Lake Margaret Nutrient TMDL

Wenck

Prepared for

The City of Lake Shore

Minnesota Pollution Control Agency

September 2010

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Lake Margaret Nutrient TMDL Report

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Prepared for:

THE CITY OF LAKE SHORE

MINNESOTA POLLUTION CONTROL AGENCY

Prepared by:

WENCK ASSOCIATES, INC.
1800 Pioneer Creek Center
P.O. Box 249
Maple Plain, Minnesota 55359-0249
(763) 479-4200

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TMDL Summary Table

EPA/MPCA Required Elements	Summary	TMDL Page #
Location	City of Lake Shore in Cass County, Minnesota, in the Upper Mississippi River Basin.	1-1
303(d) Listing Information	Margaret 11-0222 HUC 0701010 Lake Margaret was added to the 303(d) list in 2006 because of excess nutrient concentrations impairing aquatic recreation, as set forth in Minnesota Rules 7050.0150. This TMDL was prioritized to start in 2008 and be completed by 2015.	2-2
Applicable Water Quality Standards/ Numeric Targets	Criteria set forth in Minn. R. 7050.0150 (3) and (5). For Lake Margaret, the numeric target is total phosphorus concentration of 30 µg/L or less.	2-1
Loading Capacity (expressed as daily load)	The loading capacity is the total maximum daily load for each of these conditions. The critical condition for these lakes is the summer growing season. The loading capacity is set forth in Tables 6.1 & 6.2 **Total maximum daily total phosphorus load (lbs/day)** Lake Margaret south basin: 6.3 Lake Margaret north basin: 6.1	6-2
Wasteload Allocation	Portion of the loading capacity allocated to existing and future permitted sources. **Source** / **Permit #** / **Gross WLA (lbs/day)** Construction Stormwater – South Basin / MNR040000 / 0.1 Construction Stormwater –North Basin / MNR040000 / 0.003	6-2
Load Allocation	The portion of the loading capacity allocated to existing and future non-permitted sources. **Source** / **Load Allocation (lbs/day)** Stormwater Runoff/Registered Animal Units South / 6 Stormwater Runoff/Registered Animal Units North / 0.3 Septic Systems /	6-2

TMDL Summary

TMDL Summary Table			
EPA/MPCA Required Elements	**Summary**		**TMDL Page #**
	South	0	
	North	0	
	Atmospheric Load		
	South	0.1	
	North	0.1	
	Internal Load		
	South	0.1	
	North	0.2	
Margin of Safety	The margin of safety is implicit in each TMDL due to the conservative assumptions of the model and the proposed iterative nutrient reduction strategy with monitoring.		6-2
Seasonal Variation	Seasonal variation is accounted for by developing targets for the summer critical period where the frequency and severity of nuisance algal growth is greatest. Although the critical period is the summer, lakes are not sensitive to short-term changes but rather respond to long-term changes in annual load.		6-5
Reasonable Assurance	Reasonable assurance is provided by implementing the TMDL through the City of Lake Shore's Comprehensive Plan, Cass County's Comprehensive Local Water Management Plan, and activities conducted by the Lake Margaret Conservation Association.		9-1
Monitoring	The City of Lake Shore and Minnesota DNR periodically monitor these lakes and will continue to do so through the implementation period.		9-4
Implementation	This TMDL sets forth an implementation framework and general load reduction strategies that will be expanded and refined through the development of an Implementation Plan. Implementation costs will range between $500,000 and $5 Million.		8-1
Public Participation	Stakeholder and Public Meetings: March 26, 2008, July 15, 2008, August 20, 2008 and August 23, 2008 Meeting location: City of Lake Shore – City Hall		7-1

Executive Summary

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Lake Margaret (11-0222). The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients.

Lake Margaret is located in the City of Lake Shore, Cass County, Minnesota, in the Upper Mississippi River watershed. It is a highly used recreational water body with an active fishery and provides other aesthetic values as well. The drainage area to the lake is 45,206 acres of land that is predominantly timber followed by small percentages of agriculture, pasture, and wetlands. The drainage area contains portions of the City of Lake Shore in the southeast corner but is mainly comprised of rural county areas including Moose Lake, Maple, Loon Lake, Meadow Brook, Home Brook, May and Fairview townships. The outlet to Lake Margaret is a channel at the north end of the lake where it flows into Upper Gull Lake, which is part of the Gull Lake Chain of Lakes. Water quality is considered fair with the lake still viewed as a popular destination for recreational activities.

Wasteload and Load Allocations to meet State standards indicate that average nutrient load reductions of 44% would be required to consistently meet standards under average precipitation conditions. Internal load management and reduction of phosphorus from watershed runoff by controlling sources from pastures and developed land (impervious surfaces) would have the most impact on reducing phosphorus load and improving water quality in Lake Margaret.

1.0 Introduction

1.1 PURPOSE

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Lake Margaret. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients in Lake Margaret. The Lake Margaret nutrient TMDL is being established in accordance with section 303(d) of the Clean Water Act, because the State of Minnesota has determined waters in Lake Margaret exceed the State established standards for nutrients.

This TMDL provides wasteload allocations (WLAs) and load allocations (LAs) for Lake Margaret. Based on the current State standard for nutrients, the TMDL establishes a numeric target of 30 µg/L total phosphorus concentration for deep lakes in the Northern Lakes and Forests ecoregion.

1.2 PROBLEM IDENTIFICATION

Lake Margaret (DNR Lake # 11-0222), located in the City of Lake Shore, was placed on the 2006 State of Minnesota's 303(d) list of impaired waters. Lake Margaret was identified for impairment of aquatic recreation (e.g., swimming). Lake Margaret can be accessed from both the Gull Lake Chain and local public accesses making it highly accessible for a large quantity of boat traffic. Local recreation includes boating and fishing. Lake Margaret is a popular destination for water skiers because of the linear and wind protected nature of the lake.

The lake is in a highly visible within the City of Lake Shore, with a very active Lake Association comprised of lake shore property owners who are active in the management of the lake. Water quality does not meet state standards for nutrient concentrations.

2.0 Water Quality Standards and Numeric Phosphorus Targets

2.1 IMPAIRED WATERS AND MINNESOTA WATER QUALITY STANDARDS

2.1.1 State of Minnesota Water Quality Standards and Designated Uses

Lake Margaret is a highly recreational lake on the Gull Lake Chain used for boating and fishing activities. Lake Margaret is located in the Northern Lakes and Forests ecoregion. Consequently, Lake Margaret is classified as a class 2B water. The Class 2B designation specifies aquatic life and recreation as the protected beneficial use of the water body.

Minnesota's standards for nutrients limit the quantity of nutrients which may enter surface waters. Minnesota's standards at the time of listing (Minnesota Rules 7050.0150(3)) stated that in all Class 2 waters of the State "…there shall be no material increase in undesirable slime growths or aquatic plants including algae." In accordance with Minnesota Rules 7050.0150(5), to evaluate whether a water body is in an impaired condition the MPCA developed "numeric translators" for the narrative standard for purposes of determining which lakes should be included in the section 303(d) list as being impaired for nutrients. The numeric translators established numeric thresholds for phosphorus, chlorophyll-a, and clarity as measured by Secchi depth.

The numeric target used to list this lake was the numeric translator threshold phosphorus standard for Class 2B waters in the Northern Lakes and Forests ecoregion (30 µg/L). This TMDL presents load and wasteload allocations and estimated load reductions assuming an endpoint of 30 µg/L. Although the TMDL is set for the total phosphorus standard, one of the two other lake eutrophication standards must be met: chlorophyll-a and Secchi depth (Table 2.1). All three of these parameters were assessed in this TMDL to assure that the TMDL will result in compliance with State standards. As shown in Table 2.1 Lake Margaret numeric standards for chlorophyll-a and Secchi depth are 9 µg/L and 2 meters, respectively.

Table 2.1. Numeric targets for Lakes in the Northern Lakes and Forests and North Central Hardwood Forest Ecoregions. The North Central Hardwood Forest Ecoregion standards are also presented for reference.

Parameters	Ecoregions		
	Northern Lakes and Forests	North Central Hardwood Forest	
		Deep	Shallow[1]
Phosphorus Concentration (µg/L)	30	40	60
Chlorophyll-a Concentration (µg/L)	<9	14	20
Secchi disk transparency (meters)	>2	>1.4	>1

[1] Shallow lakes are defined as lakes with a maximum depth of 15 feet or less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

2.1.2 Analysis of Impairment

The MPCA included Lake Margaret (11-0222) on the 303(d) impaired waters list for Minnesota in 2006. The lake is impaired by excess nutrient concentrations, which inhibits aquatic life and recreation.

Lake Margaret has been periodically monitored over the past 15 years with the most intensive monitoring occurring between 1996 and 1998 as a part of a Clean Water Partnership grant. During this monitoring period, the average summer mean values (June 1 through September 30) for total phosphorus were 45, 55, and 48 µg/L respectively. During this period chlorophyll-a concentrations ranged from 15 to 35 with Secchi depth transparencies of around 1 meter. All three parameters exceeded the State standards for lakes in the Northern Lakes and Forests ecoregion.

3.0 Watershed and Lake Characterization

3.1 LAKE AND WATERSHED DESCRIPTION

Lake Margaret is a 224 acre lake located on the Gull Lake Chain and is about three miles southwest of Nisswa (Figure 3.1). Public access is via navigable channel from Gull Lake. The lake's maximum depth is 26 feet and about 73% of the lake is less than 15 feet deep or littoral (Table 3.1). Typically, the greater the percentage of the lake that is littoral, the greater the influences of biological processes (fish, zooplankton, and plants) on water quality. Lake Margaret likely will respond to both watershed inputs as well as changes in the biological system. Lake Margaret is a hardwater lake with moderate phosphorous fertility. Shallow water soils are predominantly sand and gravel while soils in marshy areas are primarily muck.

Lake Margaret has a very short residence time, averaging approximately 37 days. The watershed-to-lake area ratio is 206, which indicates that the lake will be very sensitive to watershed nutrient inputs. The Lake Margaret watershed and the general flow patterns of the contributing tributaries are present in Figure 3.2.

Table 3.1. Lake Margaret morphometric characteristics.

Parameter	Lake Margaret South Basin	Lake Margaret North Basin	Total
Surface Area (acres)	85	133	219
Average Depth (ft)	9.4	11.2	10.5
Maximum Depth (ft)	26	22	26
Volume (ac-ft)	802	1491	2293
Residence Time (years)	0.04	0.06	0.10
Littoral Area (acres)	74	86	161
Littoral Area (%)	87%	65%	73%
Watershed (acres)	42,254	2,916	45,170
Watershed:Lake Area ratio	494	206	206

3.2 LAND USE

Land use data for the Lake Margaret Watershed are presented in Table 3.2 and Figure 3.3. Multiple data layers were combined to determine land use across the watershed. Parcel data from the Cass County was combined with county land cover data from 2001, National Wetland Inventory data from 1994 and agricultural data from the National Agricultural Statistics Services (NASS) layer from 2006. The Lake Margaret watershed is a rural forested and agricultural watershed. Land use in the Lake Margaret watershed is predominantly timber followed by small percentages of agriculture, pasture, and wetlands. There are several feed lots in the watershed associated with the pastureland. The type of agriculture varies; however, there is a large sod grass farm in the watershed. The City of Lake Shore represents approximately 7% of the

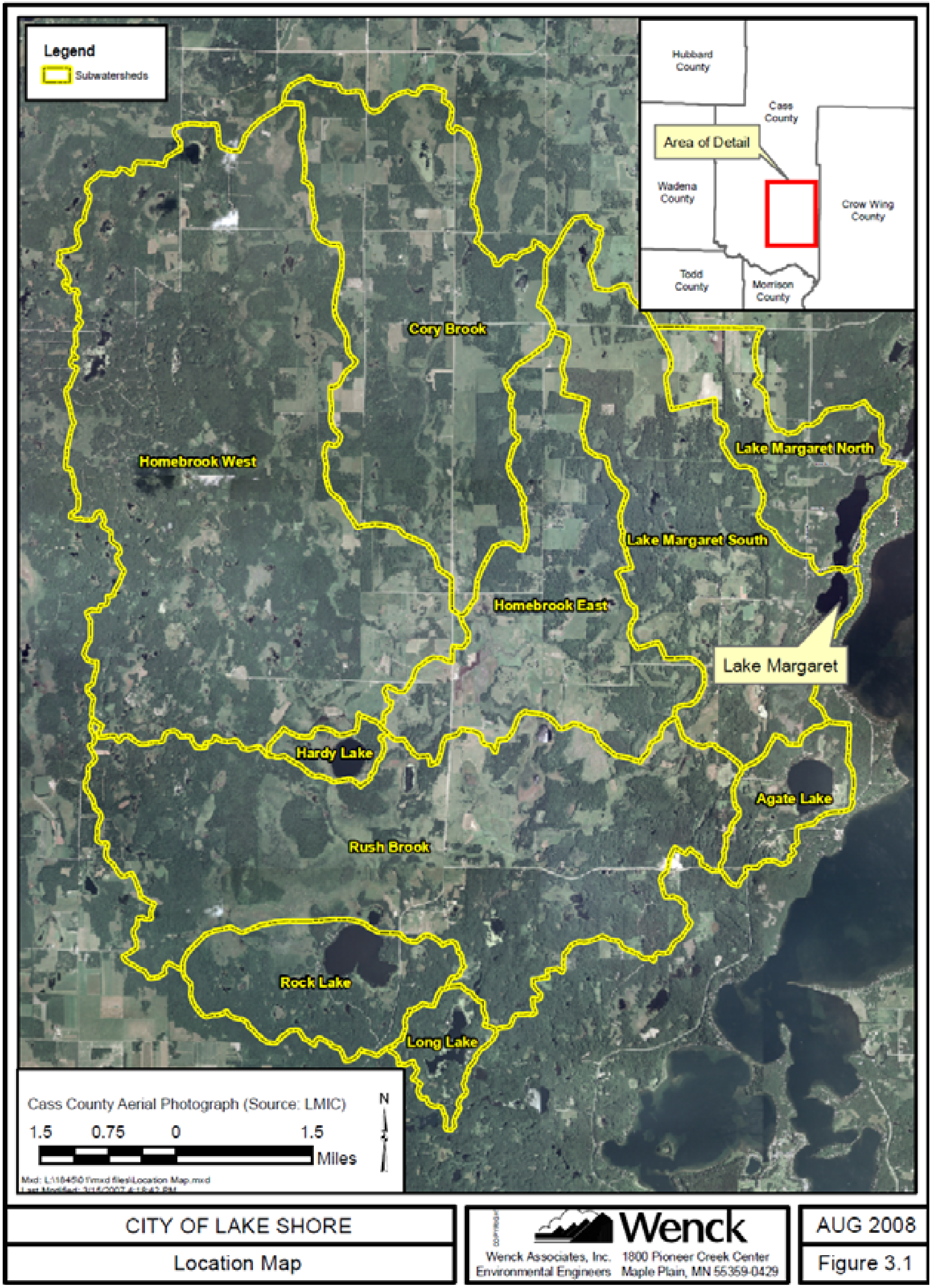


Figure 3-1. Location Map

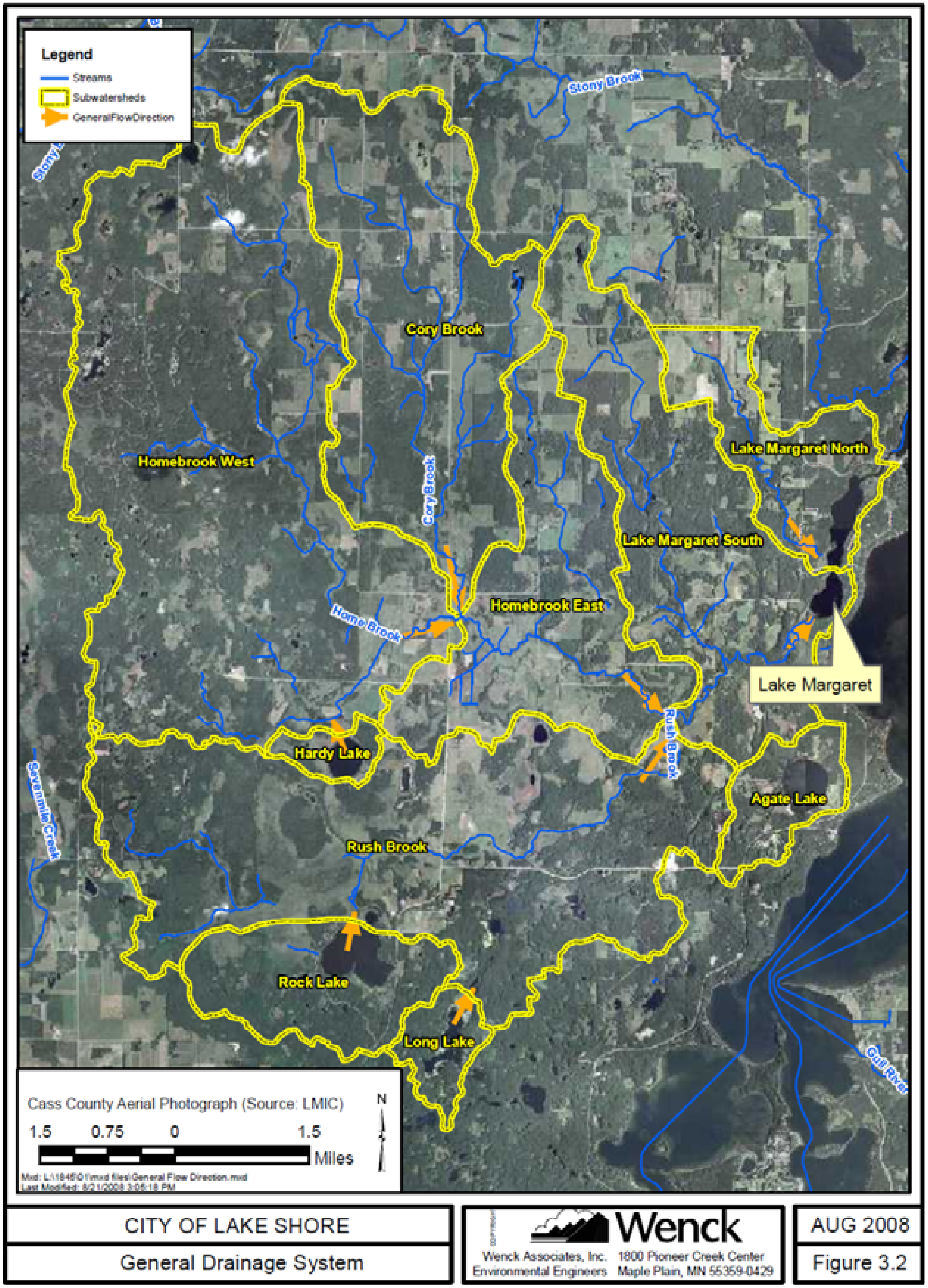


Figure 3-2. General Drainage System

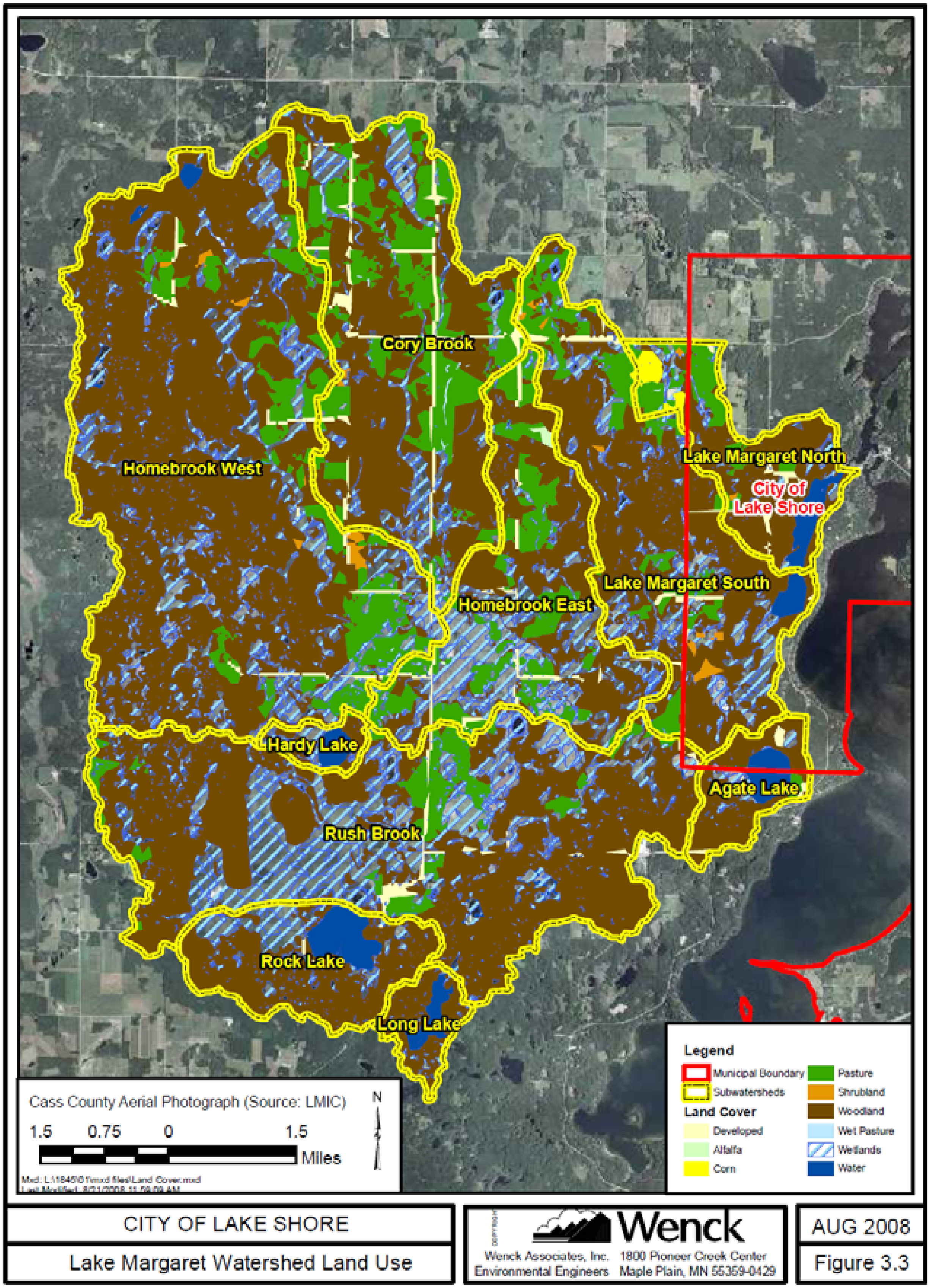


Figure 3-3. Lake Margaret Watershed Land Use

watershed. Land use in the City of Lake Shore is primarily deciduous forest with rural residential homes, many on the shores of Gull Lake and Lake Margaret. Only 1.8 percent of the land in the Lake Margaret watershed is classified as developed.

Table 3.2. Land use in the Lake Margaret watershed.

Land Use*	Acres	Percent
Cropland	122	0.3 %
Pasture	5,901	13.1%
Developed	789	1.8%
Shrubland	144	0.3%
Wetland	11,318	25.0%
Woodlands	26,833	59.4%
Water	99	0.2%
TOTAL	45,206	100%

*Source: Land use data was derived form a combination of three data sources: Cass County Land Cover Data (2001); National Agricultural Statistics Services (2006); and National Wetlands Inventory (1994)

3.3 RECREATIONAL USES

Lake Margaret provides a variety of recreational uses, including fishing and boating. Lake Margaret is connected to the Gull Lake chain of lakes, a very popular recreation destination in the Brainerd Lakes area. Lake Margaret can be accessed from both the Gull Lake Chain and local public accesses making it highly accessible for a large quantity of boat traffic. Lake Margaret is a popular destination for water skiers because of the linear and wind protected nature of the lake.

The Lake Margaret Lake Association provided recreational survey data for the lake (Doug Miller, pers. comm.). These data include:

- Approximately 124 families who reside on the lake in peak summer with approximately
  - 88 power boats,
  - 32 pontoons,
  - 25 jet skis, and
  - 15 fishing boats
  - for a total of 185 high-powered water vehicles.

DNR boat surveys show that 10 percent of the total number of lake home owners are out boating during high use weekend afternoons resulting in approximately 18 boats on the water. DNR safety guidelines suggest 20 acres per boat suggesting that Lake Margaret can sustain approximately 11 boats safely. Lake Margaret exceeds this on busy weekends.

Increased boat traffic in shallow areas, even at low or no wake speeds can increase sediment disturbance and direct vegetation impacts through cutting (Asplund and Cook 1997). Maintaining high quality habitats such as these is essential in maintaining the appropriate fish assemblage to protect water quality. Healthy shallow lake systems often depend on piscivorous fish such as bass to keep the panfish population in balance. Because Lake Margaret is relatively shallow (71% less than 15 feet in depth) and is highly used by recreational boaters, it is likely susceptible to water quality degradation caused by boating impacts.

