Status and Trend Monitoring of Selected Lakes in Hubbard County 2005

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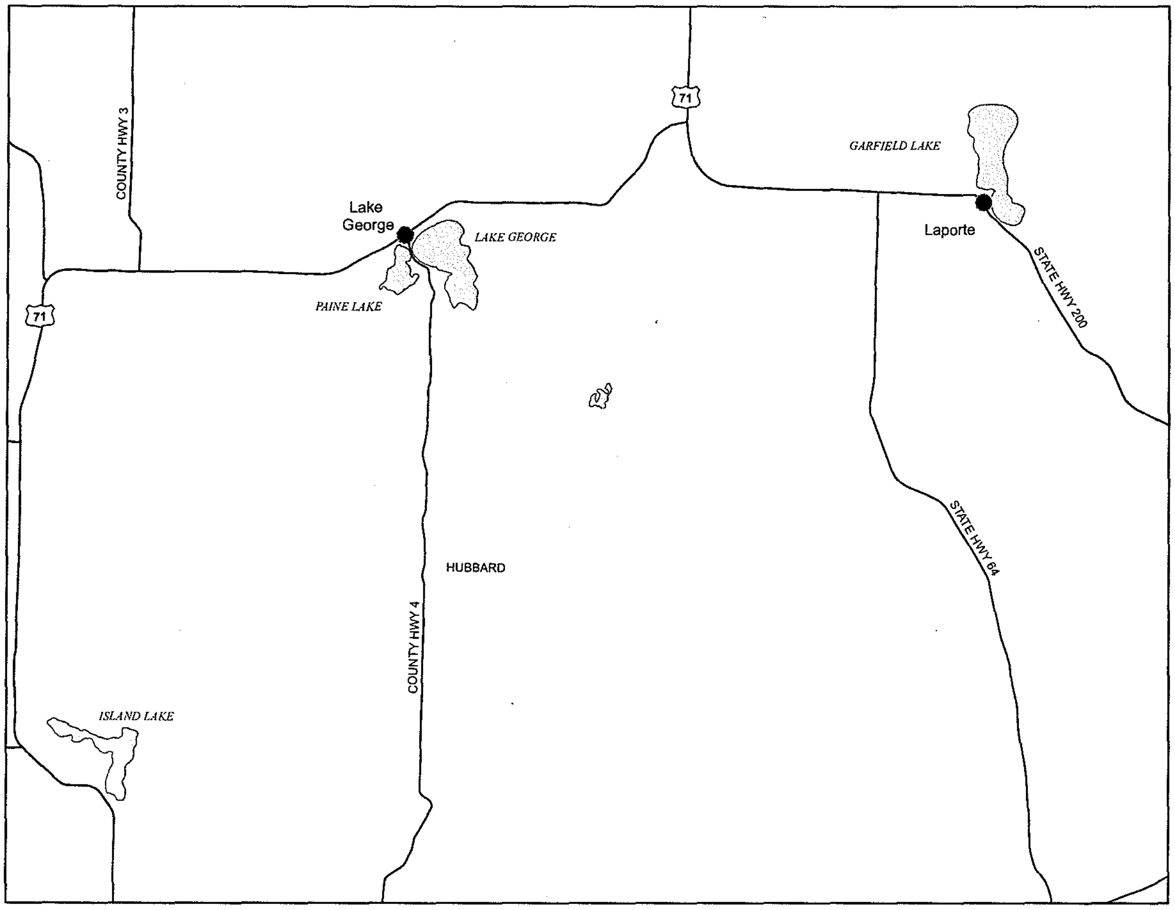

Environmental Analysis and Outcomes Division
Water Assessment and Environmental Information Section
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Minnesota Pollution Control Agency

Lake Assessment Program
2005

Lake Status and Trends for Selected Lakes in Hubbard County

Minnesota Pollution Control Agency

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Lake Name	Lake DOW# ID
Garfield	29-0061
George	29-0216
Island	29-0254
Paine	29-0217

November 2006

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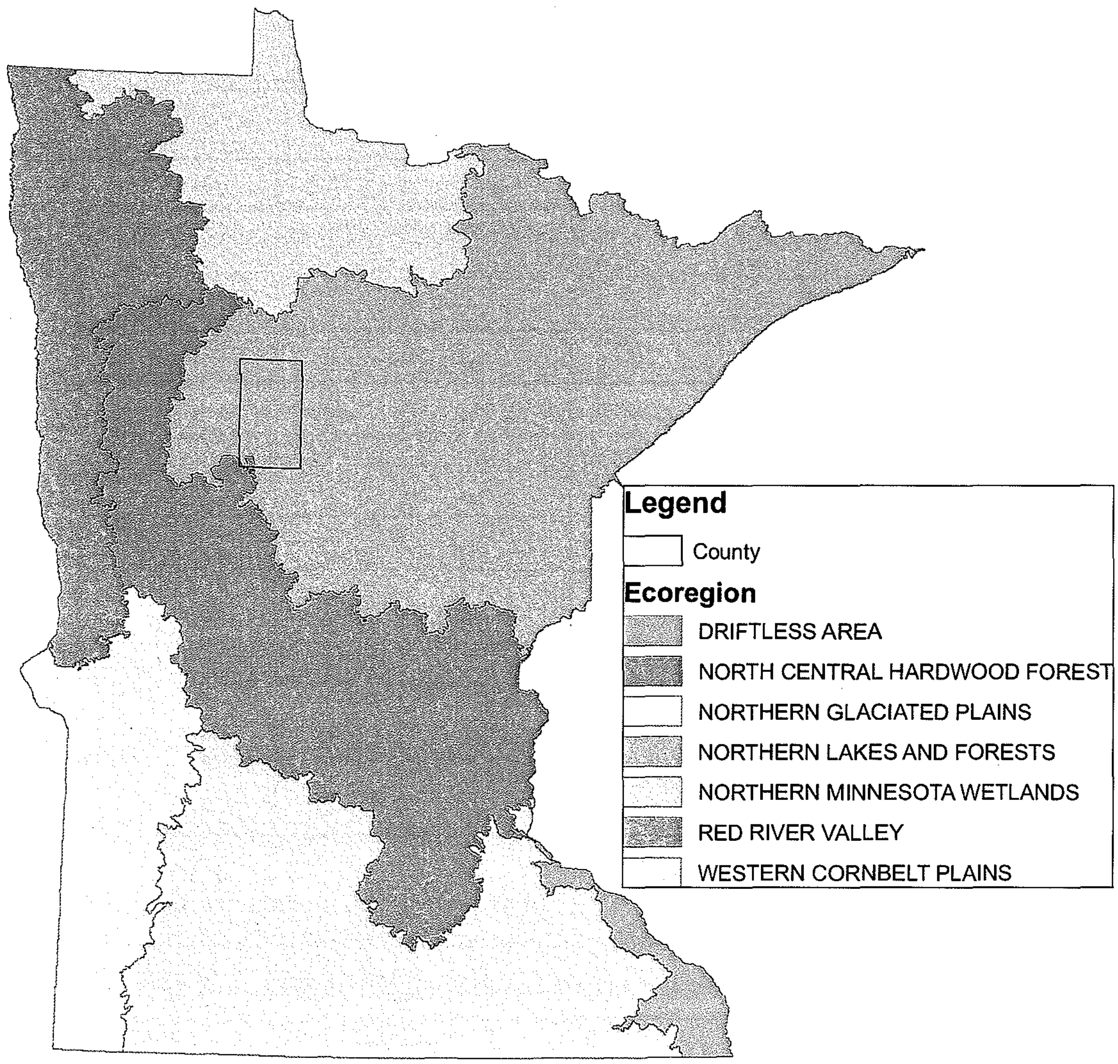
The Minnesota Pollution Control Agency's (MPCA) core lake-monitoring programs include the Citizen Lake Monitoring Program (CLMP) and Lake Assessment Program (LAP). In addition to these programs, the MPCA annually monitors numerous lakes to provide baseline water quality data, provide data for potential LAP and CWP 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 lakes sampled in Hubbard County during the 2005 season (Figure 3). 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 varied in amounts of historical data, some with Secchi records dating back to the early 1980s, and others that were visited for the first time in 2005. For data-poor lakes, the focus of the monitoring is on establishing baseline data; for data rich, the focus is to collect data to determine trends. In the selection of lakes, a focus was placed on large lakes 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 June through September. A summary of data from 2005 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 (Appendix D). Summer-mean epilimnetic (upper well-mixed layer) concentrations for each lake are compared to the "typical" range for ecoregion-reference lakes in the Northern Lakes and Forests (NLF) 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)

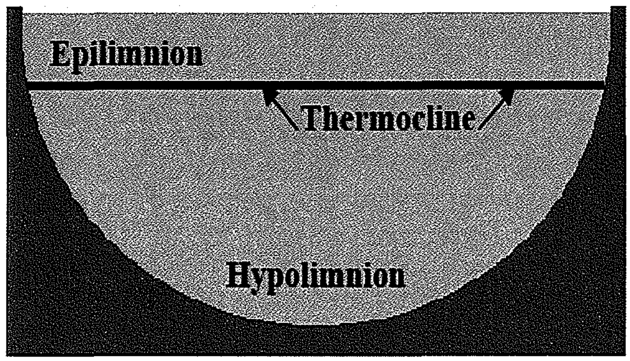
Ecoregion	TP	Chl-a	Secchi
	ppb	ppb	meters
NLF – Lake trout (Class 2A)	< 12	< 3	> 4.8
NLF – Stream trout (Class 2A)	< 20	< 6	> 2.5
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
CHF – Stream trout (Class 2a)	< 20	< 6	> 2.5
CHF – Aquatic Rec. Use (Class 2b)	< 40	< 14	> 1.4
CHF – Aquatic Rec. Use (Class 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 each 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. Further details may be found in Heiskary and Wilson (2005). These data provide an objective basis for comparing data from other lakes. In this study, data from the NLF ecoregion will be used as a basis for comparing the water quality of lakes sampled in 2005.

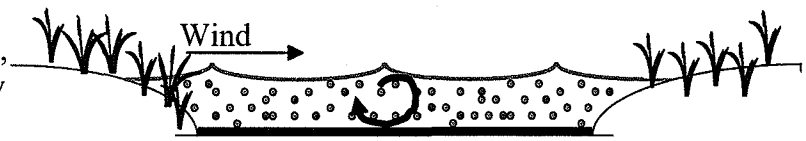
Lake depth can have a significant influence on lake processes and water quality. One such process is *thermal stratification* (formation of distinct temperature layers, see Figure 2a), in which deep lakes (maximum depths of 30 - 40 feet or more) often stratify (form layers) during the summer months and 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

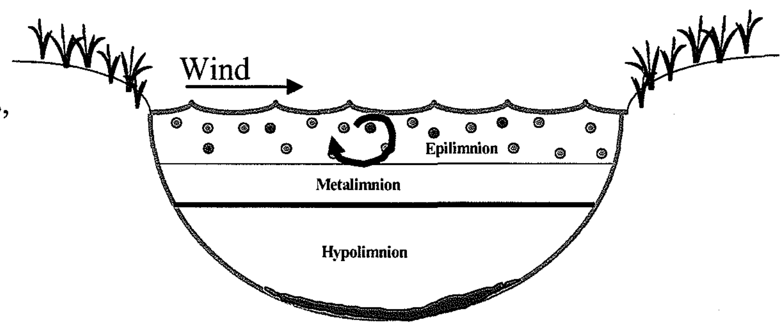
2a



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

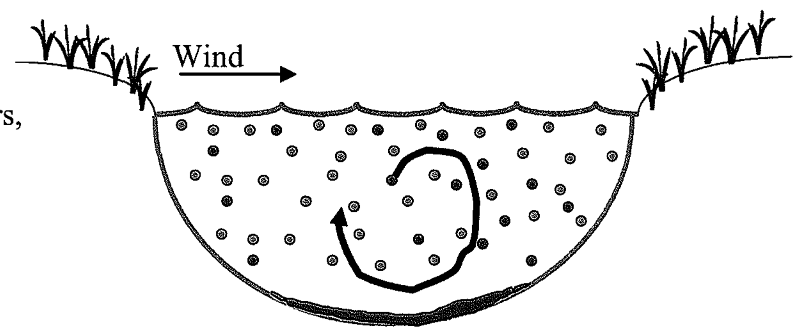


Table 2. Reference Lake Data Base Water Quality Summary
(Summer Average Water Quality Characteristics for Lakes by Ecoregion)*

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 all located in the Upper Mississippi Basin. Within this basin, lakes were located in the following watersheds: Mississippi (Headwaters-Lake Winnibigoshish) (Lake George and Paine Lake), Leech Lake River (Garfield Lake), and Crow Wing River (Island Lake). 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 records showed some fluctuation in level over time, especially between different lakes. Lake George and Paine Lake, both monitored from 1941 to 2006 (with a very limited dataset, 5 readings for George and 3 for Paine) exhibited ranges of 3.6 feet and 4.07 feet, respectively. Garfield Lake was monitored from 1992 to 2006 with a variation of 1.37 feet. Island Lake, with the most comprehensive record, 1938 to 2006, exhibited a range of 3.92 feet. Data for specific lakes and years can be found at www.dnr.state.mn.us.

