LAKE ASSESSMENT PROGRAM: 2001

Crow Wing Lake
(DNR DOW #18-0155)

Crow Wing County, Minnesota

Minnesota Pollution Control Agency
Environmental Outcomes Division
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SUMMARY AND RECOMMENDATIONS

Crow Wing Lake is located in Crow Wing County, approximately ten miles southwest of Brainerd, Minnesota and five miles north of Fort Ripley. With a surface area of approximately 382 acres, it ranks near the 85th percentile in terms of surface area as compared to over 11,000 lakes in Minnesota (only 15% of MN lakes are larger than Crow Wing Lake). Crow Wing Lake has a maximum depth of 26 feet and a mean depth of about 15 feet, which is somewhat shallow as compared to lakes of this region. The total watershed, at approximately 16.5 square miles (10,600 acres), is large compared to the size of the lake. Land use in the watershed is composed of 50% forested land, 19% cropland and 19% wetlands. Minor land uses in the watershed include residential (4%), hayland (4%), and lakes or ponds (4%). These agricultural uses (crop and hay land) are high as compared to other lake watersheds in this region of the state – *Northern Lakes and Forests (NLF) ecoregion;* however, they are somewhat more typical of the North Central Hardwoods Forests ecoregion, located immediately south of Crow Wing Lake.

Crow Wing Lake was sampled during the summer of 2001 by the Minnesota Pollution Control Agency (MPCA) staff and citizens from the Crow Wing Lake Association (Association). Water quality data collected during the study reveal summer-mean total phosphorus (TP) concentration of 45 µg/L, chlorophyll a of 26 µg/L and Secchi transparency of 4.5 feet. All three measures are outside the range of values exhibited by reference lakes in the NLF ecoregion. Total phosphorus, chlorophyll a and Secchi transparency help to characterize the trophic status of a lake. These measures indicate *eutrophic* conditions for Crow Wing Lake. Other water quality parameters measured are slightly high as compared to minimally impacted lakes in the NLF ecoregion.

Minimal historical data were available for assessing trends in Crow Wing Lake. The best data set was six year of CLMP Secchi data. No trend was evident with summer-mean transparency ranging from 4.3 to 8.3 feet.

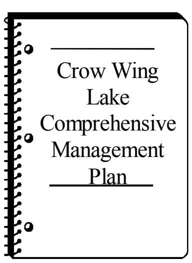
Three lake water quality models were used to estimate the water quality of Crow Wing Lake based on morphometry and watershed characteristics. These models provide a means to compare the measured water quality (2001) of the lake relative to the predicted water quality. The first model, MINLEAP, predicted a summer-mean phosphorus (P) concentration of 29 ± 8 µg/L, which is lower, but not significantly different, than the observed summer-mean of 45 ± 7 µg/L for Crow Wing Lake. This model estimated a phosphorus loading of ~ 518 kg P/year and a water residence time of about 0.7 years. Calibrating the model with an inflow P of 100 µg/L (assumed to be more typical for Crow Wing Lake's watershed) yielded a predicted P of 47 ± 13 µg/L and a loading rate of 974 kg P/yr; which is much closer to the observed in-lake P. A regression model, Vighi and Chiaudani (1985), predicted a background P concentration of 22 µg/L for Crow Wing Lake which is about one-half the 2001 summer-mean P of 45 µg/L.

The third model, Reckhow and Simpson, estimated in-lake water quality based on precipitation, land use composition, runoff and phosphorus export coefficients. Predicted P was estimated at 53 µg/L, which is essentially equal to the observed P for 2001. The P-loading rate from the model was estimated at 692 – 1,009 kg P/yr. The "estimated" relative contribution to the P-loading rate are as follows: precipitation on the lake: 2 - 3 %, runoff from the watershed: 89 - 91 % and septic systems: 7 - 8 %. The contribution from septic systems was *estimated* based on the septic system survey results and considered: the number of residences around the lake, standard per-capita P-loading rates, and an estimated soil retention of 60 (low) to 80 (high) percent. The relative contribution (loading rates) could be higher or lower, depending on the efficiency and maintenance of on-site systems and soils in the shoreland area. For example, well-maintained and up-to-code systems on good soils will retain a high percentage of P loaded to the system while poorly maintained systems on waterlogged soils will retain a low percentage of P.

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

The 2001 water quality of Crow Wing Lake was poor compared to other lakes in the NLF ecoregion. The lake could exhibit declines in transparency and increases in the amount of algae with increases in in-lake total phosphorus. Crow Wing Lake is sensitive to change in trophic status with increases in the nutrient loading from watershed or in-lake sources. These sources would increase the in-lake phosphorus leading to increased degradation of the lake. It is essential, therefore, that all local government convey the lake protection efforts groups with land use/zoning authorities for Crow Wing County. The Association should be commended for their efforts to date, which include interacting with Crow Wing County, MDNR, and participating in the Citizen Lake-Monitoring Program (CLMP).

a) **The Association should update the 2000 Lake Management Plan for protecting the water quality of the lake**. This plan should convey a series of activities in a prioritized fashion; which will aid in the long-term protection and improvement of the lake. The plan should be developed cooperatively by a committee consisting of representatives from state agencies (e.g., the Minnesota Department of Natural Resources [MDNR], Minnesota Board Water and Soil Resources, MPCA), local units of government, and association members. MDNR fisheries and vegetation plans should be included as well. Following are some activities could be included in the plan:

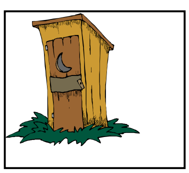


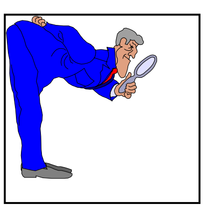
b) **The Association should continue to participate in the CLMP and related monitoring programs**. Data from this program provides an excellent basis for assessing long-term and year-to-year variations in algal productivity (i.e., trophic status) of the lakes. At a minimum, measurements should be taken weekly during the summer at a consistent site(s). The sites denoted as 202, 203, and 204, are probably the most valuable for long-term characterization of the transparency of the lake. Of these, site 203 near mid-lake is the most valuable for long term monitoring. Whenever possible measurements should be made a minimum of two times per month and weekly is preferable.

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. Properly designed sedimentation ponds should be included in any development to minimize P-loading to the lake.
- Activities in the total watershed 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 watershed may also be beneficial for reducing the amount of nutrients or sediments that reach Crow Wing Lake. The U.S. Fish and Wildlife Service at Fort Snelling may be able to provide technical and financial assistance for these activities.
- The Association 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.

d) **On-site septic systems are a *potential* source of nutrients to Crow Wing Lake**. Poorly functioning on-site systems could *potentially* be an important source of nutrient loading to Crow Wing Lake. 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. The house-to-house septic system survey revealed that, of the returned surveys, the homeowners are somewhat familiar with the age and maintenance (pumping) of their systems. The Association and Crow Wing 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 Association may want to facilitate a lake-wide schedule for pumping systems.

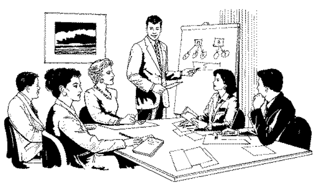




e) **An examination of land use practices in the watershed and identification of possible nutrient sources such as lawn fertilizer, the effects of ditching and draining of wetlands, and agricultural practices etc., may aid the Association in determining areas where best management practices may be needed**. 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 Crow Wing County as well. The Association, together with Crow Wing County, should encourage the use of P-free fertilizers on lawns in the watershed. The Association could work with the county to consider the feasibility of developing ordinances consistent with the 2002 State rule on phosphorus bearing fertilizers. Likewise, there may be opportunities to implement/promote Best Management Practices (BMP's) that may reduce nutrient loading from other sources in the watershed.

f) **New fisheries and vegetation management plans have been developed for Crow Wing Lake.** These plans are an important part of the overall management of Crow Wing Lake and should be considered in any future management efforts. These plans indicate the importance of maintaining or improving water quality and indicate that degraded water quality could shift the balance in this productive lake from desirable to less desirable species of fish. These plans may be obtained from the Brainerd area fishery office.

g) **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**. Since there is extensive competition for CWP funding, it may be in the best interest of the Association and Crow Wing Lake to continue to work with Crow Wing County, local water planner and the local townships to do as much as possible to protect the condition of the lake by means of local ordinances and education of shoreland residents. If these steps prove to be inadequate or lake conditions worsen (as evidenced by significant declines in Secchi transparency measurements), application to CWP may then be appropriate. *One indication of a declining trend in water quality would be if summer-mean transparency remained consistently below the current long-term means of about 5.0 to 6.5 feet or if summer-mean TP increased above 45 (±7) µg/L.*



LAKE ASSESSMENT PROGRAM: Crow Wing Lake 2001

INTRODUCTION

Crow Wing Lake was sampled by the Minnesota Pollution Control Agency (MPCA) during the summer of 2001 as a part of the Lake Assessment Program (LAP). This program is designed to assist lake associations or municipalities in the collection and analysis of baseline water quality data in order to assess the trophic status of their lakes. The general work plan for LAP includes Association participation in the Citizen Lake-Monitoring Program (CLMP), cooperative examination of land use and drainage patterns in the watershed of the lake, and an assessment of the data collected by MPCA staff.

