2012

Lake Shaokatan Phosphorus Total Maximum Daily Load Report

Prepared for the Yellow Medicine River Watershed District

Final Report

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EPA/MPCA Required Elements	Summary	TMDL Page #
Location	Lake Shaokatan is located in southwestern Minnesota in Lincoln County and is the Yellow Medicine River headwaters, which drains to the Minnesota River.	8
303(d) Listing Information	Lake Shaokatan (ID: 41-0089-00) was listed for not meeting aquatic recreation and aquatic life designated uses due to excess nutrients in 2002. The project was scheduled to begin in 2007 and be completed in 2011.	8, 13
Applicable Water Quality Standards/ Numeric Targets	Lake Shaokatan has a maximum depth of ten feet classifying it as a shallow lake in the Northern Glaciated Plains Ecoregion. The water quality standard for shallow lakes in this Ecoregion is 90 µg/L of phosphorus, 30 µg/L of chlorophyll a and not less than 0.7 meters secchi depth.	15
Loading Capacity (expressed as daily load)	The loading capacity is the Total Maximum Daily Load which is 4.21 kg/day. The critical condition, which corresponds to the time period for which the water quality standard is applicable, is June-September.	31-32
Wasteload Allocation	A wasteload allocation was defined using the average acreage size in past construction stormwater permits in the watershed. An allocation of 0.042 kg/day was attributed for construction stormwater. No other wasteload allocations were defined.	32
Load Allocation	A load allocation of 1521.63 kg/yr includes a variety of phosphorus contributions.	32
Margin of Safety	The MOS is set at 10 percent of the total phosphorus water quality standard of 90 µg/L. This essentially lowers the total phosphorus water quality standard to 81 µg/L. This margin of safety addresses the uncertainty of the TMDL method due to sampling and modeling errors, both in estimating the phosphorus concentrations and the flow regimes.	32-33
Seasonal Variation	Summer mean total phosphorus concentrations vary from year to year depending on rainfall patterns and the resulting influence on lake residence time and watershed runoff. Typically, in the early spring, Lake Shaokatan experiences an increased loading because of snowmelt and spring rains. The increased runoff usually does not cause Lake Shaokatan to exceed the water quality standard. Throughout the summer, Lake Shaokatan exhibits increasing phosphorus concentrations that exceed the water quality standard. The months of June through September are the critical period when phosphorus levels exceed the water quality standard.	34

TMDL Summary Table, continued

Reasonable Assurance	The local sponsor, Yellow Medicine River Watershed District has implemented several projects in the Lake Shaokatan watershed and would continue to provide opportunities for watershed residents. In addition, there is assurance through regulatory programs that every attempt will be made to minimize future impacts on Lake Shaokatan. The local interest, involvement, and commitment of watershed residents to improve Lake Shaokatan is the ultimate assurance in addressing the impairment.	37
Monitoring	Future monitoring is planned to assess the effectiveness of phosphorus reduction strategies. A description of current and future monitoring is described in Section 8. A more defined monitoring strategy will be illustrated in the implementation plan, which will be developed.	35
Implementation	A significant amount of work has been done in the Lake Shaokatan watershed. Section 9 describes the approach and potential phosphorus reductions strategies that may be used to address Lake Shaokatan's impairment. A detailed implementation plan will be developed utilizing the information from this study upon the EPA's approval. It is estimated that it will take over $1 million dollars to address the phosphorus impairment.	36
Public Participation	Four meetings were held throughout the development of this report.	39

Lake Shaokatan
Phosphorus Total Maximum Daily Load Report

Executive Summary

The Minnesota Pollution Control Agency (MPCA) has listed Lake Shaokatan as impaired for the designated uses of aquatic recreation and aquatic life under Section 303(d) of the Clean Water Act. Excessive phosphorus loading is the main cause of the impairment. This Total Maximum Daily Load (TMDL) document assesses the current phosphorus concentrations and the load reductions needed for Lake Shaokatan to comply with Minnesota's water quality standards. The specific problems and recommended approach and actions to control phosphorus loads are highlighted below.

The area of concern is Lake Shaokatan and its surrounding watershed, which includes an area of 13.9 square miles. Agricultural land (cropland, pasture and hayland) and grasslands dominate the land use in this watershed. There are no urban areas in this watershed. The 13.9 square mile watershed is headwaters of the Yellow Medicine River. This lake has been the subject of several investigations including an intensive MPCA Clean Water Partnership Diagnostic and Feasibility study and a successful implementation project that spanned the period of 1991-1996. Summer mean total phosphorus concentrations declined from a range of 275-350 micrograms/liter (µg/L) in 1989-1992 to 90-110 µg/L in 1994-1995 in response to several implementation activities within the watershed.

The focus and primary intent of this project is to better characterize phosphorus levels, probable sources, and estimate reductions required to meet the TMDL water quality goal. Watershed wide phosphorus loading was estimated to assess the magnitude of nonpoint and point sources and establish a cause-effect linkage of loading sources and subsequent in-lake phosphorus concentrations.

Samples were collected for the TMDL study between April and October 2005. Fourteen monitoring stations were located throughout the watershed and lake. The resulting data illustrates a declining trend in water quality through the season due to watershed and internal phosphorus loading. Water monitoring over the past two decades has resulted in estimated annual phosphorus loading rates to Lake Shaokatan from watershed runoff that range from around 600-4,300 kg/yr. A total phosphorus load of 1,537 kg/yr would be required to reach the water quality goal of 81 µg/l; the goal includes a 10 percent margin of safety. For some years, a reduction from watershed sources of up to about 2,800 kg/yr or 65 percent would be required to meet this goal. Over time, reductions in external loading should lead to reductions in internal loading.

The TMDL report includes:

- Problem Statement
- Applicable Water Quality Standards
- Stream and Lake Data Assessment
- TMDL and Allocations
- Follow-Up Monitoring Plan
- Public Participation
- Implementation Plan

1.0 Introduction

Section 303(d) of the Clean Water Act (CWA) provides authority for completing Total Maximum Daily Loads (TMDLs) to achieve state water quality standards and/or their designated uses. The TMDL process establishes the allowable loadings of pollutants for a water body based on the relationship between pollution sources and water quality conditions. TMDLs also provide a basis for determining the pollutant reductions necessary from both point and nonpoint sources to achieve water quality standards and/or their designated uses.

A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards, and an allocation of that amount to the pollutant's sources. Section 303(d) of the Clean Water Act (CWA) and its implementing regulations (40 C.F.R. § 130.7) require states to identify waters that do not or will not meet applicable water quality standards and to establish TMDLs for pollutants that are causing non-attainment of water quality standards.

States, Territories, and Tribes set water quality standards. They identify the uses for each water body, for example, drinking water supply, contact recreation (swimming), and aquatic life support (fishing), and the scientific criteria to support that use.

A TMDL needs to account for seasonal variation and must include a margin of safety (MOS). The MOS is a safety factor that accounts for any lack of knowledge concerning the relationship between effluent limitations and water quality. Also, a TMDL must specify pollutant load allocations among sources. The total of all allocations, including waste load allocations (WLA) for point sources, load allocations (LA) for nonpoint sources (including natural background), and the MOS (if explicitly defined) cannot exceed the maximum allowable pollutant load:

$$\mathbf{TMDL = \sum WLAs + \sum LAs + MOS + RC^*}$$

* The MPCA also requires that “Reserve Capacity” (RC) which is an allocation for future growth be addressed in the TMDL.

A TMDL study identifies all sources of the pollutant and determines how much each source must reduce its contribution in order to meet the quality standard. The sum of all contributions must be less than the maximum daily load.

Sources that are part of the waste load allocation, with the exception of subsurface treatment septic systems, are largely controlled through National Pollutant Discharge Elimination System (NPDES) permits. Load allocation sources are controlled through a variety of regulatory and non-regulatory efforts at the local, state, and federal level.

2.0 Problem Statement

In this section:

- Water body name and location
- Map
- Water body 303(d) list status and priority ranking
- Watershed description

The Lake Shaokatan Phosphorus TMDL represents a specific activity within a larger project addressing water quality improvements. The larger project goals relate land use to monitoring data in a cause-effect manner.

Lake Shaokatan was listed for not meeting aquatic recreation and aquatic life designated uses due to excess nutrients in 2002. Lake Shaokatan (ID: 41-0089-00) is located in southwestern Minnesota in Lincoln County. Lake Shaokatan drains to the Yellow Medicine River and is in the Minnesota River Basin. The watershed is 8,920 acres or 13.9 square miles. The average depth of the lake is 8 feet. Figure 1 shows Lake Shaokatan and its main tributaries.

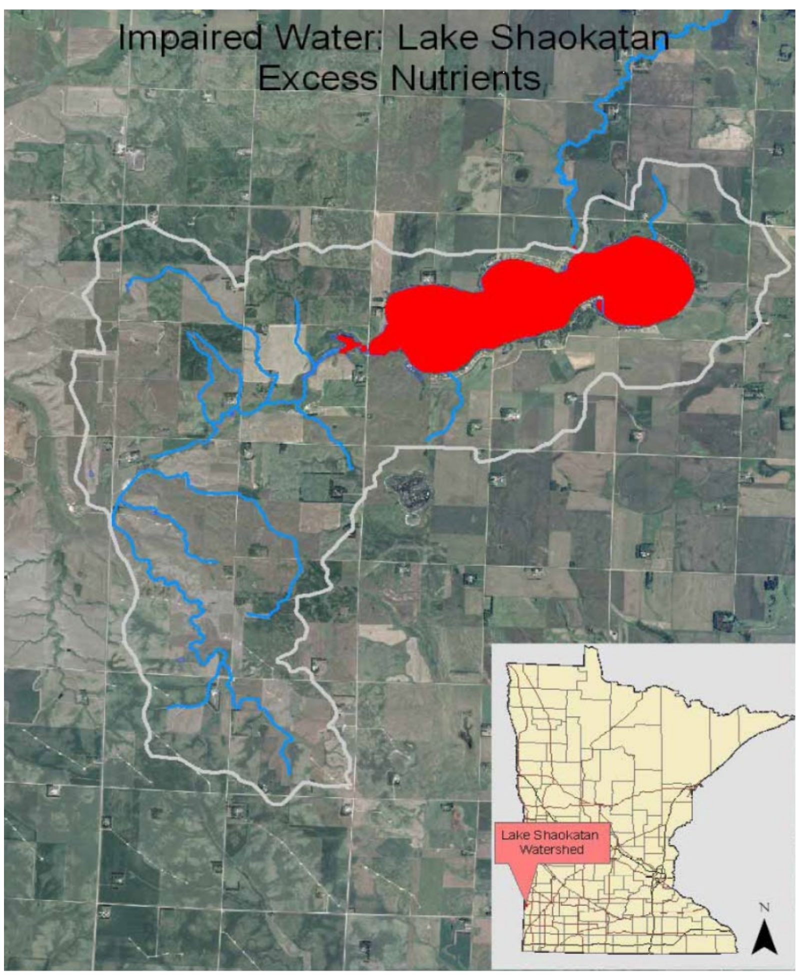

Figure 1: Lake Shaokatan Watershed

Water quality standards for shallow lakes in the Northern Glaciated Plains Ecoregion equate to 90 µg/L total phosphorus, 30 µg/L chlorophyll-a and not less than 0.7 meters Secchi depth readings (see Section 3.1 for a full discussion on standards). The historical data record for Lake Shaokatan contains total phosphorus concentrations over the 90 µg/L impairment level. Data collected during the 1999 and 2001 open water seasons show 12 samples of 22 exceeded the water quality standard. This led to a preliminary assessment of non-support, and an impaired water listing.

In 2005, 16 total phosphorus (TP), 14 chlorophyll A (Chl A), and 16 secchi disk (Secchi) observations were collected from two lake sites (Table 1). Of the 16 TP samples, 13 observations were equal or greater than the water quality standard for Lake Shaokatan (90 µg/L). There were seven samples that exceeded the ChlA standard of 30 µg/L and five Secchi disk readings that failed to meet the standard of 0.7 meters.

Table 1: 2005 Lake Shaokatan Water Quality Data

Lake Shaokatan - West				**Lake Shaokatan - East**			
Date	TP µg/L	ChlA µg/L	Secchi meters	Date	TP µg/L	ChlA µg/L	Secchi meters
5/10/2005	80		2.44	5/10/2005	40		2.44
6/6/2005	90	1.2	2.44	6/6/2005	120	2.6	2.13
6/20/2005	90	0.5	2.74	6/20/2005	90	7.3	2.74
7/5/2005	150	5.4	1.83	7/5/2005	130	3.5	2.13
7/24/2005	50	24.6	0.91	7/24/2005	170	38.6	1.22
8/17/2005	160	50.5	0.61	8/17/2005	140	81.1	1.07
9/7/2005	170	55.1	0.61	9/7/2005	200	67.2	0.46
9/18/2005	320	183	0.31	9/18/2005	430	151	0.38
Average	**139**	**45.8**	**1.49**	**Average**	**165**	**50.2**	**1.57**

Lake Shaokatan Average	TP µg/L	ChlA µg/L	Secchi meters
	152	**48.0**	**1.53**

ChlA on 6/20/05 on West was a no detect. Used half of detection limit (0.5) to calculate average.

2.1 Watershed and Water Quality History

Native Americans lived in the Lake Shaokatan vicinity beginning at least 10,000 years ago. People of the Dakota/Lakota tribes resided here when European settlers arrived in the area as early as the 17th century, trapping for furs. Later, in the 19th century, European farmers also arrived as part of the westward expansion of American settlement. The conversion of prairie sod to cultivated crops resulted in changes to soil rainfall-runoff patterns. The initial changes were minor, but with the mechanized era beginning in the 20th century, the water retention characteristics of the landscape changed.

This pattern continued to accelerate until recent decades and was exacerbated by further drainage modifications such as wetland drainage, ditch construction, and the installation of drain tile. Local catchment and infiltration processes were changed to downstream discharges and through the construction of ditch systems, continuous flows from the extended reaches of the watershed to the lake were established. Flow is present now where it was previously limited to extreme rainfall events. The cutting of the stream banks and stream bottoms was accelerated as the flow from each rainfall increased. The channels were also filled to capacity more frequently due to drainage modifications.

The introduction of row crop agriculture and animal husbandry has led to an increase in the nutrient and solids concentrations of the runoff to Lake Shaokatan. With these changes, soil loss increased, washing enriched sediments from the row crops and plowed fields into the stream channels and depositing in Lake Shaokatan.

An additional impact that may have been initiated early in the settlement period was structural control of Lake Shaokatan's water level. Today, a 30-foot wide dam on the lake outlet serves this function. Such outlet structures, which are common on Minnesota lakes, can have both positive and negative effects on property, recreation, and overall water quality conditions.

The lake and its watershed present special hydrological complications which justify careful ongoing review through an adaptive management strategy. These complications include the fact that dam was installed at the outlet of the lake, which has substantially changed the hydrological and biological characteristics of the original lake system.

In more recent years, and continuing today, substantial efforts have been made to mitigate some of the changes and impacts that have occurred in the watershed over the past two centuries. This includes the restoration of perennial vegetation and wetlands, the expansion of soil conservation practices, improved wastewater treatment for lakeshore homes and rural residences, and improvements in the way livestock manure is handled. According to the CWP Implementation – 1993-1995 Final Report, improvements resulted in annual phosphorus loading being decreased by over 1,300 kilograms. One of the drivers behind these efforts is the relatively limited opportunity for surface water recreation in this region of the state. Larger lakes such as Shaokatan, even with less than excellent water quality, are highly valued.

There have been several past studies on Lake Shaokatan:

1. Lake Shaokatan CWP Phase I Diagnostic and Feasibility Study – 1992
2. Lake Shaokatan CWP Phase II Implementation – 1993-1995
3. Lake Shaokatan Update – 1996
4. MPCA Intensive Lake Studies Program – 1999, 2001
5. Shallow Lakes of Southwestern Minnesota: Status and Trend Summary for Selected Lakes – 2003
6. Interrelationships Among Water Quality, Lake Morphometry, Rooted Plants and Related Factors for Selected Shallow Lakes of West-Central Minnesota – 2004

7. Reconstructing Historical Water Quality in Minnesota Lakes from Fossil Diatoms – 2004

These studies indicate Lake Shaokatan has been subject to water quality deterioration processes in the recent past that related to rainfall storage loss and subsequent increasing stream velocities. Nutrient and suspended solids data suggest the lake is receiving excessive loadings from the watershed. Heiskary, Swain and Edlund reported that during pre-settlement (1750 and 1800) Lake Shaokatan exhibited average total phosphorus concentrations of around 50 µg/L[1]. Some would consider this a "natural background" condition, although this remains a subject of much debate. Regardless, given normal variability, and the human-related changes that have occurred in the watershed and to the lake, this is probably not a reasonable present-day total phosphorus goal. This was recognized in the development of Minnesota's lake nutrient standards, which set a target of 90 µg/L for shallow lakes in southwest Minnesota.

2.2 Lake Shaokatan Target Watershed

The drainage area as shown in Figure 1 defines the project area. The total watershed is comprised of 13.9 square miles with a watershed:lake ratio of approximately 9:1. Lake Shaokatan is the headwaters to the Yellow Medicine River, a subwatershed of the Minnesota River. The watershed encompasses portions of three townships (Shaokatan, Drammen, and Ash Lake) and no cities. The lake has two boat launches. One access is located on the north shore off of County Road 102 and the other is located along the south shore at Picnic Point County Park. The park facilities are a local attraction and are full on major weekends. The facilities include shower buildings, public shelters, camping areas, and a swimming beach. The recreational uses of the lake include fishing, swimming, water skiing, and boating. Shaokatan Township has a census of 196 people as of 2004. Of those, there are 43 people in 19 permanent year-round residences on the lake. There are also another 33 seasonal residences on Lake Shaokatan, and two campgrounds. The private campground on the north shore has 10-12 units in it all summer. Wastewater is treated through various subsurface treatment systems around the lake and throughout the watershed.

Status of the Fishery

Lake Shaokatan, located in Lincoln County, is a 995-acre lake with more than 7 miles of shoreline and a maximum depth of 10 feet. Primarily managed for walleye, Shaokatan is also managed for northern pike and yellow perch. Following its current management plan, the lake is stocked with walleye fry every other year at the rate of 1,000 fry per acre. Yellow perch are stocked if catch rates fall below average for two consecutive assessments. In addition, winter-rescue northern pike (rate = 1 pound per acre) or fingerlings (rate = 10 fish per acre) are stocked if gill net catch rates fall below two fish per net[2].

