Lake Hendricks (41-0110)
Lake Assessment Report

Lincoln County, Minnesota
Brookings County, South Dakota

Environmental Analysis & Outcomes Division
Water Monitoring Section
April 2009

Minnesota Pollution Control Agency

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wq-lar41-0110

Table of Contents

Appendices

LIST OF TABLES

Table of Contents, continued

LIST OF FIGURES

Executive Summary

The Minnesota Pollution Control Agency (MPCA) conducts and supports lake monitoring for a variety of objectives. Staff within the MPCA's Lakes and Streams Monitoring Unit samples approximately 100 lakes per year, coordinates citizen volunteer monitoring through the Citizen Lake Monitoring Program, and manages Surface Water Assessment Grants given to local groups to monitor lake water quality. All of the data from these activities are used to assess the condition of Minnesota lakes. Water quality data are compared to state water quality standards to determine if a given lake is fully supporting or not supporting standards set for recreational use (e.g., swimming, wading, etc.). Lakes not supporting aquatic recreational use are termed 'impaired' and are placed on a list biennially. This list is formally termed the 303(d) list (referencing the section within the federal Clean Water Act that requires us to assess for condition); it is also commonly called the "Impaired Waters List". A lake placed on the Impaired Waters List is required to be intensively researched through a Total Maximum Daily Load (TMDL) study to determine the source and extent of the pollution problem. The study also requires the development of a restoration plan. The water quality data and the results of the condition assessment are incorporated into a variety of products, including lake assessment reports, status and trend/update reports, and fact sheets. Lastly, it should be noted that a great deal of additional lake monitoring is carried out by various other MPCA staff and local groups who are undertaking TMDL studies or other, special projects.

Lake Hendricks is a 1,557-acre lake in western Lincoln County within the Lac qui Parle River watershed. Hendricks, MN is on the northern shore of the lake. The lake has a maximum depth of 3.7 meters (12 feet), making it 100% littoral, and a mean depth of 1.5 meters (5 feet). There are four public accesses around the lake. The total watershed for Lake Hendricks is 24,891 acres. Lake Hendricks is located within the Northern Glaciated Plains (NGP) ecoregion.

Lake Hendricks is a shallow, polymictic lake that forms no temperature layers and is continuously mixing. Based on recent water quality data (2007-2008) presented in this report, Lake Hendricks is considered to be hypereutrophic. Increased plant growth, higher nutrient levels, and algal bloom occurrences leading to reduced transparency are all likely results. Based on the results presented in this report Lake Hendricks will be included on the 2010 303(d) list that Minnesota will submit to the United States Environmental Protection Agency.

Introduction

This report details the analysis of monitoring on Lake Hendricks in Lincoln County during the 2007 and 2008 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. Data analyzed will include all available data in STORET. Further detail on concepts and terms in this report can be found in the Guide to Lake Protection and Management: (http://www.pca.state.mn.us/water/lakeprotection.html).

This report will often make comparisons to the 1989 study for Lake Hendricks (Munson and Wilson, 1990). This report may be accessed at: http://www.pca.state.mn.us/publications/reports/lar-41-0110.pdf . This report will consider the recently collected data (2007 and 2008) as well as data used for the 1989 report located within STORET.

Background

Lake Morphometric and Watershed Characteristics

Lake Hendricks is located in west central Lincoln County within the Lac qui Parle River watershed. Hendricks, MN is on the northern shore of the lake. There are four public accesses around the lake. One is located within the town of Hendricks, one on the southern shoreline, and the remaining two are in South Dakota.

Table 1. Lake morphometric and watershed characteristics

Lake Name	Lake ID	Lake Basin	Littoral Area	Total Watershed Area	Watershed: Lake	Max. Depth	Average Depth	Lake Volume
		Acres	%	Acres	Ratio	Ft.	Ft.	Acre-Ft.
Hendricks	41-0110	1,557	100	24,891	16:1	12	5	8,000

A summary of Lake Hendricks morphometric characteristics is presented in Table 1. Percent littoral area 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 Lake Hendricks watershed lies within Lac qui Parle River major watershed. The lake's watershed has one drainage point located on the north eastern shore of the lake. The contributing watershed has a total area of 24,891 acres resulting in a watershed-to-lake area ratio of approximately 16:1. Lake Hendricks has 2 inflows and drains into the Lac qui Parle River to the north east. Watershed areas were estimated based on data from the University of Minnesota Remote and Geospatial Analysis Lab.

Lake Hendricks was formed by the irregular deposition of glacial clay-rich till from the Des Moines lobe during the Wisconsin Glaciation (Zumberge, 1952). Soils within the Minnesota watershed are medium to fine textured prairie soils of the Barnes-Aastad-Flom Association. The soils are mainly composed of dark colored soils formed from calcareous loam and glacial till (Arneman, 1963). Soils within the South Dakota portion of the watershed are of the Kranzburg-Brookings-Vienna, Forman-Buse, Singsass-Oak Lake, and Lamour associations. The soils range from well drained to poorly drained and from loamy to silty soils (SDDWNR, 1985).

Land Use Characteristics and Ecoregion

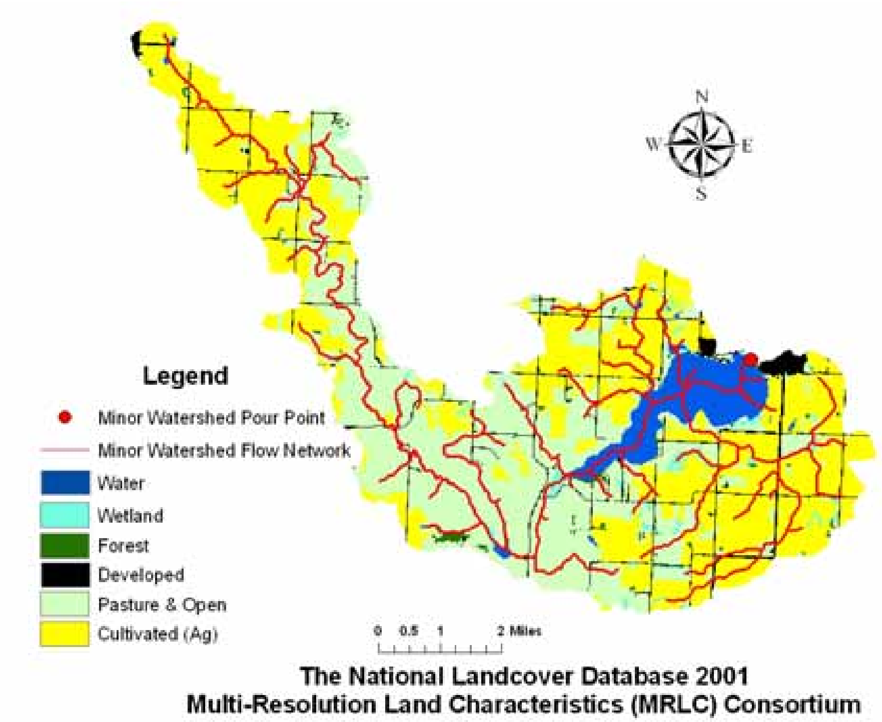
Since land use affects water quality, it has proven helpful to divide the state into regions where land use and water resources are similar. Land use in the Lake Hendricks watershed is fairly typical for this ecoregion with the exception of a large percentage of open grassland area. It should be noted that approximately 70% of the watershed lies within South Dakota (Table 2 & Figure 1).

