Sauk Lake-North Bay Excess Nutrient TMDL

Prepared for Sauk River Watershed District

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Executive Summary

This Total Maximum Daily Load (TMDL) study addresses nutrient impairments for Sauk North Bay, DNR lake #77-0150-02, located in the Upper Mississippi River Basin in Stearns County, Minnesota. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients (in this case, total phosphorus) for deep lakes in the North Central Hardwood Forests (NCHF) ecoregion. The numeric water quality standard for Sauk Lake-North Bay is a summer average total phosphorus (TP) concentration of 40 µg/L. The water quality in Sauk Lake-North Bay currently does not meet this standard for total phosphorus. The specific sources of nutrients, target reductions from each source, and strategies to achieve the reductions are discussed in this document. The assessment relied upon analyses of flow and stream sampling (FLUX), lake modeling (BATHTUB), and regression equations developed by the MPCA.

The Sauk Lake-North Bay watershed resides in parts of four counties (Douglas, Pope, Stearns, and Todd) covering an area of 557 km^2. Of this, 359 km^2 consists of the drainage area of Lake Osakis, 145 km^2, the drainage of the reach between Lake Osakis and Sauk Lake-North Bay, and 52.7 km^2 , the drainage of Sauk Lake-North Bay proper. The outflow from Sauk Lake-North Bay goes into Sauk-Southwest Bay. The Sauk River runs through four lakes between Lake Osakis and Sauk Lake-North Bay which have an influence on the water quality and hydrograph shape of the river entering Sauk Lake-North Bay.

The sub-watersheds of Sauk Lake-North Bay are dominated by agricultural use; primarily corn, soybeans, alfalfa, pasture and animal husbandry.

Sauk Lake-North Bay is eutrophic with external and internal loads contributing phosphorus loads to the lake. The external TP loading from the Sauk River represents 64 percent of the load, the internal loading represents 18 percent, and the remaining 18 percent is from atmospheric deposition, groundwater, local watershed runoff, and stormwater.

The total phosphorus loading to Sauk Lake-North Bay will need to be reduced by 36 percent to achieve the lake water quality goal of 38µg/l (reduced from the standard of 40mg/l to accommodate a margin of safety). This reduction is attained by reducing contributions from internal loading, local watershed runoff, and the main tributary, Sauk River.

Table 1. TMDL Summary

EPA/MPCA Required Elements	Summary		TMDL Page #
Location	The Sauk Lake-North Bay watershed is located primarily in Stearns County and discharges to the main-stem of the Sauk River. The Sauk River is in the Upper Mississippi River Basin.		4
303(d) Listing Information	Sauk Lake-North Bay, DNR# 77-0150-02, was added to the 303(d) list in 2004 because of excessive Nutrients		4
Applicable Water Quality Standards/ Numeric Targets	The numerical standard for Sauk Lake-North Bay is: Deep Lake Std TP <40 ug/l		5
Loading Capacity (expressed as daily load)	The loading capacity is the total maximum daily load.		
	Lake	**Total maximum daily TP load (kg/day)**	
	Sauk Lake-North Bay	22.2	28
Wasteload Allocation	Portion of the loading capacity allocated to existing and future permitted sources		
	Source and Permit #	**Load Allocation (kg/day)**	
	Sauk Lake-North Bay permitted point sources	0	
	Construction Stormwater Industrial Stormwater	0.04	27
Load Allocation	The portion of the loading capacity allocated to existing and future non-permitted sources		
	Source	**Load Allocation (kg/day)**	27
	internal	.82	27
	Atmospheric	0.19	27
	groundwater	.32	27
	Sauk River	17.1	27
	Local watershed	2.3	27
Margin of Safety	Margin of Safety	1.48	28

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.	28
Reserve Capacity	In accordance with protocol, 1% of the total capacity is allocated for both construction stormwater and industrial stormwater. There is no explicit allocation for unpermitted sources.	29
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.	30
Reasonable Assurance	Reasonable assurance is provided by implementing the TMDL through the Sauk River Watershed District Watershed Management Plan and the Stearns County Comprehensive Local Water Management Plan	33
Monitoring	The Sauk River Watershed District currently performs physical and chemical monitoring of these streams and will continue to do so throughout the implementation period. The district will also track the implementation of Best Management Practices and capital projects throughout this watershed on an annual basis.	35
Public Participation	The Sauk River Watershed District held a public meeting December, 2008 and will conduct two future stakeholder meetings upon completion of this report to update stakeholders. The District has also kept stakeholders updated through their annual newsletter, monthly District meetings, and website.	36

Introduction

Purpose

The goal of this study is to quantify the pollutant reductions needed to meet the water quality standards for excessive nutrients (total phosphorus) in Sauk Lake-North Bay. The Sauk Lake-North Bay Nutrient TMDL will be established in accordance with section 303(d) of the Clean Water Act, because the State of Minnesota has determined that waters in Sauk Lake-North Bay exceed the State-established standards for nutrients.

Problem identification

Sauk Lake-North Bay is a lake with a river running through it (Sauk River), located within the Sauk River watershed, downstream of Lake Osakis, and upstream of the town of Sauk Centre in Todd County, Minnesota. The lake flows into Sauk-Southwest Bay which outflows at the dam in Sauk (see

).

Sauk Lake (DNR Lake #77-0150-00) was first placed on the State of Minnesota's 303(d) list of impaired waters in 2004 after being identified as impaired due to excessive nutrients. In 2008, after lake assessments conducted by the MPCA, Sauk Lake was separated into two segments due to differing characteristics: the Sauk Lake-North Bay (DNR Lake #77-0150-02) and Sauk-Southwest Bay (DNR Lake #77-0150-01). Sauk Lake-North Bay is a 688 hectare(1660 acres) lake, 19 meters at its deepest point, and meets the criteria to be defined as a deepwater lake in the NCHF ecoregion. After the 2008 assessment, Sauk Lake-North Bay was identified as impaired for aquatic recreation due to excessive nutrients (total phosphorus) as set forth in Minnesota Rules 7050.0150. This water body impairment is summarized in Table 2.

Figure 1. Watershed map

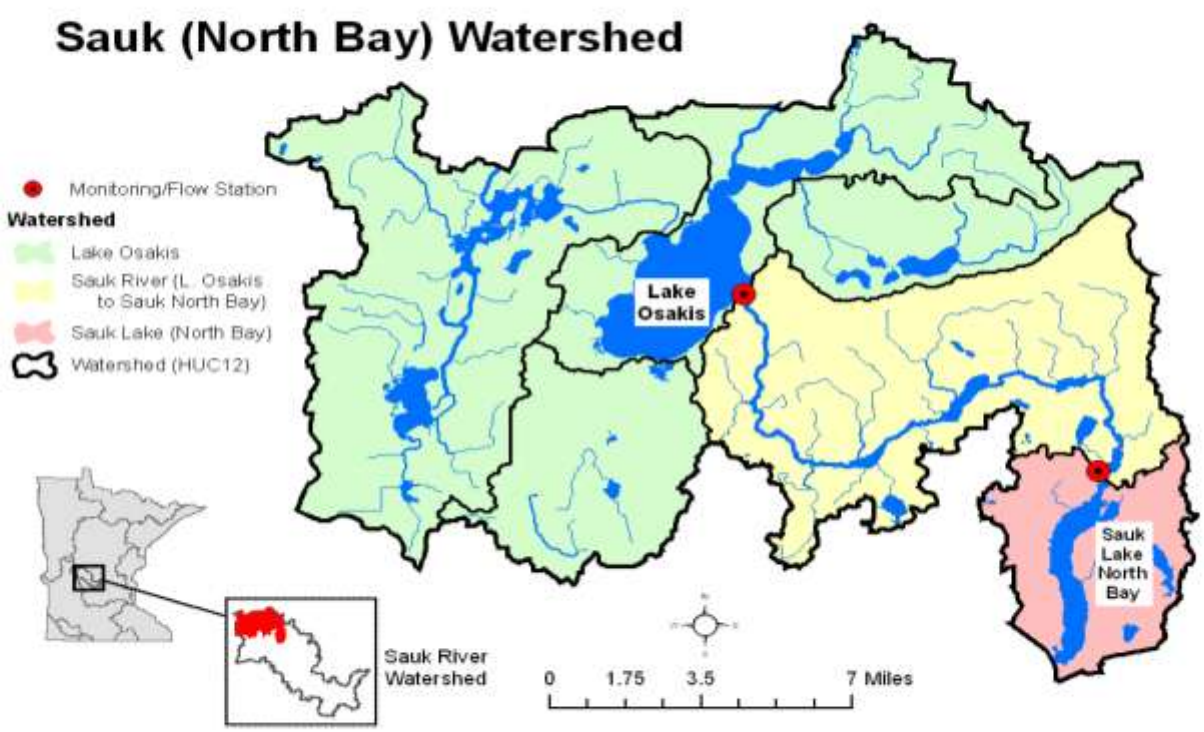


Table 2. Impaired waterbody

Lake/Reach	DNR Lake ID	Affected use	Pollutant or Stressor
Sauk Lake-North Bay	77-0150-02	Aquatic recreation	excessive nutrients (total phosphorus)

Target Identification and Determination of Endpoints

Minnesota water quality standards and endpoints

The MPCA has established numerical thresholds based on ecoregion for determination of Minnesota lakes as either impaired or unimpaired. The protected beneficial use for all lakes is aquatic recreation (swimming). Table 3 summarizes the MPCA water quality standards for lakes in the NCHF ecoregion. In 2008, these goals were used to determine that Sauk Lake-North Bay should be placed on the 303(d) list of impaired waters in Minnesota.

Table 3. MPCA Goals for Protecting Class 2B Waters Values are Summer Averages (June- September)

	North Central Hardwood Forest Ecoregion[1]
Parameters	**Deep lakes[2]**
Total Phosphorus (µg/L)	40
Chlorophyll-a (µg/L)	13
Secchi Depth (m)	>1.5

Watershed and Lake Characterization

Sauk Lake-North Bay Watershed

Sauk Lake-North bay is a 688 hectare lake located in the upper part of the Sauk River watershed (Figure 1), northeast of the town of Sauk Centre in Todd County Minnesota. The lake has an average depth of 5.8m and is 19m at its deepest point. Table 4, shows the morphometric characteristics of Sauk Lake-North bay.

[1] Values are Summer Averages (June 1 through September 30)

[2] Deep lakes are defined as lakes with a maximum depth of more than 15 ft, and with less than 80% of the lake shallow enough to support emergent and submerged rooted aquatic plants (littoral zone).

Table 4. Sauk Lake-North Bay Morphometric Characteristics

Parameter	Unit	Sauk Lake-North Bay
Lake Area	hectares(acres)	688.4(1,701)
Average Depth	m(ft)	5.8(19)
Maximum Depth	m(ft)	18.6(61)
Lake Volume	hm^3(acre-feet)	39.9(32,319)
Residence Time	Days	131
Watershed Area, excluding lake	hectares(acres)	55,000(135,895)
Lake: Watershed Area Ratio		1:80

The Sauk Lake-North Bay watershed covers parts of four counties (Douglas, Pope, Stearns, and Todd) encompassing an area of about 557 km^2, of which 359 km^2 consists of the drainage area of Lake Osakis. The remaining area is the drainage area of the Sauk River between Lake Osakis and Sauk Lake-North Bay (145 km^2), and the local watershed of Sauk Lake-North Bay (53 km^2). The main tributary for Sauk Lake-North Bay is the Sauk River. There are no other significant tributaries to Sauk Lake-North Bay. Outflow from Sauk Lake-North Bay goes into Sauk-Southwest Bay. Watershed areas are shown in Table 5.

Table 5. Sauk Lake-North Bay watershed areas, hectares (acres)

Lake Osakis watershed, lake portion is 26.7(6589)	359(88723)
Sauk River watershed, Lake Osakis to Sauk Lake-North Bay	145(35885)
Sauk Lake-North Bay local watershed, lake portion is 6.88(1701)	52.7(12988)
Entire watershed to Sauk Lake-North Bay outlet	557(137596)

Land use

Land use for the Sauk Lake-North Bay watershed is presented in Table 6. The land use is primarily tilled agriculture. Including pasture and grasslands, agriculture accounts for 71 percent of the land use in the watershed. Wetlands and forest comprise 15 percent, lakes 8 percent, developed areas less than 1 percent. The lake is moderately developed with 377 homes within 100 meters of Sauk Lake-North Bay.