Land Use

[1] Heiskary, S., Swain, E., Edlund, M. 2004.
[2] Minnesota Department of Natural Resources website, 2008.

Land use data was obtained from the 2008 National Agricultural Statistics Service and the 2001 National Landcover Dataset. The Lake Shaokatan watershed is a mixture of cropland, pasture, open water, wetland, forest, grassland, farmsteads, lakeshore lots, open space and roads. The dominant land use is cropland (49 percent) [3]. Grassland and pasture/hay make up approximately 41 percent of the land use with the remaining categories contributing to the last ten percent. Table 2 displays the land use acres by category. It is important to note that land use and land cover is not static. For example, over fifty percent of the grassland indicated in Table 2 in 2008 was enrolled in the Conservation Reserve Program. Most of the contracts are 10-15 year terms and if these contracts expire, and not renewed, this land will likely return to cropland.

Table 2: Lake Shaokatan Land Use

Use/Cover Type	Acres	Hectares	Percentage
Pasture/Hay	1,356	549	17.1%
Forest	53	21	0.7%
Water/Wetland*	155	63	2.0%
Grassland	1,929	781	24.3%
Cropland	3,884	1,572	49.0%
Lakeshore Lots	30	12	0.4%
Farmsteads	102	41	1.3%
Roads and Open Space	421	170	5.3%
Total	**7,930**	**3,209**	
* does not include Lake Shaokatan itself (995 acres; 403 hectares)			

Ecoregion

The watershed is located within the Northern Glaciated Plains Ecoregion in Western Minnesota. Lakes in this ecoregion typically exhibit total phosphorus levels of 130-250 µg/L[4] during the summer growing season, and chlorophyll-a levels range between 30-55 µg/L. Streams and rivers in this ecoregion typically have phosphorus concentrations in the 200-500 µg/L range and suspended solids that are indicative of excessive erosion processes. These erosion forces are partially due to the terrain and steep elevation changes associated with the Coteau de Prairie and are exacerbated by human influence.

2.3 Lake Shaokatan TMDL project

The focus and primary intent of this project is to better characterize phosphorus levels in the lake, the probable sources, and estimate reductions required to meet the TMDL water quality goal. The scope of the project includes identifying and quantifying the point and nonpoint sources of phosphorus, and linking these sources to the lake concentrations.

The data gathered during the diagnostic study enables the project managers and the steering committee to develop an information-based management plan to:

- Assess the magnitude of each pollution source;
- Design realistic control measures;
- Quantify the performance of the control measures implemented; and

[3] National Agricultural Statistics Service website, 2008.

[4] Heiskary S.A. and C.B. Wilson. 1991.

- Prognosticate the net effect on the lake water quality and quantity.

The basic scope of this portion of the project is comprised of three components. The first is to assess the magnitude and variability of the watershed loading quantitatively at the most cost effective resolution. The second is to assemble a technical committee involving the Yellow Medicine River Watershed District (YMRWD), the Lincoln Soil and Water Conservation District, the Lyon County Soil and Water Conservation District, the Natural Resources Conservation District (NRCS), the Minnesota Pollution Control Agency (MPCA), and local townships. This committee guides the project flow by interpreting the available information and setting goals and direction. The third component is to create and utilize a one-stop, "state of the art" information processing mechanism in the form of a Geographic Information System. The requirements of this system include, but are not limited to, compatibility within and outside of the user group, usable spatial and numeric information systems, and dynamic communication protocols linking the project information to committee members and the landowners.

The MPCA's projected schedule for TMDL completions, as indicated on Minnesota's 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. The project was scheduled to begin in 2007 and be completed in 2011. 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 TMDLs within a watershed or basin. Lake Shaokatan TMDL project was able to attain funding and had willing and ready cooperators to complete this project before the scheduled timeline.

3.0 Water Quality Standards

In this section:

- Description of applicable water quality standards, designated uses affected by the pollutant of concern, and numeric criteria.

The TMDL evaluation is a method of addressing and assessing the phosphorus levels that exceed the state standard. All waters of Minnesota are assigned classes, based on their suitability for the following beneficial uses:

Lake Shaokatan ID: 41-0089-00 - Class 2B

a. Drinking Water – Class 1
b. Aquatic Life and Recreation – Class 2
c. Industrial Use and Cooling – Class 3
d. Agricultural Use, Irrigation – Class 4A
e. Agricultural Use, Livestock and Wildlife Watering – Class 4B
f. Aesthetic and Navigation – Class 5
g. Other Uses – Class 6
h. Limited Resource Value Waters – Class 7

3.1 Applicable Minnesota Water Quality Standards

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

The Minnesota Water Quality standards were revised in 2008 to include numeric standards for phosphorus and two indicators of eutrophication that measure the response of lakes to excess phosphorus. The two indicators are chlorophyll-a (a green pigment that measures the abundance of algae), and Secchi disk transparency or Secchi depth (a measurement of water clarity).

Lakes across the state vary widely due to different morphometry (size, depth, etc.), watershed characteristics, and other relevant factors. Accordingly, it cannot be expected that the same level of water quality exist for all lakes. The ecoregion framework can serve as a basis for evaluating lake condition and setting preliminary water quality goals. Ecoregions have been mapped by the EPA for the lower 48 states based on overlaying maps of landform, soil type, land use, and potential natural vegetation.[5] Lake Shaokatan is located in the Northern Glaciated Plains Ecoregion.

Besides different standards based on the ecoregion in which the lake is located, there are separate sets of standards for the four categories of lakes listed below:

- Lake trout lakes (lakes that support natural populations of lake trout),
- Stream trout lakes (lakes managed for stream trout species),
- Lakes and reservoirs with a maximum depth greater than 15 feet (deep lakes), and
- Lakes with a maximum depth less than 15 feet (shallow lakes).

Lake Shaokatan (41-0089-00) has a maximum depth of ten feet classifying it as a shallow lake in the Northern Glaciated Plains Ecoregion. The water quality standard for Lake Shaokatan is 90 µg/L of phosphorus, 30 µg/L of chlorophyll a and not less than 0.7 meters secchi depth as shown in Table 4.

Table 3: Lake Water Quality Standards

Ecoregion and Lake Type	Total phosphorus	Chlorophyll-a	Secchi Depth
Units	µg/L	µg/L	Meters, not less than
Northern Lakes and Forests			
- Lake trout lakes	12	3	4.8
- Stream trout lakes	20	6	2.5
- Deep and shallow lakes	30	9	2.0
North Central Hardwood Forest			
- Stream trout lakes	20	6	2.5
- Deep lakes	40	14	1.4
- Shallow lakes	60	20	1.0
Western Corn Belt Plains and Northern Glaciated Plains			
- Deep lakes	65	22	0.9
- Shallow lakes	90	30	0.7

µg/L=micrograms per liter

[5] Omernik, 1987.

3.2 Impairment Assessment

Lake Shaokatan has been the subject of several investigations and diagnostic studies[6,7]. The MPCA studied the lake in 1999 and 2001[8]. The assessment showed the lake to be phosphorus-impaired during a substantial portion of the open water season. Figure 2 illustrates the seasonal trend in phosphorus concentrations in Lake Shaokatan and mirrors the results of earlier and more recent investigations. As can be seen, Lake Shaokatan exceeded the water quality standard of 90 µg/L during the mid-summer and the concentration continued to increase throughout the season.

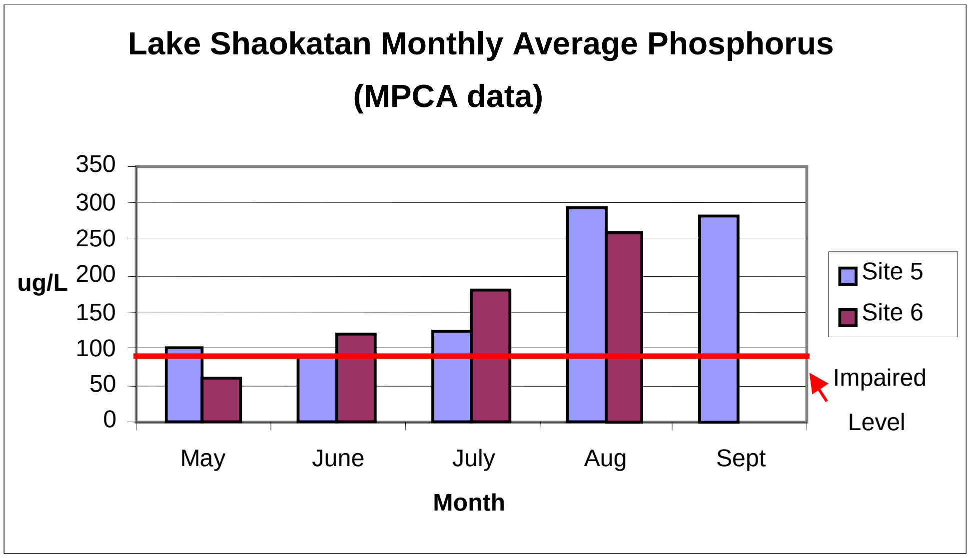

Figure 2: Seasonal Phosphorus Concentrations

Figure 3 depicts the inter-year variation of phosphorus concentrations in terms of average annual (May-September) phosphorus concentration. An intensive CWP implementation plan that realized over 75 percent reduction in watershed phosphorus loading was completed during the period 1993-1995 and the resulting water quality improvement is reflected in the graph. During that time, several feedlots in close proximity to the lake received funds to repair and upgrade their facilities. In addition, this timeframe was accompanied by significant rainfall that had a strong effect on the lake "flushing" rate that also contributed to the improvements. However, recent years have shown deterioration in lake concentrations because of nutrient loading from watershed and lake sediment sources.

Lake concentrations since 1985 show a wide range, averaging about 160 µg/L and extending to over 300 µg/L. The typical period in which the standard is not met for any given year is about 60 percent of the May-September season.

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[6] Schuler, D. 1994.
[7] Schuler, D. 1996.
[8] MPCA, Intensive Lake Studies Program, 2000.

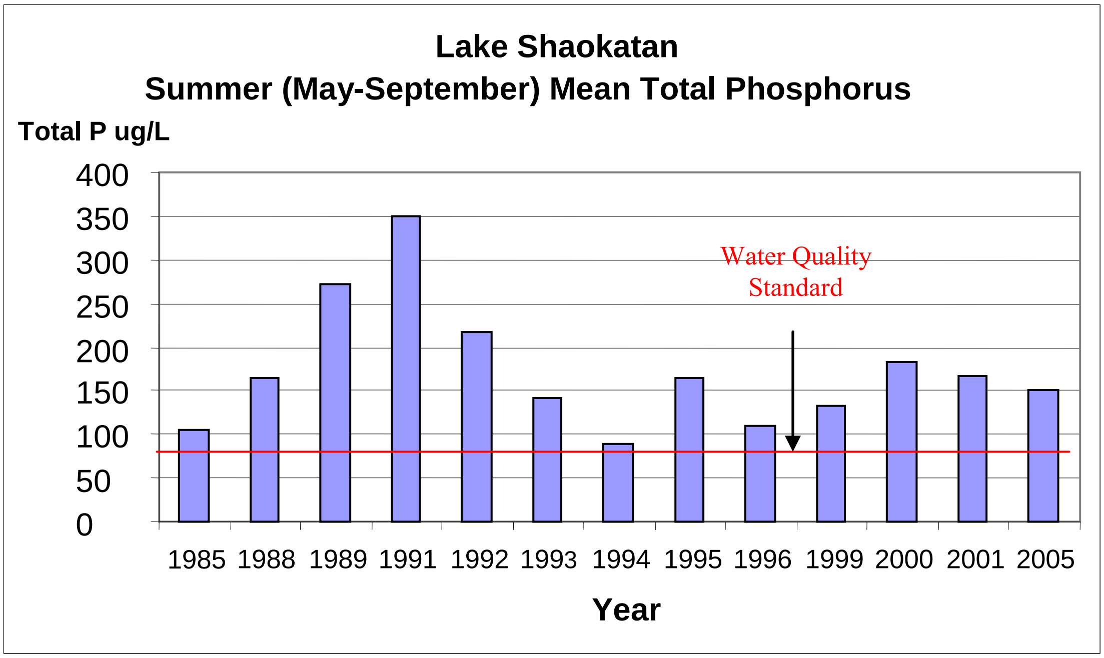

Figure 3: Historical Mean May-September Phosphorus Concentrations

4.0 Stream and Lake Data Assessment

4.1 Historical Data

The May – September total phosphorus concentrations in Lake Shaokatan, spanning the years 1985 through 2005 are represented in Figure 4. All data can also be found in Appendix 2. The TP water quality standard (90 µg/L) is also shown for reference. There has been an overall decline in phosphorus concentrations since monitoring began in the mid-1980's. However, high phosphorus levels still occur especially in the late summer.

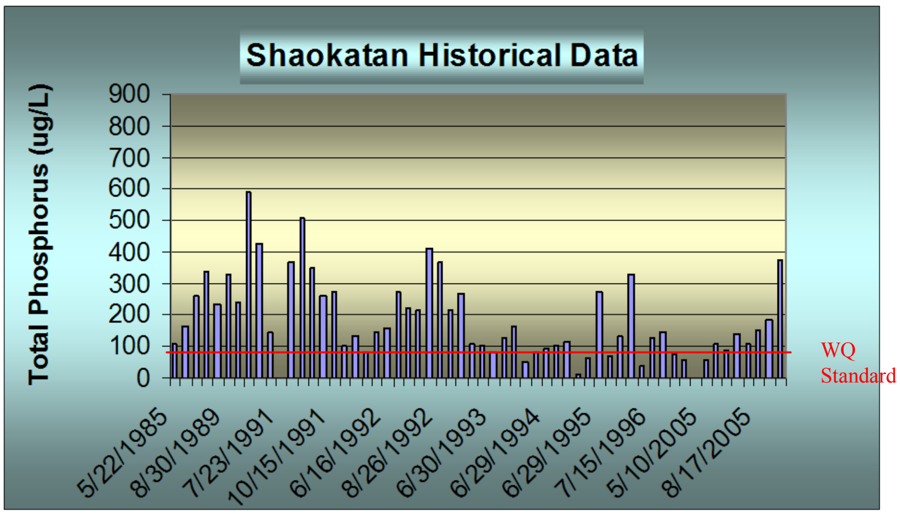

Figure 4: Historical Lake Data: Average Total Phosphorus

Figure 5 shows a substantial decrease in ortho phosphorus in recent years compared to 1991-1992. This is most likely due to implementation measures through the Clean Water Partnership grant. Ortho phosphorus is often referred to as soluble phosphorus when in fact it is particles that pass through a 1 micron filter in laboratory filtration techniques. These very small particles are the majority of the problem in the transport of phosphorus from the watershed to the lake.

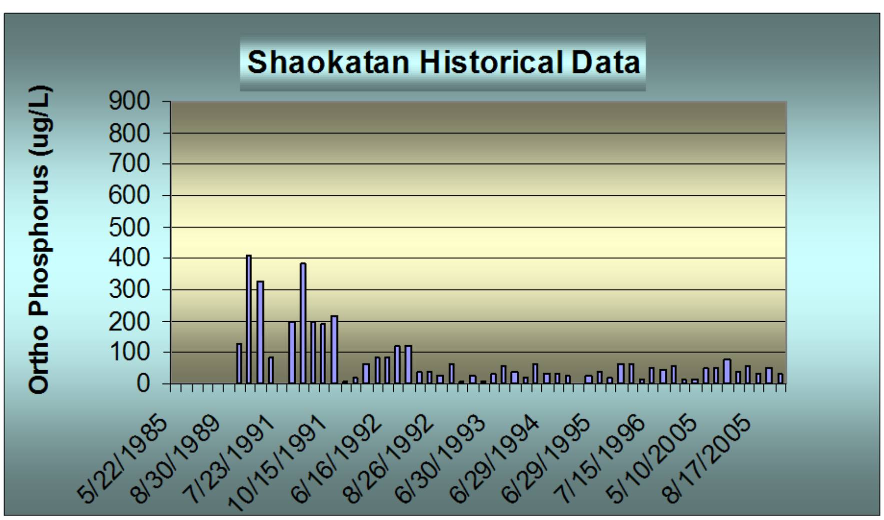

Figure 5: Historical Lake Data: Average Ortho Phosphorus

Figure 6 displays the historical data record for Chlorophyll-a. Chlorophyll-a measures the amount of algae in the water column and is a factor to the overall aquatic recreation beneficial use. Samples were not routinely collected as total phosphorus samples were. Overall, a decreasing trend can be seen on the chlorophyll-a concentrations.

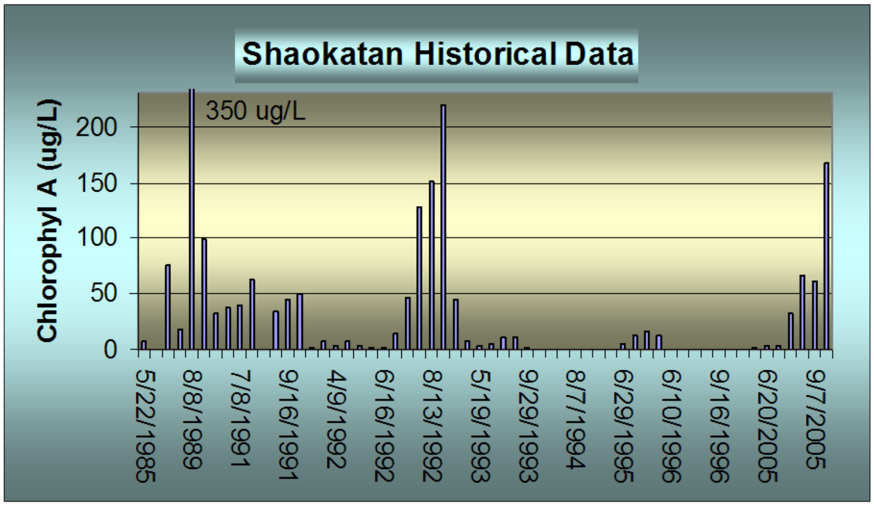

Figure 6: Historical Lake Data: Average Chlorophyll-a

4.2 Year 2005 Data

Data was collected at fourteen locations (including two lake sites) within the Lake Shaokatan watershed during the period of April through October 2005. All data can be found in Appendix 1 and 2. Figure 7 shows the stream sampling locations. Site descriptions are shown in Table 4.

