2006 Lake Assessment of Six lakes in Blue Earth County

Ballantyne (07-0054), Duck (07-0053), Eagle Lake (07-0060), George (07-0047), Loon (07-0096) and Madison Lake (07-0044)

Blue Earth County
2006
Lake Assessment Program

wq-lar07-0044

Minnesota Pollution Control Agency
Environmental Analysis and Outcomes Division

Matt Lindon

Dr. Howard Markus…………Algal Taxonomy

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INTRODUCTION

The Lake Assessment Program (LAP) is designed to assist lake associations or municipalities in the collection and analysis of baseline water quality data, in order to assess lake water quality and related concerns. The Minnesota Pollution Control Agency's (MPCA) LAP program monitored six lakes in Blue Earth County in 2006. This assessment report, as well as over 200 other lake assessment reports can be found on the MPCA's LAP Web site http://www.pca.state.mn.us/water/lakereport.html. Water quality data used in this report as well other data on the lakes, is available through the MPCA's Environmental Data Access (EDA) web site at http://www.pca.state.mn.us/data/eda/search.cfm.

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 collected by MPCA staff. None of the lake associations associated with this study were closely involved with this study. This report is a secondary product of a blue-green algal toxin study conducted in 2006. Lakes were selected for the algal toxin study based on a history or suspicion of high algal conditions. The report summarizing the algal toxin results study titled Microcystin Levels in Eutrophic South Central Minnesota Lakes is available at http://www.pca.state.mn.us/water/lakequality.html#reports

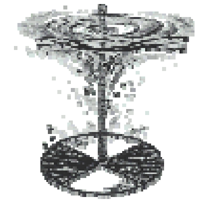
This report discusses lake water quality trends and factors that may be affecting them. The report assumes a basic knowledge on lake water quality monitoring. A good reference on this subject is the Citizens Guide to Lake Water Quality: http://www.pca.state.mn.us/publications/wq-s1-01.pdf

SUMMARY
Morphometry (shape) and watershed size varied among the studied lakes, but landuse within individual lake watersheds are similar. 2006 results showed all six lakes to be nutrient rich (eutrophic to hypereutrophic). Total Phosphorus (TP) levels on all lakes were significantly elevated from the calculated background conditions. Long term water quality trends varied among the individual lakes. Model predictions of water quality based on lake and watershed characteristics corresponded well with observations on several lakes (Duck, Eagle, George and Madison lakes) mean water quality results. At this time only Duck Lake has enough observations to be included in our 303(d) impaired water assessment. With more monitoring it is likely that other lake among this study group would be considered impaired.

RECOMMENDATIONS
It is essential that lake protection efforts for these lakes be conveyed to the local government (zoning and land use authorities) as well as local property users. The concern for protecting and improving these lakes should be elevated. These lakes are a unique natural resource that have an immense value to this area of the state.

1. A Lake Management Plan should be developed (if one has not already been developed) for each lake with cooperation from Blue Earth County Environmental Services and Blue Earth County Soil and Water Conservation District (SWCD), located in Mankato, to address lake protection issues. The plan should be lake specific and account for the watershed as well as the lake itself. This 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., Minnesota Department of Natural Resources (DNR), Board of Water Soil Resource (BWSR), and MPCA) local units of government, 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 and issues should be included in the plan:

a. The *Citizens Lake-Monitoring Program (CLMP)* data 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, Secchi measurements should be twice a month during the summer at consistent sites. Only Duck Lake has maintained a consistent participation in the CLMP program. The Lake Management Plan should specifically address coordinating volunteer monitoring as well as data analysis. For more information on CLMP go to the MPCA's website at http://www.pca.state.mn.us/water/volunteer-monitoring.html



b. *The continued education of homeowners around the lake*, with respect to septic system, lawn maintenance, and shoreline protection may be beneficial e.g., Blue Earth County Septic Systems require inspection every three or five years, depending on the age of the system. There are many good resources on educating lake property owners in protecting lake water quality such as Guide to Lake Protection and Management, Second Edition published by the freshwater society http://www.freshwater.org/publications.html.

c. *Further development or land use* change in the watershed should occur in a manner that minimizes water quality impacts on the lakes.

- In the shore land areas, setback provisions should be strictly followed.
- DNR and county shore land regulations will be important in this regard.
- Stormwater regulations should be adhered to during and following any major construction/development activities in the watershed.
- Limiting the amount of impervious surfaces can have beneficial affects as well, in terms of reduced runoff and P loading.
- Activities in the total watershed that change drainage patterns, such as wetland removal or major alterations in lake usage, should be discouraged unless they are carefully planned and adequately controlled.
- Restoring or improving wetlands in the watershed may also be beneficial for reducing the amount of nutrients or sediments reaching the lakes. The U.S. Fish and Wildlife Service at Fort Snelling may be able to provide technical and financial assistance for these activities.
- Lake associations should seek representation on boards or commissions that address land management activities so that their impact can be minimized. The booklet, "Protecting Minnesota's Waters, the Land-Use Connection", may be a useful educational tool in this area.

d. *Maintenance of shoreline vegetation* (both shoreland and aquatic) is very important. Native vegetation will help stabilize the lake shore as well as buffer against nutrient loading from run off. A good resource for shoreland owner on the subject vegetation maintenance as well as other shoreland issues is the Minnesota Shoreland Management Resources Guide. http://www.shorelandmanagement.org

f. *Nutrient loading in the watershed* is typically the most significant driver in eutrophication. An accurate assessment of the nutrient inputs and sources to the lakes will be very useful in making smart discussions in protecting lake water quality. Sources in the watersheds such as rural, agricultural runoff and septic systems are likely the major nutrient contributors. Correctly addressing current nutrient sources as well as minimizing the impact of future sources can have an impact on nutrient loading the lakes

g. *Regulations and Best Management Practices* (BMP's) can reduce nutrient loading within the watershed. BMP's may include crop rotation methods, settling ponds, buffer strips and putting land in to different use. Considering the amount of agriculture land in these watershed use of BMP's could make a significant reduction in the nutrient loading to the lakes. In recent years, state legislation banning the use of phosphorus in lawn fertilizer was passed. In addition, state feedlot rules (7020) were revised in 2000. The associations and concerned parties should work with the county and other regulators to insure compliance with these and other regulations.

2. *Partnerships and funding* will be very helpful to lake monitoring and improvement efforts

   a. Lake associations need to maintain a good relationship with other regional organizations with water quality concerns such as: Blue Earth County Soil and Water Conservation District and Blue Earth County Environmental Services.
   b. MPCA's Clean Water Partnership Program (CWP) is also an option for further assessing and addressing nonpoint sources of nutrients in the watershed. This LAP report serves as a foundation upon which further studies and assessments may be based. More information about the MPCA's CWP can be found at http://www.pca.state.mn.us/water/cwp-319.html
   c. Another source of funding is EPA's 303(d) or "Impaired Waters" program. Lakes with sufficient data showing water quality to be below established standards can be placed on Impaired Waters List. Currently Madison, George, and Loon Lakes are on the impairment list for mercury levels in fish. More lakes from this study will likely be listed for excess nutrients in future cycles of the assessment process

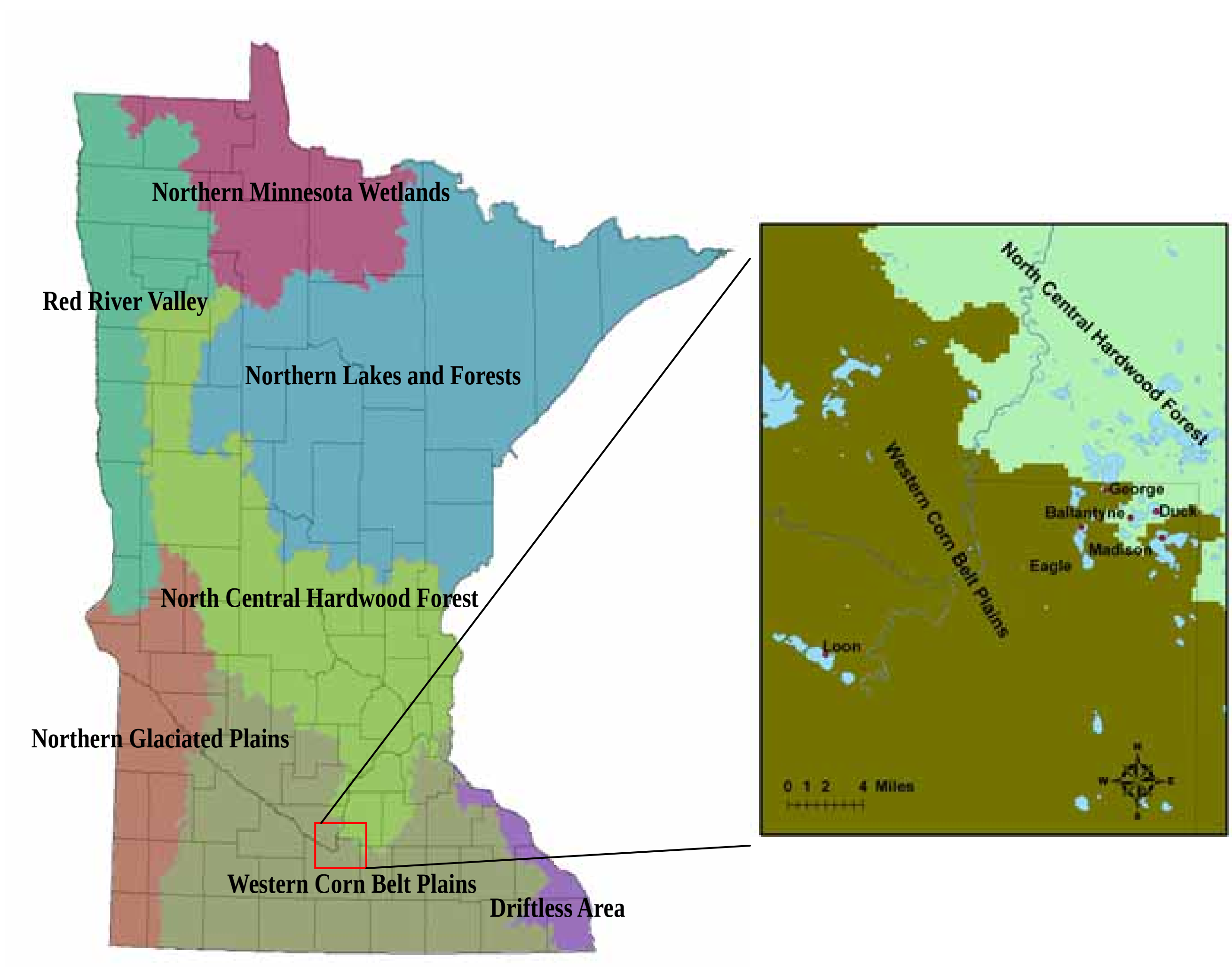
d. BACKGROUND

Soils in the study area are generally defined as well drained, medium to fine textured prairie soils (Arnerman 1963). Eagle, Ballantyne, Duck and Madison originated from irregular deposition of glacial till (Zumberge 1952). Irregular deposition of glacial till formed lakes, are typical shallow (<30ft max depth) and have gradual sloping drainages and basins. Loon Lake is classified as ice block left after glacial recession in a pre-glacial valley (Zumberge 1952).

Ecoregions

Minnesota is divided into seven somewhat distinct ecoregions based on soils, potential natural vegetation, land forms and land use and water quality. Water quality data supporting ecoregion designation was derived from extensive sampling (1985-1988). Lake sampled during the establishment of the ecoregions are referred to as ecoregion reference lakes. These lakes are not necessarily the most pristine lakes in each ecoregion; rather these lakes are "representative" of the ecoregion and are minimally impacted by man. As is evident, the relative impact by human activities does vary among ecoregions. The typical range of summer mean water quality from the reference lakes provides a basis for evaluating the quality of other lakes in the ecoregion. Eagle, George, Loon and Madison are located in the West Central Corn Belt Planes (WCBP) ecoregion while Ballantyne and Duck are located on the edge of the North Central Hardwood Forest (NCHF) ecoregion. All six lakes in this study are similar to typical shallow eutrophic lakes commonly found in the WCBP.

