Sweeney Lake
Total Phosphorus TMDL

Prepared for

Bassett Creek Watershed Management Commission

Minnesota Pollution Control Agency

FINAL DRAFT

October 25, 2010

SEH

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Funding for Phase 1 of this project was provided by the Minnesota Pollution Control Agency from the Section 319 NonPoint Source Management Fund of the Federal Water Pollution Control Act, 33 USC 1329, CFDA66.460

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TMDL Summary

This Total Maximum Daily Load (TMDL) study addresses a nutrient impairment in Sweeney Lake (Lake ID 27-0035-01). The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for nutrients and allocate total maximum daily loads for the identified loading sources and load categories.

Sweeney Lake is a 67 acre water body located in the City of Golden Valley, Hennepin County, Minnesota, in the Bassett Creek watershed. Sweeney Lake is a recreational water body with an active fishery and provides other aesthetic values as well. The drainage area to the lake is approximately 2340 acres of almost fully developed urban land. The drainage area is split between the cities of Golden Valley and St. Louis Park. Sweeney Lake has a natural outlet that discharges from the northeast end portion of the lake into the Bassett Creek system. Water quality is noted as Non-supporting (NS) for Aquatic Recreation Use Support on the MPCA's Lake Water Quality Assessment website.

Wasteload and Load Allocations to meet State standards indicate that a combination of external load reductions (wasteload) and internal load reductions (load) of 15 percent external and 55 percent internal would be needed to meet State water quality standards. An evaluation of external (wasteload) reductions was completed and indicated that a 70 percent reduction be required to consistently meet standards under average precipitation conditions if only watershed-based (external) practices were implemented. A combined approach to internal load management and reduction of phosphorus from throughout the watershed by retrofitting BMPs (Best Management Practices) and improving management activities would have the most impact on reducing phosphorus load and improving water quality in Sweeney Lake.

An important aspect of this TMDL study was to better understand the contribution that aeration has on the internal loading to Sweeney Lake. Except for the two years of monitoring under this study in 2007 and 2008, the lake had been aerated since the early 1970's. Based on the 2007-2008 monitoring, the data are not sufficient to conclude if the aeration system is increasing the internal loading to the lake or not. The water quality was better in 2007 and

2008, but insufficient data is available to conclude what portion relates to reduced watershed load from the lower than normal precipitation and what portion relates to reduced internal loading from stratification of the lake and trapping phosphorus in the bottom layer. The dissolved oxygen levels in the surface water (roughly the top 3 to 4 meters) of the lake in 2007 and 2008 were adequate to fully support fish, with levels in 2008 ranging from 16 mg/L in the spring to 8 mg/L in the fall. In either case, the recommended action is to conduct future years of monitoring with the aeration system off to see how the lake responds to a normal year of precipitation. Continued winter aeration is not a concern and likely is a good long-term management strategy for the lake.

The table on the following pages provides a summary of the key elements of this TMDL and the corresponding page(s) where more detailed discussion is provided within the report.

TMDL Summary Table

EPA/MPCA Required Elements	Summary			TMDL Page #
Location	City of Golden Valley in Hennepin County, Minnesota in the Upper Mississippi River Basin. Sweeney Lake is within the North Central Hardwood Forest (NCHF) Ecoregion.			2
303(d) Listing Information	Sweeney 27-0035-01 Sweeney Lake was added to the 303(d) list in 2004 due to excess nutrient concentrations causing impaired aquatic recreation, as set forth in Minn. Rule 7050.0150. This TMDL was targeted to start in 2006 and be completed by 2010.			1
Applicable Water Quality Standards/ Numeric Targets	Criteria set forth in Minn. R. 7050.0150 (3) and (5) and 7050.0222. For the NCHF Ecoregion, the numeric target is a **total phosphorus** concentration of **40 µg/L** or less and either a **chlorophyll-a** concentration of **14 µg/L** or less or **Secchi disk transparency** of not less than **1.4 meters**.			13 - 15
Loading Capacity (expressed as daily load)	The loading capacity is the total maximum daily load for the critical condition. The critical condition for this lake is the summer growing season. The loading capacity is set forth in Table 6.4. <u>Total Maximum Daily Load - Total Phosphorus (lb/day)</u> Sweeney Lake 5.90			37
Wasteload Allocation	Portion of the loading capacity allocated to existing and future point sources.			31 - 37
	Source	**Permit #**	**WLA (lb/day)**	
	Permitted Stormwater (MS4.)	MN R 040000	4.66	37
	Permitted Stormwater (Industrial)	None	0	37
	Permitted Stormwater (Construction)	MN R 100001	Included in MS4	37
	Reserve Capacity (and related discussion in report)	NA	0	32

TMDL Summary Table

EPA/MPCA Required Elements	Summary		TMDL Page #
Load Allocation	The portion of the loading capacity allocated to existing and future non-permitted sources and to natural sources.		37
	Source	**Load Allocation (lb/day)**	
	Atmospheric Load	0.07	37
	Internal Load	1.17	37
Margin of Safety	The margin of safety (MOS) was factored into the computations using five percent (5%) reduction applied to the 40 ug/L criteria. A summer average concentration of 38 ug/L was the target. The MOS is also implicit in the TMDL due to the conservative assumptions of the models using the worst case loading year 2004 (from recent data).		32
Seasonal Variation	Seasonal variation is accounted for by setting targets based on the summer critical period where the frequency and severity of nuisance algal growth is greatest. Although the critical period is the summer, lakes are generally not sensitive to short term changes.		33
Reasonable Assurance	Reasonable assurance is provided by the cooperative efforts of the Bassett Creek Watershed Management Commission (BCWMC), a joint powers organization with statutory responsibility to protect and improve water quality in the water resources in the Bassett Creek watershed in which this lake is located, and by the member cities of this organization. In addition, the entire contributing area to these lakes is regulated under the NPDES program, and Minnesota's General NPDES MS4 Permit requires MS4s to amend their Storm Water Pollution Prevention Plan (SWPPP) within 18 months following adoption of a TMDL to set forth a plan to meet the TMDL waste load allocation. The BCWMC is proceeding in a good faith effort to coordinate with all parties on how to implement the TMDL.		49
Monitoring	The Bassett Creek Watershed Management Commission periodically monitors these lakes and will continue to do so through the implementation period. Monitoring the in-lake conditions under non-aerated conditions is recommended to better quantify the effects of aeration on internal loading.		49 - 50

TMDL Summary Table

EPA/MPCA Required Elements	Summary	TMDL Page #
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. The implementation program will follow an adaptive management approach towards implementing the most cost effective and ecologically sound means of achieving the in-lake water quality goals.	40 – 48
Public Participation	The project involved two formal public meetings at Golden Valley City Hall. One public meeting took place at the start of the project in March 2007 and one following the second year of data collection and initial modeling work on June 3, 2009. Several written project updates and periodic meetings were also held with the Bassett Creek Watershed Management Commission. A resident meeting was held in 2008 to discuss first-year monitoring results; a Technical Team (including permitted MS4s) meeting was held on April 23, 2009, and a project webpage was created and updated on a regular basis at www.sehinc.com/online/sweeney/. The webpage maintains information on all public information meetings and contact information for the project team members. Comments received: Some preliminary comments were received during Public Meeting #2 relating to the implementation strategy and potential load reduction BMPs. Residents requested that two additional BMPs be added to the possible improvements list: Schaper Pond dredging and an inflow chemical treatment system. These were added to the implementation framework.	38 – 39

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INTRODUCTION

1.0 Introduction

1.1 Purpose

The purpose of this Total Maximum Daily Load (TMDL) study is to quantify the total phosphorus (TP) load reduction required to meet State water quality standards for nutrients in Sweeney Lake (DNR Lake #27-0035-01). In accordance with 303(d) of the Clean Water Act, TMDL studies are required for assessed waters that exceed the State water quality standards.

This TMDL provides waste load allocations (WLAs) and load allocations (LAs) for Sweeney Lake. Based on the current State standard for nutrients, the TMDL establishes a numeric target of 38 µg/L total phosphorus concentration and incorporates a five percent (2 µg/L) margin of safety to meet the 40 µg/L state standard for deep lakes in the North Central Hardwood Forest (NCHF) ecoregion.

1.2 Problem Statement

In 2004, the lake was designated as an "impaired water body" by the Minnesota Pollution Control Agency for total phosphorus for aquatic recreation based upon its water quality history. Sweeney Lake has been subject to fairly extensive previous study including a *Watershed and Lake Management Plan* completed for the Bassett Creek Watershed Management Commission (WMC) (Barr Engineering, 1994) and water quality monitoring dating back to 1972. The quality of the data available through the MPCA's Lake Water Quality Assessment website is listed as excellent and the Lake is noted as Non-supporting (NS) for Aquatic Recreation Use Support. The primary reason for Sweeney being listed as impaired is the monitored total phosphorus levels in the Lake. Data summarized on the MPCA website show that the mean TP concentration is 55 ppb. The upper limit for a Partial Support designation for lakes in the North Central Hardwood Forest (NCHF) region is 45 ppb (or µg/L).

2.0 Watershed and Lake Characteristics

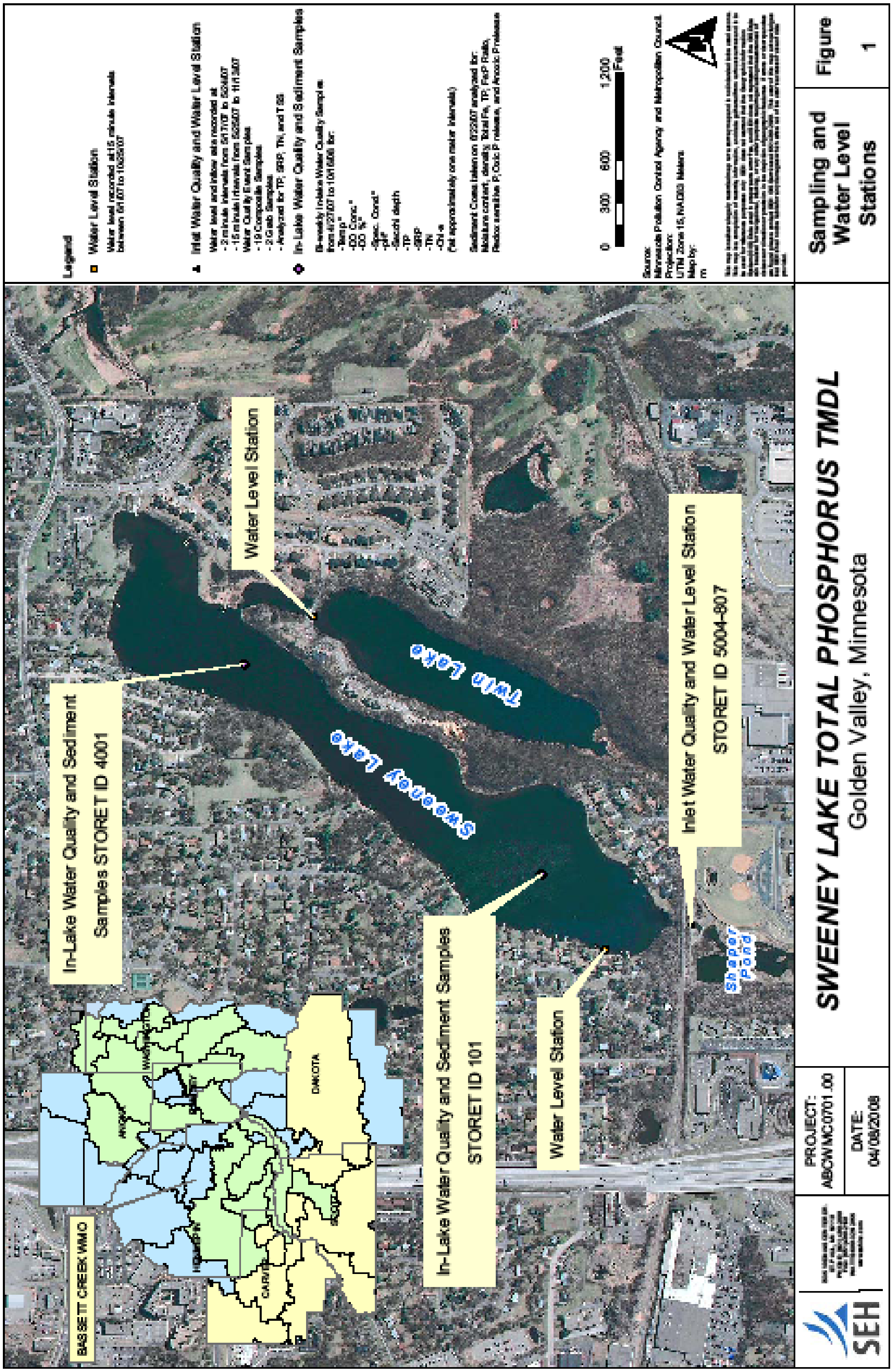
This section describes the characteristics of the Sweeney Lake watershed and of the Lake itself. Much of this information is taken from the *Sweeney Lake Watershed and Lake Management Plan* prepared by the Bassett Creek Watershed Management Commission (Barr, January 1994) and the *2008 Lake Water Quality Study: Sweeney Lake and Twin Lake* (Barr, 2009). A summary of the historic monitoring and results is included, with the more detailed information provided in the reference reports.

2.1 Watershed Characteristics

Sweeney Lake is within the Upper Mississippi River Basin in the Bassett Creek Watershed as shown in the inset in Figure 1. Sweeney Lake is oriented in a north-south direction with two deeper basins, one in each of the north and south ends of the Lake as shown in Figure 1. Surface inflow to the Lake comes from three general areas: direct drainage from the surrounding residential and commercial areas; inflow from the Schaper Pond outlet; and limited inflow from Twin Lake. A peninsula separates Sweeney Lake from Twin Lake with a small connection between the two lakes allowing flow from Twin into Sweeney Lake. During some storm event conditions, Sweeney Lake may flow into Twin Lake.

Sweeney Lake is located in Golden Valley, Minnesota; with contributing watershed areas within the City of Golden Valley and St. Louis Park as illustrated in Figure 2. The contributing watershed area is approximately 2,340 acres, excluding the lake surface area and 91 acres of land-locked area within the southern-most portion of the Spring Pond Drainage District.

The 1994 Sweeney Lake Management Plan defined seven drainage districts which are listed in Table 2.1 below. More detailed descriptions of each area are available in the 1994 Sweeney Lake Management Plan. Five of the districts listed contribute to the Schaper Pond system. Outflow from Sweeney Lake is through a weir structure located in the northeast corner of the Lake. Sweeney Lake has six storm sewer outfalls discharging into the lake including the inlet from Schaper Pond.


In-Lake Water Quality and Sediment
Samples STORET ID 4001
Water Level Station
Twin Lake
Sweeney Lake
Inlet Water Quality and Water Level Station
STORET ID 5004-807
In-Lake Water Quality and Sediment Samples
STORET ID 101
Water Level Station
Shaper Pond
BASSETT CREEK WMO
DAKOTA
SCOTT
CARVER
HENNEPIN
ANOKA
WASHINGTON
Legend
Water Level Station
Inlet Water Quality and Water Level Station
In-Lake Water Quality and Sediment Samples
0 300 600 1,200 Feet
Source:
Minnesota Pollution Control Agency and Metropolitan Council
Projection:
UTM Zone 15, NAD83 Meters
PROJECT:
ABCWMC0701.00
DATE:
04/08/2008
SWEENEY LAKE TOTAL PHOSPHORUS TMDL
Golden Valley, Minnesota
Sampling and
Water Level
Stations
Figure
1

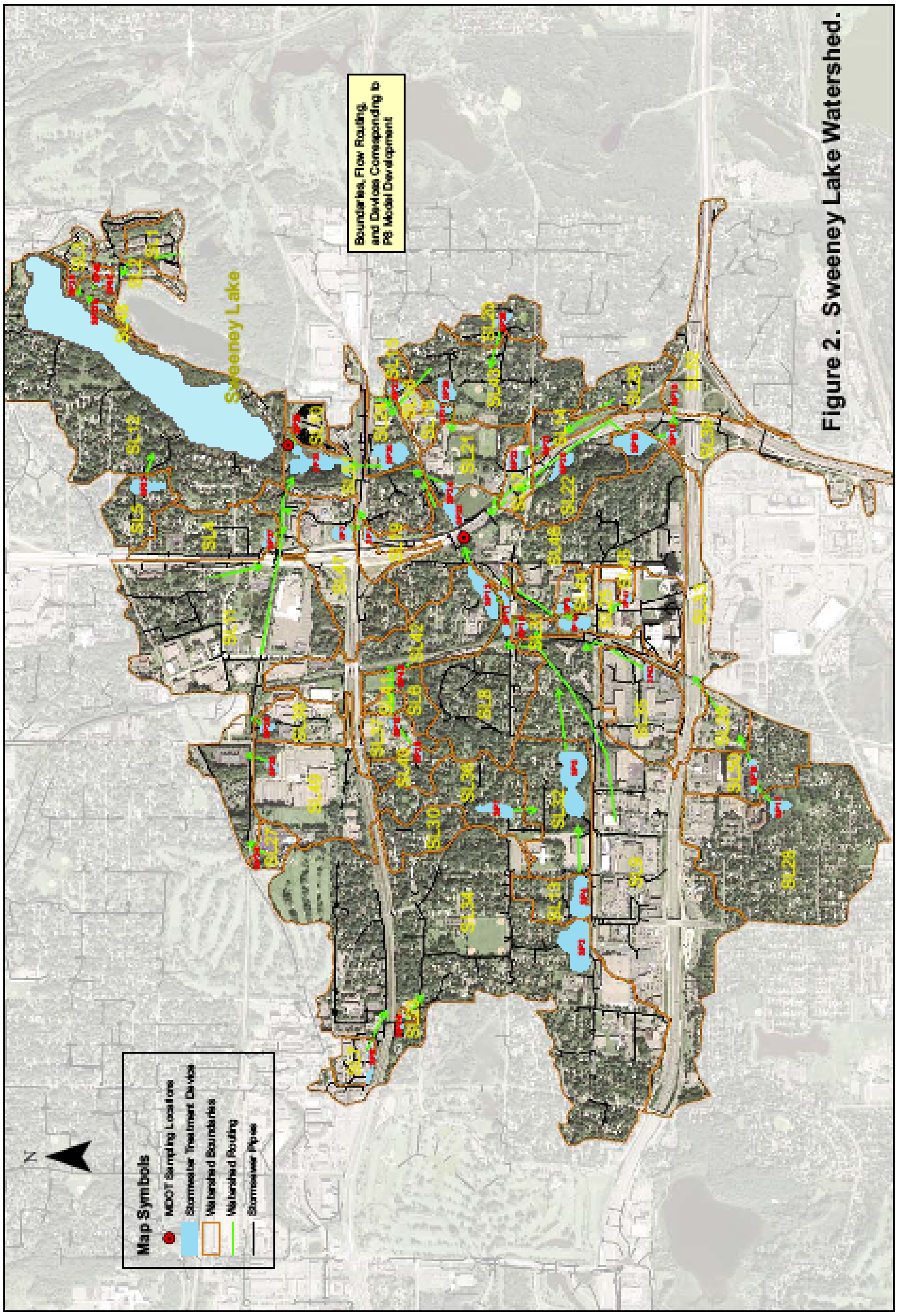


Figure 2. Sweeney Lake Watershed.

Table 2.1 Sweeney Lake Drainage Districts

Surface Inflow Point/Area	Drainage District	Area (acres)
Direct	Sweeney Lake Direct	205
Twin Lake Outlet	Twin Lake	75
Schaper Pond	West Breck	1,076
	South Breck	402
	Spring Pond*	112
	Railroad	312
	DNR	158
Total		2,340

* Does not include 91 acres of land-locked area within the Spring Pond District.

2.1.1 Climate and Precipitation

The climate in Minnesota is considered to be a humid continental-type climate which is characterized by large seasonal temperature variance and moderate precipitation typically occurring during the summer season. The average annual precipitation for the area is approximately 30 inches.

2.1.2 Land Use

The Sweeney Lake watershed is almost fully developed, with a mix of residential, commercial, institutional and open space land uses. More detailed descriptions of land uses within each drainage district are available in the *1994 Sweeney Lake Management Plan*. Since the writing of the 1994 Sweeney Lake Management Plan, the most significant change in land use has been the development of the peninsula between Twin and Sweeney Lake with low-density residential land use. For the purposes of this study, the land use within the watershed is not expected to change and, therefore, no reserve capacity is needed or provided for in the TMDL computations.