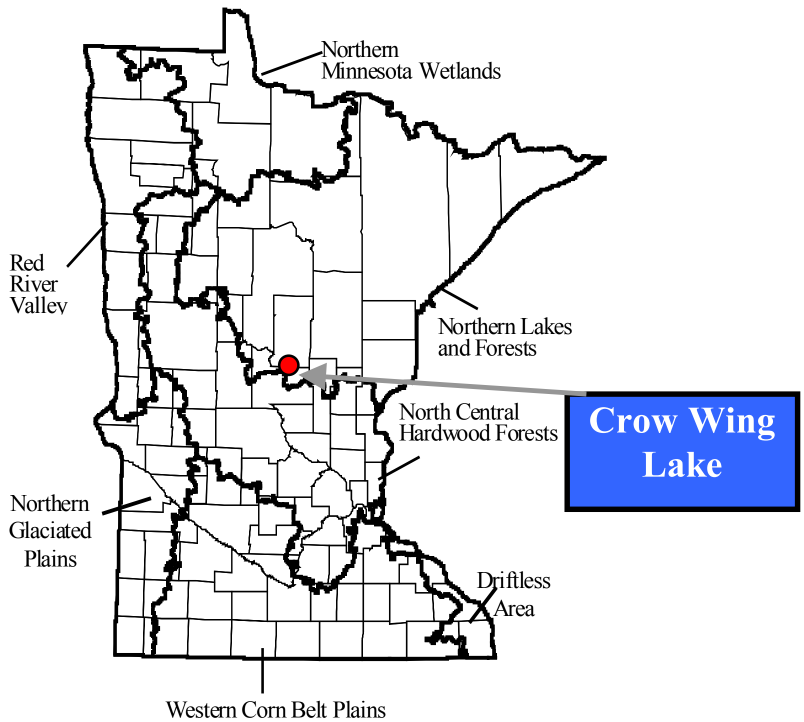
This study was conducted at the request of the Association and Crow Wing County. Crow Wing Lake was sampled on five occasions during the spring and summer of 2001. Participants in this effort included Jennifer Klang, Steve Heiskary, and Andrea Plevan (student intern) from the MPCA. The Brainerd Technical College Watershed class students assembled land-use and watershed information for Crow Wing Lake. Marvin Vik coordinated the Association's efforts on this study. Bonnie Finnerty, Crow Wing County Local Water Planner, provided information for the report as well. Dr. Howard Markus, MPCA, conducted phytoplankton analysis.

BACKGROUND: Watershed, Soils, and Land Use

Crow Wing Lake is located in Crow Wing County, near the city of Brainerd, Minnesota. Crow Wing Lake is in the upper fifteen percent of lakes in the state in terms of size (382 acres) and has a maximum depth of 26 feet and mean depth of about 15 feet. The lake has two inlets and one outlet that flows toward the Mississippi River. It has a watershed of approximately 16.6 square miles and watershed: lake surface ratio of 26.7:1. There are about 150 homes and one resort/campground on Crow Wing Lake. There is a state owned public access located on the south side of the lake in section 2. Crow Wing Lake is a class 31 lake based on Schupp's Index and its shoreland classification is general development.

Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation and current land use. Data gathered from representative, minimally impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Crow Wing Lake is located in the Northern Lakes and Forests (NLF) ecoregion near the transition to the North Central Hardwood Forests ecoregion (Figure 1). Crow Wing Lake's watershed is about 10,600 acres (16.6 mi^2), including the lake. The majority (60 %) of the watershed is in forested or wetland land use. The other predominant land use in the watershed includes hay and cultivated (30 percent) uses. The percent forest and wetland is somewhat low while the hay and cultivated land is high compared to other lake watersheds in this region of the state – *Northern Lakes and Forests ecoregion*. The composition is more comparable to that found in lakes to the south in the North Central Hardwood Forests ecoregion.

Figure 1. Crow Wing Lake Location (Ecoregion) and Bathymetric Map



100 Series = MPCA Sites,
200 Series = CLMP Sites,

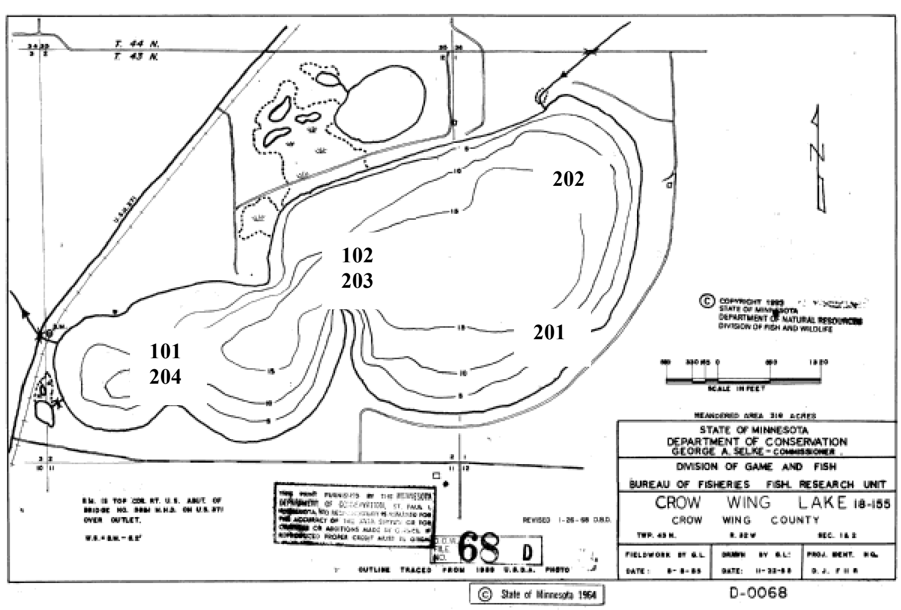


TABLE 1. MORPHOMETRIC, WATERSHED, FISHERY CHARACTERISTICS
Crow Wing Lake (18-0155)

Area[1]: 382 acres (156 ha)

Mean Depth: **15** feet (4.5 meters)

Maximum Depth: 26 feet (4.9 m)

Fetch: **1.4 miles**

Littoral: 210 acres (55 %)

Volume[1]: **5,730** acre-feet (676.5 hm^3)

Watershed Area[2]: 10,218 acres (16 mi^2) (4135 ha) (excludes lake)
10,600 acres (16.6 mi^2) (4290 ha) (includes lake)

Watershed Area Lake Surface Ratio: ~ 27:1
Estimated Average Water Residence Time: 0.7 years

Fisheries[4] - Schupp's Class: 31

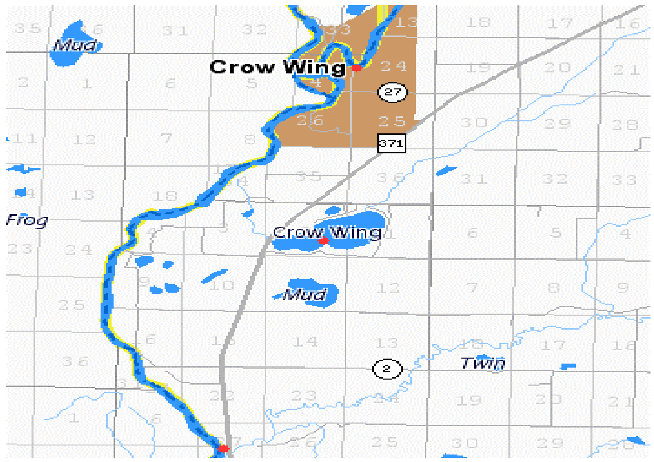
Public Access: 1 **Inlets[5]:** 2 **Outlets[5]:** 1

LAND USE	Forest	Wetlands	Lakes or ponds	Hayland	Cropland	Residential
Crow Wing Watershed[2] (Acres)	*5,300*	*1,066*	*521*	*560*	*2,642*	*504*
Crow Wing Watershed[2] (Percent)	**50**	**10**	**5**	**6**	**25**	**4**
NLF Ecoregion (Percent)	**54 - 81**	**14 - 31**		**0 - 6**	**< 1**	**0 - 7**

Development	Total	Seasonal	Permanent	Unknown
2000[5]	147			

[1]Planimetered by MPCA.
[2]Supplied by Brainerd Technical College.
[3]Derived from Heiskary and Wilson (1990) Table 6.
[4]MN Department of Natural Resources.
[5]Crow Wing Lake Association, 2000 septic system survey.

Figure 2, Crow Wing Lake Area and Watershed Map



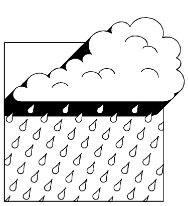
History

The Association compiled a summary of some historical events in Crow Wing Lake's watershed. The south side of Crow Wing Lake was platted in July 1922. The first cabins were built in 1923, which totaled six. At that time, Cozy Beach Resort was built. Girl Scouts used the resort for their camp from 1926 through 1929. Besides the resort, there were only three homes on the lake until after WWII.

In 1941, the Sleepy Hollow Dance Hall was built and operated until it burned down in 1965. The resort was closed at one point and the cabins were sold to several individuals. In 1945, 13 lots were sold in the Sandy Beach area, the first major development on the lake. In 1946 more lots were sold and building was started. Fishing during this time was excellent and a limit of walleye, northern pike, bass, crappies, and panfish were very common each day.

Building permits were not required until approximately January of 1970. In 1987, there were 150 homes and cottages around the lake. In 1999, the total of 150 homes had not changed, but many homes had been either torn down and replaced, or completely remodeled. There are currently no lots left to build on. There are approximately 286 residential boats and pontoons on the lake. There is one campground, Don & Mayva's Crow Wing Camp, that has 100 RV and campsites. It has been in operation on the lake for 30 years.