Table 6. Land Use in Sauk Lake-North Bay Watershed Table 5, Land Use in Sauk Lake-North Bay Watershed

Class (NLCD 2006)	Sq Meters	Acres
OPEN_WATER	47572200	11755.35
DEVELOPED__OPEN_SPACE	24755400	6117.19
DEVELOPED__LOW_INTENSITY	3347100	827.09
DEVELOPED__MEDIUM_INTENSITY	351900	86.96
DEVELOPED__HIGH_INTENSITY	91800	22.68
BARREN_LAND__ROCK	51300	12.68
DECIDUOUS_FOREST	49232700	12165.67
EVERGREEN_FOREST	1384200	342.04
MIXED_FOREST	38700	9.56
SHRUB_SCRUB	116100	28.69
GRASSLAND_HERBACEOUS	15717600	3883.90
PASTURE_HAY	143978400	35577.84
CULTIVATED_CROPS	236492100	58438.47
WOODY_WETLAND	2110500	521.52
EMERGENT_HERBACE	31602600	7809.17

Geology and soils

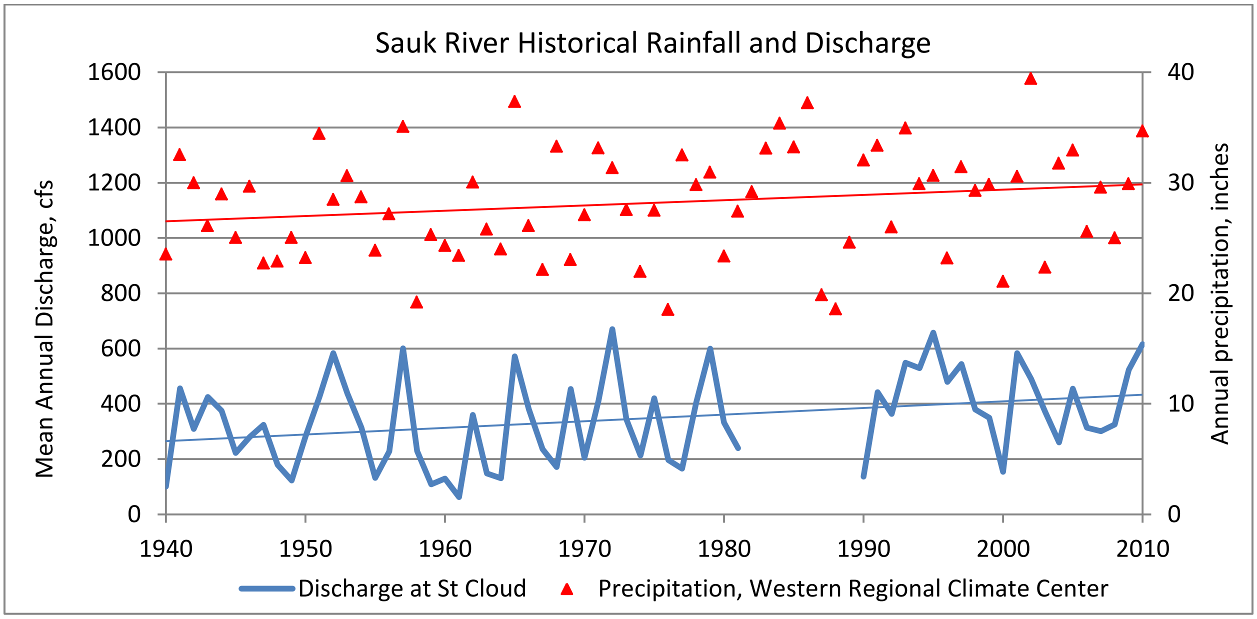
The SRWD contains a variety of soil types and geologic features due in part to the large size of the District, as well as the glacial activity which occurred to form the area. The Sauk River flows in an interglacial stream that was created by a bed of glacial outwash.

The Sauk River Watershed lies in the central portion of Minnesota's North Central Hardwood Forest (NCHF) Ecoregion (Omernik, 1988). The NCHF is dominated by glacial sediments deposited by the Des Moines Lobe of the Wisconsin glaciation approximately 12,000 years ago. Glacial till and drift dominate the landscape with outwash deposits in much of the river valley. Outwash deposits are predominately sand and gravel. Soils are classified as Mollisols and Alfisols. Till and drift contain high clay and silt fractions. The soils of the watershed are sandy or loamy, and underlie a level-to-rolling savannah consisting of prairie grass and oak openings. Many of the soil associations within the watershed are poorly drained and result in numerous wetland areas.

Precipitation and runoff

Precipitation data is maintained by the Minnesota Climatology Network using a network of volunteers who monitor rainfall in various locations throughout the district. Since 1909, the USGS has maintained a flow gaging station on the Sauk River in Waite Park near the river mouth. Figure 2 shows annual rainfall and runoff from 1940 to 2008. Both annual rainfall and mean discharge show increasing trends over this 68 year period. During this period, the annual precipitation has ranged from 18.5 to 39.5 inches per year, with an average of 28.0 inches per year. The mean annual discharge has ranged from 62 to 670 cfs, with an average of 339 cfs. During the study period, 2002-2007, the precipitation averaged 30.3 inches and ranged from 39.4 inches in 2002 to 22.4 inches in 2003. The mean annual discharge ranged from 260 to 489 cfs with an average of 365 cfs.

Figure 2. Sauk River Historical Rainfall and Discharge



Historical water quality data

The earliest water quality samples taken in Sauk Lake-North Bay consist of a Secchi depth disc measurement in 1948, a temperature-dissolved oxygen profile in 1972, and, in 1980, a temperature-dissolved oxygen profile along with nutrient analysis. Secchi depth data has been collected in each year from 1987-2009, except for 1992 and 1996. In seven of these years (1987-1988, 1993-1995, and 2007-2008), temperature-dissolved oxygen profiles were conducted. Nutrient analysis was done for the years 1989-1990, 1995, 2001 and 2002-2007. Table 7 summarizes summer means for total phosphorus, chlorophyll-a, and Secchi depth for the period 1948-2007. Figures 3-6 show summer means for total phosphorus, chlorophyll-a, and Secchi depth. As shown by Figure 3, there is insufficient Secchi depth data prior to 1987 to enable trend detection since the onset of monitoring in 1948. Figure 4is a graph of Secchi depth for the period 1987-2007 which includes 271 measurements. This plot strongly suggests that there has been no significant change in transparency since 1987.

Table 7. Water Quality data for Sauk Lake-North Bay

	Total Phosphorus		Chlorophyll-a		Secchi	
	n	mg/l	n	mg/l	n	m
1948					1.0	1.07
1972					1.0	1.16
1980	2.000	0.096	2.0	76.0	2.00	1.00
1987					17	1.32
1988					3	1.88
1989	5.000	0.080	5.0	49.9	5.00	2.39
1990	8.000	0.090	6.0	76.3	7.00	1.70
1991					15.00	1.46
1993					15.00	1.71
1994					15.00	1.25
1995	4.000	0.069	4.0	42.9	4.00	1.43
1997					16.00	1.56
1998					15.00	1.43
1999					14.00	1.42
2000					14.00	1.70
2001	5.000	0.065			17.00	1.33
2002	5.000	0.081	2.0	36.0	17.00	1.60
2003	2.000	0.094	2.0	68.0	20.00	1.77
2004	4.000	0.043	4.0	38.9	22.00	1.84
2005	7.000	0.041	7.0	30.1	18.00	2.23
2006	8.000	0.044	8.0	42.8	19.00	1.83
2007	9.000	0.061	8.0	45.4	18.00	1.07

Figure 3. Sauk Lake-North Bay, Secchi Depth, 1948-2008

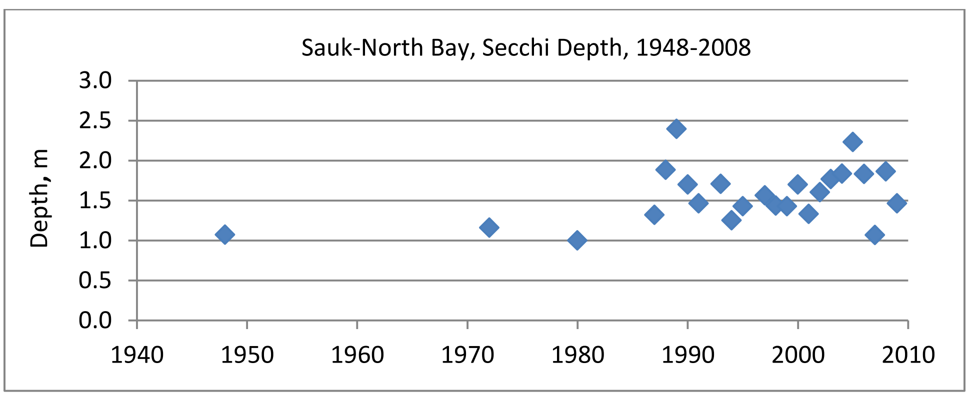


Figure 4. Secchi depth

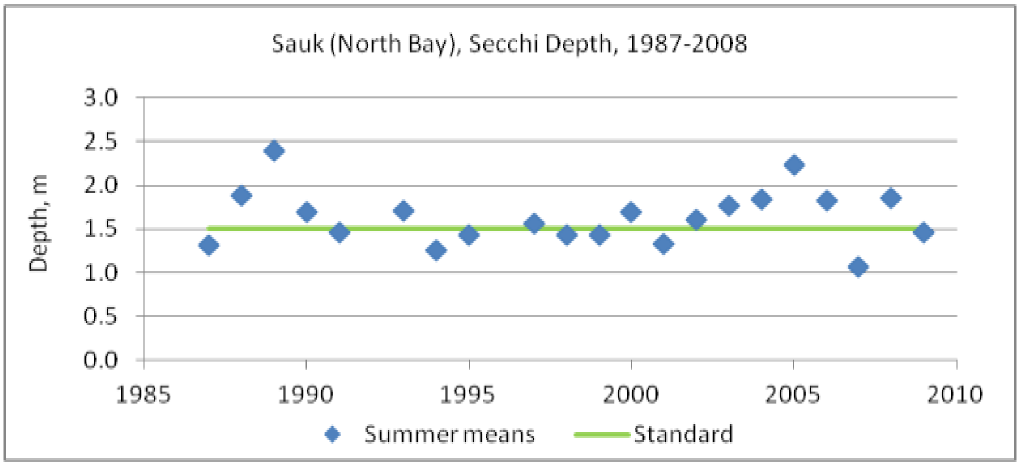


Figure 5. Total phosphorus

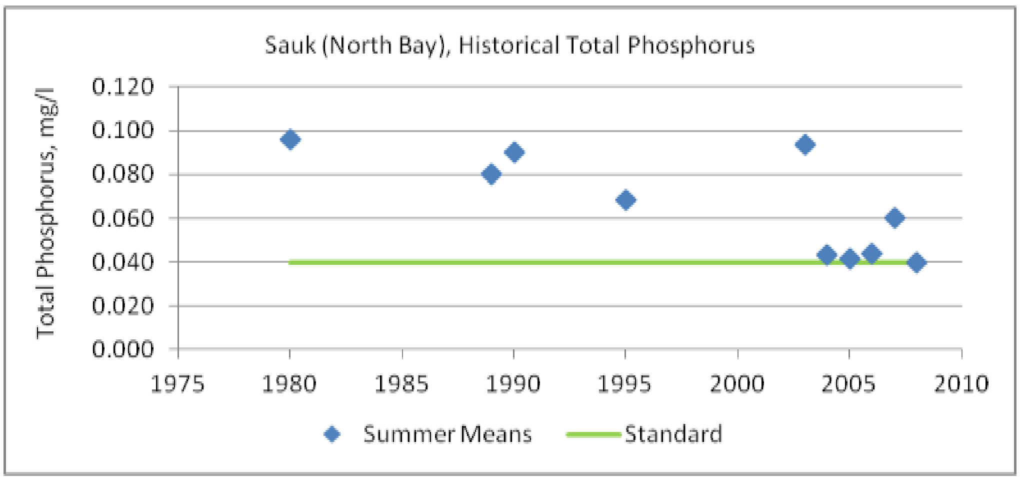


Figure 6. Chlorophyll-a

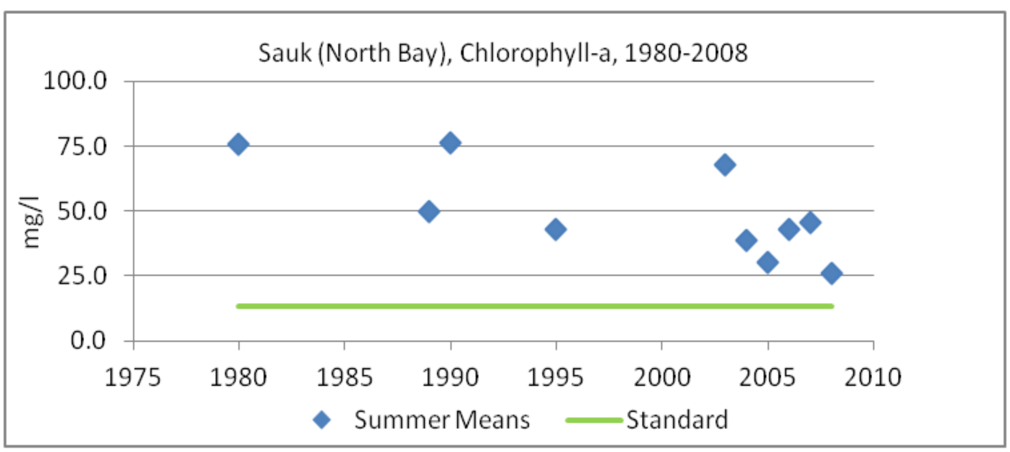


Figure 5 shows results of total phosphorus measurements (all lake sampling sites) since 1980. The low number of measurements prior to 2003 prevents a rigorous assessment. However it appears there may be a decreasing trend in total phosphorus over the period from the 1980's to the present. A similar result for chlorophyll-a is shown in Figure 6.

The years with the most complete data sets are the years 1989-1990 and 2002-2007. Figure 7- Figure 9 show summer means for total phosphorus, chlorophyll-a, and Secchi depth for the period 2002-2007 (includes only data from lake sites 77-0150-02-205 and 77-0150-02-207). For that period, the water quality standards are consistently exceeded for the months of July-September, while the water quality is generally good in June. The major external source of phosphorus to the lake is the Sauk River, which contributes most of its highest loads during spring runoff. Reduced contributions from the Sauk River during the summer along with the consistently increasing values for in-lake total phosphorus from June through September, suggests that there is significant internal loading from lake sediments. The presence of internal loading is supported by sediment analysis and modeling referred to later in this report (p18, 23-27).

