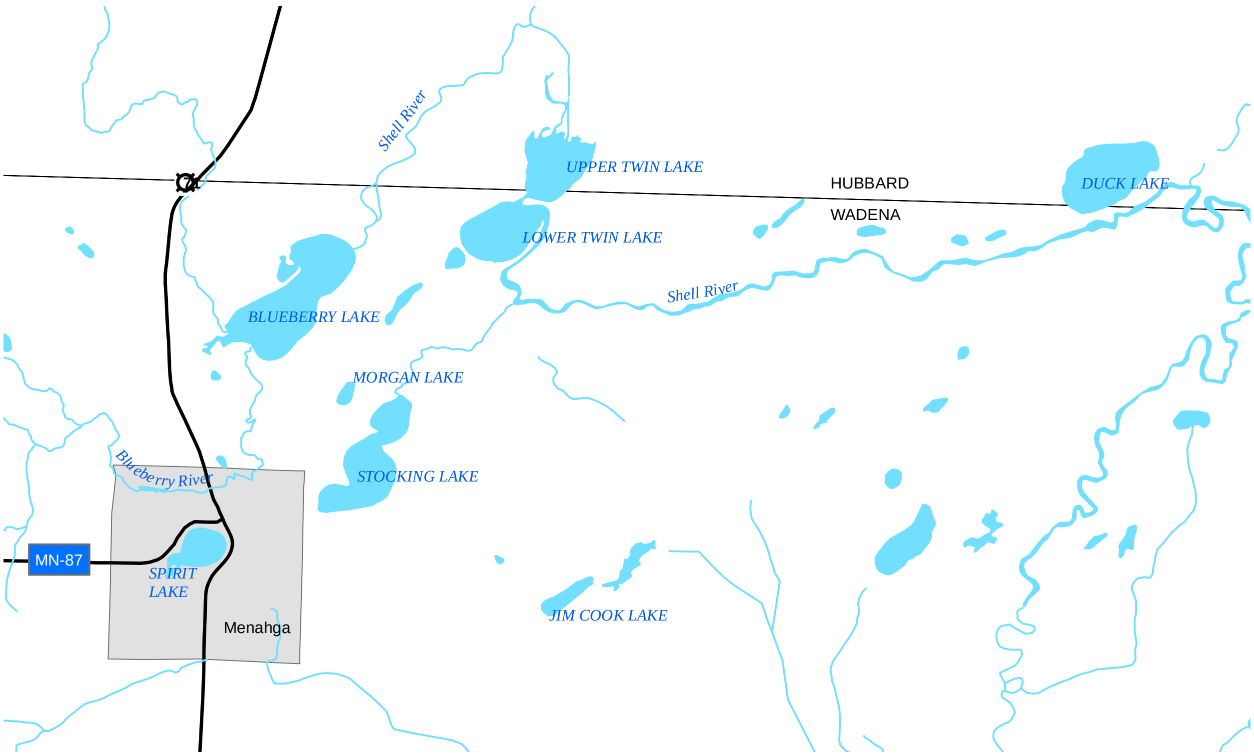
Citizen Lake-Monitoring Program (CLMP+): Advanced Volunteer Lake Monitoring in Wadena and Hubbard Counties



Minnesota Pollution Control Agency

January 2006

Citizen Lake-Monitoring Program (CLMP+): Advanced Volunteer Lake Monitoring in Wadena and Hubbard Counties

Blueberry Lake	**(80-0034)**
Duck Lake	**(29-0142)**
Jim-Cook Lake	**(80-0027)**
Morgan Lake	**(80-0038)**
Upper Twin Lake	**(29-0157)**
Lower Twin Lake	**(80-0030)**
Spirit Lake	**(80-0039)**
Stocking Lake	**(80-0037)**

Minnesota Pollution Control Agency

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Part 1: Program History and Background Information on Minnesota Lakes

Minnesota's Citizen Lake-Monitoring Program (CLMP) is the largest and oldest volunteer lake-monitoring program in the country. Volunteers in the CLMP currently use a Secchi disk to measure the clarity on hundreds of Minnesota's lakes. The expanded program, including the collection of water chemistry samples for analysis along with Secchi transparency collection, was conducted in Douglas, Hubbard, Kandiyohi, Wadena and Wright Counties. Four lakes within Wadena County and two lakes in Hubbard County were selected for monitoring in 2005. These lakes were: Blueberry, Duck, Jim-Cook, Morgan, Upper Twin and Lower Twin. All equipment and analytical costs for the samples were provided for and paid by the Minnesota Pollution Control Agency (MPCA). Two additional lakes were monitored, Spirit and Stocking Lakes, by the City of Menahga and Spirit Lake Associations and Stocking Lake Association, respectively. The data for these two lakes is also included in this report.

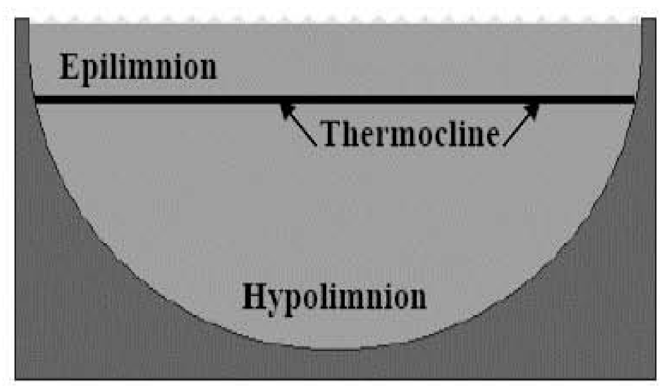
Volunteers on these lakes collected water chemistry samples and temperature profiles twice per month along with their weekly Secchi transparency readings. After sampling, the volunteers dropped off their samples at a predetermined location within their county. Kari Tomperi, Wadena County Soil and Water Conservation District (SWCD), helped plan and coordinate the sample drop-off/pick up schedule for the samples in Wadena and Hubbard Counties. Special thanks to the volunteers in Wadena and Hubbard County who helped make this project a success: Leofwin "Lefty" Lindblom (Blueberry, Jim-Cook, Morgan, and Spirit Lakes), Dewayne Mead (Duck Lake), Mark Hepokoski (Stocking Lake), and Don Broughton (Lower and Upper Twin Lakes). MPCA staff and volunteer monitors collected quality assurance and quality control (QA/QC) samples for this project. A special thanks to Paul Hanson and the entire staff of Emmaus Bible Camp for providing canoes and access to Morgan Lake via their property.

The MPCA core lake-monitoring programs include the CLMP, the Lake Assessment Program (LAP), and the Clean Water Partnership (CWP) Program. In addition to these programs, the MPCA annually monitors numerous lakes to provide baseline water quality data, provide data for potential LAP and CWP lakes, and characterize lake conditions in different regions of the state. MPCA also examines year-to-year variability in ecoregion reference lakes and provides additional trophic status data for lakes exhibiting trends in Secchi transparency.

Lake depth can have a significant influence on lake processes and water quality. One such process is *thermal stratification* (formation of distinct temperature layers, see Figure 1a), in which deep lakes (maximum depths of 30 - 40 feet or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 1c). These lakes full-mix or turn-over twice per year; typically in spring and fall (Figure 1d). Shallow lakes (maximum depths of 20 feet or less) in contrast, typically do not stratify and are often referred to as *polymictic* (Figure 1b). Some lakes, intermediate between these two, may stratify intermittently during calm periods. Measurement of temperature throughout the water column (surface to bottom) at selected intervals (e.g. every meter) can be used to determine whether the lake is well-mixed or stratified. It can also identify the depth of the thermocline (zone of maximum change in temperature over the depth interval). In general, the upper, well-mixed layer (epilimnion) is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. Most of the fish in the lake will be found in the epilimnion or near the thermocline. The combined effect of depth and stratification can influence overall water quality.

Figure 1. Diagrams of Lake Layers and Mixing

a.



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

Wind

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

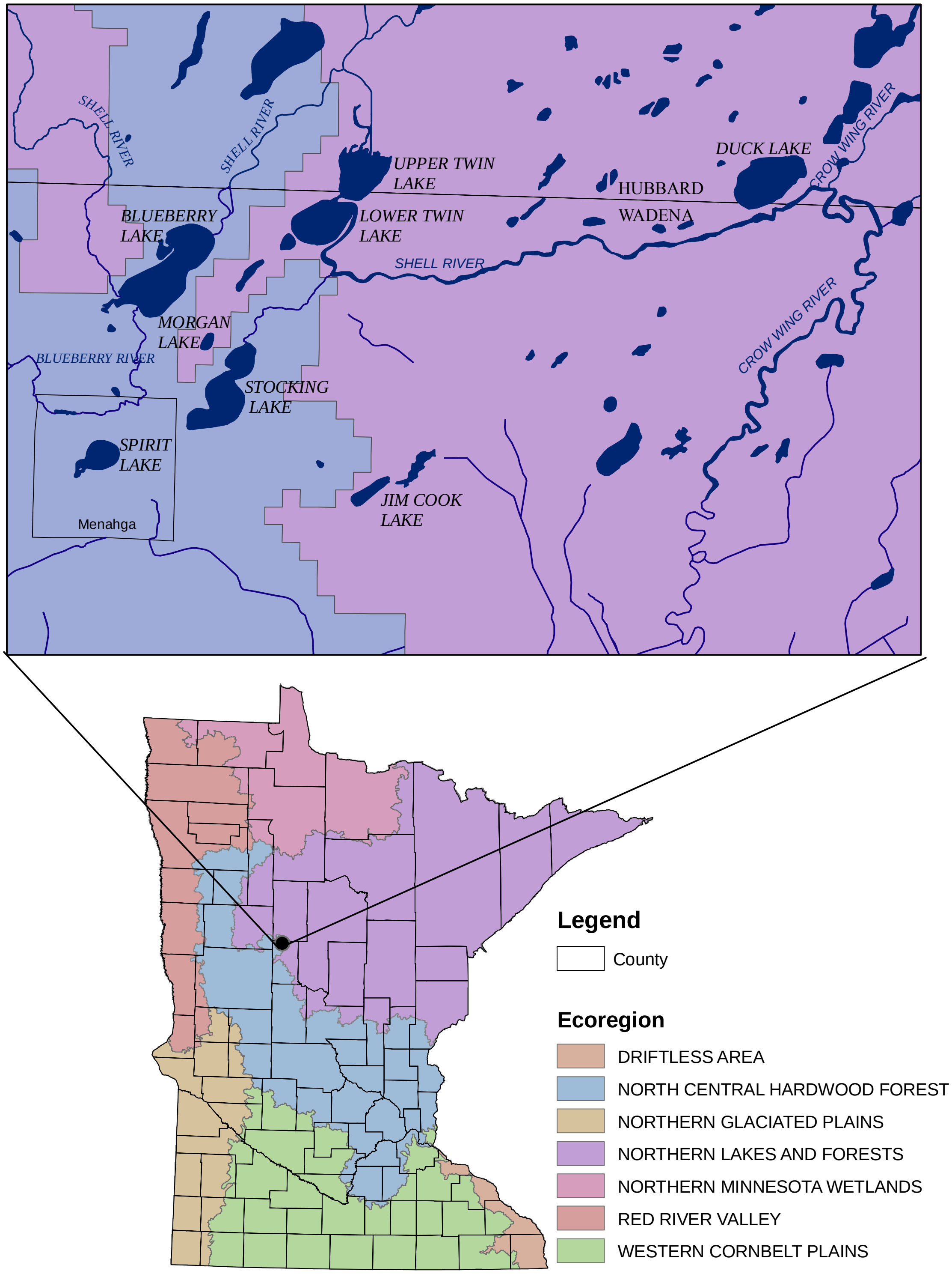
Wind

Epilimnion
Metalimnion
Hypolimnion

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

Wind

Figure 2. Lake Locations and Ecoregion Map



The state of Minnesota is divided into seven ecoregions (Figure 2), based on soils, landform, potential natural vegetation, and land use. All of the lakes monitored for this study are located in the transition zone between the Northern Lakes and Forest (NLF) and the North Central Hardwoods Forests (NCHF) ecoregions. Comparing a lake's water quality to that of reference lakes in the same ecoregion provides one basis for characterizing the condition of the lake. A lake of good water quality would have Secchi, Total Phosphorus, and Chlorophyll-*a* concentrations equal to, or better than, the range of values calculated based on minimally impacted reference lakes in their respective ecoregion. Given these lakes are located near the transition of the two ecoregions, reference lake data for both will be referred to in the discussion (Table 1).

The lakes studied in Wadena and Hubbard Counties in 2005 were of either very large, connected watersheds, or of small, rather isolated watersheds. The Kettle and Blueberry Rivers connect just upstream of Menahga, and with the Shell River flow into Blueberry Lake. This watershed alone is over 200 mi^2. The Shell River outlets Blueberry Lake to the north and connects with the Fish Hook River (which also drains over 200 mi^2) before reaching Upper Twin and Lower Twin Lakes. As a result, these relatively small lakes have a tremendous watershed, covering just less than 600 mi^2. This large drainage area will heavily influence the residence times and the available nutrients to the lake. Morgan, Jim Cook, Stocking, Spirit, and Duck Lakes drain much smaller areas (watersheds range from less than 1mi^2 to 14 mi^2) and are rather isolated from one another. Considering this, it is likely that these lakes with have much longer residence times and likely receive much fewer nutrients from runoff.

Precipitation for 2005 for the Menahga area is summarized in Appendix 2. June was characterized by frequent, small events, while August was a rather dry month, with only 2.2" inches of rainfall. Significant rainfall events (greater than 1") occurred on May 25th (2.35"), July 12th (3.98"), and September 12th (1.2"). These major events can have a strong influence on runoff and total phosphorus loading to the lakes. Water year data (October 2004 – September 2005) obtained from the MDNR indicated that rainfall was 2 – 4 inches above normal, with the area receiving approximately 30 inches of rain.

Part 2: 2005 Lake Surveys

Methods

This report includes data from 2005 as well as previously collected data available in STORET, U.S. Environmental Protection Agency's (EPA) national water quality data bank (Appendix). The following discussion assumes familiarity with basic limnology terms as used in a "Citizens Guide to Lake Protection" (http://www.pca.state.mn.us/water/lakeprotection.html) and in LAP reports. A glossary of terms is included in the appendix and can also be accessed at http://www.pca.state.mn.us/water/lakeacro.html.

One site in each lake was monitored twice per month, from June through September. Lake surface samples were collected with an integrated sampler, constructed from a PVC tube 6.6 feet (2 meters) in length with an inside diameter of 1.24 inches (3.2 centimeters). Lake-bottom samples were collected 1 meter off the bottom of the lake by MPCA staff using a Kemmerer sampler. Seasonal averages were calculated using June – September data. Sampling procedures were employed as described in the MPCA Quality Control Manual and Citizen Lake-Monitoring Program "Plus" Manual. Laboratory analyses were performed at the Minnesota Department of Health using EPA-approved methods. Surface samples from volunteers were analyzed for: total phosphorus (TP), chlorophyll-*a*, and pheophytin. Secchi disk transparency and user perception information was recorded at all sites. Volunteers also collected temperature profiles for each site using a FishHawk Model 520 digital depth and temperature meter. Algae samples were collected from the chlorophyll-*a* sample bottles and preserved with Lugol's solution.

MPCA staff collected surface samples and bottom samples for each site on three occasions. These data serve to augment the volunteer collection and provide an opportunity for comparison of results. MPCA collected surface samples were analyzed for the following parameters: TP, chlorophyll-*a*, pheophytin, total Kjeldahl nitrogen (TKN), total suspended solids (TSS), suspended volatile solids (SVS), total chloride, alkalinity and color. Conductivity, pH, and dissolved oxygen and temperature profiles were collected using a Hydrolab multi-probe unit. Lake-bottom samples were analyzed for TP. Secchi disk transparency and user perception information was recorded for each site. Qualitative analysis of zooplankton collected using a zooplankton net was also recorded for each site.

Additional information, such as bathymetric (contour) maps, site locations, and aquatic vegetation surveys, was obtained from the DNR's lakefinder Web site (http://www.dnr.state.mn.us/lakefind/index.html), the MPCA Web site (http://www.pca.state.mn.us), and from U.S. Geological Survey quad maps. Watershed area information for the lakes was obtained from the U.S. Geological Survey web site (http://gisdmnspl.cr.usgs.gov/watershed/index.htm).

Data Analysis

A series of graphs are presented for each lake including: TP, chlorophyll-*a*, Secchi disk transparency, and temperature profiles. Dissolved oxygen and algal composition were also graphed on lakes where data was available. Sample dates with a single asterisk indicate data collected by the MPCA. Dates with no asterisk were collected by CLMP volunteer lake monitors. Dates with a double asterisk were collected by the City of Menahga. All raw data for each lake and site are available in the appendix.

The Quality Assurance/Quality Control (QA/QC) samples were taken routinely throughout the sampling season. Thirteen field duplicate TP samples were taken. A field duplicate is a second sample taken right after an initial sample in the exact same location. Field duplicates assess the sampler's precision, laboratory precision, and possible temporal variability. The duplicate sample should be collected in the exact same manner as the first sample, including the normal sampling equipment cleaning procedures. Of these 13 samples, the percent difference ranged from 0 – 33 percent of the original sample, with the majority (77 %) falling within the 0 – 15 percent range. Of the 12 paired chlorophyll-*a* samples, the percent difference range was 2 – 16 percent, with the majority (83 %) falling within the 0 – 15 percent range. These results are very good considering the difference in quality of the participating lakes and varying concentration levels of these parameters. Four TP sample results from the following lakes were omitted due to sample contamination from adding Lugol's solution instead of sulfuric acid preservative: Duck Lake (Hubbard County), Upper Twin Lake (Hubbard County), Lower Twin Lake (Wadena

County), and Pleasant Lake (Wright County). One chlorophyll-*a* sample from Duck Lake (Hubbard County) was also omitted due to sample contamination from Lugol's.

Several TP samples from early June, for the CLMP+ lakes, were held for one week longer than the recommended holding time due to the 2005 government shutdown. However, given that the samples were properly preserved with acid, kept cool and in a dark place, we do not feel these samples were compromised. Several color results were also held over the recommended holding time by one day. As with the TP samples, the integrity of these samples should also still be acceptable.

The Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) computer model was used to predict the TP concentration, chlorophyll-*a* concentration, and Secchi disk transparency of each lake based on the lake area, lake depth, and the area of the lake's watershed. Mean depth and volumes were estimated for Blueberry, Morgan, Jim Cook and Stocking Lakes; the remaining lake mean depths were obtained from the MDNR. Additional information about this model can be found in the modeling section of this report or a complete explanation of this model may be found in Wilson and Walker (1989).

Table 1. Summer-Mean Water Quality Parameters for Wadena and Hubbard County CLMP+ Lakes.
(Based on 2005 summer epilimnetic data.)

Parameter	Blue-berry	Duck	Jim-Cook	Morgan	Upper Twin	Lower Twin	Spirit	Stocking	Typical Range for NLF[1] Ecoregion	Typical Range for NCHF[5] Ecoregion
TP (µg/L)	**100**	**22**	**14**	**11**	**38**	**48**	**16**	**36**	**14 – 27**	**23 – 50**
Chl-a (µg/L)[2]	**43.3**	**5.6**	**2.1**	**1.7**	**1.3**	**11.6**	**4.1**	**19.4**	**< 10**	**5 – 22**
Secchi (m)	**0.7**	**3**	**1.1**	**5.6**	**2.3**	**1.9**	**3.8**	**2.0**	**2.4 – 4.6**	**1.5 – 3.2**
Secchi (ft)	**2.5**	**9.9**	**3.6**	**18.4**	**7.6**	**6.4**	**12.4**	**6.6**	**8 – 15**	**4.9 – 10.5**
TKN (mg/l)	**1.1**	**1.1**	**-**	**0.6**	**0.9**	**0.7**	**-**	**-**	**< 0.75**	**< 0.60 – 1.2**
Alkalinity (mg/L)	**213**	**120**	**-**	**97**	**197**	**190**	**-**	**-**	**40 – 140**	**75 – 150**
Color (Pt-Co Units)	**33**	**7**	**-**	**7**	**20**	**20**	**-**	**-**	**10 – 35**	**10 – 20**
pH(SU)	**8.5**	**8.1**	**-**	**8.1**	**7.6**	**7.7**	**-**	**-**	**7.2 – 8.3**	**8.6 – 8.8**
Chloride(mg/L)	**4.2**	**10.5**	**-**	**1.0**	**6.3**	**6.2**	**-**	**-**	**< 2**	**4 – 10**
TSS (mg/L)[3]	**19.1**	**3.6**	**-**	**3.8**	**18.8**	**4.8**	**-**	**-**	**< 1 – 2**	**2 – 6**
TSIS (mg/L)[4]	**8.0**	**2.2**	**-**	**2.5**	**8.1**	**2.9**	**-**	**-**	**< 1 – 2**	**1 – 2**
Conductivity(umhos/cm)	**309**	**226**	**-**	**146.3**	**303**	**299**	**-**	**-**	**50 – 250**	**300 – 400**
TN:TP ratio	**11:1**	**50:1**	**-**	**55:1**	**25:1**	**15:1**	**-**	**-**	**25:1 – 35:1**	**25:1 – 35:1**

[1]NLF Ecoregion" range is the 25th – 75th percentile of summer means from ecoregion reference lakes.
[2]Chlorophyll-*a* measurements have been corrected for pheophytin.
[3]TSS = Total Suspended Solids.
[4]TSIS = Total Suspended Inorganic Solids = Total Suspended Volatile Solids
[5]NCHF Ecoregion range is the 25th – 75th percentile of summer means from ecoregion reference lakes.

Table 2. Lake Morphometry, Watershed Areas, and Trophic State Indicators for Wadena and Hubbard County CLMP+ Lakes.

Characteristic	Blueberry	Duck	Jim-Cook	Morgan	U Twin	L Twin	Spirit	Stocking
DNR Lake ID #	80-0034	29-0142	80-0027-01	80-0038	29-0157	80-0030	80-0039	80-0037
Maximum depth	15 ft 4.6 m	23 ft 7 m	3.7 ft 1.1 m	58 ft 17.7 m	12 ft 3.7 m	26 ft 7.9 m	45 ft 13.7 m	22 ft 6.7 m
[1]*Mean depth*	6 ft 1.8 m	13.9 ft 4.2 m	3 ft 0.9 m	16 ft 4.9 m	7 ft 2.1 m	7 ft 2.1 m	15.1 ft 4.6 m	10 ft 3.0 m
Lake area *(ha = hectares)* *(mi^2 = square miles)*	522 acres 211 ha 0.81 mi^2	326 acres 132 ha 0.51 mi^2	238 acres 96 ha 0.37 mi^2	18 acres 7 ha 0.03 mi^2	225 acres 91 ha 0.87 mi^2	391 acres 158 ha 0.61 mi^2	115 acres 47 ha 0.44 mi^2	343 acres 139 ha 0.54 mi^2
[2]*Watershed area DIRECT* *(Excludes lake area)*	1811 acres 733 ha 2.83 mi^2	5197 acres 2103 ha 8.12 mi^2	666 acres 269 ha 1.04mi^2	230 acres 93 ha 0.36 mi^2	1268 acres 513 ha 1.98 mi^2	1478 acres 598 ha 2.31 mi^2	132 acres 53.4 ha 0.2 mi^2	6726 acres 2722 ha 10.51 mi^2
[2]*Watershed area TOTAL* *(Excludes lake area)*	135809 acres 54960 ha 212.2 mi^2	5197 acres 2103 ha 8.12 mi^2	acres ha mi^2	230 acres 93 ha 0.36 mi^2	381093 acres 154223 ha 595.46 mi^2	383129 acres 155047 ha 598.64 mi^2	1678 acres 679 ha 2.62 mi^2	8686 acres 3515 ha 13.57 mi^2
[3]*Watershed:lake area ratio*	260:1	16:1	2.8:1	12.7:1	1694:1	980:1	14.6:1	25:1
Volume (acre-ft) *(hm^3)*	3,132 3.86	4,531 5.6	N/A	288 0.36	1,575 1.9	2,737 3.4	1,737 2.1	3,430 4.2
Littoral Area	522 acres 100 %	151 acres 46 %	238 acres 100 %	9 acres 50 %	225 acres 100 %	175 acres 45 %	65 acres 57 %	326 acres 95 %
Inlets[4]	2	0	0	0	1	1	1	1
Outlets[4]	1	0	1	0	1	1	0	1
Accesses[4]	1	1	0	1 - private	1	1	1	1
DNR Lake Class[4]	41	31	N/A	29	39	31	29	39
2005 TSIP	71	49	42	39	57	60	44	56
2005 TSIC	68	48	39	36	33	55	44	60
2005 TSIS	65	44	59	35	48	51	41	50
2005 Overall TSI	68	47	47	37	46	55	43	55

[1]Mean depth and volume was *estimated on Blueberry, Morgan, and Stocking Lakes.* All other mean depths were obtained from DNR.
[2]Watershed areas provided by MN DNR and USGS web site: http://gisdmnspl.cr.usgs.gov/watershed/index.htm
[3]Watershed:lake area ratio based on TOTAL watershed.
[4]Provided by MN DNR LakeFinder website: http://www.dnr.state.mn.us/lakefind/index.html

Figure 3. **Carlson's Trophic State Index, based on a scale of 0 – 100. (Carlson 1977)**

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.