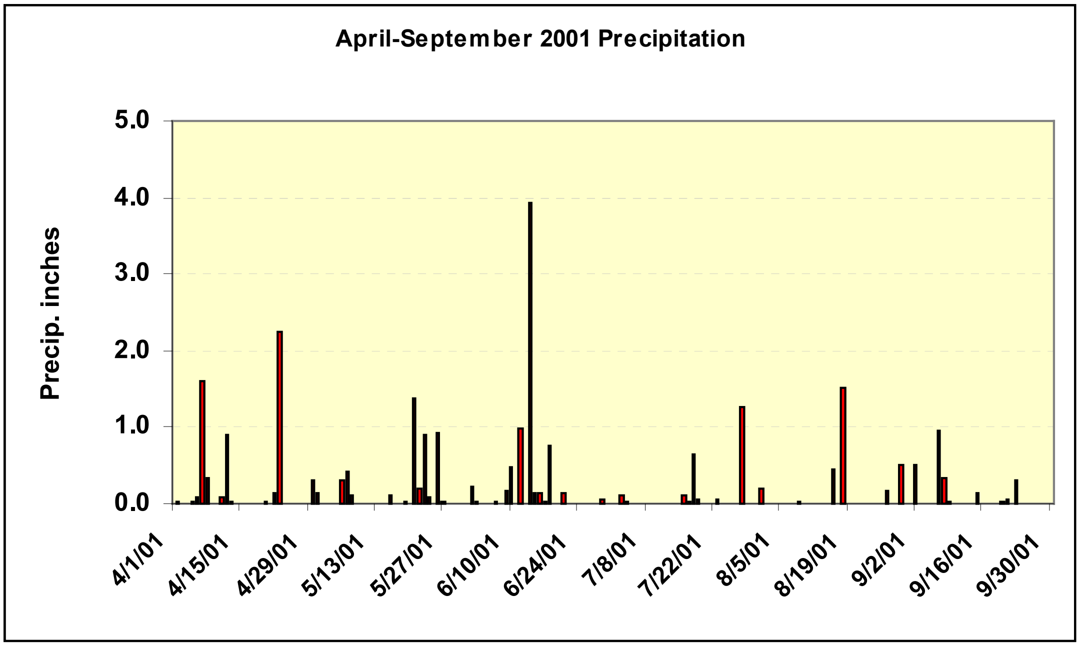
Climate



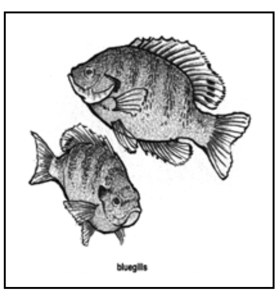
Based on State Climatology records, precipitation averages 26 inches (0.66 m) annually in this part of the state (Appendix II). Water-year precipitation in the Crow Wing Lake watershed was about six to eight inches above normal at about 34 inches in 2001 based on State Climatology Office records

(Appendix II). Evaporation approximately equals precipitation in this part of the state and averages about 26 inches (0.66 m) per year. Runoff averages about 8 inches with 1-in-10 year low and high values (low and high runoff values which might occur with a frequency of once in ten years) of 3 inches and 10 inches, respectively for this area (Gunard, 1985). There were several significant rain events in summer 2001 Figure (3). Precipitation events of one inch or more occurred on two dates in April, one in May, one in June, and two in August. An almost 4 inch rainfall was recorded on June 14th.

Figure 3. April – September 2001 Precipitation. Measured near Lake Sylvan, Morrison County



Fisheries



A summary of the fishery of Crow Wing Lake, drawn from the MDNR web site, reads as follows: Crow Wing Lake is a 382 acre lake located about 8 miles south of Brainerd, Minnesota. It is a class 31 lake according to Schupp's Index. About 55% of the lake is shallower than 15 feet. It is a hardwater lake with moderate phosphorus fertility. Water clarity is below average for the area. Shallow water areas are predominantly sand. The aquatic plant community is diverse despite rather heavy shoreline development. Bulrush beds provide important spawning habitat for bass and panfish species. Wild rice may be important to spawning northern pike. Submergent vegetation, which grows to a depth of about 12 feet, provides both protection and feeding areas for a variety of fish species.

The most recent fish survey for the lake was conducted in 1999. A vegetation survey was also conducted that summer. Northern pike were the most abundant gamefish found in the 1999 netting.

They were present in average numbers compared to similar type lakes. The majority of the pike were from the 1996 year class. Five age classes were sampled and growth was good. The average weight was 2.2 pounds.

Walleyes were caught in high numbers compared to similar lake types and compared to previous nettings of this lake. Ages 4,5 and 8 were caught and the average size was 2.7 pounds. Walleye growth appeared to be good. Walleye fry have been stocked annually since 1980. Largemouth bass were found in high numbers compared to similar lake types. Largemouth bass were sampled in gillnets, trapnets, seines and by electrofishing. Ages 2-5 and 8 were represented and growth was good. Bluegills were caught in average numbers and had an average rate of growth. Fish from the 1994 year class were most abundant in the catch. Black crappies continue to be found in high numbers. A variety of year classes were present and the growth rate was good. Yellow perch were found in average numbers and growth was slow. White suckers were also low in number. Both species provide important food sources for the lake's gamefish. Other fish species sampled in 1999 included bowfin, black, brown and yellow bullheads. All three bullhead species were captured at high rates compared to other similar lake types. A Fisheries Lake Management Plan was in prepared in 2001.

Vegetation Management

The Minnesota Department of Natural Resources Division of Fisheries conducted a fish population assessment and survey of aquatic plants August 9, 1999 on Crow Wing Lake. Previous lake survey and assessments were done in 1955, 1956, 1979, 1987, and 1994. The following description was drawn from that survey work and a report prepared by MDNR Ecological Services in Brainerd.

With about 55 percent of the lake being less than 15 feet Crow Wing Lake has a large portion of its basin that can support rooted plant growth. The 1999 survey of aquatic plants listed 9 species of emergent aquatic plants and 16 species of floating-leaf and submerged aquatic plants. Curly leaf pondweed (*Potamogeton crispus*), an exotic, is abundant during cool water periods. It had senesced [become dormant] by the time of the survey during the July warm water period and was not found at that time. The most common submerged species are northern watermilfoil (*Myriophyllum sibiricum*), coontail (*Ceratophyllum demersum*), narrowleaf pondweed (*Potamogeton strictifolius*), muskgrass (*Chara vulgaris*) and filamentous algae. Coontail and northern watermilfoil are most abundant on the north shore of the lakes westward around to the point on the south side. Muskgrass has a similar distribution but is less abundant along parts of the north shore and more common along the east side of the lake. Filamentous algae is most abundant from approximately the middle of the north shore westward around to the point on the south side of the lake. Narrowleaf pondweed is most abundant in the middle of the north shore and in one area on the southeast side of the lake. Submerged aquatic plants grow to a depth of 10 to 12 feet. Emergent aquatic plants were not abundant in the 1999 vegetation survey. Hardstem bulrush (*Scirpus acutus*), three square (*Scirpus pungens*) and swamp milkweed (*Asclepias incarnata*) had the greatest frequency of abundance of the emergent species. Although hardstem bulrush had the greatest mean abundance of the emergents, its mean abundance would be rated as rare on Crow Wing Lake. The largest beds are on the point on the south side of the lake and along the north shore on the west end of the lake. Hardstem bulrush should be protected and encouraged to expand because it provides excellent fish and wildlife habitat, aids in erosion control by acting as a wave break and utilizes nutrients such as phosphorus efficiently. Yellow water lily (*Nuphar luteum variegatum*) and white water lily (*Nymphaea tuberosa*) are abundant only along the north side of the very west end of the lake.

Changes seem to have occurred in the aquatic plant community over time (Appendix). White water lily, claspingleaf pondweed (*Potamogeton richardsonii*), variable pondweed (*Potamogeton gramineus*) hardstem bulrush and wild celery (*Valisneria americana*) each seem to have declined in relative abundance from the 1987 to the 1999 survey. Coontail and muskgrass appear to have the same relative abundance during this time period, although there is some evidence from an earlier (1970) survey that muskgrass was more abundant. Wild rice was not found in the 1999 survey but was indicated as being common in 1987. The 1970 survey indicated wild rice was rare. Fluctuating patterns such as this are not uncommon for wild rice. Wild rice, when present, should be protected because of its value to waterfowl. Northern watermilfoil abundance changes are not clear. It was not noted in the 1987 survey and its abundance was not noted in the 1970, although present. Curlyleaf pondweed has become established in the lake and grows to nuisance levels. The time when it first infested Crow Wing Lake, and its subsequent effects, if any, on the native submergent plant community are not known. Eurasian watermilfoil *(Myriophyllum spicatum*) has not been found in Crow Wing Lake. Purple loosestrife (*Lythrium spp*.) is not common, being found only near the outlet.

Septic System Survey

A voluntary septic system inspection program was initiated by the Association in conjunction with Crow Wing County Planning and Zoning during the summer of 1999. Of the 95 surveys distributed, 90 were returned. The Association asked anyone who did not have a certificate of compliance dated 1990 or later to voluntarily have their system inspected. A summary of results follows:

- Of the returned surveys, 52 had certificates dated 1990 or later, nine had certificates dated earlier than 1990.
- 63 systems were inspected and of these 55 were found to be compliant and eight were non-compliant and nine were holding tanks and will be inspected when pumped.
- Five property owners indicated they would install new systems.