Figure 7. Water Quality means for Sauk Lake-North Bay, 2002-2007, (June – September)

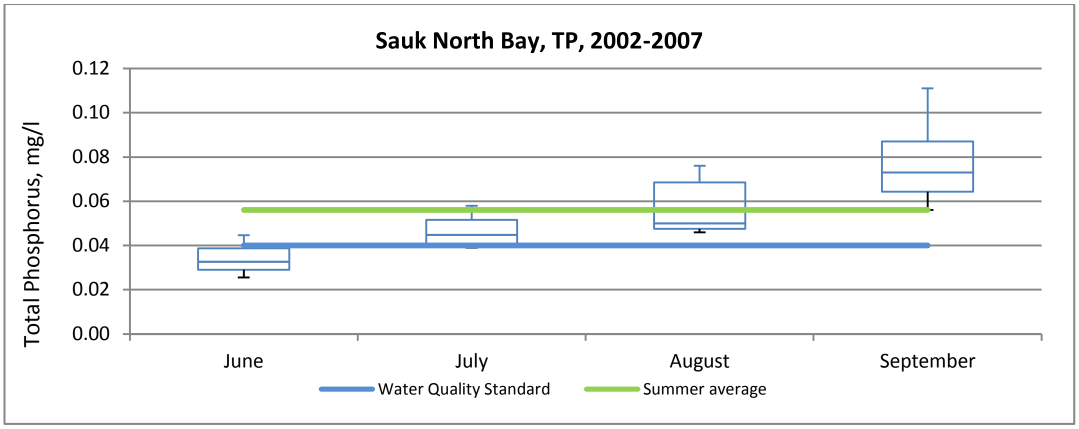


Figure 8. Water Quality means for Sauk Lake-North Bay, 2002-2007, (June – September)

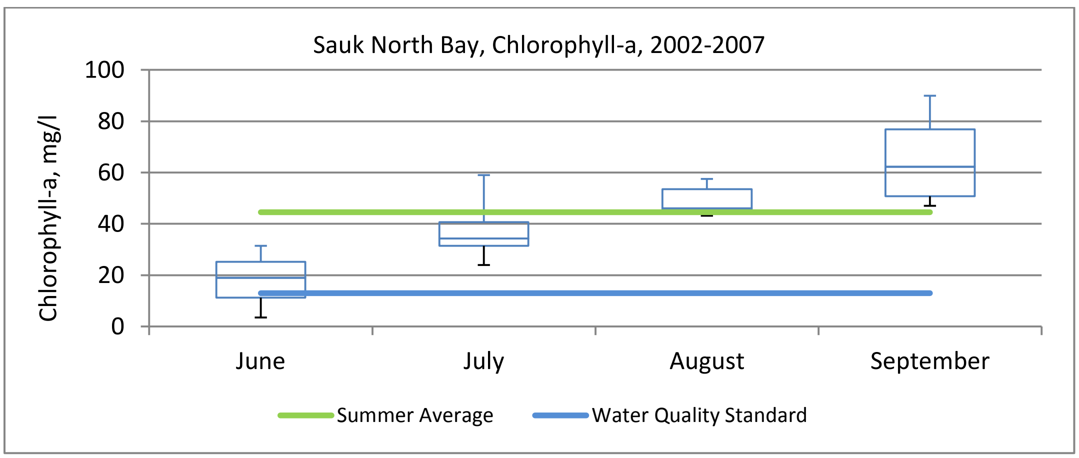
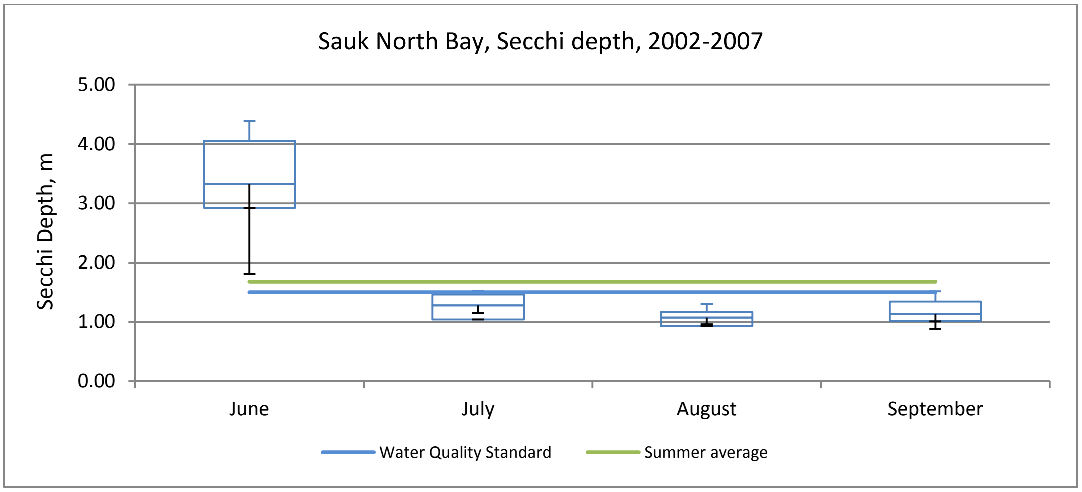


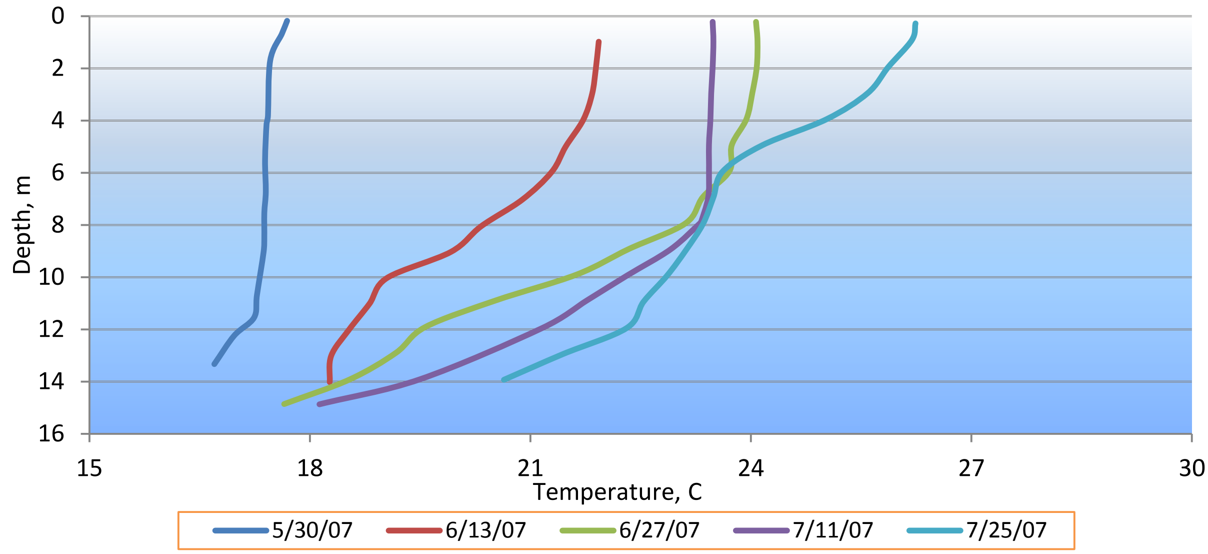
Figure 9. Sauk Lake-North Bay, Secchi depth, 2002-2007



Temperature and dissolved oxygen

Figure 10-Figure 11show temperature and dissolved oxygen profiles for the summer of 2007. The profiles show that, in 2007, thermal stratification began in early-mid June and persisted until early August, with a distinct thermocline at 8-10 meters depth. During this period, the dissolved oxygen levels are near zero at depths below 11-12 meters. From mid-July to early September, the temperature is above 20 degrees C throughout the column. On August 22, there is a significant change, indicating that mixing of the vertical column occurred. With the long fetch of the lake and exposure to westerly winds, this likely occurs on a regular basis in July and August. Mixing of the vertical column will introduce phosphorus that is released from bottom sediments during anoxic conditions to the epilimnion, possibly resulting in algae blooms. In early September, the profiles are stratified to a lesser degree than in July and then, by mid-September the thermocline is absent.

Figure 10. Temperature and dissolved oxygen profile



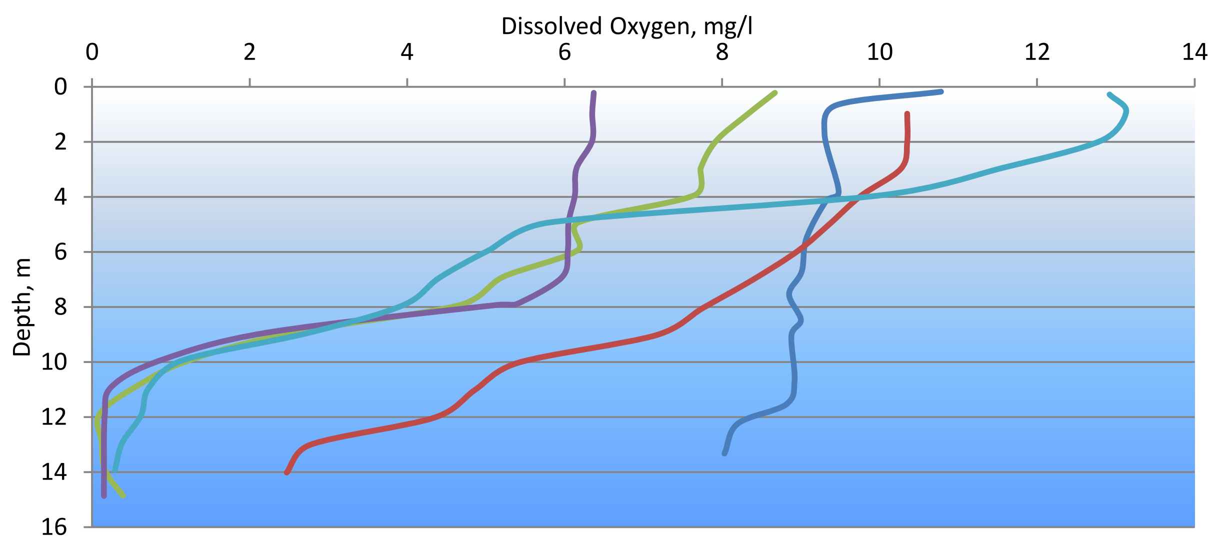
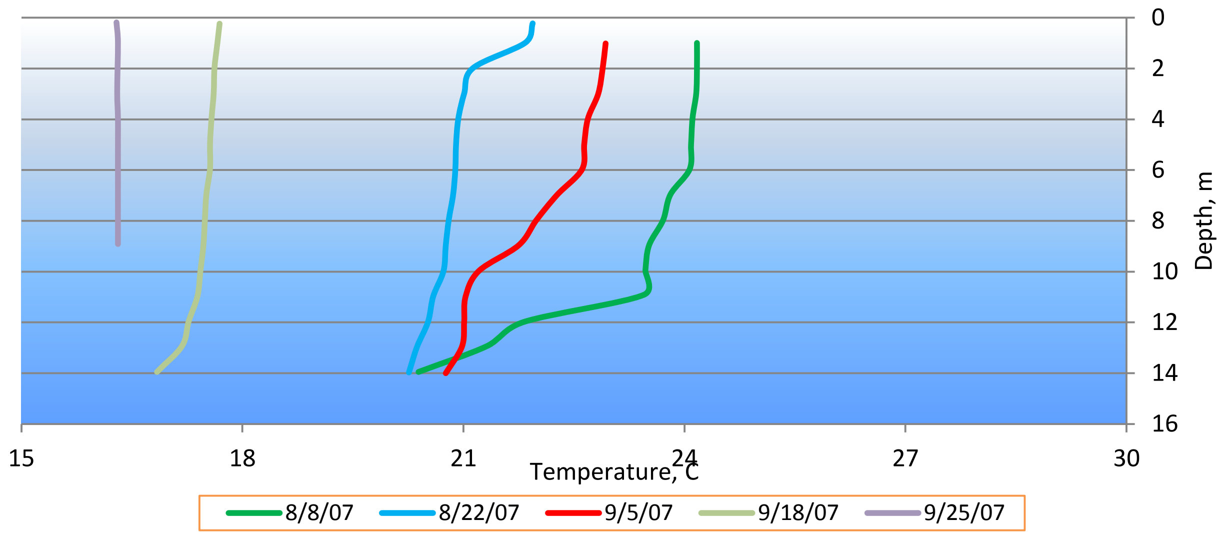
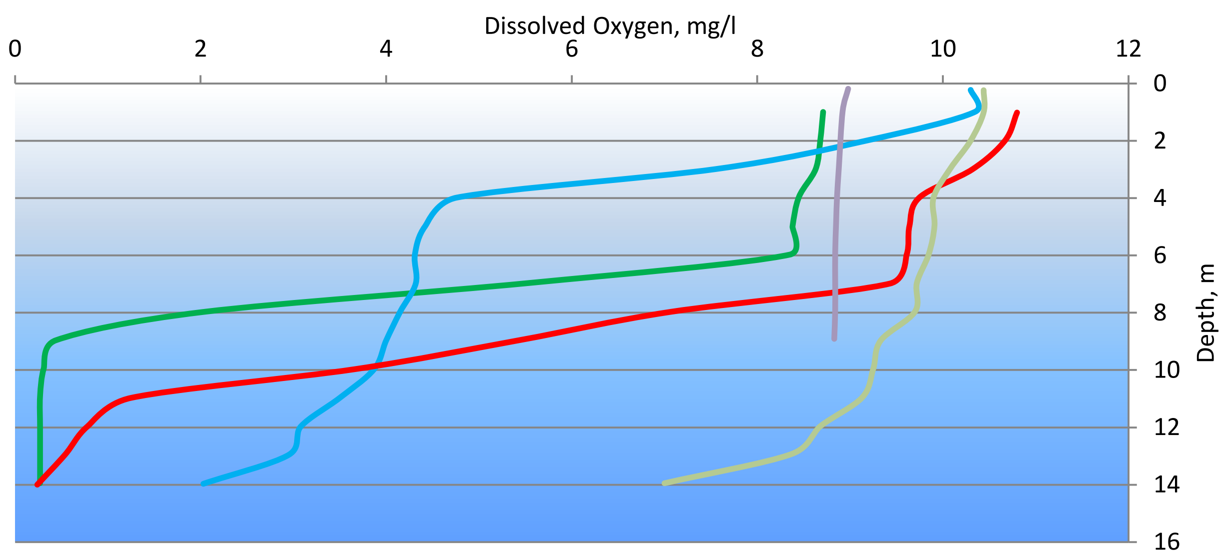