Fisheries

George (2004), Paine (2001), Garfield (2005), and Island (2005) lakes have been surveyed by the MDNR Fisheries Section. More detailed reports are available at www.dnr.state.mn.us.

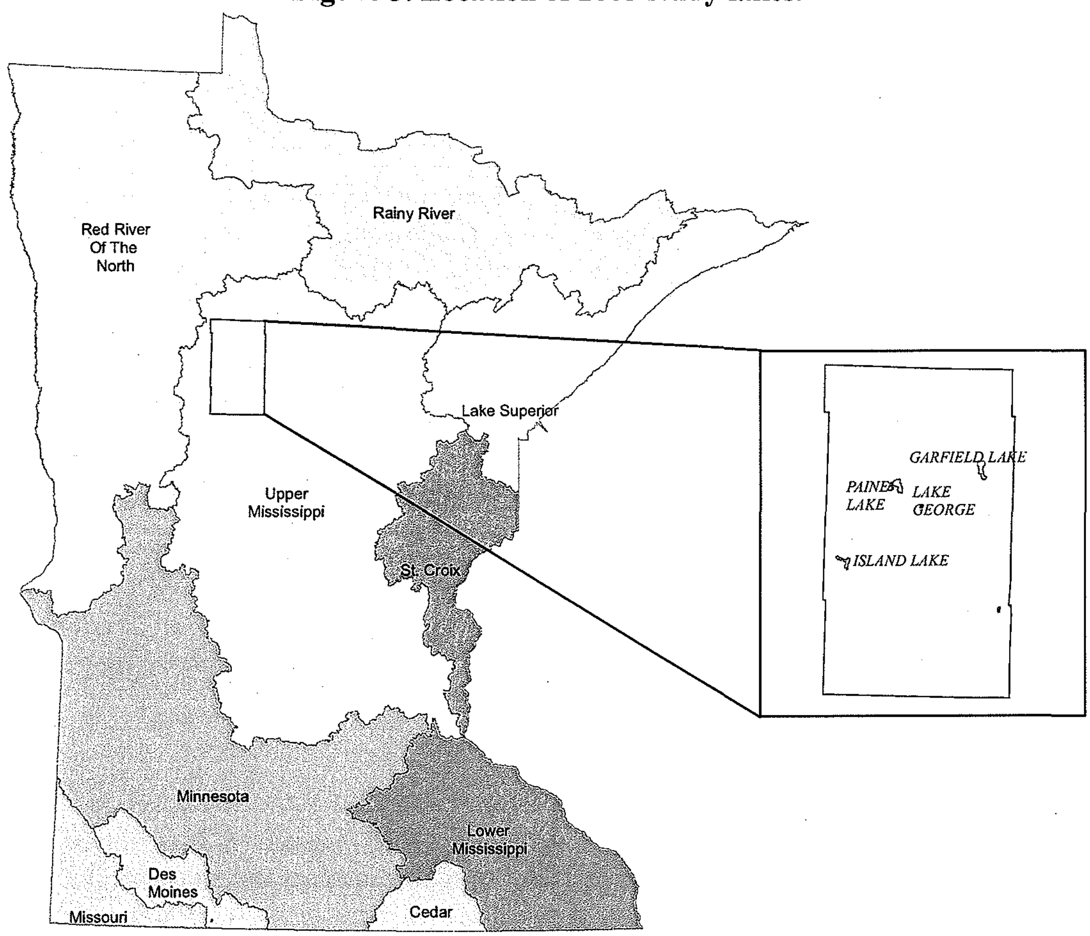
Lake George maintains good populations of walleye, northern pike, largemouth bass, and bluegill with its excellent fish habitat, consisting of submergent and emergent vegetation. The lake is currently stocked for walleye fingerlings on even numbered years.

Paine Lake, with a depth of only six feet is subject to periodic partial winterkill events. This is particularly evident during long winters with heavy snowfall. Northern pike, bluegill, and pumpkinseeds were all abundant during the most recent survey. The lake does support good numbers of fish, but not large fish.

Garfield Lake is popular for its walleye and northern pike angling opportunities. Currently the lake is stocked for walleye. In addition, Garfield does support a considerable bluegill, black crappie, and largemouth bass population. The south bay of the lake provides spawning habitat, with shallow water and submergent vegetation.

Island Lake, the deepest lake in the study, supports abundant walleye and northern pike. As with Garfield, Island Lake is also stocked for walleye, with a switch from biannual to annual stocking taking place in 2005. The lake is known for its panfish during the ice fishing season. Bluegill and pumpkinseed are abundant, while black crappie is found in lower amounts.

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. Mean depths were estimated by MPCA staff using available bathymetric maps. With 979 acres, Garfield Lake was the largest in the study, while Paine Lake (259 acres) was the smallest. Maximum depths ranged from 6 feet in Paine Lake to 65 feet in Island Lake. Estimated mean depths ranged from 3 feet in Paine Lake to 16 feet in Island. Lake volume, which is the product of mean depth times surface area ranged from 777 acre-feet in Paine Lake to 12,727 acre-feet in Garfield Lake.

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, the lakes in this study would be considered "deep" lakes, with the exception of Paine Lake, which fits the "shallow" lake description (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 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; total watershed refers to the entire watershed upstream of the lake. In some cases, such as Paine and Garfield, the immediate and total watersheds are one in the same. In others, such as Island, the immediate watershed represents less than half 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 Paine and Garfield have the smallest watershed to lake ratios, which generally means that water (and often nutrient) loading to the lakes is rather small and water residence time is long. In contrast Island Lake, with a ratio of 222:1, 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.

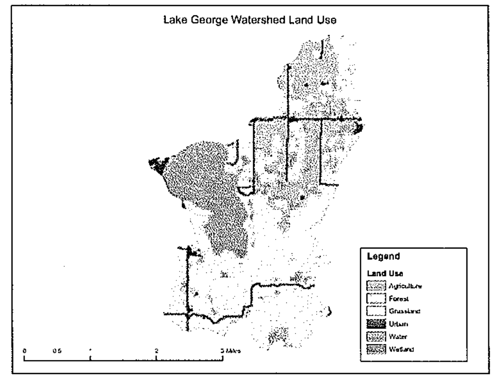
The soils found around lakes in the study are defined as medium textured forest soils and coarse to medium textured forest soils from the Nebish Rockwood and Menahga-Marquette series. These tend to be light colored, well drained soils in hilly areas, formed from loam calcareous glacial till and in level to rolling areas, droughty soils formed from noncalcareous outwash sand and gravel (Arneman 1963). The Hubbard County lakes in this study were likely formed by ice block basins in glacial till or outwash (Zumberge, 1952).

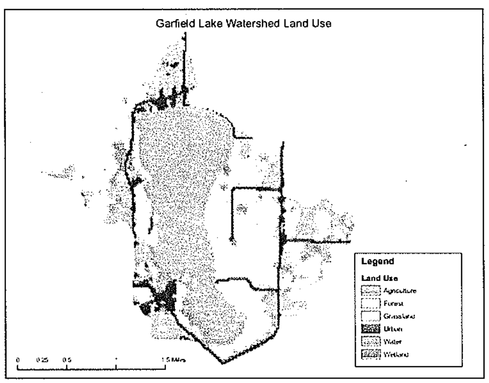
Table 4a. Lake morphometry and watershed characteristics.

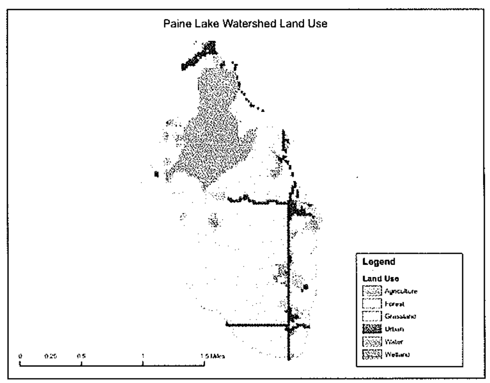
Lake Name	Lake	Lake Basin	Littoral Area		Immediate Watershed	Total Watershed Area	Total Watershed To Lake	Max. Depth	Average Depth	Lake Volume
Name	ID	Acres	Acres	% Littoral	Acres	Acres	Ratio	Ft.	Ft.	Acre-Ft.
George	29-0216	798	453	57	5,491	6,809	8.5:1	29	11	8,778
Paine	29-0217	259	259	100	1,325	1,325	5:1	6	3	777
Garfield	29-0061	979	521	53	3,443	3,443	3.5:1	32	13	12,727
Island	29-0254	544	179	33	3,898	120,806	222:1	65	16	8,704

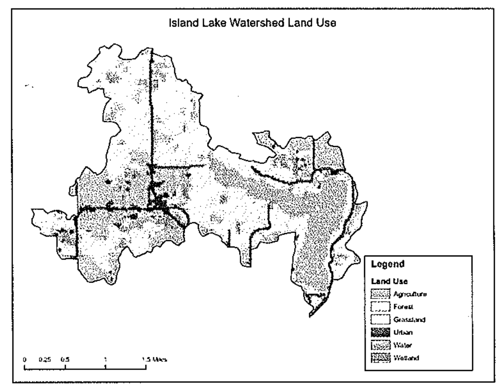
4b. Watershed land use as compared to Ecoregion Interquartile Ranges

Land Use (%)	George	Paine	Garfield	Island	NLF Ecoregion
Forest	55	71	46	50	**54 – 81**
Water/wetlands	21	21	33	22	**14 – 31**
Pasture/grasslands	1	1	0	1	**0 – 6**
Cultivated	19	2	14	21	**< 1**
Urban	4	5	7	6	**0 - 7**







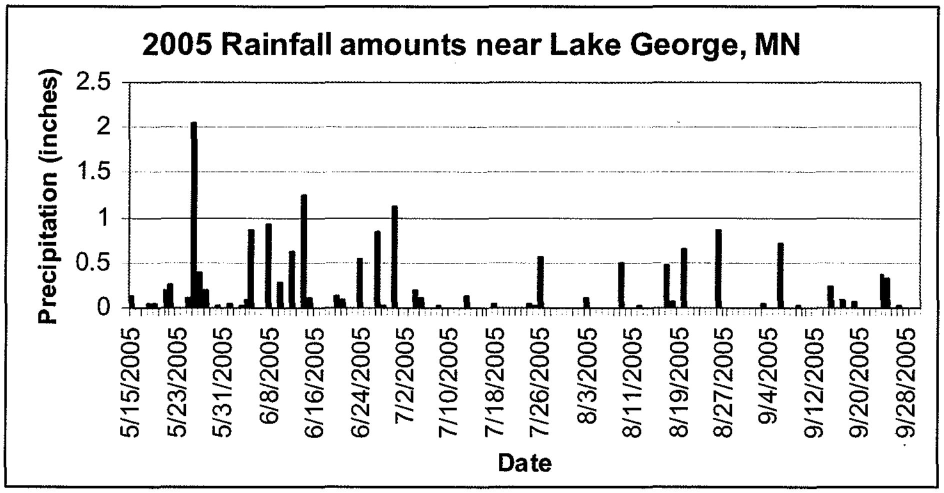


Precipitation

Approximately 31 inches of water evaporates annually in this part of the state. This typically exceeds precipitation, which averages 24 inches (0.61 m). Runoff averages about 5 inches with 1-in-10 year low and high values (may occur with a frequency of once in ten years) of 1.2 inches and 7.9 inches, respectively for this area (Gunard, 1985).