RESULTS AND DISCUSSION

Water quality data was collected in early June, late June, July, August, and September, 2001. Two sites were used on Crow Wing Lake: site 102 – over the point of maximum depth near the center of the lake; and site 101 – located on the western portion of the lake (Figure 1). 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). Phytoplankton (algae) samples were taken at site 102 with an integrated sampler. Secchi disk monitoring through the CLMP was conducted at two sites – 101 and 102 (Figure 1). Seasonal averages were calculated using June - September data.

Sampling procedures were employed as described in the MPCA Quality Control Manual. Laboratory analyses were performed by the laboratory of the Minnesota Department of Health using U.S. Environmental Protection Agency (EPA)-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, turbidity, conductivity, chloride and chlorophyll (Table 2). Temperature and dissolved oxygen profiles and Secchi disk transparency measurements were also taken.

Minimal data was available for comparison. All data was stored in STORET, the EPA's national water quality data bank. The following discussion assumes that the reader is familiar with basic water quality terminology as used in the Citizens' Guide to Lake Protection.

In-lake Conditions: 2001

Dissolved oxygen, temperature, conductivity, pH and redox profiles were taken at one-meter intervals at site 102 on each date. Surface temperatures ranged from 15 degrees C in early June to a peak of 27 degrees C in August (Table 2). Thermal stratification was evident from June through August; with the thermocline (zone of rapid change in temperature over a short range in depth) forming between 3 - 4 m (10 - 13 feet) by July and August (Table 2). Temperatures ranged from 18 - 22 degrees C in the hypolimnion (lower cooler layer). The "hypolimnion" on Crow Wing is a very small portion of the volume of the lake and hence these bottom waters are much warmer than we typically find in deeper lakes where the thermocline is very stable and the hypolimnion volume is large.

Surface dissolved oxygen concentrations ranged from 7.0 – 8.2 mg/L and saturation (amount of oxygen measured compared to that predicted for a given temperature) ranged from 80 - 105 percent. Concentrations fell below 2 mg/L in the hypolimnion during stratification (Table 2). This would be too low for game fish, which typically require a dissolved oxygen concentration of 5 mg/L or greater for long-term survival. Also, as oxygen concentrations fall below 2 mg/L at the sediment-water interface, internal recycling of phosphorus from the sediments to the water may occur. Chemical and biological reactions in the lower layer (during stratified conditions) lead to lower pH, increased conductivity, and a decline in redox potential (ORP) and oxygen saturation (Table 2). Fall turnover, caused by cooling of the surface waters and wind mixing, was underway in August as evidenced by the almost uniform temperatures and was complete by September.

Table 2. Crow Wing Lake Profiles @ Site 102.
Bold data indicate depth of thermocline

Date	Time	Depth	Temp	DO	Cond	pH	ORP	DO%
		m	^{0}C	mg/l	umhos	SU	mV	% Sat
010523	1415	0.6	15.4	7.8	197	7.9	287	80
010523	1415	1.1	15.3	7.7	196	7.9	290	78
010523	1415	2.1	15.2	7.6	196	7.8	291	78
010523	1415	3.0	15.1	7.6	196	7.8	292	78
010523	1415	4.0	14.9	7.7	196	7.8	291	78
010523	1415	4.9	14.1	7.2	197	7.8	292	70
010523	1415	6.0	14.0	6.9	197	7.7	292	69
010523	1415	6.2	14.0	4.2	210	7.6	241	39
010619	0740	0.4	19.7	6.9	189	8.3	280	82
010619	0740	1.1	19.6	6.9	189	8.4	277	82
010619	0740	1.9	19.6	6.9	189	8.4	277	82
010619	0740	3.0	19.5	6.6	190	8.4	273	79
010619	0740	4.1	19.4	6.5	191	8.3	279	77
010619	0740	4.8	19.2	5.5	203	8.0	287	65
010619	0740	**5.8**	**17.9**	**1.4**	**208**	**7.7**	**290**	**17**
010724	0830	0.3	27.0	7.5	200	8.8	189	98
010724	0830	1.0	27.0	7.3	200	8.8	190	95
010724	0830	2.1	26.9	6.6	201	8.7	190	86
010724	0830	**3.1**	**24.9**	**1.2**	**209**	**7.8**	**207**	**13**
010724	0830	4.0	22.2	0.3	222	7.8	17	3
010724	0830	5.0	20.2	0.2	238	7.8	-36	2
010821	0850	0.0	22.9	8.8	200	8.9	262	105
010821	0850	1.0	22.9	8.8	200	8.9	260	105
010821	0850	1.9	22.9	8.8	201	8.8	261	106
010821	0850	3.0	22.8	8.5	201	8.7	265	102
010821	0850	**4.0**	**22.0**	**0.4**	**213**	**7.5**	**290**	**5**
010821	0850	5.0	21.8	0.3	217	7.6	267	3
010821	0850	5.6	21.3	0.2	243	8.1	82	2

TABLE 3: AVERAGE SUMMER WATER QUALITY AND TROPHIC STATUS INDICATORS: CROW WING LAKE, Based on 2001 epilimnetic data.

Parameters	**2001 Mean**	**Typical Range for NLF Ecoregion**[1]
Total Phosphorus (µg/L)	45	14-27
Chlorophyll a (µg/L)[3]		
Mean	26.2	< 10
Maximum	45	< 15
Secchi disk (feet)	4.3	8-15
Total Kjeldahl Nitrogen (mg/l)	1.1	< 0.75
Alkalinity (mg/l)	108	40-140
Color (Pt-Co Units)	35	10-35
pH (SU)	8.5	7.2-8.3
Chloride (mg/l)		< 2
Total Suspended Solids (mg/l)	6.3	< 1 - 2
Total Suspended Inorganic Solids	5.1	< 1 - 2
Conductivity (µmhos/cm)	202	50 - 250
TN:TP Ratio	24:1	25:1-35:1

Trophic Status Indicators: 2001

		Carlson's TSI	**Percentile for NLF Ecoregion**	**Percentile for NCHF Ecoregion**
TP	TSIP =	59	10	50
Chl a	TSIC =	63	5	40
Secchi	TSIS =	56	5	30

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

[2] Relative to approximately 800 assessed lakes in the Northern Lakes and Forests and 700 in North Central Hardwood Forests Ecoregion, whereby the lower the trophic state (TSI), the higher the percentile ranking (100 percent level implies lowest TP or deepest Secchi disk for that ecoregion).

[3] Chlorophyll a measurements have been corrected for pheophytin.

Total phosphorus (TP) concentrations (an important nutrient for plant growth) averaged approximately 45 µg/L (micrograms per liter or parts per billion) in the surface waters of Crow Wing Lake during the summer of 2001. This value is above the range of concentrations typically found in reference lakes in the NLF ecoregion (Table 3). TP concentrations ranged from 20 – 65 µg/L and were generally stable from May through July and increased in August and September (Figure 3). Site 102 was slightly higher on all dates. A significant rainfall/runoff event occurred on August 18 (1.5 inches, Figure 3) just prior to the August 21 sample collection. Likewise 1.3 inches were recorded on September 8 and 9 just prior to the September 12 sample collection. These rainfall/runoff events may have contributed to the increased TP in August and September

TP samples collected one meter above the bottom of the lake ranged from 20 µg/L in May to 122 µg/L in July (Figure 4). No sample was taken in August and a decline in bottom TP was evident in September, which is consistent with fall mixing. Given the shallowness of the lake it is possible that strong winds or cold fronts could cause some mixing of the lake and bring nutrient-rich bottom waters into the epilimnion. This may have contributed to elevated surface TP in August and September (Figure 4).

Figure 4. Crow Wing Lake 2001 Total Phosphorus and Chlorophyll-a Concentrations – Surface Samples

