2006 Lake Assessment of Bowstring Lake (31-0813)

Itasca County, Minnesota

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Lake Assessment Program
Minnesota Pollution Control Agency
Environmental Analysis & Outcomes Division
Kelly O'Hara
Steve Heiskary

Minnesota Pollution Control Agency

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Summary

Bowstring Lake is a 9,220-acre lake in north-central Itasca County within the Bigfork River watershed. Bowstring Lake is approximately 12 miles north of Deer River, MN and is located in the Northern Lakes and Forests Ecoregion. The lake has a maximum depth of 32 ft and 4,736 littoral acres. Four public accesses are located around the lake. Bowstring Lake is connected to Sand Lake through a navigable channel. The total watershed for Bowstring Lake is 201.76 square miles.

A lake water quality model was used to estimate the water quality of the lakes based on morphometry and watershed characteristics. This models provides a means to compare the measured water quality of the lake relative to the predicted water quality. The modeling application Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) predicted a summer-mean total phosphorus concentration of 24µg/L using NLF ecoregion inputs. This is different than the observed total phosphorus concentration of 44 ug/L. These results indicated that the water quality of Bowstring Lake is degraded compared to expected water quality based on MINLEAP (for lakes of similar size, depth, and region of the state).

Recommendations

Bowstring Lake was sampled during the summer of 2006 by Itasca County Soil & Water Conservation District (SWCD) staff. Water quality data collected during the study for Bowstring Lake, reveal summer-mean total phosphorus (TP) concentrations of 44 µg/L; chlorophyll-*a* concentrations of 22.1 µg/L; and Secchi transparency of 13.1 feet (4 m) . Total phosphorus and chlorophyll-*a* totals exceed the typical range for the Northern Lakes and Forests ecoregion. The Secchi transparency value falls within the typical summer average for lakes in this ecoregion. These three values are used to characterize the trophic status of a lake. These measures indicate eutrophic conditions for Bowstring Lake. Based on data from 2006, Bowstring Lake is above the threshold for NLF lakes (35 µg/L TP and 12 µg/L Chl-a). However, further data is required to meet minimum assessment criteria.

The following recommendations are based on the 2006 Lake Assessment Program (LAP) study of Bowstring Lake:
1. A Lake Management Plan should be developed for the improvement and long term protection of Bowstring Lake. This plan should be developed cooperatively by a committee consisting of state agencies (e.g., MPCA, BWSR, and MN DNR), local government, and members of an established lake association. The reference document, Developing a Lake Management Plan, is available on the web at: http://www.shorelandmanagement.org/depth/plan.pdf. The following activities could be included in the plan:

A. Begin participation in the MPCA Citizen Lake Monitoring Program (CLMP). Data from this program provides an excellent basis for assessing the trophic status and monitoring trends. It is recommended that measurements be taken weekly at a consistent site from June through September. Bowstring Lake has never been involved with CLMP.

B. Education of homeowners around the lake regarding septic systems and lawn maintenance may be beneficial. Poorly functioning on-site septic systems could potentially be a source of nutrient loading in Bowstring Lake. Itasca County should educate homeowners on proper maintenance of their systems and encourage all homeowners with non code systems to bring them up to code. Property owners statewide should also be encouraged to reconsider the use of lawn fertilizer or use phosphorus free fertilizers. As of 2005 the state of Minnesota has restricted the use of phosphorus containing fertilizers.

C. Further development in the immediate watershed of the lake should occur in a manner that minimizes water quality impacts on the lake. Exploring additional safeguards in land-use, zoning, and shoreline protection that could be included in a long-term plan to address future development activity within the watershed is recommended. Activities in the total watershed that change drainage patterns, wetland removal or major alterations in lake use for instance, should be discouraged unless they are carefully planned and properly controlled.

D. Limiting the amount of impervious surfaces can also be beneficial in reducing the amount of phosphorus runoff. Stormwater regulations should be followed during and following any construction/development activities within the watershed. Properly designed sedimentation ponds should be included in any development to minimize phosphorus loading into a lake.

E. Maintenance of shoreline vegetation (both upland and aquatic) is very important. Emergent and submergent macrophytes serve to stabilize shorelines and bottom sediments from wind and wave erosion and may also serve as competition to algae for available nutrients. Additionally, macrophytes are beneficial to lakes because they provide cover for fish and substrate for aquatic invertebrates. They also produce oxygen, which assists with overall lake functioning, and provide food for some fish and other wildlife (EPA 2007).

F. 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 advisable to begin with the formation of a local lake association to work with the county and other local interest groups 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, application to CWP may be appropriate.

Lake Assessment Program: 2006

Introduction

The sampling of Bowstring Lake was conducted by the Itasca SWCD during the summer of 2006 as 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 the 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 water quality data by MPCA staff.

Bowstring Lake was sampled four times during the summer of 2006. Noel Griese from the Itasca SWCD was responsible for the sample collection. Watershed information was assembled from information in the Minnesota Department of Natural Resources' (DNR) Data Deli webpage.

Ecoregion Based Lake Water Quality

Table 1 provides the draft ecoregion-based nutrient criteria. These criteria were developed by MPCA in response to an Environmental Protection Agency (EPA) requirement that states develop nutrient criteria for lakes, rivers, wetlands and estuaries. Our approach to developing these criteria are consistent with our previous phosphorus criteria (Heiskary and Wilson, 1989) that have been used extensively for goal setting and evaluating the condition of Minnesota's lakes for our 305(b) report to Congress and have provided a basis for evaluating lakes for the 303(d) "impaired waters" list. Details on the development of the criteria may be found in Heiskary and Wilson (2005). In general, lakes that are at or below the criteria levels will have adequately high transparency and sufficiently low amounts of algae to support swimming 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 and may lead to the lake being included on the 303(d) list that is submitted to EPA biennially.

Table 2 represents the typical summer-mean water quality for lakes in each ecoregion. This data is derived from extensive sampling (1985-1988) of several reference lakes in each of the ecoregions. These "reference" lakes are not necessarily the most pristine lakes in each ecoregion; rather these lakes are "representative" of the ecoregion and are minimally impacted by humans. As is evident, the relative impact by human activities does vary among ecoregions. Further details may be found in Heiskary and Wilson (2005). These data provide an objective basis for comparing data from other lakes and, in the case of this study; data from the NLF ecoregion will be used as a basis for comparing the water quality of Bowstring Lake.

Table 3 represents the percentile distribution of summer-mean in-lake TP concentrations for each ecoregion based on the mixing (temperature stratification) status of the lake as follows:

Dimictic	Deep lake, fully mixes in spring and fall but remains stratified in summer.
Polymictic	Shallow lake, remains well mixed from spring through fall.
Intermittent	Lake with moderate depths, may stratify temporarily during summer, but may mix with strong wind action.

Sorting TP concentrations within each mixing type creates this distribution (by ecoregion) from low to high. These percentiles can provide an additional basis for comparing observed summer-mean TP and may further serve as a guide for deriving an appropriate TP goal for the lake.