3.3.1 Water Quality

3.3.2 Introduction

Water quality in Minnesota lakes is often evaluated using three associated parameters: total phosphorus, chlorophyll-a, and Secchi depth. Total phosphorus is typically the limiting nutrient in Minnesota's lakes meaning that algal growth will increase with increases in phosphorus. However, there are cases where phosphorus is widely abundant and the lake becomes limited by nitrogen availability. Chlorophyll-a is the primary pigment in aquatic algae and has been shown to have a direct correlation with algal biomass. Since chlorophyll-a is a simple measurement, it is often used to evaluate algal abundance rather than expensive cell counts. Secchi depth is a physical measurement of water clarity by lowering a black and white disk until it can no longer be seen from the surface. Higher Secchi depths indicate less light refracting particulates in the water column and better water quality. Conversely, high total phosphorus and chlorophyll-a concentrations point to poor water quality. Measurements of these three parameters are interrelated and can be combined into an index that describes water quality.

3.3.3 Monitoring in Lake Margaret

Water quality monitoring has been conducted at several locations on Lake Margaret under a variety of efforts. The two main sampling stations on Lake Margaret are the two deep holes in the north (site 101) and south basins (site 102) of the lake (Figure 3.4). Water quality samples have been collected from these monitoring locations from the early 1990's through 2005. Collection efforts have been conducted by the US Army Corps of Engineers (ACOE), the Minnesota Pollution Control Agency (MPCA), and through the Citizens Lake Monitoring Program (CLMP). Additionally there was a Clean Water Partnership study in the mid-1990s on Lake Margaret. The Clean Water Partnership study was also responsible for collecting stream monitoring data at several sites in the Lake Margaret watershed from 1996 through 1999.

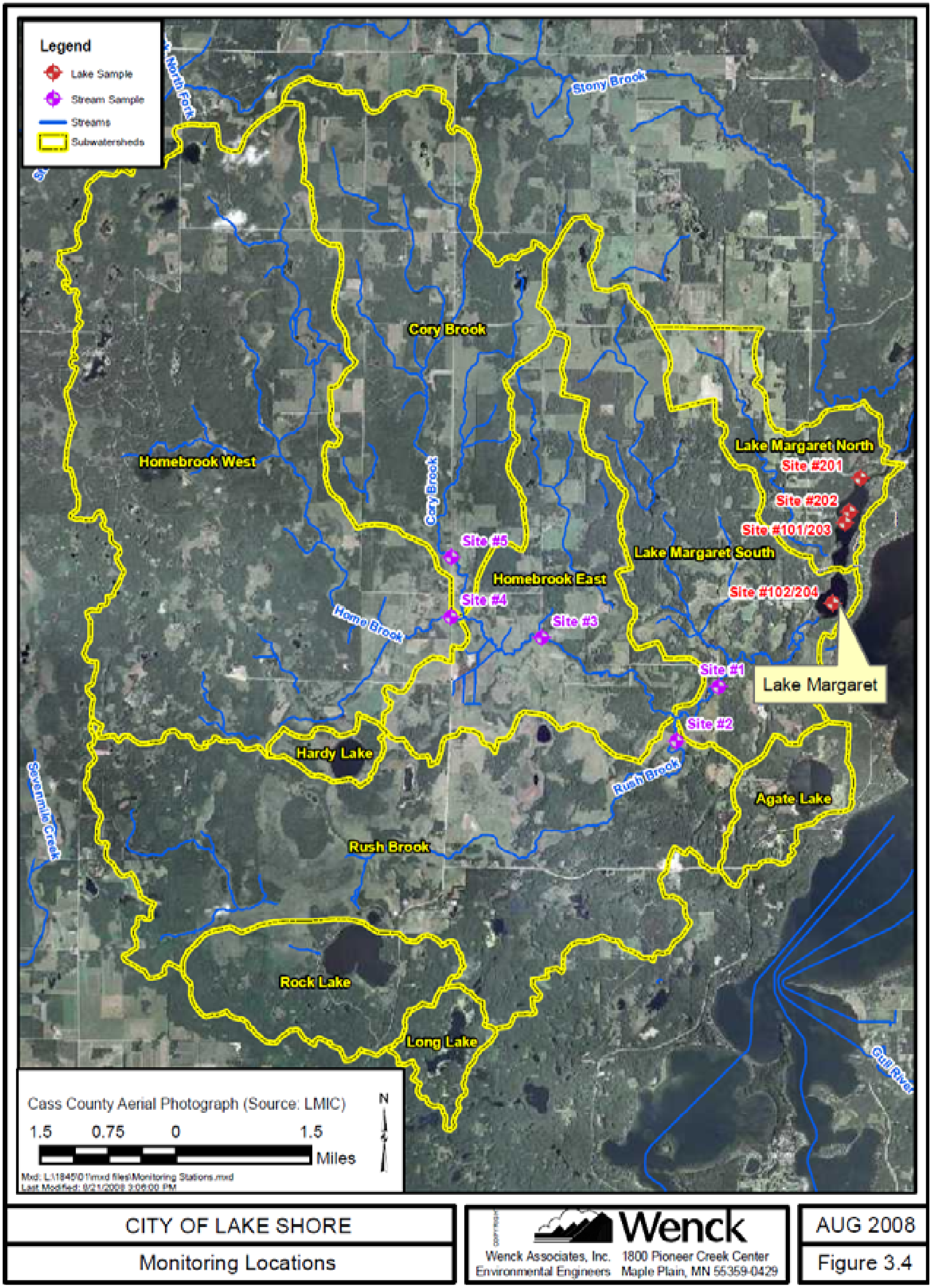


Figure 3-4. Lake Monitoring Locations

3.3.4 Lake Monitoring Results

3.3.4.1 Temperature and Dissolved Oxygen

Temperature and dissolved oxygen profile data were collected for Lake Margaret in 1994 and 2005. Temperature profiles suggest stratification in both lake basins (Appendix A). Dissolved oxygen (DO) concentration in Lake Margaret also demonstrates stratification with hypoxia (DO ≤ 2 mg/L) measured as shallow as 6.5 feet. Temperature and dissolved oxygen conditions in Lake Margaret demonstrate the potential for internal loading of phosphorus.

3.3.4.2 Total Phosphorus

Summer average total phosphorus concentrations at both monitoring sites in Lake Margaret exceeded the State standard of 30 µg/L in all monitoring years (Figure 3.5; Appendix B). The highest summer average concentration was measured in the mid-1990s and reached almost 65 µg/L. Summer average total phosphorus concentrations reached 62µg/L in 2005 suggesting that the lake has been demonstrating current water quality conditions for the past 15 years.

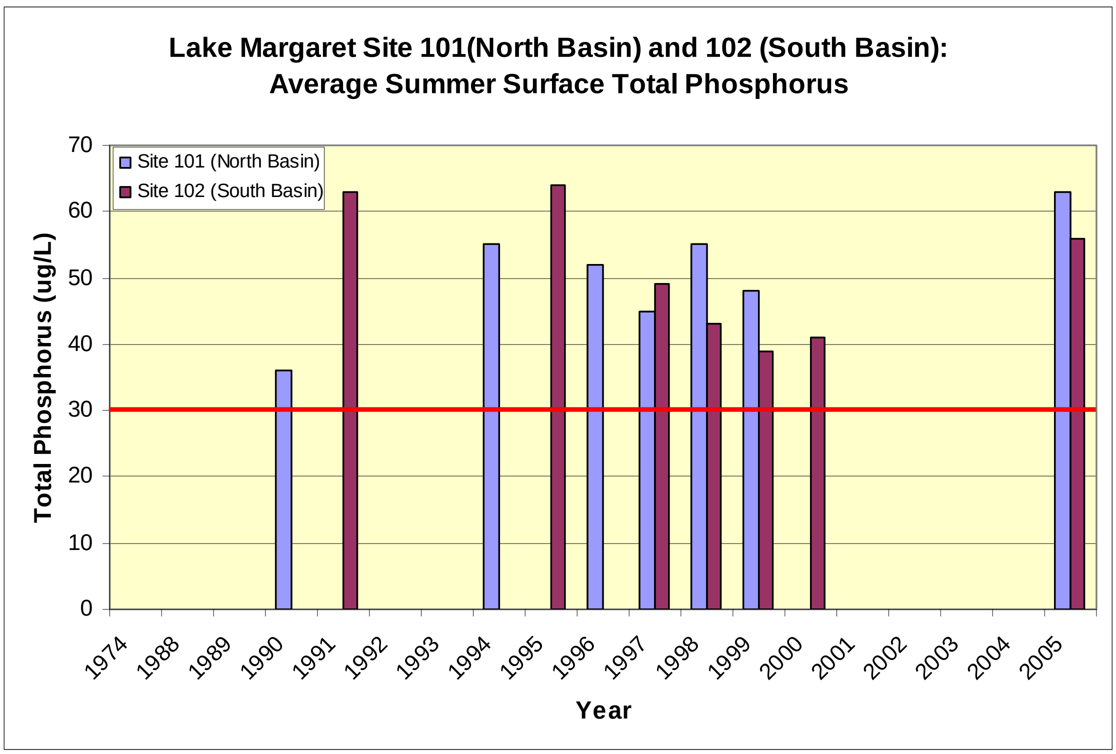


Figure 3-5. Summer (June 1 –September 30) mean total phosphorus concentrations for Lake Margaret. The red line indicates the current State standard for the Northern Lakes and Forests Ecoregion.

3.3.4.3 Chlorophyll-a

Chlorophyll-a concentrations in Lake Margaret ranged from 20 to 60 µg/L with the highest summer averages occurring in the early 1990s (Figure 3.6). Recent chlorophyll-a concentrations ranged from 20 to 30 µg/L, which are still more than 2-3 times the State standard. Chlorophyll-a concentrations in this range demonstrate a high potential for nuisance algae blooms.

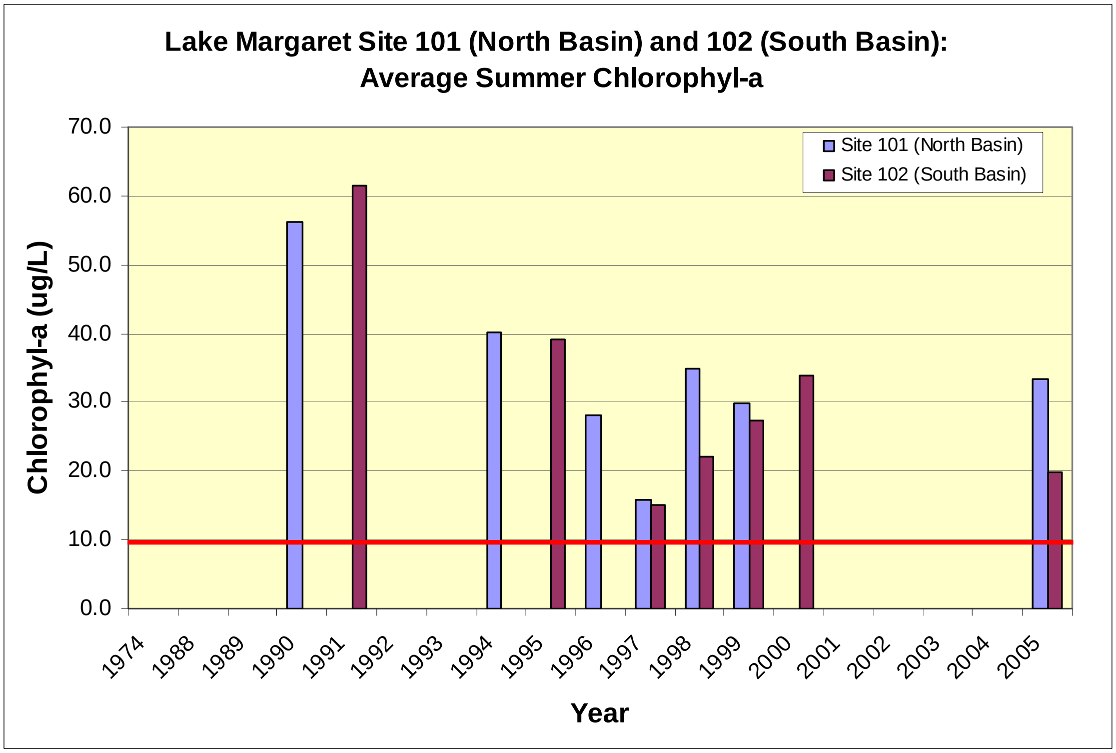


Figure 3-6. Summer (June 1 –September 30) mean chlorophyll-a concentrations for Lake Margaret. The red line indicates the current State standard for the Northern Lakes and Forests Ecoregion.

3.3.4.4 Secchi Depth

Water clarity (Secchi depth) followed the same trend as TP and chlorophyll-a and has not met the State standard over the past 30 years (Figure 3.7). There is no apparent trend in the Secchi depth data suggesting that the lake has demonstrated similar water quality over the past 30 years.

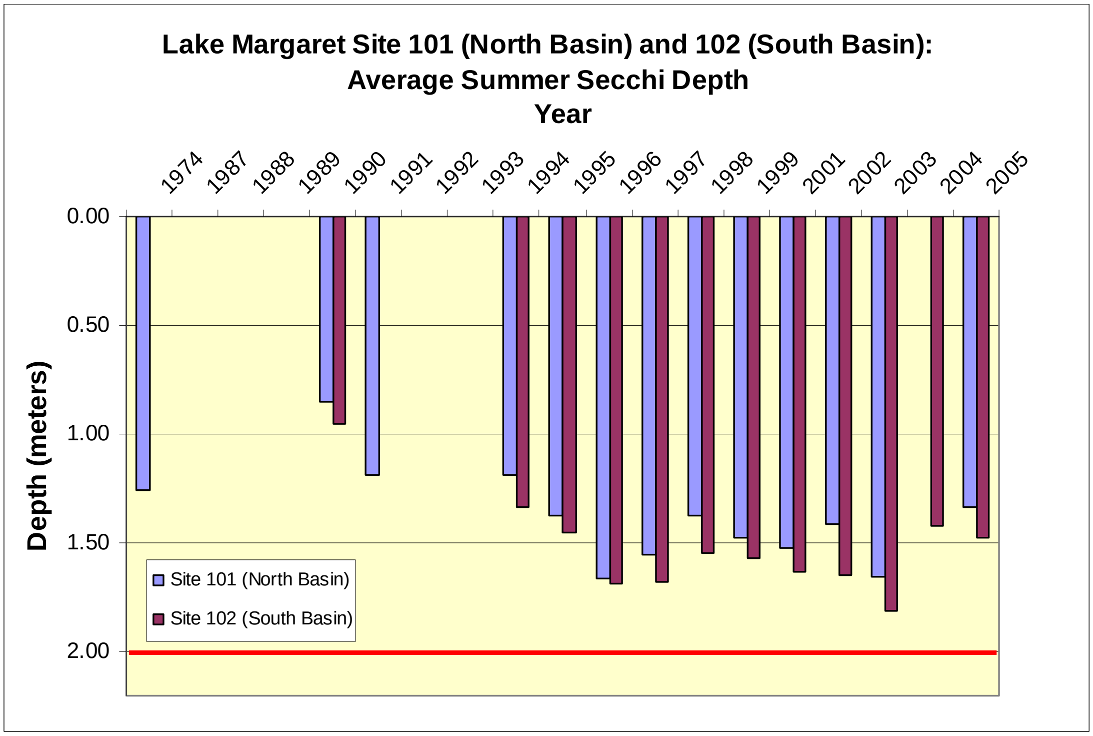


Figure 3-7. Summer (June 1 –September 30) mean Secchi depth (meters) for Lake Margaret. The red line indicates the current State standard for the Northern Lakes and Forests Ecoregion.

3.3.5 Conclusions

Overall, Lake Margaret has not met current State standards over the past fifteen years. While there is some variability in the monitoring data from year to year, trends over that time show that the water quality is relatively stable in its current state. There has not been a significant decline or improvement in the water quality of Lake Margaret in the past fifteen years.

3.4 FISH POPULATIONS AND FISH HEALTH

3.4.1 Fish Populations

The lake management plan and fish survey reports for Lake Margaret were provided by the DNR Brainerd Area Fisheries Office. The initial DNR fish survey for Lake Margaret was conducted in 1964. There have six additional surveys since that time, occurring approximately once every five years, from 1981 through 2007. Standard survey methods used by the DNR include gill net and trap nets. These sampling methods do have some sampling bias, including focusing on game management species (i.e., northern pike and walleye), under representing small minnow and darter species presence/abundance and under representing certain management species such as largemouth bass. The lake management plan developed by the Brainerd Fisheries Office for Lake Margaret indicates the lake is primarily managed as a largemouth bass and panfish lake (i.e. bluegill and black crappie). However, northern pike are also an important management and recreation species in the lake. There have been 17 species collected during DNR surveys:

- Black Bullhead
- Black Crappie
- Bluegill
- Bowfin
- Brown Bullhead
- Common Carp
- Green Sunfish
- Hybrid Sunfish
- Largemouth Bass
- Northern Pike
- Pumpkinseed
- Rockbass
- Tullibee
- Walleye
- White Sucker
- Yellow Bullhead
- Yellow Perch

Fish community data was summarized by trophic groups (Figures 3.8 and 3.9). Species within a trophic group serve the same ecological process in the lake (i.e., panfish species feed on zooplankton and invertebrates; may serve as prey for predators). Analyzing all the species as a group is often a more accurate summary of the fish community then analyzing individual species trends. The following conclusions can be drawn from the fish data:

- Panfish species, including Black Crappie and Bluegill, are the most abundant group during most DNR surveys.
- Top predators comprise the largest percentage of the total biomass catch during each of the DNR surveys, with northern pike being the main top predator collected.
- The large panfish population may be able to produce significant grazing pressure on the zooplankton community in the lake.
- Rough fish abundance and biomass is comprised mainly of yellow and black bullheads.
- Common carp are collected infrequently during DNR surveys. However, members of the local lake association indicate that there may be a significant carp population in the lake.

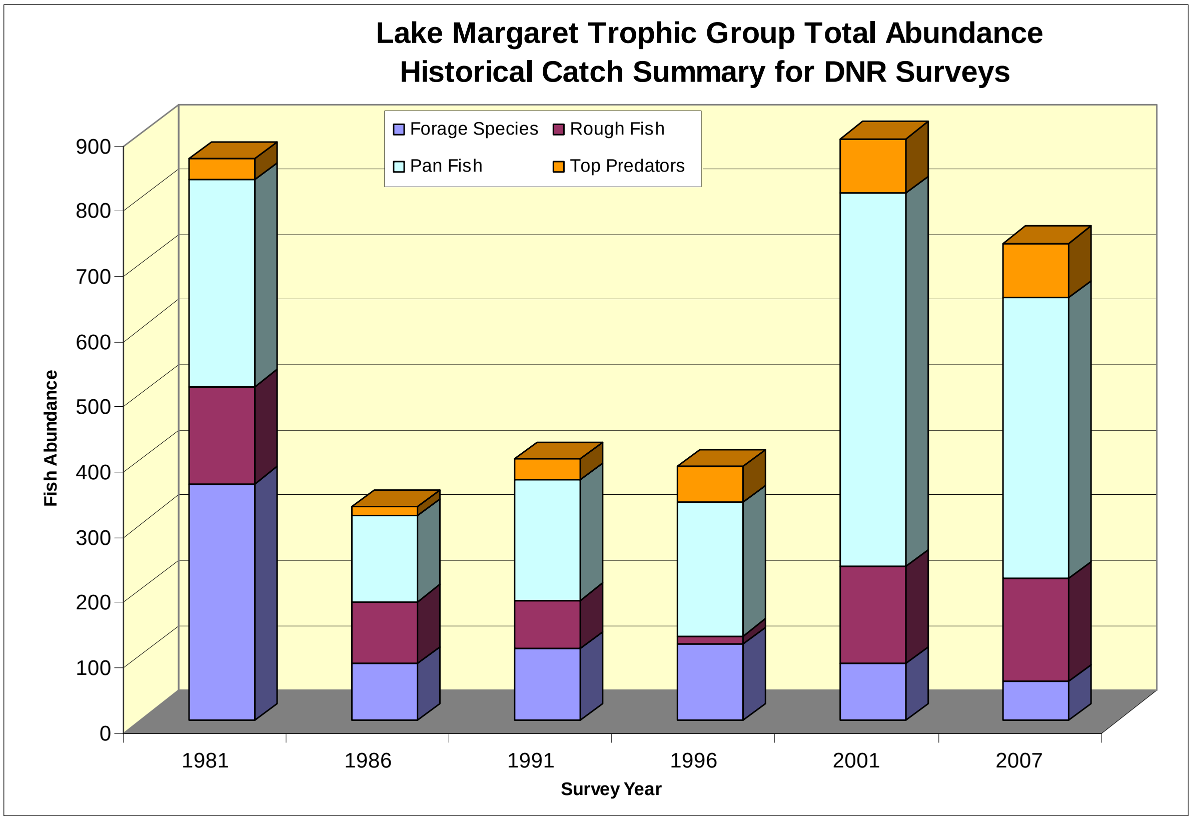


Figure 3-8. Historical fish survey results for trophic group abundance in Lake Margaret.

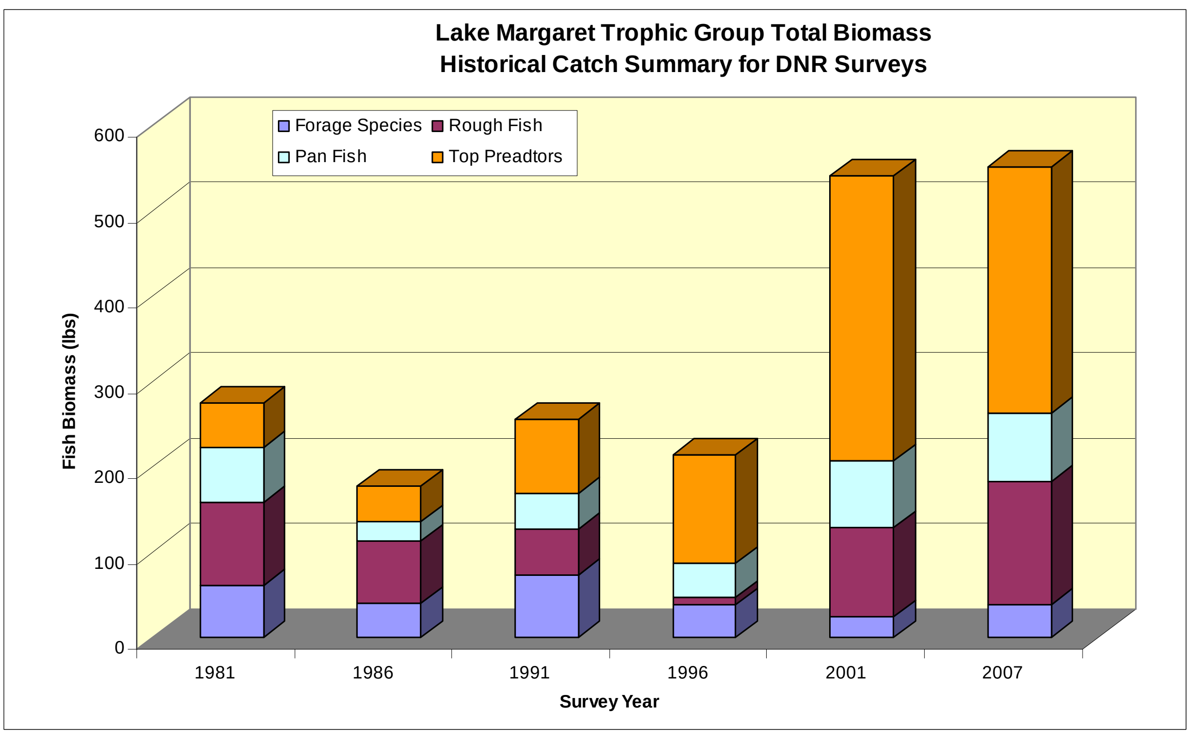


Figure 3-9. Historical fish survey results for trophic group biomass in Lake Margaret.

3.4.2 Carp

Common carp have both direct and indirect effects on aquatic environments. Carp uproot aquatic macrophytes during feeding and spawning that re-suspends bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. There may be carp and other rough fish present in Lake Margaret, but the size and composition is currently unclear. Standard DNR methods are not particularly effective at capturing carp. However, when carp populations are quite large, the DNR methods often do catch some. The only year that carp were captured during DNR surveys was 2007 where 2 carp were captured. Further analysis is needed to better characterize the carp population in Lake Margaret.

3.5 AQUATIC PLANTS

3.5.1 Introduction

Aquatic plants are beneficial to lake ecosystems providing spawning and cover for fish, habitat for macroinvertebrates, refuge for prey, and stabilization of sediments. However, in excess they limit recreation activities such as boating and swimming and reduce aesthetic value. Excess nutrients in lakes can lead to non-native, invasive aquatic plants taking over a lake. Some exotics can lead to special problems in lakes. For example, Eurasian watermilfoil can reduce plant biodiversity in a lake because it grows in great densities and out-competes all the other plants. Ultimately, this can lead to a shift in the fish community because these high densities favor panfish over larger game fish. Species such as curly-leaf pondweed can cause very specific problems by changing the dynamics of internal phosphorus loading. All in all, there is a delicate balance within the aquatic plant community in any lake ecosystem.

3.5.2 Littoral Zone

The littoral zone is defined as that portion of the lake that is less than 15 feet in depth and is where the majority of the aquatic plants are found. The littoral zone of the lake also provides the essential spawning habitat for most warm water fishes (e.g. bass, walleye, and panfish). Lake Margaret is approximately 71% littoral and should support a healthy aquatic plant community.

