Status and Trend Monitoring of Selected Lakes in Douglas County 2005

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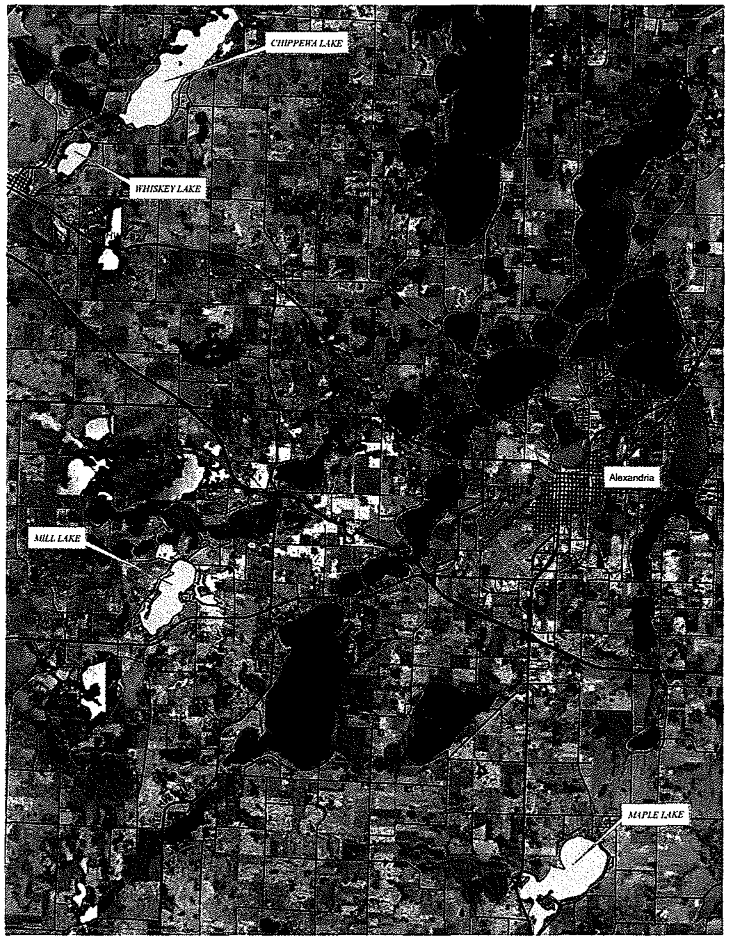

Environmental Analysis and Outcomes Division
Water Assessment and Environmental Information Section
December 2006

Minnesota Pollution Control Agency

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Lake Assessment Program
2005

Lake Status and Trends for Selected Lakes in Douglas County

Minnesota Pollution Control Agency

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Lake Name	Lake DOW# ID
Maple	21-0079
Mill	21-0180
Whiskey	21-0216
Chippewa	21-0145

December 2006

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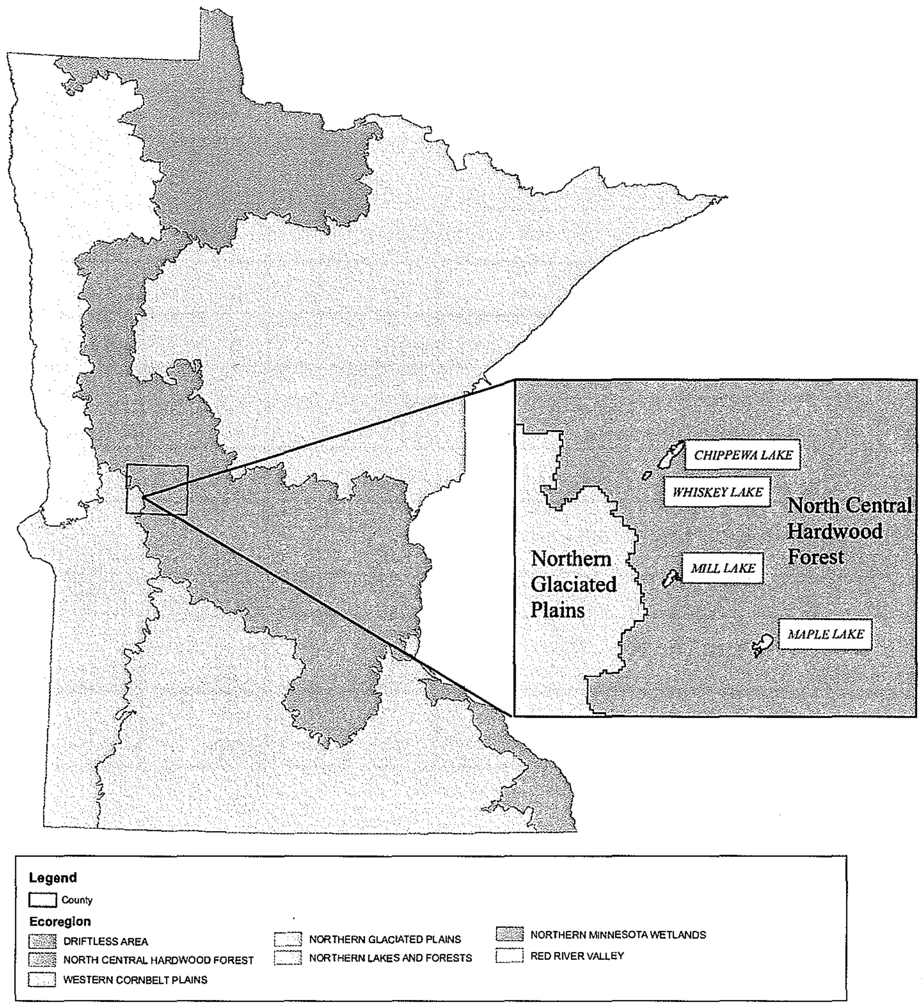
The Minnesota Pollution Control Agency's (MPCA) core lake-monitoring programs include the Citizen Lake Monitoring Program (CLMP) and Lake Assessment Program (LAP). In addition to these programs, the MPCA annually monitors numerous lakes to provide baseline water quality data, provide data for potential LAP and Clean Water Partnership lakes, characterize lake condition in different regions of the state, examine year-to-year variability in ecoregion-reference lakes, and provide additional trophic status data for lakes exhibiting trends in Secchi transparency. In the latter case, sampling is conducted to attempt to determine if the trends in Secchi transparency are "real," i.e., do supporting trophic status data substantiate whether a change in trophic status has occurred. This effort also provides a means to respond to citizen concerns about protecting or improving the lake, and in cases where no data exists, to evaluate the quality of the lake. To make for efficient sampling, geographic clusters of lakes are selected (e.g., focus on a specific county) whenever possible.

This report details efforts on 4 of the 8 lakes sampled in Douglas County during the 2005 season (Figure 1). This general area was selected for study as it is very lake-rich and extensive monitoring in the area had not been conducted in recent years. The actual lakes selected for monitoring all had varying amounts of historical data. In the data-rich lakes, identifying trends based on comparison with historic data and long-term Secchi records was a priority, while the data-poor lakes focused on establishing baseline data. In the selection of lakes, a focus was placed on large lakes, typically with surface areas of 500 acres or more, as one of the program priorities is to ensure that data is collected on as many of Minnesota's larger lakes as possible.

Water quality samples were collected monthly from May through September at most lakes. A summary of data from 2005 and available historical data follows. This summary will include data from 2005, as well as any data available in STORET, the U.S. Environmental Protection Agency's (EPA) national water quality data bank. Data used in this report is available on the MPCA's Environmental Data Access webpage at: http://www.pca.state.mn.us/data/eda/index.cfm. Summer-mean (June to September) epilimnetic (upper well-mixed layer) concentrations for each lake are compared to the "typical" range for ecoregion-reference lakes in the Northern Central Hardwood Forests ecoregion (Figure 1 and Table 2). This provides a basis for placing data from these lakes in perspective relative to one another, as well as other lakes in the same ecoregion. Additional bases for comparison and evaluation are provided with Tables 1 and 2.

Figure 1. Minnesota's Seven Ecoregions as Mapped by U.S. EPA



Ecoregion Based Lake Water Quality

Table 1 provides the draft ecoregion-based nutrient criteria. These criteria were developed by MPCA in response to an EPA requirement that states develop nutrient criteria for lakes, rivers, wetlands and estuaries. Our approach to developing these criteria are consistent with our previous phosphorus criteria (Heiskary and Wilson, 1989) that have been used extensively for goal setting and evaluating the condition of Minnesota's lakes for our 305(b) report to Congress and have provided a basis for evaluating lakes for the 303(d) "impaired waters" list. Details on the development of the criteria may be found in Heiskary and Wilson (2005). In general, lakes that are at or below the criteria levels will have adequately high transparency and sufficiently low amounts of algae to support swimmable use throughout most of the summer. Whenever possible, these lakes should be protected from increases in nutrient concentrations, which would tend to stimulate algal and plant growth and reduce transparency. For lakes above the criteria level, the criteria may serve as a restoration goal for the lake and may lead to the lake being included on the 303(d) list that is submitted to EPA biennially.

Table 1. Proposed eutrophication criteria by ecoregion and lake type
(Heiskary and Wilson, 2005)

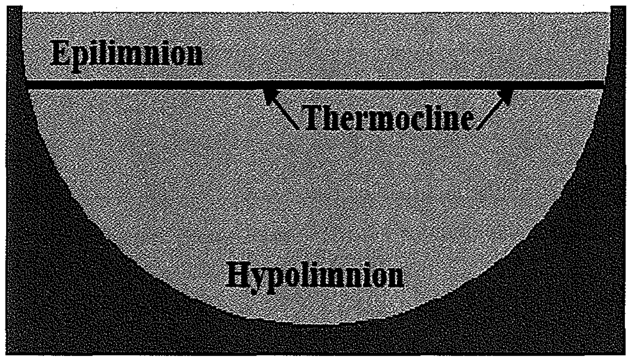
Ecoregion	TP	Chl-a	Secchi
	ppb	ppb	meters
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
CHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
CHF – Aquatic Rec. Use (Class 2b)	< 40	< 14	> 1.4
CHF – Aquatic Rec. Use (Class 2b) Shallow lakes	< 60	< 20	> 1.0
WCP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	< 90	< 30	> 0.7

Table 2 represents the typical summer-mean water quality for lakes in ecoregion. This data is derived from extensive sampling (1985-1988) of several reference lakes in each of the ecoregions. These "reference" lakes are not necessarily the most pristine lakes in each ecoregion; rather these lakes are "representative" of the ecoregion and are minimally impacted by humans. As is evident, the relative impact by human activities does vary among ecoregions. Chippewa and Maple Lakes were among the original reference lakes for the NCHF. Further details may be found in Heiskary and Wilson (2005). These data provide an objective basis for comparing data from other lakes and, in the case of this study; data from the NCHF ecoregion will be used as a basis for comparing the water quality of lakes sampled in 2005.

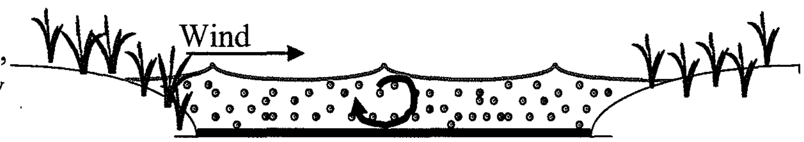
Lake depth can have a significant influence on lake processes and water quality. One such process is *thermal stratification* (formation of distinct temperature layers, see Figure 2a), in which deep lakes (maximum depths of 30 - 40 feet or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 2c). These lakes full-mix or turn-over twice per year; typically in spring and fall (Figure 2d). Shallow lakes (maximum depths of 20 feet or less) in contrast, typically do not stratify and are often referred to as *polymictic* (Figure 2b). Some lakes, intermediate between these two, may stratify intermittently during calm periods. Measurement of temperature throughout the water column (surface to bottom) at selected intervals (e.g. every meter) can be used to determine whether the lake is well-mixed or stratified. It can also identify the depth of the thermocline (zone of maximum change in temperature over the depth interval). In general, the upper, well-mixed layer (epilimnion) is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. Most of the fish in the lake will be found in the epilimnion or near the thermocline. The combined effect of depth and stratification can influence overall water quality.

Figure 2. Thermal Stratification and Lake Mixing

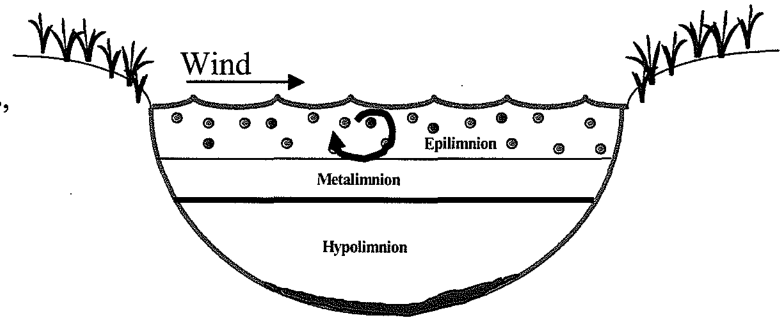
2a



2b **Polymictic Lake**
Shallow, No Layers,
Mixes Continuously
Spring, Summer & Fall



2c **Dimictic Lake**
Deep, Form Layers,
Mixes Few Times
Summer



2d **Dimictic Lake**
Deep, Form Layers,
Mixes Few Times
Spring/Fall

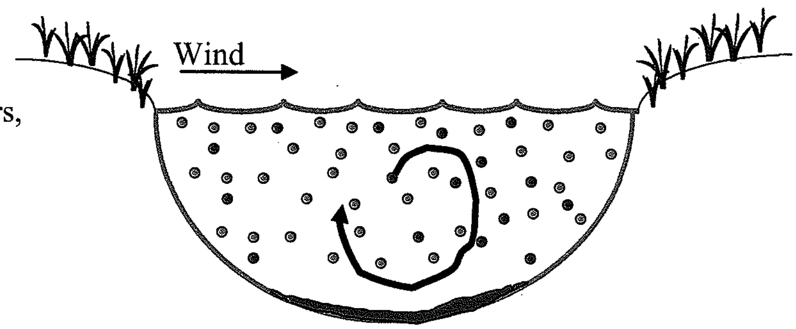


Table 2. Reference Lake Data Base Water Quality Summary
(Summer Average Water Quality Characteristics for Lakes by Ecoregion)*

Parameter	NLF	CHF	WCP	NGP
# of lakes	**32**	**43**	**16**	**13**
Total Phosphorus (ug/l)	**14 - 27**	**23 - 50**	**65 - 150**	**122 - 160**
Chlorophyll mean (ug/l)	**4 - 10**	**5 - 22**	**30 - 80**	**36 - 61**
Chlorophyll maximum (ug/l)	**< 15**	**7 - 37**	**60 - 140**	**66 - 88**
Secchi Disk (feet) (meters)	**8 - 15 (2.4 - 4.6)**	**4.9 - 10.5 (1.5 - 3.2)**	**1.6 - 3.3 (0.5 - 1.0)**	**1.3 – 2..6 (0.4 – 0.8)**
Total Kjeldahl Nitrogen (mg/l)	**0.4 – 0.75**	**< 0.60 - 1.2**	**1.3 - 2.7**	**1.8 - 2.3**
Nitrite + Nitrate-N (mg/l)	**<0.01**	**<0.01**	**0.01 - 0.02**	**0.01 - 0.1**
Alkalinity (mg/l)	**40 – 140**	**75 - 150**	**125 - 165**	**160 - 260**
Color (Pt-Co Units)	**10 – 35**	**10 - 20**	**15 - 25**	**20 - 30**
pH (SU)	**7.2 - 8.3**	**8.6 - 8.8**	**8.2 - 9.0**	**8.3 - 8.6**
Chloride (mg/l)	**0.6 – 1.2**	**4 - 10**	**13 - 22**	**11 - 18**
Total Suspended Solids (mg/l)	**< 1 – 2**	**2 - 6**	**7 - 18**	**10 - 30**
Total Suspended Inorganic Solids (mg/l)	**< 1 – 2**	**1 - 2**	**3 - 9**	**5 - 15**
Turbidity (NTU)	**< 2**	**1 - 2**	**3 - 8**	**6 - 17**
Conductivity (umhos/cm)	**50 – 250**	**300 - 400**	**300 - 650**	**640 - 900**
TN:TP ratio	**25:1 - 35:1**	**25:1 - 35:1**	**17:1 - 27:1**	**13:1 - 17:1**

*Based on Interquartile range (25th - 75th percentile) for ecoregion reference lakes.
Derived in part from Heiskary, S. A. and C. B. Wilson (1990).

