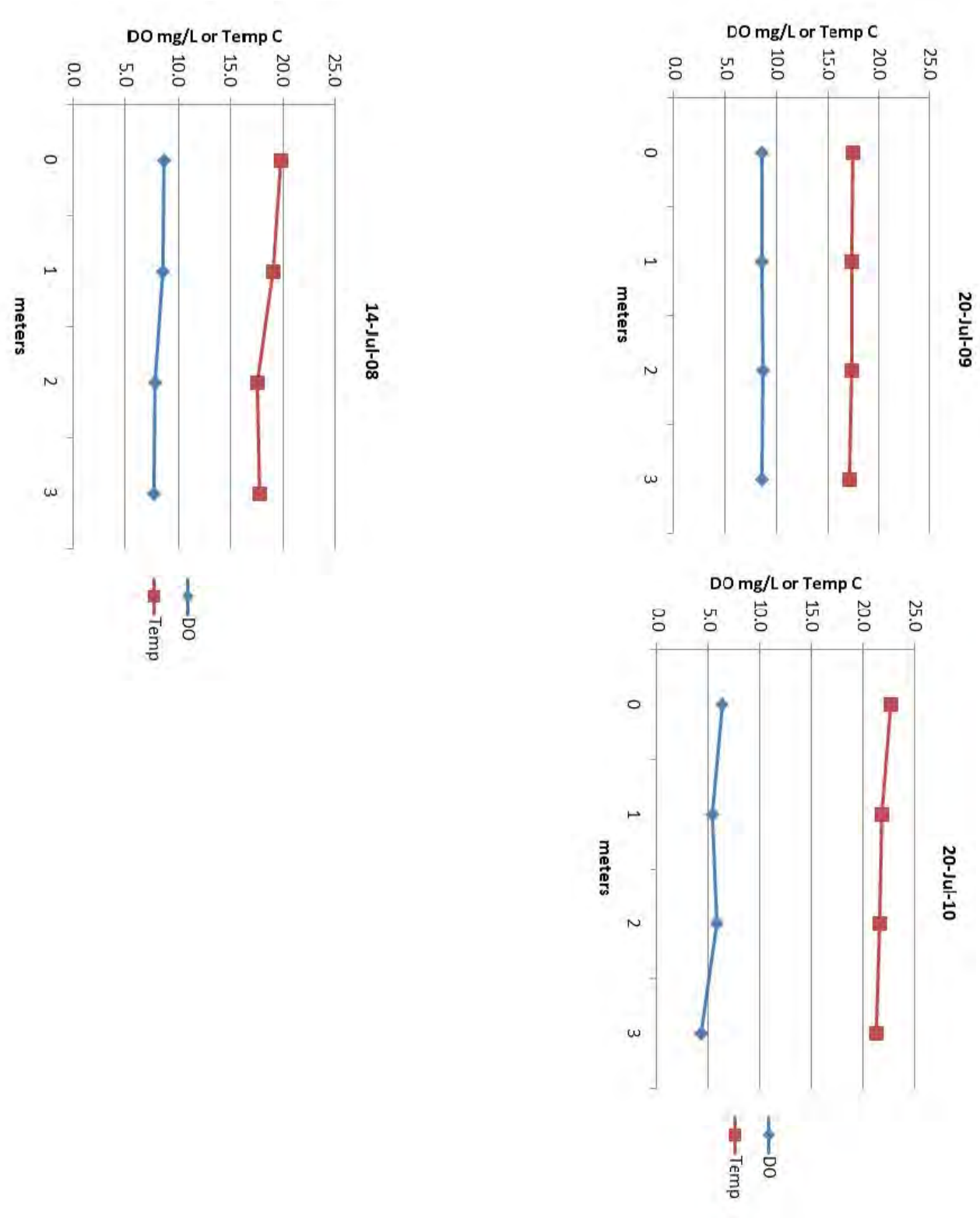
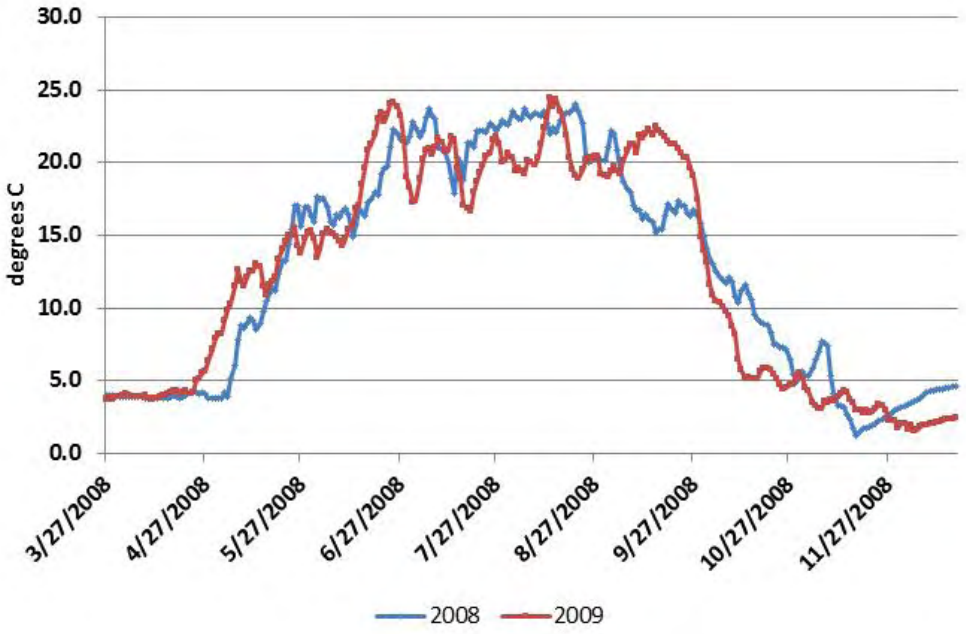


Figure 14. Surface water temperature for Echo Lake 2008 and 2009.



Total phosphorus (TP) is high in Echo Lake as compared to the typical range for NLF ecoregion lakes (Table 3). This is a bit surprising considering its forest and wetland dominated watershed (Table 1). Data collected in a 2001 study provide a basis for comparison with 2008 (Figure 11). In both years there is a mid-summer increase in TP, which most likely is not the result of watershed runoff, considering typical patterns for runoff and precipitation data for 2008 (Figure 6). This seasonal increase may be related to internal recycling within the lake – not low DO or redox driven, rather it may be a function of elevated summer temperature and wind resuspension.

Figure 16 provides a comparison of lake trophic state variables, temperature, and pH for the available data sets. Seasonal increases in TP and temperature in 2008 followed a similar pattern. Likewise, in 2010 peak TP and temperature coincide. However, data from 2001 do not exhibit the same pattern and thus there are likely other factors that influence this mid-summer increase.