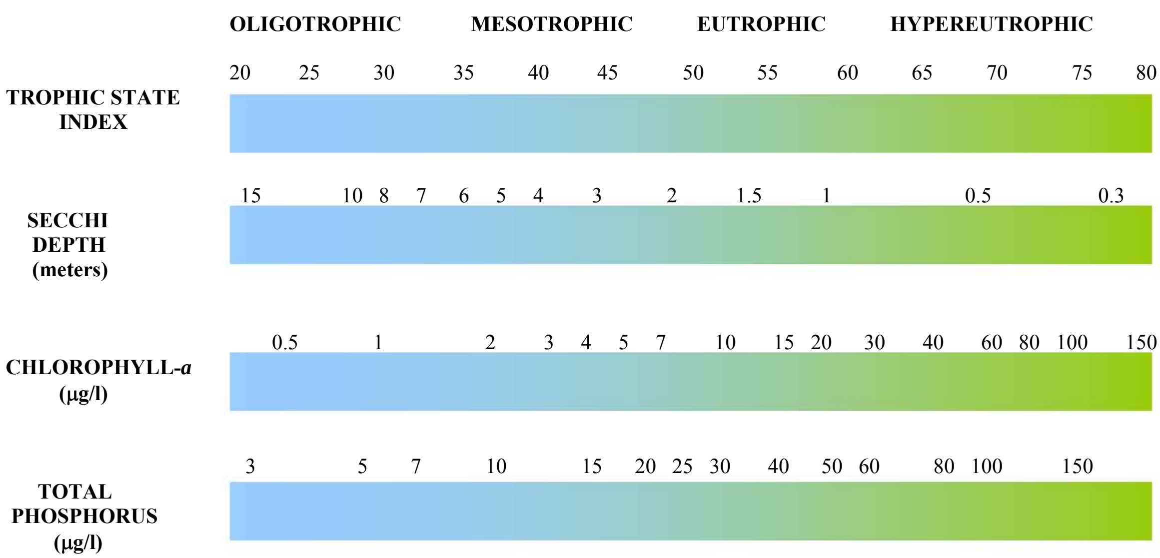
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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 bluegreen algae, algal scums probable, extensive macrophyte problems.

TSI 70 - 80 Heavy algal blooms possible throughout the summer, dense macrophyte beds, but extent limited by light penetration. Often would be classified as hypereutrophic.

TSI > 80 Algal scums, summer fish kills, few macrophytes, dominance of rough fish.



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

NLF Ecoregion Range, 25th – 75th percentile: NCHF Ecoregion Range 25th – 75th percentile:

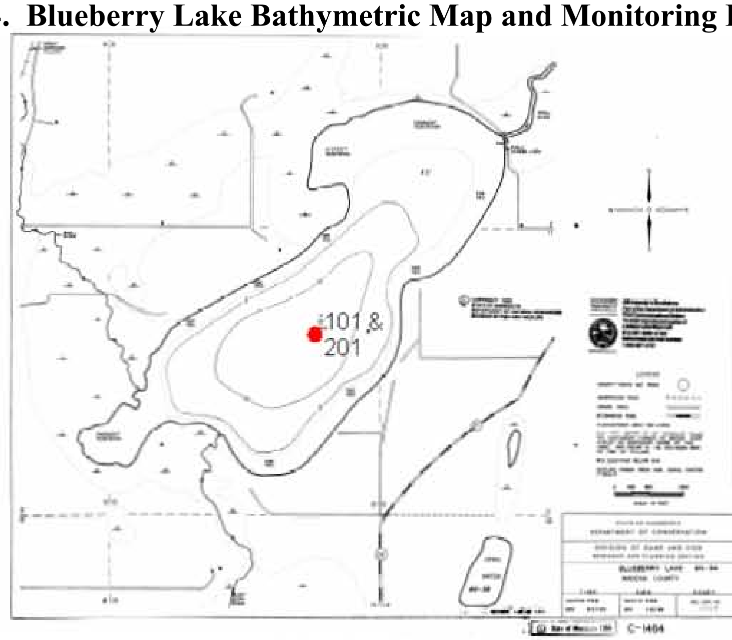
BLUEBERRY (80-0034)
Blueberry Lake is a large, shallow lake (522 acres) with a maximum depth of 15 feet (4.6 m) and estimated mean depth of 6 feet (1.8 m). It is in the upper five percent of Minnesota lakes in terms of its size, and the largest lake in Wadena County. The lake is located two miles north of Menahga, Minnesota. The lake is shallow, with 100% of the lake area being littoral and there is one public access for the lake. Blueberry Lake's direct (immediate drainage) is small relative to its total (all contributing) watershed area, 2.83 mi^2 and 212.2 mi^2, respectively. The total watershed to lake ratio is quite large at 263:1 (Table 2). Its water residence time is on the order of 20 days.

Aquatic vegetation was surveyed in June 2005 by the MN Department of Natural Resources on Blueberry Lake. A full report can be viewed online at: http://files.dnr.state.mn.us/natural_resources/water/lakes/vegetation_reports/80003400.pdf. A summary follows:

> A total of 23 native aquatic plant species were recorded in Blueberry Lake in 2005, including 3 emergent, 2 floating-leaved, 3 free-floating and 15 submerged species. Of the 353 sites sampled, vegetation occurred in 59 percent of the sample sites in Blueberry Lake but native species were found in only 25 percent of the site. The submerged plant community is dominated by the non-native species, curly-leaf pondweed (*Potamogeton crispus*), occurring in 43 percent of the sites. Narrow-leaf pondweed (*Potamogeton freisii*) was the most common native submerged plant found at 17 percent of the sites. Yellow waterlily (*Nuphar variegate*) occurred in 7 percent of the sample sites, primarily found in the shallow water in the north bay. All of the other native species were present in less than five percent of the sites and at a depth of less than six feet (Perleberg 2005a).

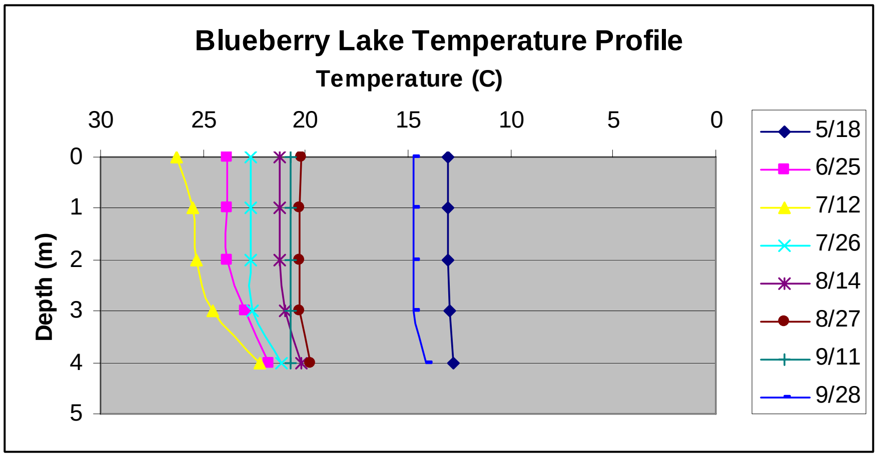
Water quality data was collected in June, July, August, and September, 2005 by volunteer lake monitor Lefty Lindblom. One site was used on Blueberry Lake: Site 101(201) – located in the center end of the lake (Figure 4).

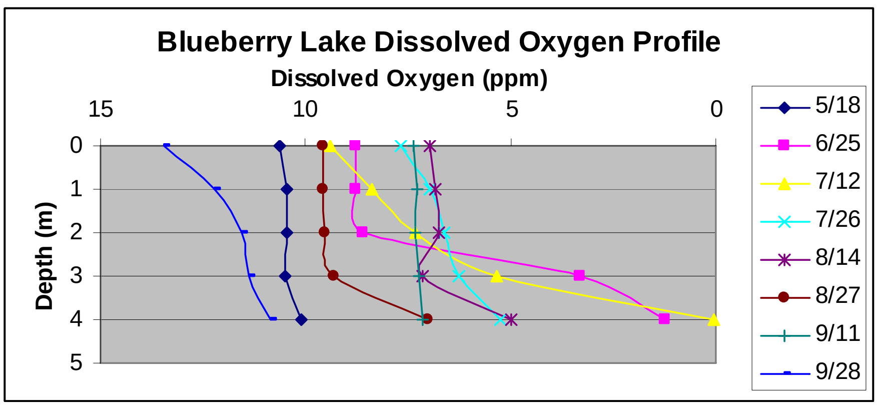
Figure 4. Blueberry Lake Bathymetric Map and Monitoring Location



Temperature data indicated that the lake was well-mixed throughout the summer months (Figure 5). Dissolved oxygen (DO) measurements were also fairly consistent from the surface to the bottom of the lake on most sample dates. However, on the late June and early July sampling dates, the DO concentration fell below the 5 mg/l necessary to support game fish at and below a depth of 3 meters.

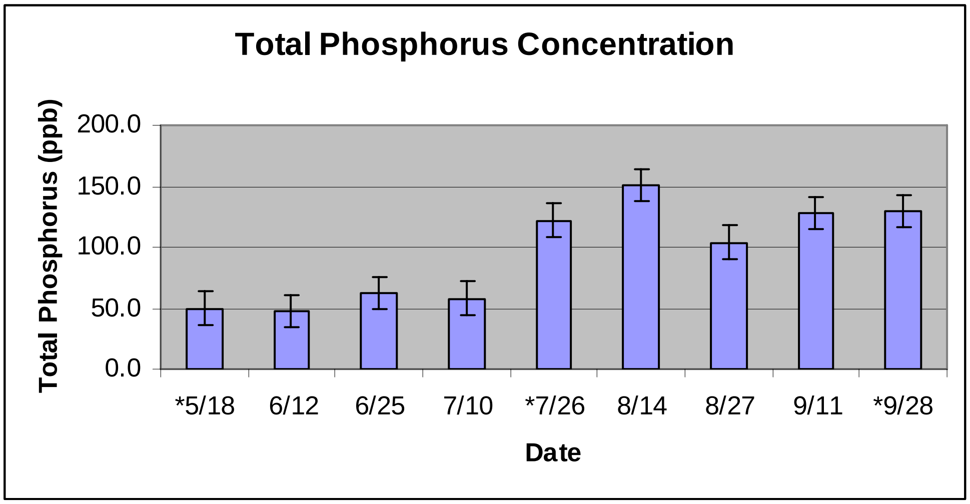
Figure 5. Blueberry Lake Temperature and Dissolved Oxygen Profile Data for 2005





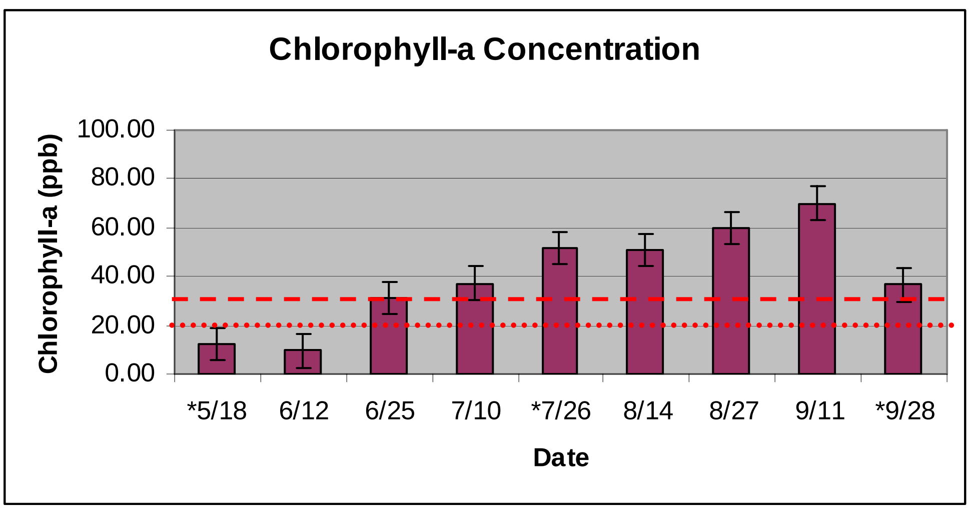
Total phosphorus (TP) concentrations averaged 100 µg/L (micrograms per liter or parts per billion) in Blueberry Lake during the summer of 2005. This value is quite high, compared to the concentrations for reference lakes in the NCHF ecoregion (Table 1). TP concentrations ranged from 48 – 151 µg/L and tended to increase over the summer (Figure 6). This tendency for increasing TP over the summer is consistent with what has been observed in other shallow lakes in MN (Heiskary and Lindon, 2005). The significant increase in TP from the July 10th to July 26th sampling dates could be attributed to two possible sources; a die off in curly leaf pondweed would result in an increase in available TP or as a result of the large rainfall measured on July 12th.

Figure 6. Blueberry Lake Total Phosphorus Results for 2005



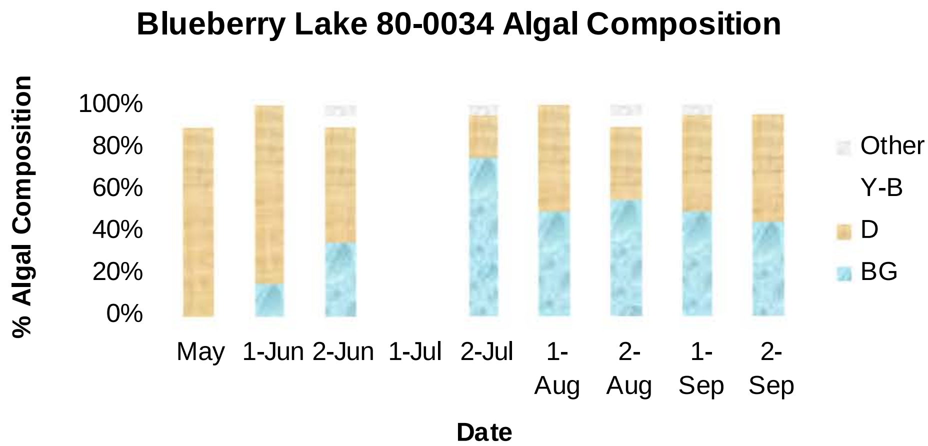
Chlorophyll-*a* concentrations for Blueberry Lake averaged 43 µg/L and were well above the NCHF ecoregion range (Table 1). Concentrations on Blueberry Lake ranged from 9.5 – 70 µg/L (Figure 7). The increase in chlorophyll-*a* concentrations mirrored the increase in TP concentrations. Chlorophyll-*a* concentrations above 20 µg/L indicate a nuisance algae bloom and concentrations above 30 µg/L indicate a severe nuisance algae bloom. All samples collected after June 12th would be considered a severe nuisance algae bloom in 2005.

Figure 7. Blueberry Lake Chlorophyll-*a* Results for 2005



The composition of the phytoplankton (algae) population of Blueberry Lake is presented in Figure 8. Data are presented in terms of algal type. Samples were collected at Site 101. The diatoms and bluegreens were well represented throughout the summer, with diatoms dominating the May and June Samples, while bluegreen algae dominated the algae population in late July and late August. Severe nuisance algae bloom conditions (>30 µg/L chlorophyll-*a*) were evident on all sampling events during the summer of 2005, with the exception of the May and early June samples. A seasonal transition in algal types from diatoms to greens to bluegreen is more typical for mesotrophic and eutrophic lakes in Minnesota.

Figure 8. Blueberry Algal Populations for 2005

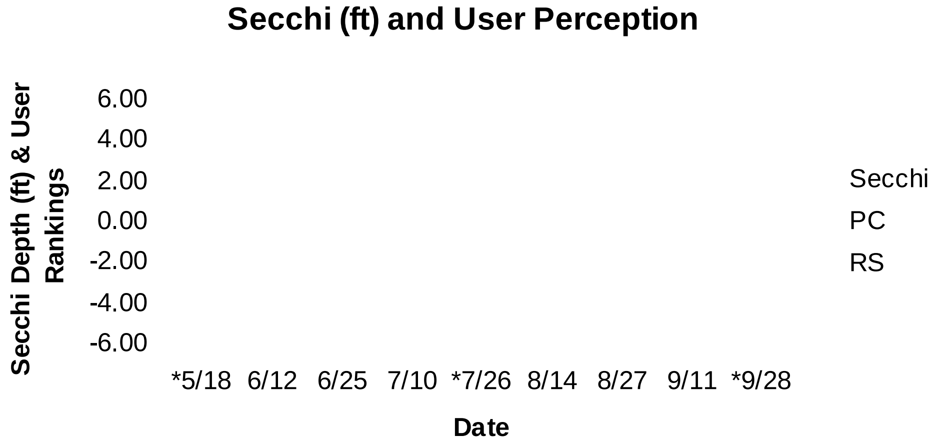


Secchi disk transparency on Blueberry Lake ranged from 1.3 feet (0.4 meters) in late September to 5 feet (1.5 meters) in early June (Figure 9) and averaged 2.5 feet (0.7 meters). These transparency measures are well below the typical range for NCHF ecoregion reference lakes (Table 1). Along with transparency measurements, subjective measures of Blueberry Lake's "physical appearance" and "recreational suitability" were made. Lake conditions varied, and characterizations ranged from as " crystal clear" (Class 1) and "beautiful" (Class 1) to "high algae levels" (Class 4) and "enjoyment of lake is substantially reduced" (Class 4) during the summer for Blueberry Lake.

Other parameters, such as total suspended solids, total suspended inorganic solids, alkalinity, and color, analyzed for Blueberry Lake were above within the typical range of values for NCHF ecoregion reference lakes (Table 1). However, parameters such as conductivity, chloride, and total Kjeldahl nitrogen were all within the NCHF ecoregion typical range of values (Table 1). The color value (Table 1) for this lake indicates moderate to dark coloration, which comes dissolved organic material from the numerous wetlands in the watershed.

Trophic State Index (TSI) values for Blueberry Lake compare very favorably to each other (Table 2); indicating *hypereutrophic* conditions. As such, Secchi transparency should continue to be a good estimator for TP and chlorophyll-*a* values as well as an indicator of overall water quality for Blueberry Lake.

Figure 9. Blueberry Secchi Transparency for 2005

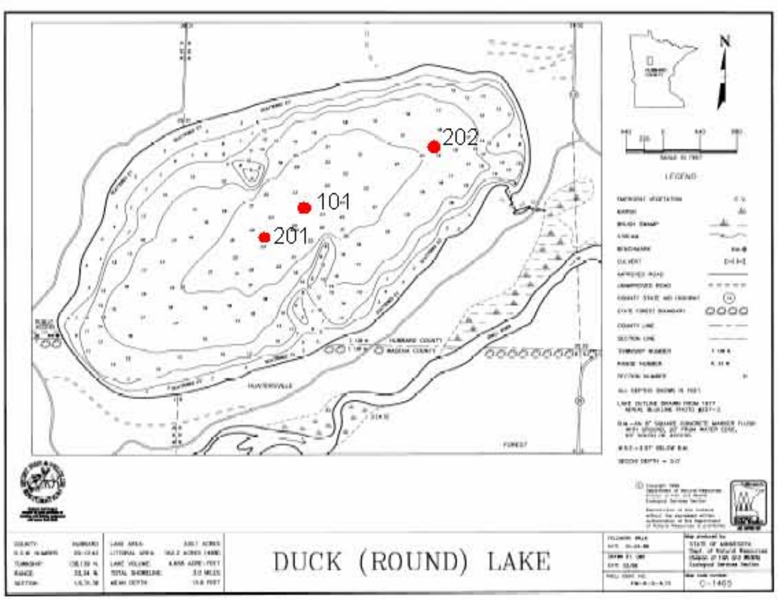


DUCK (29-0142)

Duck Lake is a 326 acre lake located two miles north of Huntersville, Minnesota. It is in the upper ten percent of lakes in terms of its size. It has a maximum depth of 23 feet (7 m) and estimated mean depth of 14 feet (4.2 m). Approximately 46 percent of the lake is littoral and there is one public access for the lake. Its direct and total watershed areas are approximately equal at 8.63 mi^2. As such, the watershed to lake ratio is also relatively small (Table 2). Its water residence time is on the order of 1.1 years.

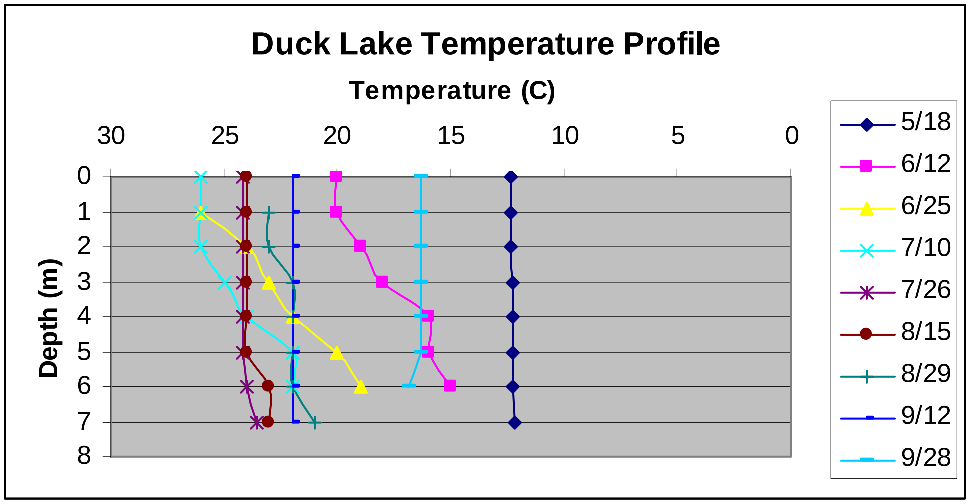
Water quality data was collected in June, July, August, and September, 2005 by volunteer lake monitor Dewayne Mead. One site was used on Duck Lake: Site 101 – located over the point of maximum depth in the middle of the lake (Figure 10).

Figure 10. Duck Lake Bathymetric Map and Monitoring Location



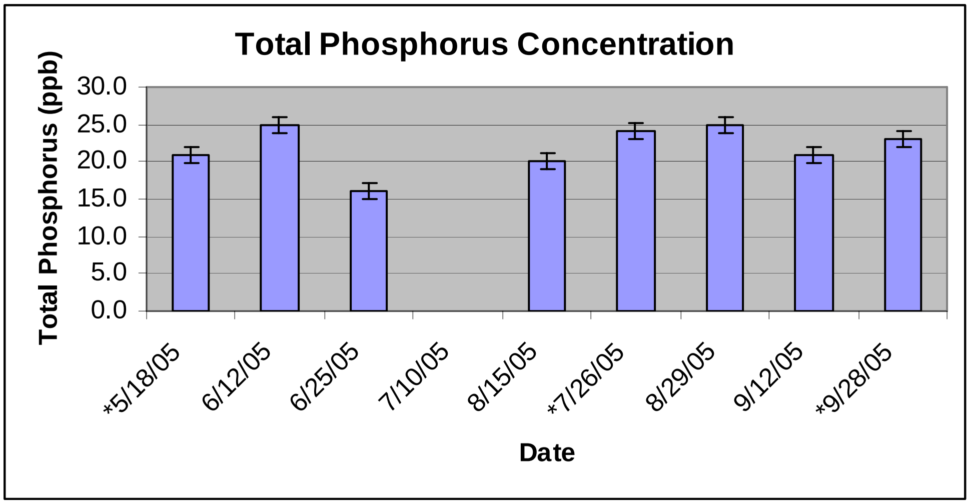
Temperature data indicated that the lake was well mixed throughout the summer (Figure 11) with very slight thermal stratification evident in June and early July. In late July, dissolved oxygen concentrations dipped below 5 mg/l at a depth below 6 meters. For the May and September dates, the water column was well oxygenated from top to bottom.

Figure 11. Duck Lake Temperature Profile Data for 2005 for Site 101



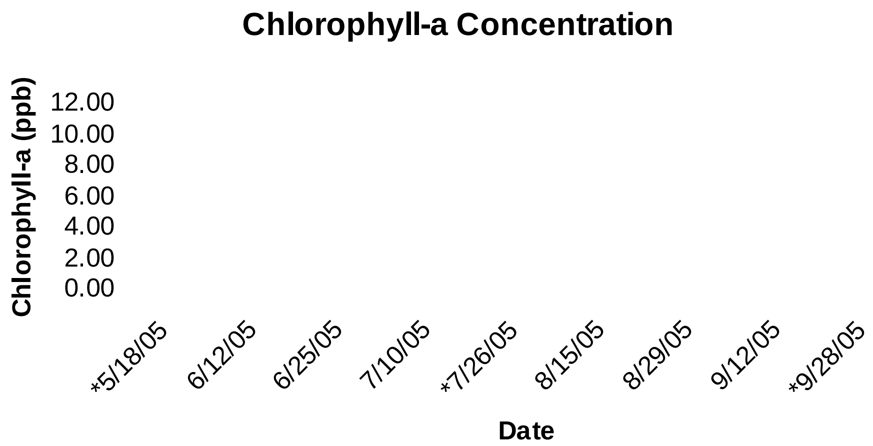
Total phosphorus (TP) concentrations averaged 22 µg/L (micrograms per liter or parts per billion) in Duck Lake during the summer of 2005. This value is within the range of concentrations for reference lakes in the NLF ecoregion (Table 1). TP concentrations ranged from 16 – 25 µg/L (Figure 12). The July 10th sample was omitted, as it was incorrectly preserved and unable to be analyzed.

Figure 12. Duck Lake Total Phosphorus Results for 2005



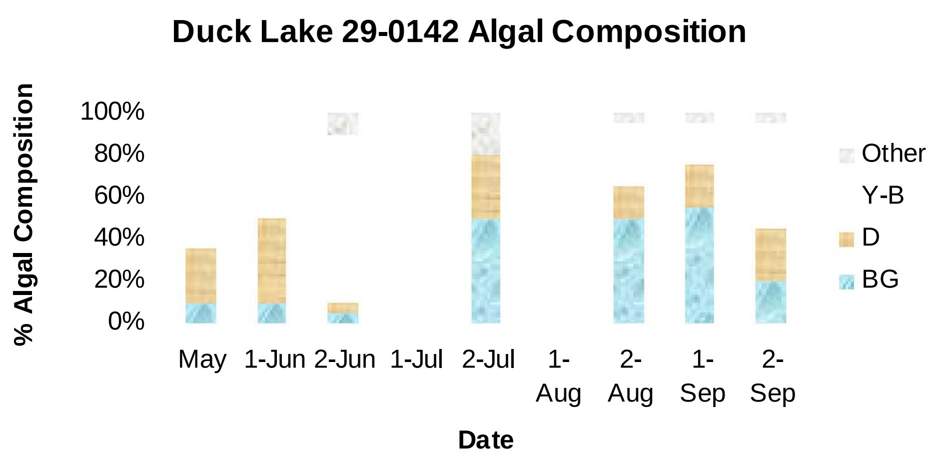
Chlorophyll-*a* concentrations for Duck Lake averaged 5.6 µg/L and were within the NLF ecoregion range (Table 1). Concentrations on Duck Lake ranged from 2.9 – 8.9 µg/. No mild or nuisance algae blooms were noted for 2005 (Figure 13) based on these concentrations.