Table 3 represents the percentile distribution of summer-mean in-lake TP concentrations for each ecoregion based on the mixing (temperature stratification) status of the lake as follows:

dimictic — Deep lake, fully mixes in spring and fall but remains stratified in summer.

polymictic — Shallow lake, remains well mixed from spring through fall.

intermittent — Lake with moderate depths, may stratify temporarily during summer, but may mix with strong wind action. Sorting TP concentrations within each mixing type creates this distribution (by ecoregion) from low to high. These percentiles can provide an additional basis for comparing observed summer-mean TP and may further serve as a guide for deriving an appropriate TP goal for the lake.

Table 3. Distribution of Total Phosphorus (µg/L) Concentrations by Mixing Status and Ecoregion. Based on all assessed lakes for each ecoregion.
D = Dimictic, **I** = Intermittent, **P** = Polymictic

	Northern Lakes and Forests			North Central Hardwood Forest			Western Corn Belt Plains		
Mixing Status:	**D**	**I**	**P**	**D**	**I**	**P**	**D**	**I**	**P**
Percentile value for [TP]									
90 %	37	53	57	104	263	344	--	--	284
75 %	29	35	39	58	100	161	101	195	211
50 %	20	26	29	39	62	89	69	135	141
25 %	13	19	19	25	38	50	39	58	97
10 %	9	13	12	19	21	32	25	--	69
# of obs.	257	87	199	152	71	145	4	3	38

Background

Watersheds

The lakes in the study are located in the Upper Mississippi and Minnesota River Basins. Within these basins, lakes were located in the following watersheds: Long Prairie River (Mill Lake) and Chippewa River (Maple, Whiskey, and Chippewa Lakes). Chippewa and Maple Lake were among the ecoregion reference lakes sampled by the MPCA in the mid-1980s. Whiskey Lake received treated wastewater effluent from the City of Brandon prior to 1988. For this report we will group lakes by these watersheds, which should provide a basis for comparison among lakes in the same watershed or lake chain.

Lake Level Trends

Lake level is measured in several of the lakes based on volunteers through MDNR's Lake Level Monitoring Program. Lake level was recorded on Mill, Chippewa, and Maples Lakes. These records showed some fluctuation in level over time, but this variation is less than 3.9 feet, based on records over the most recent twenty years. Data for specific lakes and years can be found at www.dnr.state.mn.us.

Fisheries

All lakes in this report were surveyed by the MDNR Fisheries Section between 2003 and 2005. More detailed reports are available at www.dnr.state.mn.us.

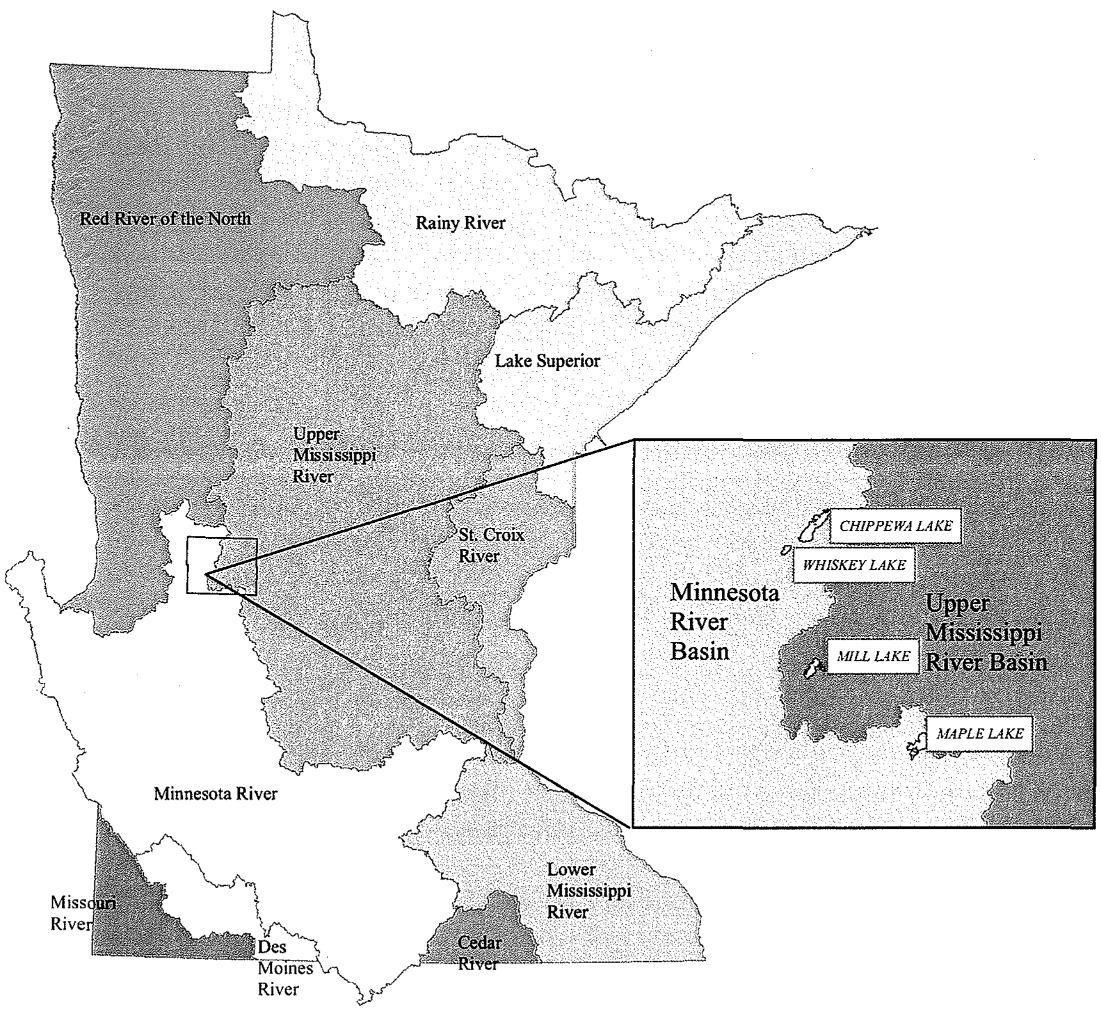
Chippewa Lake has moderate to high development and is currently managed for walleye. The lake has a variety of aquatic habitats which supports natural reproduction of fish. Currently the lake is known for its walleye, northern, and bass fisheries.

Whiskey Lake is far shallower and contains more rooted and algal vegetation. This is likely due to the internal loading from the lake receiving treated and partially-treated effluent from the City of Brandon prior to 1988. Northern, largemouth bass, bluegill and black crappie are now abundant in the lake. The walleye fishery is not as successful, and the lake is currently being managed to target that species.

Maple Lake is also relatively shallow with a diverse aquatic plant community. Like Whiskey, Maple is known for its northern, bluegill, black crappie, and largemouth bass. Walleye is also managed on this lake, and is currently meeting the goals set in the lake management plan by the DNR.

Mill Lake is moderately developed, and contains dense plant growth in the shallow, southwest bay. Again, northern, largemouth bass, bluegill, and black crappie are dominant sport species. The lake is currently being stocked for walleye, which have recently been declining in numbers.

Figure 3. Location of 2005 study lakes.



Lake Characteristics

Lake morphometric characteristics including surface area, mean and maximum depth, and percent littoral are summarized in Tables 4a and 4b. With 1,186 acres, Chippewa Lake was the largest in the study, while Whiskey Lake (158 acres) was the smallest. Maximum depths ranged from 40 feet in Mill Lake to 95 feet in Chippewa Lake. Mean depths ranged from twelve feet in Whiskey to 21 feet in Chippewa. Lake volume, which is the product of mean depth times surface area, ranged from 1,896 acre-feet in Whiskey to 26,092 acre-feet in Chippewa.

Percent littoral refers to that portion of the lake that is 15 feet or less in depth, which often represents the depth to which rooted plants may grow in the lake. Lakes with a high percentage of littoral area often have extensive rooted plant (macrophyte) beds. These plant beds are a natural part of the ecology of these lakes and are important to protect. The definition for "shallow" lakes applies to those with maximum depths of 15 feet or less or where the littoral area comprises 80% or more of the basin (Heiskary and Wilson, 2005). Based on this definition all the lakes in this study would be considered "deep" lakes (Table 4a). Shallow lakes will often remained well-mixed from top to bottom during the summer, in contrast to deep lakes that will typically form distinct thermal layers.

Watershed areas were estimated for the lakes based on previous reports (Chippewa, Maple, and Whiskey) and from DNR Data Deli Lakeshed data and USGS watershed data that may be found at: http://deli.dnr.state.mn.us/about.html and http://gisdmnspl.cr.usgs.gov/watershed/index.htm, respectively. Immediate watershed refers to that portion of the watershed that drains directly to the lake without flowing first through other lakes; while total watershed refers to the entire watershed upstream of the lake. In some cases, such as Whiskey, the immediate and total watershed is one in the same. In others such as Mill, the immediate watershed represents less than 15% of the total watershed to the lake. Differentiating between immediate and total is important as nutrient and water budgets are determined for the lake (typically requires total watershed as an input); whereas when focusing best management practices and protection efforts the immediate watershed is the first target. Total watershed: lake area ratio also provides an important perspective on the size of the watershed relative to the lake. In this study Chippewa has the smallest watershed to lake ratio, which generally means that water (and often nutrient) loading to the lakes is rather small and water residence time is long. In contrast Mill Lake, with a ratio of 59:1, has the highest ratio of any lake in the study. This implies that large volumes of water flow through the lake and residence time is short by comparison. This will be explained in greater detail in a section on modeling results.

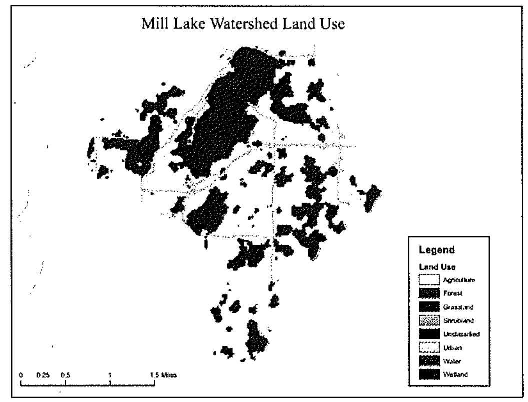
The soils found around lakes in the study are defined as medium to fine textured prairie and prairie border soils from the Barnes-Buse-Pierce and Waukon-Barnes. These tend to be well drained, dark soils found in gently rolling to hilly regions (Arneman 1963). Chippewa, Whiskey, Maple, and Mill lakes were formed by ice block basins left in glacial till (Zumberge, 1952).

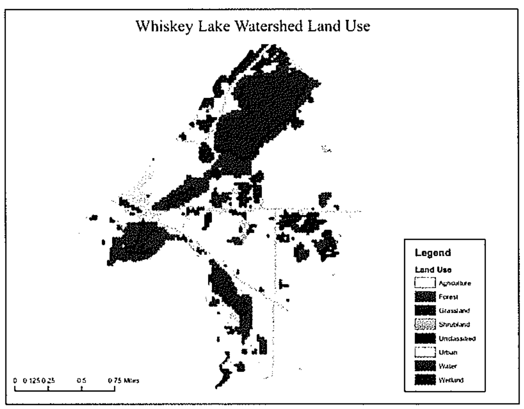
Table 4a. Lake morphometry and watershed characteristics.

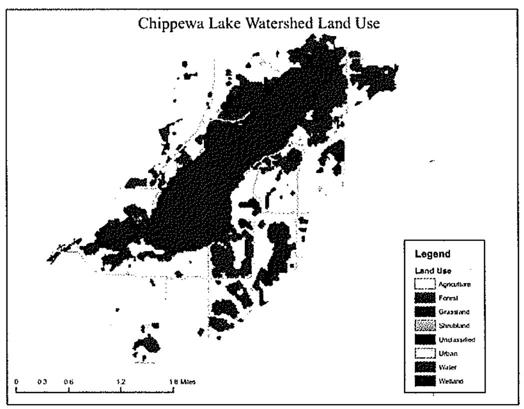
Lake Name	Lake	Lake Basin	Littoral Area		Immediate Watershed	Total Watershed Area	Total Watershed To Lake	Max. Depth	Average Depth	Lake Volume
Name	ID	Acres	Acres	% Littoral	Acres	Acres	Ratio	Ft.	Ft.	Acre-Ft.
Chippewa	21-0145	1,186	505	43	1,542	1,542	1.3:1	95	21	26,092
Whiskey	21-0216	158	74	47	960	960	6:1	46	12	1,896
Maple	21-0079	815	387	48	3,456	3,456	4.1:1	78	17	14,670
Mill	21-0180	461	240	58	3,892	27,040	59:1	40	15	6,240

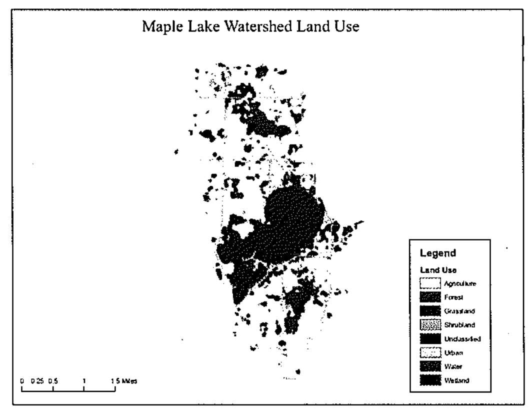
4b. Watershed land use as compared to Ecoregion Interquartile Ranges

Land Use (%)	Chippewa	Whiskey	Maple	Mill	NCHF Ecoregion
Forest	10.5	13	6	16	6 – 25
Water/wetlands	50	14	21	19	14 – 30
Pasture/grasslands	11	6	19	0	11 – 25
Cultivated	21.5	58	50	59	22 - 50
Urban	7	9	4	6	2 - 9









Precipitation

Approximately 36 inches of water evaporates annually in the part of the state. This typically exceeds precipitation, which averages 24 to 26 inches (0.61 to 0.66 m). Runoff averages about 2 inches with 1-in-10 year low and high values (may occur with a frequency of once in ten years) of 0.4 inches and 4 inches, respectively for this area (Gunard, 1985).

Rain gage records from the La Grand Township show three one-inch, two two-inch, and one four-inch rain events during summer 2005 (Figure 4a). In particular, large rain events were noted for June and between August 26th and September 6th. These rain events will increase runoff into the lakes and may influence in-lake water quality and lake levels. This will be considered in the individual discussions of lake water quality for 2005. Precipitation records for the 2005 water year (October 2004 through September 2005) showed above average rainfall (4 to 6 inches above normal) for the Douglas study area (Figure 4b).