Total Kjeldahl nitrogen (TKN) represents organic N and is highly correlated with Chl-a. TKN for Echo is slightly above the typical range for NLF lakes. The other N forms – nitrate-N and ammonia-N were near detection on most dates (Appendix), which is typical for northern Minnesota lakes. The TN: TP ratio for Echo is 20:1 and suggests it is a P-limited lake.

Chlorophyll-*a* (Chl-a) concentrations provide an estimate of the amount of algal production in a lake. While TP was above the typical range for NLF lakes, Chl-a is well within the range (Table 3). The primary reason for this is light limitation from the highly bog-stained waters. Algal blooms do occur on the lake, however, and five dates exhibited Chl-a> 10 µg/L (considered a mild bloom; Figure 12).

Secchi disk transparency averaged 1.0 m from 2008-10 and is below the typical range for NLF lakes (Table 3). High water color is a primary limiter of transparency. However, Secchi transparency is responsive to changes in algal biomass as evidenced in Figure 15.

Figure 15. Echo Lake total phosphorus, chlorophyll-a, and Secchi: comparison of 2001 and 2008.

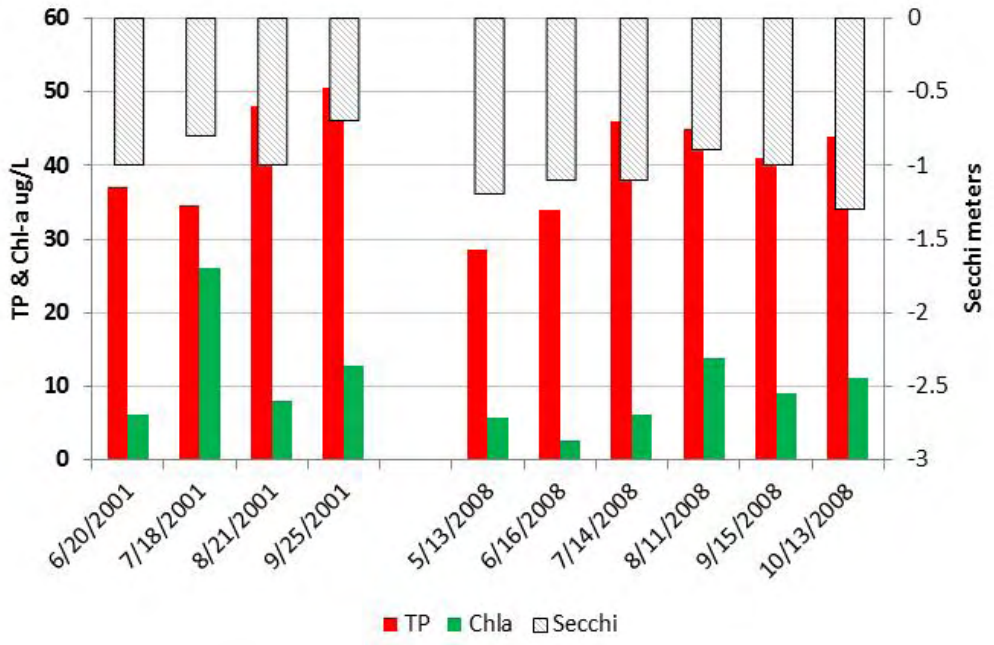
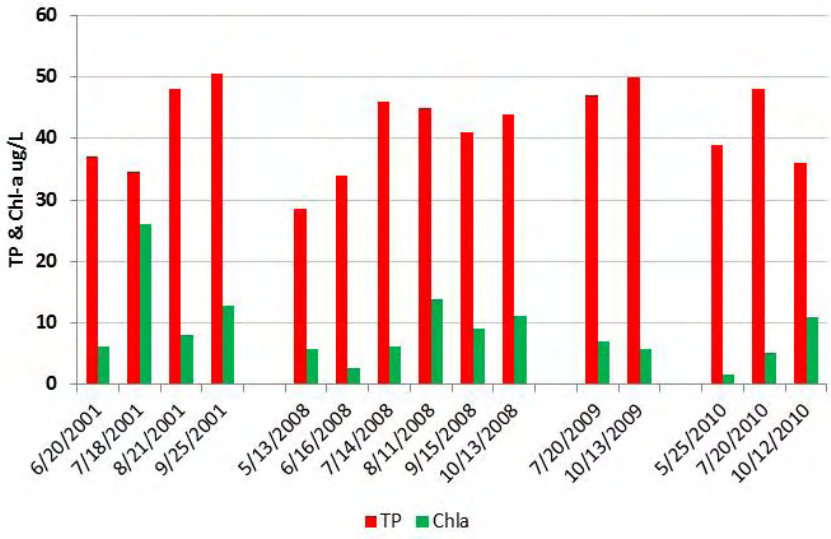
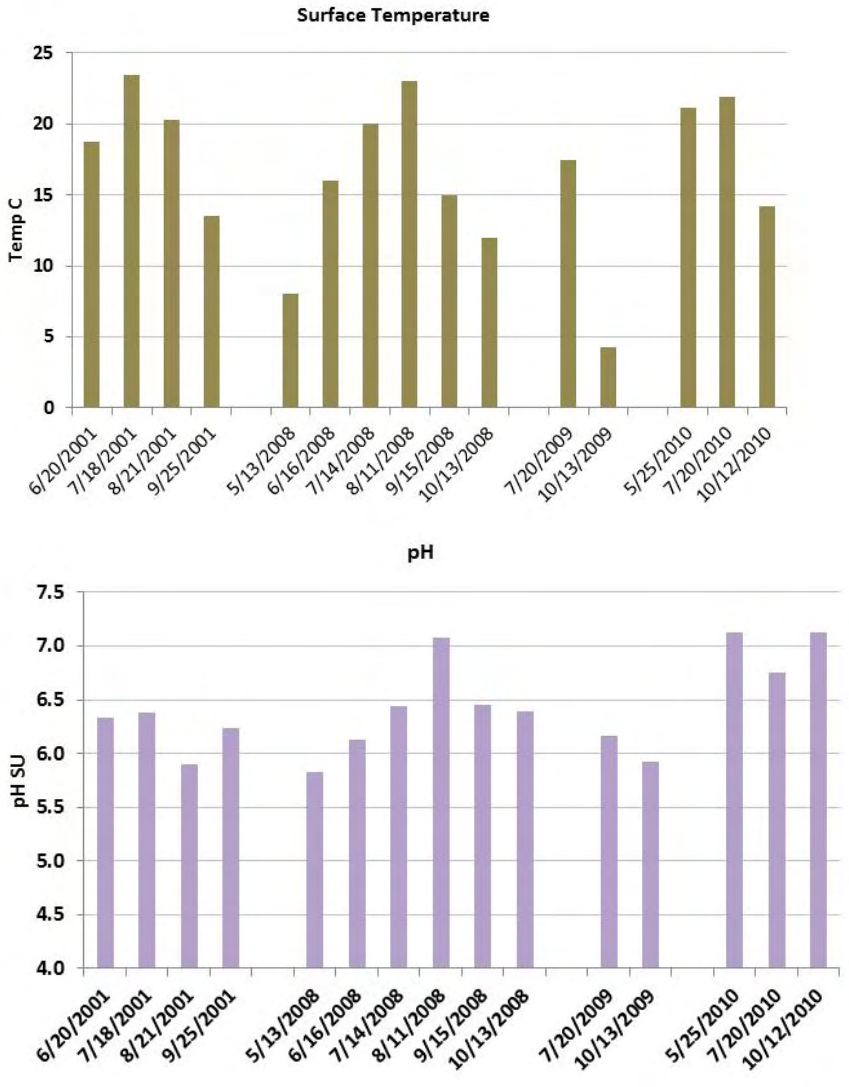


Figure 16. Echo Lake - Patterns in TP, Chl-a, temperature, and pH for 2008-2010 monitoring period.