Figure 13. Duck Lake Chlorophyll-*a* Results for 2005



The composition of the phytoplankton (algae) population of Duck Lake is presented in Figure 14. Data are presented in terms of algal type. Samples were collected at Site 101. The yellow-browns, diatoms and bluegreens comprised the majority of the types present. Yellow-browns dominated the algae population in the early half of the summer and the late September sample with bluegreens dominating in the July and August samples. Bloom conditions (>10 µg/L chlorophyll-*a*) were not evident on any sampling events during the summer of 2005. A seasonal transition in algal types from diatoms to greens to bluegreen is more typical for mesotrophic and eutrophic lakes in Minnesota.

Figure 14. Duck Lake Algal Populations for 2005

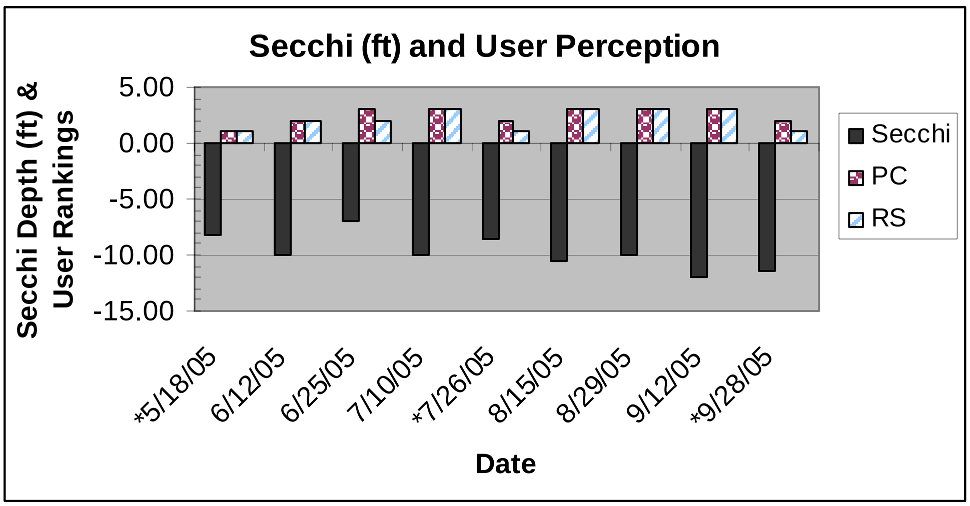


Secchi disk transparency on Duck Lake ranged from 7 feet (2.1 meters) in late June to 12 feet (3.7 meters) in mid September (Figure 15) and averaged 9.9 feet (3.0 meters). These transparency measures are within the typical range for NLF ecoregion reference lakes (Table 1). Lake conditions varied, and were characterized as "crystal clear" (Class 1) and “beautiful” (Class 1) to “definite algae present” (Class 3) and “enjoyment slightly impaired” (Class 3) during the summer for Duck Lake.

Other parameters, such as alkalinity, pH, and conductivity, analyzed for Duck Lake were all near or well within the typical range of values for NLF ecoregion reference lakes (Table 1). Parameters such as total Kjeldahl nitrogen, chloride, and total suspended solids were above the NLF ecoregion reference lake values but in or near the range for the NCHF ecoregion (Table 1).

Trophic State Index (TSI) values for Duck Lake compare very favorably to each other (Table 2. As such, Secchi transparency should still continue to be a good estimator for TP and chlorophyll-*a* values as well as an indicator of overall water quality for Duck Lake. The TSI values for Duck Lake indicate *mesotrophic to eutrophic* conditions.

Figure 15. Duck Lake Secchi Transparency for 2005

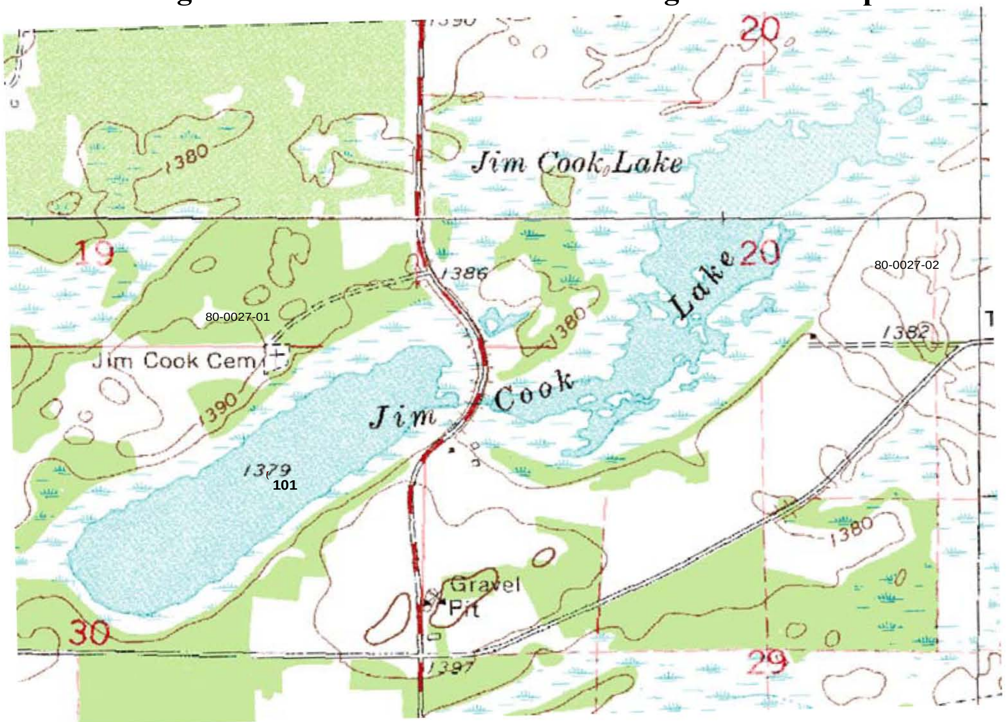


JIM-COOK (80-0027-01)

Jim-Cook Lake is a small lake located four miles east of Menahga, Minnesota. It has an estimated maximum depth of 3.7 feet (1.1 m). The entire lake is littoral and there is no public access for the lake. It has a small direct and total watershed (1.04 mi^2).

Water quality data was collected in June 2005 by volunteer lake monitor Lefty Lindblom. Due to the condition of the private access to the lake, MPCA was unable to collect samples from this lake. These same conditions resulted in limited water quality samples from the volunteer as well. One site was used on Jim-Cook Lake: Site 101 – located over the point of maximum depth in the west basin (80-0027-01) of the lake (Figure 16). Due to the limited nature of the data, no determination can be made of seasonal average or seasonal maximum or minimum values. All collected data is available in Appendix 1.

Figure 16. Jim-Cook Lake Monitoring Location Map

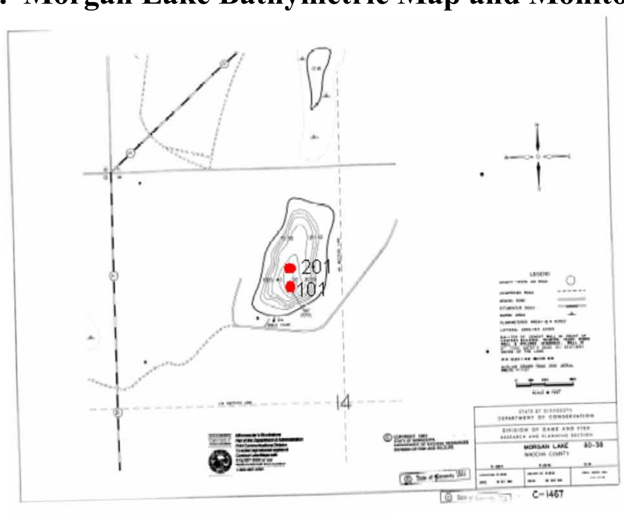


Morgan (80-0038)

Morgan Lake is a very small 18 acre lake located one mile northeast of Menahga, Minnesota. Morgan Lake has a maximum depth of 58 feet (17.7 m) and estimated mean depth of 16 feet (4.9 m). Approximately 50 percent of the lake is littoral and there is one private access for the lake. Morgan Lake has a relatively small direct watershed (2.89 mi^2) and considerably larger total watershed of 599 mi^2. Its water residence time is on the order of 1.5 years.

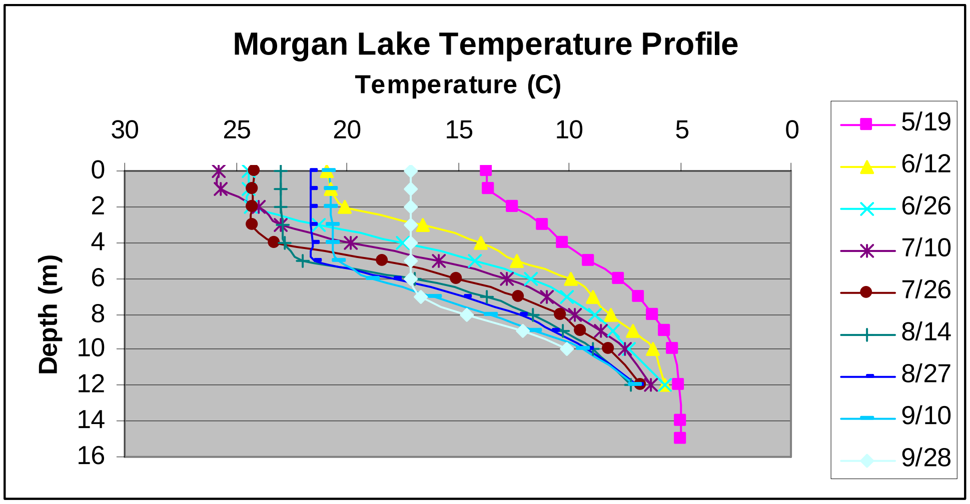
Water quality data was collected in June, July, August, and September, 2005 by volunteer lake monitor Lefty Lindblom. One site was used on Morgan Lake: Site 101 – located over the point of maximum depth in south-central end of the lake (Figure 17).

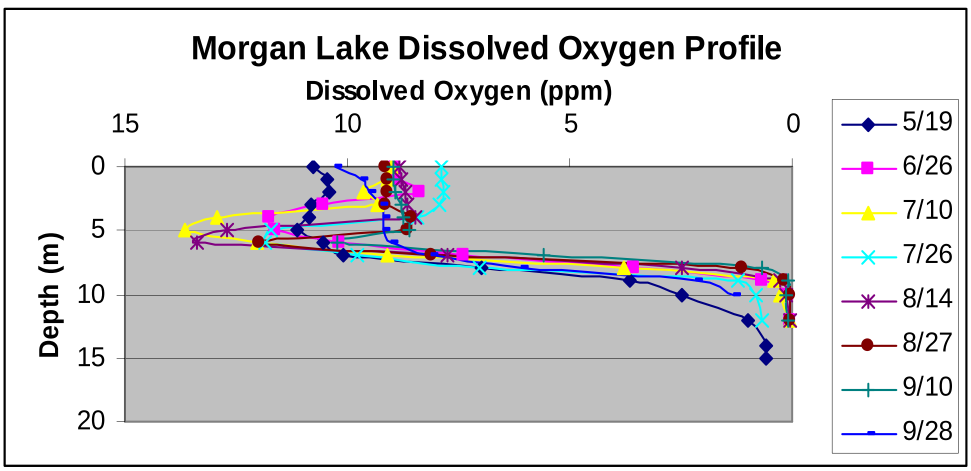
Figure 17. Morgan Lake Bathymetric Map and Monitoring Location



Temperature data indicated that the lake was stratified throughout the summer (Figure 18). Thermal stratification occurred at and below 4 meters (13.1 ft) for most of the summer. DO concentrations followed a similar pattern, with a sharp decline near 5 meters. At and below a depth of 7 meters for all sampling dates, DO was below the 5 mg/l necessary to support game fish.

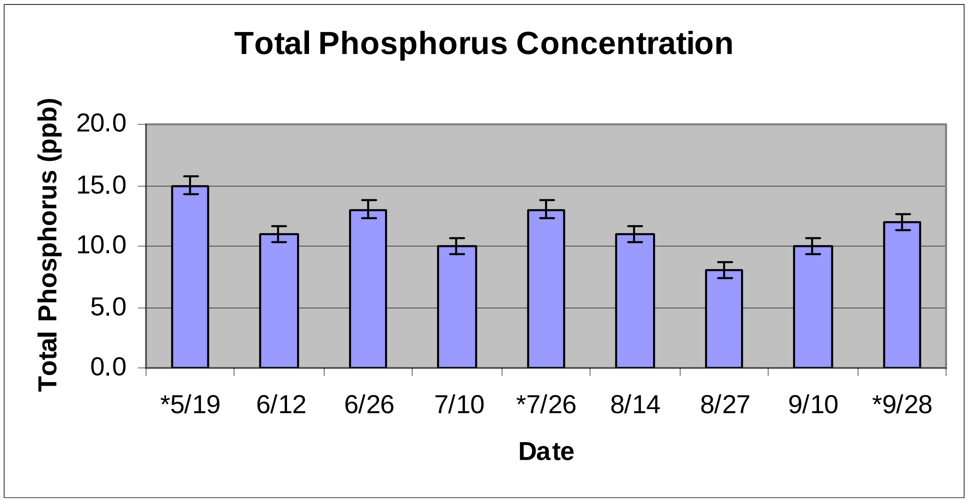
Figure 18. Morgan Lake Temperature and Dissolved Oxygen Profiles for 2005





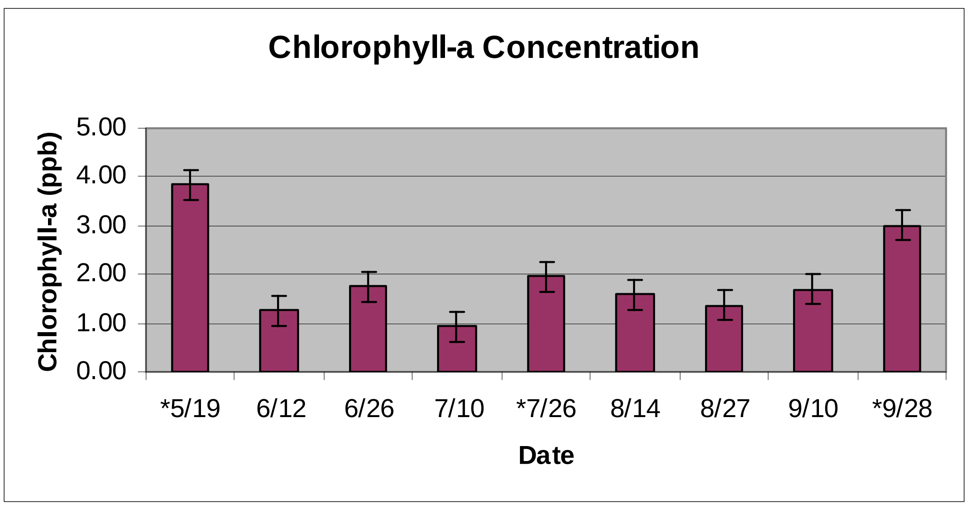
Total phosphorus (TP) concentrations averaged 11 µg/L (micrograms per liter or parts per billion) in Morgan Lake during the summer of 2005. This value is slightly below the range of concentrations for reference lakes in the NLF ecoregion (Table 1). TP concentrations ranged from 8 – 13 µg/L (Figure 19) with a slight decrease in concentrations from May through late August and then increasing again throughout the September.

Figure 19. Morgan Lake Total Phosphorus Results for 2005



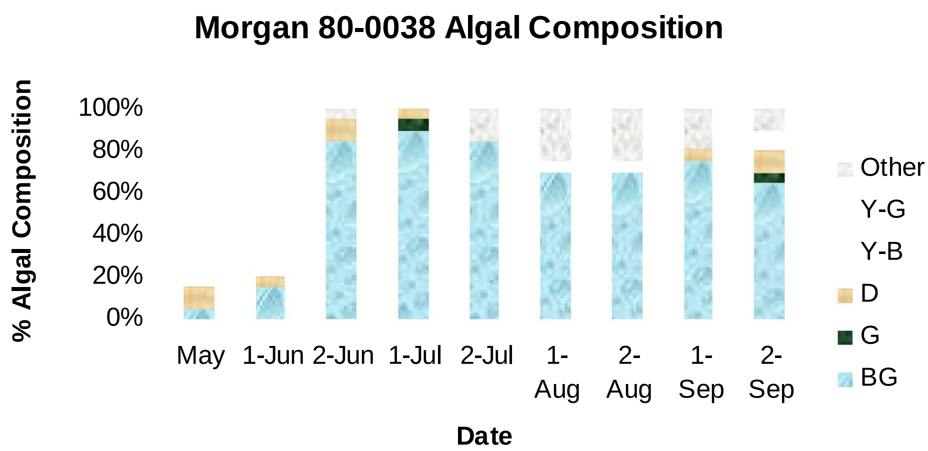
Chlorophyll-*a* concentrations for Morgan Lake averaged 1.7 µg/L and were well within the NLF ecoregion range (Table 1). Concentrations on Morgan Lake ranged from 0.9 – 3.0 µg/L. No algae blooms (chlorophyll-*a* >10 µg/L) were noted during the 2005 monitoring season based on these concentrations (Figure 20).

Figure 20. Lake Morgan Chlorophyll-*a* Results for 2005



The composition of the phytoplankton (algae) population of Morgan Lake is presented in Figure 21. Data are presented in terms of algal type. Samples were collected at Site 101. The yellow-browns dominated the May and early June samples while bluegreen algae dominated the algae populations for the remainder of the summer. However, given the low chlorophyll-*a* concentration, bluegreen blooms likely did not occur. A seasonal transition in algal types from diatoms to greens to bluegreen is more typical for mesotrophic and eutrophic lakes in Minnesota.

Figure 21. Morgan Lake Algal Populations for 2005

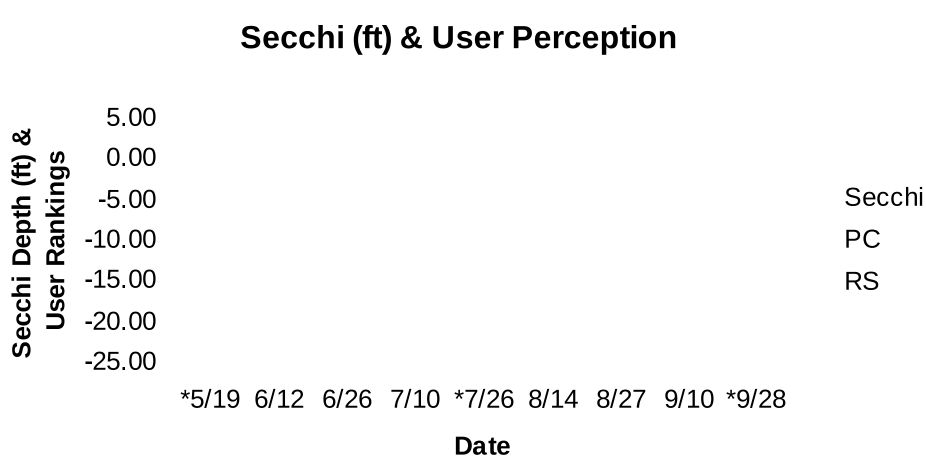


Secchi disk transparency on Morgan Lake ranged from 16.4 feet (1.2 meters) in late May, July, and September to 21.0 feet (6.4 meters) in late August (Figure 22) and averaged 18.4 feet (5.6 meters). These transparency measures are well above the typical range for ecoregion reference lakes (Table 1). Lake conditions for Morgan Lake were characterized as "crystal clear" (Class 1) and "beautiful, could not be better" (Class 1) throughout the summer.

Other parameters, such as alkalinity, color, and conductivity are all within or slightly below the typical range of values for the NLF ecoregion (Table 1). Total suspended solids and total suspended inorganic solids, analyzed for Morgan Lake were slightly above typical range of values for NLF ecoregion reference lakes (Table 1).

Trophic State Index (TSI) values for Morgan Lake compare very favorably to each other (Table 2); indicating *mesotrophic* conditions. As such, Secchi transparency should continue to be a good estimator for TP and chlorophyll-*a* values as well as an indicator of overall water quality for Morgan Lake.

Figure 22. Morgan Lake Secchi Transparency for 2005



UPPER TWIN (29-0157)

Upper Twin Lake is a moderate-sized lake (225 acres) with a maximum depth of 12 feet (3.7 m) and estimated mean depth of 7 feet (2.1 m). The lake is located three miles northeast of Menahga, Minnesota. Its total watershed (595 mi^2) is exceptionally large, and as such, the watershed to lake area ratio is also large (Table 2). The entire lake is littoral and there is one public access for the lake. Because of the large volume of water flowing through the lake, its water residence time is estimated to be less than one week.

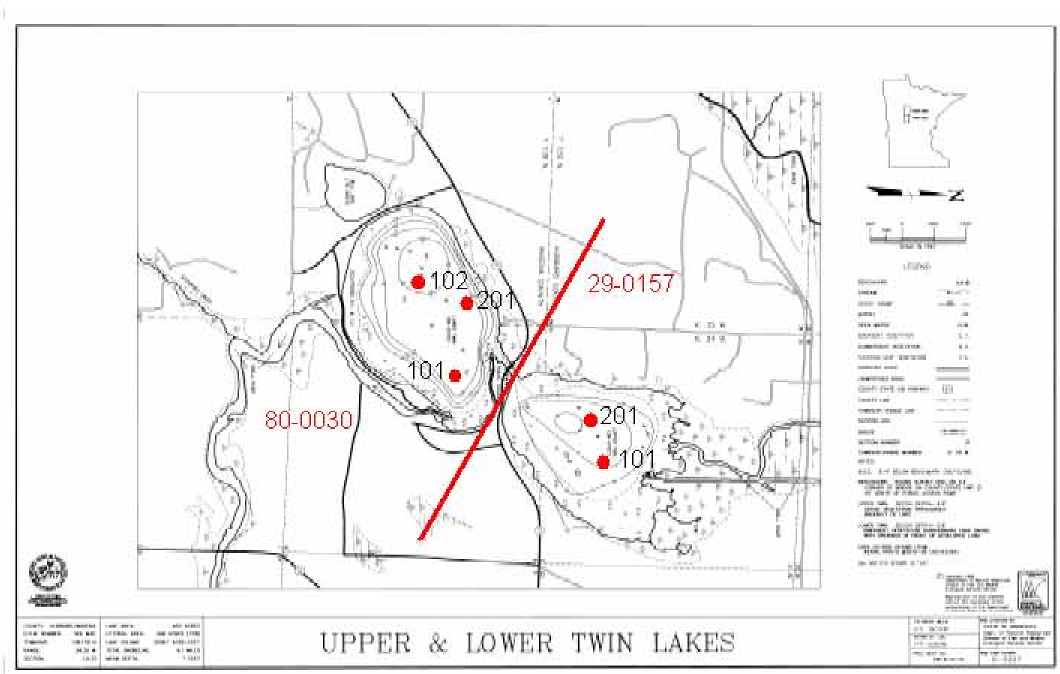
Aquatic vegetation was surveyed in June 2005 by the MN Department of Natural Resources on Upper Twin Lake. A full report can be viewed online at: http://files.dnr.state.mn.us/natural_resources/water/lakes/vegetation_reports/29015700_80003000.pdf.

A summary follows:

> A total of 26 native aquatic plant species were recorded in Upper Twin Lake in 2005, including 5 emergent, 4 floating-leaved, 2 free-floating and 15 submerged species. Of the 166 sites sampled, vegetation occurred in 95 percent of the sample sites in Upper Twin Lake. The submerged plant community is dominated by Canada waterweed (*Elodea canadensis*), which is present at 59 percent of the sample sites. However, the submerged non-native species, curly-leaf pondweed (*Potamogeton crispus*), occurred in 43 percent of the sites. Yellow waterlily (*Nuphar variegate*) occurred in 14 percent of the sample sites and wild rice (*Zizania palustris*) was present at 5 percent of the sites in 2005 (Perleberg 2005b).

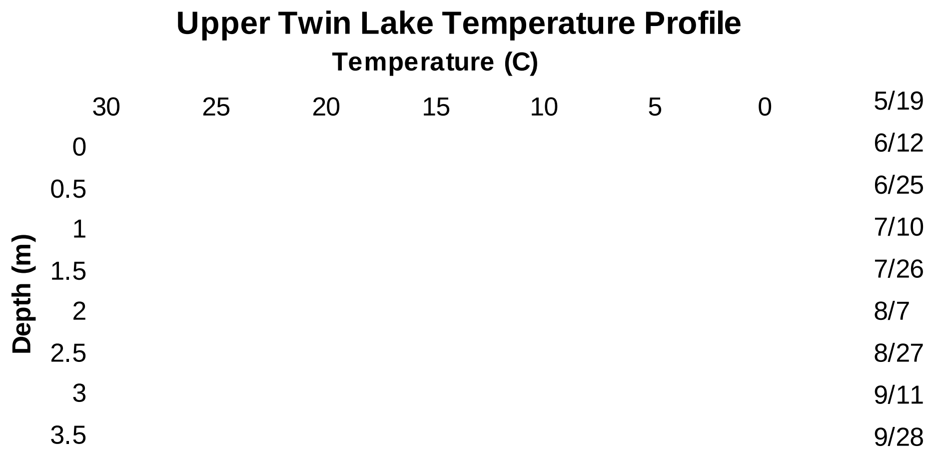
Water quality data was collected in June, July, August, and September, 2005 by volunteer lake monitor Don Broughton. One site was used on Upper Twin Lake: Site 101 – located in the north-central part of the lake (Figure 23).

Figure 23. Upper Twin Lake Bathymetric Map and Monitoring Location



Temperature data indicated that the lake was well mixed throughout the summer (Figure 24). The dissolved oxygen was measured during the three MPCA sampling dates on Upper Twin Lake. Concentrations dipped below 5 mg/l (the concentration necessary to support game fish) on the May and July sampling dates at a depth below 2 m.

Figure 24. Upper Twin Lake Temperature Profile Data for 2005 for Site 101



Total phosphorus (TP) concentrations averaged 38 µg/L (micrograms per liter or parts per billion) in Upper Twin Lake and ranged from 28 – 49 µg/L during the summer of 2005 (Figure 25). These values are within the range of concentrations for reference lakes in the NCHF ecoregion (Table 1). Total phosphorus concentrations declined throughout the summer.