3.5.3 Aquatic Plants in Lake Margaret

Vegetation surveys were first conducted in Lake Margaret in 1964 by the DNR during their initial fish population survey. The DNR conducted four additional vegetation surveys between 1981 and 1996, as part of the fish population survey efforts for Lake Margaret. The DNR conducted a more detailed aquatic vegetation survey in the summer of 2006 and a similar aquatic vegetation survey during the spring of 2007.

Lake Margaret possesses a moderately diverse aquatic plant community with 26 different species observed across the various surveys, with a mix of emergent, floating leaf and submerged plant species. The 2007 DNR lake survey report states that the aquatic plant community is “critical to maintaining healthy fish populations” in Lake Margaret. Emergent species such as bulrush and water lilies are common along much of the shoreline and are very important to the ecology of the lake by providing shoreline protection, maintaining water quality and providing critical habitat for bass and panfish species.

There have been 14 different submerged species observed across the various aquatic plant surveys (Figure 3.10). The two most common native plant species observed across all plant surveys are coontail and flat stem pondweed. Other important native submerged plant species such as clasping leaf pondweed, large leaf pondweed and sago pondweed and wild celery have been observed at varying densities across the years.

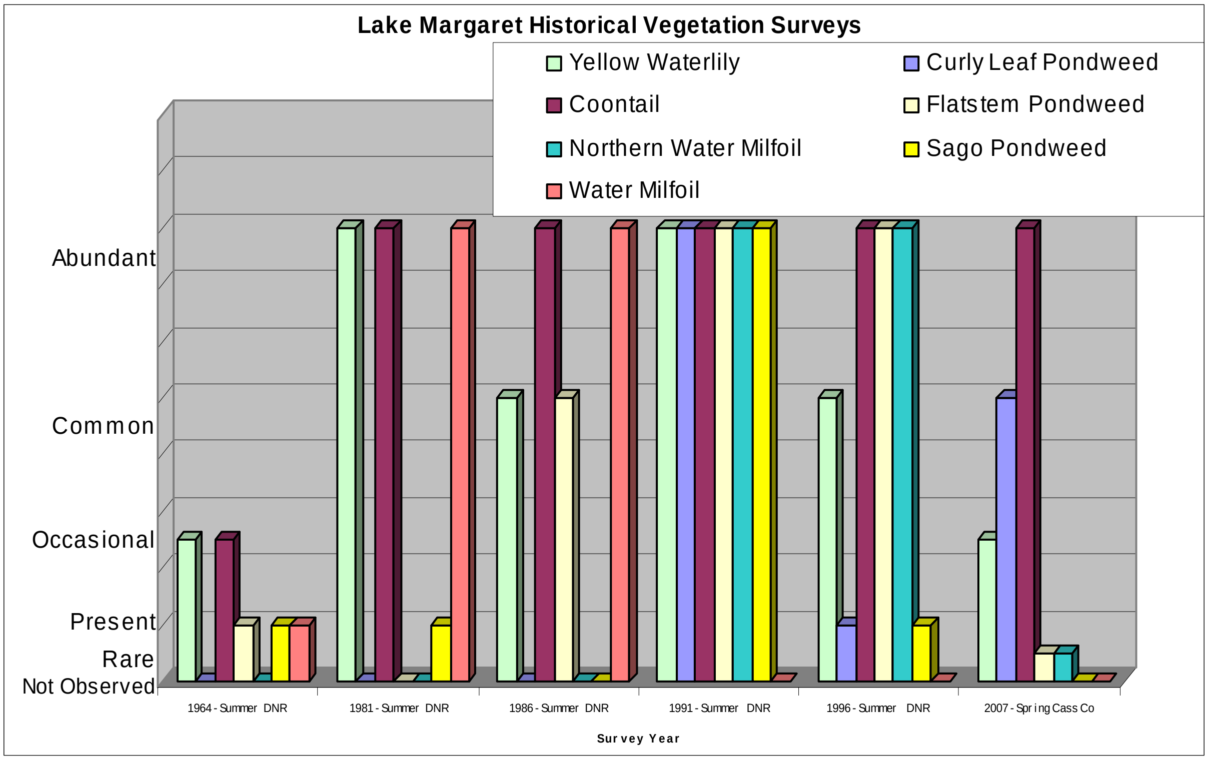
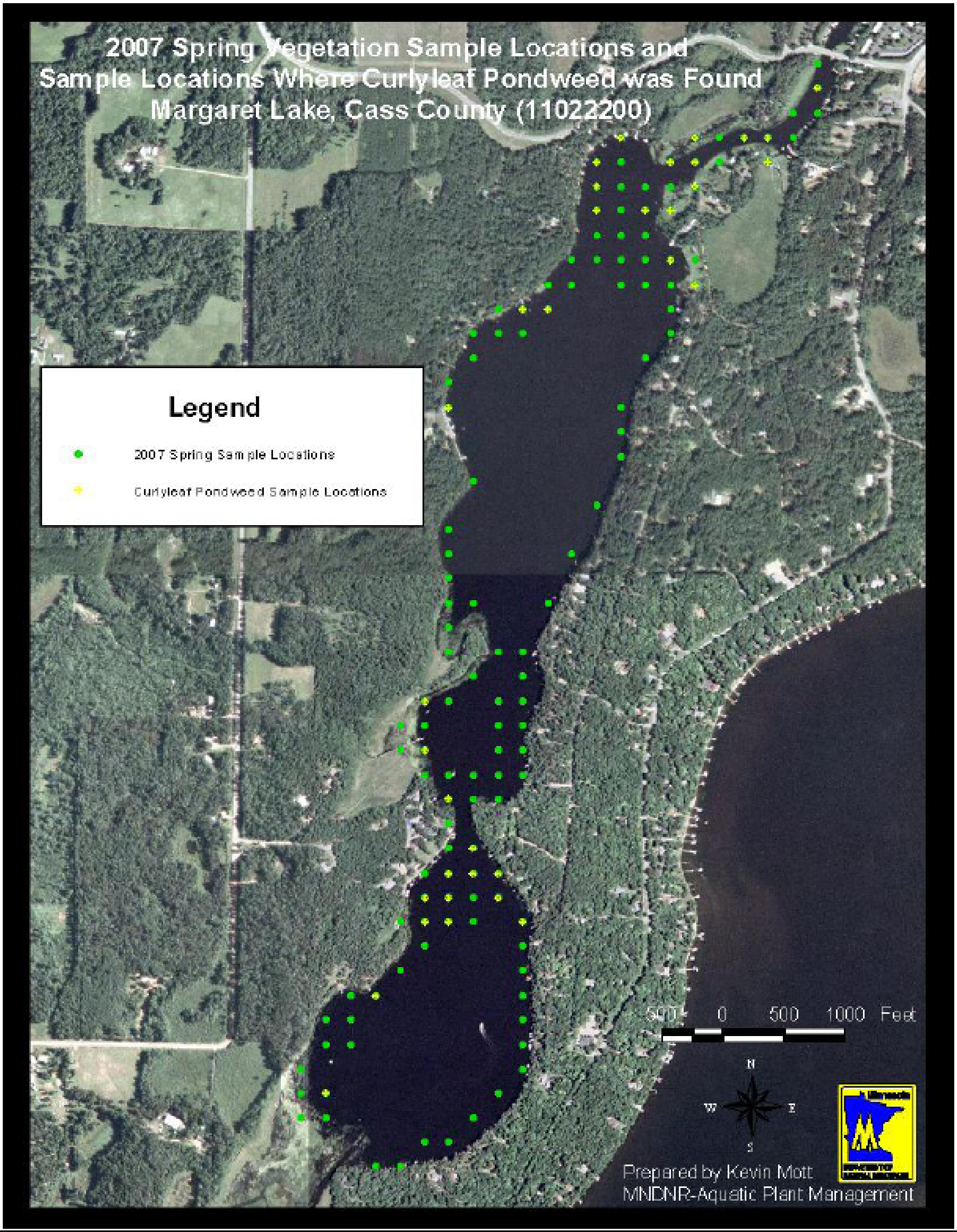


Figure 3-10. Historical vegetation survey data for Lake Margaret.

3.5.4 Curly-leaf Pondweed

Curly-leaf pondweed is an exotic like Eurasian watermilfoil that can easily take over a lake's aquatic macrophyte community. Curly-leaf pondweed presents a unique problem in that it is believed to significantly affect the in-lake production of phosphorus, contributing to the eutrophication problem. Curly-leaf pondweed grows under the ice, but dies back relatively early, releasing nutrients to the water column in summer, possibly leading to algal blooms. Curly-leaf pondweed can also out-compete more desirable native plant species. Curly-leaf pondweed was first observed during a 1991 DNR survey and was found to be abundant in the lake during that time. The DNR survey in the spring of 2007 found that the species was common throughout the lake. The extent of Curly-leaf pondweed is presented in Figure 3.11. However, this figure only represents the spatial occurrence of curly-leaf and does not address the abundance of the species. Curly-leaf pondweed does occur over the vast majority of the littoral area of the lake.



CITY OF LAKESHORE	Wenck	OCT 2008
Curly Leaf Pondweed Survey	Wenck Associates, Inc. Environmental Engineers 1800 Pioneer Creek Center Maple Plain, MN 55359	FIGURE 3.11

3.6 SHORELINE HABITAT AND CONDITIONS

The shoreline areas are defined as the areas adjacent to the lakes edge with hydrophytic vegetation and water up to 1.5 feet deep or a water table within 1.5 feet from the surface. Natural shorelines provide water quality treatment, wildlife habitat, and increased biodiversity of plants and aquatic organisms. Natural shoreline areas also provide important habitat to fisheries including spawning areas and refugia as well as aesthetic values.

Vegetated shorelines provide numerous benefits to both lakeshore owners and lake users including improved water quality, increased biodiversity, important habitat for both aquatic and terrestrial animals, and stabilizing erosion resulting in reduced maintenance of the shoreline. Identifying projects where natural shoreline habits can be restored or protected will enhance the overall lake ecosystem.

In 1998, the City of Lake Shore conducted an aerial photo analysis of the shoreline of Lake Margaret (AW Research 1998). The purpose of the study was to use aerial photography to identify shoreline development features that may contribute to water quality issues in Lake Margaret. A brief review of the study suggests that much of the shoreline of Lake Margaret lacks a natural buffer and often provides for direct runoff into Lake Margaret without any water quality treatment.

4.0 Nutrient Source Assessment

4.1 INTRODUCTION

Understanding the sources of nutrients to a lake is a key component in developing a TMDL for lake nutrients. To that end, a phosphorus budget that sets forth the current phosphorus load contributions from each potential source was developed using the modeling and collected data described below. Following is a brief description of the budget components and how these values were developed.

4.2 ATMOSPHERIC LOAD

Atmospheric inputs of phosphorus from wet and dry deposition are estimated using rates set forth in the MPCA report "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" (Barr Engineering, 2004), and are based on annual precipitation. The values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) for atmospheric deposition are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. These values are equivalent to 0.222, 0.239, and 0.259 pounds/acre-year for dry, average, and wet years in English units, respectively. The atmospheric load (pounds/year) for Lake Margaret was calculated by multiplying the lake area (acres) by the atmospheric deposition rate (pounds/acre-year). For example, in an average precipitation year the atmospheric load to Lake Margaret's southern basin would be 0.239 pounds/acre-year times the lake surface area (85 acres), which is 20.4 pounds/year. The watershed is small enough that it is unlikely that there are significant geographic differences in rainfall intensity and amounts across the watershed.

4.3 TRIBUTARY OR WATERSHED LOAD

4.3.1 Nutrient Loading and Flux

Flow and water quality data were collected by the MPCA at five sites in the Lake Margaret watershed (Figure 3.4). Rating curves for the sites are provided in Appendix C. To develop watershed loading, FLUX was applied to the most downstream site on Home Brook (site 1) since it was the most complete data set and encompassed more than 80 percent of the watershed (Figure 4.1).

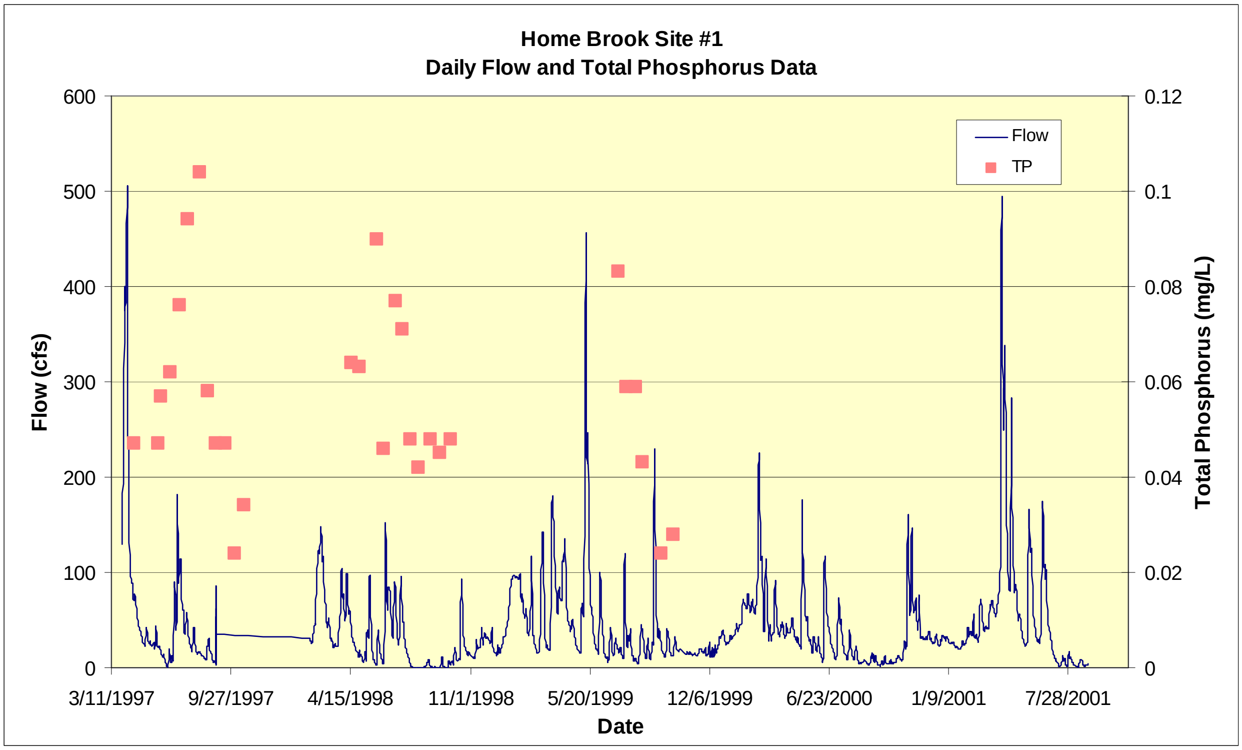


Figure 4-1. Total phosphorus concentrations and flow used with the FLUX model to determine phosphorus loads to Lake Margaret.

Results of the flux analysis for Home Brook Site 1 are presented in table 4.1. Flux estimated runoff of approximately 6 inches a year with a total phosphorus load of 3,000 to 4,000 pounds per year.

Table 4.1. Flux analysis results for Home Brook Site 1.

Year	Runoff (ac-ft)	TP (lbs)	Unit Runoff (ft/yr)	Flow Weighted TP (μg/L)
1997	19,935	3,346	0.54	62
1998	19,449	3,236	0.53	61
1999	23,744	3,973	0.64	62

The Home Brook data were then used to develop an estimate of the total watershed loading to Lake Margaret (Table 4.2). To accomplish this, a unit runoff estimate was developed for the area contributing to the Home Brook site. This unit runoff was then applied to the entire watershed to develop an annual runoff volume estimate. This runoff estimate was then multiplied by the flow weighted average TP concentration to estimate the watershed load. Watershed loading was estimated to be between 3,800 and 4,800 lbs/yr.

Table 4.2. Estimated volumes and loads for the entire watershed based on data collected at Home Brook (Site 1).

Year	Runoff (ac-ft)	TP (lbs)	Flow Weighted TP (µg/L)
1997	23,938	4,018	62
1998	23,354	3,886	61
1999	28,512	4,771	62

4.3.2 Unit Area Load Analysis (UAL)

Once the total watershed nutrient loads were estimated using the monitoring data and flux analysis, the next step was to estimate the sources of nutrients from the watershed. To accomplish the source assessment, a Unit Area Load (UAL) approach was used to estimate the relative proportions of phosphorus loading from the various sources in the watershed.

To complete the UAL model, the Soil Water Assessment Tool (SWAT) interface was used to develop Hydrologic Response Units (HRU) in the watershed. An HRU is an area of land with a unique land cover based on land use, soil, and slope. The SWAT model interface combined soil types from the county soil survey (STATSGO), slope, and land use into Hydrologic Response Units (HRUs). Soil erodibility and saturated infiltration were used to develop a soil delivery potential. Land slope was calculated from 30 meter resolution Digital Elevation Models. Land use was developed by combining several data sources as described in Section 3.2. A range of loading rates was selected to represent loading from each of the HRUs (Table 4.3). Data were selected based on literature review for land uses in Minnesota (EPA 1980).

Table 4.3. Selected loading rates for each HRU.

Land Use	Slope	Delivery	Loading Factor (lbs/ac/yr)
Alfalfa	Low	Mod-High	0.6
	Low	Low	0.5
	Mod	Mod	1.0
Corn	<4%	Low	0.9
	>8%	High	3.1
	0-8%	Moderate - High	2.2
Developed	All	All	0.7
Pasture	>8%	Low - High	0.9
	<4%	Low-Moderate	0.1
	4-8%	High	0.9
	<8%	All	0.2
Shrubland	All	All	0.1
Type 2	All	All	0.1
Wetland (Type 3-8)	All	All	0.0
Wet Pasture	All	All	0.9

The UAL loads were then validated by comparing the overall estimated loads to the monitored loads (Figure 4.2). The UAL estimated load was in good agreement with monitored loads for 1997 through 1999. The UAL model does not account for inter-annual variability or precipitation differences among years. However, it is not intended to predict loads between years. Rather the intent of the UAL model is to provide some estimate of the contribution of different nutrient sources in the watershed as well as identify areas in the watershed with the highest potential to deliver nutrients to surface waters.

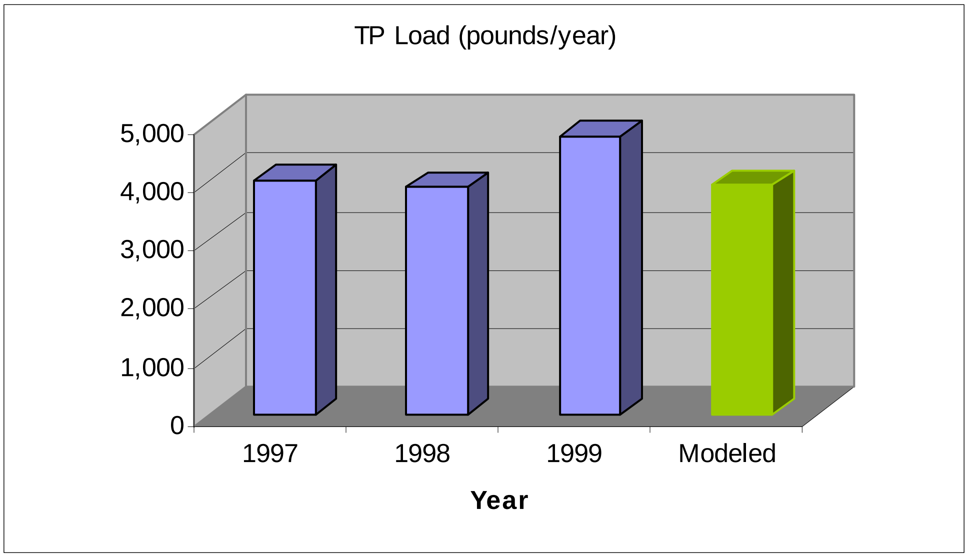


Figure 4-2. UAL estimated loads versus monitored loads in the Lake Margaret watershed.

4.4 SEPTIC SYSTEMS

Failing or nonconforming septic systems can be an important source of phosphorus to surface waters and may be an important phosphorus source to Lake Margaret. Failing or nonconforming septic systems allow nutrients into surface waters through preferential flow paths such as straight pipes, drain tiles, or overland flow.

In the City of Lake Shore, most homes are on septic systems. Homes on the north end of Lake Margaret are connected to city sewer. In 2006, homeowners along Lake Margaret were required to have compliance inspections done on their septic systems. Only one system was found failing. In 2007, the city required compliance inspections on septic systems for properties within the watershed and located within the city limits.

For the remaining portion of the watershed, Cass County provided a septic system survey. However, this survey only covers new or upgraded systems between 2001 through 2006 and indentifies very few systems that have been inspected in the Lake Margaret watershed. Consequently, it is difficult to estimate the influence of septic systems on current nutrient loading to surface waters. Gathering additional data will be an important component of implementation because of the potential for nutrient loading.

4.5 FEEDLOTS AND ANIMAL UNITS

Animal agriculture can have a large affect on water quality, especially nutrients. Animal waste, which contains large amounts of both phosphorus and nitrogen, is often applied to agricultural fields as fertilizer or left on pastures after grazing. In fact, a regional Minnesota study suggested the rate at which manure is applied contained 74% more phosphorus than the University of Minnesota recommended guidelines (Mulla et al. 2001). This can average an extra 35 pounds per acre of phosphorus, which will ultimately be available for runoff. Additionally, runoff from feedlots can transport animal waste high in phosphorus to surface waters.

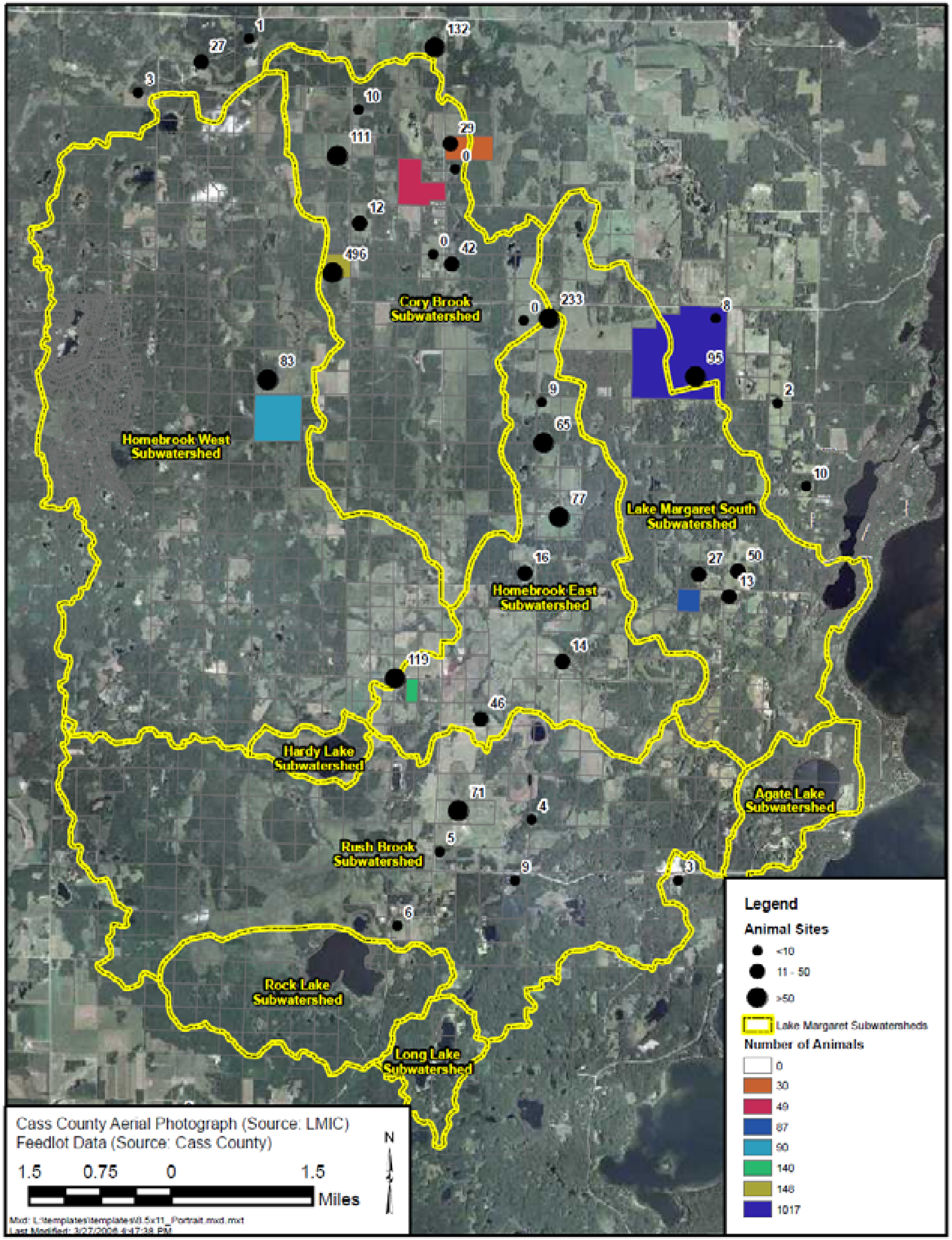
A 2001 Level II Feedlot Inventory identified 1,561 animals in the watershed (Figure 4.3). In 2008, the City of Lake Shore commissioned an over-flight of the watershed to validate the number of animals in the watershed. The 2008 inventory identified approximately 1,888 animals in the watershed with 1,836 cows. There has not been a dramatic change in the number of animals in the watershed over the past 8 years.

