Valley Branch Watershed District Total Maximum Daily Load

Lower St. Croix River - Major Watershed

Minnesota Pollution Control Agency

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Authors and contributors:

State Agencies & Staff

Minnesota Pollution Control Agency

Minnesota Department of Natural Resources

Metropolitan Council

Minnesota Department of Transportation

Watershed District & Staff

Valley Branch Watershed District

County Agencies & Staff

Washington County Public Health and Environment

Washington County Public Works

Washington Conservation District

City Staff

City of Lake Elmo

City of Afton

Consultant

Barr Engineering Co.

Master's Student

Leslie Thomas

Cover Photo of Kelle's Creek Courtesy of Valley Branch Watershed District (Barr Engineering Co.)

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Acronyms

ac-ft	acre feet
ac-ft/yr	acre feet per year
AF	Anoxic factor
AUID	Assessment Unit ID
AU	Animal Unit
BMP	Best Management Practice
BWSR	Board of Water and Soil Resources
CAFO	Concentrated Animal Feeding Operation
CAC	Citizens Advisory Committee
CAMP	Citizen Assisted Monitoring Program
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
CSAH	County State Aid Highway
DNR	Minnesota Department of Natural Resources
E. coli	*Escherichia coli* bacteria
EPA	United States Environmental Protection Agency
EQuIS	Environmental Quality Information System
FWMC	Flow weighted mean concentration
GS	Growing season
GW	Groundwater
ha	Hectare
HSPF	Hydrologic Simulation Program-Fortran
in/yr	inches per year
km^2	square kilometer
LA	Load Allocation
lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LGU	Local Government Unit
m	meter
MDA	Minnesota Department of Agriculture
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day

MIDS	Minimal Impact Design Standards
mL	milliliter
MLCCS	Minnesota Land Cover Classification System
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NCHF	North Central Hardwood Forest Ecoregion
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
P8	Program for Predicting Polluting Particle Passage thru Pits, Puddles, & Ponds
RR	Release rate
SRO	Surface runoff
SONAR	Statement of Need and Reasonableness
SDS	State Disposal System
SDT	Secchi Disk Transparency
SSTS	Subsurface Sewage Treatment System or Systems
SWPPP	Stormwater Pollution Prevention Plan
TDLC	Total Daily Loading Capacity
TMDL	Total Maximum Daily Load
TP	Total phosphorus
UAL	Unit-area Load
µg/L	microgram per liter
VBWD	Valley Branch Watershed District
WCD	Washington Conservation District
WCDPHE	Washington County Department of Public Health and the Environment
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategy
WWTF	Wastewater Treatment Facility
WWTS	Wastewater Treatment System

Executive Summary

Section 303(d) of the Clean Water Act requires that every two years all states publish a list of streams and lakes that do not meet water quality standards. Waters placed on the list are considered impaired. States are required to set Total Maximum Daily Loads (TMDLs) for impaired waters in order to define the maximum amount of pollutant a waterbody can receive while maintaining water quality standards and to determine the load reductions necessary to achieve water quality standards. A TMDL is divided into a wasteload allocation (WLA) for point sources (permitted sources), a load allocation (LA) for nonpoint sources (non-permitted sources) and natural background, and a margin of safety (MOS).

Kelle's Creek is located in the city of Afton, Washington County, Minnesota. Kelle's Creek is located in a steep-sided ravine and is a spring-fed perennial creek that flows and discharges to the St. Croix River, south of downtown Afton. The watershed is approximately 2.5 square miles in size, and land use in the watershed is predominantly very low density residential and agricultural. Kelle's Creek does not meet Minnesota water quality standards for pathogen indicator bacteria (*Escherichia (E). coli*). The creek was placed on the 303(d) list in 2012 because monitoring data indicated that *E. coli* levels typically exceeded the monthly geometric mean standard of 126 *E. coli* organisms per 100 mL. *E. coli* bacteria is used in water quality monitoring as an indicator organism to identify water that is contaminated with human or animal waste and the accompanying disease-causing organisms. Bacterial abundance in excess of the water quality standards can pose a human health risk.

A population source inventory and assumed bacteria availability was used to estimate the sources of bacteria that were available to the observed load in Kelle's Creek. The analysis indicated that runoff from nonriparian pastures and non-compliant septic systems are likely the primary sources of *E. coli* to Kelle's Creek.

Overall, *E. coli* load reductions between 33% and 96% are required in order to meet water quality standards, depending on the flow conditions. The primary implementation strategies recommended target riparian pasture management and the identification and replacement of non-compliant septic systems.

Sunfish Lake is located in the city of Lake Elmo, north of Trunk Highway 5. Sunfish Lake is a shallow landlocked lake. The total watershed area of Sunfish Lake is 566 acres (including the surface area of the lake); however, only 351 acres of the watershed contributes runoff to Sunfish Lake, 50 acres of which is the lake surface area. Much of the existing land use in the Sunfish Lake Watershed is very low density residential, park land and natural open space, and limited agricultural land.

Sunfish Lake was placed on the 303(d) list in 2008 for not meeting the Minnesota Pollution Control Agency's (MPCA's) shallow lake eutrophication standards for the North Central Hardwood Forests (NCHF) ecoregion.

The primary source of phosphorus to Sunfish Lake during the growing season (GS) is due to release from the bottom sediments in the lake. Secondary sources include watershed runoff, atmospheric deposition; die back of aquatic plants, and non-compliant subsurface sewage treatment systems (SSTS) in the watershed.

To achieve the TMDL and state water quality standards, a 16% reduction in the GS phosphorus load to Sunfish Lake is needed. The primary implementation strategies recommended are the deactivation of phosphorus from the bottom sediments through alum treatments and replacement of non-compliant SSTS in the watershed.

1. Project Overview

1.1 Purpose

The Valley Branch Watershed District (VBWD) is located on the eastern edge of the Minneapolis-St. Paul Metropolitan area and covers approximately 70 square miles. Approximately one square mile of the 70 is in Ramsey County, the remainder lies within Washington County. The VBWD was established on November 14, 1968, in response to a citizen's petition of the State of Minnesota to address water resource issues in the watershed. Ever since the VBWD's establishment, one of its primary goals has been to maintain, protect, and/or improve the quality of all surface waters within the VBWD.

This TMDL study addresses one bacteria impairment in Kelle's Creek and a nutrient impairment for Sunfish Lake, a shallow lake in the VBWD. Figure 1-1 shows the location of these water bodies in the VBWD.

The goal of this TMDL report is to quantify the pollutant reductions needed to meet the MPCA's water quality standards for bacteria in Kelle's Creek and nutrients in Sunfish Lake. This TMDL was established in accordance with Section 303(d) of the Clean Water Act and provides the WLAs and LAs for the impaired water resources.

This report outlines the development of the TMDLs for Kelle's Creek and Sunfish Lake and describes best management practices (BMPs) that can be implemented to work towards achieving the required pollutant reductions to these resources.

1.2 Identification of Waterbodies

Table 1-1 summarizes the year the water resource was listed, the targeted start date, and the completion dates for the TMDLs.

Kelle's Creek was placed on the MPCA's 303(d) list of impaired waters in 2012. The affected designated use was identified as aquatic recreation due to bacteria (*E. coli)*. *E. coli* bacteria is used in water quality monitoring as an indicator organism to identify water that is contaminated with human or animal waste and the accompanying disease-causing organisms. Bacterial abundance in excess of the water quality standards can pose a health risk to humans.

Sunfish Lake was listed on the MPCA 303(d) list of impaired waters in 2008. The affected designated use was identified as aquatic recreation due to excess nutrients. In freshwater lakes, phosphorus is often the limiting nutrient and there is typically a direct relationship between the amount of phosphorus and the amount of algae in the lake. Excess phosphorus in lakes can result in nuisance algal blooms that impact water clarity, recreational uses of the lake, and overall aesthetics.

Table 1-1 Impairments addressed in this TMDL Report

Water Body	Pollutant	Impaired Use	Year Listed as Impaired	Target Start Date	Target Completion Date
Kelle's Creek (07030005-606)	*E. coli*	Aquatic Recreation	2012	2021	2024
Sunfish Lake (82-0107-00)	Nutrient/Eutrophication Biological Indicators	Aquatic Recreation	2008	2012	2015

1.3 Priority Ranking

The MPCA's projected schedule for TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. 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 waterbody; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

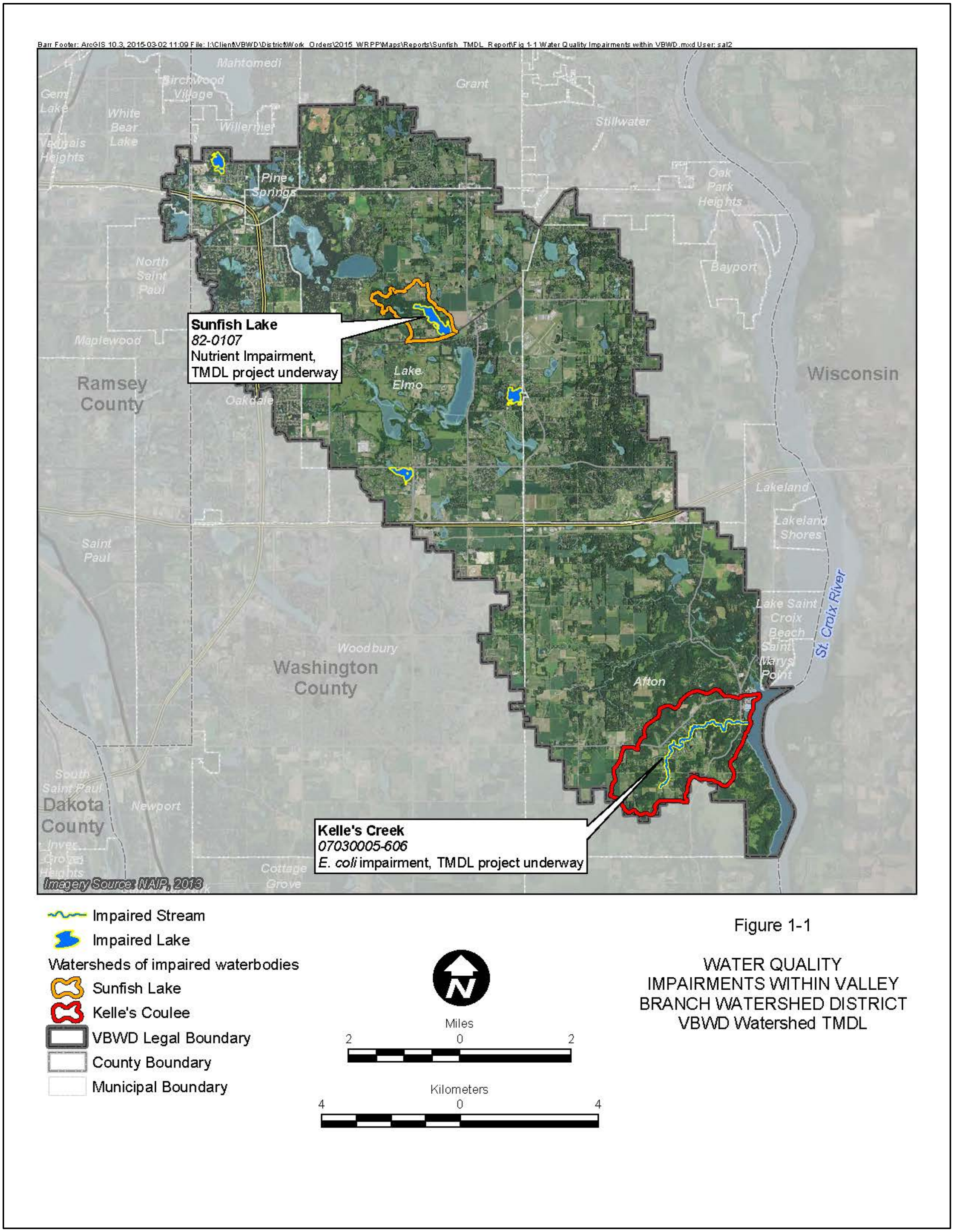

Figure 1-1 Water Quality Impairments within Valley Branch Watershed District

2. Applicable Water Quality Standards and Numeric Water Quality Targets

The following sections discuss the applicable water quality standards that apply to the TMDLs being completed as part of this study.

2.1 Bacteria (*E. coli*)

Kelle's Creek is classified as a Class 2B and 3C water. Class 2B is the most restrictive class and 3C indicates industrial use.

The narrative standard for Class 2B is defined in Minn. R. 7050.0222:

> *The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable.*

The numeric standard for Class 2B is in terms of *E. coli*:

> *Not to exceed 126 organisms per 100 milliliters as a geometric mean of not less than five samples representative of conditions within any calendar month, nor shall more than ten percent of all samples taken during any calendar month individually exceed 1,260 organisms per 100 milliliters. The standard applies only between April 1 and October 31.*

2.2 Excess Nutrients

According to Minn. R. ch. 7050.0150 and Minn. R. ch. 7050.0222, subp. 4, Sunfish Lake is located in the North Central Hardwood Forest (NCHF) ecoregion and is considered a shallow lake.

The MPCA's shallow lake eutrophication standards for the NCHF ecoregion are shown in Table 2-1. To be listed as impaired by the MPCA, the monitoring data must show that the standards for both total phosphorus (TP) (the causal factor) and either Chlorophyll *a* (Chl-*a*) or Secchi disc transparency depth (the response factors) are not met (MPCA 2009).

To demonstrate compliance with the MPCA lake eutrophication standards, in addition to meeting phosphorus limits, Chl-*a* and Secchi disc transparency standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (MPCA 2005). Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi disc transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the Chl-*a* and Secchi disc transparency standards will likewise be met.

Table 2-1 Numeric water quality standards for shallow lakes in the North Central Hardwood Forest Ecoregion.

Parameters	Shallow[1] Lake Standard
Total Phosphorus µg/L	≤ 60
Chlorophyll *a* (µg/L)	≤ 20
Secchi Disc (meters)	≥ 1.0

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

Analysis of Impairment

The criteria used for determining impairments are outlined in the MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for the Determination of Impairment: 305(b) Report and 303(d) List (2014).

3. Watershed and Waterbody Characterization

The VBWD is a special purpose unit of local government that manages water resources on a watershed basis. Watershed district boundaries generally follow natural watershed divides, rather than political boundaries. The general purposes of a watershed district are to conserve natural resources through land use planning, flood control, and other conservation projects to protect the public health and welfare and for the wise use of the natural resources. The boundaries of the VBWD are shown on Figure 1-1.

The communities that lie or partially lie within the VBWD include the city of Maplewood, city of Afton, city of Mahtomedi, city of St. Mary's Point, city of North St. Paul, Baytown Township, city of Oak Park Heights, West Lakeland Township, city of White Bear Lake, city of Grant, city of Oakdale, city of Woodbury, city of Lake Elmo, and city of Pine Springs. The land of the VBWD all eventually drains to the St. Croix River, and therefore, is within the St. Croix River Watershed.

According to the VBWD Watershed Management 2005-2015 Plan (Barr 2005a), the VBWD Mission is as follows:

To manage and protect our water resources: lakes, ponds, creeks, streams, wetlands, drainages, and groundwater (GW) by:

- Promoting open communication with our constituents, both our citizen base and pertinent governmental units.
- Improving and protecting the quality of water for all water bodies within the VBWD.
- Managing the quantity of water and minimizing the negative impact on the VBWD from floods, high flows, and droughts by providing public works projects and other prudent measures.
- Understanding the effects of community growth and other activities on GW, initially focusing on the GW-surface water interface.
- Continuing to enforce the Wetland Conservation Act requirements as the responsible local unit of government.
- Educating our constituents and the local units of government within the VBWD on water quality and quantity issues, management, and means of improvement.

3.1 Streams

Kelle's Creek is located in a steep-sided ravine located in the southern portion of the VBWD in the city of Afton. The creek is a spring-fed perennial creek that flows from the upper portions of the ravine to the St. Croix River, discharging into the river downstream (south) of downtown Afton.

Kelle's Creek flows approximately 2.8 miles from the point the creek becomes perennial-flowing (water flowing year-round) to the mouth of the creek at the St. Croix River. Kelle's Creek becomes perennial-flowing about 0.45 miles northeast of the intersection of Trading Post Trail and Afton Boulevard (County State Aid Highway (CSAH) 18). Upstream of this area, Kelle's Creek is an intermittent stream. Intermittent streams are dry most of the time, but flow during rain or snowmelt events.

Some streambank and ravine erosion have been reported in the Kelle's Creek Watershed (EOR 2007a). Additional investigations of Kelle's Creek by VBWD in 2013 indicated that erosion in the creek appears to be predominantly caused by natural processes as the creek meanders and encounters the steeper sides of the ravine and head cuts and channel incision were not observed (Barr 2013).

3.2 Lakes

Sunfish Lake is located in the city of Lake Elmo, north of Trunk Highway 5, between Kelvin Avenue North and Lake Elmo Avenue North. At elevation 890 feet, the lake has a surface area of approximately 50 acres, of which 65% is considered to be littoral (i.e., covered with aquatic plants). There is no surface outflow from the lake. The lake would not discharge overland until it reached elevation 927.8 feet, well above the highest recorded water level of elevation 905.8 observed in January 1987. At elevation 893.7 feet, the maximum depth of Sunfish Lake is 13 feet. The bathymetry of Sunfish Lake is shown in Figure 3-1.

The northwest shore of the lake is within the city of Lake Elmo's Sunfish Lake Park. The park is primarily wooded and remains in its natural state. Park activities include hiking, cross country skiing, and picnicking. Park attendees have access to the lake by means of a park trail (the Rabbit Trail), and use the lake for fishing (mainly from shore), canoeing, and passive viewing, but there is no official public boat access to the lake. During the winter months, some park attendees cross country ski across the lake. Area residents use the lake for boating (paddleboats, pontoons, and canoes), fishing, and aesthetic viewing purposes. Although there are no swimming beaches on Sunfish Lake, some residents occasionally swim in the lake.

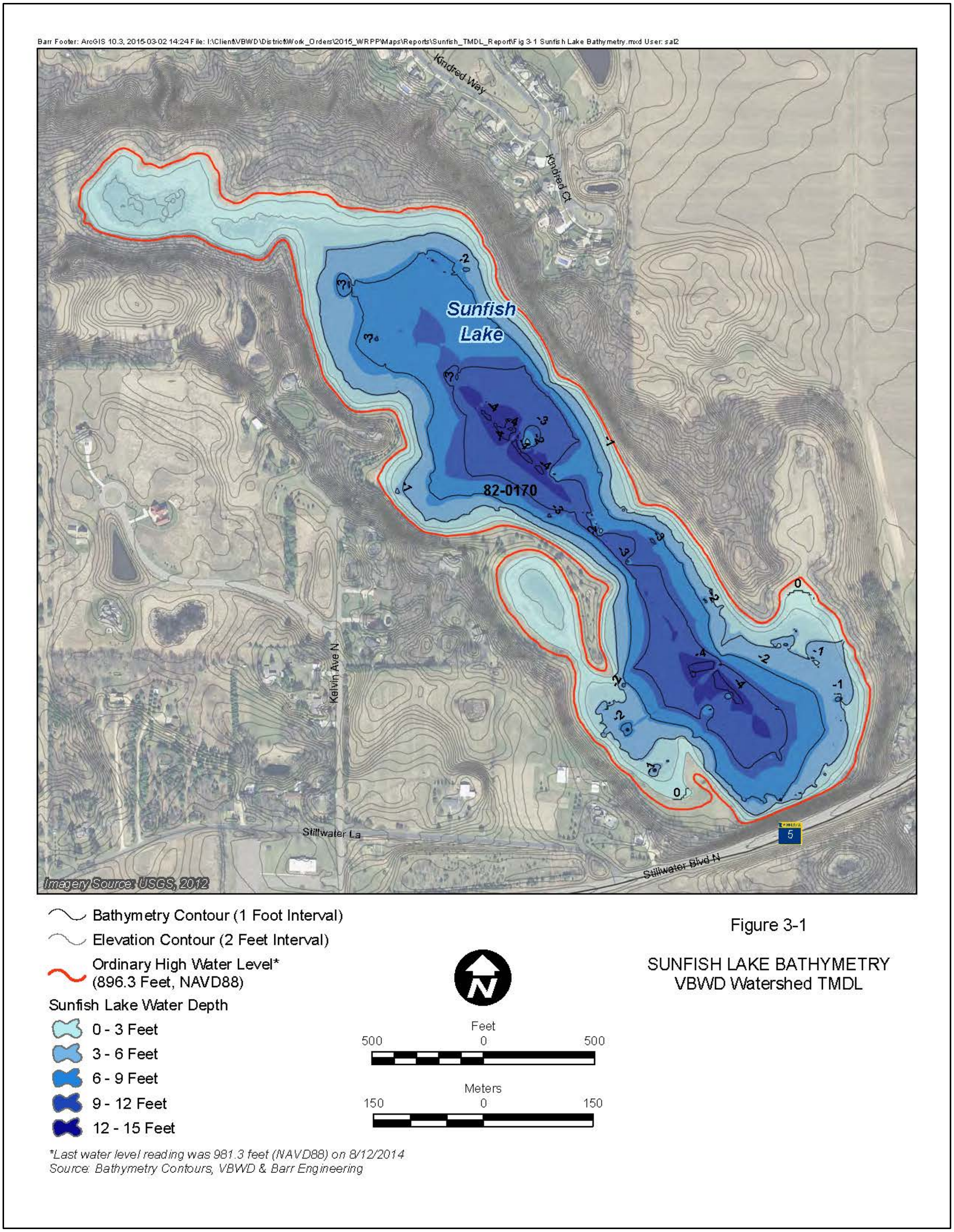

Figure 3-1 Sunfish Lake Bathymetry

3.3 Watershed Descriptions

3.3.1 Kelle's Creek Watershed

Kelle's Creek is located in a steep-sided ravine located in the southern portion of the city of Afton. Kelle's Creek has a watershed area of approximately 2.5 square miles (Figure 3-2).

The Kelle's Creek Watershed is located entirely within the city of Afton, Washington County, Minnesota and is within the jurisdiction of the VBWD. The Kelle's Creek Watershed, as managed by the VBWD, includes portions of the watershed that do not directly contribute flows to Kelle's Creek. The total VBWD-managed Kelle's Creek Watershed is approximately 3.5 square miles. However, the portion of the Kelle's Creek Watershed that drains directly to the creek has a drainage area approximately 2.5 square miles and is the portion of the watershed used for the TMDL analyses. Kelle's Creek and its tributary watershed are shown in Figure 3-2.

There are also karst features, including springs, located within the Kelle's Creek Watershed (Figure 3-2). Springs are points where subsurface GW flow is concentrated and act as foci for discharge from karst aquifers (EOR 2007b). Karst features are formed from the dissolution of soluble rocks including limestone, dolomite, and gypsum. Rainwater and pollutants can easily flow through these networks and continue to erode and enlarge the passages. In areas with septic systems and karst topography, such as in the Kelle's Creek Watershed, this can be a significant problem in relation to water quality. The presence of karst features suggests an area that is highly susceptible to GW pollution. The uplands in the upper portions of the Kelle's Creek Watershed are identified as sensitive karst areas (EOR 2007b).

Figure 3-2 shows the GW sensitivity to pollution for the Kelle's Creek Watershed.

Much of the Kelle's Creek Watershed is undeveloped and the land use is primarily rural residential in the lower portions of the watershed and agricultural uses in the uplands to the southwest. The downstream portion of the watershed includes a small portion of downtown Afton. Upstream of St. Croix Trail (CSAH 21) the riparian areas of the creek are primarily classified as forested wetlands, with upland forests on the ravine sides (EOR 2007b). There are also some unfragmented tracts of forest and grassland that provide valuable habitat in the watershed. The existing and future land use in the Kelle's Creek Watershed is shown in Figure 3-3 and Figure 3-4, respectively. Table 3-1 summarizes the Metropolitan Council 2010 land use classifications (Metropolitan Council, 2011) for the Kelle's Creek Watershed.

Based on the 2010 census data, the estimated population in the Kelle's Creek Watershed is 381 people. The watershed is served entirely by residential SSTS.

Table 3-1 Met Council 2010 Land Use Classification of Kelle's Creek Contributing Watershed

Met Council 2010 Land Use Classification	Area (Acres)	Percent of Total
Agricultural	383	24%
Farmstead	11.3	0.7%
Institutional	3.0	0.2%
Single Family Detached	272	17%
Undeveloped	911	58%

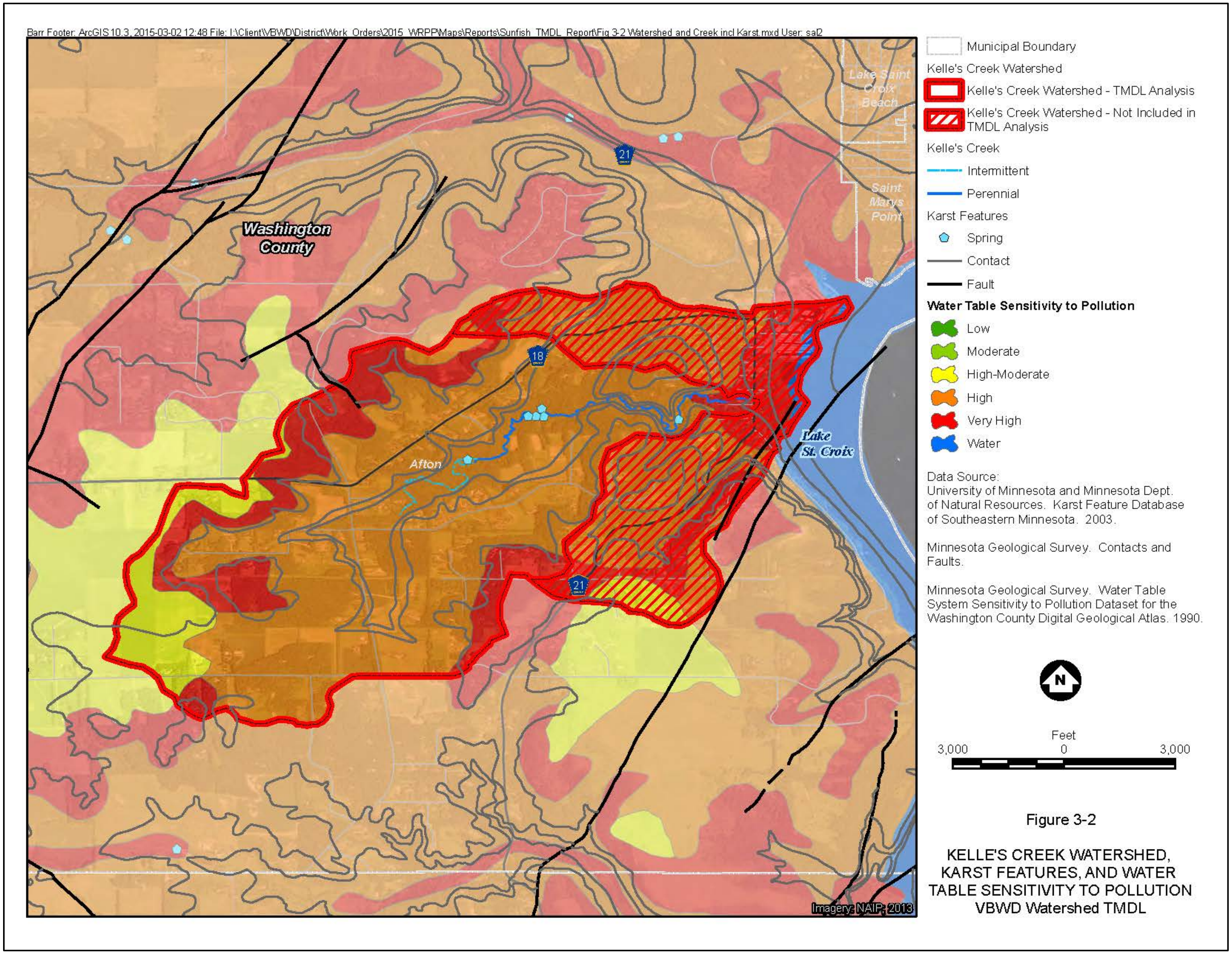

Figure 3-2 Kelle's Creek Watershed, Karst Features, and Water Table Sensitivity to Pollution