Chlorophyll-*a* concentrations for Upper Twin Lake averaged 1.3 µg/L and were well below the NCHF ecoregion range (Table 1). Summer concentrations for the lake ranged from 0.3 – 3.3 µg/L with no mild or nuisance algae blooms noted for the June to September 2005 monitoring season (Figure 26). However, there were floating algal mats of *Cladophora* (green filamentous algae - pictured right, below) observed in the throughout the lake during the MPCA May sampling event, as well as elevated total phosphorus and chlorophyll-a concentrations. There were no algal mats of this type observed in Lower Twin Lake. These floating mats were not observed during any other monitoring events. Typically, these filamentous algae tangle together on substances on the lake bottom (plants or rocks). Then, under certain buoyancy conditions, these algae mats float to the surface and

concentrate on the down-wind end of the lake. They can be common in some lakes and tend to be limited by the amount of available nutrients, light, and substrate for attachment.

Figure 25. Upper Twin Lake Total Phosphorus Results for 2005

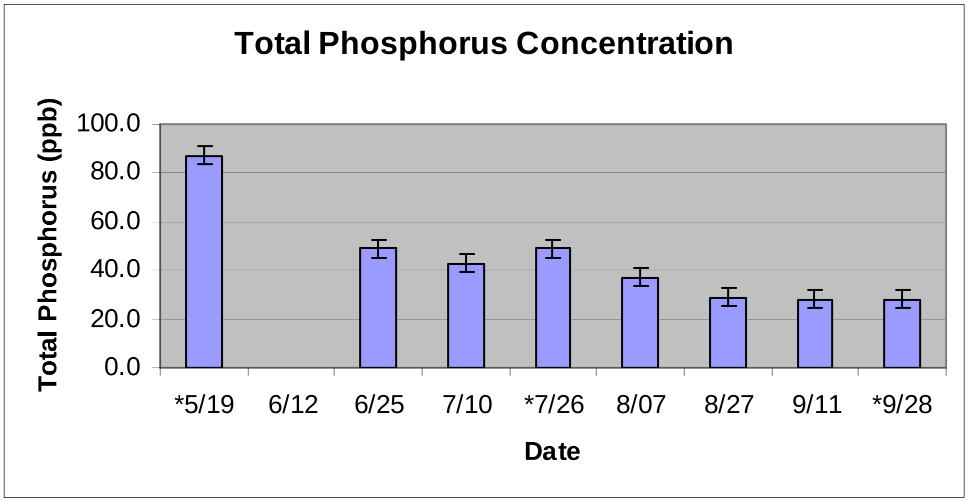
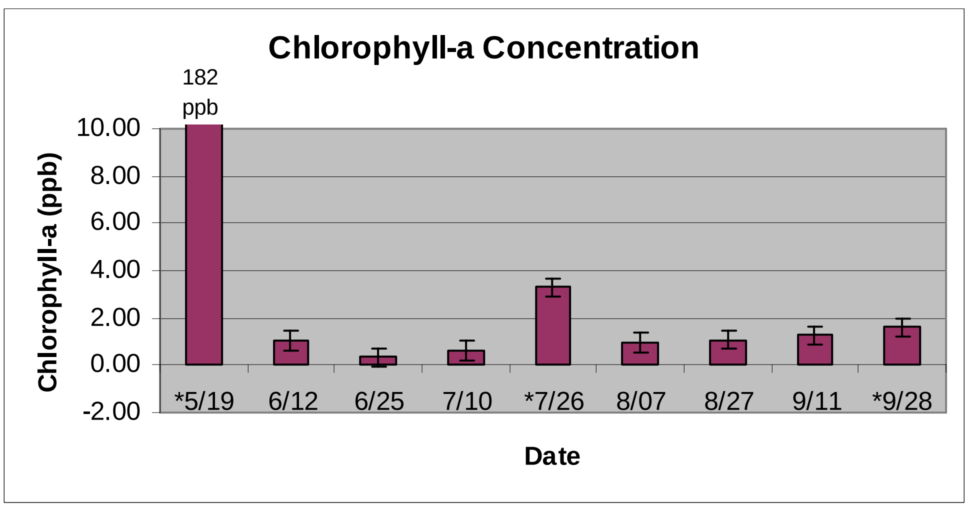


Figure 26. Upper Twin Lake Chlorophyll-*a* Results for 2005

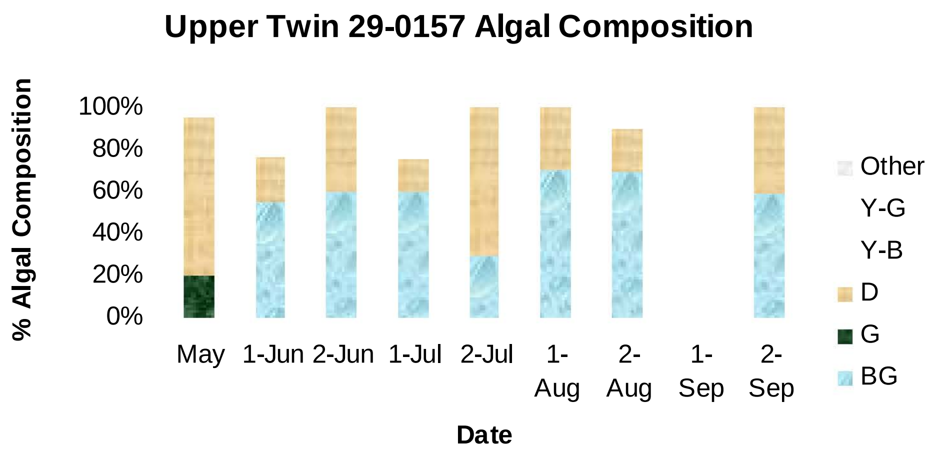


The composition of the phytoplankton (algae) population of Upper Twin Lake is presented in Figure 27. Data are presented in terms of algal type. Samples were collected at Site 101. Diatoms and bluegreen algae dominated the algae populations throughout the summer. The diatoms dominated the May and late July samples, while the bluegreens dominated the remainder of the summer. A seasonal transition in algal types from diatoms to greens to bluegreen is more typical for mesotrophic and eutrophic lakes in Minnesota.

Secchi disk transparency on Upper Twin Lake ranged from 5.5 feet (1.7 meters) in late June to 9 feet (2.7 meters) in mid September (Figure 28) and averaged 7.6 feet (2.3 meters). These transparency measures are within the typical range for NCHF ecoregion reference lakes (Table

1). Lake conditions were primarily characterized as "not quite crystal clear" (Class 2) and "minor aesthetic problems" (Class 2) throughout the summer for Upper Twin Lake.

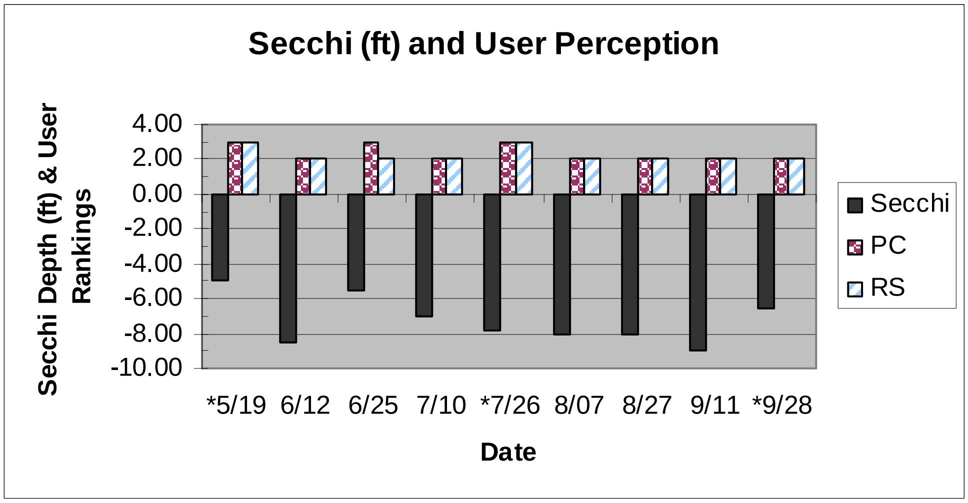
Figure 27. Upper Twin Lake Algal Populations for 2005



Other parameters, such as color and chloride, for Upper Twin Lake were within the typical range of values for NCHF ecoregion reference lakes (Table 1). However, total suspended solids and total suspended inorganic solids were extremely high (3 to 4 times higher) compared to the typical range of NCHF ecoregion values. This would likely result in reduced Secchi measurements, as elevated suspended solids and water color interfere with transparency.

Trophic State Index (TSI) values for Upper Twin Lake (Table 2) are not comparable. The lake is dominated by rooted vegetation. As a result, despite quite high total phosphorus readings, the concentration of chlorophyll-*a* was very low. Based on the abundance of rooted plants and low algae concentrations, it appears much of the P is taken up by rooted plants. As a result, the total phosphorus TSI was 57, with significantly lower values for Secchi and chlorophyll-a (48 and 33, respectively). The lake has considerably high total suspended solids and total suspended inorganic solids concentrations, and elevated color levels, which will contribute to reduced transparency. The average TSI indicated *mesotrophic to eutrophic* conditions, however, since the values do not agree, the total phosphorus TSI would more accurately represent the trophic condition in the lake - *eutrophic*.

Figure 28. Upper Twin Lake Secchi Transparency for 2005



LOWER TWIN (80-0030)

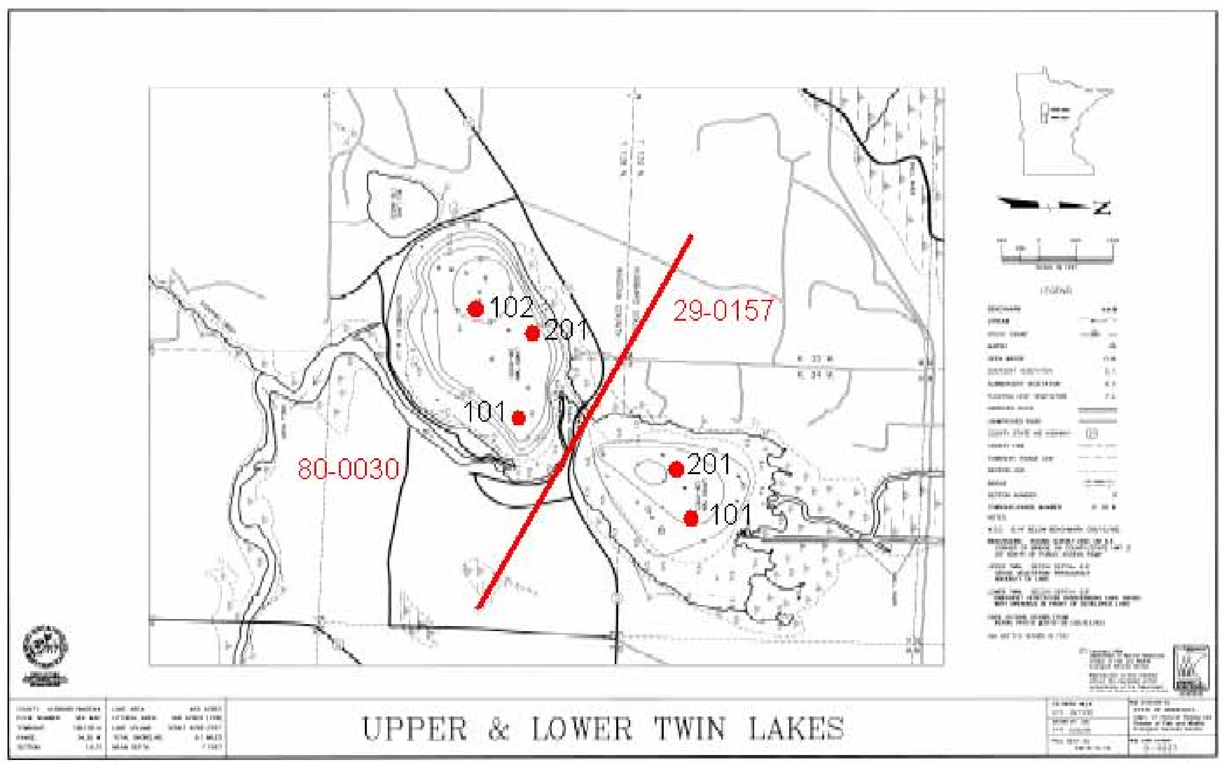
Lower Twin Lake is a moderately sized lake, located three miles northeast of Menahga, Minnesota. With a surface area of 391 acres, it is in the upper ten percent of lakes in terms of size and is immediately downstream of Upper Twin Lake. Lower Twin Lake has a maximum depth of 26 feet (7.9 m) and estimated mean depth of 7 feet (2.1 m). Approximately 45 percent of the lake is littoral and there is one public access for the lake. Its direct watershed area of 2.31 mi^2 is significantly smaller than its total watershed area of 599 mi^2. As such, the watershed to lake ratio (based on the total watershed) is also large (Table 2). Its water residence time is less than one week. Lower Twin Lake is located near the transition of the NLF and NCHF ecoregions, with a large portion of the watershed draining land in the NCHF ecoregion.

Aquatic vegetation was surveyed in June 2005 by the MN Department of Natural Resources on Lower Twin Lake. A full report can be viewed online at:
http://files.dnr.state.mn.us/natural_resources/water/lakes/vegetation_reports/29015700_80003000.pdf.
A summary follows:

> A total of 21 native aquatic plant species were recorded in Lower Twin Lake in 2005, including 3 emergent, 3 floating-leaved, and 15 submerged species. Of the 139 sites sampled, vegetation occurred in 94 percent of the sample sites in Lower Twin Lake. The submerged plant community is dominated by the Canada waterweed (*Elodea Canadensis*), occurring in 43 percent of the sites. However, the submerged non-native species, curly-leaf pondweed (*Potamogeton crispus*), was present at 38 percent of the sites. Wild rice (*Zizania aquatica*) was the most common emergent species, present at 60 percent of the sites (Perleberg 2005b).

Water quality data was collected in June, July, August, and September, 2005 by volunteer lake monitor Don Broughton. One site was used on Lower Twin Lake: Site 102 – located over the point of maximum depth in the south end of the lake (Figure 29).

Figure 29. Lower Twin Lake Bathymetric Map and Monitoring Location



Temperature data indicated that the lake was well-mixed throughout the summer (Figure 30). Early August data indicated a very slight thermal stratification at and below 4 meters (13.1 ft). Dissolved oxygen dipped below 5 mg/l at depths below 4 meters during the July 26th sampling date. The dissolved oxygen concentration remained above 5 mg/l at all depths during the May and September MPCA sampling dates.

Figure 30. Lower Twin Temperature Profile Data for 2005 for Site 102

Lower Twin Lake Temperature Profile

Temperature (C)

30 25 20 15 10 5 0

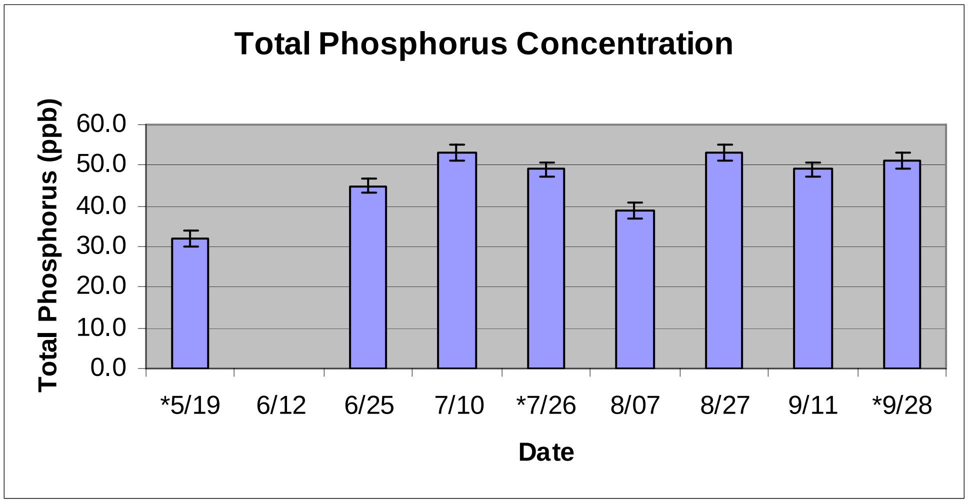
Depth (m)

0
1
2
3
4
5
6
7

5/19
6/12
6/25
7/10
7/26
8/7
8/27
9/11
9/28

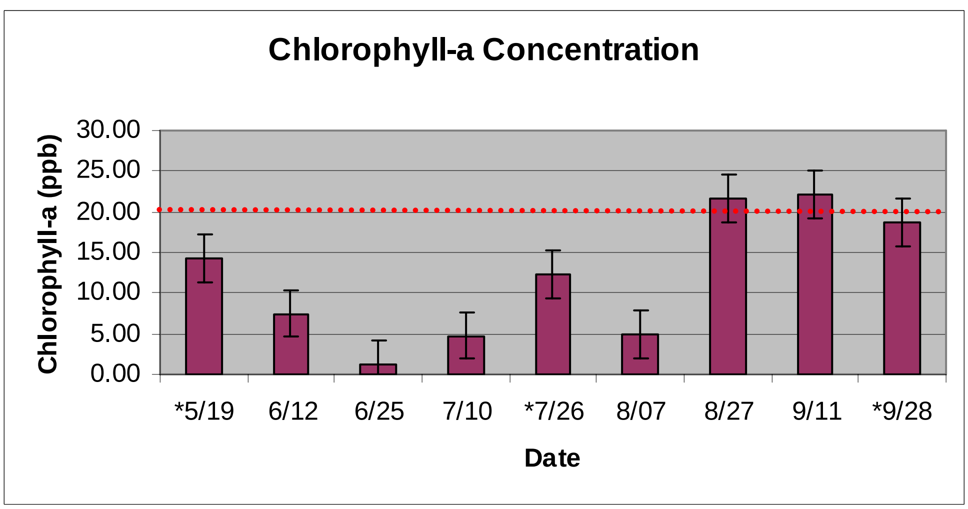
Total phosphorus (TP) concentrations averaged 48 µg/L (micrograms per liter or parts per billion) in Lower Twin Lake during the summer of 2005. This value is on the high end of the range of concentrations for reference lakes in the NCHF ecoregion (Table 1). TP concentrations ranged from 39 – 53 µg/L (Figure 31) with a pattern of slightly increasing concentrations over the summer. The early June sample was omitted, due to improper preservation.

Figure 31. Lower Twin Lake Total Phosphorus Results for 2005



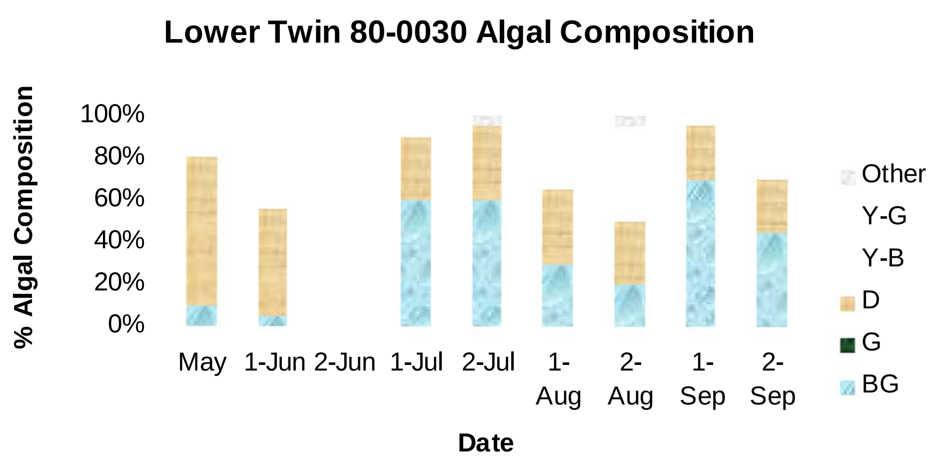
Chlorophyll-*a* concentrations for Lower Twin Lake averaged 11.6 µg/L and were within the NCHF ecoregion range (Table 1). Concentrations on Lower Twin Lake ranged from 1.4 – 22.1 µg/L with a considerable increase in late summer (Figure 32). Nuisance algae blooms (chlorophyll-*a* > 20 µg/L) were noted for the late August and early September.

Figure 32. Lower Twin Lake Chlorophyll-*a* Results for 2005



The composition of the phytoplankton (algae) population of Lower Twin Lake is presented in Figure 33. Data are presented in terms of algal type. Samples were collected at Site 102. The diatoms dominated the algal population in early June. The yellow-browns dominated the algal population from May and early June samples. Blue-green algae dominated the algae populations throughout July and September. Bloom conditions (>10 µg/L chlorophyll-*a*) were evident on the May, late July, and final 3 sampling events during the summer of 2005. A seasonal transition in algal types from diatoms to greens to bluegreen is more typical for mesotrophic and eutrophic lakes in Minnesota.

Figure 33. Lower Twin Lake Algal Populations for 2005

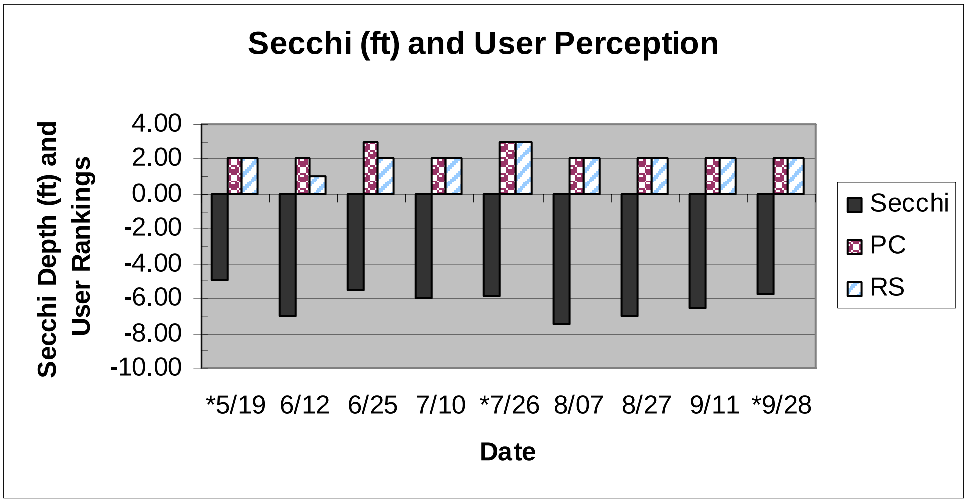


Secchi disk transparency on Lower Twin Lake ranged from 5.5 feet (1.7 meters) in late June to 7.5 feet (2.3 meters) in early August (Figure 22) and averaged 6.4 feet (1.9 meters). These transparency measures are within the typical range for NCHF ecoregion reference lakes (Table 1). Along with transparency measurements, subjective measures of Lower Twin Lake's "physical appearance" and "recreational suitability" were made. Lake conditions were predominantly characterized as "not quite crystal clear" (Class 2) and "minor aesthetic problems" (Class 2) throughout the summer for Lower Twin Lake.

Other parameters, such as total suspended solids and conductivity, analyzed for Lower Twin Lake were all near or slightly higher the typical range of values for NCHF ecoregion reference lakes (Table 1). This is not unexpected given the vast size of the watershed area and type of land uses draining to this lake.

Trophic State Index (TSI) values for Lower Twin Lake compare favorably to each other (Table 2); indicating *eutrophic* conditions. As such, Secchi transparency should continue to be a good estimator for TP and chlorophyll-*a* values as well as an indicator of overall water quality for Lower Twin Lake.

Figure 34. Lower Twin Lake Secchi Transparency for 2005



SPIRIT (80-0039)

Spirit Lake is a 115 acre lake, located in the city of Menahga, Minnesota. Spirit Lake has a maximum depth of 45 feet (13.7 m) and mean depth of 15.1 feet (4.6 m). There is a public access on the lake. Approximately 57 percent of the lake is littoral. The direct and total watershed area of Spirit Lake is 2.62 mi^2. Its water residence time is on the order of 11-12 years.

Water quality data was collected in June, July, August, and September, 2005 by volunteer lake monitor Lefty Lindblom and by the City of Menahga. One site was used on Spirit Lake: Site 202 – located over the point of maximum depth in the middle of the lake (Figure 35).

Temperature data indicated that the lake was thermally stratified for most of the summer (Figure 36). The epilimnion extended down to approximately 3 meters with the transitional metalimnion going down to approximately 5 – 6 meters. Dissolved oxygen concentrations followed a similar patter in Spirit Lake. At a depth of 5 - 6 meters, DO concentrations fell below 5 mg/l in the hypolimnion.