2.1.3 Soils

Hydrologic Soils Group of the soils relates to the runoff characteristics of the watershed and of the ability of the land to accommodate infiltration practices that can serve to reduce runoff volumes and loading to a given water body. Soils within the Sweeney Lake watershed range from hydrologic soil group (HSG) A to D soils, with much of the watershed being identified in the Soil Survey Manual for Hennepin County as having HSG A and B soils. However, much of the land is highly urbanized and, conditions are highly variable. The experience of City engineering staff and representatives of the Bassett Creek WMC indicates that much of the watershed is underlain by soils with high clay contents. Therefore, soil conditions along with the fully-developed nature of the watershed, result in somewhat limited opportunities for infiltration within the watershed.

2.2 Lake Characteristics

Sweeney Lake has a watershed-to-lake ratio of about 35:1, with a lake surface area of 67 acres. The Lake has a maximum depth of 27 feet and a mean depth of 12 feet. The littoral zone covers roughly 41 acres, which is 61 percent of the basin. The littoral zone is that portion of the lake that is less than 15 feet in depth, and is where the majority of the aquatic plants grow. Bathymetric information for Sweeney Lake was available as early as 1960 as illustrated in Figure 3. Figure 4 shows the in-lake monitoring locations on an updated bathymetric map.

2.2.1 Recreational Uses

Sweeney Lake provides water-based recreational opportunities including boating and fishing. There is a boat landing at the north end of the lake in Sweeney Park with a gated access point. The access is open to the public that use boats and canoes that do not need a trailer to launch.

2.2.2 Aquatic Life

Minnesota Department of Natural Resources (DNR) fish survey conducted in 1991 for Sweeney Lake revealed bluegill was the most abundant species, followed by black bullhead and pumpkinseed sunfish. Northern Pike were the most abundant predator species with a few largemouth bass also sampled. While not present in the 1991 survey results, recent reports indicate that some walleye have been caught by local anglers. A fish consumption advisory is currently in effect for all sizes of Largemouth Bass, recommending no more than 1 meal per week.

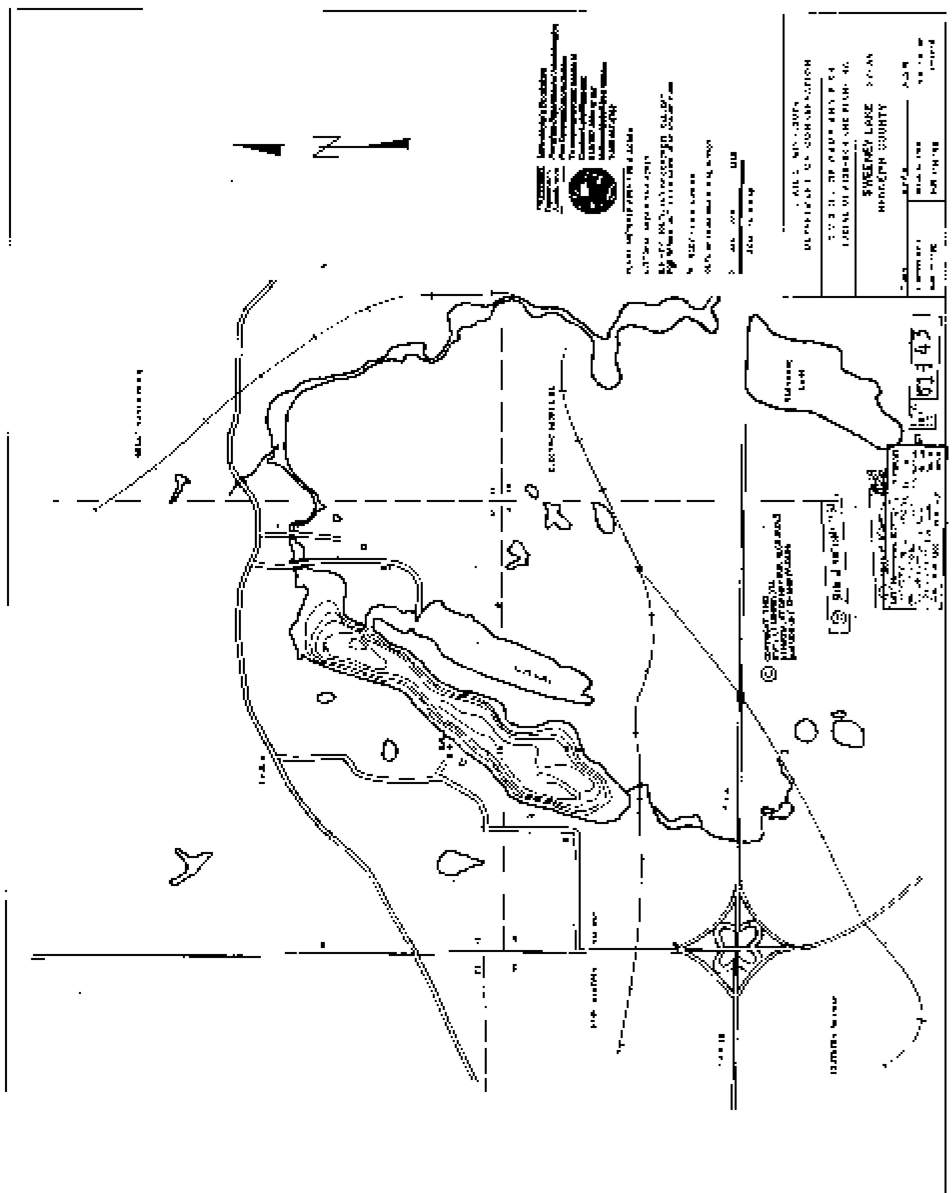
The fish species collected during the 1991 survey include:

- Yellow Perch — Yellow Bullhead — White Sucker
- Smallmouth Buffalo — Pumpkinseed Sunfish — Northern Pike
- Largemouth Bass — Hybrid Sunfish — Green Sunfish
- Common Carp — Bluegill — White Crappie
- Black Crappie — Black Bullhead

Fish kill was an important consideration during the workplan development for this TMDL study. The artificial aeration system has been operating year around for more than 30 years

Figure 3 - Sweeney Lake Bathymetry Map 1960.

Sweeney Lake - Total Phosphorus TMDL



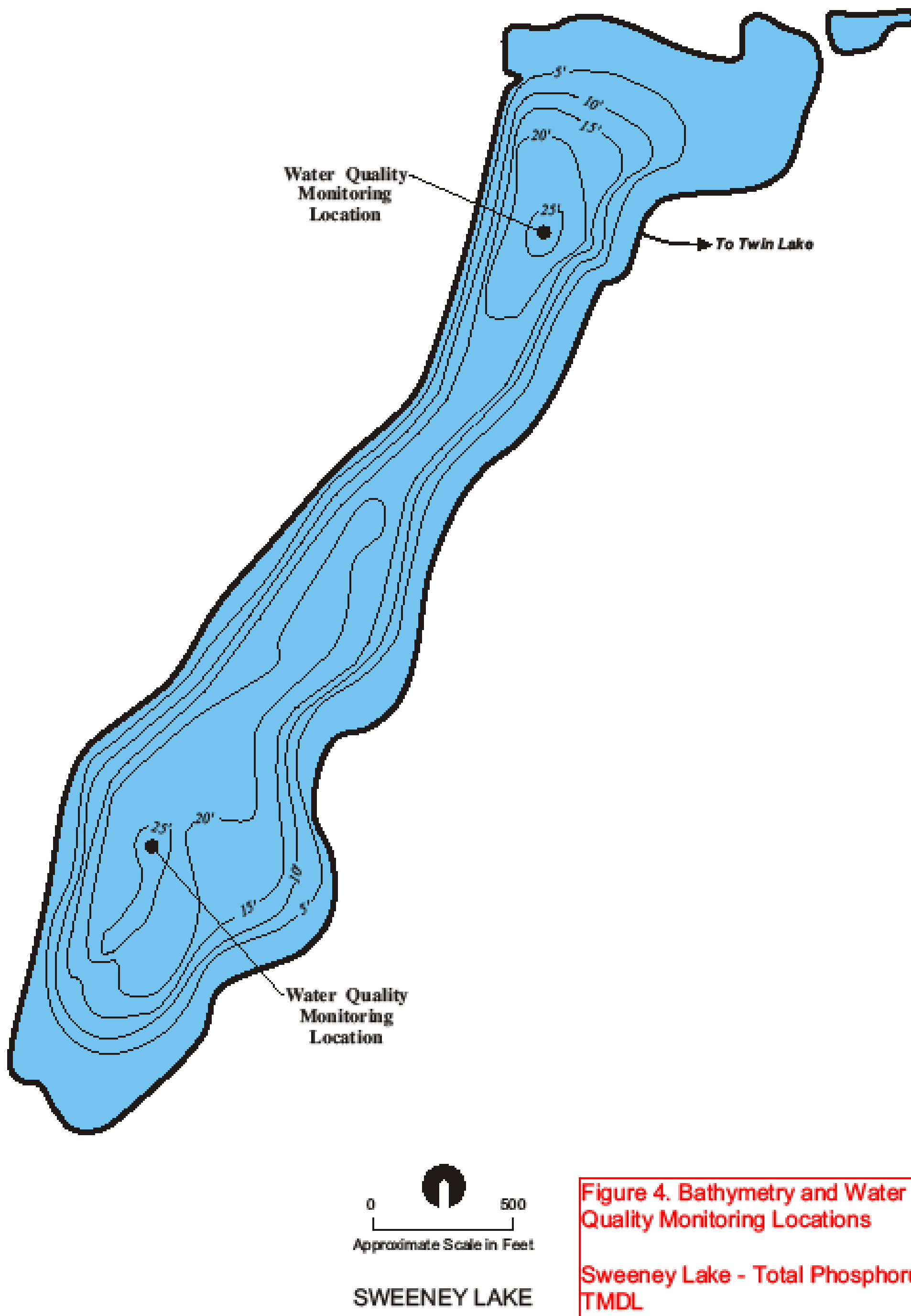


Figure 4. Bathymetry and Water Quality Monitoring Locations

Sweeney Lake - Total Phosphorus TMDL

and the focus of the monitoring was to evaluate the lake during the summer growing season under non-aerated conditions. Several lake residents own, and are responsible for, operation and maintenance of the aerators.

Fish kills occur when dissolved oxygen (DO) levels are so low that fish begin to die from the lack of oxygen. Fish kills commonly occur during the summer or winter. Summer kills are the result of high productivity (algae and macrophyte) that eventually senesce, and are subsequently broken down by bacteria. The breakdown by bacteria demands oxygen, which depletes DO in the water column. These conditions can result in a summer fish kill. Winter fish kills are the result of snow-covered ice that shades out photosynthesis under the ice. These conditions, coupled with a high sediment oxygen demand can deplete the DO under the ice and result in a fish kill. There are no known historical records of fish kills in Sweeney Lake dating back to at least the installation of the original artificial aeration system in about 1973.

Common carp have both direct and indirect effects on aquatic environments. Carp can uproot aquatic macrophytes during feeding and spawning that resuspends bottom sediments and nutrients. These activities can lead to increased nutrients in the water column ultimately resulting in increased nuisance algal blooms. There are carp and other rough fish present in Sweeney Lake and the population as of the 1991 survey was close to average for both numbers and size compared to area lakes. Given the depth and bathymetry of the lake, and the fact that the lake is destratified by aeration, it seems unlikely that carp would significantly enhance the transport of phosphorus from bottom waters to the lake surface.

2.2.3 Aquatic Habitat

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). Sweeney Lake is approximately 61 percent littoral and should support a healthy aquatic plant community.

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 outcompetes 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.

In the 2007 and 2008 monitoring seasons with the aeration system turned off, observations of lake residents indicated some new aquatic plants present that were not observed in the past. These plants were identified as typical vegetation and the presence may be attributed to improved water clarity in 2007 and 2008. The *2008 Lake Water Quality Study: Sweeney Lake and Twin Lake* (Barr, 2009) indicates that two undesirable plant species, curlyleaf pondweed and purple loosestrife, have been observed in the lake in 2005 and 2008.

While not part of this TMDL workplan, macrophyte surveys have been conducted on Sweeney Lake. Figure 5 summarizes the results of the June 2005 Macrophyte Survey completed by the Bassett Creek WMC.

2.3 Historical Water Quality Data

The water quality of Sweeney Lake has been monitored for a range of parameters dating back to 1972. Since that first monitoring, Sweeney Lake has been monitored in 1977, 1982, 1985, 1992, 1996 and 2000-present. Results of this historical monitoring are summarized in Figure 6.

Parameters monitored and sampled as part of this TMDL workplan are listed on Figure 1. A more detailed description of the parameters sampled for and analyzed is available in the *2008 Lake Water Quality Study: Sweeney Lake and Twin Lake* (Barr, 2009). The key conclusions in that report include:

- In 2008, Sweeney Lake water quality (32 ug/L summer average concentration) met the state standard of 40 ug/L total phosphorus concentration during the critical summer period.
- Sweeney Lake water quality has improved when compared to 2007 and 2005 with chlorophyll-a and total phosphorus decreasing and Secchi depth increasing. The water quality is the best observed since 1972.

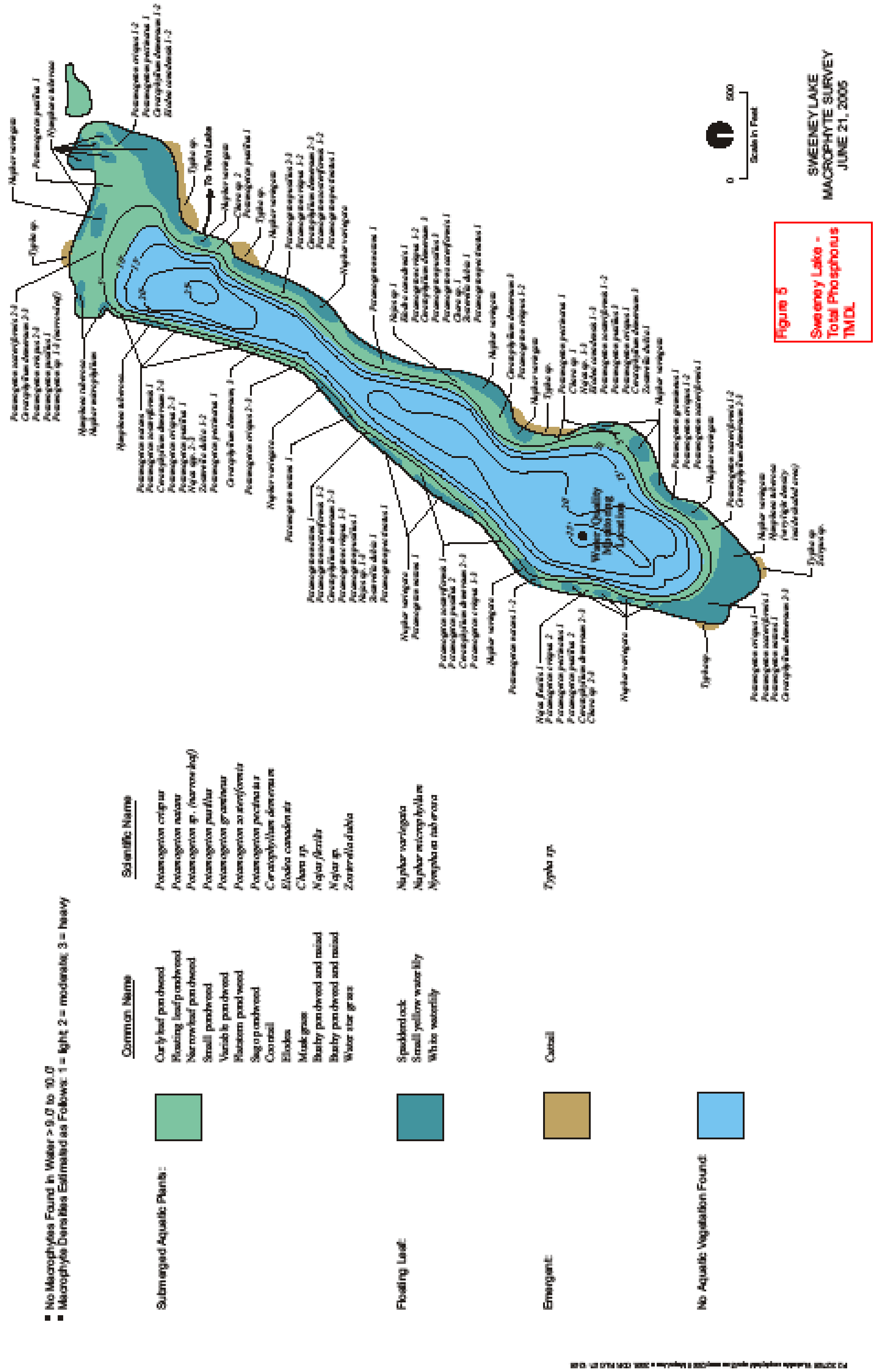
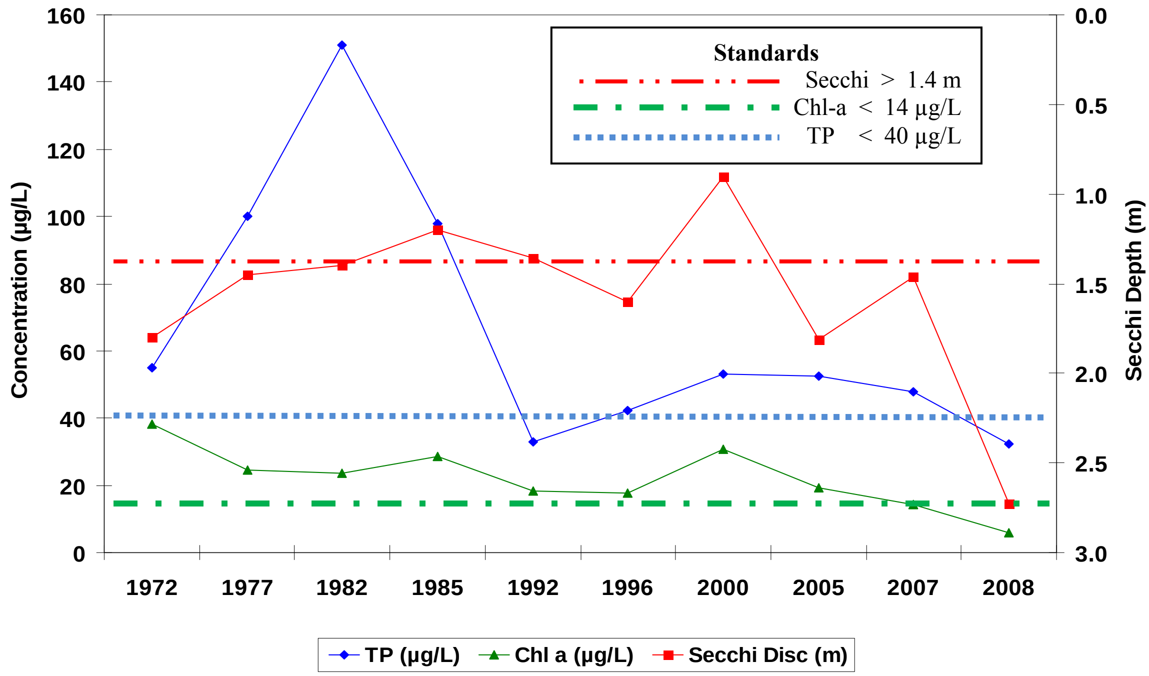

SWEENEY LAKE
MACROPHYTE SURVEY
JUNE 21, 2005
Figure 5
Sweeney Lake - Total Phosphorus TMDL
Submerged Aquatic Plants:
Floating Leaf:
Emergent:
No Aquatic Vegetation Found:
Common Name
Scientific Name
Cattail
Typha sp.
Scale in Feet
0
500

Figure 6. Historical Water Quality in Sweeney Lake



- Phosphorus buildup in the lake's bottom waters during 2008 resulted from internal loading. Because the aeration system was not in operation during 2008, lake mixing did not occur and phosphorus was trapped in the lake's bottom waters during the summer.
- A comparison of 2005 and 2008 data indicate that the lake's aeration system causes mixing of the phosphorus from the lake's bottom waters into the surface waters.