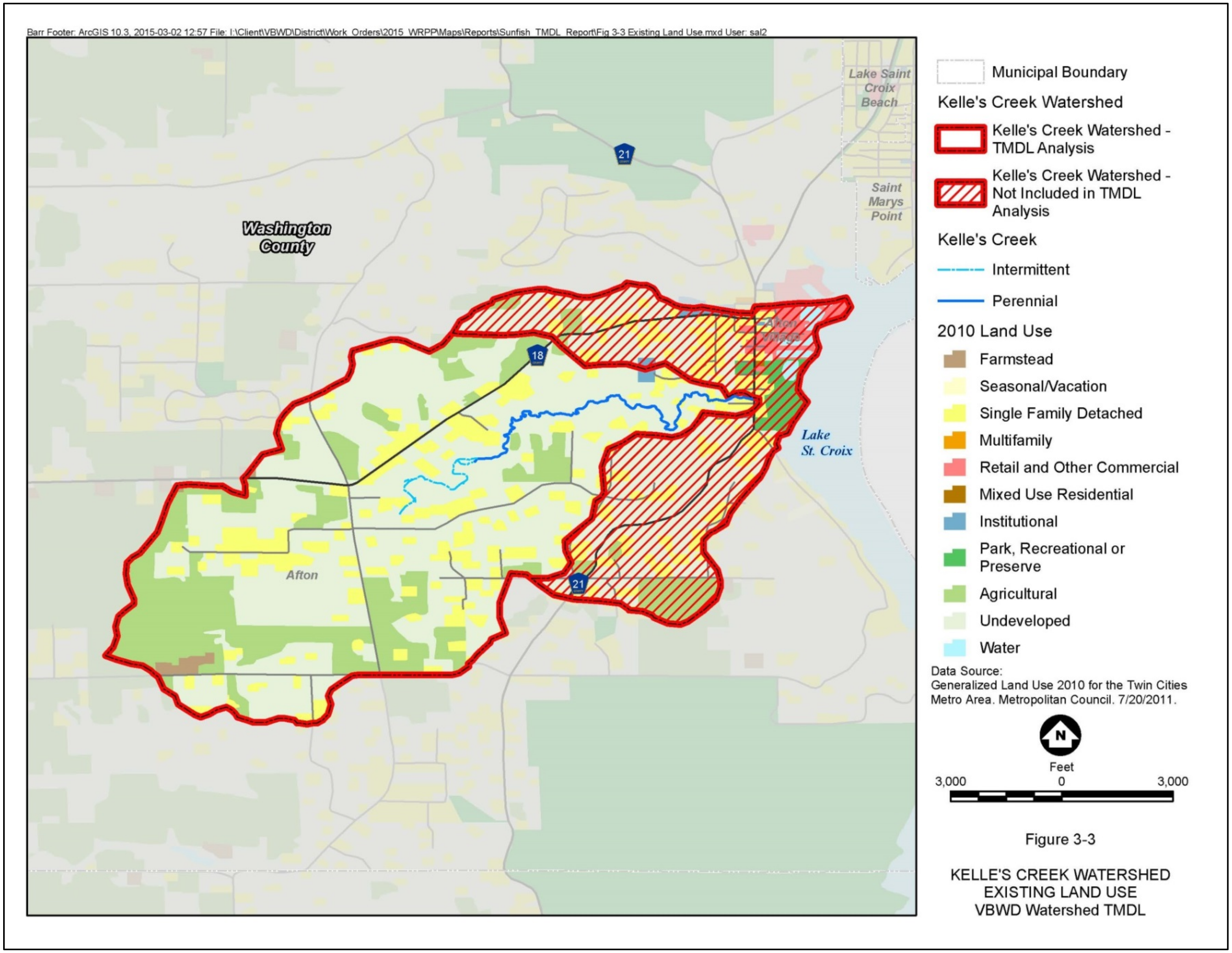

Figure 3-3 Kelle's Creek Watershed Existing Land Use

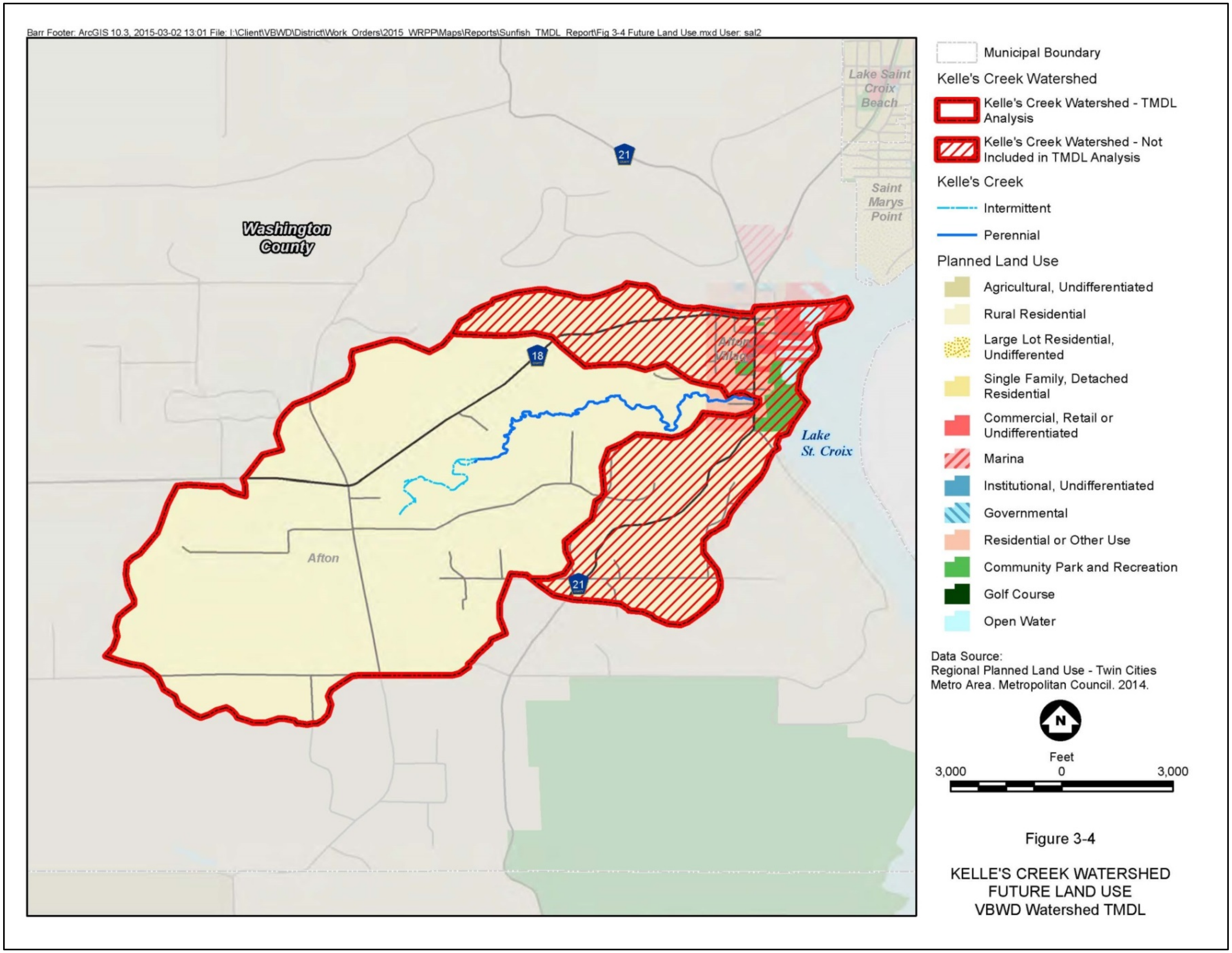

Figure 3-4 Kelle's Creek Watershed Future Land Use

3.3.2 Sunfish Lake Watershed

The Sunfish Lake Watershed is entirely located within the city of Lake Elmo. The total watershed area of Sunfish Lake is 566 acres (including the surface area of the lake); however, only 351 acres of the watershed contributes runoff to Sunfish Lake, 50 acres of which is the lake surface area. The remaining 215 acres are landlocked (approximately 38% of the total watershed), and do not contribute runoff to Sunfish Lake. The VBWD identified the landlocked (noncontributing) areas of the watershed by comparing existing storage, runoff volumes (estimated using a simple method developed by the VBWD to determine the 100-year flood levels in landlocked basins), and discharge elevations. Subwatershed divides, general flow patterns, and landlocked subwatersheds are identified on Figure 3-5. Overflow patterns for landlocked basins are indicated in Figure 3-5. Landlocked basins will overflow in the directions indicated by the arrows for flood events greater than the 100-year event. For flood events less than the 100-year event, stormwater runoff will remain within the landlocked areas.

Much of the existing land use in the Sunfish Lake Watershed is very low density residential, park land and natural open space, and limited agricultural land. The Metropolitan Council 2010 land use classifications (Metropolitan Council 2011) are summarized for the contributing watershed in Table 3-2, not including the Sunfish Lake surface area. The majority of the land use in the contributing watershed is classified as "undeveloped" (54.1%); however, most of the areas classified as "undeveloped" to the west, north, and northwest of Sunfish Lake are part of existing low density developments of single family homes and no change in land use is expected. Therefore, the future land use in the Sunfish Lake Watershed is assumed to be the same as the existing land use. Figure 3-5 shows the existing and future land use in the Sunfish Lake Watershed.

Table 3-2 Met Council 2010 Land Use Classification of Sunfish Lake Contributing Watershed

Met Council 2010 Land Use Classification	Area (Acres)	Percent of Total
Agricultural	10.8	3.6%
Farmstead	3.4	1.1%
Open Water	22.5	7.5%
Park, Recreational, or Preserve	56.5	18.8%
Single Family Attached	0.9	0.3%
Single Family Detached	44.0	14.6%
Undeveloped	162.8	54.1%

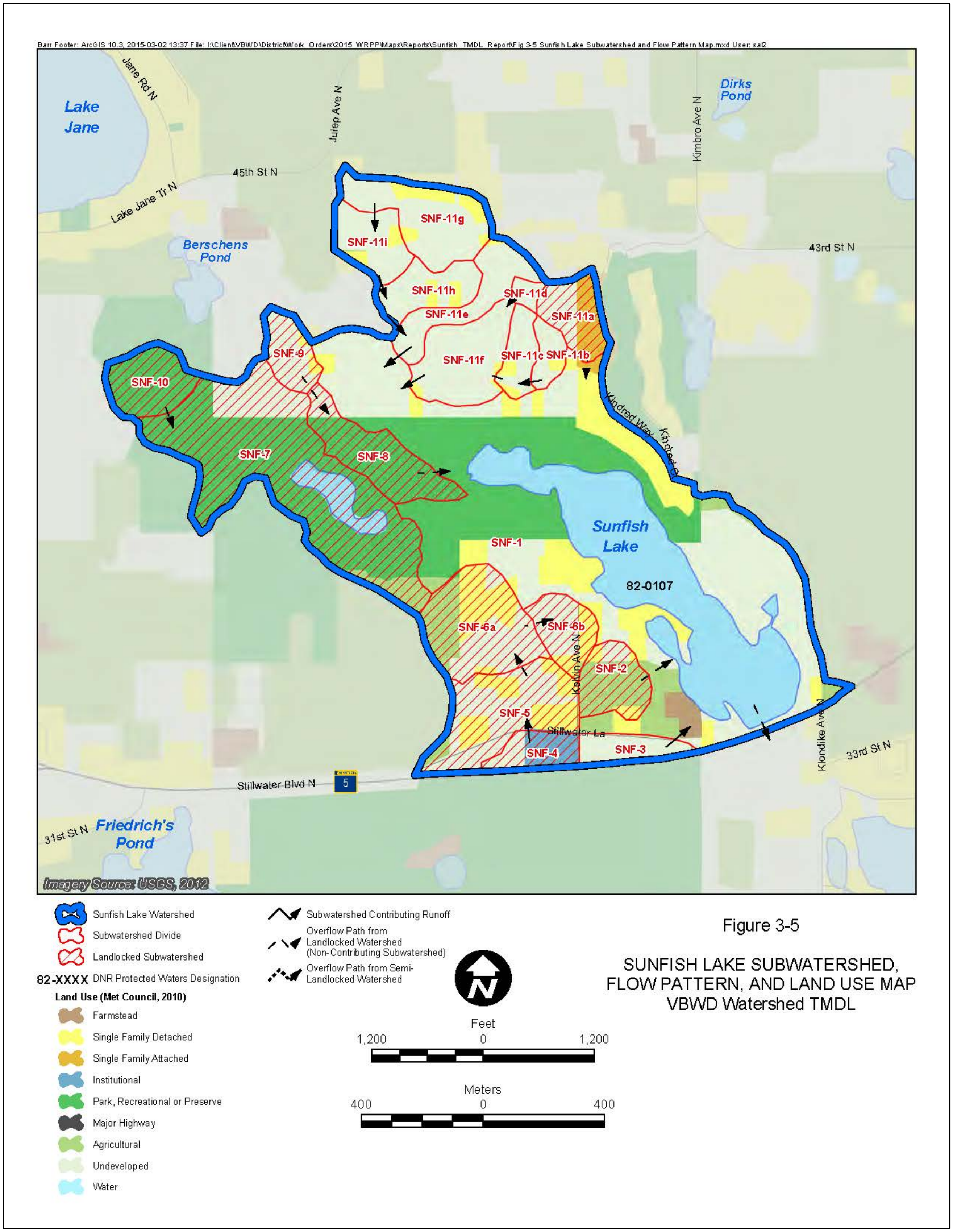

Figure 3-5 Sunfish Lake Subwatershed, Flow Pattern, and Land Use Map

3.4 Water Quality

3.4.1 Bacteria (*E. coli*)

In 2004, a continuous flow monitoring station was established on Kelle's Creek just downstream of St. Croix Trail (Station S004-462). Flow data was collected in 2004-2007, 2011 and 2013. Additionally, a continuous flow monitoring station was located on the upstream portion of the creek in 2013, although minimal flow was observed at the upstream station during the 2013 monitoring period.

Water chemistry data along with *E. coli* data was collected at the monitoring station just downstream of St. Croix Trail from 2007-2009 and 2011-2013, by the Lower St. Croix Watershed Management Organization (which dissolved as an organization in 2009), Washington Conservation District (WCD), and VBWD. In 2013, two additional water quality monitoring stations along Kelle's Creek were established. One station was located just upstream of the city of Afton and the second station was located where the perennial stream began to flow. *E. coli* grab samples were collected at each of these stations.

The stream monitoring locations with measurements of bacteria abundance within the Kelle's Creek Watershed are summarized in Table 3-3 and shown in Figure 3-6.

Table 3-3 Monitoring Locations in the Kelle's Watershed (upstream to downstream)

Station ID	Location	Dates	Num. Obs.	Range of Bacteria abundance as *E. coli* (cfu[1] per 100 mL)
S007-622	Kelle's Creek, Just SE of Afton Blvd S, Directly Upstream of Perennial Flow, 1.3 miles W of Afton, MN	2013	N/A[2]	N/A[2]
S007-623	Kelle's Creek, Just SE of Afton Blvd S, At Perennial Flow, 1.3 miles W of Afton, MN	2013	10	<1 – >2,420
S007-624	Kelle's Creek On 36th Street at Walking Bridge at Private Parking Area Near End of Road, 0.25 Miles West of Afton, MN	2013	10	14 – >2,420
S004-462	Kelle's Creek at St. Croix Trail in Afton, MN	2007 through 2013	37	28 – >2,420

[1] cfu: Colony Forming Units
[2] Station moved to S007-623 as no runoff was observed at this location during storm events.

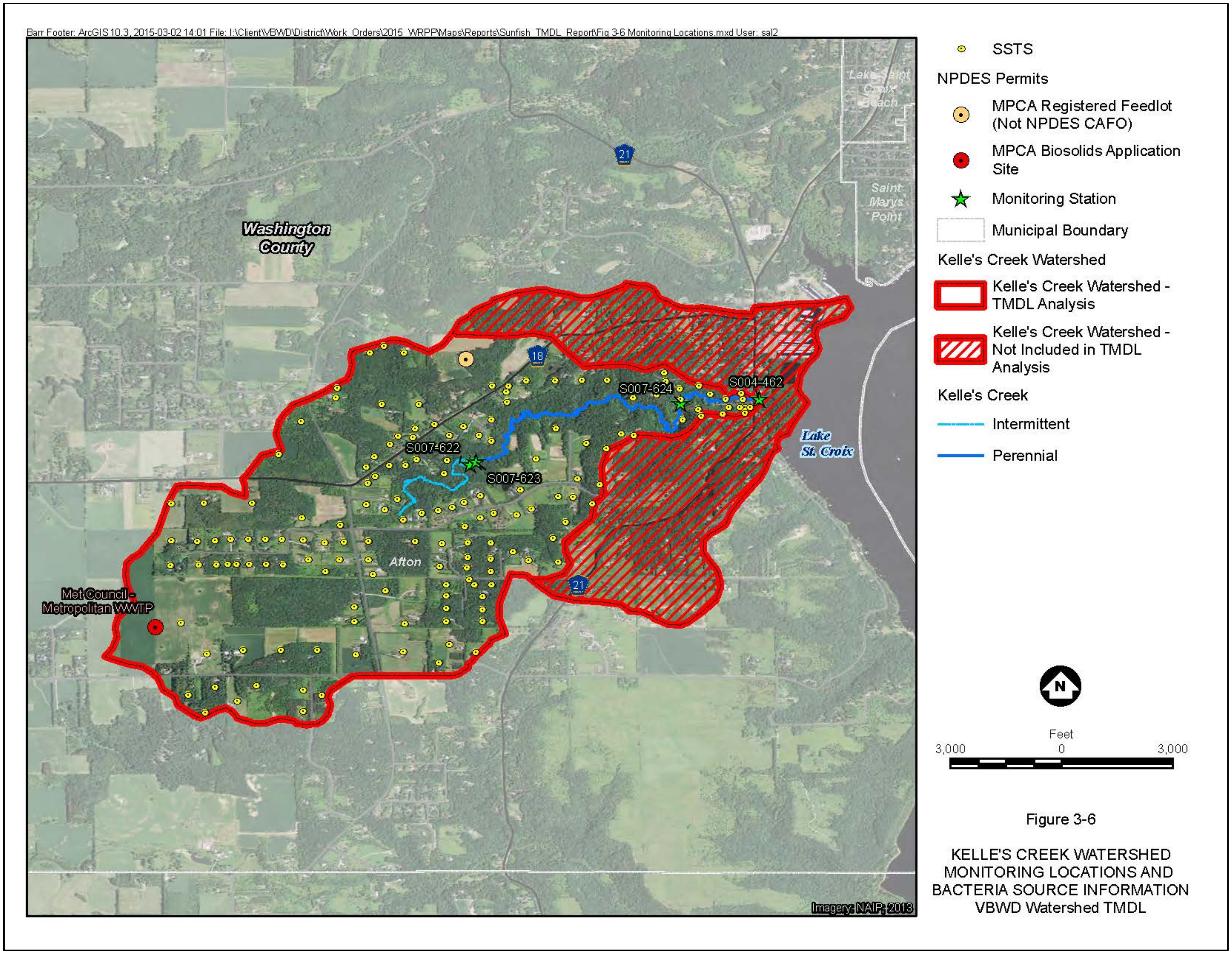

Figure 3-6 Kelle's Creek Monitoring Locations and Bacteria Source Information

3.4.1.1 Water Quality Assessment

The period of record used to determine this TMDL was May 2007 to October 2013, using the water quality data collected at the monitoring station located downstream of St. Croix Trail (Station S004-462). Table 3-4 summarizes the monthly *E. coli* data for Kelle's Creek. During the period of record, the monthly geometric mean *E. coli* abundance exceeded the chronic standard of 126 organisms per 100 mL for the months of May, June, July, August, and September (Figure 3-7).

In addition to *E. coli* levels consistently above the chronic standard, there were regular exceedances of the acute standard of 1,260 organisms per 100 mL in Kelle's Creek. For the entire data set for Station S004-462 (n = 37), 30% of the observations (n = 11) were above the acute standard.

In 2013, *E. coli* data were collected at three locations along Kelle's Creek. Figure 3-8 summarizes the monthly geometric mean for the samples collected in 2013 at each of the monitoring locations along the creek, from upstream to downstream. Elevated *E. coli* levels exceeding the MPCA chronic standard were observed at Stations S004-462 (St. Croix Trail) and S007-624 (36th Street) for all months except October. At Station S007-623 (Headwaters), *E. coli* levels in August exceeded the MPCA chronic standard.

Table 3-4 Monthly *E. coli* Summary

Month	Geometric Mean [1](cfu/100 mL)	Minimum (cfu/100 mL)	Maximum (cfu/ 100mL)	Total Number of Samples	Number of Samples Exceeding MPCA Acute Standard (1,260 cfu/100mL)	% of Sample Dates Exceeding MPCA Acute Standard
May	115	60	219	2	0	0
June	694	127	>2,420	9	3	33
July	674	201	>2,420	9	3	33
August	909	261	>2,420	9	4	44
September	251	162	365	4	0	0
October	104	28	1,986	4	1	25

[1] For *E. coli* measurements reading >2,420 given value of 2,420 for purposes of calculating geometric mean

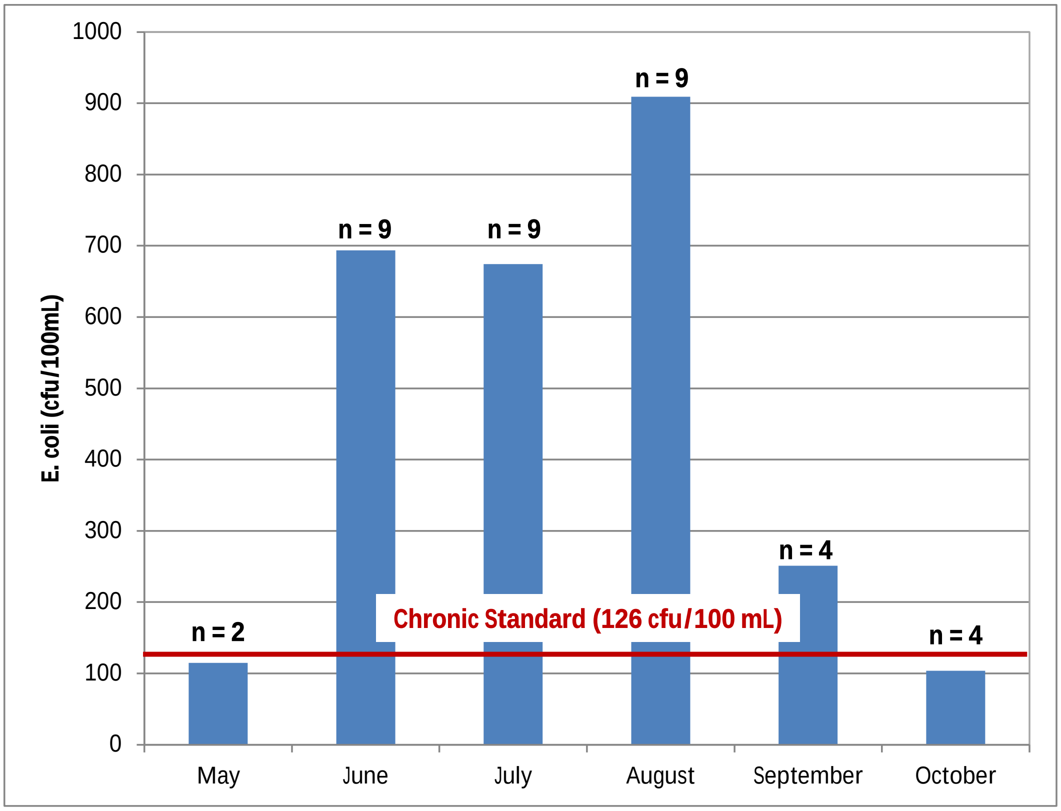

Figure 3-7 **Kelle's Creek Monthly *E. coli* Geometric Mean Summary (Station S004-462 – St. Croix Trail) from 2007-2013.**

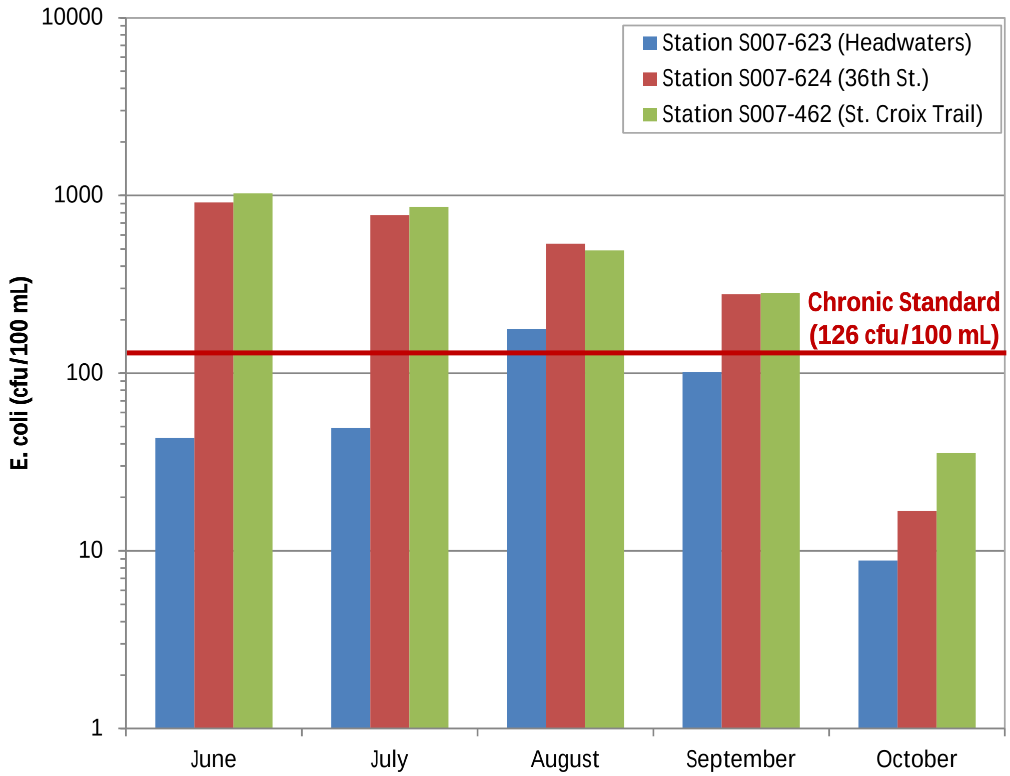

Figure 3-8 **Kelle's Creek 2013 Monthly *E. coli* Geometric Mean Summary for All Monitoring Stations**

3.4.2 Nutrients

Sunfish Lake's most recent 10 years (2003-2012) of TP, chlorophyll *a* (Chl-*a*), and Secchi disc transparency data are discussed below. For the purposes of this TMDL report, GS mean (June 1 through September 30) concentrations of TP, Chl-*a*, and Secchi disc transparency were used to evaluate the water quality in Sunfish Lake. Additionally, the summarized data reflects the surface samples (samples collected from 0-2 meters in depth). The GS is often used to evaluate lake water quality, as it is the time period encompassing the months during which the water quality is most likely to suffer due to algal growth. Figure 3-9 shows the Sunfish Lake historical GS means of TP, Chl-*a*, and Secchi disc transparency. Table 3-5 summarizes the historical water quality information compared to the MPCA shallow lake eutrophication criteria.

Table 3-5 Sunfish Lake Historical Nutrient Related Water Quality Parameters

Water Quality Parameter	MPCA Shallow Lake Eutrophication Standard	Sunfish Lake (2003-2012) Growing Season Average of the Most Recent 10-Years
Total Phosphorus (µg/L)	≤ 60	62
Chlorophyll-*a* (µg/L)	≤ 20	35
Secchi disc transparency (m)	≥ 1.0	0.7

The 2006 GS was selected as the critical period for the Sunfish Lake TMDL study, as it represented average water quality conditions for the most recent 10-year period. The 2006 GS average TP was 63 µg/L. Measurements of TP, Chl-*a*, and Secchi disc transparency that were collected in 2006 are plotted on Figure 3-10.

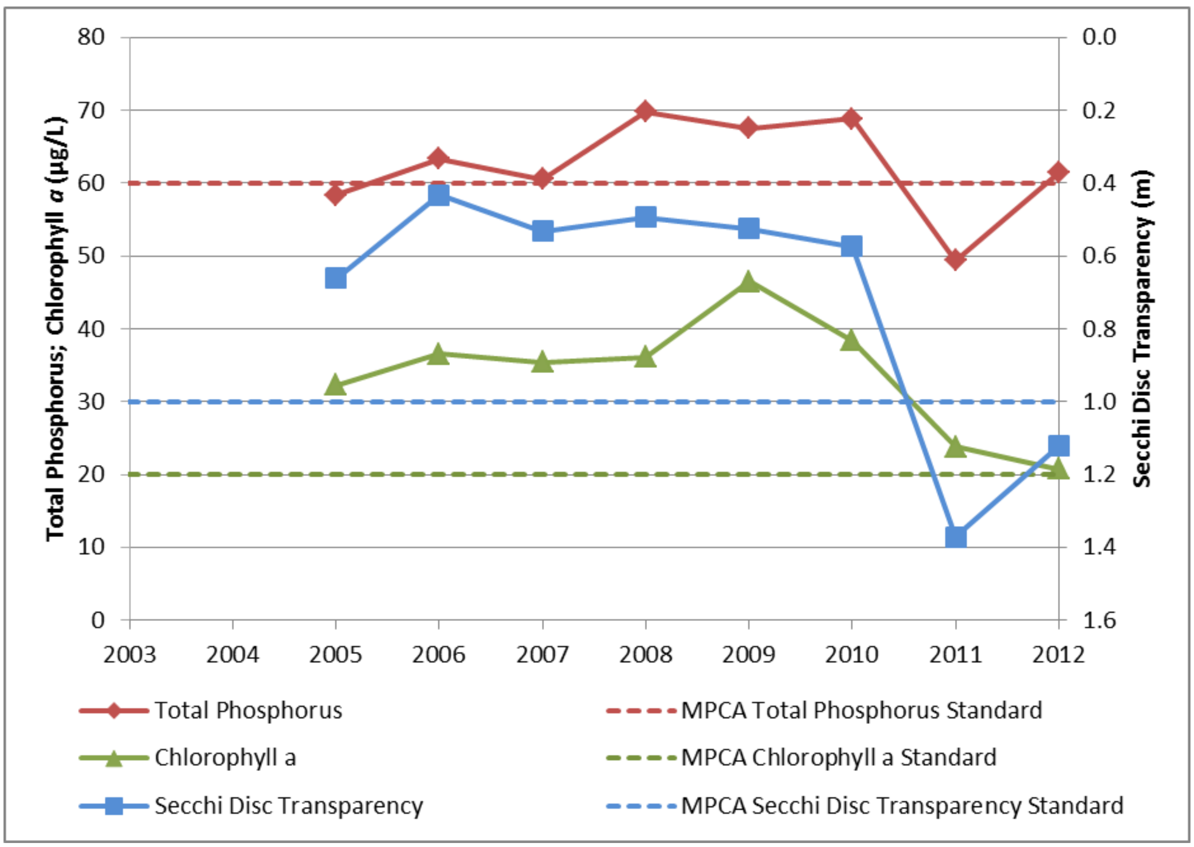

Figure 3-9 Sunfish Lake Growing Season (June-September) Averages of Water Quality Parameters, 2003-2012

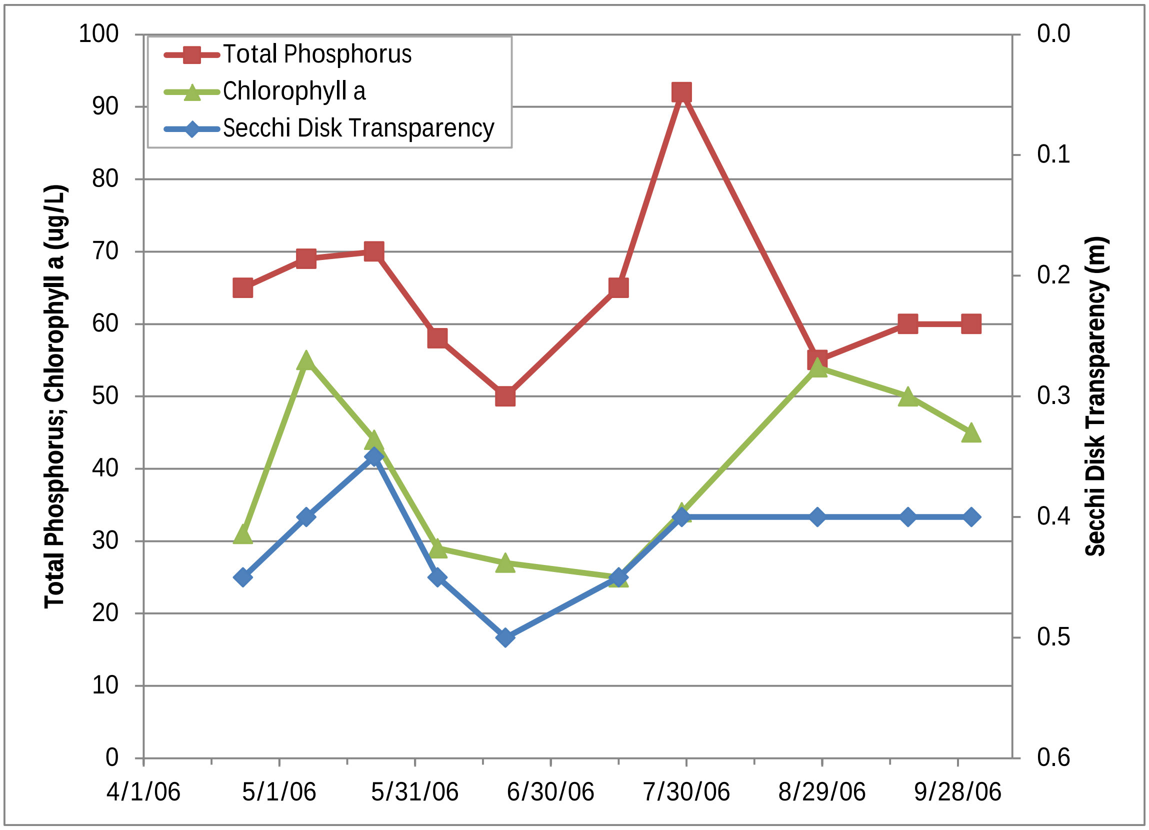

Figure 3-10 Sunfish Lake 2006 Water Quality

3.5 Pollutant Source Summary

3.5.1 Bacteria (*E. coli*)

In order to develop the linkage between watershed sources of bacteria and water quality targets, this study followed an approach that was initially developed for the Regional Total Maximum Daily Load Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Southeast Minnesota (MPCA 2002) and utilized the bacteria production estimates from the Upper Mississippi River Bacteria TMDL (EOR 2014). The bacteria production estimates used in the Upper Mississippi River Bacteria TMDL were originally modified from daily fecal coliform production rates by animal type from Metcalf and Eddy (1991).

