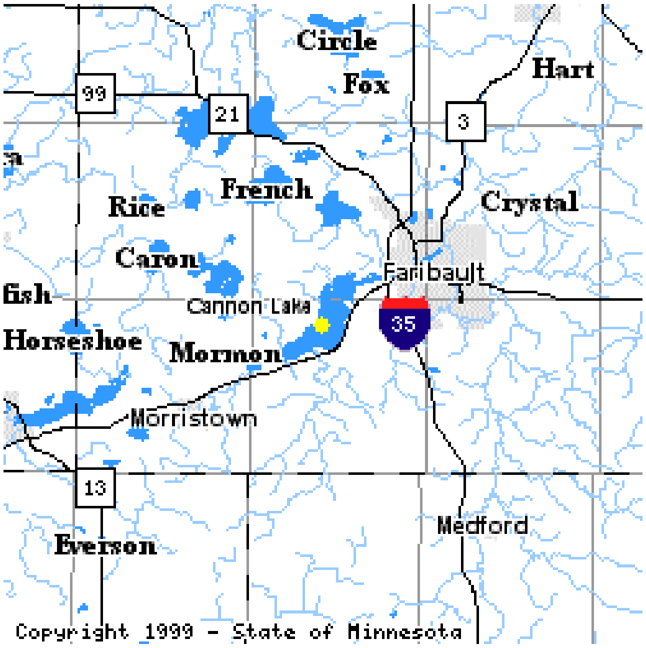
Status and Trend Monitoring Summary
for
Rice County, Minnesota
1999
(Lakes: Cannon, Wells, Kelly, Dudley, Circle, Cedar, and Roberds)



Minnesota Pollution Control Agency
Environmental Outcomes Division
Environmental Monitoring and Analysis Section
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MPCA Status and Trend Monitoring Summary for 1999
Rice County Lakes

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

In 1999 the MPCA monitored the following seven lakes in Rice County: Cannon, Wells, Kelly, Dudley, Cedar, Circle, and Roberds. Water quality samples were collected monthly from June through September at most lakes. These lakes represent a cross section of the lakes found in Rice County in terms of water quality, lake morphometry and watershed characteristics. They also represent a range in terms of the amount of data available: ranging from completed LAP studies on Circle and Roberds Lakes, extensive Secchi records on Cedar Lake, to little or no data on Cannon Lake. In addition we have also had recent requests from the Cedar Lake and Cannon Lake Associations to conduct LAP studies on their lakes. The 1999 sampling served to provide a baseline data set for some lakes (Cannon), while for others (Roberds, Circle, and Cedar), it served as a check on status and trends. This sampling was led by: Willis Munson, MPCA St. Paul office, along with assistance from Dave Morrison, MPCA Rochester office, and Matt Drewitz from Rice County Environmental Services.

A summary of data from 1999 and available historical data follows. This summary will include data from 1999 as well as any data available in STORET, U.S. EPA's national water quality data bank (Appendix). Summer-mean epilimnetic (upper well-mixed layer) concentrations for each lake are compared to the "typical" range for ecoregion-reference lakes in the North Central Hardwoods Forests ecoregion (Figure 1 and Table 4). This provides a basis for placing data from these lakes in perspective relative to one another as well as other lakes in the same ecoregion. Additional bases for comparison and evaluation are provided with Tables 1 and 2.

Table 1 provides the ecoregion-based *total phosphorus* (TP) criteria. In general, lakes that are at or below the criteria level will have adequate transparency and sufficiently low amounts of algae to support swimmable use throughout most of the summer. Whenever possible these lakes should be protected from increases in nutrient concentrations which would tend to stimulate algal and plant growth and reduce transparency. For lakes above the criteria level, the criteria may serve as a restoration goal for the lake; however, this should be determined by individual examination of the lake and its watershed characteristics.

Table 2 represents the percentile distribution of in-lake TP concentrations for each ecoregion based on the mixing (stratification) status of the lake (dimictic, polymictic, or intermittently stratified). Sorting TP concentrations within each mixing type creates this distribution (by ecoregion) from low to high. These percentiles can provide an additional basis for comparing observed summer-mean TP and may further serve as a guide for deriving an appropriate TP goal for the lake.

Lastly, Table 3 provides typical concentrations for TP and total suspended solids concentrations for streams -- should stream data be available for comparison. These data represent the “central tendency” (25th to 75th percentiles) of concentrations from representative, minimally-impacted river sites in each ecoregion. These data were derived from Minnesota’s Milestone monitoring program and should not be considered as “reference” streams nor does this represent the most pristine streams in each ecoregion. These data do, however provide useful yardsticks for evaluating data obtained from streams in the respective ecoregions.

The following discussion assumes familiarity with basic limnologic terms as used in a “Citizens Guide to Lake Protection” and as commonly used in MPCA LAP reports. A glossary is included in the Appendix as well.

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

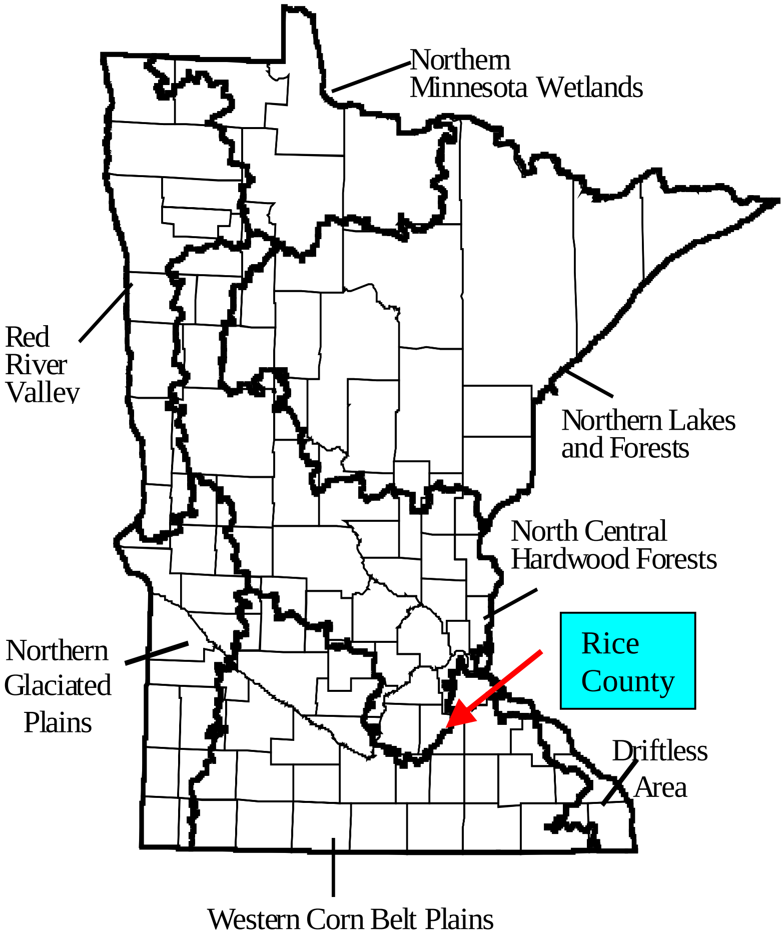


Table 1. Minnesota Lake Phosphorus Criteria (Heiskary and Wilson, 1988).

Ecoregion	Most Sensitive Use	P Criteria
Northern Lakes and Forests	drinking water supply cold water fishery primary contact recreation and aesthetics	**< 15 µg/L** **< 15 µg/L** **< 30 µg/L**
North Central Hardwood Forests	drinking water supply primary contact recreation and aesthetics	**< 30 µg/L** **< 40 µg/L**
Western Corn Belt Plains	drinking water supply primary contact recreation (*full support*) (*partial support*)	**< 40 µg/L** **< 40 µg/L** **< 90 µg/L**
Northern Glaciated Plains	primary contact recreation and aesthetics (*partial support*)	**< 90 µg/L**

Table 2. Distribution of Total Phosphorus (µg/L) Concentrations by Mixing Status and Ecoregion. Based on all assessed lakes for each ecoregion.
D = Dimictic, **I** = Intermittent, **P** = Polymictic

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

Table 3. Interquartile Range of Concentrations for Minimally Impacted Streams in Minnesota by Ecoregion. Data from 1970-1992 (McCollor and Heiskary, 1993; note 1 mg/L = 1 ppm = 1,000 ppb)

	Total Phosphorus (mg/L)			Total Suspended Solids (mg/L)		
Region/Percentile	**25%**	**50%**	**75%**	**25%**	**50%**	**75%**
NLF	0.02	0.04	0.05	1.8	3.3	6
NMW	0.04	0.06	0.09	4.8	8.6	16
NCHF	0.06	0.09	0.15	4.8	8.8	16
NGP	0.09	0.16	0.25	11.0	34.0	63
RRV	0.11	0.19	0.30	11.0	28.0	59
WCBP	0.16	0.24	0.33	10.0	27.0	61

TABLE 4. AVERAGE SUMMER WATER QUALITY AND TROPHIC STATUS INDICATORS **Rice County Lakes Monitored in 1999.** Based on 1999 epilimnetic data.

Parameters	Cannon	Wells	Dudley	Kelly	Circle	Cedar	Roberds	Typical Range: 1 NCHF Ecoregion
Total Phosphorus (µg/L)	248	225	34	27	401	105	281	**23-50**
Chlorophyll a (µg/L)[3] Mean	53	101	12	11	95	84	123	**5-22**
Maximum	139	165	16	17	126	108	130	**7-37**
Secchi disk (feet)	2.3	2.0	7.6	8.3	1.3	3.0	1.3	**4.9-10.5**
Total Kjeldahl Nitrogen (mg/l)	2.14	2.55	.90	.85	2.18	1.7	2.46	**0.60-1.2**
Nitrite + Nitrate-N (mg/l)								**<0.01**
Alkalinity (mg/l)	200	200	105	88	137	128	117	**75-150**
Color (Pt-Co Units)	30	30	20	20	37	20	23	**15-25**
pH (SU)	8.4	8.5	8.0	8.4	9.2	8.5	8.7	**8.6-8.8**
Chloride (mg/l)	15	15	14	13	12	11	15	**4-10**
Total Suspended Solids (mg/l)	30.5	44.8	3.3	3.0	50.0	14.5	35	**2-6**
Total Suspended Inorganic Solids	19.0	28.3	0.6	0.5	21.3	2.7	10	**1-2**
Turbidity (NTU)								**1-2**
Conductivity (µmhos/cm)	450	460	260	250	300	250	290	**300-400**
TN:TP Ratio	8.6	11.3	26.5	31.5	5.4	16.2	9:1	**25:1-35:1**

Trophic Status Indicators: 1999

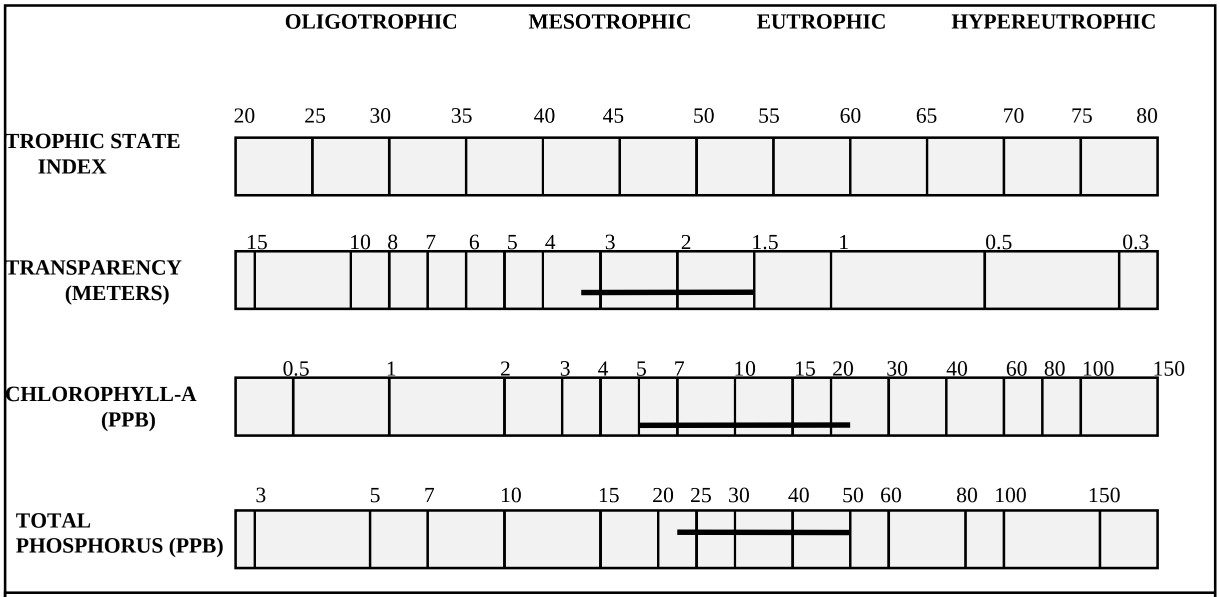
	Cannon	Wells	Dudley	Kelly	Circle	Cedar	Roberds
TP TSIP =	84	82	55	51	91	71	85
Chl a TSIC =	70	76	55	54	75	74	76
Secchi TSIS =	65	67	47	46	75	60	76
TP % tile [4]	10	10	60	60	4	25	10
Chlorophyll-a % tile [4]	25	10	60	60	10	10	10

[1] Derived from Heiskary and Wilson (1990).