The impact of aeration on the lake's water quality has been a key point of discussion throughout this TMDL study. While the data for 2007 and 2008 were collected with the aeration system not in operation, the historical data collected and analyzed to date do not provide sufficient basis to conclude if the aeration is reducing the internal load or increasing the internal load. The improved water clarity in these two years may relate to not having the aeration system in operation. However, 2007 and 2008 were lower than average precipitation years and the improved water quality may also be a result of the reduced external loading resulting from the lower precipitation. Additional monitoring of the lake under non-aerated conditions is a key recommendation of the 2008 Water Quality Study and of this TMDL. Additional discussion on this topic is contained in Section 8 of this report.

Sweeney Lake
Total Phosphorus TMDL

WATER QUALITY STANDARDS

3.0 Water Quality Standards

3.1 Impaired Waters

The Minnesota Pollution Control Agency (MPCA) first included Sweeney Lake on the 303(d) impaired waters list for Minnesota in 2004. The lake is impaired by an excess nutrient concentration, which inhibits aquatic recreation. The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. The project was originally scheduled to be started in 2009 and completed in 2012.

Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the water body; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDL studies within a watershed or basin.

3.2 Water Quality Standards And Endpoints

Minnesota's standards for nutrients limit the quantity of nutrients which may enter waters. 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. Table 3.1 lists the thresholds for listing lakes on the 303(d) list of impaired waters in Minnesota that were in place when Sweeney Lake was listed.

Table 3.1. Trophic status thresholds for determination of use support for lakes (Sweeney Lake thresholds highlighted).

305(b) Designation	Full Support			Partial Support to Potential Non-Support			
303(d) Designation	Not Listed			Review	Listed		
Ecoregion	TP (ppb)	Chl-a (ppb)	Secchi (m)	TP Range (ppb)	TP (ppb)	Chl-a (ppb)	Secchi (m)
Northern Lakes and Forests	< 30	<10	> 1.6	30 – 35	> 35	> 12	< 1.4
(Carlson's TSI)	(< 53)	(< 53)	(< 53)	(53-56)	(> 56)	(> 55)	(> 55)
North Central Hardwood Forests	**< 40**	**< 14**	**> 1.4**	40 - 45	> 45	> 18	< 1.1
(Carlson's TSI)	**(<57)**	**(<57)**	**(<57)**	(57 – 59)	(> 59)	(> 59)	(> 59)
Western Cornbelt Plain and Northern Glaciated Plain	< 70	< 24	> 1.0	70 - 90	> 90	> 32	< 0.7
(Carlson's TSI)	(< 66)	(< 61)	(< 61)	(66 – 69)	(> 69)	(> 65)	(> 65)

3.3 Endpoint Used For This TMDL

The numeric target used to list this lake was the phosphorus standard for Class 2B waters in the North Central Hardwood Forest ecoregion (40 µg/L). Therefore, this TMDL presents load and wasteload allocations and estimated load reductions assuming an endpoint of 40 µg/L.

One of the two other eutrophication standards must be met: chlorophyll-a and Secchi depth (see Table 3.2). 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 3.2 numeric standards for chlorophyll-a and Secchi depth are 14 µg/L and 1.4 meters, respectively.

Table 3.2. Numeric Targets for Lakes in the North Central Hardwood Forest Ecoregion.

Parameters	North Central Hardwood Forest	
	Shallow[1]	Deep
Phosphorus Concentration (µg/L)	60	**40**
Chlorophyll-a Concentration (µg/L)	20	**14**
Secchi disk transparency (meters)	>1	**>1.4**

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).

3.4 Natural Background Loads

Another consideration when evaluating nutrient loads to lakes is the natural background load. Ultimately, the background load represents the load the lake would be expected to receive under natural, undisturbed conditions. This load can be determined using ecoregion pre-settlement nutrient concentrations as determined by diatom fossil reconstruction. Diatom inferred total phosphorus concentrations are presented in Table 3.3.

Table 3.3. Pre-settlement total phosphorus concentrations based on water quality reconstructions from fossil diatoms.

Parameter	North Central Hardwood Forest	
	Shallow[1]	Deep
Phosphorus concentration (µg/L)	47	**26**

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).

A 2002 MPCA study reconstructed pre-settlement lake conditions based on diatom assemblages in soil cores from many different representative lakes across the state. Sweeney Lake was not included in the study. Based on the diatom fossils, pre-settlement concentrations were approximately 26 µg/L for deep lakes in the North Central Hardwood Forests ecoregion.

Sweeney Lake
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SOURCE ASSESSMENTS

4.0 Source Assessments

Understanding the sources of nutrient loading to a water body is a critical component of developing a TMDL for nutrient impairment. A summary of the potential sources of nutrient loading to the lake is provided in this section.

4.1 Permitted Sources

4.1.1 Wastewater

Permitted wastewater sources can range from industrial effluent to municipal wastewater treatment plants. No known permitted wastewater sources are present in the Sweeney Lake subwatershed.

4.1.2 Stormwater

Phosphorus transported by stormwater represents one of the largest contributors of phosphorus to lakes in Minnesota. Phosphorus export from urban watersheds can often rival that of agricultural watersheds. Impervious surfaces in the watershed improve the efficiency of water moving to streams and lakes resulting in increased transport of phosphorus into local water bodies. Phosphorus in stormwater is a result of transporting organic material such as leaves and grass clippings, fertilizers, and sediments to the water body. All of these materials contain phosphorus which can impair local water quality. Consequently, stormwater is a high priority pollution concern in urban and urbanizing watersheds.

There are permitted stormwater sources in the Sweeney Lake subwatershed. National Pollution Discharge Elimination System (NPDES) permits for small municipal separate storm sewer systems (MS4) have been issued to the cities of Golden Valley and St. Louis Park, as well as to Hennepin County and the Minnesota Department of Transportation (Mn/DOT). All four of these MS4s are covered under the General NPDES MS4 Permit No. MN R040000. Each of these MS4 developed a Storm Water Pollution Prevention Program

(SWPPP) in 2003 after issuance of the original MS4 permit, then updated their SWPPPs and obtained coverage under the revised permit in 2006. Table 4.1 provides summarizes the annual phosphorus load and relative percent contribution of these MS4s to Sweeney Lake.

Table 4.1. Permitted MS4 Contribution to Watershed Phosphorus Load

MS4	Permit #	Portion of Annual Load	
		TP Load (kg)	Percent of Total
Golden Valley	MS400021	514	77
St. Louis Park	MS400053	62	9
MnDOT	MS400170	91	14
Hennepin County	MS400138	-	<1
Totals		**667**	**100**

4.2 Non-Permitted Sources

4.2.1 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 stormwater 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.

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/km2-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 (kg/year) for Sweeney Lake was calculated by multiplying the lake area (km2) by the atmospheric deposition rate (kg/km2-year). For example, in a wet precipitation year the atmospheric load to Sweeney Lake would be 29.0 kg/km2-year times the lake surface area (0.27 km2), which is 7.9 kg/year. Converting this to the 122 day summer critical period for the 2004 monitoring period which had 16.7 inches of rainfall between June1 and September 30 gives approximately 3.8 kg of atmospheric load.

4.2.2 Groundwater Contributions

Groundwater contributions were evaluated and determined to be negligible due to the large watershed-to-lake ratio and rapid lake level response to storm events.

4.2.3 Internal Phosphorus Loading

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. Large internal loads are the result of significant amounts of phosphorus in lake-bottom sediments that are released under specific conditions. Phosphorus can build up in lake-bottom sediments as part of the eutrophication process which can be accelerated and exacerbated by an increase in phosphorus load export from developing watersheds.

Internal loading is triggered by sediment anoxia whereby poorly bound phosphorus is released in a form readily available for phytoplankton production. Internal loading can also result from sediment resuspension that may result from rough fish activity or prop wash from boat activity. These factors may all affect internal phosphorus cycling in Sweeney Lake.

Internal loading from the lake sediments was estimated using sediment release rates determined from sediment cores collected from the lake in 2007 by the US Army Corps of Engineers, ERDC Eau Galle Aquatic Ecology Laboratory. Internal loading of phosphorus from sediments was determined from sediment cores collected in the north and south hypolimnetic basins of Sweeney Lake (see Figure 1). Lake water was collected for incubation with the collected sediment. Six cores were collected at these stations for analysis of P release from sediment under oxic and under anoxic conditions using methods outlined in James and Barko (1991). The full report, *Internal Phosphorus Loading and Sediment Characteristics, Sweeney Lake, Minnesota* (ERDC, 2007), is available on the project webpage and is included as Appendix B.

Sediments at both stations exhibited a high moisture content and low sediment density, indicative of fine-grained particles. Sediment Phosphorus concentrations were very high in comparison to levels in other Minnesota metropolitan lakes. Results overall suggested the potential for high rates of Phosphorus release under anoxic conditions and that sediments might contribute (although to a much lesser degree) to the Phosphorus budget even under highly oxidized conditions. Rates of Phosphorus release from the sediments were 5 to 10 times greater under anoxic conditions and very high relative to other systems. These results suggested the potential for soluble Phosphorus accumulation in the hypolimnion during periods of summer anoxia.

Internal loading data based on the sediment core analyses, results in an estimated 261 kg of internal load over the summer critical period evaluated. This result is based on applying the oxic release rate to the littoral zone of the lake (less than 15 feet in depth) and the anoxic rate to the area deeper than 15 feet. This result is slightly higher than the internal load computed during the lake response modeling of 145 kg, but still compares well, given this simplified approach to estimating the areas to which each release rate would apply. Section 6.1.2 identifies the internal load component.

Sweeney Lake
Total Phosphorus TMDL

LOADING ANALYSIS

5.0 Loading Analysis

The TMDL work plan identified the need to assess all significant sources of nutrient loading to Sweeney Lake. External loading sources including stormwater run-off, direct overland flow, and groundwater contributions were monitored and/or estimated and used to update a previously developed watershed loading model. An overall nutrient budget was developed using both internal and external loading sources to quantify the relative contribution of internal load and external load.

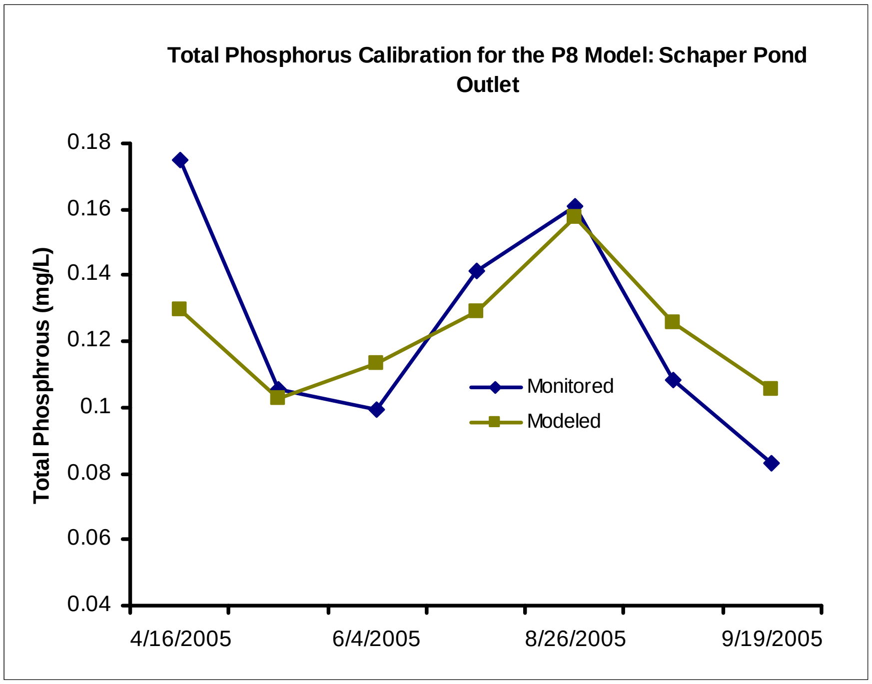
One of the key elements of this project was to evaluate the lake response under non-aerated conditions. While this was completed by monitoring the lake for two years without the aeration system in operation during the growing season, these years also had lower than normal precipitation during this critical loading period. Therefore a clear conclusion on the effect of aeration on internal loading could not be reached.

5.1 Selection of Models and Tools

5.1.1 Watershed Modeling

An existing P8 model (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds) was updated and calibrated with flow and water quality monitoring data from 2004 and 2005. The water quality calibration was validated using total phosphorus data collected at the Schaper Pond outfall in 2007 and 2008. The P8 model was calibrated using flow and water quality (phosphorus) data that were collected at two points in the Sweeny Lake watershed, one at the north end of Schaper Pond where it discharges into Sweeney Lake and the other at the MnDOT monitoring station between Turners and Breck Pond. Figure 7 shows the water quality (total phosphorus) calibration fit at the Schaper Pond monitoring station. This calibration primarily consisted of changing the build-up and wash-off functions provided in P8. Calibration was performed per storm event in which several sets of total phosphorus samples were collected throughout the storm event.

Figure 7. TP Calibration for the P8 Model at Schaper Pond



The P8 model was selected because it was easily updated and calibrated with flow and water quality data that was collected during the study. The calibrated P8 model is well suited to predict flow conditions and phosphorus loads to Sweeney Lake considering the BMPs already in place within the watershed and those that are being evaluated for possible implementation projects to achieve the load reductions identified in the TMDL. P8 can evaluate load reductions for physical practices like ponds and rain water gardens as well as management practices like street sweeping frequency. The details of the P8 modeling can be found in Appendix A.

5.1.2 Lake Response Modeling

Two models were used to estimate changes in external and internal phosphorus loading on phosphorus levels in Sweeney Lake: (1) US Army Corps of Engineer's BATHTUB Model and (2) a finite difference spreadsheet model based upon equations published in Pilgrim et al. 2007, A Method for Comparative Evaluation of Whole-lake and Inflow Alum Treatment.

Water Research. 41: 1215-1224 and equations published in Thomann and Mueller. 1987. Principles of Surface Water Quality Modeling.

The BATHTUB model predicts eutrophication-related water quality conditions (e.g., phosphorus, nitrogen, chlorophyll- a, and transparency) using empirical relationships previously developed and tested for reservoir applications. Physical lake characteristics and measured water quality of lake and inflow samples were used to set-up and calibrate a BATHTUB model representing Sweeney Lake for the 2007 and 2008 monitoring years. The Second Order Decay model was used from the menu of BATHTUB relationships as it gave the best fit to the monitored data assuming without specifying an internal load. The Canfield-Bachmann natural lake model, which was developed for northern temperate lakes, was also used to model lake phosphorus concentration response. However, the Canfield-Bachman model did not fit the monitored data as well as the Second Order Decay model. The BATHTUB modeling details can be found in Appendix B.

The spreadsheet model created by Barr (described above) was also used because the BATHTUB model was not able to accurately capture the rapid change in phosphorus in Sweeney Lake. This is largely due to frequent large inflows, which can reach upwards of 40 cfs. Sweeney Lake is small and has a very short residence time (1 to 2 months), and hence phosphorus flushes in and out the lake rapidly. The finite difference lake model developed by Barr was used to capture the rapid changes in phosphorus and determine internal phosphorus loading during the mid to late summer months.

Figures 8a and 8b show the results of lake calibration using the 2007 and 2008 lake monitoring data (averaged for both bays, surface samples). The results demonstrate that the model can be used to evaluate the response of Sweeney Lake to external and internal phosphorus load reductions.

Figure 8A. TP Lake Model Calibration for 2007

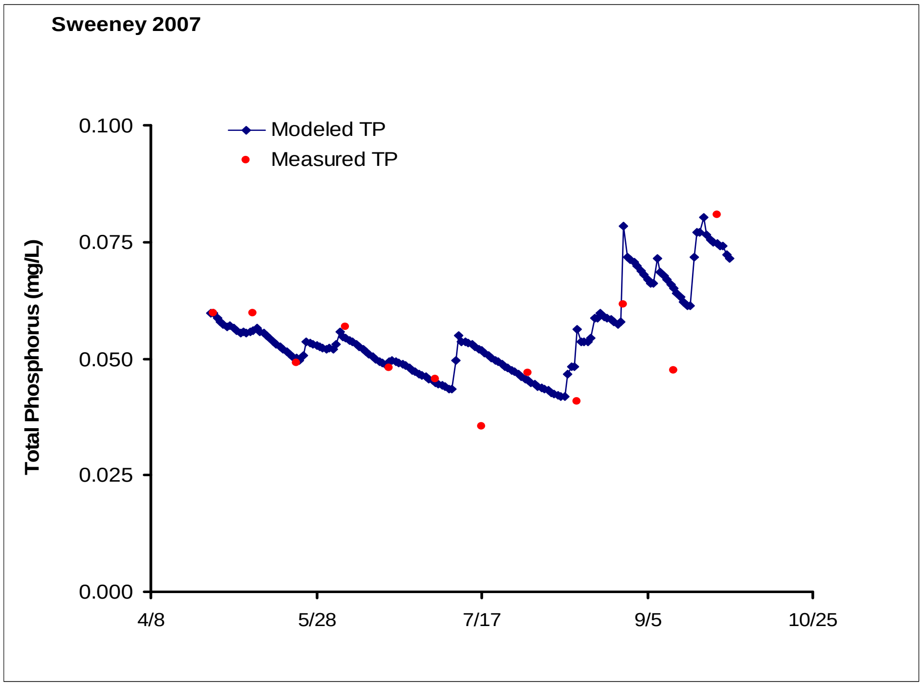
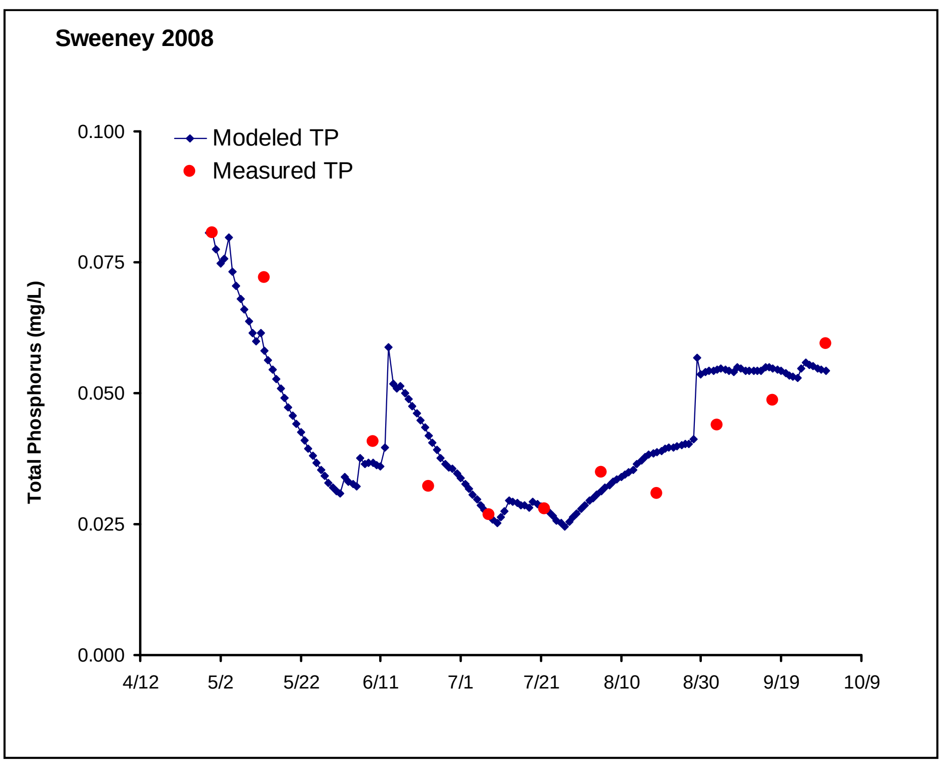


Figure 8B. TP Lake Model Calibration for 2008



5.2 Watershed Loads

Watershed total phosphorus loads were estimated from the calibrated P8 model. From that model annual loads contributed by each MS4 were estimated and are presented in Table 4.1. The percent of the total load contributed by each MS4 also roughly corresponds to the percent of the watershed area each entity is responsible for. These relative portions are the basis for allocating the individual load to MnDOT and the categorical load to Golden Valley and St. Louis Park.

5.3 Internal Loads

Internal phosphorus loading is a process where phosphorus releases from lake bottom sediments during low oxygen concentrations. This begins to occur typically in early summer when oxygen in bottom waters directly above the lake bottom drop to 4 mg/L and below. Typically, the degree of internal loading is a result of the magnitude of external loading. High internal loading is usually the result of several decades of excessive external loading.