To identify the risk of animal agriculture to surface waters, the total number of animals and pastured area was assessed to determine the potential for excess nutrients in the watershed. Almost 6,000 acres of the Lake Margaret watershed is in pasture representing 13% of the entire watershed. These pastures are used by approximately 1,836 cows. Using NRCS methods (NRCS 2007), nutrient production by the animals was compared to the assimilative capacity of the pastures (Table 4.4). Depending on the type of animals in the watershed, nutrient production was either slightly over or under the assimilative capacity of the associated pasture. Assuming there is a mixture of animal types in the watershed, it is likely that nutrient production in the watershed is right at the assimilative capacity and some pastures may be over. This suggests that the amount of animals in the Lake Margaret watershed are likely sustainable, but pastures must be managed carefully to prevent any excess nutrients from reaching surface waters.

Table 4.4. Nutrient production versus assimilative capacity for the Lake Margaret watershed.

Category	Beef Calves To Adult	Breeding Cattle
Animal Units	1,839	1,839
Manure (tons/AU)	11.32	11.5
Manure (tons)	20,817	21,149
Manure P (lbs./ton Manure)	2.33	3.79
P (pounds/year)	48,505	80,153
Pasture P Assimilation (pounds/acre)	11	11
Pasture Area	5,901	5,901
Total P Assimilated(pounds)	64,911	64,911
TP vs Assimilative Capacity (pounds)	-16,406	15,242

Better pasture management is needed to reduce runoff of nutrients from the pastures to surface waters. Management practices that should be considered include stream buffers, fencing to limit live stock access to streams, avoiding wet pasture areas, and infiltration where practical. These practices should reduce runoff of nutrients from the fields and allow for sustainable animal agriculture.



CITY OF LAKE SHORE	Wenck Associates, Inc. Environmental Engineers — 1800 Pioneer Creek Center, Maple Plain, MN 55359-0429	OCT 2008
Feed Lot Data		Figure 4.3

4.6 INTERNAL PHOSPHORUS LOADS

Internal phosphorus loading from lake sediments has been demonstrated to be an important aspect of the phosphorus budgets of lakes. However, measuring or estimating internal loads can be difficult, especially in shallow lakes that may mix many times throughout the year.
To estimate internal loading, an anoxic factor (Nürnberg 2004), which estimates the period where anoxic conditions exist over the sediments, is estimated from the dissolved oxygen profile data. The anoxic factor is expressed in days but is normalized over the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the total phosphorus load from the sediments.

In 1998, the Army Corps of Engineers collected sediment cores from Lake Margaret and Gull Lake to measure anoxic and oxic sediment phosphorus release rates (Table 4.5). The oxic and anoxic release rate in Lake Margaret was comparable to rates of internal P loading for other eutrophic systems (Nürnberg et al. 1997).

Table 4.5. Anoxic sediment P release rates for Gull Lake and Lake Margaret (James et al. 1998).

STATION	OXIC P RATE, mg m^{-2} d^{-1}	ANOXIC P RATE, mg m^{-2} d^{-1}
Gull Lake Main Basin	1.1 (---)	11.5 (5.2)
Gull Lake Wilson Bay	0.3 (0.2)	3.3 (1.3)
Gull Lake Unnamed Bay	0.3 (0.5)	1.2 (1.2)
[redacted]		
Margaret Lake	1.5 (0.2)	10.1 (1.6)
[redacted]		

The rates in Table 4.5 can then be used to estimate the gross internal loading based on an anoxic factor for the lake (Nürnburg 2004). The estimated gross loads for Lake Margaret are presented in Table 4.6. 1994 and 2205 are presented because these are the years with the best dissolved oxygen data. Gross internal loading for Lake Margaret ranges from 406 to 680 kilograms per year.

Table 4.6. Estimated gross internal loading from anoxic phosphorous release in Lake Margaret.

Year	Anoxic Factor (days)	Release Rate (mg/m2/d)	Gross Load (kg)
1994	66	10.1	600
2005	75	10.1	680
Shallow Lake[1]	45	10.1	406

[1]Based on a shallow lake equation developed to estimate anoxic factors in polymictic lakes.

Internal loading is also corroborated by the build up of phosphorus in the hypolimnion (Figure 4.7). Average hypolimnetic phosphorus concentrations ranged from approximately 200 to 1,400 µg/L (Figure 4.4). These concentrations exceeded average epilimnetic phosphorus concentrations representing as a high as a 17 fold difference.

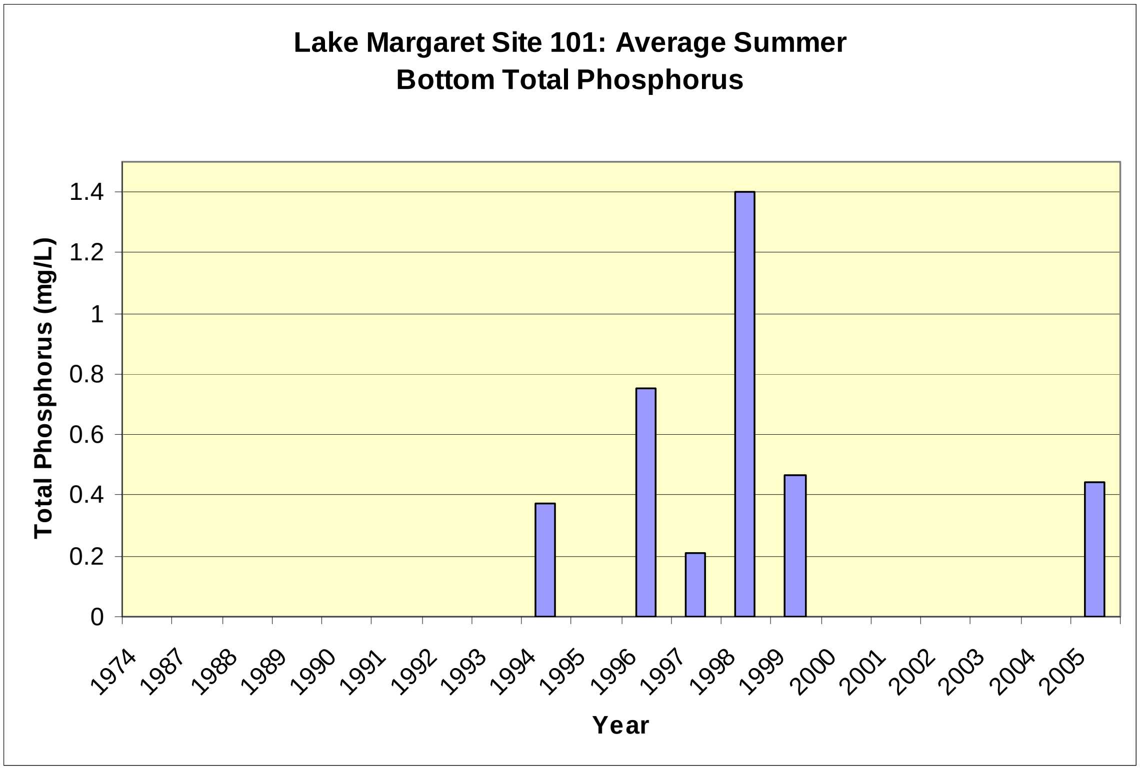


Figure 4.4. Average hypolimnetic total phosphorus concentrations for Lake Margaret.

Sediment cores collected to analyze sediment chemistry in the north and south basins of Lake Margaret exhibited very high moisture content, low sediment density, and a loss-on-ignition organic matter content of 26 to 31%. Total phosphorus concentrations were very high relative to total iron, resulting in an Fe:P ratio < 10. This pattern suggested that phosphorus bound to iron compounds was approaching saturation (i.e., low number of available binding sites; Jensen et al. 1992). Iron-bound phosphorus accounted for > 40% of the total phosphorus and was an order of magnitude greater than values reported for a variety of lakes in North America (Nürnberg 1988).

4.7 SOURCE SUMMARY AND CURRENT PHOSPHORUS BUDGET

Phosphorus budgets were developed for 1997 through 1999 to summarize the sources of nutrients to Lake Margaret. The budgets were developed separately for the south and north basins of Lake Margaret because these basins likely respond differently to changes in nutrient loading.

Loading to the south basin of Lake Margaret is dominated by watershed runoff representing 88% of the phosphorus load (Table 4.7). Internal loading represented approximately 12% of the load to the south basin.

Table 4.7. Total phosphorus budget for the south basin of Lake Margaret.

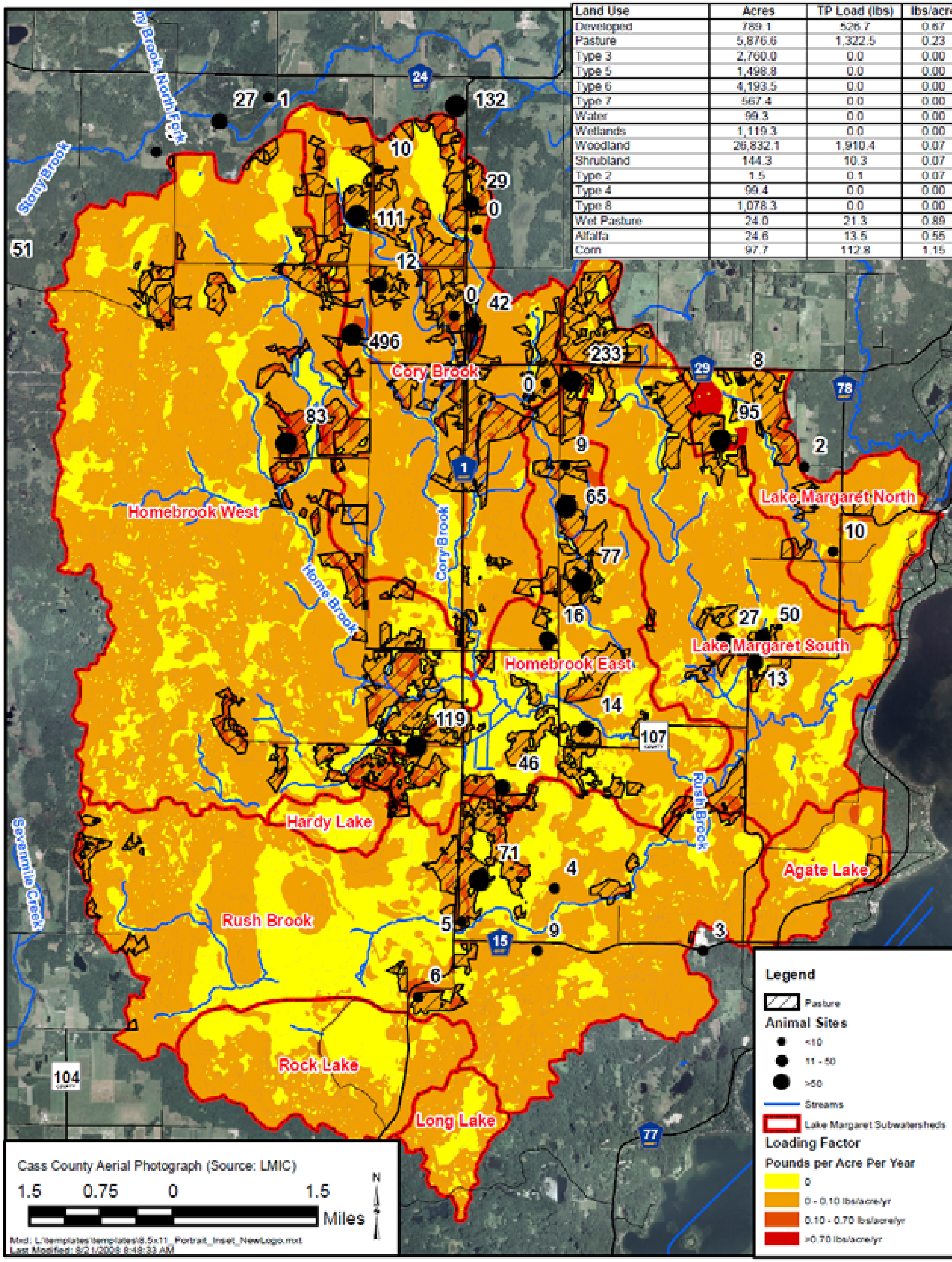
Source	Source	1997Annual TP Load (pounds/yr)	1998 Annual TP Load (pounds/yr)	1999 Annual TP Load (pounds/yr)	Average Load (1997-1999, (pounds/yr)
Load	Watershed Load	3,834	3,708	4,552	4,031
	Atmospheric Load	19	20	20	20
	Internal Load	508	508	508	508
	TOTAL LOAD	**4,361**	**4,236**	**5,080**	**4,559**

Loading to the north basin of Lake Margaret is dominated by loads from the south basin representing approximately 75% of the load (Table 4.8). Internal loading is relatively important representing approximately 20% of the load. Direct drainage to the north basin is relatively small (<5% of the total load).

Table 4.8. Total phosphorus budget for the north basin of Lake Margaret.

Source	Source	1997Annual TP Load (pounds/yr)	1998 Annual TP Load (pounds/yr)	1999 Annual TP Load (pounds/yr)	Average Load (1997-1999, (pounds/yr)
Load	Watershed Load	185	178	219	194
	Upstream Basin	2,805	2,714	3,388	2,969
	Atmospheric Load	30	32	32	31
	Internal Load	794	794	794	794
	TOTAL LOAD	**3,814**	**3,718**	**4,433**	**3,988**

The overall watershed budget was evaluated using a Unit Area Load model to indentify sources to the watershed load (Figure 4.5). Both developed land and pastures were identified as contributing large loads to the overall watershed load in Lake Margaret. However, the overall animal count in the watershed does not appear to be unsustainable based on the assimilative capacity of the fields. Rather, better management practices would reduce phosphorus contributions to surface waters. The developed loads are mostly associated with roads where better practices would reduce runoff from impervious surfaces. Nutrient loads from forested areas in the watershed represent a large proportion of the overall load because of the dominance of forested areas in the watershed. Although the forested areas are expected to load at a relatively low rate, ongoing implementation of best management practices would maintain the low rate. Because of the dominance of forested areas in the watershed, poor practices in the forested areas have a large potential to adversely affect Lake Margaret.



Land Use	Acres	TP Load (lbs)	lbs/acre
Developed	789.1	526.7	0.67
Pasture	5,876.6	1,322.5	0.23
Type 3	2,760.0	0.0	0.00
Type 5	1,498.8	0.0	0.00
Type 6	4,193.5	0.0	0.00
Type 7	567.4	0.0	0.00
Water	99.3	0.0	0.00
Wetlands	1,119.3	0.0	0.00
Woodland	26,832.1	1,910.4	0.07
Shrubland	144.3	10.3	0.07
Type 2	1.5	0.1	0.07
Type 4	99.4	0.0	0.00
Type 8	1,078.3	0.0	0.00
Wet Pasture	24.0	21.3	0.89
Alfalfa	24.6	13.5	0.55
Corn	97.7	112.8	1.15

CITY OF LAKE SHORE

Land Cover TP Load Lbs per Acre

Wenck
Wenck Associates, Inc. Environmental Engineers
1800 Pioneer Creek Center Maple Plain, MN 55359-0429

OCT 2008

Figure 4.5

5.0 Linking Water Quality Targets and Sources

5.1 INTRODUCTION

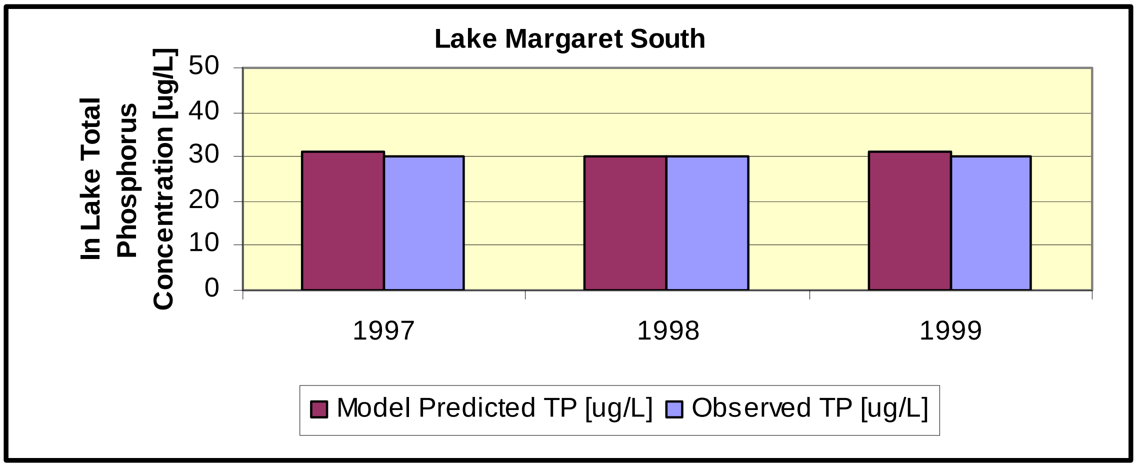
A detailed nutrient budget can be a useful tool for identifying management options and their potential effects on water quality. Additionally, lake response models can be developed to understand how different lake variables respond to changes in nutrient loads. Through this knowledge, managers can make educated decisions about how to allocate restoration dollars and efforts as well as understand the resultant effect of such efforts. At the time this report was written, only data through 2003 was available for model calibration.

5.2 SELECTION OF MODELS AND TOOLS

A BATHTUB lake response model was developed using the nutrient budget presented in Section 4. Three years were modeled to validate the assumptions of the model. Several models (subroutines) are available for use within the BATHTUB model. The selection of the subroutines is based on past experience in modeling lakes in Minnesota and is focused on subroutines that were developed based on data from natural lakes. The Canfield-Bachmann natural lake model was chosen for the phosphorus model. The chlorophyll-a response model used was model 1 from the BATHTUB package, which accounts for nitrogen, phosphorus, light, and flushing rate. Secchi depth was predicted using the “VS. CHLA & TURBIDITY” equation. For more information on these model equations, see the BATHTUB model documentation (Walker 1999). Model coefficients are also available in the model for calibration or adjustment based on known cycling characteristics and the coefficients were left at the default values. No initial calibration factors were applied.

5.3 FIT OF THE MODEL

Modeling was conducted for Lake Margaret in two cells including the south and north basins of the lake. Modeling the lake in two cells provided a better fit for the model and recognizes that the two cells function differently based on direct drainage and morphology. The model fit is reasonable for all three years (Figure 5.1; Appendix D).



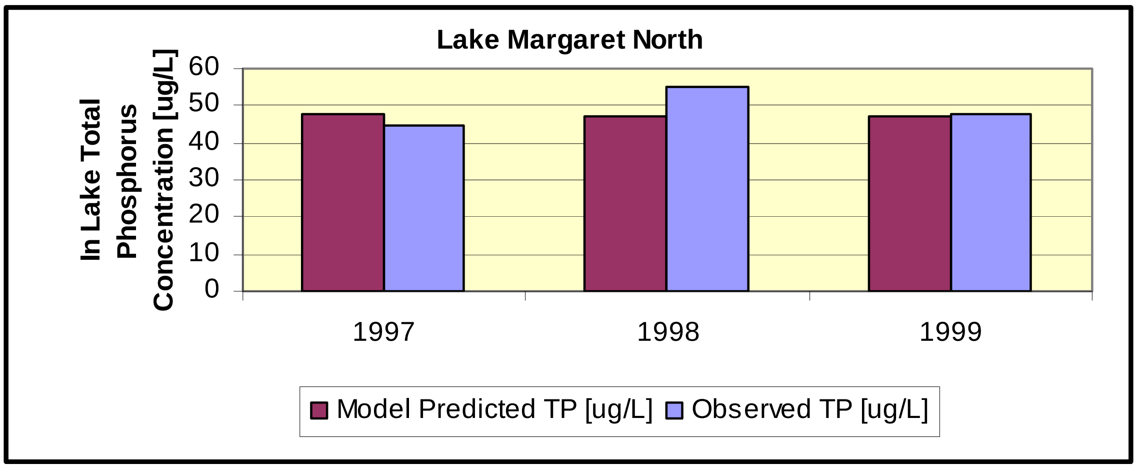


Figure 5-1. Model predicted and observed total phosphorus concentrations in the south and north basins of Lake Margaret.

6.0 TMDL Allocation

6.1 TOTAL MAXIMUM DAILY LOAD CALCULATIONS

The numerical TMDL for Lake Margaret was calculated as the sum of the Wasteload Allocation, Load Allocation and the Margin of Safety (MOS) expressed as phosphorus mass per unit time. Nutrient loads in this TMDL are set for phosphorus, since this is typically the limiting nutrient for nuisance aquatic algae. This TMDL is written to solve the TMDL equation for a numeric target of 30 µg/L of total phosphorus.

6.1.1 Wasteload Allocations

The Wasteload Allocation includes permitted discharges such as industrial point source and regulated stormwater discharges. Stormwater discharges are regulated under NPDES, and allocations of nutrient reductions are considered wasteload that must be divided among permit holders.

Construction stormwater allocations were determined following State of Minnesota guidance for determining wasteload allocations associated with permitted construction activity (sites greater than 1 acre). To determine the wasteload allocation associated with construction, the average area of the watershed under construction over the past five years was determined by evaluating construction permits. In the Lake Margaret watershed, only 0.1% of the area (49 acres) was under construction. This percentage was then multiplied by the stormwater load to determine the percentage of the stormwater load attributed to construction stormwater.

6.1.2 Load Allocations

The Load Allocation includes all nonpermitted sources including stormwater runoff not covered by a state or federal permit, atmospheric deposition and internal loading. The current nutrient budget developed in Section 4 and the lake response modeling presented in Section 5 were used to develop the appropriate load allocations for two of the three primary nutrient sources to Lake Margaret. No changes were expected for atmospheric deposition because this source is impossible to control.

To determine the allowable internal phosphorus load, measured release rates (oxic release of 1.5 mg/m^2/day and anoxic release of 10.1 mg/m^2/day) were compared to expected release rates for mesotrophic lakes (Nurnberg 2004). An internal release rate of 1 mg/m^2/day was determined to be reasonable for Lake Margaret.

To determine the allowable watershed phosphorus load, current estimated loading in the lake response models was reduced until the models predicted an in-lake phosphorus concentration of 30 µg/L. Once this reduction was identified, each of the primary phosphorus sources in the watershed was evaluated to determine potential reductions and evaluate the efficacy of meeting the required load reductions. It was determined that a 60% reduction in nutrient contributions from pastures and developed areas would meet the required watershed load reductions. It was also determined that septic systems should not contribute any phosphorus to surface waters.

6.1.3 Margin of Safety

A margin of safety has been incorporated into this TMDL by using conservative assumptions. These were utilized to account for an inherently imperfect understanding of the lake system and to ultimately ensure that the nutrient reduction strategy is protective of the water quality standard. Conservative assumptions include:

1. Applying sedimentation rates from the Canfield-Bachmann model that likely under-predicts the sedimentation rate for shallow lakes (and ultimately over-predicts in-lake phosphorus concentrations). Zooplankton grazing plays a large role in algal and subsequent phosphorus sedimentation in shallow lakes. However, the Canfield-Bachmann equation does not account for the expected higher sedimentation rates expected in healthy shallow lake systems.

2. The Canfield-Bachmann model was used to match data by only adjusting the loads and not applying calibration factors. It is likely that the sedimentation rates used in the model are conservatively low for Minnesota lakes providing an additional margin of safety.

3. Developing load allocations for the summer growing season when lake water quality is worst and most sensitive to loads.

6.1.4 Summary of TMDL Allocations

Tables 6.1 and 6.2 summarize the TMDL allocations for the south and north basins of Lake Margaret. A margin of safety is implicit in the TMDL equation and therefore not presented in the tables.

Table 6.1. TMDL total phosphorus daily loads partitioned among the major sources for the south basin of Lake Margaret assuming the lake standard of 30 μg/L.

<table>
<tr><th rowspan="2">Allocation</th><th rowspan="2">Source</th><th colspan="2">Existing TP Load [1]</th><th colspan="2">TP Allocations (WLA & LA)</th><th>Load Reduction</th></tr>
<tr><th>(lbs/year)</th><th>(lbs/day)[2]</th><th>(lbs/year)</th><th>(lbs/day)[2]</th><th>(lbs/year)</th></tr>
<tr><td>Wasteload Allocation</td><td>Construction Stormwater</td><td>40</td><td>0.1</td><td>22</td><td>0.1</td><td>18</td></tr>
<tr><td rowspan="5">Load Allocation</td><td>Stormwater Runoff</td><td rowspan="3">3,991</td><td rowspan="3">10.9</td><td rowspan="2">2,219</td><td rowspan="2">6.0</td><td rowspan="3">1,790</td></tr>
<tr><td>Registered Animal Units</td></tr>
<tr><td>Septic Systems</td><td>0</td><td>0</td></tr>
<tr><td>Atmospheric Load</td><td>20</td><td>0.1</td><td>20</td><td>0.1</td><td>0</td></tr>
<tr><td>Internal Load</td><td>508</td><td>1.4</td><td>50</td><td>0.1</td><td>458</td></tr>
<tr><td></td><td>TOTAL LOAD</td><td>4,559</td><td>12.5</td><td>2,311</td><td>6.3</td><td>2,249</td></tr>
</table>

[1] Existing load is the average for the years 1997-1999.
[2] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years

Table 6.2. TMDL total phosphorus daily loads partitioned among the major sources for the north basin of Lake Margaret assuming the lake standard of 30 μg/L.

