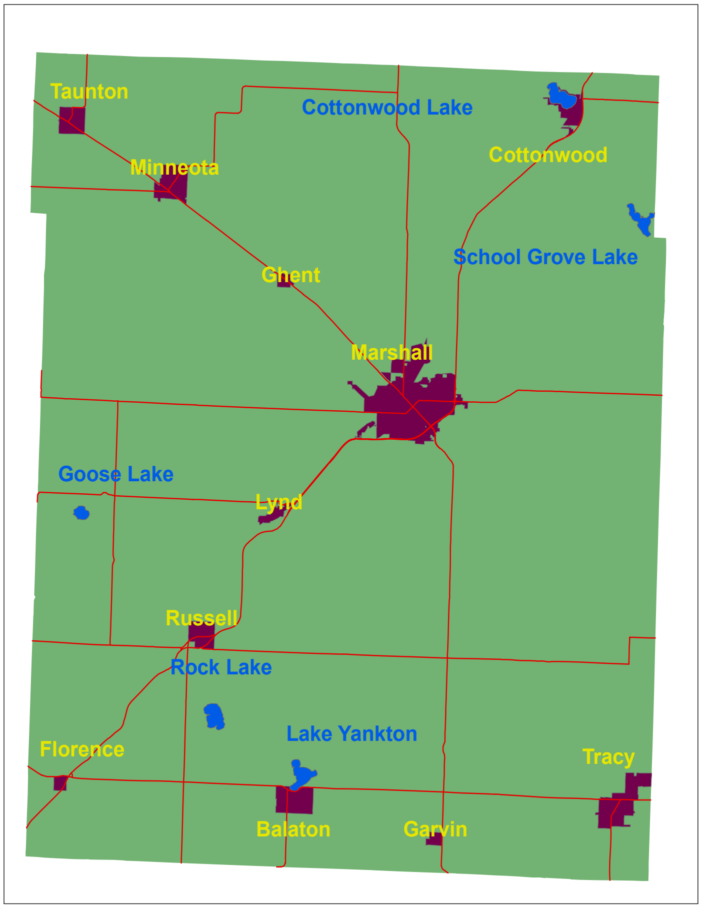

Status and Trend Monitoring of Selected Lakes in Lyon County 2007

Environmental Analysis and Outcomes Division
Water Assessment and Environmental Information Section
December 2008

Minnesota Pollution Control Agency

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Lake Assessment Program 2007

Status and Trend Monitoring of Selected Lakes in Lyon County

Minnesota Pollution Control Agency

Environmental Analysis and Outcomes Division

Water Assessment and Environmental Information Section

Lake Name	Lake DOW# ID
School Grove	42-0002
Cottonwood	42-0014
Yankton	42-0047
Rock	42-0053
Goose	42-0093

wq-lar3-14

The MPCA is reducing printing and mailing costs by using the Internet to distribute reports and information to wider audience. For additional information, see the Web site: www.pca.state.mn.us/water/lakereport.html

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Introduction

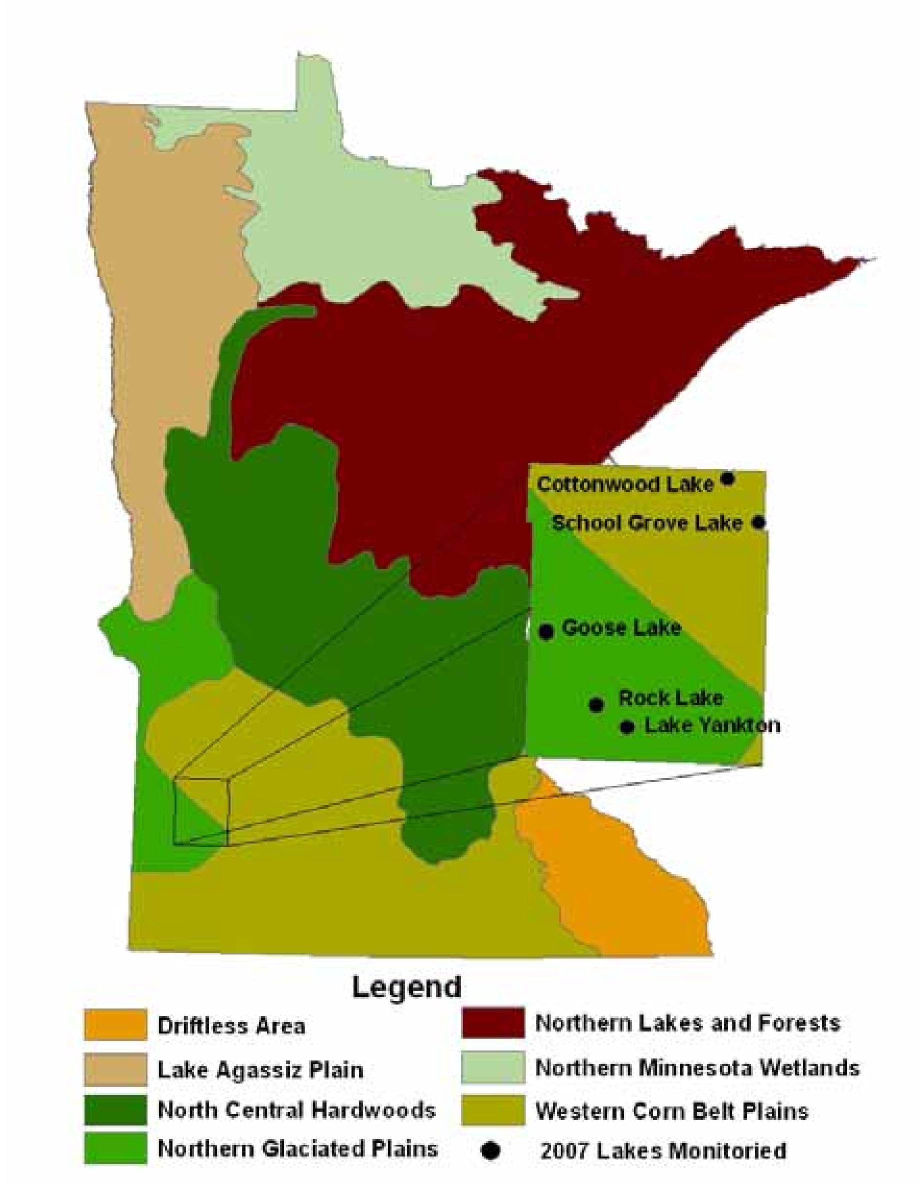
The Minnesota Pollution Control Agency's (MPCA) core lake-monitoring programs include Legacy Lake Monitoring, Citizen Lake Monitoring Program (CLMP), and Lake Assessment Program (LAP). In addition to these programs, the MPCA annually monitors numerous lakes to provide baseline water quality data, provide data for potential LAP and Clean Water Partnership (CWP) lakes, characterize lake condition in different regions of the state, examine year-to-year variability in ecoregion-reference lakes, provide additional trophic status data for lakes exhibiting trends in Secchi transparency and to provide data for the protection, restoration, and preservation of Minnesota Surface waters through the Clean Water Legacy Act (CWLA). In the latter case, sampling is conducted to provide data on water quality conditions to achieve and maintain established standards. To make for efficient sampling, geographic clusters of lakes are selected (e.g., focus on a specific county or region) whenever possible.

The MPCA prepares lake assessments under section 305(b) and 303(d) of the Clean Water Act. These assessments are done to estimate the extent to which Minnesota water bodies meet the goals of the Clean Water Act. This information is shared with planners, citizens and other partners in basin planning and watershed management activities. In the case of 303(d) assessments lakes are assessed to determine whether they meet "aquatic recreational uses".

This report details the analysis of monitoring on lakes in Lyon County during the 2007 season. Data collected in 2007 were combined with data from previous sample seasons. For data-poor lakes, monitoring establishes a baseline data. In the selection of lakes, a focus is typically placed on large lakes, typically with surface areas of 500 acres or more; however, none of the lakes monitored in Lyon County met this criteria.

Water quality samples were collected monthly from May through September. A summary of 2007 data follows (Appendix D). These lakes are all near the edge of the Western Corn Belt Plains (WCBP) and the Northern Glaciated Plains (NGP) ecoregions. Cottonwood and School Grove Lakes reside in the WCBP while Goose, Rock, and Yankton Lakes are in the NGP ecoregion (Figure 1). For this reason, both NGP and WCBP ecoregion values will be used for land use comparisons (Table 2) and lake summer-mean water quality (Table 3). Because the watershed drainage for all of the lakes flows from the NGP into the WCBP we will use NGP ecoregion for the Minnesota Lake Eutrophication Analysis Procedure (MINLEAP) model application. This provides a basis for placing data from these lakes in perspective relative to one another, as well as other lakes in the same ecoregion.

Figure 1. Minnesota's Seven Ecoregions as Mapped by U.S. Environmental Protection Agency (EPA)



Background

Lake Morphometric and Watershed Characteristics

Lake morphometric characteristics including surface area, mean and maximum depth, and percent littoral are summarized in Table 1. With 401 acres, Yankton Lake was the largest in the study, while Goose Lake (139 acres) was the smallest. Maximum depths ranged from 11 feet in School Grove Lake to seven feet in Cottonwood Lake. Mean depths ranged from five feet in Rock Lake to 7.1 feet in School Grove.

Percent littoral refers to that portion of the lake that is 15 feet or less in depth, which often represents the depth to which rooted plants may grow in the lake. Lakes with a high percentage of littoral area often have extensive rooted plant (macrophyte) beds. These plant beds are a natural part of the ecology of these lakes and are important to protect. The definition for "shallow" lakes applies to those with maximum depths of 15 feet or less or where the littoral area comprises 80 percent or more of the basin (Heiskary and Wilson, 2005). Based on this definition, all the lakes in this study would be considered shallow lakes. Shallow lakes will often remain well-mixed from top to bottom during the summer, in contrast to deep lakes that will typically form distinct thermal layers.

