LAKE ASSESSMENT PROGRAM: 2006

East Twin Lake (18-0407)
&
West Twin Lake (18-0409)

Crow Wing County, Minnesota

Environmental Analysis and Outcomes Division
Water Monitoring Section
March 2007

Minnesota Pollution Control Agency

wq-lar18-0407

Lake Assessment Program

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Pam Anderson
Steve Heiskary

March 2007

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SUMMARY AND RECOMMENDATIONS

East and West Twin Lakes are located in Crow Wing County, approximately 3 miles south of Pequot Lakes, Minnesota. East Twin Lake has a surface area of 146 acres with a maximum depth of 45 feet and an estimated mean depth of 15.9 feet. West Twin Lake covers 117 acres with a maximum depth of 42 feet and an estimated mean depth of 13.3 feet. The total watershed (including lake area) for East Twin Lake is 0.79 square miles (509 acres) and for West Twin Lake, 0.47 square miles (300 acres). Land use in the watersheds is predominantly forested, with some wetland and urban land uses. The general land use composition is representative of lakes in the *Northern Lakes and Forests* ecoregion.

East and West Twin Lakes were sampled during the summer of 2006 by Minnesota Pollution Control Agency (MPCA) staff. Water quality data collected during the study for East and West Twin Lakes, respectively, reveal summer-mean total phosphorus (TP) concentrations of 11 µg/L and 9 µg/L; chlorophyll-*a* concentrations of 2.7 µg/L and 2.6 µg/L; and Secchi transparency of 10.7 feet (3.3 m) and 11.9 feet (3.6 m). All of these measures are within or better than the range of values exhibited by reference lakes in the NLF ecoregion. Total phosphorus, chlorophyll-*a*, and Secchi transparency values help to characterize the trophic status of a lake. These measures indicate mesotrophic conditions for East and West Twin Lakes. Both lakes are well below (better than) the threshold (NLF 30 µg/L) for placement on the "impaired waters" 303(d) list.

Very limited water quality data is available for assessing trends on East and West Twin Lakes. East Twin Lake has a limited CLMP Secchi record, joining the program in 2005. On West Twin Lake, Secchi data has been collected as part of the CLMP for seven years, which is just shy of the eight years typically required for trend assessment. However, based on these seven years, no strong trend is evident – with Secchi at about 5 m (16-17 feet) in most summers. Satellite imagery from 1985 to 2005, on 5 year intervals, indicates both lakes have high transparency and no trend is evident.

Two lake water quality models were used to estimate the water quality of the lakes based on morphometry and watershed characteristics. These models provide a means to compare the measured water quality of the lake relative to the predicted water quality. The first model, MINLEAP, predicted a summer-mean total phosphorus concentration of 16 ± 6 µg/L for East Twin and 15 ± 6 µg/L for West Twin Lake. These are both higher, but not significantly different than the observed total phosphorus concentration of 11 ug/L and 9 µg/L, respectively. These results indicated that the water quality of East and West Twin Lakes is better than expected water quality based on MINLEAP (for lakes of similar size, depth, and region of the state). The second model, which is built into the MINLEAP application, is the Vighi and Chiaudani model, provides an estimate of background total phosphorus levels. For East Twin Lake, the model predicted a background total phosphorus concentration of 18.6 µg/L, and 20.1 µg/L for West Twin Lake. Summer averages on both lakes were well below this predicted background concentration.

Following are a few general observations and recommendations based on analysis of data collected in 2006:

1. Increases in the nutrient loading rates from any watershed or in-lake sources which would increase the in-lake total phosphorus concentration could degrade the lakes in this study. It is essential, therefore, that lake protection efforts be conveyed to all local government groups with land use/zoning authorities for Crow Wing County.

If not developed previously, the lakes involved with this study could benefit from the development of a plan for protecting the water quality of the lake. This plan, referred to as a lake management plan, should incorporate a series of activities in a prioritized fashion which will aid in the long-term protection and improvement of the lake. The plan should be developed cooperatively by a committee consisting of representatives from state agencies (e.g. Department of Natural Resources (DNR), Board of Water and Soil Resources (BWSR), and MPCA), local units of government, and if applicable to each specific lake, lake association members. The reference document, Developing a Lake Management Plan, is available on the web at: http://www.shorelandmanagement.org/depth/plan.pdf. The following activities could be included in the plan:

A. Secchi transparency monitoring: Monitoring Secchi transparency provides a good basis for estimating trophic status and detecting trends. Routine participation is essential to allow for trend analysis; Secchi measurements should be taken weekly at consistent sites from June to September. While West Twin Lake has a seven year Secchi record since 1987, East Twin Lake recently joined the CLMP in 2005. Participation in CLMP will contribute to the historical database and allow for future trend assessments.

B. Education of homeowners around the lake regarding septic systems, lawn maintenance, and shoreline protection may be beneficial. Because the lakes have small watersheds, these sources could be potentially significant. Staff from the MPCA and DNR, along with county officials, such as staff from the University of Minnesota Extension Service, the Crow Wing County Soil and Water Conservation District (SWCD), and the Crow Wing County Planning and Zoning Office could provide assistance in these areas.

C. Further development in the immediate watershed of the lake should occur in a manner that minimizes water quality impacts on the lake. Consideration to setback provisions, lot size, and septic systems, and urban storm water best management practices, such as rain gardens, will be important in providing water quality protection, particularly as the amount of impermeable surfaces (roofs, driveways, etc) increase due to new construction and development. The DNR and county shoreland regulations will be important in these regards and should be strictly enforced. In writing a plan, 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.

D. Maintenance of shoreline vegetation (both upland and aquatic) is very important. Macrophytes serve to stabilize shorelines and bottom sediments from wind and wave erosion and may also serve as competition to algae for available nutrients. Soil erosion from the construction of roads and homes should be minimized. The disturbance or removal of vegetation on bluffs or slopes should be avoided.

E. Representation on boards or commissions that address land management activities would be beneficial, so that the impacts of these activities can be minimized. Safeguarding the shoreland ordinance from those who would choose to weaken it should be a priority for all the lakes in this study, as well as other lakes in Crow Wing County. The pamphlet “Your Lake and You,” available from the North American Lake Management Society (www.nalms.org), may be a useful educational tool in this area.

F. Awareness of possible nutrient and sediment sources such as urban and agricultural runoff, septic systems, lawn fertilizer, and the effects of activities in the total watershed that change drainage patterns, such as wetland removal, creating new wetland discharges to the lake, ditch modifications, or major alterations in lake use is important. As these activities occur within the watershed, lake residents are encouraged to insure that the water quality effects are minimized with the use of best management practices (BMPs) for water quality. Some of the county and state offices mentioned previously may be of help in this regard.

2. The 2006 water quality of East and West Twin Lakes was good relative to other lakes in the NLF ecoregion. Changing land use practices, poor management of shorelands, failure to maintain (pump) septic tanks, and draining of wetlands in the watershed provide the greatest likelihood for changes in phosphorus loading.

Conversely, a reduction of the amount of nutrients that enter the lake may result in improved transparency and a reduction in algal concentrations. One means of reducing nutrient input is by implementing BMPs in the watershed (land management activities used to control nonpoint source pollution). Technical assistance in BMP implementation may be available through local resource management agencies. The Crow Wing County SWCD is a local agency that could help examine land use practices in the watershed and develop strategies for reducing the transport of nutrients to the lake. It may be wise to first focus efforts on the land nearest the lake. There may be few opportunities (or the need) to implement BMPs on existing land use. However, opportunities may arise during road building, construction, ditch maintenance, or other activities which may result in increased sediment and phosphorus loading to the lake.

Restoring or improving wetlands in the watershed may also be beneficial for reducing the amount of nutrients or sediments which reach a lake. The U.S. Fish and Wildlife Service may be able to provide technical and financial assistance for these activities.

MPCA’s Clean Water Partnership (CWP) Program may also be an option for further assessing and dealing with nonpoint sources of nutrients in the watershed. However, since there is extensive competition for CWP funding, it may be in the best interest of lake residents to continue to work with the Crow Wing County SWCD, Crow Wing County Planning and Zoning Department, 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 and watershed residents. If these steps prove inadequate or the lake condition declines (as evidenced by a significant reduction in summer-mean Secchi transparency), application to CWP may then be appropriate. If a CWP is not needed at that time, a repeat of a Lake Assessment Program (LAP) level effort may be necessary at some point in the future to understand and document changes in total phosphorus, chlorophyll-*a*, and Secchi within a lake.

3. Should further study be deemed necessary, this report serves as a foundation upon which further studies and assessments may be based. The next step would be to define water and nutrient sources to the lake in a much more detailed fashion. These detailed studies would allow the estimation of reasonably accurate total phosphorus, total nitrogen, and water in and out-flow summaries. This should be accomplished prior to implementation of any extensive in-lake restoration techniques.

LAKE ASSESSMENT PROGRAM: 2006

Introduction

East and West Twin Lakes were sampled by the MPCA 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 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.

This study was conducted at the request of the West Twin Lake Homeowners Association. East Twin Lake was included in the study due to its close proximity and lack of water quality data. The lakes were sampled on five occasions in the spring and summer of 2006. Participants in this effort included Jim Hodgson, Maggie Leach, Jenny Magyar, and Paul Schrieber from the MPCA. Watershed information for East and West Twin Lakes was assembled from information in the Minnesota Department of Natural Resources' (DNR) Data Deli webpage. Land use information was complied from the University of Minnesota Remote Sensing Lab's 2000 LANDSAT imagery.