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

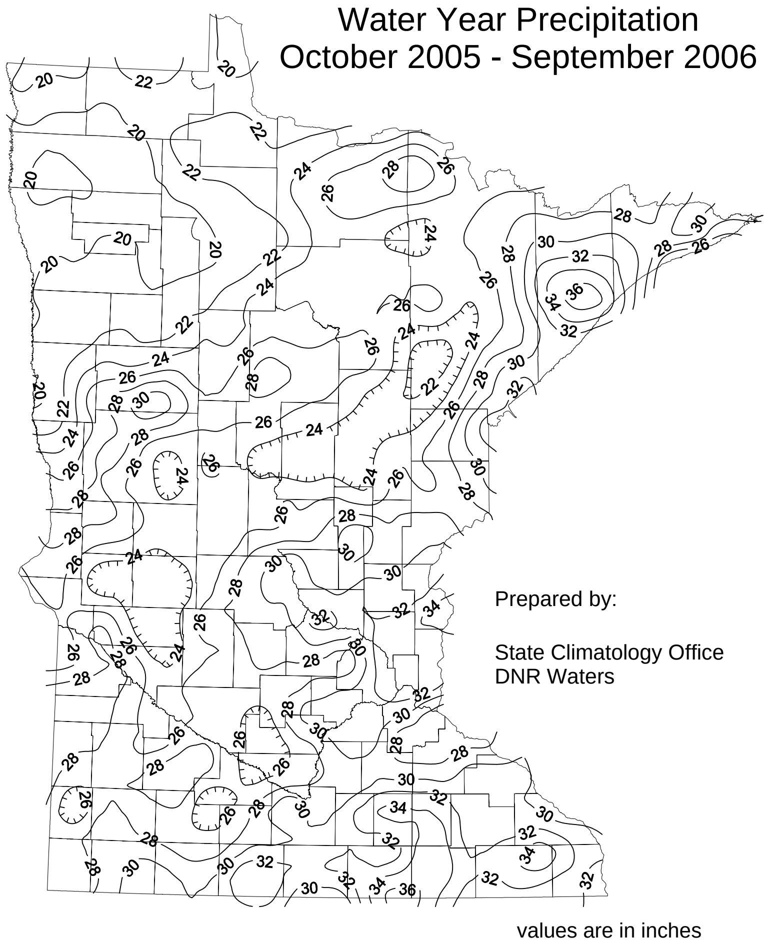


Precipitation

According to The Midwestern Regional Climate Center the historical mean for annual precipitation in the Mankato area (station 215073) is 33 inches   Minnesota Climatology Working Group show precipitation was normal in 2006 at (October 2005 through September 2006) at 30 inches (Figure 2).

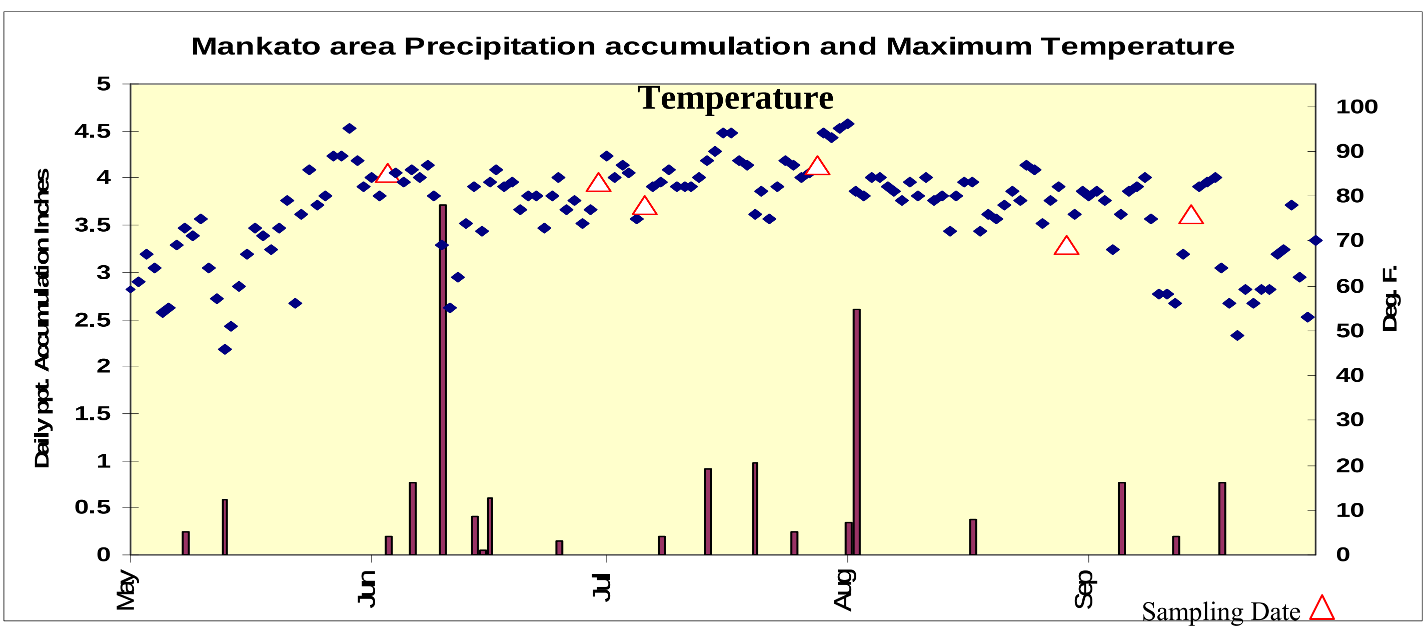
Daily rain gauge monitoring from the Mankato station and other local weather stations showed two – two inch or greater rain events as well as several one inch or greater events through the summer. Excessive runoff from the watershed often occurs in the response to these rain events. This often results in high loading of nutrients and suspended solids to the lake. Our 2006 lake monitoring did not occur directly after any significant rain events (Figure 3).

Figure 2. Water Year for 2004/2005



Climatology information can be found at: http://climate.umn.edu/climatology.htm

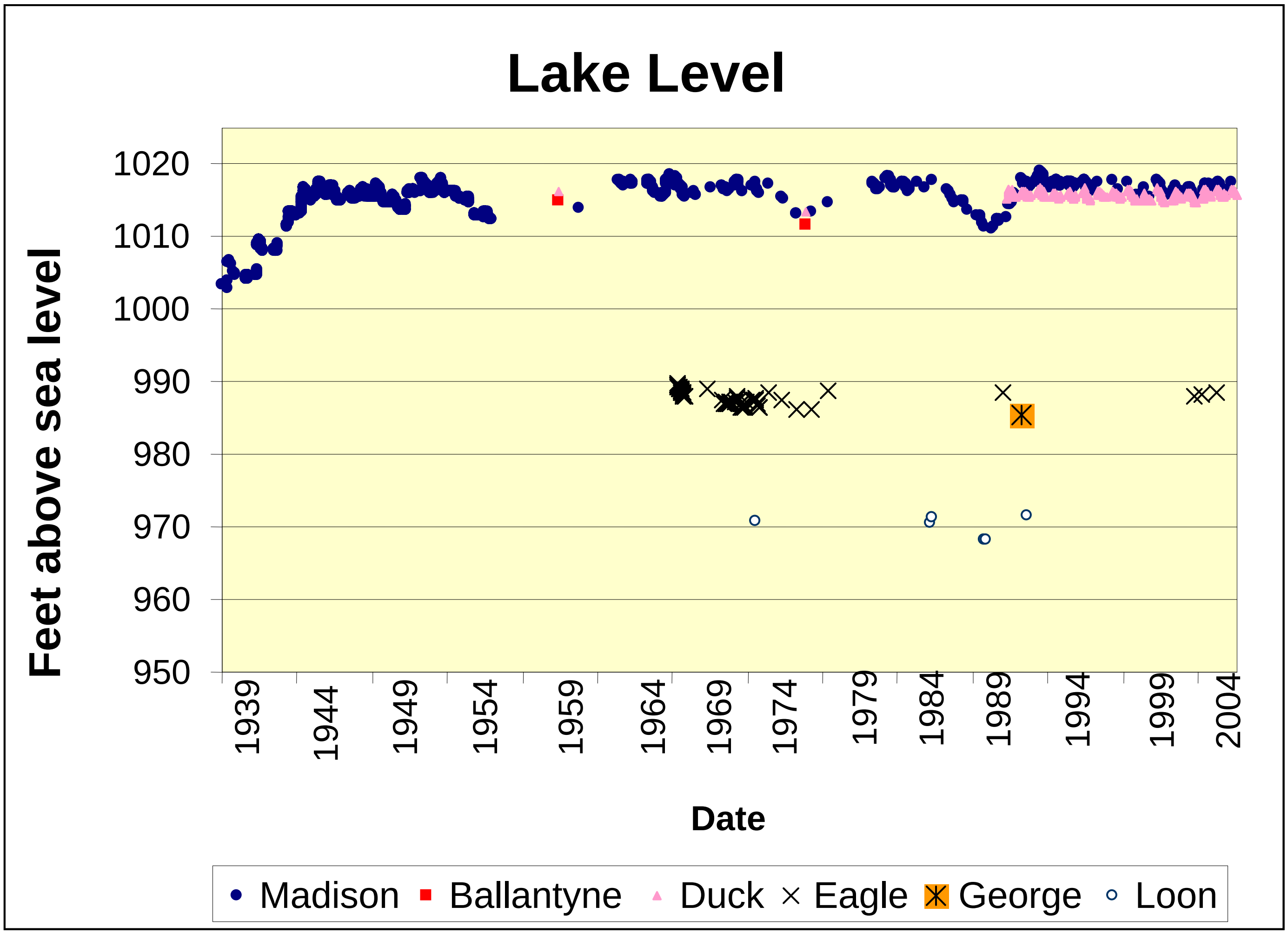
Figure 3. Daily Rain and Temperature Measurements from the Mankato area (PPT =precipitation)



Lake Levels

Lake level monitoring data for these lakes goes back to 1939 and is available from the Minnesota Department of Natural Resources (Figure 4). The best continuous lake level records are on Madison Lake going back to 1939. Lake levels on Madison Lake have been stable since 1991. Duck and Ballantyne have a direct hydraulic connection and as would be expected, recorded water levels are similar.

Figure 4. Lake Level Records



Lake Morphometry

George, Loon and Duck Lakes have very similar simple basins. Madison Lake has two distinct bays and is the deepest of the study lakes (Table 1). Eagle Lake is very shallow with the exception of the north basin which was the only area where samples were able to be collected. Ballantyne Lake, while one of the deepest lakes in the study, has a very extensive littoral area (Table 1). The littoral area of a lake is defined as the portion 15 feet or less in depth and typically supports extensive rooted plant growth.

Figure 5. Bathymetry Maps

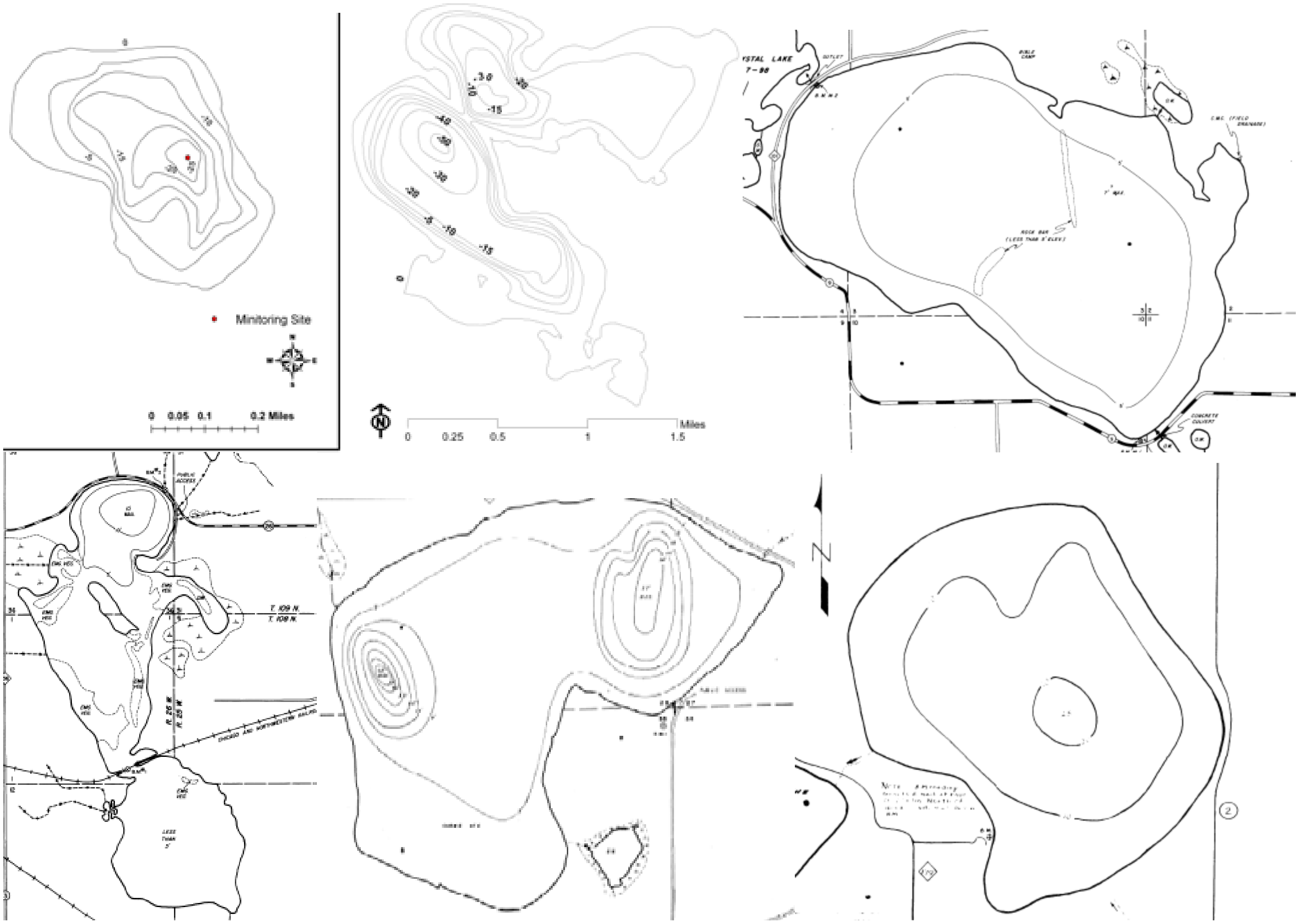


Table 1 Lake Morphometry.