Additional water quality parameters were measured, as part of the long-term monitoring of Echo and other Sentinel lakes. This includes some of the standard MPCA lake-monitoring measures of total suspended solids (TSS), alkalinity, conductivity and color (Table 7), as well as major cations, anions, and total organic carbon (Table 8). While several of these parameters have "typical" ecoregion-based concentrations, some do not. For parameters without ecoregion–based comparisons, data from the 2007 NLA study were used to provide perspective on reported concentrations. Since the NLA lakes were selected randomly, they provide a reasonable basis for describing typical ranges and distributions at the statewide level.

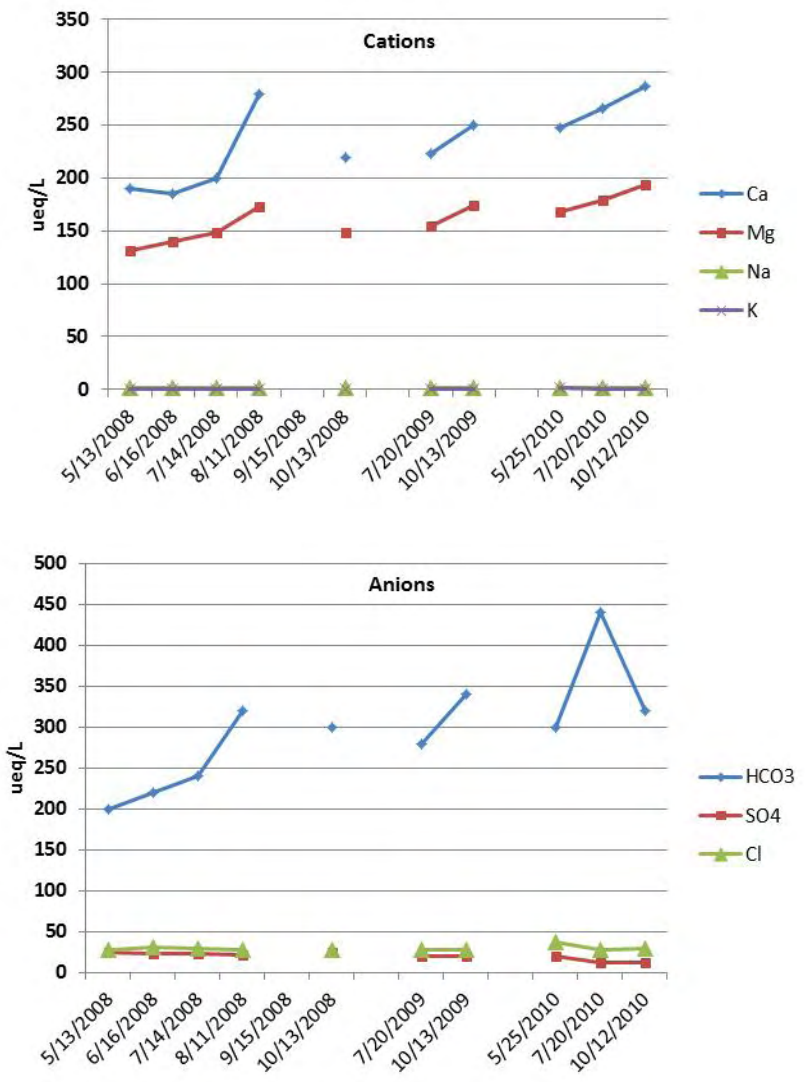
Echo Lake is a very dark lake with very soft water. The high color and total organic carbon is the result of incompletely dissolved organic matter that arises from forest and wetland runoff. Exposed bedrock and thin soils in the watershed contribute few minerals to the lake, which results in very low alkalinity and conductivity. The combination of low buffering capacity and high humic acids, cause Echo Lake to have a very low pH – even for a NLF lake (Table 7).

Since pH can be influenced by algal productivity and Echo Lake's pH, value is at or below the state water quality standard (6.5-9.0 for 2b waters); we charted available data to see how it varies relative to other factors (Figure 16). There was good correspondence among temperature, Chl-a, and pH in 2008;

however the same pattern was not evident in the other data (Figure 16). These data indicate that pH falls below 6.0 on some dates and overall seldom exceeds 7.0.

The low alkalinity, cation, and anion concentrations indicate very soft water – values that are more common in lakes in the Boundary Waters Canoe Area Wilderness. Calcium (Ca) is the dominant cation and fall increases are evident for both Ca and magnesium (Mg). Sodium (Na) and potassium (K) are near detection and both are quite conservative (Figure 17). Bicarbonate is the dominant anion and fall increases are evident as well. Both sulfate (SO4) and chloride (Cl) are quite conservative and both are at very low concentrations in Echo Lake.

Figure 17. Echo Lake cation and anion measurements for 2008-2010.



Phytoplankton (algae) for Echo Lake in 2001, 2008, and 2010 are presented in terms of algal type (Figure 18). Blue-greens were dominant on all dates in 2001. Chl-a was somewhat higher in 2001 as compared to 2008 and 2010 (Figure 11) so it is likely surface scums were evident in summer 2001.In 2008 there was more diversity in algal composition, with diatoms being prominent in May through July. Blue-greens were again prominent in August and September and mild blooms were likely evident. In 2010, blue-greens were dominant on all three sample dates. However, Chl-a was relatively low on all three dates and levels were not indicative of nuisance blooms (Figure 16).

A seasonal transition in algal types from diatoms to green to blue-green algae is often common for mesotrophic and eutrophic lakes in Minnesota. In practice, greens are seldom abundant in Minnesota lakes, and there is often a transition from diatom to blue-green dominance. In Echo, blue-greens are frequently dominant throughout the open water season. The lake's shallowness, warm temperatures down to the bottom, somewhat high TP, and high color – all favor blue-greens, which prosper in these conditions.

Figure 18. Echo Lake phytoplankton composition 2001, 2008, and 2010.