Figure 11. Temperature and dissolved oxygen profile

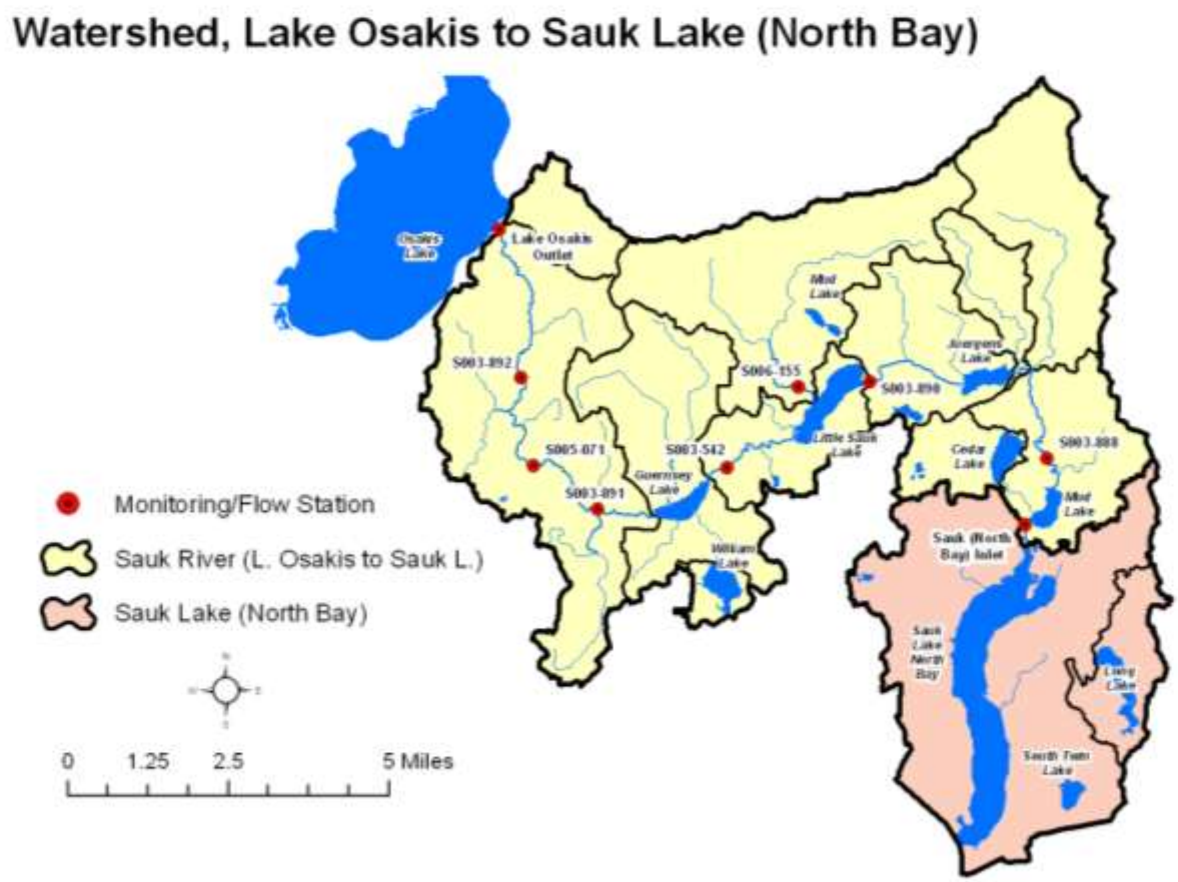




Tributary monitoring

Sauk River, which is the only significant tributary to Sauk North Bay, originates at the outlet of Lake Osakis and meanders for approximately 29 river km through predominantly agricultural areas before flowing into Sauk Lake-North Bay. Along this 29 km stretch (see Figure 12) are 4 in-river lakes ranging in size from 20-130 hectares. All four lakes are shallow, eutrophic, and designated as impaired for aquatic use.

Figure 12. Watershed map



On the Sauk River, continuous discharge data and water quality data has been collected during most years since 2001, both at the outlet of Lake Osakis and at the inlet of Sauk North Bay.

Mud Lake is 1 km upstream of Sauk Lake-North Bay and 0.2 km upstream of the monitoring site referred to as Sauk Lake-North Bay inlet. This proximity to Mud Lake means that the major inflow to Sauk Lake-North Bay is essentially outflow from an upstream lake, albeit a small lake (20 hectares), which will have a buffering effect on inflow hydrology and water quality to Sauk Lake-North Bay. The 0.2 km stretch between the inlet gaging site and entry to Sauk Lake-North Bay proper has little gradient, and contains extensive cattail marshes along its banks (comm. with SRWD, 2011).

Figure 13, shows total phosphorus concentrations at Sauk Lake-North Bay inlet by month for the period 2002-2007. With the exception of one event sample in July of 2003, all high concentrations occurred during the spring. Figure 14 is a plot of total phosphorus versus discharge for the same period. This plot shows a consistent positive correlation between concentration and discharge, suggesting that sources are of nonpoint origin. The relative weakness of the correlation provides more evidence that Mud Lake is capturing some of the phosphorus that is transported from the watershed.

Figure 13. Sauk River, inlet to Sauk Lake-North Bay, TP by Month

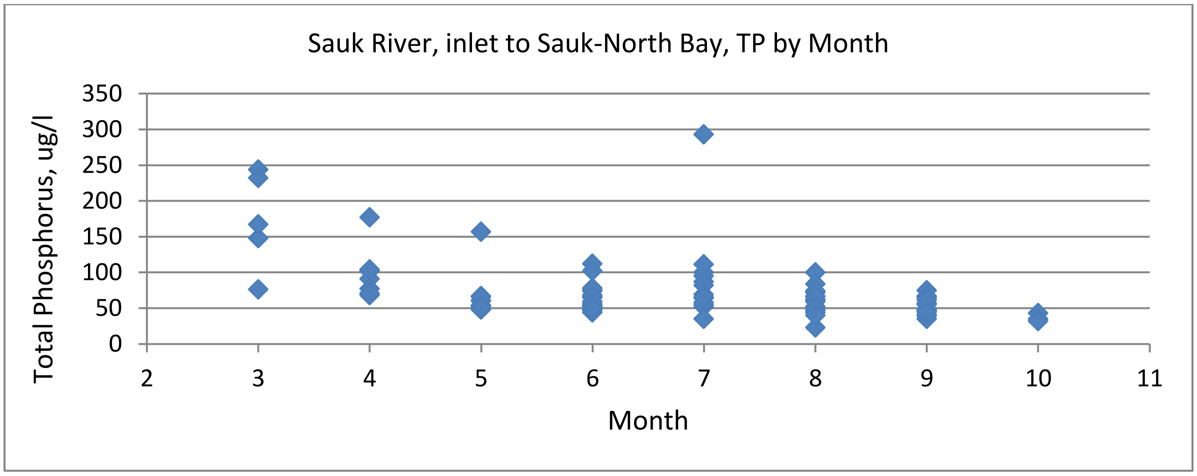
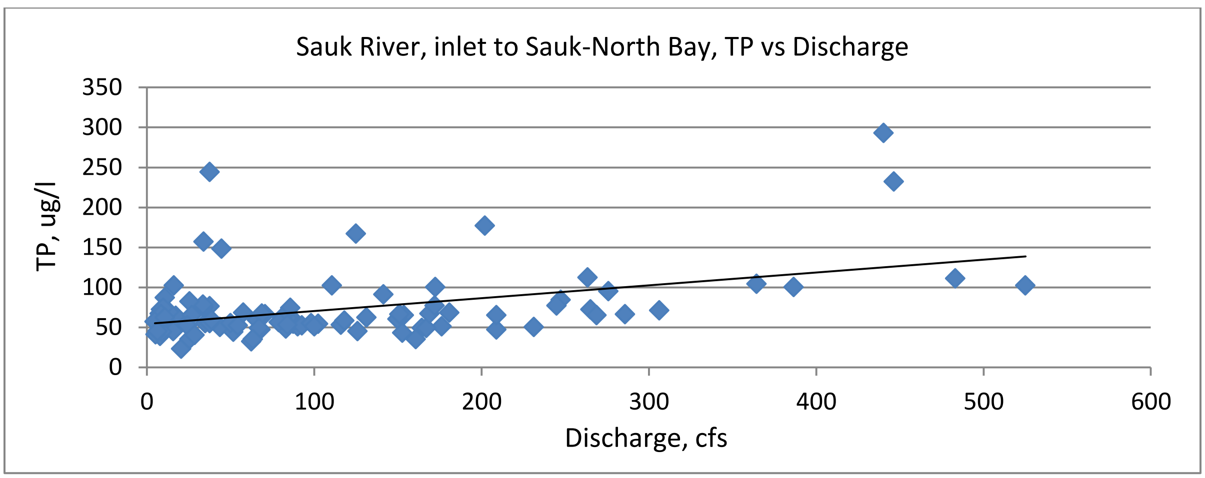


Figure 14. Sauk River, inlet to Sauk Lake-North Bay, TP vs Discharge



Nutrient source assessment

Introduction

Quantifying the sources of nutrients to a lake is a necessary component in developing a TMDL for lake nutrients. This section contains a description of the sources of phosphorus to Sauk Lake-North Bay and the estimated loadings for each source.

Point Sources

There are no permitted industrial, or wastewater effluent sources in the Sauk Lake-North Bay watershed. To comply with established TMDL protocols, 0.1 percent of the total watershed load will be assigned to both industrial stormwater and construction stormwater.

Atmospheric deposition

Precipitation contains phosphorus that can ultimately end up in the lakes as a result of direct input on the lake surface, or as a part of storm water running off of impervious surfaces in the watershed. Although atmospheric inputs must be accounted for in development of a nutrient budget, direct inputs to the lake surface are impossible to control. For use in this analysis, an atmospheric loading rate of 30 kg/km2/yr is assumed, which corresponds well to the average value suggested in the BATHTUB lake response model (Walker, 1996). Using this loading rate, Sauk Lake-North Bay receives 69 kg of total phosphorus from atmospheric deposition during the June to September period.

Internal Loading

Internal loading refers to the recycling and re-suspension into the water column of phosphorus contained in lake bed sediments and organic matter. As shown in Figure 7, the increasing amount of TP in the lake epilimnion from June to September suggests that a significant amount of internal loading is occurring. In 2007 Barr Engineering Company conducted a study (Barr, 2007) to determine the amount of phosphorus loading being contributed to the water column by release from bottom sediments during anoxic conditions. They collected twenty two sediment cores in Sauk Lake (north and southwest bays) to determine the spatial distribution of phosphorus in the lake bottom sediments. Each 30 cm core was analyzed to determine the vertical distribution of phosphorus in the sediment. The analysis produced a range of loading rates from a low of 6.2 $mg/m^2/day$ to a maximum potential loading rate of 8 $mg/m^2/day$. Applying the midpoint of this range in the Nürnberg equation (1985) yields:

$(7.1 mg/m^2/day)*(2{,}683{,}000 m^2)*(122\ days/yr)/(1e6\ mg/kg) = 2{,}324\ kg/yr$, rounding off to 2,300 kg/yr.

This result represents the internal load from sediment release, where 2,683,000m^2 is the 39% portion of the lake which is deeper than 20ft. This value will be used as a guide when selecting a rate of internal loading in the lake response model.

Groundwater

The Minnesota Pollution Control Agency (MPCA) conducts ambient ground water monitoring to enable assessment of the groundwater quality. Data downloaded from the MPCA archive showed that the surficial aquifer in the Sauk Lake area had a total phosphorus concentration of 76 µg/l.

Bonestroo, (2004) used the Modular Three-Dimensional Finite Difference Groundwater Flow Model (MODFLOW) to delineate the City of Sauk Centre wellhead protection areas. It was determined that Sauk Lake-North Bay is a local sink for the surficial aquifer. Djerrari (2009) used these results to estimate groundwater flows and phosphorus loading from the surficial aquifer into the lake (see Table 8). The estimated value for total phosphorus loading to the lake from the surficial aquifer is 116 kg/yr.

Table 8. TP loading to the Sauk Lake-North Bay from groundwater, Djerrari (2009)

	North Bay	Units
Phosphorus Concentration (mg/l)	0.076	mg/l
Flow to Lake	1.528	hm^3/yr
Phosphorus Load (Kg/yr)	116	Kg/yr

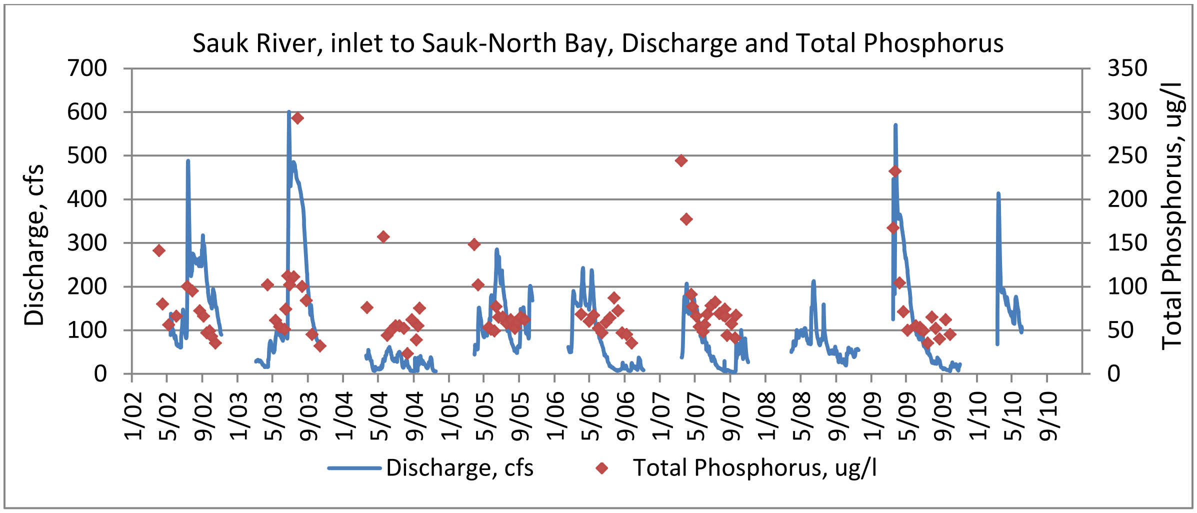
Septic Systems

There are 377 septic systems within 300 feet of Sauk Lake-North Bay. During the mid-1990's, a septic system survey was done under contract with SRWD. It was found that 70% of the septic systems around Sauk Lake were out of compliance. Currently, all lake shore properties within the city of Sauk Centre are hooked up to a sewer system. The lake shore septic systems in Stearns County and Todd County that are not within city boundaries that were failing at the time of the survey have since been brought into compliance (comm. with SRWD, Todd SWCD, Stearns County Environmental Services, May, 2012). Thus, these septic systems do not appear to be a source of nutrients to the lake. By law, septic systems cannot discharge to surface waters; hence, for this TMDL, septic systems are assigned an allowable load of zero kilograms per year.