Table 1. Proposed eutrophication criteria by ecoregion and lake type

(Heiskary and Wilson, 2005)

Ecoregion	**TP**	**Chl-a**	**Secchi**
	ppb	**ppb**	**meters**
NLF – Lake trout (Class 2A)	**< 12**	**< 3**	**> 4.8**
NLF – Stream trout (Class 2A)	**< 20**	**< 6**	**> 2.5**
NLF – Aquatic Rec. Use (Class 2B)	**< 30**	**< 9**	**> 2.0**
NCHF – Stream trout (Class 2a)	**< 20**	**< 6**	**> 2.5**
NCHF – Aquatic Rec. Use (Class 2b)	**< 40**	**< 14**	**> 1.4**
NCHF – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 60**	**< 20**	**> 1.0**
WCP & NGP – Aquatic Rec. Use (Class 2B)	**< 65**	**< 22**	**> 0.9**
WCP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 90**	**< 30**	**> 0.7**

Table 2. Reference Lake Data Base Water Quality Summary

(Summer Average Water Quality Characteristics for Lakes by Ecoregion)*

Parameter	NLF	NCHF	WCP	NGP
# of lakes	**32**	**43**	**16**	**13**
Total Phosphorus (ug/l)	**14 - 27**	**23 - 50**	**65 - 150**	**122 - 160**
Chlorophyll mean (ug/l)	**4 - 10**	**5 - 22**	**30 - 80**	**36 - 61**
Chlorophyll maximum (ug/l)	**< 15**	**7 - 37**	**60 - 140**	**66 - 88**
Secchi Disk (feet) **(meters)**	**8 - 15** **(2.4 - 4.6)**	**4.9 - 10.5** **(1.5 - 3.2)**	**1.6 - 3.3** **(0.5 - 1.0)**	**1.3 – 2..6** **(0.4 – 0.8)**
Total Kjeldahl Nitrogen (mg/l)	**0.4 – 0.75**	**< 0.60 - 1.2**	**1.3 - 2.7**	**1.8 - 2.3**
Nitrite + Nitrate-N (mg/l)	**<0.01**	**<0.01**	**0.01 - 0.02**	**0.01 - 0.1**
Alkalinity (mg/l)	**40 – 140**	**75 - 150**	**125 - 165**	**160 - 260**
Color (Pt-Co Units)	**10 – 35**	**10 - 20**	**15 - 25**	**20 - 30**
pH (SU)	**7.2 - 8.3**	**8.6 - 8.8**	**8.2 - 9.0**	**8.3 - 8.6**
Chloride (mg/l)	**0.6 – 1.2**	**4 - 10**	**13 - 22**	**11 - 18**
Total Suspended Solids (mg/l)	**< 1 – 2**	**2 - 6**	**7 - 18**	**10 - 30**
Total Suspended Inorganic Solids (mg/l)	**< 1 – 2**	**1 - 2**	**3 - 9**	**5 - 15**
Turbidity (NTU)	**< 2**	**1 - 2**	**3 - 8**	**6 - 17**
Conductivity (umhos/cm)	**50 – 250**	**300 - 400**	**300 - 650**	**640 - 900**
TN:TP ratio	**25:1 - 35:1**	**25:1 - 35:1**	**17:1 - 27:1**	**13:1 - 17:1**

*Based on Interquartile range (25th - 75th percentile) for ecoregion reference lakes.

Derived in part from Heiskary, S. A. and C. B. Wilson (1990).

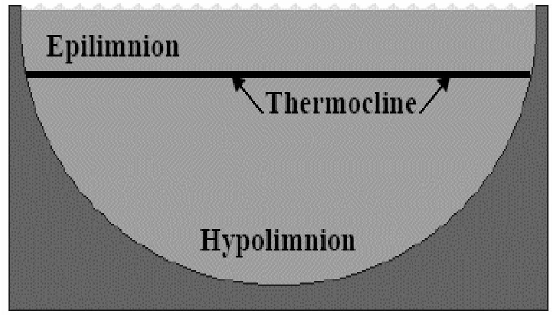
Table 3. Distribution of Total Phosphorus (μg/L) Concentrations by Mixing Status and Ecoregion. Based on all assessed lakes for each ecoregion.

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

Epilimnetic Water Quality

Stratification



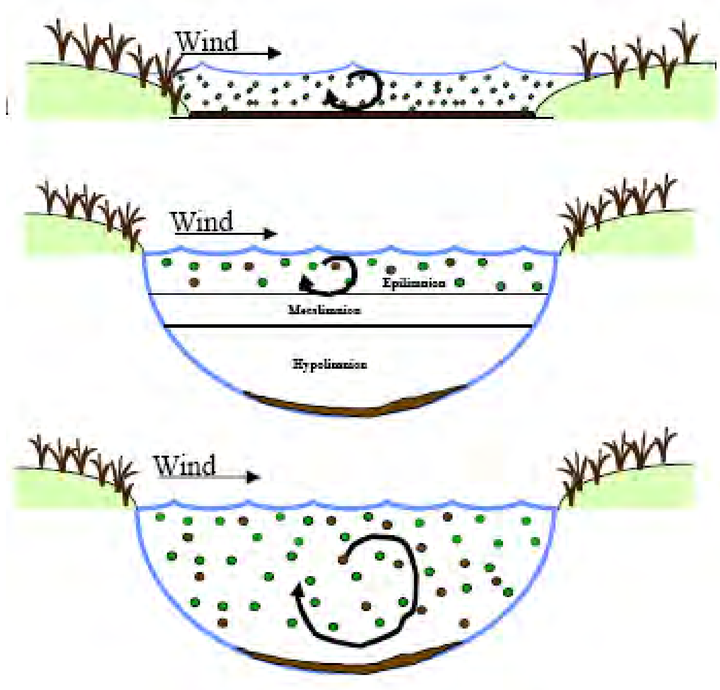
The depth of a lake can have a major influence on the water quality and lake processes. One such process is *thermal stratification* (formation of distinct temperature layers, see Figure 1), in which deep lakes (maximum depths of 30 - 40 feet or more) often stratify (form layers) during the summer months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

Figure 1. Thermal Stratification and Lake Mixing

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

Dimictic Lake
Deep, Form Layers,
Mixes Few Times
Summer

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



Background

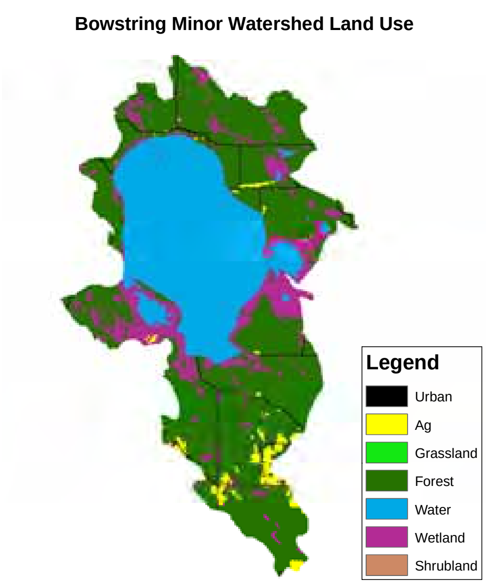
Bowstring Lake is located in Itasca County, approximately twelve miles north of Deer River, Minnesota. Bowstring Lake has a surface area of 9220 acres with a maximum depth of 32 feet and a mean depth of 15 feet (4.6 meters). Bowstring Lake is classified as a polymictic lake with a large fetch and wave mixing due to winds. The watershed lies to the north and east of the lake and water from the lake drains to the east from the Bowstring River. Bowstring Lake lies in the Big Fork Watershed (highlighted in yellow) and has a total area of 202 square miles. The watershed to lake area is 14:1.

Immediate watershed refers to that portion of the watershed that drains directly to the lake without flowing first through other lakes; while total watershed refers to the entire watershed upstream of the lake. Differentiating between immediate and total is important as lake nutrient and water budgets are determined based on the estimated total watershed; whereas best management practices and protection efforts are often focused initially on the immediate watershed. Total watershed to lake area ratio also provides an important perspective on the size of the watershed relative to the lake.