Figure 35. Spirit Lake Bathymetric Map and Monitoring Location

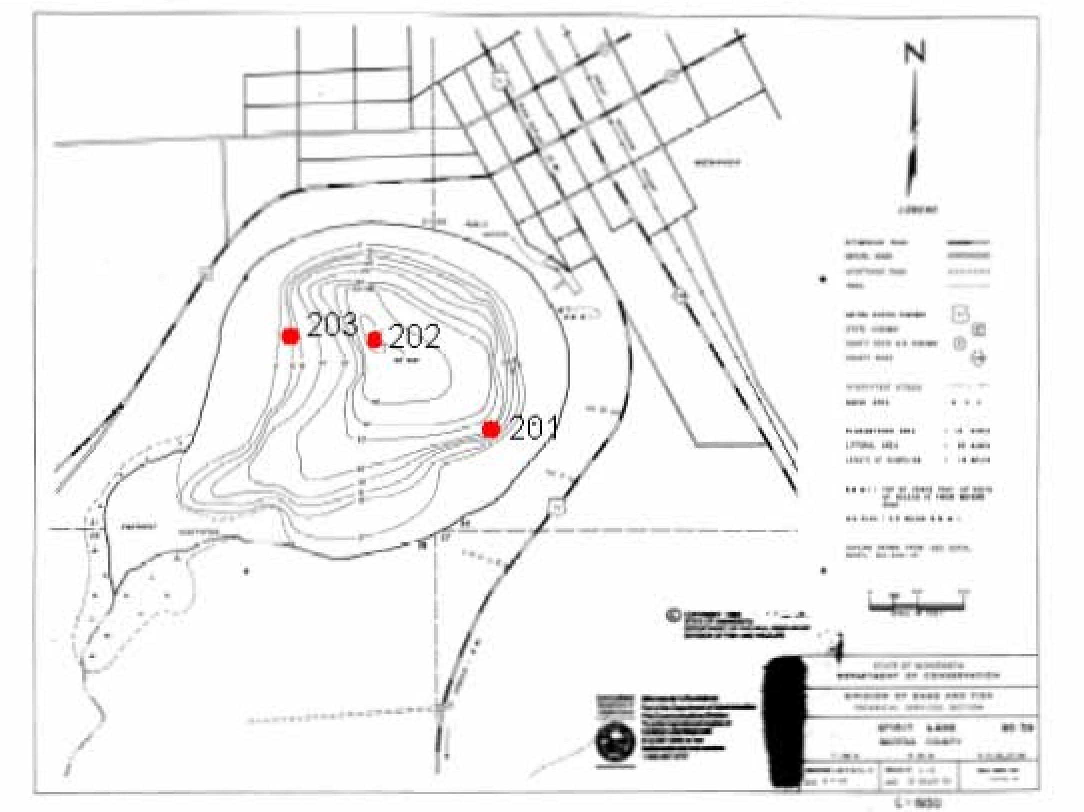
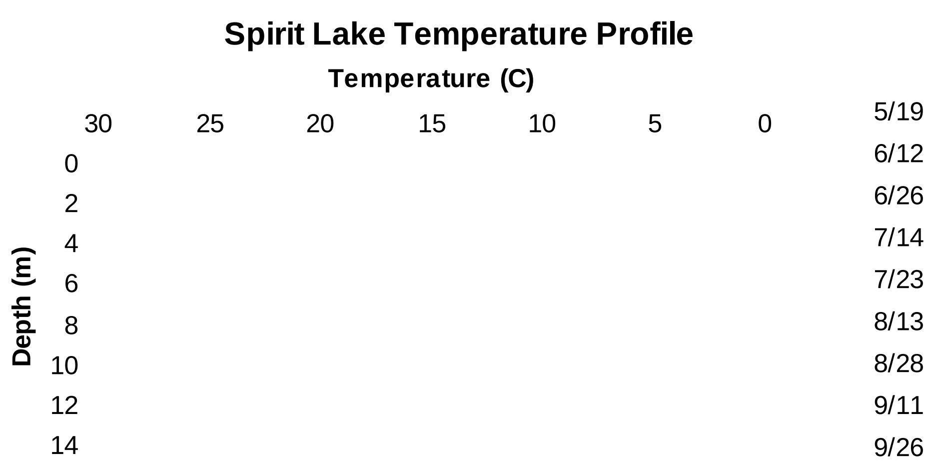
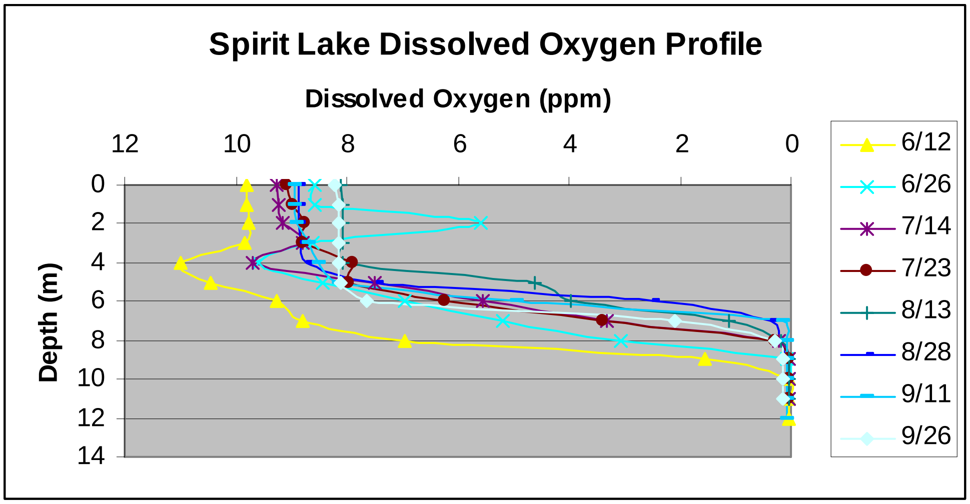


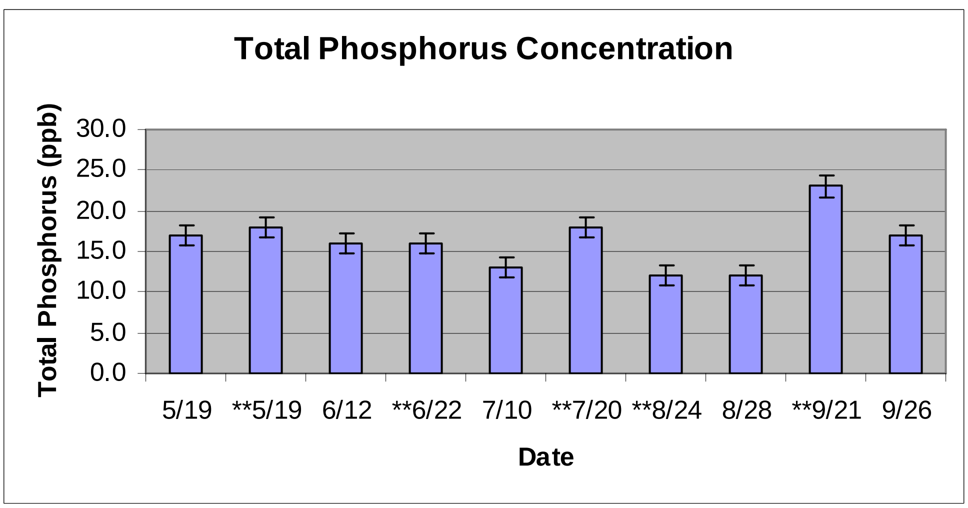
Figure 36. Spirit Lake Temperature and Dissolved Oxygen Profile Data for 2005





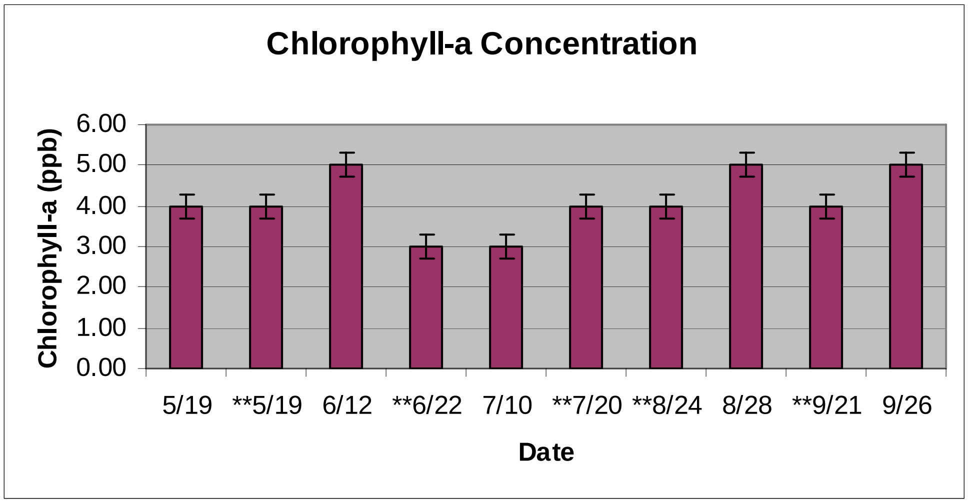
Total phosphorus (TP) concentrations averaged 16.0 µg/L (micrograms per liter or parts per billion) in Spirit Lake during the summer of 2005. This value is below (better than) the range of concentrations for reference lakes in the NCHF ecoregion (Table 1). TP concentrations ranged from 12 – 23 µg/L (Figure 37). The increase in TP from the July 10th to July 20th sample dates was likely influenced by the significant rain event on July 12th.

Figure 37. Spirit Lake Total Phosphorus Results for 2005



Chlorophyll-*a* concentrations for Spirit Lake averaged 4.1 µg/L and were again below the NCHF ecoregion range (Table 1). Concentrations on Spirit Lake ranged from 3.0 – 5.0 µg/l. No mild or nuisance algae blooms were noted for 2005 (Figure 32) based on these concentrations.

Figure 38. Spirit Lake Chlorophyll-*a* Results for 2005

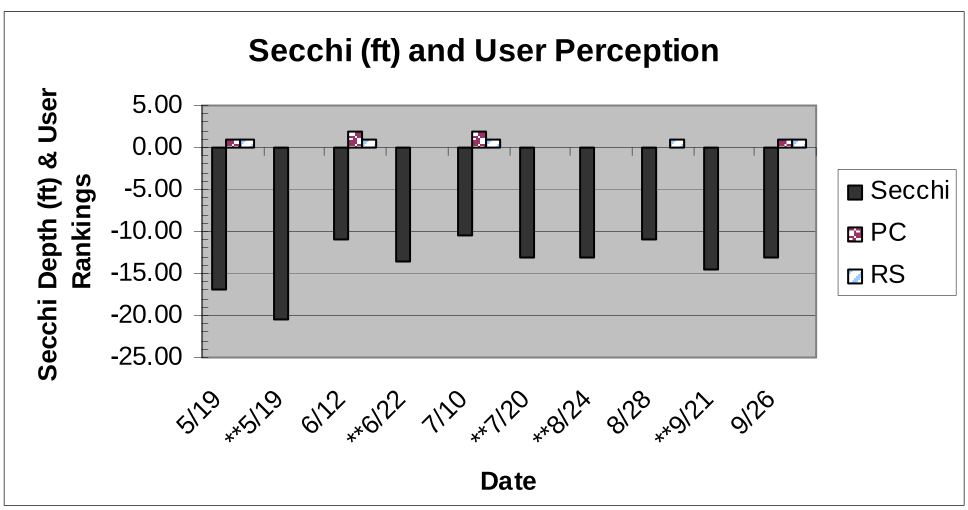


Secchi disk transparency on Spirit Lake ranged from 10.5 feet (3.2 meters) in mid July to 14.5 feet (4.4 meters) in mid September (Figure 39) and averaged 12.4 feet (3.8 meters). These transparency measures are above (better than) the typical range for NCHF ecoregion reference lakes (Table 1). Lake conditions for Spirit Lake were characterized as "crystal clear" (Class 1) and "not quite crystal clear" (Class 2) and "beautiful" (Class 1) throughout the summer.

Other parameters, such as total suspended solids and alkalinity were not collected on Spirit Lake.

Trophic State Index (TSI) values for Spirit Lake compare very favorably to each other (Table 2); indicating *mesotrophic* conditions. As such, Secchi transparency should continue to be a good estimator for TP and chlorophyll-*a* values as well as an indicator of overall water quality for the lake.

Figure 39. Spirit Lake Secchi Transparency for 2005

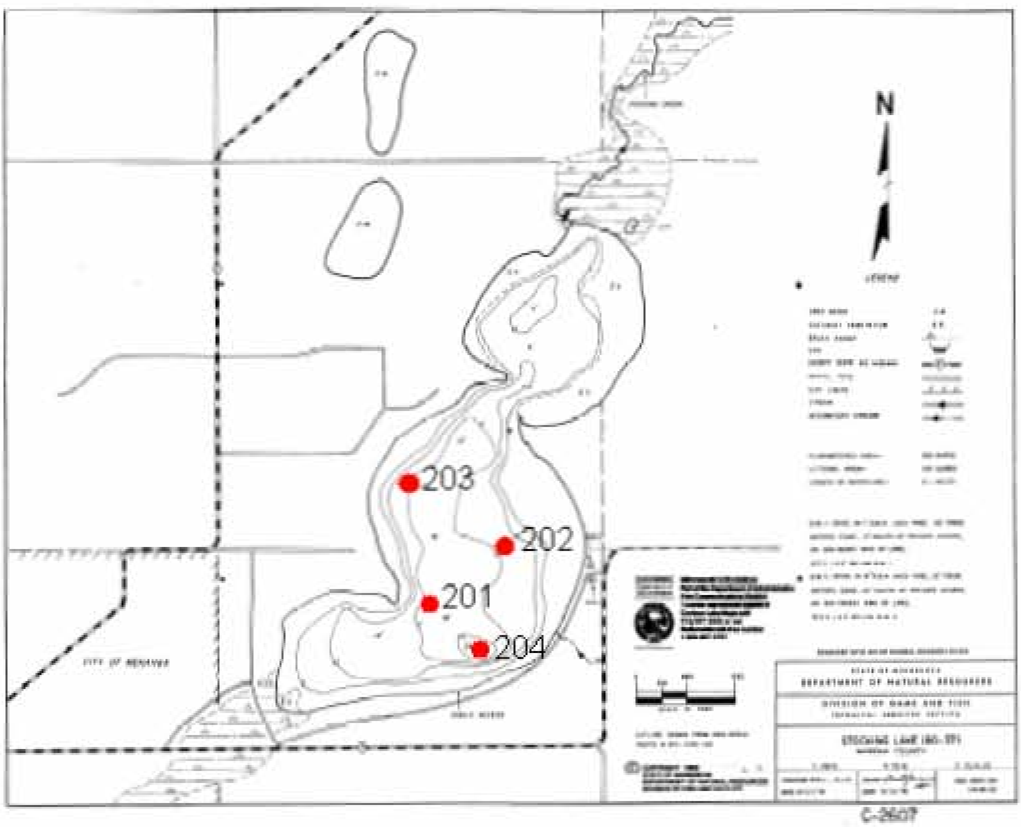


STOCKING (80-0037)

Stocking Lake is a moderate-sized lake (343 acres) with a maximum depth of 22 feet (6.7 m) and estimated mean depth of 10 feet (3.0 m). The lake is located just east of Menahga, Minnesota. Approximately 95 percent of the lake is littoral and there is one public access for the lake. Its direct watershed area of 10.5 mi^2 is slightly smaller than its total watershed area of 13.6 mi^2. As such, the watershed to lake ratio is also rather small (Table 2). Its water residence time is on the order of 0.9 years.

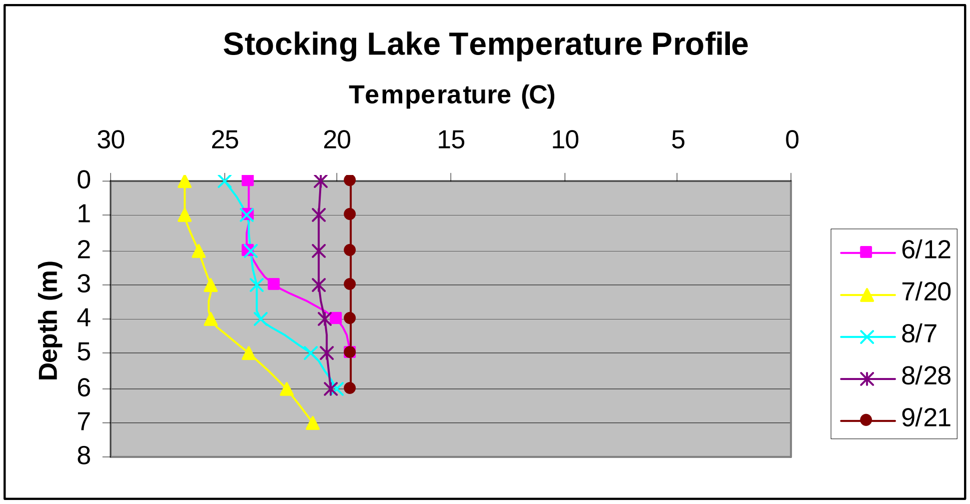
Water quality data was collected in June, July, August, and September, 2005 by volunteer lake monitors Mark Hepokowski and Lefty Lindblom. One site was used on Stocking Lake: Site 204 – located over the point of maximum depth in the southern end of the lake (Figure 40).

Figure 40. Stocking Lake Bathymetric Map and Monitoring Location



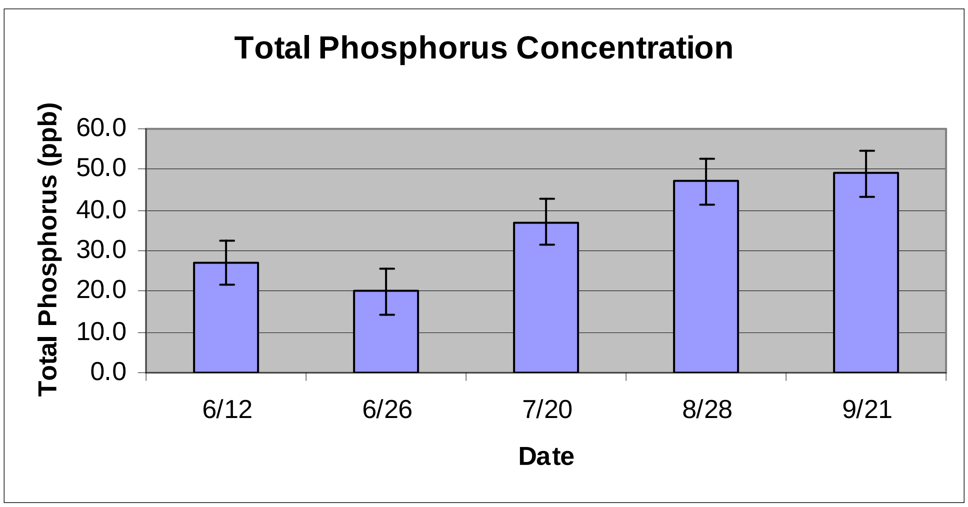
Temperature data indicated that the lake was well-mixed on the last two sampling events and was slightly thermally stratified below 4 meters (13.1 ft) for the other remaining sampling events (Figure 41). Dissolved oxygen concentrations were measured during the August sampling dates. Below a depth of 4 meters, the dissolved oxygen concentration dropped below the 5 mg/l necessary to support game fish. Temperature profiles indicated slight thermal stratification from June through early August (Figure 41). However, with the cooling and wind mixing of the water in late August, the lake became well mixed.

Figure 41. Stocking Lake Temperature Profile Data for 2005 for Site 204



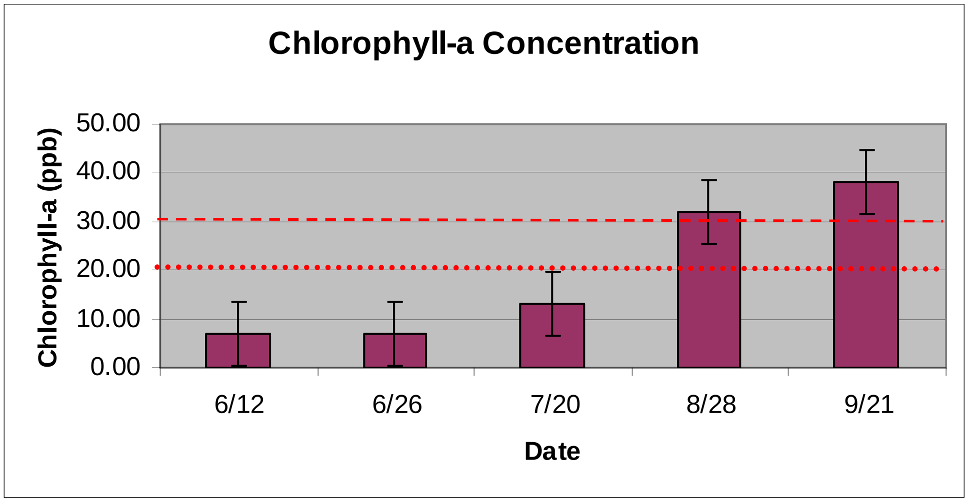
Total phosphorus (TP) concentrations averaged 36 µg/L (micrograms per liter or parts per billion) in Stocking Lake during the summer of 2005. This value is within the range of concentrations for reference lakes in the NCHF ecoregion (Table 1). TP concentrations ranged from 20 – 49 µg/L (Figure 42) with an overall increase in TP concentration throughout the summer.

Figure 42. Stocking Lake Total Phosphorus Results for 2005



Chlorophyll-*a* concentrations for Stocking Lake averaged 19.4 µg/L and were near the high end of the NCHF ecoregion range (Table 1). Concentrations on Stocking Lake ranged from 7.0 – 38.0 µg/L with an overall increase in concentrations over the summer, similar to the total phosphorus concentration. Severe nuisance algal blooms (chlorophyll-a > 30 µg/L) were evident during August and September based on the 2005 data (Figure 43).

Figure 43. Stocking Lake Chlorophyll-*a* Results for 2005

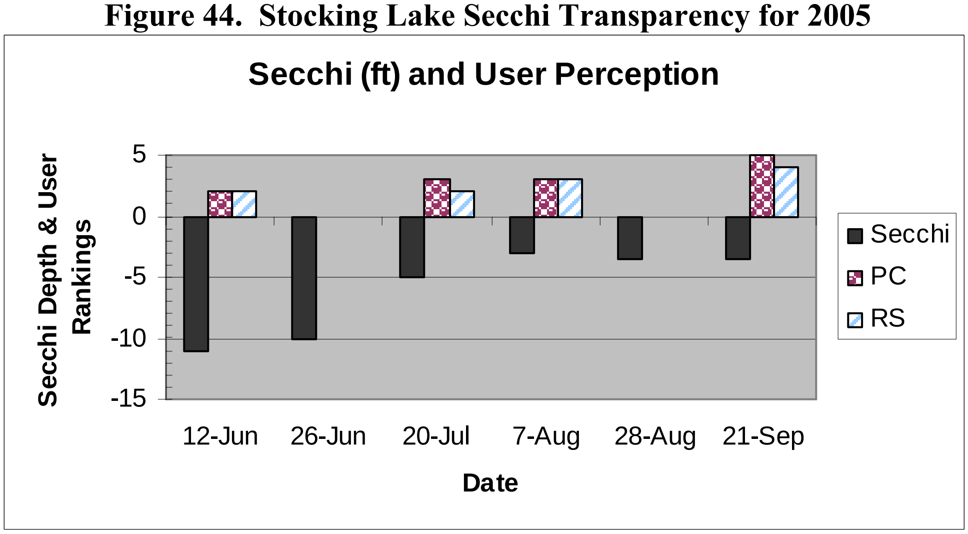


Secchi disk transparency on Stocking Lake ranged from 3.5 feet (1.1 meters) in August and September to 11 feet (3.4 meters) in mid June (Figure 44) and averaged 6.6 feet (2 meters). These transparency measures are within the typical range for NCHF ecoregion reference lakes (Table 1). Lake conditions worsened during the season, and were characterized as "not quite crystal clear" (Class 2) and “minor aesthetic problems” (Class 2) in June and had declined to “severely high algae” (Class 5) and “enjoyment substantially reduced” (Class 4) in September for Stocking Lake.

Other parameters, such as total suspended solids and conductivity were not collected for Stocking Lake (Table 1).

Trophic State Index (TSI) values for Stocking Lake compare favorably to each other (Table 2); indicating *eutrophic* conditions. As such, Secchi transparency should continue to be a good estimator for TP and chlorophyll-*a* values as well as an indicator of overall water quality for Stocking Lake.

Figure 44. Stocking Lake Secchi Transparency for 2005



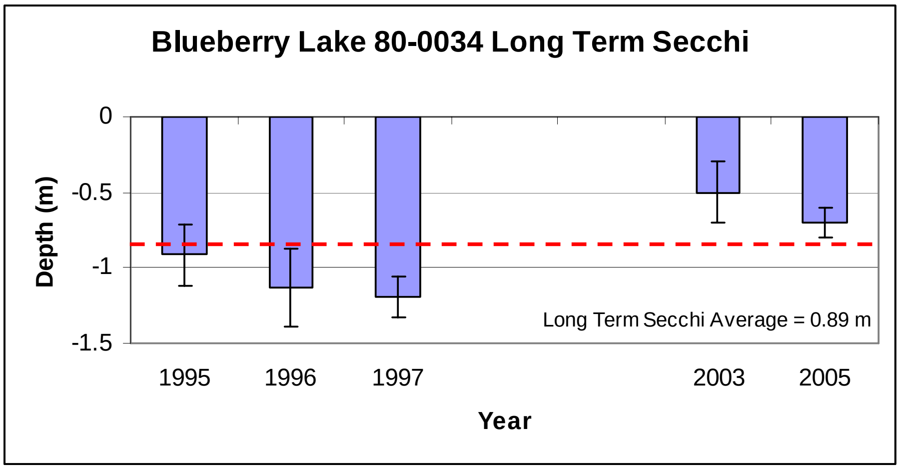
Part 3. Water Quality Trends

All available Secchi transparency data from STORET (U.S. EPA's national water quality database) were used for these assessments. The majority of the data collected is from volunteer lake monitors in the MPCA's Citizen Lake-Monitoring Program. For our trend analysis, we ran Kendall statistical test using WQ Stat Plus™ software on the CLMP+ lakes with 4 or more transparency readings per summer (June – September) and eight or more years of data. We used a probability (p) level of $p \leq 0.1$ as the basis for identifying significant trends. At this p-level, there is a 10 percent chance of identifying a trend when it does not exist. Simply stated, the smaller the p-value, the stronger the trend (i.e. more likely a trend occurred). Summer-mean transparency in a lake varies from year to year due to climatic changes (precipitation, runoff, and temperature), nutrient and sediment loading, and biological factors. Understanding and quantifying the relative magnitude of this variability is essential to assessing trends. Based on a previous study (Heiskary and Lindbloom 1993), typical year-to-year Secchi transparency variability was found to be on the order of 1 – 2 feet. In general, annual transparency in Minnesota lakes fluctuates within about 20 percent of the long-term mean. Lakes with larger fluctuations or non-random fluctuations, relative to the long-term mean, often exhibit a trend. Three of the eight CLMP+ lakes were included for Secchi trend analysis in Hubbard and Wadena Counties: Lower Twin, Stocking, and Upper Twin. The figures of this section (Figures 51 – 61) contain a factor called standard error (Std. Error). Standard error is defined as the standard deviation of a dataset divided by the square root of the number of samples from that dataset. Standard error is a measure of variability within a dataset and provides a simple basis for comparing means. The closer the values are to each other, the smaller this line will be in following figures. A small standard error, means minimal variability in Secchi measurements during a given summer, whereas a large standard error implies a high degree of variability.