Rain gauge records from Lake George township, show two one-inch and one two-inch rain events during summer 2005 (Figure 4a). In particular, large rain events were noted for May 26th, June 14th, and June 30th. 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 average rainfall (0 -2 inches below normal) for the Hubbard study area (Figure 4b).

Figure 4a. Rainfall based on records from Lake George, MN. Lat: 47.19507 Lon: -94.98357



Methods

Water quality data was collected in June, July, August, and September 2005 on the lakes in this study. 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 and dissolved oxygen profiles, field pH and conductivity, and Secchi disk transparency measurements were also taken. Phytoplankton samples were analyzed at the MPCA by Dr. Howard Markus.

Figure 4b. Water year precipitation for 2005.

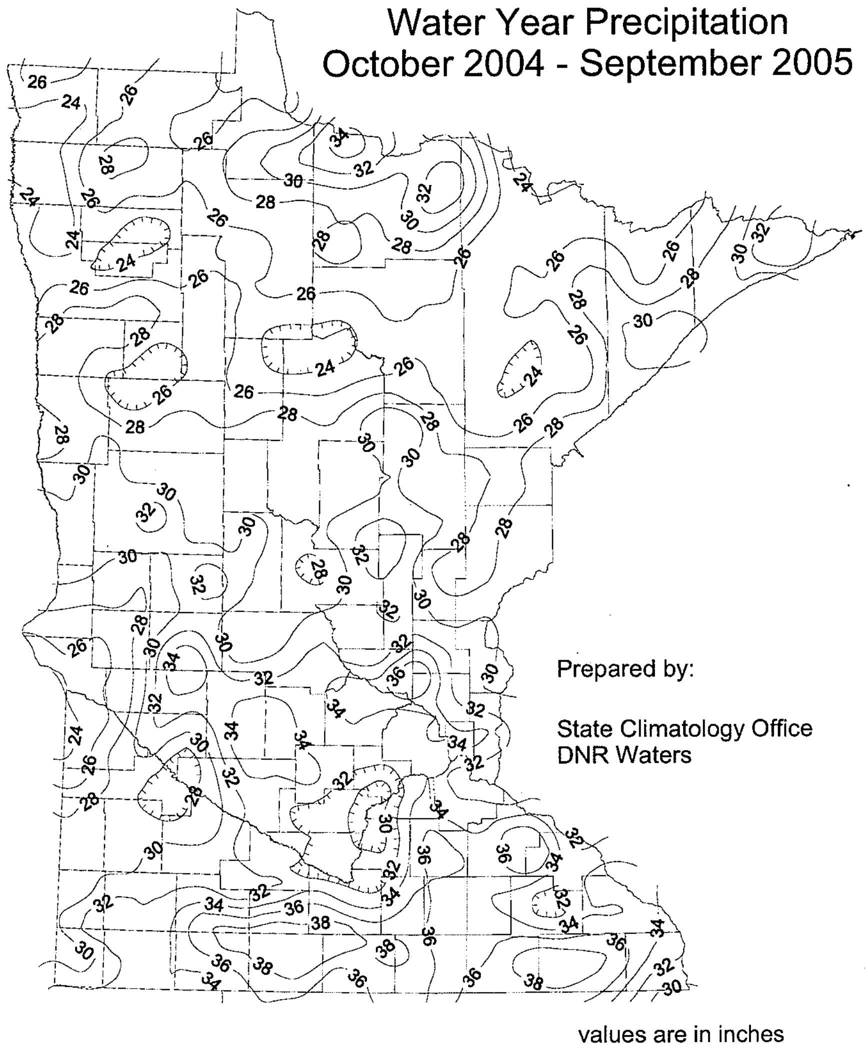


Figure 5. 2005 Site Locations for George, Paine, Garfield, and Island Lakes

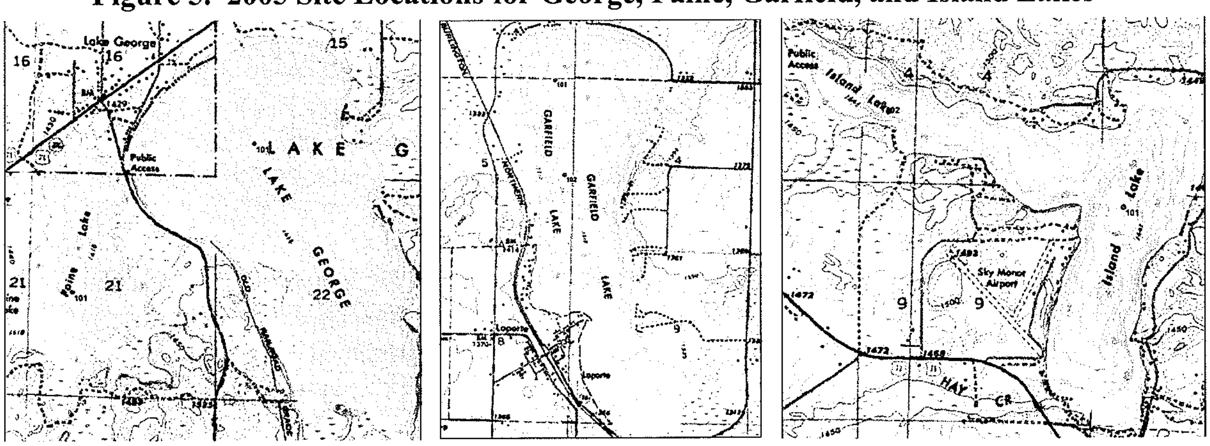


Table 5. Lake Summer Mean Water Quality

Parameter	George	Paine	Garfield	Island		Typical Range for NLF Ecoregion
				101	102	
Total Phosphorus (µg/l)	23	19	23	27	30	14 - 27
Chlorophyll-*a* (µg/l) mean	6.5	2.7	7.2	8.9	7.3	4 - 10
Chlorophyll-*a* (µg/l) max	12.7	4.0	15.2	11.9	10.7	< 15
Secchi disk (feet)	8.5	3.6	10.5	7.8	8.2	8 - 15
Secchi disk (m)	2.6	1.1*	3.2	2.4	2.5	2.4 – 4.6
Total Kjeldahl Nitrogen (mg/l)	0.6	0.7	0.6	0.6	-	0.4 – 0.75
Alkalinity (mg/l)	146	130	140	192	-	40 - 140
Color (Pt-Co Units)	6	6	7.5	20	-	10 - 35
Chloride (mg/l)	2.3	1.3	7.7	2.5	-	0.6 – 1.2
Total Suspended Solids (mg/l)	2.2	1.9	2.4	2.9	-	< 1 - 2
Total Suspended Inorganic Solids (mg/l)	2	1.6	2.1	2.4	-	< 1 - 2
Conductivity (µmhos/cm)	254	215	254	305	313	50 - 250
TN:TP Ratio	38:1	27:1	38:1	45:1	-	25:1 – 35:1

Field duplicates were collected at 10% of the sites during 2005. These are duplicate samples collected at the sampling site, immediately after the primary sample is collected. These parameters are plotted on the graphs, and denoted as "FD."

Samples were also collected for total mercury in the water column on all four lakes. A brief discussion will be included on each individual lake regarding the results.

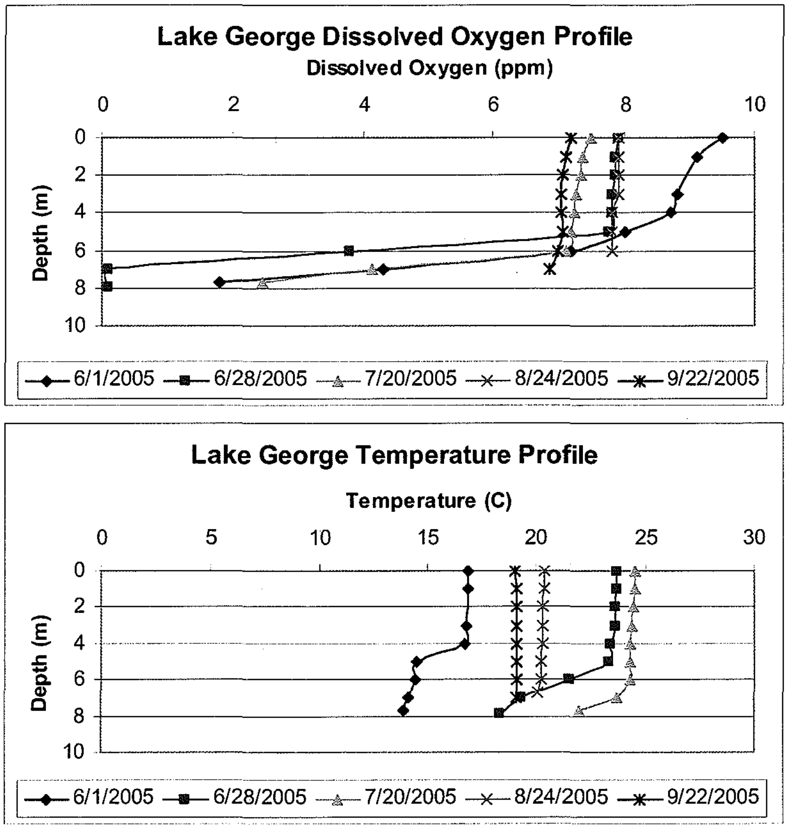
Using available historical water quality data in STORET, a comparison between historical values and 2005 will be included. All data was stored in STORET, the EPA's national water quality data bank. The following discussion assumes that the reader is familiar with basic water quality terminology as used in the Citizens' Guide to Lake Protection, which is available online at: http://www.pca.state.mn.us/water/lakeprotection.html.

Results: Lake George

Dissolved Oxygen and Temperature profiles were taken monthly at site 101. The lake was well mixed on all dates, with DO levels remaining above 5 mg/l (minimum dissolved oxygen concentration preferred for game fish) to a depth of 6 meters (Figure 6). The temperature profile also indicates a well mixed lake, with temperatures showing very weak stratification only on the June and July trips. These profiles indicate that Lake George is likely polymictic (continuously mixing throughout the summer via wind and wave action).