This section provides an inventory of the sources of bacteria within the Kelle's Creek Watershed. These sources are non-point in nature; there are no known point sources or National Pollutant Discharge Elimination System (NPDES) permitted sources of bacteria within the entire tributary watershed of Kelle's Creek. The sources of bacteria in the watershed include:

- Septic systems and human waste (Section 3.5.1.1)
- Stormwater runoff and pets (Section 3.5.1.2)
- Fecal matter from livestock and grazing animals (Section 3.5.1.3)
- Manure and biosolids land application (Section 3.5.1.4)
- Fecal matter from wildlife (Section 3.5.1.5)

Figure 3-6 shows the available source information available in the Kelle's Creek Watershed.

As part of the citizen engagement process for this study and for her Master's thesis environmental history work, Leslie Thomas, a former Kelle's Creek Watershed resident, conducted a Kelle's Creek Watershed resident survey in March 2013. The survey included eight questions directly related to the Kelle's Creek bacteria impairment, in addition to many other survey questions specific to her research.

The survey was sent to approximately 300 addresses in and around the Kelle's Creek Watershed and there were 73 responses to the survey. In general, nearly 70% of survey respondents knew whether or not their property was adjacent to Kelle's Creek. And although most respondents (76%) did not know that Kelle's Creek was impaired by bacteria, most had some understanding of potential sources of bacteria to a creek.

3.5.1.1 Septic Systems and Human Waste

Human waste can be a significant source of bacteria loading to surface waters, especially during dry and low flow periods when human waste sources continue and there is little runoff to convey other sources to surface water bodies. Septic systems (SSTS) that are not properly designed or maintained can allow untreated or partially treated sewage to flow into surface waters. The Minn. R. 7080.1500 establishes compliance criteria for individual SSTSs, including the following:

- Minn. R. 7080.1500, subp. 4(A), states the SSTS "must be protective of human health and safety. A system that is not protective is considered an imminent threat to public health or safety. At a minimum, a system that is an imminent threat to public health or safety is a system with a discharge of sewage or sewage effluent to the ground surface, drainage systems, ditches, or storm water drains or directly to surface water…"
- Minn. R. 7080.1500, subp. 4(B), states the SSTS "must be protective of groundwater. At a minimum, a system that is failing to protect groundwater is a system that is a seepage pit, cesspool, drywell, leaching pit, or other pit; a system with less than the required vertical separation distance…, and a system not abandoned in accordance with part 7080.2500."
- Minn. R. 7080.1500, subp. 4(C), states the SSTS "must be operated, meet performance standards, and be managed according to its operating permit."

The SSTS that do not meet these compliance criteria are considered non-compliant.

There are no permitted surface water discharges from municipal or industrial wastewater treatment facilities (WWTF) in the Kelle's Creek Watershed.

All residential sites within the Kelle's Creek Watershed are served by SSTS. Based on SSTS data provided by the Washington County Department of Public Health and the Environment (WCDPHE), there are 160 SSTS within the entire Kelle's Creek Watershed boundary that ultimately drains to the water quality monitoring station. Additionally, the WCDPHE provided mapping of SSTS inspections and compliance. Within the area around the Kelle's Creek Watershed, there have been 28 inspections performed, and 10 SSTS were reported as non-compliant (35%). Two of the inspections were classified as imminent threat to public health and safety. The remaining eight were classified as failing to protect groundwater (WCDPHE, 2015). These numbers correspond with the estimated non-compliant SSTS percentage of 25-30% by WCDPHE staff (LeClair 2013).

Because the Afton Village is located behind a levee there is very little separation between some of the SSTS and the GW table, potentially resulting in non-compliant SSTS and contamination of adjacent water bodies. Additionally, many of the existing SSTS in Afton Village are old systems and no longer meet today's SSTS requirements.

To evaluate the condition of existing SSTS, the city of Afton has completed studies, including an Unsewered Area Needs Documentation and a Community Assessment Report (Wenck 2012). Additionally, a wastewater collection and treatment system facility plan has been developed for the city of Afton (Wenck & WSB 2013). Based on information from this study, an estimated 26 residential and zero commercial SSTS could potentially be impacting the water quality monitored on Kelle's Creek. Of the 26 SSTS, 35% or nine were estimated to be non-compliant.

All Kelle's Creek residents are served by SSTS and the survey indicated that most residents knew where their septic system was located and half of the respondents indicated that they have had their system regularly maintained. The Kelle's Creek Watershed resident survey results provided additional information on the SSTS in the watershed, including indication from four of the respondents (5% of total respondents) that they have had problems with their septic systems in the past, with issues including a broken pump, frozen drainfield, and full replacement of SSTS.

The 160 SSTS within the Kelle's Creek watershed are serving an estimated population of 381 people. Assuming a 35% non-compliance rate based on the information previously discussed, 133 people are associated with the estimated non-compliant SSTS. Also, because the Kelle's Creek Watershed has many karst features, the susceptibility to GW pollution is high.

3.5.1.2 Stormwater Runoff and Pets

Untreated urban stormwater can have bacteria concentrations as high as or higher than runoff from pastures and cropland (EPA 2001), primarily from pet waste.

For the most part, the Kelle's Creek Watershed would not be considered urban, with the land use in the watershed primarily being rural residential in the lower portions of the watershed with some areas of agricultural uses. The area of downtown Afton is the most densely populated and urban area in the entire watershed.

Since all parcels in the Kelle's Creek Watershed are served by SSTS and there are no industrial or commercial sites in the watershed, we have assumed that the number of SSTS in the Kelle's Creek Watershed (per the Washington County SSTS data) is equivalent to the number of households in the Kelle's Creek Watershed. Based on this data, there are 160 households within the Kelle's Creek Watershed. The total number of pets in the contributing watershed of Kelle's Creek was estimated from the American Veterinary Medical Association values of 0.66 cats and 0.58 dogs per household. For the 160 households in the contributing Kelle's Creek Watershed, there are an estimated 105 cats and 93 dogs. Waste from these animals is assumed to be conveyed to surface waters with equal likelihood, regardless of the location of the household within the watershed.

3.5.1.3 Livestock and Grazing Animals

In agricultural area, livestock are typically the primary source of bacteria loading, and runoff from feedlots, pastures, and cropland that has received manure application has the potential to be a significant contributor of bacteria to surface water bodies.

Although the Kelle's Creek Watershed has some agricultural uses in the uplands, the land use in the Kelle's Creek Watershed is primarily rural residential in the lower portions of the watershed. Some landowners are identified has having hobby farms that typically have a few horses and occasionally chickens on the property. The riparian areas of the creek are primarily classified as forested wetlands, with upland forests on the ravine sides and there are no livestock or grazing animals that are able to access the creek.

There is only one farm registered with the MPCA feedlot program in the Kelle's Creek Watershed and it is not an NPDES-Permitted Concentrated Animal Feeding Operation (CAFO). The information from the MPCA indicates that the farm has a total of 53 animal units (AU). One AU represents one 1,000-pound animal, the typical weight of a beef steer, stock cow, or horse. Follow-up with the landowner indicated that he typically has 20 to 30 adult cattle and 40 to 50 young calves that are sold each year (Arends 2014). The total number of equivalent AUs based on these estimates is 34 cattle (MDA 2014).

Additionally, based on the Kelle's Creek Watershed resident survey, 10 of the 73 respondents (14%) indicated that they have livestock on their property. Seven respondents (10%) indicated having horses on their property (typically from one to five horses, average of 2.4 horse per household) that graze in pastures. Three respondents (4%) indicated having chickens/poultry on their property. Two respondents had 10 chickens or less. One respondent indicated having between 5 and 50 poultry at any given time (assuming 25 chickens for loading estimates). The average number of chickens per household is approximately 13 chickens. Based on the estimate of 160 households within the Kelle's Creek Watershed, there are approximately 38 horses and 83 chickens.

Pastured livestock can deposit manure in or immediately adjacent to surface water bodies if the pastures are not separated from streams and wetlands by fencing. Livestock management practices in the Kelle's Creek Watershed is limited to horses grazing in pasture, cattle grazing in pasture, and poultry on the property without direct access to the creek. Therefore, all livestock are assumed to be in non-riparian areas (not immediately adjacent to the stream or directly contributing bacteria loads to Kelle's Creek).

3.5.1.4 Manure and Biosolids Land Application

Manure from livestock feedlots is often applied to croplands as fertilizer and/or a soil amendment either by surface application or liquid incorporation. Large swine and dairy feedlots typically collect liquid manure in containment structures and use liquid incorporation to apply the manure to cropland, while smaller feedlots typically apply manure to field surfaces where it is worked into the soil with tillage equipment.

Because there are limited numbers of livestock within the watershed, there is a limited amount of manure that is managed (e.g., land applied) within the Kelle's Creek Watershed. Again, there is only one farm registered with the MPCA in the Kelle's Creek Watershed and it is not an NPDES permitted CAFO. The cattle are typically grazing within a 30-acre pasture and the landowner has grassed filter strips in the low areas of the pasture (Arends 2014).

Additionally, based on the Kelle's Creek Watershed resident survey, for those landowners indicating having livestock (horses and chickens), the most commonly used method for managing manure is composting the manure on the property (90% of those respondents with livestock). The remaining 10% either have it hauled away or land apply it.

Application of biosolids from WWTF is performed in accordance with Minn. R. ch. 7041, Sewage Sludge Management, and is highly regulated and monitored and tracked. There are two permitted sites within the Kelle's Creek Watershed for biosolids applications. However, the Metropolitan Council WWTF currently only applies biosolids in Dakota County, not Washington County. Therefore, these two permitted sites are not sources of bacteria in the Kelle's Creek Watershed.

3.5.1.5 Wildlife

The Minnesota Department of Natural Resources (DNR) compiles population estimates for various native wildlife species at locations throughout Minnesota. The 2009 Farmland Wildlife Populations estimate (DNR 2009) indicated that average deer populations in the management units surrounding the Kelle's Creek Watershed to the north and south (as density numbers were not available for the Twin Cities Metro area in this study) were approximately 12 deer per square mile. Based on the area of the Kelle's Creek Watershed contributing to the downstream monitoring station, there are approximately 30 deer within the watershed.

Additionally, discussion with the farmer within the Kelle's Creek indicated that there are many wild turkeys within the watershed (Arends 2014). Based on 2000 wild turkey density estimates from the National Wild Turkey Federation, the density of wild turkeys in the Kelle's Creek Watershed is approximately 6-15 wild turkeys per square mile (National Wild Turkey Federation 2001). At this density, there are approximately 38 wild turkeys in the Kelle's Creek Watershed. The total number of equivalent AUs based on these estimates is 0.69 turkeys (MDA 2014).

Because there are very few open water wetlands and ponds within the Kelle's Creek Watershed, it was assumed that water fowl are not significant contributors to the bacteria loads. However, to account for other wildlife in the watershed, the total bacteria load from deer and wild turkeys was doubled to account for all other wildlife sources.

Upstream of St. Croix Trail (CSAH 21), the riparian areas of the creek are primarily classified as forested wetlands, with upland forests on the ravine sides (EOR 2007b). There are also some unfragmented tracts of forest and grassland that provide valuable habitat in the watershed. Wildlife is expected to be most concentrated in these areas, and therefore their contributions to the overall bacteria loading in the watershed will likely be transported relatively quickly into the surface water.

3.5.1.6 Loading Potential – Bacteria Available for Runoff

In the TMDL source assessment, it is not only necessary to estimate the total bacteria production by source, but it is also necessary to (1) estimate the amount of bacteria potentially available for runoff from each source, and (2) assess the potential for the bacteria to reach surface waters under wet and dry conditions. This analysis results in the partitioning of the stream load by source, based on the total load estimated to reach surface waters under the given conditions.

The data and assumptions discussed in the previous sections result in total populations corresponding to potential sources and estimates of total bacteria production. The total source population inventory for the contributing watershed is shown in Table 3-6, along with the estimated quantity of *E. coli* bacteria produced monthly. The *E. coli* bacteria production rates were based on animal type. The results of the total monthly *E. coli* produced by source type are summarized in Figure 3-11.

Table 3-6 Estimated Population and Monthly *E. coli* Production by Source

Category	Source	Animal Units or Population	*E. coli* Organisms per Unit per Month (billions of organisms)*	Total *E. coli* Organisms Available per Month (billions of organisms)
Human	Total population	381	30.0	11,430
Runoff	Cats	105	75.0	7,875
	Dogs	93	75.0	6,975
Livestock	Cattle	25	81.0	2,025
	Calves	9	81.0	729
	Poultry	83	3.9	324
	Horses	38	6.3	239
Wildlife	Deer	30	5.4	162
	Wild Turkey	38	3.9	148
	Other Wildlife			310**

* From the Upper Mississippi River Bacteria 2014 TMDL, modified from daily fecal coliform loading rates from MetCalf and Eddy (1991) and EPA (2001)

** Monthly *E. coli* production of “other wildlife” assumed to be equal to the sum *E. coli* production of deer and turkey

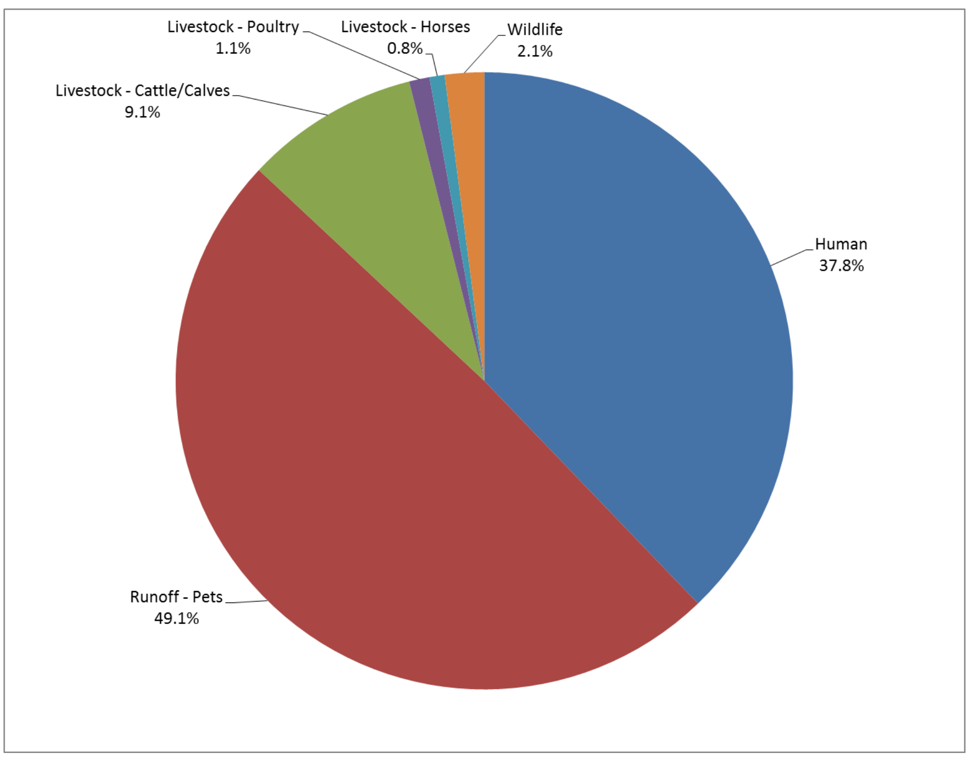

Figure 3-11 Monthly *E. coli* Production by Source

Once produced, *E. coli* bacteria is made available or applied on the land surface by several different methods, especially for livestock sources. Table 3-7 shows the fraction of bacteria generated by different sources and application types that are available to runoff into Kelle's Creek (for method used to calculate actual delivery discussed below). The assumed availability and distribution between various application methods represent the characteristics of the Kelle's Creek Watershed. The total *E. coli* produced in the watershed is divided by application method according to the assumptions in Table 3-7; the results are summarized in Figure 3-12.

Note that this analysis makes the simplifying assumption that all bacteria produced in the watershed remains in the watershed. For some sources (e.g., cattle), all bacteria produced is assumed to be available for runoff, whether via pastures or via manure applied to cropland. For some sources (e.g., humans), a portion of the bacteria produced is assumed to not be available for runoff under any circumstances, such as in adequately treated rural wastewater.

To determine the availability from inadequately treated wastewater (estimated 35% of SSTS), we utilized information from the University of Minnesota (University of Minnesota 2013). We have assumed that 100% of the bacteria associated with the systems classified as imminent threat to public health and safety (20% of non-compliant systems) would be available while for systems failing to protect groundwater (80% of non-compliant systems), 50% of the bacteria would be available.

Table 3-7 Assumed *E. coli* Availability by Application Method

Category	Application Method	Assumed Availability	Notes
Human	Adequately treated rural wastewater	79% of humans	Not available for runoff
	Inadequately treated rural wastewater	21% of humans	Assumes 60% of 35% non-compliant systems are available
Runoff	Properly managed pet waste	90% of pets	Not available for runoff
	Improperly managed pet waste	10% of pets	Available for runoff
Livestock	Riparian Livestock/Pasture (0%)	0% of cattle 0% of horses 0% of chicken/poultry	Available for Runoff
	Non-riparian Livestock/Pasture (100%)	100% of cattle 100% of horses 100% of chicken/poultry	Total 100% cattle pastured – Available for Runoff Total 100% horses pastured– Available for Runoff Total 100% of chicken pastured– Available for Runoff
Wildlife	Wildlife waste	100% of deer 100% of wild turkey	All bacteria available for runoff

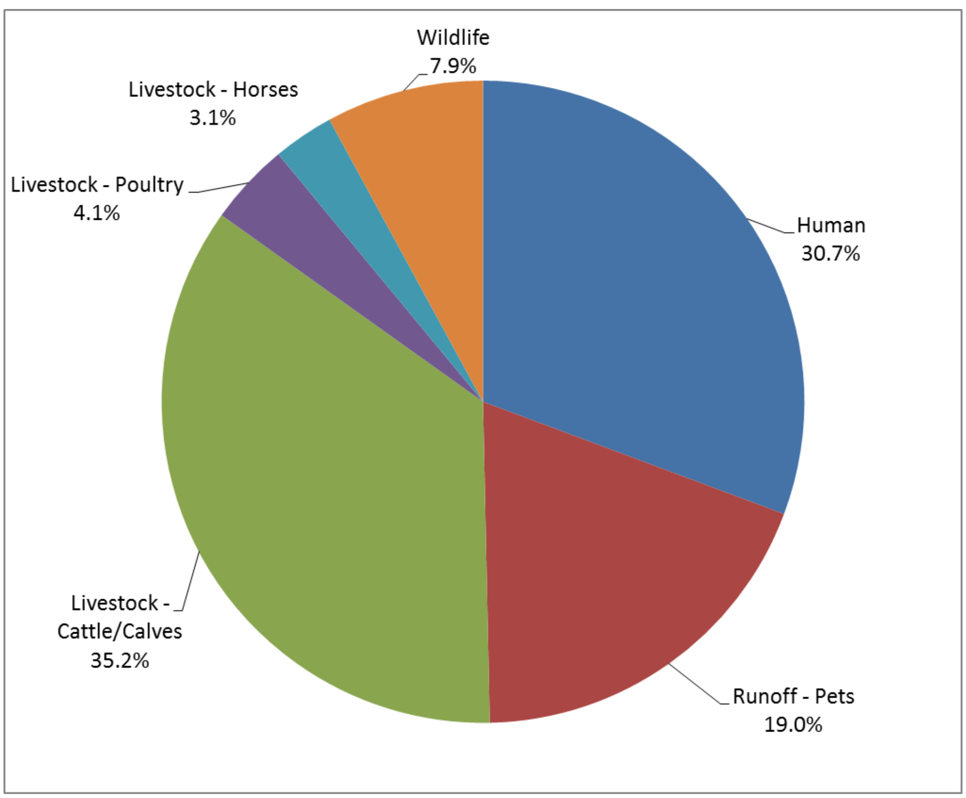

Figure 3-12 *E. coli* Availability by Application Method

Once the estimated total bacteria produced in the contributing portion of the Kelle's Creek Watershed is calculated and assigned to various application methods, final assumptions must be made on the potential for each application method to deliver bacteria to surface waters. The TMDL analyses ranked each application method according to its risk of bacteria delivery and assigned a corresponding delivery percentage (see Table 3-8). This risk of delivery to the water resource was translated into delivery percentages. A very low potential delivers 1%, low potential is 2%, moderate is 4%, high is 6% and very high is 8%. The delivery percentage represents the fraction of the total available bacteria that is assumed to be transported to Kelle's Creek for a given condition (wet or dry).

This analysis procedure reflects the conditions in the primarily agricultural and rural residential watersheds in and surrounding Kelle's Creek. The assumed dry weather application methods are inadequately treated wastewater (i.e., SSTS), livestock in non-riparian pastures, and wildlife. All application methods are assumed to contribute bacteria to the stream in wet weather.

Table 3-8 Assumed *E. coli* Delivery Potential by Application Method

Application Method	Assumed Delivery Potential*	
	Wet Conditions	**Dry Conditions**
Inadequately treated wastewater (SSTS)	Very High (8%)	Very High (8%)
Improperly managed pet waste	Moderate (4%)	None
Non-riparian pastures (100%)	Low (2%)	Very low (1%)
Wildlife	Very low (1%) for all other	Very low (1%) for all other

* Adapted from values used in MPCA (2002).

3.5.1.7 Estimated Source Load Proportions

The *E. coli* loading in the contributing Kelle's Creek Watershed was estimated by multiplying the total number of *E. coli* organisms available per month for each source by its corresponding availability and delivery potential. A comparison of sources contributing to wet weather and dry weather loading is shown in Figure 3-13 and Figure 3-14, respectively.

Loading from humans, primarily from inadequately treated wastewater, is the dominant source of bacteria to Kelle's Creek in both wet and dry weather conditions. This is due to the fact that the wastewater generated in the watershed is treated entirely by SSTS in combination with the high sensitivity of the GW to pollution due to the karst topography in the watershed.

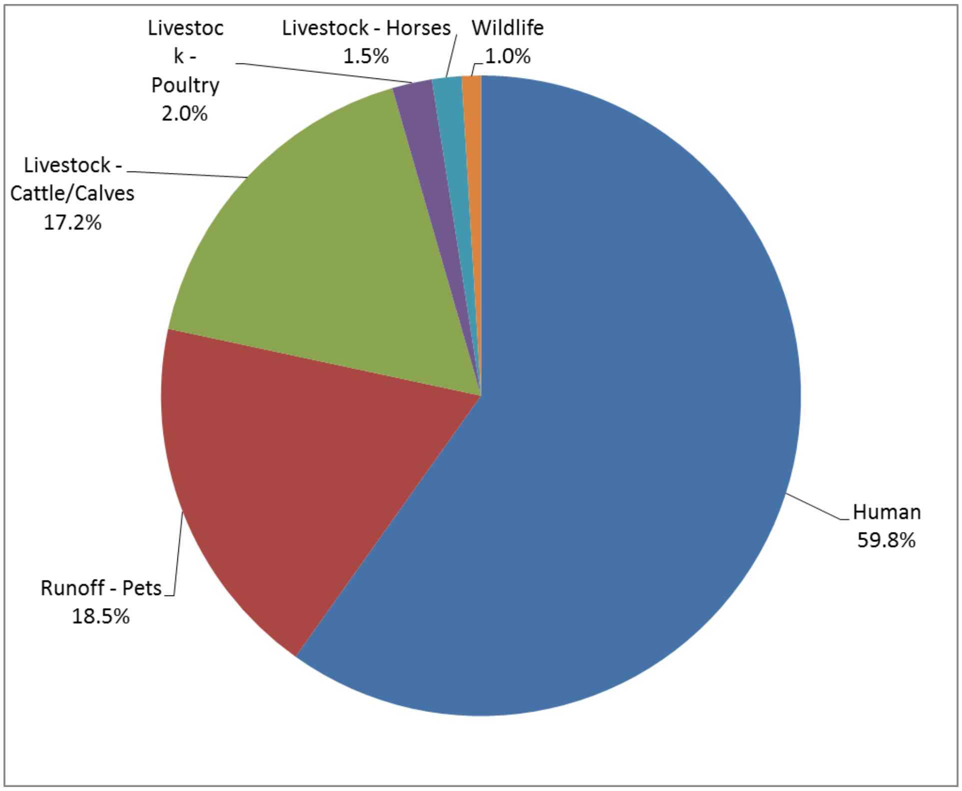

Figure 3-13 Estimated Bacteria Loading by Source for Wet Weather Conditions

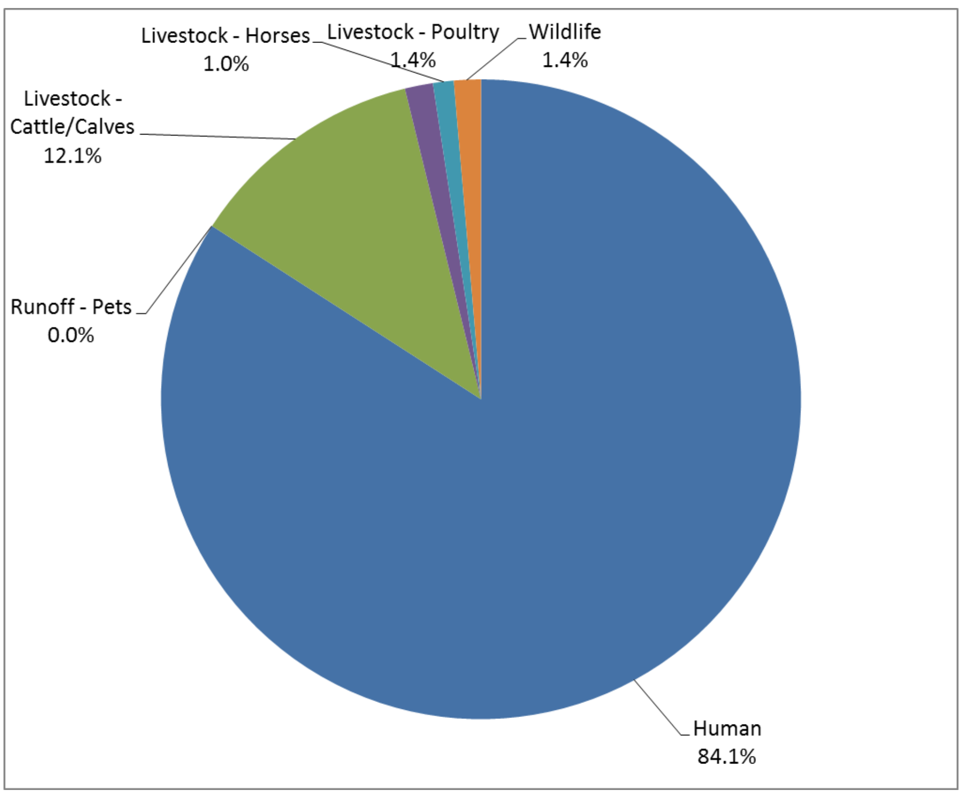

Figure 3-14 Estimated Bacteria Loading by Source for Dry Weather Conditions

3.5.2 Nutrients

One of the key components of developing a nutrient TMDL is to understand the sources of phosphorus contributing to the impairment. These sections provide a brief discussion of the potential sources of phosphorus to Sunfish Lake, although the actual quantification of these sources will be further discussed in Section 4.2 of this TMDL report. The sources of phosphorus can be classified into permitted or non-permitted sources, which will be defined and discussed in the following sections.