Blueberry Lake (80-0034)

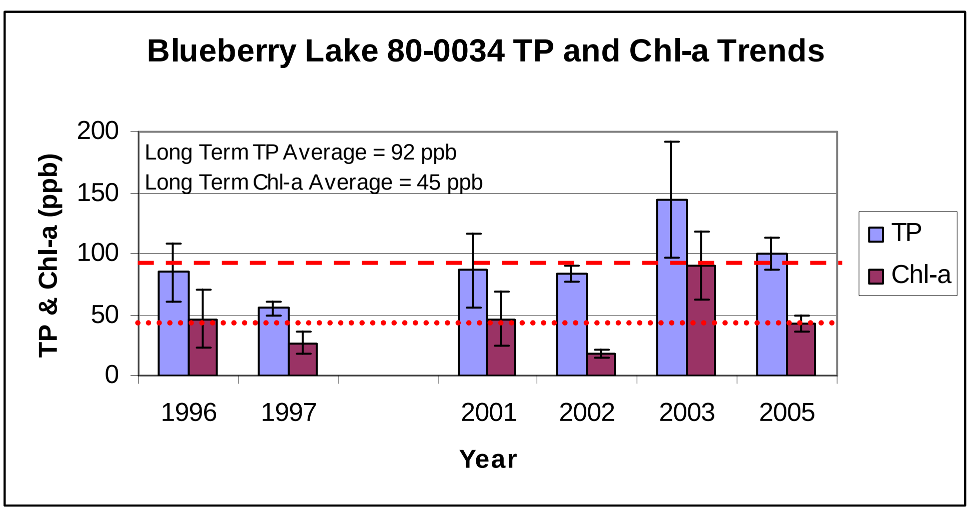
The Secchi transparency record is sparse, with data collected in 1995-1997, 2003 and 2005. With limited data, it is not possible to determine if a trend is evident, although recent measurements are considerably lower (poorer transparency) than measurements from the mid 90s. The data available ranges from a low of 0.5 m (1.6 feet) in 2003 to a maximum of 1.2 m (3.9 feet) in 1997 with a long-term average of 0.89 m (2.9 feet) (Figure 45).

Figure 45. Blueberry Lake Long Term Secchi Data



Water quality samples were collected on Blueberry Lake in 1996, 1997, and 2001 – 2003 by volunteers residing on Blueberry Lake. This historical record provides some comparison to values collected in 2005. It is interesting to note that the two years of poorest Secchi transparency (2003 and 2005) had the highest total phosphorus and chlorophyll-*a* concentrations on record for the lake (Figure 46).

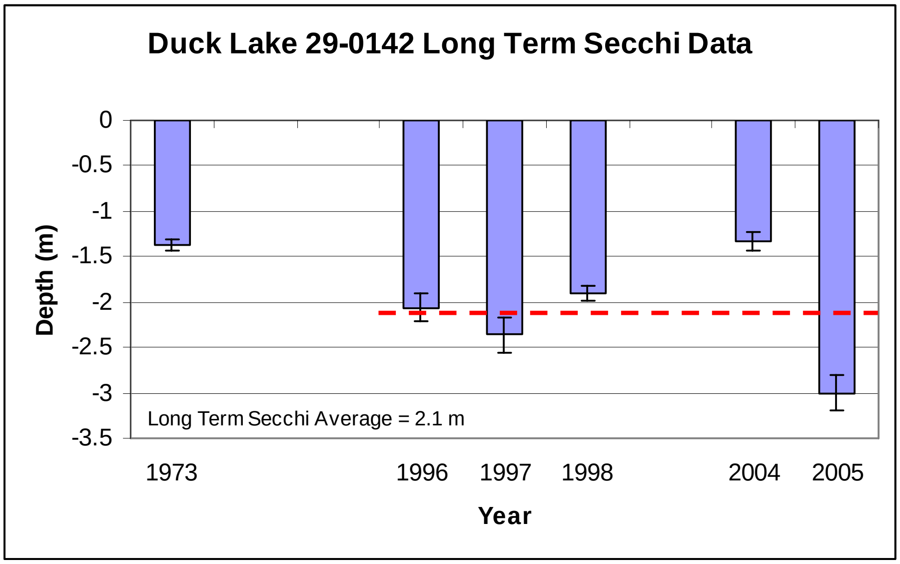
Figure 46. Blueberry Lake Long Term TP and Chlorophyll-a Data



Duck Lake (29-0142)

Six years of Secchi data have been collected on Duck Lake. Secchi transparency has ranged from a low of 1.3 m (4.3 feet) in 2004 to a maximum of 3.0 meters (9.8 feet) in 2005, with a long-term average of 2.1 meters (6.9 feet) (Figure 47). Water chemistry data was collected separate from the CLMP+ effort by residents of Duck Lake as well in 2005. When added to the CLMP+ dataset, the average and standard error remained constant.

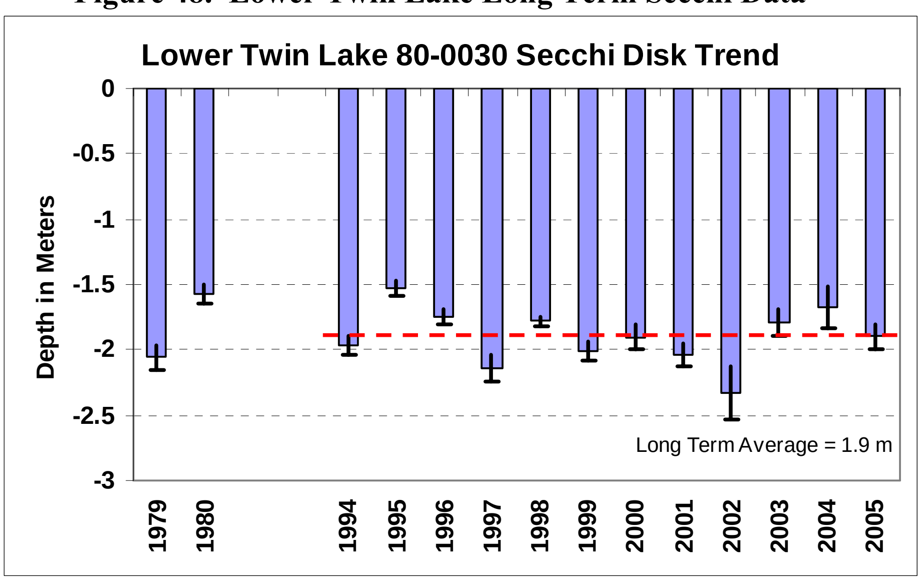
Figure 47. Duck Lake Long Term Secchi Data



Lower Twin Lake (80-0030)

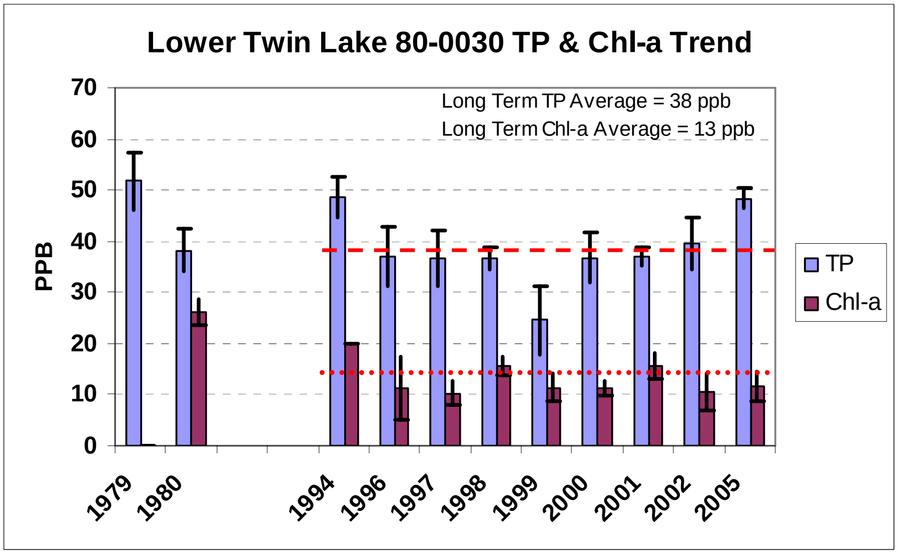
Based on the 13 years of data collected through 2004, there has been some fluctuation in transparency, but no significant trend ($p>0.2$). Secchi transparency has ranged from a low of 1.5 meters (5 feet) in 1995 to a maximum of 2.3 meters (8 feet) in 2002, with a long-term average of 1.9 meters (6 feet) (Figure 48).

Figure 48. Lower Twin Lake Long Term Secchi Data



Eleven years of water quality data have been collected on Lower Twin Lake. Total phosphorus averages have ranged from a low of 24.5 µg/L in 1999 and a high of 51.7µg/L in 1979. Using the most recent 10 years of data, the long term average for total phosphorus is 38 µg/L. Chlorophyll-*a* concentrations were also monitored on Lower Twin Lake. Concentrations range from a low of 10.3 µg/L in 1997 to a high of 26 µg/L in 1980, with a long term average of 13 µg/L (Figure 49).

Figure 49. Lower Twin Lake TP and Chlorophyll-*a* Long Term Data



Morgan Lake (80-0038)

Morgan Lake has only participated in Secchi monitoring during the 2004 and 2005 seasons. Due to this limited amount of data, no trend can be determined.

Spirit Lake (80-0039)

Based on 9 years of data, there has been some fluctuation in transparency, but not enough data was available for trend analysis in 2004. Secchi transparency has ranged from a low of 7.5 feet in 2003 to a maximum of 17 feet in 1997, with a long-term average of 11.2 feet (Figure 50).

Total phosphorus and chlorophyll-a data have been collected on Spirit Lake for 9 years, primarily by the City of Menahga. Total phosphorus concentrations range from a low seasonal average of 12 µg/L in 1996 to a high of 23 µg/L in 2003 with a long term average of 17.6 µg/L. Chlorophyll-*a* concentrations ranged from a seasonal low of 2 µg/L in 1996 (based on only one sample) to a high of 10 µg/L in 2004 with a long term average of 4.8 µg/L. Both parameters appear to be declining after a general increase in concentrations from 1996 to 2003 (Figure 51).

Figure 50. Spirit Lake Long Term Secchi Data

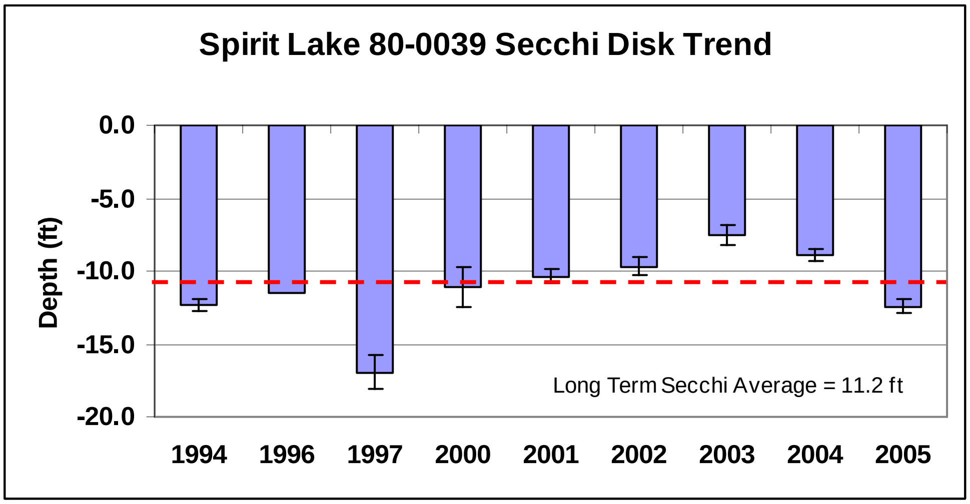
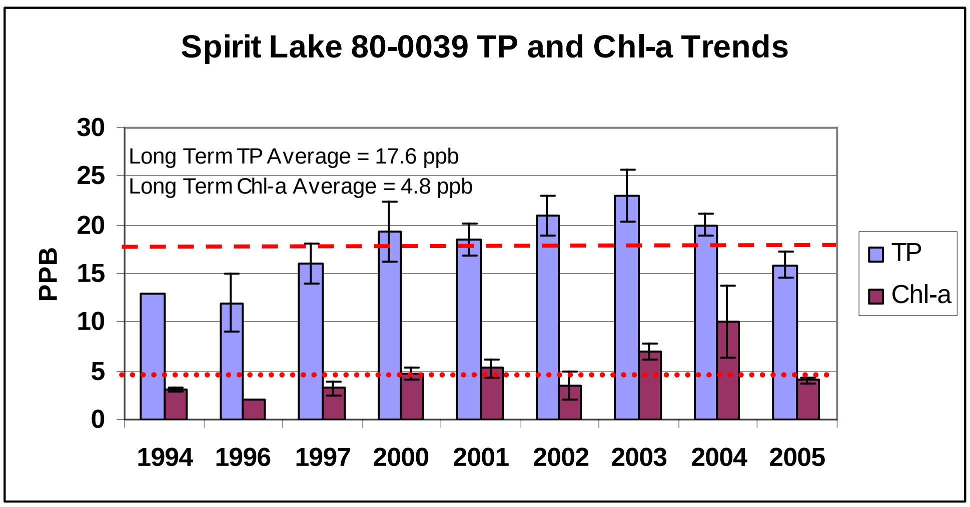


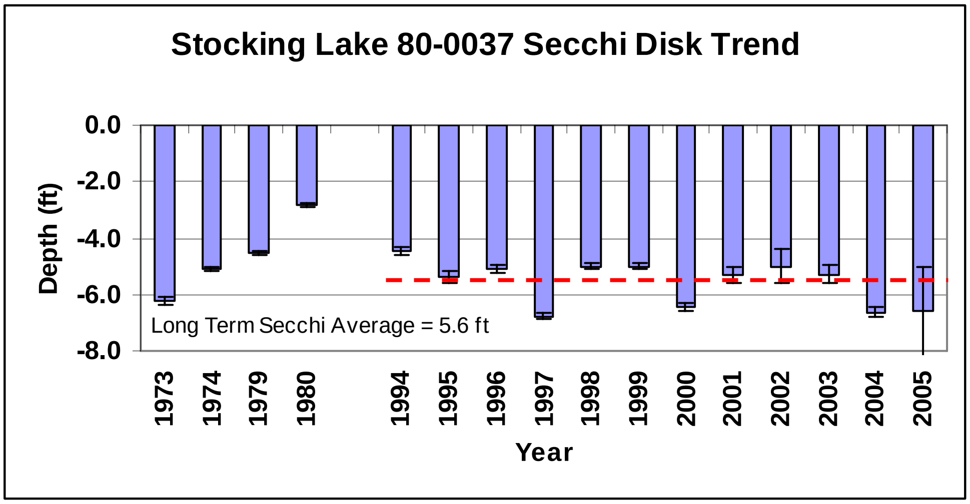
Figure 51. Spirit Lake Total Phosphorus and Chlorophyll-*a* Data



<u>Stocking Lake (80-0037)</u>

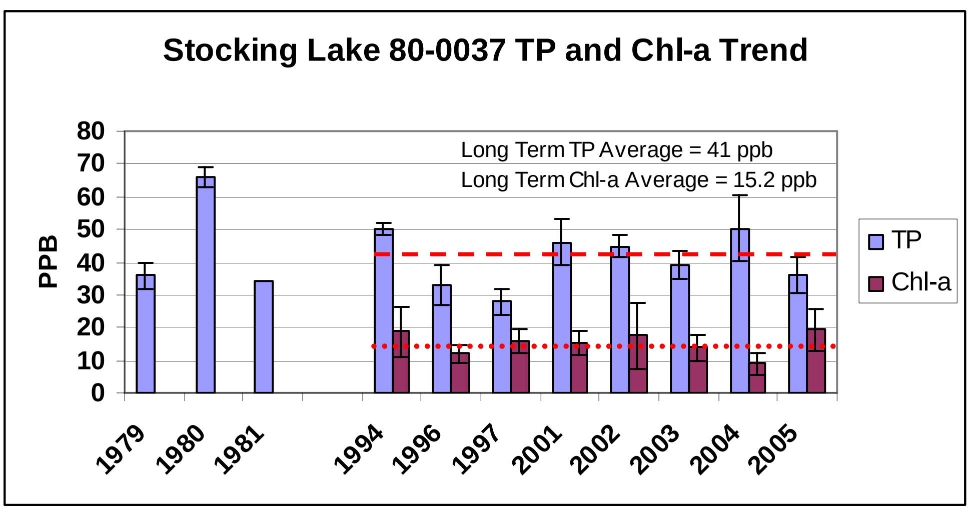
Based on data collected through 2004, there has been some fluctuation in transparency, but no significant trend (p>0.2). Secchi transparency has ranged from a low of 2.8 feet in 1980 to a maximum of 6.8 feet in 1997, with a long-term average of 5.6 feet (Figure 52).

Figure 52. Stocking Lake Long Term Secchi Data



Total phosphorus and chlorophyll-a data have been collected on Stocking Lake for 8 years, with 3 additional years of total phosphorus data collected in the early 1980s. Total phosphorus concentrations range from a low seasonal average of 28 µg/L in 1997 to a high of 66 µg/L in 1980 with a long term average of 41 µg/L. Chlorophyll-*a* concentrations ranged from a seasonal low of 9 µg/L in 2004 to a high of 19.4 µg/L in 2005 with a long term average of 15.2 µg/L (Figure 53).

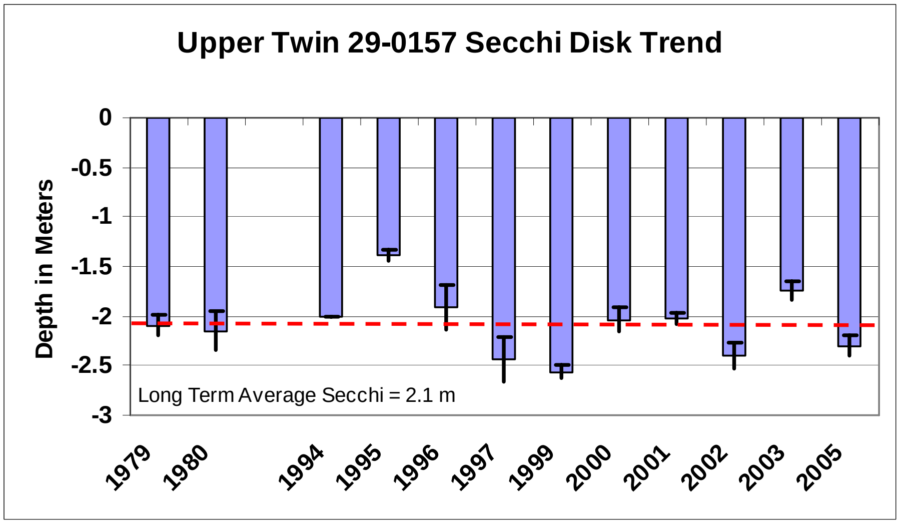
Figure 53. Stocking Lake Total Phosphorus and Chlorophyll-a Data



Upper Twin Lake (29-0157)

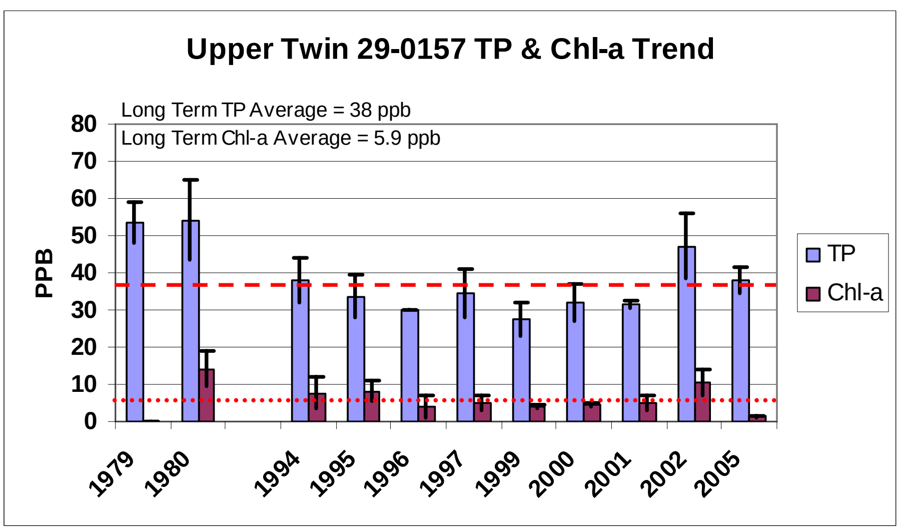
Based on data collected through 2004, there have been small fluctuations in transparency, but no significant trend (p>0.2). Secchi transparency has ranged from a low of 1.4 meters (4.6 feet) in 1995 to a maximum of 2.56 meters (8.4 feet) in 1999, with a long-term average of 2.1 meters (6.9 feet) (Figure 54).

Figure 54. Upper Twin Long Term Secchi Data



Total phosphorus and chlorophyll-*a* samples have both been collected for at least 10 years. Total phosphorus has ranged from a low of 27.5 µg/L in 1999 to a high of 53.8 µg/L in 2000, with a long term average of 40 µg/L (Figure 61). Chlorophyll-*a* concentrations have ranged from a low of 1.3 µg/L in 2005 to a high of 14.1µg/L in 1980. The long term chlorophyll-a concentration is 5.9 µg/L (Figure 55).

Figure 55. Upper Twin Long Term Total Phosphorus and Chlorophyll-*a* Data



Part 4. Water Quality Modeling

The Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) computer model was used to predict the TP concentration of each lake. These predictions are based on: lake area, mean depth, watershed area, and ecoregion in which the lake is located. Known information such as lake and watershed areas, and mean depth are inputs to the model; which in turn, computes a "predicted" TP value. The predicted TP value is used to predict a chlorophyll value, which in turn, is used to predict a Secchi value. The predicted values can then compared to the observed values (summer means) for each lake to determine if the lake's condition is what would be expected – based on its size, depth and watershed area. The model has some limitations in that it cannot take into account groundwater influence and cannot account for TP-trapping or settling in large lakes that may be upstream of the lake being modeled.

A subroutine in the MINLEAP model provides an estimate of background TP concentration for each lake based on its mean depth and alkalinity. This estimate was derived from an equation developed by Vighi and Chiaudani (1985) and is based on the morphoedaphic index commonly used in fisheries science. This equation assumes that most of the phosphorus entering the lake arises from soil erosion in the watershed, and that phosphorus and other minerals, which contribute to alkalinity, are delivered in relatively constant proportions. In turn, the mean depth of the lake will moderate the in-lake phosphorus concentration (e.g. deep lakes settle material readily, which contributes to low phosphorus concentrations). This estimated "background" concentration helps place modern-day results and goal setting in perspective. Mean depth and volumes were estimated Blueberry, Morgan, and Stocking Lakes, the values for the rest of the lakes were available from the MNDNR. Watershed area information was derived for all lakes based on the USGS web site.

The discussion of this section of the report will be organized geographically on a watershed basis. Several lakes are located in the same watershed and it makes sense from a modeling standpoint to address these lakes together. Framing the discussion in this manner allows for a more reasonable comparison of data and modeling results. In addition, several watershed maps for these area lakes will be included in the appendix.

Table 3. MINLEAP Model Outputs & Predictions

LAKE	TP (µg/L) Observed[1]	TP (µg/L) Predicted[2]	TP (µg/L) Vighi-Chiaudani	Chl-a (µg/L) Observed[1]	Chl-a (µg/L) Predicted[2]	Secchi (m) Observed[1]	Secchi (m) Predicted[2]
Blueberry	100 ± 13.8	113 ± 24.0	37	43.3 ± 6.7	65.5 ± 30.7	0.7 ± 0.1	0.7 ± 0.2
Upper Twin	38 ± 3.6	47 ± 9.0	34	1.3 ± 0.3	18.0 ± 8.2	2.3 ± 0.1	1.4 ± 0.5
Lower Twin	48 ± 1.9	35 ± 7.0	34	11.6 ± 2.9	11.9 ± 5.4	1.9 ± 0.1	1.8 ± 0.6
Morgan	11 ± 0.6	24 ± 8.0	20	1.7 ± 0.2	6.7 ± 4.1	5.6 ± 0.2	2.5 ± 1.0
Duck	22 ± 1.2	26 ± 8.0	23	5.6 ± 0.8	7.6 ± 4.5	3.0 ± 0.2	2.3 ± 0.9
Stocking	36 ± 5.6	31 ± 8.0	-	19.4 ± 6.5	9.7 ± 5.2	2.0 ± 0.5	2.0 ± 0.8
Spirit	16 ± 1.3	21 ± 9.0	-	4.1 ± 0.3	5.7 ± 4.1	3.8 ± 0.2	2.8 ± 1.3

[1]Observed Values reported as summer-mean ± standard error.

[2]Predicted Values based on the Total watershed except for Spirit Lake, which was modeled using direct watershed to compare to the 1997 LAP study.

Table 4 depicts the default values used in the MINLEAP model for the NLF and NCHF ecoregions. Since the lakes in this report fall on the transition between these ecoregions, the inputs for precipitation, evaporation, and runoff were calibrated to values specific to that region of the state (Wilson 1990). For Blueberry, Upper, and Lower Twin Lakes, the stream TP was calibrated as follows: Blueberry Stream TP = 148 ug/L, Upper Twin Stream TP = 52, and Lower Twin Stream TP = 38 ug/l to account to the specific upstream influences for each lake.

Table 4. MINLEAP Default Values and Values Calibrated for Modeling

	NLF	NCHF	Values Used in Modeling
Precipitation	0.74	0.75	0.63
Evaporation	0.61	0.71	0.83
Runoff	0.23	0.13	0.13
Stream TP	52	148	52

Blueberry and Upper Twin Lakes

Blueberry and Upper Twin Lakes are 522 and 225 acres in size, respectively. The total watershed area (212 mi^2) is approximately 75 times the size of the direct watershed area for Blueberry Lake (Table 2). The direct watershed area for Blueberry Lake is approximately 2.8 mi^2. The total watershed area for Upper Twin Lake, which includes the contributing watershed area from Blueberry Lake, is approximately 595 mi^2. MINLEAP predicted a slightly higher, but not significantly different TP concentration than the 2005 observed concentration for Blueberry and Upper Twin Lakes (Table 3). Vighi-Chiaudani predicted a background TP concentration for Blueberry Lake (37 µg/L) is much lower than observed (Table 3) TP-loading for Blueberry Lake is estimated to be on the order of 10,600 kg P/yr, and the TP-retention coefficient is estimated at 0.25 (implies lake retains 25% of P loading). TP-loading for Upper Twin Lake is estimated to be on the order of 10,000 kg P/yr, and TP-retention coefficient is estimated to be 0.07. The predicted chlorophyll-*a* concentration for Blueberry Lake is higher, but not significantly different, than the 2005 observed values. However, on Upper Twin Lake, the observed chlorophyll-*a* concentration is much lower than the predicted. This lake is heavily dominated by rooted aquatic vegetation; the uptake of total phosphorus by these plants is likely preventing the growth of algae (measured by chlorophyll-*a* concentrations). The predicted Secchi transparency value for Blueberry Lake is the same as the observed, and for Upper Twin is significantly lower than the observed value. Again, this underestimate of transparency is likely related to the extremely low chlorophyll-*a* in Upper Twin Lake. Overall, the model predictions are in relatively close agreement with observed conditions and suggest that Blueberry Lake is well above background conditions and Upper Twin Lake is near background conditions.