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. Lake Hendricks lies within the Northern Glaciated Plains (NGP) ecoregion (Figure 2). NGP values will be used for land use comparisons (Table 2) and lake summer-mean water quality (Table 3). Additionally, the NGP ecoregion will be used for the MINLEAP model application.

Table 2. Lake Hendricks ecoregional land use comparison

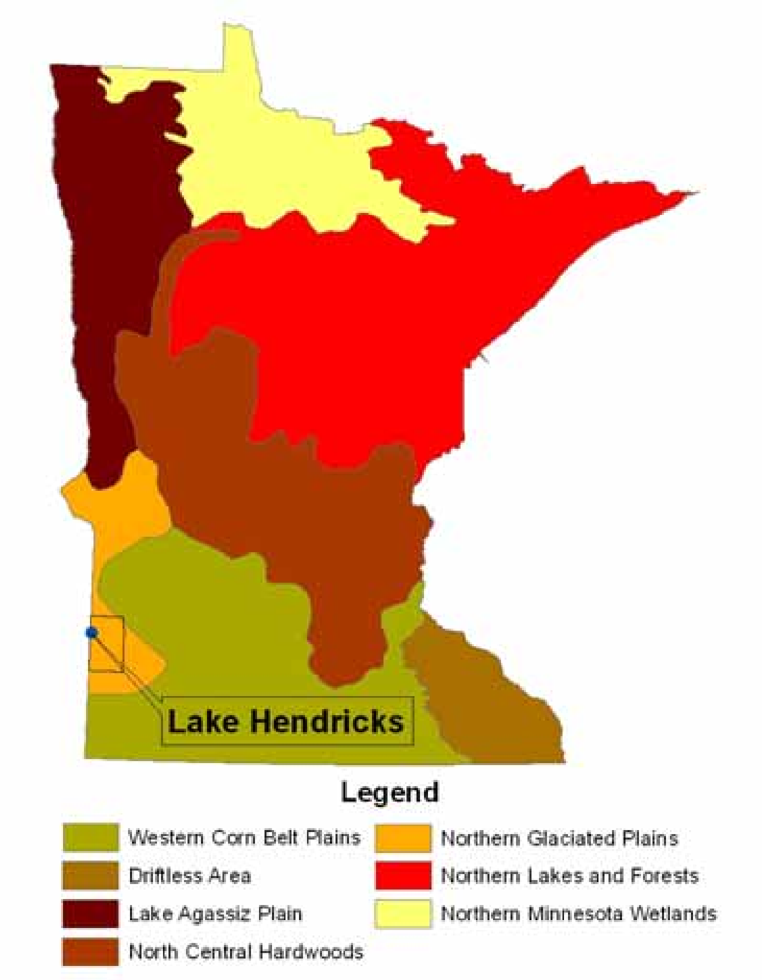
Land Use (%)	Lake Hendricks	NGP Ecoregion
Developed	5	0 - 2
Cultivated (Ag)	44	60 - 82
Pasture & Open	42	5 - 15
Forest	1	0 - 1
Water & Wetland	8	8 - 26

Figure 1. Lake Hendricks watershed and land use



The National Landcover Database 2001
Multi-Resolution Land Characteristics (MRLC) Consortium

Figure 2. Minnesota ecoregions



Lake Mixing

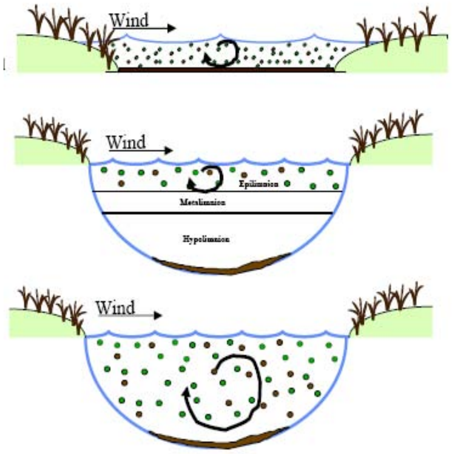
Lake depth can have a significant influence on lake processes and water quality. One such process is *thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 9.1 – 12.1 meters (30 - 40 feet) or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 3). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of 4.6 meters (15 feet) or less) in contrast, typically do not stratify and are often referred to as *polymictic*. Lakes with moderate depths may stratify intermittently during calm periods, but mix during heavy winds and during spring and fall. 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, dimictic lakes have an upper, well-mixed layer (epilimnion) that is warm and has high oxygen concentrations. In contrast, the lower layer (hypolimnion) is much cooler and often has little or no oxygen. This low oxygen environment in the hypolimnion is conducive to the release of total phosphorus (TP) from the lake sediments. During stratification, dense colder hypolimnion waters are separated from the nutrient hungry algae in the epilimnion. Mixing events allow for the nutrient rich sediments to be re-suspended and available to algae. Most of the fish in the lake are usually found in the epilimnion or near the thermocline. Lake Hendricks, based on 2008 temperature profiles, is polymictic.

Figure 3. Lake stratification

Polymictic Lake
Shallow, no layers,
Mixes continuously
Spring, Summer & Fall

Dimictic Lake
Deep, form layers,
Mixes Spring/Fall

Intermittently Stratified
Moderately deep
Mixes during high winds



Lake Level Trends

The Minnesota Department of Natural Resources (DNR) Division of Waters has measured water levels on Lake Hendricks since 1952. During the period of record (1952 – 2008) the lake had varied by 6.5 feet, based on 1,080 readings. The highest and lowest recorded elevations are 1,760 feet on 6/23/1993 and 1,753 feet on 10/5/1963, respectively. The ordinary high-water mark for Lake Hendricks is 1,756 feet.

Precipitation

Rain gauge records from Canby, Minnesota show two one-inch plus rain events during summer 2008 for the Hendricks Lake area (Figure 4). These rain events will increase runoff into the lakes and may influence in-lake water quality and lake levels. This will be considered in the discussion of lake water quality for 2008 later in this report. Precipitation records for the 2008 water year (October 2007 through September 2008) indicated average rain fall as 2 - 4 inches below normal for the areas of all three lakes (Figure 5).