Ecoregion Based Lake Water Quality

Table 1 provides the draft ecoregion-based nutrient criteria. These criteria were developed by MPCA in response to an EPA requirement that states develop nutrient criteria for lakes, rivers, wetlands and estuaries. The approach to developing these criteria is consistent with previous phosphorus criteria (Heiskary and Wilson, 1989) that have been used extensively for goal setting and evaluating the condition of Minnesota's lakes for the 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 swimmable use throughout most of the summer. Whenever possible, these lakes should be protected from increases in nutrient concentrations, which would tend to stimulate algal and plant growth and reduce transparency. For lakes above the criteria level, the criteria may serve as a restoration goal for the lake and may lead to the lake being included on the 303(d) list that is submitted to EPA biennially.

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**
CHF – Stream trout (Class 2a)	**< 20**	**< 6**	**> 2.5**
CHF – Aquatic Rec. Use (Class 2b)	**< 40**	**< 14**	**> 1.4**
CHF – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 60**	**< 20**	**> 1.0**
WCP & NGP – Aquatic Rec. Use (Class 2B)	**< 65**	**< 22**	**> 0.9**
WCP & NGP – Aquatic Rec. Use (Class 2b) Shallow lakes	**< 90**	**< 30**	**> 0.7**

Table 2 represents the typical summer-mean water quality for lakes in 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 Northern Lakes and Forests (NLF) ecoregion will be used as a basis for comparing the water quality of lakes sampled in 2006.

Table 2. Reference Lake Data Base Water Quality Summary
(Summer Average Water Quality Characteristics for Lakes by Ecoregion)*

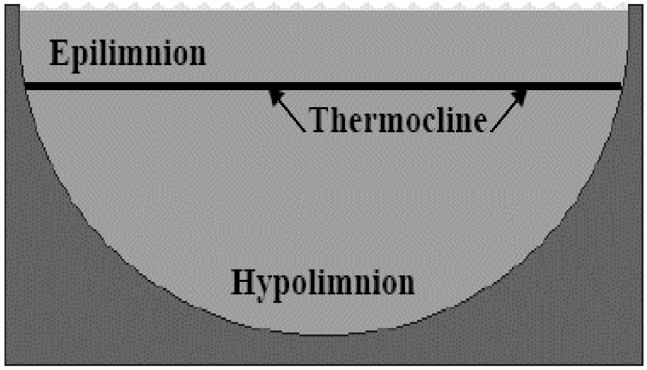
Parameter	NLF	CHF	WCP	NGP
# of lakes	**32**	**43**	**16**	**13**
Total Phosphorus (ug/l)	**14 - 27**	**23 - 50**	**65 - 150**	**122 - 160**
Chlorophyll mean (µg/L)	**4 - 10**	**5 - 22**	**30 - 80**	**36 - 61**
Chlorophyll maximum (µg/L)	**< 15**	**7 - 37**	**60 - 140**	**66 - 88**
Secchi Disk (feet) (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).

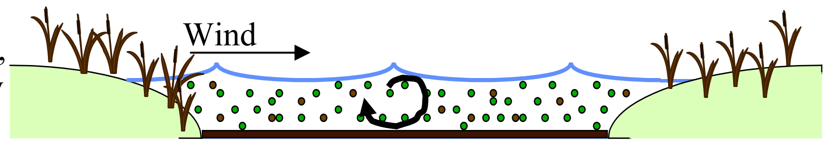
Lake depth can have a significant influence on lake processes and water quality. One such process is *thermal stratification* (formation of distinct temperature layers, see Figure 1a), in which deep lakes (maximum depths of 30 - 40 feet or more) often stratify (form layers) during the summer months and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

Figure 1. Thermal Stratification and Lake Mixing

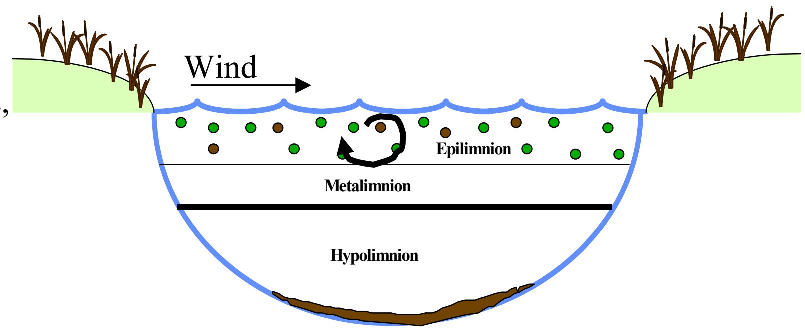
1a



1b **Polymictic Lake**
Shallow, No Layers,
Mixes Continuously
Spring, Summer & Fall



1c **Dimictic Lake**
Deep, Form Layers,
Mixes Few Times
Summer



1d **Dimictic Lake**
Deep, Form Layers,
Mixes Few Times
Spring/Fall

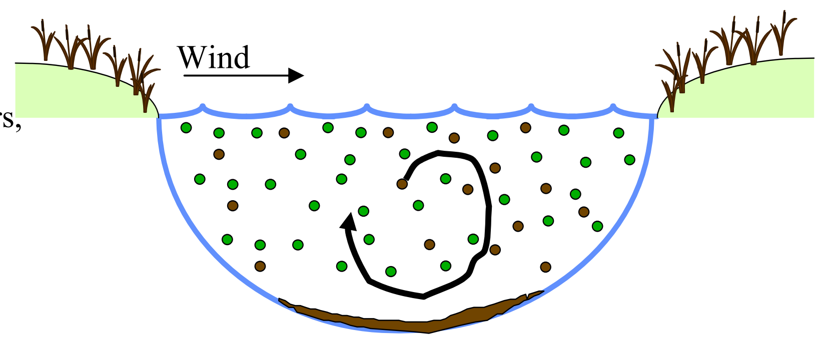


Table 3 represents the percentile distribution of summer-mean in-lake TP concentrations for each ecoregion based on the mixing (temperature stratification) status of the lake as follows:

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.

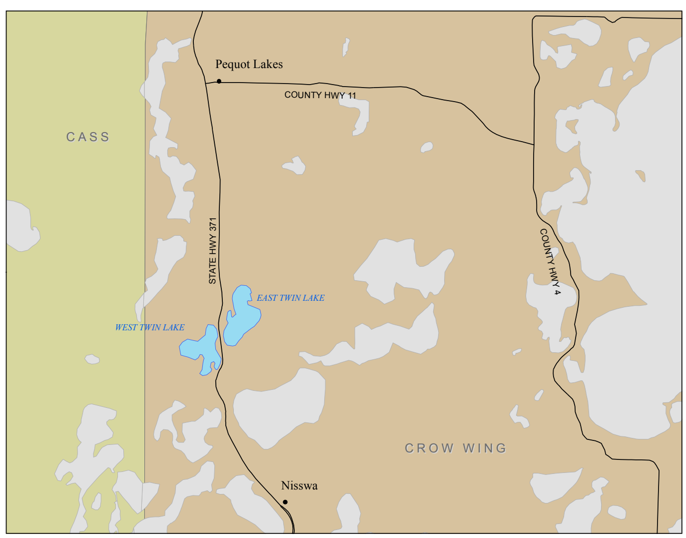
Sorting TP concentrations within each mixing type creates this distribution (by ecoregion) from low to high. These percentiles can provide an additional basis for comparing observed summer-mean TP and may further serve as a guide for deriving an appropriate TP goal for the lake.

Table 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

Background

Figure 2. Location of 2006 Lakes



East and West Twin Lakes are located in Crow Wing County, approximately three miles south of Pequot Lakes, Minnesota (Figure 2). East Twin Lake has a surface area of 146 acres with a maximum depth of 45 feet and an estimated mean depth of 15.9 feet. West Twin Lake covers 117 acres and has a maximum depth of 42 feet and an estimated mean depth of 13.3 feet. Both lakes are considered deep lakes, but have large littoral areas (area of lake with a depth of 15 feet or less and potential area that can support rooted aquatic plant growth). Shallow lakes often remain well-mixed from top to bottom during the summer, in contrast to deep lakes that will typically form distinct thermal layers.

Both lakes have very small watersheds that consist of the land immediately surrounding the individual lakes (Table 4b). East Twin Lake has a total watershed, including lake area, of 300 acres (0.47 square miles) and West Twin Lake's total watershed comprises 509 acres (0.79

square miles). 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 nutrient and water budgets are determined for the lake (typically requires total watershed as an input); whereas when focusing best management practices and protection efforts the immediate watershed is the first target. Total watershed to lake area ratio also provides an important perspective on the size of the watershed relative to the lake. In the case of East and West Lakes, the immediate watersheds and total watersheds are the same. For East Twin Lake, the watershed to lake ratio is 2.5:1 and for West Twin, the ratio is 1.6:1.

East and West Twin Lake do not appear to be hydrologically connected, and will be treated separately for the purposes of this report. Highway 371 divides the lakes, and no culverts connect the two waterbodies. Based on aerial photos, watershed maps, and field visits, both appear to be closed basins, with no major inflows or outflows. East Twin Lake's watershed drains land from the east and south sides of the lake, and has no upstream tributaries. West Twin Lake's watershed drains land immediately adjacent to the lake. Because these are relatively deep lakes, there is likely water exchange between the lake and the groundwater. This study focuses on surface water only and will not be able to characterize the groundwater contributions to both the water and phosphorus budgets.

The soils found near East and West Twin Lakes are defined as coarse to medium textured forest soils from the Flak-Brainerd-Nokay series. These tend to be light colored soils, varying greatly in drainage (well drained to poorly drained) found in gently rolling areas with moderately long slopes and were formed from stony noncalcareous sandy loam glacial till (Arneman, 1963). East and West Twin Lakes were likely formed by ice block basins in glacial till (Zumberge, 1952).