[3] Chlorophyll a measurements have been corrected for pheophytin.
[4]. Based on about 600 lakes in NCHF ecoregion

Figure 2. Carlson's Trophic State Index
R.E. Carlson

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



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

NCHF Ecoregion Range: ▬▬

Cannon and Wells Lakes

Cannon and Wells Lakes are located on the main-stem of the Cannon River. The river enters through the southwest corner of the lake and exits through the north basin and into Wells Lake (Figure 3). Cannon is quite large at about 1,591 acres but is extremely shallow with a maximum depth of 15 feet. The majority of the basin is less than 10 feet. Wells, likewise, is very shallow with depths of 3 feet or less over much of the basin. The Cannon River watershed upstream of the lakes is quite large and is estimated to be on the order of 187,530 acres. This yields a watershed to lake area ratio of about 118:1. This high ratio suggests that upstream water and nutrient loads to the lakes would be very large. When combined with the shallowness of the lakes this likely results in short water residence times and highly eutrophic conditions.

Dissolved oxygen and temperature profiles indicated well-mixed conditions in these lakes (Appendix 1). Likewise, pH and conductivity were relatively uniform from top to bottom. As anticipated, total phosphorus (TP) and total nitrogen (TN) concentrations were quite high in both lakes. TP averaged 248 and 225 µg/L, respectively, in Cannon and Wells Lakes. TN averaged 2.14 and 2.55 mg/L respectively. Both concentrations were well above the typical range for lakes in the NCHF ecoregion (Table 4). The high nutrient concentrations contributed to very high concentrations of algae (expressed as chlorophyll-a) with average concentrations of 53 and 101 µg/L for Cannon and Wells Lakes. Total suspended solids (TSS) concentrations were very high in these lakes averaging 30.5 and 44.8 mg/L respectively. Suspended inorganic sediments comprised about 62 percent of the measured TSS and is reflective of the sediment transported by the Cannon River as well as the re-suspension of bottom sediments.

TP concentrations were relatively similar between the two lakes (Figure 4) and increased over the summer. The increasing concentrations over the summer may be caused by a combination of increased loading from the watershed and internal recycling of P within the lake. If rainfall and runoff did not increase substantially over this period of time, it is likely that internal recycling from the sediments and decomposing plants may have caused the noted increases. Increasing concentrations over the summer are common in shallow lakes. Chlorophyll-a concentrations were variable between sites on the lakes (Figure 4) and much of the summer would have been characterized by “very severe nuisance blooms” (> 60 µg/L). A maximum concentration of over 160 µg/L was noted in July on Wells Lake. Secchi transparency was low throughout the summer on both lakes and averaged 0.7 m (2.3 ft) and 0.6 m (2.0 ft) respectively for Cannon and Wells Lakes (Table 4).

Carlson’s Trophic State Index (TSI) values indicate hypereutrophic conditions for both lakes (Table 4 and Figure 2). Relative to about 600 other lakes, we have assessed in the NCHF ecoregion, the trophic status of the lakes would be in the range of the 10th to 25th percentile, meaning that 90 to 75 percent of the lakes exhibited a lower trophic status. Clearly the TP concentrations in Cannon and Wells Lakes are far in excess of the 40 µg/L NCHF ecoregion criteria value, as well as the 90 µg/L WCBP ecoregion criteria value (Table 1). Shallow well-mixed lakes typically have higher TP concentrations than deeper stratified lakes (Table 2). In comparison to other shallow lakes in the NCHF ecoregion Cannon and Wells would rank in the upper 10 percent in terms of concentration (Table 2).

Figure 3. Cannon Lake Bathymetric Map.

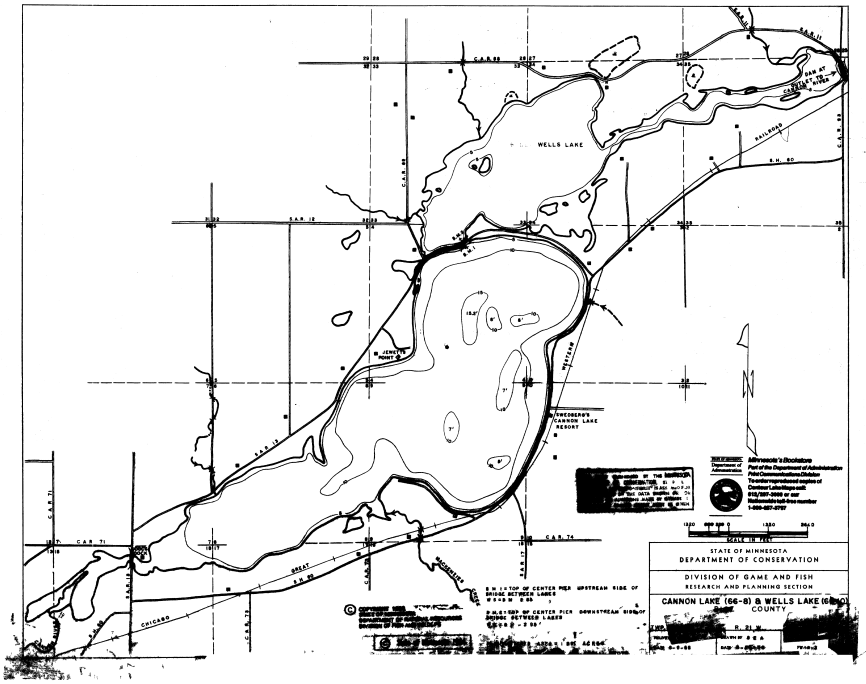
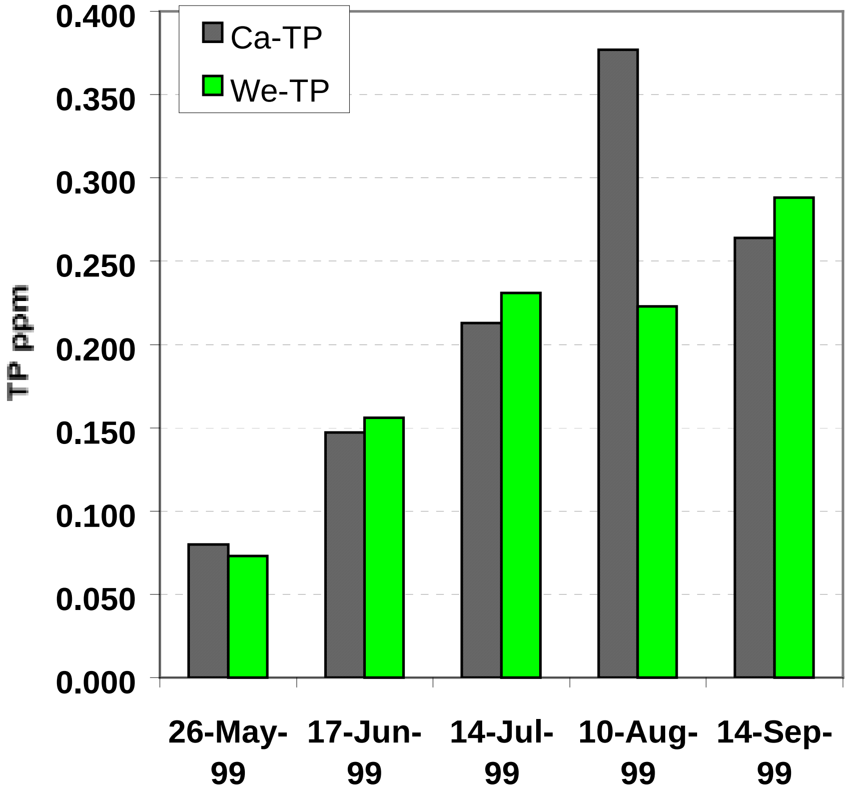
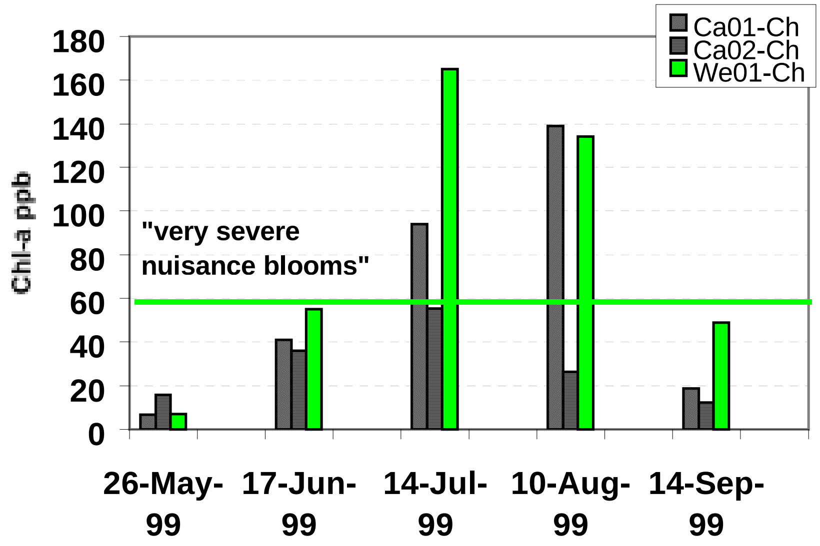


Figure 4. Cannon and Wells Lakes Total Phosphorus and Chlorophyll-a for 1999





Dudley and Kelly Lakes

Dudley and Kelly Lakes, located northwest of Fairbault, represent a stark contrast to Cannon and Wells Lakes. They are relatively small at about 60 acres each and relatively deep with maximum depths of 60 and 50 feet respectively. Their watershed is quite small and is on the order of 900 acres, based on an estimate from Rice County. Based on the combined area of the lakes, this would yield a watershed to lake-area ratio of about 7.5:1. Dudley is located to the northeast of Kelly and water flows in a southwestward direction and outlets from Kelly to French Lake.

The small surface area and great depth allow for thermal stratification in these lakes. The upper waters being warm, well oxygenated and well mixed in contrast to the cooler, lower layer that is oxygen-poor. In June and July the thermocline (zone of maximum change in temperature over smallest range in depth) was at about 3 to 4 meters in both lakes (Appendix 1). The water above the thermocline had oxygen concentrations of 6 mg/L or greater, pH in the 7.8 to 8.8 range, and conductivity in the 200 to 230 umhos/cm range. In contrast the waters below the thermocline had oxygen concentrations of 2 mg/L of less, pH values on the order of 7.3 to 7.5, conductivity values of 230 to 290 umhos/cm or higher and negative redox (ORP) values that are indicative of reducing conditions. The low oxygen (reducing conditions) in the lower layer allow for the recycling of P from the sediments; though this recycled P generally remains in the lower layer until fall turnover.

TP concentrations at 34 and 27 µg/L, respectively, for Dudley and Kelly Lakes, are within the typical range for the NCHF ecoregion (Table 4). TN values were similar between the lakes and within the typical value range as well. Chlorophyll-a concentrations were quite low at 12 and 11 µg/L, respectively. Secchi transparency was markedly higher in these lakes averaging 2.5 and 2.3 meters respectively for the two lakes. TN:TP ratios were on the order of 26: 1 and 31:1 for the two lakes; suggesting that TP is the limiting nutrient for these lakes. Total suspended solids concentrations were quite low for these lakes as well (Table 4).

TP concentrations were fairly similar between the two lakes and tended to decrease over the course of the summer – which is fairly typical for thermally stratified lakes (Figure 6). Hypolimnetic TP concentrations increased dramatically over the course of the summer. The stable stratification prevents mixing, resulting in low oxygen concentrations in the bottom waters. The low oxygen leads to reducing conditions (high redox) which promote recycling of P from the bottom sediments. Chlorophyll-a concentrations were quite comparable between the lakes and peaked at about 15 µg/L in July.

Figure 5. Kelly and Dudley Bathymetric Map.