Bowstring Lake is classified as a type seven lake basin that was produced by glacial deposition (Zumberge 1952). Soils near the lake consist of Menahga-Marquette series forest soils that are formed from glacial outwash and are coarse to medium textured. These soils are light colored and droughty. The lake occupies an area that is level to rolling (Arneman 1963).

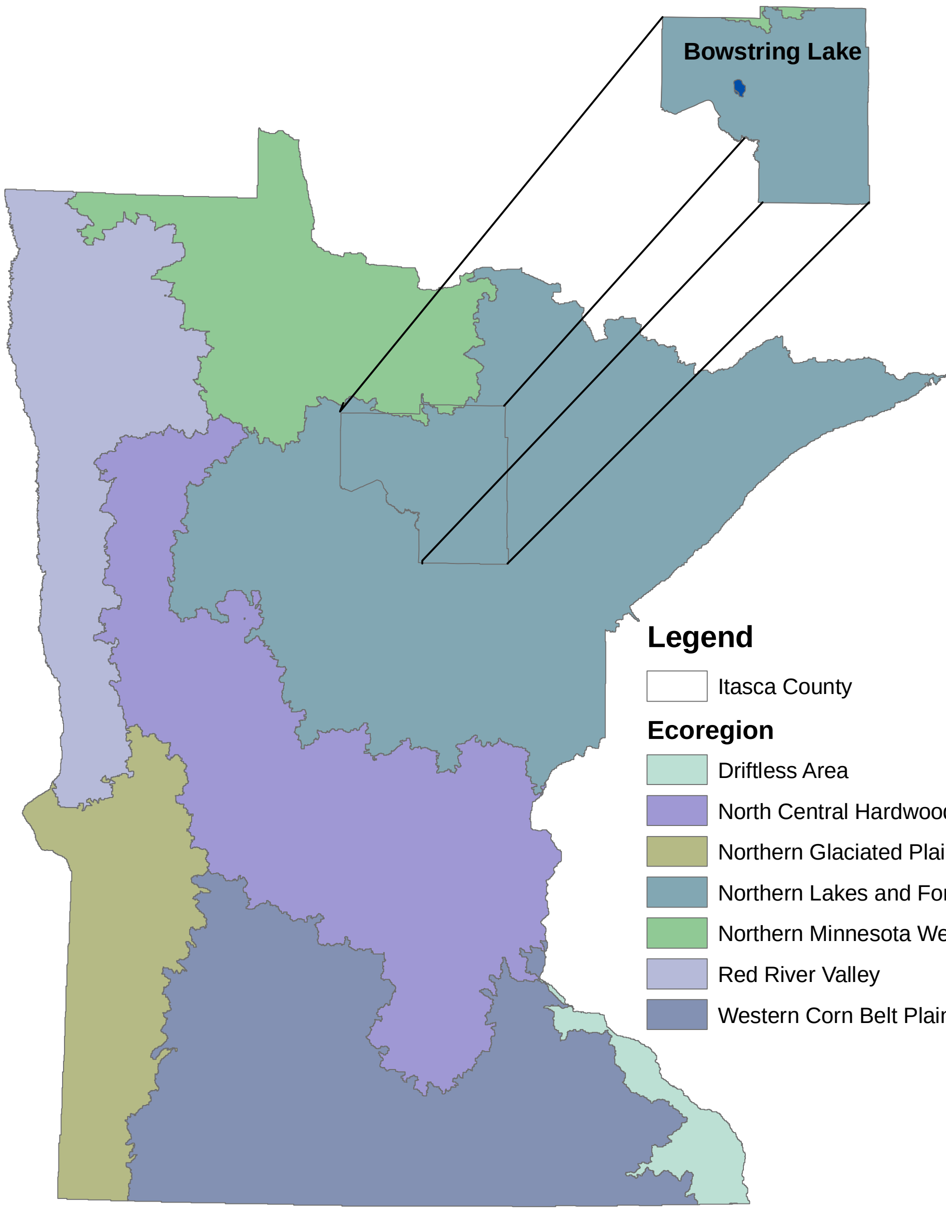
Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Minnesota is divided into seven regions, referred to as ecoregions, as defined by soils, land surface form, natural vegetation, and current land use. Data gathered from representative, minimally-impacted (reference) lakes within each ecoregion serve as a basis for comparing the water quality and characteristics of other lakes. Land use in the watershed of Bowstring Lake is rather typical for this ecoregion, with a dominance of forest followed by water/wetland areas (Figure 2 & Table 4). Bowstring Lake is located in the Northern Lakes and Forests ecoregion (Figure 3).

Figure 2 & Table 4. Bowstring Minor Watershed Land Use and Ecoregion Comparison

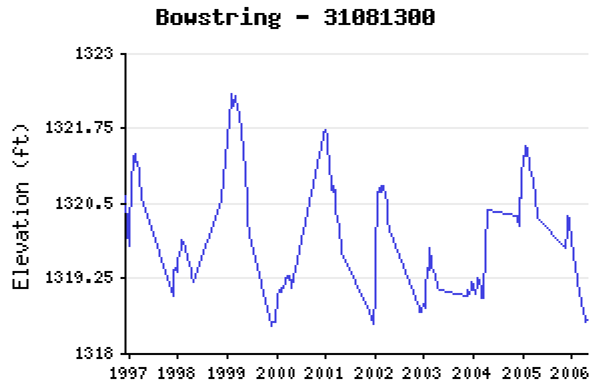


Land Use %	Bowstring	NLF Ecoregion
Urban	1.3	0-7
Cultivated (agriculture)	2.2	<1
Forest	52	54-81
Water & Marsh	44	14-31

Figure 3. Bowstring Lake Location and Minnesota Ecoregions



Lake Level

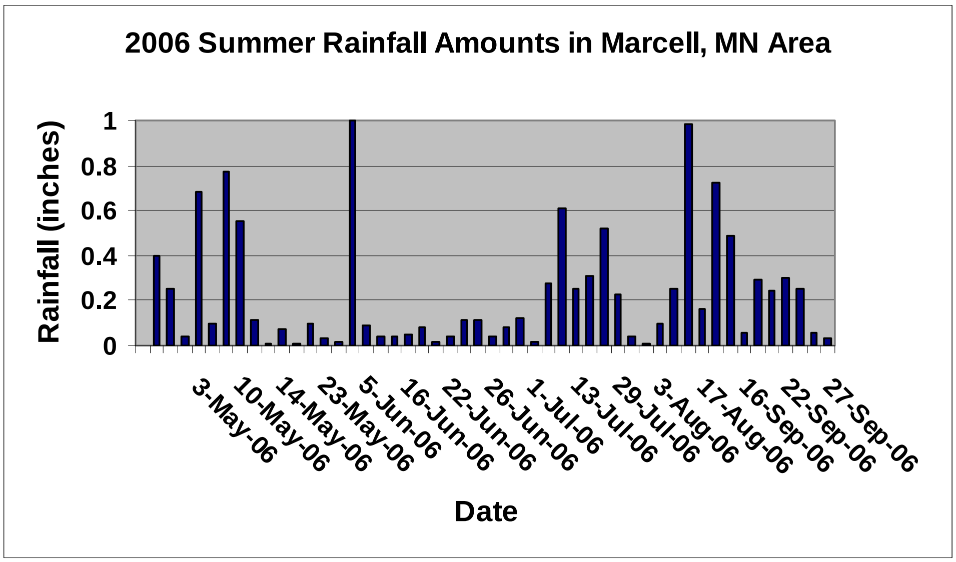


The DNR Division of Waters, with the cooperation of volunteer readers, monitored water levels in Bowstring Lake in 2006. During the period of record (1970 – 2006) the lake has varied by 4.4 feet, based on 575 readings. The highest and lowest recorded elevations are 1322.33 feet on 7/25/1999 and 1317.93 feet on 7/19/1988, respectively. The OHW (ordinary high water mark) for Bowstring Lake is 1320.5 feet.