The lakes in the study are located in the Minnesota River and Des Moines Headwaters Basins. Within these basins, lakes were located in the following watersheds: West Fork Des Moines River (Headwaters) (Lake Yankton), Cottonwood River (Rock Lake), Redwood River (School Grove and Goose Lake), and Minnesota River (Granite Falls) for Cottonwood Lake. For this report we will group lakes by these watersheds, which should provide a basis for comparison among lakes in the same watershed or lake chain.

Watershed areas were estimated for the lakes based on data from the University of Minnesota Remote and Geospatial Analysis Lab. United States Geographical Survey (USGS) watershed data was also used that may be found at: http://gisdmnspl.cr.usgs.gov/watershed/index.htm.

Land use in individual lake sheds was estimated by MPCA staff using Geographical Information Systems software (Table 2 and Figure 4). 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. In some cases, such as Goose, Rock, and Yankton, the immediate and total watersheds are one in the same. In others, such as Cottonwood and School Grove, the immediate watershed may represent less than half of the total watershed to the lake. Differentiating between immediate and total is important as nutrient and water budgets are determined for the lake based on the total watershed. However, the immediate watershed is often the focus for initial Best Management Practices (BMP) and protection efforts. Total watershed: lake area ratio also provides an important perspective on the size of the watershed relative to the lake. In this study, Lake Yankton has the smallest watershed to lake ratio, which generally means that water (and often nutrient) loading to the lakes is rather small and water residence time is long. In contrast, Cottonwood Lake, with a ratio of 42:1, has the highest ratio of any lake in the report (Table 1). This implies that large volumes of water flow through the lake and water residence time may be very short by comparison. This will be explained in greater detail in a section on modeling results.

The soils found around lakes in the study are defined as medium-to fine-textured prairie and prairie border soils of Western Minnesota from the Barnes-Aastad-Flom and Barnes-Buse-Pierce series. These tend to be dark-colored, well-drained soils in nearly level to rolling areas, formed from calcareous loam glacial till and in gently rolling to hilly areas dark, well-drained soils also formed from calcareous loam glacial till (Arneman 1963). The shallow lakes of Lyon County were likely formed by irregular deposition of glacial till (Zumberge, 1952).

Lake Level Trends

Lake level is measured in several Minnesota lakes by volunteers through Minnesota Department of Natural Resources (MDNR) Lake Level Monitoring Program. Lake levels have historically been recorded on Cottonwood, Rock, School Grove, and Yankton. Goose Lake does not have enough data to produce a fluctuation range. Cottonwood, Rock, and Yankton have lake level ranges from 4.6 feet to 4.9 feet while School Grove Lake has a fluctuation of 6.15 feet. Levels date from present day readings back to 1940. Data for specific lakes and years can be found at www.dnr.state.mn.us.

Precipitation

Rain gage records from Marshall, Minnesota, show two one-inch plus and one three-inch plus rain events during summer 2007 (Figure 2). In particular, a large rain event was noted for August 18 with 3.27 inches. Such rain events will increase runoff into the lakes and may influence in-lake water quality and lake levels. This will be considered in the individual discussions of lake water quality for 2007. Precipitation records for the 2007 water year (October 2006 through September 2007) showed average rainfall (0 - 2 inches below normal) for the Marshall study area (Figure 3).

Figure 2. Summer 2007 Rainfall Based on Records for Marshall, Minnesota

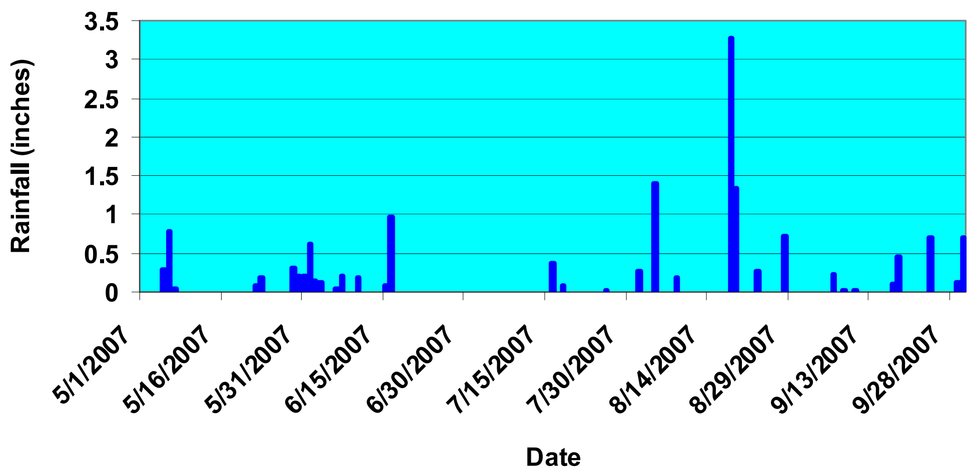
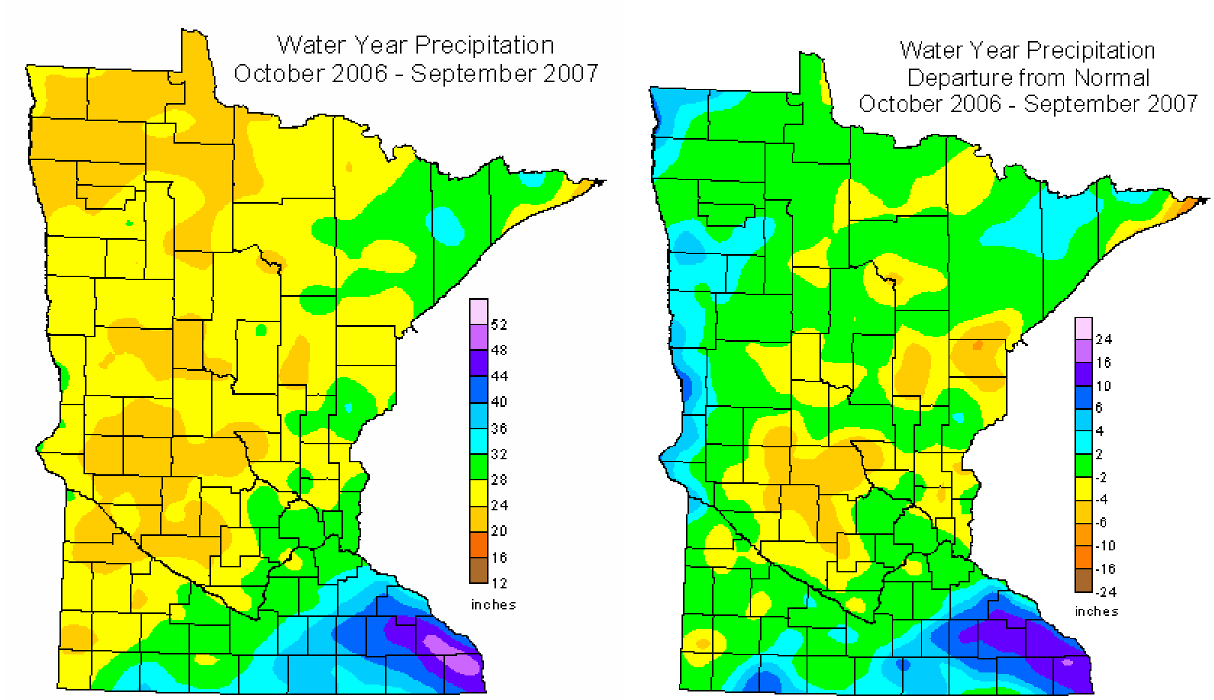


Figure 3. Water Year Precipitation for 2007
Prepared by State Climatology Office DNR Waters Values are in inches



Fisheries

All five lakes have been surveyed by the MDNR Fisheries Section. More detailed reports are available at www.dnr.state.mn.us.

Cottonwood Lake has an aeration system that is operated by the Cottonwood Sportsman's Club with the assistance of the MDNR. This lake was chemically reclaimed with the pesticide rotenone in the early 1990s and is stocked with walleye fry every other year. In 2002, carp and black bullhead was abundant and above historical range. Yellow perch and walleye were abundant. Northern pike was moderate to abundant and blue gill population was low.

School Grove Lake also has an aeration system that was installed in the mid 1980s to prevent winterkill. In 2002 yellow perch numbers were low and channel catfish numbers were moderate while walleye numbers were moderate to abundant. Natural walleye reproduction is low and the stocking has been described as "moderately successful". Black bullhead and carp populations are abundant for School Grove Lake.

Lake Yankton's walleye management has been very successful with population within the expected range and good growth. Northern pike numbers were down from a previous survey but the fish caught were healthy and sized well. Panfish population is listed as high and black bullhead numbers are very low. Lake Yankton was surveyed in 2006.

Rock Lake is also primarily managed for walleye with population numbers higher than similar lakes in the surrounding area. Yellow perch and crappie populations are comparable to surrounding lakes and black bullhead and carp numbers are low.

Goose Lake has walleye, yellow perch, and black crappie populations that are similar to surrounding lakes of this size. The black bullhead numbers dropped considerably from the sampling event previous to 2003. Goose Lake is also aerated and had a system upgrade in 2002.