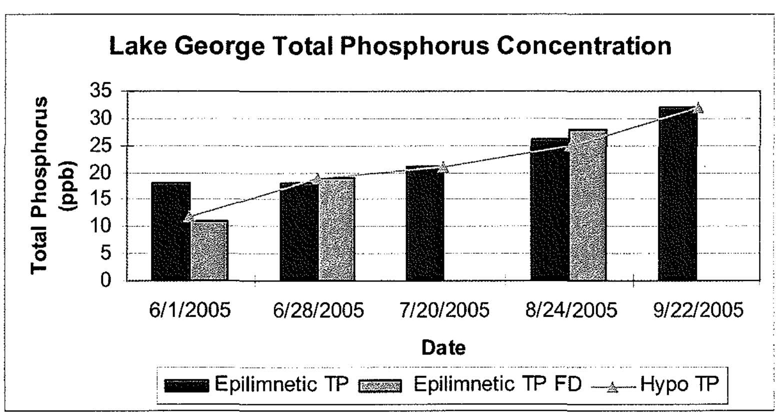
* Secchi transparency readings for all dates on Paine Lake were minimum values. The disk was visible when on the bottom of the lake, and therefore true transparency depths could not be determined. For this lake, only total phosphorus and chlorophyll-a should be used to determine trophic status.

Figure 6. Lake George Dissolved Oxygen and Temperature Profiles



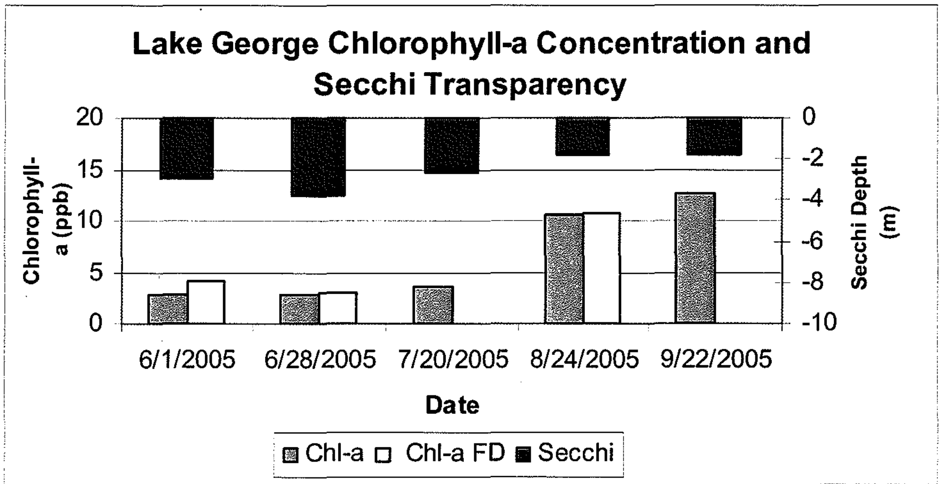
Total Phosphorus (TP) concentrations averaged 23 µg/l in the epilimnion during the summer of 2005, with a minimum of 18 µg/l in early June and a maximum of 32 µg/l in September (Figure 7). Summer-mean TP falls within the range of expected values for the NLF ecoregion (Table 5). Hypolimnetic total phosphorus is very similar to that of the surface samples, which would be expected with the continuous mixing of the lake. Phosphorus release from the sediments is often minimal when oxygen is present at the sediment-water interface. In the case of Lake George, periodic low dissolved oxygen and elevated temperatures near the sediments may have allowed for some internal release. This may explain the trend toward increasing TP from June to September (Figure 7).

Figure 7. Lake George Total Phosphorus Concentration



Chlorophyll-*a* concentrations for 2005 on Lake George averaged 6.5 µg/l, with a low of 2.8 µg/l in early June and a high of 12.7 µg/l in September (Figure 8). Concentrations from 10-20 µg/l are frequently perceived as a mild algal bloom. Considering this, mild algae blooms were evident during the August and September sampling trips. Both the average and maximum chlorophyll-*a* values were within the typical range for NLF ecoregion lakes (Table 5). Chlorophyll-*a* followed a similar pattern as total phosphorus; concentrations increasing as the summer progressed.

Figure 8. Lake George Chlorophyll-*a* Concentration and Secchi Transparency

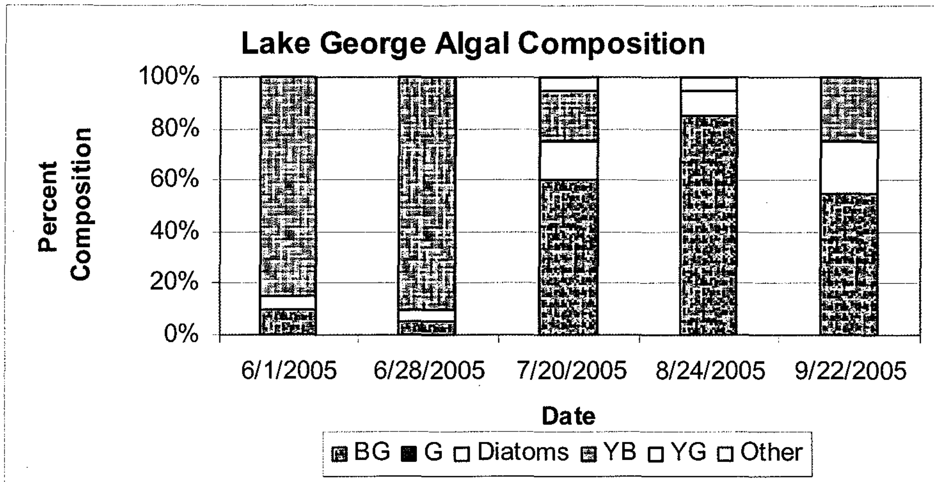


Secchi disk transparency on Lake George averaged 2.6 meters (8.5 feet) with a range of 1.8 – 3.8 m during the summer of 2005 (Figure 8). Color averaged 6 Pt-Co Units and total suspended solids averaged 2.2 mg/l. Color is just below the typical range of NLF ecoregion values and TSS is just above the range of values (Table 5). These levels should not appreciably reduce the clarity of the water. The average Secchi depth is within the typical NLF ecoregion values.

The change in the transparency of Lake George over the course of the summer closely mirrored the changes in nutrient availability (TP) and algal production (Chl-*a*), and is fairly typical for mesotrophic-eutrophic lakes in Minnesota. Transparency was the greatest in the spring when the waters were cool and algal production was relatively 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 algae become more abundant, the transparency declines (Figure 8). Later in the summer, surface blooms of algae may also appear.

Algal composition for Lake George was dominated in June by yellow-brown algae, with blue-greens dominating the system for July, August, and September. 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 present, and diatoms were present throughout the summer, but never made up more than twenty percent of the composition (Figure 9).

Figure 9. Lake George Algal Composition

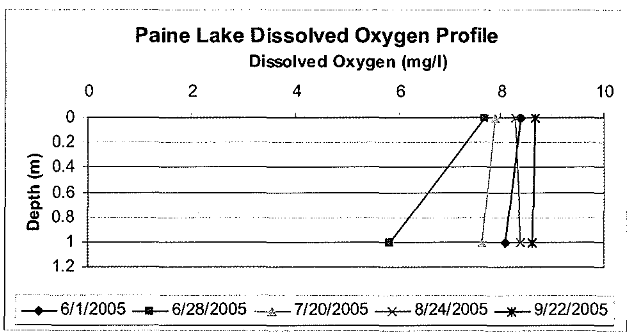


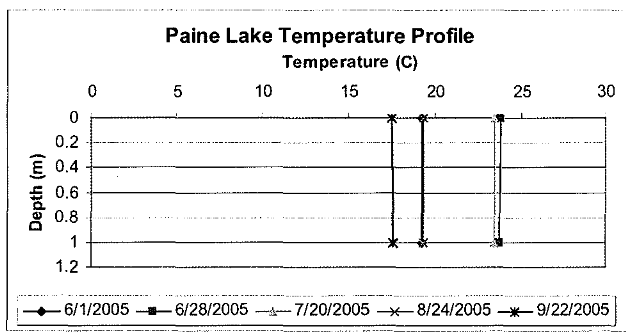
Mercury was measured at site 101 on Lake George in June, July, and August of 2005. In general, mercury concentrations above one ng/l are considered high, while the impairment threshold is 6.9 ng/l. Concentrations measured on Lake George were well below these levels, with a minimum of 0.54 ng/l in July and a maximum of 0.85 ng/l in June. It should be noted that in 1998, Lake George 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: Paine Lake

Dissolved oxygen and temperature profiles were taken at site 101 monthly from June to September (Figure 10). Dissolved oxygen concentrations remained above 5 mg/l (DO levels of 5 mg/l or greater preferred for game fish) down to the bottom of the lake (1.8 m). The temperature profile indicated a well mixed (polymictic) lake on all sampling dates. This would be expected considering the shallow nature of the lake, with wind and wave action mixing the water column.

Figure 10. Paine 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 19 µg/l (micrograms per liter or parts per billion) in the epilimnion during the summer of 2005 for site 101. This is well within the expected range for the NLF ecoregion (Table 5). Surface TP levels remained relatively constant all summer long, with a low of 16 µg/l in August and a high of 22 µg/l in late June (Figure 11).

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 1.8 µg/l in August to a high of 4.0 µg/l in September with an average of 2.7 µg/l at site 101 (Figure 12). Chlorophyll-*a* concentrations are below typical NLF ecoregion values at site 101 for the mean, and within the expected range for the maximum. No algae blooms were observed during 2005 (concentrations from 10-20 µg/l are frequently perceived as a mild algal bloom).

Figure 11. Paine Lake Total Phosphorus Concentration

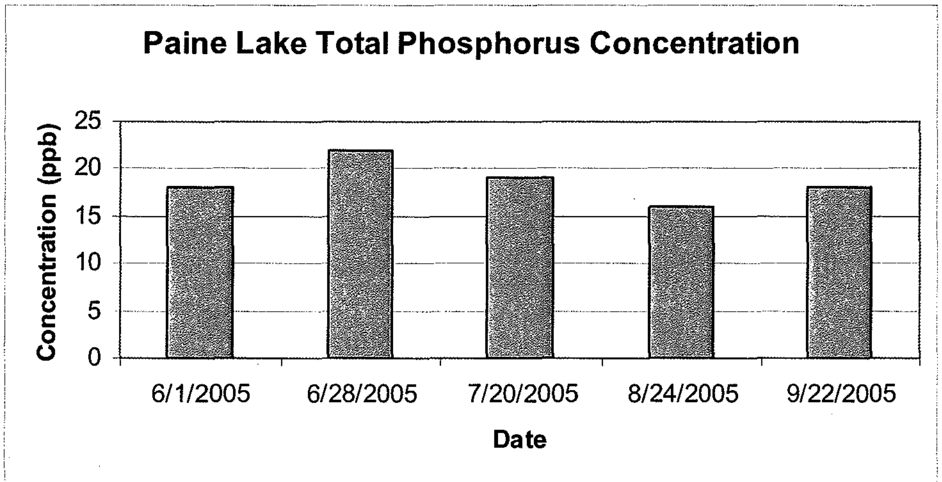
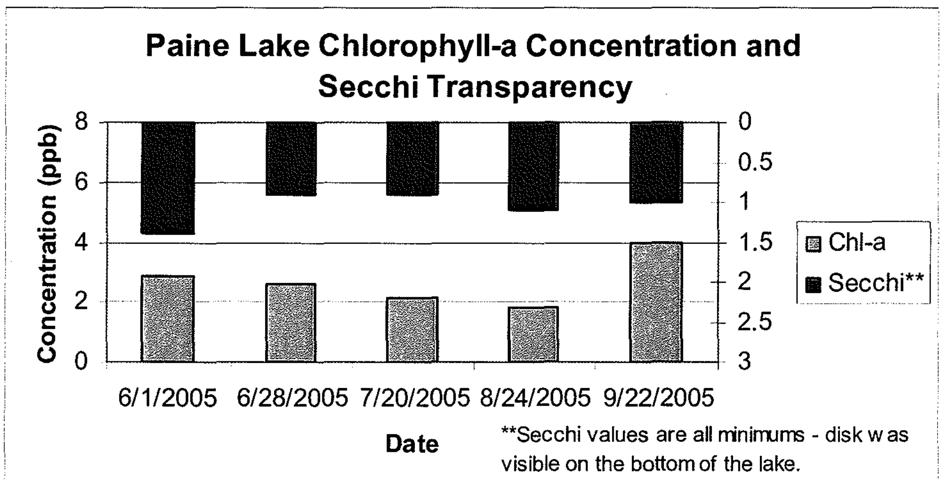
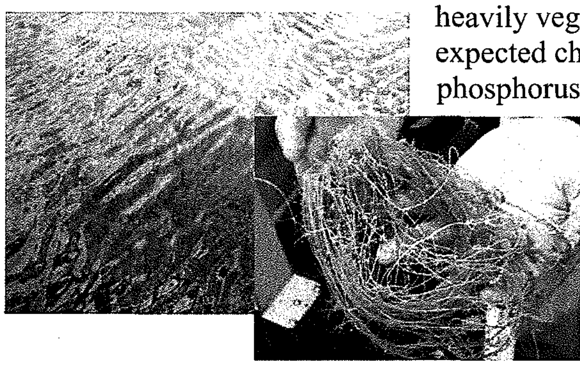