Precipitation

The summer of 2006 was marked by low precipitation for Minnesota. From May to September 2006, 11.16 inches were recorded near Marcell, MN (Figure 4). Rainfall amounts of one inch occurred only once on June 5th, 2006. Normal rainfall averages 24 to 26 inches annually. For the 2006 water year (October 1, 2005 to September 30, 2006), precipitation was found to be two inches below normal. The normal and deviation from normal maps can be found in Appendix E.

Figure 4. 2006 Summer Rainfall Amounts in Marcell, MN Area



Fisheries

DNR fisheries managers utilize net survey information to assess the well-being of fish communities and measure the efficacy of management programs. Presence, absence, abundance, physical condition of captured fishes, and community relationships among fish species within survey catch information also provide good indicators of current habitat conditions and trophic state of a lake (Schupp and Wilson, 1993). This data is stored in a long-term fisheries survey database, which has proven valuable in qualifying and quantifying changes in environmental and fisheries characteristics over time. The fishery of Bowstring is managed by the Minnesota Department of Natural Resources Fisheries Office located in Grand Rapids, Minnesota. The most recent version of the Status of the Fishery is summarized below.

Status of the Fishery (as of 08/05/2002)

Bowstring Lake is described as a lake with excellent natural reproduction of several popular varieties of game fish. Gill net and electro fishing sampling have revealed population numbers that were at or above the expected values. This includes walleye, northern pike, black crappie, and yellow perch. Walleye length was good with several fish between 16 and 19 inches, however there were few fish greater than 20 inches. The fish abundance for northern pike was as expected but the size structure was listed as poor however this is a historical trend. Bowstring Lake has a navigable channel that connects it to Sand Lake to the northwest. There are four public access locations around the lake. There is some residential development on the northern and eastern shoreline but a majority of the lake is undeveloped.

Results and Discussion

Water quality data was collected in June, July, and August 2006 from Site 101. Lake surface samples were collected with an integrated sampler, 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 also taken at site 101 with an integrated sampler. Seasonal averages were calculated using June through August data.

Sampling procedures were employed as described in the MPCA Quality Control Manual. Laboratory analyses were performed by the Minnesota Department of Health (MDH) Laboratory using EPA approved methods. Samples were analyzed for total phosphorus and chlorophyll-*a* (Table 5). Temperature and dissolved oxygen profiles were taken with a meter and Secchi disk transparency measurements were also taken at the site.

Some historical data for Bowstring Lake 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 Citizen's Guide to Lake Protection.

Table 5. Lake Summer Mean Water Quality

Parameter	Bowstring 101	Typical Range for NLF Ecoregion
Total Phosphorus (µg/L)	**44**	**14 – 27**
Chlorophyll-a (µg/L) mean	**22.1**	**4 - 10**
Chlorophyll-a (µg/L) max	**57.7**	**<15**
Secchi disk (feet)	**9.8**	**8 - 15**
Secchi disk (m)	**3**	**2.4 - 4.6**
Conductivity (µmhos/cm)	**171**	**50 – 250**

In Lake Conditions

Dissolved oxygen and temperature profiles were taken at one meter intervals at site 101 on each date. Dissolved oxygen at the surface ranged from a low of 7.4 mg/L in June to a high of 11.8 mg/L in August (Figure 5). Game fish require a minimum dissolved oxygen concentration of 5 mg/L to survive and typically would not be found below this depth. Dissolved oxygen dipped below this threshold at approximately 8 meters throughout most of the summer. Temperatures ranged from a low of 20.2 ^{0}C in June to a peak of 26.4 ^{0}C in July (Figure 6). These profiles indicate the lake is well mixed.

Figure 5. 2006 Bowstring Lake Dissolved Oxygen Profile

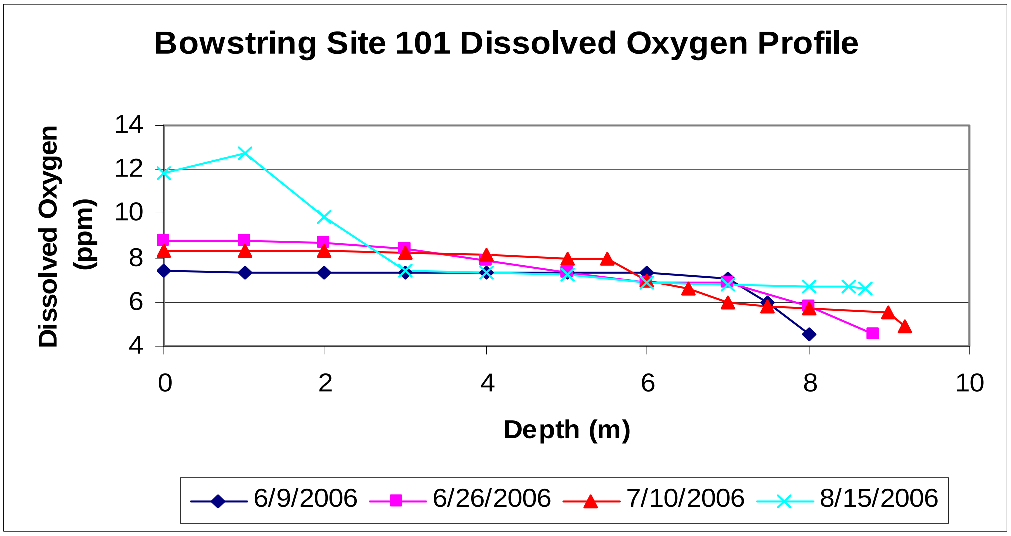
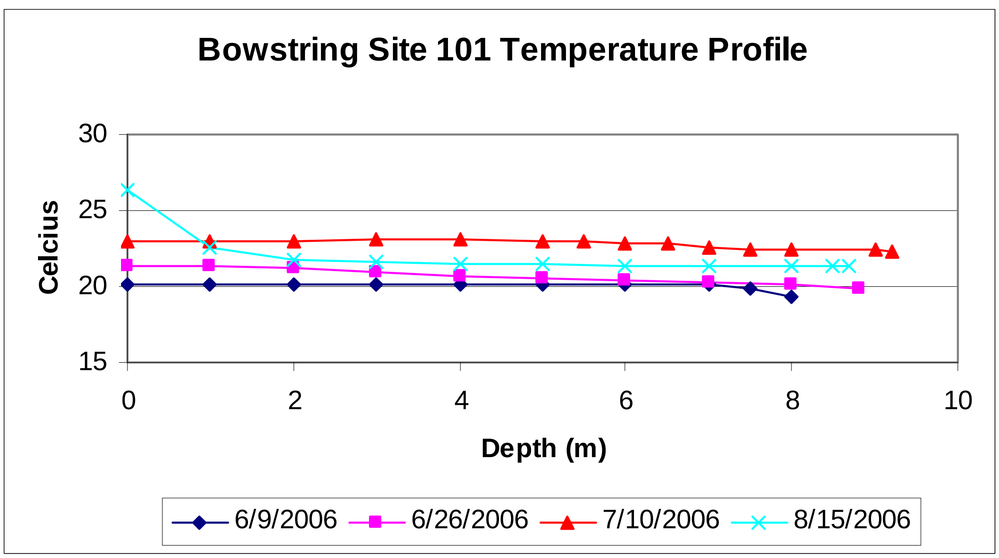


