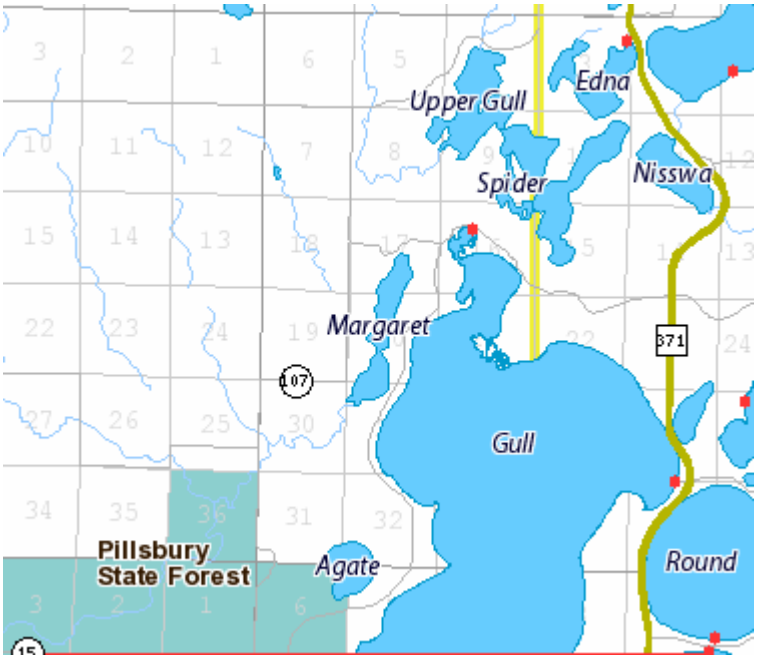
LAKE ASSESSMENT PROGRAM

Margaret Lake: #11-0222

1994

Cass County, Minnesota



Minnesota Pollution Control Agency

Environmental Analysis and Outcomes Division

AUGUST 2005

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August 2005

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

LIST OF FIGURES

SUMMARY AND RECOMMENDATIONS

Margaret Lake is located near Lake Shore, MN in Cass County. This lake has a surface area of 222 acres and a maximum depth of 26 feet. Mean depth of the lake is 10.5 feet. The total watershed of Margaret Lake is approximately 45,203 acres (including the lake surface area and all upstream tributaries). Land use in the watershed was estimated to be forested (55 percent), open water/wetland (25 percent), grassland/pasture (18 percent), cultivated (1 percent), and residential/urban areas (the remaining 1 percent). These land use percentages are somewhat typical of what would be expected for lake watersheds in the Northern Lakes and Forests (NLF) ecoregion of the state.

Margaret Lake was sampled during the summer of 1994 by Minnesota Pollution Control Agency (MPCA) staff and Gull Area Lakes Association (GALA) members. Water quality data collected during the study revealed a summer-mean total phosphorus concentration of 65 µg/l, chlorophyll-*a* concentration of 53 µg/l, and a Secchi transparency of 3.8 feet. All three of these values are well outside the typical range exhibited by reference lakes in the NLF ecoregion. Total phosphorus, chlorophyll-*a*, and Secchi transparency all help to characterize the trophic status of a lake. For Margaret Lake, these measures indicate *eutrophic to hypereutrophic* conditions.

A historical database is available for assessing trends in the transparency of Margaret Lake. Citizen Lake-Monitoring Program (CLMP) Secchi transparency data had good coverage from 1987 to present. This monitoring revealed some minor annual fluctuations in transparency. During this period, the summer-mean annual Secchi ranged from a low of 3.6 feet in 1988 and to a high of 5.8 feet in 2003. Transparency varies from year to year but a long-term improving trend was evident based on analysis of Secchi transparency data in 2004.

Two water quality models were used to estimate the water quality of Margaret Lake based on morphometry and watershed characteristics. The MINLEAP water quality model and the Vighi and Chiaudani regression model both provide a means to compare the measured water quality of the lake relative to the predicted water quality.

MINLEAP predicted summer-mean total phosphorus (TP) concentration of 42 µg/l, which is far less than the observed summer-mean of 65 µg/l in 1994. The chlorophyll-*a* prediction was also considerably below the observed summer-mean for Margaret Lake, with MINLEAP predicting 16 µg/l (53 µg/l observed). Estimated residence time for the lake (time it would take for the lake to fill if it were empty) is 0.1 years.

The following recommendations are based on the 1994 Lake Assessment Program (LAP) study of Margaret Lake:

1. Margaret Lake is sensitive to a change in trophic status because it already has relatively high total phosphorus and chlorophyll-*a* concentrations. 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 further degrade the lake. It is essential, therefore, that lake protection efforts be conveyed to all local government groups with land use/zoning authorities for Cass County.

The Gull Area Lakes Association should be commended for their efforts to date, which include participating in area lake water quality monitoring, participated in septic system surveys on area lakes and participation in the CLMP.

The Association should develop a plan for protecting the water quality of the lake. This plan, referred to as a lake management plan, incorporates 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 with assistance from representatives from state agencies (e.g., BWSR, MPCA, MDNR), local units of government (SWCD), and 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:

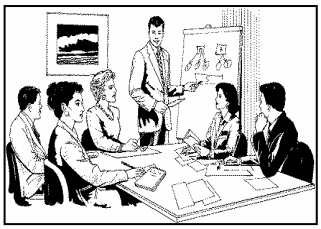
a. The Association should continue to participate in the CLMP. Data from this program provides an excellent basis for assessing long-term and year-to-year variations in algal productivity, i.e., trophic status of the lake. At a minimum, measurements should be taken weekly during the summer at consistent sites. Sites 203 and 204 are the most valuable for long-term characterization of the transparency of the lake.

b. The continued education of homeowners around the lake, with respect to septic system, lawn maintenance, and shoreline protection may be beneficial. Staff from the MPCA and the Minnesota Department of Natural Resources (MDNR), along with the county officials, such as staff from Minnesota Extension Service, the Cass County Soil and Water Conservation District and the Cass County Environmental Services Offices 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 MDNR and county shoreland regulations will be important in these regards and should be strictly enforced. The Association should also explore 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 immediate watershed.

d. Maintenance of shoreline vegetation (both upland and aquatic) is very important. Soil erosion from the construction of roads and homes should be minimized. The disturbance or the removal of vegetation on bluffs or slopes should be avoided.

e. The Association should continue to seek representation on boards or commissions that address land management activities so that their impact can be minimized. Safeguarding the shoreland ordinance from those who would choose to weaken it should be a priority for Margaret Lake as well as other lake associations in Cass 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. The Association is encouraged to be aware of the 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. As these activities occur within the watershed, the Association is 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 above may be of help in this regard.

2. The 1994 water quality of Margaret Lake was poor relative to other lakes in the NLF ecoregion. Recognition of this led to a CWP application in 1995. A Phase I diagnostic study was completed (a separate report will be prepared on that study); however no implementation was conducted. And as of 2004, the water quality remains poor.

   Lake Margaret was included in the 2006 303(d) (impaired waters) assessment. Based on available data, collected between 1995 – 2004 its trophic status values were as follows: TP = 49 μg/l (n = 52), chl-a = 32.4 μg/l (n = 49) and Secchi = 1.5 m (n = 127). All three of these values exceeded the thresholds for listing and Margaret was placed on the draft 2006 303(d) list that will be submitted to USEPA. As a part of that listing, a schedule for developing a TMDL (total maximum daily load) for Lake Margaret will be included. Details on the TMDL program may be found on MPCA's website at: http://www.pca.state.mn.us/water/tmdl/index.html.

LAKE ASSESSMENT PROGRAM: Margaret Lake 1994

INTRODUCTION

Margaret Lake was sampled by the Minnesota Pollution Control Agency (MPCA) during the summer of 1994 as a part of the Lake Assessment Program (LAP). This program is designed to assist lake associations or municipalities in the collection and analysis of baseline water quality data in order to assess the trophic status of their lakes. The general work plan for LAP includes Association participation in the Citizen Lake-Monitoring Program (CLMP), cooperative examination of land use and drainage patterns in the watershed of the lake, and an assessment of the data by MPCA staff.

Margaret Lake was sampled on five occasions during the summer and fall of 1994 by Jim Hodgson from the MPCA with assistance from Association members Bill Ewing and Dory Meech. Historical information was provided by the Association. Lake level and fisheries information were provided by the Minnesota Department of Natural Resources.

This study was conducted at the request of the Association, whose members are interested in identifying sources of pollution to the lake, characterizing the quality of the lake, and developing a program to assist in lake management. Nineteen years of data were available for Margaret Lake from the CLMP. Historical data provides a basis for assessing year-to-year fluctuations in the quality of Margaret Lake.