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. East and West Twin Lakes are located in the Northern Lakes and Forests ecoregion (Figure 3). Land use in the watersheds of these lakes is rather typical a NLF watershed, with a dominance of forested land uses followed by water/wetland land uses based on data from the early 1990s (Table 4b).

Figure 3. Minnesota's Seven Ecoregions and Location of Study Lakes

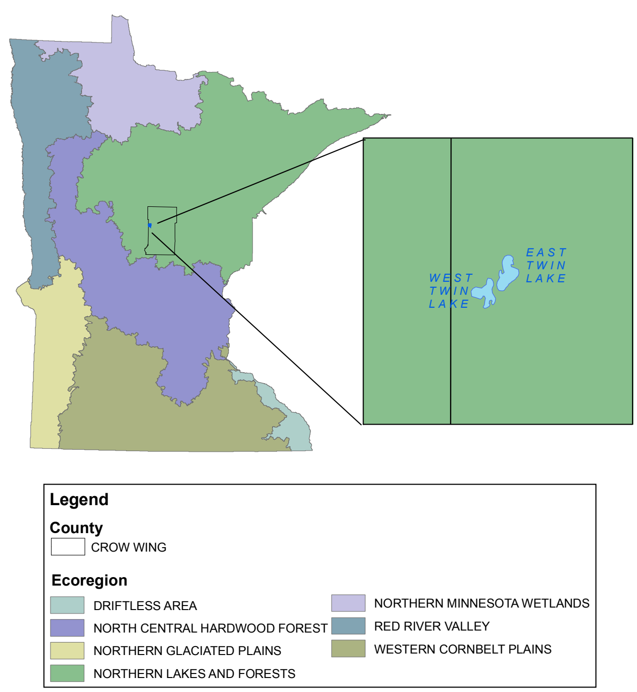
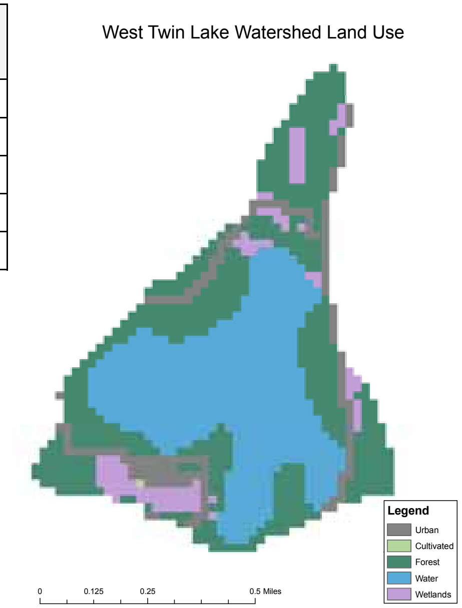


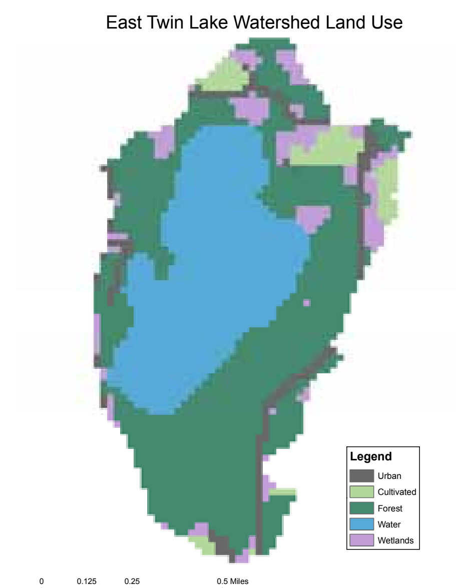
Table 4a. Lake morphometry and watershed characteristics.

Lake Name	Lake	Lake Basin	Littoral Area		Immediate Watershed Without Lake	Total Watershed Area Without Lake	Total Watershed To Lake	Max. Depth	Average Depth	Lake Volume
Name	ID	Acres	Acres	% Littoral	Acres	Acres	Ratio	Ft.	Ft.	Acre-Ft.
East Twin	18-0407	146	89	61	360	360	2.5 : 1	45	15.9	2,321
West Twin	18-0409	117	87	74	184	184	1.6 : 1	42	13.3	1,556

Table 4b. Watershed land use as compared to Ecoregion Interquartile Ranges

Land Use (%)	East Twin	West Twin	NLF Ecoregion
Forest	**49**	**42**	**54 – 81**
Water/wetlands	**39**	**47**	**14 – 31**
Pasture/grasslands	**0**	**0**	**0 – 6**
Cultivated	**5**	**0**	**< 1**
Urban	**7**	**11**	**0 - 7**



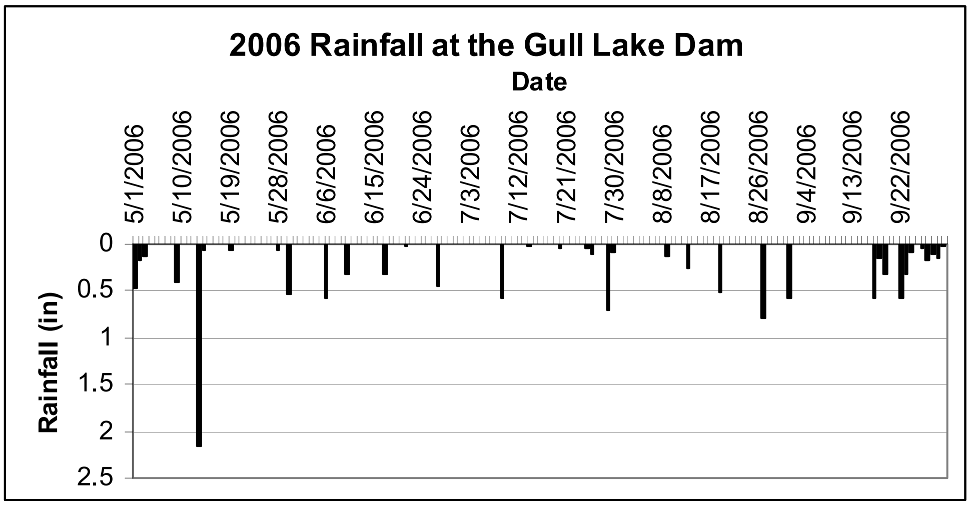


Precipitation

The summer of 2006 was marked by very low precipitation. From May to September 2006, 12.1 inches were recorded near Pequot Lakes (it should be noted that data was not collected on 9 days in May and 8 days in July). Rainfall amounts greater than one inch only occurred on May 13th, with 2.15 inches recorded (Figure 4).

Normal water year (October to September) rainfall averages 28 inches annually in this part of the state. The summer of 2006 was particularly dry, with the Pequot Lakes area receiving 24 inches, which is below normal. The normal and deviation from normal maps can be found in Appendix E.

Figure 4. 2006 Summer Rainfall Amounts near Pequot Lakes, MN.



Lake Level

The DNR Division of Waters, with the cooperation of volunteer readers, monitored water levels in East and West Twin Lakes in 2006. During the period of record (1991 – 2006) East Twin Lake has varied by 2.57 feet, based on 311 readings. The highest and lowest recorded elevations are 1219.26 feet on 7/15/1997 and 1216.69 feet on 10/29/92, respectively. For West Twin Lake, water levels have been monitored from 1990 to 2006. During this period, the lake levels have varied by 2.28 feet, with a low of 1210.62 on 10/5/1991 to a high of 1212.9 on 7/14/1997.

Fisheries

DNR fisheries managers utilize netting 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 East and West Twin Lakes is managed by the Minnesota Department of Natural Resources Fisheries Office located in Brainerd, Minnesota. The most recent version of the Status of the Fishery is summarized below.

East Twin – Status of the Fishery (as of 6/17/1996)

East Twin Lake was surveyed to assess the current fish population and evaluate the lake management goals in June of 1996. East Twin Lake has one developed public access on the western shore of the lake. The lake has a diverse aquatic plant assemblage, with both emergent (bulrush) and submergent species providing enhanced spawning habitat for bass and panfish as well as a food supply and cover for a variety of fishes.

Yellow perch, an important food source for predatory fish like walleyes, pike, and largemouth bass, were caught in low numbers in 1996. This low harvest may be in part due to large numbers of predatory fish and excessive competition with other panfishes. Walleye were also found in low numbers, compared to lakes of similar type. This continues to be a problem, despite consistent stocking efforts from 1982 to 1993.

Northern pike and largemouth bass were very abundant in 1996 compared to similar lakes, and have consistently been abundant since the 1960s.

Bluegills were also found in the lake, in quantities comparable to similar lakes. However, in previous studies, the catch rates were very high.

West Twin Lake – Status of the Fishery (as of 6/26/1991)

West Twin Lake was surveyed to assess the current fish population and evaluate the lake management goals in June of 1991.

Northern pike, walleye, yellow perch, and black crappie were all found in low abundance when compared to similar lakes. The black crappie catch was similar to the amounts found in 1949 and 1981, and the walleye catch was significantly lower than the last survey in 1986. Smallmouth bass were not present in the 1991 survey, but had been present in the 1986 sampling.

Largemouth bass and bluegills remained abundant when compared to previous studies and similar lakes.

Results and Discussion

Water quality data was collected in May, June, July, August, and September 2006. Site 101 was used on both East and West Twin Lakes. 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 taken at site 101 with an integrated sampler. Seasonal averages were calculated using June through September data.