Figure 4a. Rainfall based on records from La Grand Twp. Lat: 45.86009 Lon: -95.48240

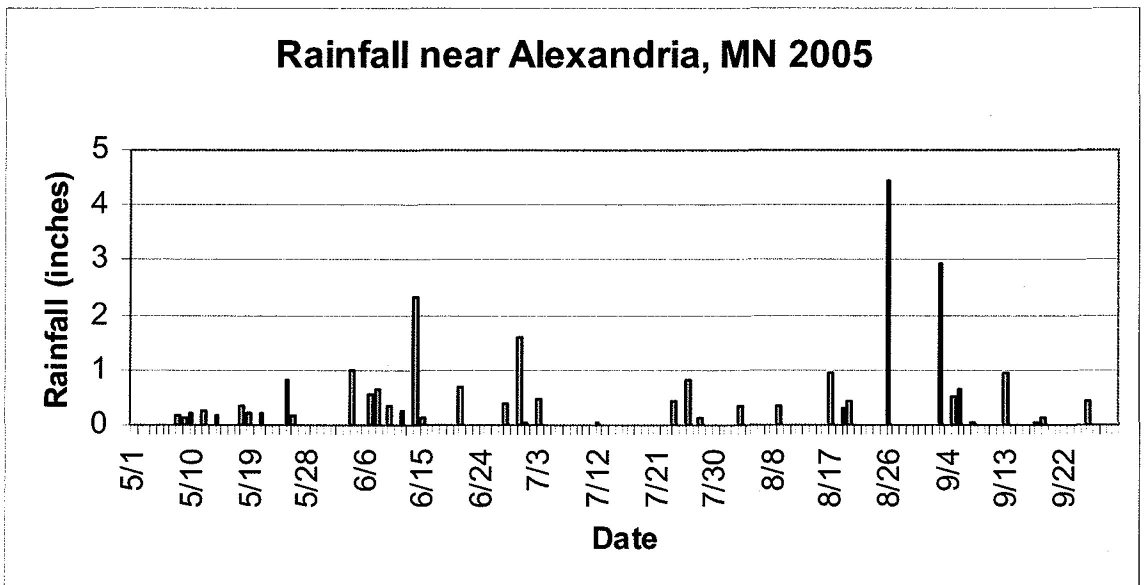
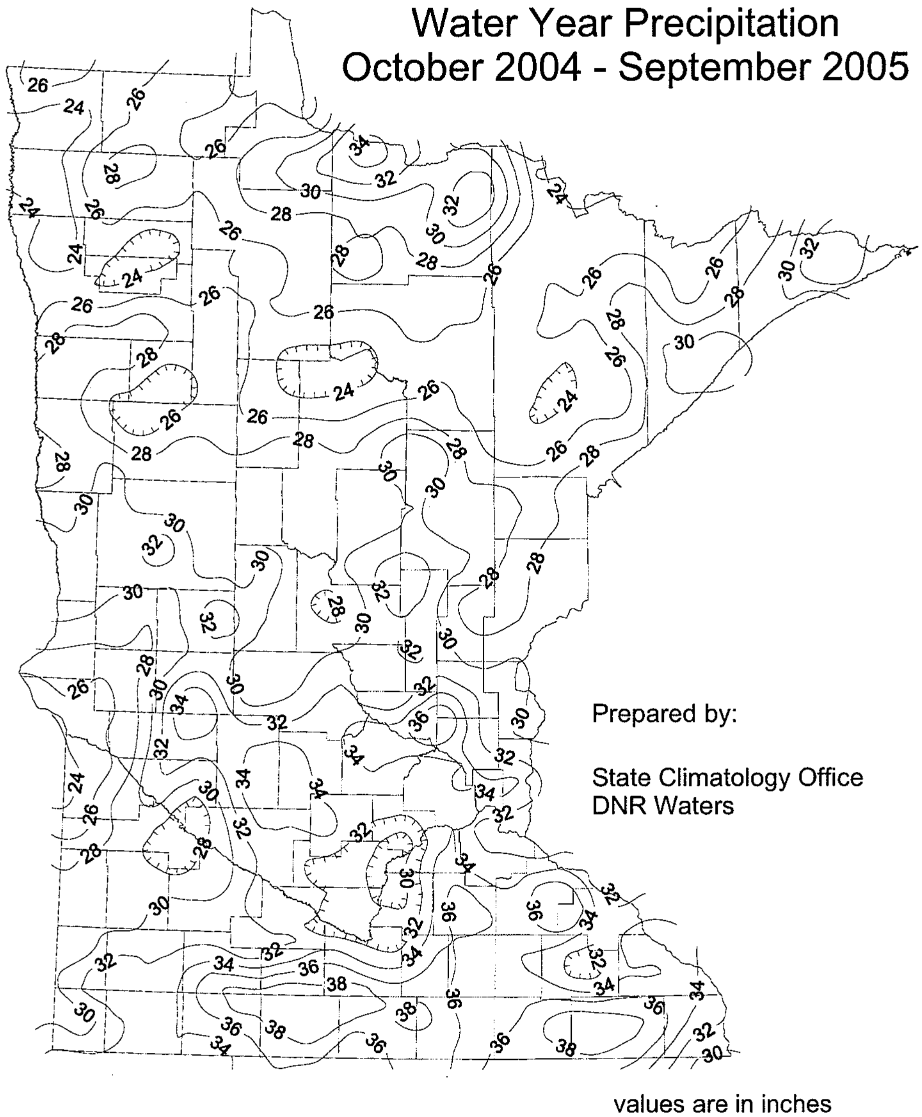


Figure 4b. Water year precipitation for 2005.



Methods

Water quality data was collected in May, June, July, August, and September, 2005 on most of the study lakes. Multiple sites were monitored on some lakes because of their size and complex morphometry. Lake surface samples were collected with an integrated sampler, which is a PVC tube 6.6 feet (2 meters) in length with an inside diameter of 1.24 inches (3.2 centimeters). Depth samples were collected with a Kemmerer depth sampler. Zooplankton samples were collected with a Wisconsin plankton net. Phytoplankton (algae) samples were taken at a primary site with an integrated sampler. Summer-means were calculated using June - September data.

Sampling procedures were employed as described in the MPCA Quality Control Manual. Laboratory analyses were performed by the laboratory of the Minnesota Department of Health using U.S. Environmental Protection Agency (EPA)-approved methods. Samples were analyzed for nutrients, color, solids, alkalinity, chloride and chlorophyll. Temperature, dissolved oxygen, pH, and conductivity profiles and Secchi disk transparency measurements were also taken. Phytoplankton samples were analyzed at the MPCA by Dr. Howard Markus.

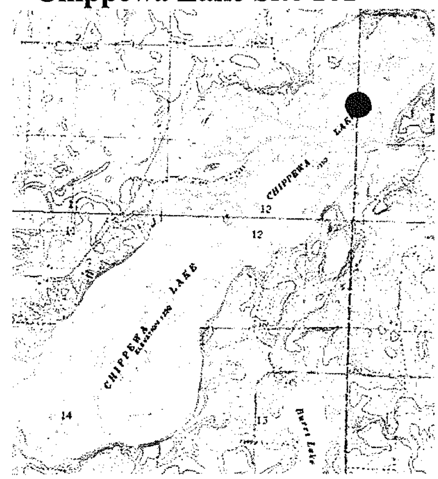
A good historical data base is available for several lakes and will be employed in a section on trends. All data was stored in STORET, the EPA's national water quality data bank. The following discussion assumes that the reader is familiar with basic water quality terminology as used in the Citizens' Guide to Lake Protection, which may be obtained from http://www.pca.state.mn.us/water/lakeprotection.html .

Table 5. Lake Summer Mean Water Quality

Parameter	Chippewa 101	Whiskey 101	Maple		Mill	Typical Range for NCHF Ecoregion
			101	102	102	
Total Phosphorus (µg/l)	20	43	16	19	32	23 – 50
Chlorophyll-a (µg/l) mean	3.8	13	3.1	3.0	11.2	5 – 22
Chlorophyll-a (µg/l) max	6.5	17	4.6	3.6	25.3	7 – 37
Secchi disk (feet)	10.5	7.2	10.8	11.8	5.4	4.9 – 10.5
Secchi disk (m)	3.2	2.2	3.3	3.6	1.65	1.5 – 3.2
Total Kjeldahl Nitrogen (mg/l)	0.7	1.2	0.9	-	1.2	<0.60 – 1.2
Alkalinity (mg/l)	189	178	223	-	188	75 – 150
Color (Pt-Co Units)	9	18	8	-	19	10 – 20
Chloride (mg/l)	7	61	23	-	19	4 – 10
Total Suspended Solids (mg/l)	3.2	6.1	2.0	-	5.2	2 – 6
Total Suspended Inorganic Solids (mg/l)	2	4.6	1.6	-	3.5	1 – 2
Conductivity (µmhos/cm)	358	493	405	415	422	300 – 400
TN:TP Ratio	28:1	36:1	17:1	-	27:1	25:1 – 33:1

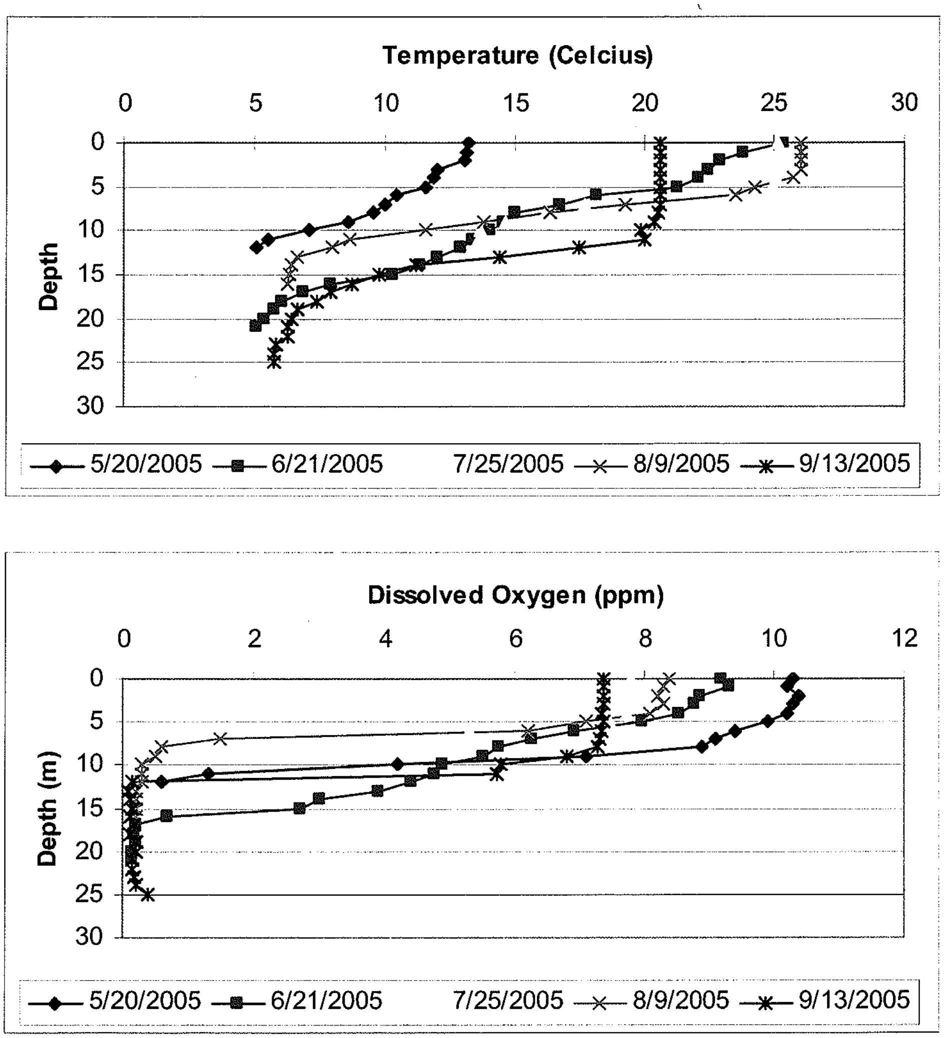
Results: Chippewa Lake

Chippewa Lake Site 101



Dissolved oxygen and temperature profiles were taken at a point near maximum depth at site 101 monthly from May to September. Dissolved oxygen concentrations declined with depth, but remained above 5 mg/l (DO levels of 5 mg/l or greater preferred for game fish) down to a depth of 6 to 12 meters (Figure 5). The July and August temperature profiles were well mixed to a depth of 5 meters, and September was well mixed to a depth of 12 meters. On all dates, stratification was apparent between 5 and 10 meters with the exception of September, which exhibited a thermocline near 14 meters.

Figure 5. Chippewa Lake Temperature and Dissolved Oxygen Profiles



Total Phosphorus (TP) is typically the limiting nutrient in algae growth in Minnesota's lakes. Summer-mean TP was 20 µg/l (micrograms per liter or parts per billion) in the epilimnion during the summer of 2005. This is in the expected range for the NCHF ecoregion (Table 5). Surface TP levels declined through the summer, with a maximum of 23 µg/l in June to a low of 17 µg/l in September (Figure 6). Hypolimnetic (depth) samples had elevated TP as compared to the surface samples, as a result of internal recycling from the sediments. The hypolimnetic concentrations increased markedly over the summer. This "source" of phosphorus tends to remain in the hypolimnion until fall turnover when it is mixed through the water column.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During the summer of 2005, chlorophyll-*a* concentrations ranged from a low of 1.6 µg/l in June to a high of 6.5 µg/l in September with an average of 3.8 µg/l (Figure 7). Chlorophyll-*a* concentrations are well below typical ecoregion values, and no algal blooms were noted during the dates sampled (Table 5).

Figure 6. Chippewa Lake Total Phosphorus Concentration

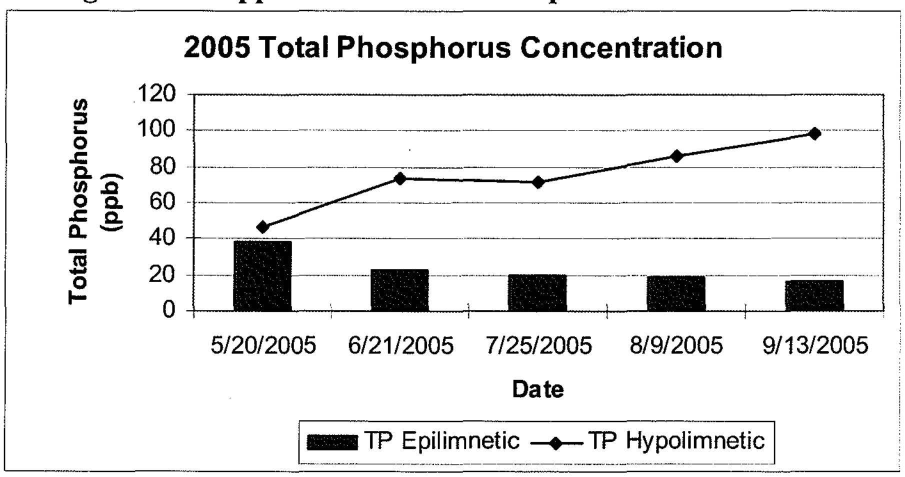
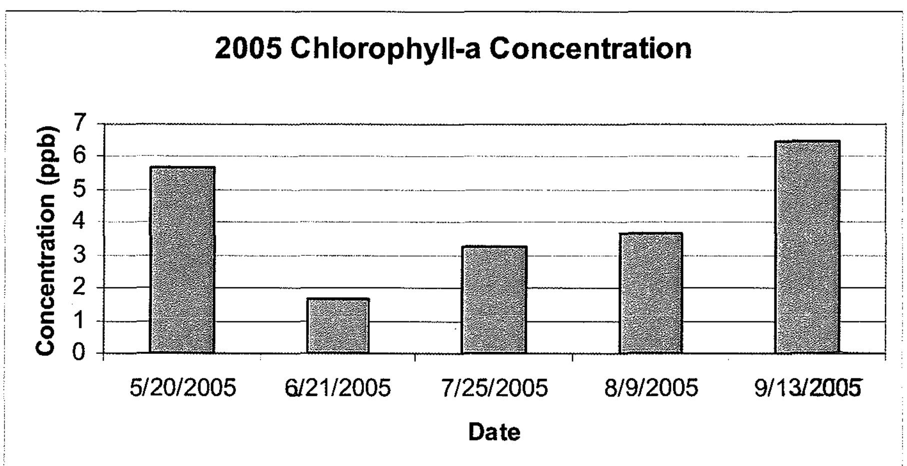


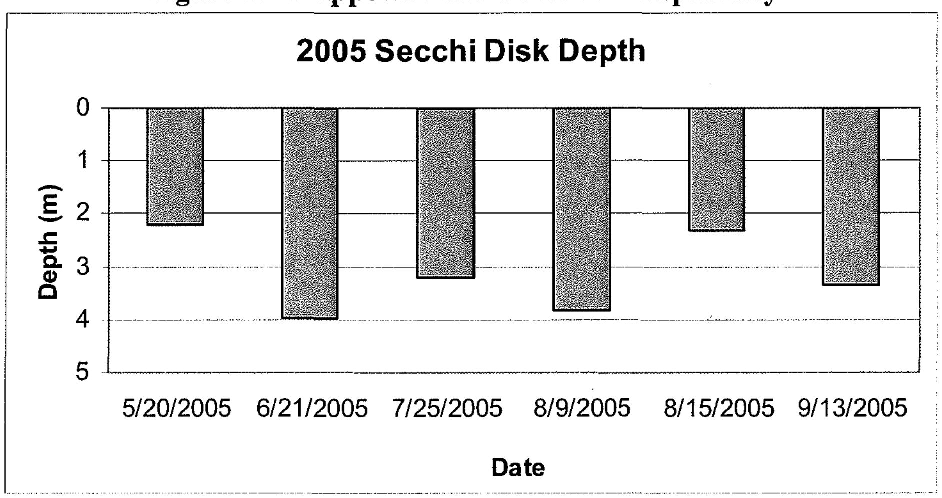
Figure 7. Chippewa Lake Chlorophyll-*a* Concentration



Secchi disk transparency is generally a function of the amount of algae in the water. Suspended sediments or color due to dissolved organics may also reduce water transparency. Color averaged 9 Pt-Co Units and total suspended solids (TSS) averaged 3.2 mg/l over the summer. Both are within or below the expected range of values for the NCHF ecoregion, and likely did not affect water transparency. Secchi transparency ranged from a low of 2.3 m in September to a high of 3.96 m in June, with an average of 3.3 m. This average is just above the typical range of Secchi disk transparencies for the NCHF ecoregion (Table 5).