BACKGROUND

Margaret Lake is located near Lake Shore, Minnesota in Cass County. It has a surface area of 222 acres and a maximum depth of 26 feet. The total watershed of Margaret Lake is 45,203 acres, which results in a 203:1 watershed:lake ratio. This implies that water runoff and nutrient loading to the lake may be high relative to the size of the lake.

Margaret Lake has two inlets and one outlet. Home Brook, the main tributary, flows into Margaret Lake in the southern end, and an unnamed, intermittent, tributary flows into the lake on the west side. Margaret Lake drains into Upper Gull Lake from the northern end.

Margaret Lake was likely formed by an ice block basin in the St. Croix morainic system in the Patrician Sheet of the middle Wisconsin Glaciation (Zumberge, 1952). Soils near the lake consist of the Flak-Brainerd-Nokay series. This area is mostly consisting of gently rolling terrain with long slopes and moderately to well drained soils. Depressions tend to be poorly drained. Soils are light colored and formed from noncalcareous sandy loam glacial till (Arneman 1963).

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally-impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Margaret Lake is in the Northern Lakes and Forests Ecoregion (Figure 2).

Land Use

Land use data was estimated from the 1995-1996 LANDSAT imagery obtained through the MDNR. The land uses observed in the watershed of Margaret Lake are somewhat representative of a lake in the NLF ecoregion (Table 1). Forested land accounts for about 55 percent of the land use in this watershed. Open water/wetland land uses account for 25 percent of the land use. Grassland and pasture make up approximately 18 percent of the land use, which is high for a lake in the NLF ecoregion. The rest of the watershed is a mix of cultivated and residential land uses (Figure 4).

Precipitation

Based on State Climatology records, precipitation averages 26 inches (0.66 meters) annually in this part of the state. Precipitation near Margaret Lake was normal in 1994, with 26-30 inches of precipitation recorded (Appendix II). Site-specific data for this area noted several events in summer 1994 where one inch of rain or more fell in the area in one day – June 25 (1.00 in), June 26 (1.06 in), August 3 (1.03 in) and September 15 (1.08 in). There were also three multiple day events in 1994 over June 15 to 18 (1.54 in), July 19 to July 22 (1.77 in) and from August 7 to 8 (1.17 in). Evaporation typically exceeds precipitation in this region of the state and averages about 34 inches (0.86 m) per year. Runoff averages for this area are about 6 inches with 1 in 10 year low and high values (low and high runoff values which might occur once in ten years) of 2 inches and 7.9 inches, respectively (Gunard, 1985).

Fisheries

DNR fisheries managers utilize netting survey information to assess the well-being of fish communities and measure the efficacy of management programs. Presence, absence, abundance, physical condition of captured fishes, and community relationships among fish species within survey catch information also provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). This long term fisheries survey database has also proven valuable in qualifying and quantifying changes in environmental and fisheries characteristics over time. This fishery of Margaret Lake is managed by the Minnesota Department of Natural Resources Fisheries Office located in Brainerd, Minnesota. A summary of Margaret Lake's fishery as surveyed by the MDNR on June 25, 2001 is available in Appendix III of this report or a current report can be found at www.dnr.state.mn.us.

Lake Survey

MDNR completed a lake survey in 1991. Past management includes the stocking (1973) and removal (1969) of various fish species. Lakeshore development is high and aquatic plants management and Division of Waters permits are important tools which can be used to minimize degradation of important fish habitat. Marshy areas at the mouth of Home Brook provide spawning habitat for northern pike. Bulrush beds are important for bass and pan fish spawning. Home Brook is a major tributary and is both a potential source of nutrient enrichment and a known spawning area for walleyes.

History

From information furnished by the lake association, the Gull Lake Chain experienced early development pressure as the area is well known as a vacation and resort destination. Margaret Lake developed slower than surrounding lakes, with no seasonal or permanent dwellings by 1967. This is likely due to the lake's small size. However, by 1982, 12 seasonal and 6 permanent dwellings had been built on Lake Margaret.