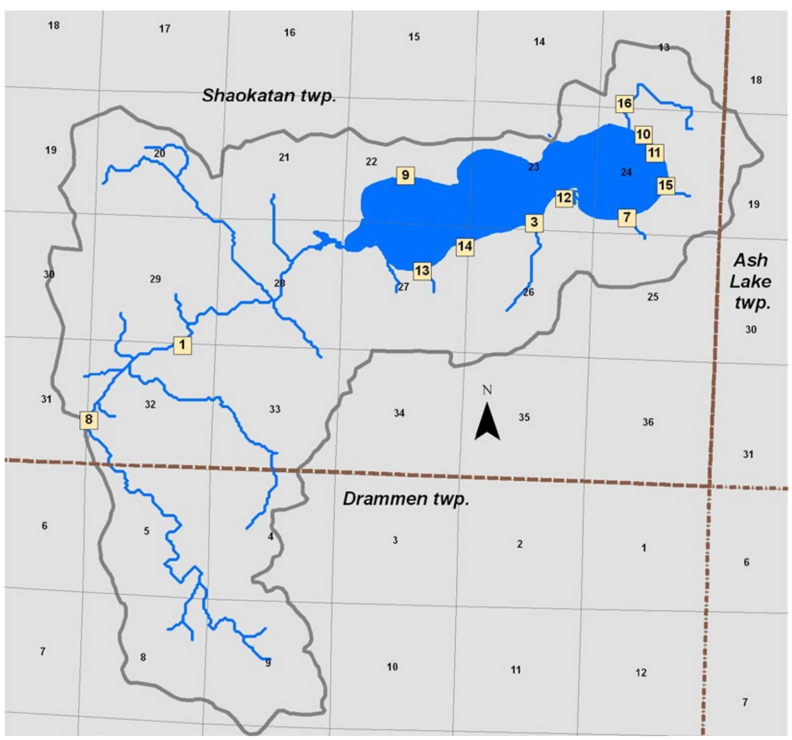

Figure 7: Stream Sampling Sites

Table 4: Stream Site Descriptions

Site	STORET ID	Description	Type
1	S002-255	Bridge	Automated
3	S002-257	1.25 ft culvert	Automated
7	S002-259	2 ft culvert	Automated
8	S002-260	Bridge	Grab
9	S002-261	0.5 ft culvert	Grab
10	S002-262	1 ft culvert	Grab
11	S002-263	1.25 culvert	Grab
12	S003-704	1.5 culvert	Grab
13	S002-395	3 ft culvert	Grab
14	S002-396	1 ft culvert	Grab
15	S003-705	2.5 ft culvert	Grab
16	S003-936	3 ft culvert	Grab

Three sites (Sites 1, 3, and 7) were deployed in 2005 consisting of data loggers, pressure transducers, and automated samplers. The remaining stations represent culverts and bridges that were sampled by hand (grab samples). Discharge measurements were made at all non-lake stations and gage-discharge ratings were developed. The staff gages at each of the non-automated stations were read at a minimum of once per week. The automated stations provided continuous gage and flow readings at a frequency of 15 minutes. The sites sampled where chosen during previous studies with the intent of capturing as much of the watershed flow into Lake Shaokatan as possible. As previously mentioned, the watershed is predominantly agricultural so several of the sub watersheds have similar characteristics. One noted difference is the area that drains the northwest portion of the watershed. This area has more wetland and storage capacity than the other sub watersheds and a monitoring site was not established in this vicinity. Figures 8-10 display the average daily flows in cubic feet per second (cfs) for sites 1, 3, and 7 respectively.

Samples were collected on a routine basis during quiescent periods and samples were taken when storm events occurred. The weather patterns were mild during the 2005 season with no severe weather patterns or heavy rainfall events. The flows at monitored sites were far below the average conditions for the Lake Shaokatan watershed and were not representative of the typical flow regime.

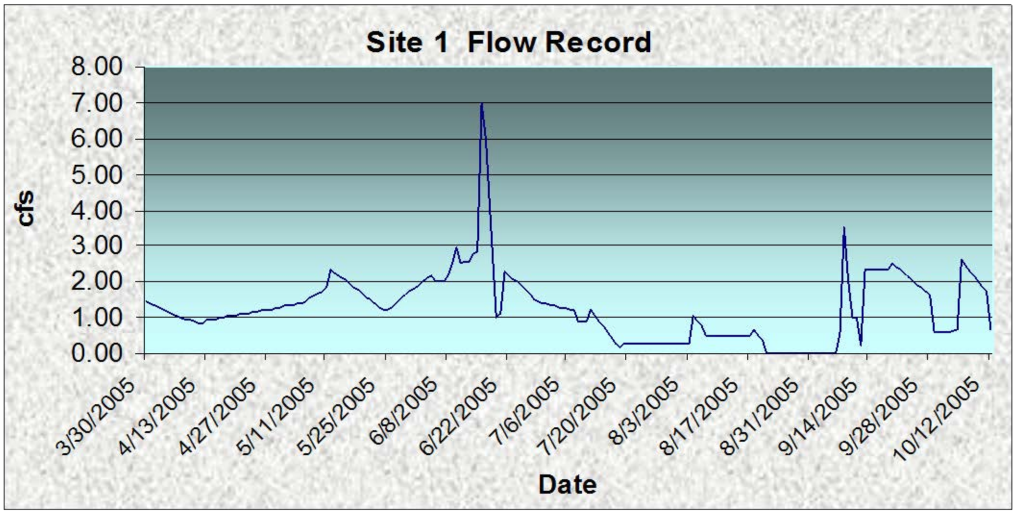

Figure 8: Site 1 2005 Hydrograph

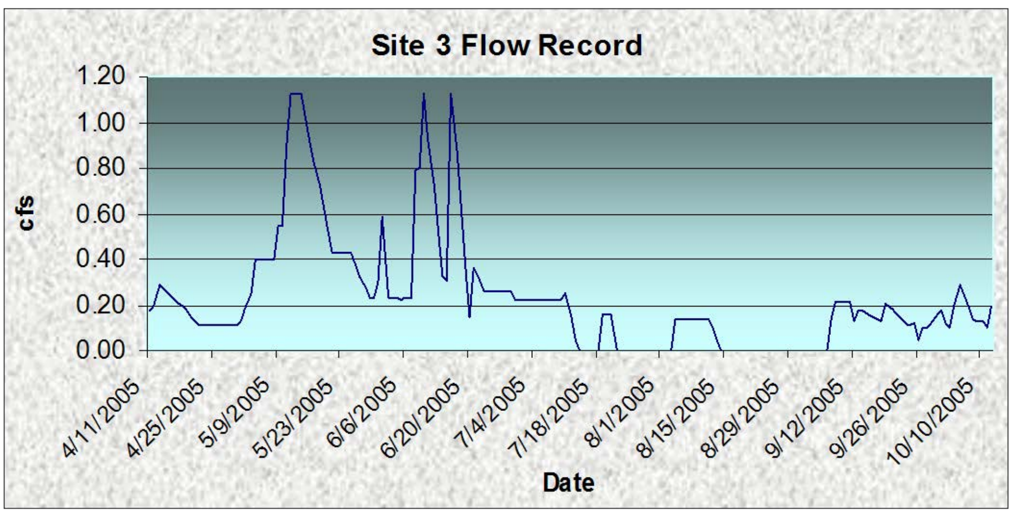

Figure 9: Site 3 2005 Hydrograph

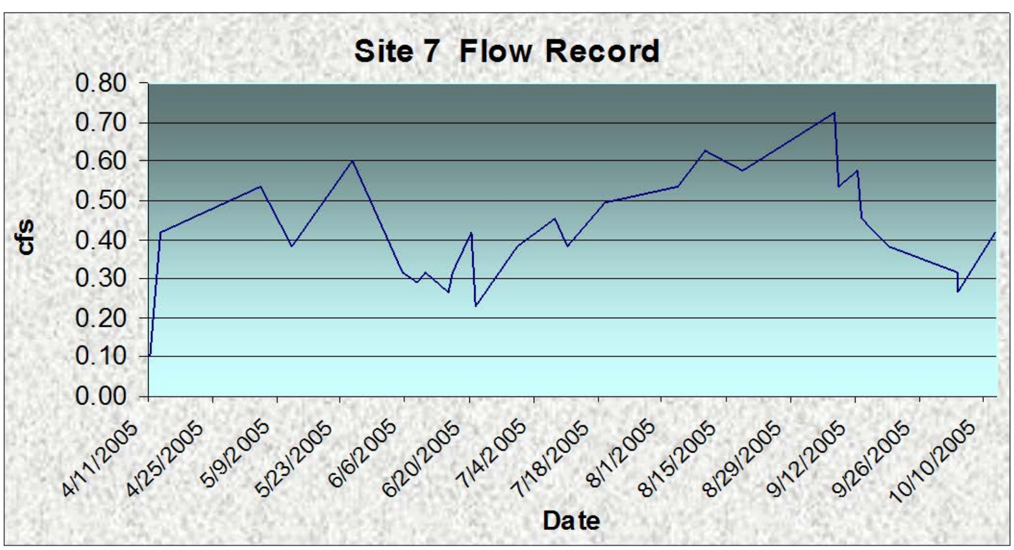

Figure 10: Site 7 2005 Hydrograph

Table 5 shows the average concentrations, standard deviations, and samples collected for ortho phosphorus (OP), and total phosphorus (TP) in 2005. It can be noted that for all sites except Site 9, the TP averages are significantly above the water quality standard for shallow lakes in the Northern Glaciated Plains Ecoregion (90 µg/L).

Table 5: 2005 Stream Summary

Site	**STORET ID**	**OP (µg/L)**			**TP (µg/L)**		
		Mean	Standard Deviation	Number of samples	Mean	Standard Deviation	Number of samples
1	S002-255	155	107	22	236	114	22
3	S002-257	203	154	21	275	187	21
7	S002-259	113	69	21	178	73	21
8	S002-260	222	157	18	322	181	18
9	S002-261	55	35	2	60	28	2
10	S002-262	512	515	11	687	541	11
11	S002-263	266	81	18	323	94	18
12	S003-704	231	182	14	314	188	14
13	S002-395	127	112	15	219	129	15
14	S002-396	90	26	17	146	82	17
15	S003-705	440	42	2	645	64	2
16	S003-936	180	14	2	205	35	2

The stream sites show a great deal of variability throughout the watershed. Many sites show significant phosphorus concentrations. Phosphorus and suspended solids concentrations varied substantially among sites. At nearly every monitoring station, the majority of the total phosphorus was measured as ortho phosphorus, which would be highly available for algal growth.

Figure 11 and Figure 12 illustrate the average and standard deviation of total phosphorus and ortho phosphorus concentrations at each of the twelve stream sampling stations in 2005. The graphs show the seasonal variability and magnitude of phosphorus concentrations. The analysis also indicates substantial loading from culverts along the lake shoreline. Sites 1, 3, and 13 showed an increase in phosphorus concentrations as the season proceeded. Only sites 7, 9, and 14 indicated low levels of phosphorus, although Site 14 had reported a single value of 400 µg/L. The remaining sites showed elevated levels of total phosphorus especially the culverts (Sites 10-13) where values were consistently in the range of 250 – 750 µg/L.

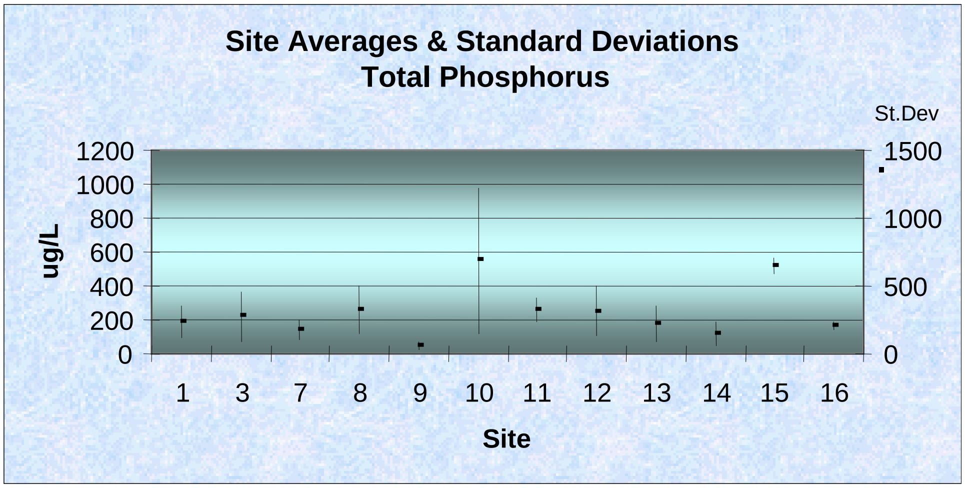

Figure 11: 2005 Stream Site Comparison: Total Phosphorus

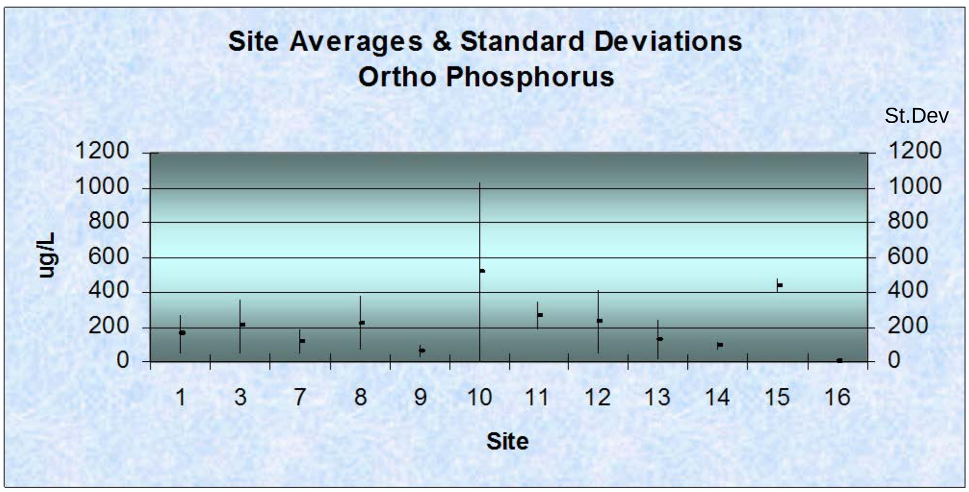

Figure 12: 2005 Stream Site Comparison: Ortho Phosphorus

Figure 13 shows the average and standard deviation of OP, TP and Chlorophyll-a for samples collected in Lake Shaokatan. The water quality standard for shallow lakes in the Northern Glaciated Plains Ecoregion is 90 µg/L for TP and 30 µg/L for Chlorophyll A. As shown, the TP and Chl A averages are well above the water quality standards.

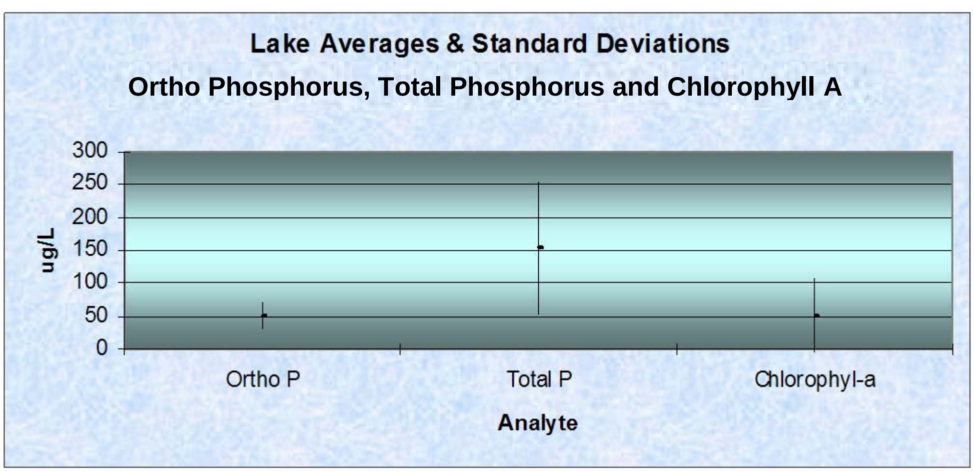

Figure 13: 2005 Lake Shaokatan: Ortho and Total Phosphorus, Chlorophyll-a

5.0 Pollutant Assessment

There are various sources of phosphorus in the Lake Shaokatan watershed. Timing and budget constraints did not allowed this project to conduct an intensive source inventory but past studies and local information sources allow some conclusions and estimates to be developed. The following is a general listing of the phosphorus sources in the watershed.

Overgrazed Pasture

There is evidence within the Shaokatan watershed (upper reaches of sub-watersheds 1, 2, 3, and 4) of stream bank erosion due to overgrazing by cattle. There are four livestock operations that have animals on pasture[9]. The practice of livestock grazing is not a significant threat to water quality unless areas are overgrazed to the point of soil erosion and increased runoff. In fact, well managed grazing land may offer benefits to water quality when compared to other types of land uses.

Feedlots and Stockpiles

According to MPCA's feedlot inventory, there are eight registered feedlots equaling 2,367 animal units of dairy and beef cattle and swine in the Lake Shaokatan watershed. There is one NPDES permitted facility (ID: 081-103230) in the watershed. The amount of loading from any given site will vary based on site specific factors as well as year-to-year climatic variability.

Manure Application

Because manure is applied over large areas of crop land where it is exposed to precipitation and runoff, and because manure is rich in nutrients, it is a significant potential source of phosphorus to the lake. On the other hand, some studies[10] have shown that the organic matter enhancement provided by manure may reduce soil erosion and runoff, thus providing a water quality benefit. In general, surface application of manure without incorporation, especially in critical areas or at critical time (e.g. frozen soils), and application at rates that allow soil test phosphorus levels to increase over time pose the greatest threat of phosphorus runoff or leaching.

Municipal Sources

There are no urban areas within the watershed and no wastewater treatment plants.

Subsurface Septic Treatment Systems (SSTS)

The septic systems within the watershed range from very good condition to very poor and assumed to be 30 percent noncompliant[11]. There are several failing systems that are within 500 feet of the lake and its tributaries. Those systems that are not functioning properly are a relatively small, but constant, source of phosphorus. Even properly functioning systems may result in the leaching of small amounts of phosphorus to Lake Shaokatan.

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[9] MPCA Feedlot Inventory, 2009.
[10] Gilley, J.E., and Risse, L.M.. 2000.
[11] Olson, 2005.

Domestic Animals (Pets)

The relatively low human population of the Lake Shaokatan watershed suggests a subsequent low pet population, and subsequent minor phosphorus load from this source.