<table>
<tr><th rowspan="2">Allocation</th><th rowspan="2">Source</th><th colspan="2">Existing TP Load [1]</th><th colspan="2">TP Allocations (WLA & LA)</th><th>Load Reduction</th></tr>
<tr><th>(lbs/year)</th><th>(lbs/day) [2]</th><th>(lbs/year)</th><th>(lbs/day)[2]</th><th>(lbs/year)</th></tr>
<tr><td>Wasteload Allocation</td><td>Construction Stormwater</td><td>2</td><td>0.01</td><td>1</td><td>0.003</td><td>1</td></tr>
<tr><td rowspan="6">Load Allocation</td><td>Upstream Basin</td><td>2,969</td><td>8.1</td><td>2,016</td><td>5.5</td><td>953</td></tr>
<tr><td>Stormwater Runoff</td><td rowspan="3">192</td><td rowspan="3">0.5</td><td rowspan="2">115</td><td rowspan="2">0.3</td><td rowspan="3">78</td></tr>
<tr><td>Registered Animal Units</td></tr>
<tr><td>Septic Systems</td><td>0</td><td>0</td></tr>
<tr><td>Atmospheric Load</td><td>31</td><td>0.1</td><td>31</td><td>0.1</td><td>0</td></tr>
<tr><td>Internal Load</td><td>794</td><td>2.2</td><td>79</td><td>0.2</td><td>715</td></tr>
<tr><td></td><td>TOTAL LOAD</td><td>3,988</td><td>10.9</td><td>2,242</td><td>6.1</td><td>1,747</td></tr>
</table>

[1] Existing load is the average for the years 1997-1999.
[2] Annual loads converted to daily by dividing by 365.25 days per year accounting for leap years

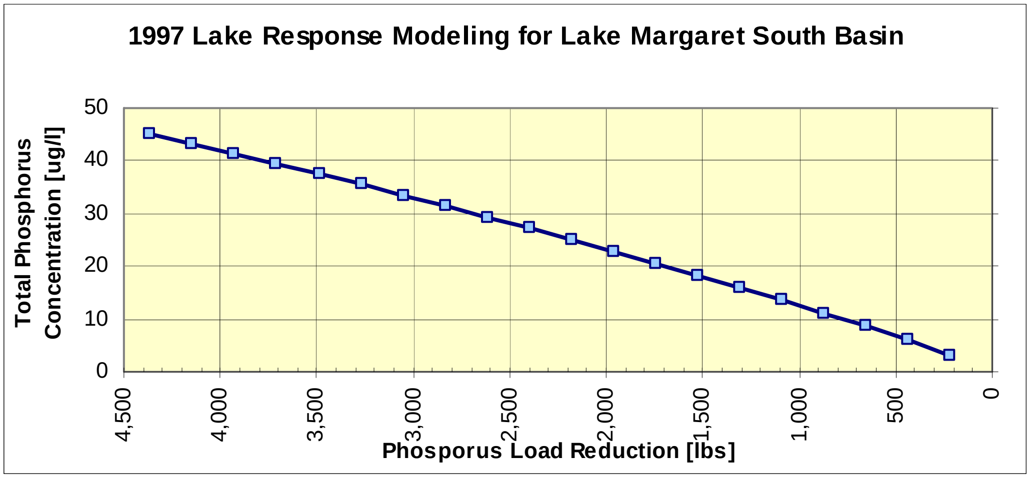
6.2 LAKE RESPONSE VARIABLES

The TMDL presented here is developed to be protective of the aquatic recreation beneficial use in lakes. However there is no loading capacity *per se* for nuisance aquatic plants. Consequently, to understand the impacts of the phosphorus loads to the lake, a water quality response model was used to predict the water quality after load reductions are implemented. Utilization of this approach allows for a better understanding of potential lake conditions under numerous load scenarios. The following sections describe the results from the water quality response modeling.

Using the previously described BATHTUB water quality response model, Secchi depth and chlorophyll-a concentrations were predicted for load reductions in 5% increments for 1997. These predicted responses can be used to develop goals for load reductions with an understanding of the overall water quality benefits.

6.2.1 Total Phosphorus

Modeled total phosphorus concentrations expected at various phosphorus loads for model year 1997 are presented in Figure 6.1. For 1997, attainment of the TMDL loads would actually result in obtaining conditions better than the state standard of 30 µg/L TP (approximately 25 µg/L for the south basin and 28 µg/L for the north basin).



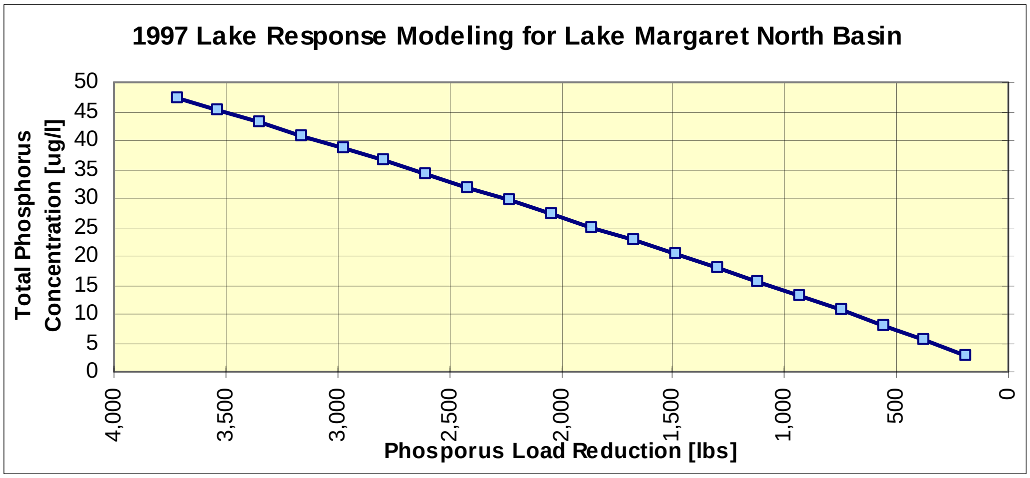
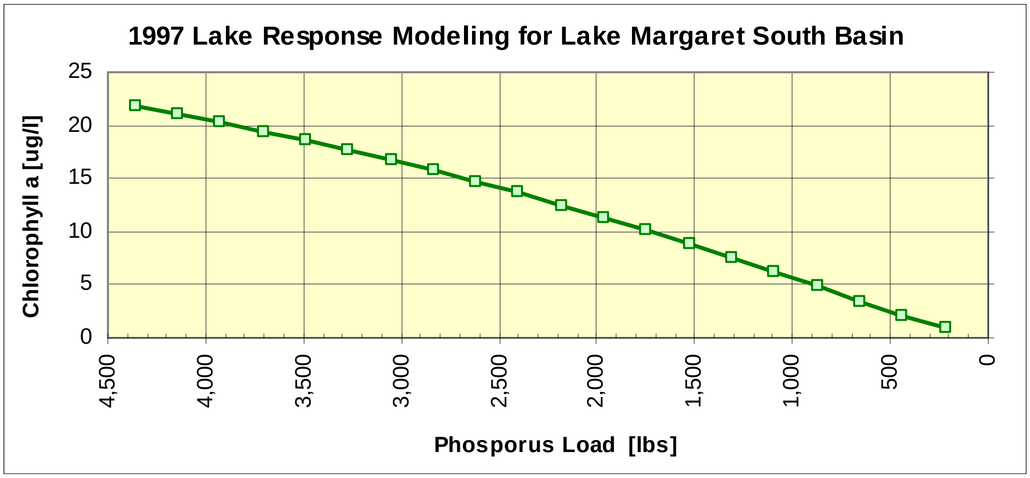


Figure 6.1 In-lake total phosphorus concentrations predicted for total phosphorus load reductions applied to all sources.

6.2.2 Chlorophyll-a

Modeled chlorophyll-a concentrations expected at various phosphorus loads for model year 1997 are presented in Figure 6.2. The model suggests that reducing the phosphorus load to the TMDL load likely will not result in the attainment of the 9 µg/L chlorophyll-a standard in either the north or south basins of Lake Margaret. However, model predictions are relatively close (approximately 12 µg/L chlorophyll-a), that it is within the uncertainty in the modeling.

This also suggests that some other in-lake management may be needed to meet the chlorophyll-a targets.



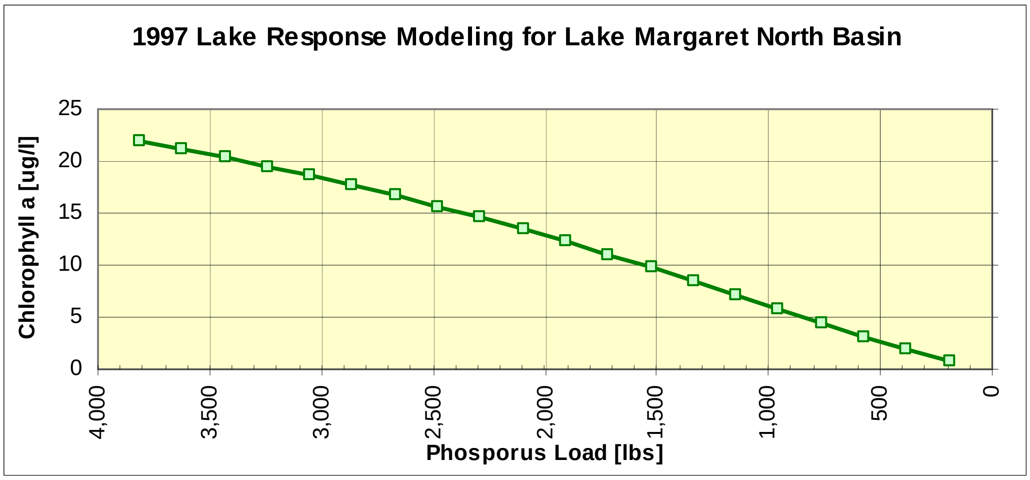
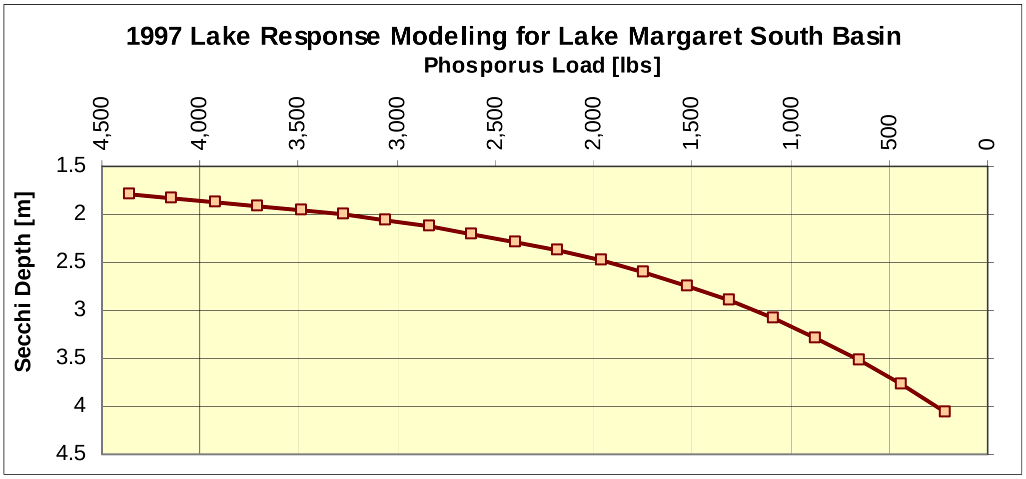


Figure 6.2. In-lake chlorophyll-a concentrations predicted for total phosphorus load reductions applied to all sources.

6.2.3 Secchi Depth

Model water clarity with incremental load reductions is presented in Figure 6.3. For both the north and south basins of Lake Margaret, water clarity is predicted to exceed the State standard of 2 meters Secchi depth at the TMDL allocations. Because the water quality modeling predicts that the phosphorus standard and water clarity standard would be met at the proposed TMDL allocations, the TMDL is considered reasonable for the protection of aquatic life and recreation in Lake Margaret.



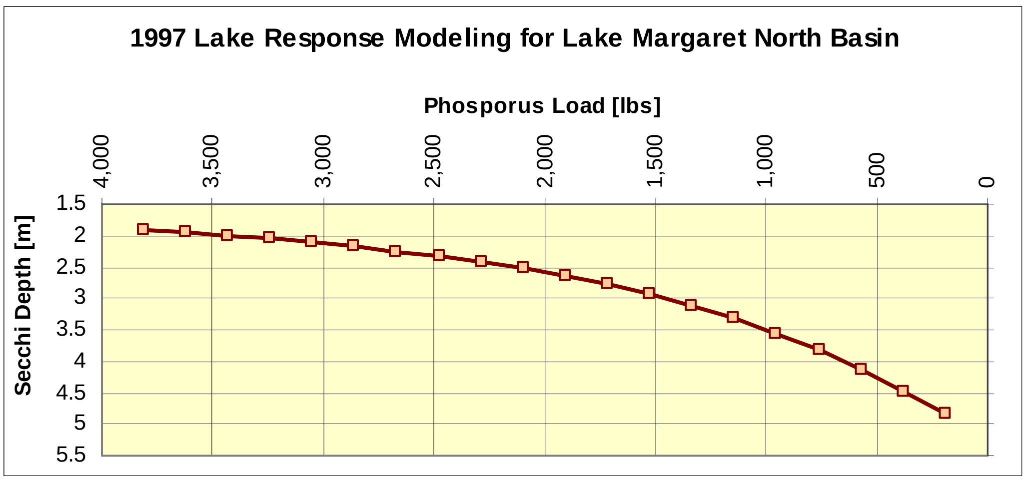


Figure 6.3. Secchi depth predicted for total phosphorus load reductions applied to all sources.

6.3 SEASONAL AND ANNUAL VARIATION

The daily load reduction targets in this TMDL are calculated from the current phosphorus budget for each of the lakes. The budget is an average of several years of monitoring data, and includes both wet and dry years. BMPs designed to address excess loads to the lakes will be designed for these average conditions; however, the performance will be protective of all conditions. For example, a stormwater pond designed for average conditions may not perform at design standards for wet years; however the assimilative capacity of the lake will increase due to increased flushing. Additionally, in dry years the watershed load will be naturally down allowing for a larger proportion of the load to come from internal loading. Consequently, averaging across several modeled years addresses annual variability in-lake loading.

Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period where the frequency and severity nuisance algal growth will be the greatest. Although the critical period is the summer, lakes are not sensitive to short term changes in water quality, rather lakes respond to long-term changes such as changes in the annual load. Therefore, seasonal variation is accounted for in the annual loads. Additionally, by setting the TMDL to meet targets established for the most critical period (summer), the TMDL will inherently be protective of water quality during all the other seasons.

7.0 Public Participation

7.1 INTRODUCTION

TMDL development should be a stakeholder-driven process that develops an understanding of the issues and the processes driving the impairments. To that end, a detailed stakeholder process was employed that included working with a Technical Advisory Committee comprised of local stakeholders. These groups represent the stakeholders ultimately responsible for implementation of the TMDLs who need to be fully engaged in the applied science. It is our goal for this TMDL to result in a science based, implementable TMDL with a full understanding of the scientific tools developed to make informed, science based decisions.

7.2 TECHNICAL ADVISORY COMMITTEE AND STAKEHOLDER MEETINGS

A technical advisory committee was established so that interested stakeholders could be involved in key decisions involved in developing the TMDL. The Technical Advisory Committee includes stakeholder representatives from the City of Lake Shore, Minnesota DNR, Cass County, Lake Margaret Conservation Association and the Minnesota Pollution Control Agency. All meetings were open to interested individuals and organizations. Technical Advisory Committee meetings to review this and other lake TMDLs in the watershed were held on March 26, 2008, July 15, 2008, August 20th, 2008, and August 23, 2008.

7.3 PUBLIC MEETINGS

All of the Technical Advisory Committee Meetings were open to the public and advertised though mailings by the City of Lake Shore. Consequently, public input was sought throughout the entire TMDL process. Several of the meetings were presentations designed to provide an overview of the TMDL formulation process, key assumptions in the models, and results of the analyses.

8.0 Implementation

8.1 INTRODUCTION

The purpose of the implementation section of the TMDL is to develop an implementation strategy for meeting the load and wasteload allocations set forth in this TMDL. This section is not meant to be a comprehensive implementation plan; rather it is the identification of a strategy that will be further developed in an implementation plan separate from this document.

8.2 REDUCTION STRATEGIES

Restoration options for lakes are numerous with varying rates of success. Consequently, each technology must be evaluated in light of our current understanding of physical and biological processes in that lake. Following is a description of potential actions for controlling nutrients in the Lake Margaret watershed that will be further developed in the Lake Margaret Implementation Plan. The estimated cost of implementing these and other potential BMPs ranges from $10,000 to $5,000,000.

8.2.1 Watershed Loads

The primary watershed sources to Lake Margaret include runoff from pastures and developed areas as well as forested areas because they comprise such a large proportion of the watershed (see Section 5). Following is a description of the approach to be taken to address each of these sources.

8.2.1.1 Pastures and Animal Agriculture

Pastures and associated animal agriculture were identified as important nutrient sources to Lake Margaret. However, the number of animals in the watershed does not appear to be unsustainable. Rather the focus of implementation will be on better management of the pastures and animal units to reduce nutrient loading to surface waters. Several practices will be considered to reduce nutrient loads from pastures including:

Feedlot management. One of the first places to start when managing animal agriculture in the watershed is feed lots. As of 2009 the county has relinquished feedlot regulation back to the MPCA. There are 7 feed lots in the Lake Margaret watershed, although none of these are large enough to be regulated CAFOs. Feed lots that meet these regulations will not discharge significant amounts of nutrients to surface waters. Cass County however does work with Cass SWCD to help farmers implement better grazing management and erosion control along with the NRCS and FSA.

Buffers and fencing. Pastures that allow animals direct access to surface waters or provide runoff directly to surface waters have a high potential to deliver nutrients to surface waters. To prevent these nutrient loads, buffers can be installed to intercept field runoff prior to reach surface waters providing removal of nutrients. Additionally, fencing prevents animals from defecating directly into surface waters and prevents damage to stream banks. The County and City will work with land owners to evaluate their pastures and install buffers and fencing where appropriate. The cost of installing exclusion fence and 30' wide native buffer is about $750 per 100 linear feet, plus the cost if necessary of a stabilized animal access point. Some or all of this cost may be eligible for funding from federal and state cost-sharing programs.

Pasture Management Plans including soil testing. Another important component of managing animal waste is developing pasture management plans. These plans develop acceptable nutrient loads to the field to prevent nutrient saturation and eventual runoff to surface waters. Included in these plans is soil testing to determine the acceptable amount of manure and associated nutrients can be applied to the watershed. The plans are usually completed by Soil and Water Conservation District personnel at no or low cost to property owners.

8.2.1.2 Sources Associated with Development

Another important component of the watershed load is development in the watershed. Most of the development in the watershed is either directly on the lake shore or associated with roads. There are numerous practices available for reducing runoff and nutrient loads from impervious surfaces. Several practices and ordinances were identified for implementation in the Lake Margaret watershed including:

Implement the Lake Margaret Overlay District. The purpose of the Lake Margaret Watershed Overlay District is to promote, preserve, improve, and enhance the environmental quality of the natural resources within the Lake Margaret Watershed without preventing reasonable use and development of land. The overlay district provides rules and standards for development, redevelopment and land use in the Lake Margaret watershed.

Increase infiltration and filtration in the lakeshed. Encourage the use of rain gardens, native plantings, and reforestation as a means to increase infiltration and evapotranspiration and reduce runoff conveying pollutant loads to the lake. These practices are especially encouraged for lake shore owners. The cost of this strategy varies depending on the BMP and may range from $500 for a single property owner installing an individual rain garden to retrofitting parks and open space with native vegetation rather than mowed turf at a cost of $10,000.

Encourage shoreline restoration. Most property owners maintain a turfed edge to the shoreline. Property owners should be encouraged to restore their shoreline with native plants to reduce erosion and capture direct runoff. Shoreline restoration can cost $30-50 per linear foot, depending on the width of the buffer installed. The City and SWCD will work together to develop some demonstration projects as well as work with all willing landowners to naturalize their shorelines.

8.2.1.3 Forested Areas and Wetlands

The overall contribution of nutrient loads from forested areas in the watershed is assumed to be low. However, because forested areas comprise such a large proportion of the watershed, minimizing nutrient loads from these areas is critical to maintaining water quality in Lake Margaret. Cass County has agreed to evaluate its Forest Management Plan to identify any areas where water quality protection is insufficient or where additional nutrient reductions may be obtainable. The County has also agreed to maintain a Smartwood Certification. The cost of implementing the forested areas BMPs is staff time from the County and City.

Cass County and the City of Lake Shore have also agreed to work together evaluate wetlands in the watershed and to identify high priority wetlands for protection and restoration. Once these high priority wetlands are identified, management plans will be developed to maintain the functions and values of those wetlands. The cost of implementing wetland management is staff time from the County and City.

8.2.1.4 Septic Systems

Little is known about the condition of septic systems outside the City of Lake Shore and in the Lake Margaret watershed. Consequently, the role of septic systems in nutrient loading to Lake Margaret is unclear. However, it is critical that all septic systems in the watershed conform to State standards. Nonconforming septic systems have a high potential to deliver nutrients to surface waters and ultimately Lake Margaret. The following action was identified to evaluate and control potential nutrient loads from septic systems.

Inspect septic systems in the Lake Margaret watershed and upgrade nonconforming systems. All of the septic systems in the Lake Margaret watershed will be inspected for compliance with current State standards. Any septic system found to be nonconforming will be upgraded to the best technology available. The estimated cost for inspection and upgrading septic systems in the Lake Margaret watershed is $50,000 to $1 Million.

8.2.1.5 Education

Another key component of any good implementation plan is education. Education will be a critical part of implementing this TMDL and includes the following task.

Conduct education and outreach awareness programs. Educate property owners in the subwatershed about proper fertilizer use, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to Lake Margaret and encourage the adoption of good individual property management practices. The City will take the lead in education and outreach programming with participation and assistance by the county, DNR, SWCD, and other interested agencies.

8.2.1.6 Construction Stormwater Activities

Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

8.2.2 Internal Loads

Although internal loading is not the primary source of nutrients to Lake Margaret, internal nutrient loads will need to be reduced to meet the TMDL allocations presented in this document. There are numerous options for reducing internal nutrient loads ranging from simple chemical inactivation of sediment phosphorus to complex infrastructure techniques including hypolimnetic aeration.

8.2.2.1 Internal Load Reduction Feasibility Study

Prior to implementation of any strategy to reduce internal loading in Lake Margaret, a feasibility study needs to be completed to evaluate the cost and feasibility of the lake management techniques available to reduce or eliminate internal loading in lakes. Several options should be considered to manage internal sources of nutrients including hypolimnetic withdrawal, alum treatment, vegetation management and hypolimnetic aeration. A feasibility study will be completed to provide recommendations for controlling internal loading in Lake Margaret. The estimated cost of this study is $30,000.

8.2.2.2 Implement Recommendations of Feasibility Study

Once the feasibility study has been completed and the preferred alternative for controlling internal phosphorus loading has been identified, the selected technique needs to be implemented. The costs associated with each technique vary, however each technique requires some engineering as well as capital costs. The estimated cost of implementing an internal load reduction project ranges from $200,000 to $1.5 Million.

8.2.3 Other Physical and Biological Strategies

Although controlling nutrients is a key component in restoring the beneficial uses to Lake Margaret, other strategies need to be implemented to provide the necessary conditions in the lake to take full advantage of the nutrient reductions. These strategies are described below.

8.2.3.1 Conduct Aquatic Plant Survey and Implement Vegetation Management Plan

Aquatic plants should periodically be surveyed on Lake Margaret to track changes in the plant community and monitor growth and extent of nuisance species such as curly-leaf pondweed. The Minnesota DNR already periodically monitors vegetation on Lake Margaret. Additionally, the Lake Margaret Conservation Association has partnered with the Minnesota DNR to develop an aquatic vegetation plan. Implementation of this plan is an important step in meeting beneficial use goals in Lake Margaret (see section 5.5.4).

8.2.3.2 Manage Fish Populations

Maintaining a balanced fishery is an important aspect of any lake management plan. To accomplish this, the Minnesota DNR will monitor and manage the fish population to maintain a beneficial community. The Minnesota DNR already periodically monitors fish populations in Lake Margaret. Additionally, the Minnesota DNR has agreed to evaluate the carp population in Lake Margaret.

8.2.3.3 Recreational Impacts Education

Because Lake Margaret is a highly used recreational lake, there is a potential for the recreation activities to have an impact on the water quality in the lake. To address these potential impacts, educational materials will be developed for lake users to make them aware of the potential impacts to the lake. The educational materials will also identify sensitive areas of the lake.

8.3 IMPLEMENTATION STRATEGY

The load allocations in the TMDL represent aggressive goals for nutrient reductions. Consequently, implementation will be conducted using adaptive management principles (Figure 8.1). Adaptive management is appropriate because it is difficult to predict the lake response that will occur from implementing strategies with the paucity of information available to demonstrate expected reductions. Future technological advances may alter the course of actions detailed here. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL.
Based on this understanding of the appropriate standards for lakes, this TMDL has been established with the intent to implement all the appropriate activities that are not considered greater than extraordinary efforts. It is expected that it may take 10-20 years to implement BMPs and load-reduction activities.