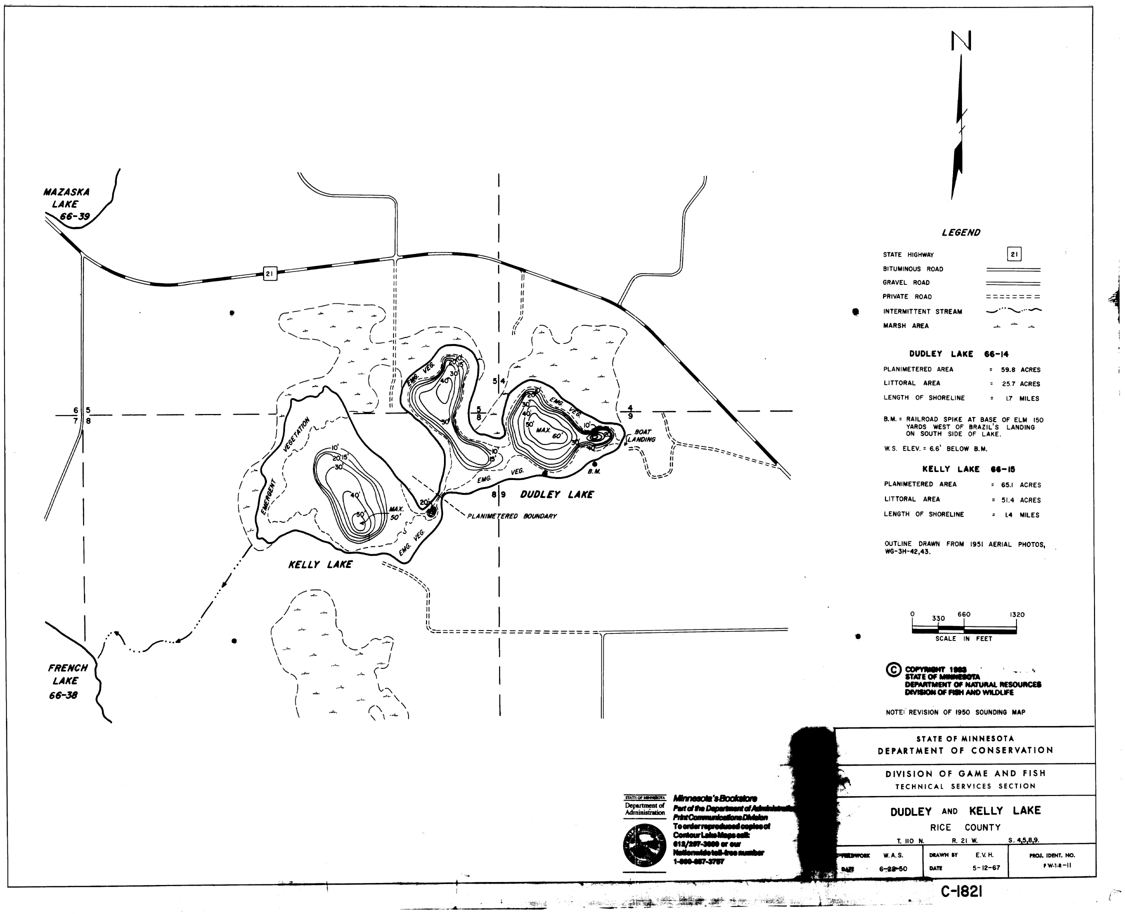
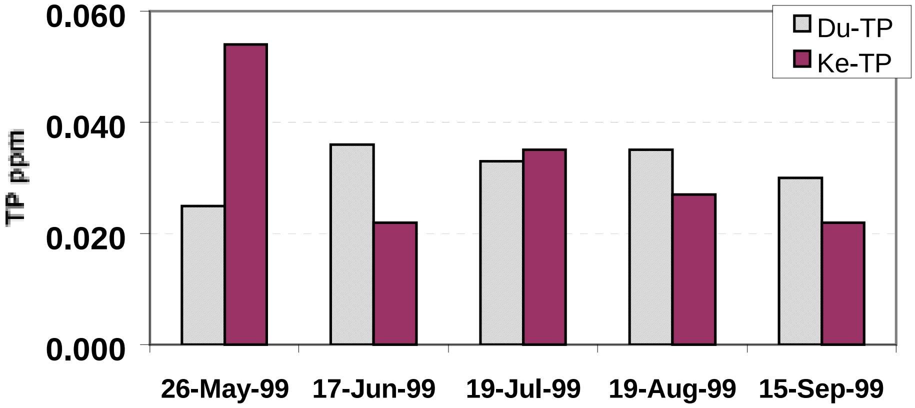
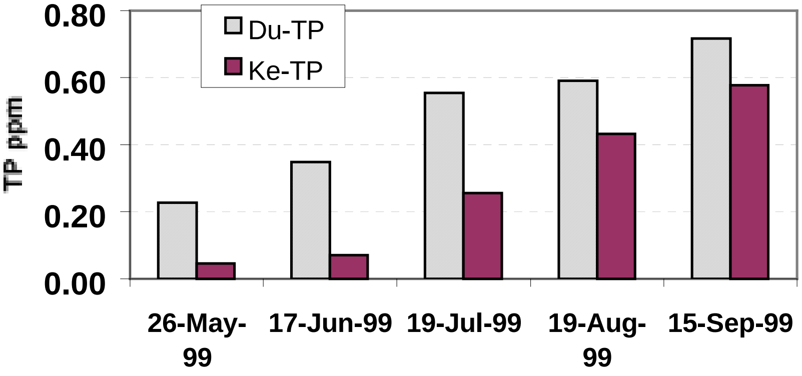


Figure 6. Dudley and Kelly Total Phosphorus: Epilimnetic and Hypolimnetic for 1999

Epilimnetic



Hypolimnetic

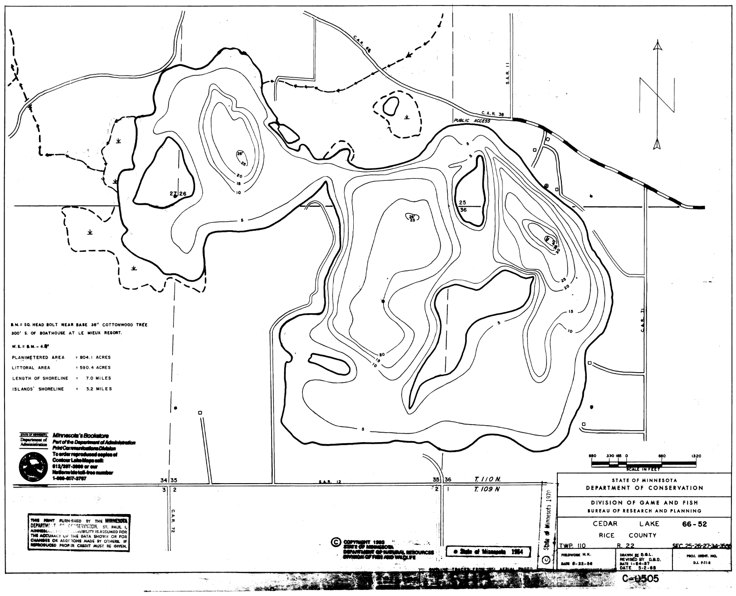


Cedar Lake

Cedar Lake is located just northwest of Cannon Lake. It is relatively large at 804 acres and has a maximum depth of about 40 feet and an average depth of about 15 feet. According to the "Cedar Lake Management Report" prepared by Blue Water Science it has a watershed of about 3,944 acres which implies a 5:1 watershed to lake ratio. Cedar Lake has two fairly distinct subwatersheds that drain from the north and the south. In addition it has a total direct drainage area of about 1,209 acres. Cedar Lake has been the subject of extensive study by the lake association and others. In 1999, two sites were monitored in the lake – the 101 site is located in the east basin over the site of maximum depth and the 102 site is located in the northwest basin (Figure 7).

Dissolved oxygen (DO) and temperature profiles from June and July indicated that Cedar Lake was well-mixed down to a depth of about 7 meters. DO concentrations rapidly fell below 1mg/L beyond that depth (Appendix). Conductivity and pH were relatively uniform in the upper waters averaging about 250 µmhos/cm and 7.9 SU in June and 260 µmhos/cm and 8.9 SU in July. The higher pH in July would correspond to greater algal productivity. Water below the thermocline had lower DO, lower pH (7.4), and higher conductivity. The lack of oxygen resulted in negative redox (reducing conditions) that can allow for internal release of P.

Figure 7. Cedar Lake Bathymetric Map.



TP concentration averaged 105 µg/L in 1999, which is well above the typical range for the ecoregion (Table 4). Concentrations peaked in July and declined slightly thereafter (Figure 9). With the exception of June, TP was relatively consistent between the two sites. Chlorophyll-a concentration averaged 84 µg/L, which is very high as compared to the typical range (Table 4). Very severe nuisance blooms were noted from July through September. The high algae concentrations resulted in low transparency that averaged 1.2 meters (3.8 feet) for 1999. Based on long-term CLMP records, this level of transparency is typical for Cedar Lake (Figure 8).

The trophic status of Cedar Lake, based on TP and chlorophyll-a, was 71 and 74 respectively, and indicative of hypereutrophic conditions (Figure 2). Based on these TSI measures Cedar Lake would rank between the 10th and 25th percentile for lakes in the NCHF ecoregion.

Figure 8. Cedar Lake Summer-mean Secchi Transparency. Based on CLMP.

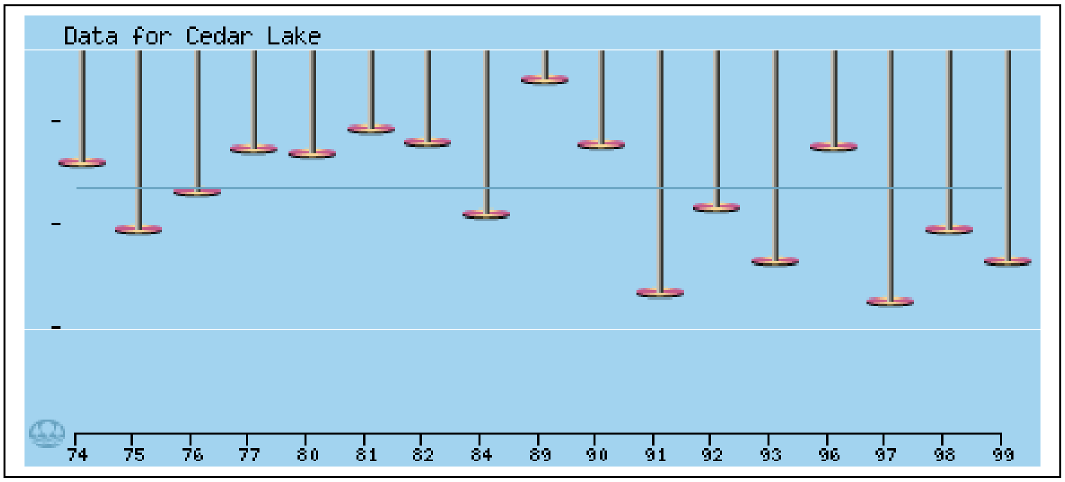
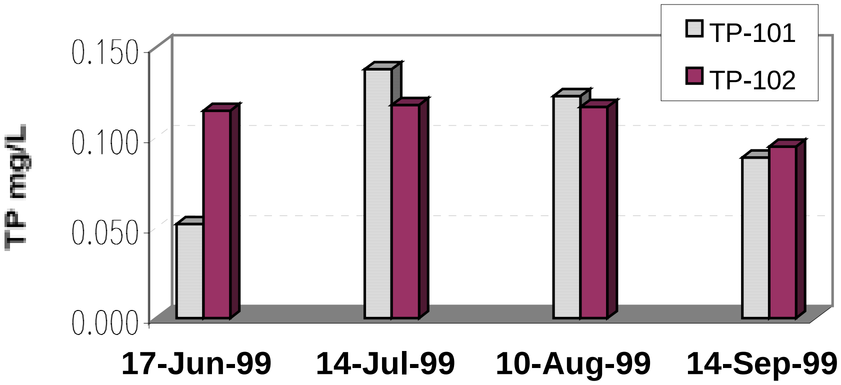
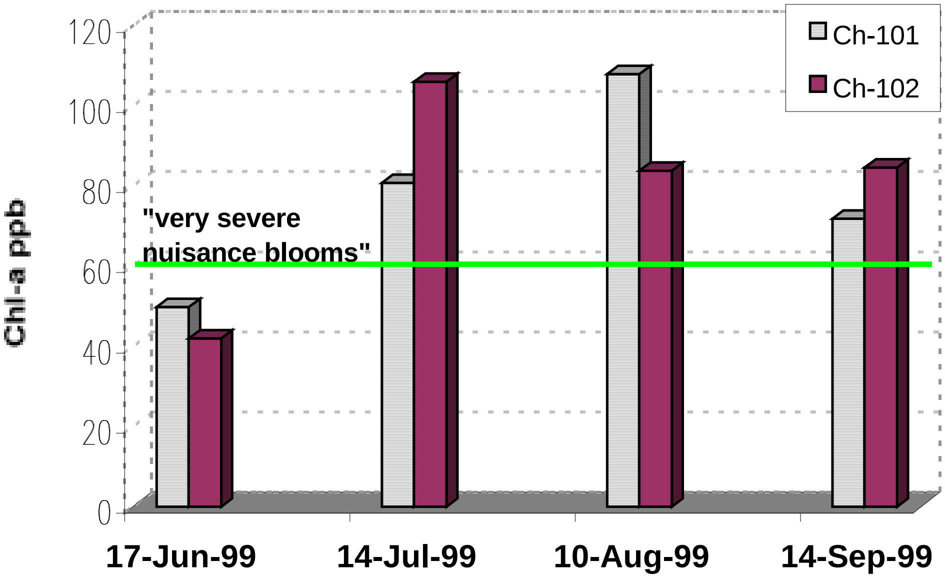


Figure 9. Cedar Lake Total Phosphorus and Chlorophyll-a for 1999.