Table 1. Lake Morphometry and Watershed Characteristics

*Watersheds estimated based on USGS Interactive Watershed Web Application and DNR Data Deli Hydrologic Units

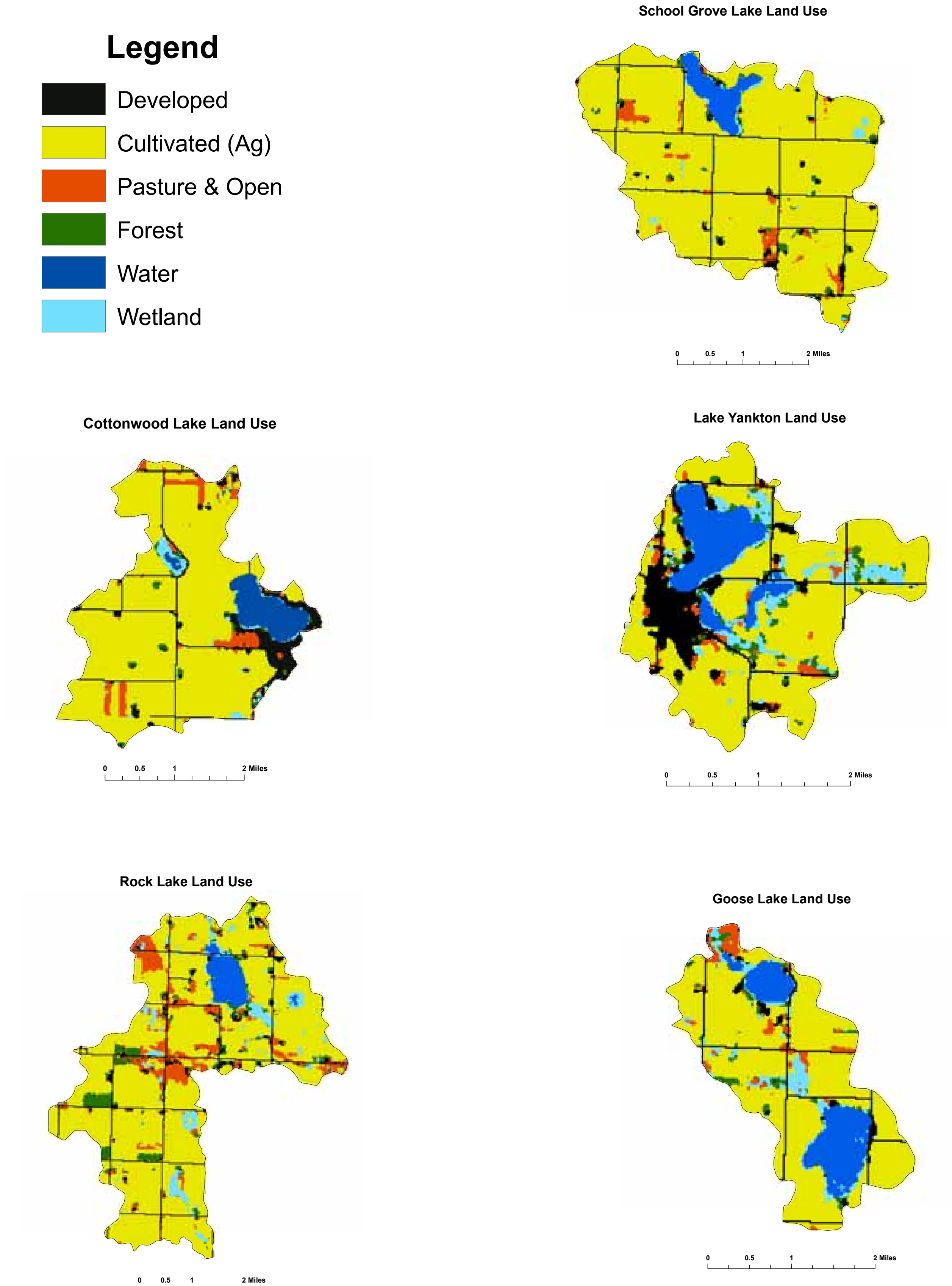
Lake Name	Lake ID	Lake Basin	Littoral Area		Immediate Watershed	Total Watershed Area*	Total Watershed To Lake	Max. Depth	Mean Depth**	Lake Volume
		Acres	Acres	% Littoral	Acres	Acres	Ratio	Ft.	Ft.	Acre-Ft.
School Grove	42-0002	318	318	100	1,431	1,984	6:1	11	7	2261
Cottonwood	42-0014	323	323	100	2,044	13,760	42:1	7	5	1751
Yankton	42-0047	401	387	100	960	960	2:1	8	6	Data NA
Rock	42-0052	375	422	100	2,752	2,752	7:1	7	5	Data NA
Goose	42-0093	139	139	100	960	960	7:1	9	7	931

**Mean depths estimated based on MDNR bathymetric maps and field inspection.

Table 2. Watershed Land Use as Compared to Ecoregion Interquartile Ranges

Land Use (%)	School Grove	Cottonwood	Yankton	Rock	Goose	WCBP Ecoregion	NGP Ecoregion
Forest	2	1	4	4	3	0 – 15	0 - 1
Water/wetlands	5	9	21	9	22	3 – 26	8 - 26
Pasture/grasslands	3	4	3	8	4	0 – 7	5 - 15
Cultivated	85	77	58	73	66	42 - 75	60 - 82
Urban	5	9	14	6	5	0 - 16	0 - 2

Figure 4. Land Use for Lyon County Lakes



Methods

Water quality data for the Lyon County lakes were collected in May, June, July, August, and September 2007. Lake surface samples were collected with an integrated sampler, a Poly Vinyl Chloride (PVC) tube 6.6 feet (two meters) in length with an inside diameter of 1.24 inches (3.2 centimeters). Depth samples were collected with a Kemmerer depth sampler. Zooplankton samples were collected with a Wisconsin plankton net. Phytoplankton (algae) samples were taken at each primary site with an integrated sampler. Summer-means were calculated using June - September data.

Sampling procedures were employed as described in the MPCA Quality Control Manual. Laboratory analysis was performed by the laboratory of the Minnesota Department of Health using EPA approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride and chlorophyll-*a*. Temperature and dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken. Phytoplankton samples were analyzed at the MPCA by Dr. Howard Markus.

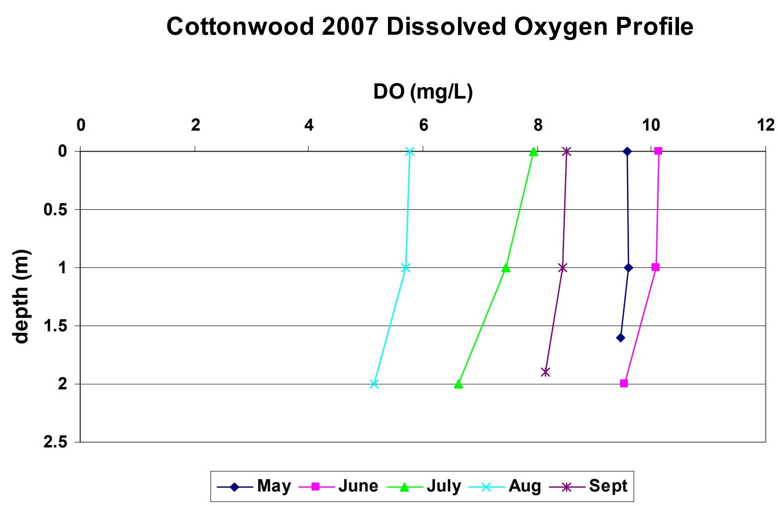
Table 3. 2007 Lake Summer Mean Water Quality

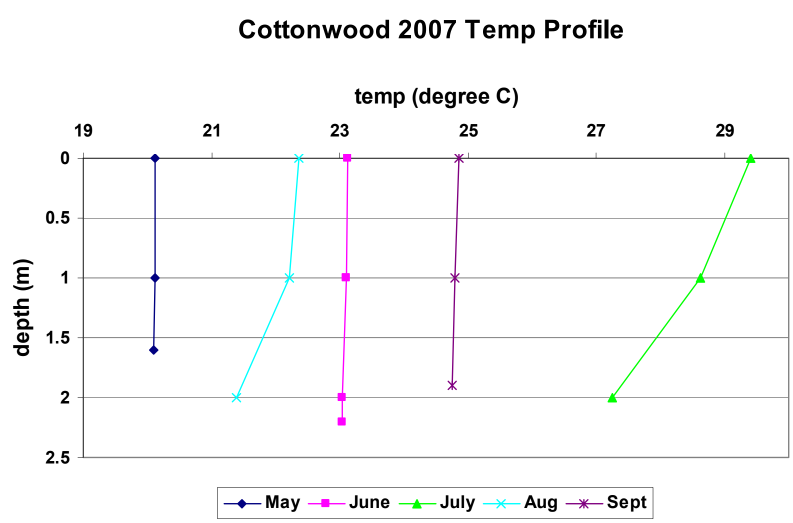
Parameter	Cottonwood	Goose	Yankton	School Grove	Rock	WCBP	NGP
Total Phosphorus (µg/L)	187	126	128	111	187	65 - 150	122 - 160
Chlorophyll mean (µg/L)	205	40	44	44	26	30 - 80	36 - 61
Chlorophyll max (µg/L)	322	106	81	79	47	60 - 140	66 - 88
Secchi Disk (feet) (meters)	0.75 0.2	1.4 0.4	0.8 0.3	1.4 0.4	0.8 0.3	1.6 - 3.3 0.5 - 1.0	1.3 – 2..6 0.4 – 0.8
Total Kjeldahl Nitrogen (mg/L)	3.8	2	2.3	2.3	2.1	1.3 - 2.7	1.8 - 2.3
Alkalinity (mg/L)	122	184	143	277	156	125 - 165	160 - 260
Color (Pt-Co Units)	22	13	12	13	15	15 - 25	20 - 30
pH (SU)	8.9	8.4	8.5	8.5	8.3	8.2 - 9.0	8.3 - 8.6
Chloride (mg/L)	31	17	34	31	21	13 - 22	11 - 18
Total Suspended Solids (mg/L)	42	36	36	36	31	7 - 18	10 - 30
Total Suspended Inorganic Solids (mg/L)	11	27	26	26	24	3 - 9	5 - 15
Conductivity (umhos/cm)	1495	851	865	1,298	752	300 - 650	640 - 900
TN:TP ratio	20:1	16:1	12:1	7:1	11:1	17:1 - 27:1	13:1 - 17:1

Results Cottonwood Lake
Western Corn Belt Plains(WCBP)

Dissolved oxygen and temperature profiles were taken monthly at site 101. The lake was well mixed on all dates, with all the DO levels remaining above 5 mg/L (milligrams per liter) to the bottom of the lake (2.1 meters) (Figure 5). The temperature profile also indicates a well-mixed lake, with temperatures remaining constant throughout the water column. These profiles indicate that Cottonwood Lake is polymictic (continuously-mixing).