Figure 4. Summer 2008 rainfall based on records for Canby, Minnesota

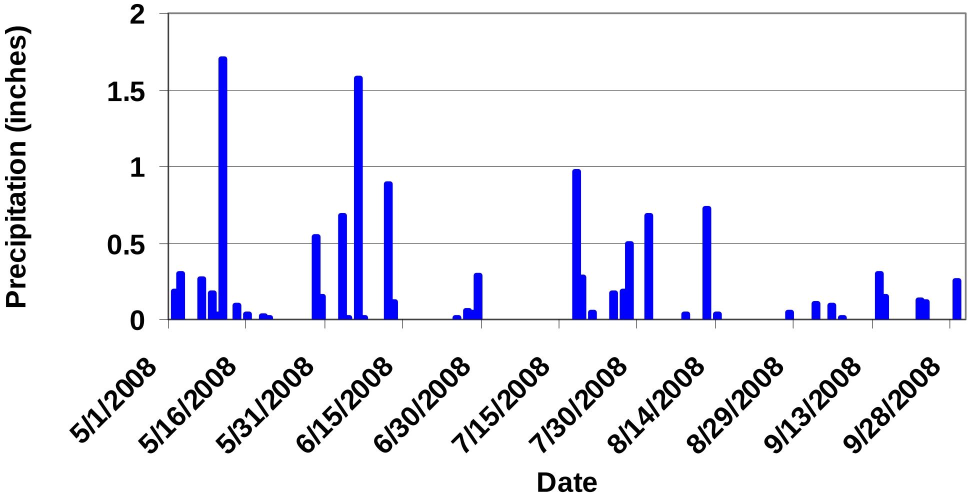
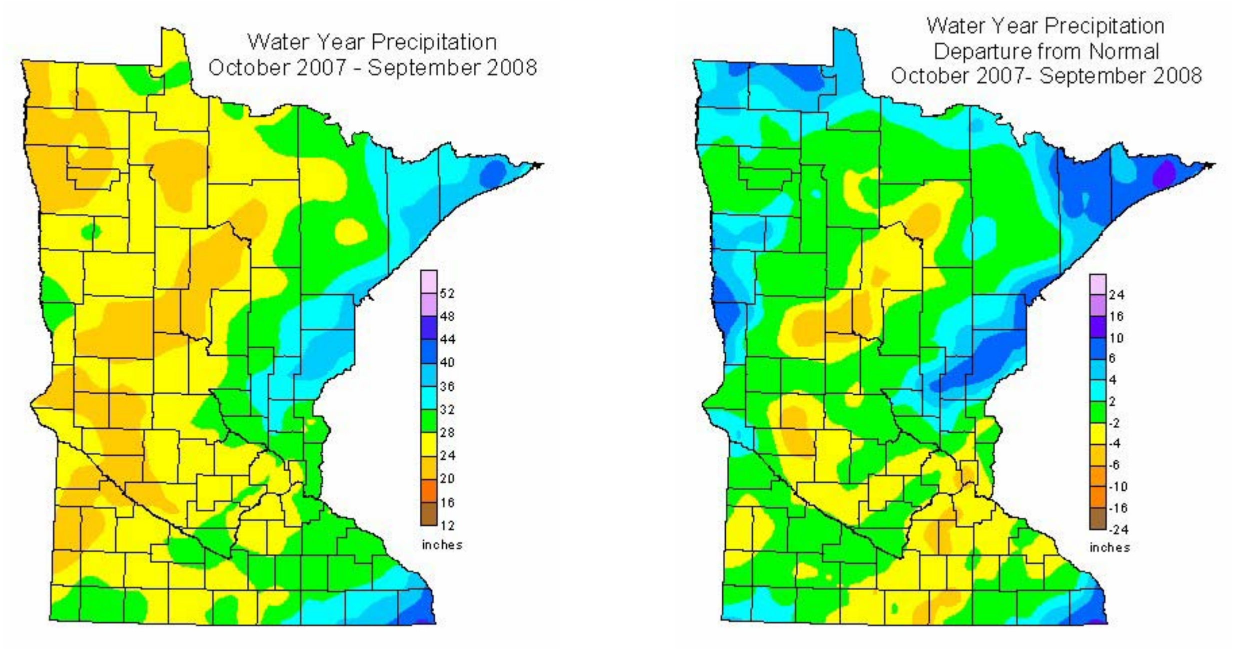


Figure 5. 2008 Minnesota water year precipitation and departure from normal
Prepared by State Climatology Office DNR Waters
Values are in inches



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 most recent fish assessment for Lake Hendricks was conducted in July 2005.

The Lake Hendricks fishery is jointly managed by the South Dakota Game, Fish and Parks and the Minnesota DNR. Historically, the lake has experienced occasional minor summer fish kills. In general, these summer kills have been confined to relatively small areas. In recent years, dead or dying carp have been a frequent sight on Lake Hendricks. Additionally, in 2005 several hundred dead carp were observed. According to the South Dakota Game, Fish and Parks, the carp die-off was caused by a bacterial disease.

Walleye were moderately abundant in 2005. Sampled walleye were growing slowly. Slow growth was attributed to a low abundance of small forage fish. Forage abundance appeared to increase in 2005 and walleye growth should improve. Approximately 800,000 walleye fry are stocked into Hendricks Lake in odd numbered years.

Yellow perch were also found in moderate numbers in 2005. Perch numbers have declined considerably over the past few years. Northern pike were sampled in low abundance. A lack of spawning habitat (flooded marshy or grass areas), has limited the northern pike population in years with normal or below normal spring run-off.

Other species of interest sampled in 2005 include a low abundance of black crappie and black bullhead. Future management activities planned for Lake Hendricks include stocking walleye yearlings in 2006, annual fall electro fishing assessments to assess walleye stocking or natural reproduction, annual monitoring of winter dissolved oxygen and angling pressure, a fisheries survey in 2008, and ongoing work within the watershed to improve water quality and fish habitat.

Additional information on the most recent fish survey for Lake Hendricks can be found at the DNR Lake Finder website: http://www.dnr.state.mn.us/lakefind/index.html Additional information on fishery management can be found at: http://www.dnr.state.mn.us/fisheries/management/index.html

Methods

Water quality data were collected in May through September 2007 and 2008. Lake surface samples were collected with an integrated sampler, a polyvinyl chloride (PVC) tube 2 meters (6.6 feet) in length with an inside diameter of 3.2 centimeters (1.24 inches). Zooplankton samples were collected with a Wisconsin plankton net. A summary of data follows (Appendix C).

Sampling procedures were employed as described in the MPCA Lake Water Quality Sampling Standard Operating Procedures. Laboratory analysis was performed by the Minnesota Department of Health using EPA-approved methods. Samples were analyzed for nutrients, color, solids, pH, alkalinity, conductivity, chloride (Cl) and chlorophyll-*a* (chl-*a*). Temperature and dissolved oxygen (DO) profiles and Secchi disk transparency measurements were also taken.