ID	Lake	Area (acres)	% Littoral	Zmax (Feet)	Zmean (Feet)
07-0044	Madison	1171	65	59	10
07-0047	George	141	76	28	6
07-0053	Duck	286	82	25	8
07-0054	Ballantyne	353	86	58	8
07-0060	Eagle	914	100	9	3
07-0096	Loon	818	100	7	5

Watersheds

All of the lakes are located in the Minnesota River Basin. The individual lake watersheds or lakesheds in this study were quite similar (Table 2). Lake to watershed ratios were rather small ranging from 3:1 to 10:1. Land use in all lakesheds was dominated by agriculture (all were above 49%). Most of the lakesheds have drainage that includes other small lakes within the lakeshed.

Figure 6 Lakeshed and Land Use

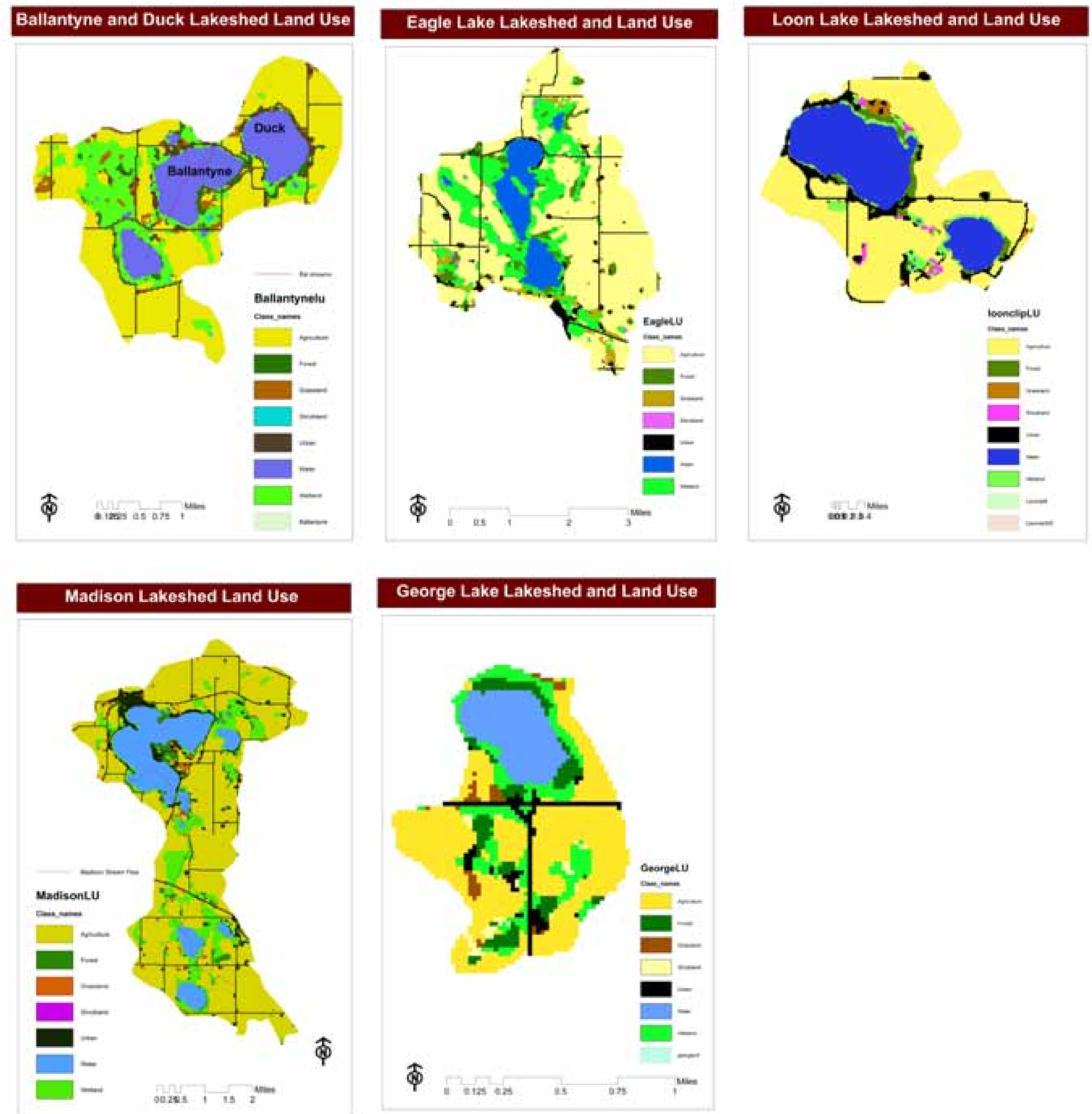
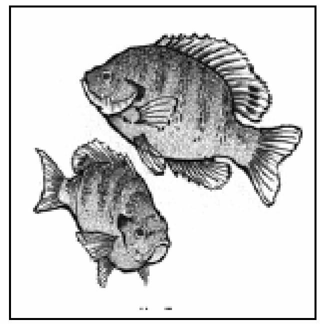


Table 2. Land Use and Watershed Information

Lake use in Acres	Ballantyne	Duck	Eagle	George	Loon	Madison
Urban	291	94	455	32	300	998
Agriculture	1,887	523	4527	274	1,977	7,387
Grassland	100	14	255	13	40	173
Forest	88	24	290	47	115	310
Water	781	282	745	81	1,011	1,865
Wetland	665	62	1402	82	162	1,513
Shrubland	10	0	36	10	38	23
Study Lake Area	350	282	941	80	754	1,441
Total Watershed area	3,823	1,000	7,710	540	3,644	12,269
Watershed	3,473	718	6,769	460	2,890	10,828
Watershed to Lake Ratio	**10:1**	**3:1**	**7:1**	**6:1**	**4:1**	**8:1**

Fishery Information

The following are summaries of most recent Minnesota Department of Natural Resources fish and aquatic habitat assessments.



Ballantyne Lake 2003 assessment

Black bullhead were the most abundant species. The number of *walleye* caught in the study was the highest number in twenty years. Walleye abundance corresponded with a 2001 stocking effort.

Duck Lake 2000 assessment

Duck Lake has had a consistent high abundance of *bluegills* since at least 1995 through the present survey in June 2000. Most bluegills were around 7 inches, with some fish up to 9 inches. The abundance of both *black* and *white crappies* is currently low, although similar to abundances in 1995. There is a good population of *northern pike* with fish up to 34 inches with most around 23 inches. *Largemouth bass* are also present and provide some fishing opportunity

Eagle Lake 2004 assessment

Low oxygen conditions occurred in Eagle Lake in early 2001 which resulted in substantial winterkill of fish. Following the winterkill *walleye* fry, *black crappie,* and *yellow perch* adults were stocked. In the 2004 survey *black bullhead* were the most abundant species in both gill and trap net catches. Most walleye captured in the assessment were around 10 to 20 inches and while northern pike were between 20 and 30 inches long.

Lake George 2005

Fish sampling from 2005 indicated above normal population of *black bullhead.*

Madison Lake 2002 assessment

Walleye catch per gill has been consistently near eight fish per net over the past four surveys since 1993. *Walleye* around 17 inches were common; the largest were over 28 inches. There were also a fair number of walleye around 8 inches that should contribute to the fishery in a few years. *Northern pike* were relatively small with a mean length of 16.5 inches; the largest was 28.5 inches long. The mean length of *bluegill* has increased over the past four surveys. The 2002 survey showed an increase in bluegill > 180 mm compared to previous surveys. *Black crappie* catch per gill and trap net has been consistent from 1993 through 2002.

Loon Lake 2001 Assessment

Low oxygen conditions in the winter of 2000 - 2001 resulted in a temporary loss of sportfish populations. In the spring of 2001, 450 lbs. of yellow *perch* adults and 1.2 million *walleye* fry were stocked into Loon Lake. The survival of the stocked fish was good. Additionally, good reproduction of *black crappie* occurred. Quality fishing may be available in a few years on Loon Lake as the fish grow to catchable sizes. Aeration equipment has been in use since 1979-80. Substantial winterkill had not occurred since the operation of the aeration equipment was started until the 2000 - 2001 winter.

METHODS

Water quality data was collected in May, June, July, twice in August, and September of 2006. 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). Phytoplankton (algae) samples were taken with an integrated sampler. Zooplankton samples were collected with a Wisconsin Plankton Tow. Lake profile data (temperature, depth, conductivity, pH, ORP) was collected with a calibrated probe. Depth samples were collected two feet above the lake bottom at the sampling point. Seasonal averages were calculated using June- September data.

RESULTS AND DISCUSSION

The 2006 water summer mean results for the study lakes are averages of the May – September results. Standard error (number to the right of **±)** is a measure of the variability of the parameter throughout the period. Summer mean values for the lakes generally compared well to the WCBP ecoregion reference lake range. TP (Total Phosphorus) and Chl-a (Chlorophyll-a) on Lake Ballantyne was in the range of the CHF ecoregion reference lakes.

Table 3. Summer Mean Epilimnetic Water Quality Results 2006

	Ballantyne	Duck	Eagle	George	Loon	Madison	NCHF Range	WCBP Range
TP ***µg/L***	39.8 ± 3	70 ± 9	142 ± 11	105 ± 10	157 ± 15	80.8 ± 11	23 - 50	65 - 150
Chl a ***µg/L***	19.3 ± 2	41.9 ± 9	75 ± 10	40 ± 10	82 ± 6	47 ± 5	5-22	30-80
Chl-a Max ***µg/L***	24	66	104	76	102	67		
Secchi ***Meter***	0.8 ± 0.1	0.8 ± 0.2	0.3 ± .04	0.5 ± .2	0.3 ± .02	0.7 ± .06	(1.5 - 3.2)	(0.5 - 1.0)
TKN ***mg/L***	1.4 ± .06	1.5 ± 0.1	3.1 ±0.1	20 ± 0.3	2.9 ± 0.2	1.8 ± 0.1	<0.60-1.2	1.3 - 2.7
Alkalinity ***mg/L***	142 ± 4	154 ± 3	118 ± 3.7	91 ± 4	136 ± 2.4	144 ± 2	75-150	125-165
Color	14 ± 2	10 ± 0	30 ± 0	24 ± 2.5	16 ± 2.4	18 ± 2	10-20	15 - 25
pH	8.6 ± 0.1	8.7 ± 0.5	9.2 ± .05	9.2 ± 0.4	8.9 ± 0.1	8.7 ± 0.1		
Cl mg/L	19 ± 1	21.4 0.2	19 ± 0.6	15.8 ± 2	24 ± 0.4	20.6 ± 0.2	4-10	13-22
TSS mg/L	10.0 ± 1	12.6 ±2	42.8 ± 6.1	23 ±5.6	55.4 ± 9.4	10.0 ± 1	2-6	7-18
TSV mg/L	5.7 ± 0.44	9.5 ± 1.8	33.2 ± 3.9	17.4 ± 3.8	67.2 ± 6.0	8.0 ± 0.8		
TS Inorganic mg/L	4.3 ± 0.6	3.1 ± 0.6	9.6 ± 2.4	5.8 ± 2.0	18.2 ± 3.7	2.1 ± .04	1-2	3-9
Spec Cond µScm	286 ± 75	284 ±71	230.8 ± 57	188 ± 44	246 ± 63	267.5 ± 67	300 - 400	300 - 650

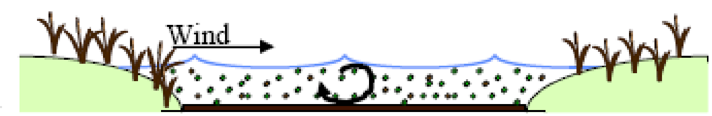
* Ranges Based on Ecoregion Reference Lakes inter quartile range

Stratification

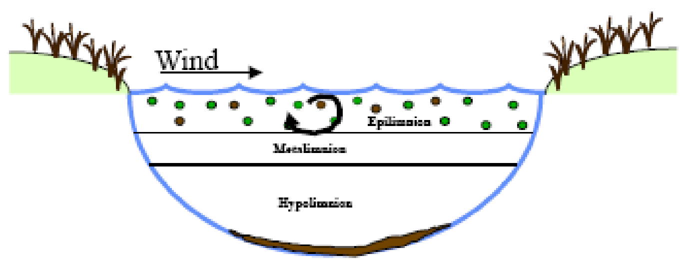
Lake depth can have a significant influence on lake processes and water quality. One such process is *thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 30 - 40 feet or more) often stratify (form layers) during the summer months and are referred to as *dimictic*. These lakes full-mix or turn-over twice per year; typically in spring and fall. Shallow lakes (maximum depths of 20 feet or less) in contrast, typically do not stratify and are often referred to as *polymictic*. 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 Dimictic lakes have an 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. The low oxygen environments in the Hypolimnion are conducive to TP being released from the lake sediments. During stratification dense colder Hypolimnion waters are separated from the nutrient hungry algae in the Epilimnion. In interment / weakly stratified polymictic lakes are mixed in high winds. Mixing events allow for the nutrient rich sediments to be re-suspended and available to algae. Most of the fish in the lake will be found in the epilimnion or near the thermocline. Of the six McLeod County lakes assessed in 2006, only Stahl's lake developed significant temperature stratification during monitoring. The other lakes in the assessment appear to be polymictic.