Figure 5. Cottonwood Lake Dissolved Oxygen and Temperature Profiles



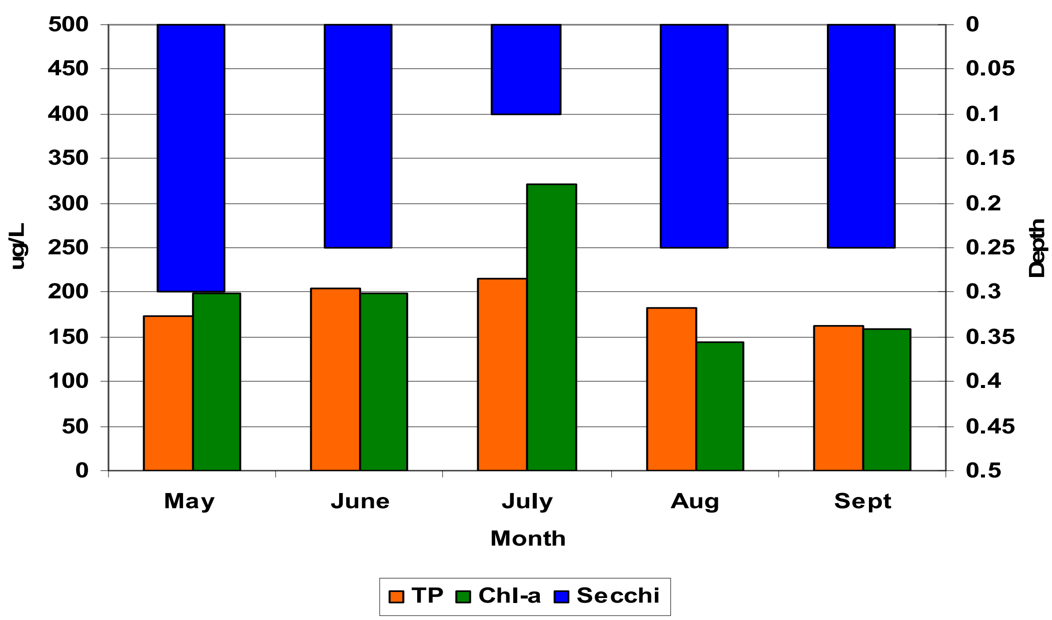


Total phosphorus (TP) concentrations averaged 187 µg/L (micro grams per liter) during the summer of 2007, with a minimum of 162 µg/L in early September and a maximum of 215 µg/L in July (Figure 6). The average TP for Cottonwood Lake falls above the range of expected values for the both WCBP and NGP ecoregions (Table 3).

Chlorophyll-a (Chl-a) concentrations for 2007 on Cottonwood Lake averaged 205 µg/L, with a low of 145 µg/L in late August and a high of 322 µg/L in July (Figure 6). Concentrations greater than 30 µg/L are frequently perceived as a severe nuisance bloom. Considering this, high algae blooms were evident during all sampling trips and a green water color was observed for the entire season. Both the average and maximum chl-*a* values were well above the typical range for NGP and WCBP ecoregion lakes (Table 3). Chl-*a* followed a similar pattern as total phosphorus; concentrations peaked in mid-summer and then declined in concentration for the remainder of the season.

Secchi disk transparency on Cottonwood Lake averaged 0.2 meters (0.75 feet) with a range of 0.1 – 0.3 m during the summer of 2007 (Figure 6). Color averaged 22 Platinum Cobalt Units (Pt-Co Units) and total suspended solids (TSS) averaged 42 mg/L. Color is within the typical ranges of both ecoregional values and TSS is well above the range of values (Table 3). The average Secchi depth is also below the typical values of each ecoregion. The change in the transparency of Cottonwood Lake over the course of the summer closely mirrored the changes in nutrient availability TP and algal production chl-*a*. Transparency was the greatest in the spring when the waters were cool and algal production was relatively low. As the chl-*a* concentrations increased, the Secchi depth generally decreased. In fall, as the waters cooled and chl-*a* concentrations decreased, the transparency improved.

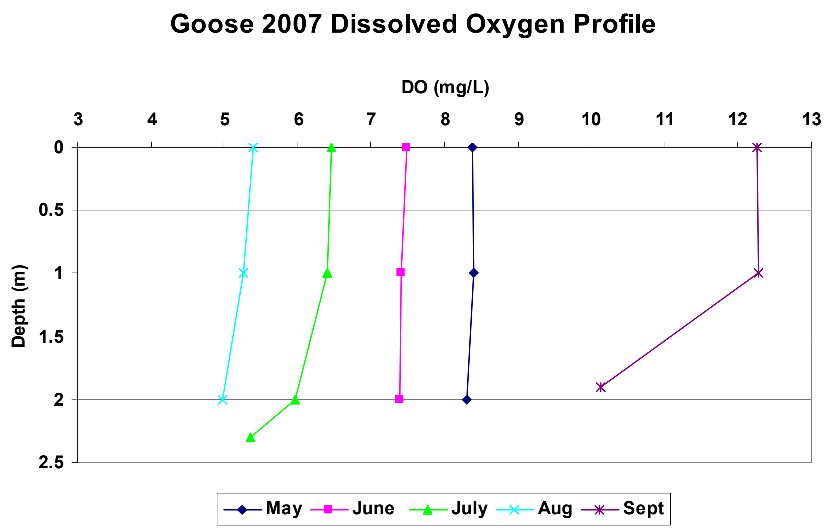
Figure 6. Cottonwood Lake Total Phosphorus and Chlorphyll-a Concentrations and Secchi Depth

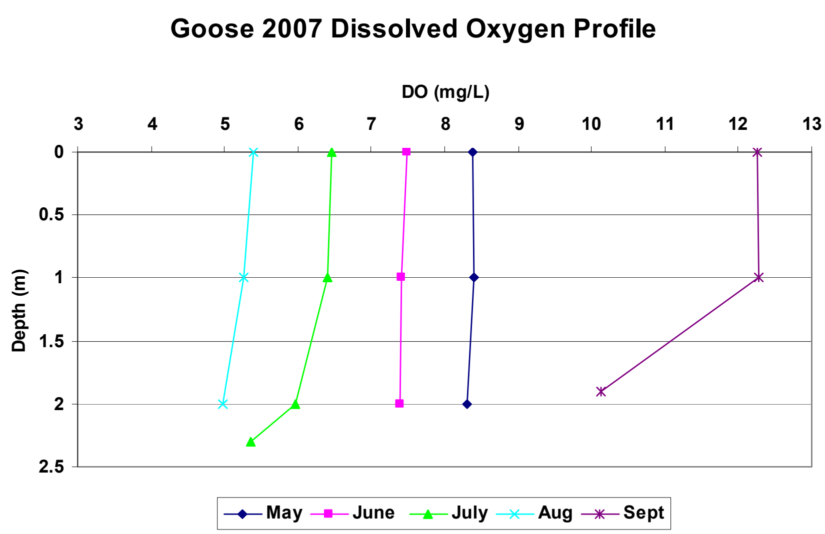


Results: Goose Lake (NGP)

Dissolved oxygen and temperature profiles were taken monthly at site 101. The lake was well-mixed on all dates, with all the DO levels remaining above 5 mg/L to the bottom of the lake (2.7 m) (Figure 7). The temperature profile also indicates a well-mixed lake, with temperatures remaining fairly constant throughout the water column. These profiles indicate that Goose Lake is polymictic (continuously mixing).

Figure 7. Goose Lake Dissolved Oxygen and Temperature Profiles



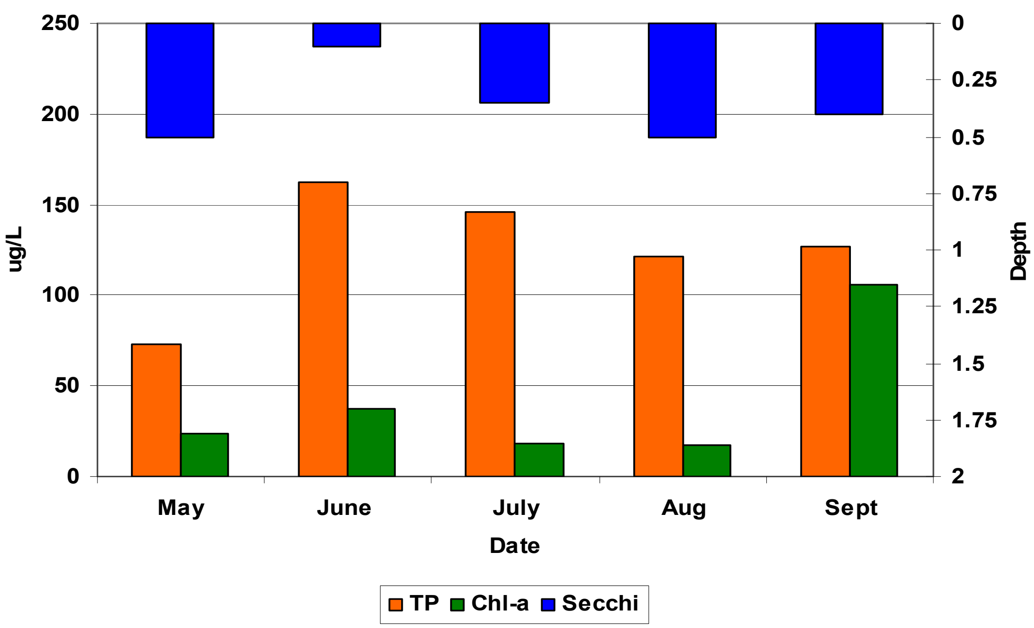


Total phosphorus concentrations averaged 126 µg/L during the summer of 2007, with a minimum of 73 µg/L in late May and a maximum of 162 µg/L in June (Figure 8). The average TO for Goose Lake falls within the range of expected values for the both WCBP and NGP ecoregions (Table 3).