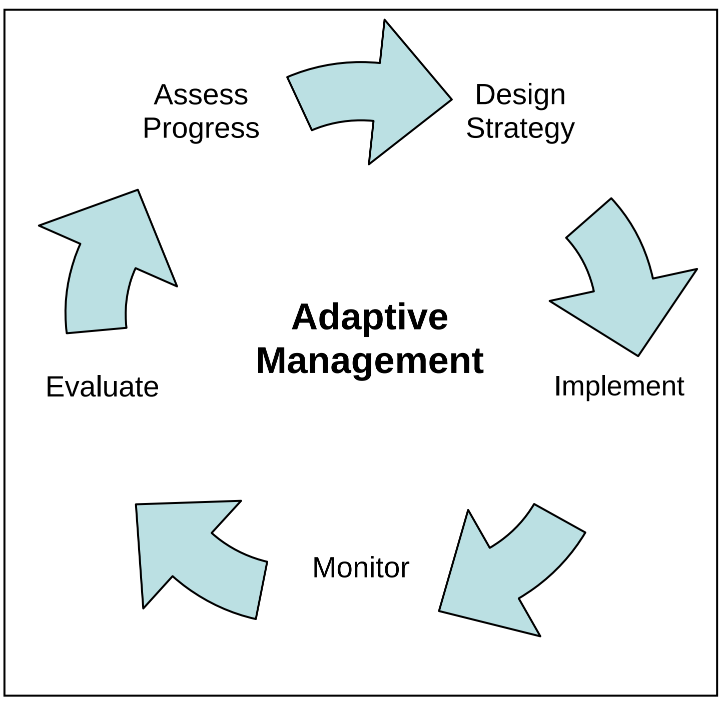


Figure 8-1. Adaptive management.

9.0 Reasonable Assurance

9.1 INTRODUCTION

When establishing a TMDL, reasonable assurances must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurance, including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the BMPs. This TMDL establishes aggressive goals for the reduction of phosphorus loads to Lake Margaret. In fact, there are few if any examples where these levels of reductions have been achieved where the sources were primarily nonpoint source in nature.

TMDL implementation will be implemented on an iterative basis so that implementation course corrections based on periodic monitoring and reevaluation can adjust the strategy to meet the standard. After the first phase of nutrient reduction efforts, reevaluation will identify those activities that need to be strengthened or other activities that need to be implemented to reach the standards. This type of iterative approach is more cost effective than over engineering to conservatively inflated margins of safety (Walker 2003). Implementation will also address other lake problems not directly linked to phosphorus loading such as invasive plant species (curly-leaf pondweed) and invasive fish (carp and rough fish). These practices go beyond the traditional nutrient controls and provide additional protection for lake water quality.

9.2 CASS COUNTY COMPREHENSIVE LOCAL WATER MANAGEMENT PLAN

Cass County maintains a Comprehensive Local Water Management Plan that outlines action strategies designed to achieve County water resources and management goals. The scope and purpose of the plan is to:

- Identify existing and potential problems and opportunities for the protection of, management and development of water and related land resources

- Preserve the pristine quality of the county's ground and surface waters and, where degradation has occurred, provide for water quality restoration

- Monitor water quality, use, and availability

- Develop objectives and carry out a plan of action to promote sound hydrologic management, and effective environmental protection

- Provide coordination and efficient delivery of environmental services to assure the long-term protection of water resources and watersheds

Implementation of the scope of the plan is accomplished through the identification of goals and implementation of action items under each of the identified goals. The goals and actions are available in the County's Comprehensive Plan (Cass County 2002). The plan is implemented in five year cycles and Cass County will continually evaluate the action items' effectiveness in achieving the load allocations in the Lake Margaret TMDL. At the end of each five year period the County will evaluate the success of BMP implementation in reducing the total phosphorus concentration in Lake Margaret and will reconvene the Technical Advisory Committee to determine if adjustments to the Implementation Plan are necessary.

9.3 CITY OF LAKE SHORE

The City of Lake Shore is located on the northwestern shore of Gull Lake in Cass County, Minnesota. Lake Shore was founded as a village in 1930; incorporated on March 19th, 1947; and adopted its first land use ordinance in 1969. Lake Margaret lies entirely within the boundaries of the City of Lake Shore.

The City of Lake Shore has developed a comprehensive plan that identifies policies, objectives, and strategies to shape the future of development within the community. The comprehensive plan serves as a basis for making land use decisions and provides a set of goals for the community to work toward. Ultimately, a comprehensive plan identifies the community's priorities and values, and identifies strategies for achieving their goals, implementing their policies and protecting and enhancing their community.

The City of Lake Shore has identified policies focused on the protection of natural resources and, in particular, lakes within the City. Some of these policies include:

- Ensure that new residential development and redevelopment is efficient, orderly, environmentally sensitive, and fiscally responsible.

- Protect, enhance, and restore the City's natural resources and environmentally sensitive areas for the community's long-term environmental, social, and economic benefit.

- Maintain and improve the quality of surface and groundwater resources for the benefit of residents and wildlife as well as protect property values.

- Promote environmental stewardship among residents visitors, and businesses to maintain a high quality of life in the City and to keep citizens involved in protecting the environment for current and future generations.

- Protect and enhance open space to manage it in an environmentally sound manner.

Both long-term and short-term strategies have been developed for each of these policies. These policies provide the framework and direction for implementing the Lake Margaret nutrient TMDL. Implementing the TMDL is consistent with the goals and policies identified by the City of Lake Shore.

9.3.1 Lake Margaret Overlay District

As a part of the City's implementation of its Comprehensive Plan and in direct response the development of this TMDL, the City of Lake Shore has developed an overlay district for the Lake Margaret watershed that outlines acceptable standards and practices for development, redevelopment, and use of land in the Lake Margaret watershed. The purpose of the Lake Margaret Watershed Overlay District (LMW) is to promote, preserve, improve, and enhance the environmental quality of the natural resources within the Lake Margaret Watershed without preventing reasonable use and development of land. The intent of this district is to protect the quality of the watershed from adverse effects occasioned by poorly sited development or incompatible activities and regulating land disturbances or development activities that would have an adverse and potentially irreversible impact on the water quality and on fragile environmentally sensitive land within the watershed of Lake Margaret.

9.4 LAKE MARGARET CONSERVATION ASSOCIATION

The Lake Margaret Conservation Association (LMCA) is devoted to the restoration and continuing preservation of the highest water quality and environmental standards achievable for the Lake Margaret basin; and to that end, it is dedicated to cooperate with any and all agencies to ensure success. The ultimate goal of the LMCA is to restore Lake Margaret to the highest achievable ecological standard. To meet that goal, several objectives have been identified by the LMCA including:

1. Cooperate with all governmental units and involved agencies to speed up and maintain the process of restoring Lake Margaret.

2. Keep property owners informed on progress and process of lake restoration.

3. Encourage "best management practices" by property owners and the general public.

4. Use the influence of the Association and cooperating agencies and organizations to draw on financial support from all funding resources.

5. Involve the Association in the formulation of ongoing plans for and evaluation of implementation efforts aimed at the restoration of Lake Margaret for continued safe use by present and future generations.

6. Affiliate with the Gull Chain of Lakes Association as a permanent task force in order to take advantage of their dedication to represent all property owners for the betterment of the water quality, safety and property values on the entire chain of lakes.

9.5 MONITORING

Two types of monitoring are necessary to track progress toward achieving a TMDL and attainment of water quality standards. The first type of monitoring is tracking implementation of Best Management Practices and capital projects. Both the City of Lake Shore and Cass County will track the implementation of these projects annually. The second type of monitoring is physical and chemical monitoring of the resource. The City of Lake Shore plans to monitor Lake Margaret on a three year cycle. The Minnesota Pollution Control Agency also plans to maintain a long term monitoring site on Home Brook to monitor nutrient and water loads to Lake Margaret.

This type of effectiveness monitoring is critical in the adaptive management approach. Results of the monitoring identify progress toward benchmarks as well as shape the next course for implementation. Adaptive management combined with obtainable benchmark goals and monitoring is the best approach for implementing TMDLs.

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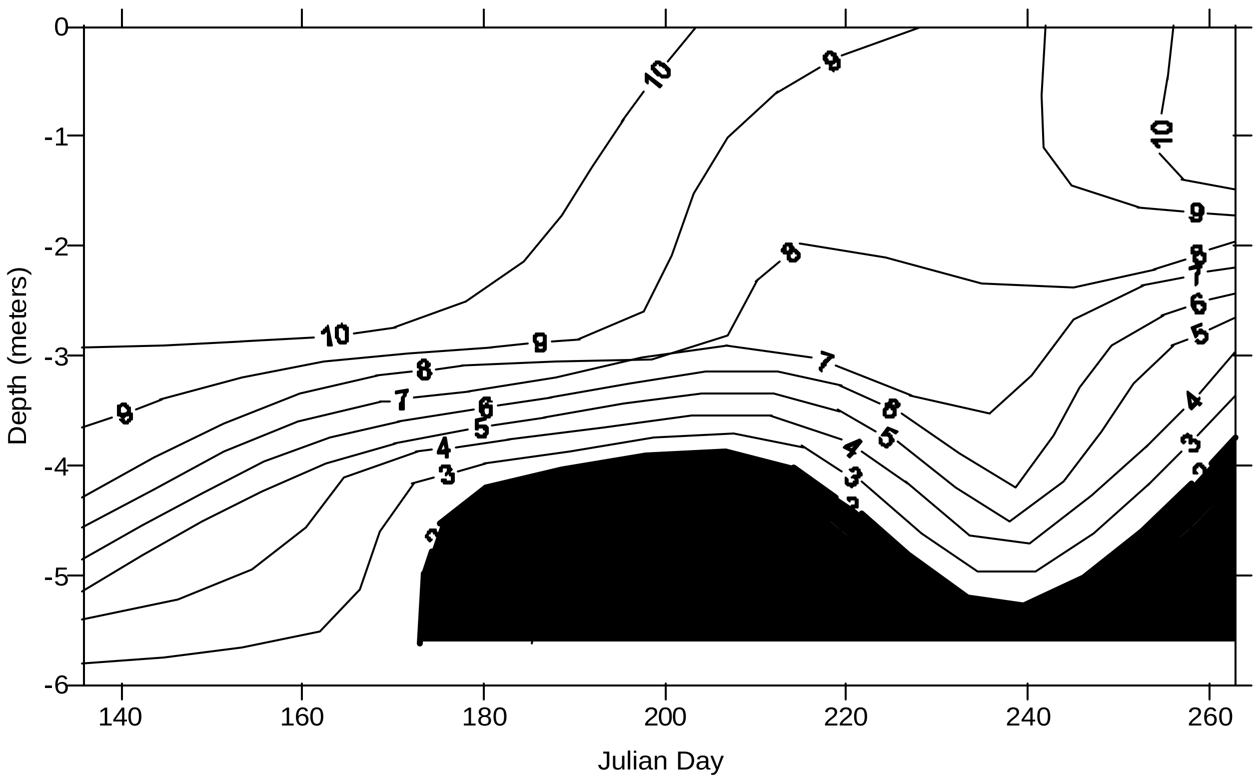
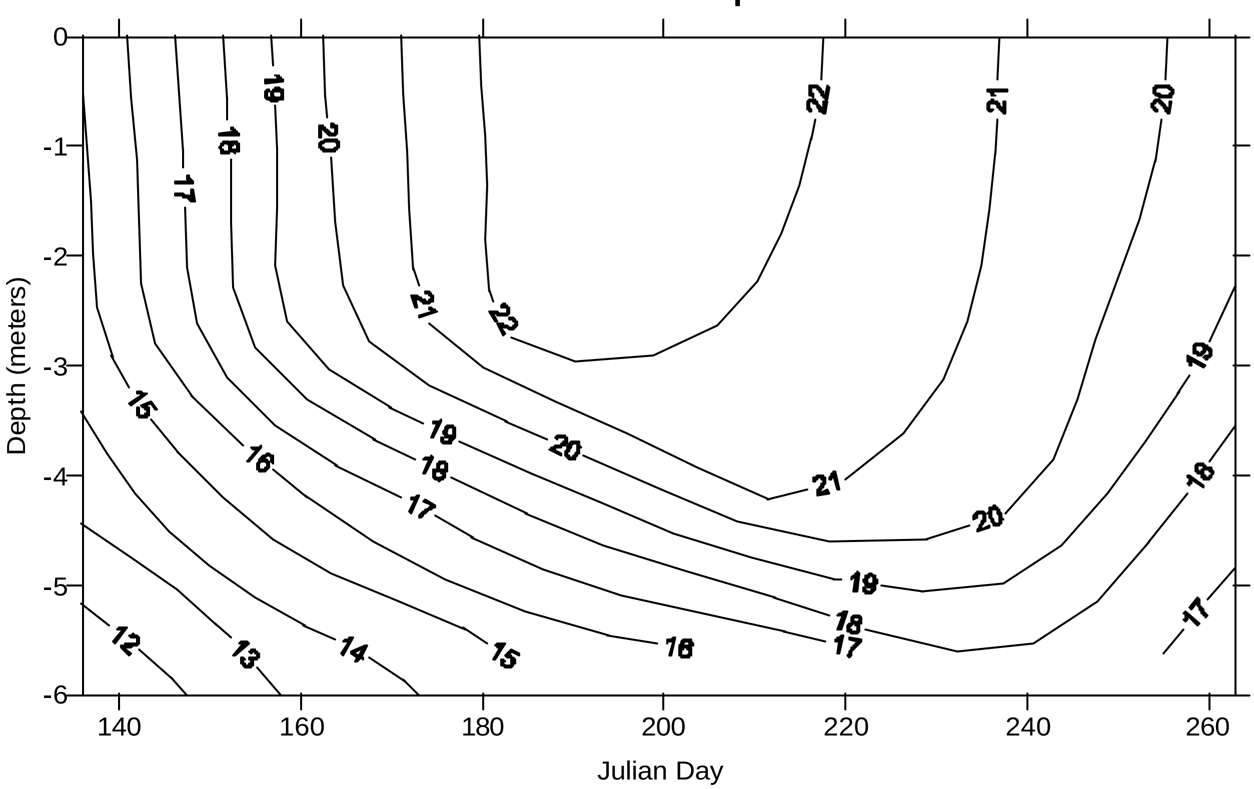
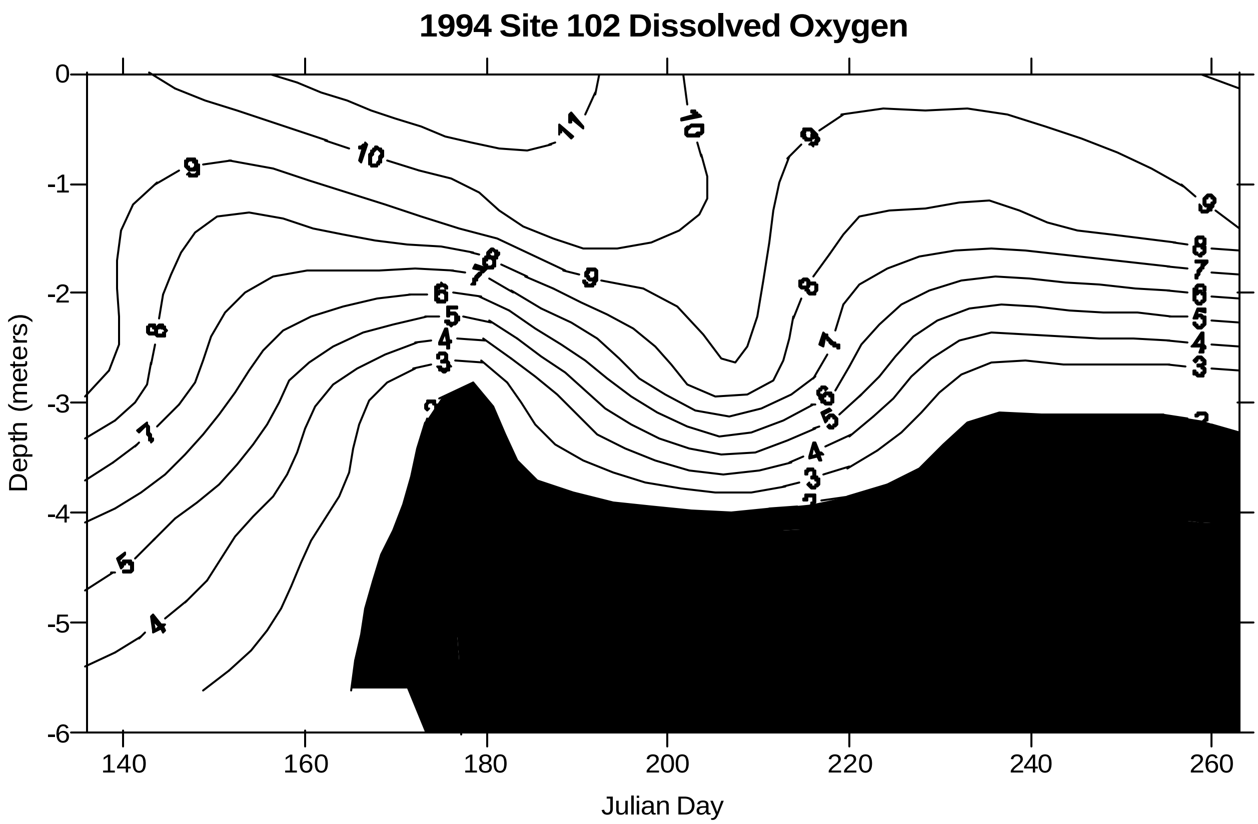
Appendix A

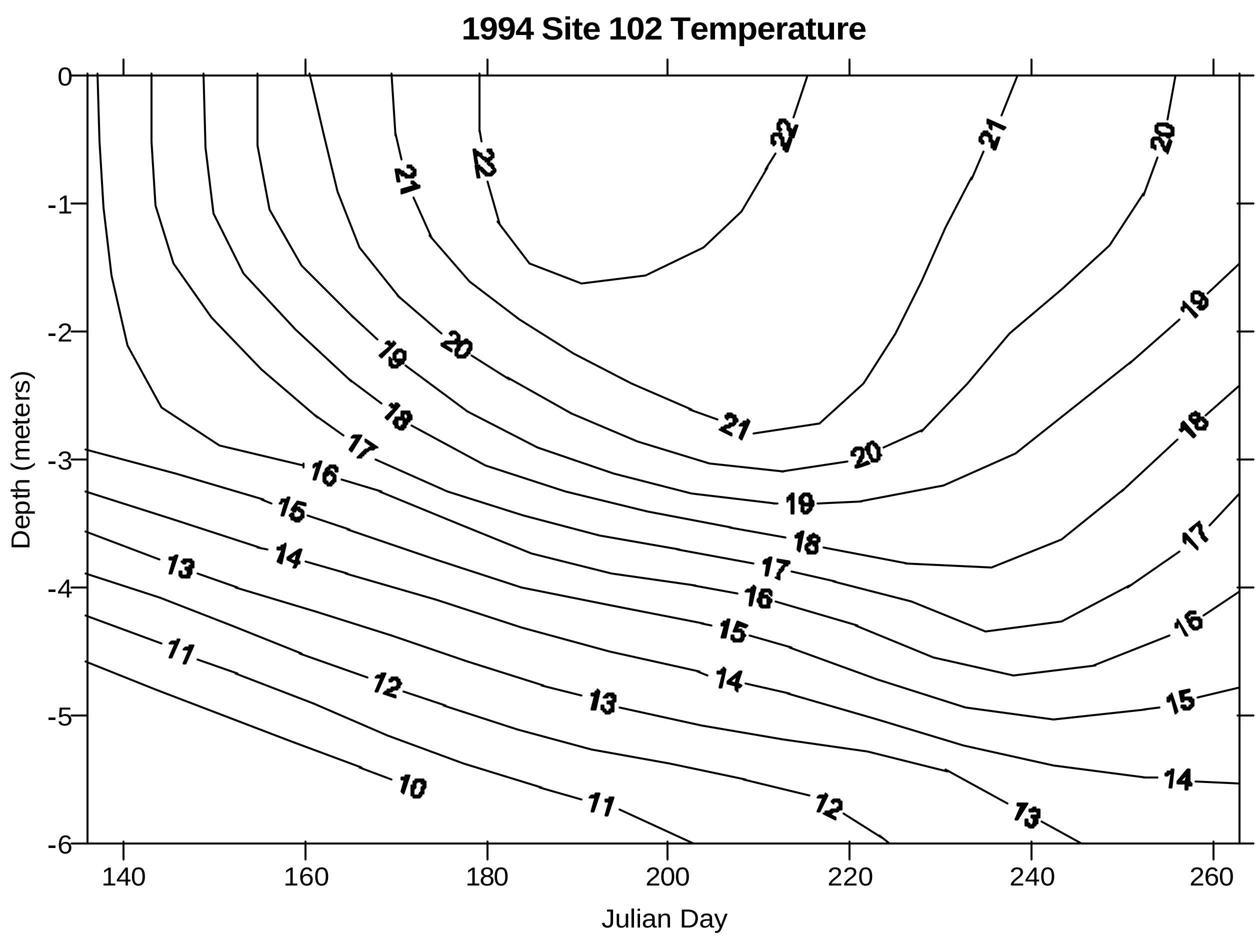
1994 Site 101 Dissolved Oxygen



1994 Site 101 Temperature




1994 Site 102 Dissolved Oxygen
Depth (meters)
Julian Day
0
-1
-2
-3
-4
-5
-6
140
160
180
200
220
240
260


1994 Site 102 Temperature
Depth (meters)
Julian Day
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-3
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-5
-6
140
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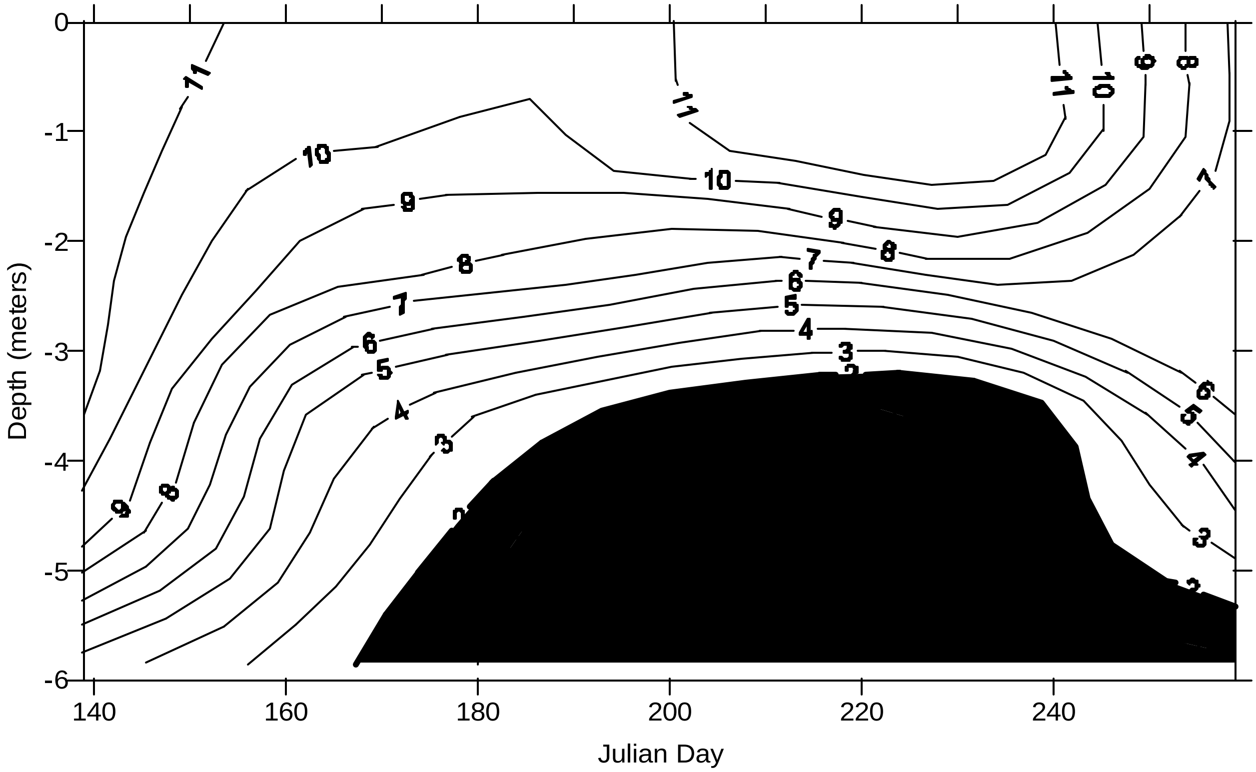
260