Results and Discussion

Profiles were taken from May through September at site 102. Temperature profiles (Figure 7) indicate that Lake Hendricks was well-mixed on all dates. With the exception of July, DO levels remain above five milligrams per liter (mg/L) to the bottom of the lake (2.5 - 3 meters) (Figure. 6). For July, the hypoxic conditions near the bottom of the lake are likely the result of increased oxygen demand from the elevated amounts of algae within the water column, higher temperatures, and lack of re-aeration from wind mixing. Higher chl-*a* values support this observation (Figure 8). As algal growth continues in August the increased DO demand results in lower levels through the water column.

Total Phosphorus concentrations at site 102 averaged 132 micrograms per liter (µg/L) (Table 3). This average was within the typical range of concentrations for NGP reference lakes. TP concentrations increased over the summer and peaked in September (Figure 8a). The late-season increase in TP is likely due to nutrient release from algal and macrophyte decomposition. A sharp drop in September chl-*a* levels coincide with this analysis. Internal loading (phosphorous recycling from lake sediment) is a likely reason for the mid to late summer increases in TP. Factors that promote internal recycling include low DO and high temperatures above the sediments, high oxygen demand from decomposing organic materials, and alternating periods of calm and windy conditions. It is conceivable that Lake Hendricks receives a majority of its nutrient contribution from internal loading rather than the external flow from the surrounding watershed. When the elevating levels of TP are compared to the low precipitation from mid June through September (Figure 4) it becomes evident that watershed runoff was limited.

Chlorophyll-*a* concentrations provide an estimate of the amount of algal production in a lake. During the summer of 2008, chl-*a* concentrations ranged from 1 µg/L to 65 µg/L with an average of 27 µg/L (Table 3). Concentrations greater than 20 µg/L will typically be perceived as a nuisance, while concentrations greater than 30 µg/L are perceived as a severe nuisance algal bloom (Heiskary and Walker, 1988). As such, severe nuisance blooms likely occurred through much of July and August (Figure 8a); however, given that the levels for May, June, and September were very low, the summer-mean for Lake Hendricks was below the range of values typical values for NGP lakes.

Secchi disk transparency on Lake Hendricks averaged 1.5 meters (4.9 feet) during the summer of 2008 (Table 3). The average Secchi depth is above (better than) the typical values of the NGP ecoregion. Additionally, the change in the transparency of Lake Hendricks over the course of the summer closely mirrored the changes in nutrient availability (TP) and algal production (chl-*a*). Lake Hendricks had a Secchi disk transparency low of 0.3 meters (1 foot) in September (Figure 8). When compared to 2007 data Lake Hendricks showed a notable improvement in water clarity. The reduced levels of nutrients, particularly in May and June, coincide with this observation (Table 3 and Figure 8b).

Table 3. Lake Hendricks summer-mean water quality as compared to the typical range for NGP ecoregion reference lakes.

Parameter	Hendricks 2007	Hendricks 2008	NGP Ecoregion
Total Phosphorus (µg/L)	172	132	122 - 160
Chlorophyll-*a* mean (µg/L)	24	27	36 - 61
Chlorophyll-*a* max (µg/L)	59	65	66 - 88
Secchi Disk (feet)	2.6	4.9	1.3 – 2.6
(meters)	0.8	1.5	0.4 – 0.8
Total Kjeldahl Nitrogen (mg/L)	1.6	1.9	0.01 – 0.1
Alkalinity (mg/L)	174	184	160 - 260
Color (Pt-Co Units)	11	12	20 - 30
pH (SU)	8.6	8.9	8.3 – 8.6
Chloride (mg/L)	12	11	11 - 18
Total Suspended Solids (mg/L)	20	12	10 - 30
Total Suspended Inorganic Solids (mg/L)	10	8	5 - 15
Conductivity (umhos/cm)	756	759	640 - 900
TN:TP ratio	9:1	14:1	13:1 - 17:1

Figure 6. Lake Hendricks site 102 dissolved oxygen profiles

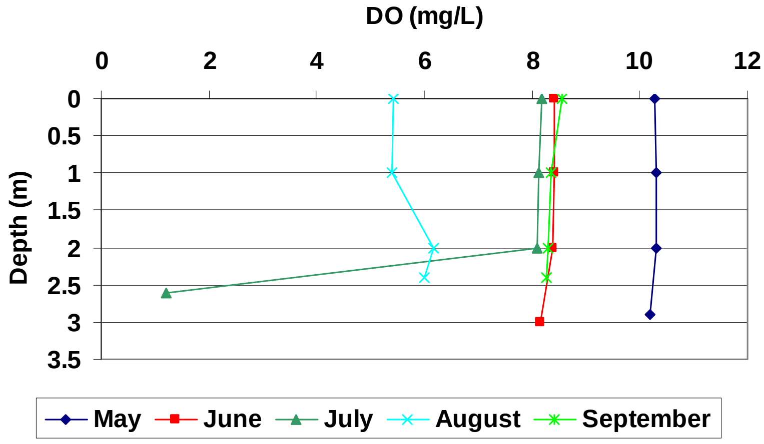


Figure 7. Lake Hendricks site 102 temperature profiles

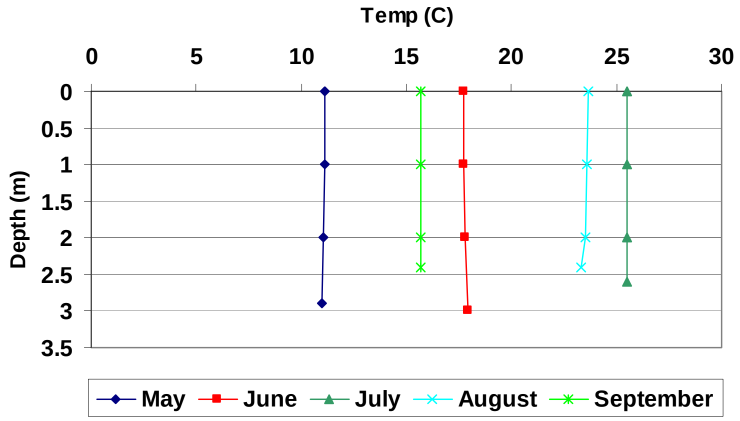


Figure 8a. Lake Hendricks 2008 Site 102 TP & chl-*a* concentrations and Secchi depth