Chlorophyll-a concentrations for 2007 on Goose Lake averaged 40 µg/L, with a low of 17 µg/L in late August and a high of 37.5 µg/L in June (Figure 8). Goose Lake also had the lowest chl-*a* concentrations of the Lyon County lakes. Concentrations from 10-20 µg/L are frequently perceived as a mild algal bloom, 20-30 µg/L is a nuisance bloom, and over 30 µg/L is a severe nuisance. Considering this, mild algae blooms were evident during the May, July, and September sampling trips. The average chl-*a* values were within the typical range for both ecoregions (Table 3). The maximum value exceeded expected levels for the NGP ecoregion. Chlorphyll-a followed a similar pattern as total phosphorus; however, a large algae bloom occurred in September.

Secchi disk transparency on Goose Lake averaged 0.4 m (1.4 feet) with a range of 0.1 – 0.5 m during the summer of 2007 (Figure 8). Color averaged 13 Pt-Co Units and total suspended solids averaged 36 mg/L. Color is below the typical ranges of both ecoregion values and TSS is above the range of values (Table 3). The average Secchi depth falls within the typical values of the NGP ecoregion. The change in the transparency of Goose Lake over the course of the summer closely mirrored the changes in nutrient availability TP and algal production chl-*a*. Transparency was the greatest in the spring when the waters were cool and algal production was relatively low. As the chl-*a* concentrations increased, the Secchi depth generally decreased. In fall, as the waters cooled, the transparency improved.

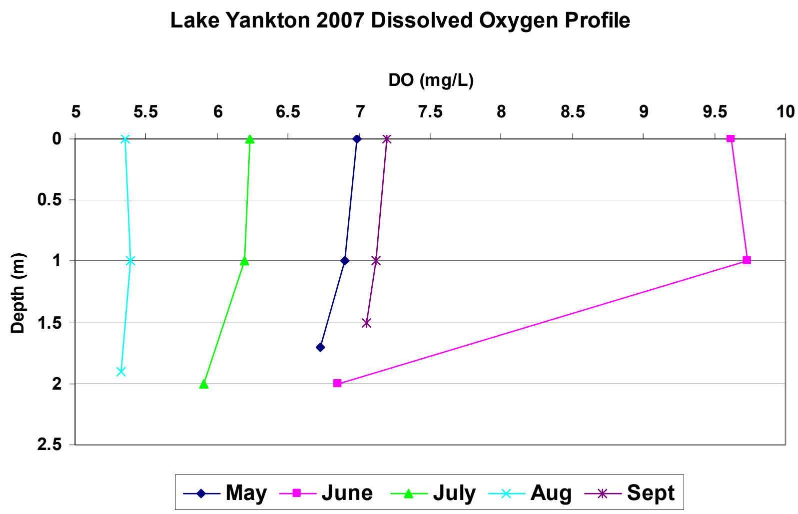
Figure 8. Goose Lake Total Phosphorus and Chlorphyll-a Concentrations and Secchi Depth

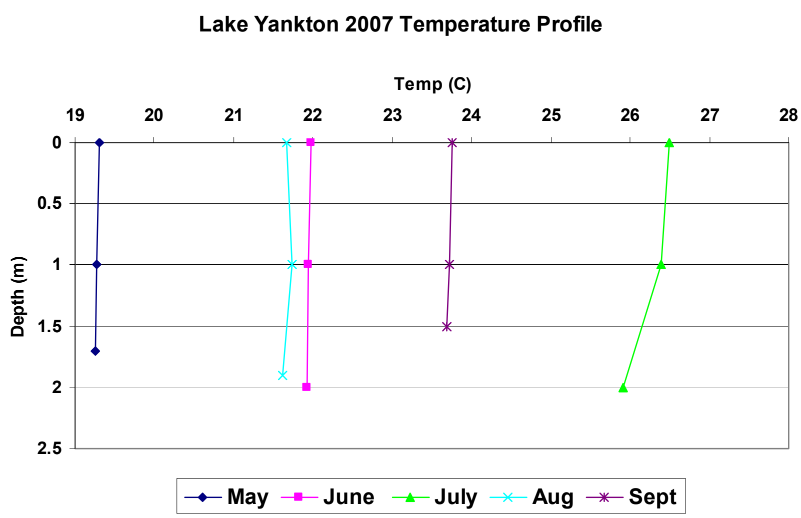


Results: Lake Yankton (NGP)

Dissolved oxygen and temperature profiles were taken monthly at site 101. The lake was well-mixed with the exception of a sharp drop in the June profile. All of the DO levels remained above 5 mg/L to the bottom of the lake (2.4 m) (Figure 9). The temperature profile also indicates a well mixed lake, with temperatures remaining constant throughout the water column. These profiles indicate that Lake Yankton is polymictic (continuously-mixing).

Figure 9. Lake Yankton Dissolved Oxygen and Temperature Profiles



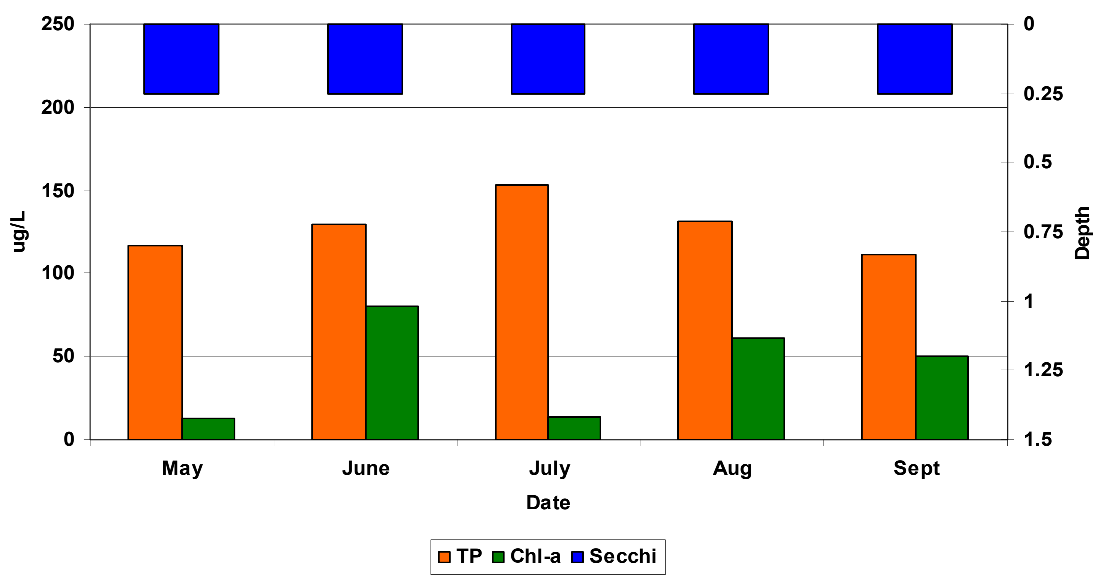


Total phosphorus concentrations averaged 128 µg/L during the summer of 2007, with a minimum of 111 µg/L in September and a maximum of 153 µg/L in July (Figure 10). During the August sampling of Lake Yankton, a thick algal scum was observed on the southern shore. An additional sample was collected at this location and the TP value was 526 µg/L. Excluding the algal scum sample collected at the shoreline, the average TP for Lake Yankton falls within the range of expected values for the both WCBP and NGP ecoregions (Table 3). Algal samples were collected and results are pending analysis.

Chlorophyll-a concentrations for 2007 on Lake Yankton averaged 44 µg/L, with a low of 13 µg/L in late May and a high of 81 µg/L in June (Figure 10). Lake Yankton also had a chl-*a* concentration spike of 1,630 µg/L near the lake access where the scum was located. Concentrations from 10-20 µg/L are frequently perceived as a mild algal bloom, 20-30 µg/L is a nuisance bloom, and over 30 µg/L is a severe nuisance. Combined with high nutrient levels and a dry hot summer a severe algal scum developed during the August sampling trip; however, excluding the spike due to the scum, the average and total chl-*a* values were within the typical range for both ecoregions (Table 3). Chlorophyll-a followed a near similar pattern as TP; concentrations peaked in mid summer and then declined in concentration for the remainder of the season.

Secchi disk transparency on Lake Yankton was 0.25 meters (0.8 feet) at each sampling event in 2007 (Figure 10). Color averaged 12 Pt-Co Units and total suspended solids averaged 36 mg/L. Color is below the typical ranges of both ecoregion values and TSS is above the range of values for each ecoregion (Table 3). The average Secchi depth falls below the typical values of the NGP and WCBP ecoregions. The transparency of Lake Yankton over the course of the summer closely mirrored the nutrient availability TP and algal production chl-*a*. Nutrient availability was consistently high throughout the season and Lake Yankton had the highest value for Total Suspended Inorganic Solids (TSIS), which would have also contributed to the low Secchi values.