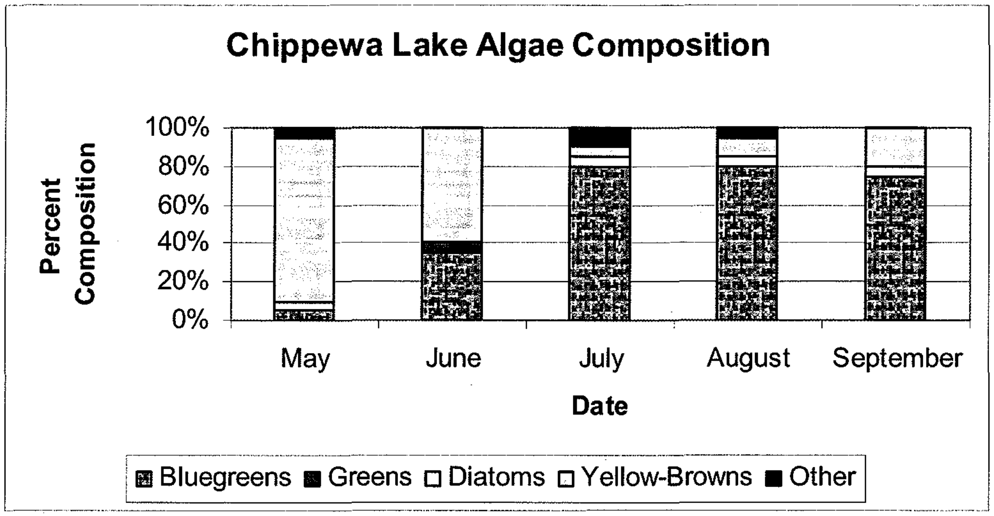
For typical mesotrophic-eutrophic lakes in Minnesota, transparency varies across the season. High readings are normally found in the spring when the water is cool and algae populations are low. Zooplankton (small crustaceans which feed on algae) populations are high at the time of year also, but decline later in the summer due to predation by young fish. As the summer goes on and the waters warm, the algae make use of available nutrients. As algae become more abundant (Figure 7), the transparency declines (Figure 8). The decrease in the abundance of zooplankton may allow for further increase in the amount of algae. Later in the summer, surface blooms of algae may also appear. In late summer, as the waters cool, the transparency typically improves.

Figure 8. Chippewa Lake Secchi Transparency



Algal composition on Chippewa Lake was dominated in May and June by yellow-brown algae and switched to a blue-green algae dominant system for the remainder of the summer. For most mesotrophic to eutrophic lakes in Minnesota, the algae composition shifts from diatoms to greens to blue-greens. On Chippewa Lake, diatoms never made up more than 5% of the composition, and were completely absent in June (Figure 9). Green algae were only present in June, and only made up 5% of the composition.

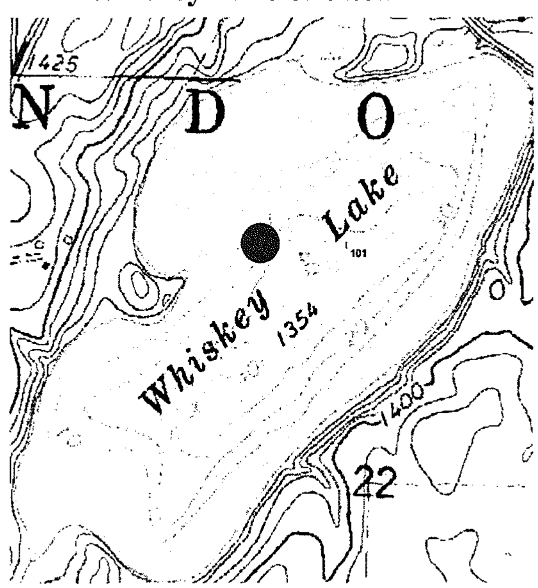
Figure 9. Chippewa Lake Algae Composition



Mercury concentration in the water column was measured at site 101 on Chippewa Lake in June and August 2005. In general, mercury concentrations above one ng/l are considered high, while the impairment threshold is 6.9 ng/l. Concentrations measured on Chippewa Lake ranged from a low of 0.56 ng/l in June to a high of 5.41 ng/l in August. It should be noted that in 1998, Chippewa Lake was listed as impaired for mercury in fish tissue, and a lake specific fish consumption advisory has been developed and is available at: http://www.dnr.state.mn.us/lakefind/index.html.

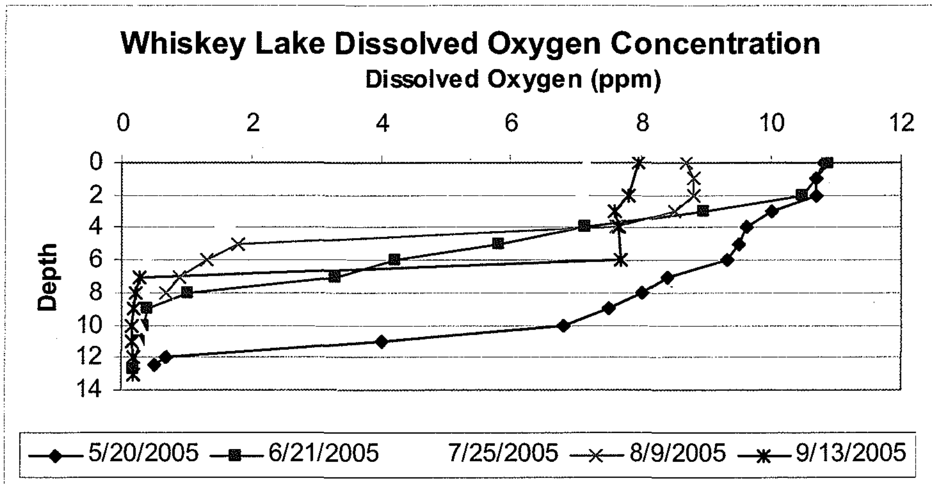
Results: Whiskey Lake

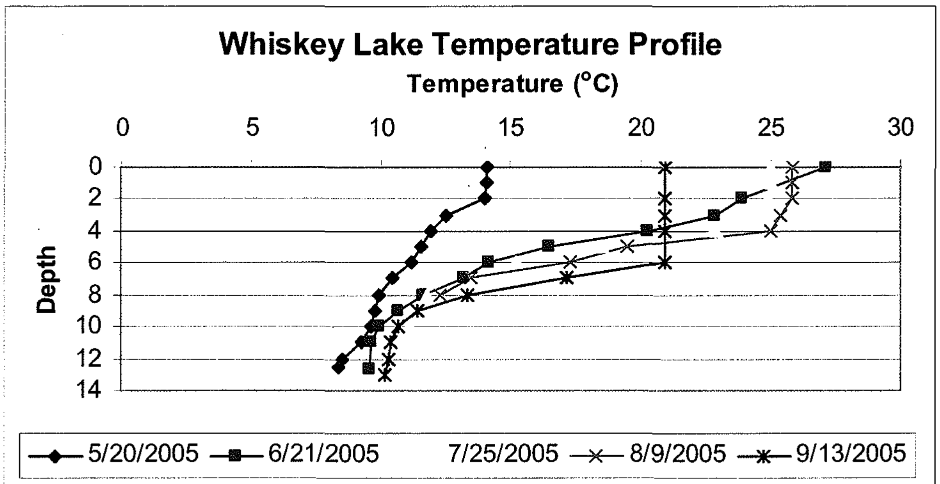
Whiskey Lake Site 101



Dissolved Oxygen and Temperature profiles were taken monthly at site 101. The May and September dissolved oxygen profiles indicated the top 6 meters was relatively well mixed, with DO levels remaining above 5 mg/l to a depth of 10 and 6 meters, respectively (Figure 10). A thermocline developed between a depth of 4 to 8 meters from June to September. The May and September temperature profiles indicated a well mixed water column in the top 2 meters and 6 meters, respectively.

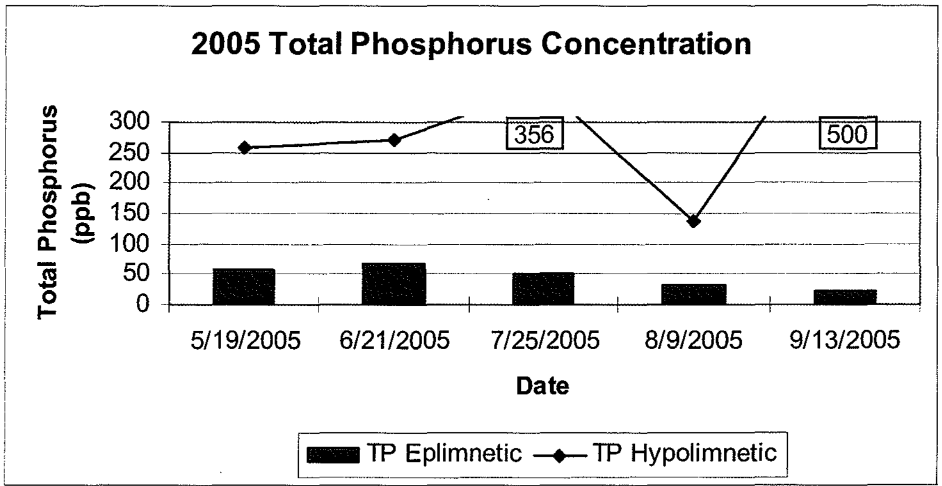
Figure 10. Whiskey Lake Dissolved Oxygen and Temperature Profiles





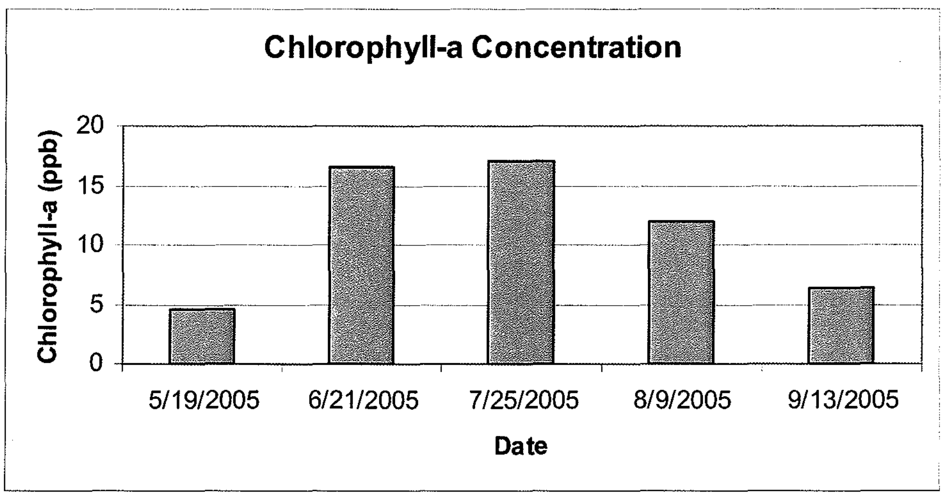
Total Phosphorus concentrations averaged 43 µg/l in the epilimnion during the summer of 2005, with a minimum of 23 µg/l in September and a maximum of 67 µg/l in June (Figure 11). While the Whiskey Lake average total phosphorus is the highest of the four lakes in the study, it is still within the range of typical values for the NCHF ecoregion (Table 5). The hypolimnetic total phosphorus was considerably higher than the surface samples, and this would be expected, considering that Whiskey Lake historically received wastewater from the City of Brandon. In late 1987, the city went online with its new wastewater treatment facility and switched to a land application spray irrigation discharge instead of discharging directly to Whiskey Lake, greatly reducing the total phosphorus load to the lake.

Figure 11. Whiskey Lake Total Phosphorus Concentration



Chlorophyll-*a* concentrations for 2005 on Whiskey Lake averaged 13 µg/l, with a low of 6.4 µg/l in September and a high of 17.1 µg/l in July (Figure 12). Concentrations from 10-20 µg/l are frequently perceived as a mild algal bloom. Considering this, mild algae blooms were evident during the June, July, and August sampling trips. Both the average and maximum chlorophyll-*a* values were within the typical range for NCHF ecoregion lakes (Table 5). Chlorophyll-*a* followed a similar pattern as total phosphorus, with a peak in early-mid summer and then a decline in concentration for the remainder of the season.

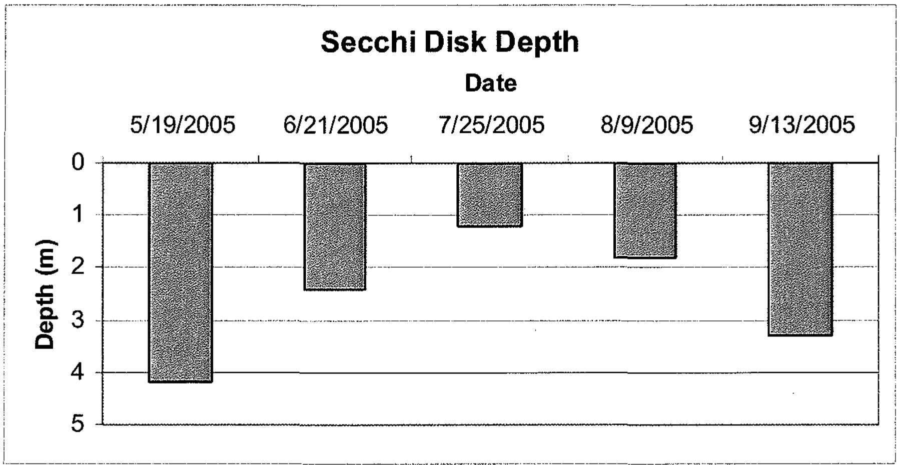
Figure 12. Whiskey Lake Chlorophyll-*a* Concentration



Secchi disk transparency on Whiskey Lake averaged 2.2 meters (7.2 feet) with a range of 1.2 – 3.3 m during the summer of 2005 (Figure 13). Color averaged 18 Pt-Co Units and total suspended solids averaged 6.1 mg/l. Color is on the high end of the typical range of NCHF ecoregion values and TSS is just above the range of values (Table 5). These levels should not appreciably reduce the clarity of the water. The average Secchi depth is in line with the typical ecoregion values.

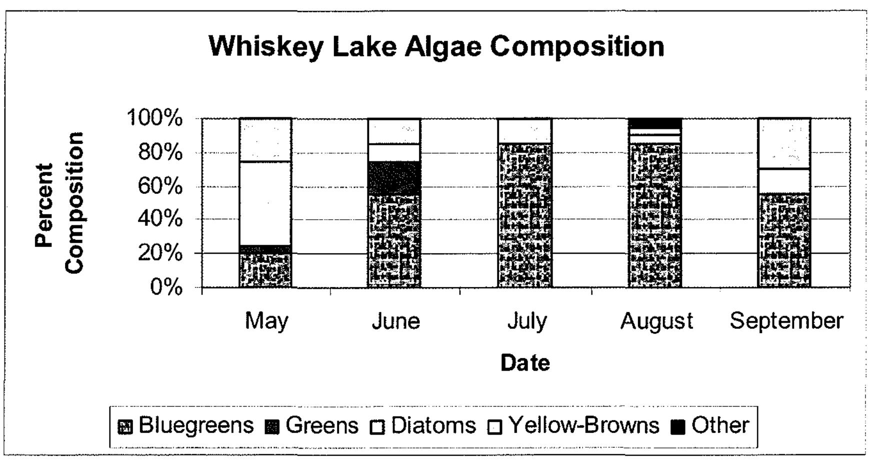
The change in the transparency of Whiskey Lake over the course of the summer closely mirrored the changes in nutrient availability (TP) and algal production (Chl-*a*). Transparency was greatest in the spring when the waters were cool and algal production was relatively low. As the chlorophyll-*a* concentrations increased, the Secchi depth decreased. In the fall, as the waters cooled, the transparency improved.