Tributaries

There are two monitoring stations on the Sauk River upstream of Sauk Lake-North Bay; at the outlet of Lake Osakis and at the inlet to Sauk Lake-North Bay (Figure 12), which have been operated by the Sauk River Watershed District. Continuous-stage data has been collected at the Lake Osakis outlet site since 2004 and at Sauk Lake-North Bay inlet since 2002. Flow measurements have been made 8-12 times per year at each site. The MPCA, using the time series data management software HYDSTRA, has constructed rating curves and converted the stage data into discharge rates. Figure 15 shows the resultant hydrograph for the Sauk Lake-North Bay inlet site, for 2002-2009, along with total phosphorus concentrations from samples taken at the same site.

Figure 15. Discharge and total phosphorus concentrations at Sauk Lake-North Bay inlet, 2002-2007.



Local watershed

To estimate overland phosphorus transport from the local watershed of Sauk Lake-North Bay, an export coefficient needed to be derived. To do this, an export coefficient for the Sauk River watershed from Lake Osakis to Sauk Lake-North Bay was computed, using available data, and then applied to the local watershed. The average load (for the years 2002-2007) at the inlet to Sauk Lake-North Bay was 8008 kg/yr. Using an area of 14,523 hectare, the export coefficient is 0.45 kg/ha. This compares to values of 0.39 kg/ha for average years reported by Mulla, et al (2003). Using an export coefficient of 0.45 kg/ha and the local watershed area of Sauk Lake-North Bay of 4,570 hectares, the overland phosphorus transport from the local watershed computes to 2060 kg/yr.

Linking water quality targets and sources

Introduction

To assess the linkages between nutrient sources and lake responses, BATHTUB (Walker, 1996) was used to estimate the lake response to external loading sources. BATHTUB is a steady state annual or seasonal model that predicts summer mean epilimnion water quality. BATHTUB uses a mass balance approach to predict nutrient concentrations given water quantity and quality inputs from tributaries, watershed runoff, groundwater and atmospheric sources, and observed lake water quality.

Model options, setup and calibration

The data set for the lake averaged less than six samples per June-September period. This does not supply adequate information to model individual years for the purpose of comparing year by year results. It was determined that the best approach would be to average all the data for the years 2002-2007 (June-September) and input those results as lake parameter observations. The river input was obtained by using the model FLUX (Walker, 1983) to estimate the annual flow weighted mean concentration (FWMC) using all the data from the same period of years.

Lake bathymetry parameters for a one segment model were constructed manually using a map from the MN DNR LakeFinder database. See appendix C for map of lake details. Model options were entered as shown in Table 9. For total phosphorus, the Canfield Bachman Lakes model was used. Nitrogen was not simulated because phosphorus is the nutrient of concern. For Chlorophyll-a, the P-linear model was used and for transparency, the "transparency versus total Phosphorus" model was used. The use of availability factors was not required, and estimated concentrations were used to generate mass balance tables.

Table 9. BATHTUB Model Options for Sauk Lake

MODEL	MODEL OPTION
Conservative substance	Computed
Total phosphorus	Canfield Bachman Lakes
Total nitrogen	Not computed
Chlorophyll-a	04 P-Linear
Transparency	03 vs Total P
Longitudinal dispersion	Fischer-Numeric
Phosphorus calibration	Decay Rates
Nitrogen calibration	Decay Rates
Error analysis	Model and Data
Availability factors	Ignore
Mass-balance tables	Use estimated concentrations

For the initial model run, default values were used for global variables, model coefficients, calibration factors, and no internal load was assumed. The predicted values for total phosphorus were lower than observed, an unsurprising result since internal loading was not included. To account for internal loading a loading rate was selected that resulted in a total internal load (2312 kg/yr) close to the value computed using the Nürnberg equation (2324 kg/yr) (refer to section on internal loading under Nutrient Source Assessment).

With the internal loading added, the model predicted a lake epilimnion phosphorus concentration of 62 ppb versus the observed value of 57 ppb. A calibration factor of 1.2 was applied to refine the prediction for total phosphorus.

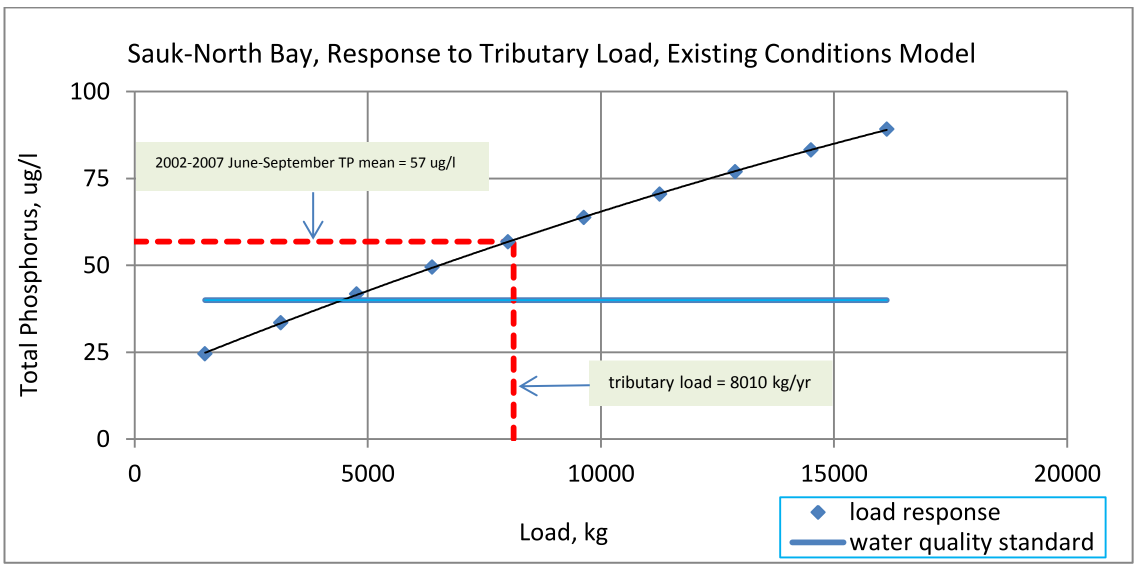
Results

Model results are presented in **Table 10**, along with observed values and coefficients of variation (standard error of the mean). Diagnostics provided by the model are included in Appendix A. The coefficients of variation, which represent uncertainty in the model predictions, are reasonable (and typical for less-than-robust data sets). **Figure 16** shows a plot of the predicted lake response to varying amounts of tributary loading, holding all loads from other sources at constant values.

Table 10. Observed and Predicted Water Quality for Sauk North Bay, 2002-2007 (June September)

Segment	Parameter	Predicted		Observed
		Mean	Coefficient of Variation	Mean
North Sauk Lake	Total Phosphorus (µg/L)	57	0.22	57

Figure 16. Sauk Lake-North Bay, lake response to tributary load, existing conditions model



After the BATHTUB model was set up and calibrated for existing conditions, the next step was to select scenarios that would enable developing a TMDL for the lake, and also provide insight on possible future approaches. For the base model and background model, the lake water quality standard for TP of 40 µg/l was used as the TP concentration to achieve. For the TMDL, alternative 1 and alternative 2 models, the TP concentration to achieve was set at 38µg/l (a 5% reduction) to accommodate a margin of safety. Except for the background model, the calibration factor for total phosphorus was kept at the calibrated value. To develop the base model (no margin of safety) and TMDL model (including margin of safety) the tributary (Sauk River) concentration was held at 60 µg/l, which was considered a practical attainable concentration for the river (0.9 miles downstream of a shallow lake).

The results for the base model, assigning for the tributary a concentration of 60µg/l (a reduction of 22 percent from existing conditions, or from 8008 kg/yr to 6240 kg/yr), reducing the local watershed contribution by 51 percent (from 2061 kg to 1017 kg), and holding other external sources constant, indicate that the internal loading would have to be reduced by 72 percent (from 2312 kg/yr to 653 kg/yr). The base model represents the reductions required to meet the water quality standard without any margin of safety. For the TMDL model, the tributary TP concentration was again constrained to 60µg/l, the reduction in loading from the local watershed was set at 60%, and other external sources were held constant. With these constraints the only available option for reducing the total load was to reduce internal loading. To achieve an in-lake concentration of 38µg/l, it was necessary to reduce the internal loading 87% (from 2312 kg/yr to 301 kg/yr).

To provide some perspective (or present possible viable alternatives) two additional scenarios were run, with the tributary TP concentration set at 50µg/l and at 45µg/l, respectively, while holding the other external loads and the margin of safety at constant values. As in the TMDL model, the only remaining option for reducing the total load to the lake was to adjust internal loading. For alternative 1, with the tributary TP concentration set at 50µg/l (a reduction of 35%, or from 8008 kg/yr to 5200 kg/yr), a reduction in internal loading of 42% (from 2312 kg/yr to 1332 kg/yr) was required for the model to predict TP concentrations of 38µg/l in the lake. For alternative two, the reductions for the tributary (set at 45µg/l) and internal loading were 42% and 21%, respectively.

A final model was constructed in an attempt to simulate pre-settlement conditions. To do this, the tributary concentration was set at 40µg/l (deemed a reasonable value for the outflow from a shallow lake 0.9 mi upstream in pre-settlement times), the calibration factors were set to model default values of 1, and the internal loading was set at 0 kg/yr. The background model predicted an in-lake TP concentration of 27 µg/l, which is near the 25th percentile for deep lakes in the North Central Hardwood Forest ecoregion in pre-settlement times. In the background model, the total TP loading is 4584 kg/yr, which is 3526 kg/yr less than the total capacity of 8110 kg/yr. This provides a rough quantification of the original reserve capacity of the lake.

Figure 17 and Table 11 summarize the modeling results. For the TMDL model, Figure 18shows predicted responses to varying tributary loads, with internal loading at 541 kg and other external sources held constant.

Figure 17. Load distributions for 6 model scenarios

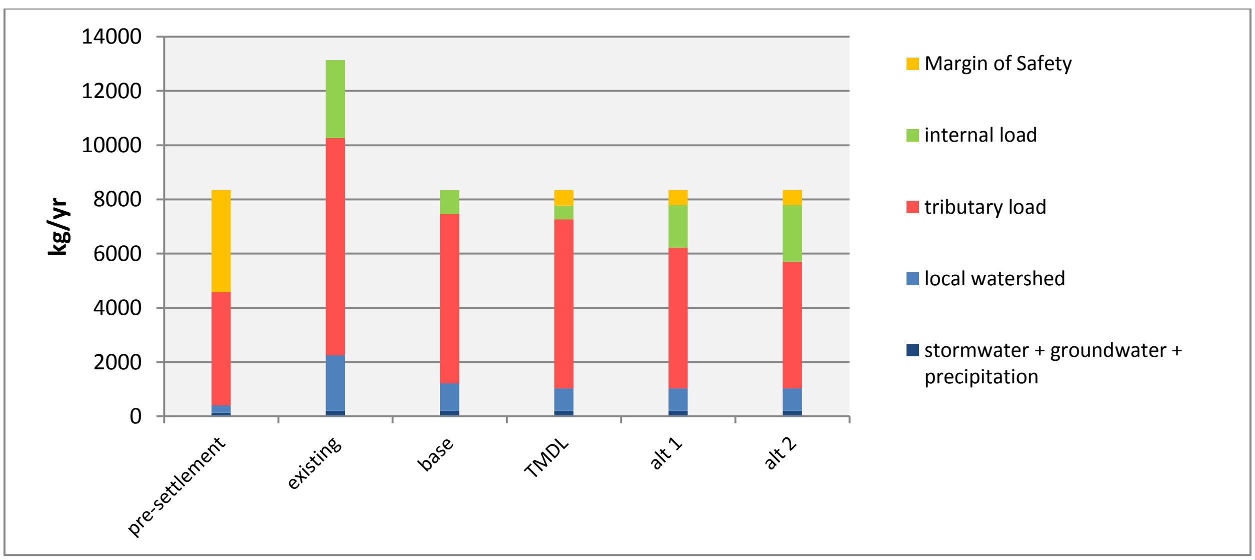
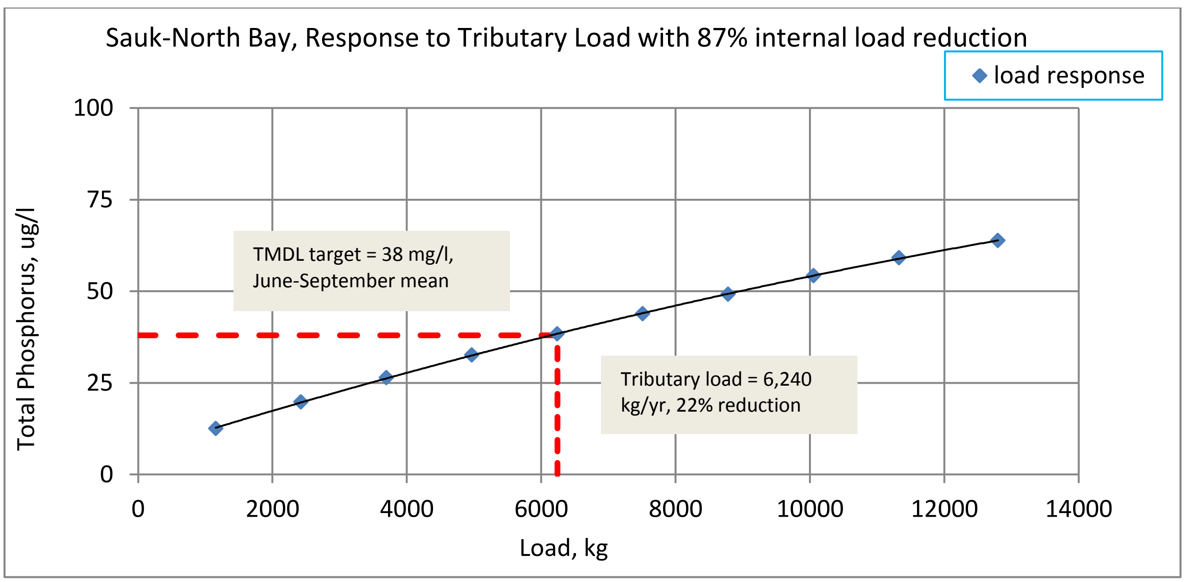