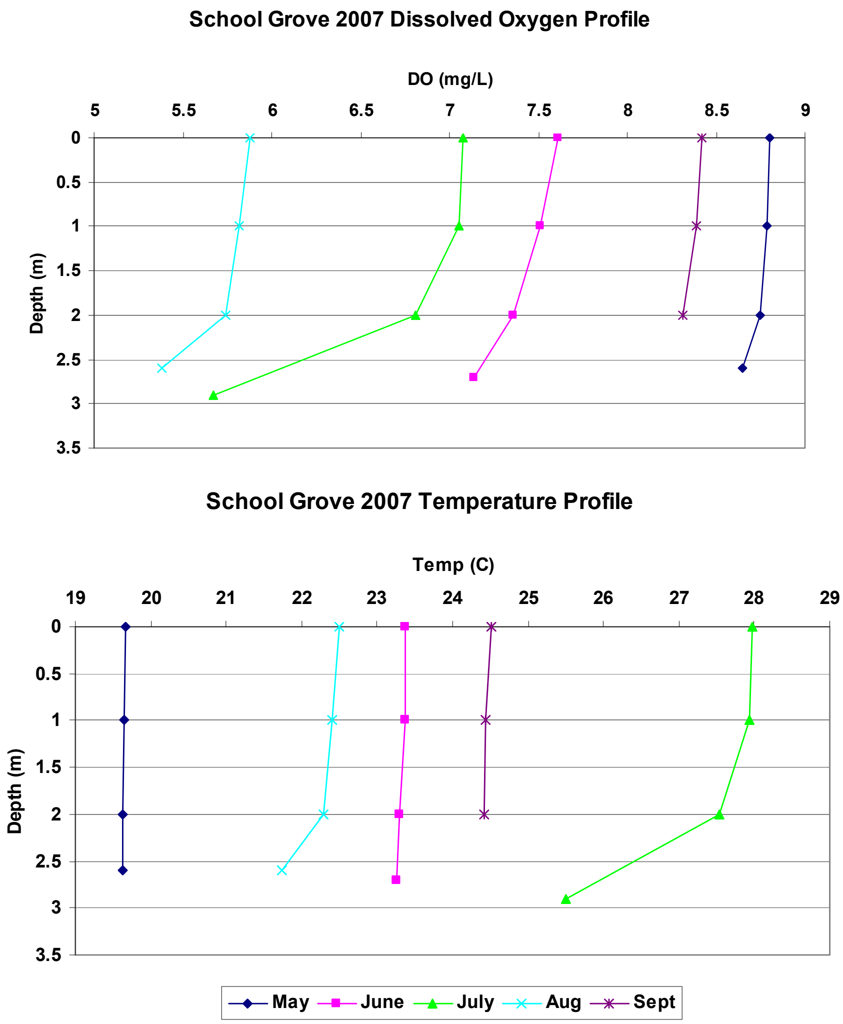
Figure 10. Lake Yankton Total Phosphorus and Chlorphyll-a Concentrations and Secchi Depth



Results: School Grove Lake (NGP)

Dissolved oxygen and temperature profiles were taken monthly at site 101. The lake was well mixed on all dates with DO concentrations remaining above 5 mg/L. All of the DO levels remained above 5 mg/L to the bottom of the lake (2.4 m) (Figure 11). The temperature profile also indicates a well mixed lake, with temperatures remaining constant throughout the water column. These profiles indicate that School Grove Lake is polymictic (continuously mixing).

Figure 11. School Grove Lake Dissolved Oxygen and Temperature Profiles

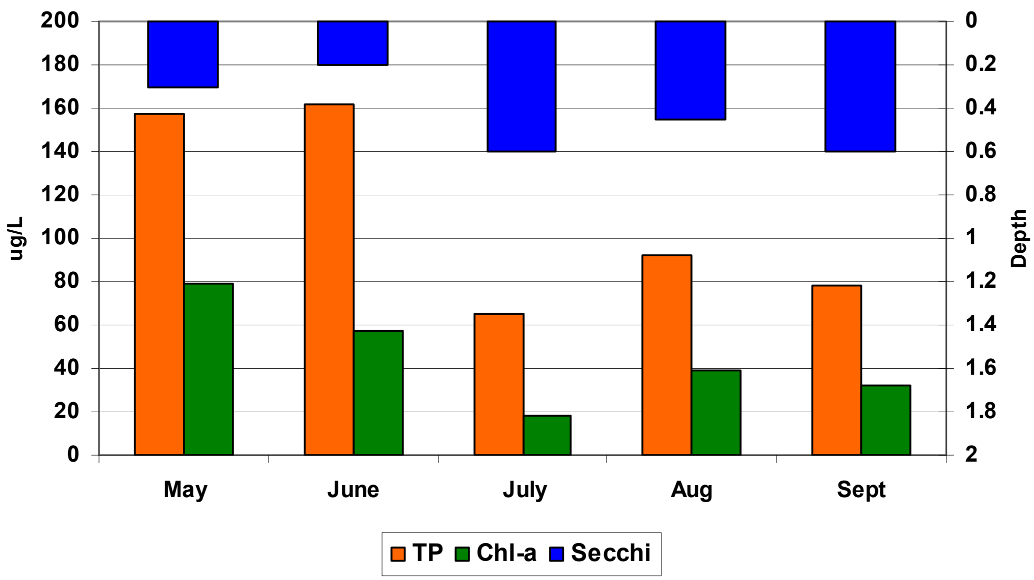


Total phosphorus concentrations averaged 111µg/L during the summer of 2007, with a minimum of 65µg/L in July and a maximum of 162µg/L in June (Figure 12). School Grove Lake had the lowest level of TP of the lakes sampled in Lyon County. The average TO for School Grove Lake falls within the range of expected values for the both WCBP and NGP ecoregions (Table 3).

Chlorophyll-a concentrations for 2007 on School Grove Lake averaged 44 µg/L, with a low of 18 µg/L in July and a high of 79 µg/L in late May (Figure 12). Concentrations above 30 µg/L are frequently perceived as a severe nuisance bloom. Both the average and maximum chl-*a* values were within the typical range for NGP and WCBP ecoregion lakes (Table 3). Chlorphyll-a followed a similar pattern as TP in 2007.

Secchi disk transparency on School Grove Lake averaged 0.4 meters (1.4 feet) with a range of 0.2 – 0.6 m during the summer of 2007 (Figure 12). Color averaged 13 Pt-Co Units and total suspended solids averaged 36 mg/L. Color is below the typical ranges of both ecoregion values and TSS is above the range of values (Table 3). The average Secchi depth falls within the typical values of the NGP ecoregion. The change in the transparency of School Grove Lake over the course of the summer closely mirrored the changes in nutrient availability TP and algal production chl-*a*. Transparency was the greatest in the spring when the waters were cool and algal production was relatively low. As the chl-*a* concentrations increased, the Secchi depth generally decreased. In fall, as the waters cooled and chl-*a* concentrations decreased, the transparency improved.

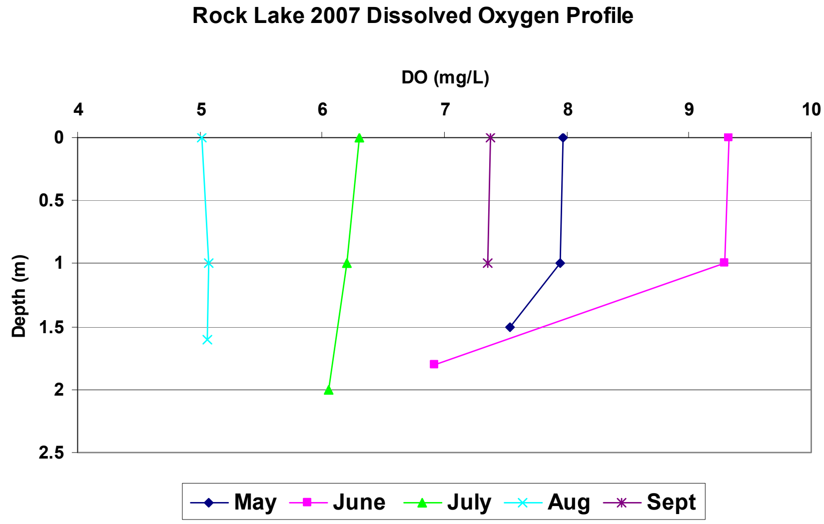
Figure 12. School Grove Lake Total Phosphorus and Chlorphyll-a Concentrations and Secchi Depth

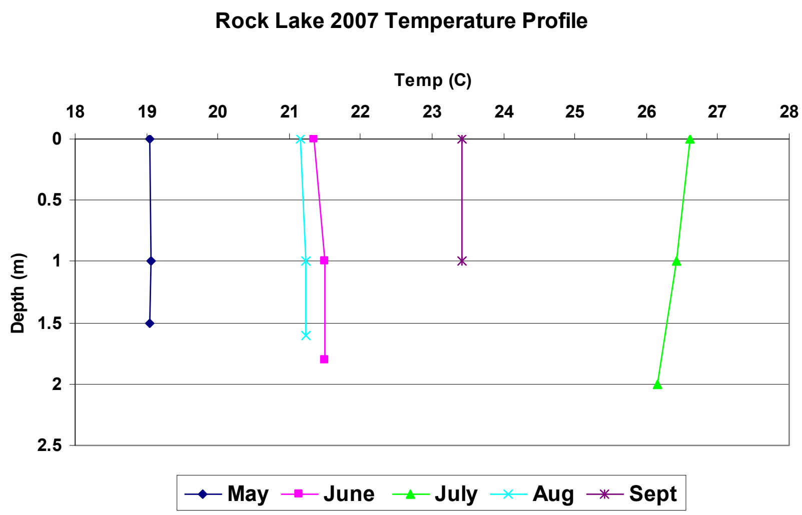


Results: Rock Lake (NGP)

Dissolved oxygen and temperature profiles were taken monthly at site 101. The lake was well-mixed on all dates with DO concentrations remaining above 5 mg/L to the bottom of the lake (2.4 m) (Figure 13). The temperature profile also indicates a well-mixed lake, with temperatures remaining constant throughout the water column. These profiles indicate that Rock Lake is polymictic (continuously-mixing).