Sampling procedures were employed as described in the MPCA Quality Control Manual. Laboratory analyses were performed by the Minnesota Department of Health Laboratory using U.S. Environmental Protection Agency (EPA) approved methods. Samples were analyzed for nutrients, color, solids, alkalinity, chloride, and chlorophyll-*a* (Table 5). Temperature, pH, conductivity, and dissolved oxygen profiles were taken with a meter and Secchi disk transparency measurements were also taken at the site. Phytoplankton analysis was conducted by Dr. Howard Markus, MPCA.

A historical database of Secchi data for West Twin Lake was available for comparison, as well as limited chemistry data on both lakes. 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.

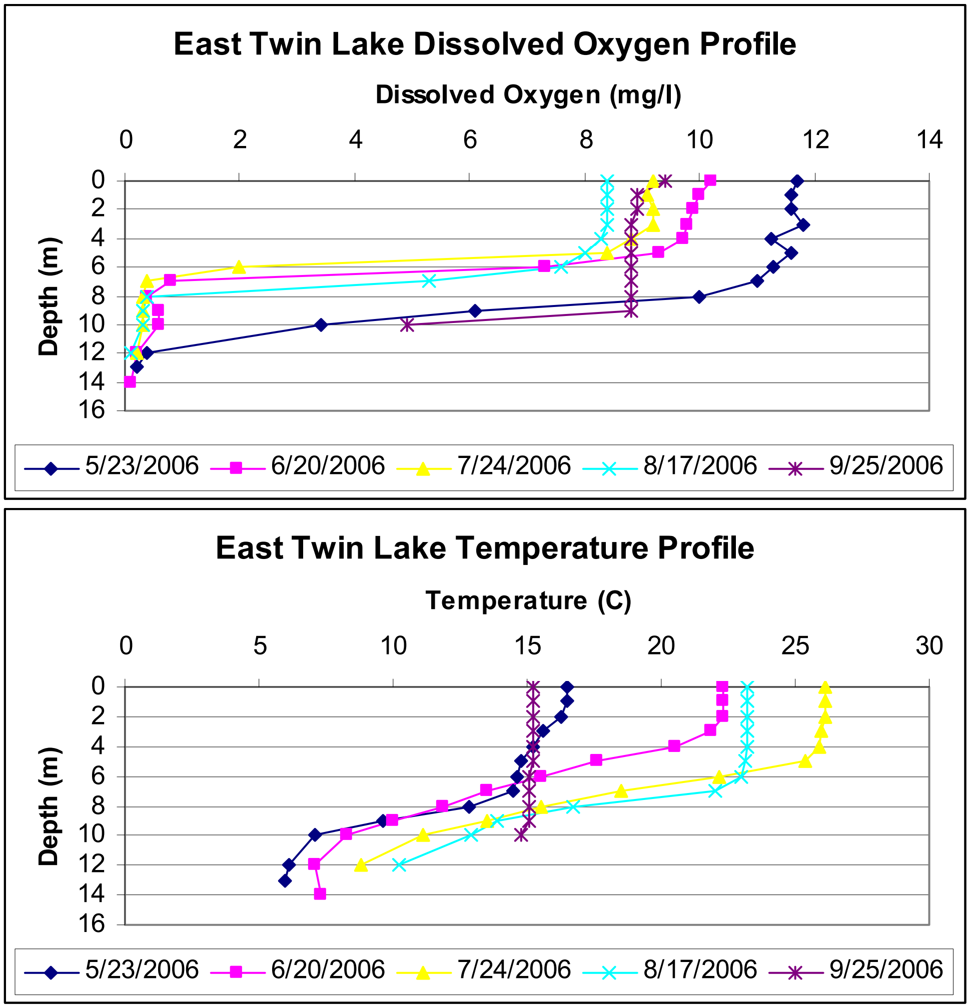
Table 5. Lake Summer Mean Water Quality

Parameter	East Twin 101	West Twin 101	Typical Range for NLF Ecoregion
Total Phosphorus (µg/L)	11	9	14 – 27
Chlorophyll-*a* (µg/L) mean	2.7	2.6	4 – 10
Chlorophyll-*a* (µg/L) max	3.3	3.3	< 15
Secchi disk (feet)	10.7	14.8	8 – 15
Secchi disk (m)	3.3	4.5	2.4 – 4.6
Total Kjeldahl Nitrogen (mg/l)	0.7	0.6	0.40 – 0.75
Alkalinity (mg/L)	73	79	40 – 140
Color (Pt-Co Units)	6.3	5	10 – 35
Chloride (mg/L)	1.4	12.3	0.6 – 1.2
Total Suspended Solids (mg/L)	2.1	1.5	< 1 – 2
Total Suspended Inorganic Solids (mg/L)	0.2	0.3	< 1 – 2
Conductivity (µmhos/cm)	141	188	50 – 250
TN:TP Ratio	63:1	65:1	25:1 – 33:1
TSI – Phosphorus	39	36	
TSI – Chlorophyll-*a*	40	40	
TSI – Secchi	43	38	
TSI - Average	41	38	

In-lake Conditions: East Twin Lake 2006

Dissolved oxygen and temperature profiles were taken at one meter intervals at site 101 on each date for East Twin Lake. Game fish require a minimum dissolved oxygen concentration of 5 mg/L to survive. Based on the profile for East Twin, there would not have been enough oxygen below a depth of 6 meters in June, July, and August to support game fish. Surface temperatures ranged from a low of 15.2 ^{0}C in September to a peak of 26.1 ^{0}C in July on East Twin Lake (Figure 5). A thermocline (zone of rapid change) was evident at a depth of 6 meters in June, July, and August. In May a weak thermocline existed, and in September, the lake was well mixed from the surface to the bottom. This indicates that the lake is dimictic, or mixes in the spring and fall, but remains stratified during the summer months.

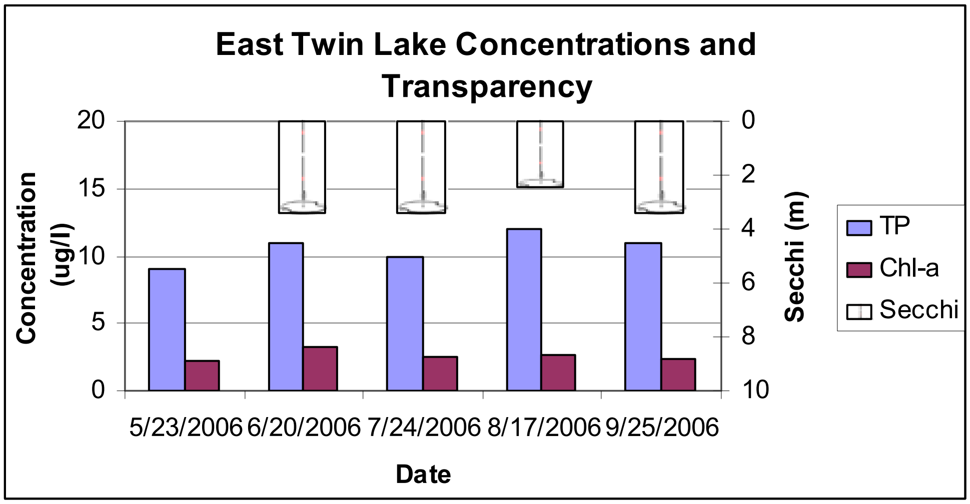
Figure 5. 2006 East Twin Lake Dissolved Oxygen and Temperature Profiles



Total phosphorus (TP) concentrations (an important nutrient for plant growth) for 2006 averaged 11 µg/L (micrograms per liter or parts per billion) on East Twin Lake (Figure 6). This mean is well below (better than) the typical range of concentrations for reference lakes found in the NLF ecoregion (Table 5). TP concentrations remained relatively constant over the summer on East Twin Lake, reaching a peak concentration of 12 µg/L in August and a low of 9 µg/L in May. In deep, thermally stratified lakes, it is common for phosphorus concentrations to decline or remain stable across the summer, as watershed loading (runoff) to the lake diminishes.

Measurements of hypolimnetic (deep) total phosphorus were also collected on East Twin Lake. In May, July, and September, the hypolimnetic concentrations were slightly elevated, as compared to the surface samples. This is likely due of internal phosphorus release from the bottom sediments as the conditions became anoxic. Because the lake did not mix during the summer months, this increased concentration remained in the deeper water and did not affect the surface concentrations.

Figure 6. 2006 Concentrations and Transparency on East Twin Lake.



Total Kjeldahl nitrogen (TKN) averaged 0.7 mg/L for East Twin Lake. This is within the range of values for TKN in the NLF ecoregion reference lakes (Table 5). The ratio of TN:TP can provide an indication as to which nutrient is limiting the production of algae in the lake. For East Twin Lake, the TN:TP ratio is about 63:1. This suggests that phosphorus is the limiting nutrient in East Twin Lake. Generally, phosphorus is the least abundant nutrient, and therefore, is the limiting nutrient for biological productivity in a lake. The ratios are well above the reference lake ecoregion range for the NLF lakes.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During the summer of 2006, chlorophyll-*a* concentrations on East Twin Lake ranged from 2.4 µg/L to 3.3 µg/L with an average of 2.7 µg/L (Figure 6). Concentrations between 10 and 20 µg/L may be perceived as a mild nuisance algal bloom (Heiskary and Walker, 1988). Based on data collected in 2006, bloom conditions would not have been present. Similar to the observed phosphorus concentrations on East Twin Lake, chlorophyll-*a* concentrations varied little across the season. The average and maximum chlorophyll-*a* concentrations for East Twin Lake were low compared to the range of values for NLF ecoregion reference lakes (Table 5).