Even though internal loads for a lake may be high, they may not affect surface water phosphorus levels if the internal loads cannot reach the surface. Monitoring data discussed below demonstrate several important functions in Sweeney Lake that relate to internal loading and transport of internal loading to the surface. The 2008 data demonstrate that oxygen levels are very low and promote phosphorus release from lake sediments. The data also show that phosphorus released from lake sediments mixes in the lake and transports to the surface. Hence, internal loading affects surface levels of total phosphorus. The 2005 data demonstrate that dissolved oxygen levels in bottoms waters, although higher because of aeration, are low enough to allow phosphorus release from bottom sediments in the summer. The 2005 monitoring data demonstrate that due to aeration the lake is completely mixed and phosphorus released from sediments is rapidly transported to the lake surface. Hence, internal loading is important with and without aeration. The precise difference in internal loading with and without aeration is difficult to evaluate with existing data and would require more sophisticated modeling approaches.

5.3.1 Temperature and Dissolved Oxygen

Understanding lake stratification is important to the development of both the nutrient budget for a lake as well as ecosystem management strategies. Lakes that are dimictic (mix from top to bottom in the spring and fall) can have very different nutrient budgets than lakes that are completely mixed all year. Typically, temperature drives the stratification of a lake because water density changes with water temperature. However, the larger impact usually lies with the dissolved oxygen profile. As cooler, denser water is trapped at the bottom of a lake, it can become devoid of oxygen affecting both aquatic organisms and the sediment biogeochemistry.

Figures 9A and 9B show how Sweeney Lake functions in the non-aerated condition during 2008. Figure 9A shows the temperature over the summer monitoring period which is generally stratified with the colder water trapped at the bottom except during the early spring and late fall.

Figure 9A. 2008 Growing Season Temperature Profile

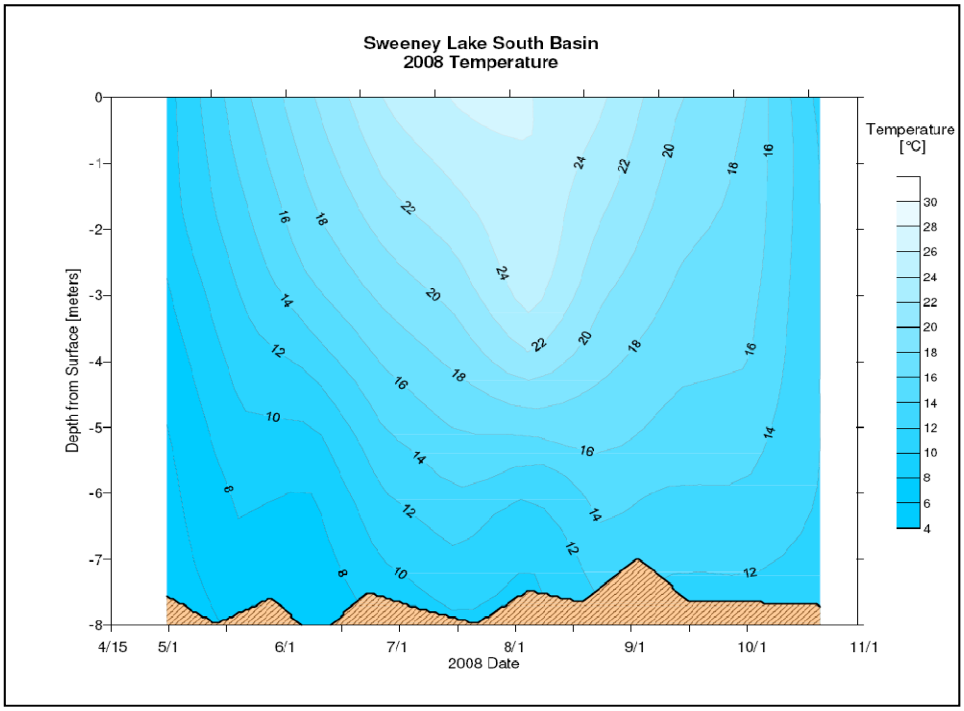


Figure 9B. 2008 Growing Season Dissolved Oxygen Profile

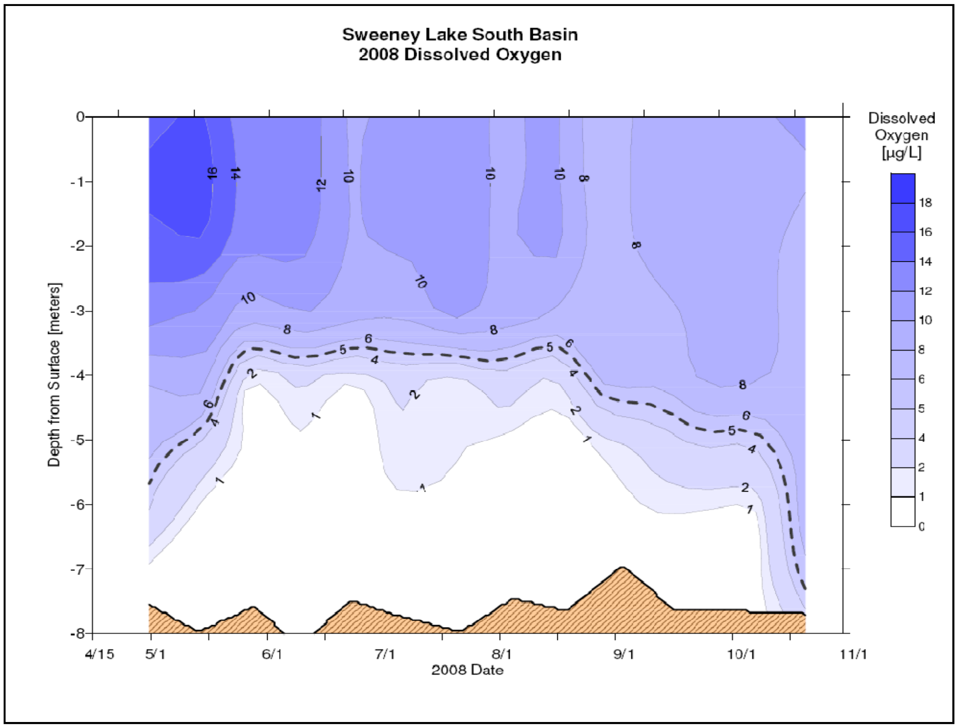
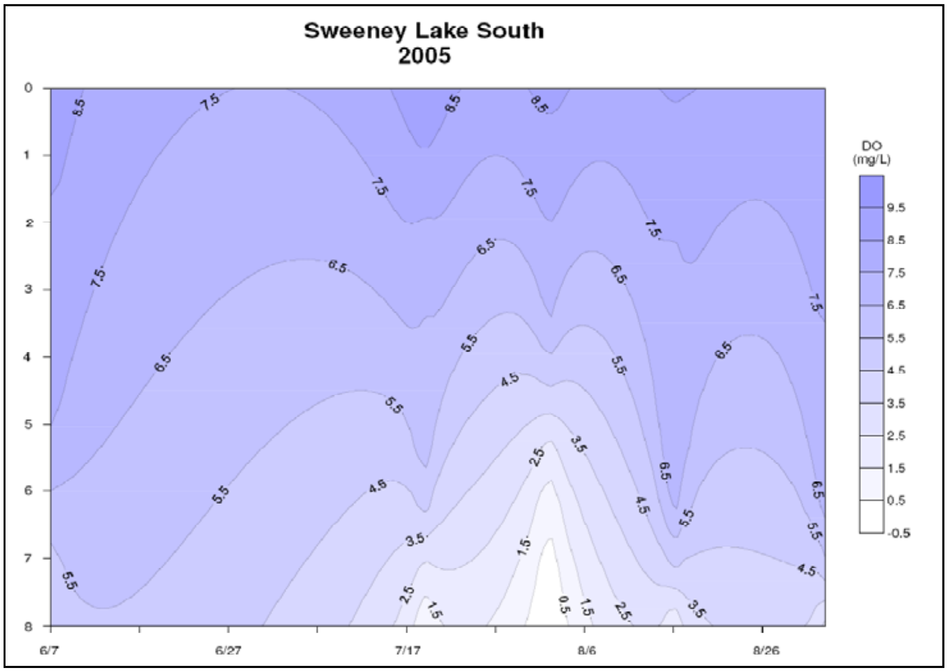


Figure 9B shows the dissolved oxygen (DO) over the same period and illustrates that the bottom waters become anoxic early in the growing season under non-aerated conditions. Figure 9C shows the DO under aerated conditions and illustrates that the oxygen levels are still low enough to have internal loading from the sediments. The bottom waters stay anoxic until the fall turnover when the lake mixes in early to mid October.

Figure 9C. 2005 Growing Season Dissolved Oxygen Profile



5.3.2 Phosphorus

Lake algal production is typically limited by phosphorus and nitrogen availability. Minnesota lakes are almost exclusively limited by phosphorus; however excessive phosphorus concentrations can lead to nitrogen limiting conditions. Phosphorus and nitrogen are measured to determine the availability of the nutrients for algal production. Dissolved and orthophosphorous are the most readily available forms of phosphorus while total phosphorus is a measure of all the phosphorus, bound and unbound.

Figure 10A shows the total phosphorus concentration in Sweeney Lake during the 2008 summer growing season. Without aeration, a thermocline develops at approximately the 5.5 meter depth; however, the plot demonstrates that there is some mixing of bottom phosphorus with surface waters (see mixing in mid-August and subsequent increase in surface phosphorus during a period of limited or no rainfall). Figure 10A also shows that the lake is mixed in the early spring prior to development of the thermocline.

Figure 10B shows the total phosphorus in Sweeney during 2005 while the lake was being aerated throughout the summer growing season. The lake remains mixed for the entire year, with fairly constant TP concentrations throughout the profile.

Figure 10A. 2008 Total Phosphorus Profile – No Aeration

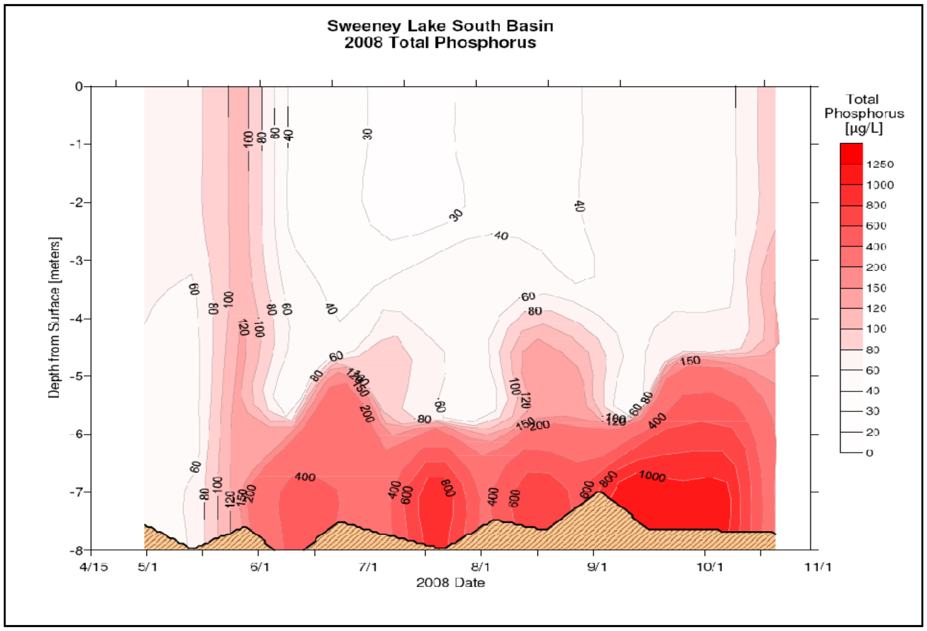


Figure 10B. 2005 Total Phosphorus Profile - Aerated

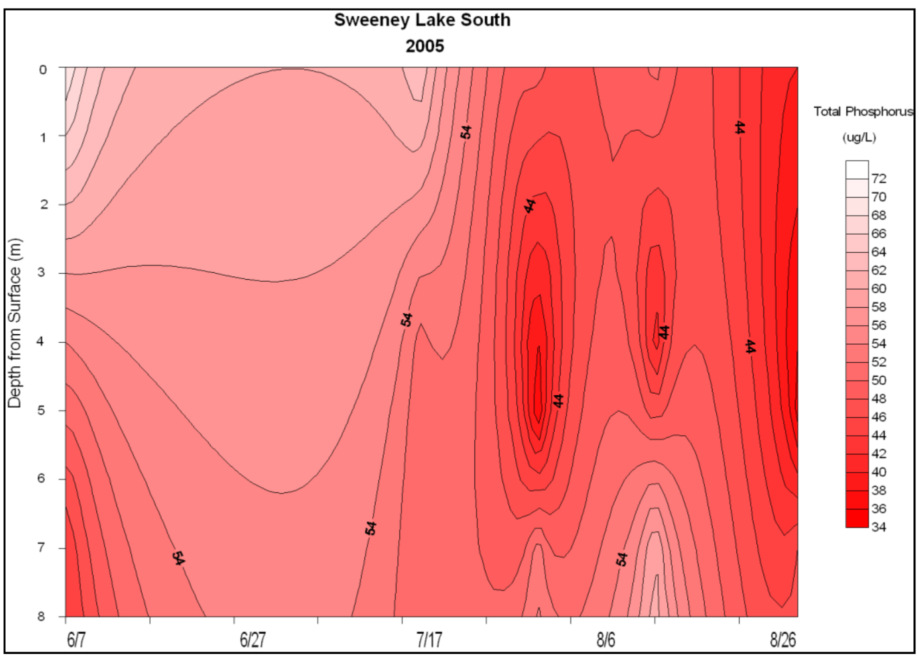


Figure 11 shows a comparison of modeled versus monitored phosphorus in Sweeney Lake surface waters in 2004. It shows how phosphorus levels are affected by large storm events and how fairly high phosphorus levels are maintained even when large storm events are not occurring (i.e. internal phosphorus loading is keeping phosphorus levels elevated).

Figure 11. 2004 Growing Season Modeled versus Monitored TP

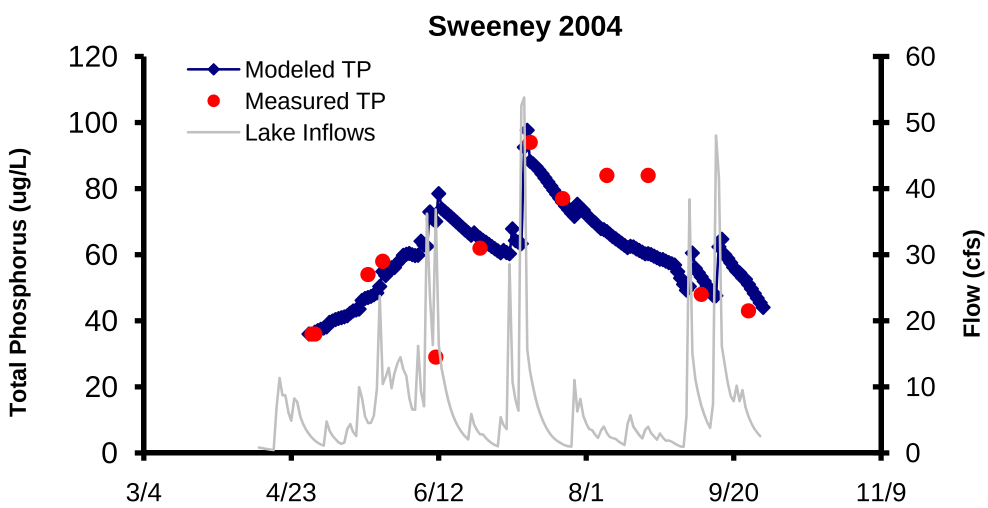
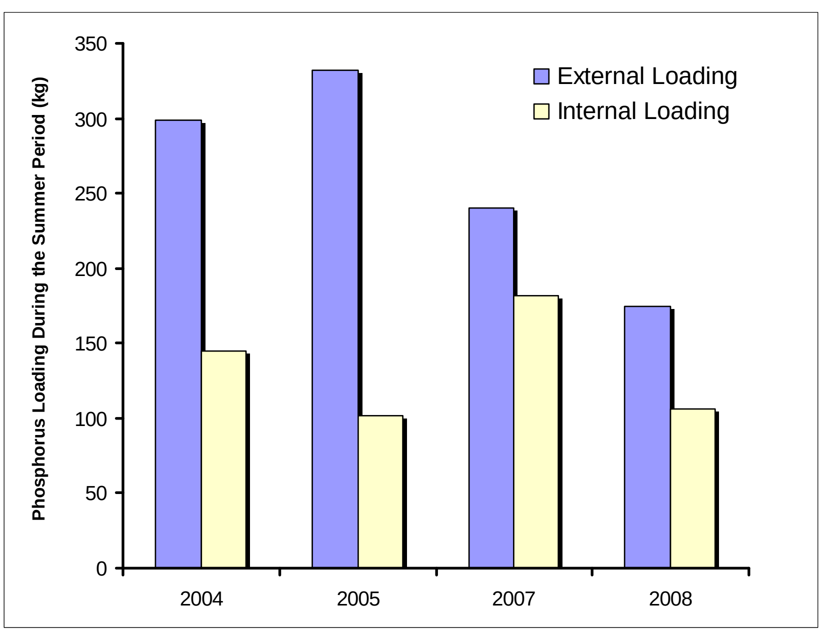


Figure 12 shows a comparison of external and internal loading during two years (2004, 2005) when the aeration system was operating and two years of this study with the aeration system turned off. There is a significant portion of internal loading under

Figure 12. Internal and External TP Loading Comparisons



both conditions and the external loading is dependent on the total rainfall during the monitoring period, which was higher in 2004 and 2005 as compared to 2007 and 2008.

5.3.3 Chlorophyll-a and Secchi Depth

Algal biomass can be measured directly by developing cell-by-cell counts and volumes. However, this is time intensive and often expensive. Chlorophyll-a has been shown to be a representative estimation of algal biomass and is inexpensive and easy to analyze.

Secchi depth is also a predictor of algal production by measuring the clarity of lake water. This is accomplished by lowering a round disk shaded black and white over the shady side of the boat and recording the depth at which the disk is no longer visible.

Figure 6 in Section 2.3 shows the historical water quality in Sweeney Lake dating back to the first monitoring in 1972. Sweeney Lake's water quality was improved in 2008 when compared to 2007 and 2005 with chlorophyll-a and total phosphorus decreasing and Secchi depth increasing. In 2008, Sweeney Lake's water quality (32 ug/L summer average concentration) met the state standard of 40 ug/L total phosphorus concentration during the critical summer period. The water quality overall is the best observed since 1972 and met the State standards for all three parameters (TP, chloropyhll-a, Secchi depth).

As stated previously, data for 2007 and 2008 were collected with the aeration system not in operation. However, the historical data collected and analyzed to date do not provide sufficient basis to conclude if the aeration is reducing the internal load or increasing the internal load. The improved water clarity in 2007 and 2008 may relate to not having the aeration system in operation. However, data for 2005 when the aeration system was in operation also shows relatively good water quality compared to historical conditions. 2007 and 2008 were lower than average precipitation years and the improved water quality is also a result of the reduced external loading resulting from the lower precipitation. Additional monitoring of the lake under non-aerated conditions is a key recommendation of the 2008 Water Quality Study and of this TMDL.

Sweeney Lake
Total Phosphorus TMDL

TMDL ALLOCATIONS

6.0 TMDL Allocations

The TMDL, or phosphorus loading capacity, must be allocated among several sources to achieve the numeric target of 40 µg/L of total phosphorus. This TMDL presents load and wasteload allocations and estimated load reductions to achieve this endpoint. The TMDL equation is shown below; with WLA representing the wasteload allocation (4.66 lb/day), LA the load allocation (1.24 lb/day), MOS the margin of safety (0 lb/day with a 5% MOS applied to the in-lake concentration target) and RC is the reserve capacity (0 lb/day).

TMDL = WLA + LA + MOS + RC

5.90 lb/day TP = 4.66 lb/day + 1.24 lb/day + 0 lb/day + 0 lb/day

6.1 Load Allocation Components

6.1.1 Wasteload Allocations

Stormwater discharges regulated under the NPDES permit program are considered wasteloads. There are no industrial dischargers in the watershed. The Wasteload Allocations for all permitted stormwater sources except the MnDOT are combined in this TMDL as Categorical Wasteload Allocations (WLA) assigned to all permitted dischargers in the contributing watershed. As stated earlier in the TMDL, the Categorical approach is well suited to situations like Sweeney Lake where there exists a local commitment to implement the improvements in a cooperative manner through an entity like the Bassett Creek WMC. The pollutant load from construction stormwater is considered to be less than 1 percent of the TMDL and is difficult to quantify. Consequently, pollutant loading from construction activities and industrial stormwater sources are included in the WLA.