Figure 6. 2006 Bowstring Lake Temperature Profile



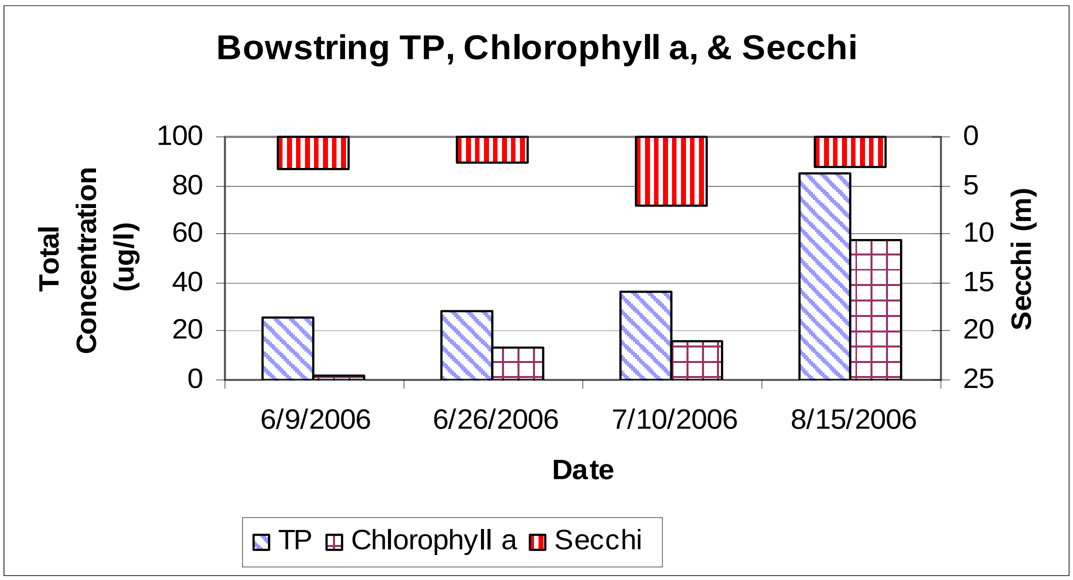
Total phosphorus (TP) concentrations (an important nutrient for plant growth) for 2006 averaged 44 µg/L, micrograms per liter or parts per billion, (Figure 7). This mean is 17 ug/L above the typical range of concentrations for reference lakes found in the NLF ecoregion (Table 2). TP concentrations increased over the summer, reaching peak concentrations in August. Bowstring Lake concentrations range from a low of 26 µg/L in May to a high of 85 µg/L in August.

The seasonal TP values for Bowstring Lake are considerably higher than other lakes in Itasca County. As summer progresses, there tends to be a marked increase in total phosphorus and chlorophyll-*a*. This pattern of increasing TP from June through August is consistent with other shallow lakes in Minnesota.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During the summer of 2006, chlorophyll-*a* concentrations on Bowstring Lake ranged from 1.5 µg/L to 57.7 µg/L with an average of 22.1 µg/l (Figure 6). Concentrations greater than 20 µg/L may be perceived as a nuisance while concentrations greater than 30 µg/L may be perceived as a severe nuisance algal bloom (Heiskary and Walker, 1988). Based on data collected in 2006 a severe nuisance bloom wouldn't have been observed until levels spiked in August. The average and maximum chlorophyll-*a* concentrations for Bowstring Lake were well above the range of values compared to NLF reference lakes (Table 2).

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. For Bowstring Lake, the Secchi disk transparency ranged from a low of 2.7 feet (0.82 meters) in June to a high of 7 feet (2.13 meters) in July, with an average 4 feet (1.22 meters) (Figure 7). The observed decline in transparency from June to August is consistent with the increase in algae over that period. These transparency measures are below (worse than) the ecoregion range of NLF reference lakes (Table 2).

Figure 7. 2006 Concentrations and Transparency on Bowstring Lake.



Along with the transparency measurements, subjective measures of Bowstring Lake's "physical condition" and "suitability for recreation" were made. Physical appearance ratings range from "crystal clear" (Class 1) to "severe bloom (odorous scum)" (Class 5) and recreational suitability ratings range from "beautiful" (Class 1) to "no aesthetics possible" (Class 5) in this rating system (Heiskary and Wilson, 1988). Based on 2006 data on Bowstring Lake, lake conditions were characterized as "definite algae present" (Class 3) and "minor aesthetic problems" (Class 2). It should be noted that these ratings were recorded only during the month of June.

The transparency of Bowstring Lake was less than the expected value for lakes in the NLF ecoregion. However, the change in the transparency over the course of the summer was typical of many 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. 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 and further limit transparency.

Algae

Algal composition on Bowstring Lake was dominated by blue-green algae for most of the summer (Figure 8). The June sample was predominantly blue-green with some yellow-browns and diatoms present. A transition from diatoms to blue-green is common in Minnesota lakes. The blue-green algae were dominant in August and would have accounted for a vast majority of the measured chlorophyll-*a* (Figure 9).

Figure 8. 2006 Bowstring Lake Algal Composition

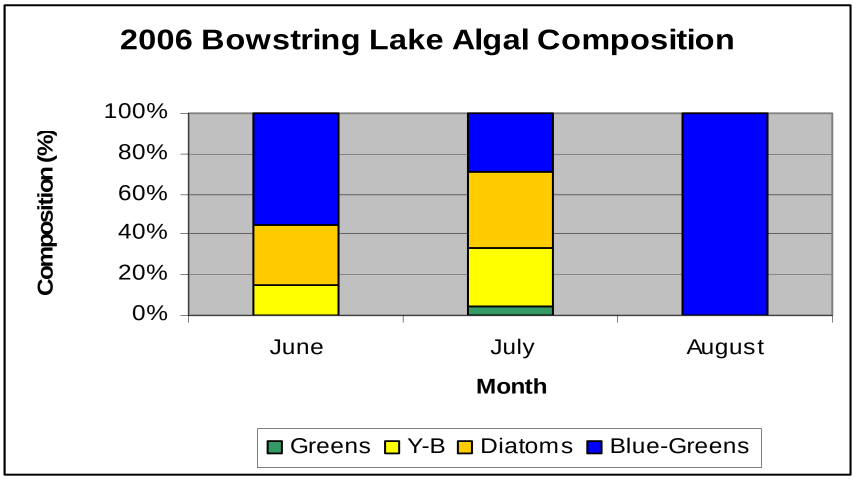
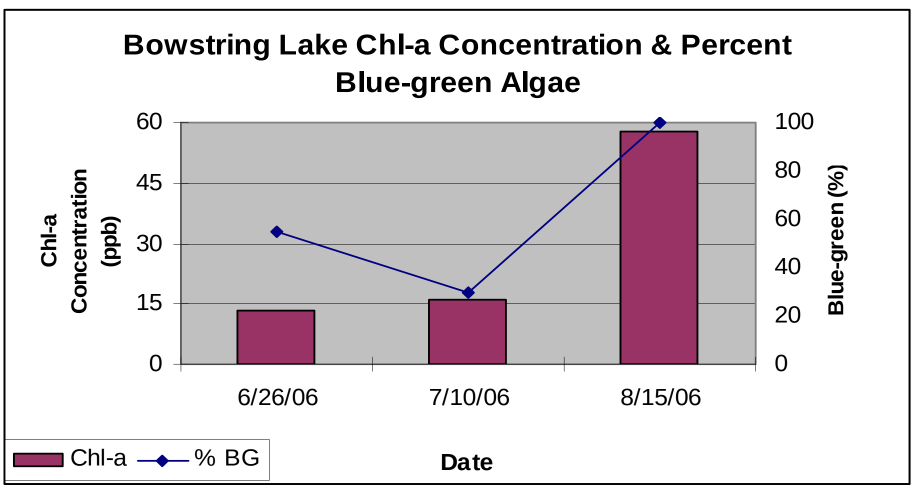


Figure 9. Bowstring Lake Chlorophyll-a Concentration and Percent Blue-green Algae



Trophic Status

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). The 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:

$$\text{Total Phosphorus TSI (TSIP)} = 14.42 \ln(\text{TP}) + 4.15$$

$$\text{Chlorophyll-}a\text{ TSI (TSIC)} = 9.81 \ln(\text{Chl-}a) + 30.6$$

$$\text{Secchi disk TSI (TSIS)} = 60 - 14.41 \ln(\text{SD})$$

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 mass.