3.5.2.1 Permitted Sources

Permitted sources of phosphorus are those that require a National Pollution Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit (Permit). Examples of typical permitted sources of phosphorus include the following:

- Phase II Municipal Separate Storm Sewer System (MS4) General Permit - Includes coverage of municipal separate storm sewer system (MS4s) operators, which are operators of infrastructure that is used solely for stormwater and often include cities, townships, and public institutions. The goal of the MS4 general permit is to improve the water quality of urban stormwater runoff and reduce pollutants in stormwater discharges.
- Construction Stormwater NPDES/SDS General Permit – Includes coverage of any construction activities disturbing one acre of more of soil, less than one acre of soil when part of a larger development that is more than one acre, or less than one acre when the MPCA determines the activity to pose a risk to water resources. The goal of the construction stormwater permit is to control erosion and reduce the amount of sediments and other pollutants being transported by runoff from construction sites.
- Multi-Sector Industrial Stormwater NPDES/SDS General Permit – Includes coverage of stormwater discharges associated with a variety of industrial activities. The goal is to reduce the amount of pollution that enters surface and ground water from industrial facilities in the form of stormwater runoff.
- NPDES/SDS Permit – Includes coverage of facilities that discharge treated wastewater to surface or ground water of the state. The goal of the permit is to establish minimum effluent limits for a variety of constituents that protect the water quality and designated uses of waters of the state.

3.5.2.2 Non-Permitted Sources

Non-permitted sources of phosphorus are those that are not regulated by the NPDES/SDS program. For many lakes, especially shallow lakes, these sources can be significant portion of the TP load to the lake and can be a major player in impaired waters. The following are examples of the typical non-permitted sources of phosphorus:

- Atmospheric Deposition – Phosphorus can be deposited directly on the surface of the lake during precipitation events and as dry deposition of particles in between events (e.g., particles suspended by wind that settle out).
- Watershed Loading – Phosphorus loads from runoff from rural and/or urban portions of a watershed that are not regulated by an NPDES/SDS MS4 permit and may also include discharges from upstream lakes (that may or may not be impaired/have an approved TMDL).

- Internal Sources – There are a variety of potential sources of phosphorus that can come from within the lake. Examples include release of phosphorus bound to lake bottom sediments during anoxic conditions, the senescence of certain aquatic vegetation (e.g., curlyleaf pondweed) during the GS, the activity of benthivorous fish such as carp, suspension of bottom sediments due to wind and/or boat traffic, and GW interaction.
- Non-compliant SSTS – In rural areas not served by sanitary sewer systems, non-compliant SSTS on lakeshore properties and in other locations in the watershed can contribute to nutrient impairments.

4 TMDL Development

The TMDL is defined by the loading capacity for a given pollutant which is distributed among its components as follows (EPA 1999):

TMDL = WLA + LA + MOS + Reserve Capacity

Where:

WLA	=	Wasteload Allocation to Point (Permitted) Sources
LA	=	Load Allocation to Nonpoint (Non-Permitted) Sources
MOS	=	Margin of Safety
Reserve Capacity	=	Load set aside for future allocations from growth or changes

4.1 Bacteria (*E. coli*)

The TMDL for Kelle's Creek was developed using the load duration approach (MPCA 2009a), as described in the following sections.

4.1.1 Flow Duration Curve

The applicable water quality standard for bacteria applies to the months of April through October. Therefore, a flow duration curve was used in the development of this TMDL. The flow duration curve was developed by calculating the average daily flow in Kelle's Creek for the months of April through October and ranking the resulting values from highest to lowest. Flow measurements were collected in Kelle's Creek for the periods of 2004-2007 and 2011-2013 at St. Croix Trail (station S004-462). The flow-duration curve for Kelle's Creek shown in Figure 4-1 depicts the percentage of time that the average daily flow in any given month between April and October exceeds a particular value.

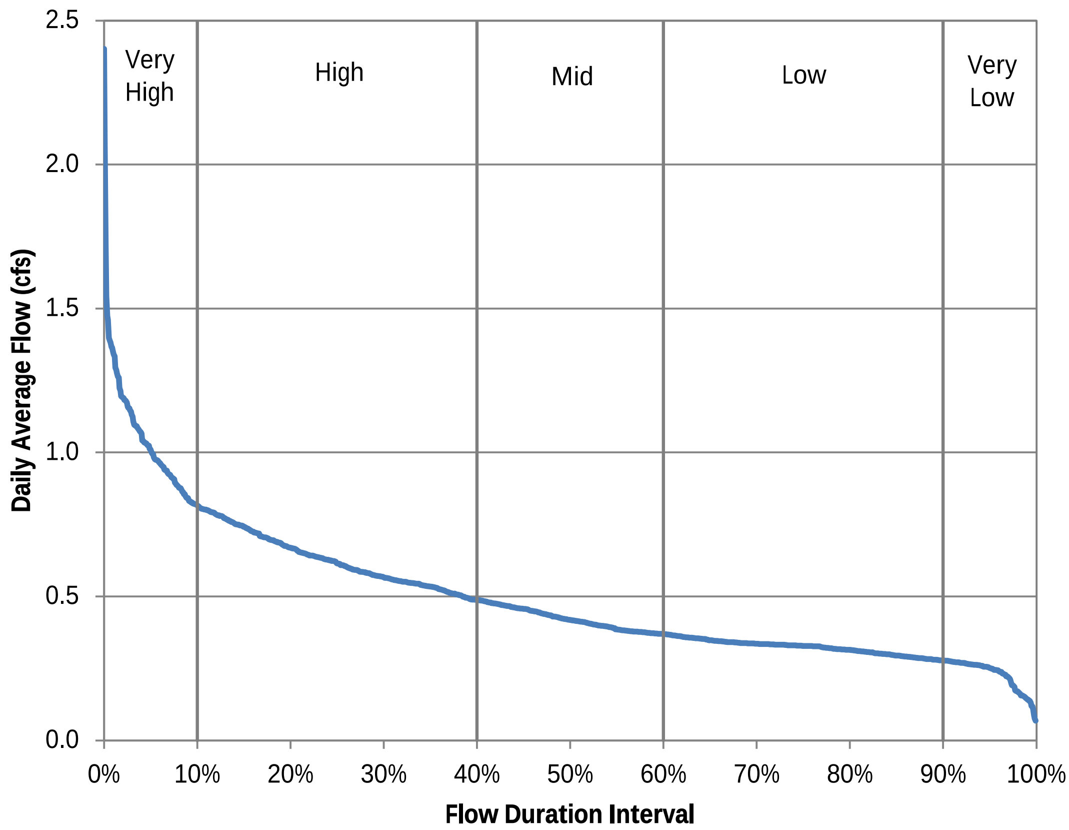

Figure 4-1 Flow Duration Curve for Kelle's Creek

4.1.2 Load Duration Curve

Similar to the flow duration curve, the load duration curve relates bacteria loading at a given flow to how often that flow value is exceeded in the stream. The load duration curve is developed by calculating the total bacteria loading (in terms of billions of organisms per day) associated with a given observation by multiplying the observed bacteria abundance by the flow. Observed average daily flow (in units of cubic feet per second) is multiplied by the corresponding observed *E. coli* abundance measured on the same day (in units of organisms per 100 mL). Conversion factors are used to convert units for water volume (from 100 mL to cubic feet) and time (from seconds to days). The resulting loading is expressed in terms of organisms per day. The resulting bacteria load is then plotted relative to the percentage of time that the daily average flow exceeds the observed flow.

Figure 4-2 shows the load duration curve developed from observations of bacteria abundance (expressed in terms of *E. coli*) for Kelle's Creek at St. Croix Trail (station ID S007-462) along with the load duration curves for the chronic *E. coli* water quality standards. Also shown on Figure 4-2 are the monthly geometric means for very high, high, mid, and low flow conditions. Actual *E. coli* monitoring data were not collected during very low flow conditions.

Figure 4-2 demonstrates that *E. coli* loading in Kelle's Creek is typically above the loading permitted by the chronic water quality standard of 126 organisms per 100 mL. For observed flow duration intervals (high, mid, and low conditions), the geometric means of the observed *E. coli* loading are typically above the loading permitted by the MPCA water quality standard.

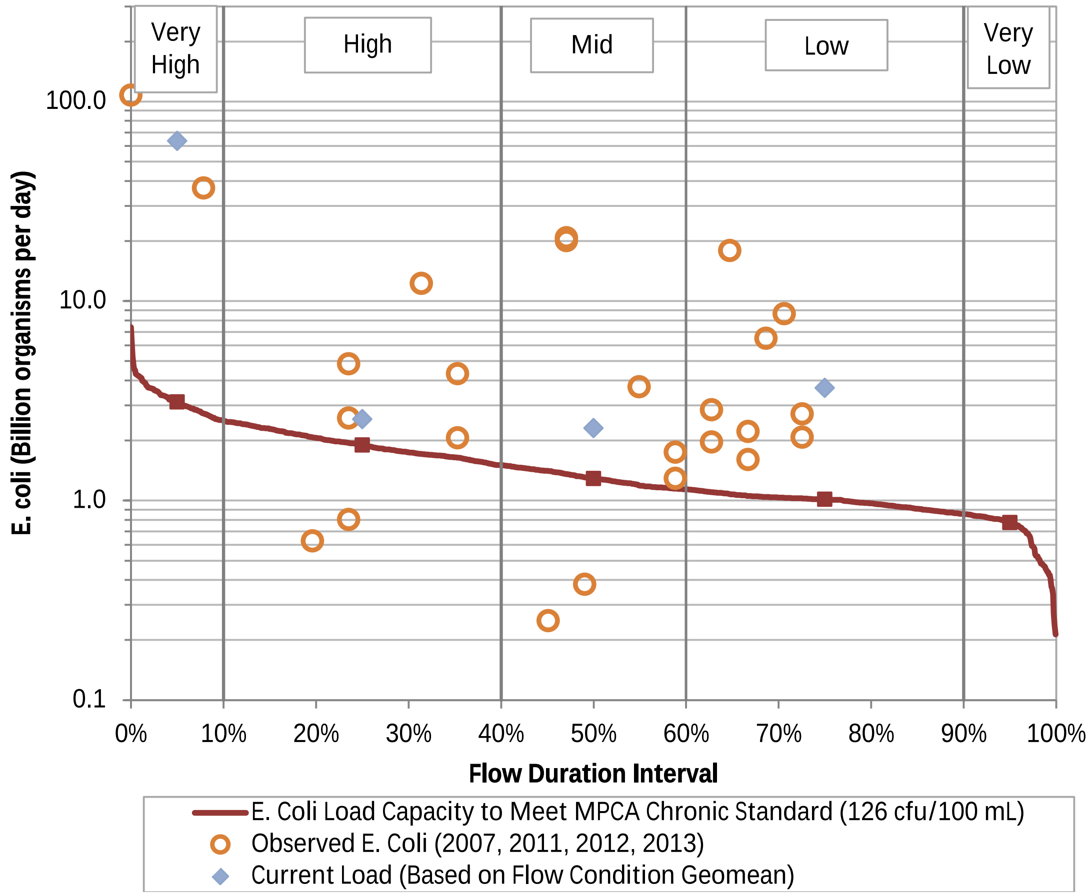

Figure 4-2 Kelle's Creek *E. coli* Load Duration Data

4.1.3 Loading Capacity

As shown in the source assessment, bacterial loading to Kelle's Creek is entirely from non-permitted sources. The allowable bacteria load is dependent upon flow conditions, and therefore is dynamic. The TMDL is expressed in terms of the total daily loading capacity (TDLC) for the various flow regimes. The focus of this analysis is on the "chronic" *E. coli* standard of 126 organisms per 100 mL (applied to the monthly geometric mean) rather than the "acute" standard of 1,260 organisms per 100 mL. Even though the focus of the TMDL calculations were on the chronic *E. coli* standard, both the chronic and acute standards apply. It is assumed that achieving the necessary reductions to meet the chronic standard will also reduce exceedances of the acute standard to within acceptable limits.

Table 4-1 shows the TMDL in terms of the total load capacity for the chronic water quality standard. The load-duration curve was developed by multiplying the flow-duration intervals from Figure 4-1 by the *E. coli* chronic water quality standard (126 organisms per 100 mL), using the calculation method described above for the observed data. To develop the TMDL equation, the midpoint daily total loading capacity for each of the five flow intervals was selected.

4.1.4 Wasteload Allocation Methodology

Since there are no NPDES/SDS permitted discharges in the Kelle's Creek Watershed, there are no WLA established in the TMDL.

4.1.5 Load Allocation Methodology

The LA, which includes all non-permitted pollution sources that are not subject to NPDES Permit requirements and are the only sources of bacteria to Kelle's Creek, was established by subtracting the MOS from the load capacity. The LA includes loads from watershed runoff as well as non-compliant SSTS, based on 2014 data from Washington County.

4.1.6 Margin of Safety

A reasonable MOS is necessary in order to account for natural variability and uncertainty in the effect that the calculated LAs will have on observed water quality. The MOS can be defined either explicitly, or implicitly, through the use of conservative assumptions. In this TMDL study, an explicit 10% MOS was applied, whereby 10% of the loading capacity for each flow regime was subtracted before WLAs and LAs were calculated. A 10% MOS was considered to be appropriate because the load duration curve minimizes uncertainties that can arise through other approaches. Load duration curves are simply a function of average daily flow multiplied by numerical water quality standards.

4.1.7 Seasonal Variation

Seasonal variation is accounted for by the use of a load duration curve to set TMDLs over seasonal flow regimes. The in-stream data used for the source assessment and the calculation of required load reductions represents observations across the range of seasonal and annual flow variation and loading conditions. Because the *E. coli* water quality standard only applies from April 1 through October 31, flow and loading data for the winter months were excluded from this analysis. Because several years of flow and bacteria monitoring data were collected and utilized in this analysis, the TMDL accounts for both seasonal and annual variations.

4.1.8 TMDL Summary

Table 4-1 presents the TDLC for Kelle's Creek, expressed as billion organisms per day of *E. coli* along with the WLA and LA for the creek. Also summarized in this table are the required bacteria reductions which were determined by comparing measured *E. coli* data with the total daily load capacity the TMDL for Kelle's Creek.

Table 4-1 Kelle's Creek TMDL Summary

	Flow Zone				
	Very High	High	Mid	Low	Very Low
	billion organisms per day (b-org/day)				
TOTAL DAILY LOADING CAPACITY	3.12	1.89	1.29	1.01	0.77
Wasteload Allocation*	--	--	--	--	--
Load Allocation	2.81	1.70	1.16	0.91	0.69
Margin of Safety (10%)	0.31	0.19	0.13	0.10	0.08
Estimated Reductions Based on Daily Loadings					
Existing Load	63.08	2.55	2.30	3.65	--
Required Load Reduction	60.27	0.85	1.14	2.74	--
Required Load Reduction (%)	96%	33%	50%	75%	

* There are no permitted point discharges from industries, municipalities, wastewater treatment plants, or individually permitted sources within the Kelle's Creek Watershed.

4.2 Nutrients

To establish the Sunfish Lake load capacity and TMDL, the 2006 water quality conditions were used as it is fairly reflective of the average water quality in the past decade and reflects the baseline conditions.

4.2.1 Loading Capacity Methodology

The following section outlines the water quality modeling efforts performed as part of the establishment of the Sunfish Lake TMDL and summarizes the results for 2006. Table 4-2 summarizes the precipitation during the water year and GS along with the GS average TP concentration in Sunfish Lake.

Table 4-2 Summary of Sunfish Lake 2006 Water Quality and Precipitation Conditions

Year	Water Year Precipitation (inches)	Growing Season Precipitation (inches)	Growing Season Average Total Phosphorus Concentration (µg/L)
2006	32.0	13.4	63

Water quality modeling provided the means to estimate the TP sources to Sunfish Lake and estimate the effects on lake water quality. Water quality modeling was a two-fold effort, involving:

- A stormwater runoff model (P8 Urban Catchment Model; IEP, Inc. 1990) that estimated the water and TP loads from the lake's tributary watershed; and
- An in-lake mass balance model that took the water and TP loads from the lake's external and internal sources, and generated the resultant lake TP concentration.

The P8 (Program for Predicting Polluting Particle Passage through Pits, Puddles and Ponds) Urban Catchment Model and the in-lake mass balance model are described in more detail below.

4.2.1.1 Watershed Loading (P8 Modeling)

The P8 Urban Catchment (computer) Model (Version 3.4) was used to estimate watershed runoff and TP loads from Sunfish Lake's Watershed. The model and its supporting information can be downloaded from the internet at http://wwwalker.net/p8/.

P8 is a useful diagnostic tool for evaluating and designing watershed improvements and BMPs because it can estimate the treatment effect of several different kinds of potential BMPs. P8 tracks stormwater runoff as it carries phosphorus across watersheds and incorporates the treatment effect of detention ponds, infiltration basins, flow splitters, etc. on the TP loads that ultimately reach downstream water bodies. P8 accounts for phosphorus attached to a range of particulate sizes, each with their own settling velocity, tracking their removal by treatment features accordingly.

The key inputs to the P8 model are based on the each subwatershed's total area, the fraction of each subwatershed that is directly-connected imperviousness and depression storage, as well as the composite pervious area curve number (representing both pervious and unconnected impervious areas). Directly-connected impervious areas create runoff that is hydraulically connected to the drainage systems, while runoff that drains from impervious surfaces to pervious surfaces is not considered directly-connected. The P8 model also requires climate data (hourly precipitation and daily average temperature), treatment device configurations information (outlets, storage volumes, seepage rates, etc.) and pollutant loading parameters to estimate pollutants in runoff and removal of those pollutants by various treatment devices.

The P8 model used in this TMDL study was developed as part of this study, and reflects the natural wetlands and other stormwater management practices constructed as part of the watershed development. Noncontributing areas of the watershed, as identified by the VBWD, were not included in the P8 model. As such, only the areas of the Sunfish Lake Watershed that are considered contributing were included in the P8 model and used to generated water and phosphorus loads from the watershed.

In this study, P8 was used to generate a range of water and phosphorus loadings from the lake's watershed during the critical water quality period. Table 4-3 summarizes the watershed water and phosphorus loads as generated by the P8 model, as well as the event average TP concentration.

Table 4-3 Summary of Sunfish Lake 2006 P8 Predicted Watershed Water and Phosphorus Loads

Year	Water Year Water Load (ac-ft)	Growing Season Water Load (ac-ft)	Water Year Total Phosphorus Load (lbs)	Growing Season Total Phosphorus Load (lbs)	Water Year Average Event Total Phosphorus Concentration (µg/L)	Growing Season Average Event Total Phosphorus Concentration (µg/L)
2006	37	7	36.5	6.1	365	321

A detailed discussion about the P8 modeling used for this study along with the estimated P8 loadings to the lake for each precipitation event is located in Appendix A.

4.2.1.2 Upstream Lakes

There are no lakes upstream of Sunfish Lake.

4.2.1.3 Atmospheric Deposition

Atmospheric deposition of phosphorus directly to the lake surface was quantified based on the estimated lake surface area throughout the year (determined by the water balance model) and a deposition rate of 0.2615 kg/ha/yr (0.000639 lb/ac/d), a rate established in the Detailed Assessment of Phosphorus Sources to Minnesota Watersheds (Barr 2005c).

Table 4-4 Summary of 2006 Estimated Atmospheric Deposition Phosphorus Loads on the Surface of Sunfish Lake

Year	Water Year Total Phosphorus Load (lbs)	Growing Season Total Phosphorus Load (lbs)
2006	15.7	5.6

4.2.1.4 Sediment Release

The net internal loading of phosphorus to Sunfish Lake was calculated by deduction, using the difference between the predicted water quality using the in-lake mass balance model and the observed water quality data after all other phosphorus inputs to and losses from Sunfish Lake were estimated (see Section 4.2.1.10, for additional details). To verify that the predicted internal load is reasonable, it was checked using available sediment data from Sunfish Lake. Sediment phosphorus data are discussed below.

Four sediment cores were collected from Sunfish Lake in November 2006 as part of a previous study conducted by the VBWD (Barr 2007 (draft)). Sediment cores were analyzed for various phosphorus fractions, including mobile phosphorus and organic phosphorus fractions (Pilgrim et al. 2007). The mobile-phosphorus fraction includes loosely-sorbed phosphorus and iron-bound phosphorous, which are the portions of the sediment phosphorus pool that can most readily be released back into the water column as soluble phosphorus. The iron-phosphorus fraction is insoluble as long as the iron remains oxidized, but can become soluble again if the iron becomes reduced under anoxic conditions (i.e., absence of oxygen). The potential sediment phosphorus release rates (RR) were estimated by comparing concentrations of sediment phosphorus fractions to relationships developed by Pilgrim et al. (Pilgrim et al. 2007). The estimated mobile phosphorus RR from the sediments ranged from 0.6 – 1.2 mg/m^2/day, with a lake wide average RR of 1.0 mg/m^2/day.

Lake sediments often become anoxic in summer months, and phosphorus that was previously bound to iron in the sediment becomes soluble and is released back into the water column. This newly released phosphorus is in the form of soluble reactive phosphorus, and is readily available for uptake and utilization by algae. Sunfish Lake is a shallow, polymictic lake, meaning the lake does not experience strong thermal stratification and will mix multiple times during the GS. However, review of dissolved oxygen levels collected along the profile of the lake during various years suggests that the sediment-water interface may experience anoxic conditions intermittently. As such, enough phosphorus can still be released from sediment to impact the relatively small volume of a shallow lake.

In addition to release of mobile phosphorus from sediment due to anoxic conditions, decomposition of dead plankton and organic matter in the sediment may also contribute to internal loading of phosphorus. Concentrations of organic phosphorus in Sunfish Lake sediment were approximately 0.026 mg/cm^3 on average in the top 10 cm of sediment, and generally 4-5 times higher than mobile phosphorus concentrations.

Table 4-5 summarizes the estimated sediment RRs over the average lake surface area during the GS used in the in-lake mass balance model. The estimated magnitude of phosphorus loads due to sediment release aligns with the estimated anoxic phosphorus RRs based on the sediment core data collected for Sunfish Lake.

Table 4-5 Summary of 2006 Estimated Growing Season Sediment Phosphorus Release Rates and Load

Year	Sediment Core Estimated Release Range (Average) (mg/m^2/d)	Estimated Growing Season Sediment Release Rate (mg/m^2/d)	Estimated Total Growing Season Phosphorus Load From Sediments (lbs)
2006	0.6 – 1.2 (1.0)	0.8	38.0

4.2.1.5 Aquatic Vegetation

The VBWD has conducted qualitative macrophyte surveys on Sunfish Lake in 1997, 2002, 2007-2011. These surveys indicate the presence of curlyleaf pondweed (*Potamogeton crispus*), a non-native submerged aquatic macrophyte. Because curlyleaf pondweed dies back in the middle of summer, it likely contributes to the GS internal phosphorus loading in the lake as it senesces. The decaying plant matter will also consume oxygen, potentially exacerbating anoxic conditions at the sediment-water interface. Estimates of phosphorus loading due to the dieback of curlyleaf pondweed were based on the coverage and density of curlyleaf pondweed in Sunfish Lake (as observed in the qualitative macrophyte surveys) and information presented in a study completed on Half Moon Lake in Wisconsin (James et al. 2001).

Additionally, coontail (*Ceratophyllum demersum*) is present in Sunfish Lake. Because this macrophyte grows suspended in the water column and does not root in the sediment, it directly uptakes phosphorus from the water column and can impact the observed phosphorus concentrations. Based on the estimated areal coverage and relative density estimates from the early and late summer surveys, the amount of TP uptake by coontail was estimated based on the coverage and density from the qualitative macrophyte surveys. These densities were associated with an amount of biomass determined from data from multiple lakes in the Twin Cities (Newman 2004) and average daily phosphorus uptake information (Lombardo and Cooke 2003).

Table 4-6 summarizes the estimated phosphorus load due to the die-back of curlyleaf pondweed and the estimated phosphorus uptake by coontail.

Table 4-6 Summary of 2006 Estimated Growing Season Curlyleaf Pondweed Phosphorus Load and Phosphorus Uptake by Coontail

Year	Estimated Curlyleaf Pondweed Total Phosphorus Load (lbs)	Estimated Total Phosphorus Uptake by Coontail (lbs)
2006	5.2	9.0

4.2.1.6 Fishery

The DNR has not performed fishery surveys in Sunfish Lake. Therefore the impact of the fishery on water quality was not quantified. However, those attending public meetings regarding Sunfish Lake indicated concern about recent fish kills in the lake, indicating two fish kills in the past decade (Kietpas 2013). Additionally, the VBWD has received anecdotal comments from Sunfish Lake residents in the past that there are goldfish present in the lake.

4.2.1.7 Non-compliant SSTS

Phosphorus contributions were estimated for non-compliant SSTS in the Sunfish Lake Watershed. It was determined that 18 homes with an SSTS were located within the direct contributing watershed of Sunfish Lake. The following assumptions were used to estimate the TP contributions from those homes:

- We assumed that 10% of the 18 SSTS within the Sunfish Lake direct watershed are non-compliant and contribute phosphorus loads to Sunfish Lake. The 10% rate of noncompliance was selected with consideration of the potential risk to shallow GW that might reach the lake, and typical rates of SSTS noncompliance. Estimated septic system noncompliance rates in Washington County range is 3-12% (Washington County 2014a). However, noncompliance rates as high as 25-30% have been observed in southern portions of the county (LeClair 2013).
- 2.76 people per household, based on population density information for the St. Croix River watershed (Barr 2004).
- Phosphorus loading rate of 1.946 lbs of phosphorus per person per year (Barr 2004)

Using the above assumptions, it was estimated that non-compliant SSTS contribute approximately 3.2 lbs of phosphorus per GS to Sunfish Lake.

4.2.1.8 Groundwater Interaction

Sunfish Lake is classified as a GW flow-through lake in the *Integrating GW and Surface Water Management Southern Washington County* (Barr Engineering 2005b). The daily water balance model and observed lake level data were used to estimate the GW exchange in Sunfish Lake. A concentration of 25 µg/L was applied to any estimated inflows of GW into Sunfish Lake (USGS 2005). For GW estimated to be leaving Sunfish Lake, the observed phosphorus concentration in the lake during that period was applied.

Table 4-7 and Table 4-8 summarize the estimated GW inflow to and outflow from Sunfish Lake, respectively.

Table 4-7 Summary of 2006 Estimated Growing Season and Water Year Groundwater Inflow into Sunfish Lake

Year	Water Year Groundwater Inflow into Sunfish Lake (ac-ft)	Growing Season Groundwater Inflow into Sunfish Lake (ac-ft)	Water Year Groundwater P Load into Sunfish Lake (lbs)	Growing Season Groundwater P Load into Sunfish Lake (lbs)
2006	36	1	2.4	0.2

Table 4-8 Summary of 2006 Estimated Growing Season and Water Year Groundwater Outflow from Sunfish Lake

Year	Water Year Groundwater Outflow from Sunfish Lake (ac-ft)	Growing Season Groundwater Outflow from Sunfish Lake (ac-ft)	Water Year Groundwater P Discharge from Sunfish Lake (lbs)	Growing Season Groundwater P Discharge from Sunfish Lake (lbs)
2006	16	0	3.5	0

4.2.1.9 Other Non-Permitted Sources

Anecdotal information provided by WCD staff at a technical stakeholder meeting indicated that significant populations of Canadian geese spend time on and around Sunfish Lake (Downing 2014). However, the impact of the geese on Sunfish Lake water quality has not been quantified.

4.2.1.10 In-Lake Mass Balance Model

In-lake modeling for Sunfish Lake was accomplished through the creation of a mass balance model that tracks the flow of both water and phosphorus through the lake for the critical water quality GS (June 1 through September 30, 2006) as well as the year prior. The mass balance model considers influent water and phosphorus loads (as discussed in the sections above) for a 17-month period.

The estimated water and phosphorus loads of the first year (12 months from May through end of April of the following year) were used to establish the steady-state phosphorus concentration in the lake at the beginning of the water quality calibration period, using published empirical models that predict lake phosphorus concentrations. The influent water and phosphorus loads from the remaining five months were used in the in-lake mass balance model which evaluated the period from the beginning of May 2006 through the end of September 2006, which includes the targeted GS. Modeling results from June 1, 2006, through September 30, 2006, were used to estimate the GS average (as defined by the MPCA).

The key input parameters for the in-lake mass balance model included direct precipitation data, evaporation data, runoff loads from the lake's watershed (as predicted by the P8 model), the lake storage and outlet rating curve, estimated GW exchange, and in-lake water quality monitoring data. Additional data, including sediment core data and macrophyte survey information, were used to verify that model estimates of internal phosphorus loading were reasonable.

Prior to conducting the phosphorus mass balance modeling for the lake, a daily water balance model was calibrated to observed historical lake level data for Sunfish Lake. The daily water balance model developed for Sunfish Lake was used in conjunction with the P8-estimated watershed runoff volumes and lake level data to estimate the GW exchange and provide the best fit between the predicted water levels and the observed water levels. Figure 4-3 shows the results of the water balance model.

A small amount of GW exchange was required for Sunfish Lake to achieve a match between the model-predicted water level and the observed water level. A net GW outflow of 0.05 inches per day was required from July 2005 through November 2005, in order for the model-predicted water level to closely match observed water levels. A net GW inflow of 0.1 inches per day was required during the months of April and May 2006, in order for the model-predicted water level to closely match observed water levels.