Each permittee has agreed to implement BMPs to the maximum extent practicable. This collective approach allows for greater reductions for some permit holders with greater opportunity and less for those with greater constraints. The collective approach is to be outlined in an implementation plan. 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, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit. Industrial storm water activities are considered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit." MnDOT is assigned an Individual WLA.

6.1.2 Load Allocations

The Load Allocation includes atmospheric deposition and internal loading. The atmospheric load was calculated by the method described in Section 4.2.1., resulting in an atmospheric load of 8.4 lb (3.8 kg) over the 122 day summer period.

Internal loading was computed as part of the lake response modeling and was also compared to rates obtained from the sediment cores taken from the lake and analyzed in 2007. Internal loading for the 2004 baseline condition is 319 lb (145 kg) over the 122 day critical summer period.

6.1.3 Margin of Safety

A margin of safety (MOS) has been incorporated into this TMDL using conservative assumptions and using the worst case total loading year in recent history as the basis for the analysis and load allocations. More specifically, a five (5) percent MOS was applied to the in-lake concentration needed to meet the state standard. This approach used an in-lake average summer concentration of 38 µg/L TP as the target concentration as the target to meet for the three load reductions scenarios that were evaluated.

6.1.4 Reserve Capacity

The Sweeney Lake watershed is essentially fully developed as discussed previously in this TMDL report. The vast majority of projects that are expected to occur in the future are redevelopment projects which will be subject to treatment standards of the Bassett Creek WMC and the cities of Golden Valley and St. Louis Park. Therefore, the reserve capacity for this TMDL is zero.

6.2 Critical Condition

The critical condition for these lakes is the summer growing season. Minnesota lakes typically demonstrate impacts from excessive nutrients during the summer recreation season (June 1 through September 30) including excessive algal blooms and fish kills. Lake goals have focused on summer-mean total phosphorus, Secchi transparency and chlorophyll-a concentrations. Consequently, the lake response models have focused on the summer growing season as the critical condition. Additionally, Sweeney Lake tends to have a relatively short residence time and therefore responds directly to summer growing season loads delivered to the lake.

6.3 Allocations

The maximum allowable loads were computed using the finite difference (as described in Section 5.1.2) for three scenarios to evaluate what reductions would be needed to achieve an in-lake concentration of 40 µg/L TP. An in-lake concentration of 38 µg/L was used to incorporate a five (5) percent margin of safety during the modeling efforts. The total loads shown in Table 6.1 represent the current loading (2004) and the Maximum Future Loading levels (in pounds) that would need to be met to reach a 38 µg/L in-lake concentration during the critical summer period.

Table 6.1. TP Load in Pounds Needed to Reach In-Lake TP Standard

Loading Scenario	Phosphorus Loading (lb – 122 days)			
	WLA	LA		
	External TP Load	Internal TP Load	Atmos-pheric Load	Total Load
Current Loading (2004)	667	319	8	994
Maximum Future Loading	568	143	8	719

These numbers are the result of simulating the three scenarios in the finite difference lake response model. The Maximum Future Loading scenario represents a combination of wasteload and load reductions that will achieve the desired endpoint.

Table 6.2 shows the corresponding load reductions (in pounds) that would be needed under the three modeled scenarios to reach a 38 ug/L in-lake concentration during the critical summer period.

Table 6.2. TP Load Reductions Needed to Meet Standard

Loading Reduction Scenario	Phosphorus Load Reduction (lb – 122 days) Includes 5% Margin of Safety				
	WLA		LA		
	External TP Load (%)	External TP Load (lb)	Internal TP Load (%)	Internal TP Load (lb)	Total Reduction (lb)
External Reduction Only	70	460	0	0	460
Internal Reduction Only	0	0	85	270	270
Combined Internal and External Load Reductions	**15**	**99**	**55**	**175**	**274**

As shown in Tables 6.1 and 6.2, a 70 percent reduction in the wasteload would be needed within the watershed to achieve the in-lake standard if only watershed-based (external) BMPs were pursued. This reduction represents a very significant load reduction relative to how much phosphorus can be removed by traditional BMPs (i.e., about 50 percent of the phosphorus at the Schaper pond outlet is in an unsettlable dissolved or fine particulate form). The BMP network currently in place results in an inflow concentration of TP at the primary inlet to Sweeney on the order of 120 µg/L TP. This level is already in the lower end of the range that could be expected from a typical urban watershed with treatment system in place throughout the watershed.

There are a number of best management practices (e.g., ponds, sump manholes, rain water gardens) already in-place throughout the watershed that are removing sediment, phosphorus and other pollutants. As shown in Table 6.3, an estimated 34 percent of the watershed TP load to Sweeney Lake is being removed by these existing BMPs. Figure 13 shows the locations of many of these in-place BMPs. Therefore, achieving an additional 406 pounds of reduction from a fully developed watershed that has limited opportunity to install significant new treatment systems would be costly and would be a long-term implementation program on the order of 20 to 30 years.

Table 6.3. TP Removal of Existing Watershed BMPs

Modeling Results – Seasonal Loads (122 Days)	TP Load Conditions
2004 Lake Model – Total Watershed Loading (lbs)	667 lbs
Total Watershed Loading Untreated (lbs)	1004 lbs
Existing Treatment Device Removal (lbs)	337 lbs
Existing BMP Performance (% TP removal)	34 %

The recommended approach used as the basis of this TMDL is to achieve a combination of external and internal loads as shown in Table 6.2. We evaluated several alternative internal and external load combinations. Starting with an internal load reduction of 55 percent (175 lbs) the resulting external load reduction would be 15 percent (99 lbs) TP reduction in the contributing watershed. This internal load reduction assumption of 55 percent is based on evaluating what would reasonably be achieved with a 1-time chemical application (in-lake alum dosing) in Sweeney Lake. The corresponding external load reduction is then established as 15 percent or 99 lbs (45 kg) TP during the critical summer period. The total watershed TP load reduction, considering existing BMPs already in the watershed will approach 50 percent.

Combined with the external load reductions, an internal load reduction of 55% (175 lbs) provides more than the necessary reduction to meet the standard. In practice, the internal load reduction for an in-lake chemical treatment would be on the order of 85% as shown for the Internal Reduction Only scenarios in Table 6.2. This additional internal load reduction represents an additional margin of safety.

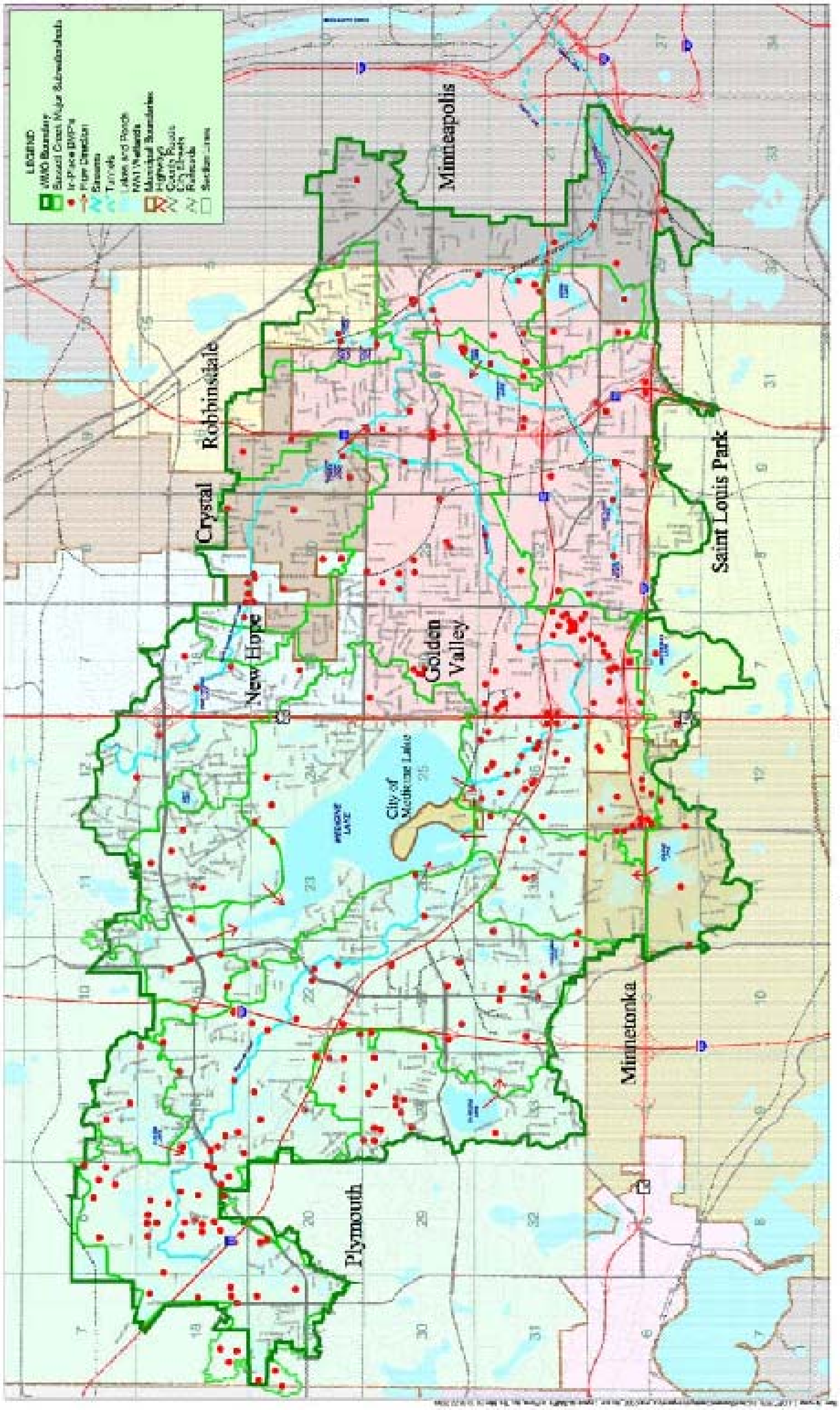


Figure 13
IN-PLACE WATER QUALITY
BEST MANAGEMENT PRACTICES (BMP'S)

Based on this combined approach to internal and external loads, and converting the seasonal loads from Table 6.1 to daily loads, the total maximum daily loads for the major sources are showing in Table 6.4.

Table 6.4. TP Daily Loads for the Major Sources

Source		Total Maximum Daily TP Load (lb/day)	Percent of Total Load
Wasteload	Watershed Load	4.66	79.0%
Load	Atmospheric Load	0.07	1.2%
	Internal Load	1.17	19.8%
TOTAL LOAD		**5.90**	**100%**

Converting the total wasteload allocation among the permitted sources result in the loads established in Table 6.5. MnDOT is allocated 14 percent of the daily load as an individual source and the cities of Golden Valley and St. Louis Park are allocated the remaining 86 percent of the wasteload as a categorical source. The resulting load reductions during the growing season are 14 lbs for MnDOT and 85 lbs for the combined categorical sources.

Table 6.5. TP Daily Loads for the Source Categories

Source		Existing TP loads (lbs/yr)	TMDL (average lbs/yr)	% Reduction
Wasteload Allocation MS4 Categorical	Permit #			
Golden Valley	MS400021			
St. Louis Park	MS400053	574	488	15
Hennepin County	MS400138			
Construction Stormwater	Various			
Industrial Stormwater	None			
MS4 Individual MnDOT	MS400170	93	79	15
Load Allocation				
Atmospheric		8	8	0
Internal		319	143	55
TOTAL		**994**	**719**	**28**

Sweeney Lake
Total Phosphorus TMDL

PUBLIC INVOLVEMENT

7.0 Public Involvement

The workplan for this study included a comprehensive stakeholder involvement effort. The public participation process was completed in close cooperation with the Bassett Creek WMC, the City of Golden Valley and surrounding municipalities and MS4s. The focus of the early public involvement efforts were to inform stakeholders of the proposed work plan, address and incorporate their concerns, and seek input into the TMDL process. This was initiated at Public Meeting #1 held in March 2007, at which an overview of the technical work plan, an explanation of the goals of each workplan component and how the data collected in the field will be used to complete the analyses, was presented. Additionally, the TMDL process as a whole was explained using information from the MPCA, as well as informing the public on ways they can track the results and become involved.

One of the key issues discussed at Public Meeting #1, and for the project overall, was the need to turn off the aerators for one or two summer growing seasons to monitor the water quality and internal loading without the systems in operation. A project webpage was created that includes periodic project updates as well as meeting information for all stakeholder meetings help over the course of the project. The webpage is available as a link from the BCWMC and Golden Valley web pages (http://www.sehinc.com/online/sweeney/index.htm).

Public Meeting #2 held in June 2009 as part of the Phase 2 workplan, following the completion of analysis of two years of monitoring data and prior to completion of the initial draft report. Between Public Meeting #1 and Public Meeting #2, several technical team meetings and key stakeholder meetings were held and are summarized in the list below. Additional information on each of the meetings is available on the project webpage.

- Public Meeting #1 — March 29, 2007
- Lake Resident Meeting — August 21, 2007
- BCWMC Update Meeting — April 17, 2008

- Technical Team Meeting April 23, 2009
- Golden Valley Meeting May 8, 2009
- Public Meeting #2 June 3, 2009

In addition to these specific meetings, Project Update summaries were posted on the project webpage on the following dates:

- April 14, 2007
- May 9, 2007
- May 29, 2007
- June 14, 2007
- July 23, 2007
- August 23, 2007
- September 26, 2007
- May 15, 2008
- October 9, 2008
- March 23, 2009

Additional public comment and input will continue to be taken as the TMDL progresses through the MPCA and EPA review and comment periods. The following stakeholders were invited to participate in this project:

- Bassett Creek Watershed Management Commission (including all member cities)
- City of Golden Valley
- City of St. Louis Park
- Minneapolis Parks and Recreation Board
- Minnesota Department of Transportation
- Hennepin County
- Minnesota Pollution Control Agency
- Minnesota Department of Natural Resources
- Sweeney lake Homeowners Association
- Metropolitan Council Environmental Services
- Minnesota Board of Soil and Water Resources

Sweeney Lake
Total Phosphorus TMDL

IMPLEMENTATION

8.0 Implementation

8.1 Implementation Strategy

A preliminary framework of potential implementation projects and activities has been developed as part of this TMDL. The overall approach will involve the Bassett Creek Watershed Management Commission taking a lead role in implementation efforts for the categorical wasteload allocations and the (internal) load reductions and in working directly with the member cities in identifying funding sources and prioritizing capital projects and management activities. MnDOT will be responsible for achieving their individual wasteload allocation, but may also realize benefits of working with the Commission on mutually beneficial projects and activities.

The Bassett Creek Watershed Management Commission (BCWMC) is committed to improving water quality with its watershed and to working with the member cities in implementing the improvements necessary to achieve the Commissions water quality goals and the water quality standards established in state and federal regulations. The Commission has a long history of working with the member cities in a cooperative manner to establish goals and policies, implementation activities and ongoing monitoring programs. The Commission will continue to work in this cooperative manner and intends to take a lead role in implementation efforts resulting from this TMDL.

The wasteload allocations in this TMDL represent very aggressive goals for nutrient reductions. Consequently, implementation will be conducted following adaptive management principles. Adaptive management is appropriate because it is difficult to predict with certainty the lake's response that will occur from implementing the strategies outlined in the implementation plan. In addition, a significant load reduction is established for the internal loading using treatment technologies that are widely accepted. However, each water body is unique and the response of this lake to practices that have been applied elsewhere may be more or less effective as assumed in this analysis.

Future technological advances may alter the course of actions detailed here, especially when looking at the wasteload portions in the fully-developed watershed. 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 or more years to implement BMPs and load-reduction activities. It is expected that multiple (NPDES MS4) permit cycles will be needed to reach the wasteload reduction targets. If all of the appropriate BMPs and activities have been implemented and the lake still does not meet the current water quality standards, the TMDL will be reevaluated and the Bassett Creek Watershed Management Commission will begin a process with the MPCA to evaluate additional BMP options. If needed, the process may result in developing a more appropriate site-specific standard for the lake. This process would be based on the MPCA's methodology for determining site-specific standards.

The Implementation approach will emphasize a hierarchy of strategies, prioritizing first, source-reduction options (street sweeping; implementation, construction and maintenance of best management practices); regulatory controls, such as runoff quality and volume-retention requirements; second, in-lake management; third, lake-inflow treatment and other in-lake treatment methodologies.

It is important to understand that regulatory controls imposed on MS4s as part of the TMDL program are not the only means to achieving the goals. Improving water quality in Sweeney Lake will require all stakeholders to participate in the efforts, including BCWMC, residents, lakeshore homeowners and other interested parties.

8.2 Load Reduction Alternatives

A number of load reduction strategies and actions were considered during development of this TMDL including discussions at the Technical Team meeting on April 23, 2009, and Public Meeting #2 on June 3, 2009. Information on the range of load reduction approaches is summarized in the following section for internal and external load reduction actions.

8.2.1 Loading Reductions

The focus of implementation efforts will be on reducing the annual phosphorus loads to the lake through structural and nonstructural Best Management Practices as well as evaluating the feasibility of reducing internal loads using chemical treatment methods. The Total Maximum Daily Load over the critical summer period by source established for Sweeney Lake is shown in Table 8.1.

Table 8.1. Phosphorus Reductions by Source.

Source		TMDL TP (lb - 122 days)	Reduction TP (lb -122 days)	Percent Reduction
Wasteload	Watershed Load	568	99	14.9%
Load	Atmospheric Load	8	0	0
	Internal Load	143	175	55.2%
LOAD REDUCTION		**719**	**274**	**27.7%**

As discussed in Section 6 of this report, MnDOT is allocated 14 percent of the daily load as an individual source and the cities of Golden Valley and St. Louis Park are allocated the remaining 86 percent of the wasteload allocation as a categorical source. The resulting seasonal load reductions to achieve the targeted 99 lbs of reduction are 14 lbs for MnDOT and 85 lbs for the combined categorical sources.

8.2.2 Internal Loading

Several options were discussed with members of the Technical Team and stakeholders overall to manage internal sources of nutrients.

- *Hypolimnetic withdrawal.* This option would require pumping nutrient-rich water from the hypolimnion to an external location where it could be chemically treated, and discharged through a constructed wetland treatment system outletting to the lake. Input suggested that problems with odors, relatively high costs and significant problems with some local examples eliminated this approach from further consideration.

- *Hypolimnetic aeration.* This option uses a specialized pump to circulate water from the hypolimnion to keep it aerated and reduce the potential for anoxic conditions that lead to sediment phosphorus release. Again input suggest local problems and eliminated this approach from consideration.

- *Chemical treatment. In-Lake Dosing.* Concurrent with or following implementation of BMPs to reduce external nutrient load sources, it may be feasible to chemically treat the lake with alum to remove phosphorus from the water column as well as bind it in sediments. Such a treatment is estimated to cost on the order of $150,000 to $200,000. Several options in addition to alum including Phoslock, activated zeolite and others to bind phosphorus in lake sediments and not allow phosphorus release during summer months or when oxygen is low in bottom waters. Some issues with dosing rates and need to control the pH, but lots of data and experience available to make sure it meets the criteria.
- *Chemical treatment. In-Flow Dosing.* Some discussions on costs related to the preferred approach of in-lake treatment to inflow treatment, with in-flow treatment being on the order of five times the cost of in-lake. Comments during Public Meeting #2 suggested that further evaluation of an inflow treatment system should be considered. Potential problems with and inflow system include available land for the treatment plant and the difficulty in dosing the variable flows that would occur at the primary inlet at Schaper Pond.
- *Vegetation management.* Curly-leaf pondweed has been observed recently in Sweeney. Chemical treatment could be applied to limit growth of this phosphorus source but this was not identified as a significant source of internal loading.
- *Aeration system management.* The general consensus was that the existing aeration system should be evaluated further to see if modifications can be made to better manage the system to avoid circulating nutrient-rich water. Discussions also related to the advantages and disadvantages to aeration during the growing season and the overall conclusion was that, based on the 2007-2008 data, the aeration system may or may not be increasing the internal loading to the lake. The water quality was better, but insufficient data is available to conclude what portion relates to reduced watershed load from the lower than normal precipitation and what portion relates to reduced internal loading from stratification of the lake and trapping phosphorus in the bottom layer. In either case, the recommended action is to conduct future years of monitoring with the aeration system off

to see how the lake responds to a normal year of precipitation. The Technical Team members generally agreed that in any case continued winter aeration is not a concern and likely is a good long-term management strategy for the lake.