Table 11. Load contributions and percent of totals for 6 model scenarios

Load Contributions. Kg/yr			Sauk R TP=77		Sauk R TP=60 mg/l						Sauk R TP=50mg/l			Sauk R TP=45mg/l		
	pre-settlement, TP=27	% of total	existing conditions TP=57 no MOS	% of total	base model TP=40 no MOS	% of total	% reduction	TMDL model TP=38 5% MOS	% of total	% reduction	Alt 1 model TP=38 5% MOS	% of total	% reduction	Alt 2 model TP=38 5% MOS	% of total	% reduction
stormwater	0	0	15	<1	15	<1	0	15	<1	0	15	<1	0	15	<1	0
groundwater	61	<1	116.3	<1	116.3	<1	0	116.3	<1	0	116.3	<1	0	116.3	<1	0
precipitation	69	<1	68.8	<1	68.8	<1	0	68.8	<1	0	68.8	<1	0	68.8	<1	0
local watershed	294	3.5	2061	16	1017	13	51	828	10	60	828	10	60	828	10	60
Sauk River Inlet	4160	50	8008	64	6240	77	22	6240	77	22	5200	64	35	4680	58	42
internal	0	0	2312	18	653	8	72	301	4	87	1332	16	42	1834	23	21
MOS	3526	45	0	0	0	0		541	7		550	7		568	7	
total	8110		12581		8110			8110			8110			8110		

Figure 18. Sauk Lake-North Bay, lake response to tributary load with 87% internal load reduction



TMDL development

Introduction

TMDL's are expressed as mass (in this case phosphorus in ug/l) per unit time. Phosphorus is the constituent of interest for this TMDL since it is the limiting nutrient that enables excessive growth of aquatic algae. The TMDL equation is:

TMDL = WLA + LA + MOS, where

WLA is the waste load allocation for point sources, LA is the load allocation for non-point sources, and MOS is the margin of safety. The units required by EPA are mass/day. In this report, units of mass/year will also be presented.

Total loading capacity

The loading capacity is defined as the maximum pollutant load that a water body can receive, and still maintain compliance with water quality standards. The loading capacity of Sauk Lake-North Bay was determined by running the BATHTUB model (calibrated for the combined dataset from 2002-2007) with reduced amounts of loading from the Sauk River and internal sources until model results predicted attainment of the water quality objective, while holding all of the other loading sources and calibration factors at a constant value. The lake's total loading capacity was then derived by summing all of the internal and external loads.

Waste load allocations

The wasteload allocation includes permitted discharges from WWTP's, industrial sources and stormwater sources (MS4's). In the Sauk Lake-North Bay watershed, there are no permitted discharges of these types. To comply with suggested protocol, a loading of 0.1 percent of the total loading capacity was included for both construction stormwater and industrial sources (a total of 0.2 percent).

Load allocations

When assessing load reduction scenarios, it was considered impractical to set the total phosphorus concentrations at the inlet to Sauk Lake-North Bay at less than 60 ug/l since it is only 0.9 miles downstream from Mud Lake, a shallow-water lake to which a standard of 60 ug/l would apply. It is unlikely that a significant amount of net phosphorus consumption would occur along the channel between Mud Lake and Sauk Lake-North Bay. Thus, for allocation purposes, the minimum allowable TP concentration at the inlet to Sauk Lake-North Bay was set at 60 ug/l. With this constraint, the load allocation was determined to be 6240 kg/yr, a reduction of 22 percent for the tributary load.

After decades of excessive importation of nutrients via the Sauk River, the sediments in Sauk Lake-North Bay have much higher phosphorus content than in pre-settlement times. In the model calibrated for existing conditions, the predicted internal loading was 2,312 kg/yr, 18 percent of the total load. To meet the water quality objective of 40µg/l including a margin of safety, and stay within the constraint of 6240 kg/yr set for the tributary allocation, and keeping the reduction for the local watershed near 50 percent, an allocation of 301 kg/yr was set for internal loading, a reduction of 87 percent.

In the model, calibrated for existing conditions, the contributing total phosphorus load from the local watershed runoff was 2061 kg/yr, or 16 percent of the total. An allocation of 828 kg was assigned to the local watershed, a reduction of 60 percent, a value that is considered reasonable and attainable.

The contributing total phosphorus loads from precipitation and groundwater were 69 kg/yr, and 116 kg/yr, respectively. Since there is no practical way to reduce these loads, no load reductions were considered for these sources.

Margin of safety

An explicit margin of safety (MOS) of 541 kg/yr TP was included in the TMDL. This done by setting a more restrictive in-lake water quality goal of 38ug/l and modeling the load reductions necessary to meet this goal. The total phosphorus load to meet this goal is 8,110 kg/yr. Therefore the MOS is 6.7% of the TMDL. This is an adequate MOS to account for uncertainties in the data and modeling.

Loading capacity

The resulting total allowable load (TMDL) required for the lake to meet the water quality standard is 8,110 kg/yr. This includes 541 kg as a margin of safety, 6,240 kg for the major tributary (77 percent), 828 kg for the local watershed (10 percent), 301 kg for internal loading (4 percent), 15.2 kg for WLA (0.2 percent), 69 kg for atmospheric deposition (0.9 percent), and 116 kg for groundwater (1.4 percent). Load allocation and load reductions necessary to achieve the TMDL are presented in Table 12.

Table 12.TMDL total phosphorus daily loads partitioned among the major sources for Sauk Lake-North Bay

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(kg/year)	(kg/day)	(kg/year)	kg/day)	(kg/year)	Percent
Wasteload	Industrial and Construction Stormwater	15.2	0.04	15.2	0.04	0	0%
Load	Sauk River	8,008	21.9	6,240	17.1	1,768	22%
	Atmospheric	69	0.19	69	0.19	0	0%
	Local watershed	2061	5.6	828	2.3	1,233	60%
	Groundwater	116	0.32	116	0.32	0	0%
	Internal Load	2,312	6.33	301	0.82	2,011	87%
	MOS	--	--	541	1.48	--	--
	Total w/o MOS	12,581	34.5	7,569	20.7	5,012	40%
	TOTAL LOAD	12,581	34.5	8,110	22.2	--	--

LAKE RESPONSE VARIABLES

Nutrient standards were developed to be protective of the aquatic recreation beneficial use. The symptom of an aquatic recreation nuisance is typically algae. However, algae are not directly modeled. The parameters of greatest interest in this case are the causal factor, phosphorus, and the response factors, chlorophyll-a and Secchi depth. BATHTUB was used to predict the in-lake phosphorus concentration to varying inputs of phosphorus from external sources (see Figure 18. Sauk Lake-North Bay, lake response to tributary load with 87% internal load reduction). To model chlorophyll-a and Secchi depth, regression equations developed by the MPCA (MPCA, 2005) were used. Using these equations, Secchi depth and chlorophyll-a concentrations were predicted over the same range of total phosphorus load reductions as was used for modeling phosphorus. The results are shown in Figure 19-

Figure 20. The plots demonstrate that the standards for chlorophyll-a (13ug/l) and Secchi depth (>1.5m) will be met under the conditions of the recommended total load allocation of 8,110 kg.

Figure 19. Sauk Lake-North Bay, chlorophyll-a response.

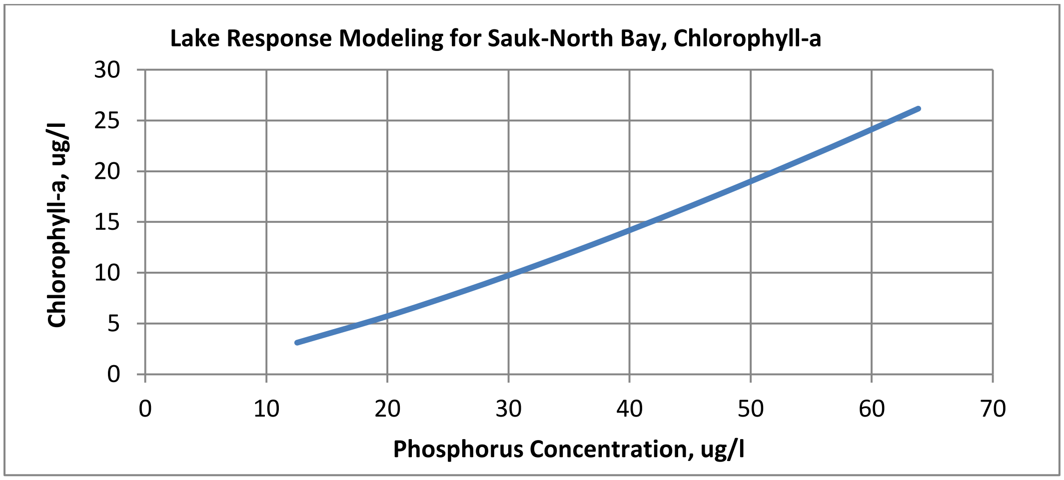
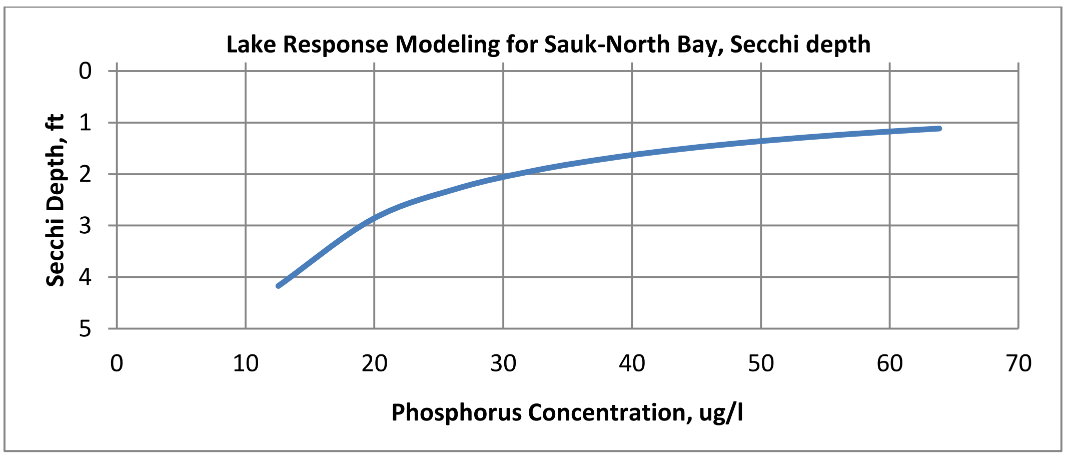


Figure 20. Sauk Lake-North Bay, Secchi depth response



Seasonal and Annual Variation

The hydrological and nutrient budgets used in this TMDL were averages computed from six years of data which included wet and dry years. The resulting allocations and implemented BMP's will be protective for a broad range of climactic and land management conditions.

Seasonal variation is accounted for by developing the allocation for the summer season which is when the nutrient levels peak and the likelihood of nuisance algae blooms is highest. By setting the TMDL to meet water quality goals during the critical summer period the allocations will be protective of the water quality during the other seasons.

Reserve Capacity

Reserve capacity is a portion of the load included in the TMDL to account for future growth or changes in land management in the watershed.

Currently there are no permitted industrial, or wastewater effluent sources in the Sauk Lake-North Bay watershed. However, to comply with established TMDL protocols, 0.1 percent of the total watershed load was assigned to both industrial stormwater and construction stormwater. This allocation establishes a reserve capacity for stormwater.

The Sauk Lake-North Bay watershed is primarily agricultural which is unlikely to undergo much change during the next few decades. Some shifts between hay/pasture and row crops will occur, but this will not affect the loading capacity of the lake since the analysis was based on long term records which likely included land management changes of the same type and magnitude.

Implementation Activities

This section provides general implementation strategies targeted toward reduction of nutrient loads in the Sauk Lake-North Bay watershed. Implementation measures are needed to limit nutrient and sediment transport from upland areas, stabilize key riparian areas, and make in-channel improvements to control scour and sediment conveyance. In-lake implementation activities will be needed to reduce internal loading. Following approval of this TMDL, a more detailed implementation plan will be developed that will result in a customized combination of BMPs to address these components for the TMDL project area.