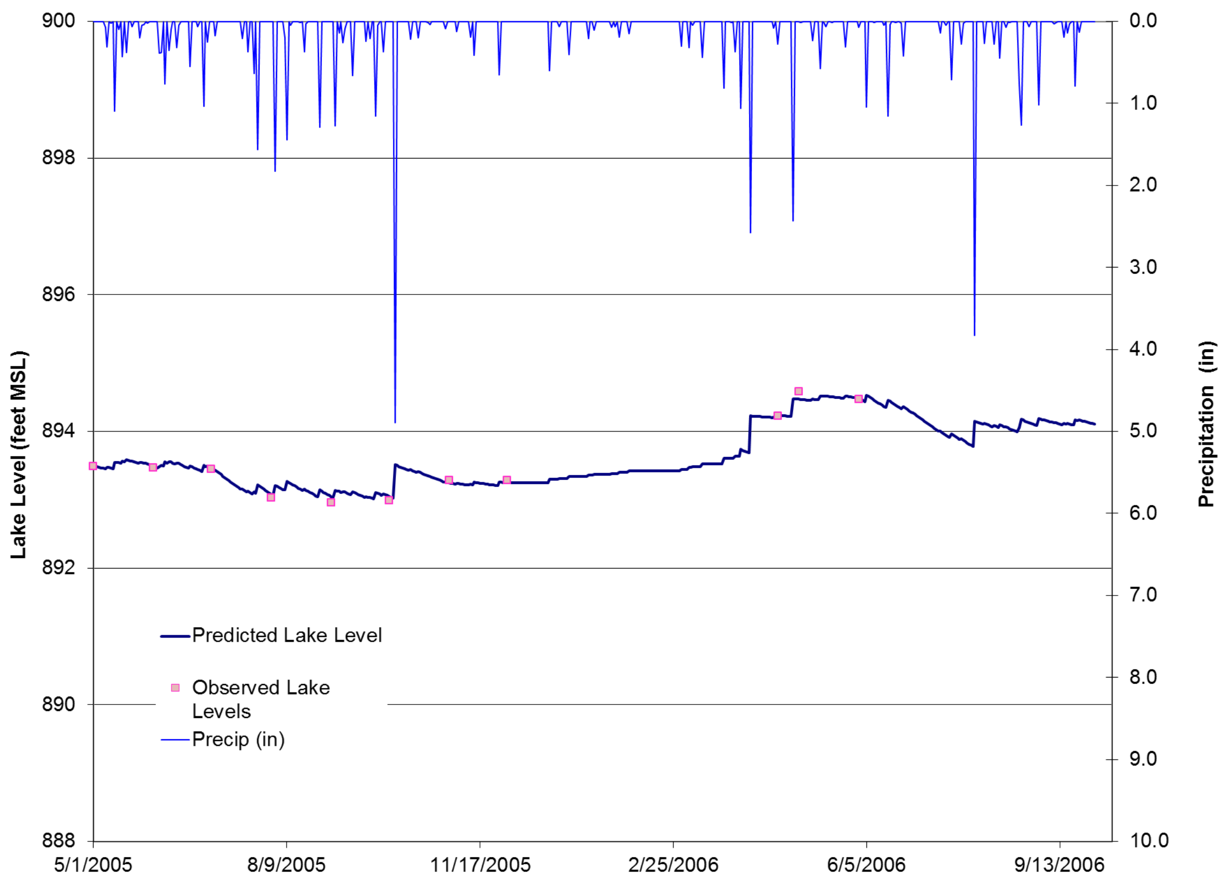

Figure 4-3 **Sunfish Lake Water Balance May 1, 2005 through September 30, 2006**

Once the water balance was calibrated, the phosphorus mass balance modeling was performed in two phases. The first step was to predict the steady-state phosphorus concentration in the lake at the beginning of the calibration period. As previously mentioned, the P8 model was used to not only estimate the watershed loads for the critical water quality year/calibration period (e.g., May 1, 2006, through Sept. 30, 2006), but also for the year prior (May 1, 2005, through April 30, 2006). These annual loads for the year prior to the calibration period were used to estimate the steady-state concentration at the beginning of the calibration period. Several published empirical models were evaluated for

Sunfish Lake and the model that provided the best fit to the observed early season phosphorus data was selected. By selecting the empirical model that best fits Sunfish Lake, the in-lake water quality model can be used to predict the impact of changes in water and phosphorus loads to the lake on the steady-state spring phosphorus concentrations in the lake and through the subsequent GS. The Following empirical relationship used to estimate the steady state phosphorus concentration in Sunfish Lake.

$P = L(1 - Rp)/(z * p)$

Where:

L = Areal loading rate (mg/m^2/yr)

z = Mean depth (m)

p = Flushing rate (1/yr)

Rp = Phosphorus Retention Coefficient $\boldsymbol{Rp} = 1/(1 + p^{\frac{1}{2}})$

The second step to the calibration of the phosphorus mass balance model was to predict the observed TP concentrations in the lake during the respective calibration periods (May through September) for the critical water quality conditions. We chose to do this at intervals coinciding with the water quality monitoring events for the lake, instead of using an empirical equation because empirical equations reflect a steady state, average condition with inflows that are completely mixed throughout the lake's water column and areal extent. We wanted to observe the changing effect of the lake's internal load over the GS.

To calibrate the phosphorus mass balance model for existing watershed conditions, phosphorus loads from the watershed were predicted for each water quality sampling period using the P8 model and were combined with atmospheric deposition directly onto the lake surface, phosphorus loading due to the die back of curlyleaf pondweed, and inflows of GW. Phosphorus losses were also estimated including particulate phosphorus settling, uptake by coontail, and losses to the GW. Since Sunfish Lake is landlocked, surface water discharges were not estimated.

To estimate the internal phosphorus loading (i.e., sediment phosphorus release), the predicted phosphorus concentration based on the loads and losses were compared to the observed in-lake water quality data on each water quality sampling dates. The magnitude of the internal phosphorus load to the lake's surface waters was deduced by comparing the observed water quality in the lake to the water quality predicted by the in-lake model using the following general mass-balance equation for each time step:

P Adjustment = Observed P + Settling P + Coontail Uptake P + Groundwater Loss P – Runoff P – Atmospheric P – Curlyleaf P –Groundwater Inflow P - P Initial

The key calibration parameter for the in-lake model was this estimation of the internal load that affects the lake's surface waters during the GS.

Table 4-9 summarizes the results of the in-lake water quality model calibration for Sunfish Lake during the spring steady state condition and during the GS.

Table 4-9 In-Lake Water Quality Model Calibration for Sunfish Lake

Year	Water Quality Monitoring Data		Calibration Conditions	
	Observed Spring TP[1] (µg/L)	Observed GS Average TP (µg/L)	Model-Predicted Spring TP[1,2] (µg/L)	Model-Predicted Growing Season Average TP (µg/L)
2006	65	63	80	63

[1] Observed spring steady-state phosphorus concentrations based on earliest sampling date collected in the respective year, typically in late April or early May.

[2] Predicted spring steady-state phosphorus based on the empirical equation of Dillon and Rigler (1974) with Larsen and Mercier (1976) phosphorus retention coefficient.

The GS TP loads for the calibrated 2006 Sunfish Lake in-lake mass balance model is summarized in Figure 4-4. Internal loading of phosphorus from lake sediment release and curlyleaf pondweed combined are estimated to contribute 43.2 lbs TP per GS, or 74% of the total GS phosphorus budget.

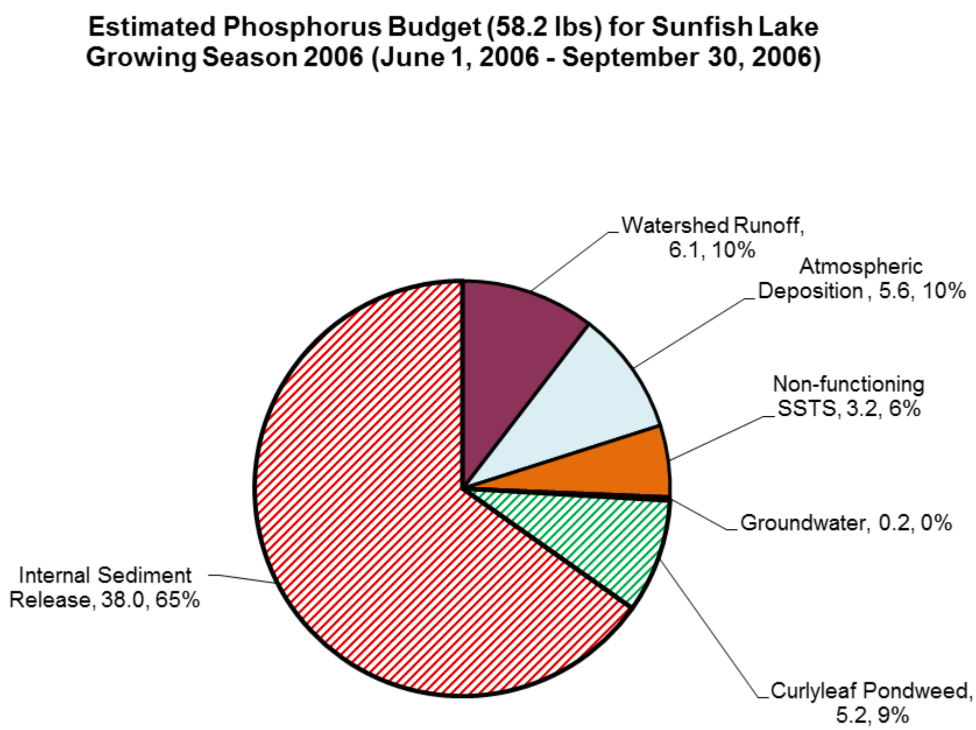

Figure 4-4 Sunfish Lake 2006 Growing Season Total Phosphorus Budget (lbs TP)

Appendix A includes details of the in-lake mass balance model methodology and Appendix B includes tables summarizing the components of the mass balance for Sunfish Lake during the 2006 conditions used to establish the TMDL for Sunfish Lake.

4.2.1.11 Load Capacity Summary

The existing conditions in-lake mass balance model was used to estimate the TP load to Sunfish Lake that would achieve the MPCA's shallow lake eutrophication TP standard (≤ 60 µg/L). This maximum allowable load is referred to as the lake's loading capacity. When estimating the load capacity, the estimated phosphorus load reduction (both internal and external) that would be required to achieve the MPCA shallow lake eutrophication standard was determined. The load capacity was estimated for 2006, the average conditions that will be used to establish the TMDL for Sunfish Lake; however Table 4-10 summarizes the estimated load capacity of Sunfish Lake under different climatic conditions.

Table 4-10 Summary of 2006 Estimated Growing Season Load Capacity for Sunfish Lake

Year	Existing Conditions Total Phosphorus Load (lbs)	Estimated Load Capacity Total Phosphorus Load (lbs)
2006	58.2	54.9

To estimate the load capacity, the various sources of phosphorus to Sunfish Lake were considered and the following assumptions were applied when evaluating phosphorus reductions to meet the MPCA water quality standards:

- The spring phosphorus concentration was assumed to be the same as for existing conditions. However, it is likely that if phosphorus loads to the lake are reduced, the springtime concentration will likely also be reduced.
- The water loads and lake volumes would not change from existing conditions as a result of the phosphorus reductions.
- For sources such as atmospheric deposition and GW inflow, we assumed that the loads from these sources would be the same as for existing conditions.
- For improperly functioning SSTS, we assumed that there would be no loading allowed (100% reduction) as discharges of phosphorus from SSTS to surface waters are illegal.
- Because the predominant land uses in the Sunfish Lake Watershed are low intensity (e.g., parkland and very low density residential housing) and the overall phosphorus load from the watershed is only a small fraction of the GS phosphorus budget (10-22%), our approach was to first target the internal sources of phosphorus (e.g., curlyleaf pondweed and sediment release), which account for 46-74% of the GS phosphorus budget. Reductions were applied to the internal phosphorus loads (with a maximum allowable reduction in internal loading of 80%) until the MPCA water quality standard was achieved.
- If the MPCA water quality standard could not be achieved through elimination of SSTS discharge and internal loading, additional phosphorus reductions from the watershed would have been targeted. However, for 2006 and the additional years analyzed, reductions in watershed loads were not necessary to achieve the MPCA water quality standard.

4.2.2 Load Allocation Methodology

This section describes the methodology used to assign LAs to non-permitted phosphorus sources as part of the Sunfish Lake TMDL study. Existing phosphorus loads from non-permitted sources to Sunfish Lake include direct atmospheric deposition to the lake surface, improperly functioning SSTS, and internal loading. The phosphorus LA for direct deposition to the lake surface and GW inflows is the same as existing conditions. Discharges of phosphorus to surface waters from SSTS are illegal, and the LA for SSTS is therefore zero. Internal loading of phosphorus is the largest source of phosphorus to Sunfish Lake during the GS, and was selected as the primary target for phosphorus reductions in order to achieve the MPCA lake eutrophication standard. The resulting LAs for direct atmospheric deposition, GW inflow, SSTS, and internal loading for Sunfish Lake are detailed in Section 4.2.6.

4.2.3 Wasteload Allocation Methodology

4.2.3.1 Construction and Industrial Stormwater Permits

The WLAs for the construction and industrial stormwater permits is based on an estimate of the average annual percentage of the county being under an MPCA Construction Stormwater Permit, using the MPCA Construction Stormwater Permit data provided from 2007-2013 for Washington County. From 2007-2013, the estimated average annual area under the MPCA Construction Stormwater Permit was 0.24% of Washington County. We assumed that the same percentage for construction stormwater would apply for the MPCA Industrial Stormwater Permits. The WLA for construction and industrial stormwater permits in the Sunfish Lake Watershed was based on the total percentage of (0.48%) to the estimated loading capacity for the Lake, or 0.3 pounds of phosphorus per GS. Load reductions for construction stormwater activities are not specifically targeted in this TMDL. It should be noted that construction stormwater activities are considered in compliance with provisions of this TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install, and maintain all stormwater BMPs required under the permit, including any applicable additional BMPs required in the Construction General Permit for discharges to impaired waters; or meet local construction stormwater requirements if they are more restrictive than requirements of the Construction General Permit. Industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an Industrial Stormwater General Permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install, and maintain all BMPs required under the permit.

4.2.3.2 MS4 Permits

There are two MS4s that comprise the entirety of the Sunfish Lake Watershed.

Table 4-11 summarizes the MS4s in the Sunfish Lake Watershed along with their associated MS4 identification number.

Table 4-11 MS4 Summary for Sunfish Lake

MS4 Name	MS4 ID Number	MS4 Area within the Contributing Watershed (acres)
City of Lake Elmo	MS400098	295
Washington County	MS400160	6

Figure 4-5 shows the MS4s in the Sunfish Lake Watershed. As previously mentioned, portions of the Sunfish Lake Watershed are landlocked and do not contribute runoff loads to Sunfish Lake. To determine the WLAs assigned to each individual MS4, only the contributing portions of the Sunfish Lake Watershed were considered, and the fraction of the watershed phosphorus wasteload from each MS4 to Sunfish Lake was allocated proportional to the area of each MS4's contributing watershed. The total area of contributing watershed to Sunfish Lake is 301 acres, 98% of which is within the city of Lake Elmo MS4 boundary, with the remaining 2% within the Washington County MS4 boundary. Therefore, the Washington County MS4 was assigned 2% of the total WLAs and the city of Lake Elmo MS4 was assigned the remaining 98%. However, no reductions in watershed phosphorus loads are required for Sunfish Lake to achieve the TMDL for the lake. The total WLA for each MS4 is equal to the existing condition load for the 2006 GS, as estimated by P8 watershed modeling.

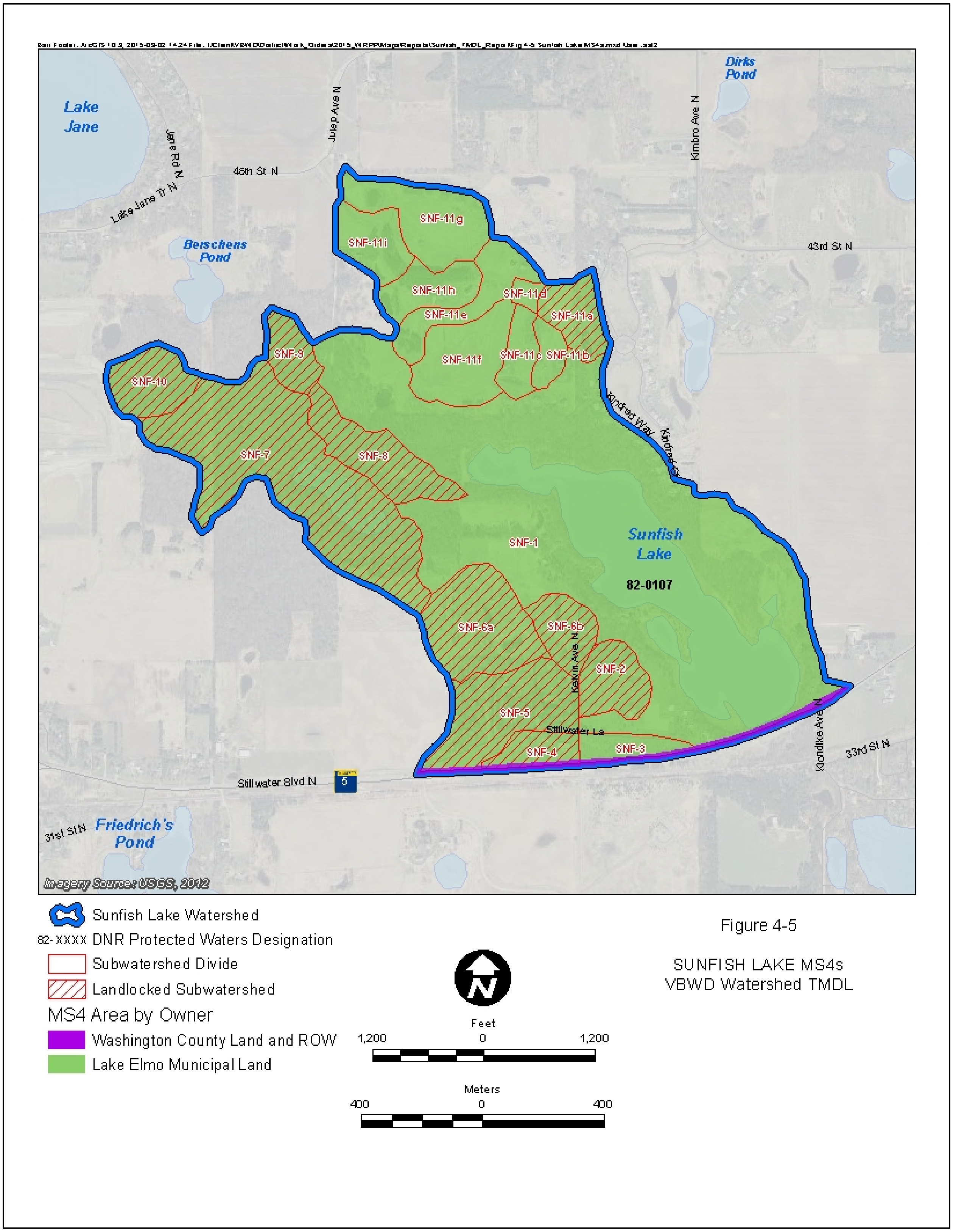

Figure 4-5 Sunfish Lake MS4s

4.2.3.3 Municipal and Industrial Wastewater Sources

There are no non-stormwater NPDES permitted point source surface dischargers identified within the Sunfish Lake Watershed. There is one facility within the Sunfish Lake Watershed that is permitted to discharge treated water to the subsurface. The Tapestry Community residential development has a wastewater treatment system (WWTS) that has a SDS Permit for its subsurface disposal system. The Tapestry WWTS is designed to treat wastewater from 67 homes, and discharge treated wastewater to infiltration beds to facilitate infiltration into the ground. The Tapestry Community WWTS (SDS Permit MN0067547) is not authorized to discharge to surface water, and is therefore not assigned a wasteload as part of the Sunfish TMDL.

4.2.4 Margin of Safety

When modeling a natural system such as Sunfish Lake, there can be some uncertainty associated with how the system will respond to changes. Therefore, a MOS is included to account for some of the unknowns associated with the behavior of the natural lake system. A 10% explicit MOS was used for the Sunfish TMDL study.

Additionally, there is also an implicit MOS due to conservative modeling assumptions. When the load capacity was estimated for Sunfish Lake, it was assumed that the spring steady-state concentration in the lake after reductions to the phosphorus load was the same as for existing conditions. In reality, a reduction in the phosphorus load to Sunfish Lake will likely result in lower spring steady-state phosphorus concentrations when compared to existing conditions.

4.2.5 Seasonal Variation

The TP concentrations in Sunfish Lake can vary during the GS, typically peaking in late summer. The TMDL guideline for TP is defined as the GS (June through September) mean concentration (MPCA 2009b). The critical period (GS) was used to estimate the required reduction of watershed and internal sources of phosphorus so that the predicted GS average met the MPCA lake standard (see additional discussion in Section 5).

4.2.6 TMDL Summary

The phosphorus load and WLAs for Sunfish Lake are described in Table 4-12 below. The load and WLAs are described in terms of the pounds of phosphorus per GS (lbs/GS), as well as pounds of phosphorus per day (lbs/day). The amount of phosphorus under existing conditions for the critical GS are also detailed for each phosphorus source, as well as the required reduction in order to achieve the MPCA lake eutrophication standard for Sunfish Lake (TP ≤ 60 µg/L).

Table 4-12 Sunfish Lake Growing Season[2] Total Phosphorus Load Allocations for 2006 Water Quality Conditions

Total Phosphorus Source	Existing Conditions (lbs/GS[4])	Existing Conditions (lbs/day)	TMDL Allocation (lbs/GS[4])	TMDL Allocation (lbs/day)	Required Load Reduction (lbs/GS[4])	Percent Reduction (%)
Wasteload Allocation (Permitted Sources)						
City of Lake Elmo (MS400098)	6.0	0.0489	6.0	0.0489	0.0	0%
Washington County (MS400160)	0.1	0.0008	0.1	0.0008	0.0	0%
NPDES-Permitted Construction and Industrial Stormwater	0.3	0.0025	0.3	0.0025	0.0	0%
Total Wasteload Sources	6.4	0.0522	6.4	0.0522	0.0	0%
Load Allocations (Non-Permitted Sources)						
SSTS	3.2	0.0266	0.0	0.0000	3.2	100%
Atmospheric Deposition	5.6	0.0461	5.6	0.0461	0.0	0%
Groundwater	0.2	0.0013	0.2	0.0013	0.0	0%
Internal Sources[3]	43.1	0.3533	37.3	0.3058	5.8	13%
Total Load Sources	52.1	0.4273	43.1	0.3532	9.0	17%
Margin of Safety[1]						
	N/A	N/A	5.5	0.0450	N/A	N/A
Overall Source Total	58.5	0.4795	54.9	0.4504	9.0	16%

1 – A 10% explicit Margin of Safety is utilized for the Sunfish Lake TMDL
2 – Based on 2006 Growing Season (June – September)
3 – Reflects the sum of all internal sources of phosphorus (e.g. curly-leaf pondweed, sediment release)
4 – GS: Growing Season
5 -- The overall load reduction is the sum of the individual load reductions; it is also equal to the overall existing load minus the overall TMDL, plus the Margin of Safety.

4.3 Future Growth Consideration/Reserve Capacity

For all TMDLs in the VBWD, the following applies to determining the impact of growth on allocations.

4.3.1 New or Expanding Permitted MS4 WLA Transfer Process

Future transfer of watershed runoff loads in this TMDL may be necessary if any of the following scenarios occur within the project watershed boundaries:

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA. An example of this is if the city of Afton would become a regulated MS4.
4. An expansion of a U.S. Census Bureau Urban Area to encompass new regulated areas for existing permittees. An example is existing state highways that were outside an Urban Area at the time the TMDL was completed, but are now inside a newly expanded Urban Area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
5. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES Permit. In this situation, a transfer must occur from the LA.

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL**.** In cases where WLA is transferred from or to a regulated MS4, the permittees will be notified of the transfer and have an opportunity to comment.

4.3.2 New or Expanding Wastewater

The MPCA, in coordination with the EPA Region 5, has developed a streamlined process for setting or revising WLAs for new or expanding wastewater discharges to waterbodies with an EPA approved TMDL (MPCA 2012). This procedure will be used to update WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the instream target and will ensure that the effluent concentrations will not exceed applicable water quality standards or surrogate measures. The process for modifying any and all WLAs will be handled by the MPCA, with input and involvement by the EPA, once a permit request or reissuance is submitted. The overall process will use the permitting public notice process to allow for the public and EPA to comment on the permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

For more information on the overall process visit the MPCA's TMDL Policy and Guidance webpage.

5 Reasonable Assurances

When establishing a TMDL, reasonable assurances must be provided, demonstrating the ability to reach and maintain the established water quality goals. Reasonable assurances typically include both regulatory and non-regulatory efforts at the state and local levels that will result in pollutant load reductions that will help achieve the wasteload and LAs.

For all TMDLs completed as part of this study, the resources are located within the VBWD. The VBWD has a comprehensive approach to managing water resources in the District and includes the following:

- All significant development, redevelopment, industrial, and construction projects need to be designed to maintain or improve existing developed hydrology and pollutant loadings to fully comply with the local watershed and government authorities, NPDES, and anti-degradation requirements. The VBWD currently implements a regulatory program that requires construction site erosion and sediment controls, post-construction stormwater management, and permits for any wetland alterations.
- The VBWD was established in 1968 in response to a citizens' petition to the State of Minnesota to address water resource issues in the watershed. Although there have been several versions of the VBWD's watershed management plan, the most current version was adopted in 2005 (and amended in 2011) and the VBWD is expected to have another 10-year overall plan adopted in 2015.
- The first VBWD rules and regulations were adopted in 1972, primarily targeting water quantity issues; however, since 1995, the rules directly impact water quantity as well as water quality. The current VBWD Rules and Regulations were adopted in 2013 and, among other standards, include the stormwater management performance standards developed through the MPCA's Minimal Impact Design Standards (MIDS) project. The VBWD plans to continue to implement volume reduction rule for development, redevelopment, and linear projects as they happen.
- The VBWD implements a water quality monitoring program and performs water quality trend analyses that will allow the District to track progress and guide adjustments in the implementation approach. In addition, the VBWD performs routine aquatic plant surveys and will consider the management of aquatic plants based on this information.
- The VBWD has a history of partnering with private landowners and member communities on water quality improvement projects. An example of this partnering effort is the VBWD's BMPs Cost-Share Program, which provides technical support and funding for individuals, communities, and some developers for stormwater management improvements.
- In additional to management of surface water and stormwater runoff, the VBWD plan acknowledges the importance of GW and has policies in place for the protection of GW quality and quantity.

Additionally, all local units of government within the VBWD are required to prepare a local watershed management plan, capital improvement program, and official controls as necessary to bring local water management into conformance with the VBWD watershed management plan. These local plans are reviewed and approved by the VBWD.

5.1 Kelle's Creek

In addition to the VBWD rules, adopted watershed management plan, and monitoring program, there are several items in place that will help assure that Kelle's Creek will reach its desired water quality:

- Washington County adopted the current version of the Washington County GW Plan (Washington County 2014b), which includes general protections of GW quality and quantity. In this plan, Washington County looks to partnering with other agencies and organizations to manage GW resources.
- Washington County has SSTS regulations in place that direct the design and installation of systems as well as requiring regular maintenance of these systems. The County ordinance also includes triggers for compliance inspections; examples include point of sale or adding a bedroom. These triggers are designed to assist the county in identifying and requiring replacement of non-compliant systems.
- Washington County established a SSTS financial assistance program that offers low interest loans and grants for low income residents to upgrade or replace non-compliant systems.
- The city of Afton is pursuing a community septic project to address failing or non-compliant systems in old Afton Village.

5.2 Sunfish Lake

In addition to the VBWD rules, adopted watershed management plan, and monitoring program, there are several items in place that will help assure that Sunfish Lake will reach its desired water quality:

- Washington County adopted the current version of the *Washington County Groundwater Plan* (Washington County 2014b), which includes general protections of GW quality and quantity. In this plan, Washington County looks to partnering with other agencies and organizations to manage GW resources.
- Washington County has SSTS regulations in place that direct the design and installation of systems as well as requiring regular maintenance of these systems. The County ordinance also includes triggers for compliance inspections; examples include point of sale or adding a bedroom. These triggers are designed to assist the county in identifying and requiring replacement of non-compliant systems.
- Washington County established a SSTS financial assistance program that offers low interest loans and grants for low income residents to upgrade or replace non-compliant systems.
- Both Lake Elmo and Washington County are permitted MS4s and are required to develop and implement a stormwater pollution prevent program (SWPPP). These permits require a program that addresses six minimum control measures including: public education and outreach, public participation, illicit discharge detection and elimination program, construction site runoff controls, post-construction runoff controls, and pollution prevention and municipal good housekeeping measures. Additionally, the WLAs established in this TMDL study will be incorporated into the MS4 permit requirements and must develop a strategy and schedule to begin achieving the WLAs.

6 Monitoring Plan

The VBWD measures lake water quality, monitors biology (macrophytes, macroinvertebrates, and sometimes zooplankton and phytoplankton), lake and GW levels, stream water quality, stream flow, and weather conditions at multiple locations throughout the entire VBWD and has collected a large amount of water quality data over its history. In addition, other agencies have collected data for VBWD waterbodies, including the MPCA, Metropolitan Council, and others. The amount of data currently available varies by waterbody.

Continued water quality data collection is necessary for the VBWD to track water quality improvement or degradation, detect trends, and better understand water quality processes, and ultimately determine if there are water quality problems (e.g., impaired uses). This information is critical for VBWD to identify and prioritize water quality improvement projects, and to determine appropriate methods for preventing water quality degradation. Detection of trends, specifically improvements, is critical to determining the effectiveness of actions implemented by the VBWD.

The VBWD will continue to monitor Kelle's Creek and Sunfish Lake, and any details are described in the sections below.

6.1 Kelle's Creek Monitoring Plan

For the purposes of this TMDL, the most important data is that from the downstream monitoring station on Kelle's Creek (Station S004-462) at St. Croix Trail. The VBWD plans to continue to collect water chemistry and flow data through a continuous water monitoring station in cooperation with other entities and will report the results of its stream monitoring. In addition, if VBWD can gain access, the VBWD plans to regularly monitor the physical condition of Kelle's Creek. The continued collection of flow and monthly *E. coli* data will be essential to track water quality trends, assess progress towards implementation goals, and make adaptive management decisions.