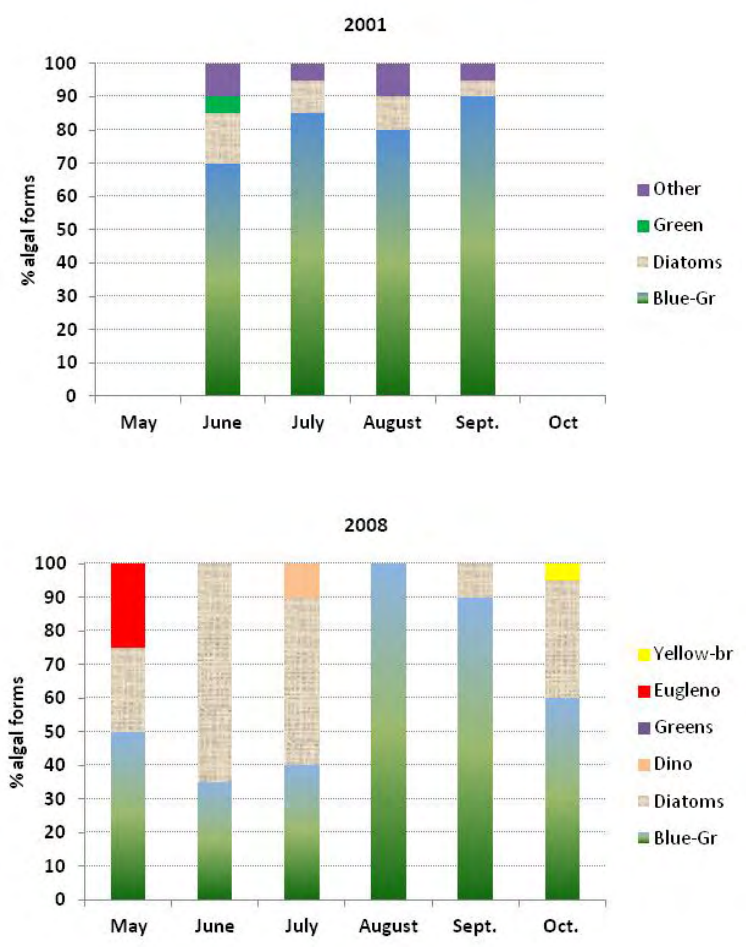
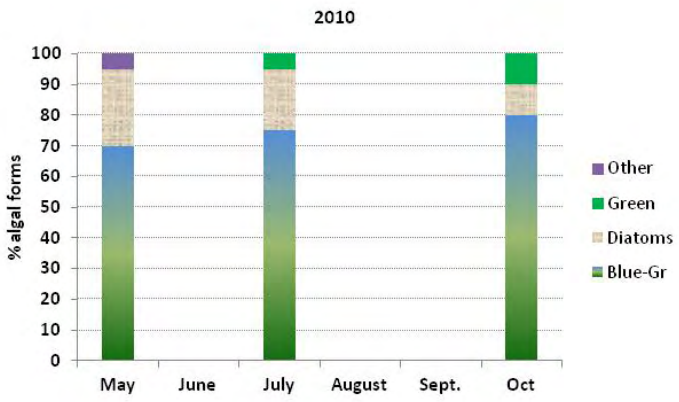


Figure 8. (continued)



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 Echo Lake (Hirsch 2009). Mean 2008 zooplankton densities in Echo were above average when compared to the five other Border region Sentinel lakes (Table 9). 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 Echo, as it is more eutrophic than the other Border region lakes (Table 10). Densities and biomass in Echo peaked in July, decreased in August and September, and rebounded in October (Figure 19).

Hirsch (2011) provided a comparison across lakes and years for the Sentinel lakes based on data from 2008-2010. Mean annual density and mean annual biomass were consistently higher in Echo as compared to the other Border (Shield) lakes and were in the range of the Forest Sentinel lakes (Table 10). Mean monthly density was consistently highest in Echo, with the exception of Tait in August (Figure 20). Zooplankton density across the three years was high in July-September. Biomass, in contrast, was at its highest in June, declined in July, and increased thereafter (Figure 20). Again, biomass in Echo was higher than most of the Shield lakes but was comparable to nearby Elephant Lake in several months. Overall, these results suggest that while zooplankton are numerous in Echo in most months, small individuals dominate the population given that biomass is low on a relative basis. June is an exception, where both density and biomass are both relatively high (Figure 20). It seems likely that the larger forms, which are more common in June, are cropped by juvenile fish and they are in turn replaced by smaller forms during most of the summer. Shifts in zooplankton forms can influence algal density as well, since the larger forms consume more algae, as compared to very small-bodied zooplankton.

Table 9. 2008 zooplankton data from Border Sentinel lakes.

Sentinel Lakes zooplankton 2008	Mean annual densities (#/L)	Mean annual biomass (µg/L)	Total# taxa
Border Lakes (NLF)			
Echo	37.03	89.68	12
Elephant	13.26	75.50	12
White Iron	10.00	38.64	14
Echo	6.28	29.52	13
Bearhead	5.15	38.37	14
Northern Light	1.03	4.16	13

Figure 19. Mean monthly zooplankton densities and biomass for Border Sentinel lakes.