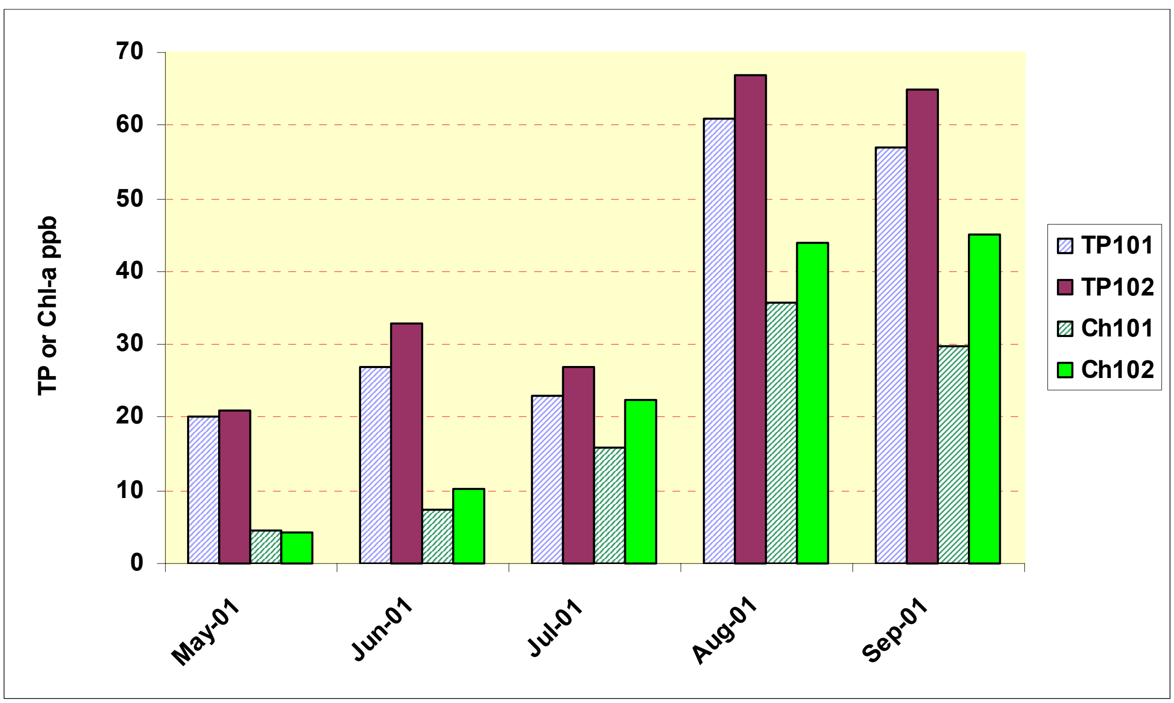
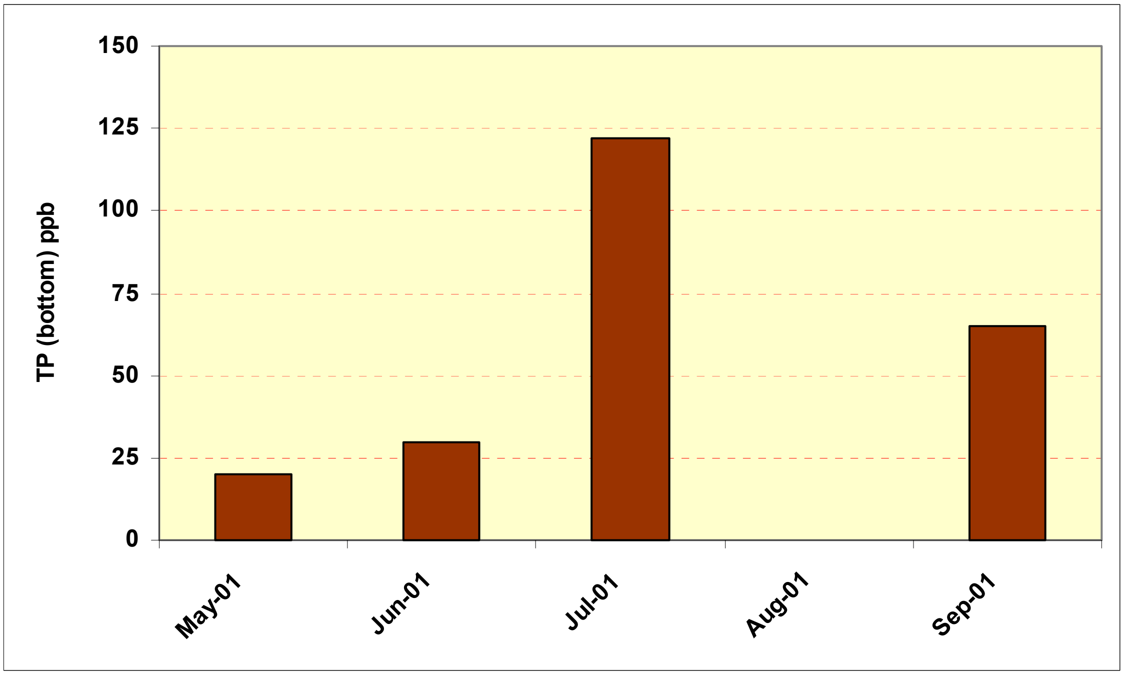


Figure 5. Crow Wing Lake 2001 Total Phosphorus Concentrations – Bottom Samples @ 102.



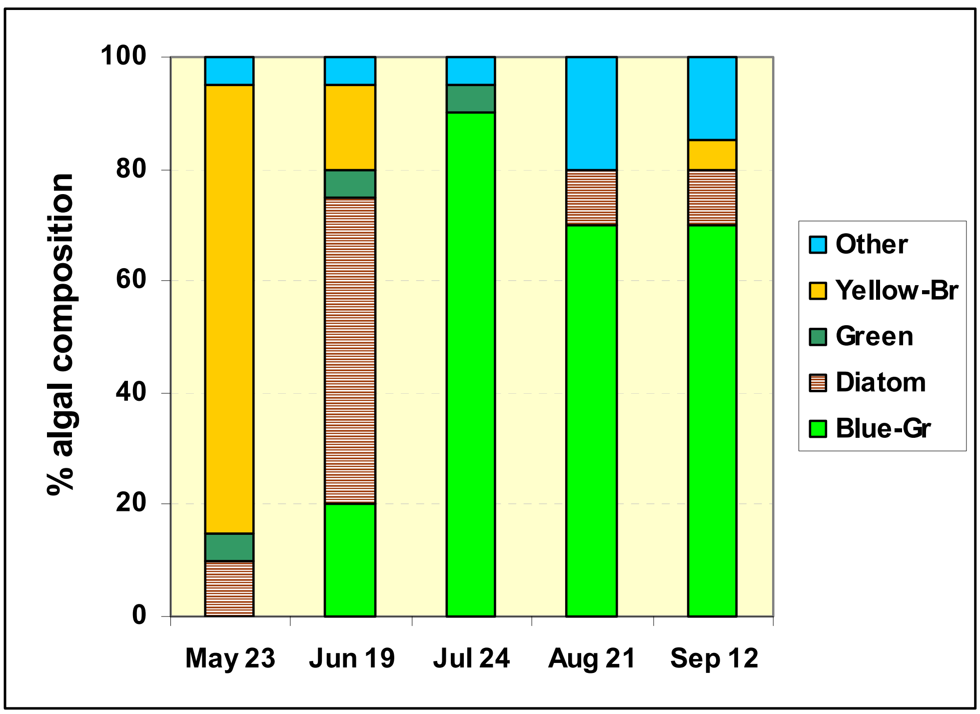
Total Kjeldahl nitrogen (TKN) averaged 1.1 mg/L on Crow Wing Lake in summer 2001. This concentration is slightly high for TKN concentrations found in reference lakes in the NLF ecoregion.

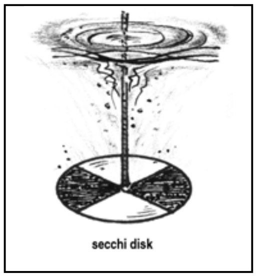
The ratio of total nitrogen: total phosphorus (TN:TP) can provide an indication as to which nutrient is limiting the production of algae in the lake. For Crow Wing Lake, the TN:TP ratio is about 24:1. This suggests that phosphorus is the limiting (controlling) nutrient in Crow Wing Lake. Generally, phosphorus is the least abundant nutrient and, therefore, is the limiting nutrient for biological productivity in a lake. The TN:TP ratio for is slightly lower than expected TN:TP ratios in the NLF reference lakes as a result the high phosphorus concentrations in Crow Wing Lake.

Chlorophyll a concentrations provide an estimate of the amount of algal production in a lake. The average and maximum chlorophyll a concentrations for Crow Wing Lake were well above the NLF reference lakes (Table 3). During the summer of 2001, chlorophyll a concentrations on Crow Wing Lake ranged from 5 µg/l to over 40 µg/L with an average of 26.2 µg/L (Figure 3). Concentrations were higher at site 102 on most dates. Concentrations ranging from 10 – 20 µg/L are frequently perceived as a *mild algal bloom*, while concentrations greater than 20 µg/L may be perceived as a nuisance bloom (Heiskary and Walker, 1988). Chlorophyll-a on the August and September sampling dates were at nuisance to severe nuisance levels.

The **composition of the phytoplankton (algae)** population of Crow Wing Lake is presented in Figure 5. Data are presented in terms of algal type. Samples were collected at site 101. In May the yellow-brown algae (Chrysophyta) Dinobryon and Synura dominated the sample. By June, the diatoms were well represented, with the forms Melosira and Fragilaria being most common. Various blue-greens were evident on this date as well. By July, blue-green algae were the most common, with the form, Anabaena being dominant. In August and September, the blue-greens dominated the algae population; with the forms Anabaena, Anacystis, and Aphanizomenon being most common. Red algae (Pyrrhophyta) in the form of Ceratium were represented as well. Bloom conditions were evident from July through September. These blooms were dominated by blue-greens that float near the surface of the water and often accumulate and cause scums on the downwind shore. A seasonal transition in algal types from diatoms to greens to blue-green is rather typical for mesotrophic and eutrophic lakes in Minnesota.