Figure 1. Margaret Lake Watershed

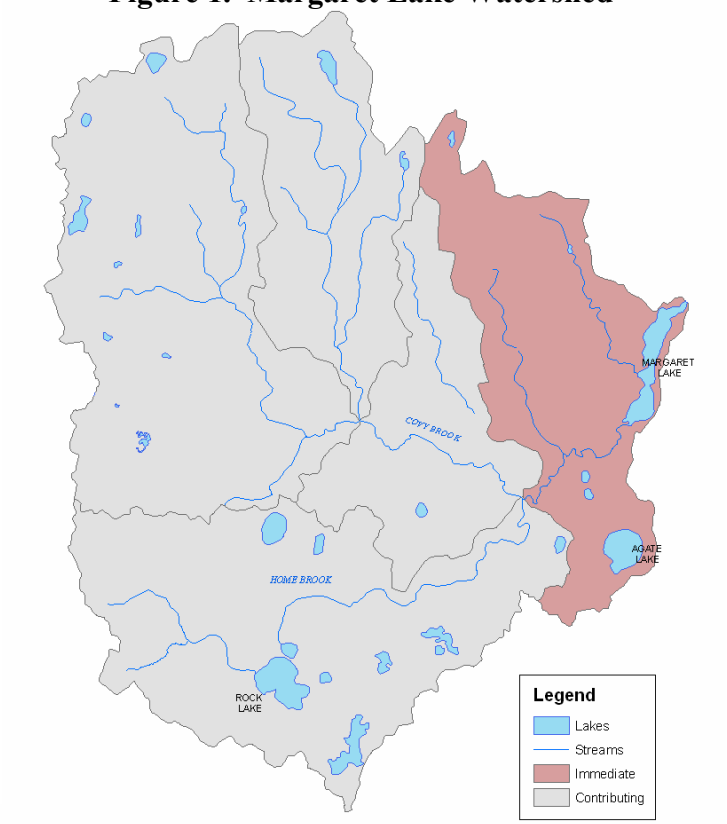


Figure 2. Margaret Lake Location Ecoregion Map

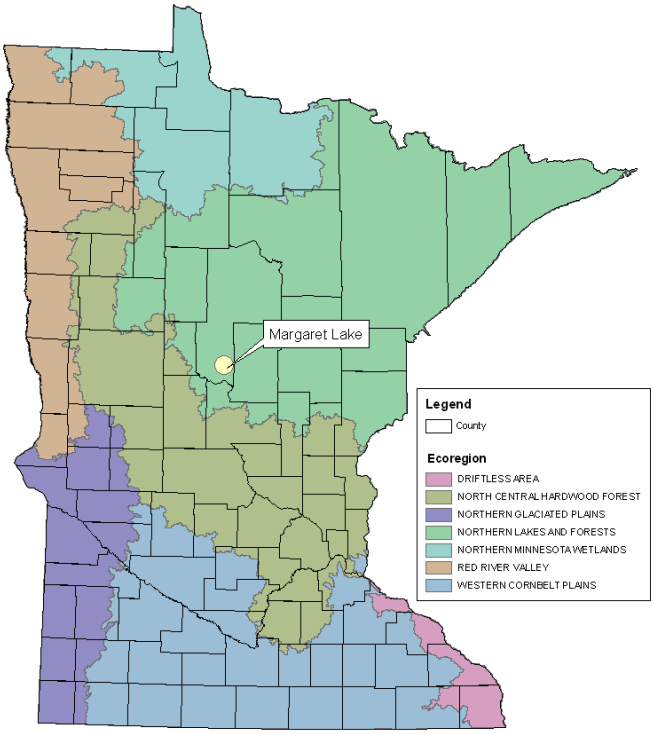


Figure 3. Margaret Lake Bathymetric Map and Monitoring Locations

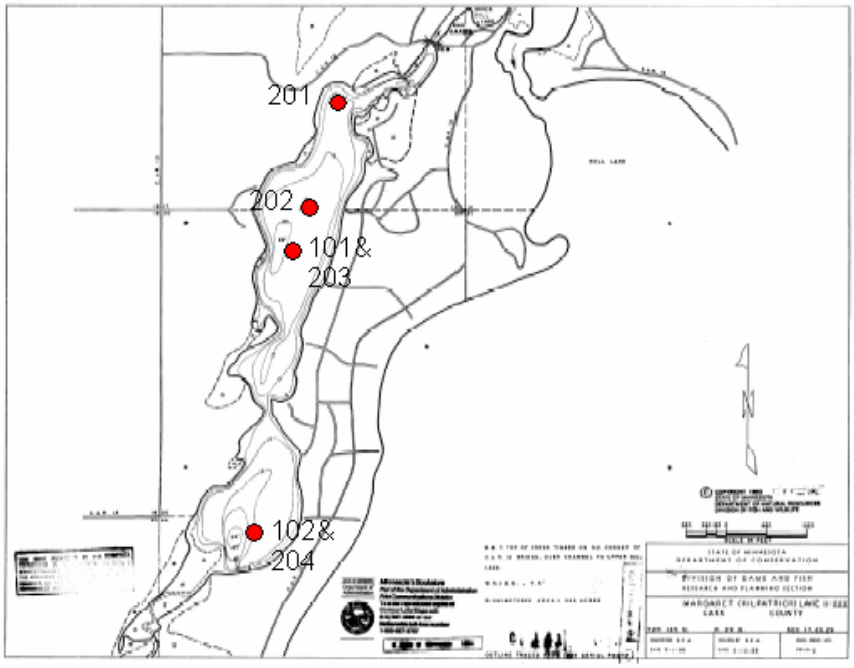


Figure 4. Margaret Lake Watershed Land Use

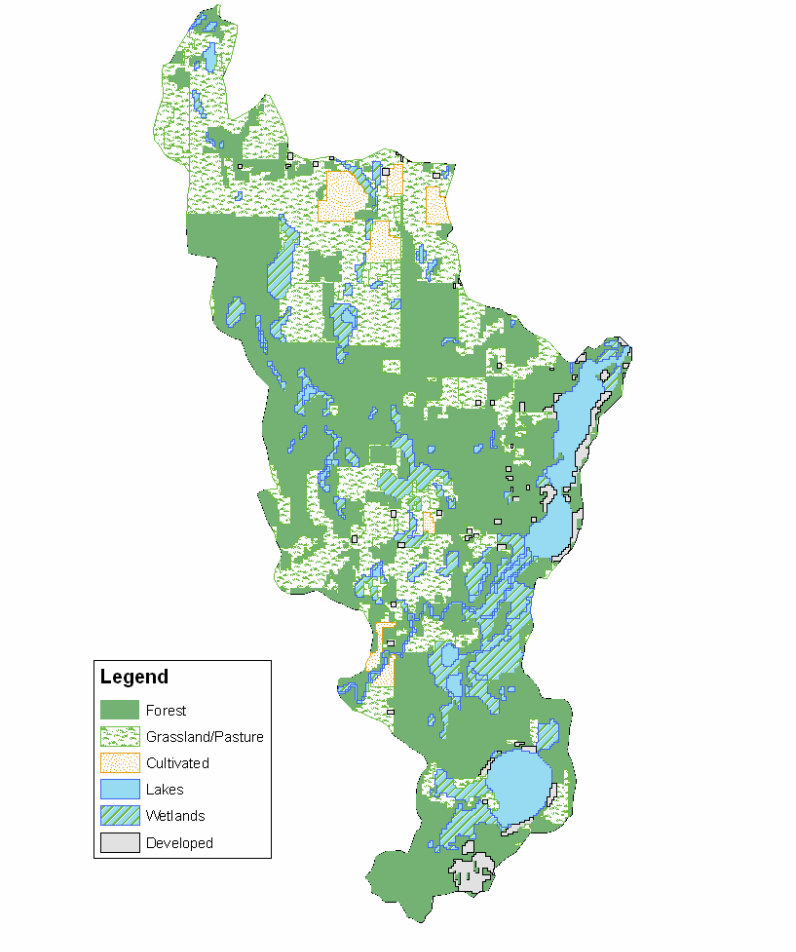


TABLE 1. Margaret Lake (11-0222): Morphometric, Watershed, and Fishery Characteristics

Area[1]: 222 acres (0.35 mi^2) (90 ha)

Mean Depth[2]: 10.5 feet (3.2 m)

Maximum Depth: 26 feet (7.9 m)

Volume: 2,322 acre-feet (2.9 hm^3)

Littoral area[1]: 64 acres (29 %)

Watershed Area[3]: 7,418 acres (11.6 mi^2) (3,002 ha) immediate watershed, includes lake
7,196 acres (11.2 mi^2) (2,918 ha) immediate watershed, excludes lake
45,203 acres (70.6 mi^2) (18,293 ha) total watershed, includes lake
44,981 acres (70.2 mi^2) (18,203 ha) total watershed, excludes lake

Contributing Watershed Area: Lake Surface Ratio: ~ 32:1

Total Watershed Area: Lake Surface Ratio: ~ 203:1

Estimated Average Water Residence Time: ~ 0.1 years

Fisheries[1] – Schupp's Lake class: 31

Public Access[1]: 1 – via Gull Lake Channel **Inlets[2]: 2** **Outlets[2]:** 1

Land Use	Forest	Wetlands or water	Pasture or grassland	Cultivated	Urban
[4]Margaret Lake (%)	55	25	18	1	1
NLF Ecoregion (%)	54 - 81	14 - 31	0 - 6	0 - 1	0 - 7

Source:
[1] MN Department of Natural Resources [2] MN Pollution Control Agency
[3] United States Geological Survey [4] LANDSAT Images 1995-1996 (MDNR)

Septic System Survey

Minnesota Extension Service recommends pumping every one to three years for a 1,000 gallon tank serving a three-bedroom house and four occupants (assumes year-round use). The importance of septic system maintenance to Margaret Lake should be emphasized to all lake residents. The Association is encouraged to look into developing a program which encourages or arranges for the periodic pumping of septic tanks. The Association should inform its membership that poor septic system maintenance can lead to the contamination of shallow wells.

Lakeshore residents are encouraged to locate on their property an alternative drain field site. This site should be picked with the necessary setbacks in mind and should be protected for the time when it will be needed in the future when the existing drain field begins to fail. This is especially crucial for small lots where there may only be one good alternative drain field site available. Drain fields typically have a design lifetime of 20 to 30 years. Keep in mind that proper maintenance of the septic tank (regular pumping), protecting the drain field from compaction (keep vehicles and other heavy objects off), and water conservation in the home will all help to extend the useful lifetime of the drain field.

The City of Lake Shore Planning and Zoning Department indicated that all but two systems on Margaret Lake are either hooked up to the City's central sewer system or have conforming systems. At that time, the two non-conforming systems were being pursued by the City Attorney. The City of Lake Shore has an aggressive program requiring septic upgrades.

Lake Level

Margaret Lake does not have a record of lake level measurement. Being of the same elevation and sharing a channel with Gull Lake, lake level information is assumed to be the same for both lakes for the purpose of this report. During normal conditions, the Gull Lake dam controls the level for the entire Gull Lake Chain. A summary of lake level information was drawn from the MDNR website: Gull Lake levels have been monitored since September 30, 1981. The highest recorded level was 1194.57 ft on October 5, 1995; the lowest recorded level was 1192.58 ft on April 2, 1996. The average lake level for the period of record is 1193.7 ft with a range of 1.99 ft. A summary of records for the most recent ten years can be found in Appendix IV.

RESULTS AND DISCUSSION

Water quality data was collected on May 16, June 27, July 27, August 23, and September 20, 1994. May data were not included in the analysis. Two sites were used: Sites 101 and 102 (Figure 3). 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).

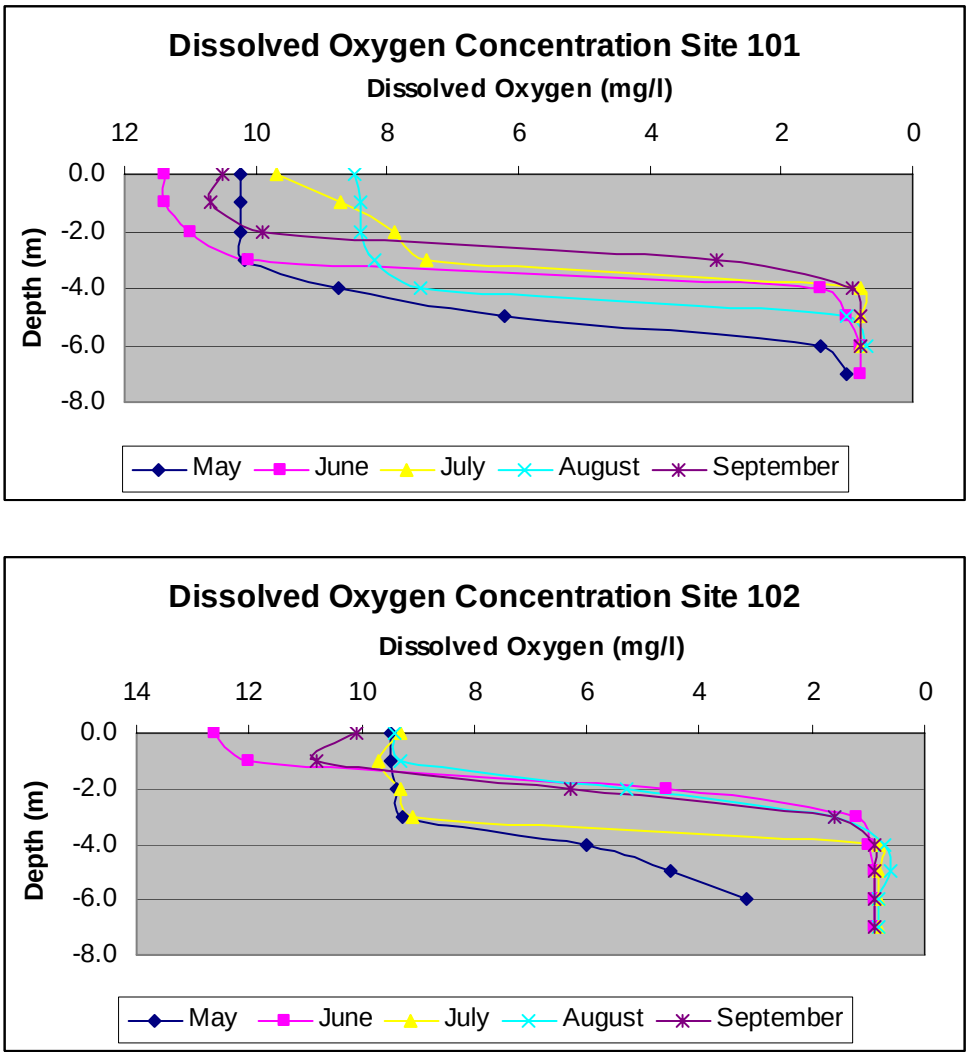
Sampling procedures were employed as described in the MPCA Quality Control Manual. Laboratory analyses were performed by the laboratory of the Minnesota Department of Health using U.S. Environmental Protection Agency (EPA) approved methods. Samples were analyzed for nutrients, color, solids, alkalinity, chloride and chlorophyll-*a* (Table 2). Temperature and dissolved oxygen profiles and Secchi transparency measurements were also taken. CLMP measurements from previous years were available for comparison. All MPCA data is 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 Guide to Lake Protection and Management (available at: http://www.pca.state.mn.us/water/lakeprotection.html).