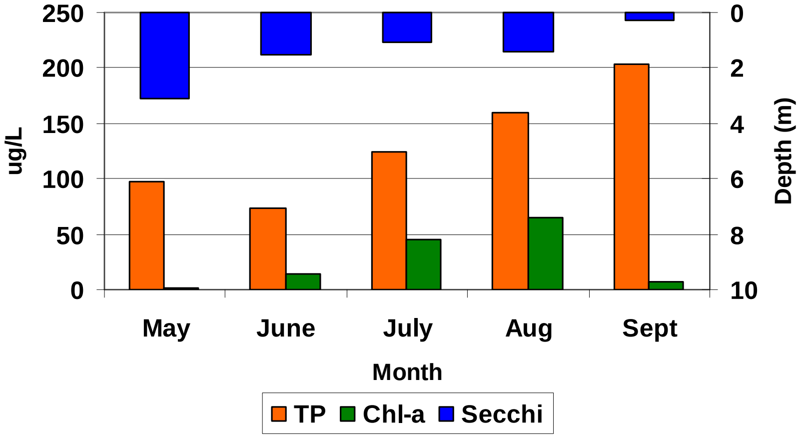
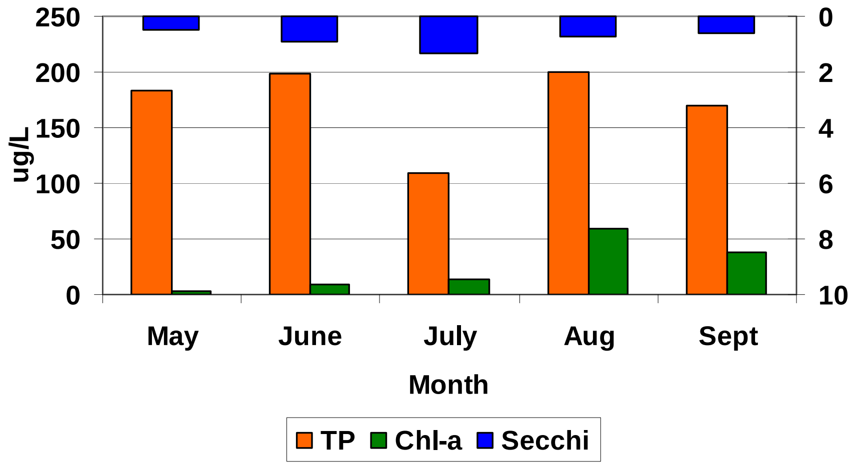


Figure 8b. Lake Hendricks 2007 Site 102 TP & chl-*a* concentrations and Secchi depth



Trophic State Index

One way to evaluate the trophic status of a lake and to interpret the relationship between TP, chl-*a*, and Secchi disk transparency is Carlson's Trophic State Index (TSI) (Carlson 1977). TSI values are calculated as follows:

Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

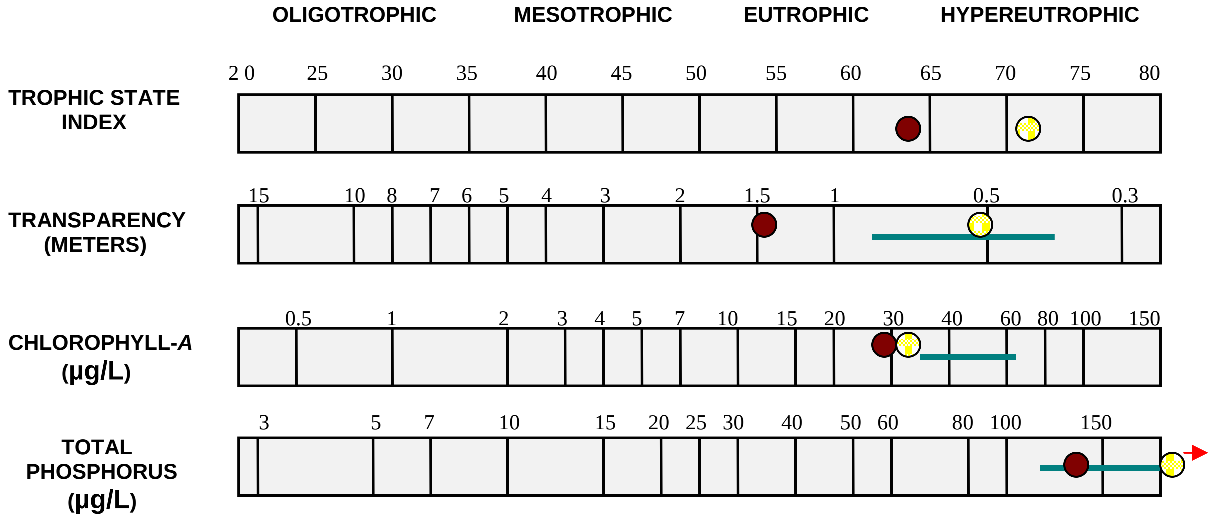
Chlorophyll-*a* TSI (TSIC) = 9.81 ln (Chl-*a*) + 30.6

Secchi disk TSI (TSIS) = 60 – 14.41 ln (SD)

TP and chl-*a* are in µg/L and Secchi disk is in meters. TSI values range from 0 (ultra-oligotrophic) to 100 (hypereutrophic). In this index, each increase of ten units represents a doubling of algal biomass. Comparisons of the individual TSI measures provides a bases for assessing the relationship among TP, chl-*a*, and Secchi (Figure 9). In general, the TSI values are in fairly close correspondence with each other with a high TP value (still within the NGP ecoregional range). The TSI values also correspond with observations for 2008. Based on the high TP values, presented in Table 3, and an average TSI score of 64 Lake Hendricks would be characterized as hypereutrophic.

Figure 9. Carlson's Trophic State Index for Lake Hendricks
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.



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

NGP Ecoregion Range: ▬▬▬ Hendricks 2008: ● Hendricks 1989: ○

Trophic Status Trends

One objective of lake monitoring is to assess historical trends, where possible, based on available STORET data. A review of these data reveals a good amount of historical Secchi data for Lake Hendricks (Figure 10). Based on historical Secchi data dating back to the 1989 study, Lake Hendricks has a long-term mean water clarity value of 0.9 meters (3 feet). This is above (better than) the normal minimal depth of 0.8 meters (2.6 feet) based on NGP ecoregion reference lakes (Table 3). An improvement in transparency over time is also evident in this record. In general, seasonal average transparencies ranged from 0.5 – 0.8 meters in the late 1980s. Average transparencies used for this assessment were 0.8 in 2007 and 1.5 in 2008. It should be noted that the 2008 value is the deepest transparency on record for Lake Hendricks.

When a comparison is made with TP and chl-*a* data from the 1989 assessment, it is evident that water quality conditions have improved (Figure 11). The average TSI score from the 1989 report was 72; this score characterized the lake as hypereutrophic. TP values have dropped from a seasonal average of 208 µg/L to the current average of 132 µg/L. Additionally, chl-*a* values have dropped below the NGP criteria of 30 µg/L dropping from 32 µg/L in 1989 to 27 µg/L in 2008.