2005 Site 101 Dissolved Oxygen



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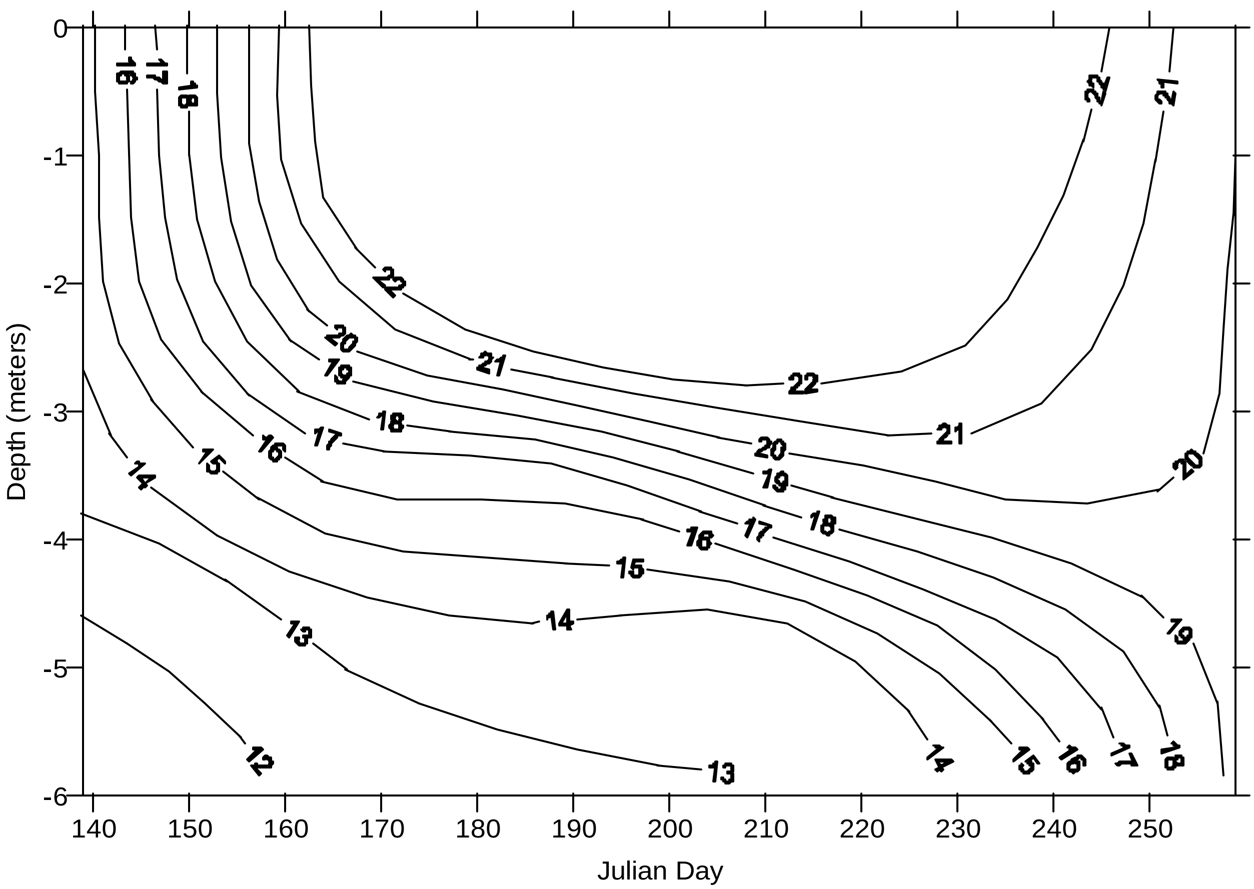

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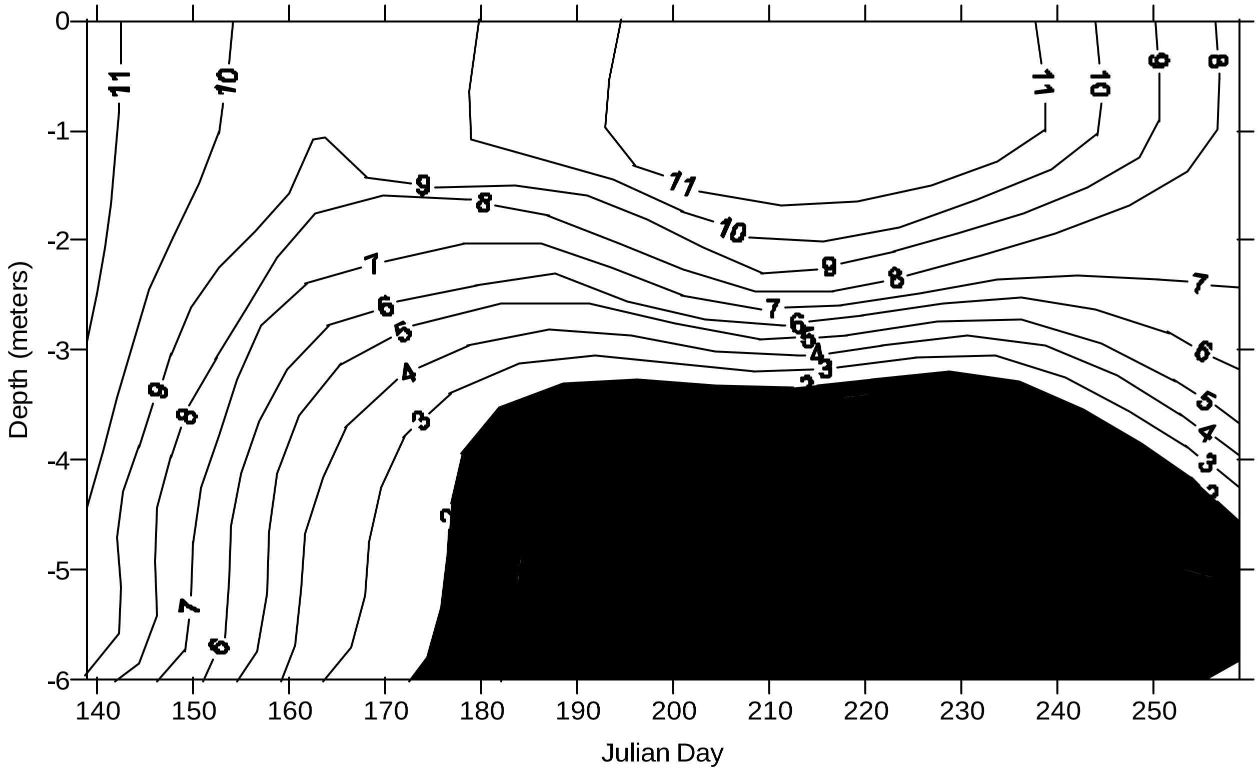
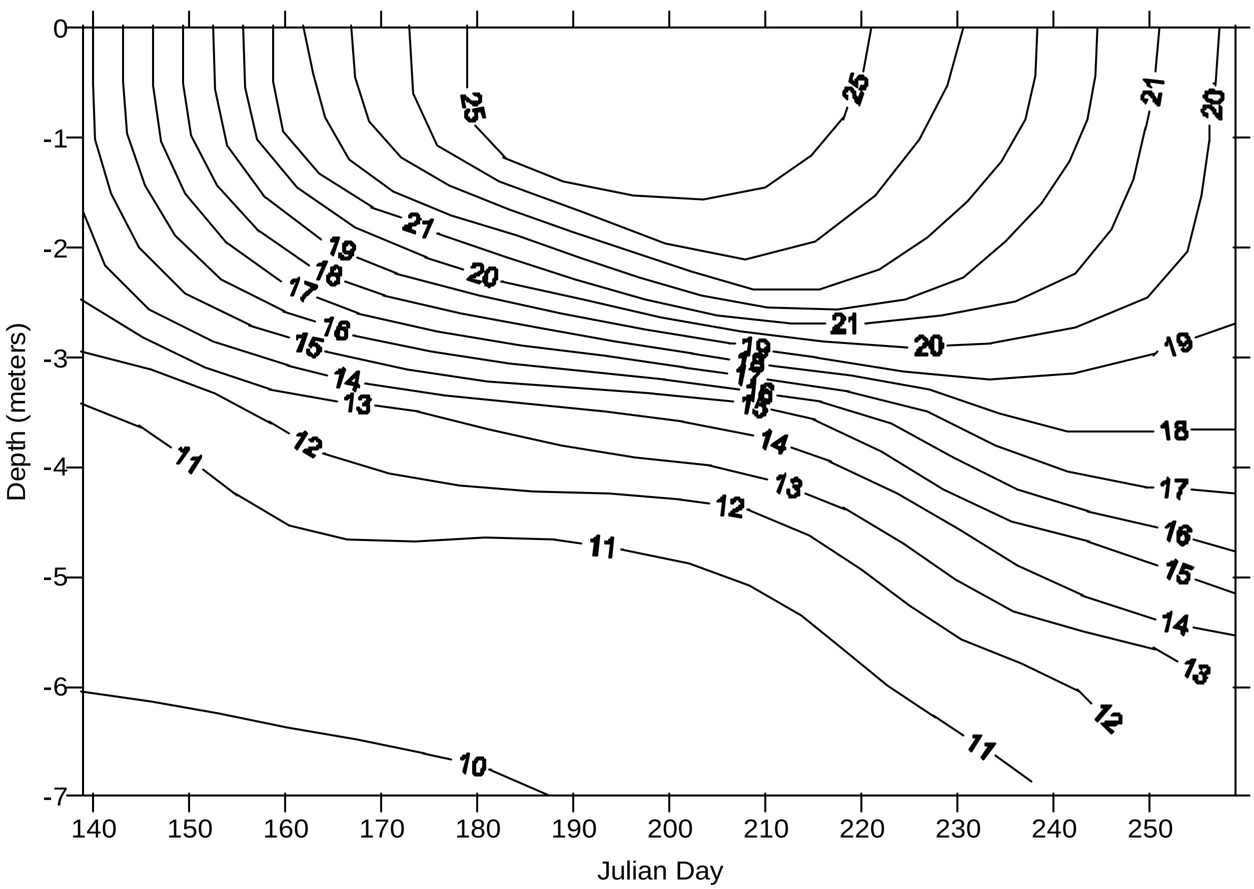


2005 Site 102 Temperature



Appendix B

Growing season (June 1 –September 30) lake water quality for Site 101 in the north basin of Lake Margaret.

Year	Secchi Depth (m)		Surface TP (µg/L)		Chlorophyll-a (µg/L)		TKN (mg/L)	
	Mean	N	Mean	N	Mean	N	Mean	N
1974	1.26	16	--	--	--	--	--	--
1990	0.85	2	36	2	56.3	2	1.12	2
1994	1.18	17	55	6	40.2	6	1.16	6
1995	1.37	10	--	--	--	--	--	--
1996	1.66	13	52	2	28.2	2	0.89	2
1997	1.55	12	45	5	15.9	3	1.05	4
1998	1.37	13	55	5	35.0	5	1.12	5
1999	1.48	13	48	5	29.8	5	1.02	5
2001	1.52	10	--	--	--	--	--	--
2002	1.41	11	--	--	--	--	--	--
2003	1.65	7	--	--	--	--	--	--
2005	1.34	4	63	3	33.5	4	1.17	3

Growing season (June 1 –September 30) lake water quality for Site 102 in the south basin of Lake Margaret.

Year	Secchi Depth (m)		Surface TP (µg/L)		Chlorophyll-a (µg/L)		TKN (mg/L)	
	Mean	N	Mean	N	Mean	N	Mean	N
1990	0.95	2	63	2	62	2	2.07	3
1994	1.33	17	64	5	39	6	1.46	3
1995	1.45	10	--	--	--	--	--	--
1996	1.69	13	49	2	15	4	0.87	2
1997	1.68	12	43	5	22	3	1.03	4
1998	1.55	13	39	5	27	5	1.14	5
1999	1.57	13	41	5	34	5	0.97	5
2001	1.63	10	--	--	--	--	--	--
2002	1.65	11	--	--	--	--	--	--
2003	1.81	7	--	--	--	--	--	--
2004	1.42	18	--	--	--	--	--	--
2005	1.47	22	56	4	20	4	1.18	2

Appendix C

Wenck Associates, Inc.
1800 Pioneer Creek Ctr.
P.O. Box 249
Maple Plain, MN 55359-0249

(763) 479-4200
Fax (763) 479-4242
E-mail: wenckmp@wenck.com

TECHNICAL MEMORANDUM

TO: Joe Bischoff

FROM: Andy Erickson

DATE: June 23, 2008

SUBJECT: Rating Curve Modification for Home Brook as part of the Lake Margaret TMDL Study

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The purpose of this memo is to document and justify changes to the rating curves for monitoring locations upstream of Lake Margaret: Home Brook (Site #1), Rush Brook (Site #2), and Corey Brook (Site #5).

Home Brook (Site #1)

Home Brook (Site #1) is located closest to Lake Margaret (i.e., farthest downstream monitoring station) and is the station with the most data collected. The current rating curve (i.e., discharge, Q, as a function of stage, h) for this location is a power function with a correction factor of 1.2 feet as shown in Figure 1.

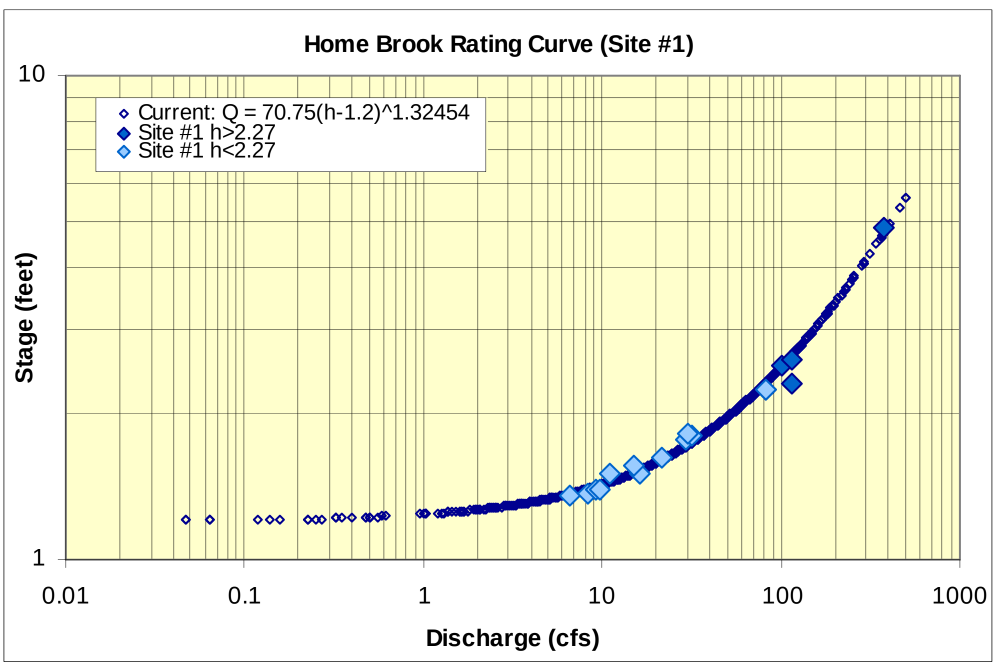

Figure 1: Current Rating Curve for Home Brook (Site #1)

The rating curve shown in Figure 1 is a reasonable representation of the measured data for stage (h) measurements between 1.36 feet and 4.85 feet. Stage measurements outside this range, however, may be significantly under- or over-estimated. There are 180 stage measurements below 1.36 feet and five measurements above 4.85 feet (1617 total measurements) in five years of measured data (1997-2001) which account for approximately 11% of all measured data. The current rating curve predicts discharge (Q) in Home Brook to range from approximately 0.05 to 503 cfs.

The proposed rating curve for Home Brook (Site #1) is a combination of two power functions (Figure 2). As shown in Figure 2, the highest measured discharge (h = 4.85 feet , Q = 375 cfs) appears to be non-linearly correlated with the other available stage-discharge data. Therefore, the rating curve was separated into two separate power functions with the transition occurring at a depth of 2.27 feet. The rating curve shown in Figure 2 predicts discharge in Home Brook to range from 3.6 to 481 cfs. A comparison of the current and proposed rating curves is shown in Figure 3.

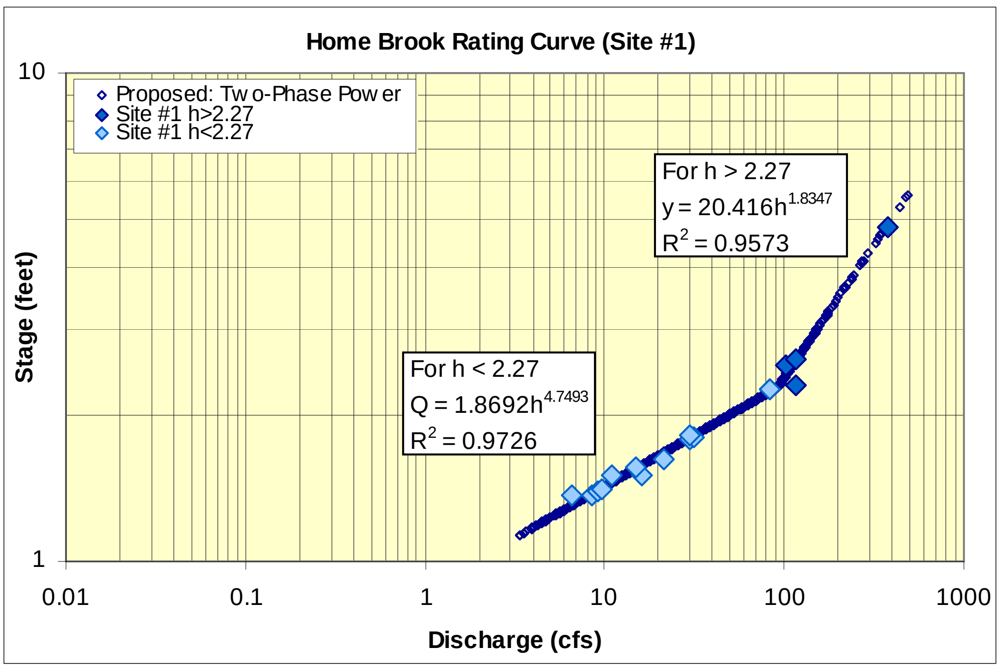

Figure 2: Proposed rating curve for Home Brook (Site#1).

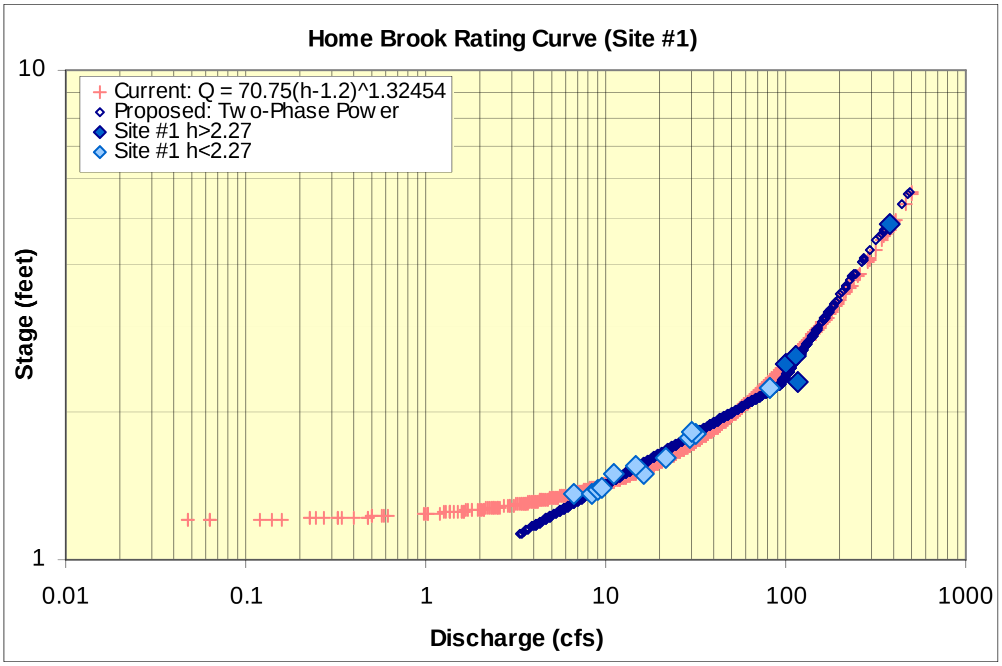

Figure 3: Current and proposed rating curves for Home Brook (Site #1).

The primary difference between the current and proposed rating curves for Home Brook (Site #1) is the prediction of discharge at low stage measurements (less than 1.36 feet). The current rating curve predicts discharge to significantly decline to a minimum of 0.05 cfs. The proposed rating curve predicts discharge at this stage to be approximately 3.6 cfs which is corroborated by city staff which indicate that Home Brook exhibits "significant baseflow."

A comparison between the current and proposed rating curves can be made based on daily discharge volume (ac-ft/day) as shown in Figure 4 and Figure 5. Compared to the current rating curve, the proposed rating curve predicts more daily discharge volume for discharge volume less than approximately 20 acre-feet per day; less volume for volumes between 20 and 120 acre feet per day; more volume for volumes between 120 and 300 acre-feet per day; and less volume for volumes greater than 300 acre-feet per day.

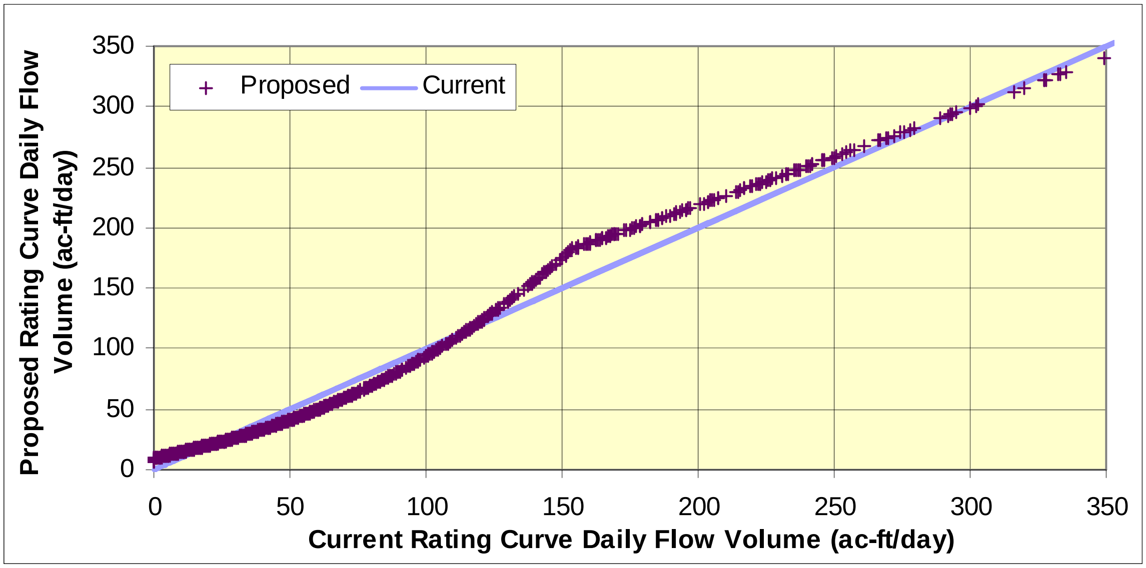

Figure 4: Daily volume comparison between current and proposed rating curves (less than 350 ac-ft/day).

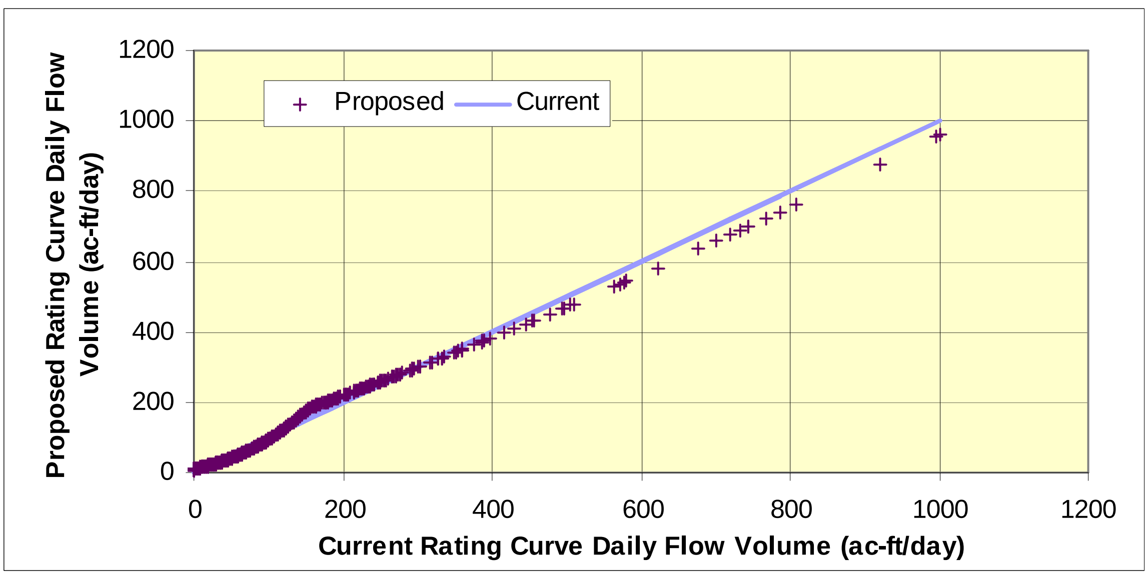

Figure 5: Daily volume comparison between current and proposed rating curves (all data).

The significance of these differences can be seen in the cumulative discharge volume for an entire year as shown in Figure 6. Lake response models are developed for discharge volume and pollutant load based on annual time steps and therefore only the difference in the annual volume and load is important for lake response modeling. For the years in which measurements were taken, the difference between the current and proposed rating curves from the perspective of lake response modeling is minimal and within the limits of uncertainty in the model itself. In relatively dry years, however, the difference could be significant because stage measurements may be below the rating curve (i.e., less than 1.36 feet) for most of the year.