Figure 13. Rock Lake Dissolved Oxygen and Temperature Profiles



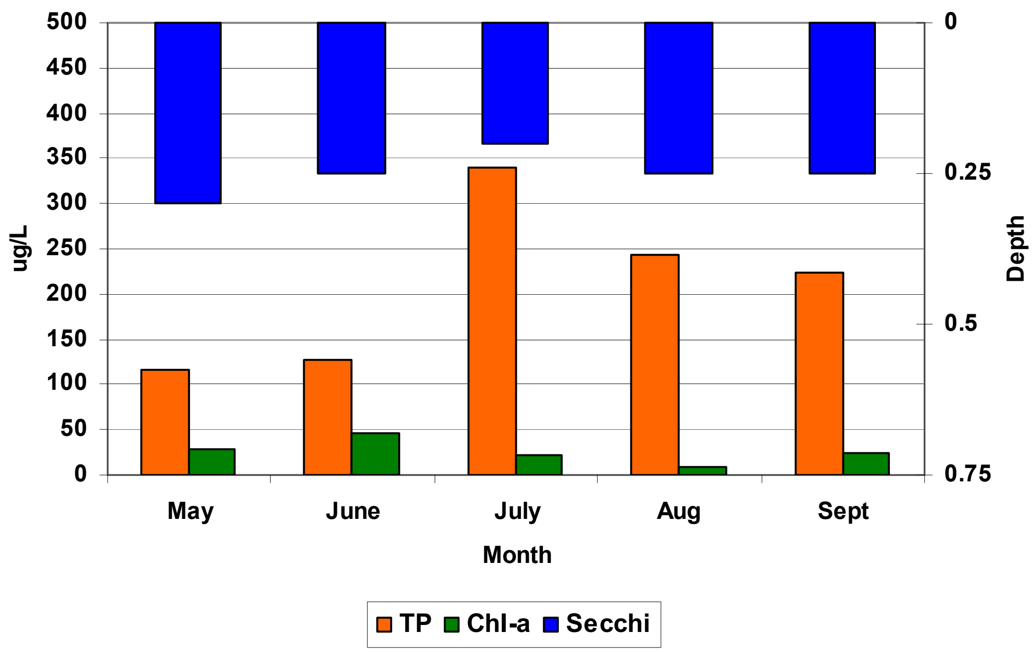


Total Phosphorus concentrations averaged 187 µg/L during the summer of 2007, with a minimum of 116 µg/L in May and a maximum of 339 µg/L in July (Figure 14). The average TP value for Rock Lake is above the typical range for the WCBP and NGP ecoregions (Table 3).

Chlorophyll-a concentrations for 2007 on Rock Lake averaged 26 µg/L, with a low of 21 µg/L in July and a high of 47 µg/L in late May (Figure 14). Concentrations from 20-30 µg/L are frequently perceived as a nuisance algal bloom. Both the average and maximum chl-*a* values were below the typical range for NGP and WCBP ecoregion lakes (Table 3). Chlorophyll-a nearly followed a similar pattern as TP; concentrations peaked earlier in the summer and then dropped for the remainder of the season.

Secchi disk transparency on Rock Lake averaged 0.25 meters (0.8 feet) with a range of 0.2 – 0.3 m during the summer of 2007 (Figure 14). Color averaged 15 Pt-Co Units and total suspended solids averaged 31 mg/L. Color is below the typical ranges of the NGP ecoregion value and TSS is above the range of values (Table 3). The average Secchi depth falls below the typical values of the NGP ecoregion. The change in the transparency of Rock Lake over the course of the summer closely mirrored the changes in nutrient availability TP and algal production chl-*a*. Transparency was the greatest in the spring when the waters were cool and algal production was relatively low. As the chl-*a* concentrations increased, the Secchi depth generally decreased. In fall, as the waters cooled, the transparency improved.

Figure 14. Rock Lake Total Phosphorus and Chlorphyll-*a* Concentrations and Secchi Depth



Trophic State Index (TSI)

Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, chl-*a* and Secchi for the lakes (Figure 16). In general, the TSI values are in fairly close correspondence with each other. All of the lakes in Lyon County are classified as hypereutrophic.

All of the lakes showed high levels of TP with Cottonwood and Rock showing exceedingly high nutrient values. Nearly all of the lakes had corresponding high levels of chl-*a* with the exception of Rock Lake.

Rock Lake had a chl-*a* TSI value slightly low relative to TP. This suggests that Rock Lake has the potential for higher chl-*a* based on TP, but some factors such as light exclusion, rooted plant growth, and/or grazing zooplankton may limit algal production.

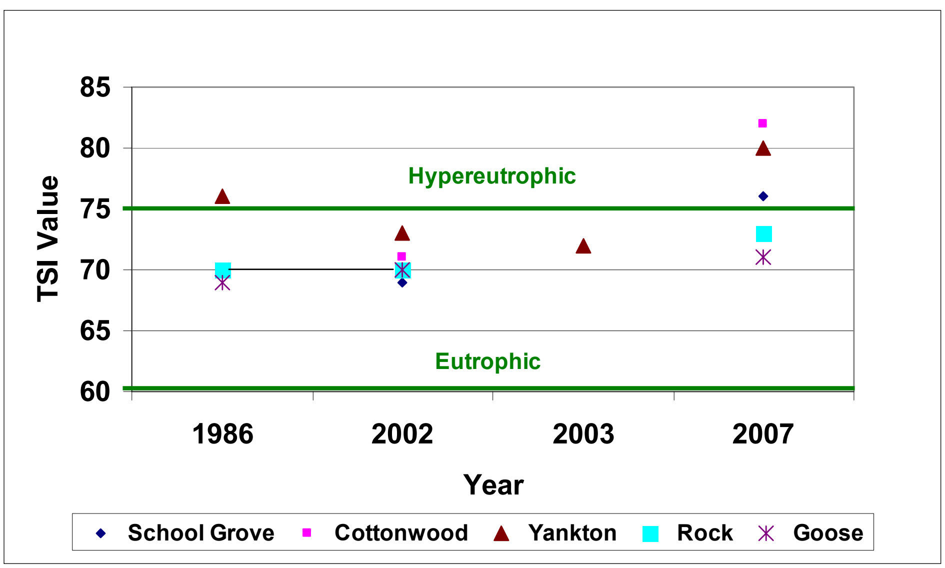
Secchi TSI values closely corresponded to TP TSI for the lakes in this study. School Grove and Cottonwood had the lowest transparency (higher TSI) based on TP.

Finally, chl-*a* and Secchi TSI were in good correspondences for most lakes. Rock Lake had lower transparency (higher TSI) with a low chl-*a* TSI value than anticipated. This may be in part due to the elevated total suspended inorganic solids in the lake. This may have interfered with light penetration into the water column and therefore reduced the transparency. All of the Lyon County lakes were at the high end of or above the range for total suspended solids and total inorganic suspended solids in each ecoregion.

Trophic Status Trend Data

One aspect of lake monitoring is to assess trends in the condition of the lakes where possible based on MPCA, Citizen Lake Monitoring Program, or other available data in STORET. A review of data in STORET indicates there is minimal data for these lakes. None of the lakes have sufficient data to statistically assess trends, since this program typically seeks a minimum of eight years of data. However, based on available data (Figure 15), all of the lakes have had a TSI value greater than 60, and have all maintained values that would classify them as hypereutrophic each year of sampling.

Figure 15. Lyon County Lakes Trophic Status 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 2007 water quality of Lyon County lakes, MINLEAP (Wilson and Walker, 1989) was used.

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). For analysis of lakes included in this study, MINLEAP was applied as a basis for comparing the observed (2007) TP, chl-*a* and Secchi values with those predicted by the model based on the size, depth and size of the watershed for each lake.

The lakes in this study are all located near the border of the NGP and WCBP ecoregions. The watersheds are all dominated by agricultural use and drain from the NGP into the WCPB ecoregion. Cottonwood and School Grove lakes were run using WCBP ecoregion-based inputs. Goose, Yankton, and Rock lakes were run with NGP inputs. It should be noted that the model predicts in-lake TP from these inputs and subsequently predicts chl-*a* based on a regression equation of TP and Secchi based on a regression equation based on chl-*a*. A comparison of MINLEAP predicted vs. observed values is presented in Table 6.

There was often a difference between observed and MINLEAP predicted TP for most of the lakes in this report. In simple terms, this means that the observed TP is not consistent with that expected for a lake of its size, depth, and watershed area in the NGP or WCBP ecoregions. For Cottonwood and Goose Lakes, the model predicted significantly higher TP concentrations than what was observed. Cottonwood Lake lies within a large watershed relative to the lake surface area; however, contributing flow to the lake is low. The model does not take this into account and will produce a high predicted value. Goose is similar in that little to no flow from the surrounding watershed contributes to the TP within the lake. All of the lakes had high TSS values that would also indicate internal TP loading. This is caused by continuous mixing that stirs sediment from the bottom and releases nutrients into the lake. School Grove, Yankton, and Rock Lakes had relatively close observed and predicted values for the summer of 2007. All five lakes exceeded the 90 µg/l draft nutrient criteria for lakes in the NGP and WCBP ecoregions (Table 4). This suggests the possibility that these lakes could be included on a future impaired waters listing; however, further data would be needed to complete an aquatic use recreation assessment of the lakes.

303(d) Assessment and Goal Setting

The federal Clean Water Act requires states to adopt water-quality standards to protect waters from pollution. These standards define how much of a pollutant can be in the water and still allow it to meet designated uses, such as drinking water, fishing and swimming. The standards are set on a wide range of pollutants, including bacteria, nutrients, turbidity and mercury. A water body is “impaired” if it fails to meet one or more water quality standards.