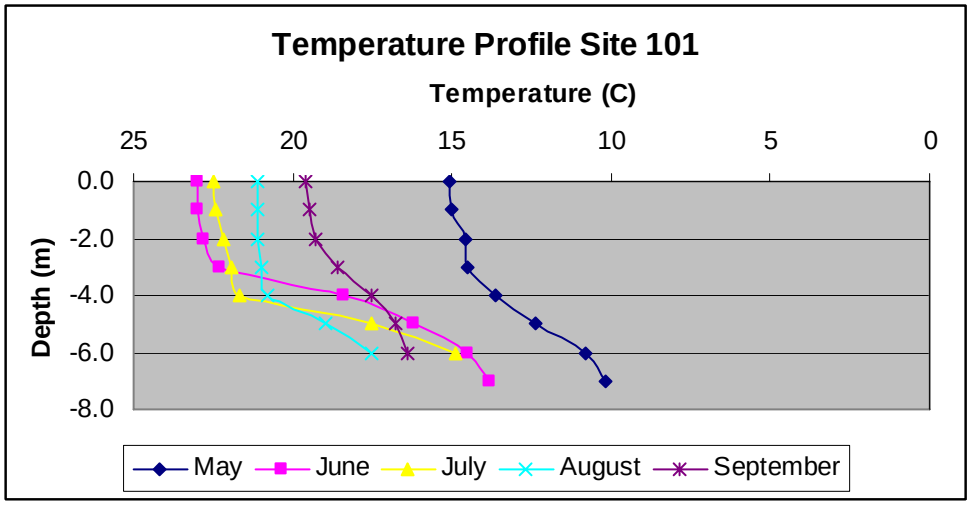
In-lake Conditions: 1994

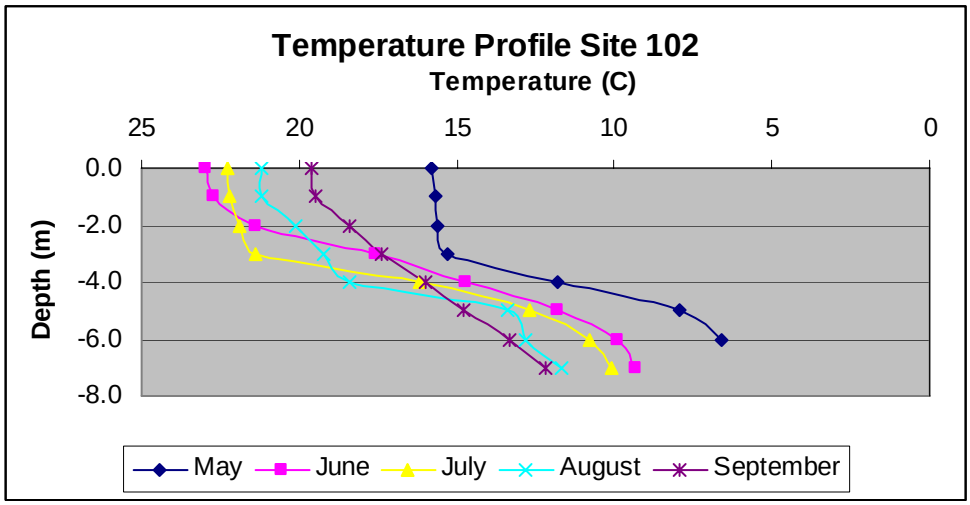
Dissolved oxygen (DO) and temperature profiles were taken at a point near maximum depth at sites 101 and 102 during May, June, July, August, and September monitoring trips. A thermocline (zone of rapid temperature change) was evident at a depth of 4 meters (Figure 5). Dissolved oxygen concentrations declined markedly between a depth of 2 and 4 meters. The dissolved oxygen remained above 5 mg/l (DO levels of 5 mg/l or greater preferred for game fish) in the upper layer (epilimnion) of the lake, but below a depth of 2-4 meters, the dissolved oxygen dropped below 5

mg/l. Dissolved oxygen concentrations of 5 mg/l or greater is preferred for game fish. Based on these temperature and dissolved oxygen profiles, Margaret Lake would be considered dimictic (mixes twice, once in spring following ice-out and fall as temperature declines, allowing for wind mixing).

Figure 5. Margaret Lake Temperature and Dissolved Oxygen Profiles





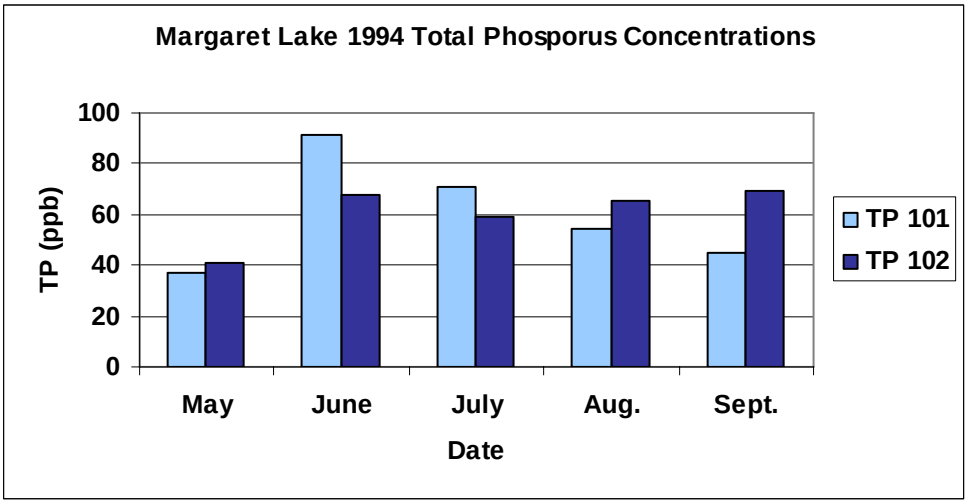


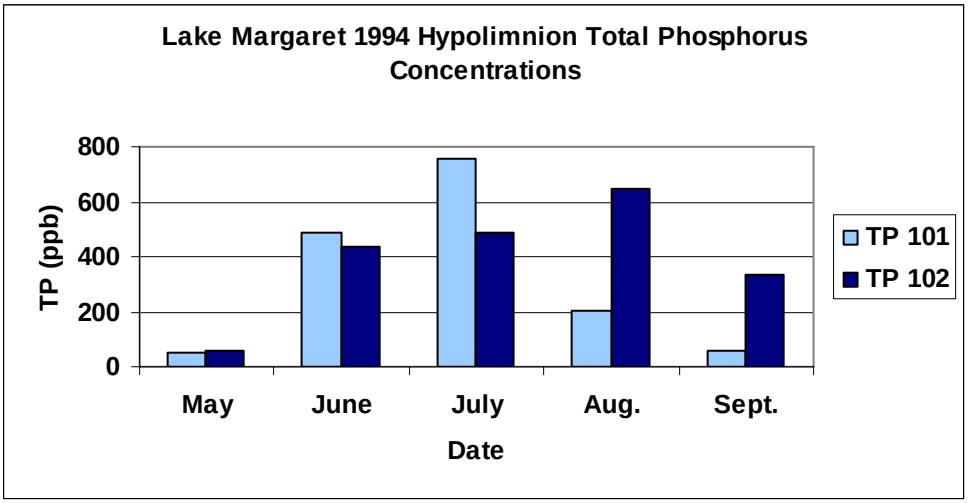
Total phosphorus (TP) concentration (an important nutrient for plant growth) averaged 65 µg/l (micrograms per liter or parts per billion) in the epilimnion during the summer of 1994. This value is more than double the range of concentrations typically found in reference lakes in the Northern Lakes and Forests ecoregion (Figure 6a and Table 2). TP decreased from June to September based on MPCA data from site 101; however, at site 102 the TP concentration remained relatively constant across the same time period (Figure 6a). A two day rain event immediately preceding the June sample may account for the slightly elevated total phosphorus concentration on that date. The pattern of declining TP concentrations from spring through summer is consistent with other stratified lakes.

