Upper Hay Lake Assessment Report

2008 Water Quality Update

Minnesota Pollution Control Agency

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Executive Summary

This report was requested by the Upper Hay Lake Association and is a follow-up to monitoring originally conducted on Upper Hay Lake by the MPCA and lake volunteers in 1997 (Hodgson and Heiskary, 1998). Updates to watershed area, lake acres, and land use have been made based on more recent data sets becoming available, and as such, the values will differ slightly from the original MPCA report.

Upper Hay Lake is a 591-acre lake in Crow Wing County within the Pine River watershed. Upper Hay Lake is approximately 1 mile east of Jenkins, MN and is located in the Northern Lakes and Forests (NLF) ecoregion. The lake has a maximum depth of 42 ft and 184 littoral acres. There is one public access on the west side of the lake. The main tributary to Upper Hay Lake is the Jenkins Creek; Upper Hay Lake outlets via Hay Creek into Lower Hay Lake. The total watershed for Upper Hay Lake is 17.8 square miles.

This report is a review of data collected from 1997 to 2008 by the Upper Hay Lake Association and the Minnesota Pollution Control Agency. An initial lake assessment report was completed based on monitoring completed in 1997; additional local monitoring has occurred since that initial report from 2003 to 2008 (no chemistry data collected in 2006). References will be made to existing reports for additional data (total suspended solids, color, etc.); this report will discuss the trophic state of Upper Hay Lake based on all available summer (June to September) data available in STORET (U.S. Environmental Protection Agency's national water quality data repository) through 2008.

Upper Hay Lake is a dimictic lake; overturning in the spring and fall and remaining stratified throughout the summer months. This allows for phosphorus to be released from the sediments during the summer and may result in a late season algae bloom when the deep and surface waters mix in September or October. Based on water quality data over the past ten years, Upper Hay Lake is considered to be eutrophic, having increased plant growth and nutrient levels and reduced transparency, as a result.

Three models were run during the initial report completed in 1997, Minnesota Lake Eutrophication Analysis Procedure (MINLEAP), BATHTUB, and Renkhow-Simpson. All models predicted phosphorus, chlorophyll-a (chl-*a*), and Secchi values to be close to those observed in 1997 (Hodgson and Heiskary, 1998). In addition, watershed runoff was predicted to be a main contributor to phosphorus in the lake and that Upper Hay Lake retains the majority of the phosphorus it receives (76%). While this provides a buffering effect for downstream lakes, it contributes to the stored phosphorus in the lake sediments. The modeling application MINLEAP predicted a summer-mean total phosphorus concentration of 26 micrograms per liter based on average values from 2003 through 2008.

Current data is within the Minnesota lake eutrophication standards adopted into rule in 2008 (Table 4). However, the lake is close to the impairment threshold. As a result, the lake will likely be reviewed for assessment, but remain unlisted, as the trophic parameters are close to the impairment threshold.

While the lake is currently supporting aquatic recreation use, it is important to take steps to keep the current nutrient levels in the lake from rising. Many of the recommendations from the 1997 MPCA lake assessment program (LAP) report have been addressed (Hodgson and Heiskary, 1998); the following are recommendations for continued action from the Upper Hay Lake Association.

- Continued participation in the Department of Natural Resources Lake Level Monitoring Program and the Minnesota Pollution Control Agency's Citizen Lake Monitoring Programs. Long-term monitoring provides a historical record for trend assessment. In addition, on years when water chemistry is not collected, Secchi transparency is a good surrogate for Upper Hay Lake to estimate the tropic state.
- Continued water quality monitoring. This lake is near the threshold for nutrient impairment and assessments are reviewed every two years. It is recommended that the association add temperature and dissolved oxygen profiles to their monthly sampling regime. There are occasional spikes in total phosphorus levels; in the fall this could likely be the result of mixing on the lake, but without profile data, it is not possible to make that determination.

- Continued work on septic system upgrades, maintenance, and education in the watershed. The 1997 LAP determined that 2-7% of the total phosphorus load to the lake was contributed by septic systems.
- Continued work with Crow Wing County Planning and Zoning and the Crow Wing County Soil and Water Conservation District on land use and development in the watershed, especially in the Hay Creek Watershed, which was identified as the main source of phosphorus loading to Upper Hay Lake in the 1997 LAP. Best management practices that are installed in the upper watershed should provide protection to the lake. The Lake Association developed a Lake Management Plan with the assistance of the Initiative Foundation in 2008. This document should be shared with local governmental units, especially the Local Water Plan Coordinator, as funding opportunities are often tied to waters being specifically identified in local water plans for restoration and protection activities.
- Continued work on shoreline restoration. The Upper Hay Lake Association has worked with DNR to develop an Aquatic Vegetation Management Plan. Restoration of shoreline provides improved habitat for fish spawning and provides food and habitat for fry and fingerlings. In addition, a natural shoreline will undergo less erosion than a disturbed shoreline; total phosphorus is typically deposited in lakes via erosion, as it binds to sediment.
- Continued communication with lake and watershed residents. The Upper Hay Lake Association has developed a webpage, has newsletters, and annual gatherings.