Figure 6. Crow Wing Lake 2001 Phytoplankton Composition

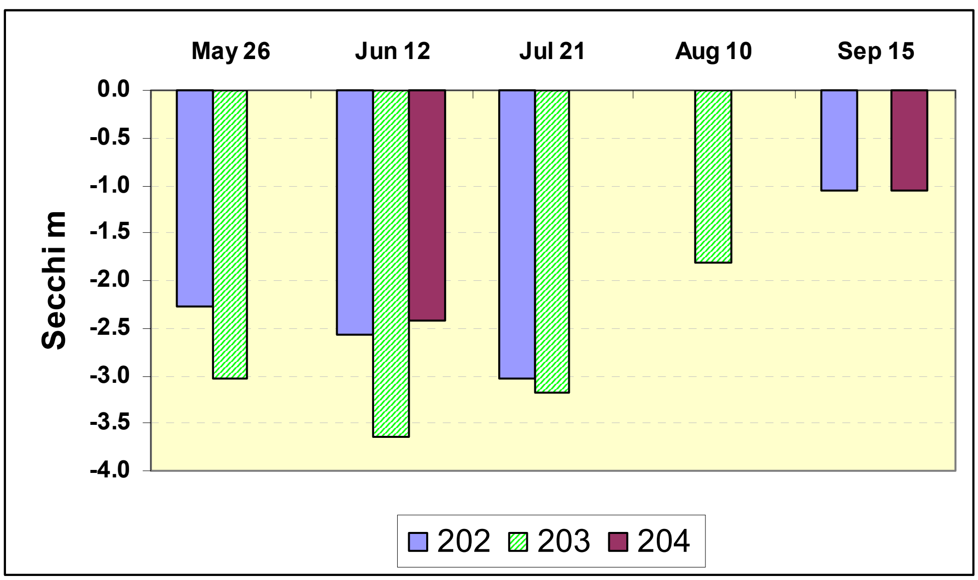




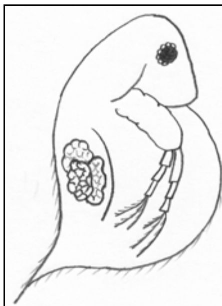
Secchi disk transparency is generally a function of the amount of algae in the water. Suspended sediments or color due to dissolved organic material may also reduce water transparency. Color for Crow Wing Lake averaged between 20 – 40 Pt-Co units, indicating moderate coloration due to incompletely dissolved organic matter (tannin from upstream wetlands). Total suspended solids (TSS) averaged 1.9 mg/L and total suspended inorganic solids averaged 6.3 mg/L for Crow Wing Lake over the summer. Suspended sediment (inorganic) is the primary contributor to the TSS. The total suspended and inorganic solids values are higher than values found in reference lakes in this region. However, these levels of color and total suspended solids should not appreciably limit water transparency in Crow Wing Lake.

Secchi disk transparency for Crow Wing Lake was monitored by Lois Vik from the MPCA's Citizen Lake-Monitoring Program (CLMP). Along with CLMP transparency measurements, subjective measures of Crow Wing Lake's "physical appearance" and "recreational suitability" were made. Secchi disk transparency on Crow Wing Lake ranged from about 3.3 feet (1.0 m) in August to 12 feet (3.7 m) in June (Figure 6) for sites 202, 203 and 204. The average transparency (4.5 feet, 1.3 m) is lower than typical range for reference lakes in the NLF ecoregion (Table 3). Secchi was slightly higher at the 203 site (mid-lake) as compared to 202 (northeast basin) and 204 (southwest basin).

Figure 7. Crow Wing Lake CLMP Secchi Transparency for 2001.
Collected by Lois Vik.



User perception rankings ranged from "algal green" in May and June to "definite algal green" in August to "severe nuisance blooms and no swimming" by September. The response "definite algal green" was associated with transparency below 2.0 m (6.6 feet) and "severe nuisance blooms" was associated with transparency of 1.0 m (3.3 feet) or less (Figure 6). The corresponding chlorophyll-a concentrations were about 40 – 45 µg/L based on MPCA data for those two months (Figure 3).



Zooplankton - Daphnia

The change in the transparency of Crow Wing Lake over the course of the summer is fairly typical for lakes in Minnesota. Typically, transparency is high in the spring when the water is cool and algae populations are low. Frequently, zooplankton (small crustaceans which feed on algae) populations are high at this time of year also, but will decline later in the summer because of predation by young fish. In Crow Wing Lake small zooplankton were abundant in May and July samples but were not observed on June, August and September sample collections. Large-bodied forms were not found in any of the surveys. As the summer goes on, the waters warm and the algae make use of available nutrients. As the algae become more abundant, the transparency declines. The decrease in the abundance of zooplankton may allow for further increases in the amount of algae. Later in the summer, surface blooms of algae may appear. On a day-to-day basis, transparency may differ between the sites measured, but the overall pattern is fairly consistent and the transparency readings are not significantly different between the MPCA and CLMP sites on Crow Wing Lake.

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

Total phosphorus TSI (TSIP) = 14.42 1n (TP) + 4.15
Chlorophyll a TSI (TSIC) = 9.81 1n (Chl-a) + 30.6
Secchi disk TSI (TSIS) = 60 - 14.41 1n (SD)

TP and chlorophyll a are in µg/L and Secchi disk transparency is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass.

Average values for the trophic variables in Crow Wing Lake and respective TSIs are presented in Figure 7. Based on these values, Crow Wing Lake's condition would be characterized as *eutrophic*. The TSIP of 57 ranks Crow Wing Lake at the 10^{th} percentile relative to other lakes in the NLF ecoregion. This implies that relative to other assessed lakes in the NLF, only 10 percent had a higher TSI value (i.e., higher TP). In contrast, relative to lakes in the NCHF ecoregion (immediately south of Crow Wing Lake) its TSIP would rank near the 50^{th} percentile. The individual TSI values for TP, chlorophyll-a and Secchi transparency agree fairly well with one

Figure 8. Carlson's Trophic State Index for Crow Wing Lake, Crow Wing County
R.E. Carlson

TSI < 30 — Classical Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion, salmonid fisheries in deep lakes.

TSI 30 - 40 — Deeper lakes still exhibit classical oligotrophy, but some shallower lakes will become anoxic in the hypolimnion during the summer.

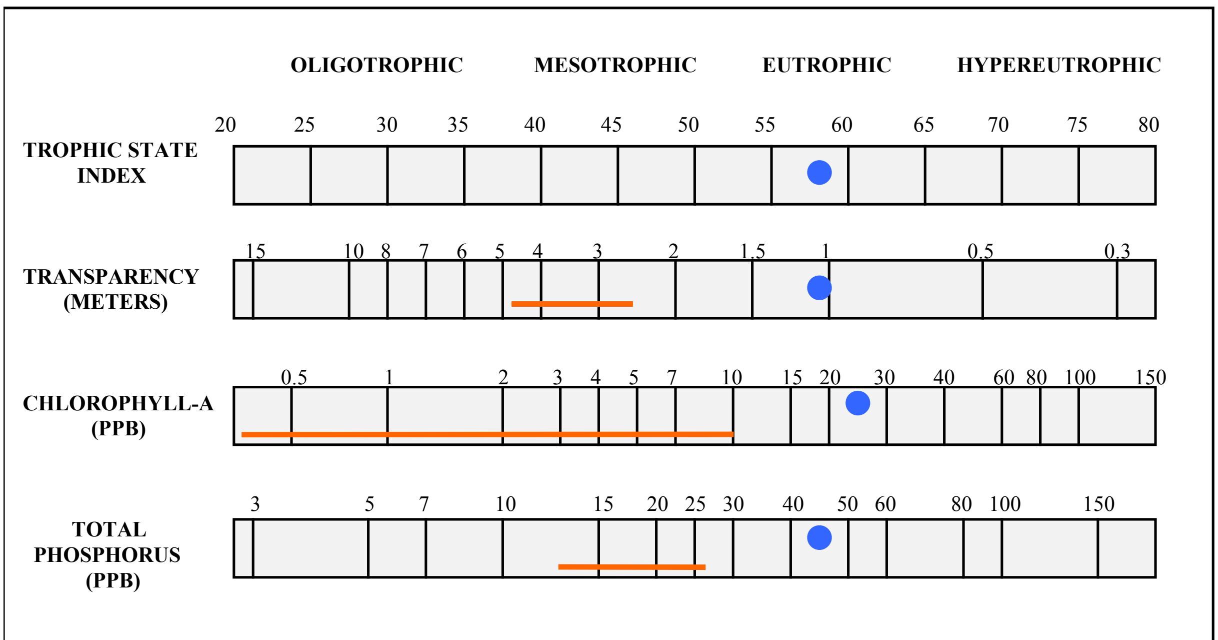
TSI 40 - 50 — Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

TSI 50 - 60 — Lower boundary of classical eutrophy: Decreased transparency, anoxic hypolimnia during the summer, macrophyte problems evident, warm-water fisheries only.

TSI 60 - 70 — Dominance of blue-green algae, algal scums probable, extensive macrophyte problems.

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

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



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

NLF Ecoregion Range: ——— Crow Wing Lake: ●

another (Figure 7) and implies that Secchi transparency should provide a good estimate of trophic status for Crow Wing Lake.

The other measured water quality parameters were above the typical range of values for the NLF reference lakes. Alkalinity and conductivity are within or near the typical range of expected values for the reference lakes, indicated hard-water (high in dissolved minerals).

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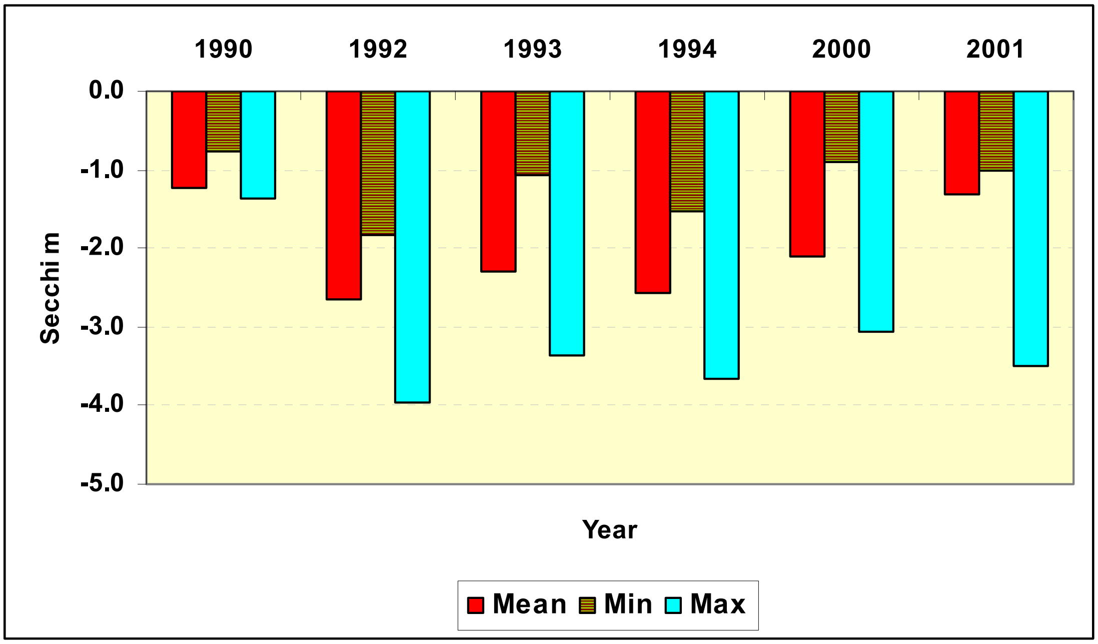
Figure 9. Summer mean, minimum and maximum Secchi for Crow Wing Lake