Wildlife

Wildlife droppings, like livestock manure, contain phosphorus. A 2001 deer survey conducted in the nearby Chippewa River watershed[12], estimated density at 2.6-9.4 deer per square mile. This suggests there could be up to 140 deer in the watershed at times. This number, combined with droppings from other wildlife not inventoried, suggests a small but not insignificant potential contribution of phosphorus from wildlife.

Lake Sediment Release (Internal Loading)

Lake Shaokatan responds each season to a combination of annual phosphorus loading from watershed sources and release of phosphorus contained in the lake sediment. The latter phosphorus source is deposition from previous watershed loading years and exerts a strong effect on the lake phosphorus concentration. This is evidenced by the annual phosphorus concentration increase that is witnessed each year. The lake concentration typically begins at about 50 µg/L in the early spring and steadily increases to levels exceeding 300 µg/L. The annual average phosphorus concentration is a central value representing a wide range. The 2005 phosphorus concentrations shown in Table 1 for sites 5 and 6 displays the increase of phosphorus throughout the season. The 2005 average total phosphorus concentration of 152 µg/L is a blend of watershed loading, which alone would result in a lake concentration of 110 µg/L, and an estimated sediment load of approximately 5 mg/m^2/day. At this rate, the sediment contribution drives the in-lake phosphorus concentration up an additional 160 µg/l over a 90-day period (Figure 14). The sediment phosphorus contribution undoubtedly varies from year to year and is a function of previous watershed inputs and degree of lake flushing. Under average conditions, internal loading may contribute 40-50 percent of the annual loading to Lake Shaokatan (Table 7).

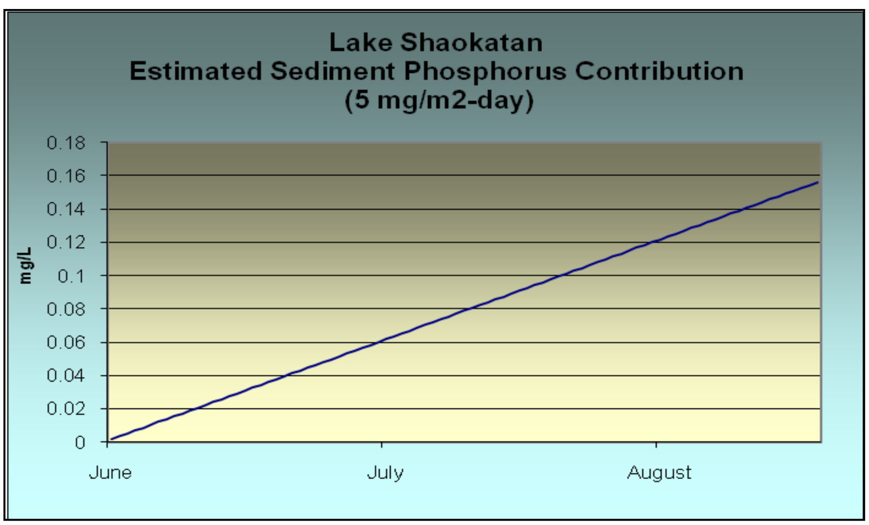

Figure 14: Lake Sediment Phosphorus Contribution

[12] Osborn, B., 2001.

Mechanisms for sediment phosphorus release are complex, and include: 1) a strong negative redox potential creating a reducing environment at the sediment-water column interface; 2) release of bound phosphorus by sediment microorganisms and algae species; and 3) mechanical mixing of the sediments by motor boats, wind and bioturbation from rough fish activity. Phosphorus is combined with insoluble ferric iron species in lake sediments. Typically, a minimum stochiometric ratio of 3:1 iron to phosphorus is required to control phosphorus in the sediments. Microbial respiration of sediment organics consume oxygen and can create a chemically reducing environment. Several metal species such as iron and sulfate can be reduced and become soluble. When ferric iron is reduced to soluble ferrous iron, the ferric-phosphorus bond is broken and phosphorus is released to the water column. An additional sediment phosphorus release mechanism occurs when sulfur compounds are reduced to sulfide species. The sulfide species have a higher affinity for iron and compete for iron in the sediments. Iron concentrations required to control phosphorus (keep sediment phosphorus insoluble) can be depleted and phosphorus is subsequently released to the water column. The redox potential in shallow lakes can change dramatically at the sediment-water interface or "pore layer". This thin layer can exhibit a strong negative redox potential and is very difficult to detect with standard dissolved oxygen measurements.

Microorganisms and algae can "pump" sediment bound phosphorus through metabolic processes and physical transport. Microorganisms within the sediment can convert phosphorus to soluble metabolites through normal metabolic processes. Certain blue-green algae species such as gleotrichia can promote the release of soluble phosphorus from the sediments as well.

Mechanical mixing from motor boats and bioturbation from rough fish can cause a stirring of the phosphorus rich lake sediment. The mixing action creates turbidity in the overlying water. The phosphorus rich particles can be available for algal growth. The extent of the sediment mixing in lake is dependent on the populations of rough fish and the magnitude and duration of motor boating activity.

Lake flushing seems to require substantial rainfall for at least two to three consecutive seasons to occur. Figure 18 shows the annual rainfall for Lake Shaokatan from 1991-2007. Substantial lake flushing occurred during the period 1992-1996, but sustained inter-year rainfall has not occurred since. From Figure 15, it appears that consecutive annual rainfall in the neighborhood of 30 inches or more a year needs to occur to drive lake flushing. During the 2005 sampling season, rainfall in excess did occur. However, the antecedent moisture conditions were low. Combined with overall mild rainfall intensity in 2005, the result was low runoff. Under these conditions, Lake Shaokatan tends to accumulate large amounts of phosphorus in the sediments that is later released to the overlying water column at large rates. These conditions promote excessive summer mean lake phosphorus concentrations exceeding 100 µg/L.

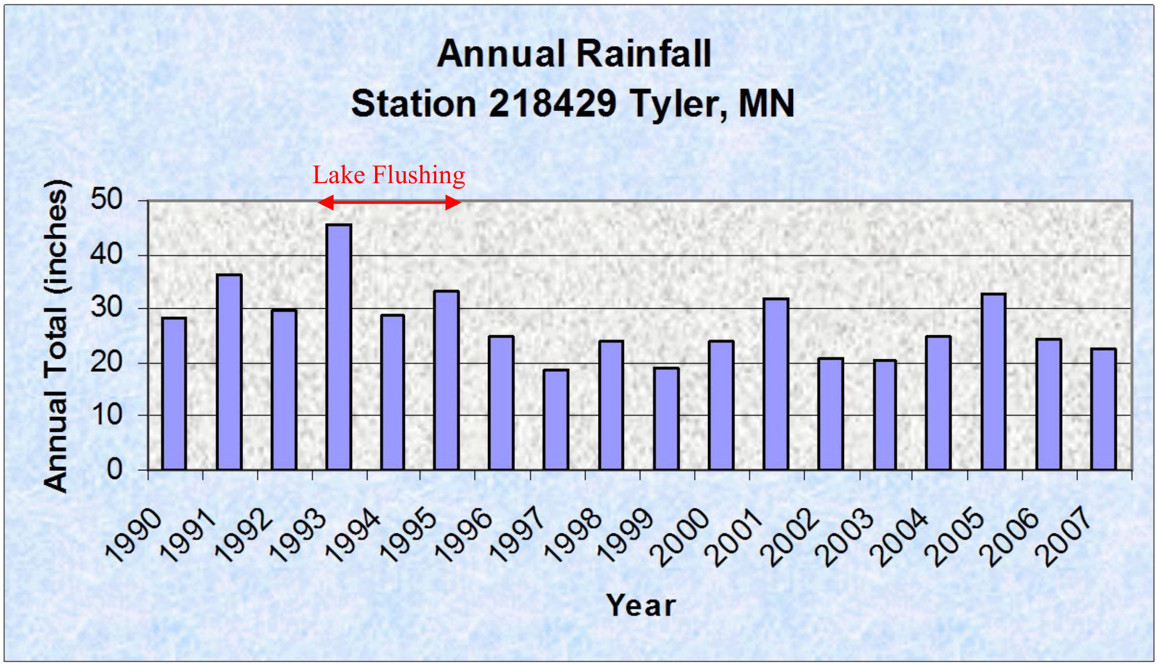

Figure 15: Annual Rainfall Totals 1991-2007

It is important to note that a review of DNR surveys indicates rough fish populations are likely not a dominant force in the internal loading process. Black bullheads were the only rough fish found in gill and trap net surveys in 2004 and are not likely to be a large factor in sediment re-suspension.

Atmospheric Deposition

Phosphorus is deposited directly onto the surface of Lake Shaokatan through precipitation and dry fallout. The origin of this phosphorus may be local (e.g. wind erosion) or more distant (e.g. stack emissions), and the annual rate of deposition will be influenced by multiple weather and climate factors including precipitation amounts and wind patterns. Based on literature values, it is estimated that atmospheric deposition could contribute 3-11 percent of the total annual phosphorus load to Lake Shaokatan.

Phosphorus from fertilized lawns

Phosphorus from fertilized lawns contributes to the annual lake phosphorus load. Fertilized lawns are not a significant load for Lake Shaokatan due to the limited lawn area relative to the watershed area. However, fertilized lawns can have large phosphorus concentrations ranging from 500 µg/L to 5,000 µg/L[13,14], and the runoff coefficient can be significantly increased with the compacting of soils during the turf installation. There are 46 lawns along the lakeshore with an average area of 0.3 acres. With an assumed average phosphorus concentration of 2,000 µg/L and a runoff coefficient of 0.25, the

[13] Easton, Z.M. and Petorvic, A.M. 2001.
[14] Shuman, L.M., 2004.

estimated load from this source would be about 25 kg/yr of total phosphorus to the lake (Table 6).

Table 6: Phosphorus Load from Lawns

Lawns	Ave Size	Ave P concentration	Runoff Coefficient	Precipitation	Runoff	Annual Load
#	m^2	µg/L		meters	hm^3/yr	kg
46	1452	2000	0.25	0.74	0.01	24.61

Land Use/Land Cover

As shown in Table 2, the Lake Shaokatan watershed land use and land cover is dominated by crop land (49 percent), and grassland (41.4 percent) that may be hayed, grazed, or in some type of a conservation easement program. The remaining 10 percent is a combination of roads, open space, farmsteads, lakeshore lots, forest, and wetlands.

Phosphorus export values or coefficients for different land use and land cover types have been provided in a number of scientific papers and reports. Table 7 provides estimates of annual phosphorus loading to Lake Shaokatan from eleven major source categories. Estimates of Lake Shaokatan watershed phosphorus loading are based the land use and land cover data and a range of the phosphorus export coefficients found in some key papers and reports. It is important to note that most of the above mentioned sources are accounted for through this approach. For example, both wildlife and manure application would be a part of a crop land phosphorus export coefficient. Regarding internal loading, the phosphorus from sediment release is not a true source, but rather a reflection of previous loading from watershed and atmospheric sources. Regardless, internal loading is part of the load allocation for Lake Shaokatan, and internal loading will need to be reduced for the allocation to be attained. The implementation planning process will need to address the question of whether it makes sense to attempt active controls in the short-term, or to allow internal loading to subside over time in response to reductions in watershed inputs.

It is also important to note that these estimates have no direct bearing on the TMDL allocations. Rather, in illustrating the range and relative magnitude of different phosphorus sources, they may help direct where any on-going efforts to reduce phosphorus are focused.

Table 7: Estimates of Average Annual Total Phosphorus Loading

Total P Source	Hectares (ha)	Low TP Coefficient (kg/ha/yr)	High TP Coefficient (kg/ha/yr)	Low TP Loading Rate (kg)	High TP Loading Rate (kg)	Total Load (%)
Atmospheric deposition	403	0.3	0.5	121	202	3-11
Pasture/Hay	549	0.2	0.24	110	132	2-7
Forest	21	0.05	0.15	1	3	<1
Water/Wetland	63	0.05	0.1	3	6	<1
Grassland	781	0.05	0.24	39	187	1-10
Cropland	1572	0.85	1.3	1336	2043	35-83
Lakeshore Lots	12	0.5	1.25	6	25	<1-1
Farmsteads	41	0.24	0.5	10	21	<1-1
Roads and Open Space	170	0.24	0.24	41	41	1-2
SSTS				80	80	2-5
Internal Loading				1812	1812	40-50
Total Load				3559	4542	
Total Load – not including internal loading				1747	2730	
· TP coefficients from various reputable sources.[15, 16, 17, 18, 19, 20]						
· Internal loading from Figure 14 value of 5 $mg/m^2/day$, multiplied by 90 days						
· "High" lakeshore lot loading rate from Table 6						

For most categories, an attempt was made to partially reflect the range (low to high) of phosphorus export coefficients reported in different publications. It is important to note, however, that values well outside of these ranges can be found, and potentially explained by a number of factors ranging from weather to site-specific conditions. For example, a rainfall simulation study on cropland found TP runoff rates ranging from 0.1 to 1.7 kg/ha TP as a function of different swine manure and fertilizer practices.[21] Another cropland study found rates ranging from 1 to 2.5 kg/ha TP as a function of solid beef manure application and tillage practice. In the latter study, TP losses were lower in the manured plots.[22]

Due to the inherent variability of phosphorus loading, Table 7 needs to be considered in average and relative, rather than absolute terms. The Total Load column of the Table 7 tries to capture the variability by showing the broadest range of possibilities. Pasture and hay land, for example, could contribute anywhere between two and seven percent of the total phosphorus load. In considering Table 7, it is important to recognize that the land area (hectares) in each source category will not remain static over time. As mentioned previously, for example, over 50 percent of the grassland is in conservation easements. As contracts expire, much of that grassland may return to crop production. Likewise, additional lakeshore development may reduce forest or cropland areas.

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[15] Harmel et al., 2006.
[16] Harmel, et al., 2008.
[17] Mandaville, S.M., 2000
[18] Ryding S.O., and Rast, W. 1989.
[19] USEPA. 1980.
[20] Reckow, K.H. and Simpson, J.T. 1980.
[21] Daverede et al., 2004.
[22] Ginting et al., 1998.

6.0 TMDL and Allocations

The quantification of phosphorus sources within a watershed and the subsequent lake response is very complex. Despite the complexity, this report draws in previous Lake Shaokatan studies, inflow and in-lake data, and a widely used modeling package (FLUX-BATHTUB[23]) to establish a total maximum daily load of phosphorus consistent with Lake Shaokatan meeting state water quality standards. The conceptual loading sequence is divided into two parts: 1) loading of phosphorus to the Lake Shaokatan; and 2) the lake response to the phosphorus loading in terms of phosphorus concentration, chlorophyll-a concentration, and the clarity or Secchi depth. The model output is the resulting mean lake phosphorus concentration as a function of the watershed loading. Establishing the total maximum daily load simply involves reducing the watershed inputs to the model until the lake phosphorus concentration meets water quality standards. The model does not directly address internal sediment loading, but it is assumed that both watershed and internal loading will need to be reduced to achieve the TMDL target.

6.1 Modeling Results and Approach to Internal Loading

A mass balance approach was used in assessing the watershed loading patterns and the lake response in terms of total phosphorus concentration. The phosphorus model is based on the watershed assessment developed during the 1991-92 Clean Water Partnership project and repeated in 1996 and 2001. Watershed phosphorus loads were calculated in each of these studies and the lake was modeled[24] for phosphorus response. Figure 16 illustrates the original watershed assessment involving the flow and mass routing of phosphorus through 24 sub-watersheds.

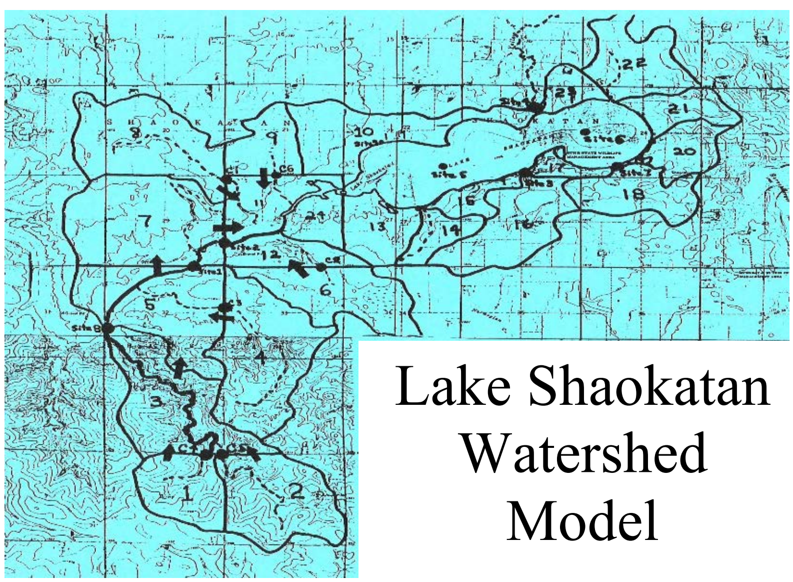

Figure 16: Subwatershed Phosphorus Routing Model

[23] Walker, W.W., 1996.
[24] Walker, W.W. and C.B. Wilson. 1989.

Figure 17 shows a comparison of a series of modeling results over a range of annual phosphorus loads to the lake ranging from 577 kg/yr to 4,300 kg/yr. This is the range of phosphorus loads that were assessed in the previous modeling work[4]. The BATHTUB model illustrates the lake response, in terms of average phosphorus concentration, as a function of watershed loading. The results of each model show that the water quality standard of 90 µg/L, 81 µg/L including a 10 percent margin of safety (MOS), would be met at a phosphorus loading rate of 1,537 kg/yr.