Figure 7 Lake Stratification Diagrams

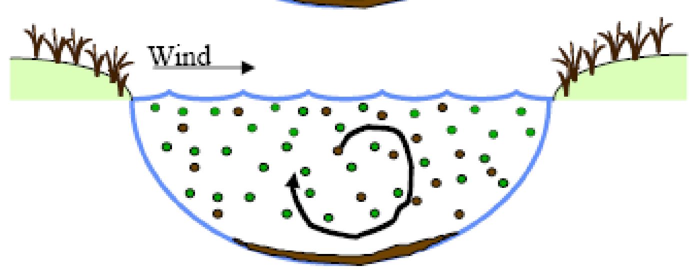
Polymictic Lake (Spring, Summer & Fall)
Shallow, No Layers,
Mixes Continuously



Dimictic Lake (Summer)
Deep, Form Layers,
Mixes Few Times



Dimictic Lake (Spring and Fall)



Lake Mixing Categories
Because thermal mixing can have such significant impact on phosphorus levels in lakes, lakes are often categorized by this status.

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

Intermittent Lake with moderate depths, may stratify temporarily during summer, but may mix with strong wind action.

Polymictic Shallow lake, remains well mixed from spring through fall.

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 4 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:

Table 4. Distribution of TP (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

Ballantyne Lake

Ballantyne is relatively deep compared to other lakes in the study (Table 1) and has two rather distinct bays. About 80 percent of the lake is zoned rural town site by the county. The lake has a fair amount of development on the north and west ends. Ballantyne has been previously sampled and is among the WCBP ecoregion reference lakes (Heiskary and Wilson, 2005).

Ballantyne appears to be dimictic with strong thermal stratification from June – September. (Fig 8 & 9) The thermocline dropped significantly from about seven to 11 meters in September. Surface temperatures ranged from 15 to 27° C with a peak in early August.

Summer mean water chemistry values were well within the typical range for WCBP ecoregion lakes (Table 3). TP concentrations were rather stable from May through September. (Figure 10). Chlorophyll-a concentrations were generally in the 10-20 µg/L range and remained below 30 µg/L (severe nuisance bloom levels) over the summer. Secchi was less than one meter for most of the summer.

Blue-green algal varieties dominated the lake from June – August (Figure 11). Commonly observed blue green taxa were Anacystis, Anabaena, and Aphanizomenon.

Figure 8. Temperature Profiles Site 102

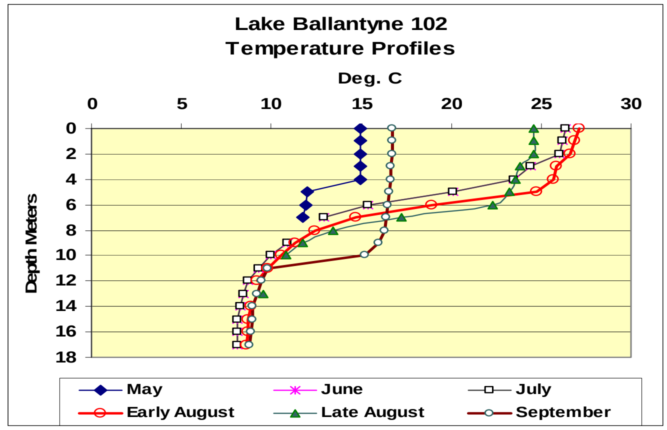


Figure 9. Temperature Profiles Site 101

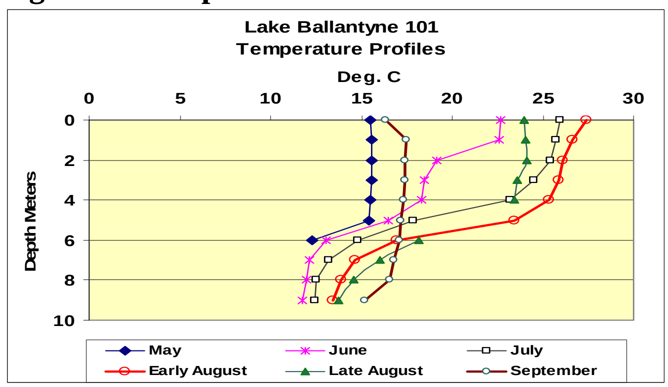


Figure 10. Summer TP,Chl-a and Secchi

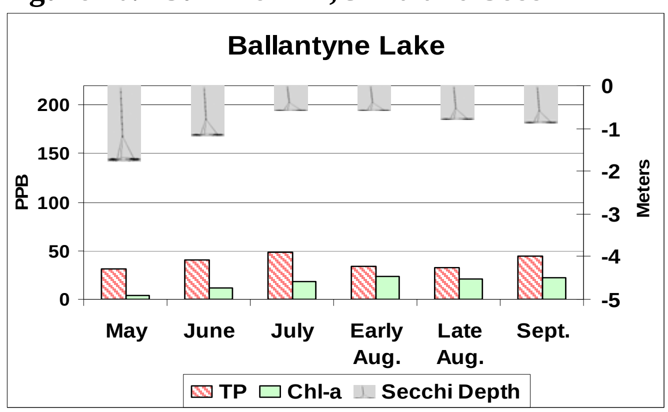
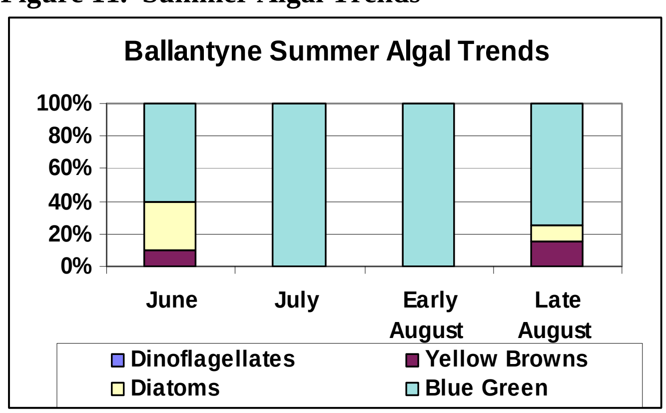


Figure 11. Summer Algal Trends



Duck Lake Results
Duck Lake was the smallest lake in the study at about 286 acres and has a relatively small watershed (~3:1) relative to its size. Its watershed is dominated by agricultural uses. Lake shore shoreline is highly developed including a large park and swimming area. The lake has been extensively sampled by MPCA and other collaborators as a part of a CWP project. Duck Lake was also part of the 55 lake diatom reconstruction study (Heiskary and Swain, 2002). Curly-leaf pondweed was first documented in 1970 and has become a dominant macrophyte in the lake. Lake water quality has improved much on Duck since the 1980's.

The lake was well-mixed on all dates and surface temperature ranged from 14 to 27° C with a peak in early August. Summer-mean water quality measurements for 2006 were all within the WCBP ecoregion reference lake range (Table 3). TP concentrations increase from May through August, consistent with a pattern seen in other shallow well-mixed lakes (Figure 13). Chlorophyll-a peaked at 67 µg/L in late August and severe nuisance blooms were common from July through September. Secchi was less than one meter from July through September.

Diatoms were dominant in May followed by blue-greens in July and August. Diatoms bio-volume increased in September as the lake was cooling and undergoing fall mixing.

Figure 12. Temperature Profiles

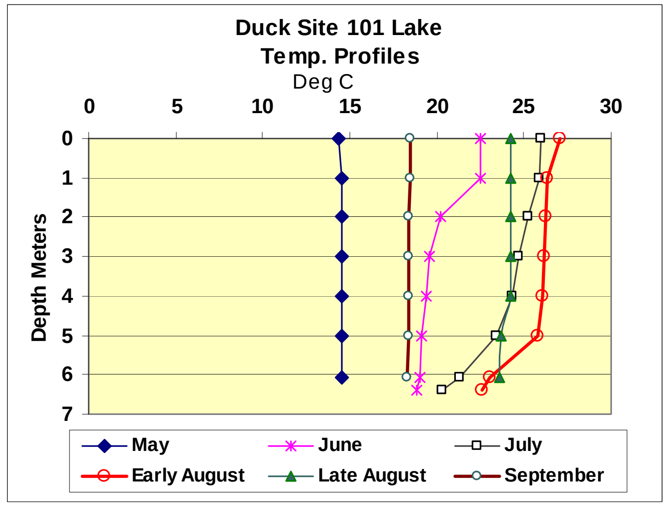


Figure 13. Duck Lake TP, Chl-a and Secchi Depth

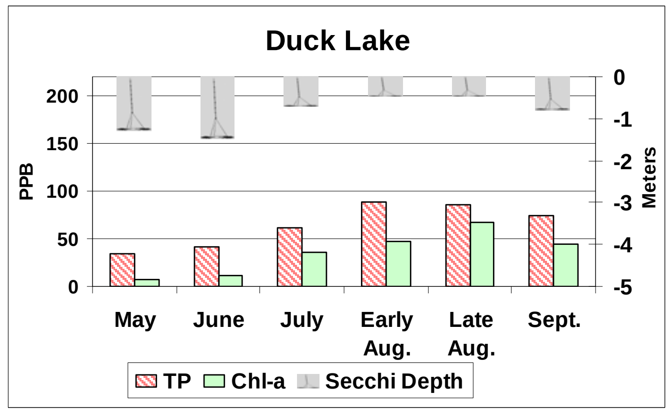
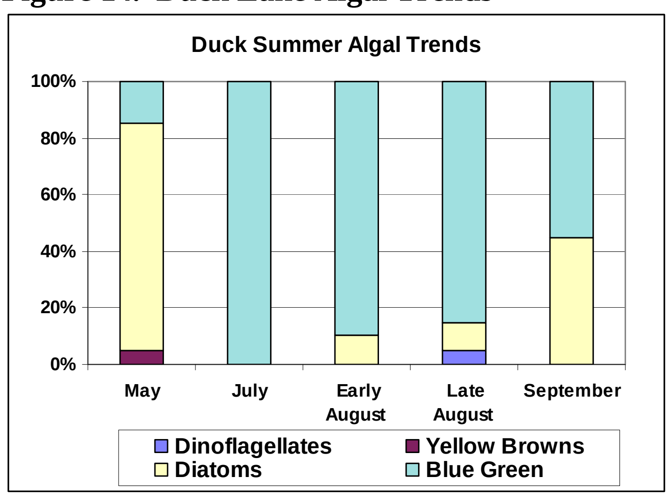


Figure 14. Duck Lake Algal Trends



Eagle Lake Results

Eagle Lake was the shallowest lake in the study based on mean depth. Low water levels throughout the summer made the south end of the lake inaccessible for monitoring. There is minimal development around the lake and much of the shoreland is covered with emergent plants. Much of the lake's south bay is surrounded by a cattail fringe.

Because of its shallowness, Eagle Lake remained well-mixed throughout the summer. Surface temperatures ranged from 15 – 27 C and peaked in early August. DO was often supersaturated near the surface and concentrations near the sediments remained above 2 mg/L.

Eagle Lake would be considered hypereutrophic based on TP, chlorophyll-a and Secchi measurements and its summer-mean values were generally above the typical range for lakes in the WCBP ecoregion (Table 3). TP concentrations were quite variable in 2006 and exhibited somewhat of a decline from May through September (Figure 16), which is not consistent with other shallow lakes. Chlorophyll-a concentrations ranged from about 50 – 100 µg/L and severe nuisance blooms would have been the norm for 2006. Secchi readings were less than 0.5 meters throughout the summer.

Blue-greens were the dominant algal form throughout the summer (Fig. 17).