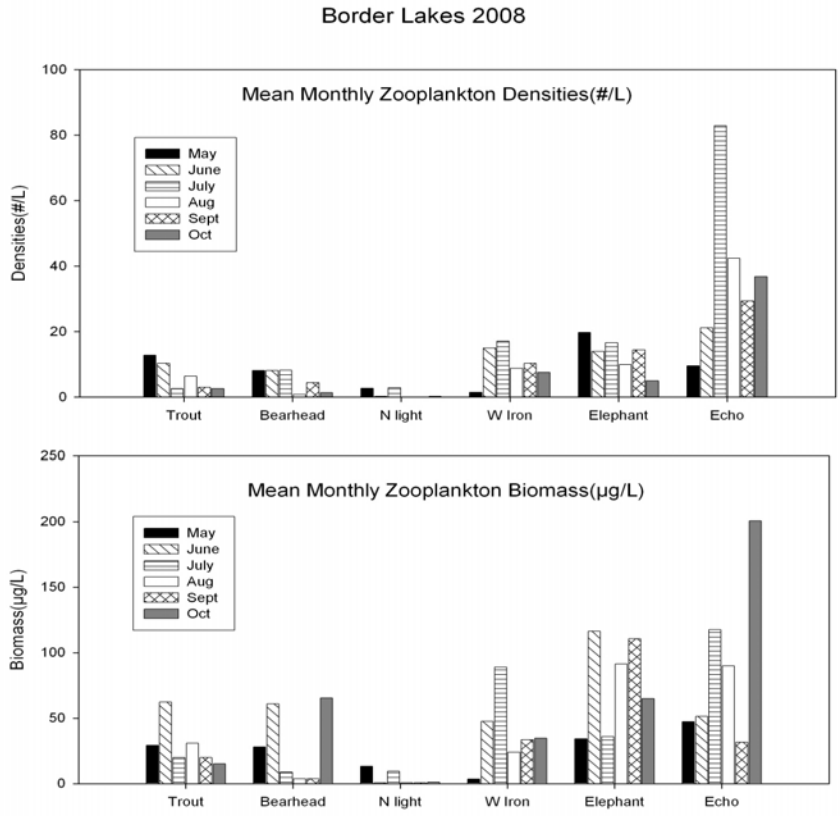
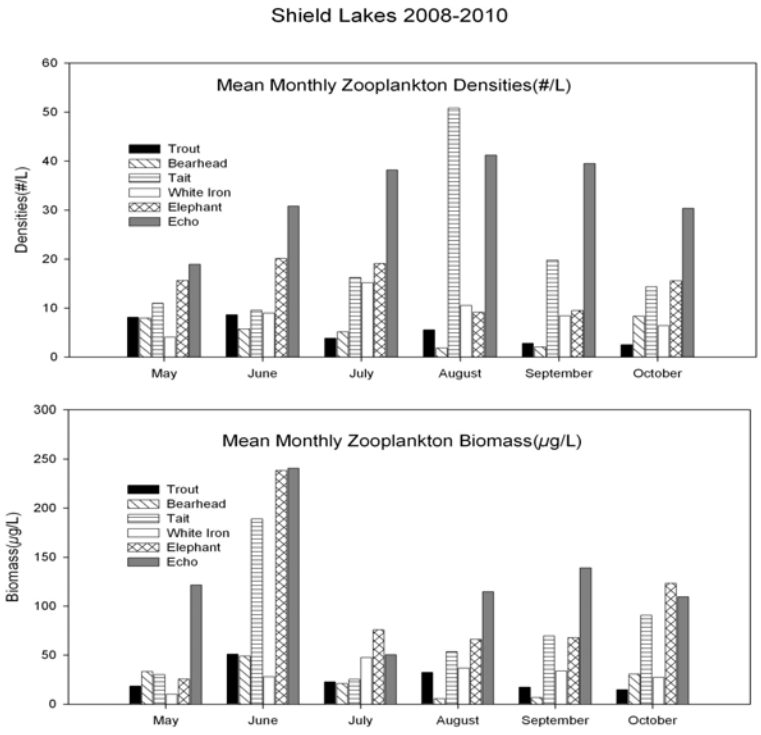


Table 10. Mean summer total phosphorus (µg/liter), mean annual zooplankton densities (number individuals/liter) and biomass (µg/liter) for the 24 Sentinel lakes, 2008-2010. Lakes arranged by landtype.

Sentinel lakes zooplankton	Lake Type	Mean summer TP (2000-2009)	Mean annual densities (2008-2010)	Mean annual biomass (2008-2010)
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-cisco	17	12.67	36.42
South Twin	deep-cisco	17	30.90	55.22
Ten Mile	deep-cisco	12	12.58	37.56
Shield				
Echo	shallow	43	33.01	126.18
Elephant	deep	21	15.95	94.96
White Iron	deep-cisco	21	9.34	31.45
Tait	shallow	16	17.04	61.46
Bearhead	deep	14	5.53	23.36
Trout	deep-cisco	7	5.02	26.00

Figure 20. Mean monthly zooplankton densities (#/liter) and biomass (µg/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

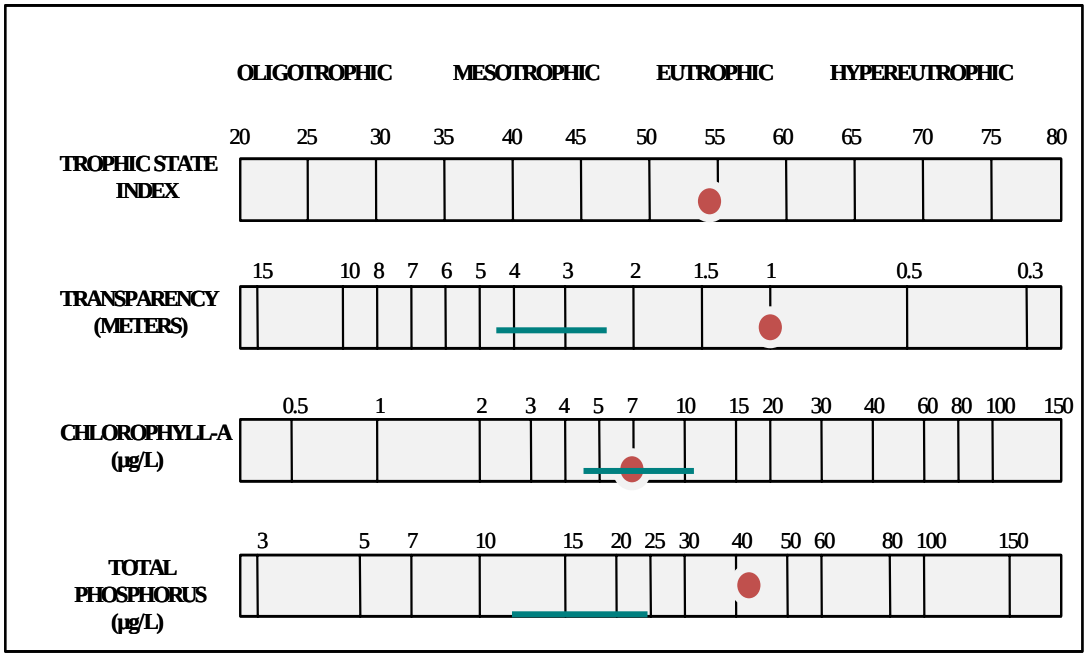
Chlorophyll-a TSI (TSIC) = 9.81 ln (Chl-a) + 30.6

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 provides a basis for assessing the relationship among TP, Chl-a, and Secchi (Figure 21). Phosphorus and chlorophyll Secchi TSI values for Echo Lake are not in close correspondence with each other. This is because of the dark coloration of the water and light limitation. The coloration has a direct effect on transparency and the Secchi value is much lower than anticipated abased on Chl-a; however it is close to the TP TSI – both indicative of eutrophic conditions. As noted previously, the TP and Secchi values are above the typical range for NLF lakes, while Chl-a is within the range. Based on an average TSI score of 54 Echo Lake is eutrophic.

Figure 21. Echo Lake TSI values from 2008-2010 MPCA Sentinel Lake monitoring data.

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.