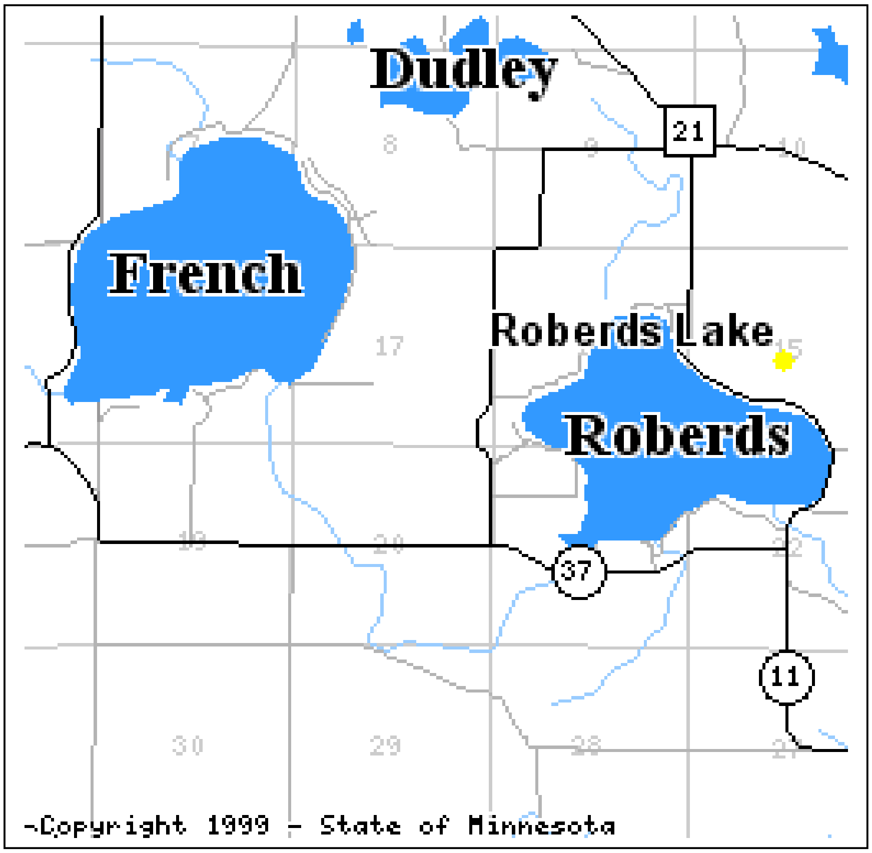


Roberds Lake

Roberds Lake is located northwest of Faribault. It was the subject of a 1992 Lake Assessment Program study that was done cooperatively by the MPCA and Dr. Zischke of St. Olaf College. It is a relatively large lake at 654 acres, has a maximum depth of 43 feet and mean depth of 11 feet. Nearly 60 percent of the basin is 15 feet or less – the depth to which rooted plants typically grow if there is adequate light. The 1992 study indicated that because of low transparency the zone for rooted plant growth was at a depth of about six to seven feet. The 1992 study indicated very poor water quality in Roberds Lake as a result of excessive external nutrient loading from the watershed and internal recycling from the lake sediments and die-off of curly leaf pond-weed in mid-summer.

Roberds watershed is moderate-sized at 8,025 acres and includes French, Dudley and Kelly Lakes in the upper portion of the watershed (Figure 10). Its watershed to lake ratio is about 14:1. The upstream lakes will serve to trap much of the upstream phosphorus loading from that portion of the watershed. Since the phosphorus concentration at the outlet of French Lake should mimic the in-lake concentration it seems likely that Roberds Lake immediate watershed may be a primary source of external P loading to the lake.

Figure 10. Roberds Lake and Watershed.



Water quality samples were collected at two sites on the lake – the 101 site was located at the site of maximum depth in the middle of the lake and site 102 in the eastern bay. Monitoring at these sites in 1992 indicated that Roberds Lake stratified thermally (temperature) for only brief periods as evidenced by minimal change in temperature from the top to the bottom of the lake. Dissolved oxygen concentrations declined rapidly and were below 5 mg/L, a level necessary for long-term survival of game fish, throughout much of the water column. The 1999 profiles showed a similar pattern (Appendix 1). Conductivity, pH, and redox measures were similar to the other Rice County lakes monitored in 1999, i.e., high pH, lower conductivity, and high redox in the upper waters and low pH, higher conductivity and low redox in the bottom waters. Low oxygen concentrations (high redox) combined with high temperatures promotes internal recycling of phosphorus from the sediments.

Total phosphorus concentrations were very high throughout the summer in Roberds Lake (Figure 12). Concentrations were in the 200 µg/L range in July and increased to the 300 µg/L range in August and September. Hypolimnetic TP concentrations were excessively high at 900 and 1,130 µg/L in July and August respectively. Any wind mixing that allows the bottom waters to mix with the surface waters will lead to increased surface water concentrations. Total Kjeldahl nitrogen concentrations were very high as well at 2.46 mg/L. Both TP and TKN were well above the typical range for the NCHF ecoregion (Table 4). The TN: TP ratio was about 9:1 suggesting nitrogen limitation; however, the ratio is low primarily because the TP concentration is so high. Hence phosphorus should be the primary focus for nutrient control.

Chlorophyll-a concentrations were far above the level of 60 µg/L, often considered as a very severe nuisance bloom, throughout the summer (Figure 12). Concentrations peaked at about 130 µg/L in September. Total suspended solids concentrations were quite high as well, even higher than Cannon Lake, however algae (organic matter) comprised about 70 percent of the measured TSS. Because of the high chlorophyll-a concentration Secchi transparency was very low and averaged about 1.3 feet based on three measurements. This range of transparency seems consistent with historic measurements from previous CLMP efforts (Figure 11).

Figure 11. Summer-mean Secchi Transparency for Roberds Lake. Based on historic CLMP record.

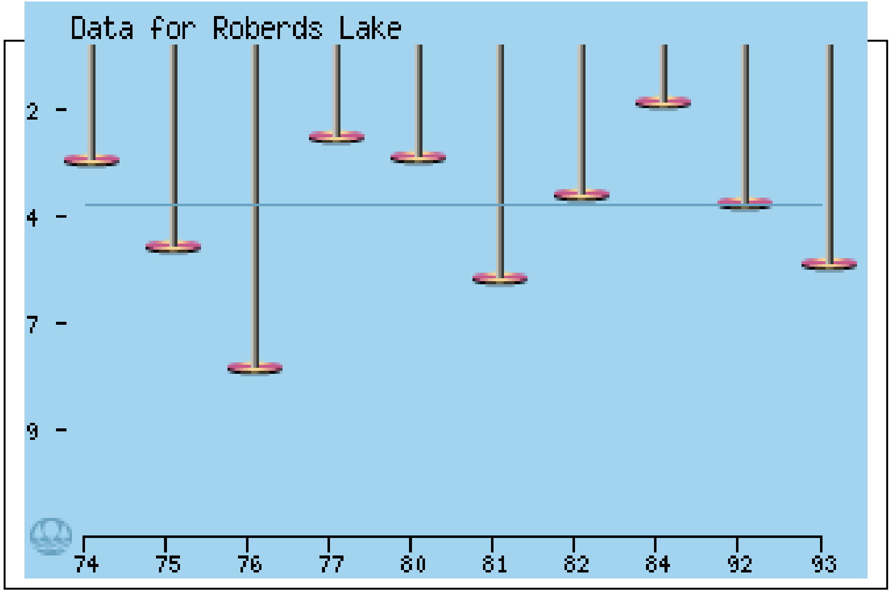
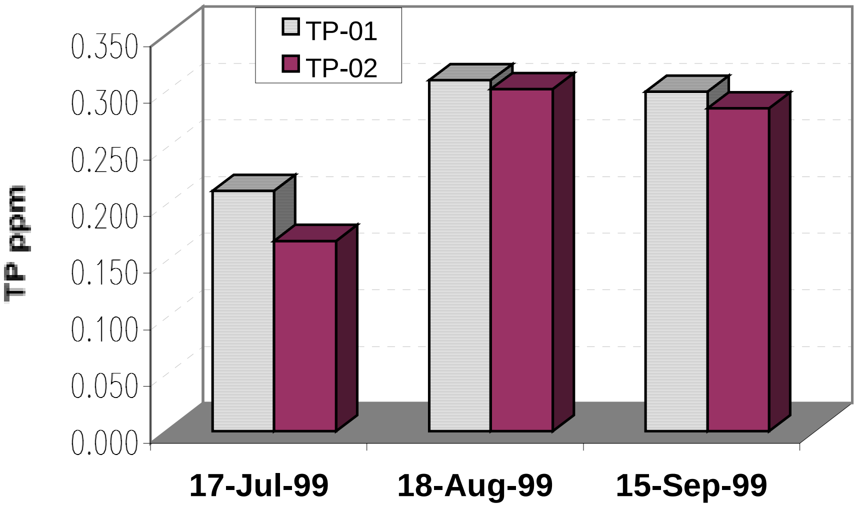
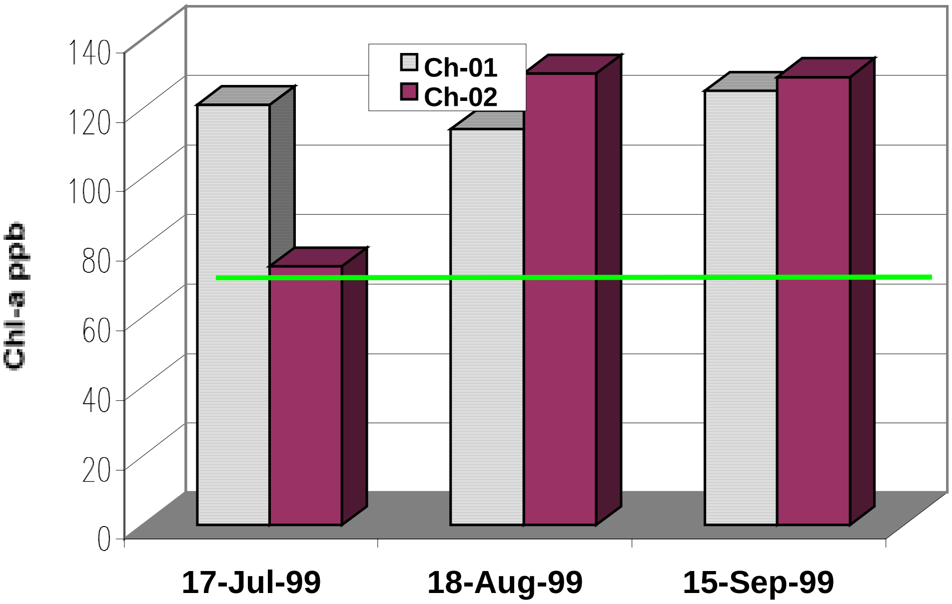


Figure 12. Roberds Lake Total Phosphorus and Chlorophyll-a for 1999

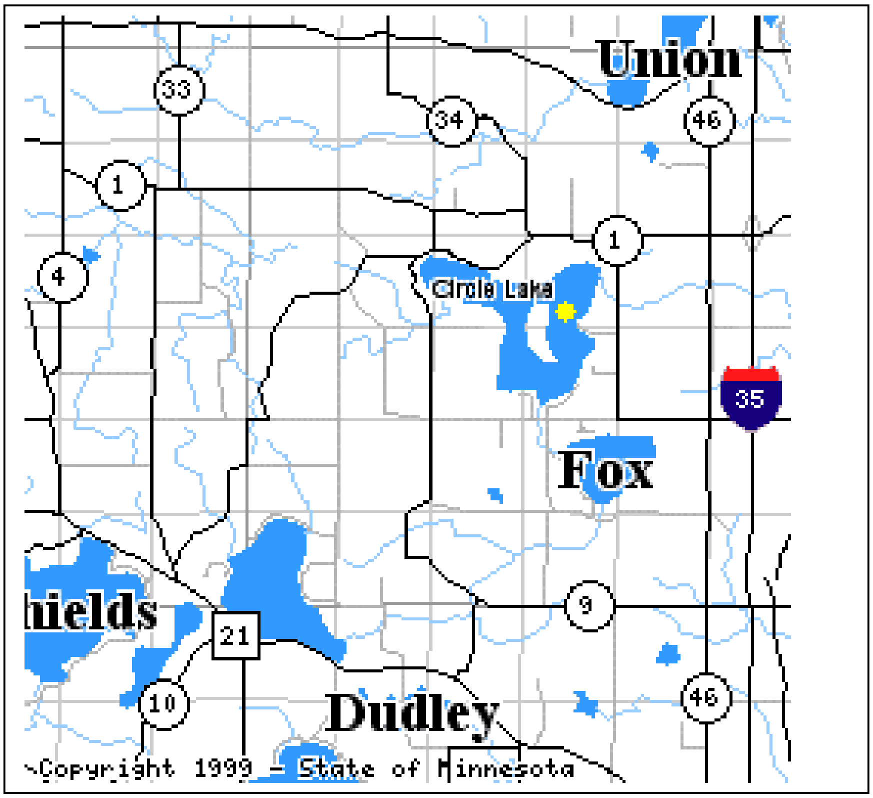




Circle Lake

Circle Lake was the subject of a 1991 LAP study. Circle Lake is located ten miles north of the city of Faribault. It is a rather large lake at 976 acres but is very shallow with a maximum depth of 16 feet and a mean depth of 6 feet. Almost 100 percent of the lake would be considered littoral and as such it is well suited for extensive (and perhaps excessive) rooted plant growth. It has a fairly big watershed of about 23,025 acres. Its watershed drains from Lake Mazaska via Wolf Creek. Circle has a watershed to lake-ratio of 24:1.

Figure 13. Map of Circle Lake and Watershed. Mazaska Lake is immediately southwest of Circle.