Lake Assessment Program: Upper Hay Lake 2008

Introduction

Upper Hay Lake was sampled in 2003, 2004, 2005, 2007, and 2008 by the Upper Hay Lake Association, and jointly in 1997 by the MPCA and Upper Hay Lake Association. This report was compiled at the request of the Upper Hay Lake Association. 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).

Background

Lake Morphometry and Mixing

Upper Hay Lake is a 591-acre lake in Crow Wing County within the Pine River watershed. Upper Hay Lake is approximately 1 mile east of Jenkins, MN. The lake has a maximum depth of 42 feet, a mean depth of 16.7 feet and 185 littoral acres.

Table 1. Lake and watershed morphometric 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.
Upper Hay	18-0412	591	31	11,400	19:1	42	16.7	9870

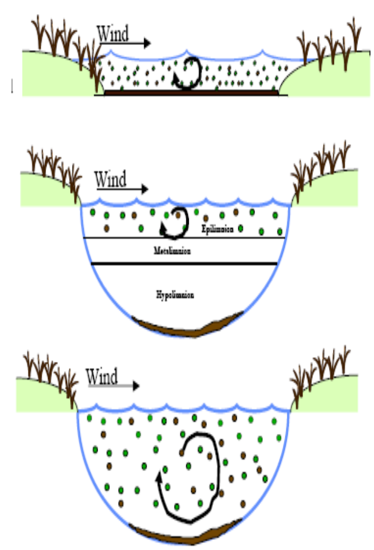
Lake depth can have a significant influence on lake processes and water quality. One such process is *thermal stratification* (formation of distinct temperature layers), in which deep lakes (maximum depths of 30 - 40 feet or more) often stratify (form layers) during the summer months and are referred to as *dimictic* (Figure 1). These lakes fully mix or turn over twice per year; typically in spring and fall. Shallow lakes (maximum depths of 20 feet or less) in contrast, typically do not stratify and are often referred to as *polymictic*. 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. Upper Hay Lake, based on historical temperature profiles, is dimictic.

Figure 1. Lake Stratification

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

Dimictic Lake
Deep, form layers,
Mixes Spring/Fall

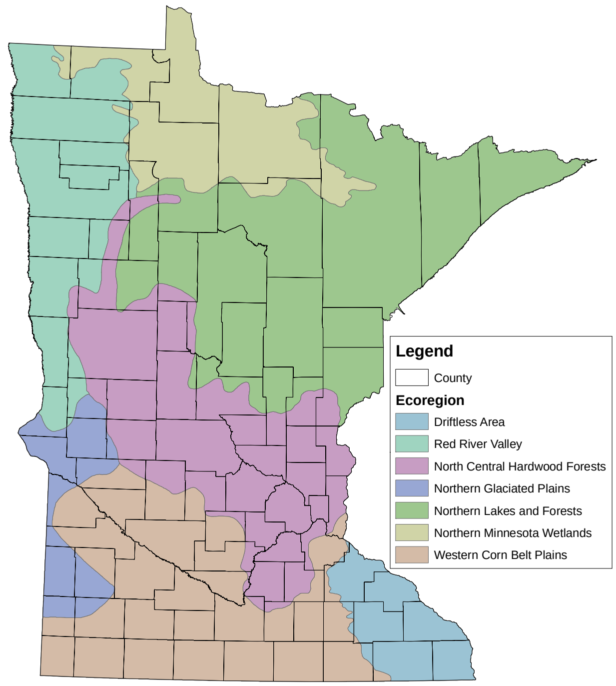
Intermittently Stratified
Moderately deep
Mixes during high winds
Spring, Summer, & Fall



Ecoregions, watershed, and land use

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. Upper Hay Lake is located in the Northern Lakes and Forests (NLF) ecoregion (Figure 2).

Figure 2. Minnesota Ecoregions



The total watershed for Upper Hay Lake is 11,400 acres with much of that lying northwest of the lake (Figure 3). The public access is on the west side of the lake. The main tributary to Upper Hay Lake is Jenkins Creek; Upper Hay Lake outlets into Lower Hay Lake via Hay Creek.

Land use for the Upper Hay Lake watershed is dominated by forested (45%) and water/wetlands (32%). Grass and pasture make up 15% of the land use in the watershed; cultivated and developed land uses make up the remaining portion (5% and 3%, respectively) (Table 2).