Figure 12. Paine Lake Chlorophyll-*a* Concentration and Secchi Transparency



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 6 Pt-Co Units at site 101 and total suspended solids (TSS) averaged 1.9 mg/l. TSS values are within the expected range of values for the NLF ecoregion, while the color fell below the range of expected values for the ecoregion, which implies very clear water. As such, neither appreciably limited water transparency. Secchi transparency at site 101 ranged from a low of 0.9 m in late June and July to a high of 1.4 m in early June, with an average of 1.1 m. This average is well below the typical range of Secchi disk transparencies for the NLF ecoregion (Table 5). However, on all dates in 2005, the Secchi disk was visible when on the bottom of the lake. This indicates that the water was more transparent than the Secchi measurement indicated.

In Paine Lake, the transparency was limited by depth of the lake (Figure 12). Paine Lake is heavily vegetated, and this may explain the better than expected chlorophyll-*a* and clear water considering the total phosphorus concentrations observed. In lakes with minimal vegetation, elevated TP typically results in increased chlorophyll-a (i.e. algae). In the case of Paine Lake, the observed phosphorus levels did not result in increased algae, but instead the phosphorus was used by the rooted vegetation. This can be observed in the photos at left, with the dense mats of vegetation visible.

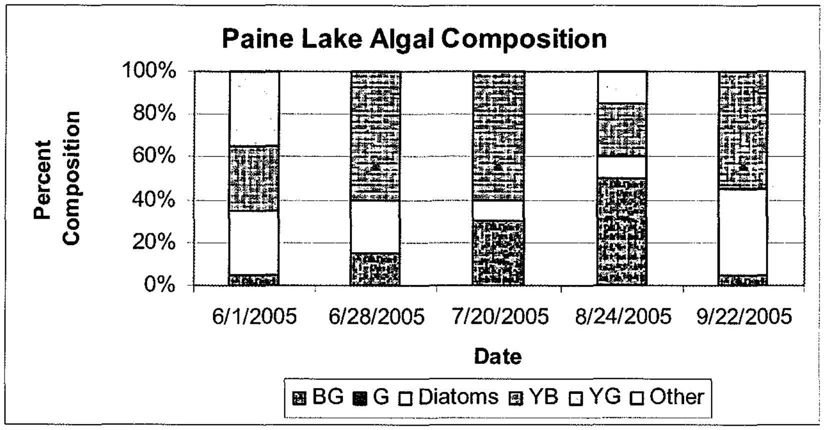


For typical mesotrophic-eutrophic lakes in Minnesota, transparency varies across the season. High readings are normally found in the spring when the water is cool and algae populations are low. Zooplankton (small crustaceans which feed on algae) populations are high at this time of year also, but decline 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 algae become more abundant, the transparency declines. 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.

Algal composition on Paine Lake at site 101 was dominated in late June, July and September by yellow-brown algae and by blue-green algae in August. The early June sample contained a mix of diatoms, yellow-browns, and dinoflagellates (Figure 13). For typical mesotrophic-eutrophic lakes in Minnesota, composition transitions from a diatom dominant system in early summer, to a green algae and then blue-green algae dominance. Green algae were never present in samples collected in 2005.

Mercury in surface water was also measured on Paine Lake in 2005. Samples were collected in July (0.55 ng/l) and August (0.74 ng/l). The standard for waters to be considered impaired for dissolved total mercury is 6.9 ng/l. Samples collected in 2005 were well below the impairment threshold.

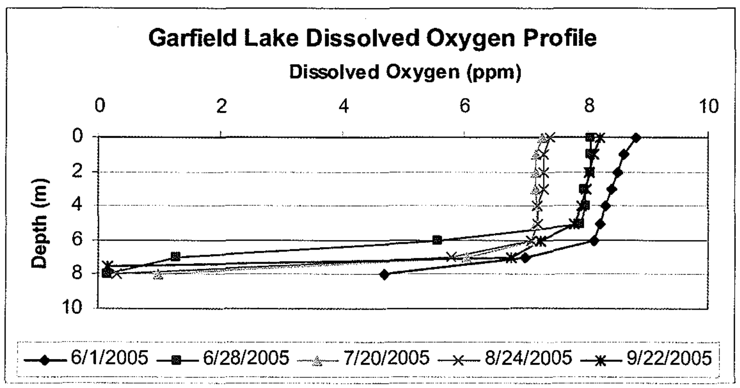
Figure 13. Paine Lake Algal Composition

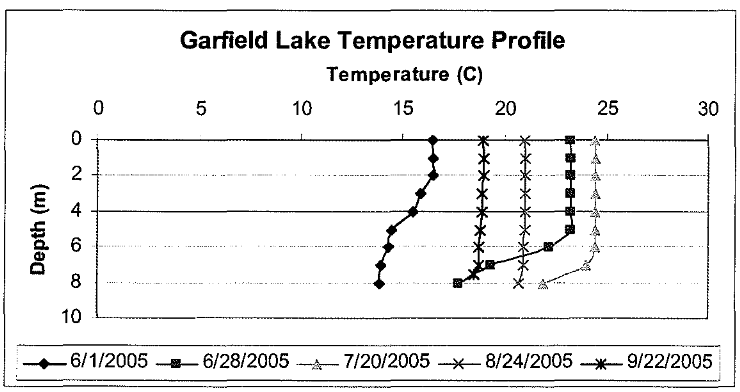


Results: Garfield Lake

Dissolved Oxygen and Temperature profiles were taken at site 102 on Garfield Lake in 2005. The dissolved oxygen remained above 5 mg/l (minimum level preferred for game fish) to a depth of 6 meters on all dates (Figure 14). Temperature profiles indicated a relatively well mixed water column (polymictic) on all dates, with slight drops in temperature at a depth greater than 4 meters on the June sampling dates. However, low DO concentrations were noted near the bottom sediments.

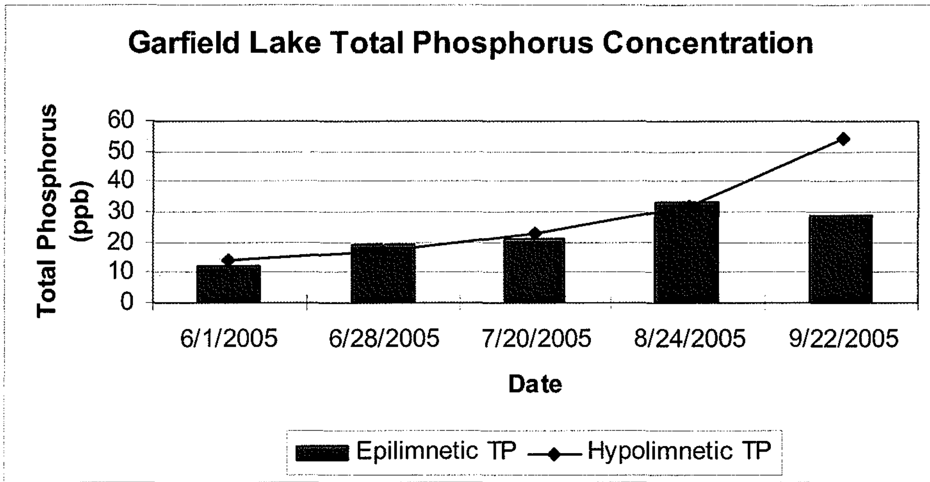
Figure 14. Garfield Lake Dissolved Oxygen and Temperature Profile





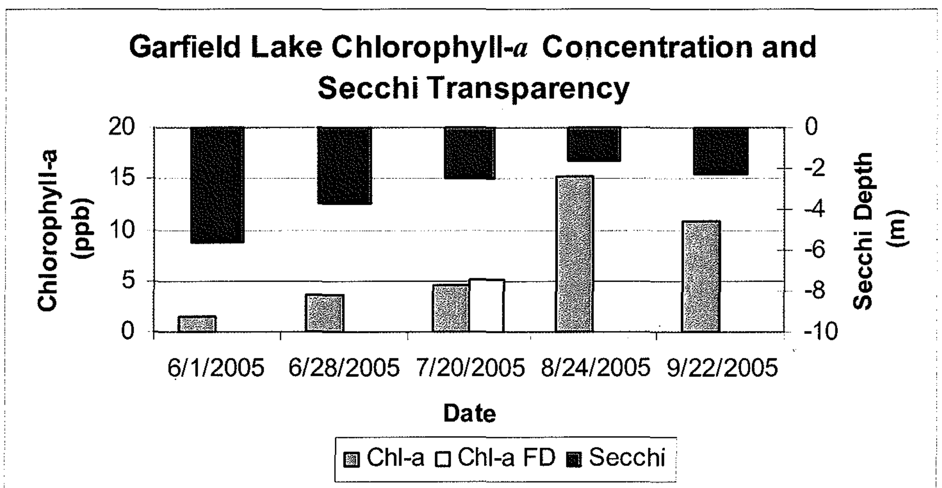
Total Phosphorus concentrations on Garfield Lake averaged 23 μg/l, with a low of 12 μg/l in early June and a high of 33 μg/l in August (Figure 15). This seasonal average is within the typical range for lakes in the NLF ecoregion. Total phosphorus concentrations increased across the summer, reaching a peak in August and then declining slightly. The hypolimnetic total phosphorus averaged 28 μg/l and exhibited a pattern similar to the surface phosphorus concentrations. This would be expected due to the polymictic nature of the lake. The pattern of increasing TP over the summer suggests that some internal recycling of phosphorus is occurring; however, the rate of recycling is low as compared to dimictic lakes.

Figure 15. Garfield Lake Total Phosphorus Concentration



Chlorophyll-*a* concentrations on Garfield Lake ranged from a low of 1.5 μg/l in early June to a high of 15.2 μg/l in August, with an average of 7.2 μg/l (Figure 16). The average is well within the typical range of values for the NLF ecoregion, and the maximum value is just outside the range. As expected, the chlorophyll-*a* concentration increases parallel the increase in total phosphorus concentration.