In 1998, the Lake Hendricks/Deer Creek Watershed project was implemented to reduce the in-lake TP concentrations, reduce the potential for fecal coliform bacteria, and reduce soil erosion and sediment loading to the lake (Brookings Conservation District 2002). Some of the notable accomplishments of this project were the reduction of 502 acres of land used for livestock grazing; the enrollment of 1,666 acres into Conservation Tillage; the implementation of 640 acres to Integrated Crop Management; the conversion of 96 acres of erosion-prone crops on steep slopes to grass and hay land use; planting of 1,054 trees on steep slopes for wildlife habitat plus water and wind erosion control; the enrollment of approximately 3,500 acres in the Conservation Reserve Program; and the stabilization of 1,575 linear feet of shoreline to reduce shoreline erosion and sedimentation on Lake Hendricks The improved water quality conditions since the completion of the watershed project indicates that these measures played a vital role in the restoration of Lake Hendricks.

Figure 10. Lake Hendricks historical Secchi depths

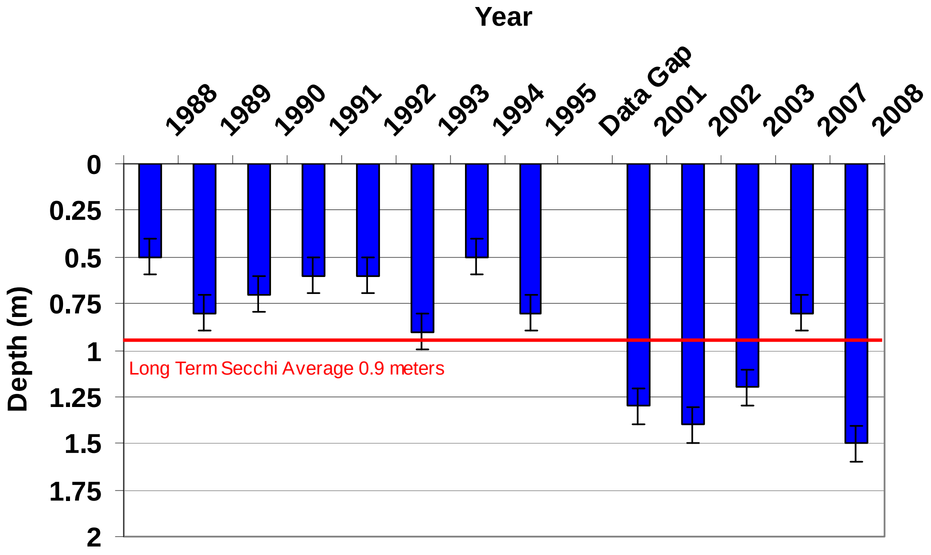
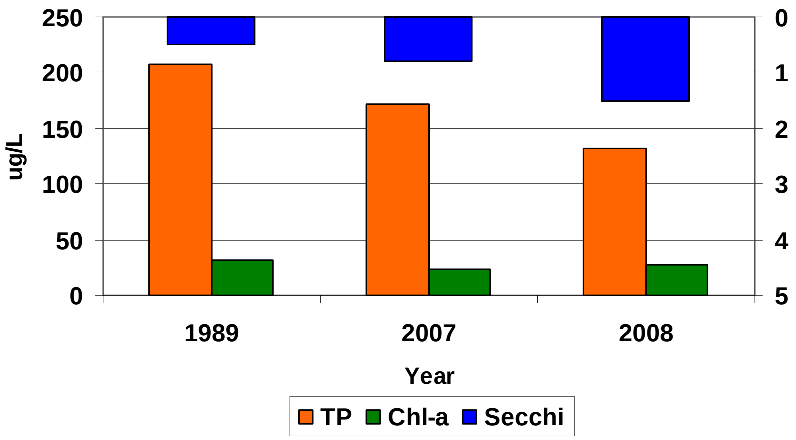


Figure 11. Lake Hendricks 2008/2007 TP, chl-a, and Secchi depths compared to 1989 values



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 2008 water quality of Lake Hendricks, the Minnesota Lake Eutrophication Analysis Procedures (MINLEAP) model (Wilson and Walker, 1989) was used.

MINLEAP was developed by MPCA staff based on an analysis of data collected from the ecoregion reference lakes. It is intended to be used as a screening tool for estimating lake conditions with minimal input data and is described in greater detail in Wilson and Walker (1989). For the analysis of Lake Hendricks, MINLEAP was applied as a basis for comparing the observed (2008) TP, chl-*a*, and Secchi values with those predicted by the model based on the lake depth and size and the size of the watershed.

Lake Hendricks is located in the NGP ecoregion and the model was run using NGP ecoregion-based 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 4.

The 2008 observed TP, chl-*a*, and Secchi values for Lake Hendricks are notably better than the MINLEAP predicted values for a lake of this size and depth and size of watershed in the NGP ecoregion (Figure 11). The 2008 observed TP falls within the expected range of ecoregion values, but is still above the 90 µg/L nutrient criteria for lakes in the NGP ecoregion for recreational use (Table 5). The significant watershed land use alterations and shoreline restorations have likely reduced the amount of external TP loading; however, it is possible that most of the TP for Lake Hendricks can be attributed to internal loading by means of mixing within the water column causing phosphorous recycling from sediments. Chl-*a* levels for 2008 were also significantly lower than the values predicted by the model. The decrease in chl-*a* may be a result of light limitation or increased TSS values of 28 mg/L in September (Appendix C). The sharp increase in TP in September also coincides with a decrease in chl-*a*. This is likely the result of vegetation dying off in the fall. TP increases as nutrients are released into the lake by the decomposition of the vegetation. Additionally, chl-*a* levels decline as plants and algae within the lake reach the end of the growing season.

Table 4. Observed summer-mean values compared to MINLEAP predicted outputs

Parameter	2008 Hendricks Observed	Hendricks MINLEAP Predicted
TP (µg/L)	132	207
Chl-*a* (µg /L	27	159
Secchi (m)	1.5	0.4
P loading rate (kg/yr)	-	7,731
P retention (%)	-	89%
P inflow conc. (µg/L)	-	1,809
Water Load (m/yr)	-	0.7
Outflow volume (hm^3/yr)	-	4.3
Residence time (yrs)	-	2.2

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) Impaired Waters List 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) Impaired Waters List and updated every even-numbered year. If a water resource is listed, an investigative study termed a Total Maximum Daily Load (TMDL) is conducted to determine the sources and magnitude of the pollution problem, and to set pollutant reduction goals needed to restore the waters. The MPCA is responsible for monitoring surface waters, assessing condition of lakes and streams, creating the 303(d) Impaired Waters List, and conducting or overseeing TMDL studies in Minnesota.