Figure 3. Upper Hay Lake Watershed and Land Use

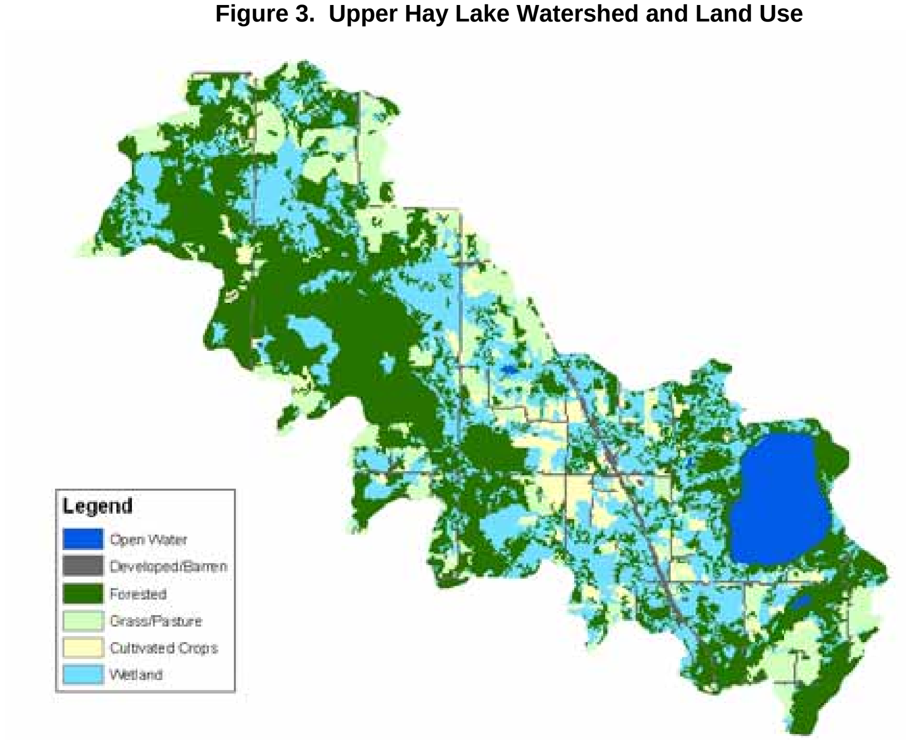


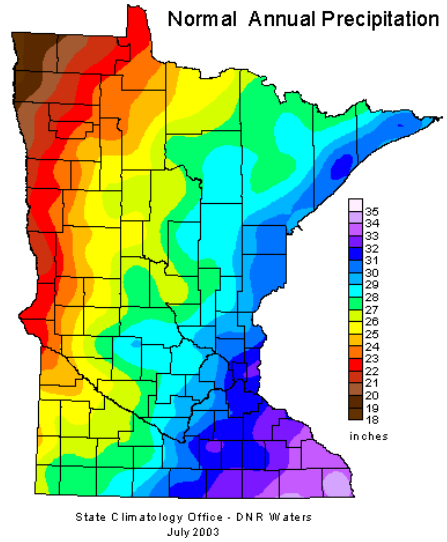
Table 2. Watershed land use as compared to ecoregion reference lake interquartile ranges

Land Use (%)	Lake	NLF Ecoregion
Forest	**45**	54 – 81
Water/wetlands	**32**	14 – 31
Pasture/grasslands	**15**	0 – 6
Cultivated	**5**	< 1
Urban	**3**	0 - 7

Precipitation

Based on state climatology records, precipitation averages 28 inches (0.7 m) annually in this part of the state (Figure 4) and 18 inches (0.45 m) between May and September. Recent summers (2004-2007) have been wetter than the normal expected precipitation and 2008 was well below the normal expected precipitation (15.53 inches). Typical annual evaporation and runoff values for lakes in the NLF ecoregion are 0.61 meters per year (m/yr) of evaporation and 0.23 m/yr of runoff.

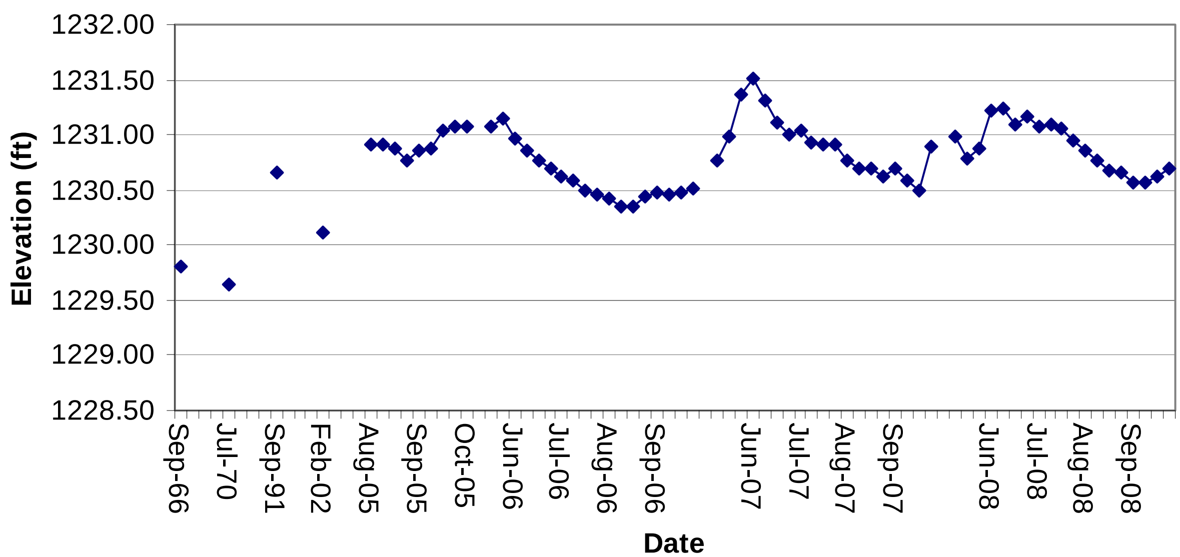
Figure 4. Normal Annual Precipitation



Lake Level

A summary of lake level information was drawn from the Minnesota Department of Natural Resources (DNR) web site. Lake level data have been collected on Upper Hay Lake from September 1966 to September 2008. The highest recorded level was 1231.51 feet in June 2007 and the lowest record was 1229.64 in July 1970. The lake level has ranged 1.87 feet since 1966. A hydrograph of the period of record indicates relatively stable water levels; however, most of the data is from the previous four years (Figure 5). There is a break in the data seen below with single measurements taken each year in 1966, 1970, 1991, and 2002, and more continuous data collected since 2005.