Figure 13. Whiskey Lake Secchi Disk Transparency



Algal composition for Whiskey Lake was dominated in May by diatoms and then shifted to a blue-green dominant system for the remainder of the summer. A seasonal transition from diatoms to greens to blue-greens is rather typical for mesotrophic and eutrophic lakes in Minnesota. During 2005, the green algae were never dominant, but did make up 20% of the composition during the June sampling event (Figure 14).

Figure 14. Whiskey Lake Algae Composition



Mercury concentration in the water column was measured at site 101 on Whiskey Lake in June and August of 2005. In general, mercury concentrations above one ng/l are considered high, while the impairment threshold is 6.9 ng/l. Concentrations measured on Whiskey Lake ranged from a low of 0.94 ng/l in June to a high of 1.45 ng/l in August. It should be noted that in 2002

Whiskey Lake was listed as impaired for mercury in fish tissue, and a lake specific fish consumption advisory has been developed and is available at: http://www.dnr.state.mn.us/lakefind/index.html.

Results: Maple Lake

Dissolved oxygen and temperature profiles were taken at sites 101 and 102 in May, June, July, and September 2005. Dissolved oxygen remained above 5 mg/l on all sampling dates above a depth 7 to 10 meters at site 101 and 6 to 9 meters at site 102 (Figure 15). Temperature profiles indicated that the lake was well mixed at 101 during the May sampling event and in May and September at the 102 site. A thermocline was evident at a depth of 10 meters at site 101 and 6 meters at site 102.

Maple Lake Site 101 and 102

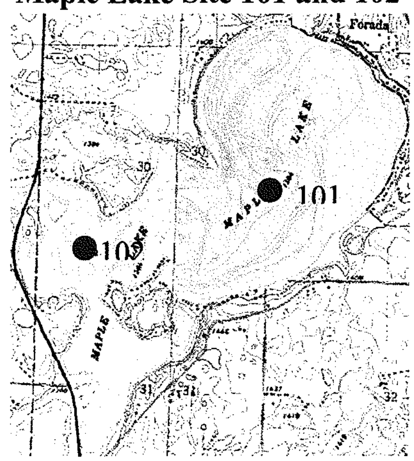
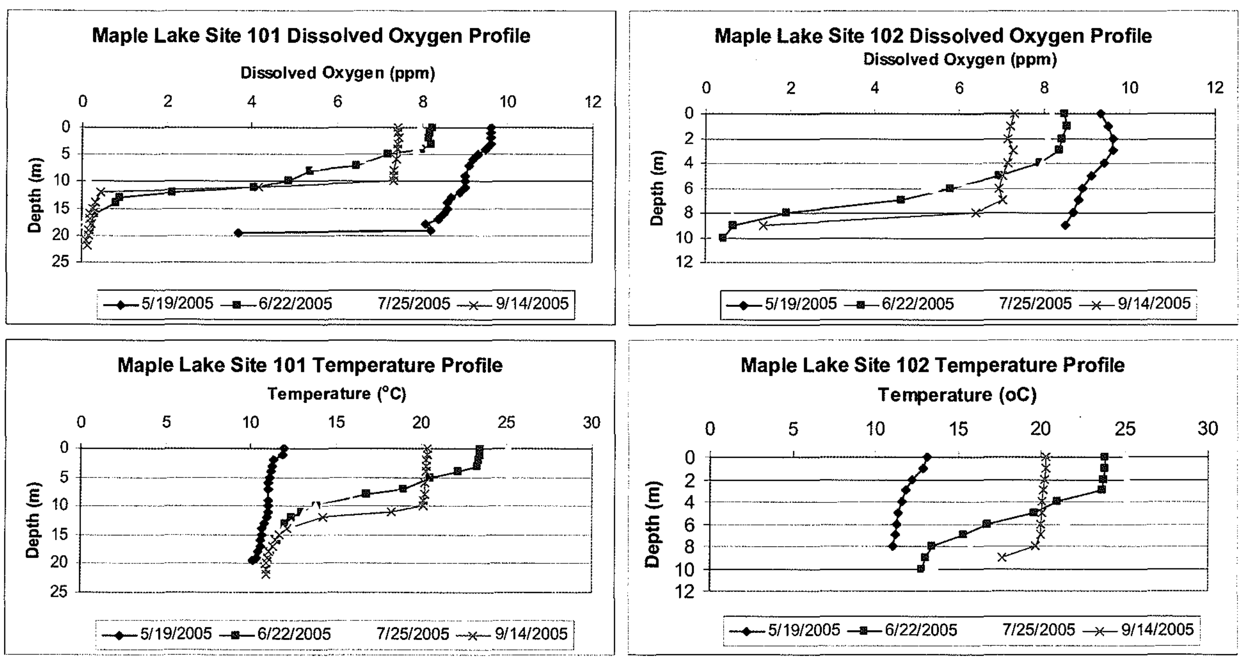
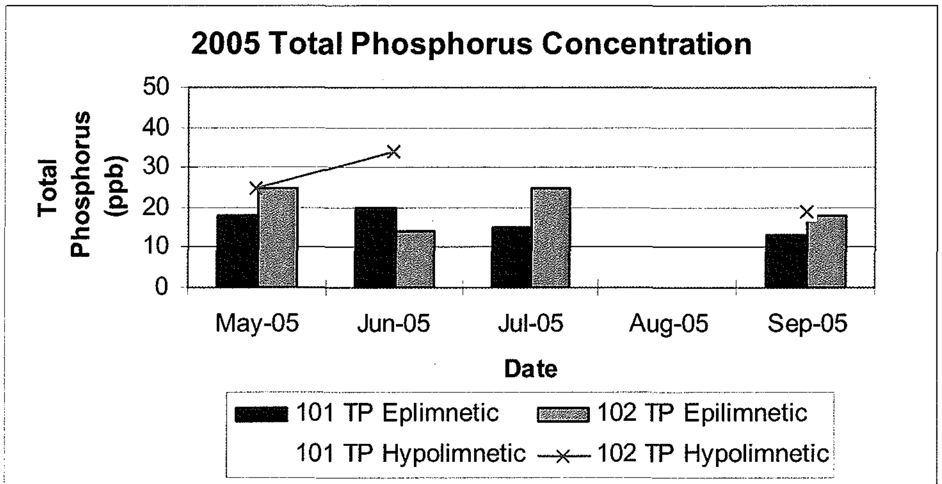


Figure 15. Maple Lake Dissolved Oxygen and Temperature Profiles



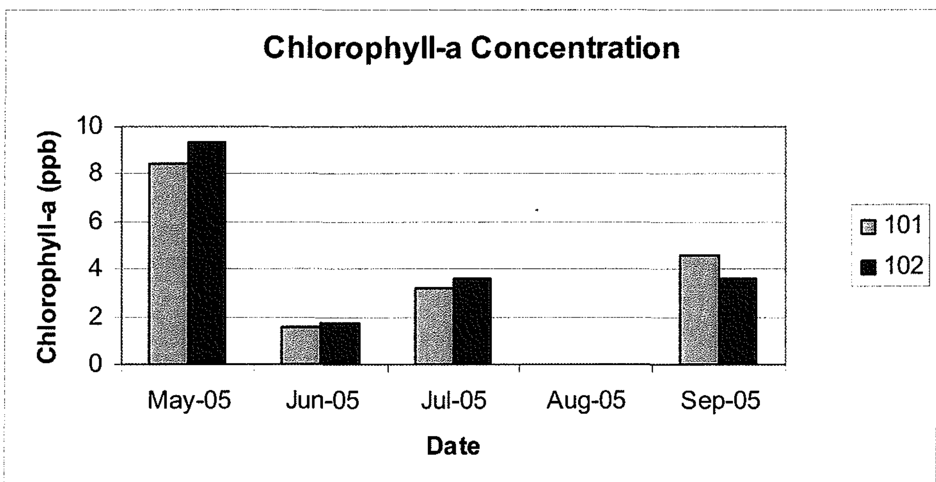
Total Phosphorus concentrations on Maple Lake averaged 16 μg/l at site 101 and 19 μg/l at site 102 (Figure 16). Both of these are well below the typical range for lakes in the NCHF ecoregion (Table 5). Hypolimnetic total phosphorus concentrations were not measured consistently, but averaged 29 μg/l at site 101 and 27 μg/l at site 102. Typically total phosphorus concentrations decline across the summer as watershed loading to the lake diminishes.

Figure 16. Maple Lake Total Phosphorus Concentration



Chlorophyll-*a* concentrations averaged 3.1 μg/l and 3.0 μg/l at sites 101 and 102, respectively (Figure 17). Both the averages and the maximums (101 = 4.6 μg/l and 102 = 3.6 μg/l) were well below the NCHF ecoregion typical ranges (Table 5). After an initial peak in concentration in May, the chlorophyll-*a* concentration decreased significantly, and then slowly increased across the summer at both sites. No algal blooms were evident based on the concentrations found during sampling events.

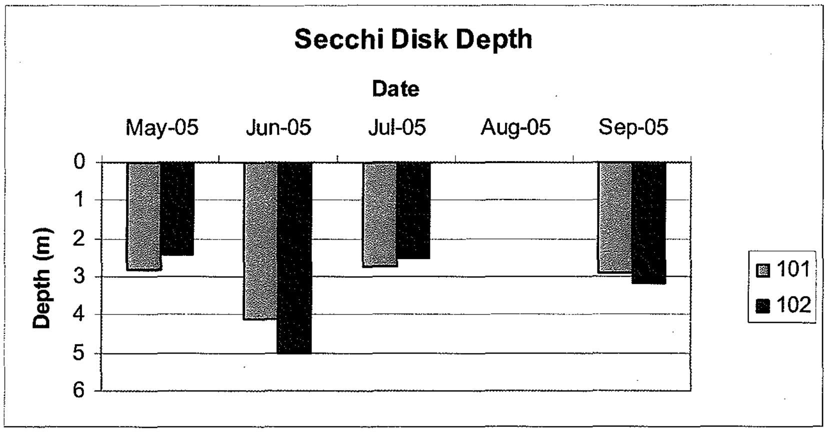
Figure 17. Maple Lake Chlorophyll-*a* Concentration



Secchi disk transparency averaged 3.3 m (10.8 feet) at site 101 and 3.6 m (11.8 feet) at site 102 (Figure 18). Both were above (better than) the typical range of expected values for the NCHF ecoregion (Table 5). Color averaged 8 Pt-Co Units at site 101 and TSS averaged 2.0 mg/l. Both are at or below the ecoregion typical range values, and should not appreciably limit transparency.

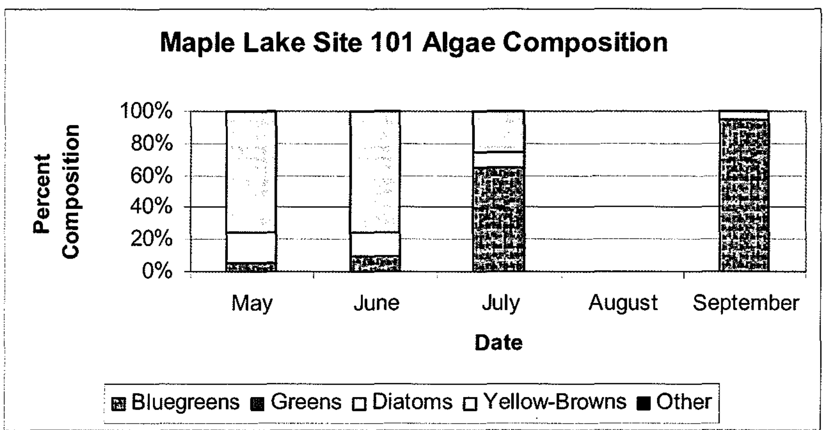
On a day-to-day basis, transparency may differ between the sites, but the overall pattern was consistent among both sites.

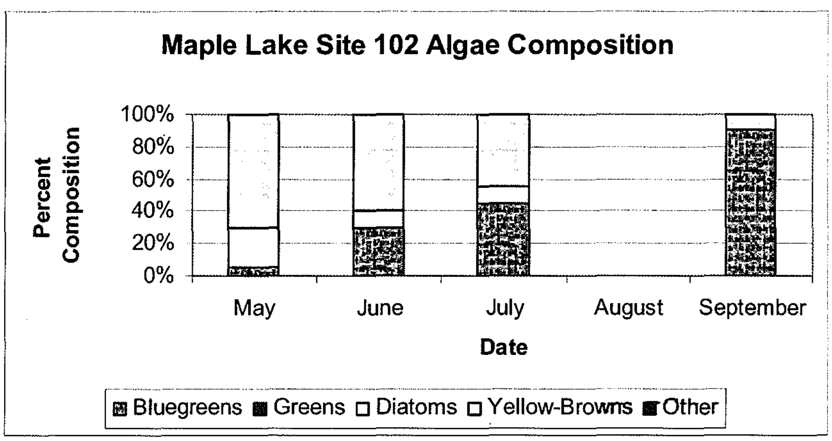
Figure 18. Maple Lake Secchi Disk Transparency



Algal composition on Maple Lake was dominated by yellow-brown algae in May and June for both sites 101 and 102. In the July and September samples, blue-green algae shifted to the dominant form (Figure 19). As with Whiskey Lake, Maple did not follow the typical progression from diatoms to greens to blue-greens.

Figure 19. Maple Lake Algae Composition





Mercury concentration in the water column was measured on Maple Lake in June and July 2005. Concentrations measured ranged from 0.76 ng/l in June to 0.63 ng/l in July, both of which are well below the impairment threshold of 6.9 ng/l. It should be noted that in 1998, Maple Lake was listed as impaired for mercury in fish tissue, and a lake specific fish consumption advisory has been developed and is available at: http://www.dnr.state.mn.us/lakefind/index.html.

Results: Mill Lake

Dissolved oxygen and temperature profiles were taken at site 102 during the May, June, July, August, and September sampling dates. During the May and September dates, the lake appeared to be well mixed at all depths. Dissolved oxygen concentrations remained above 5 mg/l on all dates to a depth of 5 meters (Figure 20). The temperature was well mixed in the May and September profiles, and exhibited a thermocline near 5 meters on the other dates. This would indicate that Mill Lake is a dimictic lake, mixing in the spring and fall and remaining stratified during the summer months.