According to Table 5, the TP and chl-*a* standards for the support of aquatic recreation in shallow lakes within the NGP ecoregion are less than 90 µg/L and 30 µg/L respectively. For chl-*a* levels at or below 30 µg/L, “nuisance algal blooms” (chl-*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. With summer averages calculated from 2007 and 2008 data reflecting TP concentrations of155 µg/L and chl-*a* concentrations of 31µg/L, Lake Hendricks still exceeds the TP standard for recreational use despite recent restoration activities. Based on these results, Lake Hendricks will be included on the 2010 303(d) Impaired Waters List that Minnesota will submit to the United States Environmental Protection Agency.

A further reduction of TP will be required in order to continue to improve overall water quality of Lake Hendricks. Previous efforts to reduce external (watershed) phosphorus loading to the lake has led to a reduction of overall concentrations; however, considering the relative shallowness and periodic mixing of the lake it is likely that internal loading of TP will continue to be a factor. The TMDL study should be able to place this in proper perspective and should provide options for addressing external and internal sources of nutrients.

Table 5. Minnesota lake eutrophication standards by ecoregion and lake type (Heiskary and Wilson, 2005) and 2010 303(d) assessment values for Lake Hendricks.

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
Lake Hendricks 2010 303(d) assessment	155	31	1.1

References

Arneman, H.F. 1963. Soils of Minnesota. University of Minnesota, Agricultural Extension Service and U.S. Department of Agriculture.

Brookings Conservation District. 2002. Section 319 Non Point Pollution Control Program Watershed Project Final Report. Lake Hendricks Watershed Project.

Carlson, R.E. 1977. A Trophic State Index for Lakes. Limnology and Oceanography 22:361-369.

'Closest Station' Climate Data Retrieval, October 2006 – September 2007. State Climatology Office, Minnesota Department of Natural Resources. 2008.

Heiskary, S.A. and W.W. Walker Jr. 1988. Developing Phosphorus Criteria for Minnesota Lakes. Lake and Reservoir Management 4(1): 1-9.

Heiskary, S.A. and C. B. Wilson. 1989 (updated 2004). Minnesota Lake Water Quality Assessment Report. MPCA, Water Quality Division St. Paul, MN.

Heiskary, S.A. and C.B.Wilson. 1990. "Minnesota Lake Water Quality Assessment Report. 2nd Ed." MPCA. St. Paul MN 95 pp.

Heiskary, S.A. and C.B. Wilson. 2005. "Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria." 3rd Ed." MPCA. St. Paul MN 150 pp.

"Macrophytes as Indicators." 2007. <u>Biological Indicators of Watershed Health</u>. Online. EPA.GOV.

Munson, W. and C.B. Wilson. 1990 Lake Assessment Program 1989. Lake Hendricks. Minnesota Pollution Control Agency. St. Paul MN

Schupp, D. and B. Wilson. 1993. Developing lake goals for water quality and fisheries. *Lakeline* 13: 18-21.

South Dakota Department of Water and Natural Resources. 1985. Lake Hendricks water quality study area report. SDDWNR. Pierre, South Dakota.

Water Year Precipitation Departure from Normal, October 2007 – September 2008. 2009. Map. State Climatology Office, Minnesota Department of Natural Resources.

Wilson, C.B. and W.W. Walker 1989. Development of lake assessment methods based upon the aquatic ecoregion concept. Lake and Reserv. Manage. 5(2):11-22.

Zumberge, J.H. 1952. The Lakes of Minnesota. Their origin and classification. Minnesota Geological Survey. University of Minnesota Press. Minneapolis, Minnesota.

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

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=Chl-*a*)
PHEO= pheophytin in ug/l
PHYS= physical appearance rating (classes=1 to 5)
REC= recreational suitability rating (classes=1 to 5)
RTP, RN2N3...= remark code; k=less than, Q=exceeded holding time

Appendix C

Lake Hendricks Surface Water Data

Lake Name	Lake ID	Sample Date	Site ID	Secchi Meters	TP µg/L	Chl-*a* µg/L	Alkalinity mg/L	Chloride mg/L	TKN mg/L	Color, Apparent PCU	TSS mg/L
Hendricks	41-0110	5/11/1989	101	1.4	92	5	140	10	1.1	10	5
Hendricks	41-0110	7/14/1989	101	0.5	162	6	170	11	1.6	10	16
Hendricks	41-0110	8/8/1989	101	0.4	254	64	180	12	1.7	20	25
Hendricks	41-0110	8/30/1989	101	0.5	379	99	180	12	2.9	20	21
Hendricks	41-0110	5/11/1989	102	0.8	106	0.3			1.2		
Hendricks	41-0110	7/14/1989	102	0.6							
Hendricks	41-0110	8/8/1989	102	0.5		22					
Hendricks	41-0110	8/30/1989	102	0.5		16					
Hendricks	41-0110	5/30/2007	102	0.5	183	3	180	11	2.0	20	19
Hendricks	41-0110	6/20/2007	102	0.9	199	9	180	11	1.4	10	19
Hendricks	41-0110	7/25/2007	102	1.4	109	13	170	12	1.3	10	8
Hendricks	41-0110	8/30/2007	102	0.7	200	59	170	12	1.8	5	34
Hendricks	41-0110	9/5/2007	102		169	38	170	12	1.7	10	18
Hendricks	41-0110	5/6/2008	102	3.1	98	1	190	11	1.4	20	2
Hendricks	41-0110	6/5/2008	102	1.5	74	14	190	10	1.1	20	9
Hendricks	41-0110	7/31/2008	102	1.1	125	45	190	11	2.1	5	6
Hendricks	41-0110	8/14/2008	102	1.4	159	65	160	11	2.4	5	6
Hendricks	41-0110	9/16/2008	102	0.3	204	7	190	12	2.6	10	28
Hendricks	41-0110	5/11/1989	103	0.9	118	2			1.3		
Hendricks	41-0110	7/14/1989	103	0.5		58					
Hendricks	41-0110	8/8/1989	103	0.5		6					
Hendricks	41-0110	8/30/1989	103	0.3		42					
Hendricks	41-0110	6/2/1988	201	1.4							
Hendricks	41-0110	6/12/1988	201	0.6							
Hendricks	41-0110	6/30/1988	201	0.9							
Hendricks	41-0110	7/10/1988	201	0.6							