Under Section 303(d) of the Clean Water Act the state is required to asses all waters of the state to determine if they meet water-quality standards. Waters that do not meet standards are added to the 303(d) list and updated every even-numbered year. Once the waters are listed, an investigative study (termed a Total Maximum Daily Load (TMDL) study) is conducted to determine the source of the pollution and to set pollutant reduction goals needed to restore the waters. The MPCA is responsible for performing assessment activities, listing impaired waters, and conducting TMDL in Minnesota.

According to Table 4 the phosphorus standard for shallow lakes in the WCBP and NGP ecoregion is less than 90 µg/L for support of aquatic recreation use. For Cottonwood and Rock Lakes, it would be desirable to reduce in-lake TP concentrations from levels observed in 2007. Should in-lake TP concentrations increase, it is likely that the frequency of nuisance algal blooms would increase resulting in a degradation of transparency. All of the lakes exceeded the 90 µg/L TO criteria, and had less transparency than the Secchi criteria of greater than 0.7 meters (Table 5). It would be important to reduce as much external phosphorus loading to the lake as possible to reduce the current concentrations. Considering the depth of the lakes, it appears that internal loading of phosphorus will continue to be a considerable source of nutrients to the lake.

Important considerations include land use practices in the shore land and watershed area of the lake. A more comprehensive review of land use practices in the watershed may reveal opportunities for implementing BMPs in the watershed and reducing phosphorus loading to the lake.

Table 4. Eutrophication Standard 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
WCBP & NGP – Aquatic Rec. Use (Class 2B)	< 65	< 22	> 0.9
WCBP & NGP – Aquatic Rec. Use (Class 2b) shallow lakes	< 90	< 30	> 0.7

Table 5. Lyon County Lakes Aquatic Recreational Use Comparison

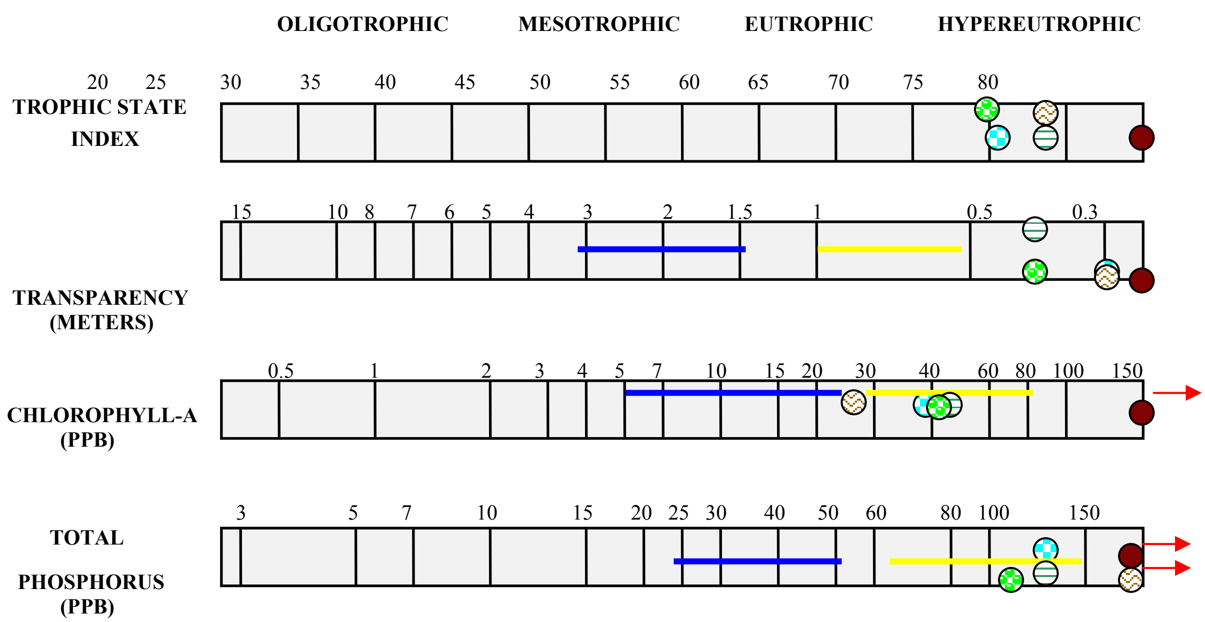
Ecoregion	TP	Chl-*a*	Secchi
WCBP & NGP – Aquatic Rec. Use (Class 2b) shallow lakes	< 90	< 30	> 0.7
Lyon County Lakes (2007)	TP	Chl-*a*	Secchi
School Grove	352	44	0.4
Cottonwood	187	205	0.2
Yankton	128	44	0.3
Goose	126	40	0.4
Rock	187	26	0.3

Table 6. Observed and Modeled Summer Mean Total Phosphorus, Chlorphyll-a, and Secchi

Parameter	200 Cottonwood Observed	Cottonwood MINLEAP Predicted WCBP	2007 Goose Observed	Goose MINLEAP Predicted	2007 Yankton Observed	Yankton MINLEAP Predicted WCBP	2007 School Grove Observed	School Grove MINLEAP Predicted WCBP	2007 Rock Observed	Rock MINLEAP Predicted NGP
TP (µg/L)	187	232	126	215	128	132	111	98	187	146
Chl-*a* (µg/L)	205	188	40	168	44	82.5	44	54	26	96
Secchi (m)	0.2	0.4	0.4	0.4	0.25	0.6	0.4	0.7	0.25	0.5
P-Loading Rate (kg/yr)	--	4,117	--	1,002	--	922	--	626	--	871
% P Retention	--	59	--	87	--	94	--	83	--	94
P inflow (µg/L)	--	569	--	1,700	--	2,378	--	565	--	2,350
Water Load (m/yr)	--	5.6	--	1.1	--	0.3	--	0.9	--	0.3
Outflow volume (hm3/yr)	--	7.2	--	0.6	--	0.4	--	1.1	--	0.4
Background P	--	32.3	--	33.7	--	32.1	--	37.9	--	35.1
Residence time (Years)	--	0.3	--	1.9	--	7.5	--	2.4	--	6.1

Figure 16. Carlson's Trophic State Index for Lyon County 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 scum 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 scum, summer fish kills, few macrophytes, dominance of rough fish.



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NGP Ecoregion Range: (blue line)
WCBP Ecoregion Range (yellow line)

Cottonwood:
Yankton:
Rock
School Grove:
Goose:

Appendix A

Glossary

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

Algal Bloom: An unusual or excessive abundance of algae.

Alkalinity: Capacity of a lake to neutralize acid.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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. 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 µg/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 µg/l

TSI = Carlson's TSI (P=TP, S=Secchi, C=Chla)

PHEO = pheophytin in µg/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

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Appendix D

2007 Surface Water Results

Lake Name	Lake ID	Sample Date	Site ID	Sample Depth	Secchi	TP	Chl-*a*	Total Alk	Cl	TKN	Color, Appearent	TSS	VSS
				Meters	Meters	µg/l	µg/l	mg/l	mg/l	mg/l	PCU	mg/l	mg/l
School Grove	42-0002	5/29/07	101	3	0.3	154	78.9	280	27	2.94	20	57	14
School Grove	42-0002	6/19/07	101	2.7	0.2	162	57.2	280	30	2.62	20	69	14
School Grove	42-0002	7/24/07	101	2.8	0.6	65	18.4	290	32	2.06	5	14	6.4
School Grove	42-0002	8/29/07	101	2.8	0.5	92	37.8	270	31	2.11	7.5	27.5	10
School Grove	42-0002	9/5/07	101	2.7	0.6	78	31.9	270	32	2.12	20	20	8.4
Cottonwood	42-0014	5/29/07	101	2	0.3	173	199	130	29	3.59	20	49	26
Cottonwood	42-0014	6/19/07	101	2.2	0.3	204	198	130	31	3.62	20	49	30
Cottonwood	42-0014	7/24/07	101	2	0.1	215	322	120	34	2.53	30	46	40
Cottonwood	42-0014	8/29/07	101	2.2	0.3	183	145	110	31	4.68	20	36	32
Cottonwood	42-0014	9/5/07	101	2.1	0.3	162	159	120	32	4.42	20	28	28
Yankton	42-0047	5/30/07	101	2	0.3	117	12.5	150	30	1.91	10	42	6.4
Yankton	42-0047	6/20/07	101	2.2	0.3	130	80.7	140	33	2.28	5	32	10
Yankton	42-0047	7/25/07	101	2	0.3	153	14	160	36	2.53	20	26	6.4
Yankton	42-0047	8/30/07	100	S. Shoreline		526	1630	140					
Yankton	42-0047	8/30/07	101	2.1	0.3	131	61.1	140	36	2.48	5	42	15
Yankton	42-0047	9/6/07	101	2	0.3	111	50	130	37	2.52	20	38	11
Rock	42-0052	5/30/07	101	2	0.3	121	29.8	140	18.5	1.68	12.5	29	7.35
Rock	42-0052	6/20/07	101	2.1	0.3	128	47	140	20	1.68	5	30	11
Rock	42-0052	7/25/07	101	2	0.2	239	21.3	160	22	3.03	20	17	5.2
Rock	42-0052	8/30/07	101	1.8	0.3	243	8.36	170	23	2.34	5	26	6
Rock	42-0052	9/6/07	101	2	0.3	229	22.75	170	23.5	2.165	25	42	7.3
Goose	42-0093	5/30/07	101	2.5	0.5	73	23.5	180	15	2.05	20	21	6.8
Goose	42-0093	6/20/07	101	2.1	0.1	162	37.5	200	16	1.75	10	77	13
Goose	42-0093	7/25/07	101	2.4	0.4	146	17.8	200	18	1.99	20	22	5.2
Goose	42-0093	8/30/07	101	2.4	0.5	121	17.4	180	17	1.75	5	24	5.2
Goose	42-0093	9/5/2007	101	2.5	0.4	127	106	160	18	2.62	10	34	13