Average values for the trophic variables in Bowstring Lake TSIs are presented in Figure 10. Based on these values and an average TSI score of 53 for Bowstring Lake, the lake would be characterized as *eutrophic*. The individual TSI values for TP, chlorophyll-*a*, and Secchi transparency agree very well with one another for each lake. As such, Secchi transparency should provide a good estimation of trophic status.

FIGURE 10. Carlson's Trophic State Index for Bowstring Lake
R.E. Carlson

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

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

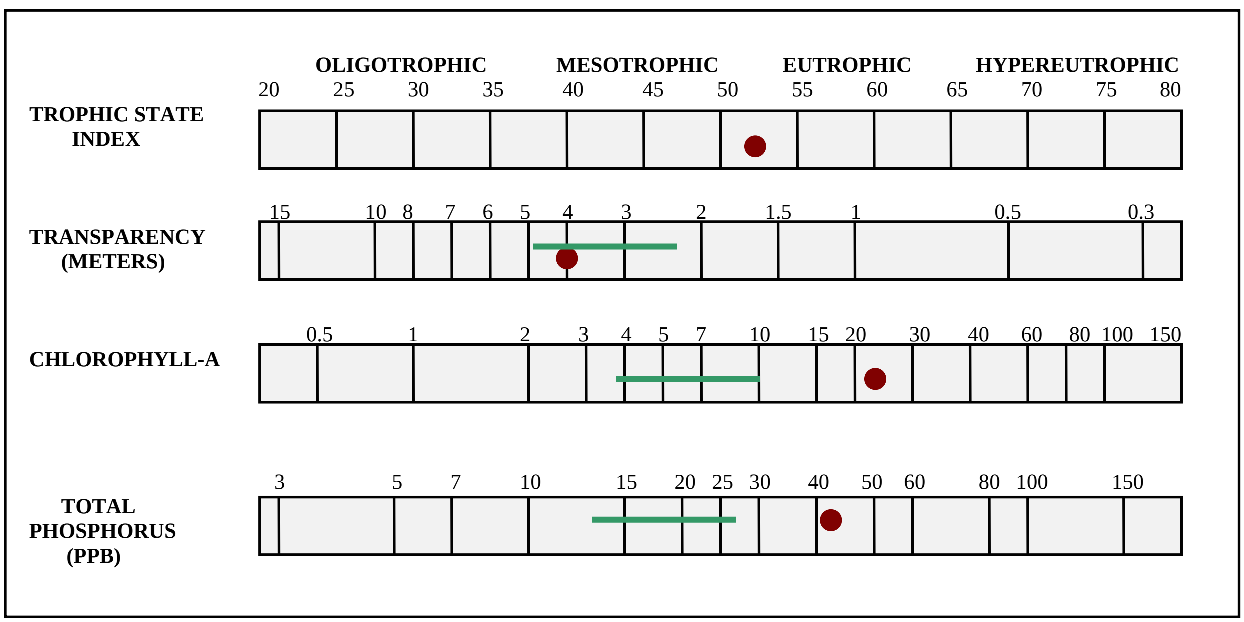
TSI 40 – 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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

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

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

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



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NLF Ecoregion Range: —— Bowstring: ●

Water Quality Trends

A statistical analysis of trends often requires eight or more years of data. Unless noted otherwise, most graphs will depict summer-mean measurements plus or minus the standard error (SE) of the mean. A large SE implies either high variability among seasonal measures and/or very few measures were taken. When comparing mean measures among years, the SE provides somewhat of a “confidence interval” for the mean; if the mean plus or minus the SE overlaps with another mean then it is likely the two means (measurements) are not significantly different.

In this instance four years of data was available for comparison. Individual summer-mean data for each year may be found in Appendix D. The data was collected by the MPCA and Itasca County Soil and Water Conservation District (SWCD). Secchi transparency data date back to 1981. Based on four years of data, the long-term mean (June through September data) Secchi is 9.6 feet (2.9 meters) (Figure 11). It should be noted that there are significant gaps between lake monitoring activities. No significant change in Secchi transparency over time was noted based on the data. The transparency typically remained within one to two meters from the mean depth

Four years of total phosphorus and chlorophyll-*a* data are available from 1981 to 2006. The long-term average concentration is 35 µg/L for total phosphorus and 18.7 µg/L for chlorophyll-*a*, based on data from sites 101 and 20501 over the period of record (Figures 11 and 12). These are above (worse than) the expected range for reference lakes in the NLF ecoregion (Table 5). No trend is evident with this data.

Figure 11. Bowstring Lake Secchi Transparency Trends

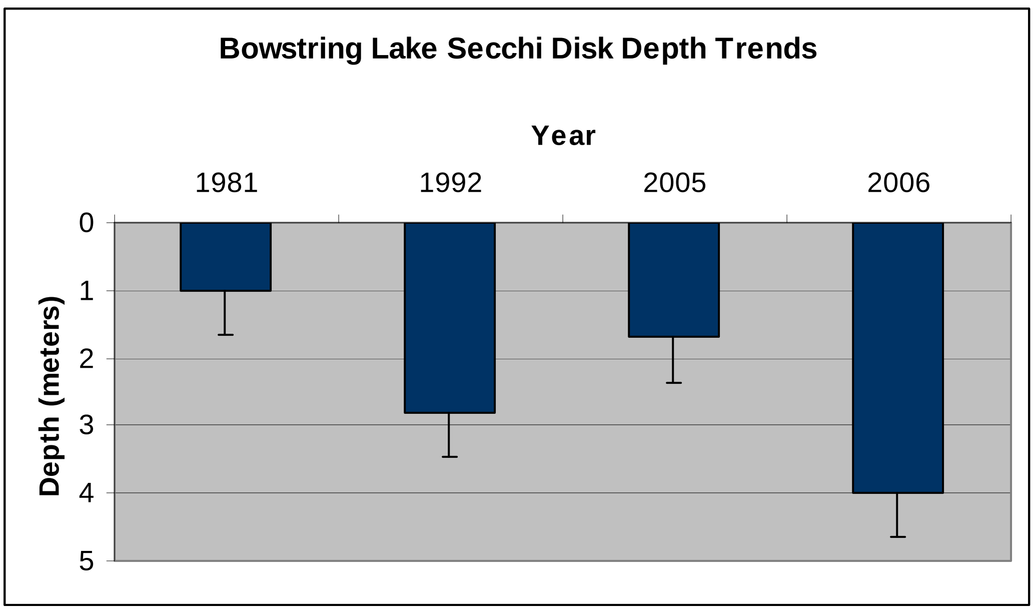
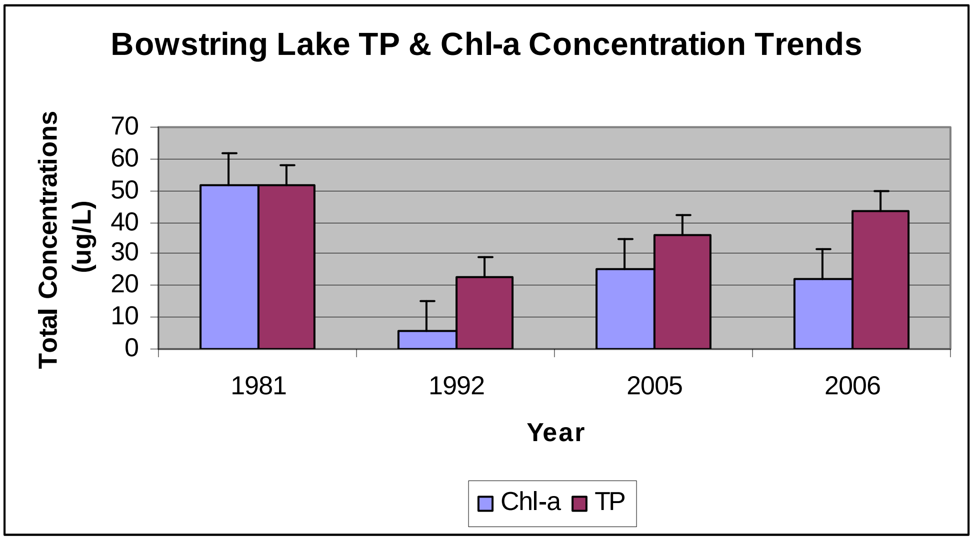