Figure 5. Upper Hay Lake Level Hydrograph

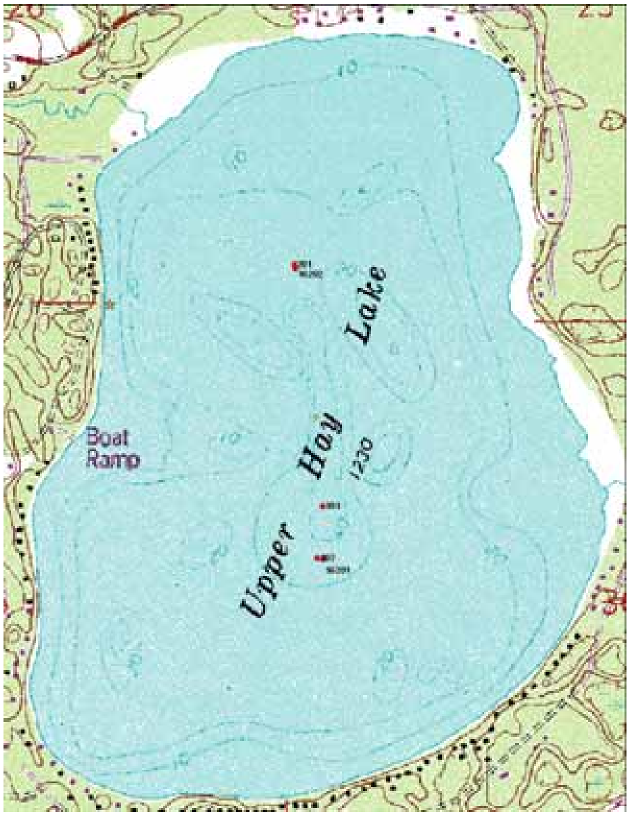


A summary of fisheries information was drawn from the DNR web site. Upper Hay Lake was most recently surveyed for fish population in August 2002. This survey provided results similar to those found in the 1997 survey. Largemouth bass catch was average, with the majority of the fish larger than 12". Bluegill, walleye, and northern pike were all considered to be average catches. Bluegill and yellow perch were found in below average numbers. Walleye are actively managed in the lake, with fry stocked annually at a rate of 1000 fry per littoral acre (184,000 fry). It was noted that the plant community was quite diverse, with 31 species present. The emergent and submerged aquatic plant species were essential to providing spawning habitat and food and cover for game fish and other aquatic species.

Methods

Data have been collected on Upper Hay Lake for many years primarily by the Upper Hay Lake Association over the May to September monitoring window. Most recently data have been collected monthly by lake association volunteers at Site 101 (Figure 7; 2003-2005, 2007, 2008) and analyzed by ERA Laboratories in Duluth, MN. In 1997, MPCA staff sampled the lake with the assistance of volunteers at sites 101 and 201 (Figure 7). Samples were collected monthly and were analyzed by the Minnesota Department of Health Laboratory. All data were analyzed using U.S. Environmental Protection Agency (EPA) approved methods.

Figure 6. Established Sites on Upper Hay Lake



Samples were primarily analyzed for TP and chl-*a* . Secchi disk transparency was also collected during sampling events. All data for this report was stored in STORET, EPA's national water quality data bank.

Results and Discussion

Dissolved oxygen and temperature. Profiles were taken at one-meter intervals at site 101 from 1994 to 2002. A comparison of the mid-summer profiles is found in Figure 8. Upper Hay Lake stratifies consistently at a depth of 4 to 6 meters. The dissolved oxygen (DO) typically drops below 5 milligrams per liter (mg/L), the concentration necessary to support game fish, below a depth of 4 to 7 meters (Figure 7). Under these low oxygen conditions, TP can often be released from the sediments, creating an internal cycling of nutrients that promote algal growth.