Hypolimnetic phosphorus concentrations were measured 1 meter above the bottom of Margaret Lake during the 1994 sampling season. If conditions become anoxic (little or no oxygen present), phosphorus may be released into the water column from the sediment. While the lake is stratified, the phosphorus released generally remains in the hypolimnion (bottom of the lake). However, when the lake 'turns over' or destratifies in the spring and fall, this phosphorus can mix throughout the water column, and become available for plant use. Margaret Lake had extremely high levels of

phosphorus in the hypolimnion, with a maximum concentration of 758 µg/l measured in July (Figure 6b). Based on these data there appeared to be minimal mixing between surface and bottom water until September, when hypolimnetic phosphorus declined and epilimnetic phosphorus increased.

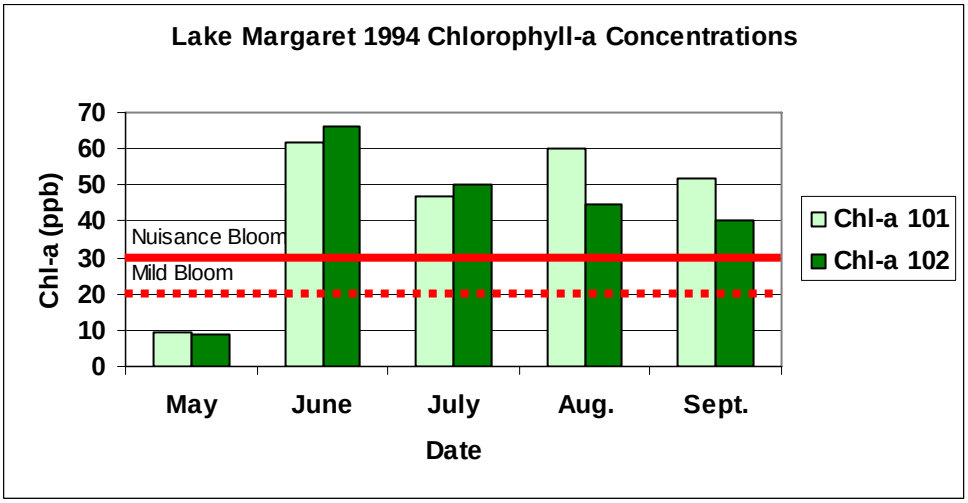
Figure 6a & b. Margaret Lake 1994 Epilimnetic Total Phosphorus and Hypolimnetic Phosphorus Concentrations





Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During the summer of 1994, chlorophyll-*a* concentrations ranged from 9 – 66 µg/l with an average of 52.7 µg/l. Both the average and maximum chlorophyll-*a* concentrations for Margaret Lake are well above the range of values for reference lakes from the NLF ecoregion. Concentrations from 10-20 µg/l are frequently perceived as a mild algal bloom, while concentrations greater than 30 µg/l may be perceived as a severe nuisance (Heiskary and Walker, 1988). Based on these data (Figure 7) nuisance blooms were common in Lake Margaret during summer of 1994 and severe algae blooms likely occurred. It should be noted that significant rainfall occurred the two days prior to the June sampling date. This may explain the elevated chlorophyll-*a* concentration on that date.

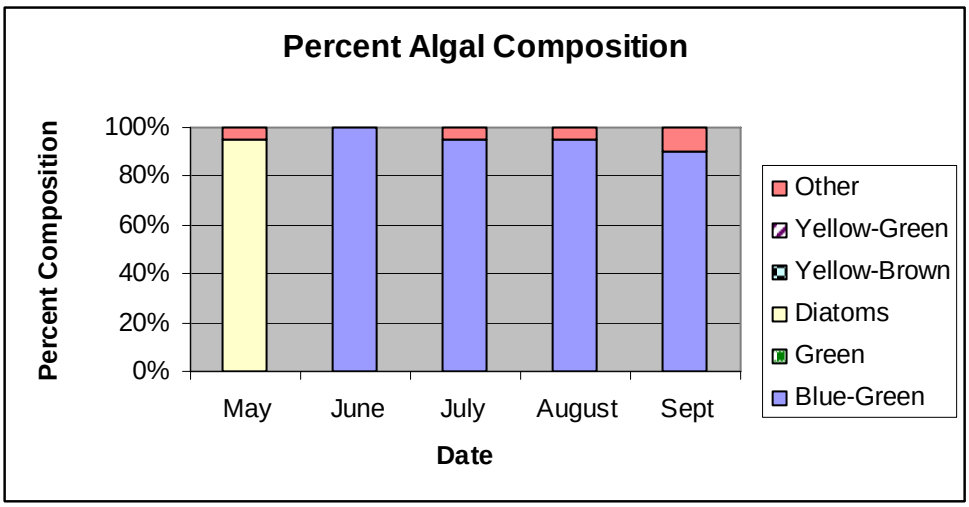
Figure 7. Margaret Lake 1994 Chlorophyll-*a* Concentrations



Algal Composition

The composition of the phytoplankton (algae) population of Margaret Lake is presented in Figure 8. Data are presented in terms of algal type. Samples were collected at Site 101. Diatoms were present and dominant in only the May sample. Blue-green algae were dominant for the remainder of the summer (June to September). July – September up to 10% of the alga species were composed of dinoflagellates. Bloom conditions (>10 µg/l chlorophyll-*a*) were evident on all sampling events during the summer of 1994, except for in May, based on the samples collected. Nuisance blooms (>20 µg/l chlorophyll-*a*) were noted for Margaret Lake in 1994 based on samples collected in June through September. A seasonal transition in algal types from diatoms to greens to blue-green is typical for mesotrophic and eutrophic lakes in Minnesota. However, in Lake Margaret, the blue-green alga's dominance established itself earlier than is typical. This is suggestive of excessive nutrients in the system.

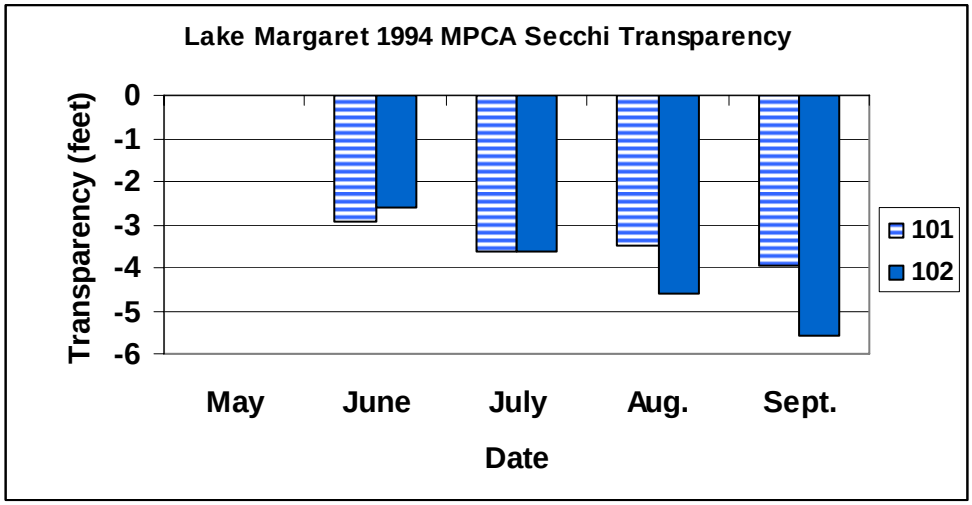
Figure 8. Percent Algal Composition of Margaret Lake at Site 101