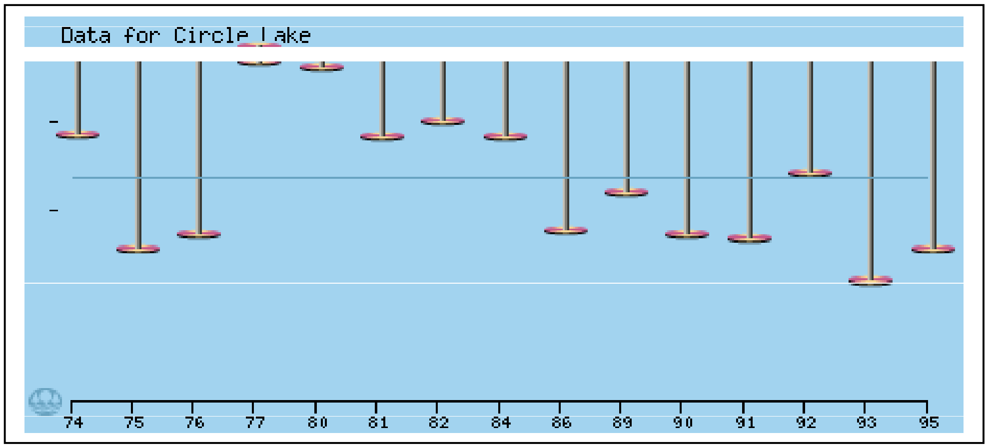


Because of its large surface area and shallow depth, Circle Lake would not be expected to thermally stratify. Based on the 1991 study dissolved oxygen concentrations often fell below 2 mg/L in the bottom waters of the lake. On most dates there was adequate oxygen for game-fish down to a depth of about five to perhaps ten feet at the most. Data from 1999 revealed a similar situation. The low DO concentrations and high temperatures above the sediments serve to promote the release of phosphorus from the sediments during much of the summer.

TP concentrations averaged 401 µg/L in Circle during the summer of 1999. While this is slightly lower than the summer-mean for 1991 (575 µg/L), it is well within the range of previously observed concentrations for the lake. These concentrations are well above the typical range for lakes in the NCHF (Table 4) and are very high as compared to other well-mixed lakes in the NCHF as well (upper 10 percent, Table 2). Total Kjeldahl nitrogen concentrations at 2.18 mg/L were about two-fold higher than the typical range (Table 4). Because of the extremely high TP concentration the TN:TP ratio was about 5:1 for Circle Lake.

The high nutrient concentrations led to very high chlorophyll-a concentrations that averaged 95 µg/L in 1999. While this is extremely high, chlorophyll-a in 1991 was even higher with an average of 126 µg/L. Total suspended solids concentrations were high at 50 mg/L, however 60 percent could be attributed to algae or other organic matter. As a result of the high algae and suspended sediment concentrations Secchi transparency was very low – averaging about 1 foot in 1999 based on MPCA data. This is below the long-term average of about 3 feet (Figure 14).

Figure 14. Circle Lake Summer-mean Secchi. Based on CLMP data.



Water Quality Trends

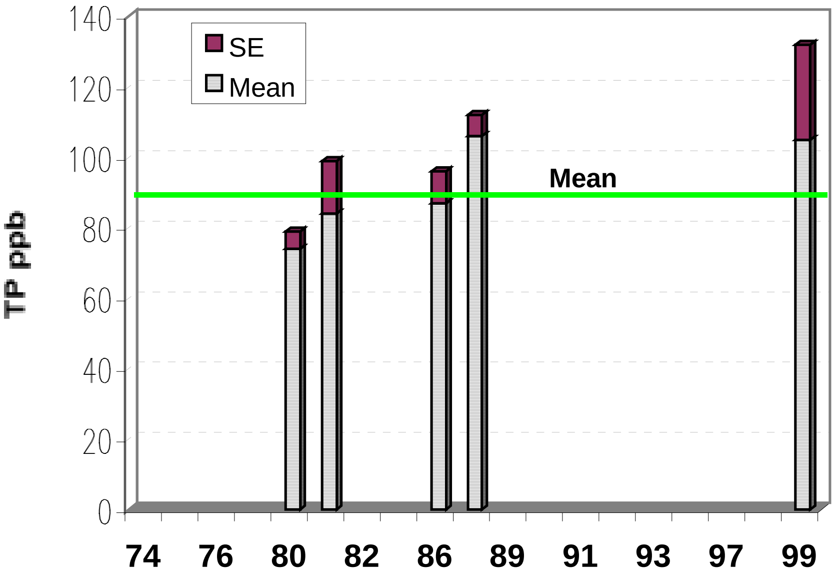
There is a variety of historical data for several of these lakes based on previous MPCA or lake association studies -- some of which is summarized in previous LAP reports. Typically our best database for identifying trends is derived from Secchi transparency data collected through the CLMP. While these data are permanently stored in STORET, USEPA's national water quality database, they are available as well on MPCA's Web site. Figure 14, for example was derived from the Web page. Based on an analysis of Secchi data trends were summarized for the lakes in Table 5.

Table 5. Trend statistics based on CLMP data.

Lake	**Mean Secchi**	**# of years**	**Kendall-tau (b)**	**Prob.**
Cannon	0.5 m	8	+0.41	0.16
Dudley	2.5 m	8	-0.37	0.20
Kelly	2.3 m	7	-0.04	0.80
Circle	0.9 m	14	+0.47	0.03
Roberds	1.0 m	11		
Cedar	0.8 m	17	-0.023	0.09

Based on this analysis, only Circle Lake exhibited a significant trend. Based on CLMP data collected through 1995 its average transparency was 0.9 m. and an improving trend was revealed (Figure 16). As we review the TP data, we see no such indication of a downward trend in TP. Based on Figure 16 TP concentrations have been around the 400 to 500 µg/L level since the late 1980's. Insignificant declining trends were noted for Kelly and Dudley Lakes, however these data are current only through the early 1990s. This is also the case for Cannon Lake where CLMP participation was suspended in the 1980s. The best database was Cedar Lake with 17 years of data. Based on this data, the long-term mean is 0.8 m and no significant change is evident (Figure 15) – though measures in 1999 were among the highest of record. TP concentrations range from about 80 µg/L in the 1980s to about 100 µg/L in 1999 – with no evident trend (if the standard error of the means is considered).

Figure 15. Cedar Lake Summer-mean TP and Secchi



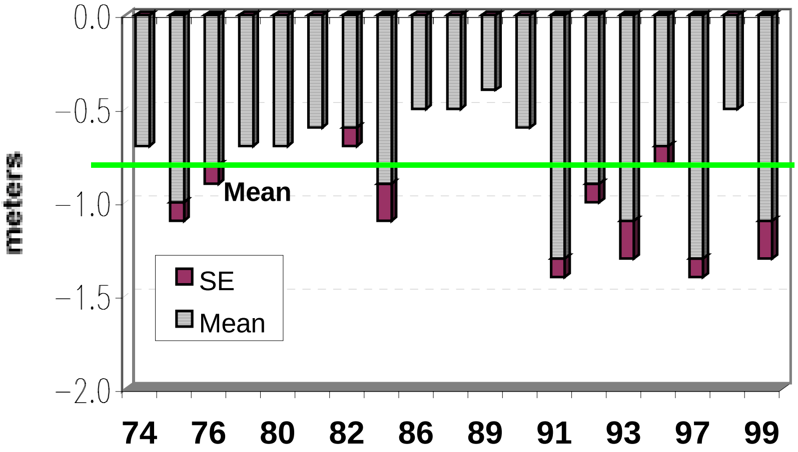
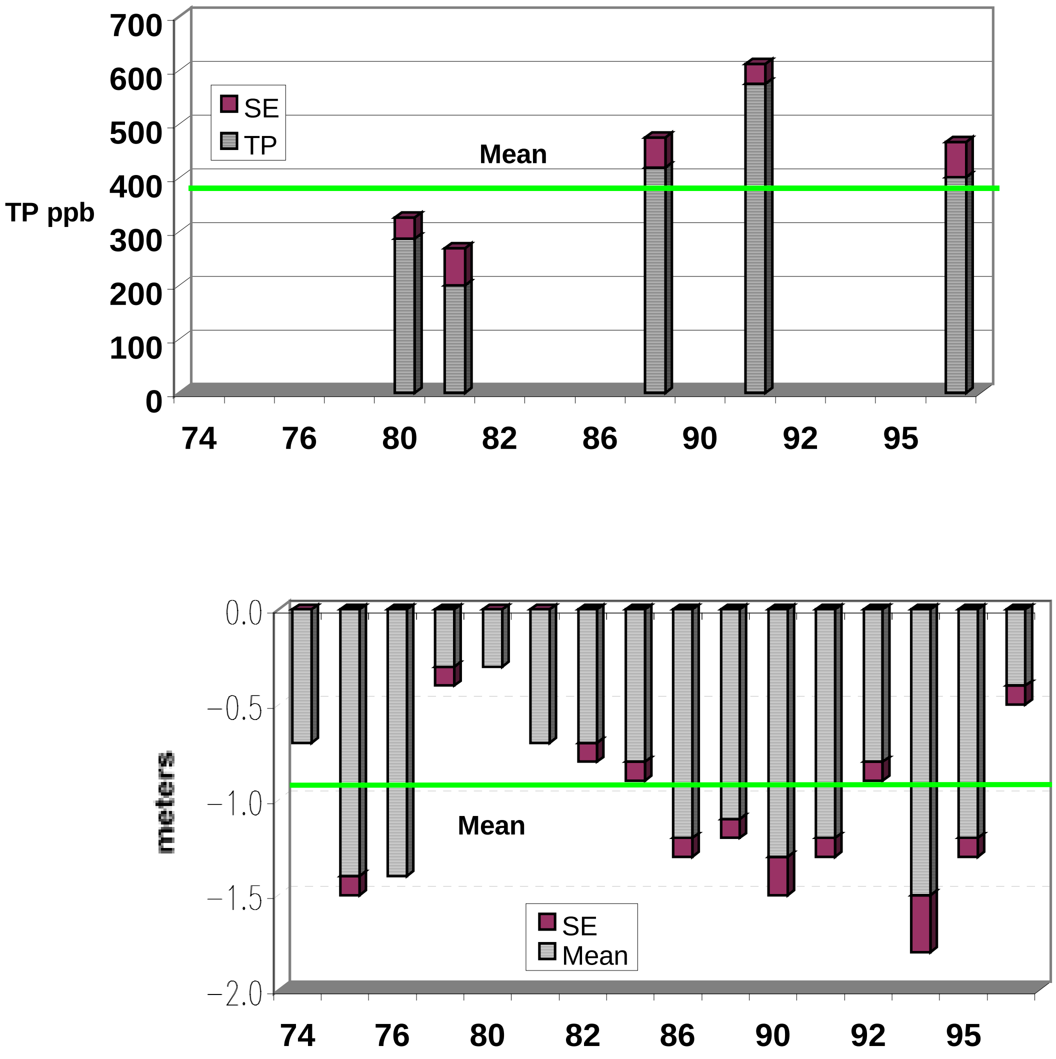


Figure 16. Circle Lake Summer-mean TP and Secchi



Modeling and Goal Setting

As a part of LAP studies we make predictions of the water quality of lakes using some basic characteristics such as lake surface area, mean depth, and watershed area. Other factors often used may include landuse – as a basis for estimating P export in the absence or actual water and phosphorus loading information, and regional estimates of precipitation, evaporation, and runoff. Another alternative is to employ our ecoregion-based eutrophication model -- MINLEAP. MINLEAP uses the basic lake morphometric and watershed information in conjunction with ecoregion-based estimates of precipitation, evaporation, runoff, and stream P concentration to provide estimated P and water loading, water residence time along with in-lake P, chlorophyll-a, and Secchi. This provides an estimate of the water quality one might expect from a lake given its size, depth, watershed area and ecoregion it is located in. This information can be used as part of a goal setting process. A summary of pertinent model outputs will be noted here based on some previous modeling and some new model runs for some of the lakes included in this report.

Table 6. Summary of Lake and Watershed Characteristics and MINLEAP Model Predictions.

Parameter	Cannon/Wells	Kelly/ Dudley	Cedar	Circle	Roberds
Area (acres)	1,591	124	804	976	654 acres
Depth, mean	~ 7	~ 22	15	6 feet	11 feet
Volume	11,137	2,728	12,060	5,856	7,194 acre-ft
Wshed area	187,530	900	3,944	23,025 ac	8,025 ac
Wshed:lake	118:1	7.5:1	5:1	24:1	14:1
Observed - P	**240**	**30**	**105**	**401**	**281 ppb**
Predicted - P	**96 ± 22**	**28 ± 11**	**31 ± 12**	**70**	**48 ppb**
Predicted P load rate	32,285	165	891	4,206	1,550 # P/yr

(note: hectare=acres/2.47; kg = 2.2 lbs.; P loading rate based on predicted P)

The MINLEAP model predictions provide a basis for making some general comparisons between the lakes and general statements on setting goals for the lakes. A summary of these observations follows:

1. The morphometry (*area, mean depth and volume*) of the lakes is very important and contributes to a lake's ability (or inability) to assimilate nutrient loading. Kelly and Dudley Lakes are relatively small and deep. This allows these lakes to thermally stratify during the summer and serves to keep excess phosphorus from being freely recycled from the sediments during the summer. The other lakes are much shallower, larger, and are more subject to wind mixing throughout the summer. The combination of wind mixing, rough fish activity stirring up bottom sediments, and die-off of curley leaf pond weed in mid summer all contribute to internal recycling of phosphorus in these lakes and the highly eutrophic conditions in these lakes.
2. The *size of the watershed* relative to the surface area or volume of the lake provides some indication of the phosphorus and water loading a lake might receive and its ability to assimilate phosphorus. For example, Cannon and Wells volume of about 11,137 acre-feet which is less than Cedar Lake at about 12,060 acre-feet. The watershed area for Cannon and Wells Lakes, however, is about 47 times larger than that of Cedar. This translates to extremely high phosphorus and water loading and very little volume to assimilate the loads in Cannon and Wells Lakes. Watershed to lake-area ratios provide another basis for comparison. For Cannon and Wells this ratio is 118:1, while all the other lakes are less than

25:1. Kelly /Dudley and Cedar are particularly small at 7.5:1 and 5:1 respectively. The small ratio, small overall watershed size (900 acres), and greater depth of Kelly/Dudley Lakes contribute to the good water quality of the lakes.