Figure 7. Upper Hay Lake Mid-Summer Temperature and Dissolved Oxygen Profiles

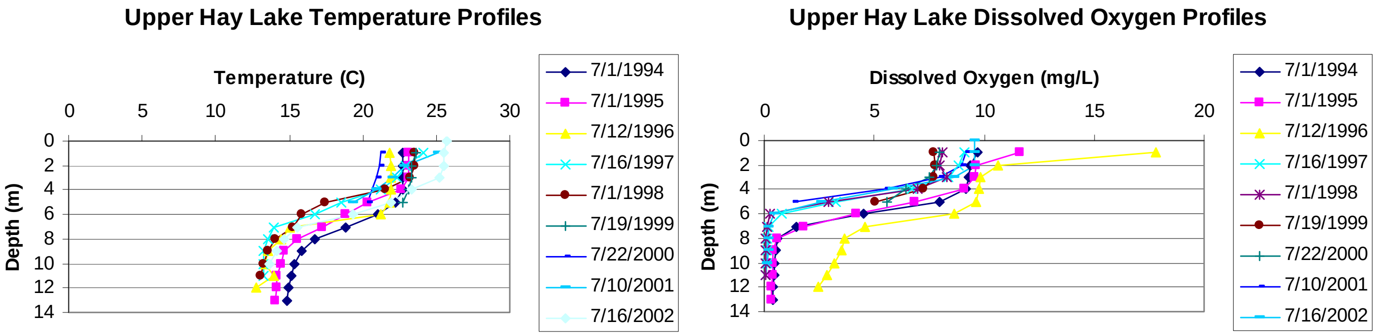
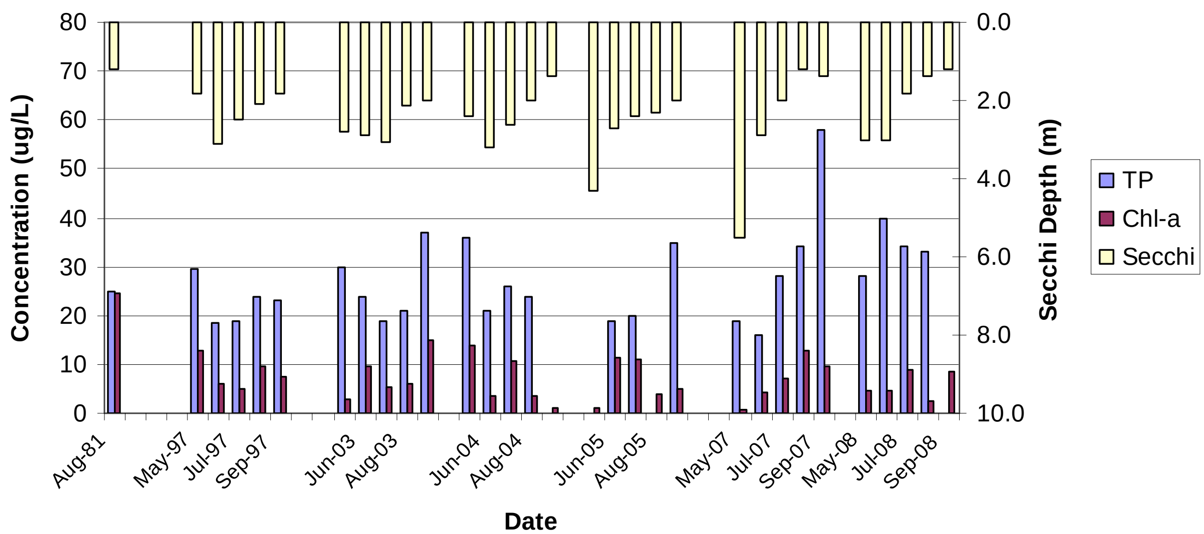


Figure 8. Upper Hay Lake Long Term Summer-Mean Trophic State Parameters



Total Phosphorus. TP is the limiting nutrient for plant growth in fresh waters. Since 2003, summer average TP concentrations have ranged from 21 to 58 micrograms per liter (µg/L) in the surface waters of Upper Hay Lake (Figure 9). In general, TP is high at spring overturn, somewhat stable in June through August, and then increases in September. The September increase likely coincides with fall overturn. Based on a review of the data record, 4 data points were either changed or excluded in STORET as the data were suspect. TP values collected on 5/23/05, 8/22/05, and 9/21/08 were all extremely high considering the reported chl-*a* and Secchi values, and the TP data were therefore excluded from STORET. The 5/22/07 sample collected at site 101 was likely switched – the surface sample is now in STORET as 31 µg/L and the depth sample is 47 µg/L. The original 1997 report used 31 µg/L in the surface TP calculation.

Chlorophyll-a. Chl-*a*, a pigment found in algae, is used to estimate the amount of algal production in a lake. Since 2003, the chl-*a* concentration has been well within the ecoregion reference typical range (Figure 9). Concentrations greater than 10 µg/L would be considered a mild algal bloom. Samples collected since 2003 show that this level has only been exceeded 5 times.

Secchi disk transparency. Transparency is generally a function of the amount of algae in the water. Suspended sediments or color (due to dissolved organic material) may also reduce water transparency. Color (10 to 30 Pt-Co Units) was within the expected range for the ecoregion; total suspended solids and total suspended inorganic solids concentrations were on the high end of ecoregion reference lake expected values (data only available for 1997). As a result, these parameters likely would not have affected the transparency readings. Secchi transparency has been on the low end of the typical range for NLF reference lakes.