6.2 Sunfish Lake Monitoring Plan

The VBWD plans to continue the regular collection of water quality and macrophyte data for Sunfish Lake. Water quality measurements of Sunfish Lake is expected to typically follow the Metropolitan Council's Citizen-Assisted Monitoring Program (CAMP) protocol, which measures Secchi disc transparency depth, TP, chlorophyll-*a (*Chl-*a)*, and other lake eutrophication parameters at the lake surface. Several measurements will likely be collected each year over the course of the GS, as well as in the spring. When degrading water quality trends are identified, the VBWD may collect more detailed water quality data, including evaluation of phosphorus concentrations, dissolved oxygen, specific conductance, turbidity, and pH data at depth which can be used to help assess the problems.

In addition to the water quality monitoring, the VBWD plans to continue to compile a water quality report every year for all water bodies sampled. In the past, these reports include data from other units of government, if available/possible. All of the water qualities monitoring results for that year have been consolidated into a single report that includes data analysis, a data summary, and calculation of water quality trends (VBWD 2013 Annual Report). The VBWD uses the results, and historic data, to determine needed monitoring and other water quality management actions for the next year.

7 Implementation Strategy Summary

7.1 Implementation Framework

This section provides implementation strategies designed to help meet the required pollutant load reductions that are required as a result of this TMDL study. These strategies are potential actions that will help reduce bacteria and nutrient loading in the VBWD Watershed and will be incorporated into the separate Watershed Restoration and Protection Strategies (WRAPS) Report.

7.1.1 Adaptive Management

The proposed implementation strategies will typically follow the adaptive management approach. Proposed projects will be implemented in a phased manner, selecting specific projects for construction/implementation followed by a period of monitoring to evaluate the impact of the projects on the water quality of the impaired resources. Depending on the resulting water quality, additional projects may be evaluated and selected for implementation, or it may be determined that the water quality meets the MPCA standards and the management approach may change from improvement to anti-degradation/protection.

7.2 Permitted Sources

7.2.1 MS4s

There are no permits for surface water discharges within the Kelle's Creek Watershed. The city of Lake Elmo and the Washington County are the only permitted MS4s within the Sunfish Lake Watershed and are also the only permitted sources of surface water discharges within the watershed. No reductions in phosphorus loads from MS4s were identified as part of the Sunfish Lake TMDL. Since the VBWD is the permitting authority for development and redevelopment in both the Sunfish Lake and Kelle's Creek Watersheds, any development will be required to meet the VBWD rules.

7.2.2 Construction Stormwater

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.

The WLA for stormwater discharges from sites where there are construction activities reflects the number of construction sites one or more acres expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs required under the permit, including those related to discharges to impaired waters and any applicable additional requirements found in Appendix A of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met, which likely require water quality treatment greater than required by the State's NPDES/SDS General Stormwater Permit for Construction Activity.

7.2.3 Industrial Stormwater

The WLA for stormwater discharges from sites where there is industrial activity reflects the number of sites in the watershed for which NPDES Industrial Stormwater Permit coverage is required, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at the industrial sites are defined in the State's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

7.3 Strategies

7.3.1 Bacteria (*E. coli*)

The findings of this study indicate that the primary *E. coli* sources to Kelle's Creek are from non-permitted sources including non-riparian pastures and from inadequately treated wastewater (non-compliant SSTS). Bacteria load reductions from these sources will be the most effective in meeting water quality goals.

The calculated reductions in *E. coli* loading that are required for Kelle's Creek to achieve compliance with the water quality standards were compared to the estimated proportional source loading determined for Kelle's Creek (see Table 7-1). This information was used to guide the implementation strategies that complement this TMDL study and are further discussed in this section.

The Kelle's Creek LA was divided among the sources discussed in Section 3.5. A LA of zero was assigned to inadequately treated wastewater (i.e., human), as this represents SSTS that are not functioning properly, which is currently not allowed by regulation. To protect public health and safety, the Washington County SSTS regulations require that any systems determined to be non-compliant must be repaired, upgraded, replaced or its use discontinued within a specific timeframe of notice.

Table 7-1 Kelle's Creek Observed and Required Load Allocations by Source

Source	Estimated Existing Wet Conditions	Estimated Existing Dry Conditions	Estimated Existing Very High Flow Loading (b-org/day)	Estimated Existing High Flow Loading (b-org/day)	Estimated Existing Mid Flow Loading (b-org/day)	Estimated Existing Low Flow Loading (b-org/day)	Load Allocations (billions of organisms per day)				
							Very High	High	Mid	Low	Very Low
Human	59.8%	84.1%	44.97	3.55	1.77	4.61	0	0	0	0	0
Runoff	18.5%	0.0%	8.33	0.66	0	0	1.44	0.88	0.00	0.00	0.00
Livestock - Cattle	17.2%	12.1%	7.76	0.61	0.15	0.40	1.34	0.81	1.00	0.78	0.59
Livestock - Poultry	2.0%	1.4%	0.88	0.07	0.014	0.04	0.15	0.09	0.09	0.08	0.06
Livestock - Horses	1.5%	1.0%	0.69	0.055	0.02	0.04	0.12	0.07	0.13	0.08	0.06
Wildlife	1.0%	1.4%	0.45	0.03	0.01	0.04	0.08	0.04	0.07	0.08	0.06
Total	100%	100%	63.08	4.98	1.97	5.13	3.12	1.89	1.29	1.01	0.77

7.3.1.1 Non-Riparian Pasture Management

One important measure that can be taken to reduce *E. coli* loading in Kelle's Creek is to improve non-riparian pasture management. Since livestock do not have direct access to the creek and creek banks, the emphasis should be on reducing and treating runoff from the current pasture and grazing areas before discharging into waterways draining to the creek. This includes the use of BMPs such as grassed waterways and filter strips that can reduce the amount of bacteria from reaching Kelle's Creek via surface runoff (SRO).

Rotational grazing can also be used to reduce grazing pressure on pastures and to minimize the subsequent erosion of soil and fecal material into surface waters. Pastures are subdivided into paddocks and livestock are moved between paddocks frequently. Consequently, forage plants do not become overgrazed and they continue to slow overland flow of water and to hold soil (and fecal matter/bacteria) in place and minimize erosion.

The Kelle's Creek resident survey indicated that residents are interested in information in relation to improved management of grazing lands as well as manure management. Outreach and education about pasture and manure management and promotion of existing programs to help interested landowners improve management on their property may help reduce bacteria loads to Kelle's Creek. Financial and technical assistance in the development of BMPs for pasture runoff management and rotational grazing plans can be obtained through the WCD, other partner agencies such as the VBWD and the University of Minnesota Extension, the Board of Water and Soil Resources (BWSR), the Minnesota Department of Agriculture (MDA), and the Natural Resource Conservation Service (NRCS).

The MDA *The Agricultural BMP Handbook for Minnesota* (MDA 2012) provides additional information on agricultural BMPs to improve and protect water quality.

7.3.1.2 SSTS Management

Inadequately treated wastewater has been identified as a significant source of bacteria to Kelle's Creek during all climatic conditions. Because of the karst topography and features in the Kelle's Creek Watershed and high susceptibility of the water table to pollution, inadequately functioning SSTS throughout the surface watershed and possibly outside the surface watershed, but within the "groundwatershed" are likely contributing to the elevated bacteria levels in the creek. The 2013 monitoring data collected along the length of Kelle's Creek indicates that bacterial levels were elevated in low-flow (non-storm event) conditions upstream of Afton Village, suggesting that SSTS throughout the watershed are sources of the bacteria in the creek, not just those in Afton Village. Improving wastewater treatment in Afton Village will not be enough to meet water quality goals of Kelle's Creek.

In the lower reaches of Kelle's Creek, efforts by the city of Afton to better treat wastewater could have a positive effect on the creek. To address the inadequately functioning SSTS identified in Afton Village, the city of Afton completed a study to evaluate the performance of the SSTS serving both commercial and residential properties within a flood reduction project area, which generally includes the eastern side of Afton Village. Alternatives were evaluated looking at opportunities for a community septic system that would be constructed above the water table and a preferred alternative has been selected. Also, the city of Afton has secured State of Minnesota BWSR Clean Water Fund grant moneys for the construction of this system and the city has purchased the property where the community septic system will be located.

The city of Afton is in the permitting and environmental review phases of the project with construction expected in 2016 and 2017.

Outside of the area that will be served by the city of Afton's future community sewage treatment system, there are also efforts that could reduce the bacteria in Kelle's Creek.

The current Washington County GW Plan has identified SSTS financial assistance as a priority, and the County has several opportunities for financial assistance to upgrade or fix non-compliant SSTS. Washington County received State of Minnesota Clean Water Fund (CWF) funds for SSTS Fix-up Grants, available to low income residents only. These funds can only be used for SSTS that are non-compliant (i.e. failing to protect groundwater or an imminent public health threat). A very small amount of SSTS Fix-Up Grants are available in 2016. Availability of SSTS Fix-Up Grants in future years is dependent on MPCA Clean Water Fund allocations, as well as the county's ability to obtain these funds. Additionally, Washington County has established a low interest loan program for SSTS upgrades for home owner and rural business owners, regardless of income, whose systems have been identified as non-compliant. This program is administered through Washington County, who acts as local lender, utilizing funds from the Minnesota Department of Agriculture (MDA) AgBMP loan program.

In 2014, the first year of the County's program, nearly half of the SSTS loans and grants administered in Washington County were in the VBWD. There is an opportunity to continue to educate homeowners in the Kelle's Creek Watershed about the maintenance of SSTS and to target the Washington County financial assistance programs.

Additionally, the VBWD will cooperate with other entities to inspect and replace (or fund through cost share) non-functioning or non-compliant SSTS in the Kelle's Creek Watershed. In 2014, the VBWD, in partnership with Washington County, applied for State of Minnesota Clean Water Fund grant funds to help promote the participation of private residences in having inspections done to help evaluate the function of existing SSTS. These efforts would be targeted in portions of Washington County with known bacteria impairments resulting from inadequately functioning SSTS, such as the Kelle's Creek Watershed. Opportunities to incentivize participation in the voluntary SSTS inspection program will be considered along with targeted promotion of the existing Washington County financial assistance program. In January 2015, the VBWD was notified that they received the State of Minnesota Clean Water Fund grant and will begin the development of a targeted program to begin addressing inadequately functioning SSTS in the Kelle's Creek Watershed.

7.3.2 Nutrients

For Sunfish Lake, the primary source of phosphorus to the lake is from the internal loading from sediments and die-back of curlyleaf pondweed. Other secondary sources include watershed runoff, atmospheric deposition, and non-compliant SSTS.

7.3.2.1 Alum Treatment of Lake Sediments

Both monitoring and modeling has indicated that phosphorus loading from the lake sediments is a significant source of phosphorus to Sunfish Lake. The addition of aluminum sulfate (alum) has been proven to be effective in controlling phosphorus release from sediment, especially when an adequate dose has been delivered and where watershed sediment and phosphorus loads have been minimized (Moore and Thorton 1988). The aluminum binds with phosphorus from the water column as it settles and then forms a layer on the lake bottom that covers the sediments and prevents release from the sediments, preventing the mobile phosphorus from being recycled back into the water column. Alum application can decrease internal phosphorus loads by up to 80% (Welch and Cook 1999) and can be effective for nearly 10 years, depending on the dose and watershed inputs.

A whole-lake alum treatment of Sunfish Lake would reduce internal loading of phosphorus from lake sediments substantially; however, to apply the appropriate dosage, multiple applications of alum would be required due to the buffering capacity of Sunfish Lake. For Sunfish Lake, the estimated dosing is based on the sediment core data, including both the mobile phosphorus and organic phosphorus.

In 2008, the VBWD treated Sunfish Lake was treated with approximately 25% of the estimated dose required. The full dose was not applied due to buffering capacity and post-treatment aquatic plant growth concerns. Water quality data collected following the alum treatment indicate no sustained decrease in average summer TP concentrations or improved water clarity. Since 2008, the VBWD has not applied additional alum doses because of low lake water levels, difficult lake access, and other funding priorities.

Application of alum often results in improved clarity of the water column and can result in increased macrophyte growth. Currently, extensive macrophyte growth is not an issue in Sunfish Lake; however, with alum treatments, the VBWD will continue to monitor macrophytes in the lake. Should extensive macrophyte growth occur, especially of nonnative or invasive species, VBWD may consider macrophyte management, such as mechanical harvesting or chemical treatment.

7.3.2.2 SSTS Management

All residences and structures within the Sunfish Lake Watershed are served by SSTS. Inadequately treated wastewater has been identified as a secondary source of phosphorus to Sunfish Lake during the GS.

As mentioned above, SSTS in Washington County are governed by the County SSTS ordinance. The current Washington County GW Plan has identified SSTS financial assistance as a priority, and the County has several opportunities for financial assistance to upgrade or fix non-compliant SSTS, including the SSTS Fix-Up Grants and low interest loans.

In 2014, the first year of the County's program, nearly half of the SSTS loans and grants administered in Washington County were in the VBWD. There is an opportunity to continue to educate homeowners in the Sunfish Lake Watershed about the maintenance of SSTS and to target the Washington County financial assistance programs. In addition, the VBWD is considering the development of a program to assist in the inspection and replacement (or fund through their cost share) non-functioning or non-compliant SSTS in targeted watersheds.

7.3.2.3 Sunfish Lake Park Erosion Inventory

Sunfish Lake Park, a city of Lake Elmo Park, is located on the north side of Sunfish Lake. The park is a 284 acre natural area that the DNR has recognized as a "regionally significant ecological area" including woodlands, wetlands, and prairie. The topography along the north shore of Sunfish Lake is fairly steep with several ravines that flow through Sunfish Lake Park to the lake. An erosion inventory, similar to those performed in the past by the VBWD, could be performed to determine if there are any actively eroding areas in the ravines in Sunfish Lake Park that should be addressed. Restoration activities can be defined after the completion of the ravine erosion inventory, if areas have been identified.

7.4 Cost

The estimated cost for implementation of the Kelle's Creek and Sunfish Lake pollution reduction strategies are summarized in Table 7-2. Currently, most of the pollution reduction strategies identified for both Kelle's Creek and Sunfish Lake target non-permitted sources of pollutants. There are a few pollution reduction strategies that target currently permitted sources.

Table 7-2 Potential Pollutant Reduction Strategies, Potential Partners, and Estimated Costs

Potential BMP/Reduction Strategy	Estimated Cost
Kelle's Creek – Non-permitted Sources	
Non-Riparian Pasture Management: Outreach and education to promote existing programs that provide financial and technical assistance	$25,000 - $50,000
Outreach and education in relation to SSTS management and promote existing programs that provide financial and technical assistance and development of incentive program for the inspection and replacement of SSTS (beyond the existing programs).	$300,000 - $750,000
Kelle's Creek – Permitted Sources	
Afton Community Wastewater Collection and Cluster Septic System Project	$5,400,000
Sunfish Lake – Non-permitted Sources	
Alum Dosing (and macrophyte management, as needed)	$200,000 - $280,000
Outreach and education in relation to SSTS management and promote existing programs that provide financial and technical assistance and development of incentive program for the inspection and replacement of SSTS (beyond the existing programs).	$10,000 - $50,000
Erosion inventory in Sunfish Lake Park	$25,000 - $50,000
Sunfish Lake – Permitted Sources	
Continued implementation of the MPCA MS4 permit for VBWD, Lake Elmo, and Washington County, including activities such as implementation of the VBWD rules, outreach and education, street sweeping and other housekeeping activities, etc.	$200,000 - $500,000
TMDL Total Costs	
Total Estimated Cost for Non-permitted Implementation Strategies	**$560,000 - $1,180,000**
Total Estimated Cost for Permitted Implementation Strategies	**$5,600,000 - $5,900,000**
Total Cost	**$6,160,000 - $7,080,000**

8 Public Participation

Several TMDL stakeholder meetings were held between representatives of the various stakeholders in the watershed, and other applicable local and state agencies. Public meetings were also held. The goal of this process was to discuss the development and conclusions of the TMDL study, obtain input from, review results with, and take comments from those interested and affected parties.

8.1 Kelle's Creek

The TMDL technical stakeholder meetings were held on the following dates:

June 6, 2013: Kickoff meeting presenting the project and historic water quality

August 18, 2014: Presentation of the source assessment and draft TMDL WLA and LA and discussion of implementation ideas

May 27, 2015: Presentation of the final Kelle's Creek TMDL and implementation strategies

As part of this TMDL study, two public meetings were held on the following dates:

June 6, 2013: A public kickoff meeting was held at Afton City Hall to inform the general public about the Kelle's Creek TMDL study. Also included in the presentation at this meeting were the results of the Kelle's Creek resident survey conducted by Leslie Thomas (M.S. in Environmental History) and the environmental history of the Kelle's Creek Watershed.

August 18, 2014: A public meeting was held at Afton City Hall to inform the general public about the findings of the Kelle's Creek TMDL and to discuss the proposed implementation strategies.

8.2 Sunfish Lake

The TMDL technical stakeholder meetings were held on the following dates:

June 4, 2013: Kickoff meeting presenting the project and historic water quality

August 19, 2014: Presentation of the source assessment and draft TMDL WLAs and LAs and discussion of implementation ideas

May 27, 2015: Presentation of the final Sunfish Lake TMDL and implementation strategies

As part of this TMDL study, two public meetings were held on the following dates:

June 4, 2013: A public kickoff meeting was held at the Nordic Center at Lake Elmo Park Reserve to inform the general public about the Sunfish Lake TMDL study.

August 19, 2014: A public meeting was held at North St. Paul City Hall to inform the general public about the findings of the Sunfish Lake TMDL and to discuss the proposed implementation strategies.

The official TMDL public comment period was held from September 28, 2015, through October 27, 2015. Three comment letters were received.

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Appendices

Appendix A: Lake (Nutrient) TMDL Modeling

The lake water quality modeling performed for the *Valley Branch Watershed District TMDL Study* (TMDL study) included three different models to estimate the TMDL phosphorus load capacity required to meet the MPCA water quality standards. The models in the P8 pollutant loading model, a daily water balance model, and a phosphorus mass balance model that included empirical steady-state phosphorus equations and GS phosphorus balance model. Figure A-1 shows a schematic of the TMDL modeling approach.

1.0 P8 Pollutant Loading Model

The P8 pollutant loading model was used to estimate the water and phosphorus loads to Sunfish Lake. The runoff volumes predicted by the P8 model were verified using a water balance model and observed lake level data (see Water Balance Model discussion). The P8 event load file was used to extract the watershed runoff volume (acre-ft) and the predicted phosphorus associated with the different particle classes in P8 (i.e., TP loads in lbs) for each event that was modeled. Both the water and the TP loads were used in the steady state phosphorus model and the phosphorus mass balance model.

1.1 P8 Model Parameter Selection

The P8 models used to estimate the watershed loads to Sunfish Lake was developed in version 3.4 specifically for this TMDL study. The following section discusses the selected P8 model parameters used for the TMDL study. P8 parameters not discussed in the following paragraphs were left at the default setting.

1.1.1 Time Step, Snowmelt, & Runoff Parameters

Time Steps Per Hour (Integer)— 10. Selection was based upon the number of time steps required to minimize continuity errors.

Minimum Inter-Event Time (Hours)— 10. The selection of this parameter was based upon an evaluation of storm hydrographs to determine which storms should be combined and which storms should be separated to accurately depict runoff from the lake's watershed. It should be noted that the average minimum inter-event time for the Minneapolis area is 6.

Rainfall Breakpoint (inches) – 999. The rainfall breakpoint was added to the P8 model to better align with results from WinSLAMM. The default is 0.8 inches; however to not use this added parameter, the recommendation in the P8 help is to change the input to 999.

Passes Through Storm File—5. The number of passes through the storm file was determined after the model had been set up and a preliminary run completed. The selection of the number of passes through the storm file was based upon the number required to achieve model stability. Multiple passes through the storm file were required because the model assumes that dead storage waters contain no phosphorus. Consequently, the first pass through the storm file results in lower phosphorus loading than occurs with subsequent passes. Stability occurs when subsequent passes do not result in a change in phosphorus concentration in the pond waters. To determine the number of passes to select, the model was run with three passes, five passes, and ten passes. A comparison of phosphorus predictions for all devices was evaluated to determine whether changes occurred between the three scenarios.

1.1.2 Particle Selection

Particle File - nurp50.p8p: The particle file reflects the values typically associated with the NURP50 particle file. To estimate pollutant loading, P8 tracks the build-up, washoff, and settling of particles of varying size classes and settling velocities (5 sizes classes, with the smallest particle size class representing non-settleable particles). A mass of pollutant (e.g. phosphorus) is associated with a given mass of the particle size classes. The model uses pollutant loading values consistent with the National Urban Runoff program (NURP50 particle file). Table A-1 summarizes the particle class settling velocities as well as the mass of phosphorus associated with a given mass of each particle class.

Table A-1 P8 Particle Classes and Associated Phosphorus

P8 Particle Class	Description	% of TSS	Settling Velocity (ft/hr)	TP (mg TP/kg Particle)
P0%	Non-Settleable/ Dissolved	0	0	99,000
P10%	10th Percentile	20	0.03	3,850
P30%	30th Percentile	20	0.3	3,850
P50%	50th Percentile	20	1.5	3,850
P80%	80th Percentile	40	15	0

1.1.3 Climatic Data Selection

Precipitation File - MSP4813_StPaularpt2011.pcp: The P8 model uses long-term climatic data so that watershed runoff and BMPs can be evaluated for varying hydrologic conditions. Most of the hourly precipitation obtained from the Minneapolis-St. Paul airport. The St. Paul airport hourly precipitation data was used to fill in gaps in the hourly data from the Minneapolis-St. Paul airport and was used for the period from May through September 2011. A monthly adjustment factor was applied to the hourly precipitation data to match the monthly totals from a daily precipitation gage in Lake Elmo that is part of the high density precipitation network through the Minnesota State Climatology Office.

Air Temperature File - Msp4913.tmp: Average daily temperature data was obtained from the Minneapolis-St. Paul airport for the period from 1949 through 2013.

1.1.4 Watersheds Parameter Selection

Watersheds included in the VBWD Watershed Management Plan (Barr 2005) were used in the development of the Sunfish Lake P8 models. Some subwatershed divides were modified based on more recent topographic data (DNR 2012) and constructions plans for those developments constructed since the original subwatershed divides for the VBWD were created. Also, several of the subwatersheds in the Sunfish Lake watershed are landlocked and do not contribute runoff to the lake. The Sunfish Lake P8 model only includes watersheds that contribute runoff to Sunfish Lake.

Outflow Device — The device (BMP or pipe) receiving runoff from the watershed.

Impervious Fractions— The impervious fractions entered in the P8 model is reflective of the amount of directly-connected and indirectly-connected impervious area. To estimate the imperviousness within the Sunfish Lake Watershed, the 2010 Metropolitan Council land use data was used in conjunction with impervious assumptions for various land use classifications used in past VBWD watershed studies. Table A-2 summarizes the land use classifications with the assumed total percent impervious and the percent directly-connected impervious.

Table A-2 VBWD Land Use Classifications and Impervious Percentages

Historic VBWD Study Land Use Classifications	Met Council 2010 Land Use Classifications	Total Percent Impervious (%)	Directly-Connected Impervious (%)
Agricultural	Agricultural	5	0
Commercial	Retail and Other Commercial	85	80
Golf Course	Golf Course	5	2
High Density Residential	Multifamily	75	65
Highway	Major Highway	65	45
Industrial/Office	Industrial and Utility	72	70
Institutional	Institutional	40	35
Low Density Residential	Single Family Detached; Single Family Attached	25	16
Natural/Park/Open	Park, Recreational, or Preserve; Undeveloped	2	0
Other (Mining)	Extractive	2	0
Very Low Density Residential	Farmstead; Seasonal/Vacation	12	8
Open Water	Open Water	Open water surface removed from the P8 watershed areas	

Pervious Curve Number— The pervious curve number selected for the Sunfish Lake Watershed was based on current soils (hydrologic soils group) and land use information. The soils data was based on the Washington County soil survey. The curve numbers for lawns, open spaces, parks, golf courses, and cemeteries in good conditions (NRCS 1986) were selected for the pervious areas in the watershed. A weighted curve number was calculated based on the estimated pervious area and the various soils types within each subwatershed.

Swept/Not Swept—An "Unswept" assumption was made for the entire impervious watershed area, meaning the P8 model does not account for the impact of street sweeping on the watershed runoff water quality.

Depression Storage (inches) — 0.03 inches

Impervious Runoff Coefficient— 0.94

1.1.5 Device Parameter Selection

The P8 model for Sunfish Lake includes devices that represent existing wetlands and constructed watershed BMPs (devices). Information for the various BMPs includes the bathymetry of ponds and wetlands within the watersheds as well as information about the outlet structures.

Detention Pond— Permanent Pool— Area and Volume— The surface area and dead storage (water quality) volume of each detention pond was determined and entered here.

Detention Pond— Flood Pool— Area and Volume— The surface area and storage volume under flood conditions (i.e., the storage volume between the normal level and flood elevation) was determined and entered here.

Detention Pond— Infiltration Rate (in/hr) — Infiltration from the ponds was assumed to be 0.001 in/hr. This rate was selected to allow for the pond levels to drop below the normal water level (control elevation), especially during periods of limited rainfall, as is often observed in the field.

Detention Pond— Orifice Diameter and Weir Length— The orifice diameter or weir length was determined from field surveys, development plans, or storm sewer data provided by the city of Lake Elmo of the area for each detention pond and entered here.

Detention Pond or Generalized Device— Particle Removal Scale Factor— Particle Removal Scale Factor— 0.3 for ponds less than two feet deep and 1.0 for all ponds three feet deep or greater. For ponds with normal water depths between two and three feet, a particle removal factor of 0.6 was selected. The particle removal factor for watershed devised determines the particle removal by device.

1.2 P8 Model Results

Table A-3 summarizes the total event precipitation (based on the hourly precipitation and average daily temperature data, as processed by P8) for the Sunfish Lake Watershed for the 17-month period (May 1, 2005-September 30, 2006) used to perform the water quality modeling for Sunfish Lake and establish the TMDL. Also summarized in Table A-3 is the P8 predicted event watershed runoff water load and phosphorus load to Sunfish Lake, along with the event TP concentration.