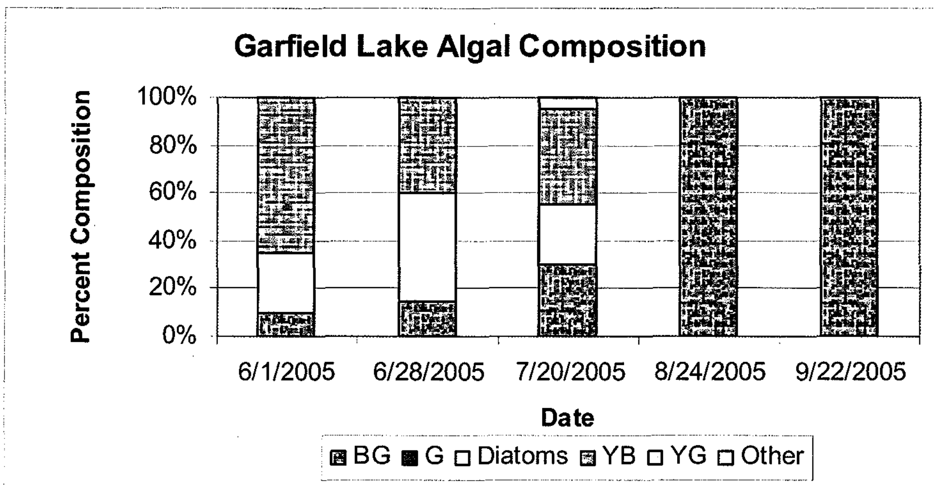
Figure 16. Garfield Lake Chlorophyll-*a* Concentration and Secchi Depth



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 7.5 Pt-Co Units on Garfield Lake, and total suspended solids averaged 2.4 mg/l. TSS values are just above the expected range of values for the NLF ecoregion, while color was just below the range. These values indicate that those parameters did not limit transparency. Transparency ranged from a low transparency of 1.6 m in August to a high of 5.6 m in early June. The seasonal average transparency on Garfield Lake was 3.2 m. This is within the typical range for the NLF ecoregion. Again, these changes in transparency (decrease in clarity) follow the increase of chlorophyll-*a* concentrations (algal growth) and total phosphorus concentration.

Algal Composition on Garfield Lake was dominated by yellow-brown algae in early June and July (Figure 17). The late June sample was dominated by diatoms, and blue-green algae made up the entire population for the August and September sampling dates. For most mesotrophic to eutrophic lakes in Minnesota, the algae composition shifts from diatoms to greens to blue-greens. As seen previously on lakes in this study, green algae were absent from all of the samples collected.

Figure 17. Garfield Lake Algal Composition

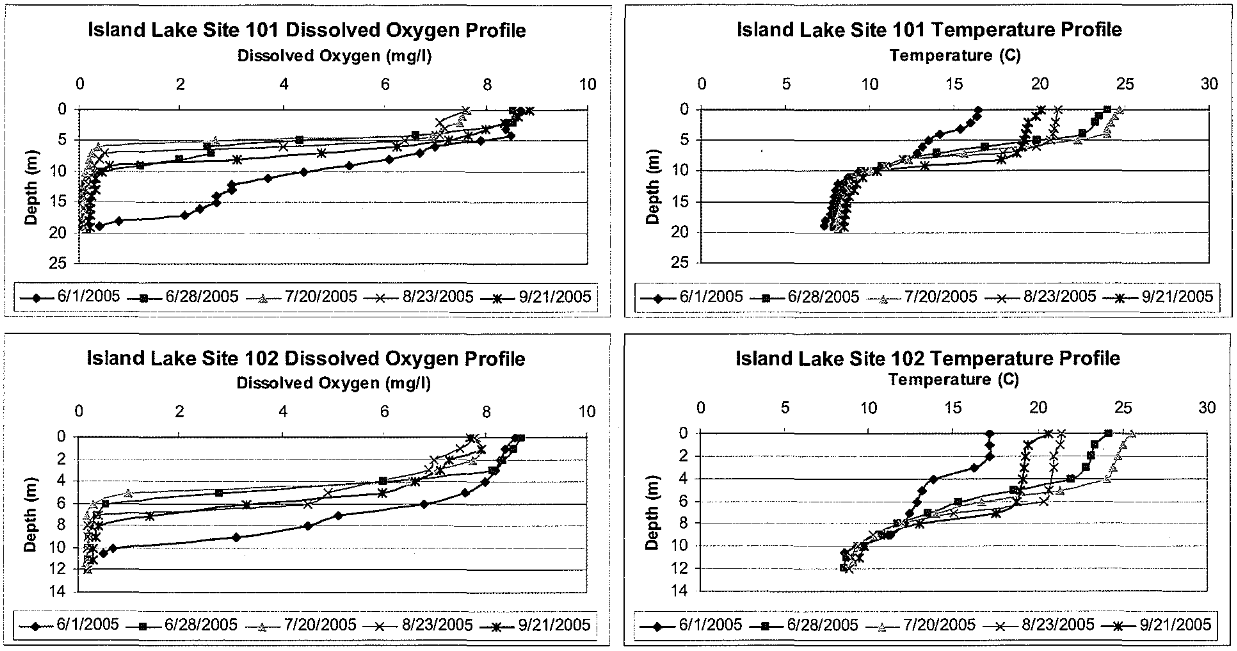


Mercury samples were collected on Garfield Lake in June, July, and August 2005 at site 102. Concentrations ranged from a low of 0.32 ng/l in July to a high of 0.87 ng/l in June. This range of values is well below the impairment threshold of 6.9 ng/l.

Results: Island Lake

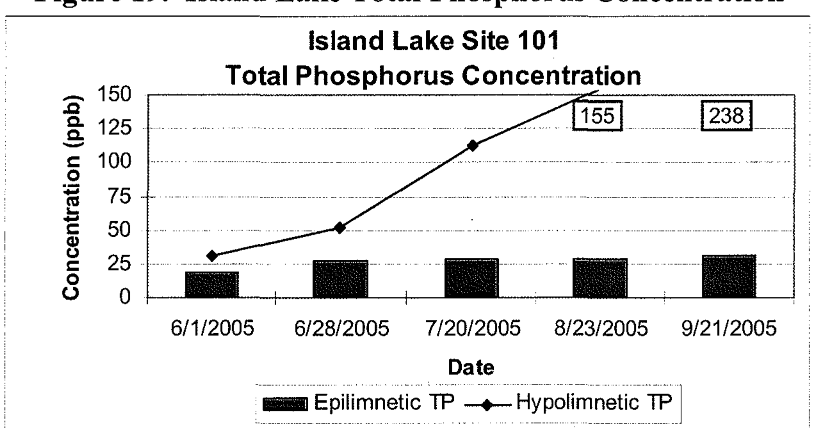
Dissolved oxygen and temperature profiles were taken at sites 101 and 102 on Island Lake in June, July, August, and September 2005. Dissolved oxygen remained above 5 mg/l on all sampling dates above a depth 5 meters at both sites (Figure 18). Temperature profiles indicated that the lake was stratified on all dates, with a thermocline developing near 8 meters at site 101 and 6 meters at site 102. The stratification was weaker in early June and September, suggesting that the lake is dimictic (mixed in the spring and fall).

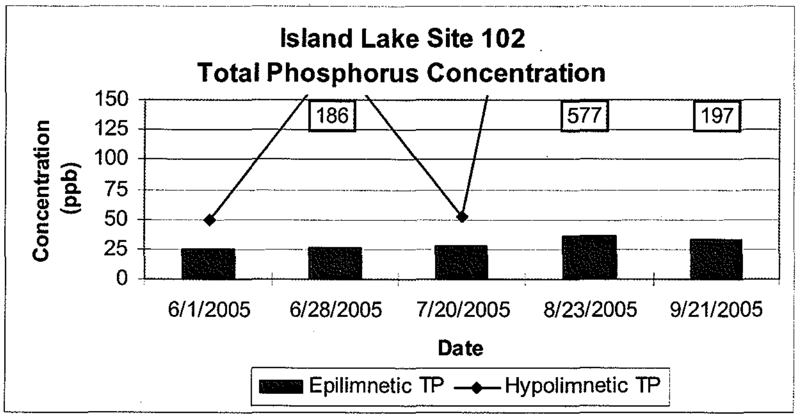
Figure 18. Island Lake Dissolved Oxygen and Temperature Profiles



Total Phosphorus concentrations on Island Lake averaged 27 µg/l at site 101 and 30 µg/l at site 102 in 2005 (Figure 19). The seasonal average for site 101 is at the high end of the typical range of values in the NLF ecoregion, while the average for 102 is just outside the range (Table 5). Hypolimnetic total phosphorus concentrations averaged 118 µg/l and 212 µg/l at sites 101 and 102, respectively. This high hypolimnetic total phosphorus concentration is consistent with the dimictic nature of the lake. Under stratified conditions, the deep water (hypolimnion) becomes anoxic (without oxygen); anoxic conditions favor the release of sediment bound phosphorus into the water column. Typically total phosphorus concentrations decline across the summer as watershed loading to the lake diminishes. While the epilimnetic total phosphorus didn't vary drastically, it generally increased across the season, reaching a peak concentration in September at site 101 and August at site 102.

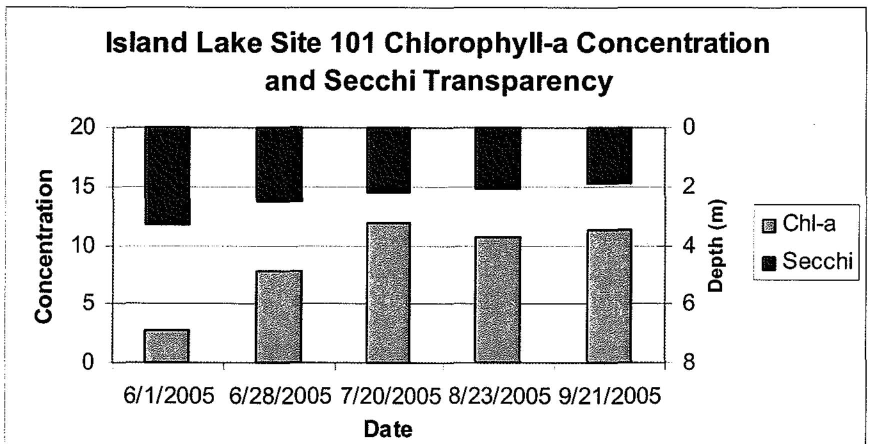
Figure 19. Island Lake Total Phosphorus Concentration

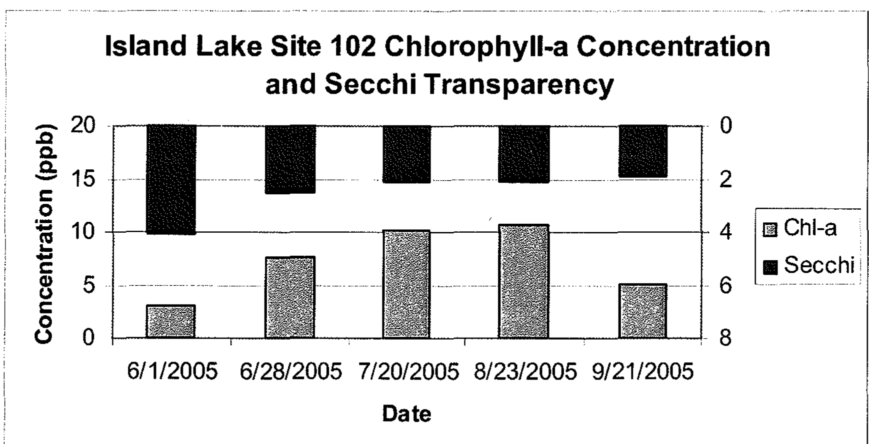




Chlorophyll-*a* concentrations in Island Lake averaged 8.9 µg/l at site 101 and 7.3 µg/l at site 102 in 2005 (Figure 20). Both the average and the maximum (101 = 11.9 µg/l, 102 = 10.7 µg/l) values were within the range of expected values for the NLF ecoregion (Table 5). Mild algae blooms (Chl-a between 10 µg/l and 20 µg/l) were present during the July and August trips at both sites and also in September at site 101. Similar to the total phosphorus concentrations, chlorophyll-*a* increased from a low in early June to maximum values in later summer.