Table 3. Upper Hay lake summer-mean measurements as compared to typical reference lake ranges

Parameter	1997	2003	2004	2005	2007	2008	NLF
Number of reference lakes							30
Total Phosphorus (µg/L)	21.5	25	24	25	34	36	14 - 27
Chlorophyll mean (µg/L)	7.3	8.9	4.7	7.8	8.5	6.2	4 - 10
Secchi Disk (meters)	2.3	2.5	2.3	2.4	1.9	1.9	2.4 – 4.6
Total Kjeldahl Nitrogen (mg/L)	0.55						0.4 – 0.75
Nitrite + Nitrate-N (mg/L)	<0.05						< 0.01
Alkalinity (mg/L)	90						40 - 140
Color (Pt-Co U)	27						10 - 35
Chloride (mg/L)	3.4						0.6 – 1.2
Total Suspended Solids (mg/L)	2.3						<1 - 2
Total Suspended Inorganic Solids (mg/L)	1.7						<1 - 2
TN:TP ratio	22:1						25:1 - 35:1
TSI	48	50	48	50	53	52	

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). This index was developed from the interrelationships of summer Secchi disk transparency and the concentrations of surface water chl-*a* and TP. TSI values are calculated as follows:

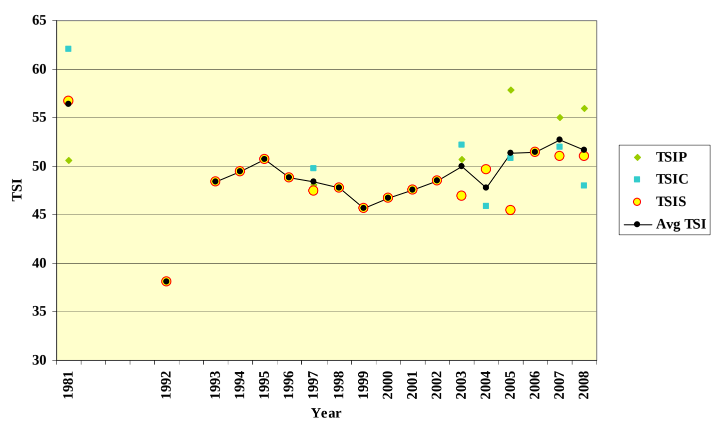
Total Phosphorus TSI (TSIP) = 14.42 ln (TP) + 4.15

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.

Figure 9. Annual Trophic State Index



Average values for trophic parameters in Upper Hay Lake and respective TSIs are presented in Figure 9 (calculated using 1999 to 2008 data; the current assessment cycle). Based on these values, Upper Hay Lake's current trophic condition would be considered to be on the borderline between *mesotrophic and eutrophic*. Individual TSI values for TP, chl-*a*, and Secchi all agree quite well with each other (Figure 10). As a result, Secchi disk transparency provides a good basis for characterizing lake trophic status and trends over time. TSI values for individual years can be found in Table 2.

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

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

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

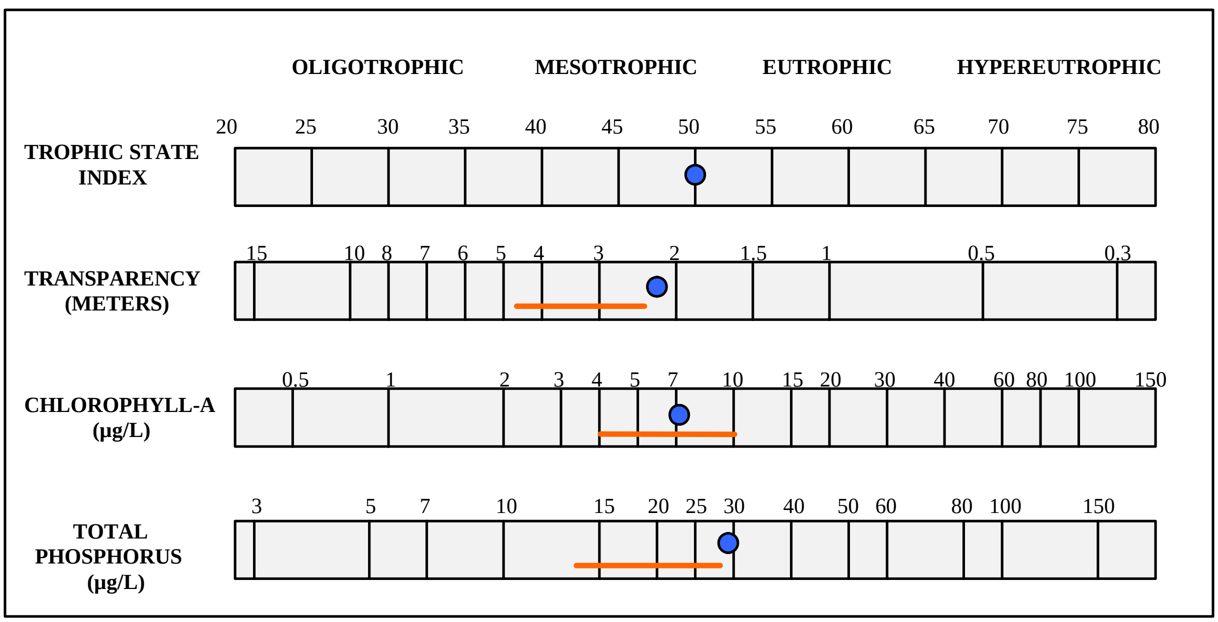
TSI 40 - 50 Water moderately clear, but increasing probability of anoxia in hypolimnion during summer.