Table A-3 P8 Event Water and Phosphorus Loads to Sunfish Lake (5/1/2005-9/30/2006)

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
	5/7/2005	0.01	0.0	0.0	0
	5/7/2005	0.06	0.0	0.0	355
	5/8/2005	0.31	0.1	0.2	631
	5/10/2005	0.02	0.0	0.0	1749
	5/12/2005	1.09	0.5	0.5	323
	5/14/2005	0.10	0.0	0.0	135
	5/16/2005	0.43	0.2	0.3	457
	5/18/2005	0.38	0.2	0.1	206
	5/21/2005	0.06	0.0	0.0	208
	5/25/2005	0.20	0.1	0.1	428
	5/26/2005	0.05	0.0	0.0	381
	5/27/2005	0.04	0.0	0.0	216
	5/29/2005	0.02	0.0	0.0	4742
	6/4/2005	0.39	0.2	0.3	678
	6/5/2005	0.38	0.2	0.3	581
	6/7/2005	0.03	0.0	0.0	452
	6/7/2005	0.73	0.4	0.3	301
	6/9/2005	0.35	0.2	0.2	431
	6/10/2005	0.10	0.0	0.0	158
	6/13/2005	0.32	0.2	0.2	431
	6/14/2005	0.05	0.0	0.0	153
	6/20/2005	0.55	0.3	0.5	628
	6/24/2005	0.06	0.0	0.0	353
	6/27/2005	1.03	0.5	0.5	370
	6/29/2005	0.25	0.1	0.1	396
	7/3/2005	0.17	0.1	0.1	480
	7/17/2005	0.21	0.1	0.2	1120
	7/20/2005	0.37	0.2	0.3	636
	7/23/2005	0.63	0.3	0.4	466
	7/25/2005	1.56	0.9	0.4	181
	8/3/2005	1.83	1.0	0.7	248

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
	8/8/2005	0.20	0.1	0.1	407
	8/9/2005	1.45	0.8	0.5	230
	8/11/2005	0.05	0.0	0.0	154
	8/16/2005	0.01	0.0	0.0	0
	8/18/2005	0.37	0.2	0.2	570
	8/19/2005	0.03	0.0	0.0	811
	8/26/2005	1.29	0.7	0.6	326
	9/3/2005	1.27	0.7	0.6	324
	9/5/2005	0.14	0.1	0.0	229
	9/7/2005	0.26	0.1	0.1	330
	9/8/2005	0.09	0.0	0.0	172
	9/12/2005	0.66	0.3	0.4	472
	9/19/2005	0.24	0.1	0.2	899
	9/21/2005	0.21	0.1	0.1	397
	9/24/2005	1.15	0.6	0.5	303
	9/25/2005	0.05	0.0	0.0	116
	9/28/2005	0.37	0.2	0.2	384
	10/4/2005	4.89	5.9	2.2	140
	10/12/2005	0.22	0.1	0.1	297
	10/16/2005	0.20	0.1	0.1	644
	10/21/2005	0.01	0.0	0.0	0
	10/22/2005	0.04	0.0	0.0	165
	10/30/2005	0.09	0.0	0.0	262
	11/5/2005	0.12	0.0	0.0	281
	11/12/2005	0.19	0.1	0.1	483
	11/14/2005	0.41	0.2	0.1	288
	11/27/2005	0.65	0.3	0.3	313
	12/23/2005	0.60	0.3	0.1	162
	12/28/2005	0.06	0.0	0.0	116
	1/2/2006	0.40	0.2	0.1	263
	1/12/2006	0.21	0.1	0.0	160
	1/15/2006	0.10	0.0	0.0	142
	1/24/2006	0.07	0.0	0.0	126

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
	1/26/2006	0.04	0.0	0.0	137
	1/26/2006	0.02	0.0	0.0	297
	1/28/2006	0.19	0.1	0.0	247
	2/2/2006	0.15	0.1	0.0	143
	3/1/2006	0.30	0.1	0.1	193
	3/5/2006	0.32	0.1	0.2	510
	3/7/2006	0.05	0.0	0.0	189
	3/12/2006	0.43	0.2	0.3	583
	3/23/2006	0.82	0.6	0.2	143
	3/27/2006	0.02	0.0	0.0	250
	3/29/2006	0.37	0.2	0.2	421
	4/1/2006	1.06	0.5	0.5	338
	4/6/2006	2.58	18.9	23.8	466
	4/18/2006	0.08	0.0	0.0	392
	4/20/2006	0.28	0.1	0.2	501
	4/28/2006	2.43	1.3	0.9	259
	5/2/2006	0.01	0.0	0.0	174
	5/8/2006	0.23	0.1	0.2	794
	5/12/2006	0.57	0.3	0.2	238
	5/14/2006	0.01	0.0	0.0	105
	5/15/2006	0.06	0.0	0.0	270
	5/18/2006	0.01	0.0	0.0	0
	5/25/2006	0.31	0.1	0.4	1134
	6/1/2006	0.07	0.0	0.0	375
	6/5/2006	1.04	0.5	0.6	418
	6/9/2006	0.01	0.0	0.0	9467
	6/14/2006	0.05	0.0	0.0	196
	6/16/2006	1.15	0.6	0.6	361
	6/17/2006	0.04	0.0	0.0	145
	6/20/2006	0.01	0.0	0.0	8569
	6/23/2006	0.02	0.0	0.0	0
	6/24/2006	0.42	0.2	0.2	516
	7/13/2006	0.14	0.0	0.1	608

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
	7/16/2006	0.05	0.0	0.0	229
	7/19/2006	0.71	0.3	0.5	603
	7/24/2006	0.28	0.1	0.2	773
	7/25/2006	0.02	0.0	0.0	1785
	7/31/2006	3.83	2.6	1.2	168
	8/5/2006	0.27	0.1	0.2	710
	8/10/2006	0.28	0.1	0.2	481
	8/13/2006	0.45	0.2	0.3	469
	8/16/2006	0.07	0.0	0.0	294
	8/18/2006	0.01	0.00	0.00	3199
	8/23/2006	0.76	0.37	0.51	507
	8/24/2006	1.26	0.71	0.34	178
	8/28/2006	0.06	0.01	0.01	226
	9/2/2006	1.02	0.52	0.56	394
	9/10/2006	0.03	0.00	0.00	0
	9/11/2006	0.01	0.00	0.00	0
	9/15/2006	0.19	0.07	0.13	664
	9/17/2006	0.14	0.05	0.08	570
	9/18/2006	0.03	0.00	0.00	99
	9/21/2006	0.79	0.36	0.32	325
	9/23/2006	0.13	0.05	0.04	285
	9/26/2006	0.03	0.00	0.00	99
	9/27/2006	0.06	0.01	0.01	197
Steady State Year (May 1, 2005 - April 30, 2006)		37	39	39	368
Oct 1, 2005 - April 30, 2006)		17	29	30	372
5/1/2005	**4/30/2006**	37.0	39.1	39.0	368
5/1/2006	**5/7/2006**	0.0	0.0	0.0	174
5/8/2006	**5/22/2006**	0.9	0.4	0.4	374
5/23/2006	**6/5/2006**	1.4	0.6	1.0	561
6/6/2006	**6/20/2006**	1.3	0.6	0.6	356
6/21/2006	**7/15/2006**	0.6	0.2	0.3	536

	Event Date	Event Precipitation (in)	Total P8 Runoff Volume to Lake (acre-ft)	Total P8 TP Load to Lake (lbs)	P8 Event TP Conc (ug/L)
7/16/2006	7/29/2006	1.1	0.4	0.7	640
7/30/2006	8/28/2006	7.0	4.1	2.7	242
8/29/2006	9/17/2006	1.4	0.6	0.8	438
9/18/2006	9/30/2006	1.0	0.4	0.4	316
Growing Season Load (June 1, 2006 - Sept 30, 2006)		13.4	7.0	6.1	321
Total Load (2006 Water Year - Oct 1, 2005 - Sept 30, 2006)		32.0	37	37	365

2.0 Water Balance Model

A daily water balance spreadsheet model was used to verify the runoff volumes predicted by the P8 model as well as observed lake level data (when available) to estimate the lake's volume, and discharge. A stage-area-storage-discharge curve was developed for the lake based on available bathymetry data as well as outlet geometry. The water balance was estimated using the following equation:

$$\Delta \text{ in Lake Storage} = WR + DP + US - EV - GW - D - OL$$

Where:

WR = Watershed Runoff

DP = Direct Precipitation on the surface area of the lake

US = Flows from Upstream Lakes/Sources (when applicable; based on water balance models and/or lake levels & rating curves for upstream lakes)

EV = Evaporation for lake surface based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory

GW = Average groundwater exchange fit to lake level monitoring data

D = Estimated average daily discharge based on outlet geometry

OL = Other losses (when applicable)

The results of the water (and phosphorus) balance model for Sunfish Lake are included in Appendix B.

3.0 Phosphorus Mass Balance Model

Once the P8 and water balance models are developed and checked against observed water level data, a phosphorus mass balance model was calibrated to observed water quality data using a differencing methodology. This differencing method allowed the model to be used to estimate phosphorus loading sources and losses not explicitly accounted for in the mass balance modeling during the GS of interest.

The phosphorus mass balance model was comprised of two phases, evaluating a period of 17 months (beginning on May 1 of a given year through September 30 of the following year). The first phase uses water and phosphorus loads for the first 12 months of the period (May 1 through April 30 of the following year) are used as the inputs to the empirical steady-state phosphorus equation to predict the in-lake phosphorus concentration at the beginning of the calibration period. The steady-state equations used to establish the late-spring phosphorus concentration are discussed in more detail in the main body of the report and in Appendix B.

The second phase of the water quality modeling considers the 5 month period from May 1 through September 30 to calibrate the mass balance model to observed water quality data and estimate phosphorus sources and losses to the lakes required to match the water quality monitoring data. The phosphorus mass balance model time step is variable, based on the period of time between each of the water quality monitoring events.

The mass balance equation used to estimate the internal load and calibrate the model to observed water quality data for each time step is as follows (also discussed in the main body of the report):

P Adjusted = Observed P + Outflow P + Coontail Uptake P –

Runoff P – Upstream P - Atmospheric P – Curlyleaf Pondweed P – P Initial

The following discusses each of the components of the mass balance equation and where these numbers come from based on the data available for this study as well as the P8 and water balance modeling that was performed. Appendix B includes the water and phosphorus balance modeling summary.

Observed P

The water quality data collected for each water body was used for the calibration of the mass balance model (estimation of the internal loading/losses). Surface TP is the primary parameter used for calibration (sampled collected at a depth of 0-2 m). The observed P is the amount of phosphorus in the epilimnion based on the TP concentration and the estimated epilimnion volume (estimated in the daily water balance model) at the time of the monitoring event (the end of the current timestep).

Other water quality parameters typically used to verify the water quality model include TP measurements along the water column profile (if available), water temperature, and dissolved oxygen data. Some of the water quality sampling dates have monitoring data available along the depth profile of the lake. The temperature profiles help identify the depth to the thermocline and when used in conjunction with the water balance, can estimate the epilimnetic volume during each period. Additionally, the TP and dissolved oxygen profile data can help verify if there is internal loading from the sediments due to anoxia below the thermocline and along the bottom sediments. Some of the water quality sampling dates may have only included surface water quality measurements and therefore, parameters such as depth to the thermocline, was estimated based on interpolation between known data.

Outflow P

Outflow P typically includes losses of phosphorus through surface discharge as well as through losses to the GW. The volumes of discharge during each time step were based on the daily water balance model.

The TP concentration of the discharge is assumed to be the observed surface TP data from the prior time step.

Coontail Uptake P

Qualitative macrophyte surveys were available for several years for Sunfish Lake. These surveys included areal coverage estimates as well as relative densities for a variety of macrophyte species including Coontail. Typically, surveys were also available in early and late summer, so changes in coverage and density could be estimated throughout the GS. The uptake of TP by Coontail was estimated based on average daily uptake rates presented by Lombardo and Cooke (2003) and the estimated density and coverage of the macrophyte.

Runoff P

The P8 model results were used to estimate the phosphorus associated with watershed runoff. To estimate pollutant loading, the P8 model tracks the build-up, wash-off, and settling of particles and a mass of phosphorus is associated with each particle size (see P8 discussion above). The phosphorus mass balance model tracks the various particle sizes estimated by the P8 model and assumes particles will settle out of the epilimnion based on their settling velocity (as used in P8). As a result, the SRO TP used by the mass balance model to predict the water quality in the lake is less than the TP load directly estimated by the P8 model due to particle settling.

Upstream P

The in-lake mass balance model accounts for loads from upstream lakes and water bodies. In the case of Sunfish Lake, there are no upstream lakes. However, if there were upstream waterbodies (not modeled in the P8 model), the mass balance model estimates volumes from upstream sources during each timestep were based on the daily water balance model. Typically, discharge estimates are based on lake level data and the discharge rating curves or water balance models for the upstream lakes (if available). The TP concentrations associated with upstream sources are typically based on water quality monitoring data or the phosphorus mass balance model (if available).

Atmospheric P

Atmospheric phosphorus was applied at a constant loading rate of 0.2615 kg/ha/yr (Barr 2005). This was applied to the estimated surface area of the lake at each time step.

Curlyleaf P

Qualitative macrophyte surveys were available for several years for Sunfish Lake. These surveys included areal coverage estimates as well as relative densities for a variety of macrophyte species including Curlyleaf pondweed. Using the late-spring or early-summer surveys, the coverage and density of the Curlyleaf pondweed could be estimated. The estimated biomass phosphorus content was based on data collected as part of a study of Big Lake in Wisconsin (Barr 2001) and compared to recent biomass measurements made for Medicine Lake (Vlach & Barten 2006). The phosphorus RR was based on the Half Moon Lake study (James et al. 2001).

P Initial

This parameter represents the amount of phosphorus that currently exists in the epilimnion at the start of the timestep. It is equivalent to the amount of phosphorus in the epilimnion at the end of the previous time step. At the beginning of the calibration period, the initial phosphorus concentration is based on the spring steady state phosphorus concentration estimated from the empirical relationship selected for Sunfish Lake. At the subsequent time steps in the model, the phosphorus concentrations are calibrated to the observed water quality in the lake throughout the GS.

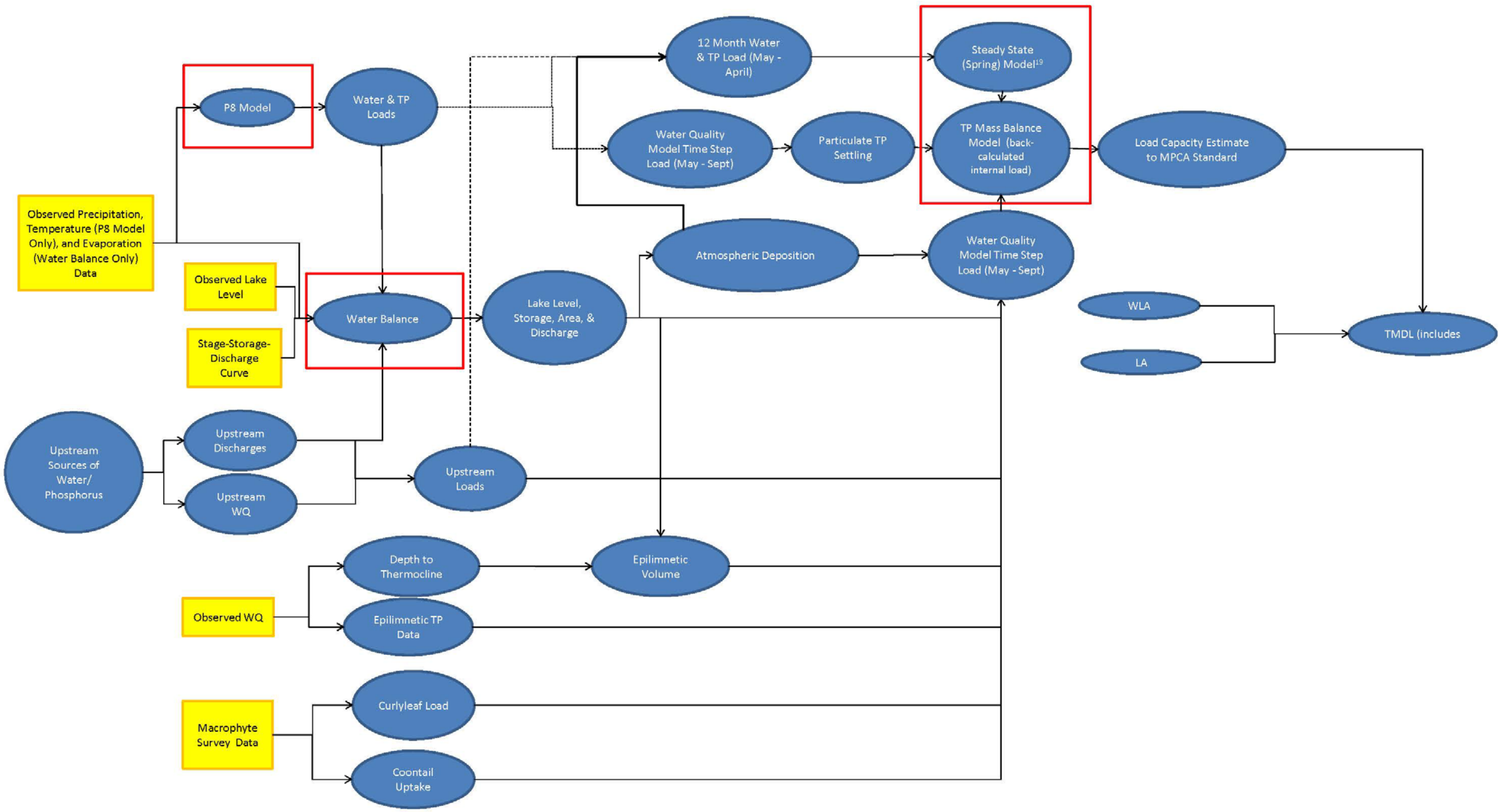
P Adjusted

Once the known sources and losses of phosphorus were quantified, the required TP loading adjustment could be back calibrated so that the predicted phosphorus concentration in the epilimnion matches the observed TP data. The phosphorus adjustment can be either loading or losses of phosphorus. Losses of phosphorus are minimized through the calibration process and the estimated TP loading into the lake is verified against the results of the sediment core analysis.

Using the Calibrated Mass Balance Model

Once the in-lake mass balance model was calibrated for each lake, the models were used in a predictive manner to evaluate the impact of changes in water and phosphorus loading on the lake water quality. Additionally, the mass balance was used to estimate the TMDL load capacity and required phosphorus load reduction that would result in the expected in-lake water quality that would meet the MPCA water quality standards during the GS period.

Figure A-1 TMDL Modeling Process Flow Chart



Appendix B Sunfish Lake Water and Phosphorus Balance Model

B-1: Sunfish Lake 2006 Climatic Conditions - Water Balance Summary

	Sample Period		A	B	C	D	E	F	G	H	I	J
			Total Lake Volume at the Start of the Period (acre-ft)	Direct Precipitation (acre-ft)	Evaporation (acre-ft)	Watershed Runoff (acre-ft)	Groundwater Inflow (acre-ft)	Surface Discharge (acre- ft)	Groundwater Outflow (acre-ft)	Change in Lake Volume (acre-ft)	Total Lake Volume at the End of the Period (acre- ft)	Lake Level at End of Period (ft MSL)
				+	-	+	+	-	-			
Steady State Year (May 1, 2005 - April 30, 2006)	5/1/2005	4/30/2006	371	198	153	39	15	0	40	60	431	894.5
(Oct 1, 2005 - April 30, 2006)	10/1/2005	4/30/2006	343	95	36	29	15	0	16	88	431	894.5
In-Lake Water Quality Phosphorus Mass Balance Calibration Period (May 1, 2006 - Sept 30, 2006)	5/1/2006	5/7/2006	431	0	6	0	4	0	0	-1	429	894.5
	5/8/2006	5/22/2006	429	6	13	0	10	0	0	3	432	894.5
	5/23/2006	6/5/2006	432	9	14	1	6	0	0	2	434	894.5
	6/6/2006	6/20/2006	434	8	17	1	0	0	0	-9	425	894.4
	6/21/2006	7/15/2006	425	4	30	0	0	0	0	-26	399	894.0
	7/16/2006	7/29/2006	399	6	17	0	0	0	0	-10	389	893.8
	7/30/2006	8/28/2006	389	41	24	4	0	0	0	21	410	894.1
	8/29/2006	9/17/2006	410	8	10	1	0	0	0	-1	408	894.1
	9/18/2006	9/30/2006	408	6	6	0	0	0	0	0	408	894.1
Total for Growing Season (June 1, 2006 - Sept 30, 2006)	6/1/2006	9/30/2006	432	79	111	7	1	0	0	-24	408	894.1
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)	10/1/2005	9/30/2006	343	182	173	37	36	0	16	66	408	894.1

Annual (2006 Water Year) Water Load to Sunfish Lake (acre-ft)	10/1/2005	9/30/2006	255	Water Load = B + D + E

A - Based on the daily water balance model (calibrated to lake level data and using the lake stage-storage-discharge curve). See Tab "WaterBalance"
B - Based on precipitation data used for the P8 modeling and the daily water balance model (Direct Precip Volume = Depth of Precip * Lake Surface Area). See Tab "P8EventSummary".
C - Based on adjusted pan evaporation data from the University of Minnesota St. Paul Campus Climatological Observatory and the daily water balance model (Evap Volume = 0.7 * Depth of Evap * Lake Surface Area). See Tab "Evap" D - Based on the water loads from the P8 model. See Tab "P8EventSummary"
E - Groundwater Inflow estimated in the daily water balance model. See tab "WaterBalance". Sunfish Lake defined as a groundwater flow through water body in the "Integrating Groundwater and Surface Water Management in Southern Washington County" (Barr, Washington County, WCD, 2005).
F - Surface discharge assumed to be zero based on lake level data and the fact that Sunfish Lake is landlocked (no outlet). See Tab "Lake Rating Curve"
G - Groundwater Discharge estimated in the daily water balance model. See tab "WaterBalance". Sunfish Lake defined as a groundwater flow through water body in the "Integrating Groundwater and Surface Water Management in Southern Washington County" (Barr, Washington County, WCD, 2005).
H - Change in Lake Volume = B - C + D + E - F - G I -
Total Lake Volume @ End of Period = A + G
J - Estimated lake level based on the total lake volume and the stage-storage-discharge curve. See Tab "Lake Rating Curve"

B-2: Sunfish Lake 2006 Climatic Conditions - In-Lake Growing Season Mass Balance Model Summary[1]

Period Start		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		Epilimnion Volume	P In-Lake @ Start of Period	Total P Watershed Runoff	P Surface Runoff (after Particulate Settling)[5]	P From SSTS	P Atmospheric	P GW	P Release from Curlyleaf Pondweed[4]	P Uptake by Coontail[4]	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observed In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)[6]	P In-Lake @ End of Period	Predicted In-Lake P[2]
		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/l	ug/L	ug/l	lbs	lbs	ug/L
Steady State Total (May 1, 2005 - April 30, 2006)[3,4,7]		362	N/A	39.0	19.1	9.7	15.7	1.0	N/A	N/A	8.7	N/A	N/A	N/A	N/A	N/A	N/A	79.9
(Oct 1, 2005 - April 30, 2006)[3,7]		362	N/A	29.7	14.5	5.6	8.6	1.0	0	0	3.5	N/A	N/A	N/A	N/A	N/A	N/A	79.9
5/1/06	5/7/06	402	79	0.0	0.0	0.2	0.3	0.3	0.0	0.5	0.0	79.0	72	69	-3	-3.6	75.4	69
5/8/06	5/22/06	404	75	0.4	0.1	0.4	0.7	0.6	0.0	1.1	0.0	76.2	69	70	1	0.6	76.9	70
5/23/06	6/5/06	405	77	1.0	0.7	0.4	0.7	0.4	0.0	1.0	0.0	78.1	71	58	-13	-14.1	64.0	58
6/6/06	6/20/06	399	64	0.6	0.3	0.4	0.7	0.0	0.0	1.1	0.0	64.3	59	50	-9	-10.1	54.2	50
6/21/06	7/15/06	378	54	0.3	0.1	0.7	1.1	0.0	4.1	1.9	0.0	58.4	57	65	8	8.5	66.8	65
7/16/06	7/29/06	370	67	0.7	0.3	0.4	0.6	0.0	0.8	1.0	0.0	67.9	67	92	25	24.7	92.6	92
7/30/06	8/28/06	386	93	2.7	1.3	0.8	1.4	0.0	0.2	2.2	0.0	94.1	90	55	-35	-36.3	57.8	55
8/29/06	9/17/06	385	58	0.8	0.3	0.5	0.9	0.0	0.0	1.5	0.0	58.1	55	60	5	4.8	62.9	60
9/18/06	9/30/06	386	63	0.4	0.2	0.3	0.6	0.0	0.0	1.0	0.0	63.1	60	60	0	-0.2	62.9	60
Growing Season Total (June 1, 2006 - Sept 30, 2006)[7]		N/A	N/A	6.1	2.7	3.2	5.6	0.2	5.2	9.0	0.0	N/A	N/A	N/A	N/A	-13.6	N/A	N/A
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)[3,7]		N/A	N/A	36.5	18	9.7	15.7	2.4	5.2	11.3	3.5	N/A	N/A	N/A	N/A	-25.7	N/A	N/A
																	Growing Season Average (6/1/2006 - 9/30/2006)[3]	63

General Mass Balance Differencing Equation: Padj = Pobs - Pinitial - Psurf - PISTS - Patm - Pclpw + Pcoon + Pdis

Ratio of Watershed Runoff After Settling to Total Watershed Runoff: 0.489

1 - Reflective of in-lake water quality model calibration conditions (2006 watershed conditions)
2 - Growing Season Average Reflects WQ data from June through September
3 - An empirical model (Dillon and Rigler (1974) with Larsen and Mercier (1976)) retention coefficient) was used to predict the steady state phosphorus concentration at the beginning of the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006.
4 - Phosphorus release from Curlyleaf pondweed and uptake by coontail was not estimated for the Steady State year because phosphorus mass balance modeling was not performed for the period from May 1, 2005 - April 30, 2006. Also, it was assumed that during the period from October 1 - April 30 the phosphorus loading due to Curlyleaf pondweed and uptake by coontail would be negligible due to the growth/die back cycles of these macrophytes during this season.
5 - The reported phosphorus load associated with surface runoff during the Steady State period, as well as the period from October 1, 2005 - April 30, 2006 reflects the total watershed runoff load multiplied by the ratio of watershed runoff P load after settling to the total watershed runoff P load.
6 - The growing season and water year total phosphorus adjustment values represents the net phosphorus adjustment (including both phosphorus loads to the lake as well as losses such as sedimentation). The total phosphorus adjustment will not match the total "internal loading from other sources" in Tab "PSourceSummary" which only summarizes the (positive) loads to the lake.
7 - For Total Loads, total rounded to the nearest tenth of a pound for reporting purposes.
A - See Tab "PhysicalParameters". The epilimnion volume represents the predicted epilimnion volume at the end of the time period.
B - Amount of phosphorus present in lake at the beginning of the timestep (based on spring steady state or observed TP concentration and epilimnetic volume from the previous timestep). C - Based on the Watershed TP Load before Particle Settling. See Tab "Particle Settling Summary"
D - Based on the Watershed TP Load after Particle Settling. See Tab "Particle Settling Summary"
E - Based on estimated load from failing SSTS in the direct watershed. See Tab "Upstream_DischargeSummary" F - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) over the surface area of the lake G - Load from Groundwater Inflow. See Tab "Upstream_DischargeSummary"
H - Based on a phosphorus release rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Tab "Curlyleaf Decay Summary" I - Based on average daily uptake rate that is applied throughout the growing season according to estimated areal coverage and density from the available macrophyte survey information. See Tab "Coontail Uptake Summary" J - Discharge from the lake includes surface discharge and losses to groundwater multiplied by the total phosphorus concentration from the previous time period. See Tab "Upstream_DischargeSummary"
K - P Remaining in Lake = B + D + E + F + G + H - I - J L - In-Lake P before Adj = K / A / 0.00272
M - Water quality monitoring data. See Tab "WQ Data"
N - Residual Adjustment = M - L; The Residual Adjustment is the calibration parameter used to describe the internal phosphorus loads to the lake not explicitly estimated (e.g. release from bottom sediments, resuspension due to fish activity or wind, etc.), to estimate the O - Residual Adj Load = N*A * 0.00272. Positive values are treated as a phosphorus source to the lakes such as sediment release while negative values are handled as a sink, such as sedimentation.
P - P In-Lake at End of Period = K + O
Q - Predicted In-Lake P is a check against the Observed In-Lake P.

B-3: Sunfish Lake 2006 Climatic Conditions - In-Lake Growing Season Mass Balance Model - Load Reduction Estimate

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
		Epilimnion Volume	P In-Lake @ Start of Period	Total P Watershed Runoff	P Surface Runoff (after Particulate Settling)	P From SSTS	P Atmospheric	P GW	P Release from Curlyleaf Pondweed	P Uptake by Coontail	P Loss due to Discharge	P Remaining in lake	In-Lake P before Adjustment	Observed In-Lake P	Residual Adjustment (Internal Loading / Losses)	Residual Adjustment (Internal Loading / Losses)	P In-Lake @ End of Period	Predicted In-Lake P
Period Start		acre-ft	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs	ug/l	ug/L	ug/l	lbs	lbs	ug/L
Steady State Total (May 1, 2005 - April 30, 2006)		362																79.9
(Oct 1, 2005 - April 30, 2006)		362																79.9
5/1/06	5/7/06	402	78.7	0.0	0.0	0.0	0.2	0.3	0.0	0.5	0.0	78.7				-3.6	75	69
5/8/06	5/22/06	404	75.1	0.4	0.2	0.0	0.4	0.6	0.0	1.1	0.0	75.2				0.6	76	69
5/23/06	6/5/06	405	75.9	1.0	0.5	0.0	0.4	0.4	0.0	1.0	0.0	76.1				-13.7	62	57
6/6/06	6/20/06	399	62.4	0.6	0.3	0.0	0.4	0.0	0.0	1.1	0.0	62.0				-9.7	52	48
6/21/06	7/15/06	378	52.3	0.3	0.2	0.0	0.7	0.0	4.1	1.9	0.0	55.4				8.5	64	62
7/16/06	7/29/06	370	63.8	0.7	0.4	0.0	0.4	0.0	0.8	1.0	0.0	64.3				24.7	89	88
7/30/06	8/28/06	386	89.0	2.7	1.3	0.0	0.8	0.0	0.2	2.2	0.0	89.2				-34.4	55	52
8/29/06	9/17/06	385	54.8	0.8	0.4	0.0	0.5	0.0	0.0	1.5	0.0	54.2				4.8	59	56
9/18/06	9/30/06	386	59.0	0.4	0.2	0.0	0.3	0.0	0.0	1.0	0.0	58.6				-0.2	58	56
Growing Season Total (June 1, 2006 - Sept 30, 2006)																		
Total for Water Year 2006 (Oct 1, 2005 - Sept 30, 2006)																		
																		59.9

B-4 Sunfish Lake 2006 Water Quality

Date	Water Surface Elevation (ft msl)	Secchi Disc Depth (m)	Depth to Thermocline (m)	Sample Depth (m)	Chl-a (µg/l)	D.O. (mg/l)	Temp. (°C)	Total P (mg/L)
4/23/06	894.23	0.5	4	0-2	31			0.065
4/23/06	894.23			0.0			15.3	
5/1/06	894.47	0.4	4	0-2	45			0.0673
5/1/06	894.47			0.0			15.5	
5/7/06	894.45	0.4	3	0-2	55			0.069
5/7/06	894.45			0.0			15.8	
5/22/06	894.49	0.4	3	0-2	44			0.07
5/22/06	894.49			0.0			18.4	
6/5/06	894.53	0.5	3	0-2	29			0.058
6/5/06	894.53			0.0			25.2	
6/20/06	894.39	0.5	3	0-2	27			0.05
6/20/06	894.39			0.0			24.8	
7/15/06	893.96	0.5	3	0-2	25			0.065
7/15/06	893.96			0.0			28.8	
7/29/06	893.80	0.4	3	0-2	34			0.092
7/29/06	893.80			0.0			28.9	
8/28/06	894.13	0.4	3	0-2	54			0.055
8/28/06	894.13			0.0			22.9	
9/17/06	894.11	0.4	3	0-2	50			0.06
9/17/06	894.11			0.0			20.8	
9/30/06	894.12	0.4	3	0-2	45			0.06
9/30/06	894.12			0.0			16	
10/1/06	894.11	0.4	3	0-2	45			0.06
10/1/06	894.11			0.0			16	

B-5 Sunfish Lake Stage/Storage/Discharge Rating Curve

Elevation (NGVD29 (ft MSL)	(ac)	Cumulative (ac-ft)	(cfs)
879.6	0.0	0.0	0.0
880.6	0.6	0.3	0.0
881.6	2.4	1.8	0.0
882.6	6.0	6.0	0.0
883.6	10.8	14.4	0.0
884.6	15.8	27.7	0.0
885.6	21.5	46.3	0.0
886.6	27.0	70.6	0.0
887.6	31.7	99.9	0.0
888.6	36.2	133.8	0.0
889.6	40.7	172.2	0.0
890.6	45.0	215.1	0.0
891.6	50.1	262.6	0.0
892.6	57.0	316.2	0.0
893.6	67.2	378.3	0.0
894.6	77.5	440.4	0.0
895.6	87.7	502.6	0.0
902.1	91.5	1079.5	0.0
905.3	99.1	1392.1	0.0
908.6	105.0	1726.9	0.0