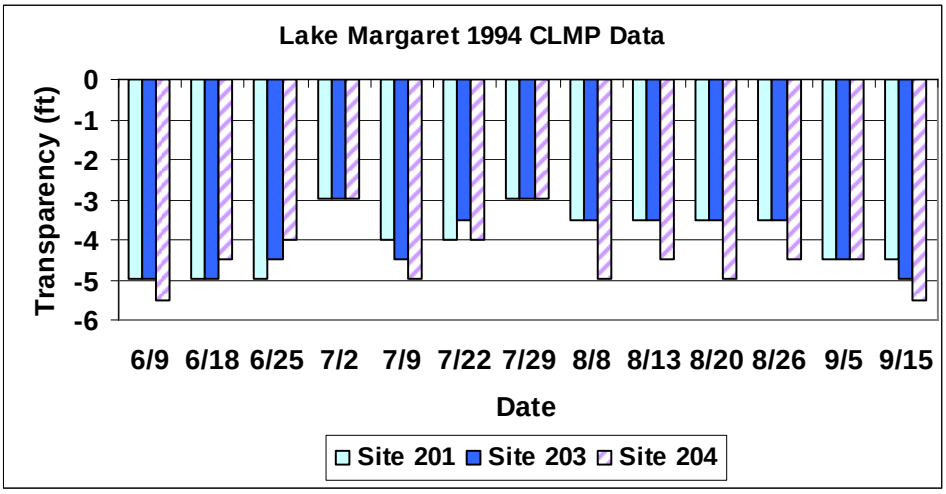


Secchi disk transparency is generally a function of the amount of algae in the water. Suspended sediments or color due to dissolved organics may also reduce water transparency. Color averaged 36 Pt-Co units and total suspended solids averaged 7.5 mg/l. Both are slightly higher than the reference lakes in this region. This level of color could be observed as a mild tea-color stain (color > 20 Pt-Co units). Secchi transparency ranged from 2.6 – 5.6 feet and averaged 3.8 feet during the summer of 1994 (Figure 9a & b). These transparency measures are below the typical range of values (8 – 15 feet) for reference lakes in this ecoregion (Table 2). Long-term monitoring of Secchi transparency at a consistent site will yield the best data for performing water quality trend analysis.

The change in the transparency of Margaret Lake over the course of the summer is not typical for 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 (Figure 7). As 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. For Margaret Lake in 1994, the pattern may be a function of the dominance of blue-green algae late in the summer. Aphanizomenon was the dominant algal form in the June, August, and September samples. This type of algae resembles grass clippings, and is easily dispersed by wind. This allows for increased transparency readings even during bloom conditions. On a day-to-day basis, transparency may differ between the sites, but the overall pattern was consistent among the two MPCA sites (Figure 9a) and three CLMP sites (Figure 9b).

Figure 9a & b. Margaret Lake 1994 Secchi Transparency





One means to evaluate the **trophic status** of a lake and to interpret the relationship between total phosphorus, chlorophyll-*a* and Secchi transparency is Carlson's Trophic State Index (TSI, Carlson 1977). This index was developed from the interrelationships of summer Secchi transparency and the concentrations of surface water chlorophyll-*a* and total phosphorus. TSI values are calculated as follows:

Total phosphorus TSI (TSIP) = 14.42 1n (TP) + 4.15
Chlorophyll-*a* TSI (TSIC) = 9.91 1n (Chl-*a*) + 30.6
Secchi disk TSI (TSIS) = 60 - 14.41 1n (SD)

TP and chlorophyll-*a* are in µg/l and Secchi transparency is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of 10 units represents a doubling of algal biomass. Average values for the trophic variables in Margaret Lake and respective TSI's are presented in Table 2. Based on these values, Margaret Lake is considered eutrophic to hypereutrophic in condition (Figure 13). The individual TSI values agree fairly well and therefore Secchi transparency should be a good predictor for overall water quality for Margaret Lake.

Water Quality Trends

Nineteen years of Secchi data are available for determining trends in the quality of Margaret Lake from the Citizen Lake-Monitoring Program (CLMP). These data reveal a slight increase in transparency over time based on data through 2004. Summer-mean transparency varies between about 3.6 feet and 5.8 feet and long-term mean transparency is 4.7 feet (Figure 10). The year-to-year fluctuations in transparency may be related to differences in the amount of precipitation, runoff, and groundwater which enter the lake. This amount of variability (23% of long-term mean) is rather typical for Minnesota lakes.

FIGURE 10. Margaret Lake Long-Term Secchi Transparency

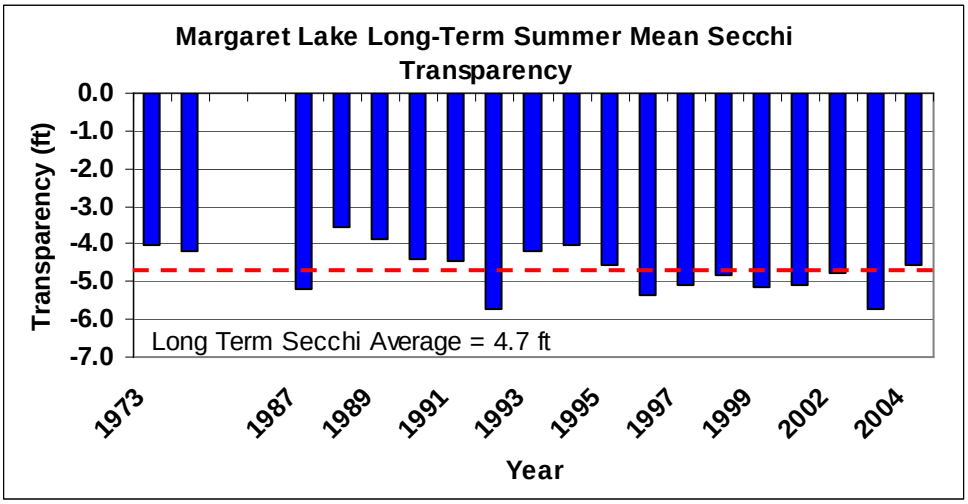


TABLE 2: Average Summer Water Quality and Trophic Status Indicators: Margaret Lake based on 1994 Epilimnetic Data.

Parameter	Mean	Typical Range for NLF Ecoregion[1]
Total Phosphorus µg/l	65	14 – 27
Chlorophyll-*a* (µg/l) Mean Chlorophyll-*a* (µg/l) Maximum	53 66	< 10 < 15
Secchi disk (meters)	1.2	2.4 – 4.6
Secchi disk (feet)	3.8	8 – 15
Total Kjeldahl Nitrogen (mg/l)	1.3	< 0.75
Alkalinity (mg/ l)	128	40 – 140
Color (Pt-Co Units)	36	10 – 35
pH (SU)	8.5	7.2 – 8.3
Chloride (mg/l)	1.3	< 2
Total Suspended Solids (mg/l)	7.5	< 1 - 2
Total Suspended Inorganic Solids (mg/l)	6.3	< 1 - 2
Conductivity (µmhos/cm)	236	50 – 250
TN:TP Ratio	21:1	25:0 – 35 :1

Carlson's Trophic Status Indicators: 1994

PARAMETER	*TSI LABEL*	*TSI VALUE*
Total Phosphorus	TSIP	64
Chlorophyll-*a*	TSIC	69
Secchi	TSIS	63
MEAN	***TSI***	***65***

Modeling Summary

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. To analyze the 1994 quality of Margaret Lake, the model MINLEAP (Wilson, 1988) was used. "Minnesota Lake Eutrophication Analysis Procedures" (MINLEAP) was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data including: lake area and mean depth, watershed area, and observed water quality data. The model is described in greater detail in Wilson and Walker (1988).

No actual measure of water flow into or out of the lake was made. Rather, ecoregion-specific runoff coefficients, precipitation and evaporation data, and nutrient export coefficients were used in this modeling.

MINLEAP was initially conducted on Margaret Lake using the immediate watershed (minus lake area). This yielded extremely low predicted values for TP and chlorophyll-a. This scenario also neglected to consider the large watershed which drains to Margaret Lake. A second scenario was run, using the total watershed (minus lake area) as noted in Table 1. In this scenario, the **MINLEAP model** predicts summer-mean total phosphorus (TP) concentration of 42 μg/l for Margaret Lake (Table 3). This value is significantly lower than the observed summer-mean TP concentration (65 μg/l) for 1994. Similar results are found with a model prediction of chlorophyll-*a* summer mean concentrations of 15.7 μg/l (53 μg/l observed). The predicted Secchi disk depth of 1.5 meters was quite close to the observed summer-mean of 1.2 meters. Under this scenario, MINLEAP under predicted phosphorus and chlorophyll-*a*, and predicted reasonable Secchi depth from data observed in the 1994 sampling season (Table 3). Because the observed values for phosphorus and chlorophyll-a were so much higher than expected, a calibrated scenario was run to estimate the phosphorus loading that would correspond to the observed in-lake phosphorus. For this purpose, stream inflow P was set at 80 μg/l, rather than 52 μg/l, which is more typical for NLF. This yielded a loading rate of 3,400 kg P/yr, which is ~50% higher than the estimated P loading (2,200 kg P/yr) anticipated from a 'minimally' impacted watershed of this size. This indicates that the Margaret Lake Watershed likely contributes significantly higher amounts of total phosphorus than expected in a watershed in the NLF ecoregion. Based on the original scenario, MINLEAP predicts that Margaret Lake retains about 19 percent of the P which enters the lake, which implies remainder is transported to Gull Lake. Water residence time (time it would take to fill the lake if it were empty) is on the order of 0.1 years (Table 3).