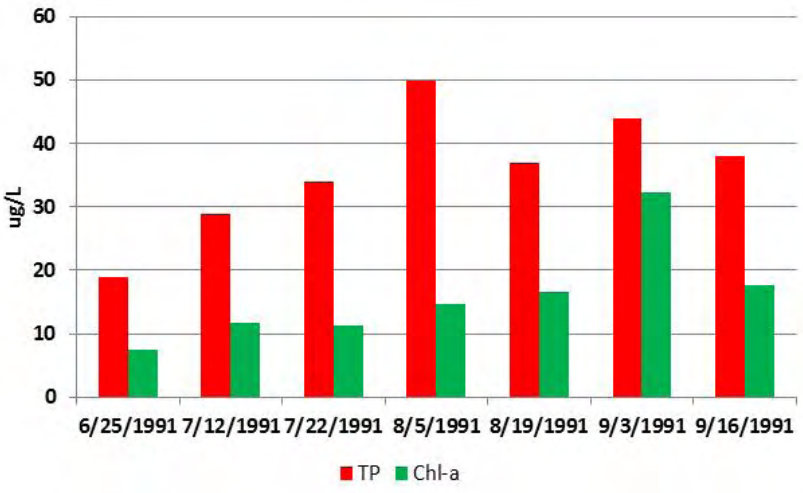
NLF Ecoregion Range — Echo Lake 2008-2010

Trophic Status Trends

One aspect of lake monitoring is to assess trends in the condition of the lakes, where possible, based on data gathered through the MPCA's Citizen Lake Monitoring Program or other available data in STORET. A review of EQuiS data indicates there is minimal data for Echo Lake to describe annual variability and to assess trends. Though there is minimal data for the lake, the data record does benefit from a MDNR study in 1991 and a MPCA study in 2001. When combined with the 2008 data this provides three summers of data that can be used to assess year-to-year variability and look for any apparent trends.

The MDNR data from the 1991 study (Figure 22) reveal a similar pattern to that observed in the more recent Sentinel sampling (Figure 16); whereby TP increases over the summer and Chl-a remains lower than anticipated based on TP. Nuisance bloom levels of algae were evident in September 1991.

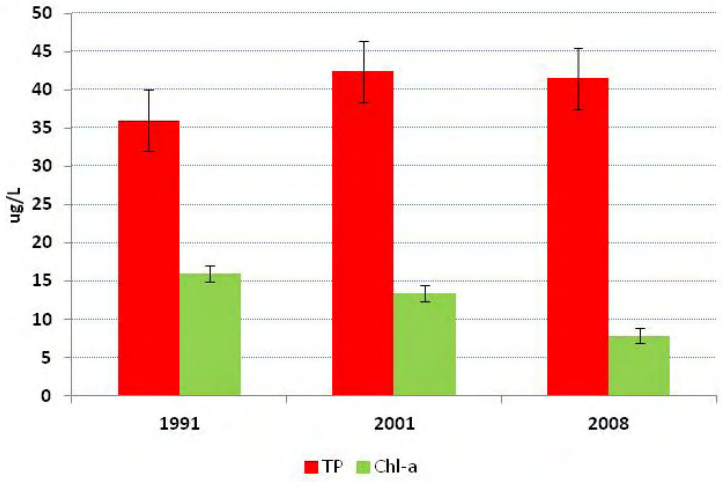
Figure 22. MDNR Echo Lake water quality study from 1991.



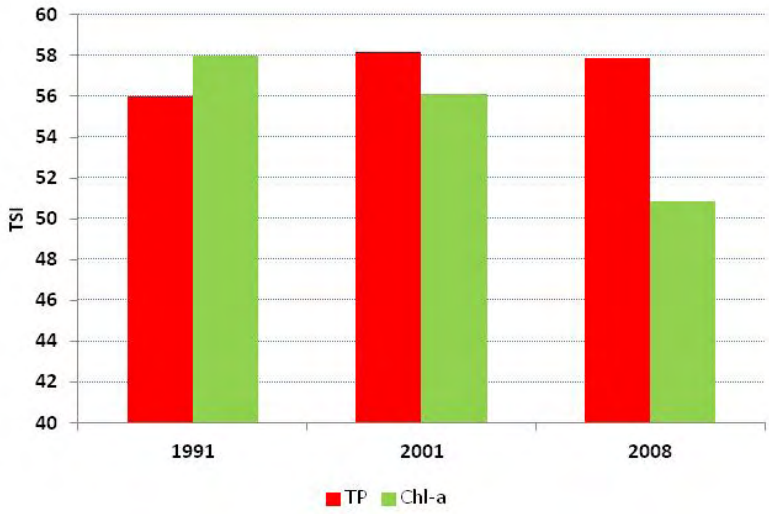
While there is not sufficient data to assess trends, the three study years do provide a basis for characterizing year-to-year variability and relationships among TP and Chl-a (Figure 23). These data suggest mean TP varies between about 35-43 µg/L; while Chl-a ranges from about 7-15 µg/L. TSI values are in the "eutrophic" range in each of the three years. The relationship among TP and Chl-a does vary among years, with 1991 and 2001 exhibiting farily close agreement (based on Carlson TSI) and 2008 with low Chl-a relative to TP. Possible explanations could include wet year/dry year differences (higher color in wet years) or frequency of monitoring (more likely to catch blooms with higher frequency of monitoring as in 1991). Whatever the case, future monitoring and attention to climatological conditions will be of value in understanding the water quality of Echo Lake.

Figure 23. Echo Lake long-term summer-mean (a) total phosphorus and chlorophyll-a concentrations and (b) corresponding TSI values. Standard error of the mean noted for each year.

a)



b)



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 Echo Lake, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used. The BATHTUB model (Walker 2004) provides a further basis for estimating water and nutrient budgets for Echo.

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. Chl-a and Secchi predictions are derived from Minnesota-based regression equations. For analysis of Echo 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.

Echo Lake is located in the NLF ecoregion and the model was run using NLF-based inputs. Observed TP is slightly higher, but not significantly different from predicted. Observed Chl-a and Secchi are both lower than predicted. MINLEAP predicts a P loading rate of about 1,567 kilograms per year entering Echo Lake from its large forested and wetland-dominated watershed. The model predicts approximately 34 percent of the TP will be retained in the lake. This value is relatively low as compared to many lakes but is a result of the shallowness of the lake and small volume relative to the size of the watershed, P loading, and water loading. 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 Echo Lake, this value is estimated to be 15 µg/L, lower than the observed concentration (Table 11). However, the dataset used by Vighi and Chiaudani (1985) did not include extremely dark water and extremely softwater lakes, like Echo, so the utility of their equation for estimating “background” may be limited in this instance.

The BATHTUB model provides a further basis for estimating water and nutrient budgets for Echo 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 lake is relatively undeveloped with the exception of two small resorts and a USFS campground. The number of cabins at each resort provided the basis for estimating potential on-site inputs into the lake. It was assumed that the USFS campground had vault toilets and this precludes any seepage to 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. Model inputs and outputs are included in the Appendix.