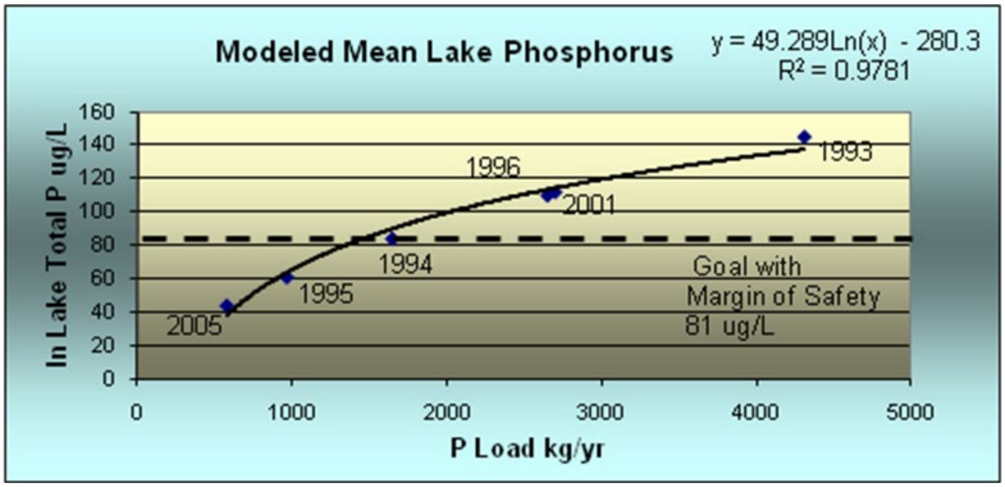

Figure 17: Phosphorus Loading vs. Lake Response Model Comparison

It is reasonable to assume the phosphorus sediment release rate is variable both within a given growing season and especially year to year. The lake does not flush on a regular basis and is a function of the particular rainfall pattern and volumes for a given year, and to a large extent, seems to be highly related to the preceding ground water levels. The internal loading is much more difficult to assess in terms of rate and magnitude of loading, and as such, is not included directly in the modeling. Nevertheless, the target for cumulative loading from both watershed and internal sources is 1,537 kg/yr.

6.2 TMDL

Defining a total maximum load for the Lake Shaokatan watershed is challenging because the watershed loading and lake response varies greatly from year to year. Estimates of annual phosphorus loading to Lake Shaokatan have ranged from about 577 kilograms to well over 4,300 kilograms per year. The large variances in lake phosphorus concentration during the past ten years appear to be a function of flushing and lake sediment phosphorus loading. The years of sustained rainfall and subsequent lake flushing tend to reflect lower lake phosphorus concentrations and the low rainfall years tend to have higher TP concentrations.

The target phosphorus load is 1,537 kilograms per year or 4.21 kg/day, corresponding to a resulting lake concentration of 81 µg/L phosphorus. It is recognized that the TMDL target of 1,537 kg/yr is less than the internal loading estimate of 1,812 kg/yr found in Table 7. It is important to note, however, that internal loading should not be viewed as constant from year to year. Furthermore, it is believed that over time, with watershed loading reductions, internal loading will subside.

The TMDL for Lake Shaokatan is 4.21 kg total phosphorus/day. Stormwater discharges are regulated under the NPDES program and allocations of nutrient reductions are considered wasteloads. Of this 4.21 kg/day, 0.042 kg/day is attributed to wasteload allocations to account for possible future development along the lakeshore or elsewhere in the watershed that would require an NPDES construction stormwater permit. Disturbances over one acre in size are required to obtain an NPDES construction permit. These permits regulate erosion control and require that best management practices be employed at a construction site. However, even with BMP implementation at a construction site, there invariably will be some impacts in terms of phosphorus loads due to construction. Because there is not enough information available to assign loads to individual permit holders, the wasteload allocations are combined in this TMDL as categorical wasteload allocations assigned to all permitted dischargers in the contributing watershed.

Table 8: TMDL Allocations

	TMDL	WLA	LA
Annual (kg/yr)	1,537*	15.37	1,521.63
Daily (kg/day)	4.21	0.042	4.17

* The margin of safety is 10 percent of the water quality standard of 90 µg/L which is 81 µg/L (1,537 kg/yr).

The wasteload allocation value was determined by reviewing records of development/construction activity that has taken place in the watershed over the past ten years. At any given time, less than one percent of the watershed area was covered under a construction stormwater permit, hence the allocation of 0.042 kg/day allocation. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit. There are no known industrial dischargers in the watershed. The remainder of the TMDL load allocation is 4.17 kg/day and encompasses all other watershed, atmospheric, and internal sources, including the portion of any of those that may be considered natural background.

6.3 Margin of Safety and Rationale

The TMDL process provides for two primary means of dealing with uncertainty[25]:

1. Using a phased approach when developing and implementing the TMDL study

[25] USEPA, January 2001.

2. Incorporating a margin of safety (MOS) in calculating pollutant load reduction requirements.

Under the phased approach, load allocation and waste load allocations are based on the best available information, and monitoring is planned to generate additional data to determine if the load reductions required by the TMDL are being achieved following a prescribed period of implementation. The MOS accounts for scientific uncertainties and other factors to help ensure that water quality standards are achieved and maintained. The MOS can be expressed in the calculation of the WLA and LA, or can be expressed as a separate value. The MOS is set at 10 percent of the total phosphorus water quality standard of 90 µg/L. This essentially lowers the total phosphorus water quality standard to 81 µg/L. This margin of safety addresses the uncertainty of the TMDL method due to sampling and modeling errors, both in estimating the phosphorus concentrations and the flow regimes.

6.4 Reserve Capacity

Reserve capacity is typically considered in area where new or expanded NPDES permits are likely. With the possible exception of temporary construction stormwater permits, or NPDES permits issued to livestock facilities (no-discharge permits), no other NPDES permits are anticipated in this watershed. As such, no reserve capacity is warranted.

7.0 Seasonal Variation and Critical Condition

There is a definite seasonal variation in this TMDL. Phosphorus samples and flow measurements were conducted over the spring, summer, and fall months (April-October). The results indicated a wide range of flows and phosphorus concentrations. In the early spring, Lake Shaokatan typically experiences an increased loading because of snowmelt and spring rains. The increased runoff usually does not cause Lake Shaokatan to exceed the water quality standard. In the fall, when flows are low, Lake Shaokatan does exhibit phosphorus concentrations exceeding the water quality standard. The months of June, July, August and September are the critical period when phosphorus levels vastly exceed the level of impairment. Furthermore, the exceedences in the tributaries are limited mostly to storm event periods.

The lake water quality standards apply to the summer (June-September) mean. The normal seasonal variability was taken into account in setting the standard in this way, based on a large body of research and monitoring data for many lakes. Therefore, Minnesota's lake water quality standards themselves reflect the inherent variability in quality throughout the summer season. The critical condition for lakes is the summer months when most water recreation occurs in Minnesota. Excessive nutrient loads lead to increased algae blooms and reduced transparency – both of which may significantly impair or prohibit the use of lakes for aquatic recreation.

8.0 Follow-Up Monitoring Plan

The goal of this monitoring plan is to assess the effectiveness of the source reduction strategies for attaining the water quality standards and designated use. The monitoring approach will be similar to the initial 2005 sampling design using 16 sampling stations. Flow measurements and phosphorus concentrations will be monitored at a frequency that will allow for statistical significance in estimates of implementation performance, as well as subsequent stream concentrations. This level of sampling will give the level of resolution needed to determine the effectiveness of the specific implementation activities, especially high priority. The effectiveness of implementation activities can be assessed on a sub-watershed basis offering a higher level of control and evaluation in implementation. The sampling design will also address inter-year variation.

The monitoring effort will commence after two years of significant implementation activities have been installed. The monitoring results will be used to assess the effectiveness of the implementation activities installed, and will be the basis for assessing the future implementation requirements needed to reach the water quality goal. Monitoring will resume after each two years of significant implementation until the water quality goal is satisfied.

The monitoring plan will be coordinated with MPCA and DNR since both agencies are using Lake Shaokatan as part of a long-term study to determine the effects of climate change.

The monitoring effort will be coordinated with the MPCA framework for implementation of the “watershed approach”. Monitoring results will be used to assess the effectiveness of implementation activities, and will be the basis for assessing the future implementation requirements needed to reach the water quality goal.

9.0 Implementation

The YMRWD has embraced a watershed-wide goal of achieving the water quality standard for phosphorus within ten years. To achieve the water quality goal of 81 μg/L, a 67 percent reduction in phosphorus loading is required. The YMRWD is committed to developing a comprehensive implementation plan upon approval of the TMDL report.

The goals of any water quality project should be based on practical considerations. Two important considerations are the potential for improvement for the specific watershed and how feasible the implementation is. The implementation controls have to be compatible with the local culture, in that a great degree of local "buy in" is necessary for the general success of the project. Project partners believe that the water quality goal is realistic and obtainable when considering the watershed-to-lake acre ratio. The initial success of the implementation plan is crucial to the long-term management of the watershed water quality. The availability of programs, funding, local technical expertise and experience, and public acceptance will all be considered when developing the implementation plan.

Based on the results of the data analysis, specific correspondence was made with targeted landowners that are suspected loading contributors. These landowners were selected based on the data results, feedlot and septic surveys, production rates, application rates, and geographical features that promote the discharge of fecal material and therefore phosphorus to the lake. This correspondence will be the basis for a successful implementation plan that will require a cooperative effort from the affected parties. A partnership will be formed with the YMRWD office, landowners, and the technical committee that will review implementation scenarios and available funding for project suitability. Following the final TMDL report, several meetings with the watershed "stakeholders" will be conducted in order to develop a comprehensive implementation plan.

Implementation strategies under consideration for phosphorus control include terraces, grass waterways, sediment control watersheds, sewer systems upgrades, tillage practices, buffer strips, replace open intakes with blind intakes, nutrient and pest management, the EQIP program, manure management, wetland restoration, lawn care education, shoreland erosion control, and feedlot control methods. Addressing internal loading will also be a topic of consideration. Common in lake phosphorus controls include drawdowns, chemical treatment, dredging, harvesting and pumping. Consideration of local ordinances may also be discussed as an effort to minimize further degradation of Lake Shaokatan. It is estimated that it will cost over $1 million to address the phosphorus impairment on Lake Shaokatan.
The watershed has been divided into subwatersheds (Figure 16). This was done in an attempt to determine the locations of large discharges of water and pollutants, and prioritize the sub-watersheds. There are twenty-four subwatersheds ranging in drainage areas from 12.5 acres to 750 acres, but the average is about 335 acres. This information will be useful for determining priority areas in the implementation plan.

9.1 Adaptive Management

Adaptive management is an iterative implementation process that makes progress toward achieving water quality goals while using any new data and information to reduce uncertainty and adjust implementation activities. In using the adaptive management approach, the YMRWD will continue to engage stakeholders to evaluate project progress as well as to determine if the implementation plan should be amended. Implementation of TMDL related activities can take many years, and water quality benefits associated with these activities can also take many years. The YMRWD intends to facilitate implementation of practicable controls even while additional data collection and analysis are conducted to guide future implementation actions. The follow up water monitoring program outlined in Section 8.0 will be integral to the adaptive management approach, providing assurance that implementation measures are succeeding in attain water quality standards.

Adaptive management is an ongoing process of evaluating and adjusting the strategies and activities that will be developed to implement the Lake Shaokatan TMDL. Adaptive management does not include changes to water quality standards or TMDL allocations. Any changes to water quality standards or TMDL allocations must be preceded by appropriate administrative processes.

10.0 Reasonable Assurance

The Yellow Medicine River Watershed District Managers will sponsor the leadership of the Lake Shaokatan Implementation. They will have the responsibility to direct the staff consisting of a Project Manager and a Project Technician. This will be accomplished informally with daily interaction with the project elements and formally with monthly Watershed District Board meetings to keep current on the progress. They will also conduct quarterly meetings with the Project Partners, which will consist of representatives from the Lincoln County Soil and Water Conservation District, Lincoln County, Natural Resources Conservation Service, Board of Soil and Water Resources, Department of Natural Resources, and the Minnesota Pollution Control Agency. The project partners will advise the managers on technical matters and priorities concerning implementation progress.

The YMRWD successfully completed the Lake Shaokatan CWP Diagnostic and Implementation phases in 1991-96, and is currently implementing a Phase II Clean Water Partnership program in the Yellow Medicine River watershed. These programs have successfully implemented watershed-based nutrient control measures, and the intent is to use a similar approach for the Lake Shaokatan TMDL project.

Through local, state, and federal regulatory programs such as shoreland ordinance, state feedlot and SSTS rules, Wetland Conservation Act, Farm Bill and county ordinances, potential sources of phosphorus are being addressed. The continuation of these programs along with additional voluntary programs provides assurance that the impaired water of Lake Shaokatan watershed is addressed.

This project shows its best indication of success through the commitment of the landowners and homeowners in the Lake Shaokatan watershed. Many of these residents have lived in the watershed and used the lake and the county park for their entire life. The success of the CWP implementation and resulting water quality improvement is a prime example of neighbors and landowners working together to create a better environment for future generations. The lake response is also encouragement to those involved that changes do result in better water quality.

11.0 Public Participation

Many local, state, and federal agencies have been involved in the public participation process including, but not limited to the Lincoln Soil and Water Conservation District, the Lincoln County Environmental Services, the Lincoln County Board of Commissioners, the MN Department of Natural Resources, the MN Board of Soil and Water Resources, the MN Pollution Control Agency, the US Natural Resources Conservation Service, the US Fish and Wildlife Service, and the Yellow Medicine River Watershed District. These agencies, in cooperation with the local residents, landowners, and farm operators, have contributed to the understanding of the political, economic, and natural resource aspects of the TMDL and ultimately the implementation plan.

The following is a list of public participation activities that have been completed to date:

September 5, 2005 Picnic Point County Park, Lake Shaokatan, Minnesota 6:00 p.m.
Review of the Lake Shaokatan TMDL project.

September 25, 2006 Brick Manor, Arco, Minnesota
Powerpoint presentation and question and answer session.

March 19, 2007 Lincoln County Courthouse, Ivanhoe, MN. 1:00 p.m.
Power point presentation, with print out of presentation, public input, with comments, questions and answers

July 2, 2009 Picnic Point County Park, Lake Shaokatan, Minnesota, 7:00 p.m.
Public meeting: Review of the TMDL report

July 6, 2009 - August 5, 2009 Public comment period
Public notice was sent to over 90 individuals. A press release was sent to local and state media outlets. Sixty-five comments were received during the comment period, which many comments expressed support for the project. Some comments requested a review of the report content, which resulted in changes to the draft report. A second public comment period was held to provide an additional opportunity for comment

February 8, 2010 – March 10, 2010 Public comment period
Public notice was sent to over 150 individuals. A press release was sent to local and state media outlets. Seven comment letters, one request for a contested case hearing and one support letter for a contested case hearing were received during the second public notice.

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Appendix 1: Phosphorus Load Calculations

Date	Site	Description	Time	Gage	Flow	Analyte	Result	q fraction
3/30/2005	1	Co. Rd. 15	3:45 p.m.	0.78	1.46	Total-P	0.38	0.011339
4/11/2005	1	Co. Rd. 15	4:45p.m.	0.51	0.82	Total-P	0.19	0.003181
4/13/2005	1	Co. Rd. 15	6:15p.m.	0.56	0.93	Total-P	0.12	0.002282
5/5/2005	1	Co. Rd. 15	9:20 a.m.	0.76	1.40	Total-P	0.05	0.00144
5/12/2005	1	Co. Rd. 15	6:40 p.m.	1.1	2.32	Total-P	0.15	0.007143
5/25/2005	1	Co. Rd. 15	9:50 a.m.	0.68	1.21	Total-P	0.09	0.002228
6/5/2005	1	Co. Rd. 15	11:00 a.m.	1	2.04	Total-P	0.16	0.006693
6/8/2005	1	Co. Rd. 15	3:25 p.m.	1.05	2.18	Total-P		0
6/10/2005	1	Co. Rd. 15	10:00 a.m.	1.32	2.98	Total-P	0.16	0.009764
6/15/2005	1	Co. Rd. 15	9:45 a.m.	1.28	2.85	Total-P		0
6/16/2005	1	Co. Rd. 15	9:20 a.m.	1.8	7.01	Total-P	0.15	0.021565
6/20/2005	1	Co. Rd. 15	4:25 p.m.	0.65	1.14	Total-P		0
6/21/2005	1	Co. Rd. 15	10:20 a.m.	1.09	2.29	Total-P	0.17	0.007996
6/28/2005	1	Co. Rd. 15	9:15 a.m.	0.8	1.51	Total-P		0
6/30/2005	1	Co. Rd. 15	3:15 p.m.	0.76	1.40	Total-P		0
7/8/2005	1	Co. Rd. 15	2:30 p.m.	0.54	0.88	Total-P	0.24	0.004343
7/11/2005	1	Co. Rd. 15	6:45 p.m.	0.68	1.21	Total-P		0
7/19/2005	1	Co. Rd. 15	9:05 a.m.	0.24	0.29	Total-P	0.31	0.001862
8/4/2005	1	Co. Rd. 15	9:10 a.m.	0.61	1.04	Total-P	0.28	0.00598
8/18/2005	1	Co. Rd. 15	9:10 a.m.	0.44	0.67	Total-P	0.37	0.005068
9/7/2005	1	Co. Rd. 15	2:25 p.m.	0.39	0.57	Total-P	0.34	0.003952
9/8/2005	1	Co. Rd. 15	9:40 a.m.	1.5	3.54	Total-P	0.52	0.037758
9/12/2005	1	Co. Rd. 15	2:55 p.m.	0.19	0.21	Total-P	0.26	0.001137
9/13/2005	1	Co. Rd. 15	9:35 a.m.	1.1	2.32	Total-P	0.23	0.010953
9/19/2005	1	Co. Rd. 15	9:15 a.m.	1.17	2.53	Total-P	0.27	0.013984
10/4/2005	1	Co. Rd. 15	9:40 a.m.	0.45	0.69	Total-P	0.26	0.003672
10/4/2005	1	Co. Rd. 15	6:40 p.m.	1.2	2.61	Total-P	0.37	0.019834
10/12/2005	1	Co. Rd. 15	6:00 p.m.	0.44	0.67	Total-P	0.13	0.001781
			Total Q		48.76		FWMC	184 ug/L
			Ave Q		1.15	(flux HM3)	Load	212 kg/yr