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 averaged 6.3 Pt-Co units for East Twin Lake. Total suspended solids (TSS) averaged 2.1 mg/L and total suspended inorganic solids (i.e., clay) averaged 0.2 mg/L (Table 5). Organic matter (primarily algae) was the dominant contributor to TSS. Both the TSS and TSIS values were on the high end of the range of ecoregion values for lakes in the NLF, but should not appreciably diminish transparency.

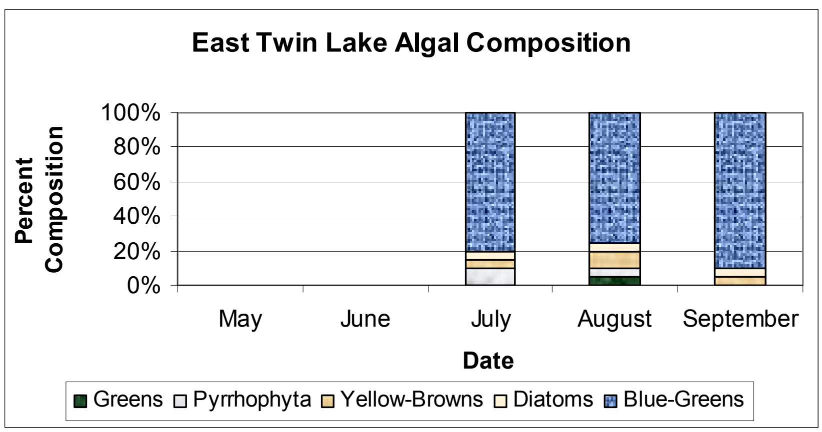
For East Twin Lake, the Secchi disk transparency ranged from a low of 8.2 feet (2.5 meters) in August to a high of 11.5 feet (3.5 m) in June, July, and September, with an average 10.7 feet (3.3 m) (Figure 6). These transparency measures are within the expected ecoregion range of NLF reference lakes (Table 5).

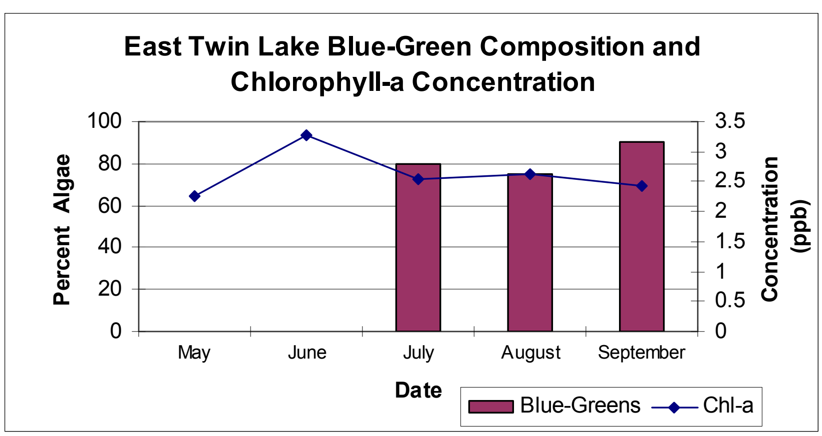
Along with the transparency measurements, subjective measures of East Twin Lake's "physical appearance" and "recreational suitability" were made. Physical appearance ratings range from "crystal clear" (Class 1) to "dense algal blooms, odor, etc." (Class 5) and recreational suitability ratings range from "beautiful, could not be any nicer" (Class 1) to "no recreation possible" (Class 5) in this rating system (Heiskary and Wilson, 1988). Based on 2006 data on East Twin Lake, lake conditions were characterized as "crystal clear" and "some algae present" (Classes 1 and 2) and "beautiful" (Class 1) throughout the summer.

The change in transparency in East Twin Lake was very similar to the observed changes in phosphorus and chlorophyll-*a*. For dimictic lakes, 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.

Algal composition on East Twin Lake was dominated by blue-green algae in July, August, and September (Figure 7). A seasonal progression from diatoms to blue-greens is more typical of mesotrophic to eutrophic lakes in Minnesota. Relatively low chlorophyll-*a* concentrations were observed in 2006, which would indicate very low concentrations of algae present (Figure 7).

Figure 7. 2006 East Twin Lake Algal Composition



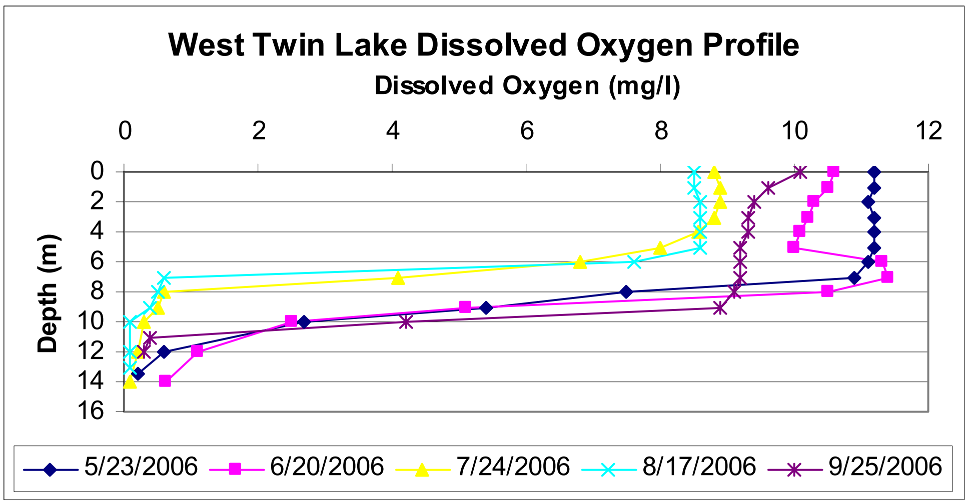


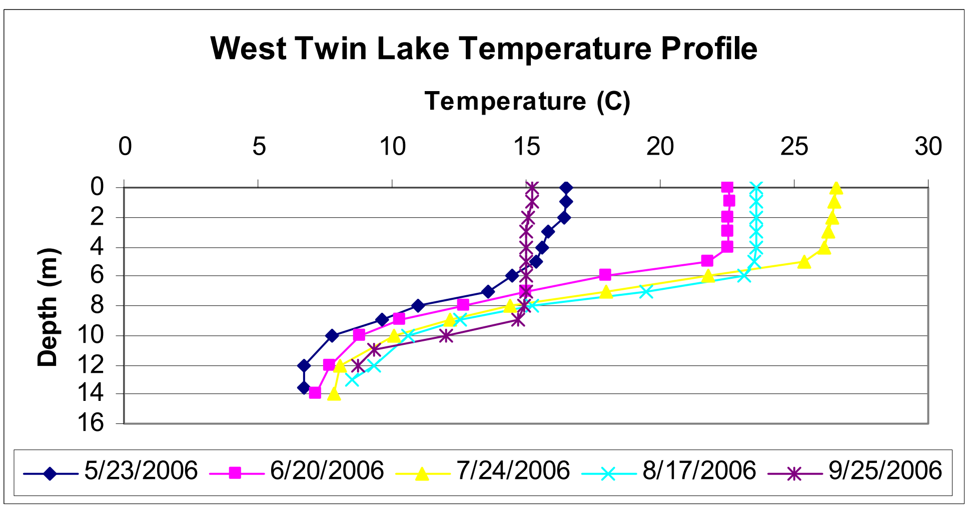
Other parameters monitored included alkalinity, conductivity, pH, and chloride. Alkalinity and conductivity are well within typical values and indicates moderate hardness. Chloride is low, which is consistent with typical values for the NLF ecoregion (Table 5).

In-lake Conditions: West Twin Lake 2006

Dissolved oxygen and temperature profiles were taken at one meter intervals at site 101 on each date for West Twin Lake. Surface dissolved oxygen ranged from a low of 8.5 mg/L in August to a high of 11.2 mg/L in May on West Twin Lake (Figure 8). Below a depth of 7 meters, the dissolved oxygen drops below 5 mg/L, and would not support game fish. Temperatures ranged from a low of 15.2 ^{0}C in September to a peak of 26.6 ^{0}C in July on West Twin Lake. A thermocline was evident at a depth of 7 meters in June, July, and August. These profiles would indicate that the lake is stratified during the summer months, or dimictic.

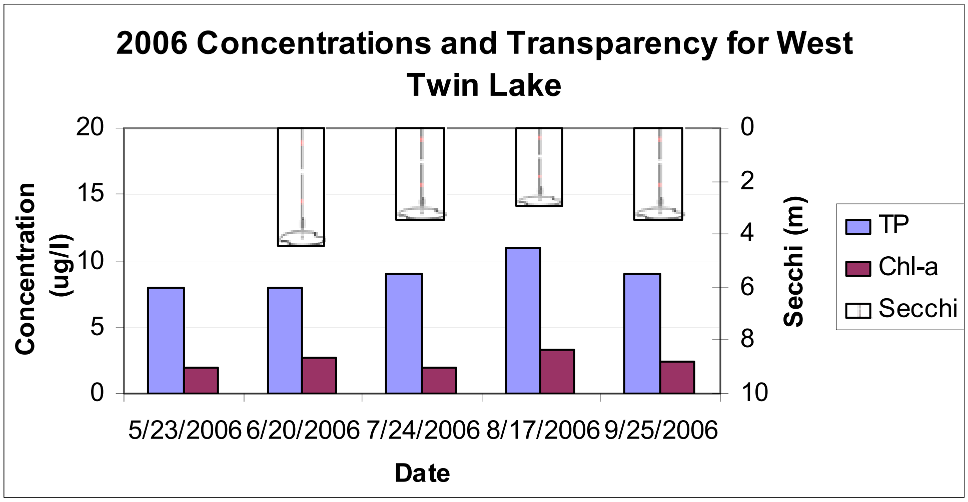
Figure 8. West Twin Lake Dissolved Oxygen and Temperature Profiles





Total phosphorus (TP) concentrations (an important nutrient for plant growth) for 2006 averaged 9 µg/L (micrograms per liter or parts per billion) on West Twin Lake (Figure 9). This mean concentration is well below (better than) the typical range of concentrations for reference lakes found in the NLF ecoregion (Table 5). TP concentrations increased slightly over the summer on West Twin Lake, reaching peak concentrations in August. West Twin Lake concentrations range from a low of 8 µg/L in May and June to a high of 11 µg/L in August.