Figure 20. Island Lake Chlorophyll-*a* Concentration and Secchi Transparency

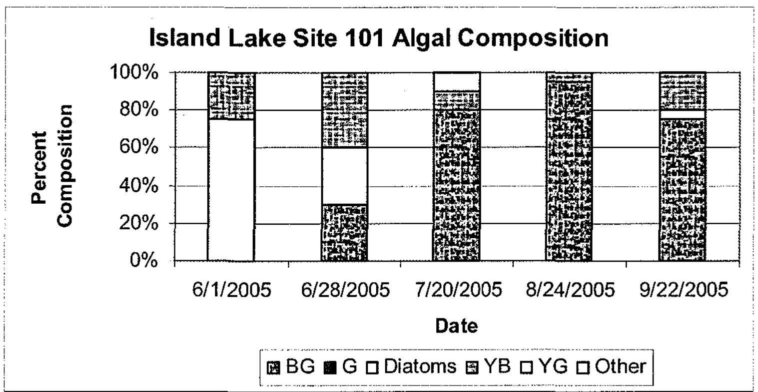


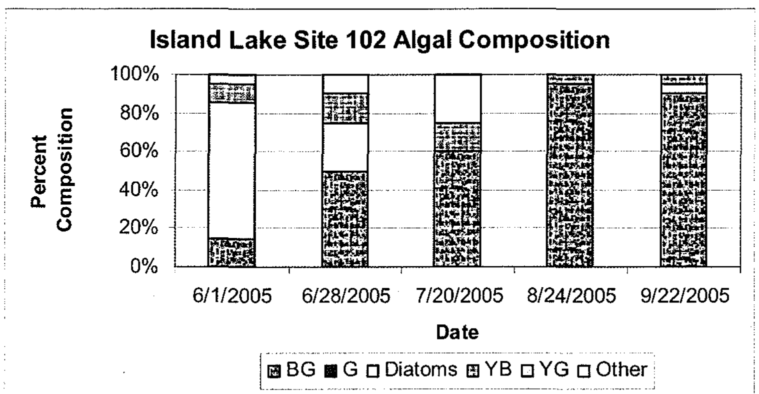


Secchi disk transparency averaged 2.4 m (7.8 feet) at site 101 and 2.5 µg/l (8.2 feet) at site 102 (Figure 20). This average is on the low end of the typical range of expected values for the NLF ecoregion (Table 5). At site 101, color averaged 20 Pt-Co Units and TSS averaged 2.9 mg/l. The average for color is within the typical ecoregion values and TSS is just above the expected range; however, they should not appreciably limit transparency. Transparency followed a similar pattern to chlorophyll-*a* (algae) concentrations in 2005 (Figure 20). When the chlorophyll-*a* levels were elevated, a corresponding drop in transparency was observed.

Algal composition on Island Lake was dominated by diatoms in early June 2005 and by blue-greens from July through September at both sites. In the late June samples, yellow-brown algae dominated site 101, while blue-greens dominated at site 102 (Figure 21). As with George, Paine, and Garfield Lakes, Shell did not follow the typical progression from diatoms to greens to blue-greens.

Figure 21. Island Lake Algal Composition





Mercury samples were collected on Island Lake at site 101 in June (0.60 ng/l) and August (0.88 ng/l) of 2005. Levels above 1 ng/l are considered high, and if above 6.9 ng/l, the waterbody would be in violation of the water quality standard and therefore impaired. Both dates are well below the impairment threshold. It should be noted that in 1998, Island 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.

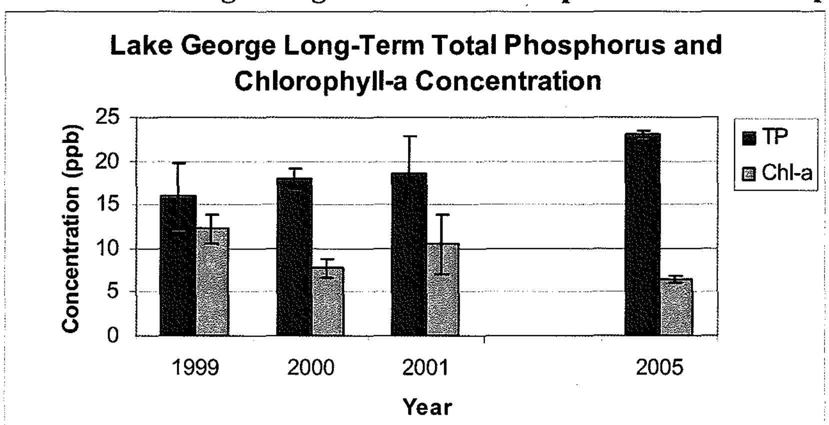
Water Quality Trends

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, providing additional data. For this report we will examine trends for Lake George and Garfield Lake, as these lakes meet the minimum of 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 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; whereby if the mean plus or minus the SE overlaps with another mean then it is likely the two means (measurements) are not significantly different.

Lake George

Four years of water chemistry data are available for analysis (June through September data was used in the analysis). Total phosphorus and chlorophyll-*a* data are available for four years from 1999 to 2005. The long-term average concentration is 19 µg/l for total phosphorus and 9.3 µg/l for chlorophyll-*a*, based on data from all sites over the period of record (Figure 22). These are both within the expected range for reference lakes in the NLF ecoregion (Table 5).

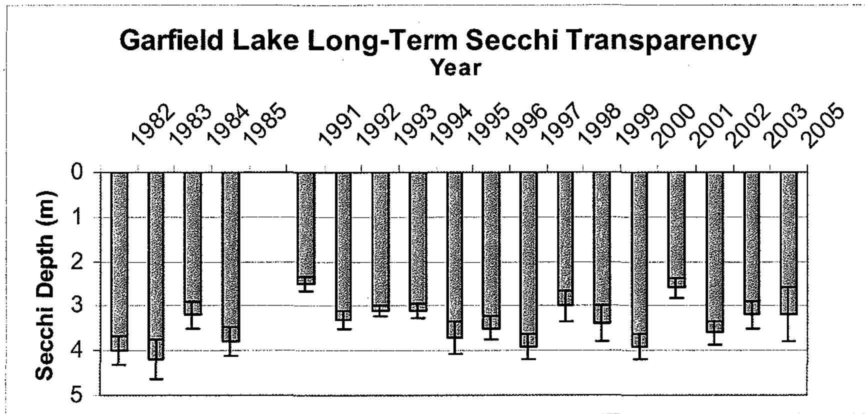
Figure 22. Lake George Long-Term Total Phosphorus and Chlorophyll-*a*



Garfield Lake

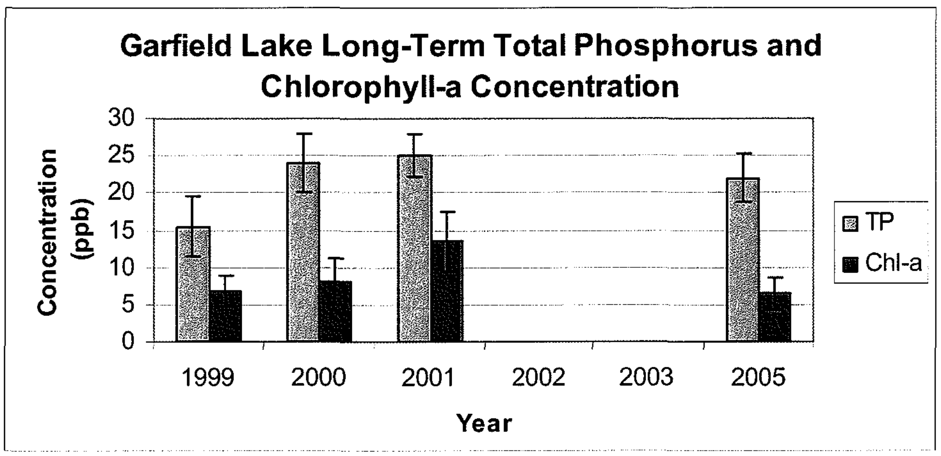
Eighteen years of Secchi transparency data and four years of water chemistry data are available for analysis (June through September data was used in the analysis). Based on statistics run as part of the Citizen Lake-Monitoring Program, no trend in transparency was evident on Garfield Lake. Secchi data was collected from 1982-1985 and then again from 1991 to 2005 (Figure 23). The long term average transparency was 3.4 meters (11.2 feet). This falls within the range of typical values for the NLF ecoregion.

Figure 23. Garfield Lake Long-Term Secchi Transparency



Total phosphorus and chlorophyll-*a* data are available for four years from 1999 to 2005. The long-term average concentration is 22 µg/l for total phosphorus and 8.7 µg/l for chlorophyll-*a*, based on data from all sites over the period of record (Figure 24). These are within the expected range for reference lakes in the NLF ecoregion (Table 5).

Figure 24. Garfield Lake Long-Term Total Phosphorus and Chlorophyll-*a*



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 Hubbard 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.

The lakes in this study are all located in the NLF ecoregion. The MINLEAP model was run using NLF 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 George and Garfield 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 of similar watershed size in the NLF ecoregion. However, in Island and Paine lakes, MINLEAP predicted significantly higher values. Island Lake has an extremely large upstream contributing watershed; water draining into the lake has already traveled through a number of lakes. Each lake acts as a sink for phosphorus, with the out flowing water carrying less phosphorus than the inflowing water. To account for this, the model was calibrated, reducing the inflow phosphorus to 35 µg/l, (a one-third reduction). Upon calibration, the model provides an estimate of TP, Chl-a, and Secchi that is more consistent with the observed measurements. The seasonal average for total phosphorus in Island Lake (29 µg/l) was very close to the 30 µg/l draft nutrient criteria for lakes in the NLF ecoregion (Table 1). This suggests the possibility that Island Lake could be included on a future impaired waters list should total phosphorus increase above levels noted in 2005; however further data would be needed to complete an aquatic use recreation assessment of the lake. Paine Lake's observed TP is much lower than the predicted. Given its shallowness and dominance of macrophytes (rooted vegetation), this lake is very difficult to model using MINLEAP. As noted previously, the Secchi disk was visible on the lake bottom on all occasions, further complicating the modeling.

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 Garfield Lake. The inverse is the case for Paine Lake, where observed chlorophyll-*a* is significantly lower than predicted, similar to the total phosphorus result (Table 6). Again, the dominance of macrophytes in Paine Lake would most likely explain the lower than expected chlorophyll-a values.

Trophic State Index

TSI Comparison

Comparisons of the individual TSI measures provides a basis for assessing the relationship among TP, Chl-*a* and Secchi for the lakes (Figure 25). The TSI values are in close correspondence with each other, with all lakes in the study being mesotrophic.

Paine Lake had a Chl-*a* TSI value quite low relative to TP. This suggests that Paine Lake has the potential for higher Chl-a based on TP, likely rooted plant growth is limiting algal production.

Secchi TSI's closely corresponded to TP TSI for Lake George in this study. Paine had lower than anticipated Secchi (based on TP); however, transparency was limited by the depth of the lake as the disk was still visible on the lake bottom (Figure 25). Therefore the Secchi TSI is not an accurate measure of trophic status for Paine Lake. Garfield and Island lakes had higher than expected Secchi values (based on TP). Both lakes had blue-green algae dominance in the later summer, specifically the algae Aphanizomenon, which allows greater light penetration than other algal types of the same concentration.