TABLE 3. MINLEAP Model Results

Parameter	Observed 1994	Contributing Watershed MINLEAP	Total Watershed MINLEAP	Calibrated Total Watershed MINLEAP
TP (µg/l)	65 ± 5	33 ± 8	42 ± 9	62 ± 13
chl-*a* (µg/l)	53 ± 3.2	10.7 ± 5.3	15.7 ± 7.2	27.7 ± 12.9
% chl-*a* >20 µg/l	96	6	23	67
% chl-*a* >30 µg/l	83	1	6	34
Secchi (meters)	1.2 ± 0.1	1.9 ± 0.7	1.5 ± 0.5	1.1 ± 0.4
P-loading rate (kg/yr)	--	362	2,191	3,363
% P retention	--	38	19	22
P inflow conc. (µg/l)	--	53	52	80
water load (m/yr)	--	7.59	46.65	46.65
outflow volume (hm^3/yr)	--	6.83	41.98	41.98
"background P"	--	25.6	25.6	25.6
residence time (years)	--	0.4	0.1	0.1

Goal Setting

The current phosphorus criteria value for lakes in the NLF ecoregion, for support of swimmable use, is less than 30 µg/L (Heiskary and Wilson, 1990). At or below 30 µg P/L, "nuisance algal blooms" (chlorophyll a > 20 µg/L) should occur less than 10 percent of the summer. Based on data collected in 1994, mild blooms (chlorophyll-a > 10 µg/L) were common throughout the summer, with nuisance blooms (chlorophyll a > 20 µg/L) present over 80% of the summer.

For Margaret Lake, it will be desirable to reduce in-lake P concentrations below levels observed in 1994. As such, watershed loading must be reduced. Based on MINLEAP model runs P loading rates may be 50% higher than anticipated for a lake of this size, with this size watershed, in the NLF ecoregion.

For now the goal should be to achieve a summer-mean in-lake P of 30 µg/l, which would be consistent with the current P criteria for NLF (and the draft water quality standard for the NLF). A TMDL study, which will make use of previous data from the LAP and CWP studies, will seek to identify sources of excess nutrient loading and present some potential solutions for addressing these sources. At this point, further consideration can be given to determining water quality goals for the lake.

FIGURE 11. Carlson's Trophic State Index for Margaret Lake, Cass County
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.

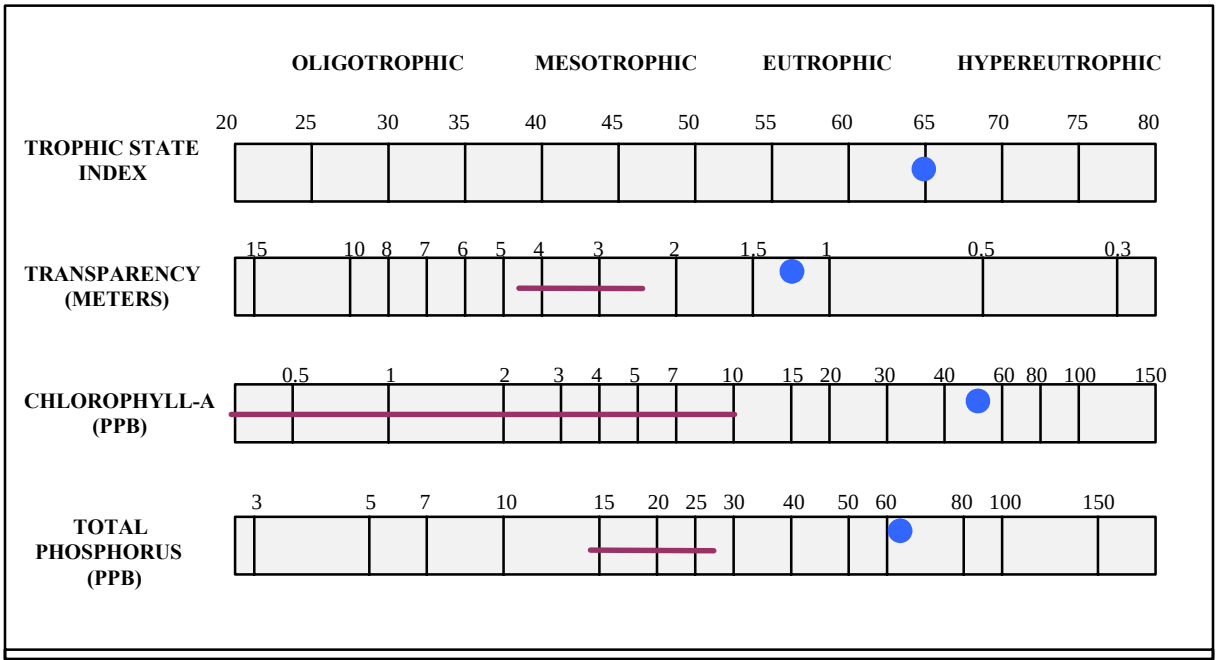
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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: ——— Margaret Lake: ●

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Appendix

I. MPCA Water Quality Data
II. Precipitation Maps
III. Fisheries Status
IV. Lake Level
V. MPCA Secchi Depth and User Perceptions

Appendix I.
Water Quality Data
Margaret Lake 11-0222
1994

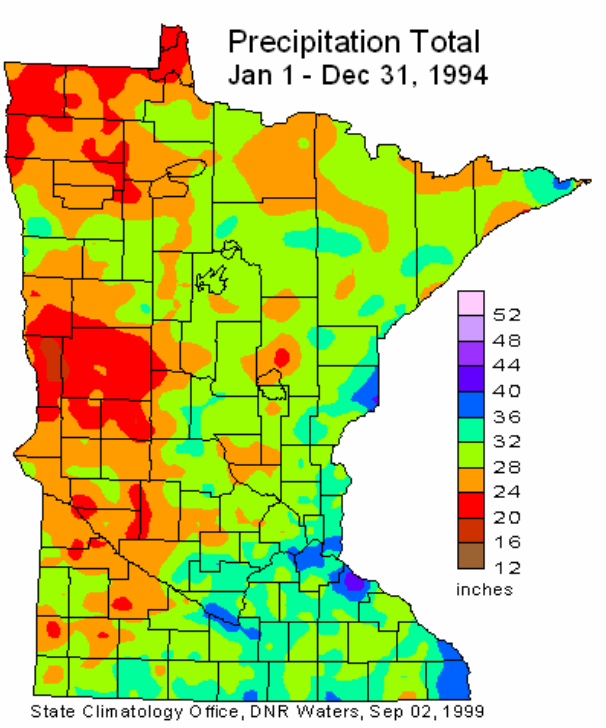
Date	Site	TP (ppb)	Chl-a (ppb)	Pheo (ppb)	SDM	SDF	TKN (mg/L)	pH	TSS (mg/L)	TSVS (mg/L)	ALK (mg/L)	CL (mg/L)	Color	Cond
5/16/94	101	*37*	*9.61*	*2.56*			*0.69*	*7.28*	*3.4*	*1.6*	80	1.2	60	140
5/16/94	102	*41*	*8.97*	*< 0.64*				*7.44*	*2.8*	*1.4*				160
6/27/94	101	*91*	*61.5*	*0.64*	0.9	-3.0	*1.53*	*9.03*	*6.4*	*5.8*	110	1.3	40	200
6/27/94	102	*68*	*65.9*	*< 0.62*	0.8	-2.6		*8.57*	*7.6*	*6.4*			50	250
7/27/94	101	*71*	*46.8*	*3.2*	1.1	-3.6	*1.23*	*8.03*	*8.8*	*6.8*	130	1.4	30	210
7/27/94	102	*59*	*50*	*< 0.64*	1.1	-3.6		*8.37*	*6.4*	*6.4*				240
8/23/94	101	*54*	*60.2*	*1.92*	1.06	-3.5	*1.26*	*8.42*	*10*	*8*	140	1.2	30	230
8/23/94	102	*65*	*44.9*	*< 0.64*	1.4	-4.6	*1.26*	*8.38*	*8*	*6.4*			40	250
9/20/94	101	*45*	*51.9*	*< 0.64*	1.2	-3.9	*1.08*	*8.61*	*6.2*	*5.2*	130	1.4	30	230
9/20/94	102	*69*	*40.4*	*< 0.64*	1.7	-5.6		*8.4*	*6.6*	*5.6*			30	270
N		**8.0**	**8.0**	**3.0**	**8.0**	**8.0**	**5.0**	**8.0**	**8.0**	**8.0**	**4.0**	**4.0**	**7.0**	**8.0**
Mean		***65.3***	***52.7***	***1.9***	***1.2***	***-3.8***	***1.3***	***8.5***	***7.5***	***6.3***	***127.5***	***1.3***	***35.7***	***235.0***
Std. Err		**4.8**	**3.2**	**0.7**	**0.1**	**0.3**	**0.1**	**0.1**	**0.5**	**0.3**	**6.3**	**0.0**	**3.0**	**8.0**
Min		45.0	40.4	0.6	0.8	-5.6	1.1	8.0	6.2	5.2	110.0	1.2	30.0	200.0
Max		91.0	65.9	3.2	1.7	-2.6	1.5	9.0	10.0	8.0	140.0	1.4	50.0	270.0
Std Dev		13.6	9.0	1.3	0.3	0.9	0.2	0.3	1.4	0.9	12.6	0.1	7.9	22.7