Figure 9. 2006 Concentrations and Transparency on West Twin Lake.



Total Kjeldahl nitrogen (TKN) averaged 0.6 mg/L for West Twin Lake. This is within the range of values for TKN in the NLF ecoregion reference lakes (Table 5). The ratio of TN:TP can provide an indication as to which nutrient is limiting the production of algae in the lake. For West Twin Lake, the TN:TP ratio is about 65:1. This suggests that phosphorus is the limiting nutrient in West Twin Lake. Generally, phosphorus is the least abundant nutrient, and therefore, is the limiting nutrient for biological productivity in a lake. The ratios are above the reference lake ecoregion range for the NLF lakes.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During the summer of 2006, chlorophyll-*a* concentrations on West Twin Lake ranged from 1.9 µg/L to 3.3 µg/L with an average of 2.6 µg/L (Figure 9). Concentrations between 10 and 20 µg/L may be perceived as a mild nuisance algal bloom (Heiskary and Walker, 1988). Based on data collected in 2006, algal blooms were not present on any of the sampling dates. Concentrations changed little across the season, with the low and peak concentrations observed in July and August, respectively. The average and maximum chlorophyll-*a* concentrations for West Twin Lake were well below the range of values compared to NLF reference lakes (Table 5).

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 averaged 5 Pt-Co units for West Twin Lake. Total suspended solids (TSS) averaged 1.5 mg/L and total suspended inorganic solids averaged 0.3 mg/L for West Twin Lake. Organic matter (primarily algae) was the dominant contributor to TSS. Both the TSS and TSIS values were within the ecoregion values for lakes in the NLF reference lakes and did not appreciably limit the transparency of the lake.

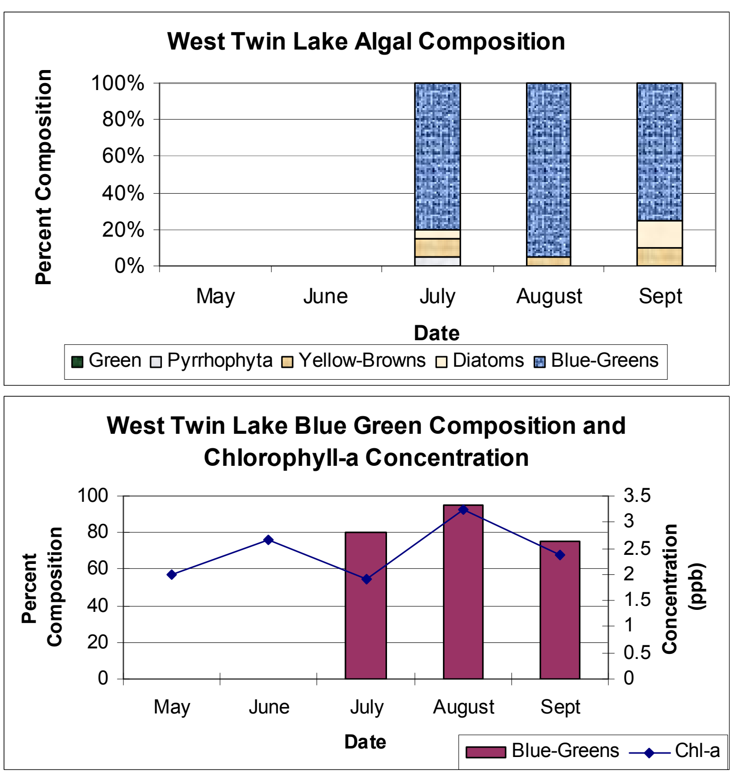
For West Twin Lake, the Secchi disk transparency ranged from a low of 9.8 feet (3.0 meters) in July to a high of 14.8 feet (4.5 m) in June, with an average 11.9 feet (3.6 m) (Figure 9). These transparency measures are well within the ecoregion range of NLF reference lakes (Table 5).

Along with the transparency measurements, subjective measures of West Twin Lake's "physical appearance" and "recreational suitability" were made. Physical appearance ratings range from "crystal clear" (Class 1) to "dense algal blooms, odor, etc." (Class 5) and recreational suitability ratings range from "beautiful, could not be any nicer" (Class 1) to "no recreation possible" (Class 5) in this rating system (Heiskary and Wilson, 1988). Based on 2006 data on West Twin Lake, lake conditions were characterized as "crystal clear" and "some algae present" (Classes 1 and 2) and "beautiful" (Class 1) throughout the summer.

The change in nutrients, algae, and transparency in West Twin Lake was similar to many dimictic 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.

Algal composition on West Twin Lake was also dominated by blue-green algae in July, August, and September (Figure 10). A typical seasonal transition from diatoms to blue-greens would be expected on mesotrophic to eutrophic lakes. Low chlorophyll-*a* concentrations were observed for the summer, and as such, the blue-greens were well below "bloom" levels.

Figure 10. 2006 West Twin Lake Algal Composition



Other parameters including alkalinity and conductivity, we well within the typical range of values for the NLF ecoregion (Table 5). Chloride, however, was well above this typical range (Table 5) and much higher than concentrations in East Twin. Though chloride is high relative to the typical range, it is well below concentrations that may be problematic for aquatic life and plants. The most likely source of excess chloride is from the use of road salt.

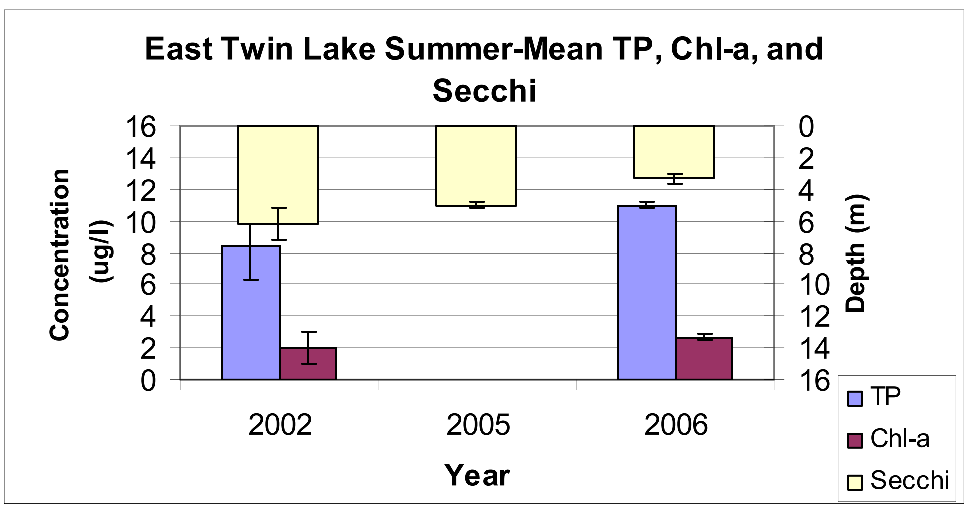
Historical Water Quality

Because both East and West Twin Lakes have limited historical water quality data, it is not possible to determine trends for either Secchi or chemistry parameters (at least eight years of Secchi and/or four or more years of TP or chlorophyll-*a* data). However, the following will include historical data for comparison purposes to the 2006 data. Unless noted otherwise, 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.

East Twin Lake

A limited database is available for water quality on East Twin Lake. Data was available through the Citizen Lake-Monitoring Program from 2005 to 2006, and water chemistry data was available from 2002. The Secchi concentrations appear to be declining, but there are not enough years of data available to determine if a real trend exists (Figure 11). Water chemistry data is not significantly different between 2002 and 2006, suggesting that water quality has not changed much in the past four years.

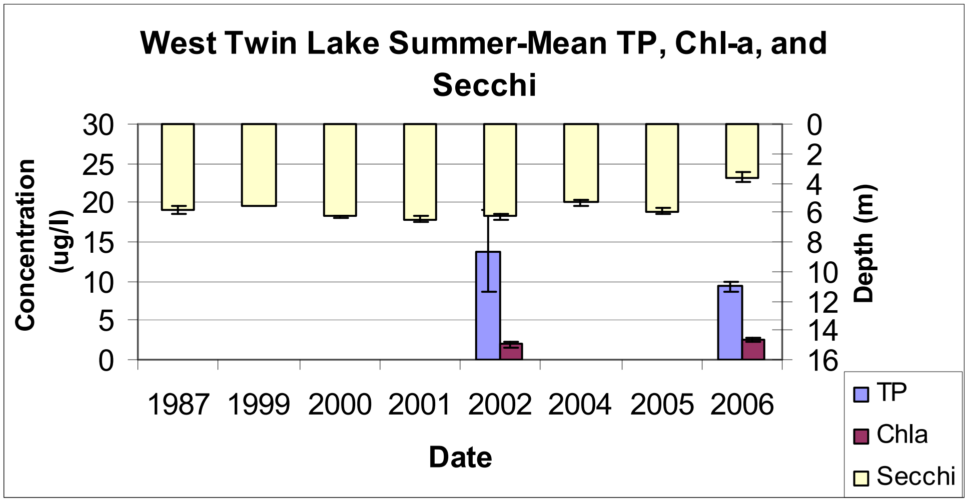
Figure 11. East Twin Lake Summer-Mean TP, Chl-a, and Secchi



West Twin Lake

A good database is available for Secchi data on West Twin Lake. Data was available through the Citizen Lake-Monitoring Program from 1987 to 2005. Limited water chemistry data was available from 2002. The Secchi concentrations vary from year to year, but there are not enough years of data available to determine if a real trend exists (Figure 12). Water chemistry data does not appear to be significantly different between 2002 and 2006, suggesting that water quality has not changed much in the past four years.