Water Quality Trends

Crow Wing Lake lacks sufficient data to assess trends in trophic status. Its best data source is six summers of CLMP measurements. Based on non-consecutive data for the period 1990 – 2001, summer-mean has ranged from 1.1 to 2.5 m (Figure 8). Likewise no distinct trend is evident for summer minima or maxima either. The mean and minima from 2001; however, were comparable to 1990, which were the lowest on record. There was a single TP measure of 40 µg/L in STORET from the summer of 1982, which is fairly similar to the TP concentration in 2001. Limited sampling by the Association in 2000 indicated surface TP concentrations on the order of 50 to 70 µg/L – again comparable to this study.

Modeling and Phosphorus Loading

Numerous complex mathematical models are available for estimating nutrient and water budgets for lakes. These models can be used to relate the flow of water and nutrients from a lake's watershed to observed conditions in the lake. Alternatively, they may be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake (e.g., changing land uses in the watershed) or altering the flow of amount of water that enters the lake. To analyze the in-lake water quality of Crow Wing Lake, the models **MINLEAP** (Wilson and Walker, 1989) and **Reckhow and Simpson** (Reckhow and Simpson, 1980) were used. The "Minnesota Lake Eutrophication Analysis Procedures" (MINLEAP), was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). Reckhow and Simpson is a spreadsheet model that estimates phosphorus loading to the lake based on phosphorus and runoff coefficients.

The first model, **MINLEAP,** predicted an in-lake TP of 29 (± 8) µg/L which is lower, but not significantly different (based on T-test), than the 2001 observed mean of 45 (± 7) µg/L. Subsequently the predicted chlorophyll-a and Secchi are lower and higher, respectively as compared to the observed values. The P-loading rate based on the first MINLEAP model run was estimated at 974 kg/yr. A second, calibrated, model run was made. In the second model run, we modified (calibrated) the stream P from 53 µg/L to a concentration of 100 µg/L, which might be more realistic based on some inflow sampling by the Association and the high percentage of agriculture in the watershed. The calibrated MINLEAP predicted an in-lake TP of 47 (± 13) µg/L, which is much closer to the 2001 observed mean (Table 4). Subsequently, the predicted chlorophyll-a and Secchi were more comparable to observed values as well. The P-loading and retention rates were also higher in the calibrated model run at 974 kg P/yr and 0.53 percent, respectively. The models estimated water residence time (time it would take to fill the lake if it was completely empty) at about 0.7 years.

TABLE 4. MINLEAP Model Results for Crow Wing Lake.

Parameter	**Observed 2001**	**Standard MINLEAP**	**Calibrated MINLEAP**
TP (µg/L)	45 ± 7	29 ± 8	47 ± 13
chl-a (µg/L)	26 ± 5	9 ± 4.7	18 ±10
% chl-a >20 µg/L		11%	40 %
% chl-a >30 µg/L		4%	21 %
Secchi (meters)	1.1 ±0.1	2.1 ± 0.8	1.4 ± 0.5
P loading rate	--	518 kg P/yr	974 kg P/yr
P retention (%)	--	0.46	
P inflow conc. µg/L	--	53	100
water load	--	6.23 m/yr	6.23 m/yr
outflow volume	--	9.71 hm^3/yr	9.71 hm^3/yr
"background P"	--	22	22
residence time	--	0.7	0.7

A second mathematical model, developed by Vighi and Chiaudani (1985), estimated a background phosphorus (P) concentration for Crow Wing Lake at 22 µg/L. This prediction is based on the morphoedaphic index, routinely used in fishery science, and predicts background (i.e. natural) P based on the lake's alkalinity and mean depth. The model assumes that P is delivered to the lake in proportion to other minerals like calcium and magnesium from the watershed. Based on past experience this model provides a reasonable estimate of background P for lakes that were naturally oligotrophic to mesotrophic in nature. The model may; however, underestimate P for lakes that may have been eutrophic in nature. The model does provide an estimate of the proportion of P in the lake that might be due to natural background loading, which in the case of Crow Wing Lake, would be about 50 percent of the observed TP in 2001.

The **Reckhow-Simpson model** was used to estimate the water quality of Crow Wing Lake. For Reckhow-Simpson modeling, estimates of precipitation, runoff and evaporation for Crow Wing's watershed were used. P-loading to the lake was estimated based on land use composition, as provided by the Brainerd Technical College Watershed Class, and export coefficients. The Reckhow and Simpson model provides a basis for estimating water and nutrient budgets for Crow Wing Lake using a combination of runoff and P export coefficients based on land use in the watershed. Estimates for P and water loading were made as follows:

1. *P export coefficients* - standard coefficients based on the literature and past experience were used.
2. *Precipitation* - was estimated based on 2001 water year data and runoff was estimated from statewide isopleth maps.
3. *Atmospheric coefficients* – estimated at 15 - 20 $kg/km^2/yr$.
4. *Septic Systems* – based on the number of seasonal and annual residences, standard per capita loading rate, and a soil retention coefficient of 60 (low) – 80 (high) percent.

The "average or most likely" range of P export coefficients provided the best estimate of in-lake P for Crow Wing Lake (53 µg/L predicted vs. 45 µg/L observed). Using a range of P export values yielded an estimated P- loading rate of 692 – 1,736 kg P/yr, with a most likely value of 1,107 kg P/yr. The model estimates that precipitation on the lake could potentially contribute about 2 to 3 percent; watershed sources could contribute about 89 to 91 percent; and septic systems could potentially contribute about 7 percent (Table 5). The predicted loading rate seems to be a reasonable estimate of P loading generated from this watershed based on the calibrated MINLEAP model run. [Note: The validity of these estimates is somewhat contingent on the model accurately predicting the in-lake P concentration of the lake.] In the "most likely" case, the model estimated in-lake P at 53 µg/L, which is similar to the "calibrated" MINLEAP model, and not significantly different from the observed concentration in 2001. The high percent contribution from the watershed seems reasonable as well because of the large watershed to lake ratio and the fairly high percentage of agricultural land in the watershed.

Table 5. Crow Wing Lake Potential P-Loading Source Relative for Relative Contributions

Potential Source	**Estimated Relative Contribution (%)**
Precipitation	**2 to 3 %**
Watershed	**89 to 91 %**
Septics	**7 to 8 %**

Goal Setting

The current phosphorus criteria value for lakes in the Northern Lakes Forest ecoregion, for support of swimmable use, is less than 30 µg/L (Heiskary and Wilson, 1990). At or below 30 µg P/L, "nuisance algal blooms" (chlorophyll a > 20 µg/L) should occur less than 5 percent of the summer. Crow Wing Lake, with a summer-mean P of 45 µg/L and a summer-mean chlorophyll a of 26 µg/L, experienced nuisance to severe nuisance blooms about 40 percent of the time during summer 2001 (MINLEAP model, Table 3).

For Crow Wing Lake, it would be desirable to reduce in-lake P concentration. An in-lake P goal on the order of 30 – 40 µg/L may be appropriate based on data from 2001, and model results (Table 6). The summer-mean P concentration for 2001 was above the background concentrations estimated by Vighi and Chiaudani regression -- 22 µg/L. Attaining a P concentration of 30 – 40 µg/L or lower should keep chlorophyll-a concentrations at or below 20 µg/L about 75 to 90 percent of the summer and Secchi at or above 2 meters 60 to 80 percent of the summer.

Attaining a summer-mean P concentration of about 30 - 40 µg/L or lower, over the long term, would require that P loading to the lake be reduced. Important considerations 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 buffer areas between lawns and the lakeshore, minimizing use of fertilizers, and bringing on-sites up-to-code are all important considerations. Additionally there will be a need to minimize upstream loading that may arise from development activities (ensure proper handling of stormwater) or agricultural practices (ensure use of BMPs whenever possible). These and other considerations will be important if reductions in in-lake P are to be made.

Table 6. Crow Wing Lake Summer-Mean Phosphorus Concentrations & Model Estimates.