Lastly Ch-*a* and Secchi TSI were in good correspondences for most lakes (Figure 25). Paine had lower transparency (higher TSI) than anticipated. This is due to the fact that the Secchi measurements on Paine were all recorded as minimums (disk was visible on the bottom of the lake). Garfield Lake had higher transparency (lower TSI) than anticipated. This is likely due to the type of algae dominant in the later part of the summer, Aphanizomenon, which allows higher than expected light penetration (transparency) during algal blooms.

Goal Setting

The phosphorus criteria value for lakes in the Northern Lakes and Forests ecoregion is less than 30 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 over 85 percent of the summer.

For Island Lake, it would be desirable to reduce in-lake TP concentrations and for George, Paine, and Garfield, to maintain in-lake TP concentrations from 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. Island Lake was near the 30 μg/l total phosphorus criteria. It would be important to reduce as much external phosphorus loading to the lake as possible to maintain or reduce the current concentrations.

Recommendations

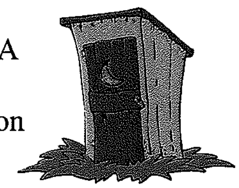
Following are a few general observations and recommendations based on analysis of data collected in 2005:

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 Hubbard 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. Only Garfield Lake had enough years of data for trend analysis. Paine Lake has never participated in CLMP, and George and Garfield Lakes are currently without volunteer monitors. 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 Hubbard County Soil and Water Conservation District (SWCD), and the Hubbard County Environmental Services Department could provide assistance in these areas.



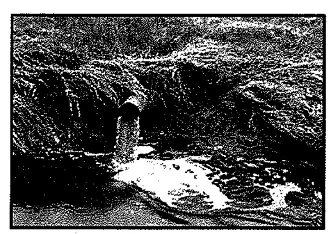
C. Further development in the immediate watershed of the lake should occur in a manner that minimizes water quality impacts on the lake. Consideration to setback provisions, lot size, and septic systems will be important in providing water quality protection. The DNR and county shoreland regulations 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 Hubbard 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 George, Paine, Garfield, and Island Lakes were good relative to other lakes in the NLF ecoregion. However, all of the lakes, especially Island, 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 Hubbard 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 Hubbard County SWCD, Hubbard County Environmental Services Department, 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 George Observed	Total Watershed MINLEAP
TP (μg/l)	23 ± 2.7	24 ± 7
chl-a (μg/l)	6.5 ± 2.1	6.8 ± 3.8
% chl-a > 20 μg/l	40	6
% chl-a > 30 μg/l	20	2
Secchi (m)	2.6 ± 0.4	2.6 ± 1.0
P-loading rate (kg/yr)	--	378
% P retention	--	57
P inflow conc. (μg/l)	--	56
water load (m/yr)	--	2.09
outflow volume (hm3/yr)	--	6.76
"background P"	--	26.2
residence time (years)	--	1.6

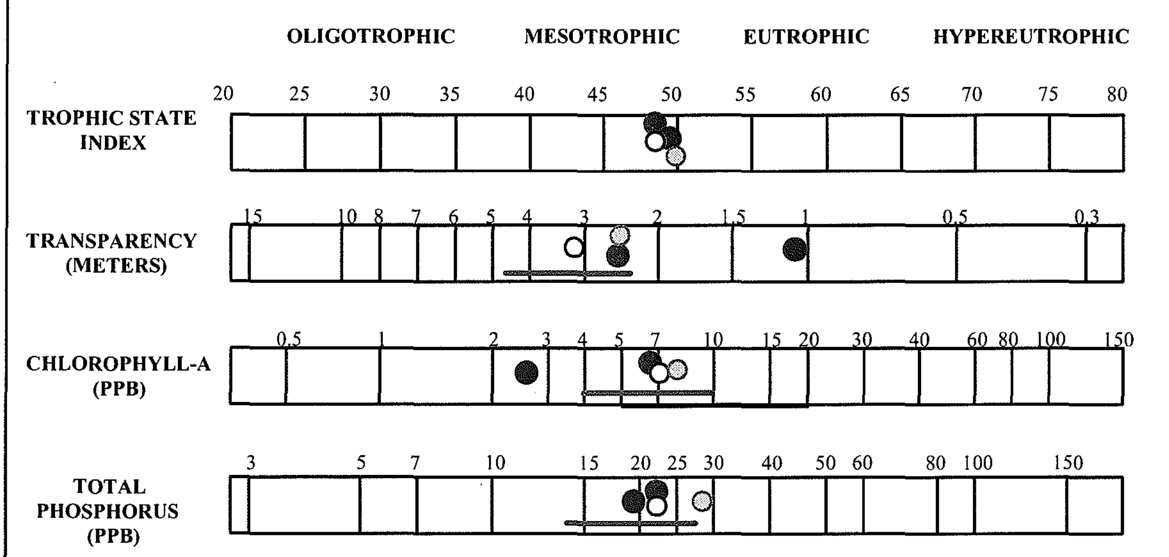
Parameter	2005 Paine Observed	Total Watershed MINLEAP
TP (μg/l)	19 ± 1.0	31 ± 8
chl-a (μg/l)	2.7 ± 0.4	10.2 ± 5.3
% chl-a > 20 μg/l	20	14
% chl-a > 30 μg/l	0	5
Secchi (m)	1.1 ± 0.1	2.0 ± 0.7
P-loading rate (kg/yr)	--	80
% P retention	--	46
P inflow conc. (μg/l)	--	58
water load (m/yr)	--	1.3
outflow volume (hm3/yr)	--	1.37
"background P"	--	39.1
residence time (years)	--	0.7

Parameter	2005 Garfield Observed	Total Watershed MINLEAP
TP (μg/l)	23 ± 3.7	18 ± 6
chl-a (μg/l)	7.2 ± 2.5	4.6 ± 2.8
% chl-a > 20 μg/l	0	2
% chl-a > 30 μg/l	0	1
Secchi (m)	3.2 ± 0.7	3.2 ± 1.3
P-loading rate (kg/yr)	--	226
% P retention	--	70
P inflow conc. (μg/l)	--	61
water load (m/yr)	--	0.94
outflow volume (hm3/yr)	--	3.72
"background P"	--	24.5
residence time (years)	--	4.3

Parameter	2005 Island Observed	Total Watershed MINLEAP
TP (μg/l)	29 ± 2.1	29 ± 6
chl-a (μg/l)	8.1 ± 1.5	8.8 ± 4.1
% chl-a > 20 μg/l	0	9
% chl-a > 30 μg/l	0	3
Secchi (m)	2.5 ± 0.3	2.1 ± 0.7
P-loading rate (kg/yr)	--	3,968
% P retention	--	19
P inflow conc. (μg/l)	--	35
water load (m/yr)	--	51.24
outflow volume (hm3/yr)	--	112.73
"background P"	--	25.4
residence time (years)	--	0.1

FIGURE 25. Carlson's Trophic State Index for Hubbard 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.



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NLF Ecoregion Range: George : ● Paine: ● Garfield: ○ Island: ◎

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

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Appendix D Surface water results

Lake Name	Lake ID	Date	Site	Sample Depth		TP	Chl-a	Secchi	TKN	Total Alk	Color	Cl	TSS	VSS
				Up	Lwr	ug/l	ug/l	m	mg/l	mg/l	PCU	mg/l	mg/l	mg/l
George	29-0216	6/1/2005	101	0	2	18	2.84	2.9	0.54	140	5		1.2	1.2
		6/1/2005	101	7	7	12								
		6/28/2005	101	0	2	18	2.86	3.8	0.56	150	5	2.1	2	1.6
		6/28/2005	101	7	7	19								
		7/20/2005	101	0	2	21	3.59	2.6	0.55	150	5	2	1.2	1.2
		7/20/2005	101	7	7	21								
		8/24/2005	101	0	2	26	10.6	1.8	0.62	140	5	2.5	4	3.6
		8/24/2005	101	6	6	25								
		9/22/2005	101	0	2	32	12.7	1.8	0.74	150	10	2.7	2.8	2.4
		9/22/2005	101	7	7	32								
Paine	29-0217	6/1/2005	101	0	1.4	18	2.84	>1.4	0.54	140	5	<1.0	1.2	1.2
		6/28/2005	101	0	1	22	2.59	>0.9	0.61	120	5		2	1.6
		7/20/2005	101	0	1	19	2.17	>0.9	0.72	130	10		2	1.6
		8/24/2005	101	0	1.1	16	1.8	>1.1	0.71	120	5	1.2		
		9/22/2005	101	0	1	18	3.99	>1	0.79	140	5	1.4	2.4	2
Garfield	29-0061	6/1/2005	102	0	2	12	1.51	-5.6	0.52	150	5	7.4	1.6	
		6/1/2005	102	8	8	14								
		6/28/2005	102	0	2	19	3.59	-3.75						
		6/28/2005	102	7	7	17								
		7/20/2005	102	0	2	21	4.65	-2.5	0.62	140	10	7.4	1.6	1.2
		7/20/2005	102	8	8	23								
		8/24/2005	102	0	2	33	15.2	-1.6	0.61	130	5	7.9	4.4	3.6
		8/24/2005	102	7	7	32								
		9/22/2005	102	0	2	29	10.8	-2.3	0.68	140	10	8.2	2	1.6
		9/22/2005	102	7	7	54								

Lake Name	Lake ID	Date	Site	Sample Depth		TP	Chl-a	Secchi	TKN	Total Alk	Color	Cl	TSS	VSS
				Up	Lwr	µg/l	µg/l	m	mg/l	mg/l	PCU	mg/l	mg/l	mg/l
Garfield	29-0061	6/22/1999	100	0	2	17	3	7						
		7/21/1999	100	0	2	15	4	1.8						
		8/24/1999	100	0	2	25	12	2.3						
		9/22/1999	100	0	2	5	8	2.9						
		6/22/2000	100	0	2	17	4	4.3						
		7/24/2000	100	0	2	22	4	3.7						
		8/22/2000	100	0	2	35	17	3.1						
		9/14/2000	100	0	2	22	7	3.2						
		6/21/2001	100	0	2	22	8	3.4						
		7/19/2001	100	0	2	20	6	1.8						
		8/22/2001	100	0	2	33	23	1.5						
		9/19/2001	100	0	2	25	17	2.1						
Island	29-0254	6/1/2005	101	0	2	19	2.79	3.3	0.43	200	20	2.4		
		6/1/2005	101	18	18	31								
		6/1/2005	102	0	2	25	3.05	4.1	0.43	200	10	2.5	1.2	1.2
		6/1/2005	102	10.5	10.5	47								
		6/28/2005	101	0	2	27	7.84	2.5	0.51	190	20	1.9	2	1.6
		6/28/2005	101	19	19	52								
		6/28/2005	102	0	2	26	7.67	2.5						
		6/28/2005	102	11	11	186								
		7/20/2005	101	0	2	28	11.9	2.2	0.6	190	20	1.9	2.8	2
		7/20/2005	101	18.5	18.5	113								
		7/20/2005	102	0	2	28	10.2	2.1						
		7/20/2005	102	7.5	7.5	52								
		8/23/2005	101	0	2	28	10.7	2.1	0.62	180	20	2.6	3.6	3.2
		8/23/2005	101	18	18	155								
		8/23/2005	102	0	2	36	10.7	2.1						
		8/23/2005	102	11	11	577								
		9/21/2005	101	0	2	31	11.3	1.9	0.71	200	20	3.6	3.3	2.7
		9/21/2005	101	17	17	238								
		9/21/2005	102	0	2	33	5.09	1.9						
		9/21/2005	102	9.5	9.5	197								