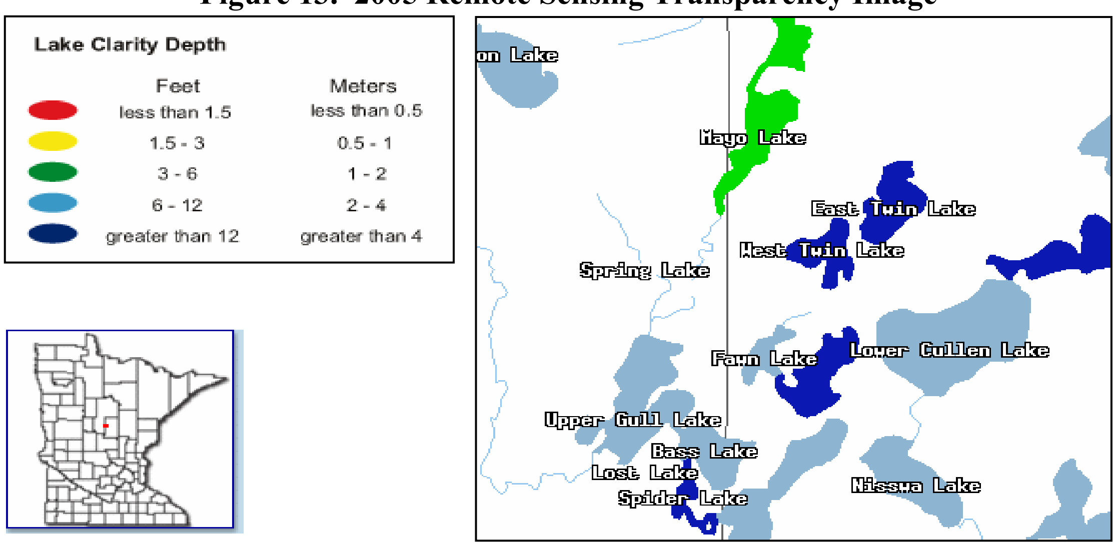
Figure 12. West Twin Lake Summer-Mean TP, Chl-a, and Secchi



Satellite Imagery

Based on remotely sensed satellite imagery from 1985 to 2005 (on 5 year intervals), East and West Twin Lakes were consistently as good as or better than neighboring lakes in terms of water clarity. Both lakes exceeded 12 feet in clarity each time the images were collected, while neighboring lakes range from a low of 3 – 6 feet in clarity to a high of greater than 12 feet in transparency. Images from all years can be viewed online at the Minnesota Lake Brower web page at: http://water.umn.edu/lakebrows.html. Figure 13 contains the image collected in the summer of 2005.

Figure 13. 2005 Remote Sensing Transparency Image



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:

Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15
Chlorophyll-*a* TSI (TSIC) = 9.81 ln (Chl-*a*) + 30.6
Secchi disk TSI (TSIS) = 60 – 14.41 ln (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 East and West Twin Lakes and respective TSIs are presented in Figure 14. Based on these values and an average TSI score of 41 and 38 (Table 5), respectively for East and West Twin Lakes, the lakes would be characterized as *mesotrophic*. 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 for both lakes.

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 East and West Twin Lakes, 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. Since all lakes located in the NLF ecoregion, the model 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 East and West Twin Lakes.

Parameter	East Twin 2006	East Twin MINLEAP	West Twin 2006	West Twin MINLEAP
TP (µg/L)	11 ± 0.2	16 ± 6	9 ± 0.6	15 ± 6
Chlorophyll-*a* (µg/L)	2.7 ± 0.2	3.7 ± 2.3	2.6 ± 0.3	3.5 ± 2.3
Secchi (m)	3.3 ± 0.3	3.6 ± 1.5	3.6 ± 0.3	3.7 ± 1.6
P loading rate (kg/yr)	-	26	-	16
P retention (%)	-	76	-	78
P inflow conc. (µg/L)	-	64	-	69
Water Load (m/yr)	-	0.70	-	0.50
Outflow volume (hm^3/yr)	-	0.41	-	0.23
Residence time (yrs)	-	6.9	-	8.2

The observed values for TP, chlorophyll-*a*, and Secchi were consistently lower, but not significantly different from the MINLEAP predicted TP for both East and West Twin Lakes (Table 6). In simple terms this means that the observed TP appears to be better than what is expected for lakes of that size and depth and size watershed in the NLF ecoregions. Both East and West Twin Lakes are essentially closed basins. As such, ground water interactions likely play a very large role in the water budget and possibly the phosphorus budget as well. The MINLEAP, Vighi-Chiaudani, and Reckhow-Simpson models all assume that the basins have outflows. Because of this, it is difficult to accurately model/predict values.

The Vighi-Chiaudani model, run as part of MINLEAP, predicted a background TP concentration of 18.6 µg/L for East Twin and 20.1 µg/L for West Twin. Both lakes had summer mean TP concentrations well below this predicted value. Again this difference between the predicted and observed values is likely due to groundwater interactions.

The Reckhow-Simpson Model was run on West Twin Lake to estimate the contribution from septic systems on the lake. Data provided by the association suggest that of the 60 homes on the lake, approximately one-third are lived in year round and two-thirds are seasonal. Because the amount of groundwater flow is unknown, it is not possible to accurately predict the load being contributed by septic systems. While the model estimates that approximately 27% of the phosphorus loading to the lake comes from septic systems during normal precipitation years, it is possible that it is considerably lower. It appears, based on this data, that septic systems could potentially be a significant part of the phosphorus budget.

FIGURE 14. Carlson's Trophic State Index for East and West Twin Lakes
R.E. Carlson

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

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

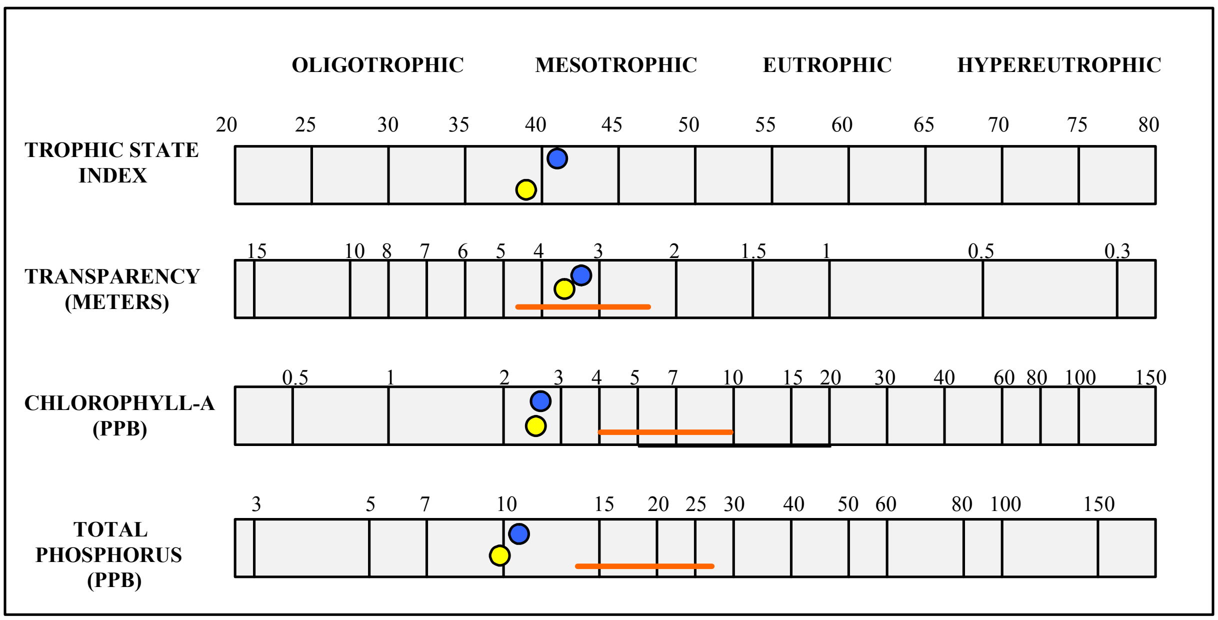
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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

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

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

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



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

NLF Ecoregion Range: East Twin : West Twin:

Goal Setting

The phosphorus criteria values for lakes in the Northern Lakes and Forests ecoregions are 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 10 percent of the summer and transparency should remain at or above 3 meters (9.8 feet) over 85 percent of the summer.

For East and West Twin Lakes, it would be desirable to maintain in-lake TP concentrations at levels observed in 2006. Given their small watersheds, both lakes would be susceptible to increases in runoff and phosphorus with increased development (reduced shoreline vegetation, increased impervious surfaces, additional septic systems, etc.). It will be important for the Association and lakeshore residents to work to minimize the effects of development on the lakes.