2001 Mean	Standard MINLEAP	Calibrated MINLEAP	Vighi – P	Reckhow- Simpson
45 ± 7	29 ± 8	47 ± 13	22	37 (low) – 53 (avg) -75 (high)

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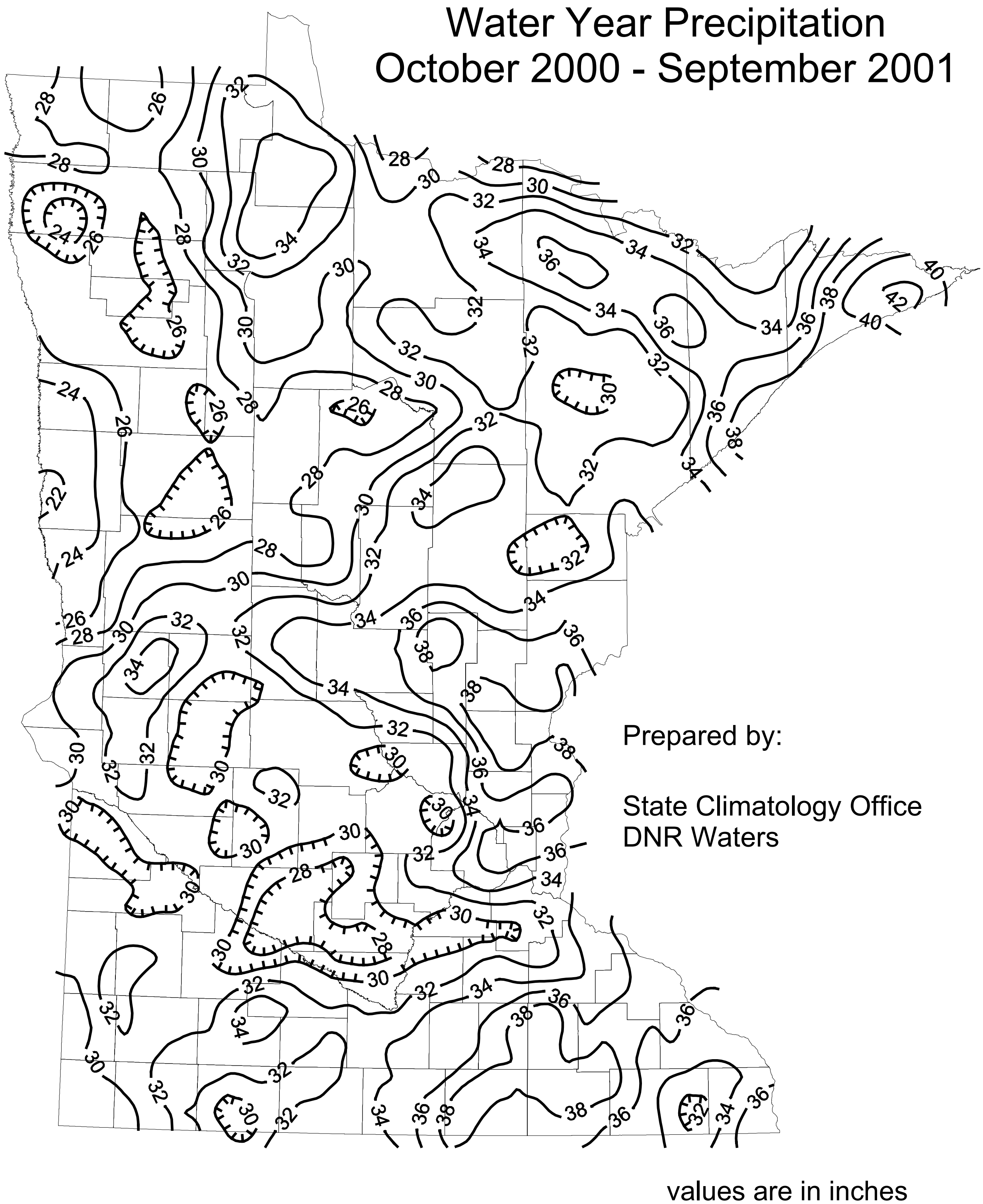
Appendix

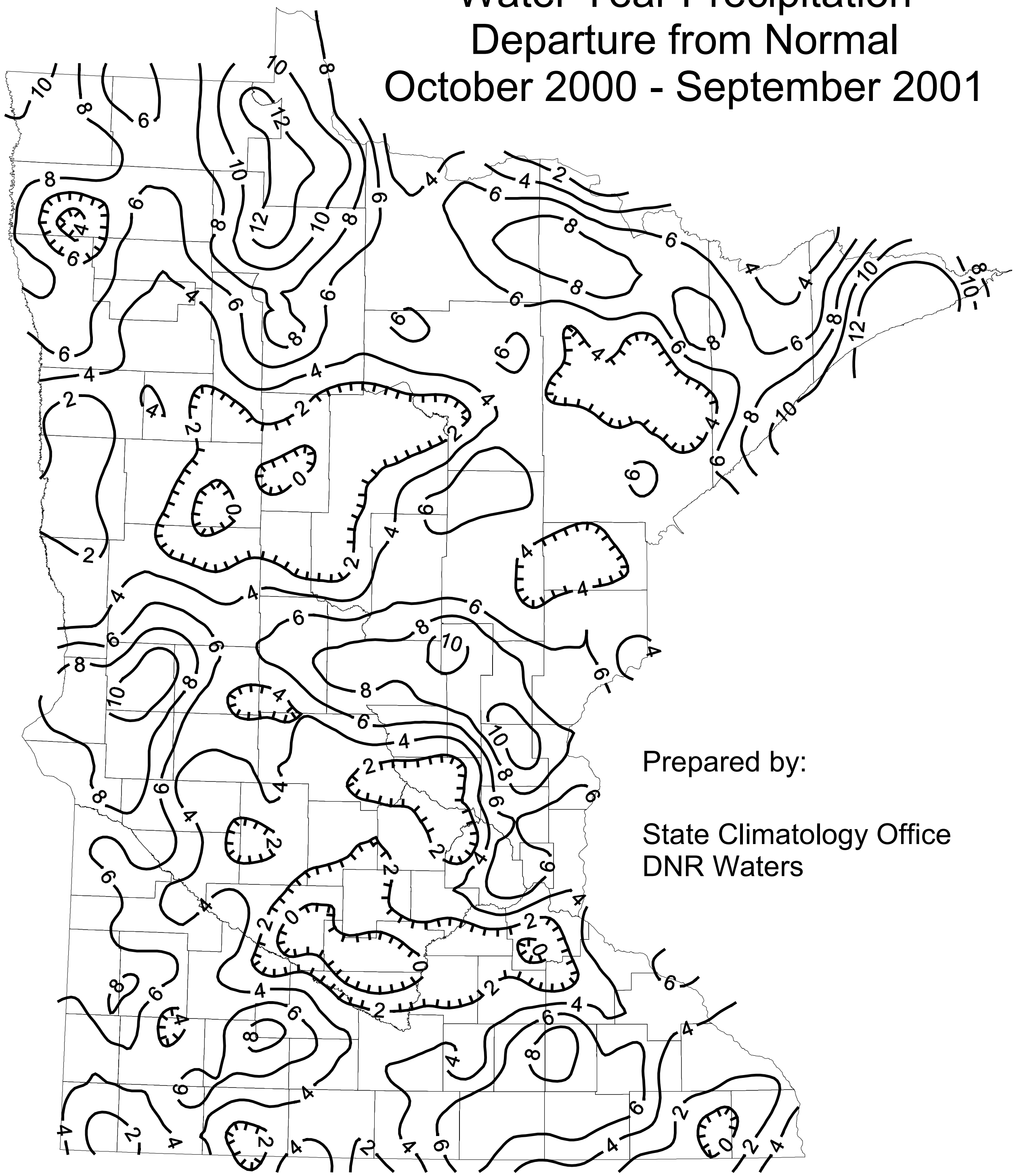
Appendix I. 2001 Water Quality Data

Start Date	Start Time	site #	Depth, ft	Alk mg/L	TP mg/L	Chl-a ug/L	Pheo Ug/L	Phys Appear	Rec Suit	TKN mg/L	TSS mg/L	TSV mg/L	Cond	Secchi m
5/23/01	1415	102	0	110	0.021	4.0	1.0			0.6	1.2	1 (K)		
5/23/01	1415	102	2					2	1				197	3.5
5/23/01	1415	102	20										197	
5/23/01	1415	102	20										210	
5/23/01	1440	101	0					2	1					3.0
5/23/01	1440	101	0		0.020	4.0	1.2							
6/19/01	730	101	0					2	2					2.0
6/19/01	730	101	0		0.027	7.3	3.0							
6/19/01	740	102	0	100	0.033	10.2	3.8			0.67	2.8	1.2		
6/19/01	740	102	1					2	2				189	1.8
6/19/01	740	102	19										208	
7/24/01	830	102	0	110	0.027	22.3	1.3			1.15	6	5.6		
7/24/01	830	102	1					3	3				200	1.0
7/24/01	830	102	3										200	
7/24/01	845	101	0					3	3					1.5
7/24/01	845	101	0		0.023	15.8	0.9							
8/21/01	850	102	0										200	
8/21/01	850	102	0	110	0.067	43.9	6.3			1.35	8.6	6.6		
8/21/01	850	102	3					3	3				200	1.0
8/21/01	905	101	0					3	3					1.1
8/21/01	905	101	0		0.061	35.6	6.5							
9/12/01	845	102	0	110	0.065	45.0	7.8			1.23	7.6	6.8		
9/12/01	845	102	0					4	3				211	1.0
9/12/01	845	102	5										211	
9/12/01	855	101	0		0.057	29.8	4.6							
Mean				**107.5**	**0.045**	**26.2**	**4.3**	**2.9**	**2.7**	**1.1**	**6.3**	**5.1**	**202.4**	**1.3**
N				**4**	**8**	**8**	**8**	**7**	**7**	**4**	**4**	**4**	**8**	**7**
Std Err				**2.5**	**0.007**	**5.2**	**0.9**	**0.3**	**0.2**	**0.1**	**1.3**	**1.3**	**2.6**	**0.2**

Appendix II. Water Year Precipitation Maps



Water Year Precipitation Departure from Normal October 2000 - September 2001



values are in inches