- *Fish population management* [e.g., carp, bullheads]. Discussed recent work in area lakes related to carp effects on internal loads. While this approach may result in some limited improvements, it is not expected to be a significant factor in the TMDL implementation plan.
- *Barley straw/corn meal applications.* This practice was discussed briefly but determined to be fairly expensive and requires significant efforts for annual application and maintenance.

8.2.3 External Loading

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. The watershed draining to Sweeney Lake is almost fully developed, and options for reducing external nutrient loads are somewhat limited and will likely be costly to implement. Following is a description of potential actions for controlling nutrients in the watershed that will be further developed in the Sweeney Lake Implementation Plan.

Small, incremental reductions are possible through retrofit as redevelopment occurs and through the implementation of Best Management Practices (BMPs) throughout the subwatershed.

- *Maximize load reduction through redevelopment.* As redevelopment occurs, areas with little or no treatment will be required to meet current water quality standards of providing a pond volume based on the runoff volume from a 2.5 inch rainfall over the contributing watershed. It may be possible to “upsize” water quality treatment BMPs to increase treatment efficiency beyond the minimum required by city and Commission requirements to maximize the amount of load reduction achieved. Incorporating BMPs to bring a redevelopment site to these standards would be at the developer’s cost. The public cost of upsizing to provide additional treatment (e.g., over sizing a treatment pond) would be dependent on the specific BMPs, negotiations with developers, and the availability of funding. Regulatory changes are another option to address redevelopment loading reductions.

- *Increase infiltration and filtration.* Encourage the use of rain gardens, native plantings, and reforestation as a means to increase infiltration or filtration and evapotranspiration and reduce runoff conveying pollutant loads to the lake. The cost of this strategy varies depending on the BMP, and may range from a single property owner installing an individual rain garden to retrofitting parks and open space with native vegetation rather than mowed turf. Because of the extent of clay soils throughout much of the Sweeney Lake watershed, filtration systems would be more likely than true infiltration systems. The City of Golden Valley offered this approach in a local street reconstruction project in 2005 and while some residents were interested in learning more about the approach, no residents committed to having a rain water garden installed as part of the street project.
- *Target street sweeping.* The City of Golden Valley and St. Louis Park are currently conducting aggressive street sweeping programs. The discussions on this approach focused on identify key areas and targeting those areas for more frequent street sweeping, which again Golden Valley is currently doing. Additional improvements in load reductions would include replacing mechanical street sweepers with more efficient regenerative air sweepers which can cost significantly more than a traditional broom sweeper. As the drainage area to Sweeney Lake encompasses both Golden Valley and St. Louis Park, each city should evaluate if it's feasible to realize improvements within the context of their street sweeping program. The City of Golden Valley has the purchase of a vacuum or regenerative air sweeper identified in its Capital Improvement Plan for 2011.
- *Retrofit BMPs.* As opportunities arise, retrofit water quality treatment through a variety of Best Management Practices including detention ponds, native plantings, sump manholes, swirl separators, and trash collectors. These small practices are effective in removing debris, leaf litter, and other potential pollutants. Depending on the type of BMP, location, easement requirements, and other factors, costs can range from $2,000 for a sump manhole to $30,000 for a mechanical manhole device to $250,000 or more for a detention pond. Removal estimates for several specific BMPs have been calculated and are identified in Table 8.2.

- *Encourage shoreline restoration.* Many property owners maintain a mowed grass edge to the shoreline. Property owners should be encouraged to restore their shoreline with native plants to reduce erosion and capture direct runoff. The City and local business have already installed buffers in portions of the Sweeney Lake shoreline.
- *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 Sweeney Lake and encourage the adoption of good individual property management practices.

8.3 Implementation Program

A number of best management practices are already in-place throughout the watershed that are removing an estimated 34 percent of the TP load to Sweeney Lake as shown previously in Table 6.3. When factoring the additional 15 percent TP reduction established in the TMDL, the total watershed removal will approach 50 percent.

Table 8.2 provides a list of best management practices that were evaluated for external and internal load reductions. The list is intended as the basis of the implementation program that will be established as a separate document from this TMDL report. TP removal estimates for most of the listed BMP are provided and are based on a combination of modeling using the P8 model that served as the basis of this study and published literature. Quantifying the true removal rates for these practices is quite difficult. However, these estimates represent the best available data for the practices listed, and the practices will provide reductions in the loading of phosphorus to Sweeney Lake. The list represents the recommended implementation activities for the permitted sources over approximately the next 20 years.

In all cases, the partners associated with the load reduction responsibilities under this program will need to work together to maximize the extent of these BMPs that can be implemented given the available resources. They must also identify and access available funding methods towards implementation actions. Funding options may include, but not be limited to, local, state and federal grant funds, such as the Clean Water Legacy Act funds for water quality improvement projects. The estimated total cost of implementing these and other potential BMPs ranges from $500,000 to $5,000,000.

Table 8.2. Sweeney Lake Management Plan

Watershed Management Practice (Ongoing)	Potential Phosphorus Removal in Pounds (annual / seasonal)
Best Management Practices (BMPs) that achieve a level of removal of phosphorus and total suspended solids equal to or greater than the level that would be achieved by a permanent pool that provides for storage of 2.5 inches of runoff volume from the entire development site will be required for all new development and redevelopment. This policy of the Bassett Creek Watershed Management Commission (BCWMD) and the City of Golden Valley has been required of all new development and redevelopment in the watershed since 1994.	30 / 14 [1]
The program to promote the development of shoreline buffers will be continued.	15 / 7 [2]
Existing BMPs will be monitored and maintained to insure that they continue to provide the water quality benefits that they were intended to provide.	20/9
The city street sweeping program will continue and as new technology and new techniques are developed they will be evaluated to determine if they would provide a water quality benefit to the Lake and implemented if found to be reasonable and practicable.	18 / 18
The water quality education program will continue to work with watershed residents to increase their understanding of practices that would reduce the amount of pollutants entering the Lake	10 / 5
Total Estimated Potential External (Watershed) Load Reductions	**93 / 53**

[1]Load reduction estimate based on an estimated 300 acres of redevelopment over the next 20-year period. Since the mid 1980's more than 35 new best management practices have been constructed or existing best management practices have been improved in the watershed. The load reduction that resulted from the construction or improvement of those BMP's is calculated to be approximately 260 pounds of phosphorous on an annual basis.
[2]Assumes 5,000 feet of shoreline buffer restoration

Table 8.2. Sweeney Lake Management Plan (continued)

Watershed Management Practice (Under Consideration)	Potential Phosphorus Removal in Pounds (annual / seasonal)
Existing BMPs will be evaluated to determine if modifications are possible to improve their TSS and phosphorus removal efficiency.	25 / 11
Best Management Practices that infiltrate the first one inch of rainfall from all impervious surfaces will be required for all new development and redevelopment where feasible. This policy is being considered by the City of Golden Valley and the BCWMC for future adoption.	20 / 9
As new BMPs and water quality improvement technologies are developed they will be evaluated to determine if they can provide a water quality benefit to the Lake and they will be implemented if they are determined to be reasonable and practicable.	20/9
The feasibility of modifying the pond in Shaper Park to improve its ability to remove phosphorus will be evaluated and implemented if it is found to be reasonable and practicable. **Alternative**: Filtration barrier to improve Shaper Park pond performance.	40 / 18 20 / 9
The feasibility of dredging Spring Pond and diverting low flows from the Sweeney Lake branch of Bassett Creek to the pond will be evaluated and implemented if it is found to be reasonable and practicable. **Alternative**: Filtration barrier to improve pond performance.	20 / 9 20 / 9
Hennepin County and the Minnesota Department of Transportation are MS4s in the watershed and it is assumed that they will implement a load reduction program for untreated highway runoff.	50 / 22 [3]
Total Estimated Potential External (Watershed) Load Reductions	**155-175 / 69-78**

[3]Assumes 50% load reduction of untreated highway runoff and sweeping program

Possible Chemical Treatment Management Practices	Potential Phosphorus Removal in Pounds (annual / seasonal)
The feasibility of chemically treating storm water from the Sweeney Lake branch of Bassett Creek will be investigated and implemented if it is found to be reasonable and practicable.	200 / 90
The feasibility of in-lake treatment to limit the internal phosphorus load from bottom sediments will be evaluated and implemented if it is found to be reasonable and practicable.	175 / na (for 85% Internal Load Reduction)

Sweeney Lake
Total Phosphorus TMDL

9.0 REASONABLE ASSURANCE

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 realistic goals for the reduction of phosphorus waste loads to Sweeney Lake as well as significant internal load reductions.

TMDL implementation activities will be carried out on an iterative basis so that 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.

Each stakeholder has agreed to implement BMPs to the maximum extent practicable. The collective approach to the categorical sources allows for greater reductions for some permit holders with greater opportunity and less for those with greater constraints. The collective approach with the member cities is currently in place under the direction of the Bassett Creek Watershed Management Commission. The BCWMC is proceeding in a good faith effort to coordinate with all parties on how to implement the TMDL. Once the external load has been reduced to the maximum extent possible, the BCWMC will coordinate with the other stakeholders to discuss alternatives for addressing the internal load. Federal, State, and local funding sources will be explored to assist with reducing the internal load, if an internal load reduction is determined to be reasonable and practicable.

9.2 Monitoring

The BCWMC will evaluate progress toward meeting the goals and policies outlined in the Watershed Management Plan. The Commission's Annual Report is presented to the public at the Commission's annual public meeting. The findings of the Annual Report and the comments received from the member cities and the public are used to formulate the work plan, budget, CIP and specific measurable goals and objectives for the coming year as well as to propose modifications or additions to the management goals, policies, and strategies. At the end of each five year period the Commission intends to evaluate the success of BMP implementation in reducing the total phosphorus concentration in Sweeney Lake, and will reconvene the Technical Advisory Committee to determine if adjustments to the Implementation Plan are necessary.

The BCWMC monitors water quality in local lakes through the funding of special studies and citizen volunteer efforts. Sweeney Lake has been monitored annually under the Citizen Assisted Monitoring Program (CAMP) program through MCES. Citizen volunteers collect in-lake data on a biweekly basis. In addition, BCWMC has conducted more extensive monitoring of the lake at a frequency of about once every three to four years. This approximate frequency of monitoring is expected to continue for the parameters listed below.

- Vertical profiles of temperature, dissolved oxygen concentration, specific conductivity, and pH
- 0-2 meter composite samples analyzed for chlorophyll *a*, total phosphorus, soluble reactive phosphorus, and total nitrogen
- Total phosphorus above and below the thermocline and near bottom
- Secchi disc transparency
- Phytoplankton and zooplankton

Sweeney Lake
Total Phosphorus TMDL

10.0 LITERATURE CITED

10.0 Literature Cited

Barr Engineering. 1994. Sweeney Lake Watershed and Lake Management Plan. Bassett Creek Watershed Management Commission, Golden Valley, Minnesota.

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Pilgrim et al. 2007. A Method for Comparative Evaluation of Whole-lake and Inflow Alum Treatment. Water Research. 41: 1215-1224 and equations published in Thomann and Mueller. 1987. Principles of Surface Water Quality Modeling.

Barr Engineering. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Minnesota Pollution Control Agency, St. Paul, Minnesota.

Appendix A P8 and Finite Difference Model Summary

P8 and Finite Difference Modeling Documentation

Hydrology and Watershed Loading

For TMDL development and lake modeling, a watershed runoff and water quality model called P8 (model available at http://wwwalker.net/p8/) was used. This model was needed to estimate hydrologic and phosphorus loads for years that lacked water quality and inflow data and for areas tributary to Sweeney Lake that were not monitored for flow or water quality as part of the TMDL workplan. Another benefit of using the P8 model is that the model can generate daily runoff and phosphorus loading data. These types of daily data are needed as inputs to a finite difference lake model.

Inputs into the model included 52 sub-watershed areas and 44 treatment devices. Using land use and soil type coverage, percent impervious area and curve numbers were calculated for each watershed. An existing P8 model and engineering drawings were used to define the dimensions (e.g., volume, area, and average depth) and the outlet configurations of the treatment devices. Climatology inputs to the model include air temperature (maximum and minimum) and precipitation (hourly). Temperature and precipitation data was provided by the Minnesota Climatology Working Group. Some general characteristics of the watershed and input to the model area are as follows:

- Total watershed area modeled was 2209 acres. This area does not include areas directly tributary to Twin Lake, or areas that are land locked.
- Watershed wide average impervious area: 36 percent
- Watershed wide average curve number: 78
- Precipitation for the 2004 (year upon which the TMDL is Based) water year: 36 inches
- Precipitation for June through September 2004: 16.7 inches

The P8 model was calibrated using flow and water quality data collected by the Minnesota Department of Transportation (MDOT) in 2004 and 2005 at the outlet of Schaper Pond. The Schaper Pond outlet is also the direct inlet to Sweeney Lake, with most of the watershed runoff directed through this pond. MDOT collected continuous flow data throughout the open water season and water quality (phosphorus and total suspended solids) samples for seven storm events. For each storm event, several samples were collected throughout the storm event to enable the calculation of a flow-weighted average storm event phosphorus concentration. Hydrologic calibration was done to by uniformly changing the runoff curve number for tributary watersheds so that the overall hydrologic yield of the monitored and modeled data was the same, and to match the modeled and monitored hydrograph of several storm events (Figure 1).

The water quality calibration of the P8 model consisted of changing the build-up and wash-off function in the P8 model (Figure 2). What this function does is determine the rate of phosphorus accumulation in each watershed, and then when a storm event occurs, the accumulated phosphorus is delivered into the storm water runoff at a particular rate which is based primarily upon the intensity of the storm event.

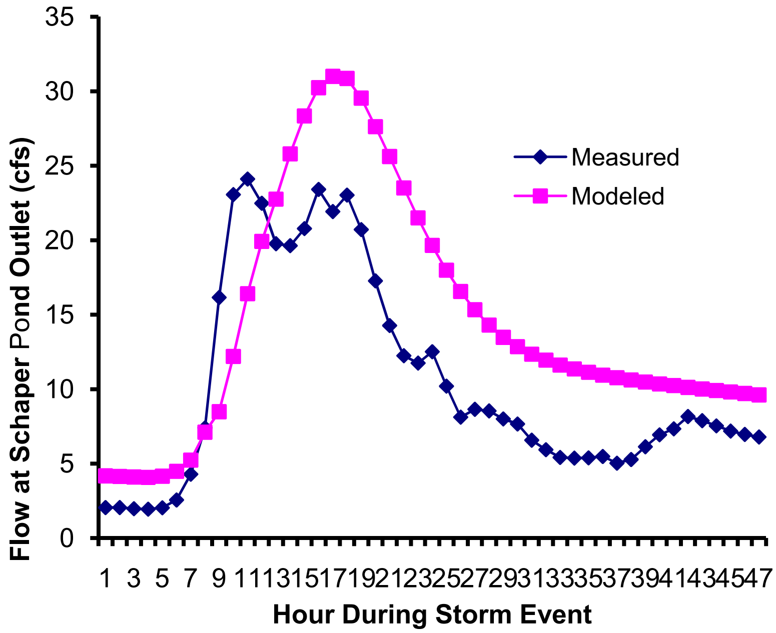

Figure 1. Storm event (2004) used as part of the hydrology calibration of the P8 model.

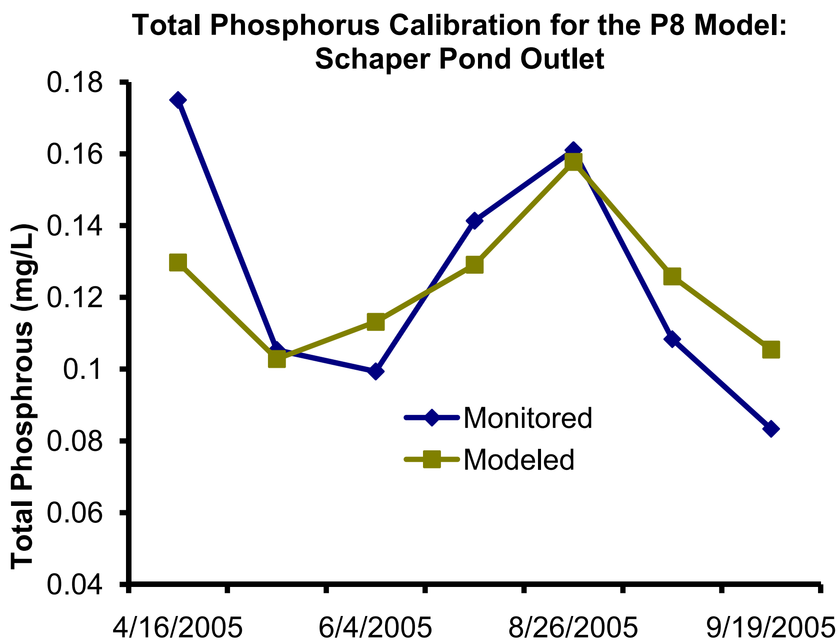

Figure 2. Results of the water quality calibration of the P8 model.

The rate at which phosphorus is delivered "washed off" can be controlled by changing the value of certain coefficients. Coefficients used are as follows:

- Build up rate: 2 pounds/acre/day
- Decay Rate (1/d): 0.25 (limits the amount of phosphorus that can build up on the watershed)
- Wash-off Coefficient: 6
- Wash-off Exponent: 3
- Pervious Runoff Exponent: 1.6

Lake Modeling

Lake modeling to determine the concentration of phosphorus in the lake water column with a given hydrologic and phosphorus load was conducted using a finite difference model and the assumption that the lake is completely mixed. The finite difference model used is described by the following equation:

$$C = Co + \frac{(W * t - Qout * C - K * V * S) * \Delta T}{V}$$

Where: C = phosphorus concentration in the lake, Co = initial phosphorus concentration, or phosphorus concentration from the previous time step, W = phosphorus loading from external sources, internal sources, and dry or wet deposition directly on the lake, Qout = flow out of the lake, which is assumed to be equal to the seven day running average inflow rate, K = net apparent settling velocity (units of 1/y, and KVS=phosphorus mass loss by settling). The net apparent settling velocity (K) can also be expressed in units of m/y if the average lake depth is used in the settling loss equation.

The first step in developing the model was the development of a water balance for Sweeney Lake. The water balance model including modeled inflows from all tributary watersheds, direct precipitation, evaporative loss from the lake (function of lake and air temperature, relative humidity, and wind speed), and lake outflows. Using the water balance, the lake model was built using modeled phosphorus inflow concentrations, a dry deposition rate of 0.3 kg/ha/y, and initial estimates of net apparent settling velocities and internal loading rates.

Net apparent settling rate and internal loading rates were the primary calibration parameters for the model. The net apparent settling rate was calibrated by selecting different values to match the phosphorus decline rate in Sweeney Lake following a storm event (see Figure 3). The internal load rate was then changed to improve the fit between the modeled and observed concentrations of phosphorus in Sweeny Lake. The calibrated net apparent settling velocity was 4.2m/y or 17 m/y. The lake wide average internal load rate (this is the fraction of internal load that is released from the sediments to the bottom waters that reaches the top 2 meters of the lake) used to calibrate the model was 5.7 mg/m2/d. This rate was applied to the entire 67-acre surface area of the lake for simplicity. Clearly, the actual area of the lake that is anoxic and where release occurs is much less.