Mill Lake Site 101 and 102

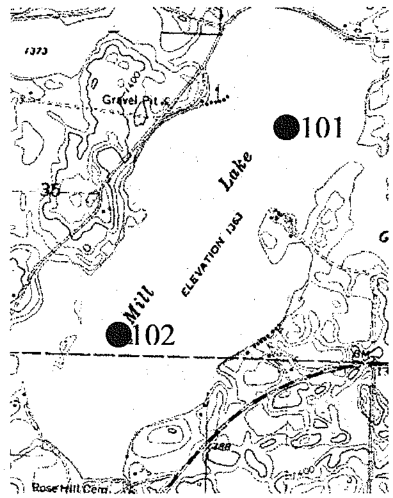
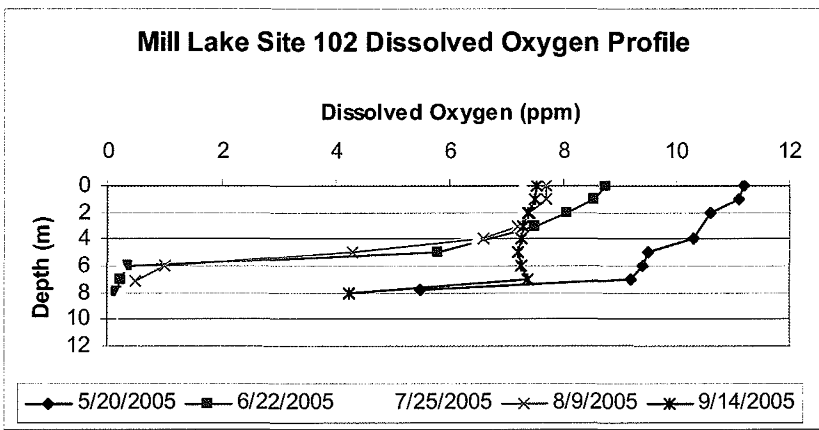
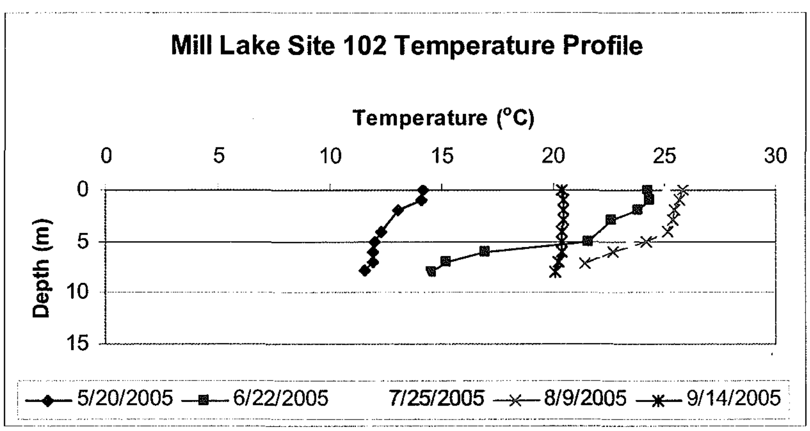


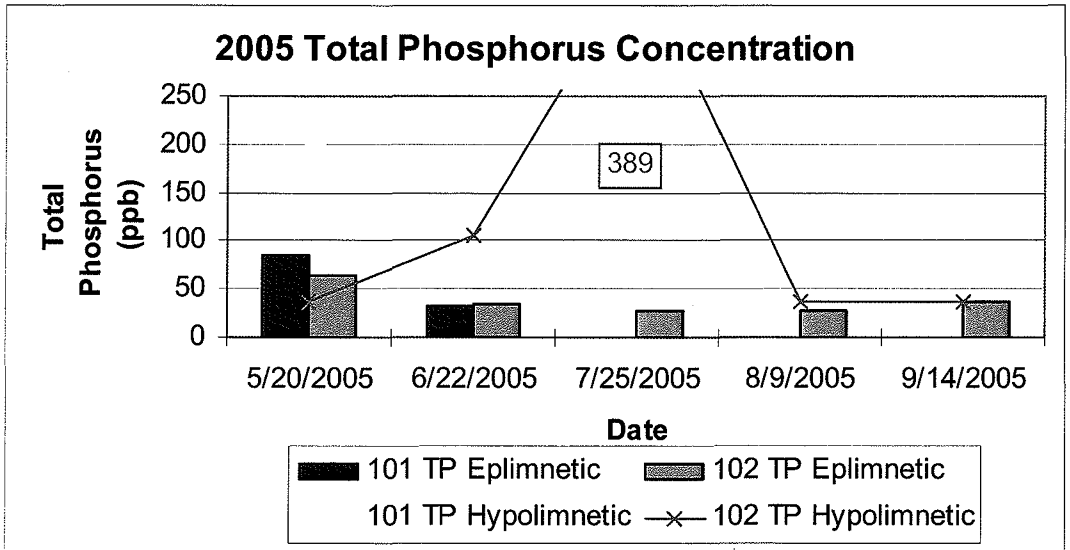
Figure 20. Mill Lake Dissolved Oxygen and Temperature Profiles





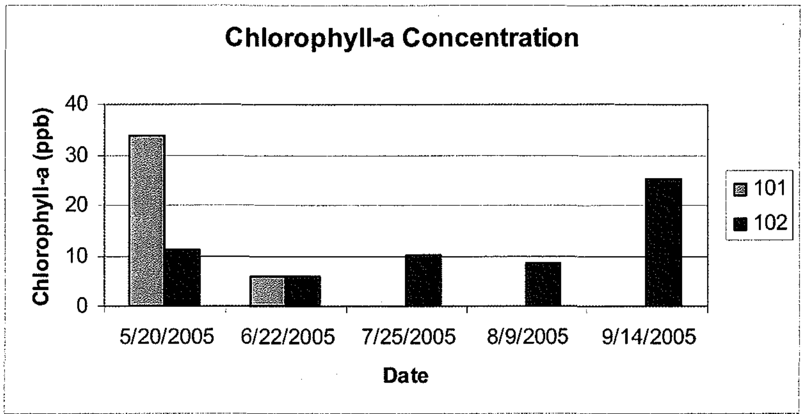
Total phosphorus concentrations averaged 32 µg/l for Mill Lake during 2005. This value is well within the typical ecoregion values for lakes in the NCHF ecoregion (Table 5). Total phosphorus decreased across the sampling period until September, where levels increased slightly at site 102 (Figure 21). Hypolimnetic total phosphorus concentrations peaked in July at site 102, and then returned to levels below 50 µg/l in August and September. This is consistent with stratified conditions present in the lake, with levels of hypolimnetic TP dropping during lake mixing when oxygen is present throughout the water column.

Figure 21. Mill Lake Total Phosphorus Concentration



Chlorophyll-*a* concentrations provide an estimate of the algal production in the lake. During the summer of 2005, chlorophyll-*a* concentrations averaged 11.2 µg/l with a maximum of 25.3 µg/l (Figure 22). As with phosphorus concentrations, these values are also within the NCHF ecoregion typical values (Table 5). Concentrations between 10-20 µg/l are frequently percieved as a mild aglae bloom, whiles concentrations between 20-30 µg/l are considered a nuissance bloom. Based on these ranges, blooms were evident on the May, July, and September sampling dates. Chlorophyll-*a* concentrations followed a similar pattern as the phosphorus, with relatively low levels in the summer and an increase in the fall. An increase in chlorophyll-*a* concentrations from late spring to late summer is more typical of Minnesota lakes.

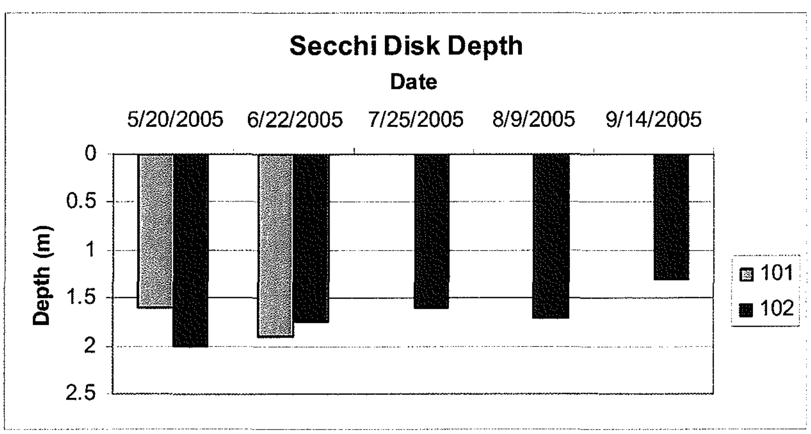
Figure 22. Mill Lake Chlorophyll-*a* Concentrations



Secchi disk transparency is generally a function of the amount of algae in the water. Suspended sediments or color due to dissolved organics may also reduce water transparency. Color averaged 19 Pt-Co Units and total suspended solids averaged 5.2 mg/l. These levels of color and TSS should not appreciably limit water transparency in Mill Lake. Secchi transparency averaged 1.65 m (5.4 feet) with a low of 1.3 m and a high of 1.9 m (Figure 23). This average is within the typical range of values for reference lakes in this ecoregion (Table 5).

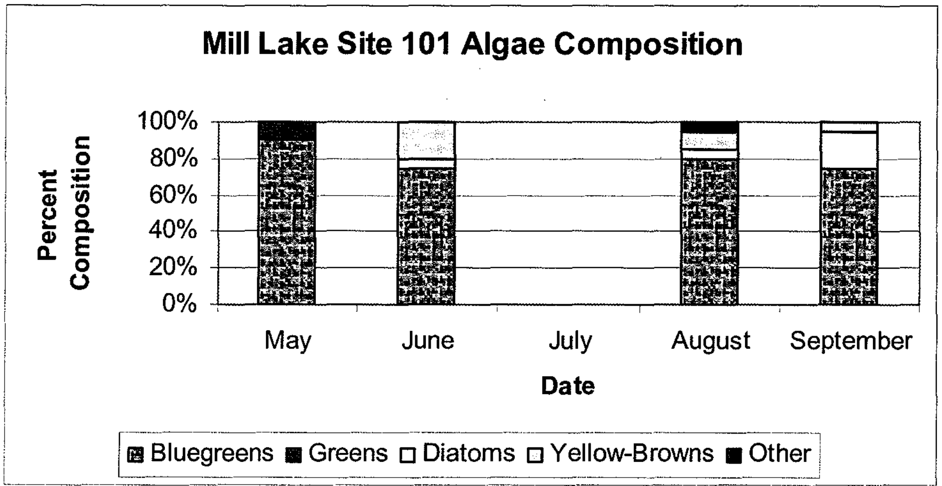
The change in transparency of Mill Lake over the course of the summer is fairly typical for mesotrophic-eutrophic lakes in Minnesota. Transparency is typically highest in the spring when the water is cool and algae populations are low. Frequently, zooplankton (small crustaceans which feed on algae) populations are high at this time of year also, but decline later in the summer due to predation by young fish. As the summer goes on and the waters warm, the algae make use of available nutrients. As the algae become more abundant, the transparency declines. The decrease in the abundance of zooplankton may allow for further increases in the amount of algae. Later in the summer, surface blooms of algae may also appear.

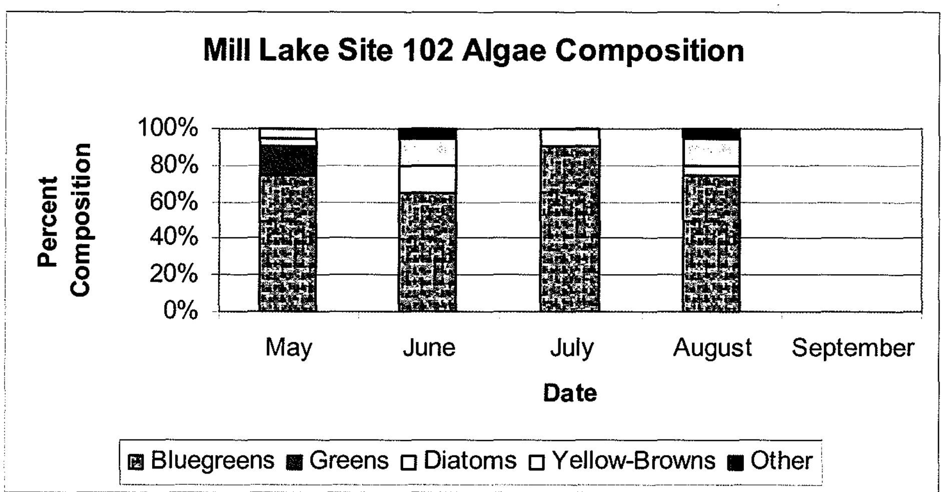
Figure 23. Mill Lake Secchi Disk Transparency



Algal composition on Mill Lake is depicted in Figure 24. Samples were collected at both sites 101 and 102. Blue-green algae dominated the composition throughout the summer at both sites. A seasonal transition from diatoms to green to blue-green algae is typical for mesotrophic and eutrophic lakes in Minnesota. In contract, diatoms and green algae never comprized more than 20% of the algae population on any date or site in 2005.

Figure 24. Algal Composition of Mill Lake





Mercury was measured at site 101 on Mill Lake in June and August 2005. In general, concentrations above one ng/l are considered high, while the impairment threshold is 6.9 ng/l. Concentrations measured ranged from 0.68 ng/l in June to 2.5 ng/l in August. There is currently no mercury impairment for fish consumption on Mill Lake.

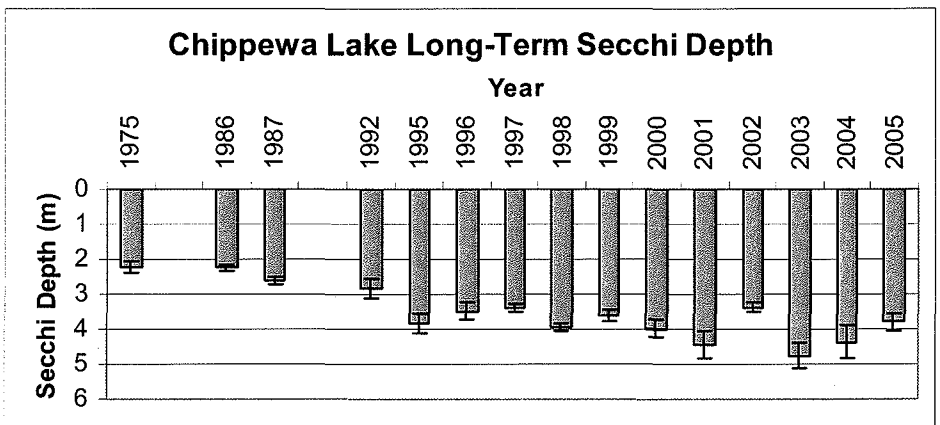
Water Quality Trends

Many of the lakes have good long-term Secchi records due to participation of volunteers in the CLMP. Also, some have had previous water quality studies conducted and these data were available for comparison as well. For this report we will examine trends for lakes with at least eight years of Secchi and/or four or more years of TP or chlorophyll-*a* data. Unless noted otherwise, most graphs will depict summer-mean measurements plus or minus the standard error (SE) of the mean. A large SE implies either high variability among seasonal measures and/or very few measures were taken. When comparing mean measures among years, the SE provides somewhat of a "confidence interval" for the mean; if the mean plus or minus the SE overlaps with another mean then it is likely the two means (measurements) are not significantly different.

Chippewa Lake

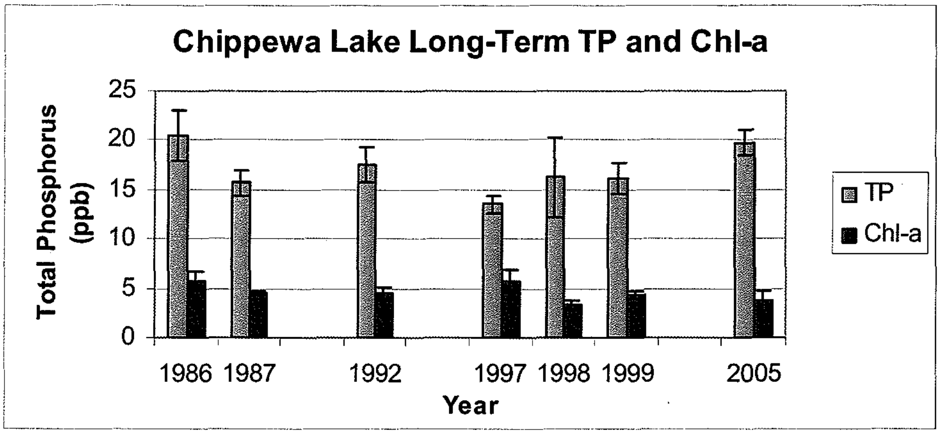
Fifteen years of Secchi disk transparency data and seven years of water chemistry data are available for analysis (June through September data). Based on analysis completed as part of the Citizen Lake-Monitoring Program, it was determined that Chippewa Lake was exhibiting a positive trend in transparency (clarity is increasing). The long term average Secchi depth is 3.8 meters (12.5 feet) (Figure 25).

Figure 25. Chippewa Lake Long-Term Secchi Transparency



Total phosphorus and chlorophyll-*a* data are available for seven years from 1986 to 2005. The long-term average concentration is 17 µg/l for total phosphorus and 4.6 µg/l for chlorophyll-*a*, based on data from all sites over the period of record (Figure 26). These are below (better than) the expected range for reference lakes in the NCHF ecoregion (Table 5). No trend is evident in these data.