Figure 12. Bowstring Lake Total Phosphorus and Chlorophyll-*A* Trends



Modeling

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 or amount of water that enters the lake. To analyze the 2006 water quality of Bowstring Lake, MINLEAP (Wilson and Walker, 1989) was used.

MINLEAP, which refers to "Minnesota Lake Eutrophication Analysis Procedures," was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989).

MINLEAP uses the total watershed area of the lake (minus lake surface area) combined with ecoregion based typical runoff and stream TP as a basis for predicting P-loading to the lake. The model for Bowstring Lake was run using the specific ecoregion-based inputs for precipitation, runoff, evaporation, and average stream TP. It should be noted that the model predicts in-lake TP from these inputs and subsequently predicts chlorophyll-*a* based on a regression equation with TP, and Secchi based on a regression equation based on chlorophyll-*a*. A comparison of MINLEAP predicted vs. observed values is presented in Table 6.

Table 6. MINLEAP Model Results for Bowstring Lake

Parameter	Bowstring 2006	Bowstring NLF MINLEAP
TP (µg/L)	44	24 ± 7
Chl-a (ug/L	22.1	7 ± 3.9
Secchi (m)	4	2.5
P loading rate (kg/yr)	-	6352
P retention (%)	-	57
P inflow conc. (µg/L)	-	55
Water Load (m/yr)	-	3.12
Outflow volume (hm^3/yr)	-	116.26
Residence time (yrs)	-	1.6

Observed TP is higher than predicted for a lake of this size (depth & area) in th Northern Lakes and Forests ecoregion based on MINLEAP. As a result Chl-a is much higher as well. Though minimal data is used in this model it often provides a useful (and reasonably accurate) estimate of the anticipated TP, Chl-a, and Secchi readings for lakes.

Goal Setting

The phosphorus criteria values for shallow lakes in the Northern Lakes and Forests ecoregion is less than 30 µg/l for support of aquatic recreation use. At or below 30 µg/l, "nuisance algal blooms" (chlorophyll-*a* > 20 µg/l) should occur less than 5 percent of the summer and transparency should remain at or above 2 meters (6.6 feet) over 85 percent of the summer.

For Bowstring Lake, it would be desirable to reduce in-lake TP concentrations below levels observed in 2006. Based on Figure 11 this level (<30 µg/l) is a reasonable goal for this lake. Attaining a summer-mean P concentration of 30 µg/l or lower over the long term will ultimately require that P loading to the lake be reduced. Important considerations include implementation of BMPs in the shore land area and ultimately throughout the watershed. 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. This work could begin in the immediate watershed and expand upstream to the entire watershed. Proper maintenance of buffer areas between lawns and the lake shore, minimizing use of fertilizers, and minimizing the introduction of new significant sources of P loading, e.g., stormwater from near shore development activities in the watershed will serve to minimize loading to the lake. These and other considerations will be important if improvements to the water quality of Bowstring Lake are to be realized.

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Appendix A Glossary

Acid Rain: Rain with a higher than normal acid range (low pH). Caused when polluted air mixes with cloud moisture; can cause lakes to be devoid of fish.

Algal Bloom: An unusual or excessive abundance of algae.

Alkalinity: Capacity of a lake to neutralize acid.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Meromictic: A lake that does not mix completely

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

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

pH Scale: A measure of acidity.

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

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

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

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

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

Respiration: Oxygen consumption

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

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

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

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

Watershed storage area The percentage of a drainage area labeled lacustrine (lakes) and palustrine (wetlands) on U.S. Fish and Wildlife Service National Wetlands Inventory Data.

Zooplankton: The animal portion of the living particles in water that freely float in open water, eat bacteria, algae, detritus and sometimes other zooplankton and are in turn eaten by planktivorous fish.

Appendix B Water Quality Data: Abbreviations and Units

TP= total phosphorus in mg/l(decimal) or ug/L as whole number
TKN= total Kjeldahl nitrogen in mg/l
TNTP=TN:TP ratio
pH= pH in SU (F=field, or L=lab)
ALK= alkalinity in mg/l (lab)
TSS= total suspended solids in mg/l
TSV= total suspended volatile solids in mg/l
TSIN= total suspended inorganic solids in mg/l
TURB= turbidity in NTU (F=field)
CON= conductivity in umhos/cm (F=field, L=lab)
CL= chloride in mg/l
DO= dissolved oxygen in mg/l
TEMP= temperature in degrees centigrade
SD= Secchi disk in meters (SDF=feet)
Chl-a= chlorophyll-a in ug/l
TSI= Carlson's TSI (P=TP, S=Secchi, C=Chla)
PHEO= pheophytin in ug/l
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