BMP guidance based on agroecoregion

Minnesota has 39 agro-ecoregions. Each agro-ecoregion is associated with a specific combination of soil types, landscape and climatic features, and land use. Agro-ecoregions are units having relatively homogeneous climate, soil and landscapes, and land use/land cover. Agro-ecoregions can be associated with a specific set of soil and water resource concerns, and with a specific set of management practices to minimize the impact of land use activities on soil and water resource quality.

A matrix has been developed by Dr. David Mulla of the University of Minnesota to provide general planning-level guidance on the application of Best Management Practices (BMPs) within each agroecoregion in the state. The BMPs were developed through a focus group process that included experts from the University of Minnesota, Minnesota Pollution Control Agency, Minnesota Department of Agriculture, and the Minnesota Board of Water and Soil Resources. Four broad categories of management practices discussed include nutrient management, vegetative practices, tillage practices, and structural practices. Selection of appropriate management practices for the pollutant(s) of concern depends on site-specific conditions, stakeholder attitudes and knowledge, and on economic factors. This information is intended to be used as a starting point in the development of a custom set of BMPs to reduce nutrient and sediment transport through improved management of uplands and riparian land within the Sauk Lake-North Bay TMDL project area.

The focus group identified a list of riparian and upland management practices that appear especially appropriate within the Central Till agro-ecoregion, which contains the Sauk Lake-North Bay project watershed. BMPs recommended for reducing nutrient and sediment transport under the Vegetative, Primary Tillage, and Structural Practices categories include the following:

Vegetative Practices

- Contour farming
- Strip cropping
- Grassed waterways
- Grass filter strip for feedlot runoff
- Forest management practices
- Alternative crop in rotation
- Field windbreak
- Pasture management (IRG)
- Conservation reserve Program (CRP) or Conservation Reserve Enhancement program (CREP)

Primary Tillage Practices

- Chisel Plow
- One pass tillage
- Ridge till
- Sustain surface roughness

Structural Practices

- Wetland restoration
- Livestock exclusion
- Liquid manure waste facilities

A brief summary of each type of practice as it applies to the Sauk Lake TMDL watershed follows.

Vegetative management practices

Vegetative practices include those focusing on the establishment and protection of crop and non-crop vegetation to minimize sediment mobilization from agricultural lands, and decrease nutrient and sediment transport to receiving waters. Grassed waterways and grass filter strips increase entrainment of sediment. Other practices, such as alternative crop rotations, forest management, and field windbreaks, are designed to minimize exposure of bare soils to wind and water which can transport soil off-site. Pasture management can involve rotational grazing techniques where pastures are divided into paddocks, and the livestock moved from one paddock to another before forage is over-grazed. Maintaining the vegetation allows for greater water infiltration, reducing runoff, and associated nutrient and sediment transport.

There are a number of programs available to compensate land owners for moving environmentally sensitive cropland out of production for varying periods of time. These include the Conservation Reserve Program (CRP), Re-Invest in Minnesota (RIM) Reserve Program, and the Conservation Reserve Enhancement Program-Minnesota II (CREP-II).

Primary Tillage Practices

Certain kinds of tillage practices can significantly reduce runoff from fields. Conservation tillage techniques emphasize the practice of leaving at least some vegetation cover or crop residue on fields to reduce the exposure of the soil to wind and water. If it is managed properly, conservation tillage can reduce soil erosion on active fields by up to two-thirds (Randall et. al. 2002).

Structural Practices

Structural practices emphasize elements that generally require a higher level of site-specific planning and engineering design. Most structural practices focus on watershed improvements to decrease nutrient loading to the receiving water. For example, restoration of wetlands can create a natural method of slowing overland runoff and storing runoff water, which can both reduce channel instability and flooding downstream. Livestock exclusion involves fencing or creating other structural barriers to limit or eliminate access to stream by livestock, and may involve directing livestock to an area that is better designed to provide limited access with minimal impact.

Stream and Channel Restoration

Other practices which may be considered for the project area involve making improvements to improve channel stability and decrease in-stream sources of sediment. In-stream structures need to be carefully designed to direct flow where appropriate under a wide range of discharge conditions, and make sure that solution of one-channel stability problem doesn't create another elsewhere. Also important is, where possible, making sure that the main stream channel can overflow into its floodplain at high flows to allow the stream to temporarily store water outside the streambank, reducing flow velocity and excessive scouring of the channel. Intact natural vegetation in the floodplain also acts to slow flow velocities, and encourages deposition and permanent capture of sediment and nutrients.

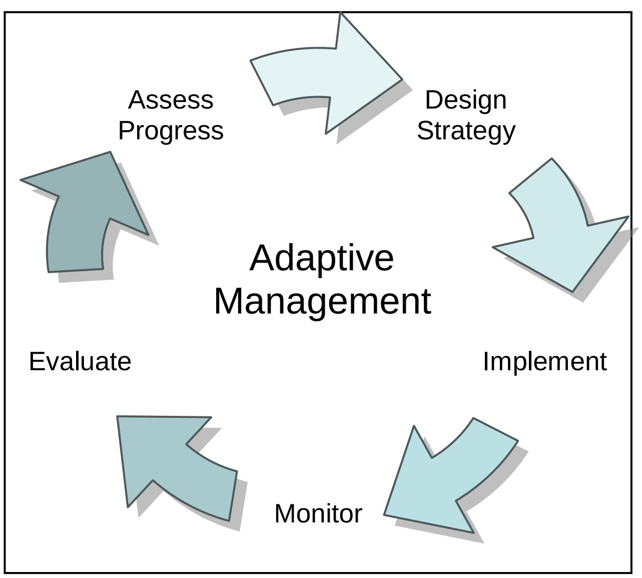
Internal Nutrient Load Reduction

Internal loads will need to be reduced to meet the lake goals outlined in this document. Options that should be reviewed for potential effectiveness include chemical treatment to bind sediment phosphorus, vegetation management, and hypolimnetic withdrawal or aeration.

Adaptive Management

This list of implementation elements, and the more detailed implementation plan that will be prepared following this TMDL assessment, should be considered within the framework of adaptive management (Figure 21). With continued monitoring and assessment the linkages between nutrient sources and lake response will become better understood and strategies for improving lake water quality can be refined. Because there are no known point sources in the project area watershed, the implementation elements will focus exclusively on non-point source controls.

Figure 21. Adaptive management



Reasonable Assurance

Introduction

As a requirement of TMDL studies, reasonable assurance must be provided, demonstrating the ability to reach and maintain water quality endpoints. The source reduction strategies detailed in Section 5 have been shown to be effective in reducing nutrient loads to receiving waters. It is reasonable to expect that these measures will be widely adopted by landowners and resource managers, in part because they have already been implemented in some parts of the watershed over the last 20 years.

Many of the goals outlined in this TMDL study are consistent with objectives outlined in the Stearns County Comprehensive Local Water Management Plan and the Sauk River Watershed District Watershed Management Plan. These plans have the same objective of developing and implementing strategies to bring impaired waters into compliance with appropriate water quality standards, and thereby establish the basis for removing those impaired waters from the 303(d) Impaired Waters List. These plans provide the watershed management framework for addressing water quality issues. In addition, the stakeholder processes associated with both this TMDL effort, as well as the broader planning efforts mentioned previously, have generated commitment and support from the local government units affected by this TMDL, and will help ensure that this TMDL project is carried successfully through implementation.

Various technical and funding sources will be used to execute measures detailed in the implementation plan that will be developed within one year of the approval of this TMDL. Technical resources include the Sauk River Watershed District and Stearns County Soil and Water Conservation District, as well as the Minnesota Department of Natural Resources. Funding resources include a mixture of state and federal programs, including (but not limited to) the following:

- Conservation Reserve Program
- Federal Section 319 program for watershed improvements
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the state's citizens in November 2008.
- Sauk River Watershed District program funds
- Local government cost-share funds

Following is a discussion of the key agencies at the local level that will help assure that implementation activities proposed under this TMDL will be executed.

Sauk River Watershed District

The Sauk River Watershed District (SRWD) has been active in water resources management and protection since it was formed in 1986. The SRWD current watershed management plan identifies the following major roles for the District:

1. Collection of monitoring data, with an emphasis on collection of a comprehensive set of surface water quality data to support diagnostic studies.
2. Development and implementation of a regulatory program that requires a permit from the SRWD for:
    a. The development or redevelopment of properties which create greater than one acre of impervious.
    b. Land disturbance within 500 feet of water bodies or wetlands.
    c. Work in the Right of Way of any legal drainage system
    d. Construction, installation, or alteration of certain water control structures
    e. Diversion of water into a different sub-watershed or county drainage system
3. Providing technical assistance to landowners, farmers, businesses, lake associations, cities, townships, counties, state agencies, and school districts. Much of this technical assistance pertains to planning and installing best management practices for water quality protection and improvement.
4. Implementation of capital improvements.
5. Public education.

In March of 2010, the SRWD concluded the process of updating its rules, including addition of new requirements for stormwater runoff management, erosion control, drainage and water use. The SRWD will also begin working on updating its existing watershed management plan, the term for which currently extends from 2003-2012. This will provide the opportunity to more closely link SRWD policies, programs and projects with implementation of TMDLs affecting its jurisdiction, including the Sauk Lake-North Bay TMDL.

Stearns County Comprehensive Local Water Management Plan

Stearns County has adopted a county water plan that articulates goals and objectives for water and land-related resource management initiatives. The adopted plan is for the time period 2008-2017. Completion of TMDL assessments of impaired waters within the county was identified as one of the top three priorities in the plan. In addition, the implementation section of the plan focuses on a number of areas important in restoring impaired waters to a non-impaired status, including:

1. Support and cooperation with watershed districts and the Minnesota Pollution Control Agency on on-going TMDL projects.
2. Educate feedlot owners on proper feedlot management, including manure storage and application, for the purpose of meeting regulatory requirements.
3. Provide information, technical and/or financial assistance to Stearns County landowners implementing agricultural BMPs on working lands to reduce soil erosion, protect streambanks, and improve water resources.

4. Actively promote and market federal/state/local conservation programs to targeted landowners and help prepare them for eligibility in program such as Conservation Reserve Program (CRP) and Environmental Quality Incentives Program (EQIP).
5. Promote and market conservation programs that provide cost-share and assistance to livestock producers for the adoption of comprehensive nutrient management plans.
6. Ensure the proper use and abandonment of manure pits.
7. Continue to inspect feedlots and work with owner/operators to bring their facilities into compliance with those feedlots that are within identified TMDL watersheds having priority.
8. Promote and establish buffers on public and private ditches
9. Establish and maintain vegetative buffers in accordance with existing Stearns County Land Use and Zoning Ordinance #209 and MN Rules 61.20.3300 Subpart 7.

Stearns County Soil and Water Conservation District

The purpose of the Stearns County Soil and Water Conservation District (SWCD) is to plan and execute policies, programs, and projects which conserve the soil and water resources within its jurisdictions. It is particularly concerned with erosion of soil due to wind and water. The SWCD is heavily involved in the implementation of practices that effectively reduce or prevent erosion, sedimentation, siltation, and agricultural-related pollution in order to preserve water and soil as resources. The District frequently acts as local sponsor for many types of projects, including grassed waterways, on-farm terracing, erosion control structures, and flow control structures. The SRWD has established close working relationships with the SWCD on a variety of projects. One example is the conservation buffer strip cash incentives program that provides cash incentives to create permanent grass buffer strips along stream corridors. The SRWD currently participates in the program by providing matching grants, and will work to target such practices in the GUS watersheds so that the practices are implemented as cost effectively as possible to achieve the load reduction required for that TMDL (Getchell Creek, Unnamed Creek and Stony Creek turbidity TMDL).

Monitoring

Future monitoring of water quality in Sauk Lake-North Bay and the major tributary, Sauk River, is necessary to enable assessment of whether progress is being made towards achievement of TMDL goals. A second, but no less important, purpose for additional monitoring is to improve upon the current understanding of the lake dynamics. A better understanding of the linkages between load sources and lake response will reduce uncertainties associated with model predictions, and allow refinement of load allocations to various sources. Some specific areas where the monitoring could be improved are: more samples per season in the lake (epilimnion); more temperature-dissolved oxygen profiles in the lake; additional samples in the hypolimnion for total phosphorus and including iron and sulfate; lake bioassays; and adding chlorophyll to the parameter list at the Sauk Lake-North Bay inlet site.

An optimal time to begin effectiveness monitoring depends on the progress of implementation. After a substantial portion of the implementation work has been completed, effectiveness monitoring should begin and be maintained for a minimum of 3-4 years. Following is a recommended strategy for the monitoring.

1) At the sampling location in Sauk Lake-North Bay, site id: 77-0150-02-207

- 10-12 times per summer (June-September) season:
  Total phosphorus (epilimnion)
  Chlorophyll-a (epilimnion)
  Secchi depth
  Temperature and dissolved oxygen profile, pH
- 5-6 times per summer season
  Total phosphorus (hypolimnion)
  OrthoP (hypolimnion)
  Total Iron (hypolimnion)
  Total Sulfate (hypolimnion)

2) At the inlet to Sauk Lake-North Bay site id: S000-552

- Continuous flow (gaging site with electronic logger)
- 18-20 times per year:
  Total phosphorus
  Chlorophyll-a
  Temperature, pH, dissolved oxygen, conductivity (with portable sonde), t-tube
- 9-10 times per year:
  OrthoP
  TSS

3) Blue-green toxicity testing if excessive algae blooms occur.

Public Participation

As part of the strategy to achieve implementation of the necessary allocations, the Sauk River Watershed District (SRWD) held a public meeting in December, 2008. The purpose of this meeting was to inform the general public and stakeholders about the TMDL process, and preliminary results of the Sauk Lake TMDL study. Additional stakeholder meetings, following the public noticing of the TMDL, will be held to update residents and to seek additional input on implantation efforts and planning. In addition to the public meetings, the SRWD intends to publish these results and project updates in their annual newsletter, as they have done on past TMDL studies in addition to their website (www.srwdmn.org). The SRWD's Board of Managers and Stearns County Soil and Water Conservation District staff also made efforts to discuss the TMDL process and findings with their constituents and local landowners.