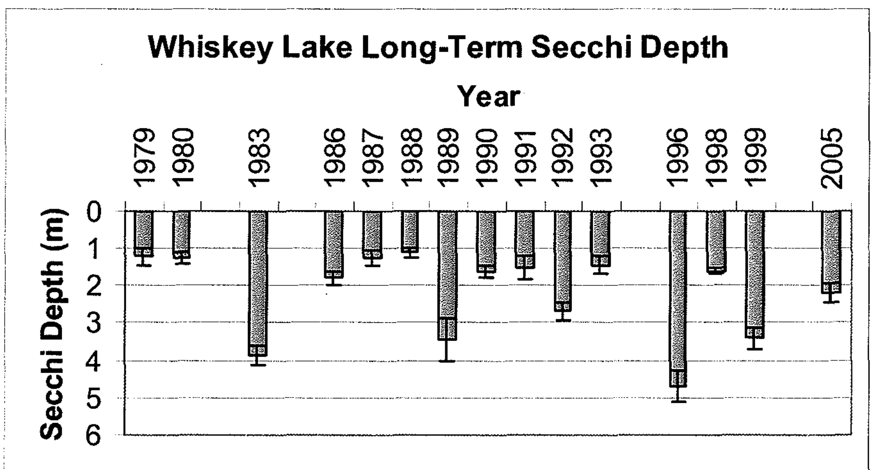
Figure 26. Chippewa Lake Long-Term Total Phosphorus and Chlorophyll-*a*



Whiskey Lake

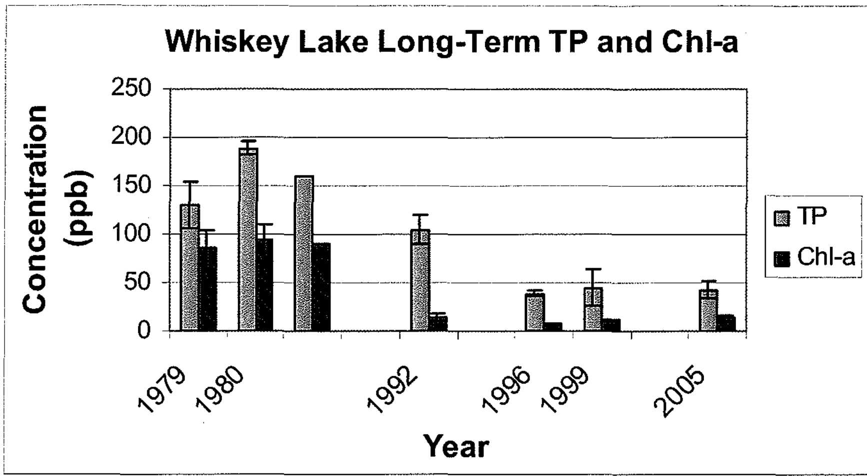
Fifteen years of Secchi disk data and six years of water chemistry data are available for Whiskey Lake. When analyzing the data, it is important to note that the City of Brandon Wastewater Treatment Plant began land application in 1987, after years of discharging to a ditch that flowed into Whiskey Lake. The average Secchi over the period of record, using June to September data is 2.2 meters (Figure 27). If you break the record into two periods, one prior to 1987 and one after 1987, the averages are 1.9 and 2.4 meters, respectively. Based on recent statistical analysis of data from all years, no significant trend is evident. The lake does, however, exhibit rather large year-to-year fluctuation in transparency (Figure 27).

Figure 27. Whiskey Lake Long-Term Secchi Transparency



Total phosphorus and chlorophyll-*a* concentrations are available for six years between 1979 and 2005. Again, the averages before 1987 and after show the gradual recovery from the wastewater discharge, with total phosphorus averaging 160 μg/l prior to 1987 and 58 μg/l after (Figure 28). Chlorophyll-*a* values changed similarly, with 90 μg/l prior to 1987 and 11.4 μg/l after.

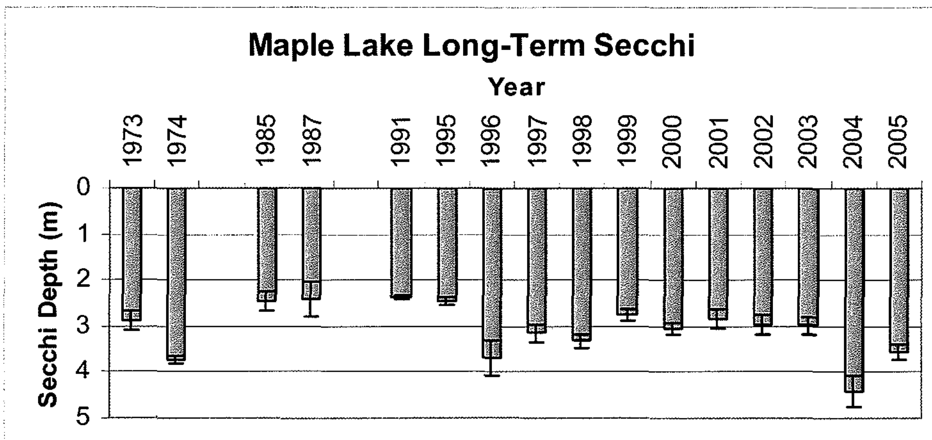
Figure 28. Whiskey Lake Long-Term Total Phosphorus and Chlorophyll-*a*



Maple Lake

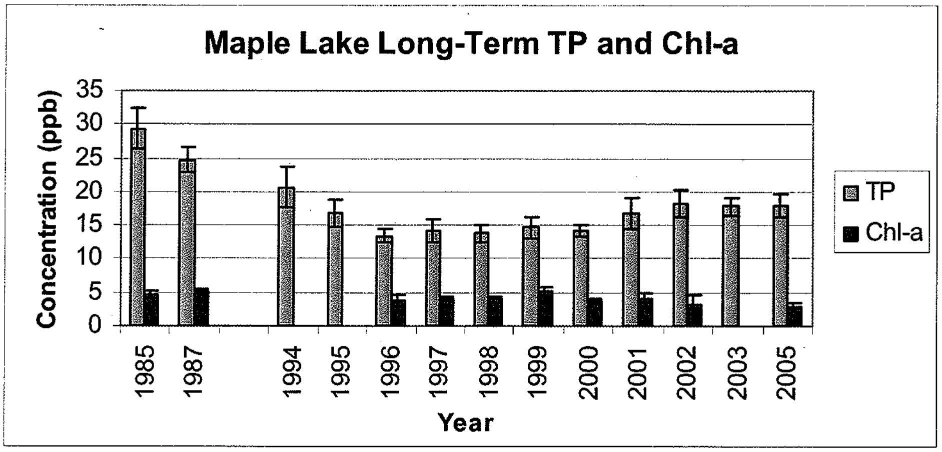
Sixteen years of Secchi transparency data, thirteen years of total phosphorus, and ten years of chlorophyll-*a* data are available for Maple Lake. The long-term average Secchi transparency is 3.1 m (10.2 feet) from data collected between 1973 and 2005 (Figure 29). Maple Lake is exhibiting a long-term improving trend in transparency, based on analysis done through the Citizen Lake-Monitoring Program.

Figure 29. Maple Lake Long-Term Secchi Transparency



Total phosphorus (13 years) and chlorophyll-*a* (10 years) data are available from 1985 to 2005. The long-term total phosphorus averaged 18 µg/l, and chlorophyll-*a* averaged 4.1 µg/l (Figure 30). These averages are below (better than) the North Central Hardwood Forest ecoregion expected values (Table 5).

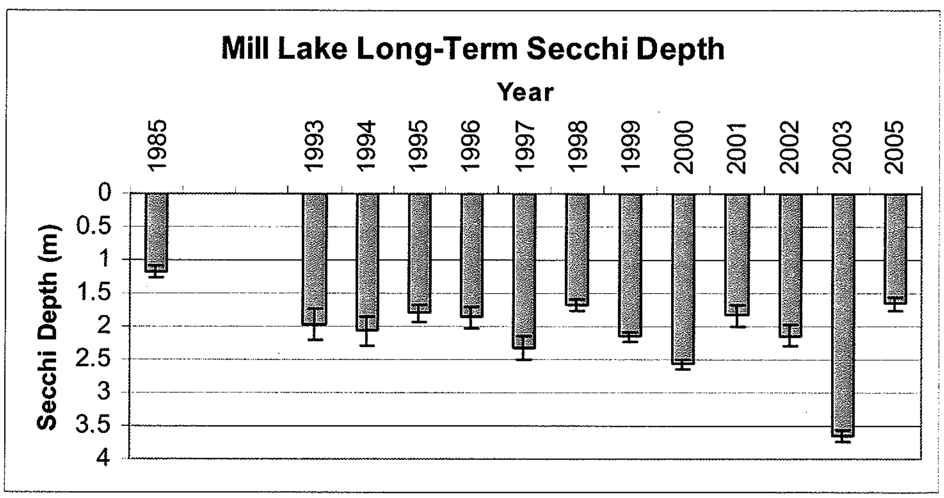
Figure 30. Maple Lake Long-Term Total Phosphorus and Chlorophyll-*a*



Mill Lake

Thirteen years of Secchi transparency data are available for Mill Lake. Based on analysis completed by the Citizen Lake-Monitoring Program, it was determined that Mill Lake is not exhibiting a trend in transparency. The long-term average based on data from 1993 to 2005 is 2.1 meters (6.9 feet) (Figure 31). This is within the expected range of values for reference lakes in the North Central Hardwood Forest ecoregion.

Figure 31. Mill Lake Long-Term Secchi Transparency



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 2005 water quality of Douglas County lakes, MINLEAP (Wilson and Walker, 1989) was used.

MINLEAP which refers to "Minnesota Lake Eutrophication Analysis Procedures" 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). In this instance, we applied it as a basis for comparing the observed (2005) TP, chlorophyll-*a* and Secchi values with that predicted based on the size, depth and size of the watershed for each lake. Since all lakes are in the NCHF ecoregion – the ecoregion-based inputs for precipitation, runoff, evaporation and average stream TP remain constant for all cases. It should be noted that the model predicts in-lake TP from these inputs and subsequently predicts chlorophyll-*a* based on a regression equation with TP, and Secchi based on a regression equation based on chlorophyll-*a*. A comparison of MINLEAP predicted vs. observed values is presented in Table 6.

There was not a significant difference between observed and MINLEAP predicted TP for most of the lakes in this report. In simple terms this means that the observed TP is consistent with that expected for a lake of that size and depth and size watershed in the NCHF ecoregion. Mill Lake's observed TP is lower than predicted. In this case the model estimated a much larger P load to the lake than what actually reaches the lake – due to its large watershed. However the model does not consider the affect of upstream lakes such as Mary and Lobster which serve to trap TP from the watershed, resulting in lower downstream loads to Mill Lake. To account for this, the model was calibrated for Mill Lake, reducing the inflow total phosphorus concentration to 50 µg/l. This is more representative of upstream in-lake concentrations. The calibrated run more closely predicted the results observed in 2005.

MINLEAP predicts chlorophyll-*a* as a function of TP and hence lakes with predicted TP lower than observed will tend to have lower than observed predicted chlorophyll-*a* – as is the case for Whiskey and Mill Lakes. The inverse is the case for Chippewa and Maple where observed chlorophyll-*a* is lower than predicted (Table 6). None of the lakes chlorophyll-*a* values were in excess of the 14 µg/L draft chlorophyll-*a* criteria (Table 1).

Of the four lakes, only Whiskey had TP values that equaled or exceed the 40 µg/L draft nutrient impairment criteria (Table 1). This suggests the possibility that Whiskey Lake could be included on a future impaired waters listing for aquatic recreation (excess nutrients); however further data would be needed to complete an aquatic use recreation assessment of the lake. Whiskey, Chippewa, and Maple Lakes are all currently on the impaired waters list for aquatic consumption (mercury in fish).

Trophic State Index

TSI Comparison

Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, Chl-*a* and Secchi for the lakes (Figure 32). In general, the TSI values are in fairly close correspondence with each other. Chippewa and Maple lakes both fall under the mesotrophic category, while Whiskey and Mill are borderline eutrophic. Both Chippewa and Maple lakes had Chl-*a* values that were slightly low relative to TP. This suggests that these lakes have the potential for higher Chl-*a* based on TP, but some factors such as light exclusion, rooted plant growth, and/or grazing zooplankton may limit algal production.

Secchi TSI values closely corresponded to the TP TSI values for most lakes. Lakes which had higher than anticipated Secchi (based on TP) include Whiskey and Chippewa (Figure 32). Chippewa also had lower than expected Chl-*a* based on TP.

Lastly Ch-*a* and Secchi TSI were in good correspondence for most lakes (Figure 32). Whiskey Lake had higher transparency (lower TSI) than anticipated. Whiskey Lake had both blue-green algae dominance by *Aphanizomenon*, a large algae which typically allows greater light penetration into the water column (higher than expected Secchi depth), and high abundances of zooplankton, which feed on the algae.

Goal Setting

The phosphorus criteria value for lakes in the North Central Hardwoods Forests ecoregion is less than 40 μg/l for support of aquatic recreation use. At or below 30 μg/l, "nuisance algal blooms" (chlorophyll-a > 20 μg/l) should occur less than 10 percent of the summer and transparency should remain at or above 3 meters (9.8 feet) over 85 percent of the summer.

For Chippewa, Maple, and Mill lakes, it would be desirable to keep in-lake TP concentrations at or below levels observed in 2005. Should in-lake TP concentrations increase, it is likely that the frequency of nuisance algal blooms would increase and transparency would decrease. Maintaining current summer mean concentrations (Table 5) over the long-term may require that phosphorus loading to the lake be reduced.

For Whiskey Lake, it would be desirable to further reduce in-lake TP concentrations from levels observed in 2005 (summer-mean of 43 μg/l), which are just above the TP criteria (Table 1). The current chlorophyll-*a* summer mean concentration is just below the threshold of 14 μg/l. With the historical input of wastewater to the lake, internal loading of phosphorus will likely continue to be a problem for Whiskey Lake. However, based on the MINLEAP model results, Whiskey Lake is quite close to the concentrations expected based on its morphometric and watershed characteristics. It would be important to reduce as much external phosphorus loading to the lake as possible to maintain or reduce the current concentrations.

Important considerations include land use practices in the shoreland and watershed area of the lake. A more comprehensive review of land use practices in the watershed may reveal opportunities for implementing BMPs in the watershed and reducing phosphorus loading to the lake.

Recommendations

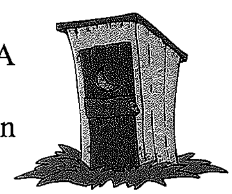
Following are a few general observations and recommendations based on analysis of data collected in 2005:

1. Relatively minor increases in the nutrient loading rates from any watershed or in-lake sources which would increase the in-lake total phosphorus concentration could degrade the lakes in this study. It is essential, therefore, that lake protection efforts be conveyed to all local government groups with land use/zoning authorities for Douglas County.

The lakes involved with this study could benefit from the development of a plan for protecting the water quality of the lake. This plan, referred to as a lake management plan, should incorporate a series of activities in a prioritized fashion which will aid in the long-term protection and improvement of the lake. The plan should be developed cooperatively by a committee consisting of representatives from state agencies (e.g. DNR, BWSR, and MPCA), local units of government, and if applicable to each specific lake, lake association members. The reference document, Developing a Lake Management Plan, is available on the web at: http://www.shorelandmanagement.org/depth/plan.pdf. The following activities could be included in the plan:

A. Secchi transparency monitoring: Monitoring Secchi transparency provides a good basis for estimating trophic status and detecting trends. Routine participation is essential to allow for trend analysis; Secchi measurements should be taken weekly at consistent sites from June to September. Mill Lake is currently without a volunteer monitor. Resuming participation in CLMP will contribute to the historical database and allow for future trend assessments.

B. Education of homeowners around the lake regarding septic systems, lawn maintenance, and shoreline protection may be beneficial. Staff from the MPCA and DNR, along with county officials, such as staff from the University of Minnesota Extension Service, the Douglas County Soil and Water Conservation District (SWCD), and the Douglas County Land and Resource Management Office could provide assistance in these areas.



C. Further development in the immediate watershed of the lake should occur in a manner that minimizes water quality impacts on the lake. Consideration to setback provisions, lot size, and septic systems will be important in providing water quality protection. The DNR and county shoreland regulations will be important in these regards and should be strictly enforced. In writing a plan, exploring additional safeguards in land-use, zoning, and shoreline protection that could be included in a long-term plan to address future development activity within the watershed is recommended.

D. Maintenance of shoreline vegetation (both upland and aquatic) is very important. Macrophytes serve to stabilize shorelines and bottom sediments from wind and wave erosion and may also serve as competition to algae for available nutrients. Soil erosion from the construction of roads and homes should be minimized. The disturbance or removal of vegetation on bluffs or slopes should be avoided.

E. Representation on boards or commissions that address land management activities would be beneficial, so that the impacts of these activities can be minimized. Safeguarding the shoreland ordinance from those who would choose to weaken it should be a priority for all the lakes in this study, as well as other lakes in Douglas County. The pamphlet "Your Lake and You," available from the North American Lake Management Society (www.nalms.org), may be a useful educational tool in this area.

F. Awareness of possible nutrient and sediment sources such as urban and agricultural runoff, septic systems, lawn fertilizer, and the effects of activities in the total watershed that change drainage patterns, such as wetland removal, creating new wetland discharges to the lake, or major alterations in lake use is important. As these activities occur within the watershed, lake residents are encouraged to make sure that the water quality effects are minimized with the use of best management practices (BMPs) for water quality. Some of the county and state offices mentioned previously may be of help in this regard.