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

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

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

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



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

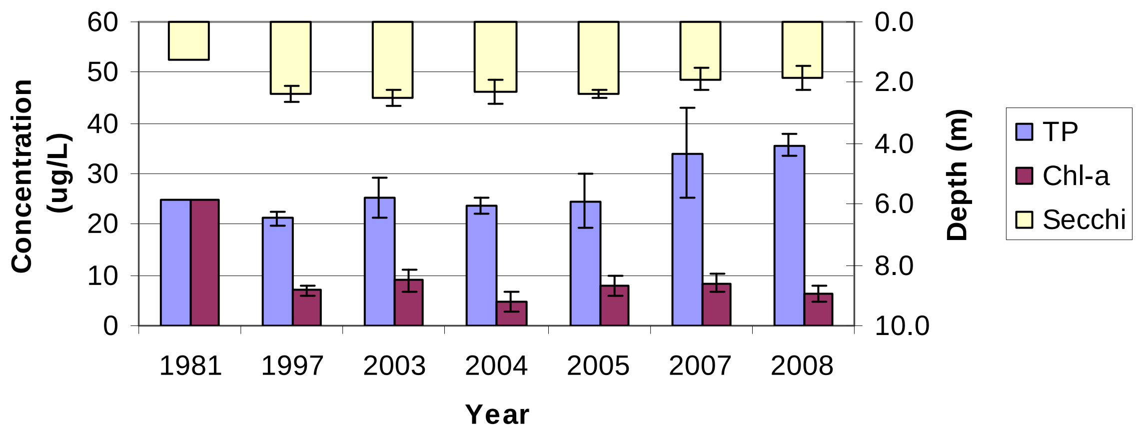
NLF Ecoregion Range: Upper Hay :

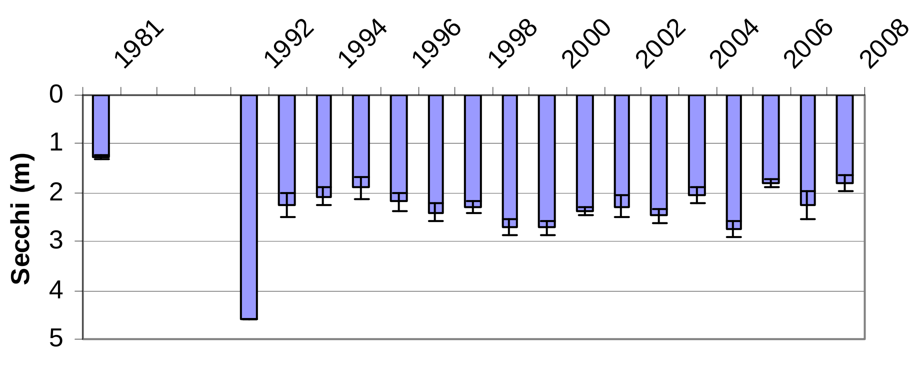
Trophic Status Trends

Upper Hay Lake has been routinely monitored for TP, chl-*a*, and Secchi depth since 1997. All parameters have been quite consistent over this period of record with TP ranging from 20-25 µg/L, chl-*a* from 5-8 µg/L, and Secchi from 2.0 -2.2 m (Figure 11). In 2007 and 2008, there was a marked increase in TP; however chl-*a* and Secchi did not exhibit a corresponding change. In calculating these trends, it is important to note that TP values were removed from the data set as the TP was disproportionately high compared to the response parameters of chl-*a* and Secchi (May and August 2005, and September of 2008). Based on the most recent trend analysis for Secchi transparency, Upper Hay Lake does not show a statistically significant trend of declining or improving transparency. It is possible, with the higher rainfall amounts in recent years that the coloration of the water has increased; however, no color samples have been analyzed since 1997. Chl-*a* concentrations have not increased over the last decade; transparency does not appear to be limited by algal production.

Figure 11 includes standard error bars; if no bars exist; only a single sample was taken for that year. The graph includes data collected from June to September each year; the actively growing season for lakes. Where data were available on multiple sites, they were averaged and a whole lake value was depicted (Figure 11 and Table 2).

Figure 11. Long-Term Summer-Mean Trophic State Parameters and Secchi Transparency





Modeling

Numerous 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. These models can also be used for estimating changes in the quality of the lake as a result of altering nutrient inputs to the lake or altering the amount of water that flows into the lake.

To analyze the water quality data recently collected on Upper Hay Lake, MINLEAP (Wilson and Walker, 1989) was used. MINLEAP was developed by MPCA staff based on an analysis of data collected from ecoregion reference lakes. It was intended to be used as a screening tool for estimating lake nutrient conditions with minimal input data. MINLEAP was run for Upper Hay Lake and model results were compared to recent data (Table 3). Model predictions are comparable to the lower values observed in recent years (2000 and 2006). Estimated background phosphorus was predicted using 1997 data only, with a predicted TP level of 20 µg/L.