Date	Site	Description	Time	Gage	Flow	Analyte	Result	q fraction
4/11/2005	3	Guggisburg	3:00p.m.	0.08	0.17	Total-P	0.39	0.007095
4/13/2005	3	Guggisburg	4:35p.m.	0.2	0.29	Total-P	0.25	0.007642
5/5/2005	3	Guggisburg	8:15 a.m.	0.28	0.40	Total-P	0.12	0.005003
5/12/2005	3	Guggisburg	4:55 p.m.	0.6	1.13	Total-P	0.34	0.039982
5/25/2005	3	Guggisburg	8:15 a.m.	0.3	0.43	Total-P	0.09	0.00404
6/5/2005	3	Guggisburg	11:55 a.m.	0.14	0.23	Total-P	0.32	0.007613
6/8/2005	3	Guggisburg	2:00 p.m.	0.48	0.79	Total-P		0
6/10/2005	3	Guggisburg	8:20 a.m.	0.6	1.13	Total-P	0.22	0.02587
6/15/2005	3	Guggisburg	10:10 a.m.	0.21	0.30	Total-P		0
6/16/2005	3	Guggisburg	10:00 a.m.	0.6	1.13	Total-P	0.12	0.014111
6/20/2005	3	Guggisburg	4:50 p.m.	0.05	0.15	Total-P		0
6/21/2005	3	Guggisburg	2:15 p.m.	0.24	0.36	Total-P	0.67	0.025209
6/28/2005	3	Guggisburg	9:40 a.m.	0.17	0.26	Total-P		0
6/30/2005	3	Guggisburg	3:37 p.m.	0.14	0.23	Total-P		0
7/8/2005	3	Guggisburg	3:05 p.m.	0.14	0.23	Total-P	0.16	0.003807
7/11/2005	3	Guggisburg	7:00 p.m.	0.16	0.25	Total-P		0
7/19/2005	3	Guggisburg	9:40 a.m.	0.06	0.16	Total-P	0.15	0.002484
8/4/2005	3	Guggisburg	9:50 a.m.	0.03	0.14	Total-P	0.08	0.001146
8/10/2005	3	Guggisburg	9:25 a.m.	0.03	0.14	Total-P		0
8/18/2005	3	Guggisburg	9:35 a.m.	0.02	0.13	Total-P	0.08	0.00109
9/7/2005	3	Guggisburg	3:10 p.m.	0.03	0.14	Total-P	0.14	0.002005
9/8/2005	3	Guggisburg	10:20 a.m.	0.13	0.22	Total-P	0.39	0.008884
9/12/2005	3	Guggisburg	3:25 p.m.	0.02	0.13	Total-P	0.17	0.002317
9/13/2005	3	Guggisburg	10:05 a.m.	0.08	0.17	Total-P	0.37	0.006731
9/19/2005	3	Guggisburg	10:00 a.m.	0.12	0.21	Total-P	0.64	0.013953
10/4/2005	3	Guggisburg	10:20 a.m.	0.1	0.19	Total-P	0.53	0.010566
10/4/2005	3	Guggisburg	5:30 p.m.	0.2	0.29	Total-P	0.48	0.014673
10/12/2005	3	Guggisburg	5:25 p.m.	0.1	0.19	Total-P	0.07	0.001396
			Total Q		9.57		FWMC	206 ug/L
			Ave Q		0.21	(flux HM3)	Load	39 kg/yr

Date	Site	Description	Time	Gage	Flow	Analyte	Result	q fraction	
4/11/2005	7	Old Bridge	3:15p.m.	0.05	0.10	Total-P	0.26	0.002231	
4/13/2005	7	Old Bridge	5:20p.m.	3.68	0.42	Total-P	0.12	0.004289	
5/5/2005	7	Old Bridge	8:40 a.m.	3.62	0.53	Total-P	0.05	0.002292	
5/12/2005	7	Old Bridge	5:35 p.m.	3.7	0.38	Total-P	0.26	0.008516	
5/25/2005	7	Old Bridge	8:50 a.m.	3.59	0.60	Total-P	0.06	0.003095	
6/5/2005	7	Old Bridge	12:05 p.m.	3.74	0.32	Total-P	0.19	0.005189	
6/8/2005	7	Old Bridge	2:20 p.m.	3.76	0.29	Total-P		0	
6/10/2005	7	Old Bridge	9:00 a.m.	3.74	0.32	Total-P	0.18	0.004916	
6/15/2005	7	Old Bridge	10:15 a.m.	3.78	0.26	Total-P		0	
6/16/2005	7	Old Bridge	10:10 a.m.	3.74	0.32	Total-P	0.11	0.003004	
6/20/2005	7	Old Bridge	4:55 p.m.	3.68	0.42	Total-P		0	
6/21/2005	7	Old Bridge	1:55 p.m.	3.88	0.23	Total-P	0.14	0.002763	
6/28/2005	7	Old Bridge	9:45 a.m.	3.72	0.35	Total-P		0	
6/30/2005	7	Old Bridge	3:55 p.m.	3.7	0.38	Total-P		0	
7/8/2005	7	Old Bridge	3:15 p.m.	3.66	0.45	Total-P	0.19	0.007394	
7/11/2005	7	Old Bridge	7:05 p.m.	3.7	0.38	Total-P		0	
7/19/2005	7	Old Bridge	9:50 a.m.	3.64	0.49	Total-P	0.14	0.005919	
8/4/2005	7	Old Bridge	10:00 a.m.	3.62	0.53	Total-P	0.1	0.004585	
8/10/2005	7	Old Bridge	9:30 a.m.	3.58	0.62	Total-P		0	
8/18/2005	7	Old Bridge	9:55 a.m.	3.6	0.58	Total-P	0.19	0.009428	
9/7/2005	7	Old Bridge	3:30 p.m.	3.54	0.73	Total-P	0.32	0.019916	
9/8/2005	7	Old Bridge	10:35 a.m.	3.62	0.53	Total-P	0.18	0.008253	
9/12/2005	7	Old Bridge	3:40 p.m.	3.6	0.58	Total-P	0.25	0.012405	
9/13/2005	7	Old Bridge	10:15 a.m.	3.66	0.45	Total-P	0.17	0.006616	
9/19/2005	7	Old Bridge	10:05 a.m.	3.7	0.38	Total-P	0.21	0.006878	
10/4/2005	7	Old Bridge	10:30 a.m.	3.74	0.32	Total-P	0.28	0.007648	
10/4/2005	7	Old Bridge	5:40 p.m.	3.78	0.26	Total-P	0.23	0.005184	
10/12/2005	7	Old Bridge	6:45 p.m.	3.68	0.42	Total-P	0.1	0.003574	
				Total Q	11.66		FWMC	134	ug/L
				Ave Q	0.37	HM3	Load	50	kg/yr

Date	Site	Description	Time	Gage	Flow	Analyte	Result	q fraction	
4/11/2005	8	Hwy 1 Bridge	4:30 p.m.	RP 4.1	1.2	Total-P	0.15	0.006647	
4/13/2005	8	Hwy 1 Bridge	6:00p.m.	1.08	2.3	Total-P	0.08	0.006795	
5/12/2005	8	Hwy 1 Bridge	6:30 p.m.	0.8	1.04	Total-P	0.25	0.009601	
5/25/2005	8	Hwy 1 Bridge	9:45 a.m.	0.28	0.23	Total-P	0.14	0.001189	
6/5/2005	8	Hwy 1 Bridge	10:45 a.m.	0.68	0.69	Total-P	0.31	0.007899	
6/8/2005	8	Hwy 1 Bridge	3:20 p.m.	0.88	1.5	Total-P		0	
6/10/2005	8	Hwy 1 Bridge	9:50 a.m.	1.1	3.1	Total-P	0.26	0.029764	
6/15/2005	8	Hwy 1 Bridge	9:40 a.m.	1.06	2.1	Total-P		0	
6/16/2005	8	Hwy 1 Bridge	9:15 a.m.		0.9	Total-P	0.18	0.005982	
6/20/2005	8	Hwy 1 Bridge	4:25 p.m.	0.5	0.5	Total-P		0	
6/21/2005	8	Hwy 1 Bridge	10:15 a.m.	0.8	1.04	Total-P	0.26	0.009985	
6/28/2005	8	Hwy 1 Bridge	9:10 a.m.	0.52	0.5	Total-P		0	
6/30/2005	8	Hwy 1 Bridge	3:10 p.m.	0.5	0.5	Total-P		0	
7/8/2005	8	Hwy 1 Bridge	2:20 p.m.	0.42	0.46	Total-P	0.31	0.005266	
7/11/2005	8	Hwy 1 Bridge	6:40 p.m.	0.7	0.88	Total-P		0	
7/19/2005	8	Hwy 1 Bridge	8:55 a.m.	0.24	0.22	Total-P	0.34	0.002762	
8/4/2005	8	Hwy 1 Bridge	9:05 a.m.	0.038	0.4	Total-P	0.58	0.008567	
8/18/2005	8	Hwy 1 Bridge	8:55 a.m.	0.36	0.4	Total-P	0.63	0.009306	
9/8/2005	8	Hwy 1 Bridge	9:30 a.m.	0.72	0.9	Total-P	0.52	0.017282	
9/13/2005	8	Hwy 1 Bridge	9:25 a.m.	0.6	0.65	Total-P	0.39	0.009361	
9/19/2005	8	Hwy 1 Bridge	9:05 a.m.	1.24	4.2	Total-P	0.65	0.100812	
10/4/2005	8	Hwy 1 Bridge	9:35 a.m.	0.6	0.65	Total-P	0.46	0.011041	
10/4/2005	8	Hwy 1 Bridge	6:30 p.m.	1.04	2.1	Total-P	0.19	0.014734	
10/12/2005	8	Hwy 1 Bridge	5:55 p.m.	0.58	0.62	Total-P	0.09	0.002061	
				Total Q	27.08		FWMC	259	ug/L
				Ave Q	1.01	HM3	Load	261	kg/yr

Date	Site	Description	Time	Gage	Flow	Analyte	Result	q Fraction	
7/11/2005	9	Eidems	6:15 p.m.	0.08	0	Total-P		0	
10/4/2005	9	Eidems	6:15 p.m.		0.28	Total-P	0.08	0.050909	
10/12/2005	9	Eidems	6:20 p.m.		0.16	Total-P	0.04	0.000236	
			Total Q		0.44		FWMC	51	ug/L
			Ave Q		0.13	HM3	Load	7	kg/yr

Date	Site	Description	Time	Gage	Flow	Analyte	Result	q Fraction	
5/25/2005	10	Michaels	9:15 a.m.		0.1	Total-P	0.82	0.017597	
9/12/2005	10	Michaels	2:25 p.m.		0.11	Total-P	0.27	0.006373	
6/20/2005	10	Michaels	4:10 p.m.		0.13	Total-P		0	
5/12/2005	10	Michaels	6:05 p.m.		0.14	Total-P	0.34	0.010215	
6/28/2005	10	Michaels	9:05 a.m.		0.16	Total-P		0	
10/4/2005	10	Michaels	9:10 a.m.		0.18	Total-P	0.29	0.011202	
6/8/2005	10	Michaels	3:00 p.m.		0.2	Total-P		0	
6/16/2005	10	Michaels	8:50 a.m.		0.2	Total-P	0.53	0.022747	
10/4/2005	10	Michaels	5:55 p.m.		0.21	Total-P	0.86	0.038755	
6/15/2005	10	Michaels	9:25 a.m.		0.22	Total-P		0	
6/21/2005	10	Michaels	9:50 a.m.		0.23	Total-P	0.1	0.004936	
9/8/2005	10	Michaels	9:00 a.m.		0.28	Total-P	1.08	0.064893	
9/13/2005	10	Michaels	9:10 a.m.		0.3	Total-P	1.6	0.103004	
9/19/2005	10	Michaels	8:55 a.m.		0.32	Total-P	1.55	0.106438	
6/10/2005	10	Michaels	9:25 a.m.		1.88	Total-P	0.12	0.048412	
			Total Q		4.66		FWMC	435	ug/L
			Ave Q		0.28	HM3	Load	121	kg/yr

Date	Site	Description	Time	Flow	Analyte	Result	q Fraction	
4/11/2005	11	Bradley's Tile	3:45 p.m.	0.17	Total-P	0.38	0.015129	
4/13/2005	11	Bradley's Tile	5:40 p.m.	0.24	Total-P	0.32	0.017986	
5/5/2005	11	Bradley's Tile	8:55 a.m.	0.22	Total-P	0.45	0.023185	
5/12/2005	11	Bradley's Tile	5:55 p.m.	0.15	Total-P	0.35	0.012295	
5/25/2005	11	Bradley's Tile	9:10 a.m.	0.1	Total-P	0.34	0.007963	
6/5/2005	11	Bradley's Tile	10:15 a.m.	0.18	Total-P	0.31	0.013068	
6/10/2005	11	Bradley's Tile	9:15 a.m.	0.15	Total-P	0.25	0.008782	
6/16/2005	11	Bradley's Tile	8:40 a.m.	1.78	Total-P	0.29	0.12089	
6/21/2005	11	Bradley's Tile	9:45 a.m.	0.16	Total-P	0.18	0.006745	
7/6/2005	11	Bradley's Tile	1:55 p.m.	0.08	Total-P	0.29	0.005433	
7/19/2005	11	Bradley's Tile	8:25 a.m.	0.04	Total-P	0.31	0.002904	
8/4/2005	11	Bradley's Tile	8:35 a.m.	0.03	Total-P	0.36	0.002529	
9/8/2005	11	Bradley's Tile	8:50 a.m.	0.16	Total-P	0.54	0.020234	
9/13/2005	11	Bradley's Tile	9:00 a.m.	0.14	Total-P	0.2	0.006557	
9/19/2005	11	Bradley's Tile	8:45 a.m.	0.2	Total-P	0.3	0.014052	
10/4/2005	11	Bradley's Tile	8:55 a.m.	0.1	Total-P	0.47	0.011007	
10/4/2005	11	Bradley's Tile	5:50 p.m.	0.28	Total-P	0.25	0.016393	
10/12/2005	11	Bradley's Tile	6:35 p.m.	0.09	Total-P	0.22	0.004637	
			Total Q	427		FWMC	310	ug/L
			Ave Q	0.21	HM3	Load	66	kg/yr

Date	Site	Description	Time	Flow	Analyte	Result	q fraction
10/4/2004	12	Camp Site	10:10 a.m.	0.42	Total-P	0.28	0.022572
4/13/2005	12	Camp Site	4:30 p.m.	0.7	Total-P	0.8	0.107486
5/12/2005	12	Camp Site	4:45 p.m.	0.38	Total-P	0.33	0.024069
5/25/2005	12	Camp Site	8:10 a.m.	0.5	Total-P	0.21	0.020154
6/5/2005	12	Camp Site	11:45 a.m.	0.63	Total-P	0.24	0.029021
6/10/2005	12	Camp Site	8:15 a.m.	0.4	Total-P	0.25	0.019194
6/16/2005	12	Camp Site	9:55 a.m.	0.38	Total-P	0.13	0.009482
6/21/2005	12	Camp Site	2:10 p.m.	0.48	Total-P	0.16	0.014741
7/8/2005	12	Camp Site	3:00 p.m.	0.28	Total-P	0.32	0.017198
7/19/2005	12	Camp Site	9:35 a.m.	0.03	Total-P	0.3	0.001727
8/4/2005	12	Camp Site	9:40 a.m.	0.14	Total-P	0.62	0.01666
9/19/2005	12	Camp Site	9:45 a.m.	0.06	Total-P	0.41	0.004722
10/4/2005	12	Camp Site	5:25 p.m.	0.41	Total-P	0.21	0.016526
10/12/2005	12	Camp Site	5:20 p.m.	0.4	Total-P	0.14	0.010749
			Total Q	5.21		FWMC	314 ug/L
			Ave Q	0.33	HM3	Load	105 kg/yr

Date	Site	Description	Time	Flow	Analyte	Result	q fraction
4/13/2005	13	Nelson's Pond	5:15p.m.	0.14	Total-P	0.19	0.008693
5/12/2005	13	Nelson's Pond	5:20 p.m.	0.54	Total-P	0.18	0.031765
5/25/2005	13	Nelson's Pond	8:40 a.m.	0.3	Total-P	0.19	0.018627
6/5/2005	13	Nelson's Pond	11:30 a.m.	0.1	Total-P	0.14	0.004575
6/10/2005	13	Nelson's Pond	8:45 a.m.	0.6	Total-P	0.03	0.005882
6/16/2005	13	Nelson's Pond	9:45 a.m.	0.6	Total-P	0.09	0.017647
6/21/2005	13	Nelson's Pond	2:40 p.m.	0.3	Total-P	0.12	0.011765
7/8/2005	13	Nelson's Pond	2:50 p.m.	0.07	Total-P	0.16	0.00366
8/4/2005	13	Nelson's Pond	9:30 a.m.	0.06	Total-P	0.31	0.006078
9/8/2005	13	Nelson's Pond	10:00 a.m.	0.06	Total-P	0.26	0.005098
9/13/2005	13	Nelson's Pond	9:50 a.m.	0.06	Total-P	0.44	0.008627
9/19/2005	13	Nelson's Pond	9:35 a.m.	0.08	Total-P	0.34	0.008889
10/4/2005	13	Nelson's Pond	10:00 a.m.	0.08	Total-P	0.47	0.012288
10/4/2005	13	Nelson's Pond	5:05 p.m.	0.03	Total-P	0.28	0.002745
10/12/2005	13	Nelson's Pond	5:50 p.m.	0.04	Total-P	0.08	0.001046
			Total Q	3.06		FWMC	147 ug/L
			Ave Q	0.18	HM3	Load	27 kg/yr

Date	Site	Description	Time	Flow	Analyte	Result	q fraction
5/12/2005	14	Thompson	5:10 p.m.	0.1	Total-P	0.18	0.025714
5/25/2005	14	Thompson	8:30 a.m.	0.05	Total-P	0.07	0.005
6/5/2005	14	Thompson	11:15 a.m.	0.05	Total-P	0.4	0.028571
6/10/2005	14	Thompson	8:40 a.m.	0.08	Total-P	0.12	0.013714
6/16/2005	14	Thompson	9:30 a.m.	0.08	Total-P	0.14	0.016
6/21/2005	14	Thompson	2:30 p.m.	0.03	Total-P	0.06	0.002571
7/8/2005	14	Thompson	2:40 p.m.	0.02	Total-P	0.21	0.006
7/19/2005	14	Thompson	9:15 a.m.	0.02	Total-P	0.2	0.005714
8/4/2005	14	Thompson	9:30 a.m.	0.03	Total-P	0.1	0.004286
9/7/2005	14	Thompson	2:40 p.m.	0.02	Total-P	0.04	0.001143
9/8/2005	14	Thompson	9:55 a.m.	0.02	Total-P	0.14	0.004
9/12/2005	14	Thompson	3:10 p.m.	0.02	Total-P	0.1	0.002857
9/13/2005	14	Thompson	9:45 a.m.	0.03	Total-P	0.13	0.005571
9/19/2005	14	Thompson	9:30 a.m.	0.04	Total-P	0.21	0.012
10/4/2005	14	Thompson	9:55 a.m.	0.03	Total-P	0.12	0.005143
10/4/2005	14	Thompson	5:00 p.m.	0.04	Total-P	0.14	0.008
10/12/2005	14	Thompson	5:35 p.m.	0.04	Total-P	0.12	0.006857
			Total Q	0.70		FWMC	122 ug/L
			Ave Q	0.04	HM3	Load	5 kg/yr