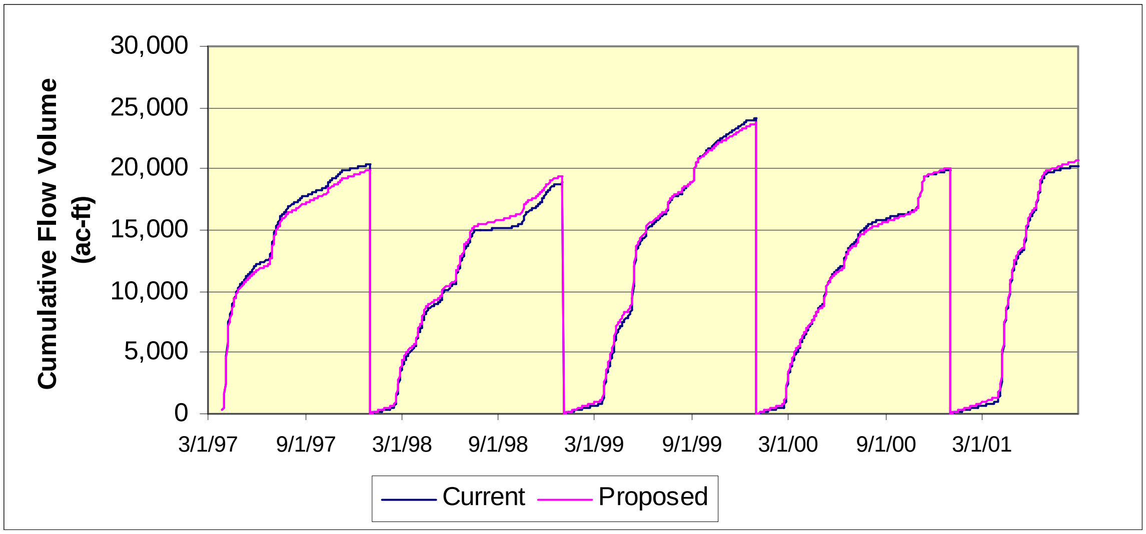

Figure 6: Cumulative discharge volume for Home Brook for two different rating curves.

Rush Brook (Site #2)

A similar process was used to develop rating curves for Rush Brook (Site #2) upstream of Home Brook in the Lake Margaret watershed. The current and proposed rating curves for Rush Brook are shown in Figure 7. There are 476 stage measurements within the limits of the measured rating data (3.65 feet < h < 4.76 feet). There are also, however, 90 stage measurements below 3.65 feet and 53 stage measurements above 4.76 feet which account for approximately 23% of all measured data.

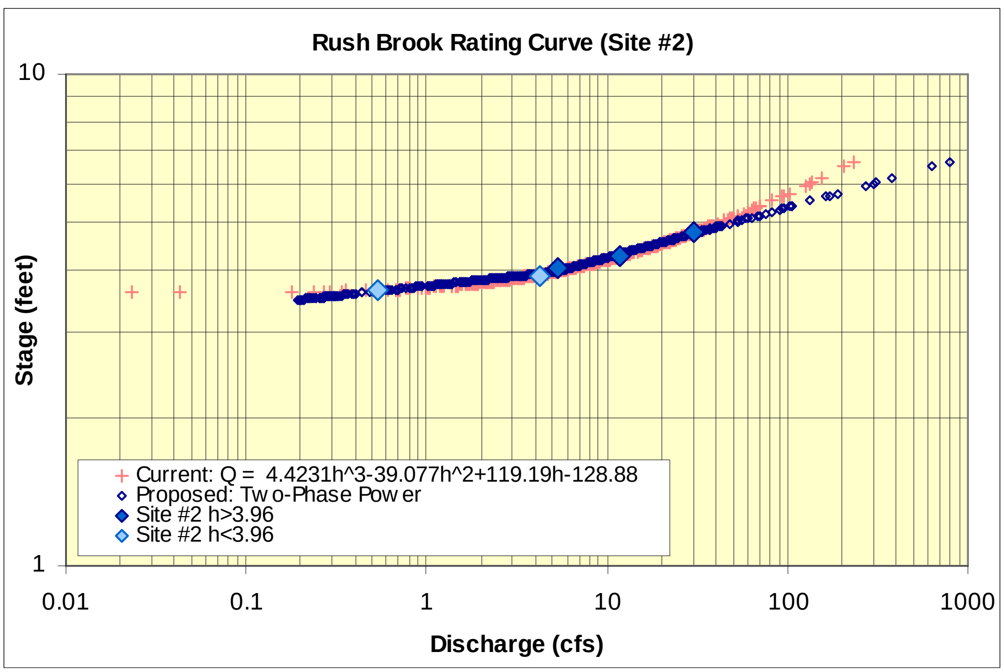

Figure 7: Current and proposed rating curves for Rush Brook (Site #2).

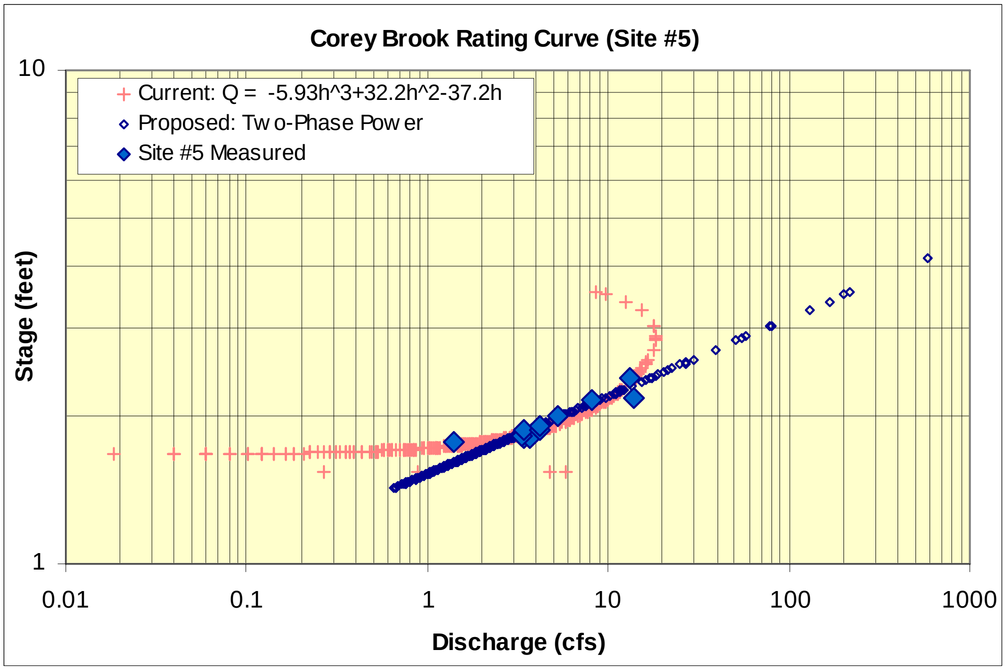

Figure 8: Current and proposed rating curves for Corey Brook (Site #5).

Corey Brook (Site #5)

Rating curves were also developed for Corey Brook (Site #5) upstream of Home Brook in the Lake Margaret watershed. The current and proposed rating curves for Corey Brook are shown in Figure 8. There are 221 stage measurements within the limits of the measured rating data (1.76 feet < h < 2.17 feet). There are also, however, 658 stage measurements below 1.76 feet and 23 stage measurements above 2.17 feet which account for approximately 75% of all measured data.

Rating Curve Coefficients

The rating curve equation coefficients and general form of the rating curve equation for Home Brook, Rush Brook, and Corey Brook are provided in Table 1.

Table 1: Rating Curve Equation Coefficients for Home Brook (Site #1), Rush Brook (Site #2), and Corey Brook (Site #5).

Site	**C_1**	**C_2**
Home Brook (Site #1)		
h < 2.27	1.87	4.75
h > 2.27	20.42	1.83
Rush Brook (Site #2)		
h < 3.96	5.000×10^{-15}	25.11
h > 3.96	7.031×10^{-06}	9.81
Corey Brook (Site #5)		
All data	0.0696	6.346
General Rating Curve Equation: $Q = C_1 \times h^{C_2}$		

Conclusions

It is important to use a theory-based rating curve for predicting discharge in natural channels; especially for stage measurements that are outside the range of the rating curve data. The significant differences in discharge prediction between the current and proposed rating curves occur at the stage measurements below the rating curve data (i.e., less than 1.36 feet) for Home Brook (Site #1), above and below the rating curve data for Rush Brook (Site #2), and above and below the rating curve data for Corey Brook (Site #5). There is a significant amount of stage measurements above and below the rating curve data for Rush Brook and Corey Brook. Measuring discharge in the range of these values to extend the rating curves for these locations will ensure that future predictions of discharge are accurate.

Appendix D

1997 Loading Summary for Lake Margaret Basin 2

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed	2,916	4.5	1,099	61.725	1.0	184
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*2,916*	*5*	*1,099*	*61.7*		*184.4*

Failing Septic Systems

Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	2,916	0	0%	0.0	0.0	0.0
2						
3						
4						
5						
Summation	*2,916*	*0*	*0%*		*0.0*	*0.0*

Inflow from Upstream Lakes

Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1 Lake Margaret Bas	22,839.5	45.2	1.0	2,805
2		-	1.0	
3		-	1.0	
Summation	*22,839*	*45.2*		*2,805*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
133	23.8	23.8	0.00	0.22	1.0	29.6
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
133	0.0	0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
133	66.0	10.10	1.0	794

Net Discharge [ac-ft/yr] =	**23,938**	**Net Load [lb/yr] =**	**3,813**

NOTES

1 Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

1997 Lake Response Modeling for Lake Margaret Basin 2

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	3,813 [lb/yr]
		Q (lake outflow) =	23,938 [ac-ft/yr]
		V (modeled lake volume) =	1,492 [ac-ft]
		T = V/Q =	0.06 [yr]
		P_i = W/Q =	59 [ug/l]
Model Predicted In-Lake [TP]			**47.5 [ug/l]**
Observed In-Lake [TP]			**45.0 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**13.3 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	48 [ug/l]
		N (Total Nitrogen) =	1053 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	31.5 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	40.2 [ug/l]
		G (Kinematic factor) =	0.61 [--]
		F_s (Flushing Rate) =	16.05 [$year^{-1}$]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	9.84 [ft]
		C_a (non-algal turbity coefficient) =	0.015 [-]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - C_a \times [\text{Chl}a]$	a (Non algal turbidity) =	0.19 [m^{-1}]
		S (Secchi Depth) =	6.27 [ft]
		Maximum lake depth =	21.98 [ft]
Model Predicted In-Lake [Chl-a]			**21.9 [ug/l]**
Observed In-Lake [Chl-a]			**15.9 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + C_a \times [\text{Chl }a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.19 [m^{-1}]
Model Predicted In-Lake SD			**1.91 [m]**
Observed In-Lake SD			**1.55 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**718** [lb/yr]
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**3,094 [lb/yr]**

1998 Loading Summary for Lake Margaret Basin 2

	Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed	2,916	4.4	1,072	61.189	1.0	178
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*2,916*	*4*	*1,072*	*61.2*		*178.3*

Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	2,916	0	0%	0.0	0.0	0.0
2						
3						
4						
5						
Summation	*2,916*	*0*	*0%*		*0.0*	*0.0*

Inflow from Upstream Lakes				
Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1 Lake Margaret Bas	22,282.4	44.8	1.0	2,714
2		-	1.0	
3		-	1.0	
Summation	*22,282*	*44.8*		*2,714*

Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
133	26.9	26.9	0.00	0.24	1.0	31.9

Dry-year total P deposition = 0.222
Average-year total P deposition = 0.239
Wet-year total P deposition = 0.259
(Barr Engineering 2004)

Groundwater					
Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
133	0.0	0.00	0	1.0	0

Internal				
Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
133	66.0	10.10	1.0	794

Net Discharge [ac-ft/yr] = 23,354 **Net Load [lb/yr] = 3,718**

NOTES
[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

1998 Lake Response Modeling for Lake Margaret Basin 2

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	3,718 [lb/yr]
		Q (lake outflow) =	23,354 [ac-ft/yr]
		V (modeled lake volume) =	1,492 [ac-ft]
		T = V/Q =	0.06 [yr]
		P_i = W/Q =	59 [ug/l]
Model Predicted In-Lake [TP]			**47.4 [ug/l]**
Observed In-Lake [TP]			**54.8 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**13.3 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	47 [ug/l]
		N (Total Nitrogen) =	1120 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	32.3 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	40.9 [ug/l]
		G (Kinematic factor) =	0.20 [--]
		F_s (Flushing Rate) =	15.66 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	3.28 [ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - C_a \times [\text{Chl}a]$	C_a (non-algal turbity coefficient) =	0.015 [-]
		a (Non algal turbidity) =	0.19 [m^{-1}]
		S (Secchi Depth) =	5.30 [ft]
		Maximum lake depth =	21.98 [ft]
Model Predicted In-Lake [Chl-a]			**28.3 [ug/l]**
Observed In-Lake [Chl-a]			**35.0 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(a + C_a \times [\text{Chl } a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.19 [m^{-1}]
Model Predicted In-Lake SD			**1.62 [m]**
Observed In-Lake SD			**1.37 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**708 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**3,010 [lb/yr]**

1999 Loading Summary for Lake Margaret Basin 2

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Watershed	2,916	5.4	1,308	61.535	1.0	219
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*2,916*	*5*	*1,308*	*61.5*		*218.9*

Failing Septic Systems

	Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1	Watershed	2,916	0	0%	0.0	0.0	0.0
2							
3							
4							
5							
	Summation	*2,916*	*0*	*0%*		*0.0*	*0.0*

Inflow from Upstream Lakes

	Name	Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Lake Margaret Bas	27,203.1	45.8	1.0	3,388
2			-	1.0	
3			-	1.0	
	Summation	*27,203*	*45.8*		*3,388*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
133	30.3	30.3	0.00	0.24	1.0	31.9

Dry-year total P deposition =	0.222
Average-year total P deposition =	0.239
Wet-year total P deposition =	0.259
(Barr Engineering 2004)	

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]	Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
133	0.0	0.00	0	1.0	0

Internal

Lake Area [acre]	Anoxic Factor [days]	Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
133	66.0	10.10	1.0	794

Net Discharge [ac-ft/yr] =	**28,512**	**Net Load [lb/yr] =**	**4,433**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

1999 Lake Response Modeling for Lake Margaret Basin 2

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	4,433 [lb/yr]
		Q (lake outflow) =	28,512 [ac-ft/yr]
		V (modeled lake volume) =	1,492 [ac-ft]
		T = V/Q =	0.05 [yr]
		P_i = W/Q =	57 [ug/l]
Model Predicted In-Lake [TP]			**47.3 [ug/l]**
Observed In-Lake [TP]			**47.8 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**13.2 [ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	47 [ug/l]
		N (Total Nitrogen) =	1022 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	31.0 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	39.6 [ug/l]
		G (Kinematic factor) =	0.21 [--]
		F_s (Flushing Rate) =	19.11 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	3.28 [ft]
		C_a (non-algal turbity coefficient) =	0.015 [-]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - C_a \times [\text{Chl}a]$	a (Non algal turbidity) =	0.19 [m^{-1}]
		S (Secchi Depth) =	5.47 [ft]
		Maximum lake depth =	21.98 [ft]
Model Predicted In-Lake [Chl-a]			**27.0 [ug/l]**
Observed In-Lake [Chl-a]			**29.8 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\text{a} + C_a \times [\text{Chl } a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.19 [m^{-1}]
Model Predicted In-Lake SD			**1.67 [m]**
Observed In-Lake SD			**1.48 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**766 [lb/yr]**
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**3,667 [lb/yr]**

1997 Loading Summary for Lake Margaret Basin 1

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed	42,255	6.5	22,839	62	1.0	3,834
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*42,255*	*6*	*22,839*	*61.7*		*3,833.7*
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	42,255	0	0%	0.0	0.0	0.0
2						
3						
4						
5						
Summation	*42,255*	*0*	*0%*		*0.0*	*0.0*
Inflow from Upstream Lakes						
Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1				-	1.0	
2				-	1.0	
3				-	1.0	
Summation			*0*	-		*0*
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
85	23.8	23.8	0.00	0.22	1.0	19.0
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
85	0.0		0.00	0	1.0	0
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
85	66.0			10.10	1.0	508
			Net Discharge [ac-ft/yr] = 22,839			**Net Load [lb/yr] = 4,361**

NOTES

1 Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

1997 Lake Response Modeling for Lake Margaret Basin 1

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	3.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	4,361 [lb/yr]
		Q (lake outflow) =	22,839 [ac-ft/yr]
		V (modeled lake volume) =	803 [ac-ft]
		T = V/Q =	0.04 [yr]
		P_i = W/Q =	70 [ug/l]
Model Predicted In-Lake [TP]			**45.2 [ug/l]**
Observed In-Lake [TP]			**43.4 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\mathrm{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**12.6 [ug/l]**
	$[\mathrm{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \mathrm{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	45 [ug/l]
		N (Total Nitrogen) =	1028 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	29.7 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N-150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	38.4 [ug/l]
		G (Kinematic factor) =	0.50 [--]
		F_s (Flushing Rate) =	28.46 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	6.56 [ft]
		C_a (non-algal turbity coefficient) =	0.015 [-]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - C_a \times [\mathrm{Chl}a]$	a (Non algal turbidity) =	0.23 [m^{-1}]
		S (Secchi Depth) =	5.87 [ft]
		Maximum lake depth =	25.92 [ft]
Model Predicted In-Lake [Chl-a]			**21.7 [ug/l]**
Observed In-Lake [Chl-a]			**22.0 [ug/l]**
SECCHI DEPTH			
	$SD = \dfrac{CS}{(\mathrm{a} + C_a \times [\mathrm{Chl}\ a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.23 [m^{-1}]
Model Predicted In-Lake SD			**1.79 [m]**
Observed In-Lake SD			**1.68 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**1,556** [lb/yr]
PHOSPHORUS OUTFLOW LOAD			
	$W\text{-}P_{sed}$ =		**2,805 [lb/yr]**

1998 Loading Summary for Lake Margaret Basin 1

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed	42,255	6.3	22,282	61	1.0	3,708
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*42,255*	*6*	*22,282*	*61.2*		*3,707.7*
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	42,255	0	0%	0.0	0.0	0.0
2						
3						
4						
5						
Summation	*42,255*	*0*	*0%*		*0.0*	*0.0*
Inflow from Upstream Lakes						
Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1				-	1.0	
2				-	1.0	
3				-	1.0	
Summation			*0*	-		*0*
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
85	26.9	26.9	0.00	0.24	1.0	20.4
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
85	0.0		0.00	0	1.0	0
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
85	66.0			10.10	1.0	508
			Net Discharge [ac-ft/yr] = 22,282			**Net Load [lb/yr] = 4,237**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

1998 Lake Response Modeling for Lake Margaret Basin 1

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	3.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	4,237	[lb/yr]
		Q (lake outflow) =	22,282	[ac-ft/yr]
		V (modeled lake volume) =	803	[ac-ft]
		T = V/Q =	0.04	[yr]
		P_i = W/Q =	70	[ug/l]
Model Predicted In-Lake [TP]			**44.8**	**[ug/l]**
Observed In-Lake [TP]			**38.8**	**[ug/l]**
CHLOROPHYLL-A CONCENTRATION				
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4		
		CB (Calibration factor) =	1.00	[--]
Model Predicted In-Lake [Chl-a]			**12.5**	**[ug/l]**
	$[\text{Chl}a] = \dfrac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times a)]}$	as f(TP, N, Flushing), Walker 1999, Model 1		
		CB (Calibration factor) =	1.00	
	$B_x = \dfrac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	45	[ug/l]
		N (Total Nitrogen) =	1140	[ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	30.7	[ug/l]
	$X_{pn} = \left[P^{-2} + \left(\dfrac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	39.4	[ug/l]
		G (Kinematic factor) =	0.50	[--]
		F_s (Flushing Rate) =	27.76	[year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	6.56	[ft]
	$F_s = \dfrac{Q}{V}$; $a = \dfrac{1}{SD} - C_a \times [\text{Chl}a]$	C_a (non-algal turbity coefficient) =	0.015	[-]
		a (Non algal turbidity) =	0.23	[m^{-1}]
		S (Secchi Depth) =	5.77	[ft]
		Maximum lake depth =	25.92	[ft]
Model Predicted In-Lake [Chl-a]			**22.4**	**[ug/l]**
Observed In-Lake [Chl-a]			**27.4**	**[ug/l]**
SECCHI DEPTH				
	$SD = \dfrac{CS}{(a + C_a \times [\text{Chl}\,a])}$	as f(Chla), Walker (1999)		
		CS (Calibration factor) =	1.00	[--]
		a (Non algal turbidity) =	0.23	[m^{-1}]
Model Predicted In-Lake SD			**1.76**	**[m]**
Observed In-Lake SD			**1.55**	**[m]**
PHOSPHORUS SEDIMENTATION RATE				
	$P_{sed} = C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times [TP] \times V$			
		P_{sed} (phosphorus sedimentation) =	**1,523**	**[lb/yr]**
PHOSPHORUS OUTFLOW LOAD				
	W-P_{sed} =		**2,714**	**[lb/yr]**

1999 Loading Summary for Lake Margaret Basin 1

Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas						
Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1 Watershed	42,255	7.7	27,203	62	1.0	4,552
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*42,255*	*8*	*27,203*	*61.5*		*4,552.0*
Failing Septic Systems						
Name	Area [ac]	# of Systems	Failure [%]	Load / System	[lb/ac]	[lb/yr]
1 Watershed	42,255	0	0%	0.0	0.0	0.0
2						
3						
4						
5						
Summation	*42,255*	*0*	*0%*		*0.0*	*0.0*
Inflow from Upstream Lakes						
Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1				-	1.0	
2				-	1.0	
3				-	1.0	
Summation			*0*	-		*0*
Atmosphere						
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
85	30.3	30.3	0.00	0.24	1.0	20.4
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			
Groundwater						
Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
85	0.0		0.00	0	1.0	0
Internal						
Lake Area [acre]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
85	66.0			10.10	1.0	508
			Net Discharge [ac-ft/yr] = 27,203		**Net Load [lb/yr] =**	**5,081**

NOTES

[1] Loading calibration factor used to account for special circumstances such as wetland systems, fertilizer use, or animal waste, among others, that might apply to specific loading sources.

1999 Lake Response Modeling for Lake Margaret Basin 1

Modeled Parameter	Equation	Parameters	Value [Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
	$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	3.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	5,081 [lb/yr]
		Q (lake outflow) =	27,203 [ac-ft/yr]
		V (modeled lake volume) =	803 [ac-ft]
		T = V/Q =	0.03 [yr]
		P_i = W/Q =	69 [ug/l]
Model Predicted In-Lake [TP]			**45.8 [ug/l]**
Observed In-Lake [TP]			**40.6 [ug/l]**
CHLOROPHYLL-A CONCENTRATION			
	$[\text{Chl}a] = CB \times 0.28 \times [TP]$	as f(TP), Walker 1999, Model 4	
		CB (Calibration factor) =	1.00 [--]
Model Predicted In-Lake [Chl-a]			**12.8 [ug/l]**
	$[\text{Chl}a] = \frac{CB \times B_x}{[(1 + 0.025 \times B_x \times G)(1 + G \times \text{a})]}$	as f(TP, N, Flushing), Walker 1999, Model 1	
		CB (Calibration factor) =	1.00
	$B_x = \frac{X_{pn}^{1.33}}{4.31}$	P (Total Phosphorus) =	46 [ug/l]
		N (Total Nitrogen) =	968 [ug/l]
		B_x (Nutrient-Potential Chl-a conc.) =	29.3 [ug/l]
	$X_{pn} = \left[P^{-2} + \left(\frac{N - 150}{12}\right)^{-2}\right]^{-0.5}$	X_{pn} (Composite nutrient conc.)=	38.0 [ug/l]
		G (Kinematic factor) =	0.54 [--]
		F_s (Flushing Rate) =	33.89 [year^{-1}]
	$G = Z_{mix}(0.14 + 0.0039 F_s)$	Z_{mix} (Mixing Depth) =	6.56 [ft]
		C_a (non-algal turbity coefficient) =	0.015 [-]
	$F_s = \frac{Q}{V}$; $a = \frac{1}{SD} - C_a \times [\text{Chl}a]$	a (Non algal turbidity) =	0.23 [m^{-1}]
		S (Secchi Depth) =	6.00 [ft]
		Maximum lake depth =	25.92 [ft]
Model Predicted In-Lake [Chl-a]			**21.0 [ug/l]**
Observed In-Lake [Chl-a]			**33.8 [ug/l]**
SECCHI DEPTH			
	$SD = \frac{CS}{(\text{a} + C_a \times [\text{Chl}\,a])}$	as f(Chla), Walker (1999)	
		CS (Calibration factor) =	1.00 [--]
		a (Non algal turbidity) =	0.23 [m^{-1}]
Model Predicted In-Lake SD			**1.83 [m]**
Observed In-Lake SD			**1.57 [m]**
PHOSPHORUS SEDIMENTATION RATE			
	$P_{sed} = C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times [TP] \times V$		
		P_{sed} (phosphorus sedimentation) =	**1,693** [lb/yr]
PHOSPHORUS OUTFLOW LOAD			
	W-P_{sed} =		**3,388 [lb/yr]**