Figure 15. Eagle Lake Temperature Profiles

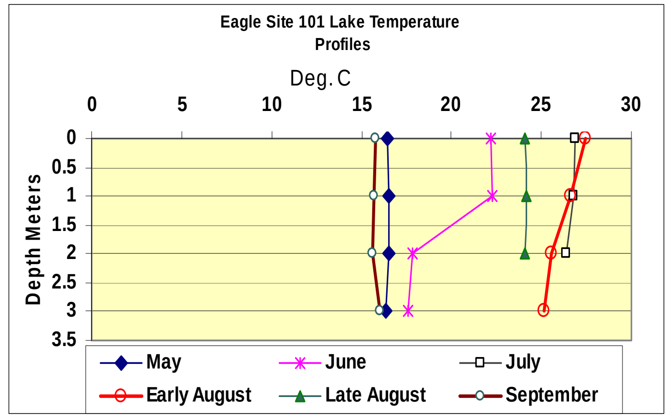


Figure 16. Summer TP, Chl-a and Secchi Depth

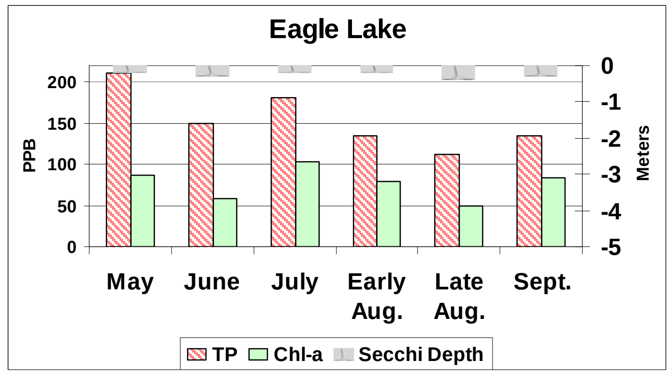
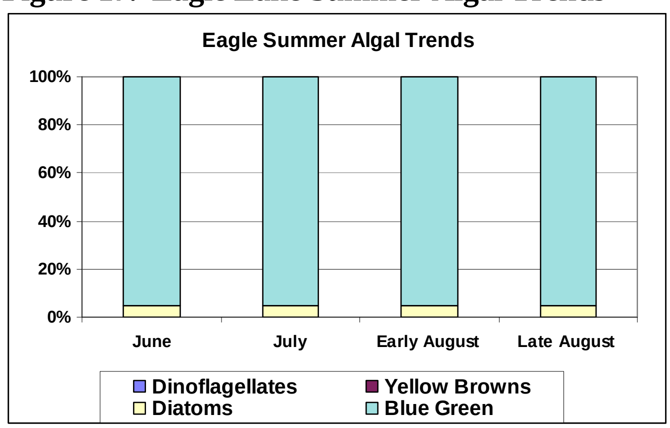


Figure 17. Eagle Lake Summer Algal Trends



Lake George

Lake George is located in the northeast corner of Blue Earth County. The lake is relatively small, with a small agriculturally-dominated watershed. Blue Earth County zoned the north and east section of the lake shore rural residence while the rest of the lake is zoned agriculture. George is a typically shaped basin with a maximum depth of 28 feet. The lake is 60 % littoral. George was among the WCBP ecoregion reference lakes (Heiskary and Wilson, 2005) and was also included in a statewide diatom-reconstruction study (Heiskary and Swain, 2002).

Lake George was weakly stratified over much of the summer (Figure x). Surface temperatures ranged from 14 to 28°C with the peak temperature occurring in early August. DO was at or near 0 mg/L below a depth of four meters over much of the summer.

Summer mean water quality values at the mid lake site are within the typical range for WCBP ecoregion lakes for all of the monitored parameters except TSS (Table 3). TP concentrations were variable with a peak in July but declining thereafter. Chlorophyll-a co-varied with TP concentrations and severe nuisance bloom conditions were common in 2006 (Figure 19). With the exception of June, Secchi depth was below 1 meter during the monitoring.

Blue-greens were the dominant algal form throughout the summer (Fig. 20) and Mycrocystis and Aphanizomenon were the most common genera.

Figure 18. Lake George Temperature Profiles

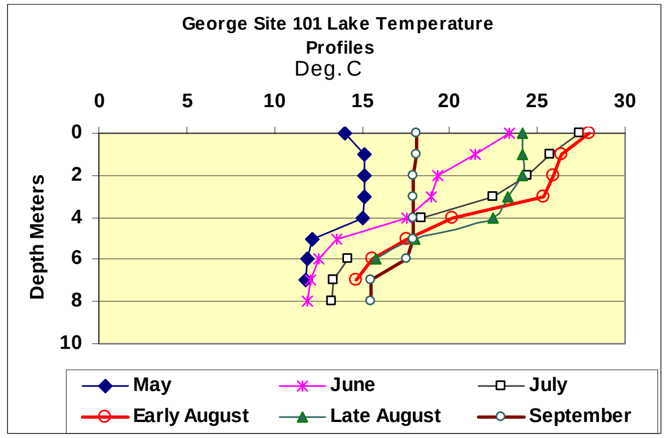


Figure 19. Lake George Secchi, Chl-a and TP

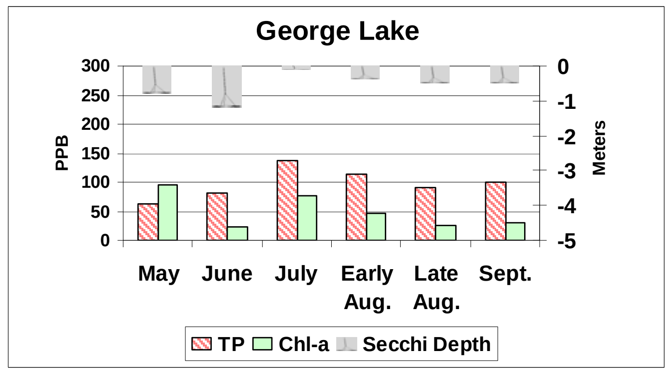
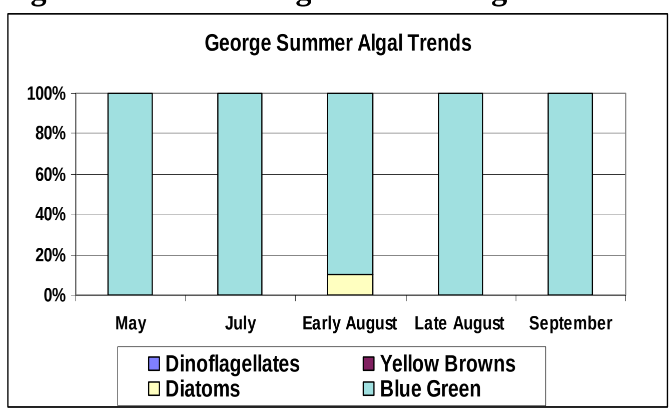


Figure 20. Lake George Summer Algal Trends



Loon Lake Results

Development is minimal around the lake. Nearly all of the lake shore of Loon is zoned conservation. Because of its extreme shallowness, Loon was well-mixed on all sample dates. Surface temperature ranged from 8°C (September) to 27° C (early August) (Figure 21).

The summer means results showed Loon Lake to be high (> 75th of the WCBP ecoregion reference lake range) for total suspended solids, total inorganic solids, and color. TP was quite variable throughout the summer and no distinct pattern was evident. Chlorophyll-a was at severe nuisance blooms levels throughout the summer (Figure 22). The high chlorophyll-a resulted in very low transparencies of 0.4 m or less.

Summer algal trends showed a mix of diatoms and blue-greens in May followed by blue-green dominance through the rest of the summer (Figure 23). The prevalent blue-green variety was *Anacystis*.

Figure 21. Loon Lake Temperature Profiles

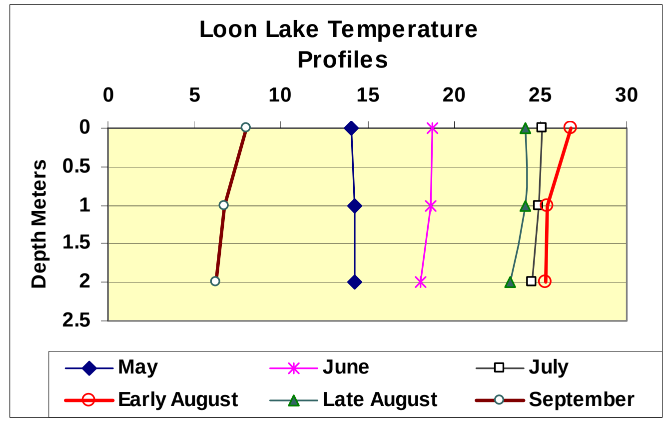


Figure 22. TP, Chl-a and Secchi Depth

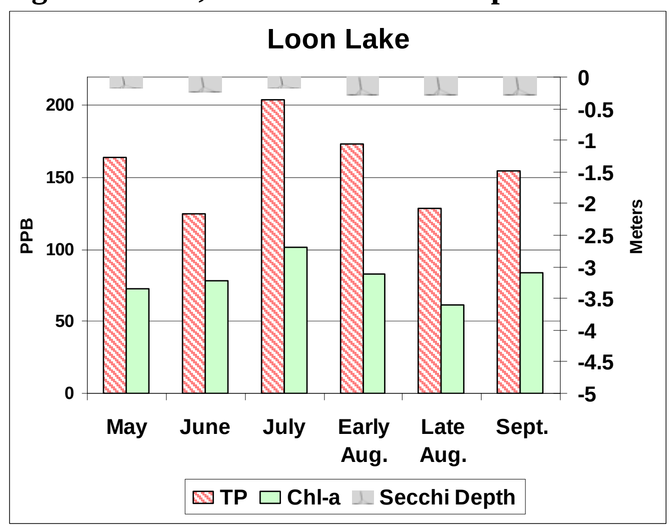
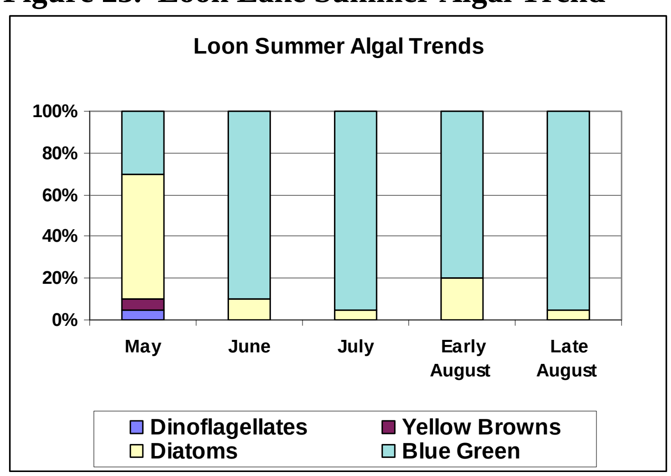


Figure 23. Loon Lake Summer Algal Trend



Madison Lake Results

Madison was one of the largest and deepest lakes in the study group. The southern portion of the lake shore is zoned conservation while the rest of the lake is a mixture of the following: rural residence, rural town site, municipality, and conservation. It has two distinct bays both having a max depth of over 30 feet. The southern bay is the deepest and was stratified from June through September. The northern bay was only temperature stratified in July and early August.

Summer-mean water quality at site 102 was in the range on the WCBP ecoregion reference lakes (Table 4). The seasonal pattern was variable, but generally declining TP from June through September is fairly consistent with that of other stratified lakes. The slight TP increase in September coincides with the onset of fall mixing. Chlorophyll-a is quite variable and severe nuisance blooms (chlorophyll-a > 30 µg/L) were common throughout the summer. Secchi was high in May, which is often the result of high zooplankton populations that serve to reduce the algal population – as evidenced by the low chlorophyll-a concentration (Figure 26).

Algal composition varied from May through September. The algal community showed a mix of diatoms and blue-greens in May followed by blue-green dominance through the rest of the summer (Figure 27**).**

Figure 24 Madison 102 Temperature Profiles

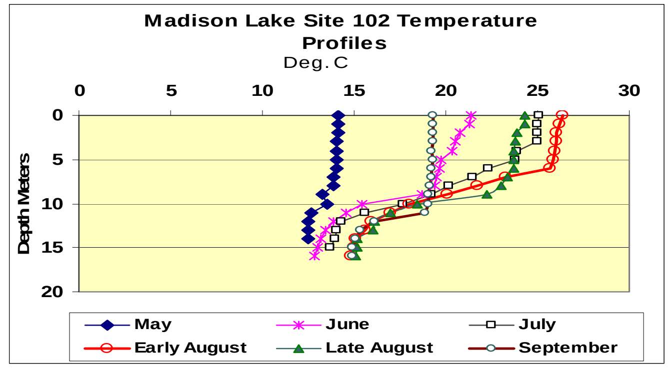


Figure 25 Madison site 101 Temperature Profiles

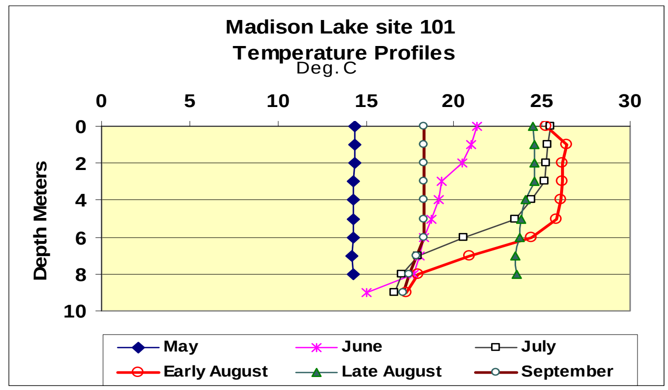


Figure 26. Madison TP, Chl-a and Secchi Depth

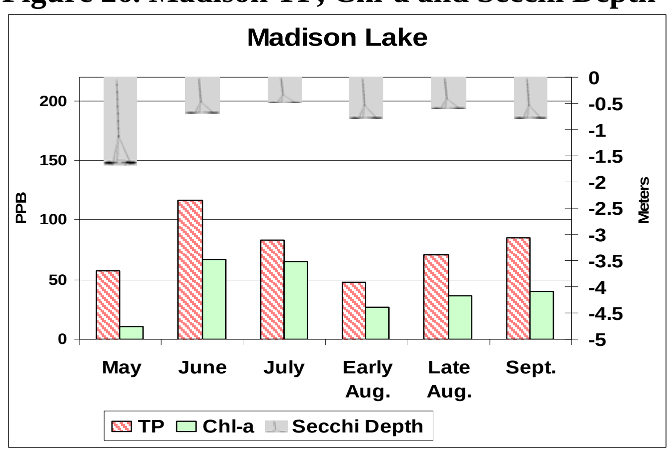
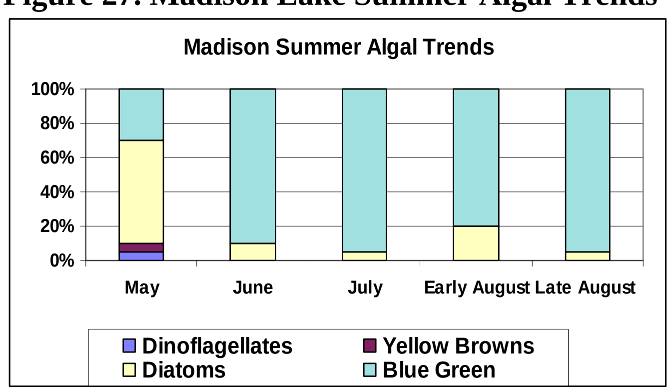