Morgan Lake

Morgan Lake is a small lake (18 acres) with a very small estimated watershed (0.36 mi^2, Table 2). Morgan Lake is on the upstream end of a shared total watershed with Lower Twin Lake. MINLEAP predicted a significantly higher TP concentration than the 2005 observed value for Morgan Lake (Table 3). The Vighi-Chiaudani model also predicted a significantly higher TP concentration than the 2005 observed value (Table 3). TP-loading for Morgan Lake is estimated to be on the order of 8 kg P/yr, and the TP-retention coefficient is estimated to be 0.69. The predicted TP, chlorophyll-*a* and Secchi values are all significantly different than the observed values in 2005 (Table 3). This lake is minimally impacted, with the only development being a camp situated along the southwestern shore, and the shoreline is relatively unaltered. This may account for the significant differences between observed 2005 values and the predicted values. Extensive groundwater inflow may be a factor to closed basin lakes as well.

Lower Twin Lake

The direct watershed area for Lower Twin Lake is 2.3 mi^2. The total watershed area for Lower Twin Lake, which includes the contributing watershed areas from Upper Twin, Blueberry and Morgan Lakes, is approximately 598 mi^2(Table 2). MINLEAP inflow stream TP concentrations for Lower Twin Lake were calibrated based on Upper Twin Lake in-lake TP concentrations. MINLEAP predicted a lower and significantly different TP concentration than the 2005 observed value for Lower Twin Lake (Table 3). The Vighi-Chiaudani model also predicted a significantly lower TP background for Lower Twin Lake compared to the 2005 observed values (Table 3). TP-loading for Lower Twin Lake is estimated to be on the order of 7,707 kg P/yr, and the TP-retention coefficient is estimated to be 0.09. Retention is low in Lower and Upper Twin Lakes because of the high water and P loading relative to the volume of these lakes. The predicted chlorophyll-*a* concentrations for Lower Twin was slightly higher than, but not significantly different from the 2005 observed values. Similarly, the predicted Secchi transparency value was not significantly different than the 2005 observed values for Lower Twin Lake. Overall, the model predictions are in relatively close agreement with observed measurements when the model is “calibrated” to account for P-retention in Upper Twin Lake.

Duck Lake

Duck Lake is a medium sized lake covering 326 acres. The total and direct watershed area is 8.12 mi^2 (Table 2). MINLEAP predicted a slightly higher, but not significantly different TP concentration than the 2005 observed value (Table 3). The Vighi-Chiaudani model predicted a background TP that is relatively close to the 2005 observed value (Table 3). TP-loading for the lake is estimated to be on the order of 176 kg P/yr, and the TP-retention coefficient is estimated to be 0.64. The predicted chlorophyll-*a* concentration was higher and predicted Secchi transparency value was lower than the 2005 observed values. Based on the model predictions, the lake is very close to background conditions.

Stocking Lake

Stocking Lake is a medium sized lake covering 343 acres. The total watershed area is slightly larger than the direct contributing watershed (13.6 mi^2 and 10.5 mi^2, respectively). MINLEAP predicted a slightly lower, but not significantly different TP concentration than the 2005 observed value for Stocking Lake (Table 3). TP-loading for Stocking Lake is estimated to be on the order of 270 kg P/yr, and the TP-retention coefficient is estimated to be 0.52. The predicted chlorophyll-*a* value is considerably lower, but not significantly different than the 2005 observed value for Stocking Lake. Predicted and observed values for Secchi depth was equivalent. Overall, model predictions for Stocking Lake were comparable to the observed.

Spirit Lake

Spirit Lake is a small lake (115 acres) and has a relatively small direct watershed area (0.2 mi^2, Table 2). MINLEAP predicted a slightly higher, but not significantly different TP concentration than the 2005 observed value for Spirit Lake (Table 3). TP-loading for Spirit Lake is estimated to be on the order of 24 kg P/yr, and the TP-retention coefficient is estimated to be 0.92. The predicted chlorophyll-*a* concentration for the lake was slightly, but not significantly higher, than the 2005 observed value. The predicted Secchi transparency is lower, but not significantly different, from the 2005 observed value for Spirit Lake. Overall, model predictions are comparable to observed and suggest the lake's condition is close to anticipated values for a lake of this size, depth, and watershed area.

A Lake Assessment Program Study was completed for Spirit Lake in 1997 (Klang and Heiskary, 1998). Data collected and modeling conducted in 1997 agrees favorably with data collected and modeled in 2005. The overall TSI value of 43 calculated in 2005 is very similar to the 1997 value (41). This indicates that Spirit Lake is maintaining a mesotrophic status, and TP inputs are likely similar to 1997 levels.

Part 5. Goal Setting

For several of the lakes in this study (Morgan, Duck, and Spirit), it would be desirable to maintain the currently low in-lake P-concentrations. The summer-mean P-concentrations for these lakes were near or better than both the predicted P-value and Vighi and Chiaudani "background" estimate. Although Blueberry, Lower Twin, and Upper Twin Lakes' in-lake P-concentrations were near predicted P-values, they were considerably higher than "background" conditions; suggesting that an overall reduction in TP would be desirable to reduce in-lake TP concentrations. Although we are unable to calculate the background condition TP for Stocking Lake, the observed values are near the predicted values and similar to those found in Upper and Lower Twin Lakes – it is likely that a reduction in TP would be desirable.

Minnesota's lakes and streams are assessed every two years as part of the 303(d) assessment process as required by USEPA. Waters found not to be in compliance with water quality standards are placed on the "TMDL" (total maximum daily load) or "Impaired Waters" list. Two of the "impairments" assessed for lakes include mercury (in fish tissue) and "nutrient impairment." Mercury is addressed extensively on MPCA's website at: http://www.pca.state.mn.us/water/tmdl/tmdl-mercuryplan.html. Thresholds for nutrient impairment are expressed in Table 5.

Stocking Lake is currently on the impaired waters list for mercury. In terms of nutrient impairment, Lower Twin, Upper Twin, and Stocking Lake's values based on data collected from 1995 – 2004 (time period considered for 2006 draft list). In general, TP values are at or above NLF thresholds; however, chlorophyll-*a* tends to be lower than the threshold values. Blueberry Lake is above the TP, chlorophyll-*a* and Secchi thresholds based on 2005 data. All the rest of the lakes (Morgan, Duck, and Spirit) are below the 30 μg/L TP threshold for the NLF ecoregion. Twelve pairs of TP, chlorophyll-*a*, and Secchi data are needed to "officially" determine whether a lake is listed on the impaired waters list. Upper Twin and Stocking Lakes were included in the 2006 assessment process, but were not listed as impaired for nutrients.

Once a lake is listed, a detailed and formal study of the lake and watershed are conducted to determine actual nutrient sources and loadings to the resource. Subsequently, a plan is developed for the resource for overall nutrient reduction. This can be a long, detailed, and sometimes complicated process. In the meantime, some important considerations for improving and protecting the water quality of all the lakes in this include implementation of BMP's in the shoreland area and ultimately through the watershed with a particular emphasis on the direct drainage area. A more comprehensive review of land use practices in the watershed may reveal opportunities for implementing BMPs in the watershed and reducing P-loading to the lake. Proper maintenance of buffers areas between lawns and the lakeshore, minimizing use of fertilizers, and minimizing the introduction of new significant sources of P-loading (e.g., stormwater from near-shore development activities in the watershed), will serve to minimize loading to the lake. These and other considerations will be important if the water quality of these Hubbard and Wadena County lakes is to be maintained or improved over the long term.

Table 5. Nutrient and Trophic Status Thresholds for Determination of Use Support for Lakes.

Ecoregion (TSI)	TP (ppb)	Chl-a (ppb)	Secchi (m)	TP Range (ppb)	TP (ppb)	Chl-a (ppb)	Secchi (m)
305(b) →	**Full Support**			**Partial Support to Potential Non-Support**			
303(d) →	**Not Listed**			**Review**	**Listed**		
NCHF	**< 40**	**< 15**	**≥ 1.2**	**40 - 45**	**> 45**	**> 18**	**< 1.1**
(TSI)	(< 57)	(< 57)	(< 57)	(57 – 59)	(> 59)	(> 59)	(> 59)
NLF	**< 30**	**<10**	**≥ 1.6**	**30 – 35**	**> 35**	**> 12**	**< 1.4**
TSI	**< 53**	**< 53**	**< 53**	**53 – 56**	**> 56**	**> 55**	**> 55**

Derived from MPCA Guidance Manual for Assessing Minnesota Surface Waters for Determination of Impairment (MPCA 2003). *TSI* = Carlson's Trophic State Index; *Chl-a* = Chlorophyll-*a*, includes both pheophytin-corrected and non-pheophytin-corrected values; *ppb* = parts per billion or µg/L; *m* = meters

Part 6. Summary & Recommendations

During the summer of 2005, eight lakes in Wadena and Hubbard Counties were sampled by volunteers as a part of a monitoring program, six of these lakes via CLMP "Plus". These lakes were selected because they were a priority in the county and lacked data beyond CLMP Secchi data. The combination of water chemistry and Secchi data provides a good baseline for these lakes.

Following are a few general observations and recommendations based on our monitoring and data analysis:

A. Secchi transparency monitoring: All CLMP+ lakes, except Jim Cook, have participated in CLMP in the past. All of the lakes except Blueberry exhibited Secchi transparency values comparable to their respective NCHF or NLF reference lakes. Monitoring Secchi transparency provides a good basis for estimating trophic status and detecting trends. Routine participation is essential to allow for trend analysis. Of the eight lakes, only three had enough years of data needed for trend analysis. Continued CLMP monitoring on all the lakes will contribute to the database, which already exists and allow for future trend assessments.

B. Water quality and tropic status: Based on data collected in 2005, all of the lakes except Blueberry (NCHF ecoregion) exhibited TP concentrations comparable to the typical range for minimally-impacted lakes in the NLF ecoregion (Morgan, Spirit, Duck Lakes) and in the NCHF ecoregion (Lower Twin, Upper Twin, Stocking Lakes). The TP concentrations for Blueberry Lake was much higher than the typical range; most likely as a result of the lake being large, shallow and well-mixed; and having a very large watershed. Conversely, Morgan Lake's TP, chlorophyll-*a* concentrations, and Secchi depths were actually better than the expected range for NLF lakes. Morgan and Spirit Lakes would be considered *mesotrophic* while Duck and Upper Twin Lakes would be considered *mesotrophic – eutrophic* in condition. Lower Twin and Stocking Lakes would be considered *eutrophic* and Blueberry Lake, with its elevated TP and chlorophyll-a concentrations and reduced Secchi depth would be *hypereutrophic*. Since a full season of data was not collected for Jim-Cook, a trophic state could not be determined.

C. Water quality trends: Of the 8 lakes monitored, only 3 had a sufficient number of previous years of Secchi data for trend analysis. These three lakes had consistent data since 1994, but have a significant break in the overall record from 1980 to 1994. None of the lakes showed a statistical decline or improvement in water transparency over time. Continued monitoring of all of these lakes will enhance our ability to assess trends.

D. Model predictions: In general, observed TP and predicted (MINLEAP) TP were fairly comparable for all of the lakes except Morgan and Lower Twin Lakes. For Morgan Lake, observed TP was significantly lower than predicted. Since these predictions were based on estimated mean depths, actual planimetry of Morgan Lake's volume could help improve these model estimates. For Lower Twin Lake, the observed TP was significantly higher than predicted values. Due to the extremely large size of the watershed and the very low residence time, it is possible that more TP reaches the lake than predicted in the model. However, the chlorophyll-*a* and Secchi values predicted were very similar to observed values.

E. Morgan, Duck, and Spirit Lakes are of very good water quality and every effort to protect them from degradation should be taken. Blueberry, Stocking, Lower and Upper Twin Lakes, while more eutrophic, would all benefit from protection efforts. Further development or land use change in the watersheds should occur in a manner that minimizes water quality impacts on the lakes. In the shoreland areas, setback provisions should be strictly followed. MDNR and County shoreland 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. Properly designed sedimentation ponds should be included in any development to minimize P-loading to the lakes. A "no-net-increase" in TP is recommended.
- Activities in the watersheds that change drainage patterns, such as wetland removal or major alterations in lake use, should be discouraged unless they are carefully planned and adequately controlled. Restoring or improving wetlands in the watersheds may also be beneficial for reducing the amount of nutrients or sediments that reach the lakes. The U.S. Fish and Wildlife Service at Fort Snelling may be able to provide technical and financial assistance for these activities.
- The lake associations should continue to 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.
- Macrophyte population and distribution maps for each lake may be beneficial to the associations. Exotic species such as *Eurasian water milfoil* and *curly-leaf pondweed* can dramatically impact quality resources such as these CLMP+ lakes in Wadena and Hubbard Counties. Tracking the population and distribution of rooted aquatic plants can be helpful in determining if changes within the system are occurring and be a possible warning signs for those changes.

F. On-site septic systems are a *potential* source of nutrients to lakes that are not sewered. While their influence may not be express in terms of dramatic increases in algae in the lake, they may be expressed by increased near-shore weed growth or excessive attached algae on docks and plants. A house-to-house septic system survey may help the individual lake associations and Wadena and Hubbard Counties determine if homeowners are somewhat familiar with the age and maintenance (pumping) of their systems and if further education is needed on proper maintenance of their systems. This may also help them encourage all homeowners with non-code systems to bring their systems up to code. The lake associations may want to facilitate a lake-wide schedule for pumping systems.

G. An examination of land use practices in the watershed and identification of possible nutrient sources such as lawn fertilizer, the effects of ditching and draining of wetlands, and development practices etc., may aid the lake associations in determining areas where best management practices may be needed. For example, recent studies indicated that a majority of lawns in the Twin Cities metro area do not need additional phosphorus – this may be true for lawns in Wadena and Hubbard Counties as well. In April 2005, a new law came into effect restricting the use of phosphorus fertilizers in Minnesota. The lake associations, together with Wadena and Hubbard Counties, should encourage the use of P-free fertilizers and educate property owners on the phosphorus ban in the watershed. There may be other opportunities to implement/promote Best Management Practices (BMP's) that may reduce nutrient loading from other sources in the watershed as well.

H. Results from the Wadena and Hubbard Counties CLMP+ show that properly trained volunteers can collect consistent and reliable data for use in lake water quality assessments, and are a resource that can and should be used to gather additional information.

Appendix

1. **Hubbard and Wadena County CLMP+ Lakes Data for 2005 and Historic Data**

2. **Precipitation Events Near Menahga, MN (CLMP+ Lakes)**

3. **Lake Level Data for CLMP+ Lakes**

4. **Status of the Hubbard and Wadena County CLMP+ Lakes' Fishery**

Appendix 1. Hubbard and Wadena County CLMP+ Lakes Data

2005 CLMP+ Data for Hubbard and Wadena County Lakes

Lake ID	Lake Name	Date	TP ppb	RMK	Chla ppb	Pheo ppb	RMK	TSS mg/l	TSV mg/l	COL cu	ALK mg/l	CHL mg/l	RMK	TKN mgl	SDF	pH	Cond
29-0142	Duck	05/18/2005	21.0		1.88	0.34	K	5.3	2.7	10.0	130.0	9.6		1.51	8.20	7.45	233
29-0142	Duck	05/18/2005	21.0														
29-0142	Duck	05/18/2005	25.0		2.24	0.32	K										
29-0142	Duck	06/12/2005	25.0	Q	8.94	0.73									10.00		
29-0142	Duck	06/25/2005	16.0		5.35	0.95									7.00		
29-0142	Duck	07/10/2005													10.00		
29-0142	Duck	07/26/2005	20.0		2.85	0.31	K	2.0	1.6	5.0	110.0	11.0		0.91	8.53	8.50	200
29-0142	Duck	07/26/2005	22.0														
29-0142	Duck	08/15/2005	24.0		7.91	1.93									10.50		
29-0142	Duck	08/29/2005	25.0		5.13	0.66									10.00		
29-0142	Duck	09/12/2005	21.0		5.26	0.45									12.00		
29-0142	Duck	09/28/2005	23.0		4.05	1.21		3.6	2.4	5.0	120.0	11.0		0.90	11.50	8.27	244
29-0142	Duck	09/28/2005	22.0														
80-0034	Blueberry	05/18/2005	50.0		12.40	0.75		9.2	3.2	30.0	220.0	3.7		0.67	4.10	8.85	306
80-0034	Blueberry	05/18/2005	56.0														
80-0034	Blueberry	06/12/2005	48.0	Q	9.48	1.34									5.00		
80-0034	Blueberry	06/25/2005	62.0		31.20	4.15									3.50		
80-0034	Blueberry	07/10/2005	58.0		37.20	3.77									2.70		
80-0034	*Blueberry*	*07/12/2005*													*2.50*		
80-0034	Blueberry	07/26/2005	122.0		51.80	9.37		11.0	6.8	40.0	220.0	3.9		1.37	2.46	8.24	297
80-0034	Blueberry	07/26/2005	132.0														
80-0034	Blueberry	08/14/2005	151.0		50.70	3.73									1.80		
80-0034	Blueberry	08/27/2005	104.0		59.90	4.82									1.50		
80-0034	Blueberry	09/11/2005	128.0		69.90	4.36									1.40		
80-0034	Blueberry	09/28/2005	129.0		36.60	1.55	K	37.0	14.0	30.0	200.0	4.9		1.24	1.31	8.46	324
80-0034	Blueberry	09/28/2005	129.0														
80-0038	Morgan	05/19/2005	15.0		3.84	0.32	K	3.3	2.0	10.0	110.0	1.0	K	0.59	16.40	7.27	161
80-0038	Morgan	05/19/2005	62.0														
80-0038	Morgan	06/12/2005	11.0	Q	1.26	0.13									18.00		
80-0038	Morgan	06/12/2005	11.0	Q	1.15	0.14	K										
80-0038	Morgan	06/26/2005	13.0		1.75	0.30									18.00		
80-0038	Morgan	07/10/2005	10.0		0.93	0.14	K								17.00		
80-0038	Morgan	07/26/2005	13.0		1.95	0.21	K	1.6	1.6	5.0	87.0	1.0	K	0.54	16.40	8.71	123
80-0038	Morgan	07/26/2005	79.0														
80-0038	Morgan	08/14/2005	11.0		1.59	0.14	K								20.00		
80-0038	Morgan	08/27/2005	8.0		1.37	0.13									21.00		
80-0038	Morgan	08/27/2005	8.0		1.24	0.14	K										
80-0038	Morgan	09/10/2005	10.0		1.70	0.14									20.00		
80-0038	Morgan	09/28/2005	12.0		3.01	0.33	K	6.5	4.0	5.0	94.0	1.0	K	0.54	16.40	8.32	155
80-0038	Morgan	09/28/2005	22.0														

LakeID = DNR Lake Identification Number
Lake Name = Name of Water Resource
TP = Total Phosphorus in parts per billion
Chla = Chlorophyll-*a* in parts per billion
Pheo = Pheophytin in parts per billion
RMK = Remark Codes for parameters *(K=less than the detection limit; Q = over holding time)*

SDF = Secchi Transparency in feet
pH = pH of sample (SU)
Cond = Conductivity in umhos/cm
TSS = Total Suspended Solids in mg/L

TSV = Total Suspended Volatile Solids in mg/L
COL = Color in Pt-Co units
Alk = Alkalinity in mg/L
CL = Chloride in mg/L
TKN = Total Kjeldahl Nitrogen in mg/L

2005 CLMP+ Data for Hubbard and Wadena County Lakes

			TP	R M	Chla	Pheo	R M	TSS	TSV	COL	ALK	CHL	R M	TKN			
Lake ID	Lake Name	Date	ppb	K	ppb	ppb	K	mg/l	mg/l	cu	mg/l	mg/l	K	mgl	SDF	pH	Cond
80-0027-01	Jim-Cook	06/12/2005	15.0	Q	2.56	0.60									3.75		
80-0027-01	Jim-Cook	06/26/2005	12.0		1.72	0.96									3.50		
29-0157	Upper Twin	05/19/2005	87.0		182.00	32.80		50.0	19.0	20.0	200.0	5.4		1.43	4.92	7.28	288
29-0157	Upper Twin	06/12/2005			1.06	0.33									8.50		
29-0157	Upper Twin	06/25/2005	49		0.33	0.22	K								5.50		
29-0157	Upper Twin	07/10/2005	43		0.62	0.46									7.00		
29-0157	Upper Twin	07/26/2005	49		3.30	1.03	K	2.4	1.6	30.0	200.0	6.7		0.65	7.87	7.77	290
29-0157	Upper Twin	08/07/2005	37		0.95	0.82									8.00		
29-0157	Upper Twin	08/27/2005	29		1.07	0.79									8.00		
29-0157	Upper Twin	09/11/2005	28		1.26	0.83									9.00		
29-0157	Upper Twin	09/28/2005	28		1.60	1.03		4.0	3.6	10.0	190.0	6.7		0.50	6.6L	7.85	331
80-0030	Lower Twin	05/19/2005	32.0		14.20	1.72		3.2	2.0	20.0	190.0	5.3		0.60	4.92	7.18	281
80-0030	Lower Twin	05/19/2005	26.0														
80-0030	Lower Twin	06/12/2005			7.48	1.86									7.00		
80-0030	Lower Twin	06/25/2005	45		1.35	1.37									5.50		
80-0030	Lower Twin	07/10/2005	53		4.75	1.49									6.00		
80-0030	Lower Twin	07/26/2005	49		12.30	1.10	K	3.6	2.4	20.0	190.0	5.6		0.65	5.91	8.04	272
80-0030	Lower Twin	07/26/2005	152														
80-0030	Lower Twin	08/07/2005	39		4.85	0.43									7.50		
80-0030	Lower Twin	08/27/2005	53		21.60	2.35									7.00		
80-0030	Lower Twin	09/11/2005	49		22.10	1.43									6.50		
80-0030	Lower Twin	09/28/2005	51		18.70	4.55		7.6	4.4	20.0	190.0	7.6		0.72	5.74	7.97	343
80-0030	Lower Twin	09/28/2005	54														
80-0037	Stocking	6/12/2005	27		7.0										11.0		
80-0037	Stocking	6/26/2005	20		7.0										10.0		
80-0037	Stocking	7/20/2005	37		13.0										5.0		
80-0037	Stocking	8/28/2005	47		32.0										3.5		
80-0037	Stocking	9/21/2005	49		38.0										3.5		
80-0039	Spirit	5/19/2005	17		4.0										17.0		
80-0039	Spirit	5/19/2005*	18		4.0										20.5		
80-0039	Spirit	6/12/2005	16		5.0										11.0		
80-0039	Spirit	6/22/2005*	16		3.0										13.5		
80-0039	Spirit	7/10/2005	13		3.0										10.5		
80-0039	Spirit	7/20/2005*	18		4.0										13.0		
80-0039	Spirit	8/24/2005*	12		4.0										13.0		
80-0039	Spirit	8/28/2005	12		5.0										11.0		
80-0039	Spirit	9/21/2005*	23		4.0										14.5		
80-0039	Spirit	9/26/2005	17		5.0										13.0		

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RMK = Remark Codes for parameters *(K=less than the detection limit; Q = over holding time it)*

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pH = pH of sample (SU)
Cond = Conductivity in umhos/cm
TSS = Total Suspended Solids in mg/L

TSV = Total Suspended Volatile Solids in mg/L
COL = Color in Pt-Co units
Alk = Alkalinity in mg/L
CL = Chloride in mg/L
TKN = Total Kjeldahl Nitrogen in mg/L

Temperature Profiles (C°)

Blueberry @ 101	**Depth (m)**	**5/18**	**6/12**	**6/25**	**7/12**	**7/26**	**8/14**	**8/27**	**9/11**	**9/28**
80-0034	0	13.1		23.8	26.3	22.6	21.3	20.2	20.7	14.7
80-0034	1	13.1		23.8	25.5	22.7	21.3	20.3	20.7	14.7
80-0034	2	13.1		23.8	25.3	22.7	21.3	20.3	20.7	14.7
80-0034	3	13.0		22.9	24.5	22.6	21.0	20.3	20.7	14.7
80-0034	4	12.8		21.8	22.2	21.2	20.2	19.8	20.7	14.2
Duck @ 101	**Depth (m)**	**5/18**	**6/12**	**6/25**	**7/10**	**7/26**	**8/15**	**8/29**	**9/12**	**9/28**
29-0142	0	12.3	20		26	24.2	24		22	16.3
29-0142	1	12.3	20	26	26	24.2	24	23	22	16.3
29-0142	2	12.3	19	24	26	24.2	24	23	22	16.3
29-0142	3	12.3	18	23	25	24.2	24	22	22	16.4
29-0142	4	12.3	16	22	24	24.2	24	22	22	16.4
29-0142	5	12.3	16	20	22	24.1	24	22	22	16.4
29-0142	6	12.3	15	19	22	24.0	23	22	22	16.9
29-0142	7	12.2				23.5	23	21	22	
Jim-Cook @ 101	**Depth (m)**	**5/18**	**6/12**	**6/26**	**7/10**	**7/26**	**8/14**	**8/27**	**9/11**	**9/28**
80-0027-01	0		22.6	24.0						
80-0027-01	1			24.0						
Lower Twin @ 102	**Depth (m)**	**5/19**	**6/12**	**6/25**	**7/10**	**7/26**	**8/7**	**8/27**	**9/11**	**9/28**
80-0030	0	13.6	13.6	27.0	27.5	23.2	29.0	22.0	24.0	15.0
80-0030	1	13.6	13.6		27.0	23.2	28.0	21.0	23.0	15.0
80-0030	2	13.4	13.4		25.0	23.2	28.0	21.0	22.0	15.0
80-0030	3	13.2	13.2	25.0	25.0	23.1	27.0	21.0	22.0	15.0
80-0030	4	12.9	12.9		25.0	22.5	25.0	20.0	21.0	15.0
80-0030	5	12.0	12.0		25.0	21.3	23.0	20.0	21.0	15.0
80-0030	6	10.2	10.2	20.0	25.0	19.1	22.0	20.0	20.0	14.9
Morgan @ 101	**Depth (m)**	**5/19**	**6/12**	**6/26**	**7/10**	**7/26**	**8/14**	**8/27**	**9/10**	**9/28**
80-0038	0	13.7	20.9	24.4	25.8	24.2	23.0	21.6	20.8	17.1
80-0038	1	13.6	20.7	24.4	25.7	24.2	23.0	21.6	20.7	17.1
80-0038	2	12.5	20.1	24.3	24.0	24.2	23.0	21.6	20.7	17.1
80-0038	3	11.2	16.6	21.3	23.0	24.2	22.9	21.6	20.6	17.2
80-0038	4	10.3	14.0	17.5	19.8	23.3	22.8	21.5	20.6	17.2
80-0038	5	9.1	12.3	14.2	15.9	18.4	22.0	21.4	20.4	17.1
80-0038	6	7.8	9.9	11.7	12.8	15.0	16.9	17.8	18.8	17.1
80-0038	7	6.8	8.9	10.1	11.0	12.2	13.7	14.7	16.0	16.7
80-0038	8	6.2	8.1	8.8	9.7	10.4	11.6	12.2	13.5	14.6
80-0038	9	5.6	7.1	8.0	8.6	9.5	10.3	10.7	11.5	12.0
80-0038	10	5.4	6.2	7.3	7.5	8.2	8.9	9.2	9.4	10.1
80-0038	12	5.0	5.7	5.7	6.3	6.8	7.2	6.9	7.0	
80-0038	14	5.0								
80-0038	15	5								