BATHTUB predicted in-lake P at 37 µg/L, which is not significantly different from the observed P (Table 12). Predicted Chl-a was slightly higher than observed; however Secchi was 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 ~92 percent, atmospheric ~8 percent and on-site septic systems <1

percent. Because of its large watershed the model estimated the majority of water inflow (~92 percent) arose from runoff and the remainder from precipitation on the lake. Water residence time is rather short at about 0.3 year, which implies that on average the lake replaces its volume about three times per year. The modeling results are estimates, based on the limited information that was available. To refine these 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 application, is included in the Appendix and could be modified in the future should more accurate estimates be required.

Table 11. MINLEAP model results for Echo Lake.

Parameter	2008- 2010 Echo Lake Observed	MINLEAP Predicted NLF Ecoregion
TP (µg/L)	44	35 +/-8
Chl-a(µg /L)	7.3	12.1 +/-5.9
Secchi (m)	1.0	1.8 +/-0.6
P loading rate (kg/yr)		1,567
P retention (%)		34
P inflow conc. (µg/L)		53
Water Load (m/yr)		6.38
Outflow volume (hm^3/yr)		29.4
Residence time (yrs)		0.3
Vighi & Chiaudani		15

Table 12. BATHTUB model results for Echo Lake.

Parameter	2008- 2010 Echo Lake Observed	BATHTUB Predicted
TP (µg/L)	44 ±2	37 ±5
Chl-*a* (µg /L)	7.3 ±0.3	15.7 ±5
Secchi (m)	1.0 ±0.1	0.8 ±0.2
P loading rate (kg/yr)	-	1,747
P retention (percent)	-	33
P inflow conc. (µg/L)	-	51
Water Load (m/yr)	-	6.9
Outflow volume (hm^3/yr)	-	31.8
Residence time (yrs)		0.3

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 for which we assess Minnesota's water resources. An example is mercury found in fish tissue. If a water body is listed, an investigative Total Maximum Daily Load (TMDL) study must be conducted to determine the sources and extent of pollution, and to establish pollutant reduction goals needed to restore the resource to meet the determined water quality standards for its ecoregion. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL studies in Minnesota.

Echo Lake was assessed relative to the NLF Class 2B ecoregion standards (Table 11). The long-term summer-mean TP for Echo Lake is above the standard. Likewise, Secchi is less than the standard for the NLF ecoregion. While these numbers suggest Echo does not meet standards it can be argued that this is because of natural background conditions. Both BATHTUB and MINLEAP predict a TP greater than the standard, as a function of the small volume of Echo relative to its large watershed. The low Secchi can be attributed to the very high organic coloration in the water. This again, is natural and is a direct reflection of its forest and wetland-dominated watershed. Echo Lake was not assessed in the most recent 303(d) assessment. When the assessment is conducted for the Vermilion River Watershed in 2015 this will be taken into account.

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

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
Echo Lake long-term mean	**44**	**7.3**	**1.0**

References

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography 22:361-369.

Charpentier, F. and B.H. Jamnick. 1994. ZCOUNT-A zoological counting program. Version 2.4 Voila Data Inc., Gloucester, Ontario.

Claramunt, R. M., J. L. Jonas, J. D. Fitzsimons, and J. E. Marsden. 2005. Influences of spawning habitat characteristics and interstitial predators on egg deposition and mortality. Transactions of the American Fisheries Society 134:1048-1057.

Close, T. L., Colvin, S. E., and R. L. Hassinger. 1985. Kamloops, Madison, and Donaldson strains of rainbow Echo in an oligotrophic lake. Minnesota Department of Natural Resources, Investigational Report Number 385.

Drake, M. T., and D. L. Pereira. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. North American Journal of Fisheries Management 22:1105-1123.

Drake, M. T., and R. D. Valley. 2005. Validation and application of a fish-based index of biotic integrity for small central Minnesota lakes. North American Journal of Fisheries Management 25:1095-1111.

Heiskary, S.A. and W.W. Walker Jr. 1988. Developing Phosphorus Criteria for Minnesota Lakes. Lake and Reservoir Management 4(1): 1-9.

Heiskary, S.A. and C.B. Wilson, 2005. Minnesota lake water quality assessment report: Developing nutrient criteria, 3rd edition. Minnesota Pollution Control Agency, 176 p.

Heiskary, S.A. and C.B. Wilson. 2008. Minnesota's approach to lake nutrient criteria development. Lake and Reserv. Manage. 24:282-297.

Hirsch, J. 2009. Sentinel Lakes Study Progress Report- Zooplankton 2008

Hirsch, J. 2011. Sentinel Lakes Study Progress Report- Zooplankton 2008-2010

Madsen, J. D. 1999. Point intercept and line intercept methods for aquatic plant management. Army

Corps of Engineers Waterways Experiment Station, MI-02, Vicksburg, MS.

McCollor, S. and S. Heiskary. Selected water quality characteristics of minimally impacted streams from Minnesota's seven ecoregions. Addendum to Descriptive characteristics of the seven ecoregions of Minnesota. MPCA. St. Paul MN

Minasny, B., McBratney, A.B., and Whelan, B.M. 2002. VESPER version 1.6. Australian Centre for

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Asso. Amer. Geogr. 77(1):118-125.

Valley, R. D., M. T. Drake, and C. S. Anderson. 2005. Evaluation of alternative interpolation techniques for the mapping of remotely-sensed submersed vegetation abundance. Aquatic Botany 81(1):13-25.

Valley, R. D. 2009 Sustaining Lakes in a Changing Environment: operational research and management plan. Division of Fish and Wildlife, unpublished draft report.

Walter, C., McBratney, A.B., Douaoui, A., Minasny, B., 2001. Spatial prediction of topsoil salinity in the Chelif Valley, Algeria, using local ordinary kriging with local variograms versus whole-area variogram. Aust. J. Soil Res. 39, 259–272.

Wilson, C.B. and W.W. Walker 1989. Development of lake assessment methods based upon the aquatic ecoregion concept. Lake and Reserv. Manage. 5(2):11-22.

Yule, D., Siesennop, G., and L. Bergquist. 2002. Assessment of fish densities, size structures and distribution patterns in a small oligotrophic lake in northeast Minnesota using a scientific-grade echosounder. Minnesota Department of Natural Resources, Staff Report Number 59.