Figure 27. Madison Lake Summer Algal Trends

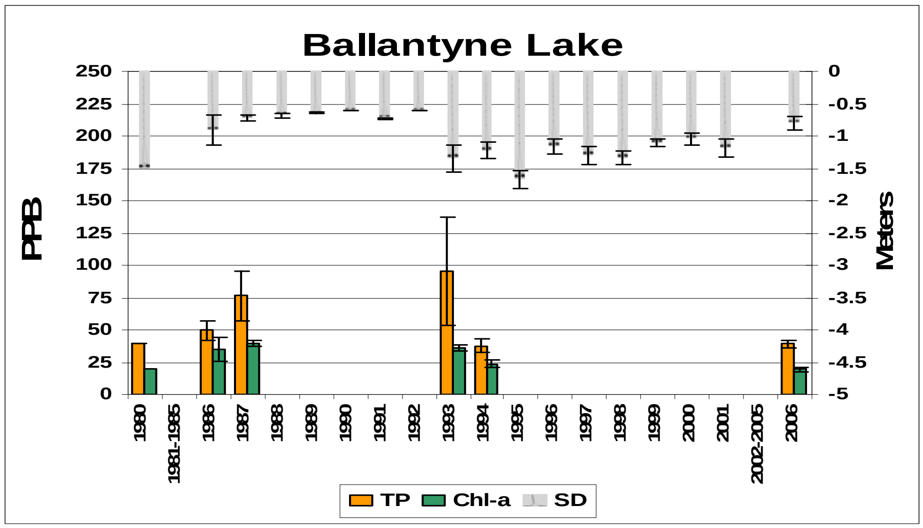


WATER QUALITY TRENDS

Ballantyne

Ballantyne has one of the longest water quality records of any lake in the study with Secchi readings taken on the lake as far back as 1950. The majority of the Secchi readings were taken at the 202 and 203 sites. Transparency results among the two sites are virtually identical. Transparency depth readings declined until 1992 (Figure 28). Summer mean transparency readings were generally stable from 1993 – 2001. TP and Chl-a results are variable among years with readings dating back to 1990 (Fig. 28). No other trend is evident. TP and Chl-a in 2006 was comparable to concentrations measured in 1990 & 1994.

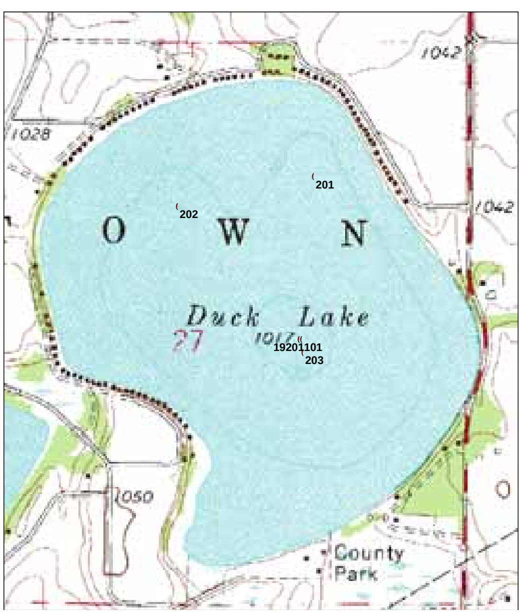
Figure 28 Ballantyne Summer Mean Water Quality Trend and Sampling Locations

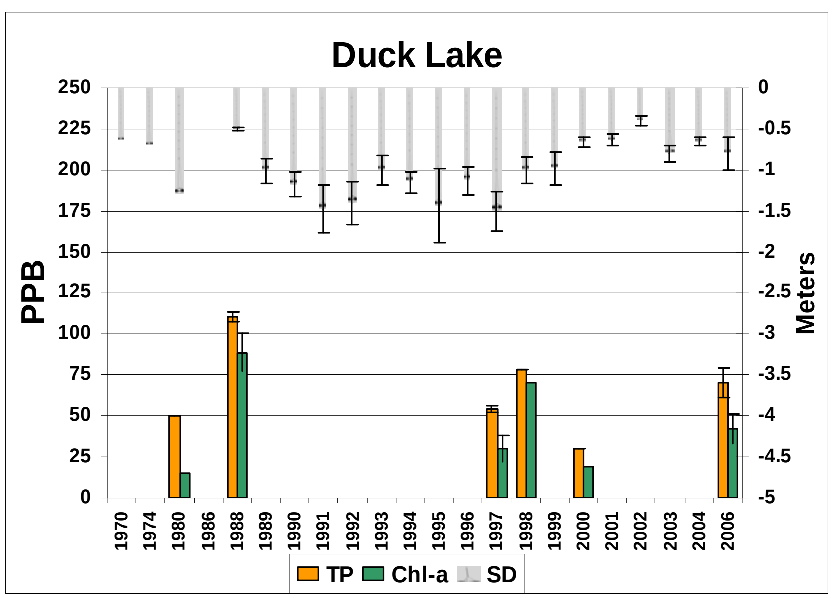


Duck

Water quality records on Duck Lake go back to 1970. A significant decrease in transparency was observed from 1997-2002. TP and Chl-a are quite variable and no consistent trend is evident.

Figure 29. Duck Summer Mean Water Quality Trend and Sampling Locations

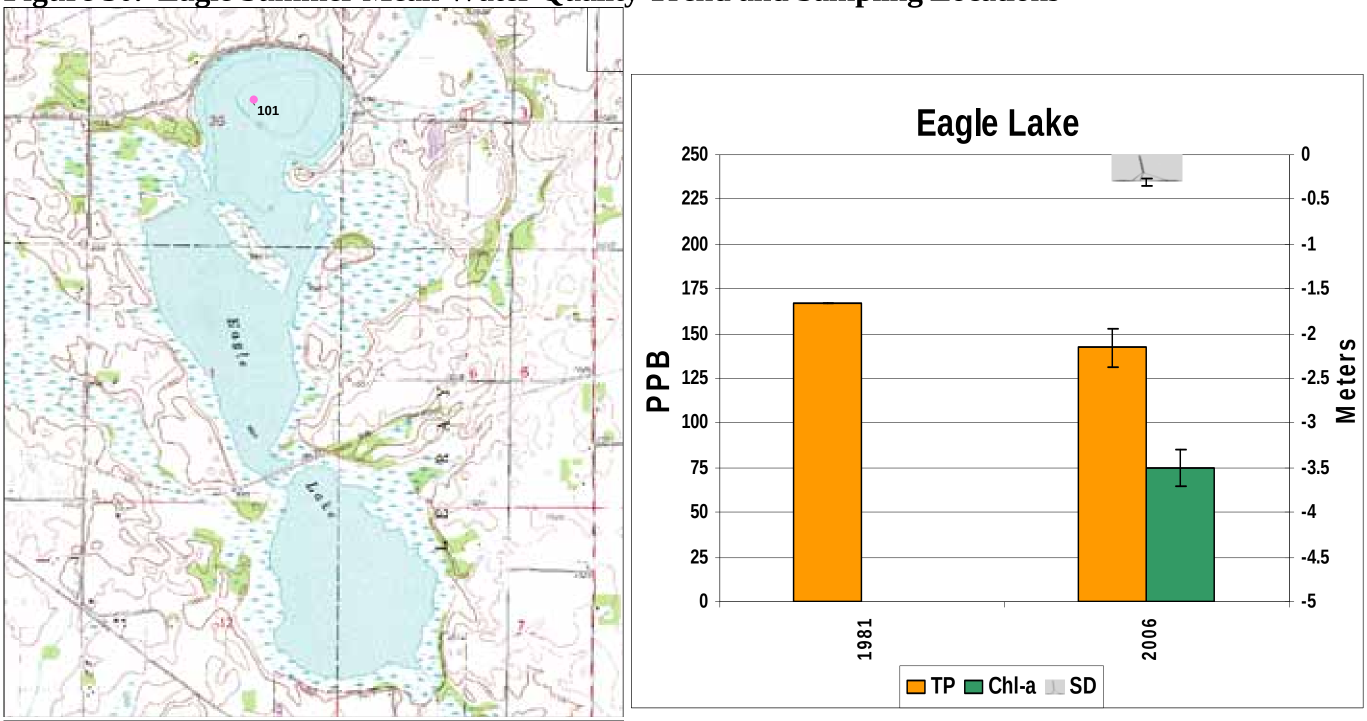




Eagle Lake

Only one additional water quality record was found on Eagle Lake, a single summer TP measurement of 167 ppb. The result was similar to 2006 observations.

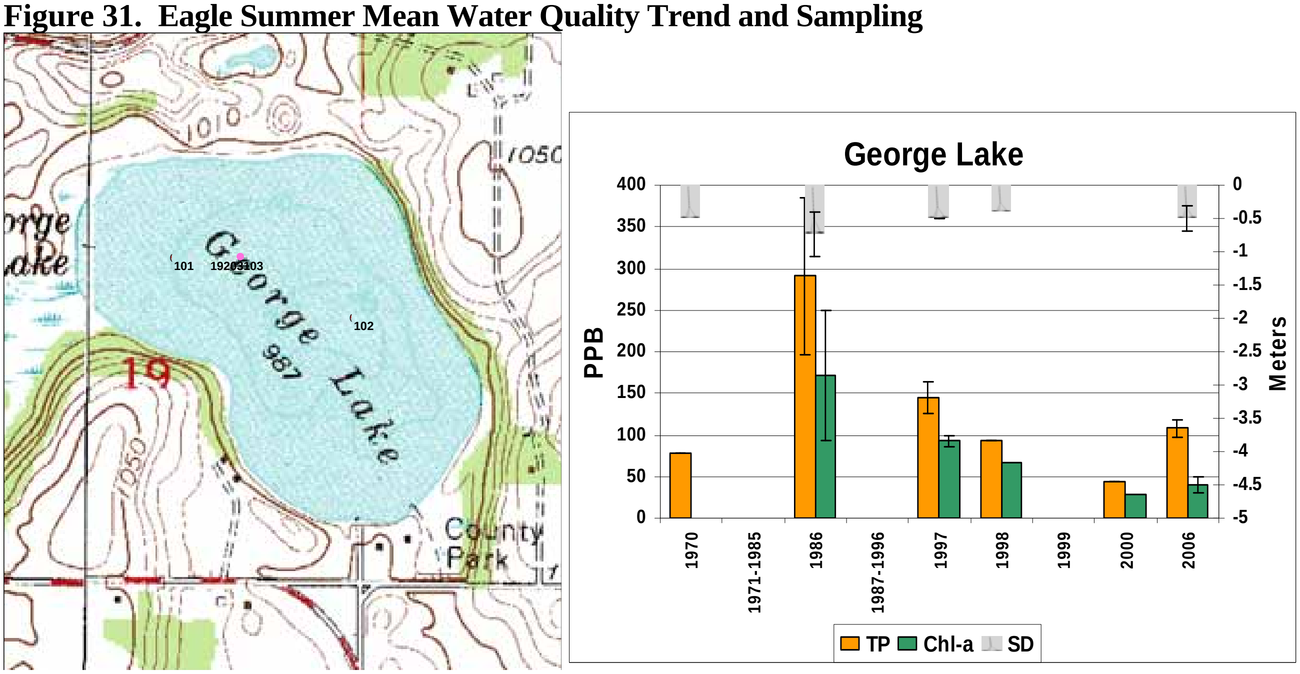
Figure 30. Eagle Summer Mean Water Quality Trend and Sampling Locations



Lake George

Water quality records for Lake George go back to 1970. The majority of the monitoring was done at the 101 and 102 sites. TP and Chl-a exhibit a declining trend from 1986 to 2000.