2. The 2005 water quality of Chippewa, Mill, and Maple Lakes were good relative to other lakes in the NCHF ecoregion. The water quality of Whiskey Lake was near impairment criteria thresholds in 2005. However, all of the lakes, could exhibit a measurable decline in transparency, increase in the amount of algae, or possible increase in the amount of rooted vegetation from a fairly small increase of in-lake total phosphorus. Changing land use practices, poor management of shorelands, failure to maintain (pump) septic tanks, and draining of wetlands in the watershed provide the greatest likelihood for changes in phosphorus loading.

Conversely, a reduction of the amount of nutrients that enter the lake may result in improved transparency and a reduction in algal concentrations. One means of reducing nutrient input is by implementing BMPs in the watershed (land management activities used to control nonpoint source pollution). Technical assistance in BMP implementation may be available through local resource management agencies. The Douglas County SWCD is a local agency that could help examine land use practices in the watershed and develop strategies for reducing the transport of nutrients to the lake. It may be wise to first focus efforts on the water of the watershed nearest the lake. There may be few opportunities (or the need) to implement BMPs on existing land use. However, opportunities may arise during road building, construction, or other activities which may result in increased sediment and phosphorus loading to the lake.

Restoring or improving wetlands in the watershed may also be beneficial for reducing the amount of nutrients or sediments which reach a lake. The U.S. Fish and Wildlife Service may be able to provide technical and financial assistance for these activities.

MPCA's Clean Water Partnership (CWP) Program may also be an option for further assessing and dealing with nonpoint sources of nutrients in the watershed. However, since there is extensive competition for CWP funding, it may be in the best interest of lake residents to continue to work with the Douglas County SWCD, Douglas County Land and Resource Management, and the local townships to do as much as possible to protect the condition of the lake by means of local ordinances and education of shoreland and watershed residents. If these steps prove inadequate or the lake condition declines (as evidenced by a significant reduction in Secchi transparency), application to CWP may then be appropriate. A CWP may not be needed at that time, but a repeat of a Lake Assessment Program (LAP) level effort may be necessary to understand and document changes in total phosphorus, chlorophyll-*a*, and Secchi within a lake.

3. Should further study be deemed necessary, this report serves as a foundation upon which further studies and assessments may be based. The next step would be to define water and nutrient sources to the lake in a much more detailed fashion. These detailed studies would allow the estimation of reasonably accurate total phosphorus, total nitrogen, and water in and out-flow summaries. This should be accomplished prior to implementation of any extensive in-lake restoration techniques.

Table 6. MINLEAP Model Results

Parameter	2005 Chippewa Observed	Total Watershed MINLEAP
TP (µg/l)	20 ± 1.3	18 ± 8
chl-a (µg/l)	3.8 ± 1.0	4.7 ± 3.4
% chl-a > 20 µg/l	0	0
% chl-a > 30 µg/l	0	0
Secchi (m)	3.2 ± 0.4	3.1 ± 1.5
P-loading rate (kg/yr)	--	264
% P retention	--	93
P inflow conc. (µg/l)	--	263
water load (m/yr)	--	0.21
outflow volume (hm3/yr)	--	1.00
"background P"	--	23.1
residence time (years)	--	30.6

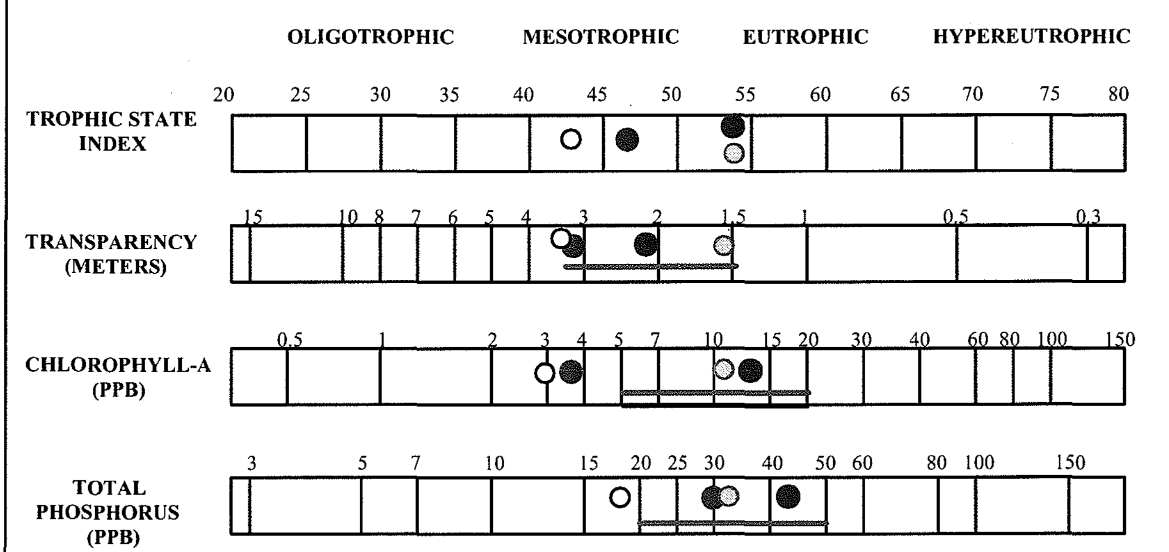
Parameter	2005 Maple Observed	Total Watershed MINLEAP
TP (µg/l)	17.5 ± 1.8	28 ± 11
chl-a (µg/l)	3.0 ± 0.5	8.5 ± 5.8
% chl-a > 20 µg/l	0	2
% chl-a > 30 µg/l	0	0
Secchi (m)	3.4 ± 0.5	2.2 ± 1.0
P-loading rate (kg/yr)	--	368
% P retention	--	85
P inflow conc. (µg/l)	--	189
water load (m/yr)	--	0.59
outflow volume (hm3/yr)	--	1.95
"background P"	--	26.2
residence time (years)	--	8.8

Parameter	2005 Whiskey Observed	Total Watershed MINLEAP
TP (µg/l)	43 ± 9.7	36 ± 14
chl-a (µg/l)	13 ± 2.5	12.4 ± 8.2
% chl-a > 20 µg/l	0	11
% chl-a > 30 µg/l	0	2
Secchi (m)	2.2 ± 0.5	1.8 ± 0.8
P-loading rate (kg/yr)	--	94
% P retention	--	80
P inflow conc. (µg/l)	--	177
water load (m/yr)	--	0.83
outflow volume (hm3/yr)	--	0.53
"background P"	--	27.2
residence time (years)	--	4.5

Parameter	2005 Mill Observed	Total Calibrated Watershed MINLEAP
TP (µg/l)	32 ± 1.8	30 ± 8
chl-a (µg/l)	11.2 ± 3.6	9.7 ± 5
% chl-a > 20 µg/l	1	4
% chl-a > 30 µg/l	0	0
Secchi (m)	1.65 ± 0.1	2.0 ± 0.7
P-loading rate (kg/yr)	--	767
% P retention	--	43
P inflow conc. (µg/l)	--	54
water load (m/yr)	--	7.65
outflow volume (hm3/yr)	--	14.3
"background P"	--	25.8
residence time (years)	--	0.6

FIGURE 32. Carlson's Trophic State Index for Douglas County Lakes
R.E. Carlson

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.



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

NCHF Ecoregion Range: ————

Chippewa: ● Whiskey: ●
Maple: ○ Mill: ◎

Appendix A Glossary

Acid Rain: Rain with a higher than normal acid range (low pH). Caused when polluted air mixes with cloud moisture. Can make lakes devoid of fish.

Algal Bloom: An unusual or excessive abundance of algae.

Alkalinity: Capacity of a lake to neutralize acid.

Bioaccumulation: Build-up of toxic substances in fish flesh. Toxic effects may be passed on to humans eating the fish.

Biomanipulation: Adjusting the fish species composition in a lake as a restoration technique.

Dimictic: Lakes which thermally stratify and mix (turnover) once in spring and fall.

Ecoregion: Areas of relative homogeneity. EPA ecoregions have been defined for Minnesota based on land use, soils, landform, and potential natural vegetation.

Ecosystem: A community of interaction among animals, plants, and microorganisms, and the physical and chemical environment in which they live.

Epilimnion: Most lakes form three distinct layers of water during summertime weather. The epilimnion is the upper layer and is characterized by warmer and lighter water.

Eutrophication: The aging process by which lakes are fertilized with nutrients. *Natural eutrophication* will very gradually change the character of a lake. *Cultural eutrophication* is the accelerated aging of a lake as a result of human activities.

Eutrophic Lake: A nutrient-rich lake – usually shallow, "green" and with limited oxygen in the bottom layer of water.

Fall Turnover: Cooling surface waters, activated by wind action, sink to mix with lower levels of water. As in spring turnover, all water is now at the same temperature.

Hypolimnion: The bottom layer of lake water during the summer months. The water in the hypolimnion is denser and much colder than the water in the upper two layers.

Lake Management: A process that involves study, assessment of problems, and decisions on how to maintain a lake as a thriving ecosystem.

Lake Restoration: Actions directed toward improving the quality of a lake.

Lake Stewardship: An attitude that recognizes the vulnerability of lakes and the need for citizens, both individually and collectively, to assume responsibility for their care.

Limnetic Community: The area of open water in a lake providing the habitat for phytoplankton, zooplankton and fish.

Littoral Community: The shallow areas around a lake's shoreline, dominated by aquatic plants. The plants produce oxygen and provide food and shelter for animal life.

Mesotrophic Lake: Midway in nutrient levels between the eutrophic and oligotrophic lakes

Meromictic A lake that does not mix completely

Nonpoint Source: Polluted runoff – nutrients and pollution sources not discharged from a single point: e.g. runoff from agricultural fields or feedlots.

Oligotrophic Lake: A relatively nutrient- poor lake, it is clear and deep with bottom waters high in dissolved oxygen.

pH Scale: A measure of acidity.

Photosynthesis: The process by which green plants produce oxygen from sunlight, water and carbon dioxide.

Phytoplankton: Algae – the base of the lake's food chain, it also produces oxygen.

Point Sources: Specific sources of nutrient or polluted discharge to a lake: e.g. stormwater outlets.

Polymictic: A lake that does not thermally stratify in the summer. Tends to mix periodically throughout summer via wind and wave action.

Profundal Community: The area below the limnetic zone where light does not penetrate. This area roughly corresponds to the hypolimnion layer of water and is home to organisms that break down or consume organic matter.

Respiration: Oxygen consumption

Secchi Disk: A device measuring the depth of light penetration in water.

Sedimentation: The addition of soils to lakes, a part of the natural aging process, makes lakes shallower. The process can be greatly accelerated by human activities.

Spring Turnover: After ice melts in spring, warming surface water sinks to mix with deeper water. At this time of year, all water is the same temperature.

Thermocline: During summertime, the middle layer of lake water. Lying below the epilimnion, this water rapidly loses warmth.

Watershed storage area The percentage of a drainage area labeled lacustrine (lakes) and palustrine (wetlands) on U.S. Fish and Wildlife Service National Wetlands Inventory Data.

Zooplankton: The animal portion of the living particles in water that freely float in open water, eat bacteria, algae, detritus and sometimes other zooplankton and are in turn eaten by planktivorous fish.

Appendix B Water Quality Data: Abbreviations and Units

TP= total phosphorus in mg/l(decimal) or ug/L as whole number
TKN= total Kjeldahl nitrogen in mg/l
TNTP=TN:TP ratio
pH= pH in SU (F=field, or L=lab)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TSIN= total suspended inorganic solids in mg/l
TURB= turbidity in NTU (F=field)
CON= conductivity in umhos/cm (F=field, L=lab)
CL= chloride in mg/l
DO= dissolved oxygen in mg/l
TEMP= temperature in degrees centigrade
SD= Secchi disk in meters (SDF=feet)
Chl-a= chlorophyll-a in ug/l
TSI= Carlson's TSI (P=TP, S=Secchi, C=Chla)
PHEO= pheophytin in ug/l
PHYS= physical appearance rating (classes=1 to 5)
REC= recreational suitability rating (classes=1 to 5)
RTP, RN2N3...= remark code; k=less than, Q=exceeded holding time

Appendix C References

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Appendix D Surface water results

Lake Name	Lake ID	Date	Site	Sample Depth		TP	Chl-a	Secchi	Total Alk	Cl	TKN	Color, Apparent	Pheo	TSS	VSS
			Site	Up	Lwr	ug/l	ug/l	m	mg/l	mg/l	mg/l	PCU	ug/l	mg/l	mg/l
Chippewa	21-0145	5/20/2005	101	0	2	38	5.69	2.2	210	6	0.8	20	1.11	3.2	2
		5/20/2005	101	14	14	47									
		6/21/2005	101	0	2	23	1.64	3.96	200	7	0.72	10	0.3	2	
		6/21/2005	101	26	26	73									
		7/25/2005	101	0	2	20	3.285		185	7.1	0.655	7.5	0.505	2.6	2.4
		7/25/2005	101	22	22	71									
		8/9/2005	101	0	2	19	3.68	3.2	180	6.9	0.79	10	0.4	2.4	1.6
		8/9/2005	101	17	17	86									
		9/13/2005	101	0	2	17	6.46	2.3	190	7.1	0.65	10	2.1	5.6	2
		9/13/2005	101	26	26	98									
Whiskey	21-0216	5/19/2005	101	0	2	59	4.54	4.2	200	58	1.22	20	0.8	2	1.6
		5/19/2005	101	13.7	13.7	257									
		6/21/2005	101	0	2	67	16.6	2.4	200	59	1.32	20	1.5	6.8	4.4
		6/21/2005	101	12.7	12.7	271									
		7/25/2005	101	0	2	50	17.1	1.2	170	62	1.37	10	3.17	7.4	6.2
		7/25/2005	101	12	12	356									
		8/9/2005	101	0	2	33	12	1.8	170	61	1.17	20	0.7	7.2	5.2
		8/9/2005	101	7	7	138									
		9/13/2005	101	0	2	23	6.42	3.3	170	60	1.01	20	1.92	2.8	2.4
		9/13/2005	101	14	14	500									

Lake Name	Lake ID	Date	Site	Sample Depth		TP	Chl-a	Secchi	Total Alk	Cl	TKN	Color, Apparent	Pheo	TSS	VSS
			Site	Up	Lwr	ug/l	ug/l	m	mg/l	mg/l	mg/l	PCU	ug/l	mg/l	mg/l
Maple	21-0079	5/19/2005	101	0	2	18	8.48	2.8	240	20	0.99	10	0.92	3.6	2.4
		5/19/2005	102	0	2	25	9.31	2.4	240	21	1.26	10	0.69	4.4	2.4
		5/19/2005	102	9	9	25									
		6/22/2005	101	0	2	20	1.55	4.1	230	22	0.95	10	0.16	2	1.2
		6/22/2005	101	9	9	33									
		6/22/2005	102	0	2	14	1.7	5					0.53		
		6/22/2005	102	9	9	34									
		7/25/2005	101	0	2	15	3.17	2.75	220	23	0.85	5	0.6	2	2
		7/25/2005	101	9	9	34									
		7/25/2005	102	0	2	25	3.58	2.5					0.55		
		9/14/2005	101	0	2	13	4.59	2.9	220	23	0.83	10	1.28	2	1.6
		9/14/2005	101	9	9	19									
		9/14/2005	102	0	2	18	3.62	3.2					0.63		
		9/14/2005	102	9	9	19									
Mill	21-0180	5/20/2005	101	0	2	85	33.7	1.6					0.85		
		5/20/2005	101	7	7	199									
		5/20/2005	102	0	2	65	11.3	2	200	17	1.5	20	0.95	4	4
		5/20/2005	102	11	11	36									
		6/22/2005	101	0	2	32	6.04	1.9	200	19	1.3	20	0.67	4	2.4
		6/22/2005	101	11	11	213									
		6/22/2005	102	0	2	35	5.78	1.75					0.49		
		6/22/2005	102	11	11	106									
		7/25/2005	102	0	2	28	10.2	1.6	190	19	1.17	20	1.56	5.2	4
		7/25/2005	102	11	11	389									
		8/9/2005	102	0	2	28	8.52	1.7	180	2	1.28	15	1.34	5.9	3.6
		8/9/2005	102	7.5	7.5	37									
		9/14/2005	102	0	2	37	25.3	1.3	180	19	1.2	20	3.06	5.6	4
		9/14/2005	102	14	14	36									