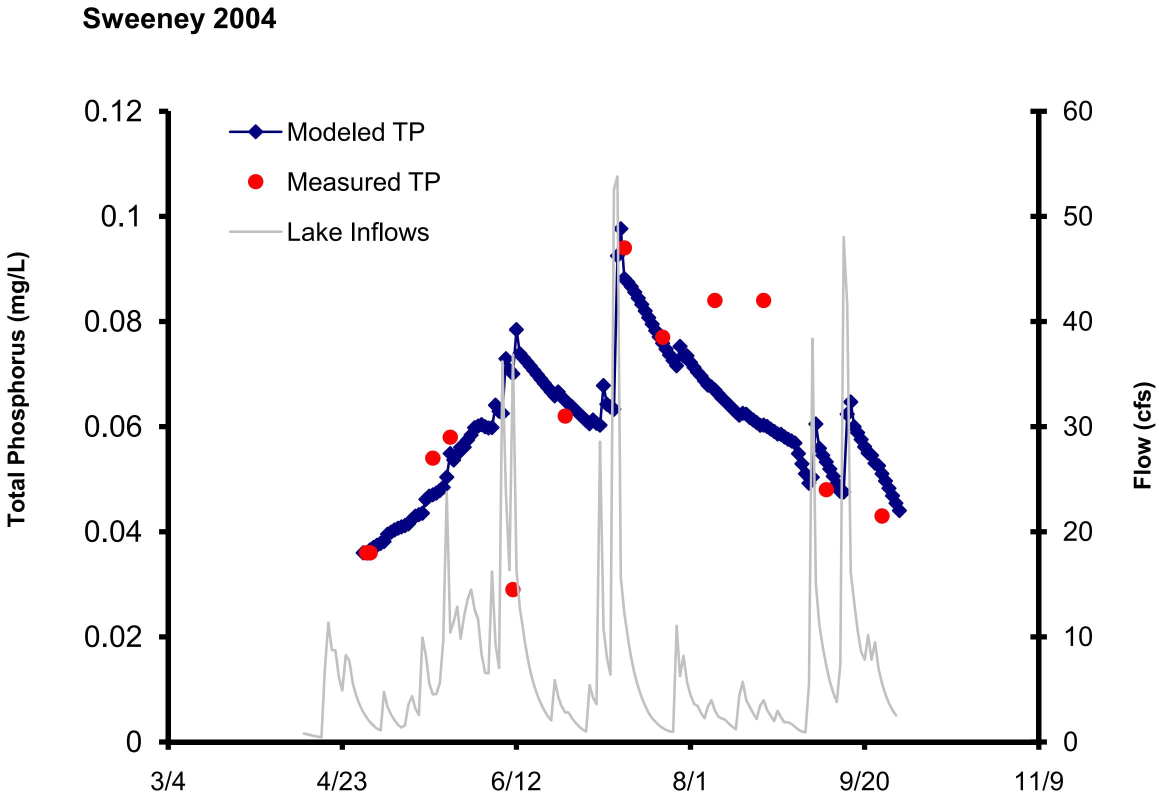

Figure 3. Results of the water quality calibration of the in lake water quality model for 2004.

Load Reduction Scenarios

Once the model was built, different load reduction scenarios were run to identify several different external and internal load reduction combinations that could be used to meet an in-lake phosphorus concentration of 38 µg/L (this concentration was used to provide a margin of safety-the water quality criterion is 40 µg/L). The graph in Figure 4 shows the potential combinations of external and internal loads that can be used to achieve 38 µg/L in Sweeney Lake during June through September (defined with the calibrated model. The load allocation identified in this report includes an additional 50 pounds of external phosphorus control over what would be needed (according to the analysis presented in Figure 4). The additional 50 pounds of external load control will lead to an average summer in-lake phosphorus concentration of 35 µg/L.

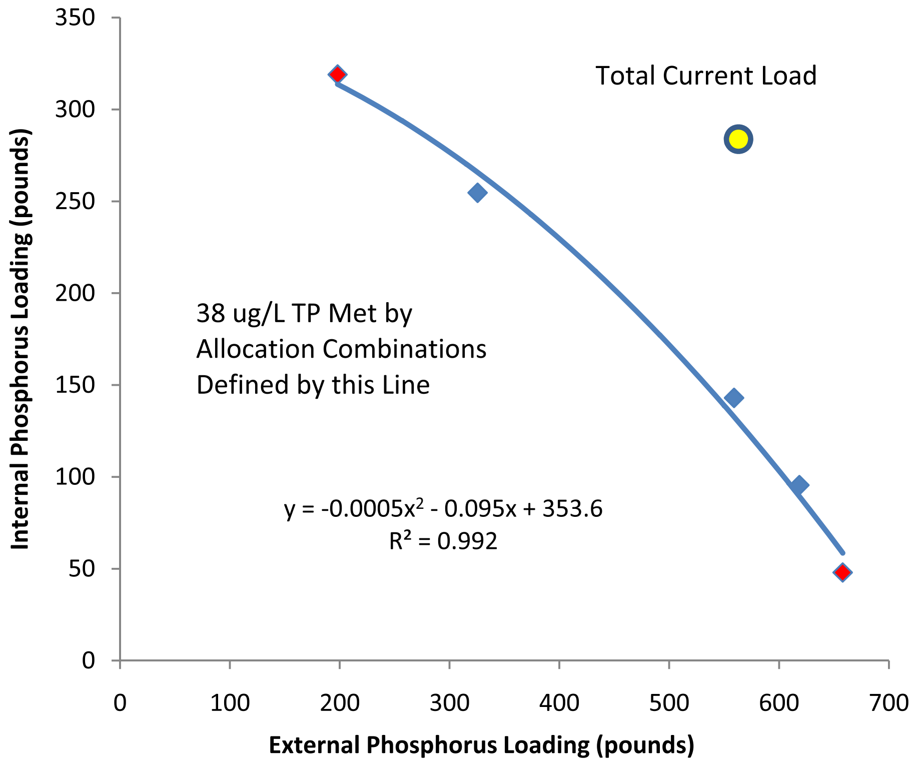

Figure 4. Combinations of external and internal load control that will lead to an in-lake phosphorus level of 38 ug/L during the June through September averaging period.

Appendix B BATHTUB Modeling Summary

SEH **MEMORANDUM**

TO: Ron Leaf

FROM: Rebecca Nestingen

DATE: February 12, 2010

RE: BATHTUB Modeling Summary for Sweeney Lake
SEH No. BCWMC0701.00

Sweeney Lake was modeled in BATHTUB as a two segment reservoir (South and North) with one tributary (Schaper Pond). The in-lake observed water quality data analysis and reduction was performed in PROFILE by SEH and the monitored tributary water quality and flow data analysis was performed in FLUX by Three Rivers Park District. The flow weighted mean concentrations from FLUX were used in BATHTUB as the tributary input and the PROFILE mean concentrations were used as the segment water quality input.

Other input data in BATHTUB included:

- Evaporation estimates from observed 2007 and 2008 growing season pan evaporation at the UMN Climatological Observatory multiplied by a pan coefficient of 0.75
- Precipitation depths obtained from Three Rivers Park District during the flow monitoring period
- Averaging period which corresponds with the duration of flow monitoring
- Atmospheric deposition estimate from "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Atmospheric Deposition: 2007 Update" (Barr Engineering, 2007)
- Tributary mean annual flow rate from Barr Engineering P8 simulated runoff volume in Sweeney Lake watershed
- Segment morphometry measured from bathymetric map of Sweeney Lake (Minnesota DNR, 1993)

The significant model selections used which gave the best calibration to the measured in-lake water quality data are shown in the following table.

Model Options	BATHTUB Model Equation
Phosphorus Balance	2nd order, available P
Chlorophyll-*a*	P, light, flushing
Secchi Depth	Total P
Phosphorus Calibration	Decay rates

The BATHTUB model also allows users to specify internal phosphorus loading rates and the model runs were performed with and without specification of the internal loading. By specifying an internal loading rate, the additional sediment release inherent in the sedimentation model causes the model to overestimate the TP concentrations. Thus, the phosphorus decay rate calibration coefficient was increased in the model with internal loading to offset the sediment P recycling inherent in the model.

When internal loading was specified, the internal phosphorus load accounted for approximately 70% of the total load. The load/response curve for the model scenario with internal loading indicated that the goal in-lake total phosphorus concentration of 40 ppb, could not be reached through only reducing the external load.

rsn
Attachment – Input/Output Summary

s:\se\bl\bcwmc\070100\bathtub\seh memo.docx

Sweeney Lake 2007
File: S:\AE\B\Bcwmc\070100\Bathtub\Sweeney07.btb
Description:

Global Variables	Mean	CV
Averaging Period (yrs)	0.493	0.0
Precipitation (m)	0.529	0.0
Evaporation (m)	0.751	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	24.9	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	1	2ND ORDER, AVAIL P
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	3	VS. TOTAL P
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	South	2	1	0.179	3.963	0.85	3.543	0	0	0	0.25	1.81	0	0	0	0	0	0
2	North	0	1	0.097	3.301	0.52	2.883	0	0	0	0.24	1.57	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	53.4	0.234	805.8	0.265	20.9	0.794	1.3	0.213	0	0	47.5	0.915	0	0	0	0
2	0	0	52.9	0.21	769.9	0.228	19	0.731	1.4	0.205	0	0	47.5	0.928	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	SchaperPond	1	1	0	6.128	0	0	0	114.37	0.115	1240.12	0.052	17.48	0.146	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.150	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	0.700	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0
Avail. Factor - Inorganic N	0.790	0

Sweeney Lake 2007
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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 3 Area-Wtd Mean

Variable	Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P MG/M3	56.2	0.17	57.0%	53.2	0.23	54.7%
TOTAL N MG/M3	793.2	0.19	35.7%	793.2	0.25	35.7%
C.NUTRIENT MG/M3	38.8	0.15	54.1%	37.8	0.24	52.8%
CHL-A MG/M3	15.9	0.35	75.3%	20.2	0.77	84.1%
SECCHI M	0.8	0.17	36.8%	1.3	0.21	61.0%
ORGANIC N MG/M3	538.1	0.25	59.8%			
TP-ORTHO-P MG/M3	30.0	0.32	50.1%	47.5	0.92	68.6%
ANTILOG PC-1	406.6	0.34	65.1%	395.9	0.58	64.3%
ANTILOG PC-2	7.8	0.27	64.3%	12.9	0.40	90.7%
(N - 150) / P	11.5	0.29	28.2%	12.1	0.29	30.8%
INORGANIC N / P	9.9	0.82	13.4%			
TURBIDITY 1/M	0.2	1.31	15.2%	0.2	1.31	15.2%
ZMIX * TURBIDITY	0.8	1.35	4.1%	0.8	1.35	4.1%
ZMIX / SECCHI	4.0	0.16	38.0%	2.5	0.16	13.2%
CHL-A * SECCHI	13.3	0.34	64.6%	27.0	0.60	91.5%
CHL-A / TOTAL P	0.3	0.33	72.1%	0.4	0.61	85.1%
FREQ(CHL-a>10) %	66.9	0.30	75.3%	79.5	0.31	84.1%
FREQ(CHL-a>20) %	24.8	0.72	75.3%	38.5	0.92	84.1%
FREQ(CHL-a>30) %	9.1	1.02	75.3%	17.2	1.41	84.1%
FREQ(CHL-a>40) %	3.6	1.25	75.3%	8.0	1.82	84.1%
FREQ(CHL-a>50) %	1.5	1.44	75.3%	3.9	2.15	84.1%
FREQ(CHL-a>60) %	0.7	1.59	75.3%	2.0	2.44	84.1%
CARLSON TSI-P	62.2	0.04	57.0%	61.5	0.04	54.7%
CARLSON TSI-CHLA	57.7	0.06	75.3%	60.1	0.09	84.1%
CARLSON TSI-SEC	62.6	0.04	63.2%	55.8	0.04	39.0%

Segment: 1 South

Variable	Predicted Values---> Mean	CV	Rank	Observed Values---> Mean	CV	Rank
TOTAL P MG/M3	58.8	0.17	59.0%	53.4	0.23	54.8%
TOTAL N MG/M3	805.8	0.26	36.7%	805.8	0.26	36.7%
C.NUTRIENT MG/M3	40.0	0.19	55.7%	38.2	0.25	53.4%
CHL-A MG/M3	15.7	0.40	74.9%	20.9	0.79	85.1%
SECCHI M	0.8	0.16	34.9%	1.3	0.21	59.6%
ORGANIC N MG/M3	534.7	0.26	59.3%			
TP-ORTHO-P MG/M3	29.8	0.32	49.8%	47.5	0.92	68.6%
ANTILOG PC-1	418.3	0.37	65.8%	417.5	0.78	65.8%
ANTILOG PC-2	7.5	0.31	61.4%	12.9	0.56	90.7%
(N - 150) / P	11.2	0.37	26.8%	12.3	0.40	31.7%
INORGANIC N / P	9.4	0.99	12.3%			
TURBIDITY 1/M	0.3	1.81	15.6%	0.3	1.81	15.6%
ZMIX * TURBIDITY	0.9	1.81	5.1%	0.9	1.81	5.1%
ZMIX / SECCHI	4.4	0.16	44.5%	2.7	0.21	16.8%
CHL-A * SECCHI	12.7	0.40	62.0%	27.2	0.82	91.7%

CHL-A / TOTAL P	0.3	0.39	68.8%	0.4	0.83	86.2%
FREQ(CHL-a>10) %	66.3	0.36	74.9%	81.0	0.41	85.1%
FREQ(CHL-a>20) %	24.3	0.84	74.9%	40.5	1.21	85.1%
FREQ(CHL-a>30) %	8.8	1.19	74.9%	18.6	1.86	85.1%
FREQ(CHL-a>40) %	3.5	1.45	74.9%	8.7	2.37	85.1%
FREQ(CHL-a>50) %	1.5	1.66	74.9%	4.3	2.79	85.1%
FREQ(CHL-a>60) %	0.7	1.84	74.9%	2.2	3.15	85.1%
CARLSON TSI-P	62.9	0.04	59.0%	61.5	0.05	54.8%
CARLSON TSI-CHLA	57.6	0.07	74.9%	60.4	0.13	85.1%
CARLSON TSI-SEC	63.1	0.04	65.1%	56.2	0.05	40.4%

Segment: 2 North

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	51.3	0.19	53.0%	52.9	0.21	54.4%
TOTAL N MG/M3	769.9	0.23	34.0%	769.9	0.23	34.0%
C.NUTRIENT MG/M3	36.4	0.17	51.0%	37.0	0.22	51.7%
CHL-A MG/M3	16.2	0.36	76.1%	19.0	0.73	82.0%
SECCHI M	0.9	0.18	40.1%	1.4	0.20	63.4%
ORGANIC N MG/M3	544.4	0.25	60.7%			
TP-ORTHO-P MG/M3	30.4	0.34	50.6%	47.5	0.93	68.6%
ANTILOG PC-1	385.1	0.37	63.5%	356.0	0.72	61.2%
ANTILOG PC-2	8.4	0.27	69.3%	12.8	0.51	90.5%
(N - 150) / P	12.1	0.34	30.8%	11.7	0.35	29.2%
INORGANIC N / P	10.8	1.07	15.5%			
TURBIDITY 1/M	0.2	1.57	14.5%	0.2	1.57	14.5%
ZMIX * TURBIDITY	0.7	1.57	2.5%	0.7	1.57	2.5%
ZMIX / SECCHI	3.2	0.18	25.1%	2.1	0.20	7.4%
CHL-A * SECCHI	14.5	0.34	68.9%	26.6	0.76	91.2%
CHL-A / TOTAL P	0.3	0.33	77.3%	0.4	0.76	83.0%
FREQ(CHL-a>10) %	68.0	0.31	76.1%	76.6	0.46	82.0%
FREQ(CHL-a>20) %	25.8	0.74	76.1%	34.7	1.25	82.0%
FREQ(CHL-a>30) %	9.6	1.05	76.1%	14.8	1.86	82.0%
FREQ(CHL-a>40) %	3.9	1.29	76.1%	6.5	2.34	82.0%
FREQ(CHL-a>50) %	1.7	1.49	76.1%	3.1	2.74	82.0%
FREQ(CHL-a>60) %	0.8	1.65	76.1%	1.5	3.08	82.0%
CARLSON TSI-P	60.9	0.05	53.0%	61.4	0.05	54.4%
CARLSON TSI-CHLA	57.9	0.06	76.1%	59.5	0.12	82.0%
CARLSON TSI-SEC	61.6	0.04	59.9%	55.2	0.05	36.6%

Sweeney Lake 2007
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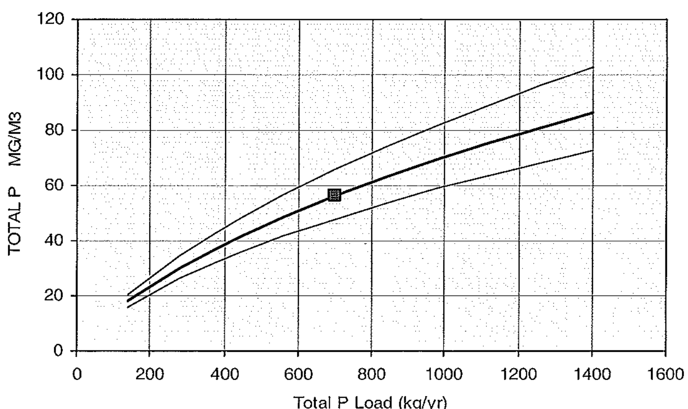
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m^3	TOTAL P MG/M3 Mean	CV	Low	High
Base:	6.1	700.9	114.4	56.2	0.17	47.9	65.8
0.20	6.1	140.2	22.9	18.1	0.13	16.1	20.4
0.40	6.1	280.3	45.7	30.2	0.15	26.3	34.6
0.60	6.1	420.5	68.6	40.0	0.16	34.6	46.3
0.80	6.1	560.7	91.5	48.6	0.17	41.7	56.6
1.00	6.1	700.9	114.4	56.2	0.17	47.9	65.8
1.20	6.1	841.0	137.2	63.1	0.18	53.6	74.2
1.40	6.1	981.2	160.1	69.5	0.18	58.9	82.0
1.60	6.1	1121.4	183.0	75.5	0.18	63.8	89.3
1.80	6.1	1261.5	205.9	81.1	0.19	68.4	96.2
2.00	6.1	1401.7	228.7	86.4	0.19	72.7	102.7



Means +/- 1 Std Error

Sweeney Lake 2008
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Description:

Global Variables	Mean	CV
Averaging Period (yrs)	0.526	0.0
Precipitation (m)	0.409	0.0
Evaporation (m)	0.714	0.0
Storage Increase (m)	0	0.0

Atmos. Loads (kg/km^2-yr)	Mean	CV
Conserv. Substance	0	0.00
Total P	24.6	0.50
Total N	1000	0.50
Ortho P	15	0.50
Inorganic N	500	0.50

Model Options	Code	Description
Conservative Substance	0	NOT COMPUTED
Phosphorus Balance	1	2ND ORDER, AVAIL P
Nitrogen Balance	0	NOT COMPUTED
Chlorophyll-a	2	P, LIGHT, T
Secchi Depth	3	VS. TOTAL P
Dispersion	1	FISCHER-NUMERIC
Phosphorus Calibration	1	DECAY RATES
Nitrogen Calibration	1	DECAY RATES
Error Analysis	1	MODEL & DATA
Availability Factors	0	IGNORE
Mass-Balance Tables	1	USE ESTIMATED CONCS
Output Destination	2	EXCEL WORKSHEET

Segment Morphometry

		Outflow		Area	Depth	Length	Mixed Depth (m)		Hypol Depth		Non-Algal Turb (m^{-1})		Internal Loads (mg/m2-day) Conserv.		Total P		Total N	
Seg	Name	Segment	Group	km^2	m	km	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	South	2	1	0.179	3.963	0.85	3.543	0	0	0	0.15	1.82	0	0	0	0	0	0
2	North	0	1	0.097	3.301	0.52	2.883	0	0	0	0.13	2.4	0	0	0	0	0	0

Segment Observed Water Quality

	Conserv		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	0	0	54.5	0.512	724	0.225	13.8	0.62	2	0.442	0	0	44	0.591	0	0	0	0
2	0	0	58	0.491	696	0.217	12.6	0.728	2.1	0.485	0	0	48.9	0.523	0	0	0	0

Segment Calibration Factors

	Dispersion Rate		Total P (ppb)		Total N (ppb)		Chl-a (ppb)		Secchi (m)		Organic N (ppb)		TP - Ortho P (ppb)		HOD (ppb/day)		MOD (ppb/day)	
Seg	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0
2	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

Tributary Data

				Dr Area	Flow (hm^3/yr)		Conserv.		Total P (ppb)		Total N (ppb)		Ortho P (ppb)		Inorganic N (ppb)	
Trib	Trib Name	Segment	Type	km^2	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1	SchaperPond	1	1	0	4.975	0	0	0	124.51	0.086	1405.56	0.038	13.39	0.183	0	0