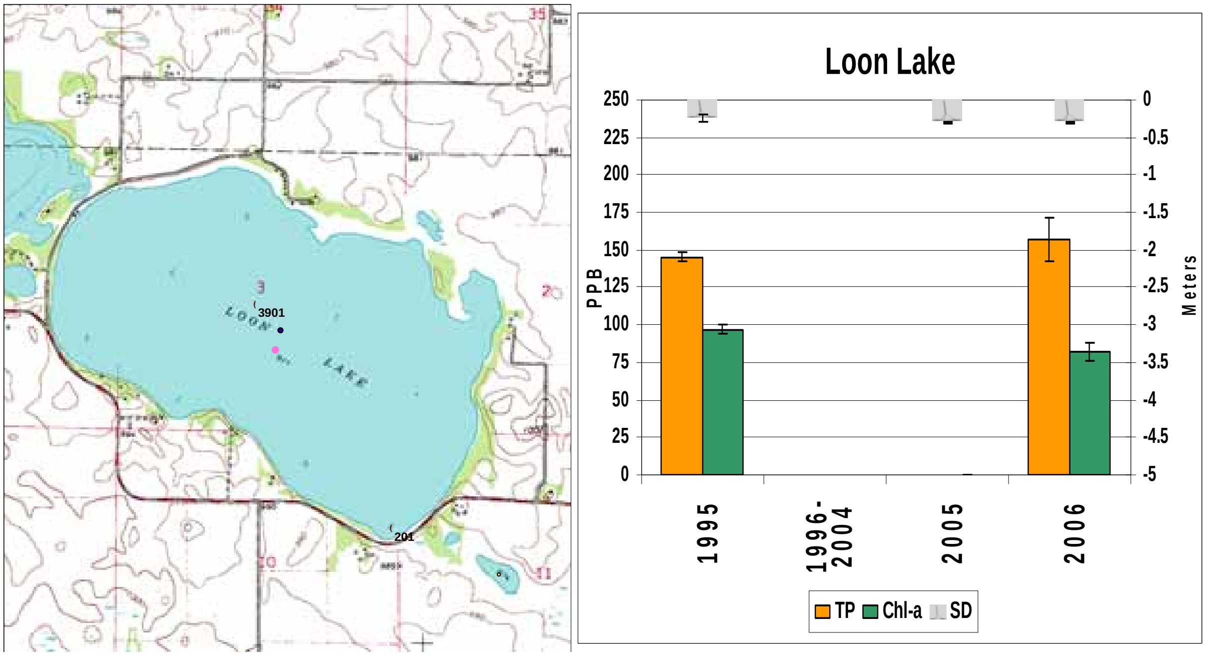
Figure 31. Eagle Summer Mean Water Quality Trend and Sampling



Loon

Only two years of additional lake monitoring data was found for Loon Lake (1995 and 2005). 2006 Chl-a and TP results were similar to 1995 (Figure 32).

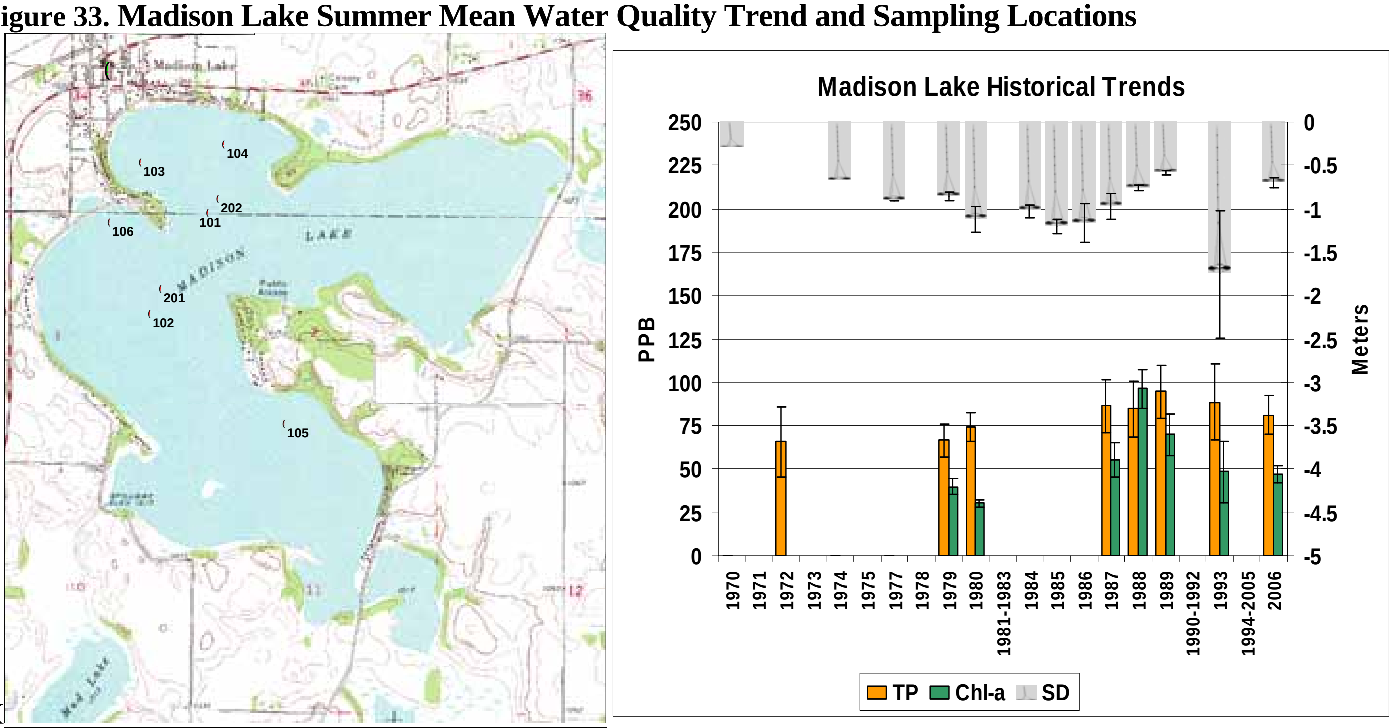
Figure 32. Loon Lake Summer Mean Water Quality Trend and Sampling Locations



Madison

Water quality monitoring data for Madison Lake goes back to 1947. The 101 and 102 sites have a significant amount of monitoring results, showing similar conditions. Transparency has been monitored at a total of seven sites. The most readings and the highest transparency average were found at the 201 site (Figure 33). There is a significant break in the CLMP record so it is hard to discern trends for this lake. TP and Chl-a are variable and no trend is evident.

Figure 33. Madison Lake Summer Mean Water Quality Trend and Sampling Locations



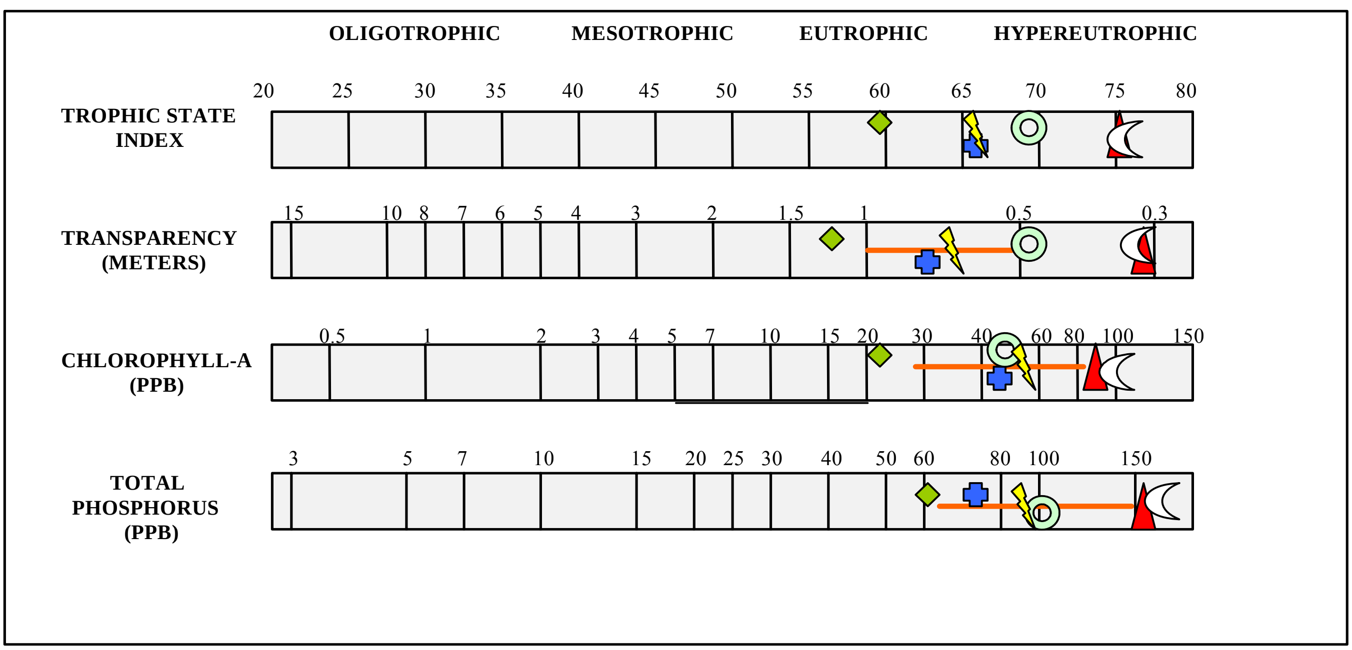
X

Trophic Status

Determining a lakes eutrophication status is typically done using the Carlson Trophic State Index (TSI). The index combines the Secchi, Chl-a and TP summer means values into an eutrophication index number. TSI indexes based on TP, Chl-a and Secchi corresponded fairly close on all six lakes. Calculated TSI's values for the lakes ranged between 60 and 75 (Figure 34).

FIGURE 34. Carlson's Trophic State Index for study Lakes
R.E. Carlson

TSI < 30	Classical Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.
TSI 30 - 40	Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.
TSI 40 - 50	Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.
TSI 50 - 60	Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.
TSI 60 - 70	Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.
TSI 70 - 80	Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.
TSI > 80	Algal scums, summer fish kills, few macrophytes, dominance of rough fish.

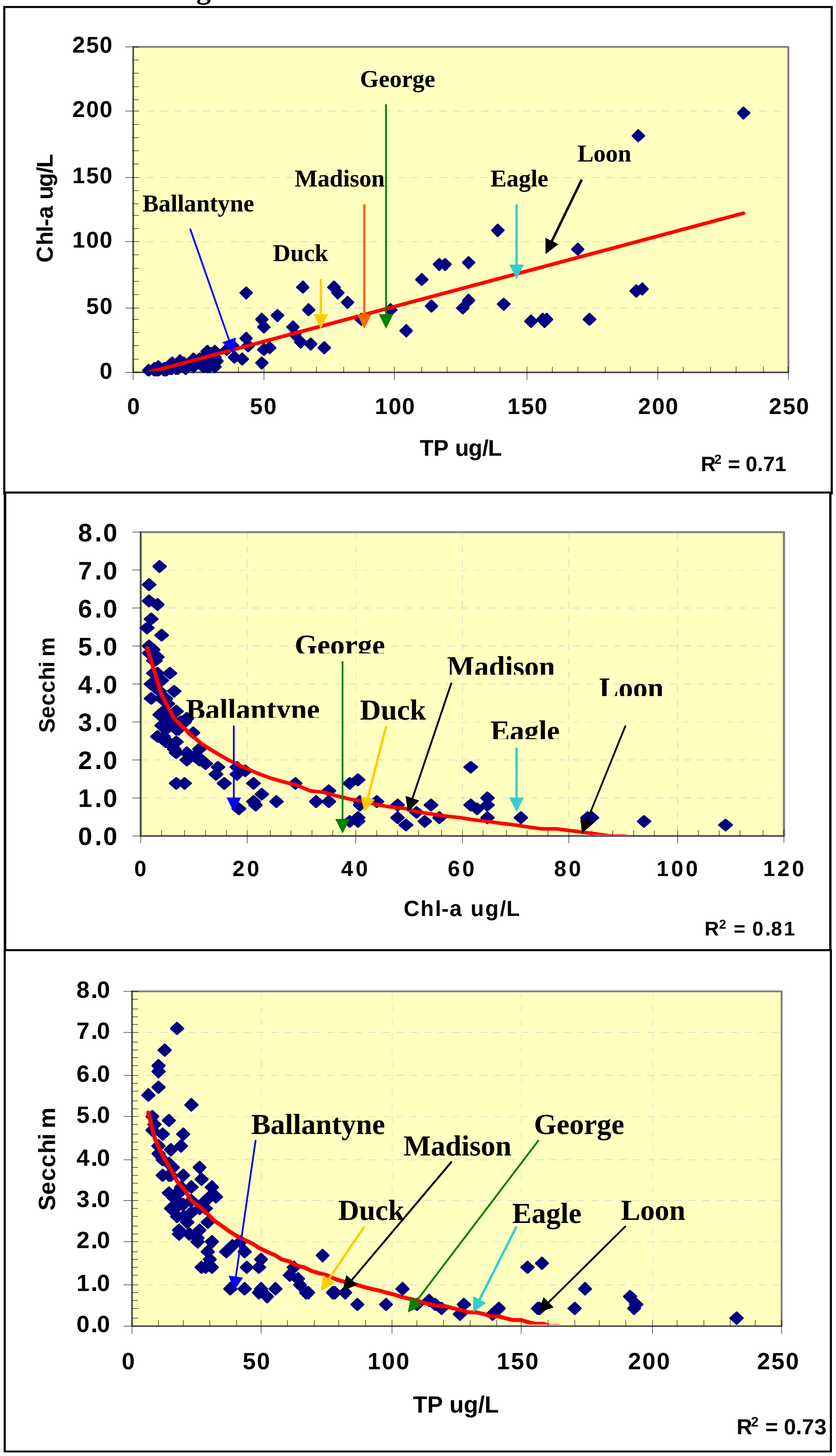


<u>After</u> Moore, l. and K. Thornton, [Ed.]1988. Lake and Reservoir Restoration Guidance Manual. USEPA>EPA 440/5-88-002.
WCBP Ecoregion Range: ———
Ballantyne Duck Eagle George Loon Madison

TP, Chl-A and Secchi Relationships

Another approach to comparing summer mean TP, Chl-a and Secchi relationships to other lakes is to graphically plot them along with other lake data. Summer mean Chl- a and TP relationships were similar to those seen on other lakes.