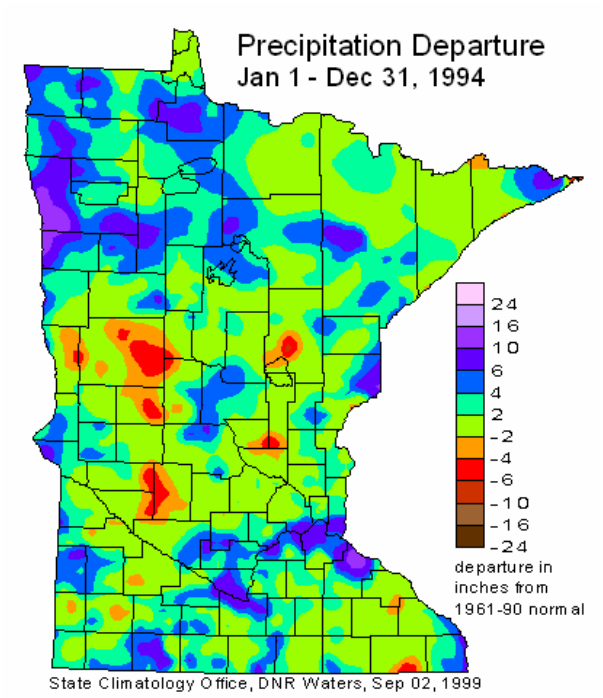
Site	Location where sample was collected
Date	Date when sample was collected
TP	Total Phosphorus concentration, in parts per billion (µg/L)
Chl-a	Chlorophyll-*a* concentration, in parts per billion (µg/L)
Secchi (ft)	Secchi transparency, measured in feet
Secchi (m)	Secchi transparency, measured in meters
Alk	Alkalinity (mg/L)
Cl	Chloride (mg/L)
Color	Color of the water, lab tested
TKN	Total Kjeldahl Nitrogen (mg/L)
Pheo	Pheophytin (µg/L)

Station_ID	Year	TP	Chl-a	SD	SES	TSI_S
11-0222	1973			1.2	0.0	57
11-0222	1974			1.3	0.1	56
11-0222	1987			1.6	0.1	53
11-0222	1988			1.1	0.1	59
11-0222	1989			1.2	0.1	58
11-0222	1990	0.050	58.9	1.3	0.1	56
11-0222	1991			1.4	0.1	56
11-0222	1992			1.7	0.1	52
11-0222	1993			1.3	0.1	57
11-0222	1994	0.065	52.7	1.2	0.1	57
11-0222	1995			1.4	0.1	55
11-0222	1996			1.6	0.1	53
11-0222	1997			1.6	0.1	54
11-0222	1998			1.5	0.1	55
11-0222	1999			1.6	0.1	53
11-0222	2001			1.6	0.1	54
11-0222	2002			1.5	0.1	55
11-0222	2003			1.7	0.1	52
11-0222	2004			1.4	0.1	55

TP = Total Phosphorus (mg/l)
Chl-a = Chlorophyll-a (ug/l)
SD = Secchi transparency (m)
SES = Standard Error for Secchi
TSI_S = Trophic State Index for Secchi

Appendix II. Precipitation Maps





Appendix III. Fisheries Status

From: http://www.dnr.state.mn.us/lakefind/showreport.html?downum=11022200

Status of the Fishery (as of 06/25/2001)

Margaret is a 222 acre lake located on the Gull Lake Chain and is about three miles southwest of Nisswa. Public access is via navigable channel from Gull Lake. Maximum depth is 26 feet and about 29% of the lake is less than 15 feet deep. It is a hardwater lake with moderate phosphorous fertility. Water clarity is below average for the area. Shallow water soils are predominantly sand and gravel. Soils in marshy areas are primarily muck. The aquatic plant community is fairly diverse. Emergent species like bulrush provide protection from erosion caused by wave action, help cycle nutrients and improve the quality of spawning habitat for northern pike, especially in shallow water areas. Submergent plants provide vital food and cover for a wide variety of aquatic species.

Northern pike was the most abundant gamefish present in the 2001 netting, while bluegill was the most abundant panfish. Pike were caught in average numbers when compared to similar lake types. Eight age classes were sampled and growth was good. Average size was 25 inches and 4.3 pounds, larger than in past nettings. Only three walleyes were sampled, a catch rate of 0.5/gill net. Largemouth bass are difficult ot sample in stationary nets. Past nettings have caught bass in low numbers. Typically, only one bass was caught in 2001 sampling.

Black crappies were caught in "average" numbers and appeared to have good growth. Bluegills were caught in "high" numbers that were similar to the 1981 catch rate. Six age classes were sampled. Growth was slow. About 5% of bluegills measured from trapnets in 2001 were 7.0 inches or more in length.

Yellow perch, white sucker and tullibee are important food sources for the lake's gamefish. Perch were caught in numbers which were "average" when compared to similar type lakes and to past catches in Margaret. The white sucker catch was also in the "average" category. Tullibee were caught in "average" numbers in 1996, in "low" numbers in 1991 and were absent from the 2001 sampling.

Other species sampled in 2001 included: bowfin, brown bullhead, yellow bullhead, rock bass, green sunfish, pumpkinseed and hybrid sunfish. Catch rates were generally low-average when compared to similar type lakes.

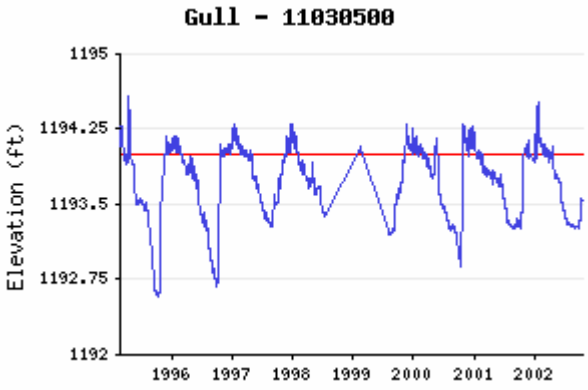
Appendix IV. Lake Level

Lake water level report

Lake Name: Gull
County: Cass

Water Level Data

Period of record: 09/30/1981 to 04/03/2003
# of readings: 2910
Highest recorded: 1194.57 ft (10/05/1995)
Lowest recorded: 1192.58 ft (04/02/1996)
Recorded range: 1.99 ft
Average water level: 1193.7 ft
Last reading: 1193.54 ft (04/03/2003)
OHW elevation: 1194 ft
Datum: 1929 (ft)



Appendix V.
Secchi Depth and Physical Condition / Recreational Suitability Rankings

11-0222 **Margaret Lake**				
Date	**Site**	**Secchi (ft)**	**Physical Condition**	**Recreational Suitability**
6/27/94	**101**	**3**	**3**	**2**
6/27/94	**102**	**2.6**	**3**	**2**
7/27/94	**101**	**3.6**	**2**	**2**
7/27/94	**102**	**3.6**	**2**	**2**
8/23/94	**101**	**3.5**	**2**	**2**
8/23/94	**102**	**4.6**	**2**	**2**
9/20/94	**101**	**3.9**	**3**	**2**
9/20/94	**102**	**5.6**	**3**	**2**

Number	**Physical Condition**	**Recreational Suitability**
1	Crystal clear water	Beautiful, could NOT be better
2	Not quite crystal clear – a little algae present/visible	Very minor aesthetic problems; excellent for swimming, boating
3	Definite algae green, yellow, or brown color apparent	Swimming and aesthetic enjoyment slightly impaired because of algae levels
4	High algal levels with limited clarity and/or mild odor apparent	Desire to swim and level of enjoyment of the lake substantially reduced because of algae levels (i.e., would not swim, but boating is okay)
5	Severely high algae levels with one or more of the following: massive floating scums on the lake or washed up on shore, strong, foul odor, and/or fish kill	Swimming and aesthetic enjoyment of the lake nearly impossible because of algae levels