Appendix A

Lake surface water quality data for Echo Lake for 2008-2010 (MPCA data)

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

	TP	Chla	Secchi	TKN	NO3	NH4-N	Ca	Mg	Na	K	Si	Alk.	SO4	Cl	Color	TOC	TSS	TVS	pH
	mg/L	ug/L	m	mg/L			mg/L								Pt-Co	mg/L			SU
5/6/1981	0.025		1.2	0.90	0.01		4.0	1.7	1.3	1.2		12	2.0	0.7	80				6.7
6/20/2001	0.037	6.1	1.0	0.78								18		1.6	140		4.8	1.6	6.3
7/18/2001	0.035	26.1	0.8	1.13								18		1.5	140		6.4	4.4	6.4
8/21/2001	0.048	8.0	1.0	1.09								19		1.9	200		3.4	2.0	5.9
9/25/2001	0.051	12.8	0.7	0.95								26		1.8	200		4.4	3.2	6.2
5/13/2008	0.029	5.7	1.2	0.71	0.05		3.8	1.6	1.4	0.9		10	2.1	1.0	80	14.0	2.8	1.2	5.8
6/16/2008	0.034	2.7	1.1	0.76	0.05		3.7	1.7	1.4	0.8		11	1.9	1.1	80	16.0	2.8	1.2	6.1
7/14/2008	0.046	6.1	1.1	0.66	0.05		4.0	1.8	1.6	0.7		12	2.0	1.1	100	14.0	4.0	1.2	6.4
8/11/2008	0.045	13.8	0.9	1.10	0.05		5.6	2.1	1.8	0.7		16	1.8	1.0	100	15.0	10.0	3.6	7.1
9/15/2008	0.041	9.0	1.0	0.76	0.05														6.5
10/13/2008	0.044	11.1	1.3	0.73	0.05		4.4	1.8	2.0	0.8		15	2.1	1.0	80	12.0	3.2	2.0	6.4
7/20/2009	0.047	7.0	0.9	0.90	0.05	0.05	4.5	1.88	1.6	0.7	3.5	14	1.6	1.0	70	14.0	6.0	2.4	6.2
10/13/2009	0.050	5.7	1.0	0.88	0.05	0.07	5.0	2.12	1.7	0.8	5.8	17	1.7	1.0	100	13.5	4.8	2.4	5.9
5/25/2010	0.039	1.6	1.0	0.76	0.05	0.05	5.0	2.04	1.9	1.2	3.7	15	1.7	1.3	100	12.1	5.2	2.0	7.1
7/20/2010	0.048	5.2	1.0	1.28	0.05	0.07	5.3	2.17	1.4	0.8	4.5	22	1.1	1.0	210	20.4	4.8	1.6	6.8
10/12/2010	0.036	11.0	0.8	0.78	0.05	0.05	5.7	2.35	1.8	0.9	4.2	16	1.1	1.1	200	18.3	5.6	1.6	7.1

BATHTUB input and output files

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

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean
1	Main Basin	0	1	4.6	1.8	3.7	1.8	0.12	0	0	0.82

Segment Observed Water Quality

	Conserv	Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)	
Seg	Mean	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	44	0.2	500	0	7.3	0.2	1	0.15	0	0

Segment Calibration Factors

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

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (p
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean
1	Echo wshed	1	2	125.2	0	0	0	0	30	0.2	0
2	On-site	1	1	0	0.001	0	0	0	5000	0	0

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

		Land Use Category--->							
Trib	Trib Name	1	2	3	4	5	6	7	8
1	Echo wshed	124	1.2	0	0	0	0	0	0
2	On-site	0	0	0	0	0	0	0	0

Non-Point Source Export Coefficients

		Runoff (m/yr)		Conserv. Subs.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)	
Categ	Land Use Name	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	wetlands / forest	0.25	0	0	0	50	0	0	0	0	0
2	open/developed	0.3	0	0	0	150	0	0	0	0	0
3	landuse3	0	0	0	0	0	0	0	0	0	0
4	landuse4	0	0	0	0	0	0	0	0	0	0
5		0	0	0	0	0	0	0	0	0	0
6		0	0	0	0	0	0	0	0	0	0
7		0	0	0	0	0	0	0	0	0	0
8		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**

Trib	Type	Location	Flow hm^3/yr	Flow %Total	Load kg/yr	Load %Total	Conc mg/m^3
1	2	Echo wshed	31.4	90.1%	1604.0	91.8%	51
2	1	On-site	0.0	0.0%	5.0	0.3%	5000
PRECIPITATION			3.4	9.9%	138.0	7.9%	40
TRIBUTARY INFLOW			0.0	0.0%	5.0	0.3%	5000
NONPOINT INFLOW			31.4	90.1%	1604.0	91.8%	51
***TOTAL INFLOW			34.8	100.0%	1747.0	100.0%	50
ADVECTIVE OUTFLOW			31.8	91.3%	1172.7	67.1%	37
***TOTAL OUTFLOW			31.8	91.3%	1172.7	67.1%	37
***EVAPORATION			3.0	8.7%	0.0	0.0%	
***RETENTION			0.0	0.0%	574.3	32.9%	

Hyd. Residence Time =	0.2606	yrs
Overflow Rate =	6.9	m/yr
Mean Depth =	1.8	m

	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
TOTAL P MG/M3	36.9	0.15	38.6%	44.0	0.20	46.2%
TOTAL N MG/M3	500.0		13.9%	500.0		13.9%
C.NUTRIENT MG/M3	22.9	0.06	28.9%	24.3	0.08	31.6%
CHL-A MG/M3	15.7	0.34	74.8%	7.3	0.20	37.2%
SECCHI M	0.8	0.20	36.1%	1.0	0.15	46.0%
ORGANIC N MG/M3	577.2	0.24	65.0%			
TP-ORTHO-P MG/M3	43.3	0.28	65.0%			
ANTILOG PC-1	306.5	0.35	56.8%	196.5	0.23	43.3%
ANTILOG PC-2	8.6	0.22	71.2%	5.2	0.18	34.1%
(N - 150) / P	9.5	0.15	19.6%	8.0	0.19	13.2%
INORGANIC N / P	1.0		0.0%			
TURBIDITY 1/M	0.8	0.20	63.2%	0.8	0.20	63.2%
ZMIX * TURBIDITY	1.5	0.23	16.4%	1.5	0.23	16.4%
ZMIX / SECCHI	2.2	0.23	9.0%	1.8	0.19	4.7%
CHL-A * SECCHI	13.0	0.28	63.2%	7.3	0.25	31.8%
CHL-A / TOTAL P	0.4	0.27	88.9%	0.2	0.28	39.7%
FREQ(CHL-a>10) %	66.3	0.30	74.8%	20.7	0.45	37.2%
FREQ(CHL-a>20) %	24.2	0.71	74.8%	2.6	0.77	37.2%
FREQ(CHL-a>30) %	8.8	1.01	74.8%	0.5	0.98	37.2%
FREQ(CHL-a>40) %	3.5	1.23	74.8%	0.1	1.14	37.2%
FREQ(CHL-a>50) %	1.5	1.41	74.8%	0.0	1.26	37.2%
FREQ(CHL-a>60) %	0.7	1.57	74.8%	0.0	1.37	37.2%
CARLSON TSI-P	56.2	0.04	38.6%	58.7	0.05	46.2%
CARLSON TSI-CHLA	57.6	0.06	74.8%	50.1	0.04	37.2%
CARLSON TSI-SEC	62.8	0.05	63.9%	60.0	0.04	54.0%