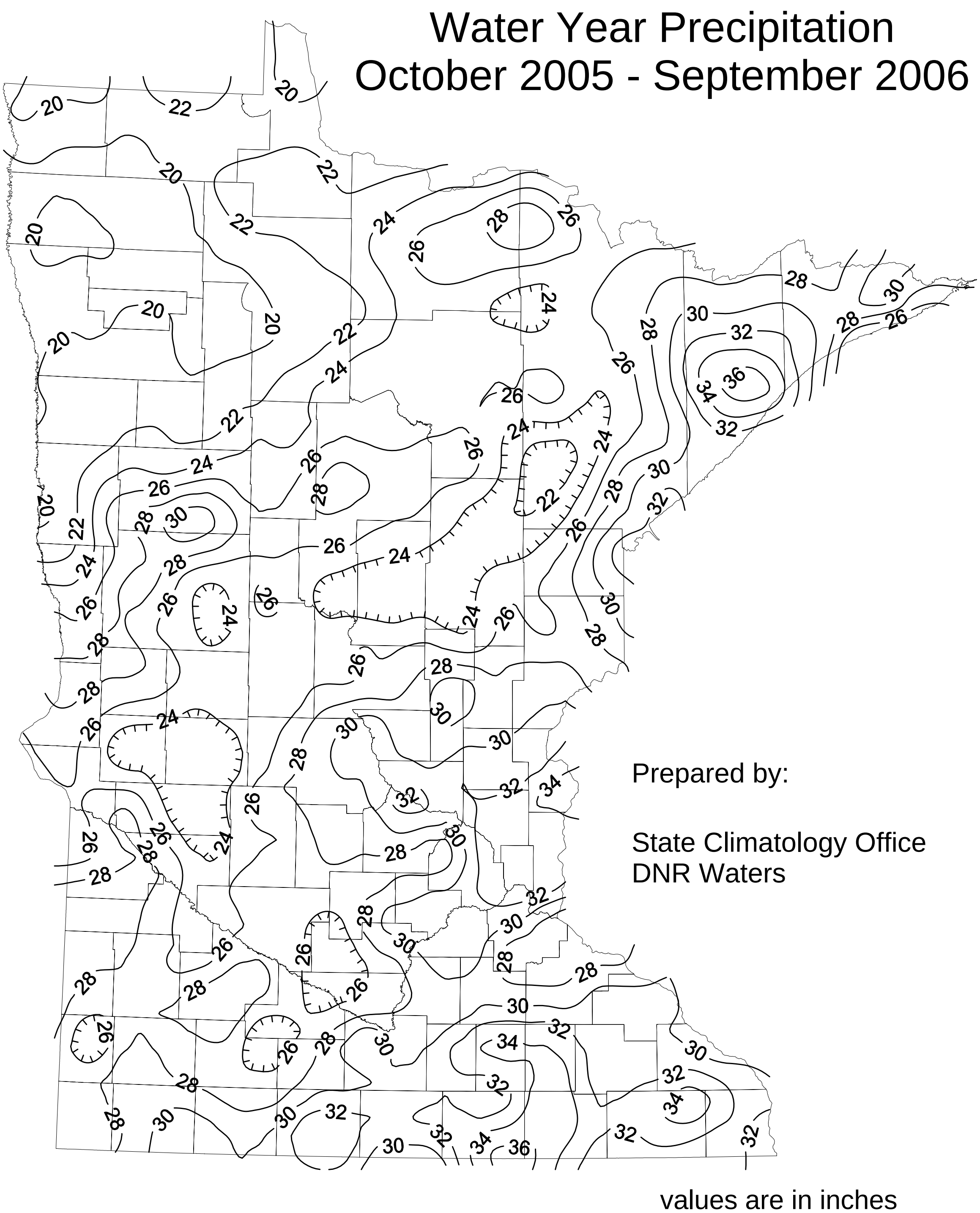
Appendix C Surface Water Results

Lake Name	Lake ID	Date	Location ID	Sample Depth Upper	Sample Depth Lower	Chl-*a* ug/l	Secchi Depth m	Dissolved oxygen (DO) mg/l	pH None	Pheophytin-a ug/l	TP ug/l	Water Temp deg C
Bowstring Lake	31-0813	6/9/2006	101	0	8.0	1.5	3.3	7.4		1.7	26	20.2
		6/26/2006	101	0	8.8	13.4	2.7	8.8		2.8	28	21.3
		7/10/2006	101	0	9.2	15.9	7.0	8.3	9.89	5.0	36	22.9
		8/15/2006	101	0	8.7	57.7	3.0	11.8	6.32	2.7	85	26.4

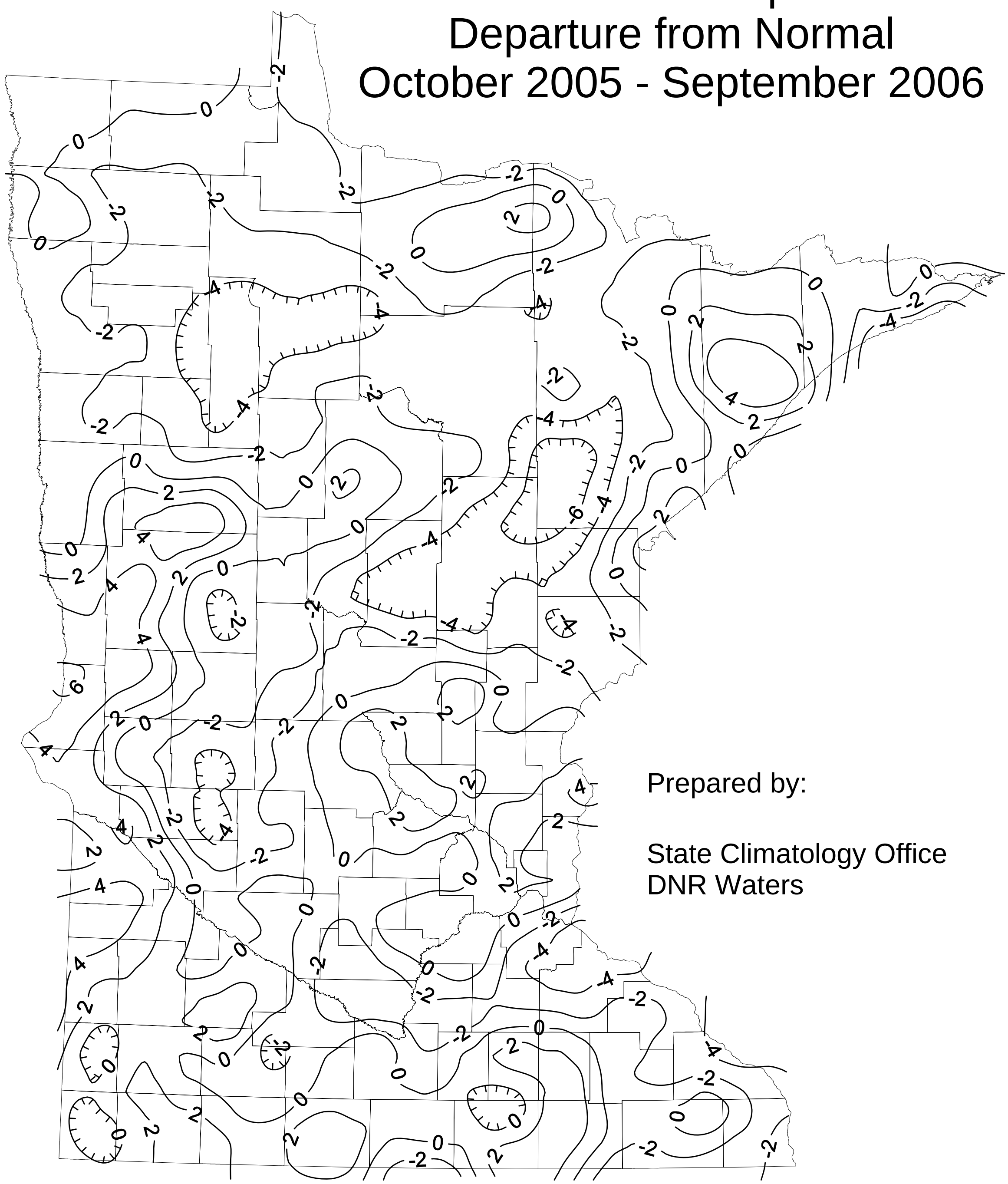
Long-Term Secchi, TP, and Chl-a for Bowstring Lake (31-0813)

Date	Site ID	Chl-a ug/l	Secchi Disk Depth meters	TP ug/l
8/20/1981	101	52.0	1.0	52
6/10/1992	20501	1.6	4.6	9
7/20/1992	20501	5.4	2.0	18
8/25/1992	20501	6.8	2.8	26
9/29/1992	20501	7.9	1.7	39
8/1/2005	101	25.0	1.7	36
6/9/2006	101	1.5	3.3	26
6/26/2006	101	13.4	2.7	28
7/10/2006	101	15.9	7.0	36
8/15/2006	101	57.7	3.0	85

Appendix D   Normal and Departure from Normal Rainfall Maps



Water Year Precipitation Departure from Normal October 2005 - September 2006



Prepared by:

State Climatology Office
DNR Waters

values are in inches