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

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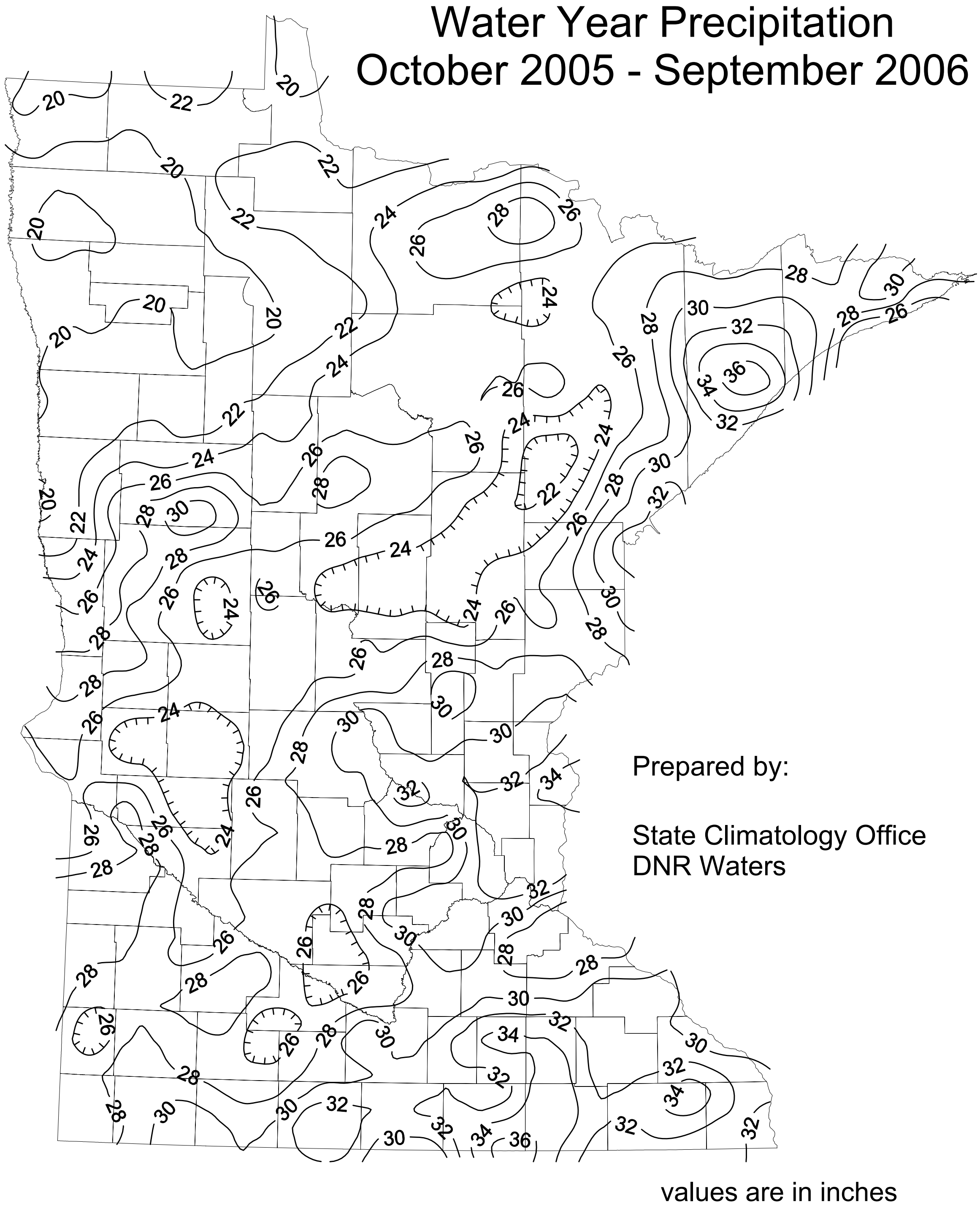
Appendix D Surface water results

Lake Name	Lake ID	Date	Site	Sample Depth		TP	Chl-a	Secchi	Total Alk	Cl	TKN	Color, Apparent	TSS	VSS
				Up	Lwr	ug/l	ug/l	m	mg/l	mg/l	mg/l	PCU	mg/l	mg/l
East Twin	18-0407	5/23/2006	101	0	2	9	2.25		83	1.3	0.65	5		
		6/20/2006	101	0	2	11	3.27	3.5	79	1.5	0.62	5	2	1.6
		7/24/2006	101	0	2	10	2.53	3.5	67	1.3	0.7	5	2	1.2
		8/17/2006	101	0	2	12	2.63	2.5	70	1.4	0.68	5	3.2	2.8
		9/25/2006	101	0	2	11	2.43	3.5	77	1.4	0.69	10	1.2	
West Twin	18-0409	5/23/2006	101	0	2	8	2.01		89	12	0.65	5	1.3	1.3
		6/20/2006	101	0	2	8	2.67	4.5	82	12	0.59	5	1.2	1.2
		7/24/2006	101	0	2	9	1.91	3.5	74	12	0.64	5	2	1.2
		8/17/2006	101	0	2	11	3.25	3	77	13	0.67	5	1.6	
		9/25/2006	101	0	2	9	2.38	3.5	83	12	0.65	5	1.2	1.2

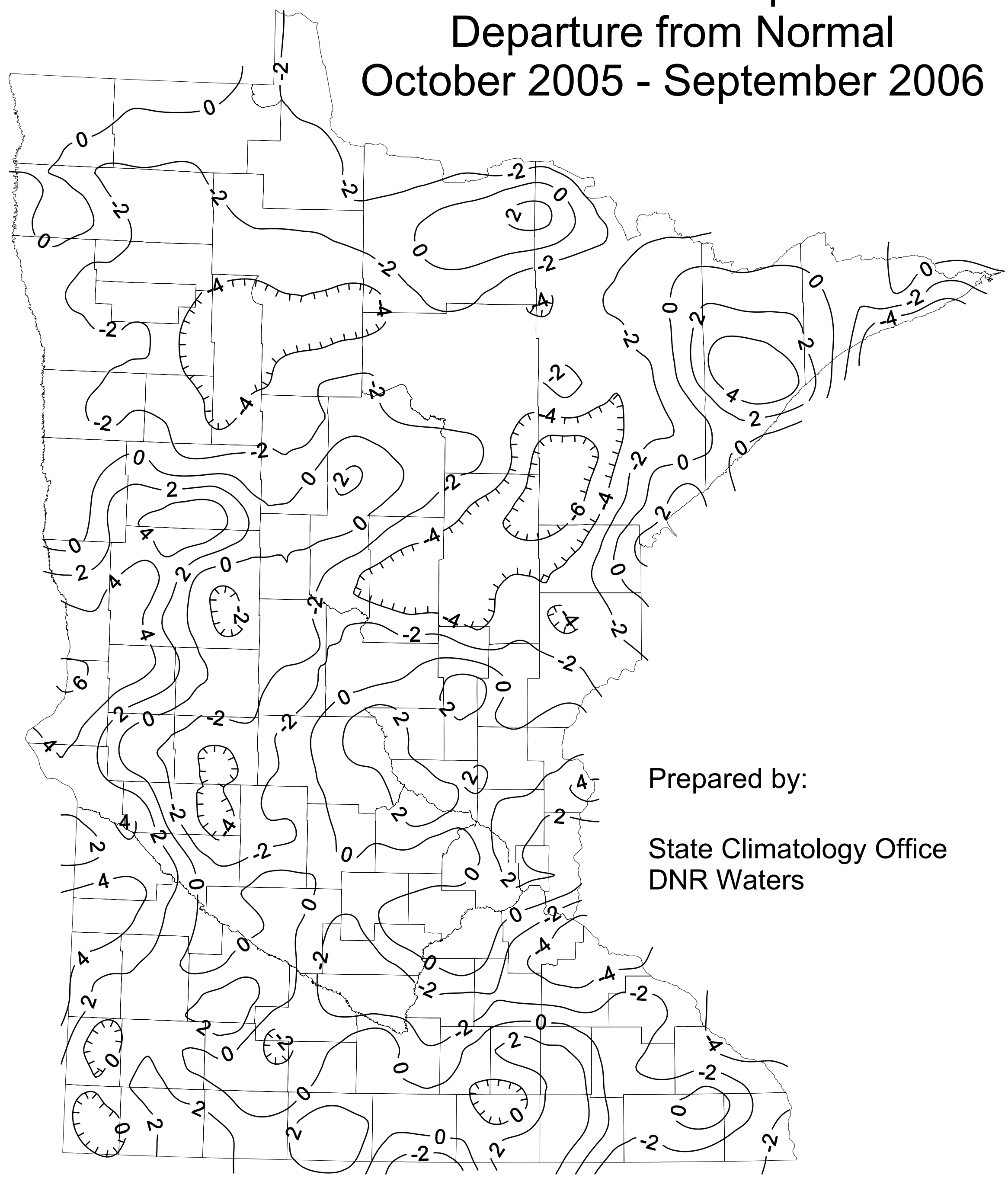
Long-Term Secchi, TP, and Chl-a for East and West Twin Lakes

East Twin	TP	Chl-a	Secchi	TP Se	Chl-a SE	Secchi SE
2002	8.5	2	6.2	2.2	1	1
2005			5			0.2
2006	11	2.7	3.3	0.2	0.2	0.3
West Twin	**TP**	**Chl-a**	**Secchi**	**TP SE**	**Chl-a SE**	**Secchi SE**
1987			5.8			0.3
1999			5.6			
2000			6.3			0.08
2001			6.5			0.2
2002	13.8	2	6.3	5.2	0.4	0.2
2004			5.3			0.2
2005			5.9			0.2
2006	9.3	2.6	3.6	0.6	0.3	0.3

Appendix E. 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