3. The <u>predicted</u> phosphorus loading for the lakes is a direct function of watershed size. Cannon and Wells Lakes with a watershed area of over 187,000 acres has a predicted P loading rate of about 32,000 pounds P/year. In contrast, Kelly and Dudley Lakes with a watershed area of about 900 acres have a predicted phosphorus loading of about 165 pounds P/year. It should be noted though that unless the predicted in-lake P is similar to the observed in-lake P it is likely that the estimated P loading rate is not an accurate representation of the actual P loading to the lake. For example the predicted in-lake P for Cannon and Wells Lakes is about 96 µg/L ± 22 while the observed in-lake P was about 240 µg/L. Hence it is likely that the actual loading rate is much higher than that noted in Table 6.
4. *Comparions of predicted and observed in-lake P* provide an initial basis for goal setting and diagnosis of lake and watershed interaction. If observed in-lake P is similar to (or not signficantly different from) the predicted P we interpret this to mean that the lake is "operating" as we would expect for a lake of its size, depth, and size of watershed in the ecoregion in which it is located. For example, the observed in-lake P for Kelly and Dudley lakes was about 30 µg/l which is quite similar to the predicted P of 28 µg/L ± 11.   This suggests that the 1999 in-lake conditions are very close to that predicted for a lake with Kelly and Dudley's morphometry and watershed area. For all the other lakes, the observed in-lake P is significantly greater than the predicted P.   Likely explanations could include: a) The watershed P loading is much higher than anticipated based on general ecoregion characteristics. Sources that might contribute to higher than anticipated loads could include: point source discharges, feedlots without proper containment of wastes or poor land application practices, and/or excessive tiling or drainage of lands that might allow for direct conduits between sources of excess nutrients and tributaries that feed the lake. The model uses a stream inflow concentration of about 150 to 170 µg/L as an input to the lake. If measured stream inflow P concentrations are substantially higher than this range, it is likely that the watershed is contributing higher amounts of P than predicted by MINLEAP. b) Internal recycling, especially in shallow lakes like these can be a significant contributor to the P budget for the lake. This internal recycling can arise from wind resuspension of lake sediments, P release from sediments as a result of high temperatures and low oxygen (< 2 mg/L) near the sediment-water interface, and the die-off of plants such as curly leaf pond weed. All can be important sources and mechanisms and it can be hard to differentiate between these "sources."

All of the previously noted information is useful in diagnosing the status of the lakes, setting goals, and determining strategies for rehabilitating the condition of the lakes. For lakes like Kelly and Dudley, it would be reasonable to set a goal of "protecting current conditions." This would be based both on the observed data and model predictions. In turn, a plan could be derived that would look at things that could be done to protect the condition of the lakes.

For the other lakes, this would be a much more complex problem – likely requiring more data collection, in particular data on watershed nutrient loading. This would aid in determining the relative contributions of nutrients from watershed sources versus internal sources. More detailed studies, as conducted through the Clean Water Partnership (CWP) Program, would help identify specific subwatersheds that may need attention (BMP implementation for example). In each case (Cannon, Cedar, Circle and Roberds), the observed in-lake P is far in excess of the predicted P (Table 6). However, model predictions suggest that Cedar and Roberds Lakes, in particular, would be expected to have much better water quality than observed in 1999. In each case the model predictions are below (Cedar) or just above (Roberds) the ecoregion P criteria of 40 µg/L (Table 1). Achievement of the predicted in-lake P would result in measurable and perceptible declines in the frequency and intensity of nuisance algal blooms and increases in transparency. In turn, increased transparency would likely result in increased rooted vegetation in these shallow lakes – which would hopefully favor native species.

Summary and Recommendations

The following recommendations are based on an analysis of 1999 data, available historic data, model predictions and other information assembled in this report

In general, the 1999 water quality of most of these lakes was very poor compared to other lakes in the NCHF ecoregion. The only exceptions were Kelly and Dudley Lakes, which are rather deep as compared to the other lakes and have a relatively small watershed.

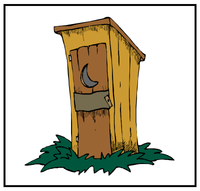
a) The Associations should consider developing a Lake Management Plan. This plan should incorporate a series of activities in a prioritized fashion which will aid in the long-term protection (e.g., Kelly and Dudley) or improvement of the lakes. The plans should be developed cooperatively by a committee consisting of representatives from state agencies (e.g., the Minnesota Department of Natural Resources [MDNR], Minnesota Board Water and Soil Resources, MPCA), local units of government, lake association members and Cannon River Partnership. The following listed activities could be included in the plans:

b) The Associations should continue to participate (or get re-enrolled) in the CLMP and any county-sponsored monitoring programs**.** Few of the lakes, with the exception of Cedar, have good continuous databases for evaluating trends. At a minimum, measurements should be taken weekly during the summer at a consistent mid-lake site(s).

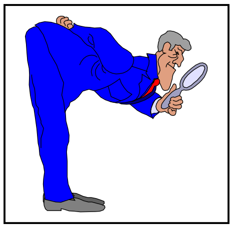
c) Further development or land use change in the lake's watershed should occur in a manner that minimizes water quality impacts on the lake.

- 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.
- Activities in the total watershed that change drainage patterns, such as wetland removal or major alterations in land use, should be discouraged unless they are carefully planned and adequately controlled. Restoring or improving wetlands in the watershed may also be beneficial for reducing the amount of nutrients or sediments 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 Associations should continue to seek representation on boards or commissions that address land management activities so that their impact can be minimized. Being involved in the Rice County Water Planning process, county coalition of lakes, and activities sponsored by the Cannon River Partnership will be essential.

d) On-site septic systems are a *potential* source of nutrients to each of the lakes**.** The relative significance of this source of nutrients will vary between lakes based on a variety of factors including the overall nutrient budget for the lake, size of watershed, age, status, and maintenance (pumping) of systems around the lakes. The Associations and Rice County should continue to educate homeowners on proper maintenance of their systems and encourage all homeowners with non-code systems to bring their systems up to code. The Associations may want to facilitate a lake-wide schedule for pumping systems. The Associations should cooperate with any county-sponsored efforts to inspect systems.



e) An examination of land use practices in the watershed and identification of the possible nutrient sources such as lawn fertilizer, the effects of ditching and draining of wetlands, and agricultural practices may aid the Association 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 Rice County as well. The Association, together with Rice County, <u>should encourage the use of P-free fertilizers</u> on lawns in the watershed. The Association could work with the county to consider the feasibility of developing ordinances which require the use of P-free fertilizers, as municipalities like Shoreview and Plymouth have done. Likewise, there may be opportunities to implement/promote Best Management Practices (BMP's) that may reduce nutrient loading from other sources in the watershed**.**
- Agricultural producers in the watershed of these lakes should ensure that nutrient inputs to soils in the watershed are done at agronomic rates and every attempt is made to ensure that

land-applied fertilizers and bio-solids get incorporated into soils and crops. Setbacks or buffers from watercourses should be observed as a part of normal cultivation, land application, and pasturing practices in order to minimize the transport of soil and phosphorus to adjacent water courses.

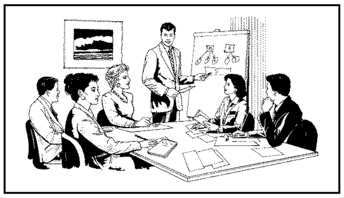
f) Lakeshore property owners should be encouraged to maintain emergent vegetation in the near-shore areas and restore a percentage of their shoreline to "natural conditions." Extensive modification of the shorelines of the lakes was apparent. Various man-made erosion control structures including rock rip-rap and landscape timbers have been used. A diverse aquatic plant community provides critical fish and wildlife habitat. A diverse plant community will also lessen the opportunity for dominance by single exotic species such as curly-leaf pond weed. Emergent plants such as bulrush and cattail serve to stabilize shorelines and provide habitat.

Some specific recommendations could include:
- Minimize the amount of native aquatic plant control.
- Exercise slow-no-wake motor use near shore and in shallow areas to reduce disturbance of aquatic plant beds.
- Encourage lake residents to restore a percentage of their shoreline to "natural conditions." Many shoreline areas lack vegetation buffer zones and would benefit from vegetation re-establishment. Often, native plants will re-establish in areas that are left undisturbed. Refraining from mowing a two foot or greater strip next to the lake would provide an excellent buffer strip to trap nutrients and minimize the need for man-made erosion controls.

g) The lake associations should consider collaborating with the Cannon River Partnership, Rice County Environmental Services, and a local university on an assessment of the contribution these lakes make to the local economy. Defining the economic significance of lakes to the local and state economy is an important, but often overlooked, part of lake and watershed assessments. Assembling an economic summary of the value of the lakes to the local economy will help local decision-makers make appropriate decisions regarding lakes and their watershed, and activities that may affect the long-term health of the lakes.

$ $ $

h) The MPCA's Clean Water Partnership Program (CWP) is also an option for further assessing and dealing with nonpoint sources of nutrients in the watershed. However, since there is extensive competition for CWP funding, it may be in the best interest of the Associations to continue to work with Rice County and other lakes in the county through a county coalition. The Cannon River Partnership can be a valuable partner as well in these efforts. Working with lakes that have conducted CWP studies, like French Lake, may be one way to gain ideas on how to conduct these studies and possible solutions for addressing watershed problems or in-lake problems such as curly leaf pond weed.



Appendix

1. Water Quality Data from STORET

Water Quality Data: Abbreviations and Units

DATE= yr-mo-da
SITE= sampling site ID, 100 series=MPCA, 200=CLMP, etc.
DM= sample depth in meters(0=0-2 m integrated)
TP= total phosphorus in mg/l(decimal) or ug/L as whole number
OP= total ortho-phosphorus in mg/l
DP= dissolved phosphorus in mg/l
TKN= total Kjeldahl nitrogen in mg/l
N2N3= nitrite+nitrate N in mg/l
NH4= ammonia-N in mg/l
TNTP=TN:TP ratio
PH= pH in SU (F=field, or L=lab)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TSIN= total suspended inorganic solids in mg/l
TURB= turbidity in NTU (F=field)
CON= conductivity in umhos/cm (F=field, L=lab)
CL= chloride in mg/l
SI= total silica in mg/L
DO= dissolved oxygen in mg/l
TEMP= temperature in degrees centigrade
SD= Secchi disk in meters (SDF=feet)
CHLA= chlorophyll-a in ug/l
TSI= Carlson's TSI (P=TP, S=Secchi, C=Chla)
PHEO= pheophytin in ug/l
PHYS= physical appearance rating (classes=1 to 5)
REC= recreational suitability rating (classes=1 to 5)
RTP, RN2N3...= remark code; k=less than, Q=exceeded holding time

Commonly used statistical abbreviations in data printouts

NTP, NSD,....= number of observations
MTP, MSD,....= mean TP, Secchi, etc.(typically June-Sept. mean)
STP, SSD, ...= standard error of the mean for TP, Secchi, etc.
[std err = std deviation/square root of number of observations]
TPCV, SDCV, .= coefficient of variation of mean for TP, Secchi, etc.
[CV=(100*std deviation)/mean]; and is expressed as a % of the mean]