Table 4. Observed Summer-Mean Compared to MINLEAP Predicted Outputs

Parameter	1997	2003	2004	2005	2007	2008	MINLEAP Prediction
Total Phosphorus (µg/L)	21.5	25	24	25	34	36	26
Chlorophyll mean (µg/L)	7.3	8.9	4.7	7.8	8.5	6.2	7.7
Secchi Disk (meters)	2.3	2.5	2.3	2.4	1.9	1.9	2.3

Another way to place lake condition in perspective is to compare modern-day TP concentrations to historic, specifically pre-European conditions (1750 – 1800 time period). One technique for estimating pre-European conditions or changes over time involves the collection of a sediment core from the bottom of the lake. The core is sectioned and the various sections are "dated" by means of various techniques. Diatom fossils in cores can be used to estimate the trophic status of the lake as their environmental requirements are well known (i.e. range phosphorus concentrations). Lakes from across Minnesota's four main ecoregions were sampled and pre-European trophic status and trends were developed (Heiskary and Swain, 2002). Upper Hay Lake was not a part of this study, but several nearby lakes in Crow Wing County were included. Based on twenty NLF lakes, pre-European interquartile range for TP was 8 – 27 µg/L.

303(d) Impaired Waters Assessment and Goal Setting

Eutrophication standards are now in place for assessing the aquatic recreation use support for lakes in Minnesota. For deep lakes in the NLF ecoregion to be considered supporting aquatic recreation use, the following must be met: TP < 30 µg/L, chl-*a* < 9 µg/L, and Secchi disk transparency > 2.0 meters. To be deemed impaired, TP and either chl-*a* or Secchi depth must exceed the standards. Based on data that will be used in the 2010 assessment cycle, Upper Hay Lake would not exceed the eutrophication standards and would not appear on the 303(d) impaired waters list. However, a continued increase in total phosphorus, coupled with either an increase in chl-*a* or a decline in Secchi transparency could cause the lake to be listed in future assessment cycles.

Table 5. Minnesota Lake Eutrophication Standards

Ecoregion	TP	Chl-a	Secchi
	µg/L	µg/L	meters
NLF – Aquatic Rec. Use (Class 2B)	< 30	< 9	> 2.0
Upper Hay Lake 1999 to 2008 data	29	7.2	2.2

For Upper Hay Lake, it would be desirable to reduce in-lake TP levels. Based on modeling done in previous studies and this report and the pre-European diatom-inferred TP of NLF ecoregion lakes, maintaining an in-lake TP on the order of 20-25 µg/L would be recommended.

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Appendix A: Glossary

Acid Rain: Rain with a higher than normal acid range (low pH) often caused by polluted air mixing with cloud moisture.

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

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 which does not thermally stratify in the summer. Polymictic lakes 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.

Trophic Status: The level of growth or productivity of a lake as measured by phosphorus content, algae abundance, and depth of light penetration.

Turbidity: Particles in solution (e.g. soil or algae) which scatter light and reduce transparency.

Water Density: Water is most dense at 39 degrees F (4 degrees C) and expands (becomes less dense) at both higher and lower temperatures.

Watershed: The surrounding land area that drains into a lake, river or river system.

Zooplankton: Microscopic animals

Appendix B: Abbreviations and Units

DATE= yr-mo-da
SITE= sampling site ID,
TP= total phosphorus in mg/L (decimal) or µ/L as whole number
TKN= total Kjeldahl nitrogen in mg/L
N2N3= nitrite+nitrate N in mg/L
NH4= ammonia-N in mg/L
TNTP=TN:TP ratio
PH= pH in SU (F=field, L or _=lab)
ALK= alkalinity in mg/L (lab)
TSS= total suspended solids in mg/L
TSV= total suspended volatile solids in mg/L
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)
CHLA= chlorophyll-a in µ/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)

Appendix C: Data

Sample Date	Site ID	Chl-a µg/L	TP µg/l	Secchi m	TP depth µg/L
Aug-81	101	24.7	25	1.2	
Jun-97	101	5.9	18.5	3.1	101
Jul-97	101	4.9	19	2.5	172
Aug-97	101	9.5	24	2.1	305
Sep-97	101	7.6	23	1.8	323
Jun-03	101	9.5	24	2.9	
Jul-03	101	5.3	19	3.1	
Aug-03	101	6.2	21	2.1	
Sep-03	101	14.9	37	2.0	
Jun-04	101	3.6	21	3.2	
Jul-04	101	10.6	26	2.6	
Aug-04	101	3.7	24	2.0	
Sep-04	101	<1		1.4	
Jun-05	101	11.4	19	2.7	
Jul-05	101	10.9	20	2.4	
Aug-05	101	4	92*	2.3	
Sep-05	101	5	35	2.0	
Jun-07	101	4.2	16	2.9	
Jul-07	101	7.2	28	2.0	
Aug-07	101	12.9	34	1.2	
Sep-07	101	9.6	58	1.4	
Jun-08	101	4.7	40	3.0	
Jul-08	101	9	34	1.8	
Aug-08	101	2.4	33	1.4	
Sep-08	101	8.7	120*	1.2	

*excluded data from analysis