Temperature Profiles (C°)

Spirit @ 202	Depth (m)	5/19	6/12	6/26	7/14	7/23	8/13	8/28	9/11	9/26
80-0039	0	16.0	21.3	24.5	27.0	25.5	23.0	21.1	21.1	17.6
80-0039	1	14.5	21.2	24.5	27.0	25.4	23.1	21.1	21.0	17.6
80-0039	2	14.5	20.6	24.5	27.0	25.3	23.1	21.1	20.9	17.5
80-0039	3	13.5	20.1	24.5	26.4	25.2	23.1	21.1	20.9	17.5
80-0039	4	13.0	17.5	19.0	22.3	23.8	23.1	21.1	20.8	17.5
80-0039	5	12.5	14.7	15.2	18.3	20.5	21.2	20.8	20.3	17.3
80-0039	6	10.5	12.6	12.8	14.2	14.0	15.5	16.7	18.3	16.9
80-0039	7	10.5	10.8	11.3	12.0	12.2	12.4	13.2	14.2	15.9
80-0039	8	9.0	9.6	9.7	10.0	10.4	10.5	10.8	11.2	12.4
80-0039	9	9.0	8.1	8.2	8.5	8.7	8.9	9.2	9.3	10.0
80-0039	10	8.5	7.4	7.5	7.8	7.9	8.0	8.3	8.2	8.6
80-0039	11	8.0	7.0	7.1	7.3	7.4	7.5	7.6	7.8	7.9
80-0039	12		6.9						7.7	
Stocking @ 204	**Depth (m)**		**6/12**			**7/20**	**8/7**	**8/28**		**9/21**
80-0037	0		23.9			26.7	25.0	20.7		19.4
80-0037	1		23.9			26.7	24.0	20.8		19.4
80-0037	2		23.9			26.1	23.8	20.8		19.4
80-0037	3		22.8			25.6	23.6	20.8		19.4
80-0037	4		20.0			25.6	23.4	20.6		19.4
80-0037	5		19.4			23.9	21.2	20.5		19.4
80-0037	6					22.2	20.0	20.3		19.4
80-0037	7					21.1				
Upper Twin @ 101	**Depth (m)**	**5/19**	**6/12**	**6/25**	**7/10**	**7/26**	**8/7**	**8/27**	**9/11**	**9/28**
29-0157	0	13.1	25.0	28.0	29.0	20.3	29.0	22.0	23.0	12.6
29-0157	1	13.2	20.0	27.0	27.0	20.3	28.0	22.0	23.0	12.6
29-0157	2	12.3	20.0	25.0	26.5	20.0	27.0	21.0	22.0	12.5
29-0157	3		20.0	25.0	26.5	20.0	27.0	21.0	21.0	

Dissolved Oxygen Profiles for Wadena and Hubbard County CLMP+ Lakes

		5/18	6/12	6/25	7/12	7/26	8/14	8/27	9/11	9/28
Lake Name	Depth	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)
Blueberry	0	10.6		8.8	9.4	7.7	7.0	9.6	7.4	13.5
Blueberry	1	10.5		8.8	8.4	7.0	6.9	9.6	7.3	12.2
Blueberry	2	10.5		8.6	7.3	6.6	6.8	9.5	7.3	11.6
Blueberry	3	10.5		3.3	5.4	6.3	7.1	9.3	7.2	11.4
Blueberry	4	10.1		1.3	0.1	5.3	5.0	7.0	7.2	10.9
Duck	0	10.7				7.3				10.5
Duck	1	10.3				6.5				9.1
Duck	2	10.2				6.4				8.8
Duck	3	10.1				6.4				8.6
Duck	4	10.0				6.3				8.6
Duck	5	9.9				6.3				8.6
Duck	6	9.9				6.6				5.5
Duck	7	9.8				0.33				
Jim-Cook	0			6.6						
Jim-Cook	1			6.6						
L Twin	0	10.5				6.6				9.2
L Twin	1	10.5				6.5				9.0
L Twin	2	10.5				6.6				8.9
L Twin	3	10.8				6.7				8.8
L Twin	4	11.1				5.5				8.9
L Twin	5	11.3				1.8				8.9
L Twin	6	9.9				0.9				8.8
Morgan	0	10.8		8.9	9.0	7.9	8.8	9.1	9.0	10.3
Morgan	1	10.5		8.9	9.1	7.9	8.8	9.1	9.0	9.7
Morgan	2	10.4		8.4	9.6	7.8	8.7	9.1	8.9	9.5
Morgan	3	10.8		10.5	9.3	7.9	8.6	9.1	8.8	9.2
Morgan	4	10.9		11.8	12.9	8.4	8.5	8.6	8.8	9.2
Morgan	5	11.1		11.6	13.6	11.7	12.7	8.7	8.6	9.2
Morgan	6	10.6		10.2	12.0	11.8	13.4	12.0	10.2	9.0
Morgan	7	10.1		7.4	9.1	9.8	7.8	8.1	5.6	8.1
Morgan	8	7.0		3.6	3.8	7.0	2.5	1.1	0.7	6.1
Morgan	9	3.7		0.7	0.4	1.2	0.3	0.2	0.1	2.2
Morgan	10	2.5		0.1	0.3	0.8	0.2	0.1	0.1	1.3
Morgan	12	1.		0.1	0.1	0.7	0.1	0.1	0.1	
Morgan	14	0.6								
Morgan	15	0.6								
U Twin	0	9.0				5.3				10.9
U Twin	1	10.2				5.0				9.9
U Twin	2	4.5				5.4				9.5
U Twin	3					4.9				

Dissolved Oxygen Profiles for Wadena and Hubbard County CLMP+ Lakes

		5/18	6/12	6/25	7/12	7/26	8/14	8/27	9/11	9/28
Lake Name	Depth	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)	DO (mg/L)
Spirit	**0**		9.8	8.6	9.3	9.1	8.1	8.9	8.9	8.2
Spirit	**1**		9.8	8.6	9.2	9.0	8.1	8.9	8.9	8.2
Spirit	**2**		9.8	5.6	9.1	8.8	8.1	8.9	8.9	8.1
Spirit	**3**		9.8	8.6	8.8	8.8	8.1	8.8	8.7	8.1
Spirit	**4**		11.0	9.6	9.7	7.9	8.1	8.7	8.5	8.1
Spirit	**5**		10.5	8.5	7.5	8.0	4.6	7.5	8.1	8.1
Spirit	**6**		9.3	7.0	5.6	6.2	4.0	2.5	4.9	7.6
Spirit	**7**		8.9	5.2	3.3	3.4	1.1	0.4	0.1	2.1
Spirit	**8**		6.9	3.1	0.2	0.3	0.2	0.2	0.1	0.3
Spirit	**9**		1.5	0.1	0.0	0.1	0.0	0.1	0.1	0.2
Spirit	**10**		0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Spirit	**11**		0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1
Spirit	**12**		0.0						0.1	

Historic Data

Lake Name	Lake ID	Year	SDM	SES	NS	TP (ppb)	SEP	NP	Chl-a (ppb)	SEC	NC
Blueberry	80-0034	1995	0.9	0.2	4						
Blueberry	80-0034	1996	1.1	0.3	6	85	23.7	3	46.3	24.0	3
Blueberry	80-0034	1997	1.2	0.1	6	55	5.1	4	27.0	8.8	4
Blueberry	80-0034	2001				86.5	30.5	2	46.5	22.5	2
Blueberry	80-0034	2002				83.5	6.6	4	17.8	3.6	4
Blueberry	80-0034	2003	0.5	0.2	3	144	47.7	3	90.3	28.3	3
Duck	29-0142	1973	1.4	0.1	16						
Duck	29-0142	1996	2.1	0.2	4						
Duck	29-0142	1997	2.4	0.2	4						
Duck	29-0142	1998	1.9	0.1	2						
Duck	29-0142	2004	1.3	0.1	13						
L Twin	80-0030	1979	2.1	0.1	14	51.8	5.7	4			
L Twin	80-0030	1980	1.6	0.1	2	38.2	4.2	6	26.1	2.5	4
L Twin	80-0030	1994	2.0	0.1	17	48.5	4.0	4	20.0	0.1	4
L Twin	80-0030	1995	1.5	0.1	21						
L Twin	80-0030	1996	1.7	0.1	16	37.0	5.8	4	11.3	6.2	4
L Twin	80-0030	1997	2.1	0.1	15	36.8	5.5	4	10.3	2.4	4
L Twin	80-0030	1998	1.8	0.0	17	36.5	2.2	4	15.8	1.8	4
L Twin	80-0030	1999	2.0	0.1	15	24.5	6.7	4	11.3	2.7	4
L Twin	80-0030	2000	1.9	0.1	4	36.8	5.0	4	11.3	1.4	4
L Twin	80-0030	2001	2.0	0.1	4	37.0	1.8	4	15.5	2.5	4
L Twin	80-0030	2002	2.3	0.2	4	39.5	4.9	4	10.5	3.6	4
L Twin	80-0030	2003	1.8	0.1	4	29.7	3.0	4	11.0	5.2	4
L Twin	80-0030	2004	1.7	0.2	4	35.5	4.0	4	18.8	3.1	4
Morgan	80-0038	2004	5.3		1						
Spirit	80-0039	1994	3.7	0.1	8	12.5	0.5	2	3.0	0.2	2
Spirit	80-0039	1996	3.5		1	12.0	2.5	3	2.0		1
Spirit	80-0039	1997	5.2	0.4	4	15.8	2.3	4	3.2	0.7	4
Spirit	80-0039	1999	3.0		1	15.0	0.0	1	3.0		1
Spirit	80-0039	2000	3.4	0.4	4	19.3	3.0	4	4.8	0.6	4
Spirit	80-0039	2001	3.2	0.1	7	18.5	2.0	4	5.3	0.9	4
Spirit	80-0039	2002	2.9	0.2	6	21.0	2.0	4	3.5	1.5	4
Spirit	80-0039	2003	2.3	0.2	10	23.0	3.0	4	7.0	0.8	4
Spirit	80-0039	2004	2.7	0.1	13	20.0	1.0	4	10.0	3.7	4

Lake Name = Name of Water Resource
Lake ID = DNR Lake Identification Number
Year = Year Monitored
SDF = Secchi Transparency in feet
SES = Standard Error for SDF
NS = # Secchi Readings/yr

TP = Total Phosphorus in parts per billion
SEP = Standard Error for TP
NP = # TP samples/yr
Chla = Chlorophyll-*a* in parts per billion
SEC = Standard Error for Chl-a
NC = # Chl-a samples/yr

Lake Name	Lake ID	Year	SDM	SES	NS	TP (ppb)	SEP	NP	Chl-a (ppb)	SEC	NC
Stocking	80-0037	1973	1.9	0.1	15						
Stocking	80-0037	1974	1.6	0.1	14						
Stocking	80-0037	1979	1.4	0.1	14	35.8	4.2	4			
Stocking	80-0037	1980	0.9	0.1	13	66.3	3.2	3			
Stocking	80-0037	1981				34.0	0.0	1			
Stocking	80-0037	1994	1.4	0.2	12	50.3	1.7	5	18.7	7.6	4
Stocking	80-0037	1995	1.6	0.2	12						
Stocking	80-0037	1996	1.5	0.1	14	32.9	5.9	8	12.1	2.7	8
Stocking	80-0037	1997	2.1	0.1	18	28.3	4.3	4	15.8	3.6	4
Stocking	80-0037	1998	1.5	0.1	17						
Stocking	80-0037	1999	1.5	0.1	14						
Stocking	80-0037	2000	2.0	0.1	13						
Stocking	80-0037	2001	0.8	0.5	2	46.0	7.0	4	15.3	3.9	4
Stocking	80-0037	2002	1.5	0.2	4	44.8	3.0	4	17.5	10.1	4
Stocking	80-0037	2003	1.6	0.3	5	39.0	4.0	4	14.0	4.0	4
Stocking	80-0037	2004	2.0	0.2	7	50.3	10.2	4	9.0	3.4	4
U Twin	29-0157	1979	2.1	0.1	14	53.5	5.4	4			
U Twin	29-0157	1980	2.2	0.2	2	54.3	10.8	4	14.1	4.7	4
U Twin	29-0157	1994	2.0		1	38.0	6.0	2	7.7	4.2	2
U Twin	29-0157	1995	1.4	0.1	10	33.8	5.7	4	8.3	2.8	4
U Twin	29-0157	1996	1.9	0.2	2	30.0	0.0	2	4.0	3.0	2
U Twin	29-0157	1997	2.4	0.2	4	34.5	6.3	4	5.0	1.8	4
U Twin	29-0157	1999	2.6	0.1	5	27.5	4.5	4	4.0	0.7	4
U Twin	29-0157	2000	2.0	0.1	4	53.8	23.2	4	4.5	0.6	4
U Twin	29-0157	2001	2.0	0.1	6	31.5	0.9	4	5.0	1.9	4
U Twin	29-0157	2002	2.4	0.1	4	47.3	8.9	4	10.5	3.4	4
U Twin	29-0157	2003	1.7	0.1	5						

Lake Name = Name of Water Resource
Lake ID = DNR Lake Identification Number
Year = Year Monitored
SDF = Secchi Transparency in feet
SES = Standard Error for SDF
NS = # Secchi Readings/yr

TP = Total Phosphorus in parts per billion
SEP = Standard Error for TP
NP = # TP samples/yr
Chla = Chlorophyll-*a* in parts per billion
SEC = Standard Error for Chl-a
NC = # Chl-a samples/yr

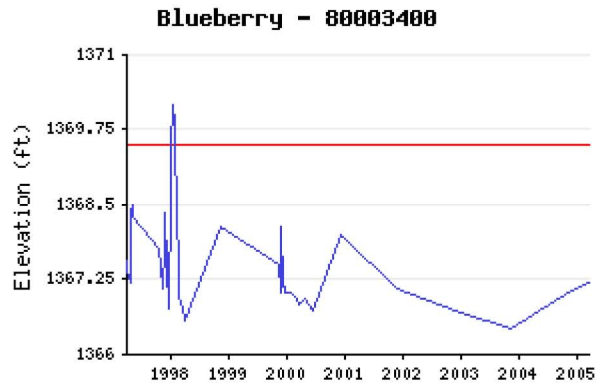
Appendix 2. Precipitation Events near Menahga, MN
Hubbard and Wadena County CLMP+ Lakes
(Precipitation Values are in Inches)

Date	May	June	July	August	Sept
1	0	0.04	0	0	0
2	0	0.03	0.06	0	0
3	0	0	0	0.17	0.33
4	0	0.6	0	0.05	0
5	0	0.47	0.03	0	0.05
6	0	0.02	0	0	0.84
7	T	0.23	0	0	0
8	0.13	0.35	0	0	0
9	0.2	0	0	0.84	0
10	0.05	0.17	0	0	0
11	0	0.39	0	0	0.08
12	0.1	0.18	3.98	0	1.2
13	0.65	0.4	0	0	0.46
14	0	0.38	0	0	0
15	0	0.08	0	0	0.06
16	0	0	0	0	0
17	0	0	0	0.46	0.33
18	0.3	0	0.04	0	0
19	0	0	0	0.45	0.03
20	T	0.68	0	0.04	0
21	0.47	0	0	0	0
22	0	0	0	0	0
23	0	0	0.11	0	0
24	0	0.22	0	0	0.61
25	2.35	0	0.51	0	0.2
26	0.37	0	0	0.13	0.08
27	0.2	0.13	0	0	0
28	0.3	0	0.45	0	0
29	T	0.23	0	0	0
30	0	0.82	0	0	0
31	0		0	0.03	

Appendix 3. Lake Level Information for CLMP+ Lakes
(From MN DNR Web site: www.dnr.state.mn.us)

Water Level Data – Blueberry Lake 80-0034

Period of record: 06/27/1963 to 08/23/2005
# of readings: 51
Highest recorded: 1370.14 ft (07/01/1998)
Highest known: 1371.4 ft
Lowest recorded: 1366.4 ft (04/29/2004)
Recorded range: 3.74 ft
Average water level: 1367.62 ft
Last reading: 1367.18 ft (08/23/2005)
OHW elevation: 1369.5 ft
Datum: 1929 (ft)

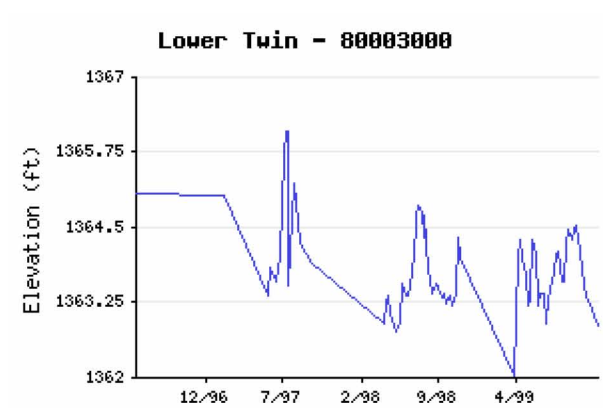


Water Level Data – Duck Lake 29-0142

No data available.

Water Level Data – Lower Twin 80-0030

Period of record: 05/11/1995 to 11/07/1999
# of readings: 102
Highest recorded: 1366.09 ft (07/09/1997)
Lowest recorded: 1362.01 ft (03/27/1999)
Recorded range: 4.08 ft
Average water level: 1363.79 ft
Last reading: 1362.85 ft (11/07/1999)
Datum: 1929 (ft)



Water Level Data – Morgan Lake 80-0038

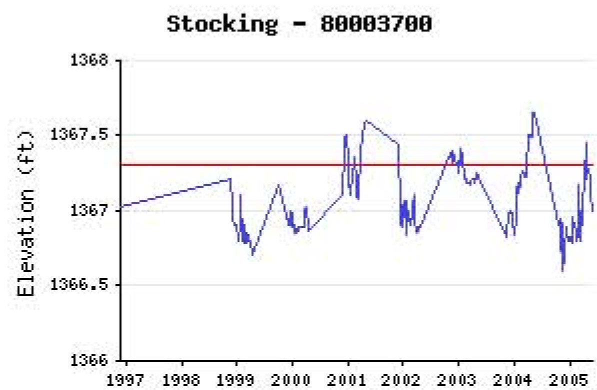
No data available.

Water Level Data – Spirit Lake 80-0039

Period of record: 05/06/1999 to 11/22/2005
# of readings: 209
Highest recorded: 1383.89 ft (07/19/1999)
Lowest recorded: 1377.82 ft (08/30/2004)
Recorded range: 6.07 ft
Average water level: 1380.31 ft
Last reading: 1380.08 ft (11/22/2005)
OHW elevation: 1382.9 ft
Datum: 1929 (ft)

Water Level Data – Stocking Lake 80-0037

Period of record: 05/17/1938 to 11/11/2005
# of readings: 786
Highest recorded: 1367.64 ft (10/29/2004)
Highest known: 1368.1 ft (9/10/91)
Lowest recorded: 1366.02 ft (07/01/1944)
Recorded range: 1.62 ft
Average water level: 1366.55 ft
Last reading: 1367 ft (11/11/2005)
OHW elevation: 1367.3 ft
Datum: 1929 (ft)



Water Level Data - Upper Twin Lake 29-0157

Period of record: 03/14/1996 to 05/13/1997
# of readings: 3
Highest recorded: 1365.53 ft (03/14/1996)
Lowest recorded: 1364.63 ft (05/13/1997)
Recorded range: 0.9 ft
Average water level: 1365.07 ft
Last reading: 1364.63 ft (05/13/1997)
Datum: 1929 (ft)

No graph available.

Appendix 5. Status of the Hubbard and Wadena County CLMP+ Lakes' Fishery

Excerpts from DNR Lakefinder http://www.dnr.state.mn.us/lakefind/index.html

For a complete report, please visit the MDNR web site

Blueberry Lake

The status of the fishery for Blueberry Lake is current as of 06/03/2002. Anglers can expect to find good populations of walleye and northern pike in Blueberry. Yellow perch, white sucker, and shorthead redhorse provide forage for the game species. While not known as a panfish lake, Blueberry does provide fishing opportunities for black crappie and bluegill. However, there is a high carp population present in the lake, which stirs up bottom sediments and contributes to reduced water quality. Other species sampled included high numbers of yellow and brown bullhead, while black bullhead and bowfin (dogfish) were sampled in moderate numbers.

Duck Lake

The status of the fishery for Duck Lake is current as of 08/21/2000. Duck Lake supports good populations of walleye, black crappie, and largemouth bass. Duck Lake has a low population of large-sized northern pike and an abundant large mouth bass population.

Lower Twin Lake

The status of the fishery for Lower Twin Lake is current as of 7/7/2003. Lower Twin is a popular fishing lake and receives moderate to heavy fishing pressure for northern pike, walleye, and panfish and some of the heaviest winter ice fishing pressure for this area. Yellow perch are abundant in Lower Twin and provide a plentiful forage base for the walleye population. Anglers can expect to find lots of small, "hammer handle" northern pike in Lower Twin and panfish are a popular choice year-round. Bluegills are found in good numbers in the 6-8 inch size range, and black crappie are present in low to moderate numbers.

Morgan Lake

Morgan Lake was last surveyed in 8/21/1963. Bluegill, yellow perch, and large mouth bass were all present in the lake at that time.

Spirit Lake

The status of the fishery for Spirit Lake is current as of 6/18/2001. Spirit Lake provides angling opportunities for bluegill, black crappie, northern pike and largemouth bass. Spirit Lake has an abundant panfish population and can provide good fishing for both bluegill and black crappie, as well as a healthy largemouth bass population. Other species sampled included moderate numbers of yellow bullhead and low numbers of white sucker and brown bullhead.

Stocking Lake

The status of the fishery for Stocking Lake is current as of 6/11/2001. Stocking Lake provides angling opportunities for walleye, northern pike, and panfish. Starting in 1975, the Stocking Lake Association has operated two bubbler type aeration systems to help prevent oxygen depletion and winterkill; however, low dissolved oxygen levels can still occur. The yellow perch population in Stocking Lake are small in size with few perch of an acceptable size for angling and the northern population dominated by small, "hammer handle" pike. Panfish are a popular choice for anglers especially during the winter season, including bluegill, black crappie, and pumpkinseed.

Upper Twin Lake

The status of the fishery is current as of 7/14/2003. Upper Twin is a popular lake for bluegill and northern pike fishing. While not know as a walleye lake, anglers will find that Upper Twin can provide some walleye fishing, especially early in the season. Upper Twin has both largemouth bass and smallmouth bass populations. White sucker and shorthead redhorse were abundant in Upper Twin, and anglers looking to pursue these species will find high numbers in the inlet and outlet areas.

GLOSSARY

Alkalinity: Capacity of a lake to neutralize acid.

Chloride: Common anionic form of chlorine which carries one net negative charge. A common anion in many waters.

Chlorophyll a: The main pigment in algae. It is used to measure aquatic productivity.

Ecoregion: Areas of relative homogeneity based on land use, soils, topography and potential natural vegetation.

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.

Eutrophic: Describes a lake of high photosynthetic productivity. Nutrient rich.

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.

Littoral Area: The shallow areas around a lake's shoreline, dominated by aquatic plants.

Mesotrophic: Describes a lake of moderate photosynthetic productivity.

Metalimnion: The middle layer of lake water during the summer months.

Nitrite/Nitrate Nitrogen: The weight of concentration of the nitrogen in the nitrate ion.

Oligotrophic: Describes a lake of low photosynthetic productivity.

Phosphate: An essential nutrient containing phosphorus and oxygen. Phosphate is often a critical nutrient in lake eutrophication management.

Phosphorus: Phosphorus is an element that can be found in commercial products such as foods, detergents, and fertilizers as well as in larger amounts naturally in organic materials, soils, and rocks. Phosphorus is one of many essential plant nutrients. Phosphorus forms are continually recycling throughout the aquatic environment. All forms are measured under the term "Total Phosphorus" in parts per billion (ppb).

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

Secchi Disk: A metal plate used for measuring the depth of light penetration in water.

Suspended Solids: Small particles that hang in the water column and create turbid, or cloudy conditions.

Thermocline: During summertime, the middle layer of lake water. Lying below the epilimnion, this water rapidly loses warmth. Zone of maximum change in temperature over the depth interval.

Trophic Status: The level of growth or productivity of a lake as measured by phosphorus content, algae abundance, and depth of light penetration.

Turnover (Overturn): Warming or cooling surface waters, activated by wind action, mix with lower, deeper layers of water.

Watershed: Geographical area that supplies water to a stream, lake, or river.

Zooplankton: Microscopic animals.

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