Hendricks	41-0110	7/13/1988	201	0.6
Hendricks	41-0110	7/24/1988	201	0.6
Hendricks	41-0110	7/27/1988	201	0.5
Hendricks	41-0110	8/4/1988	201	0.3
Hendricks	41-0110	8/14/1988	201	0.3
Hendricks	41-0110	8/29/1988	201	0.5
Hendricks	41-0110	9/5/1988	201	0.3
Hendricks	41-0110	9/12/1988	201	0.3
Hendricks	41-0110	5/27/1989	201	1.2
Hendricks	41-0110	6/3/1989	201	1.2
Hendricks	41-0110	6/15/1989	201	0.9
Hendricks	41-0110	6/22/1989	201	0.9
Hendricks	41-0110	7/13/1989	201	0.8
Hendricks	41-0110	7/28/1989	201	0.5
Hendricks	41-0110	8/8/1989	201	0.3
Hendricks	41-0110	8/16/1989	201	0.8
Hendricks	41-0110	9/2/1989	201	0.5
Hendricks	41-0110	9/25/1989	201	0.8
Hendricks	41-0110	7/14/1990	201	0.9
Hendricks	41-0110	8/1/1990	201	0.8
Hendricks	41-0110	8/18/1990	201	0.8
Hendricks	41-0110	9/4/1990	201	0.6
Hendricks	41-0110	9/9/1990	201	0.6
Hendricks	41-0110	9/16/1990	201	0.5
Hendricks	41-0110	6/18/1991	201	0.6
Hendricks	41-0110	6/26/1991	201	0.6
Hendricks	41-0110	7/9/1991	201	0.8
Hendricks	41-0110	7/17/1991	201	0.6
Hendricks	41-0110	8/2/1991	201	0.5
Hendricks	41-0110	8/15/1991	201	0.5
Hendricks	41-0110	8/27/1991	201	0.6
Hendricks	41-0110	9/9/1991	201	0.8
Hendricks	41-0110	5/25/1992	201	0.6

Hendricks	41-0110	6/20/1992	201	0.6
Hendricks	41-0110	7/23/1992	201	0.3
Hendricks	41-0110	8/1/1992	201	0.6
Hendricks	41-0110	8/9/1992	201	0.9
Hendricks	41-0110	8/31/1992	201	0.5
Hendricks	41-0110	6/8/1993	201	1.4
Hendricks	41-0110	7/6/1993	201	1.2
Hendricks	41-0110	7/26/1993	201	0.9
Hendricks	41-0110	8/20/1993	201	0.8
Hendricks	41-0110	9/6/1993	201	0.5
Hendricks	41-0110	9/16/1993	201	0.5
Hendricks	41-0110	6/14/1994	201	0.6
Hendricks	41-0110	6/19/1994	201	0.5
Hendricks	41-0110	7/1/1994	201	0.5
Hendricks	41-0110	8/14/1994	201	0.5
Hendricks	41-0110	8/24/1994	201	0.5
Hendricks	41-0110	9/9/1994	201	0.6
Hendricks	41-0110	7/9/1995	201	0.6
Hendricks	41-0110	7/18/1995	201	2.0
Hendricks	41-0110	8/11/1995	201	0.5
Hendricks	41-0110	9/2/1995	201	0.6
Hendricks	41-0110	9/12/1995	201	0.5
Hendricks	41-0110	6/3/1989	202	1.2
Hendricks	41-0110	6/15/1989	202	0.8
Hendricks	41-0110	7/13/1989	202	0.6
Hendricks	41-0110	7/28/1989	202	0.6
Hendricks	41-0110	8/16/1989	202	0.9
Hendricks	41-0110	9/2/1989	202	0.8
Hendricks	41-0110	9/25/1989	202	0.8
Hendricks	41-0110	7/14/1990	202	0.8
Hendricks	41-0110	9/4/1990	202	0.8
Hendricks	41-0110	9/16/1990	202	0.6
Hendricks	41-0110	6/18/1991	202	0.6

Hendricks	41-0110	6/26/1991	202	0.6
Hendricks	41-0110	5/28/2001	202	1.7
Hendricks	41-0110	6/10/2001	202	1.1
Hendricks	41-0110	6/24/2001	202	1.2
Hendricks	41-0110	7/7/2001	202	1.5
Hendricks	41-0110	7/29/2001	202	1.5
Hendricks	41-0110	8/12/2001	202	1.1
Hendricks	41-0110	5/25/2002	202	1.8
Hendricks	41-0110	6/15/2002	202	1.7
Hendricks	41-0110	7/13/2002	202	1.5
Hendricks	41-0110	8/24/2002	202	1.2
Hendricks	41-0110	9/7/2002	202	0.9
Hendricks	41-0110	6/7/2003	202	1.4
Hendricks	41-0110	7/27/2003	202	1.2
Hendricks	41-0110	8/16/2003	202	1.1
Hendricks	41-0110	9/6/2003	202	1.2
Hendricks	41-0110	5/27/1989	203	0.8
Hendricks	41-0110	6/3/1989	203	1.2
Hendricks	41-0110	6/15/1989	203	1.1
Hendricks	41-0110	7/13/1989	203	0.8
Hendricks	41-0110	7/28/1989	203	0.5
Hendricks	41-0110	8/8/1989	203	0.3
Hendricks	41-0110	8/16/1989	203	0.8
Hendricks	41-0110	9/2/1989	203	0.6
Hendricks	41-0110	7/14/1990	203	0.8
Hendricks	41-0110	8/1/1990	203	0.9
Hendricks	41-0110	8/18/1990	203	0.8
Hendricks	41-0110	9/4/1990	203	0.9
Hendricks	41-0110	9/16/1990	203	0.6
Hendricks	41-0110	6/18/1991	203	0.5
Hendricks	41-0110	7/22/1991	203	0.3
Hendricks	41-0110	5/28/2001	203	2.4
Hendricks	41-0110	6/10/2001	203	1.2

Hendricks	41-0110	6/24/2001	203	1.1
Hendricks	41-0110	7/7/2001	203	1.4
Hendricks	41-0110	7/29/2001	203	0.9
Hendricks	41-0110	8/12/2001	203	0.8
Hendricks	41-0110	5/25/2002	203	2.0
Hendricks	41-0110	6/15/2002	203	1.7
Hendricks	41-0110	7/13/2002	203	1.5
Hendricks	41-0110	8/24/2002	203	1.2
Hendricks	41-0110	9/7/2002	203	1.1
Hendricks	41-0110	6/7/2003	203	1.2
Hendricks	41-0110	7/27/2003	203	1.2
Hendricks	41-0110	8/16/2003	203	0.9
Hendricks	41-0110	9/6/2003	203	0.9
Hendricks	41-0110	6/3/1989	204	1.1
Hendricks	41-0110	6/15/1989	204	1.2
Hendricks	41-0110	7/13/1989	204	0.9
Hendricks	41-0110	7/28/1989	204	0.5
Hendricks	41-0110	8/8/1989	204	0.5
Hendricks	41-0110	8/16/1989	204	0.5
Hendricks	41-0110	7/14/1990	204	0.5
Hendricks	41-0110	9/4/1990	204	0.6
Hendricks	41-0110	9/16/1990	204	0.3