Date	Site	Description	Time	Flow	Analyte	Result	q fraction	
6/16/2005	15	Suhr's Basin	8:30 a.m.	0.3	Total-P	0.69	0.304412	
6/21/2005	15	Suhr's Basin	9:30 a.m.	0.38	Total-P	0.6	0.335294	
			Total Q	0.68		FWMC	640 ug/L	
			Ave Q	0.05		Load	32 kg/yr	*short flow period

Date	Site	Description	Time	Flow	Analyte	Result	q fraction	
10/4/2005	16	Dritz Culvert	6:05 p.m.	0.47	Total-P	0.23	0.112604	
10/12/2005	16	Dritz Culvert	6:30 p.m.	0.49	Total-P	0.18		
			Total Q	0.96		FWMC	113 ug/L	
			Ave Q	0.07	HM3	Load	8 kg/yr	*short flow period

Appendix 2. Water Quality Data

TP and OP values in mg/L

STORET ID	Date	Parameter	Result
S002-255	3/30/2005	OP	0.27
S002-255	3/30/2005	TP	0.38
S002-255	4/11/2005	OP	0.11
S002-255	4/11/2005	TP	0.19
S002-255	4/13/2005	OP	0.08
S002-255	4/13/2005	TP	0.12
S002-255	5/5/2005	OP	0.05
S002-255	5/5/2005	TP	0.05
S002-255	5/12/2005	OP	0.08
S002-255	5/12/2005	TP	0.15
S002-255	5/25/2005	OP	0.06
S002-255	5/25/2005	TP	0.09
S002-255	6/5/2005	OP	0.08
S002-255	6/5/2005	TP	0.16
S002-255	6/10/2005	OP	0.08
S002-255	6/10/2005	TP	0.16
S002-255	6/16/2005	OP	0.06
S002-255	6/16/2005	TP	0.15
S002-255	6/21/2005	OP	0.09
S002-255	6/21/2005	TP	0.17
S002-255	7/8/2005	OP	0.09
S002-255	7/8/2005	TP	0.24
S002-255	7/19/2005	OP	0.14
S002-255	7/19/2005	TP	0.31
S002-255	8/4/2005	OP	0.18
S002-255	8/4/2005	TP	0.28
S002-255	8/18/2005	OP	0.26
S002-255	8/18/2005	TP	0.37
S002-255	9/7/2005	OP	0.24
S002-255	9/7/2005	TP	0.34
S002-255	9/8/2005	OP	0.5
S002-255	9/8/2005	TP	0.52
S002-255	9/12/2005	OP	0.25
S002-255	9/12/2005	TP	0.26
S002-255	9/13/2005	OP	0.15
S002-255	9/13/2005	TP	0.23
S002-255	9/19/2005	OP	0.16
S002-255	9/19/2005	TP	0.27
S002-255	10/4/2005	OP	0.14
S002-255	10/4/2005	OP	0.27
S002-255	10/4/2005	TP	0.26
S002-255	10/4/2005	TP	0.37
S002-255	10/12/2005	OP	0.08
S002-255	10/12/2005	TP	0.13
S002-257	4/11/2005	OP	0.3
S002-257	4/11/2005	TP	0.39

STORET ID	Date	Parameter	Result
S002-257	4/13/2005	OP	0.25
S002-257	4/13/2005	TP	0.25
S002-257	5/5/2005	OP	0.11
S002-257	5/5/2005	TP	0.12
S002-257	5/12/2005	OP	0.23
S002-257	5/12/2005	TP	0.34
S002-257	5/25/2005	OP	0.09
S002-257	5/25/2005	TP	0.09
S002-257	6/5/2005	OP	0.2
S002-257	6/5/2005	TP	0.32
S002-257	6/10/2005	OP	0.13
S002-257	6/10/2005	TP	0.22
S002-257	6/16/2005	OP	0.06
S002-257	6/16/2005	TP	0.12
S002-257	6/21/2005	OP	0.53
S002-257	6/21/2005	TP	0.67
S002-257	7/8/2005	OP	0.06
S002-257	7/8/2005	TP	0.16
S002-257	7/19/2005	OP	0.05
S002-257	7/19/2005	TP	0.15
S002-257	8/4/2005	OP	0.08
S002-257	8/4/2005	TP	0.08
S002-257	8/18/2005	OP	0.06
S002-257	8/18/2005	TP	0.08
S002-257	9/7/2005	OP	0.11
S002-257	9/7/2005	TP	0.14
S002-257	9/8/2005	OP	0.17
S002-257	9/8/2005	TP	0.39
S002-257	9/12/2005	OP	0.12
S002-257	9/12/2005	TP	0.17
S002-257	9/13/2005	OP	0.37
S002-257	9/13/2005	TP	0.37
S002-257	9/19/2005	OP	0.51
S002-257	9/19/2005	TP	0.64
S002-257	10/4/2005	OP	0.37
S002-257	10/4/2005	OP	0.4
S002-257	10/4/2005	TP	0.48
S002-257	10/4/2005	TP	0.53
S002-257	10/12/2005	OP	0.06
S002-257	10/12/2005	TP	0.07
S002-259	4/11/2005	OP	0.15
S002-259	4/11/2005	TP	0.26
S002-259	4/13/2005	OP	0.12
S002-259	4/13/2005	TP	0.12
S002-259	5/5/2005	OP	0.05
S002-259	5/5/2005	TP	0.05

STORET ID	Date	Parameter	Result	STORET ID	Date	Parameter	Result
S002-259	5/12/2005	OP	0.14	S002-260	6/10/2005	OP	0.16
S002-259	5/12/2005	TP	0.26	S002-260	6/10/2005	TP	0.26
S002-259	5/25/2005	OP	0.06	S002-260	6/16/2005	OP	0.1
S002-259	5/25/2005	TP	0.06	S002-260	6/16/2005	TP	0.18
S002-259	6/5/2005	OP	0.01	S002-260	6/21/2005	OP	0.15
S002-259	6/5/2005	TP	0.19	S002-260	6/21/2005	TP	0.26
S002-259	6/10/2005	OP	0.07	S002-260	7/8/2005	OP	0.17
S002-259	6/10/2005	TP	0.18	S002-260	7/8/2005	TP	0.31
S002-259	6/16/2005	OP	0.04	S002-260	7/19/2005	OP	0.21
S002-259	6/16/2005	TP	0.11	S002-260	7/19/2005	TP	0.34
S002-259	6/21/2005	OP	0.09	S002-260	8/4/2005	OP	0.48
S002-259	6/21/2005	TP	0.14	S002-260	8/4/2005	TP	0.58
S002-259	7/8/2005	OP	0.04	S002-260	8/18/2005	OP	0.5
S002-259	7/8/2005	TP	0.19	S002-260	8/18/2005	TP	0.63
S002-259	7/19/2005	OP	0.06	S002-260	9/8/2005	OP	0.43
S002-259	7/19/2005	TP	0.14	S002-260	9/8/2005	TP	0.52
S002-259	8/4/2005	OP	0.07	S002-260	9/13/2005	OP	0.39
S002-259	8/4/2005	TP	0.1	S002-260	9/13/2005	TP	0.39
S002-259	8/18/2005	OP	0.12	S002-260	9/19/2005	OP	0.48
S002-259	8/18/2005	TP	0.19	S002-260	9/19/2005	TP	0.65
S002-259	9/7/2005	OP	0.25	S002-260	10/4/2005	OP	0.13
S002-259	9/7/2005	TP	0.32	S002-260	10/4/2005	OP	0.21
S002-259	9/8/2005	OP	0.14	S002-260	10/4/2005	TP	0.19
S002-259	9/8/2005	TP	0.18	S002-260	10/4/2005	TP	0.46
S002-259	9/12/2005	OP	0.25	S002-260	10/12/2005	OP	0.06
S002-259	9/12/2005	TP	0.25	S002-260	10/12/2005	TP	0.09
S002-259	9/13/2005	OP	0.11	S002-261	10/4/2005	OP	0.08
S002-259	9/13/2005	TP	0.17	S002-261	10/4/2005	TP	0.08
S002-259	9/19/2005	OP	0.13	S002-261	10/12/2005	OP	0.03
S002-259	9/19/2005	TP	0.21	S002-261	10/12/2005	TP	0.04
S002-259	10/4/2005	OP	0.14	S002-262	5/12/2005	OP	0.23
S002-259	10/4/2005	OP	0.25	S002-262	5/12/2005	TP	0.34
S002-259	10/4/2005	TP	0.23	S002-262	5/25/2005	OP	0.08
S002-259	10/4/2005	TP	0.28	S002-262	5/25/2005	TP	0.82
S002-259	10/12/2005	OP	0.08	S002-262	6/10/2005	OP	0.08
S002-259	10/12/2005	TP	0.1	S002-262	6/10/2005	TP	0.12
S002-260	4/11/2005	OP	0.09	S002-262	6/16/2005	OP	0.27
S002-260	4/11/2005	TP	0.15	S002-262	6/16/2005	TP	0.53
S002-260	4/13/2005	OP	0.07	S002-262	6/21/2005	OP	0.09
S002-260	4/13/2005	TP	0.08	S002-262	6/21/2005	TP	0.1
S002-260	5/12/2005	OP	0.09	S002-262	9/8/2005	OP	1.06
S002-260	5/12/2005	TP	0.25	S002-262	9/8/2005	TP	1.08
S002-260	5/25/2005	OP	0.14	S002-262	9/12/2005	OP	0.22
S002-260	5/25/2005	TP	0.14	S002-262	9/12/2005	TP	0.27
S002-260	6/5/2005	OP	0.13	S002-262	9/13/2005	OP	1.36
S002-260	6/5/2005	TP	0.31	S002-262	9/13/2005	TP	1.6

STORET ID	Date	Parameter	Result
S002-262	9/19/2005	OP	1.35
S002-262	9/19/2005	TP	1.55
S002-262	10/4/2005	OP	0.17
S002-262	10/4/2005	OP	0.72
S002-262	10/4/2005	TP	0.29
S002-262	10/4/2005	TP	0.86
S002-263	4/11/2005	OP	0.32
S002-263	4/11/2005	TP	0.38
S002-263	4/13/2005	OP	0.3
S002-263	4/13/2005	TP	0.32
S002-263	5/5/2005	OP	0.42
S002-263	5/5/2005	TP	0.45
S002-263	5/12/2005	OP	0.29
S002-263	5/12/2005	TP	0.35
S002-263	5/25/2005	OP	0.34
S002-263	5/25/2005	TP	0.34
S002-263	6/5/2005	OP	0.24
S002-263	6/5/2005	TP	0.31
S002-263	6/10/2005	OP	0.19
S002-263	6/10/2005	TP	0.25
S002-263	6/16/2005	OP	0.19
S002-263	6/16/2005	TP	0.29
S002-263	6/21/2005	OP	0.15
S002-263	6/21/2005	TP	0.18
S002-263	7/8/2005	OP	0.18
S002-263	7/8/2005	TP	0.29
S002-263	7/19/2005	OP	0.23
S002-263	7/19/2005	TP	0.31
S002-263	8/4/2005	OP	0.34
S002-263	8/4/2005	TP	0.36
S002-263	9/8/2005	OP	0.39
S002-263	9/8/2005	TP	0.54
S002-263	9/13/2005	OP	0.19
S002-263	9/13/2005	TP	0.2
S002-263	9/19/2005	OP	0.22
S002-263	9/19/2005	TP	0.3
S002-263	10/4/2005	OP	0.22
S002-263	10/4/2005	OP	0.36
S002-263	10/4/2005	TP	0.25
S002-263	10/4/2005	TP	0.47
S002-263	10/12/2005	OP	0.21
S002-263	10/12/2005	TP	0.22
S002-395	4/13/2005	OP	0.05
S002-395	4/13/2005	TP	0.19
S002-395	5/12/2005	OP	0.07
S002-395	5/12/2005	TP	0.18
S002-395	5/25/2005	OP	0.09
S002-395	5/25/2005	TP	0.19
S002-395	6/5/2005	OP	0.06
S002-395	6/5/2005	TP	0.14
S002-395	6/10/2005	OP	0.01
S002-395	6/10/2005	TP	0.03
S002-395	6/16/2005	OP	0.02
S002-395	6/16/2005	TP	0.09
S002-395	6/21/2005	OP	0.09
S002-395	6/21/2005	TP	0.12
S002-395	7/8/2005	OP	0.06
S002-395	7/8/2005	TP	0.16
S002-395	8/4/2005	OP	0.17
S002-395	8/4/2005	TP	0.31
S002-395	9/8/2005	OP	0.22
S002-395	9/8/2005	TP	0.26
S002-395	9/13/2005	OP	0.38
S002-395	9/13/2005	TP	0.44
S002-395	9/19/2005	OP	0.14
S002-395	9/19/2005	TP	0.34
S002-395	10/4/2005	OP	0.15
S002-395	10/4/2005	OP	0.35
S002-395	10/4/2005	TP	0.28
S002-395	10/4/2005	TP	0.47
S002-395	10/12/2005	OP	0.05
S002-395	10/12/2005	TP	0.08
S002-396	5/12/2005	TP	0.180
S002-396	5/12/2005	OP	0.09
S002-396	5/25/2005	TP	0.070
S002-396	5/25/2005	OP	0.07
S002-396	6/5/2005	TP	0.400
S002-396	6/5/2005	OP	0.07
S002-396	6/10/2005	TP	0.120
S002-396	6/10/2005	OP	0.07
S002-396	6/16/2005	TP	0.140
S002-396	6/16/2005	OP	0.05
S002-396	6/21/2005	TP	0.060
S002-396	6/21/2005	OP	0.06
S002-396	7/8/2005	TP	0.210
S002-396	7/8/2005	OP	0.10
S002-396	7/19/2005	TP	0.200
S002-396	7/19/2005	OP	0.10
S002-396	8/4/2005	TP	0.100
S002-396	8/4/2005	OP	0.10
S002-396	9/7/2005	TP	0.040
S002-396	9/7/2005	OP	0.04

STORET ID	Date	Parameter	Result
S002-396	9/8/2005	TP	0.140
S002-396	9/8/2005	OP	0.10
S002-396	9/12/2005	TP	0.100
S002-396	9/12/2005	OP	0.09
S002-396	9/13/2005	TP	0.130
S002-396	9/13/2005	OP	0.13
S002-396	9/19/2005	TP	0.210
S002-396	9/19/2005	OP	0.12
S002-396	10/4/2005	TP	0.120
S002-396	10/4/2005	TP	0.140
S002-396	10/4/2005	OP	0.11
S002-396	10/4/2005	OP	0.12
S002-396	10/12/2005	TP	0.120
S002-396	10/12/2005	OP	0.11
S003-704	4/13/2005	OP	0.75
S003-704	4/13/2005	TP	0.8
S003-704	5/12/2005	OP	0.25
S003-704	5/12/2005	TP	0.33
S003-704	5/25/2005	OP	0.2
S003-704	5/25/2005	TP	0.21
S003-704	6/5/2005	OP	0.12
S003-704	6/5/2005	TP	0.24
S003-704	6/10/2005	OP	0.19
S003-704	6/10/2005	TP	0.25
S003-704	6/16/2005	OP	0.09
S003-704	6/16/2005	TP	0.13
S003-704	6/21/2005	OP	0.15
S003-704	6/21/2005	TP	0.16
S003-704	7/8/2005	OP	0.18
S003-704	7/8/2005	TP	0.32

STORET ID	Date	Parameter	Result
S003-704	7/19/2005	OP	0.21
S003-704	7/19/2005	TP	0.3
S003-704	8/4/2005	OP	0.52
S003-704	8/4/2005	TP	0.62
S003-704	9/19/2005	OP	0.18
S003-704	9/19/2005	TP	0.41
S003-704	10/4/2005	OP	0.15
S003-704	10/4/2005	OP	0.15
S003-704	10/4/2005	TP	0.21
S003-704	10/4/2005	TP	0.28
S003-704	10/12/2005	OP	0.1
S003-704	10/12/2005	TP	0.14
S003-705	6/16/2005	OP	0.47
S003-705	6/16/2005	TP	0.69
S003-705	6/21/2005	OP	0.41
S003-705	6/21/2005	TP	0.6
S003-936	10/4/2005	OP	0.19
S003-936	10/4/2005	TP	0.23
S003-936	10/12/2005	TP	0.18
S003-936	10/12/2005	OP	0.17

Lake Shaokatan Data

Chl-a, corrected for pheophytin

Date	ug/l	Date	ug/l
5/22/1985	7.7	7/9/2002	25.3
5/11/1989	110	8/20/2002	81.2
5/11/1989	59	8/20/2002	163
5/11/1989	58	9/10/2002	28.6
7/14/1989	22	9/10/2002	106
7/14/1989	13	7/22/2003	10.2
8/8/1989	304	7/22/2003	8.62
8/8/1989	365	8/13/2003	13.1
8/8/1989	381	8/13/2003	10.8
8/30/1989	49	9/16/2003	29.2
8/30/1989	208	9/16/2003	62
8/30/1989	38	6/6/2005	1.2
5/20/1999	0.8	6/6/2005	2.6
5/20/1999	0.4	6/20/2005	0.5
6/15/1999	7.2	6/20/2005	7.3
6/15/1999	7.9	7/5/2005	5.4
7/14/1999	26	7/5/2005	3.5
7/14/1999	36	7/24/2005	24.6
9/20/1999	98	7/24/2005	38.6
9/20/1999	148	8/17/2005	50.5
5/17/2000	12	8/17/2005	81.1
5/17/2000	18	9/7/2005	55.1
6/12/2000	8.9	9/7/2005	67.2
6/12/2000	11	9/18/2005	183
6/25/2000	20	9/18/2005	151
6/25/2000	99		
7/19/2000	45		
7/19/2000	67		
8/10/2000	11		
8/10/2000	9		
9/7/2000	102		
5/8/2001	8		
5/8/2001	8		
6/5/2001	38		
6/5/2001	62		
6/24/2001	183		
6/24/2001	210		
7/10/2001	57		
7/10/2001	71		
8/8/2001	98		
8/8/2001	149		
8/27/2001	140		
8/27/2001	169		
6/18/2002	13		
6/18/2002	15		
7/9/2002	9.2		