Model Coefficients	Mean	CV
Dispersion Rate	1.000	0.70
Total Phosphorus	1.150	0.45
Total Nitrogen	1.000	0.55
Chl-a Model	0.700	0.26
Secchi Model	1.000	0.10
Organic N Model	1.000	0.12
TP-OP Model	1.000	0.15
HODv Model	1.000	0.15
MODv Model	1.000	0.22
Secchi/Chla Slope (m^2/mg)	0.025	0.00
Minimum Qs (m/yr)	0.100	0.00
Chl-a Flushing Term	1.000	0.00
Chl-a Temporal CV	0.620	0
Avail. Factor - Total P	0.330	0
Avail. Factor - Ortho P	1.930	0
Avail. Factor - Total N	0.590	0

Sweeney Lake 2009

Sweeney Lake 2008
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Predicted & Observed Values Ranked Against CE Model Development Dataset

Segment: 3 Area-Wtd Mean

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	57.1	0.17	57.7%	55.7	0.50	56.7%
TOTAL N MG/M3	714.2	0.17	29.8%	714.2	0.22	29.8%
C.NUTRIENT MG/M3	36.3	0.14	50.8%	35.9	0.35	50.3%
CHL-A MG/M3	17.4	0.32	78.8%	13.4	0.66	67.7%
SECCHI M	0.8	0.17	36.2%	2.0	0.46	79.8%
ORGANIC N MG/M3	563.5	0.24	63.3%			
TP-ORTHO-P MG/M3	30.2	0.33	50.3%	45.7	0.57	67.1%
ANTILOG PC-1	419.9	0.32	66.0%	180.3	0.55	40.7%
ANTILOG PC-2	8.4	0.24	69.4%	13.5	0.41	92.2%
(N - 150) / P	9.9	0.27	21.5%	10.1	0.43	22.4%
INORGANIC N / P	5.7	1.18	4.8%			
TURBIDITY 1/M	0.1	1.46	5.0%	0.1	1.46	5.0%
ZMIX * TURBIDITY	0.5	1.47	0.7%	0.5	1.47	0.7%
ZMIX / SECCHI	4.0	0.16	38.8%	1.6	0.33	3.3%
CHL-A * SECCHI	14.3	0.31	68.5%	27.2	0.58	91.7%
CHL-A / TOTAL P	0.3	0.29	75.8%	0.2	0.61	62.6%
FREQ(CHL-a>10) %	71.9	0.24	78.8%	56.3	0.53	67.7%
FREQ(CHL-a>20) %	29.5	0.60	78.8%	16.9	1.16	67.7%
FREQ(CHL-a>30) %	11.6	0.87	78.8%	5.4	1.63	67.7%
FREQ(CHL-a>40) %	4.9	1.08	78.8%	1.9	1.99	67.7%
FREQ(CHL-a>50) %	2.2	1.25	78.8%	0.8	2.28	67.7%
FREQ(CHL-a>60) %	1.0	1.39	78.8%	0.3	2.53	67.7%
CARLSON TSI-P	62.4	0.04	57.7%	62.1	0.09	56.7%
CARLSON TSI-CHLA	58.6	0.05	78.8%	56.0	0.08	67.7%
CARLSON TSI-SEC	62.8	0.04	63.8%	49.8	0.10	20.2%

Segment: 1 South

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	60.1	0.16	59.9%	54.5	0.51	55.7%
TOTAL N MG/M3	724.0	0.22	30.6%	724.0	0.22	30.6%
C.NUTRIENT MG/M3	37.4	0.18	52.3%	36.0	0.36	50.3%
CHL-A MG/M3	17.3	0.34	78.6%	13.8	0.62	69.1%
SECCHI M	0.8	0.16	34.2%	2.0	0.44	79.1%
ORGANIC N MG/M3	562.5	0.25	63.1%			
TP-ORTHO-P MG/M3	30.2	0.33	50.3%	44.0	0.59	65.7%
ANTILOG PC-1	434.7	0.33	66.9%	188.5	0.71	42.1%
ANTILOG PC-2	8.1	0.26	66.8%	13.7	0.54	92.4%
(N - 150) / P	9.6	0.33	19.9%	10.5	0.57	24.1%
INORGANIC N / P	5.4	1.31	4.3%			
TURBIDITY 1/M	0.2	1.82	5.6%	0.2	1.82	5.6%
ZMIX * TURBIDITY	0.5	1.82	1.1%	0.5	1.82	1.1%
ZMIX / SECCHI	4.5	0.16	45.6%	1.8	0.43	4.4%
CHL-A * SECCHI	13.7	0.33	66.1%	27.6	0.76	92.0%

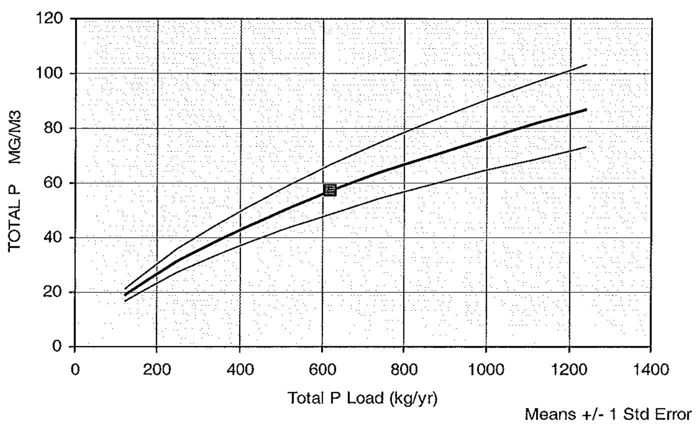
CHL-A / TOTAL P	0.3	0.32	72.7%	0.3	0.79	65.6%
FREQ(CHL-a>10) %	71.7	0.25	78.6%	58.3	0.66	69.1%
FREQ(CHL-a>20) %	29.3	0.64	78.6%	18.2	1.46	69.1%
FREQ(CHL-a>30) %	11.5	0.92	78.6%	5.9	2.04	69.1%
FREQ(CHL-a>40) %	4.8	1.14	78.6%	2.1	2.48	69.1%
FREQ(CHL-a>50) %	2.2	1.32	78.6%	0.9	2.83	69.1%
FREQ(CHL-a>60) %	1.0	1.47	78.6%	0.4	3.13	69.1%
CARLSON TSI-P	63.2	0.04	59.9%	61.8	0.12	55.7%
CARLSON TSI-CHLA	58.6	0.06	78.6%	56.3	0.11	69.1%
CARLSON TSI-SEC	63.4	0.04	65.8%	50.0	0.13	20.9%

Segment: 2 North

	Predicted Values--->			Observed Values--->		
Variable	**Mean**	**CV**	**Rank**	**Mean**	**CV**	**Rank**
TOTAL P MG/M3	51.5	0.20	53.2%	58.0	0.49	58.4%
TOTAL N MG/M3	696.0	0.22	28.5%	696.0	0.22	28.5%
C.NUTRIENT MG/M3	34.1	0.17	47.7%	35.8	0.34	50.1%
CHL-A MG/M3	17.5	0.35	79.0%	12.6	0.73	64.9%
SECCHI M	0.9	0.18	39.9%	2.1	0.49	80.9%
ORGANIC N MG/M3	565.2	0.26	63.5%			
TP-ORTHO-P MG/M3	30.1	0.36	50.1%	48.9	0.52	69.6%
ANTILOG PC-1	392.7	0.37	64.1%	165.2	0.82	38.2%
ANTILOG PC-2	9.0	0.26	73.7%	13.3	0.62	91.7%
(N - 150) / P	10.6	0.34	24.4%	9.4	0.55	19.3%
INORGANIC N / P	6.1	1.61	5.6%			
TURBIDITY 1/M	0.1	2.40	4.0%	0.1	2.40	4.0%
ZMIX * TURBIDITY	0.4	2.40	0.3%	0.4	2.40	0.3%
ZMIX / SECCHI	3.2	0.18	25.3%	1.4	0.47	1.6%
CHL-A * SECCHI	15.5	0.33	72.4%	26.5	0.87	91.1%
CHL-A / TOTAL P	0.3	0.32	80.6%	0.2	0.87	56.4%
FREQ(CHL-a>10) %	72.3	0.26	79.0%	52.5	0.88	64.9%
FREQ(CHL-a>20) %	29.9	0.66	79.0%	14.6	1.86	64.9%
FREQ(CHL-a>30) %	11.9	0.96	79.0%	4.4	2.55	64.9%
FREQ(CHL-a>40) %	5.0	1.19	79.0%	1.5	3.08	64.9%
FREQ(CHL-a>50) %	2.2	1.37	79.0%	0.6	3.50	64.9%
FREQ(CHL-a>60) %	1.1	1.53	79.0%	0.2	3.86	64.9%
CARLSON TSI-P	61.0	0.05	53.2%	62.7	0.11	58.4%
CARLSON TSI-CHLA	58.7	0.06	79.0%	55.5	0.13	64.9%
CARLSON TSI-SEC	61.7	0.04	60.1%	49.3	0.14	19.1%

Sweeney Lake 2008
File: S:\AE\B\Bcwmc\070100\Bathtub\Sweeney08.btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale	Flow	Load	Conc	TOTAL P MG/M3			
Factor	hm3/yr	kg/yr	mg/m^3	Mean	CV	Low	High
Base:	5.0	619.4	124.5	57.1	0.17	48.7	66.8
0.20	5.0	123.9	24.9	19.0	0.12	17.0	21.3
0.40	5.0	247.8	49.8	31.2	0.14	27.3	35.7
0.60	5.0	371.7	74.7	41.1	0.16	35.5	47.5
0.80	5.0	495.5	99.6	49.5	0.16	42.5	57.7
1.00	5.0	619.4	124.5	57.1	0.17	48.7	66.8
1.20	5.0	743.3	149.4	63.9	0.18	54.4	75.1
1.40	5.0	867.2	174.3	70.2	0.18	59.5	82.8
1.60	5.0	991.1	199.2	76.1	0.18	64.3	90.0
1.80	5.0	1115.0	224.1	81.6	0.19	68.9	96.8
2.00	5.0	1238.9	249.0	86.9	0.19	73.1	103.2



SEH

Project: Sweeney Lake TMDL
Subject: BATHTUB Model Summary
Date: 06/09/09 By: R. Nestingen SEH #:
Checked by: Date: Office: File #:
Sheet No: 1 Of: 2

Assumptions:

- Models:
  - TP Model – 2nd Order, Avail. P
  - Chl-a – P, Light, T
  - Secchi – Total P
  - P Calibration – decay rates
- No Internal Loading Specified
- Flow Rate (hm³/yr) = 6.128 (2007), 4.975 (2008) } NOT adjusted for seasonal precip. patterns, based on P8 simulated runoff volume in Sweeney watershed

Calibration Factors:

	TP	Chl-a
2007	1.23	0.89
2008	1.08	0.52
Avg.	1.16	0.71

Results (Area-Weighted Means):

		TP Conc. (ppb)	Chl-a Conc. (ppb)	Secchi (m)
2007	Predicted	56.0	16.1	0.8
	Observed	53.2	20.2	1.3
	Obs/Pred. Ratio	0.95	1.26	1.59
2008	Predicted	56.9	17.6	0.8
	Observed	55.7	13.4	2.0
	Obs/Pred. Ratio	0.98	0.76	2.46

Load Reduction: (to get to in-lake TP conc. of 40 ppb)

	2007	2008
Obs. Load	701 kg/yr	619 kg/yr
Goal Load	422 kg/yr	359 kg/yr
Load Reduction	279 kg/yr	260 kg/yr

SEH

Project: Sweeney Lake TMDL
Subject: BATHTUB Model Summary
Date: 06/09/09 By: R. Nestingen SEH #:
Checked by: Date: Office: File #:
Sheet No: 2 Of: 2

Assumptions:

- → Internal Loading Rates = 17.3 mg m^{-2} d^{-1} - North Basin
  (Assuming Anoxic Cond.) = 15.6 mg m^{-2} d^{-1} - South Basin
- → See sheet 1 for other assumptions

Calibration Factors:

	TP	Chl-a
2007	6.57	0.89
2008	6.32	0.52
Avg.	6.45	0.71

Results (Area-Weighted Means):

	TP Conc. (ppb)	Chl-a Conc. (ppb)	Secchi (m)
Predicted	54.3	15.8	0.9
Observed	53.2	20.2	1.3
Obs./Pred. Ratio	0.98	1.28	1.56
Predicted	55.7	17.4	0.8
Observed	55.7	13.4	2.0
Obs./Pred. Ratio	1.00	0.76	2.46

Internal vs. External TP Loads:

	'07 Load (kg/yr)	% Total	'08 Load (kg/yr)	% Total
Internal	1684	70.4	1633	72.3
External*	708	29.6	626	27.7

* Incudes precipitation load

Load Reduction: (to get to in-lake TP Conc. of 40 ppb)

	2007	2008
Obs. Load	701	619
Goal Load		N/A*
Load Reduction		619

* Goal conc. can not be achieved with external load reduction only. At Ø external load, in-lake TP conc. remains at 44.9 ppb and 46.8 ppb for 2007 and 2008 modeling years, respectively.

Appendix C ERDC Sediment Core Analysis Report

Internal Phosphorus Loading and Sediment Characteristics: Sweeney Lake, Minnesota

7 December, 2007

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Approach

Internal loading of phosphorus from sediments was determined for sediment cores collected in the north and south hypolimnetic basins of Sweeney Lake, Minnesota (Table 1). A Wildco KB Sediment Core Sampler (Wildco Wildlife Supply Co.), equipped with an acrylic core liner (6.5-cm ID and 50-cm length), was used to collect intact sediment cores (undisturbed) at each station. The core liners, containing both sediment and overlying water, were sealed using stoppers and stored in a protective box until analysis. Additional lake water was collected for incubation with the collected sediment. Six cores were collected at these stations for analysis of P release from sediment under oxic conditions (3 replicates) and under anoxic conditions (3 replicates) using methods outlined in James and Barko (1991).

In the laboratory, the cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Lake water was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that are sealed with rubber stoppers. The sediment incubation systems were placed in a darkened environmental chamber and incubated at a constant temperature for up to 3 weeks. The incubation temperature was 20 C. The oxidation-reduction environment in each system was controlled by gently bubbling either air (oxic) or nitrogen (anoxic) through an air stone placed just above the sediment surface. Bubbling action insured complete mixing of the water column but did not disrupt the sediment.

Water samples for soluble reactive phosphorus (SRP) were collected from the center of each sediment incubation system using an acid-washed syringe and immediately filtered through a 0.45 μm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. SRP was measured colorimetrically using the ascorbic acid method (APHA 1998). Sampling was conducted at daily intervals for 5 days, then every other day for an additional 14 days. Rates of SRP release from the sediment (mg m^{-2} d^{-1}) were calculated as the linear change in concentration in the overlying water divided by time and the area of the incubation core liner.

Sediment moisture content (%) and density (g/mL) were determined gravinometrically as the change in mass of a known volume of fresh sediment after drying at 105 C. Organic matter content was estimated as loss-on-ignition (LOI) by combusting sediment at 500 C for twenty-four hours. Additional sediment subsamples were dried and ground to pass through a 2 mm mesh for analysis of phosphorus (P) and iron (Fe) using ICP spectrophotometry after microwave digestion (APHA 1998). Fresh sediment was sequentially extracted with 0.1 M ammonium chloride and 0.11 M bicarbonate-dithionate for determination of loosely-bound and iron-bound P (Psenner and Puckso 1988). These functionally-defined fractions have been linked to eH-related (i.e., redox potential) sediment diffusive P flux (Boström et al. 1982; Nürnberg 1988; Jensen and Thamdrup 1993; Petticrew and Arocena 2001; Søndergaard et al. 2003; Pilgrim et al. 2007). Thus, the sum of the concentration of these variables represents redox-sensitive P and can be used to estimate internal P loading from sediment.

Results and Interpretation

Sediments at both stations exhibited a high moisture content and low sediment density, indicative of fine-grained particles (Table 2). Sediment P concentrations were moderate but fell within ranges reported for eutrophic lakes world-wide (Barko and Smart 1986; Ostrofsky 1987; Nürnberg 1988). Sediment iron concentration was greatest in the south basin, resulting in a greater Fe:P ratio than for the north basin. The Fe:P ratio for Sweeney Lake was moderate, suggesting that there was excess iron available for phosphorus binding. Redox-sensitive P concentrations were high relative to literature values (Nürnberg 1988), and constituted 39 and 53% of the sediment P for the north and south basin, respectively. These trends suggested the potential for high rates of P release under anoxic conditions.

Diffusive P flux occurred under oxic conditions for sediment cores collected at both stations (Table 1). These rates were moderate but within ranges reported for eutrophic lakes (Nürnberg 1988), suggesting that sediments might contribute to the P budget of the system even under oxidized conditions. Rates of P release were 5 to 10 times greater under anoxic conditions and very high relative to other systems (Figure 1). These results suggested the potential for soluble P accumulation in the hypolimnion during periods of summer anoxia as a result of diffusive P flux from sediments.

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Table 1. Sediment core station locations. UTM coordinates are NAD83.

Station	UTM East	UTM North	Depth (ft)
North Basin	473575	4982740	24.9
South Basin	473066	4982016	24.6

Table 2. Means (n=3) and standard errors for sediment characteristics in the North and South Basin of Sweeney Lake.

Variable	North Basin		South Basin	
	Mean	SE	Mean	SE
Moisture content (%)	78.4	0.2	81.5	0.5
Sediment Density (g/mL)	0.243	0.014	0.221	0.001
Total Fe (mg/g)	13.245	0.101	25.686	0.309
Total P (mg/g)	0.719	0.045	0.86	0.018
Fe:P	18.6	1.2	29.9	0.9
Loosely-bound P (mg/g)	0.037	0.001	0.008	0.001
Iron-bound P (mg/g)	0.241	0.005	0.446	0.017
Redox-sensitive P (mg/g)	0.278	0.006	0.453	0.018
Redox-sensitive P (%)	39.0	2.7	52.7	1.0
Oxic P release (mg m^{-2} d^{-1})	3.3	1.1	1.6	0.1
Anoxic P rlease (mg m^{-2} d^{-1})	17.3	0.1	15.6	1.0

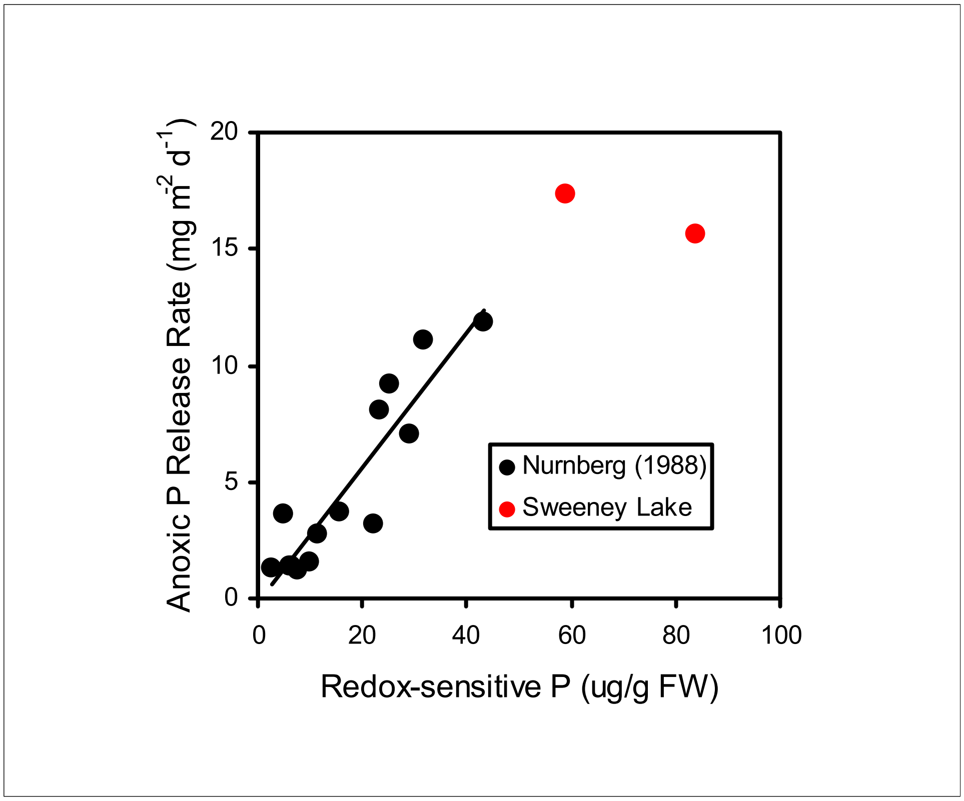

Figure 1. Comparison of Sweeney Lake sediments versus relationship between redox-sensitive P and the anoxic P release rate developed by Nürnberg (1988).