2. Glossary

1999 Water Quality Data for Rice County Lakes

STATION	Date	Top m	Bot m	P29 Site	P76 Turb Ntu	P80 Col Pt-C	P410 Alk ppm	P530 TSS ppm	P535 TSV ppm	P625 TKN ppm	P665 TP ppm	P940 Cl ppm	P32211 Chl-a ppb	P32218 Pheo ppb
Cannon														
66-0008	26-May-99	0.0	2.0	101	3.0	40		4.4	2.8	1.47	0.080	15	6.79	4.02
66-0008	26-May-99	0.0	2.0	102	6.0	40		11.0	4.0	1.29	0.080	14	15.90	3.80
66-0008	17-Jun-99	0.0	2.0	101		30	190	20.0	7.6	2.12	0.147	15	41.00	7.88
66-0008	17-Jun-99	0.5	0.5	102							0.201		36.10	6.10
66-0008	14-Jul-99	0.0	2.0	101		30	200	45.0	16.0	2.16	0.213	14	93.90	16.70
66-0008	14-Jul-99	0.5	0.5	102							0.218		55.40	16.30
66-0008	10-Aug-99	0.5	0.5	101		30	210	30.0	16.0	2.70	0.377	15	139.00	2.19
66-0008	10-Aug-99	0.5	0.5	102							0.329		26.40	9.12
66-0008	14-Sep-99	0.0	2.0	101		30	200	27.0	6.4	1.59	0.264	15	18.60	5.41
66-0008	14-Sep-99	0.5	0.5	102							0.237		12.30	8.41
Wells														
66-0010	26-May-99	0.5	0.5	101	2.7	30		4.0	2.8	1.44	0.073	14	7.05	2.51
66-0010	17-Jun-99	0.5	0.5	101		30	200	20.0	8.0	2.38	0.156	15	55.00	4.41
66-0010	14-Jul-99	0.5	0.5	101		30	200	73.0	25.0	2.68	0.231	14	165.00	19.80
66-0010	10-Aug-99	0.5	0.5	101		30	200	32.0	18.0	2.63	0.223	15	134.00	3.86
66-0010	14-Sep-99	0.5	0.5	101		30	200	54.0	15.0	2.49	0.288	17	48.90	24.40
Dudley														
66-0014	26-May-99	0.0	2.0	101	2.2	30		2.8	2.0	0.87	0.025	14	5.70	2.10
66-0014	**26-May-99**	**17.0**	**17.0**	**101**							**0.227**			
66-0014	17-Jun-99	0.0	2.0	101		20	98	4.4	3.6	0.91	0.036	13	10.30	2.04
66-0014	**17-Jun-99**	**17.0**	**17.0**	**101**							**0.348**			
66-0014	19-Jul-99	0.0	2.0	101		20	100	4.0	3.2	0.85	0.033	14	16.20	2.22
66-0014	**19-Jul-99**	**16.0**	**16.0**	**101**							**0.554**			
66-0014	19-Aug-99	0.0	2.0	101		20	110	2.4	2.4	1.00	0.035	14	12.80	2.79
66-0014	**19-Aug-99**	**17.0**	**17.0**	**101**							**0.591**			
66-0014	15-Sep-99	0.0	2.0	101		20	110	2.4	1.6	0.84	0.030	14	8.07	2.33
66-0014	**15-Sep-99**	**16.0**	**16.0**	**101**							**0.716**			
Kelly														
66-0015	26-May-99	0.0	2.0	101	1.6	20		2.8	2.0	0.86	0.054	13	3.27	1.94
66-0015	**26-May-99**	**13.0**	**13.0**	**101**							**0.045**			
66-0015	17-Jun-99	0.0	2.0	101		20	78	3.2	2.4	0.79	0.022	13	8.14	0.79
66-0015	**17-Jun-99**	**14.0**	**14.0**	**101**							**0.071**			
66-0015	19-Jul-99	0.0	2.0	101		20	86	4.8	3.6	0.83	0.035	13	16.50	1.63
66-0015	**19-Jul-99**	**14.0**	**14.0**	**101**							**0.256**			
66-0015	19-Aug-99	0.0	2.0	101		20	94	2.0	2.0	0.96	0.027	14	9.42	1.70
66-0015	**19-Aug-99**	**14.0**	**14.0**	**101**							**0.433**			
66-0015	15-Sep-99	0.0	2.0	101		20	94	2.0	2.0	0.82	0.022	13	9.87	3.50
66-0015	**15-Sep-99**	**15.0**	**15.0**	**101**							**0.577**			
Circle														
66-0027	26-May-99	0.0	2.0	101	32	50	0	33.0	18.0	2.33	0.215	10	115.00	14.30
66-0027	26-May-99	0.5	0.5	102							0.163		85.40	12.90
66-0027	19-Jul-99	0.0	2.0	101		40	140	55.0	35.0	2.53	0.396	10	126.00	6.94
66-0027	19-Jul-99	0.5	0.5	102							0.410		148.00	14.30

66-0027	19-Aug-99	0.0	2.0	101	40	140	53.0	29.0	2.07	0.480	11	79.30	1.87
66-0027	19-Aug-99	0.5	0.5	102						0.495		109.00	2.77
66-0027	15-Sep-99	0.0	2.0	101	30	130	42.0	22.0	1.95	0.428	15	59.40	5.38
66-0027	15-Sep-99	0.5	0.5	102						0.434		55.00	6.84
French													
66-0038	23-Jun-99	0.0	2.0	101	20	110	4.8	4.8	1.28	0.093	9	34.10	2.95
66-0038	23-Jun-99	14.0	14.0	101						0.177			
Cedar													
66-0052	17-Jun-99	0.0	2.0	101	20	120	11.0	9.2	1.21	0.052	11	49.80	7.90
66-0052	**17-Jun-99**	**8.0**	**8.0**	**101**						**0.076**			
66-0052	17-Jun-99	0.0	2.0	102						0.115		42.10	6.18
66-0052	14-Jul-99	0.0	2.0	101	20	120	19.0	17.0	1.79	0.138	11	80.90	1.29
66-0052	**14-Jul-99**	**8.0**	**8.0**	**101**						**0.128**			
66-0052	14-Jul-99	0.0	2.0	102						0.118		106.00	8.64
66-0052	10-Aug-99	0.0	2.0	101	20	140	13.0	10.0	2.13	0.123	11	108.00	4.45
66-0052	**10-Aug-99**	**8.0**	**8.0**	**101**						**0.101**			
66-0052	10-Aug-99	0.0	2.0	102						0.117		83.80	8.88
66-0052	14-Sep-99	0.0	2.0	101	20	130	15.0	11.0	1.66	0.089	12	71.90	12.00
66-0052	14-Sep-99	0.0	2.0	102						0.095		84.60	5.35

STATION	Date			P29	P80	P410	P530	P535	P625	P630	P665	P940	P32211	P32218
Roberds		**top**	**bott**		**Col**	**Alk**	**TSS**	**TSV**	**TKN**	**NO3**	**TP**	**Cl**	**Chl-a**	**Pheo**
66-0018	17-Jul-99	0	2	101	20	130	25	18	2.13		0.212	12	121.0	11.1
66-0018		10	10	101							0.905			
66-0018		0	2	102							0.168		74.5	12.8
66-0018	18-Aug-99	0	2	101	30	110	38	28	2.84		0.310	13	114.0	5.4
66-0018		9	9	101							1.130			
66-0018		0	2	102							0.302		130.0	5.5
66-0018	15-Sep-99	0	2	101	20	110	41	29	2.40		0.300	20	125.0	9.2
66-0018		0	2	102							0.285		129.0	6.8

Profile data for Rice County Lakes for 1999

		Date	Time		Depth	Temp	DO	SpCond	pH	ORP	DO%
Lake ID	**Lake**	**MMDDYY**	**HHMMSS**	**Site**	**meters**	**øC**	**mg/l**	**æS/cm**	**Units**	**mV**	**Sat**
66-0008	CANNON	5/26/99	1857	101	0.0	21.1	10.7	462	8.4	93	123.4
66-0008	CANNON	5/26/99	1857	101	1.0	18.4	10.4	457	8.3	94	113.8
66-0008	CANNON	5/26/99	1857	101	2.0	16.7	9.6	458	8.2	95	101.8
66-0008	CANNON	6/17/99	1030	101	0.1	21.9	11.7	449	8.5	157	136.4
66-0008	CANNON	6/17/99	1030	101	1.0	19.9	8.1	459	8.2	163	89.6
66-0008	CANNON	6/17/99	1030	101	2.0	19.8	7.8	459	8.2	163	86.0
66-0008	CANNON	6/17/99	1030	101	3.0	19.6	7.4	459	8.2	164	82.2
66-0008	CANNON	7/14/99	1000	101	0.0	24.4	7.8	437	8.5	180	96.6
66-0008	CANNON	7/14/99	1000	101	1.0	24.4	7.7	437	8.5	177	95.0

66-0008	CANNON	7/14/99	1000	101	2.0	24.4	7.7	438	8.5	176	94.1
66-0008	CANNON	7/14/99	1000	101	2.9	24.4	7.6	438	8.6	175	93.0

Lake ID	Lake	Date MMDDYY	Time HHMMSS	Site	Dep100 meters	Temp øC	DO mg/l	SpCond æS/cm	pH Units	ORP mV	DO% Sat
66-0010	WELLS	5/26/99	1947	101	0.1	20.1	10.0	456	8.4	82	113.4
66-0010	WELLS	5/26/99	1947	101	1.0	17.6	12.4	448	8.5	85	133.4
66-0010	WELLS	6/17/99	1130	101	0.1	22.7	11.1	455	8.5	153	130.3
66-0010	WELLS	6/17/99	1130	101	1.0	19.4	6.6	462	8.2	157	71.8
66-0010	WELLS	7/14/99	1040	101	0.0	24.9	8.9	420	8.8	163	111.2
66-0010	WELLS	7/14/99	1040	101	1.0	24.8	8.7	421	8.8	161	108.7

Lake ID	Lake	Date MMDDYY	Time HHMMSS	Site	Dep100 meters	Temp øC	DO mg/l	SpCond æS/cm	pH Units	ORP mV	DO% Sat
66-0014	DUDLEY	5/26/99	1500	101	0.0	20.6	9.8	252	8.3	96	112.5
66-0014	DUDLEY	5/26/99	1500	101	1.0	17.6	10.8	250	8.4	99	116.0
66-0014	DUDLEY	5/26/99	1500	101	2.0	17.1	10.9	249	8.3	100	116.2
66-0014	DUDLEY	5/26/99	1500	101	3.0	16.8	10.7	251	8.0	102	112.7
66-0014	DUDLEY	5/26/99	1500	101	4.0	16.2	9.7	252	7.9	104	101.2
66-0014	**DUDLEY**	**5/26/99**	**1500**	**101**	**5.0**	**12.3**	**6.4**	**260**	**7.6**	**111**	**61.1**
66-0014	**DUDLEY**	**5/26/99**	**1500**	**101**	**6.0**	**9.7**	**4.8**	**257**	**7.4**	**114**	**42.8**
66-0014	DUDLEY	5/26/99	1500	101	7.0	8.8	4.7	257	7.4	116	41.3
66-0014	DUDLEY	5/26/99	1500	101	8.1	8.5	5.3	255	7.6	115	46.4
66-0014	DUDLEY	5/26/99	1500	101	9.0	8.2	5.0	255	7.5	116	43.8
66-0014	DUDLEY	5/26/99	1500	101	10.0	8.0	3.7	256	7.3	118	32.4
66-0014	DUDLEY	5/26/99	1500	101	12.0	7.6	1.3	260	7.3	121	11.0
66-0014	DUDLEY	5/26/99	1500	101	14.0	7.0	0.1	267	7.4	30	1.1
66-0014	DUDLEY	5/26/99	1500	101	16.0	6.6	0.1	282	7.4	-73	0.8
66-0014	DUDLEY	6/17/99	1730	101	0.1	23.1	10.0	238	8.5	123	117.7
66-0014	DUDLEY	6/17/99	1730	101	1.0	21.1	10.4	236	8.5	125	117.8
66-0014	DUDLEY	6/17/99	1730	101	2.0	20.4	10.7	235	8.6	127	118.8
66-0014	DUDLEY	6/17/99	1730	101	3.0	19.8	8.2	238	8.0	131	90.2
66-0014	**DUDLEY**	**6/17/99**	**1730**	**101**	**4.0**	**16.9**	**5.1**	**255**	**7.6**	**137**	**52.6**
66-0014	DUDLEY	6/17/99	1730	101	5.0	13.5	0.9	258	7.3	143	8.7
66-0014	DUDLEY	6/17/99	1730	101	6.0	10.4	0.4	259	7.3	146	3.9
66-0014	DUDLEY	6/17/99	1730	101	7.0	9.3	1.6	257	7.3	146	13.8
66-0014	DUDLEY	6/17/99	1730	101	8.0	8.7	2.0	256	7.3	146	17.4
66-0014	DUDLEY	6/17/99	1730	101	9.0	8.4	2.7	254	7.4	146	23.3
66-0014	DUDLEY	6/17/99	1730	101	10.0	8.0	1.6	255	7.3	146	14.3
66-0014	DUDLEY	6/17/99	1730	101	11.0	7.8	0.1	260	7.3	148	1.0
66-0014	DUDLEY	6/17/99	1730	101	12.0	7.6	0.0	263	7.3	132	0.2
66-0014	DUDLEY	6/17/99	1730	101	13.0	7.4	0.1	267	7.4	57	0.4