Chl-a, uncorrected for pheophytin

Date	ug/l	Date	ug/l
6/24/1991	46.8	7/2/1993	13
6/24/1991	27.2	7/2/1993	8.3
7/8/1991	32.7	7/26/1993	11
7/8/1991	46.7	7/26/1993	9.5
7/22/1991	70.5	9/29/1993	1
7/22/1991	56.5	9/29/1993	1
8/5/1991	46.2		
8/5/1991	17.4		
8/19/1991	22		
8/19/1991	46		
9/16/1991	53		
9/16/1991	36		
9/30/1991	34		
9/30/1991	66		
10/3/1991	2		
10/3/1991	2		
10/15/1991	6.8		
10/15/1991	6.8		
4/9/1992	7.8		
4/9/1992	6.2		
4/22/1992	9.5		
4/22/1992	4.5		
5/26/1992	2.2		
5/26/1992	3.9		
6/3/1992	2		
6/3/1992	1.1		
6/16/1992	3.1		
6/16/1992	2		
7/1/1992	13		
7/1/1992	15		
7/17/1992	23		
7/17/1992	71		
7/28/1992	95		
7/28/1992	160		
8/13/1992	290		
8/13/1992	13		
8/26/1992	290		
8/26/1992	150		
9/16/1992	82		
9/16/1992	8.4		
5/2/1993	7.8		
5/2/1993	6.8		
5/19/1993	3.8		
5/19/1993	2.9		
6/13/1993	3.9		
6/13/1993	5.6		

Secchi	
Date	m
5/22/1985	1.1
5/11/1989	1.75
5/11/1989	2.6
5/11/1989	2
5/20/1989	2.29
5/20/1989	2.13
5/20/1989	1.68
5/23/1989	2.29
5/23/1989	2.13
5/23/1989	1.83
5/27/1989	2.44
5/27/1989	2.13
5/27/1989	2.29
6/4/1989	2.44
6/4/1989	2.13
6/4/1989	2.44
6/8/1989	2.29
6/8/1989	2.13
6/8/1989	2.29
6/12/1989	2.44
6/12/1989	1.83
6/12/1989	2.29
6/16/1989	2.44
6/16/1989	1.83
6/16/1989	2.29
6/18/1989	2.59
6/18/1989	2.59
6/18/1989	2.29
6/21/1989	2.44
6/21/1989	1.98
6/21/1989	2.29
6/24/1989	2.44
6/24/1989	1.98
6/24/1989	2.29
6/30/1989	2.13
6/30/1989	1.98
6/30/1989	2.13
7/1/1989	1.98
7/1/1989	1.83
7/1/1989	1.83
7/3/1989	1.68
7/3/1989	1.37
7/3/1989	1.37
7/7/1989	1.22
7/7/1989	1.22
7/7/1989	1.07
7/9/1989	1.98

Secchi	
Date	m
7/9/1989	1.68
7/9/1989	1.68
7/14/1989	1
7/14/1989	1.2
7/14/1989	1.1
7/15/1989	1.37
7/15/1989	1.98
7/15/1989	0.76
7/19/1989	1.52
7/19/1989	1.52
7/19/1989	1.52
7/23/1989	1.52
7/23/1989	1.37
7/23/1989	1.37
7/28/1989	1.07
7/28/1989	1.68
7/28/1989	1.52
8/4/1989	0.76
8/4/1989	1.07
8/4/1989	0.91
8/8/1989	0.2
8/8/1989	0.4
8/8/1989	0.4
8/9/1989	0.3
8/9/1989	0.61
8/9/1989	0.61
8/30/1989	0.85
8/30/1989	0.75
8/30/1989	1.35
6/9/1990	1.83
6/9/1990	1.52
6/9/1990	1.52
6/16/1990	1.68
6/16/1990	1.52
6/16/1990	1.37
6/23/1990	1.83
6/23/1990	1.52
6/23/1990	1.37
7/1/1990	1.83
7/1/1990	1.52
7/1/1990	1.07
7/4/1990	0.91
7/4/1990	0.91
7/4/1990	1.07
7/8/1990	0.46
7/8/1990	0.61
7/8/1990	0.61

Secchi	
Date	m
7/14/1990	0.46
7/14/1990	0.61
7/14/1990	0.46
7/21/1990	0.46
7/21/1990	0.46
7/21/1990	0.46
7/28/1990	0.61
7/28/1990	0.46
7/28/1990	0.61
8/5/1990	0.61
8/5/1990	0.61
8/5/1990	0.46
8/12/1990	0.61
8/12/1990	0.61
8/12/1990	0.3
8/19/1990	0.3
8/19/1990	0.46
8/19/1990	0.3
8/26/1990	0.15
8/26/1990	0.46
8/26/1990	0.15
9/2/1990	0.15
9/2/1990	0.3
9/2/1990	0.15
9/9/1990	0.15
9/9/1990	0.3
9/9/1990	0.15
5/11/1991	1.22
5/11/1991	1.37
5/11/1991	1.37
5/25/1991	1.37
5/25/1991	1.37
5/25/1991	1.37
6/9/1991	0.91
6/9/1991	0.91
6/9/1991	0.91
6/12/1991	1.22
6/12/1991	1.22
6/12/1991	1.22
6/16/1991	0.46
6/16/1991	0.46
6/16/1991	0.46
6/22/1991	0.61
6/22/1991	0.76
6/22/1991	0.76
6/30/1991	0.61
6/30/1991	0.61

Secchi	
Date	m
6/30/1991	0.76
7/8/1991	0.91
7/8/1991	0.91
7/8/1991	1.07
7/14/1991	1.07
7/14/1991	1.07
7/14/1991	0.91
7/22/1991	0.91
7/22/1991	0.91
7/22/1991	1.07
8/10/1991	0.91
8/10/1991	0.91
8/10/1991	0.91
8/19/1991	0.61
8/19/1991	0.91
8/19/1991	0.76
8/26/1991	0.76
8/26/1991	0.76
8/26/1991	0.61
9/2/1991	0.61
9/2/1991	0.76
6/1/1992	2.74
6/8/1992	2.44
6/15/1992	2.74
6/20/1992	2.74
6/27/1992	2.44
7/4/1992	1.83
7/11/1992	1.22
7/25/1992	0.76
8/1/1992	0.46
8/10/1992	0.46
4/18/1999	1.83
4/18/1999	1.83
5/20/1999	3.05
5/20/1999	3.35
5/24/1999	3.05
5/24/1999	3.35
5/25/1999	3.05
5/25/1999	3.35
6/1/1999	3.05
6/1/1999	3.35
6/8/1999	2.9
6/8/1999	3.2
6/15/1999	2.9
6/15/1999	3.05
6/15/1999	2.74
6/15/1999	3.05

Secchi		
Date		m
6/22/1999		2.29
6/22/1999		2.59
6/30/1999		1.98
6/30/1999		2.44
7/5/1999		1.37
7/5/1999		1.52
7/14/1999		0.61
7/14/1999		0.91
7/14/1999		0.61
7/14/1999		0.91
7/20/1999		1.98
7/20/1999		0.91
7/28/1999		0.91
7/28/1999		0.91
8/3/1999		0.76
8/3/1999		0.76
8/10/1999		0.46
8/10/1999		0.61
8/16/1999		0.46
8/16/1999		0.61
8/16/1999		0.46
8/16/1999		0.61
8/24/1999		0.76
8/24/1999		0.76
9/1/1999		1.07
9/1/1999		0.91
9/7/1999		1.07
9/7/1999		0.91
9/20/1999		1.12
9/20/1999		1
9/20/1999		1.07
9/20/1999		0.91
5/17/2000		2.6
5/17/2000		2
5/17/2000	>	2.59
5/17/2000		1.98
5/27/2000		1.83
5/27/2000		2.13
6/7/2000		1.52
6/7/2000		1.83
6/12/2000		1.4
6/12/2000		2
6/12/2000		1.37
6/12/2000		1.98
6/25/2000		1.09
6/25/2000		0.94
6/25/2000		0.91

Secchi	
Date	m
6/25/2000	0.91
7/19/2000	0.9
7/19/2000	0.8
7/19/2000	0.91
7/19/2000	0.76
7/26/2000	0.76
7/26/2000	0.46
8/3/2000	1.22
8/3/2000	1.37
8/10/2000	2.13
8/10/2000	2.13
8/23/2000	0.76
8/23/2000	0.46
9/3/2000	1.07
9/3/2000	1.07
5/8/2001	1.3
5/8/2001	1.4
5/26/2001	1.98
5/26/2001	2.29
6/2/2001	1.52
6/2/2001	1.22
6/5/2001	1.1
6/5/2001	1.2
6/10/2001	0.46
6/10/2001	1.07
6/24/2001	0.5
6/24/2001	0.5
6/25/2001	0.91
6/25/2001	0.46
7/7/2001	0.91
7/7/2001	2.13
7/10/2001	1.3
7/10/2001	1.6
7/22/2001	0.61
7/22/2001	0.61
7/31/2001	1.07
7/31/2001	1.07
8/8/2001	0.9
8/8/2001	0.7
8/19/2001	0.46
8/19/2001	0.46
8/27/2001	0.5
8/27/2001	0.5
9/3/2001	1.07
9/3/2001	0.76
9/12/2001	0.91
9/12/2001	0.91

Secchi		
Date		m
9/22/2001		1.22
9/22/2001		1.22
9/27/2001		1.52
9/27/2001		1.37
5/12/2002		0.91
5/12/2002		0.91
5/19/2002		1.07
5/19/2002		1.07
5/26/2002	>	3.05
5/26/2002	>	3.05
6/2/2002		2.74
6/2/2002		2.59
6/9/2002		2.44
6/9/2002		2.44
6/15/2002		2.44
6/15/2002		2.29
6/18/2002		1.5
6/18/2002		1.8
6/30/2002		2.13
6/30/2002		2.13
7/7/2002		0.91
7/7/2002		0.76
7/9/2002		1.1
7/9/2002		1
7/14/2002		1.22
7/14/2002		1.22
7/26/2002		0.91
7/26/2002		0.91
8/11/2002		0.61
8/11/2002		0.61
8/20/2002		0.7
8/20/2002		0.6
8/25/2002		0.76
8/25/2002		0.76
9/8/2002		1.07
9/8/2002		1.07
9/10/2002		0.7
9/10/2002		0.8
9/29/2002		1.83
9/29/2002		1.52
7/22/2003		1
7/22/2003		0.8
8/13/2003		0.5
8/13/2003		0.6
9/16/2003		0.9
9/16/2003		0.9
5/29/2004	>	2.23

Secchi		
Date		m
5/29/2004	>	2.9
6/5/2004	>	2.19
6/5/2004	>	2.9
6/12/2004	>	1.95
6/12/2004	>	2.9
6/19/2004	>	2.13
6/19/2004	>	2.9
6/26/2004		2.29
6/26/2004		2.44
7/4/2004	>	2.29
7/4/2004	>	2.9
7/11/2004		2.29
7/11/2004		1.98
7/18/2004		1.52
7/18/2004		0.61
7/25/2004		0.15
7/25/2004		0.46
8/4/2004		0.91
8/4/2004		0.61
8/11/2004		0.61
8/11/2004		0.46
9/5/2004		1.98
9/5/2004		0.91
9/12/2004		0.76
9/12/2004		0.61
9/19/2004		0.61
9/19/2004		0.61
9/26/2004		0.61
9/26/2004		0.91
5/10/2005		2.44
5/10/2005		2.44
5/22/2005	>	2.74
5/22/2005	>	2.44
5/29/2005	>	2.74
5/29/2005	>	2.44
6/5/2005	>	2.74
6/5/2005	>	2.44
6/6/2005		2.44
6/6/2005		2.13
6/12/2005	>	2.74
6/12/2005	>	2.44
6/19/2005	>	2.9
6/19/2005	>	2.59
6/20/2005		2.74
6/20/2005		2.74
6/27/2005		1.83
6/27/2005		1.68

Secchi

Date		m
7/5/2005		1.8
7/5/2005		2.1
7/24/2005		0.9
7/24/2005		1.2
8/17/2005		0.6
8/17/2005		1.1
9/7/2005		0.6
9/7/2005		0.5
9/18/2005		0.3
9/18/2005		0.4
5/20/2006	>	3.2
5/20/2006	>	3.1
5/26/2006	>	3.2
5/26/2006	>	3.1
6/4/2006	>	3.4
6/4/2006	>	3.1
6/11/2006		2.6
6/11/2006		2.6
6/19/2006		2.7
6/19/2006		2.4
6/25/2006		2.1
6/25/2006		2
7/4/2006		1.4
7/4/2006		2
7/11/2006		2.4
7/11/2006		0.8
7/16/2006		0.9
7/16/2006		0.8
7/23/2006		0.6
7/23/2006		0.6
7/31/2006		0.6
7/31/2006		0.6
8/6/2006		0.9
8/6/2006		0.9
8/14/2006		0.9
8/14/2006		0.9
8/21/2006		1.4
8/21/2006		1.4
8/28/2006		2.3
8/28/2006		2.3
9/4/2006		1.1
9/4/2006		1.5
9/20/2006		1.8

TP

Date	mg/L
5/22/1985	0.105
5/6/1986	0.165
5/11/1989	0.28
5/11/1989	0.233
5/11/1989	0.262
7/14/1989	0.333
8/8/1989	0.236
8/30/1989	0.328
6/24/1991	0.54
6/24/1991	0.634
7/8/1991	0.42
7/8/1991	0.435
7/22/1991	0.14
7/22/1991	0.15
8/5/1991	0.26
8/5/1991	0.22
8/19/1991	0.33
8/19/1991	0.4
9/16/1991	0.51
9/16/1991	0.5
9/30/1991	0.32
9/30/1991	0.38
10/3/1991	0.26
10/3/1991	0.26
10/15/1991	0.25
10/15/1991	0.3
4/9/1992	0.12
4/9/1992	0.2
4/22/1992	0.14
4/22/1992	0.13
5/26/1992	0.08
5/26/1992	0.08
6/3/1992	0.13
6/3/1992	0.16
6/16/1992	0.15
6/16/1992	0.17
7/1/1992	0.31
7/1/1992	0.24
7/17/1992	0.2
7/17/1992	0.25
7/28/1992	0.19
7/28/1992	0.24
8/13/1992	0.52
8/13/1992	0.3
8/26/1992	0.42
8/26/1992	0.32
9/16/1992	0.21

TP

Date	mg/L
9/16/1992	0.22
5/2/1993	0.09
5/2/1993	0.44
5/19/1993	0.09
5/19/1993	0.12
6/13/1993	0.01
6/13/1993	0.1
6/13/1993	0.01
6/13/1993	0.1
7/2/1993	0.07
7/2/1993	0.1
7/26/1993	0.12
7/26/1993	0.13
9/29/1993	0.14
9/29/1993	0.19
5/7/1994	0.02
5/7/1994	0.08
6/9/1994	0.1
6/9/1994	0.07
6/29/1994	0.1
6/29/1994	0.09
8/7/1994	0.11
8/7/1994	0.09
9/29/1994	0.13
9/29/1994	0.1
5/20/1999	0.063
5/20/1999	0.066
6/15/1999	0.042
6/15/1999	0.067
7/14/1999	0.08
7/14/1999	0.087
8/16/1999	0.224
8/16/1999	0.181
9/20/1999	0.196
9/20/1999	0.184
5/17/2000	0.061
5/17/2000	0.147
6/12/2000	0.083
6/12/2000	0.078
6/25/2000	0.136
6/25/2000	0.131
7/19/2000	0.148
7/19/2000	0.17
8/10/2000	0.195
8/10/2000	0.207
9/7/2000	0.34
5/8/2001	0.063

TP

Date	mg/L
5/8/2001	0.058
6/5/2001	0.059
6/5/2001	0.078
6/24/2001	0.115
6/24/2001	0.246
7/10/2001	0.18
7/10/2001	0.185
8/8/2001	0.265
8/8/2001	0.289
8/27/2001	0.203
8/27/2001	0.274
6/18/2002	0.122
6/18/2002	0.154
7/9/2002	0.129
7/9/2002	0.15
8/20/2002	0.075
8/20/2002	0.084
9/10/2002	0.117
9/10/2002	0.159
7/22/2003	0.19
7/22/2003	0.221
7/22/2003	0.203
7/22/2003	0.218
8/13/2003	0.165
8/13/2003	0.174
9/16/2003	0.125
9/16/2003	0.163
5/10/2005	0.08
5/10/2005	0.04
6/6/2005	0.09
6/6/2005	0.12
6/20/2005	0.09
6/20/2005	0.09
7/5/2005	0.15
7/5/2005	0.13
7/24/2005	0.05
7/24/2005	0.17
8/17/2005	0.16
8/17/2005	0.14
9/7/2005	0.17
9/7/2005	0.2
9/18/2005	0.32
9/18/2005	0.43

OP

Date	mg/L
6/24/1991	0.407
6/24/1991	0.407
7/8/1991	0.34
7/8/1991	0.315
7/22/1991	0.08
7/22/1991	0.08
8/5/1991	0.13
8/5/1991	0.13
8/19/1991	0.21
8/19/1991	0.189
9/16/1991	0.26
9/16/1991	0.5
9/30/1991	0.21
9/30/1991	0.19
10/3/1991	0.2
10/3/1991	0.18
10/15/1991	0.21
10/15/1991	0.22
4/9/1992	0.017
4/9/1992	0.019
4/22/1992	0.019
4/22/1992	0.014
5/26/1992	0.07
5/26/1992	0.06
6/3/1992	0.1
6/3/1992	0.06
6/16/1992	0.09
6/16/1992	0.08
7/1/1992	0.13
7/1/1992	0.11
7/17/1992	0.12
7/17/1992	0.12
7/28/1992	0.049
7/28/1992	0.024
8/13/1992	0.005
8/13/1992	0.076
8/26/1992	0.005
8/26/1992	0.04
9/16/1992	0.054
9/16/1992	0.07

OP

Date	mg/L
5/2/1993	0.008
5/2/1993	0.005
5/19/1993	0.018
5/19/1993	0.031
6/13/1993	0.01
6/13/1993	0.009
7/2/1993	0.03
7/2/1993	0.03
7/26/1993	0.05
7/26/1993	0.06
9/29/1993	0.04
9/29/1993	0.04
5/7/1994	0.02
5/7/1994	0.02
6/9/1994	0.085
6/9/1994	0.049
6/29/1994	0.049
6/29/1994	0.019
8/7/1994	0.031
8/7/1994	0.034
9/29/1994	0.022
9/29/1994	0.033
5/10/2005	0.07
5/10/2005	0.03
6/6/2005	0.05
6/6/2005	0.05
6/20/2005	0.08
6/20/2005	0.07
7/5/2005	0.05
7/5/2005	0.03
7/24/2005	0.05
7/24/2005	0.07
8/17/2005	0.04
8/17/2005	0.03
9/7/2005	0.02
9/7/2005	0.08
9/18/2005	0.03
9/18/2005	0.04