Figure 35. Total Phosphorus, Chlorophyll-a, and Secchi Scatter Plots and Regressions Based on Reference Lake Data



MODELING

Table 5. Background TP and Water Residence Time.

	Chiaudani/Vighi Estimated Background TP	Residence Time in Years
Ballantyne	32.	1
Duck	30	6
Eagle	38	2
George	28	4
Loon	33	3
Madison	27	2

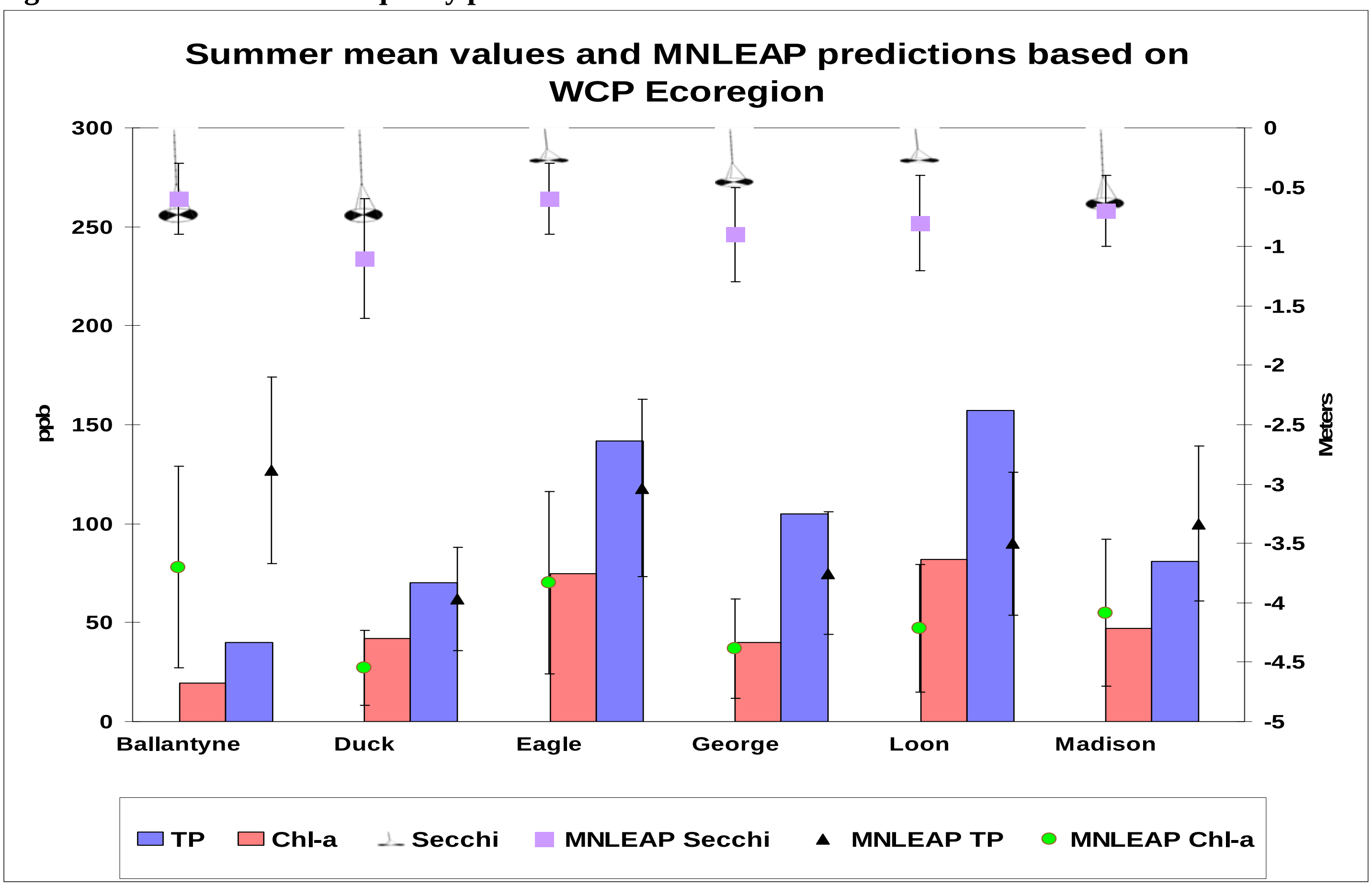
A water quality model was used to predict water quality based on morphometry, watershed characteristics, location and other environmental conditions. Note that groundwater is not considered in this modeling effort, as no measurements are available.

The model used known as 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).

A calculation included in MINLEAP provides an estimate of the background Phosphorus for the lake based on equations developed by Vighi and Chiadudani (1985). This equation is based on the morphoedaphic index, which has been used to estimate fish productivity. The Vighi and Chiadudani equation uses alkalinity and mean depth to predict background TP. All lakes, with the exception of Ballantyne, were significantly above background (Fig. 36)

The MINLEAP model also estimates lake water residence time. Residence time is the amount of time it would take to replenish the water in a lake had all the water been removed. These calculations are made using lake morphometry and watershed size. These results show water moves relatively quickly through Ballantyne and Eagle.

Figure 36. MINLEAP water quality prediction and Summer Mean Results



MINLEAP Results

In general, model predicted TP and Chl- a on the lakes was comparable to observed with the exception of Ballantyne and Loon. On Loon Lake the model under predicted Chl-a and over predicted transparency. On Lake Ballantyne TP and Chl-a were over predicted. Some of the possible variance between model prediction and observed summer mean values include:

- The actual portion of the watershed that drains to the lakes may be much smaller than the mapped area because of non-contributing wetlands and/or lakes, which could result in lower than predicted TP loads.
- The TP loading to the lake is much higher than predicted by the model.
- P retention in the upstream lakes is not adequately addressed in a simple model such as MINLEAP.
  The model does show that Duck, Eagle, George and Madison lakes water quality was similar to other lakes in the WCBP ecoregion relative to their watershed and mean depth

GOAL SETTING

Impairments Listing

The draft eutrophication standards (Table 6) will come into effect in 2008. They will be used in the 2010 impaired waters 303 (d) assessment which will consider data from 1999-2008. Water quality impairments will be based 10 or more results averaging above the criteria value. If the values exceed the TP, and either the Chl-a or Secchi criteria it is considered impaired and is placed on the 303 (d) list, that is submitted to USEPA every two years. The deadline for data to be considered for the next impairment cycle (2010) listing will be December of 2008. There are separate criteria for shallow lakes, which are defined as lakes with a maximum depth of 15 feet or less or 80% or more of the lake is littoral. Madison and George lakes are among the study lakes that did not meet the shallow lake definition. Duck Lake is the only lake within the study group to have met the requirements to be put on the 2008 303 (d) list for eutrophication impairment. Other lakes in the study such as Madison, George, Eagle and Loon would likely meet the criteria with additional observations. On the 303 (d) list a schedule for developing the TMDL is made. Funds are made available to local units of government to conduct the TMDL study. Thus, it would prove beneficial for lakes with minimal observations to achieve the minimum of 10 by September of 2008. More information can be found on this lake impairment listing process can be found at http://www.pca.state.mn.us/publications/reports/lrwq-iw-2sy04.pdf.

Table 6. Eutrophication Criteria by Ecoregion and Lake Type

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 7. Summary of existing impairment data from study lakes

	TP Count	TP Mean	Chl-a Count	Chl-a Mean	Secchi Count	Secchi Mean
Madison	4	82	5	50	23	1
George	9	109	9	65.3	8	0.5
Duck	17	116	9	45.8	128	0.9
Ballantyne	5	40	5	18.2	62	1.2
Eagle (North)	5	157	5	79.1	5	0.3
Loon	5	152	5	72.9	19	0.3

Lake Improvement and Protection

A continued effort to protect these lakes from further degradation is strongly recommended. Some important considerations for improving and protecting the water quality of the lake include

- A more comprehensive review of land use practices in the watershed
- Implementation of BMP's in the shoreland area and ultimately through the watersheds
- Proper maintenance of buffer areas between lawns and the lakeshore
- Minimizing use of fertilizers
- Ensure septic systems are maintained and up to code
- Reduce other Phosphorous loading into the lakes (e.g., stormwater from near-shore development activities in the watershed)
- Raise public awareness on the condition of these lake
- Property owners and community to take ownership in the quality of these lakes

These considerations will be important in improving the water quality of these Blue Earth county lakes as well as maintaining them over the long term. .The improvement and protection of the lakes is essential not only for the future of the lakes, but the community as well. This is well stated by Krysel, et al (2003) "The evidence shows that management of the quality of lakes is important to maintaining the natural and economic assets of this region."

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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
TP at Depth = total phosphorus in mg/l at deep sites with temperature stratification 2 feet above sediments.
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
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

Appendix C Data

Lk. Name	Date	TP µg/L	TP at Depth µg/L	Chl a µg/L	Secchi meters	Pheo µg/L	TKN mg/L	TSS mg/L	TSV mg/L	Cl mg/L	Color
Ballantyne	5/17/2006	31	32	4.51	1.8	1.78	0.83	2.4	1.2	17	10
	6/13/2006	40	159	11.7	1.2		1.23	8.4	4.8	19	20
	7/11/2006	48		18.5	0.6	1.99	1.31	13	7.2	19	20
	8/7/2006	34	133	23.5	0.6	2	1.54	9.7	6	19	10
	8/28/2006	33	117	20.8	0.8	2.99	1.5	8	5.2	20	10
	9/12/2006	44		22	0.9	3.79	1.58	11	5.2	20	10
Duck	5/17/2006	35	36	7.28	1.3	1.28	0.9	6.4	3.6	20	10
	6/14/2006	42	82	12	1.5		1.01	5.3	4	21	10
	7/11/2006	61		35.4	0.7	3.79	1.28	11	8.7	21	10
	8/7/2006	89	335	46.9	0.5	15.8	1.92	15	10	21	10
	8/28/2006	86	95	66.8	0.5	7.05	1.82	18	15	22	10
	9/12/2006	74	78	44.8	0.8	6.56	1.45	14	10	22	10
Eagle	6/14/2006	150	174	58.3	0.3		2.66	36	26	18	30
	7/11/2006	181		104	0.2	7.94	3.51	66	48	18	30
	8/7/2006	134		79.5	0.2	10	3.17	40	32	19	30
	8/28/2006	112		50.1	0.4	6.17	2.94	31	28	20	30
	9/12/2006	134		84.1	0.3	8.08	3.31	41	32	21	30
George	5/17/2006	63	77	32.4	0.8	2.33	1.32	16	8.8	14	20
	6/13/2006	82	104	22.8	1.2		1.46	11	11	15	30
	7/11/2006	137		76	0.1	7.18	2.95	39	30	16	30
	8/7/2006	114	118	45.6	0.4	3.85	2.17	34	23	16	20
	8/28/2006	90	131	25.2	0.5	4.41	1.64	15	12	16	20
	9/12/2006	100		29.2	0.5	5.34	1.67	17	11	16	20
Loon	5/17/2006	168		72.5		3.74	3.28	78	41	23	10
	6/13/2006	125		78.4	0.25		2.97	54	32	24	20
	7/11/2006	204		102	0.2	3.2	3.43	80	54	23	20
	8/7/2006	173		83.4	0.3	3.58	3.02	62	42	23	20
	8/28/2006	129	130	61.9	0.3	4.04	2.54	22	18	25	10
	9/12/2006	155		83.7	0.3	13	2.72	59	40	25	10
Madison	5/17/2006	57	50	10.7	1.7	6.77	1.22	7.6	2.8	20	20
	6/13/2006	117	305	66.9	0.7		2.25	11	9	20	20
	7/11/2006	83		64.7	0.5	15.2	1.8	12	10	20	20
	8/7/2006	48	634	27.2	0.8	5.49	1.53	6.4	5.2	21	20
	8/28/2006	71	602	35.9	0.6	7.88	1.57	8.8	7.2	21	20
	9/12/2006	85	1100	39.7	0.8	6.62	1.78	12	8.4	21	10