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Appendix A: Sauk Lake-North Bay Watershed, map and areas

Class (NLCD 2006)	Sq Meters	Acres
OPEN_WATER	47572200	11755.35
DEVELOPED__OPEN_SPACE	24755400	6117.19
DEVELOPED__LOW_INTENSITY	3347100	827.09
DEVELOPED__MEDIUM_INTENSITY	351900	86.96
DEVELOPED__HIGH_INTENSITY	91800	22.68
BARREN_LAND__ROCK	51300	12.68
DECIDUOUS_FOREST	49232700	12165.67
EVERGREEN_FOREST	1384200	342.04
MIXED_FOREST	38700	9.56
SHRUB_SCRUB	116100	28.69
GRASSLAND_HERBACEOUS	15717600	3883.90
PASTURE_HAY	143978400	35577.84
CULTIVATED_CROPS	236492100	58438.47
WOODY_WETLAND	2110500	521.52
EMERGENT_HERBACE	31602600	7809.17

Watershed	HU_12_NAME	ACRES
Lake Osakis	Clifford Lake	14742.24
Lake Osakis	Osakis Lake	23919.68
Lake Osakis	Boss Creek	11427.69
Lake Osakis	Crooked Lake Ditch	38633.09
Sauk River (L. Osakis to Sauk North Bay)	Little Sauk Lake-Sauk River	35884.57
Sauk Lake (North Bay)	Sauk Lake	12988.04

Appendix B: Sauk Lake-North Bay Bathymetry

Appendix C: BATHTUB Output, Existing Conditions Model

Sauk North Bay, existing conditions model 2002-2007 - Growing Season (June - September)							
Segment Mass Balance Based Upon Predicted Concentrations							
Component:		**TOTAL P**		**Segment:**	**1**	**North Bay**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	**1**	**Sauk River Inlet**	**104.0**	**87.4%**	**8008.0**	**63.7%**	**77**
2	**2**	**storm water**	**0.1**	**0.1%**	**15.2**	**0.1%**	**200**
3	**2**	**local shed**	**7.4**	**6.2%**	**2060.8**	**16.4%**	**280**
4	**1**	**groundwater**	**1.5**	**1.3%**	**116.3**	**0.9%**	**76**
PRECIPITATION			**6.0**	**5.1%**	**68.8**	**0.5%**	**11**
INTERNAL LOAD			**0.0**	**0.0%**	**2311.9**	**18.4%**	
TRIBUTARY INFLOW			**105.5**	**88.7%**	**8124.3**	**64.6%**	**77**
NONPOINT INFLOW			**7.4**	**6.2%**	**2076.0**	**16.5%**	**279**
*****TOTAL INFLOW**			**119.0**	**100.0%**	**12580.9**	**100.0%**	**106**
ADVECTIVE OUTFLOW			**113.0**	**94.9%**	**6418.0**	**51.0%**	**57**
*****TOTAL OUTFLOW**			**113.0**	**94.9%**	**6418.0**	**51.0%**	**57**
*****EVAPORATION**			**6.0**	**5.1%**	**0.0**	**0.0%**	
*****RETENTION**			**0.0**	**0.0%**	**6162.9**	**49.0%**	
Hyd. Residence Time =			**0.3551**	**yrs**			
Overflow Rate =			**16.4**	**m/yr**			
Mean Depth =			**5.8**	**m**			

Sauk North Bay, existing conditions model 2002-2007 - Growing Season (June - September)						
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**North Bay**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
CONSERVATIVE SUB	14269.8	0.02		15500.0		
TOTAL P MG/M3	56.8	0.22	57.5%	57.0		57.7%
TP-ORTHO-P MG/M3				43.0		64.8%
CARLSON TSI-P	62.4	0.05	57.5%	62.5		57.7%

Appendix C: Base Model

Sauk North Bay, base model 2002-2007 - Growing Season (June - September)							
Segment Mass Balance Based Upon Predicted Concentrations							
Component:		**TOTAL P**		**Segment:**	**1**	**North Bay**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	1	Sauk River Inlet	104.0	88.4%	6240.0	76.9%	60
2	2	storm water	0.1	0.1%	15.2	0.2%	200
3	2	local shed	6.0	5.1%	1016.6	12.5%	170
4	1	groundwater	1.5	1.3%	116.3	1.4%	76
PRECIPITATION			6.0	5.1%	68.8	0.8%	11
INTERNAL LOAD			0.0	0.0%	653.4	8.1%	
TRIBUTARY INFLOW			105.5	89.7%	6356.3	78.4%	60
NONPOINT INFLOW			6.1	5.1%	1031.8	12.7%	170
***TOTAL INFLOW			117.6	100.0%	8110.2	100.0%	69
ADVECTIVE OUTFLOW			111.6	94.9%	4518.1	55.7%	40
***TOTAL OUTFLOW			111.6	94.9%	4518.1	55.7%	40
***EVAPORATION			6.0	5.1%	0.0	0.0%	
***RETENTION			0.0	0.0%	3592.1	44.3%	
Hyd. Residence Time =			0.3595	yrs			
Overflow Rate =			16.2	m/yr			
Mean Depth =			5.8	m			

Sauk North Bay, base model 2002-2007 - Growing Season (June - September)						
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**North Bay**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
CONSERVATIVE SUB	14446.3	0.02		15500.0		
TOTAL P MG/M3	40.5	0.20	42.6%	57.0		57.7%
TP-ORTHO-P MG/M3				43.0		64.8%
CARLSON TSI-P	57.5	0.05	42.6%	62.5		57.7%

Appendix C: TMDL Model

Sauk North Bay, TMDL model 2002-2007 - Growing Season (June - September)							
Segment Mass Balance Based Upon Predicted Concentrations							
Component:		TOTAL P		Segment:	1	North Bay	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Sauk River Inlet	104.0	88.8%	6240.0	82.4%	60
2	2	storm water	0.1	0.1%	15.2	0.2%	200
3	2	local shed	5.5	4.7%	828.0	10.9%	150
4	1	groundwater	1.5	1.3%	116.3	1.5%	76
PRECIPITATION			6.0	5.2%	68.8	0.9%	11
INTERNAL LOAD			0.0	0.0%	301.6	4.0%	
TRIBUTARY INFLOW			105.5	90.1%	6356.3	84.0%	60
NONPOINT INFLOW			5.6	4.8%	843.2	11.1%	151
***TOTAL INFLOW			117.2	100.0%	7569.8	100.0%	65
ADVECTIVE OUTFLOW			111.1	94.8%	4268.3	56.4%	38
***TOTAL OUTFLOW			111.1	94.8%	4268.3	56.4%	38
***EVAPORATION			6.0	5.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	3301.6	43.6%	
Hyd. Residence Time =			0.3609	yrs			
Overflow Rate =			16.2	m/yr			
Mean Depth =			5.8	m			

Sauk North Bay, TMDL model 2002-2007 - Growing Season (June - September)						
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	North Bay				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
CONSERVATIVE SUB	14506.1	0.02		15500.0		
TOTAL P MG/M3	38.4	0.19	40.3%	57.0		57.7%
TP-ORTHO-P MG/M3				43.0		64.8%
CARLSON TSI-P	56.8	0.05	40.3%	62.5		57.7%

Appendix C: Alternative 1 Model

Sauk North Bay, Alternative 1 model 2002-2007 - Growing Season (June - September)							
Segment Mass Balance Based Upon Predicted Concentrations							
Component:		TOTAL P		Segment:	1	North Bay	
			Flow	Flow	Load	Load	Conc
Trib	Type	Location	hm^3/yr	%Total	kg/yr	%Total	mg/m^3
1	1	Sauk River Inlet	104.0	88.8%	5200.0	68.8%	50
2	2	storm water	0.1	0.1%	15.2	0.2%	200
3	2	local shed	5.5	4.7%	828.0	11.0%	150
4	1	groundwater	1.5	1.3%	116.3	1.5%	76
PRECIPITATION			6.0	5.2%	68.8	0.9%	11
INTERNAL LOAD			0.0	0.0%	1331.8	17.6%	
TRIBUTARY INFLOW			105.5	90.1%	5316.3	70.3%	50
NONPOINT INFLOW			5.6	4.8%	843.2	11.2%	151
***TOTAL INFLOW			117.2	100.0%	7560.1	100.0%	65
ADVECTIVE OUTFLOW			111.1	94.8%	4263.9	56.4%	38
***TOTAL OUTFLOW			111.1	94.8%	4263.9	56.4%	38
***EVAPORATION			6.0	5.2%	0.0	0.0%	
***RETENTION			0.0	0.0%	3296.2	43.6%	
Hyd. Residence Time =			0.3609	yrs			
Overflow Rate =			16.2	m/yr			
Mean Depth =			5.8	m			

Sauk North Bay, Alternative 1 model 2002-2007 - Growing Season (June - September)						
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	1	North Bay				
	Predicted Values--->			Observed Values--->		
Variable	Mean	CV	Rank	Mean	CV	Rank
CONSERVATIVE SUB	14506.1	0.02		15500.0		
TOTAL P MG/M3	38.4	0.19	40.3%	57.0		57.7%
TP-ORTHO-P MG/M3				43.0		64.8%
CARLSON TSI-P	56.7	0.05	40.3%	62.5		57.7%

Appendix C: Alternative 2 Model

Sauk North Bay, Alternative 2 model 2002-2007 - Growing Season (June - September)							
Segment Mass Balance Based Upon Predicted Concentrations							
Component:		**TOTAL P**		**Segment:**	**1**	**North Bay**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	**1**	**Sauk River Inlet**	**104.0**	**88.8%**	**4680.0**	**62.0%**	**45**
2	**2**	**storm water**	**0.1**	**0.1%**	**15.2**	**0.2%**	**200**
3	**2**	**local shed**	**5.5**	**4.7%**	**828.0**	**11.0%**	**150**
4	**1**	**groundwater**	**1.5**	**1.3%**	**116.3**	**1.5%**	**76**
PRECIPITATION			**6.0**	**5.2%**	**68.8**	**0.9%**	**11**
INTERNAL LOAD			**0.0**	**0.0%**	**1834.4**	**24.3%**	
TRIBUTARY INFLOW			**105.5**	**90.1%**	**4796.3**	**63.6%**	**45**
NONPOINT INFLOW			**5.6**	**4.8%**	**843.2**	**11.2%**	**151**
*****TOTAL INFLOW**			**117.2**	**100.0%**	**7542.7**	**100.0%**	**64**
ADVECTIVE OUTFLOW			**111.1**	**94.8%**	**4256.0**	**56.4%**	**38**
*****TOTAL OUTFLOW**			**111.1**	**94.8%**	**4256.0**	**56.4%**	**38**
*****EVAPORATION**			**6.0**	**5.2%**	**0.0**	**0.0%**	
*****RETENTION**			**0.0**	**0.0%**	**3286.7**	**43.6%**	
Hyd. Residence Time =			**0.3609**	**yrs**			
Overflow Rate =			**16.2**	**m/yr**			
Mean Depth =			**5.8**	**m**			

Sauk North Bay, Alternative 2 model 2002-2007 - Growing Season (June - September)						
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**North Bay**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
CONSERVATIVE SUB	14506.1	0.02		15500.0		
TOTAL P MG/M3	38.3	0.19	40.2%	57.0		57.7%
TP-ORTHO-P MG/M3				43.0		64.8%
CARLSON TSI-P	56.7	0.05	40.2%	62.5		57.7%

Appendix C: Background Model

Sauk North Bay, Background model 2002-2007 - Growing Season (June - September)							
Segment Mass Balance Based Upon Predicted Concentrations							
Component:		**TOTAL P**		**Segment:**	**1**	**North Bay**	
			Flow	**Flow**	**Load**	**Load**	**Conc**
Trib	**Type**	**Location**	**hm^3/yr**	**%Total**	**kg/yr**	**%Total**	**mg/m^3**
1	**1**	**Sauk River Inlet**	**104.0**	**87.4%**	**4160.0**	**90.7%**	**40**
2	**2**	**local shed**	**7.4**	**6.2%**	**294.4**	**6.4%**	**40**
3	**1**	**groundwater**	**1.5**	**1.3%**	**61.2**	**1.3%**	**40**
PRECIPITATION			**6.0**	**5.1%**	**68.8**	**1.5%**	**11**
TRIBUTARY INFLOW			**105.5**	**88.7%**	**4221.2**	**92.1%**	**40**
NONPOINT INFLOW			**7.4**	**6.2%**	**294.4**	**6.4%**	**40**
*****TOTAL INFLOW**			**118.9**	**100.0%**	**4584.4**	**100.0%**	**39**
ADVECTIVE OUTFLOW			**112.9**	**94.9%**	**3047.5**	**66.5%**	**27**
*****TOTAL OUTFLOW**			**112.9**	**94.9%**	**3047.5**	**66.5%**	**27**
*****EVAPORATION**			**6.0**	**5.1%**	**0.0**	**0.0%**	
*****RETENTION**			**0.0**	**0.0%**	**1536.9**	**33.5%**	
Hyd. Residence Time =			**0.3553**	**yrs**			
Overflow Rate =			**16.4**	**m/yr**			
Mean Depth =			**5.8**	**m**			

Sauk North Bay, Background model 2002-2007 - Growing Season (June - September)						
Predicted & Observed Values Ranked Against CE Model Development Dataset						
Segment:	**1**	**North Bay**				
	Predicted Values--->			**Observed Values--->**		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
CONSERVATIVE SUB	14279.4	0.02		15500.0		
TOTAL P MG/M3	27.0	0.15	26.2%	57.0		57.7%
TP-ORTHO-P MG/M3				43.0		64.8%
CARLSON TSI-P	51.7	0.04	26.2%	62.5		57.7%