66-0014	DUDLEY	6/17/99	1730	101	14.0	7.2	0.1	272	7.5	-36	0.2
66-0014	DUDLEY	6/17/99	1730	101	15.0	6.9	0.0	279	7.4	-63	0.4
66-0014	DUDLEY	6/17/99	1730	101	16.0	6.7	0.0	286	7.4	-90	0.5
66-0014	DUDLEY	6/17/99	1730	101	17.0	6.6	0.0	290	7.4	-110	0.2
66-0014	DUDLEY	7/19/99	1035	101	0.0	24.8	6.9	249	7.7	79	86.3
66-0014	DUDLEY	7/19/99	1035	101	1.0	24.8	6.8	249	7.8	82	85.0
66-0014	DUDLEY	7/19/99	1035	101	2.0	24.8	6.8	249	7.8	85	84.5
66-0014	**DUDLEY**	**7/19/99**	**1035**	**101**	**3.0**	**23.5**	**3.8**	**249**	**7.4**	**90**	**45.7**
66-0014	**DUDLEY**	**7/19/99**	**1035**	**101**	**4.0**	**20.0**	**0.2**	**253**	**7.2**	**94**	**1.6**
66-0014	DUDLEY	7/19/99	1035	101	4.9	15.0	0.2	258	7.2	95	2.3
66-0014	DUDLEY	7/19/99	1035	101	6.0	11.4	0.1	265	7.2	78	0.5
66-0014	DUDLEY	7/19/99	1035	101	7.0	9.8	0.0	262	7.3	62	0.5
66-0014	DUDLEY	7/19/99	1035	101	8.0	8.8	0.0	259	7.3	59	0.1
66-0014	DUDLEY	7/19/99	1035	101	9.0	8.3	0.1	260	7.3	53	0.8
66-0014	DUDLEY	7/19/99	1035	101	10.0	8.0	0.0	263	7.3	29	0.5
66-0014	DUDLEY	7/19/99	1035	101	12.0	7.5	0.0	271	7.3	-29	0.3
66-0014	DUDLEY	7/19/99	1035	101	14.0	7.1	0.0	281	7.4	-68	0.4
66-0014	DUDLEY	7/19/99	1035	101	16.1	6.8	0.0	292	7.3	-94	0.4
66-0014	DUDLEY	7/19/99	1035	101	17.9	6.6	0.1	403	6.8	-105	0.7
66-0014	DUDLEY	7/19/99	1035	101	18.0	6.6	0.1	406	6.8	-112	0.6

Lake ID	Lake	Date MMDDYY	Time HHMMSS	Site	Dep100 meters	Temp øC	DO mg/l	SpCond æS/cm	pH Units	ORP mV	DO% Sat
66-0015	KELLY	5/26/99	1555	101	0.0	20.9	10.1	86	8.5	39	116.5
66-0015	KELLY	5/26/99	1555	101	1.0	17.5	10.3	219	8.4	46	110.6
66-0015	KELLY	5/26/99	1555	101	2.0	16.8	10.3	217	8.7	60	109.0
66-0015	KELLY	5/26/99	1555	101	3.0	16.6	9.7	222	8.3	65	102.7
66-0015	KELLY	5/26/99	1555	101	4.0	16.2	9.4	219	8.1	69	98.3
66-0015	**KELLY**	**5/26/99**	**1555**	**101**	**5.0**	**13.2**	**5.1**	**231**	**7.6**	**77**	**49.0**
66-0015	KELLY	5/26/99	1555	101	6.0	10.6	4.6	235	7.5	83	42.3
66-0015	KELLY	5/26/99	1555	101	7.0	9.1	4.8	233	7.5	86	43.0
66-0015	KELLY	5/26/99	1555	101	8.0	8.8	4.2	234	7.4	87	36.5
66-0015	KELLY	5/26/99	1555	101	9.0	8.5	3.2	235	7.3	89	28.0
66-0015	KELLY	5/26/99	1555	101	10.0	8.4	2.6	235	7.3	91	22.7
66-0015	KELLY	5/26/99	1555	101	12.0	8.2	0.5	240	7.3	94	4.5
66-0015	KELLY	5/26/99	1555	101	14.0	8.1	0.2	246	7.4	-82	1.6
66-0015	KELLY	6/17/99	1815	101	0.1	22.8	9.9	195	8.8	80	116.7
66-0015	KELLY	6/17/99	1815	101	1.0	21.0	9.9	194	8.7	87	112.4
66-0015	KELLY	6/17/99	1815	101	2.1	20.3	9.9	195	8.7	91	110.9
66-0015	KELLY	6/17/99	1815	101	3.0	19.7	7.6	199	8.1	98	82.9
66-0015	**KELLY**	**6/17/99**	**1815**	**101**	**4.0**	**17.7**	**4.2**	**218**	**7.6**	**102**	**44.8**
66-0015	KELLY	6/17/99	1815	101	5.0	14.3	1.7	232	7.4	108	16.5
66-0015	KELLY	6/17/99	1815	101	6.0	11.3	1.2	236	7.3	110	10.9
66-0015	KELLY	6/17/99	1815	101	7.0	10.0	1.1	236	7.3	112	9.5
66-0015	KELLY	6/17/99	1815	101	8.0	9.0	0.4	239	7.3	114	3.1
66-0015	KELLY	6/17/99	1815	101	8.9	8.7	0.1	241	7.3	110	0.9
66-0015	KELLY	6/17/99	1815	101	10.0	8.5	0.1	240	7.3	99	0.4

66-0015	KELLY	6/17/99	1815	101	11.0	8.4	0.0	243	7.3	39	0.6
66-0015	KELLY	6/17/99	1815	101	12.0	8.3	0.0	245	7.4	-19	0.1
66-0015	KELLY	6/17/99	1815	101	13.0	8.2	0.0	249	7.4	-47	0.3
66-0015	KELLY	6/17/99	1815	101	14.0	8.1	0.0	264	7.4	-84	0.2
66-0015	KELLY	7/19/99	1115	101	0.0	25.0	7.2	210	8.1	46	91.1
66-0015	KELLY	7/19/99	1115	101	1.0	24.9	7.3	210	8.2	52	91.2
66-0015	KELLY	7/19/99	1115	101	2.0	24.8	6.6	209	7.9	57	82.5
66-0015	**KELLY**	**7/19/99**	**1115**	**101**	**3.0**	**23.4**	**3.1**	**212**	**7.5**	**63**	**37.9**
66-0015	KELLY	7/19/99	1115	101	4.0	20.2	0.4	215	7.3	67	4.5
66-0015	KELLY	7/19/99	1115	101	5.0	15.8	0.1	237	7.3	62	0.8
66-0015	KELLY	7/19/99	1115	101	6.0	12.1	0.0	242	7.3	47	0.2
66-0015	KELLY	7/19/99	1115	101	7.0	10.5	0.1	242	7.3	31	0.6
66-0015	KELLY	7/19/99	1115	101	8.0	9.6	0.1	245	7.4	-1	0.6
66-0015	KELLY	7/19/99	1115	101	9.0	9.3	0.1	248	7.4	-41	0.2
66-0015	KELLY	7/19/99	1115	101	10.0	8.8	0.1	251	7.4	-71	0.1
66-0015	KELLY	7/19/99	1115	101	12.0	8.4	0.0	257	7.5	-95	0.4
66-0015	KELLY	7/19/99	1115	101	14.0	8.2	0.0	269	7.5	-123	0.4

Lake ID	**Lake**	**Date MMDDYY**	**Time HHMMSS**	**Site**	**Dep100 meters**	**Temp øC**	**DO mg/l**	**SpCond æS/cm**	**pH Units**	**ORP mV**	**DO% Sat**
66-0027	CIRCLE	5/26/99	1045	101	0.0	19.9	13.2	300	9.1		
66-0027	CIRCLE	5/26/99	1045	101	1.0	16.7	14.4				
66-0027	CIRCLE	5/26/99	1045	101	2.0	16.5	14.0				
66-0027	CIRCLE	5/26/99	1045	101	3.0	16.5	13.9				
66-0027	CIRCLE	7/19/99	1345	101	0.0	25.1	9.2	309	9.3	77	116.1
66-0027	CIRCLE	7/19/99	1345	101	1.0	25.0	9.0	310	9.5	80	112.8
66-0027	CIRCLE	7/19/99	1345	101	2.1	24.8	8.5	310	9.4	82	105.9

Lake ID	**Lake**	**Date MMDDYY**	**Time HHMMSS**	**Site**	**Dep100 meters**	**Temp øC**	**DO mg/l**	**SpCond æS/cm**	**pH Units**	**ORP mV**	**DO% Sat**
66-0052	CEDAR	6/17/99	1445	101	0.1	23.6	9.9	249	8.4	122	119.1
66-0052	CEDAR	6/17/99	1445	101	1.0	21.9	15.2	242	8.9	119	177.3
66-0052	CEDAR	6/17/99	1445	101	2.0	20.8	11.4	247	8.6	123	127.1
66-0052	CEDAR	6/17/99	1445	101	3.0	20.5	8.4	250	8.2	127	93.2
66-0052	CEDAR	6/17/99	1445	101	4.0	20.3	6.0	252	7.9	132	67.0
66-0052	CEDAR	6/17/99	1445	101	5.0	20.1	5.1	252	7.8	134	56.8
66-0052	CEDAR	6/17/99	1445	101	6.0	20.0	5.6	254	7.8	135	62.5
66-0052	CEDAR	6/17/99	1445	101	7.0	19.8	5.8	252	7.8	137	64.3
66-0052	CEDAR	6/17/99	1445	101	8.0	19.0	0.8	260	7.4	143	8.4
66-0052	CEDAR	6/17/99	1445	101	9.1	16.2	0.1	288	7.4	-115	1.1
66-0052	CEDAR	7/14/99	1300	101	0.0	25.6	10.0	255	8.9	122	125.3
66-0052	CEDAR	7/14/99	1300	101	1.0	25.6	10.0	255	9.0	120	126.1
66-0052	CEDAR	7/14/99	1300	101	2.0	25.5	9.8	255	9.0	120	123.0
66-0052	CEDAR	7/14/99	1300	101	3.0	25.4	9.1	256	8.9	120	114.8
66-0052	CEDAR	7/14/99	1300	101	4.0	25.0	7.7	258	8.8	122	94.9
66-0052	CEDAR	7/14/99	1300	101	5.0	24.7	6.5	260	8.7	123	81.3

66-0052	CEDAR	7/14/99	1300	101	6.0	24.4	3.1	264	8.1	130	36.8
66-0052	**CEDAR**	**7/14/99**	**1300**	**101**	**7.0**	**23.5**	**0.2**	**270**	**7.7**	**71**	**2.3**
66-0052	CEDAR	7/14/99	1300	101	8.0	23.1	0.1	275	7.6	-73	1.6

Lake ID	**Lake**	**Date MMDDYY**	**Time HHMMSS**	**Site**	**Dep100 meters**	**Temp øC**	**DO mg/l**	**SpCond æS/cm**	**pH Units**	**ORP mV**	**DO% Sat**
66-0018	ROBERDS	7/19/99	0920	101	0	24.9	6.5	291	8.7	159	81.9
66-0018	ROBERDS	7/19/99	0920	101	1	24.9	6.5	290	8.8	157	81.5
66-0018	ROBERDS	7/19/99	0920	101	2	24.9	6.3	291	8.8	156	79.7
66-0018	ROBERDS	7/19/99	0920	101	3	24.9	6.3	291	8.8	155	79.9
66-0018	ROBERDS	7/19/99	0920	101	4	24.9	6.4	292	8.8	157	78.2
66-0018	ROBERDS	7/19/99	0920	101	5	24.8	4.9	296	8.7	157	60.3
66-0018	**ROBERDS**	**7/19/99**	**0920**	**101**	**6**	**23.6**	**0.2**	**333**	**8.2**	**5**	**1.5**
66-0018	ROBERDS	7/19/99	0920	101	7	22.2	0.1	351	8.2	-172	0.6
66-0018	ROBERDS	7/19/99	0920	101	8	18.5	0.1	385	8.2	-197	0.9
66-0018	ROBERDS	7/19/99	0920	101	9	16.1	0.0	405	7.8	-193	0.3
66-0018	ROBERDS	7/19/99	0920	101	10	15.6	0.1	414	7.6	-196	0.5
66-0018	ROBERDS	7/19/99	0920	101	11	15.4	0.1	424	7.5	-203	0.7
66-0018	ROBERDS	8/11/99	0950	101	0	24.2	6.4				
66-0018	ROBERDS	8/11/99	0950	101	1	24.0	4.7				
66-0018	ROBERDS	8/11/99	0950	101	2	23.9	4.3				
66-0018	ROBERDS	8/11/99	0950	101	3	23.9	4.0				
66-0018	ROBERDS	8/11/99	0950	101	4	23.5	0.9				
66-0018	ROBERDS	8/11/99	0950	101	5	23.3	0.3				
66-0018	ROBERDS	8/11/99	0950	101	6	23.3	0.1				
66-0018	ROBERDS	8/11/99	0950	101	7	23.3	0.1				
66-0018	**ROBERDS**	**8/11/99**	**0950**	**101**	**8**	**19.8**	**0.1**				
66-0018	ROBERDS	8/11/99	0950	101	9	17.2	0.1				
66-0018	ROBERDS	9/15/99	1020	101	0	17.7	9.4				
66-0018	ROBERDS	9/15/99	1020	101	4	17.3	7.8				
66-0018	ROBERDS	9/15/99	1020	101	7	17.3	7.7				
66-0018	ROBERDS	9/15/99	1020	101	9	17.3	7.7				

Glossary

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

Algal Bloom: An unusual or excessive abundance of algae.

Alkalinity: Capacity of a lake to neutralize acid.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

pH Scale: A measure of acidity.

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

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

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

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

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

Respiration: Oxygen consumption

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

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

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

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

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

Turbidity: Particles in solution (e.g. soil or algae) which scatter light and reduce transparency.

Water Density: Water is most dense at 39 degrees F (4 degrees C) and expands (becomes less dense) at both higher and lower temperatures.

Watershed: The surrounding land area that drains into a lake, river or river system.

Zooplankton: Microscopic animals