B-6 Sunfish Lake Historic Lake Level Data

	Elevation (NGVD29 datum)
1/1/1999	896.76
2/1/1999	896.71
3/1/1999	896.48
4/8/1999	896.89
4/16/1999	896.94
5/1/1999	896.81
5/1/1999	896.8
5/20/1999	896.94
6/1/1999	896.93
6/16/1999	896.9
7/1/1999	896.81
7/22/1999	896.44
8/1/1999	896.57
8/18/1999	896.34
9/1/1999	896.45
9/15/1999	896.32
10/4/1999	896.14
10/12/1999	896
10/26/1999	895.82
10/28/1999	895.89
12/1/1999	895.76
1/1/2000	895.86
2/1/2000	895.99
3/1/2000	895.81
3/24/2000	895.61
4/1/2000	895.71
4/6/2000	895.47
4/19/2000	895.37
5/1/2000	895.3
5/19/2000	895.41
6/1/2000	895.39
6/30/2000	895.17
7/1/2000	895.18
7/6/2000	895.11
7/19/2000	895.15
8/1/2000	894.93
8/10/2000	894.92
9/1/2000	894.94
9/8/2000	895.06
9/28/2000	894.71
10/25/2000	894.45
11/1/2000	894.56
12/1/2000	894.64
1/1/2001	894.68
2/1/2001	894.85
3/1/2001	894.83
4/1/2001	894.73
4/19/2001	894.66
5/1/2001	894.94
6/1/2001	894.9
7/1/2001	894.96
8/1/2001	894.71
9/1/2001	894.41
10/1/2001	894.4
10/26/2001	894.28
12/1/2001	894.46
1/1/2002	894.48
2/1/2002	894.48
3/1/2002	894.48
4/1/2002	894.48
4/15/2002	894.75
5/1/2002	894.98
5/29/2002	894.9
8/1/2002	895.1
9/1/2002	895.06
10/4/2002	895.12
11/1/2002	895.16
11/12/2002	894.75
12/1/2002	895.1
1/1/2003	895.12
4/1/2003	894.62
4/14/2003	894.97
5/1/2003	894.79
6/1/2003	895.14

B-6 Sunfish Lake Historic Lake Level Data

	Elevation (NGVD29 datum)
7/1/2003	895.25
8/1/2003	894.96
9/1/2003	894.45
10/3/2003	894.25
11/4/2003	894.17
12/1/2003	894.17
1/1/2004	894.19
4/1/2004	894.27
4/12/2004	894.45
5/1/2004	894.15
5/27/2004	894.46
6/4/2004	893.85
7/1/2004	894.21
8/1/2004	893.83
9/1/2004	893.45
10/1/2004	893.47
11/1/2004	893.47
12/1/2004	893.36
4/1/2005	893.24
4/14/2005	894.24
4/25/2005	894.24
4/25/2005	894.24
5/1/2005	893.49
6/1/2005	893.47
7/1/2005	893.45
8/1/2005	893.03
9/1/2005	892.96
10/1/2005	892.99
11/1/2005	893.29
12/1/2005	893.29
4/20/2006	894.23
5/1/2006	894.58
6/1/2006	894.47
4/12/2007	893.79
4/28/2008	891.83
5/1/2008	891.84
6/1/2008	891.74
7/1/2008	891.6
8/1/2008	891.15
9/1/2008	890.9
9/30/2008	890.75
10/1/2008	890.47
11/1/2008	889.37
4/17/2009	890.51
6/29/2009	889.76
7/15/2009	889.47
4/14/2010	888.99
4/28/2011	889.56
5/5/2011	889.62
6/3/2011	889.76
6/14/2011	889.68
7/13/2011	889.98
9/7/2011	890.86
10/3/2011	890.78
11/3/2011	890.86
4/11/2012	891.78
5/9/2012	892.32
6/4/2012	892.24
6/19/2012	892.24
7/19/2012	891.92
8/13/2012	891.68
9/12/2012	891.22
10/9/2012	890.88
11/6/2012	890.56
5/7/2013	891.79
5/16/2013	891.71
6/11/2013	891.85
7/10/2013	892.59
8/6/2013	892.27
9/4/2013	891.75
9/24/2013	891.55
10/22/2013	891.75

B-7: 2006 Precipitation and Snowmelt (as predicted by the P8 model)

	Rainfall	Snowmelt
5/7/2005	0.07	0.00
5/8/2005	0.31	0.00
5/10/2005	0.02	0.00
5/12/2005	1.09	0.00
5/14/2005	0.10	0.00
5/16/2005	0.43	0.00
5/18/2005	0.38	0.00
5/21/2005	0.06	0.00
5/25/2005	0.20	0.00
5/26/2005	0.05	0.00
5/27/2005	0.04	0.00
5/29/2005	0.02	0.00
6/4/2005	0.39	0.00
6/5/2005	0.38	0.00
6/7/2005	0.76	0.00
6/9/2005	0.35	0.00
6/10/2005	0.10	0.00
6/13/2005	0.32	0.00
6/14/2005	0.05	0.00
6/20/2005	0.55	0.00
6/24/2005	0.06	0.00
6/27/2005	1.03	0.00
6/29/2005	0.25	0.00
7/3/2005	0.17	0.00
7/17/2005	0.21	0.00
7/20/2005	0.37	0.00
7/23/2005	0.63	0.00
7/25/2005	1.56	0.00
8/3/2005	1.83	0.00
8/8/2005	0.20	0.00
8/9/2005	1.45	0.00
8/11/2005	0.05	0.00
8/16/2005	0.01	0.00
8/18/2005	0.37	0.00
8/19/2005	0.03	0.00
8/26/2005	1.29	0.00
9/3/2005	1.27	0.00
9/5/2005	0.14	0.00
9/7/2005	0.26	0.00
9/8/2005	0.09	0.00
9/12/2005	0.66	0.00
9/19/2005	0.24	0.00
9/21/2005	0.21	0.00
9/24/2005	1.15	0.00
9/25/2005	0.05	0.00
9/28/2005	0.37	0.00
10/4/2005	4.89	0.00
10/12/2005	0.22	0.00
10/16/2005	0.20	0.00
10/21/2005	0.01	0.00
10/22/2005	0.04	0.00
10/30/2005	0.09	0.00
11/5/2005	0.12	0.00
11/12/2005	0.19	0.00
11/14/2005	0.41	0.00
11/27/2005	0.52	0.13
12/23/2005	0.00	0.60
12/28/2005	0.00	0.06
1/2/2006	0.22	0.18

	Rainfall	Snowmelt
1/12/2006	0.00	0.21
1/15/2006	0.00	0.10
1/24/2006	0.01	0.06
1/26/2006	0.02	0.04
1/28/2006	0.19	0.00
2/2/2006	0.00	0.15
3/1/2006	0.00	0.30
3/5/2006	0.31	0.02
3/7/2006	0.05	0.00
3/12/2006	0.43	0.00
3/23/2006	0.06	0.75
3/27/2006	0.02	0.00
3/29/2006	0.37	0.00
4/1/2006	1.06	0.00
4/6/2006	2.58	0.00
4/18/2006	0.08	0.00
4/20/2006	0.28	0.00
4/28/2006	2.43	0.00
5/2/2006	0.01	0.00
5/8/2006	0.23	0.00
5/12/2006	0.57	0.00
5/14/2006	0.01	0.00
5/15/2006	0.06	0.00
5/18/2006	0.01	0.00
5/25/2006	0.31	0.00
6/1/2006	0.07	0.00
6/5/2006	1.04	0.00
6/9/2006	0.01	0.00
6/14/2006	0.05	0.00
6/16/2006	1.15	0.00
6/17/2006	0.04	0.00
6/20/2006	0.01	0.00
6/23/2006	0.02	0.00
6/24/2006	0.42	0.00
7/13/2006	0.14	0.00
7/16/2006	0.05	0.00
7/19/2006	0.71	0.00
7/24/2006	0.28	0.00
7/25/2006	0.02	0.00
7/31/2006	3.83	0.00
8/5/2006	0.27	0.00
8/10/2006	0.28	0.00
8/13/2006	0.45	0.00
8/16/2006	0.07	0.00
8/18/2006	0.01	0.00
8/23/2006	0.76	0.00
8/24/2006	1.26	0.00
8/28/2006	0.06	0.00
9/2/2006	1.02	0.00
9/10/2006	0.03	0.00
9/11/2006	0.01	0.00
9/15/2006	0.19	0.00
9/17/2006	0.14	0.00
9/18/2006	0.03	0.00
9/21/2006	0.79	0.00
9/23/2006	0.13	0.00
9/26/2006	0.03	0.00
9/27/2006	0.06	0.00
9/29/2006	0.01	0.00

B-8: St. Paul Campus Monthly Pan Evaporation Data

ST. PAUL CAMPUS CLIMATOLOGICAL OBSERVATORY 21-8450-6

Source http://climate.umn.edu/img/wxsta/pan-evaporation.htm

MONTHLY PAN EVAPORATION, INCHES

Year		APRIL 21-30	MAY	JUNE	JULY	AUG.	SEPT.	OCT. 1-10	TOTAL
1972	*	1.86	6.08	8.03	6.76	5.62	4.08	0.92	33.35
1973		1.75	5.82	8.45	8.73	7.64	4.33	0.89	37.61
1974		2.03	5.54	7.46	9.46	6.49	4.62	1.29	36.89
1975		0.7	7.02	6.34	9.41	6.58	4.29	2.08	36.42
1976	*	1.86	8.4	11.08	10.96	10.54	6.62	1.61	51.07
1977		2.94	9.42	8.48	9.2	6.65	4.06	0.96	41.71
1978		1.61	8	7.21	6.87	8.3	6.02	1.21	39.22
1979		1.3	6.32	8.53	7.82	5.23	5.33	1.18	35.71
1980		2.88	7.62	7.75	8.83	6.55	4.51	1.47	39.61
1981		1.14	6.45	6.61	7.72	5.83	4.97	0.84	33.56
1982		2.77	6.29	7.49	8.52	7.81	4.21	0.85	37.94
1983	*	1.86	6.53	7.05	8.47	7.23	4.52	1.23	36.89
1984		2.37	7.13	6.88	8.88	7.26	5.24	1.03	38.79
1985		1.98	7.79	7.89	9.07	5.95	4.39	0.95	38.02
1986		1.65	7.21	8.34	7.97	6.71	3.88	1.2	36.96
1987		2.88	8.33	10.96	8.62	7.01	5.36	1.74	44.9
1988		1.77	10.38	11.83	11.73	8.96	5.2	1.54	51.41
1989		1.74	6.47	7.8	8.93	7.26	5.9	1.57	39.67
1990		1.96	6.27	7.24	7.65	6.63	5.45	1.71	36.91
1991		2.09	5.24	7.9	7.44	6.31	4.04	1.08	34.1
1992		1.32	8.83	6.89	5.8	6.69	4.8	1.3	35.63
1993		2.01	5.44	6.46	6.94	6.38	4.1	1.58	32.91
1994		1.32	8.67	7.36	7.02	6.58	3.94	1.18	36.07
1995		1.45	6.16	7.24	7.98	5.8	4.66	0.84	34.13
1996		1.75	5.95	6.53	7.53	7.71	4.6	1.47	35.54
1997		1.99	5.91	7.42	5.43	4.97	4.34	1.51	31.57
1998		2.22	7.5	5.57	7.32	5.79	5.13	0.72	34.25
1999		1.95	6.15	6.26	7.92	5.57	4.71	1.01	33.57
2002		1.11	6.25	7.25	6.69	6.09	4.47	0.71	32.57
2003		2.09	5.93	6.23	6.88	6.84	5.25	1.39	34.61
2004		1.91	5.41	6.3	6.63	5.14	4.91	1.27	31.57
2005		1.2	4.35	6.96	8.82	6.49	4.81	1.2	33.83
2006		1.21	5.98	7.91	9.16	5.72	3.29	1.41	34.68
2007		2.19	6.86	8.81	8.7	6.12	5.38	1.37	39.43
2008	*	1.86	6.83	6.42	8.71	7.83	4.57	1.26	37.48
2009		1.81	8.22	6.94	7.1	6.09	4.78	0.71	35.65
2010		1.81	6.02	5.99	7.66	7.72	4.19	1.35	34.74
2011	*	1.86	5.17	7.21	7.7	6.57	4.83	2.32	35.66
2012		1.48	7.74	8.13	8.41	7.14	6.37	1.34	40.61
2013	*	1.86	6.09	7.31	8.39	7.26	4.89	1.44	37.24
	*	TOO FEW DAYS FOR THESE APRILS, AVERAGE SUBSTITUTED							

Evaporation from November to March assumed to be negligible.

Pan Coefficient

0.7

B-9: Sunfish Lake - 2006 - In-Lake Steady State Summary

Parameter	Value[1]	Comments
L=Areal Load (mg/m²/yr) From May to May	109.1	(Watershed Load + Atmospheric Load) / Surface Area
Point Source Loading (mg/yr)	0.0	
Watershed Load (mg/yr)	22604357	P8 Watershed Load[2] + Upstream Source Loads[3]
Atmospheric Load (mg/yr)	7128874	Atmospheric Deposition Rate * Surface Area = 0.2915 kg/ha/yr * Surface Area
qs =Overflow Rate (m/yr)	0.5	Outflow / Surface Area
V=Volume (m³)	467581	Lake Volume[4]
A=Surface Area (m²)	272615	Surface Area[4]
td= Residence Time (yr)	3.7	Volume / Outflow
z= mean Depth (m)	1.7	Volume / Surface Area
Q=Outflow (m³/yr)	127806	Inflow = Watershed Runoff + Upstream Inflows + Direct Precip = Outflow
r =Flushing Rate (yr-1)	0.3	1 / Residence Time
	Predicted TP Conc (ug/L)	
Larsen and Mercier (1976) Rp=1/(1+r^(1/2))	80	

1 - Based on May 1, 2005 through April 30, 2006

2 - See Tab "P8EventSummary"

3 - See Tab "UpstreamDischargeSummary", Column G

4 - At Average Water Level; See Tab "General Information"

B-10: Sunfish Lake 2006 Physical Parameter Summary

Period		A	B	C		D	E	F	G	H
		Atmos. Dep	Water Surface Elev	Depth to Thermocline		Elevation of Thermocline	Epilimnion Volume	Surface Area	Hypolimnion Volume	Hypolimnion Area
From	To	(lbs)	(ft MSL)	(m)	(ft)	(ft MSL)	(acft)	(acre)	(acft)	(ac)
5/1/05	4/30/06	15.7	893.6	3.0	9.8	883.8	362	67	17	12
5/1/06	5/7/06	0.3	894.5	3.0	9.8	884.6	402	76	27	16
5/8/06	5/22/06	0.7	894.5	3.0	9.8	884.7	404	76	28	16
5/23/06	6/5/06	0.7	894.5	3.0	9.8	884.7	405	76	29	16
6/6/06	6/20/06	0.7	894.4	3.0	9.8	884.5	399	75	27	15
6/21/06	7/15/06	1.1	894.0	3.0	9.8	884.1	378	71	21	13
7/16/06	7/29/06	0.6	893.8	3.0	9.8	884.0	370	69	19	12
7/30/06	8/28/06	1.4	894.1	3.0	9.8	884.3	386	72	23	14
8/29/06	9/17/06	0.9	894.1	3.0	9.8	884.3	385	72	23	14
9/18/06	9/30/06	0.6	894.1	3.0	9.8	884.3	386	72	23	14

A - Atmospheric deposition applied at rate of 0.2915 kg/ha/yr (0.000639 lbs/ac/d) (Barr, 2005) over the surface area of the lake: A = F * (0.000639 lb/ac/d) * (# of Days)
B - Based on the daily water balance model. See Tab "WaterBalanceSummary", Column J
C - Estimated based on historic water quality profile data for Sunfish Lake (as profile data not available in 2006).
D - Elevation of the Thermocline: D = B - C
E - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"
F - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"
G - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"
H - Estimated using the lake stage-storage-discharge curve. See Tab "Lake Rating Curve"

B-11: Sunfish Lake Summary of 2006 Upstream Loads and Discharges

		A	B	C	D	E	F	G	H	I	J	K	L	M	N
		Upstream Inflows							Discharges						
		Groundwater Inflow Volume	Groundwater [TP]	Groundwater Inflow Load	SSTS Inflow Volume	SSTS [TP]	SSTS Inflow Load	Total TP Load From Upstream Sources	Surface Discharge Volume	Discharge [TP]	Surface Discharge Load	Groundwater Discharge Volume	Discharge [TP]	Groundwater Discharge Load	Total Discharge
From	To	(acft)	(µg/L)	(lbs)	(acft)	(µg/L)	(lbs)	(lbs)	(acft)	(µg/L)	(lbs)	(acft)	(µg/L)	(lbs)	(lbs)
Steady State Year (May 1, 2005 - April 30, 2006)[1,2]		15.3	25	1.0	0.0	1204545	9.7	10.7	0.0	80	0.0	40	80	8.7	8.7
(Oct 1, 2005 - April 30, 2006)[1,2]		15.3	25	1.0	0.0	1204545	5.6	6.7	0.0	80	0.0	16	80	3.5	3.5
5/1/2006	5/7/2006	4.4	25	0.3	0.0	1204545	0.2	0.5	0.0	80	0.0	0	80	0.0	0.0
5/8/2006	5/22/2006	9.5	25	0.6	0.0	1204545	0.4	1.0	0.0	69	0.0	0	69	0.0	0.0
5/23/2006	6/5/2006	6.3	25	0.4	0.0	1204545	0.4	0.8	0.0	70	0.0	0	70	0.0	0.0
6/6/2006	6/20/2006	0.0	25	0.0	0.0	1204545	0.4	0.4	0.0	58	0.0	0	58	0.0	0.0
6/21/2006	7/15/2006	0.0	25	0.0	0.0	1204545	0.7	0.7	0.0	50	0.0	0	50	0.0	0.0
7/16/2006	7/29/2006	0.0	25	0.0	0.0	1204545	0.4	0.4	0.0	65	0.0	0	65	0.0	0.0
7/30/2006	8/28/2006	0.0	25	0.0	0.0	1204545	0.8	0.8	0.0	92	0.0	0	92	0.0	0.0
8/29/2006	9/17/2006	0.0	25	0.0	0.0	1204545	0.5	0.5	0.0	55	0.0	0	55	0.0	0.0
9/18/2006	9/30/2006	0.0	25	0.0	0.0	1204545	0.3	0.3	0.0	60	0.0	0	60	0.0	0.0
Growing Season Total				**0.2**			**3.2**	**3.4**	0.0		**0.0**			**0.0**	**0.0**
Total for Water Year 2006				**2.4**			**9.7**	**12.1**	0.0		**0.0**			**3.5**	**3.5**

1 - A phosphorus mass balance was not performed specifically for the Steady State period (May 1, 2005 - April 30, 2006). An empirical model (Dillon and Rigler (1974) with Larsen and Mercier (1976) retention coefficient) was used to predict the steady state phosphorus concentration used as the starting concentration for the phosphorus mass balance model developed for the period from May 1, 2006 - September 30, 2006. See Tab "SpringSteadyStateSummary"
2 - For Total Loads, total rounded to the nearest tenth of a pound for reporting purposes. A - Based on daily water balance model.
See Tab "WaterBalanceSummary"
B - Based on estimated load from groundwater inflow. Concentration from USGS Scientific Investigations Report 2005-5120
Water Quality Assessment of Part of the Upper Mississippi River Basin, Minnesota & Wisconsin - Ground Water Quality Along a Flow System in the Twin Cities Metropolitan Area, Minnesota 1997-1998 C = (A * B * 0.00272)
D - Based on estimated load from failing SSTS in the direct watershed. Assume 10L/day for SSTS volume (8.107e-6 ac-ft/day)
E - Based on estimated load from failing SSTS in the direct watershed. Assumes 10% of the 18 SSTS in the direct watershed are failing, 2.76 people per household at a loading rate of 1.946 lbs/person/yr (based on annual loading rates from MPCA Phosphorus Study)
F = (D * E * 0.00272) G = C + F
H - Based on daily water balance model. See Tab "WaterBalanceSummary" I - In-lake TP Concentration from the previous time step
J = (H * I * 0.00272)
K - Based on daily water balance model. See Tab "WaterBalanceSummary" L - In-lake TP Concentration from the previous time step
M = (K * L * 0.00272) N = J + M

B-12: Sunfish Lake 2006 Estimated Curlyleaf Pondweed Loads

Macrophyte Area[1] = 25.0 acres

% Covered w/Curlyleaf[1] 33% ==> Curlyleaf Area = 8.3

1 - Based on May 25, 2007 Qualitative Macrophyte Survey Data

Curlyleaf load based on estimated density & coverage

Stem Density	100	
Mat/stem	0.35	
P Content	2000	
Areal P load	70	mg/m²
P Load	5.2	lbs

Estimated Season Average Curlyleaf

Release Rate Check 0.8 mg/m²/d normilized over 90 days (per James et. al. 2001)
(estimated rate from James 2001 for Half Moon Lake - 1.2 mg/m2/day)

Estimated Internal Loading from Curlyleaf Pondweed

Sampling Dates	Cumulative P Load into Water Column (lbs)	Incremental P Load into Water Column (lbs)
4/30/06	0	**0.0**
5/7/06	0	**0.0**
5/22/06	0	**0.0**
6/5/06	0	**0.0**
6/20/06	0	**0.0**
7/15/06	4.1	**4.1**
7/29/06	4.9	**0.8**
8/28/06	5.1	**0.2**
9/17/06	5.2	**0.0**
9/30/06	5.2	**0.0**
10/1/06	5.2	**0.0**

B-13: Sunfish Lake 2006 Estimated Uptake by Coontail

Date Coontail Uptake Begins	5/1/2006		
Maximum Coontail Plant Density	661.9	g (wet weight)/m²	(Newman, 2004)
Macrophyte Area =	25	Ac	Based on 2007 and 2008 Macrophyte Surveys
% Covered w/Coontail at Date Coontail Uptake Begins	100%		
Coontail Area	25.0	acres	
	101171	m^2	

Summary of Uptake by Coontail

Sampling Dates	Cumulative TP Uptake (lbs)	Incremental TP Uptake (lbs)
4/30/06	0.0	**0.0**
5/7/06	0.5	**0.5**
5/22/06	1.6	**1.1**
6/5/06	2.7	**1.0**
6/20/06	3.8	**1.1**
7/15/06	5.6	**1.9**
7/29/06	6.7	**1.0**
8/28/06	8.9	**2.2**
9/17/06	10.4	**1.5**
9/30/06	11.3	**1.0**
10/1/06	11.4	**0.1**

B-14: Sunfish Lake 2006 Summary of Estimated P8 Watershed Runoff Particle Class Settling From Epilimnion & Watershed TP Loads Before and After Settling

			Number of Days to Settle P8 Particle Class[1,2,3]					
P8 Particle Class			P10	P30	P50	P80		
			0.03	0.3	1.5	15		
P8 Settling Velocity			vs = 0.03 ft/hr	vs = 0.3 ft/hr	vs = 1.5 ft/hr	vs = 15 ft/hr		
Sample Period		Epilimnion Depth (De)[4]	Particle Settling Time	Particle Settling Time	Particle Settling Time	Particle Settling Time	Total Watershed TP Load before Particle Settling	Watershed TP Load after Particle Settling[2,3]
		(ft)	(days)	(days)	(days)	(days)	(lbs)	(lbs)
5/1/2006	5/7/2006	9.8	13.7	1.4	0.3	0.0	0.0	0.0
5/8/2006	5/22/2006	9.8	13.7	1.4	0.3	0.0	0.4	0.1
5/23/2006	6/5/2006	9.8	13.7	1.4	0.3	0.0	1.0	0.7
6/6/2006	6/20/2006	9.8	13.7	1.4	0.3	0.0	0.6	0.3
6/21/2006	7/15/2006	9.8	13.7	1.4	0.3	0.0	0.3	0.1
7/16/2006	7/29/2006	9.8	13.7	1.4	0.3	0.0	0.7	0.3
7/30/2006	8/28/2006	9.8	13.7	1.4	0.3	0.0	2.7	1.3
8/29/2006	9/17/2006	9.8	13.7	1.4	0.3	0.0	0.8	0.3
9/18/2006	9/30/2006	9.8	13.7	1.4	0.3	0.0	0.4	0.2

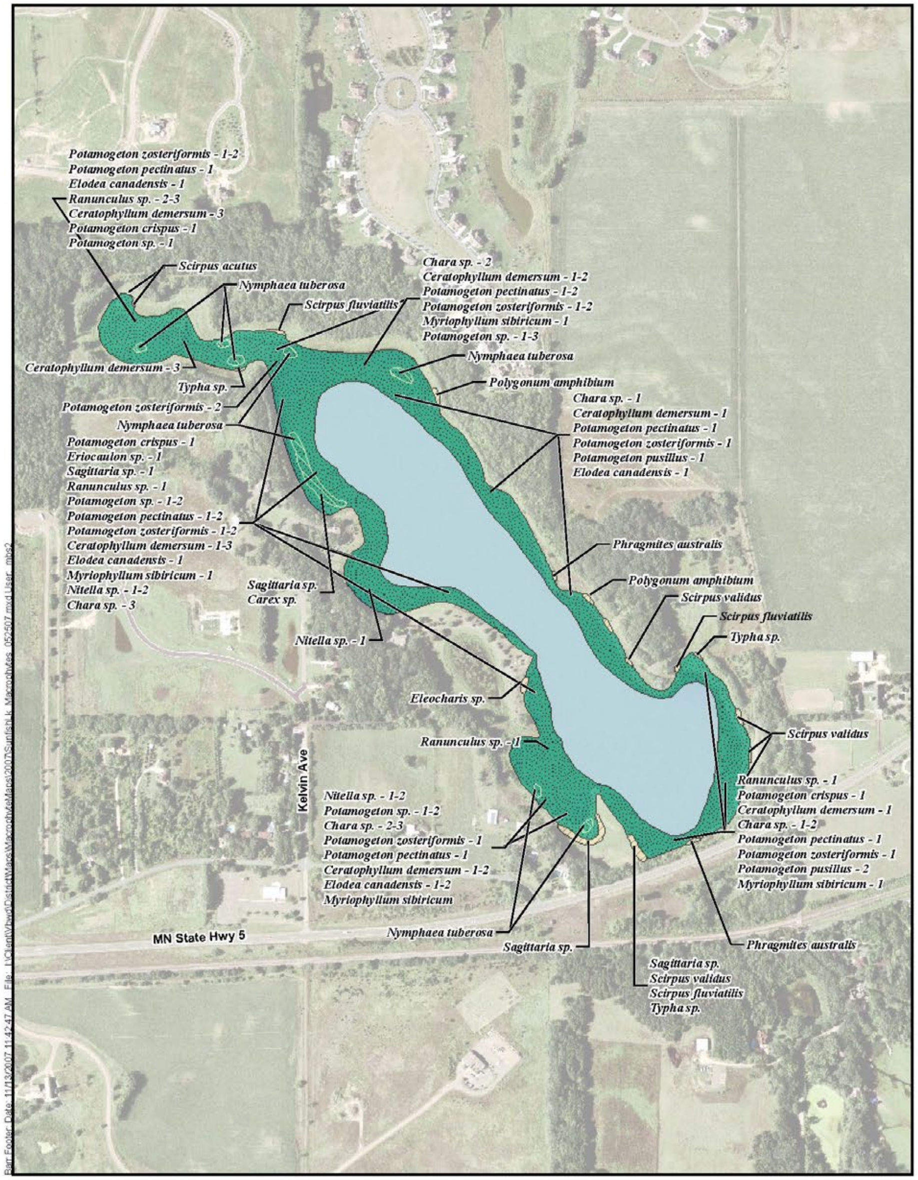
1 - Number of Days to Settle Particles = De/vs/24

2 - The P0 particle class in P8 reflects the non-settleable (or dissolved) fraction of the particles.

3 - The pollutant loading in P8 is based on the build-up and wash-off of particles. There are 5 particle size classes, each with a mass of pollutant associated with it (e.g. phosphorus) as well as a settling velocity. The majority of the phosphorus is associated with the P0 (or non-settleable fraction). The in-lake mass balance model tracks the mass of each particle size class (from the P8 model) and determines how long the particles will remain in the epilimnion (thus impacting observed water quality). The model considers the number of days between the water quality sampling dates and the prior storm events, and only includes the phosphorus load from those particles that would remain in the epilimnion during that period. See Tab "P8EventSummary".

4 - Epiliminion Depth See Tab "PhysicalParameters"

Appendix C Sunfish Lake Qualitative Macrophyte Surveys – 2007



Submerged Aquatic Plants

Common Name	Scientific Name
Canada waterweed	*Elodea canadensis*
coontail	*Ceratophyllum demersum*
curlyleaf pondweed	*Potamogeton crispus*
flatstem pondweed	*Potamogeton zosteriformis*
muskgrass	*Chara sp.*
northern watermilfoil	*Myriophyllum sibiricum*
pipewort	*Eriocaulon sp.*
pondweed	*Potamogeton sp.*
sago pondweed	*Potamogeton pectinatus*
small pondweed	*Potamogeton pusillus*
stonewort	*Nitella sp.*
water crowfoot	*Ranunculus sp.*

Floating Leaf Plants

Common Name	Scientific Name
white waterlily	*Nymphaea tuberosa*

Emergent Plants

Common Name	Scientific Name
arrowhead	*Sagittaria sp.*
cattail	*Typha sp.*
giant reed grass	*Phragmites australis*
hardstem bulrush	*Scirpus acutus*
river bulrush	*Scirpus fluviatilis*
sedge	*Carex sp.*
softstem bulrush	*Scirpus validus*
spikerush	*Eleocharis sp.*
water knotweed	*Polygonum amphibium*

FIELD NOTES:
- Macrophyte densities estimated as follows:
  1=light; 2=moderate; 3=heavy
- Densities generally not noted for emergent and floating leaf plants
- No macrophytes found in water >9-10'
- Sporadic areas of Sagitarria sp. growing around entire lake perimeter. Dense in small areas.

Legend

- Emergent Plants
- Floating Leaf Plants
- Submerged Aquatic Plants
- No Aquatic Vegetation

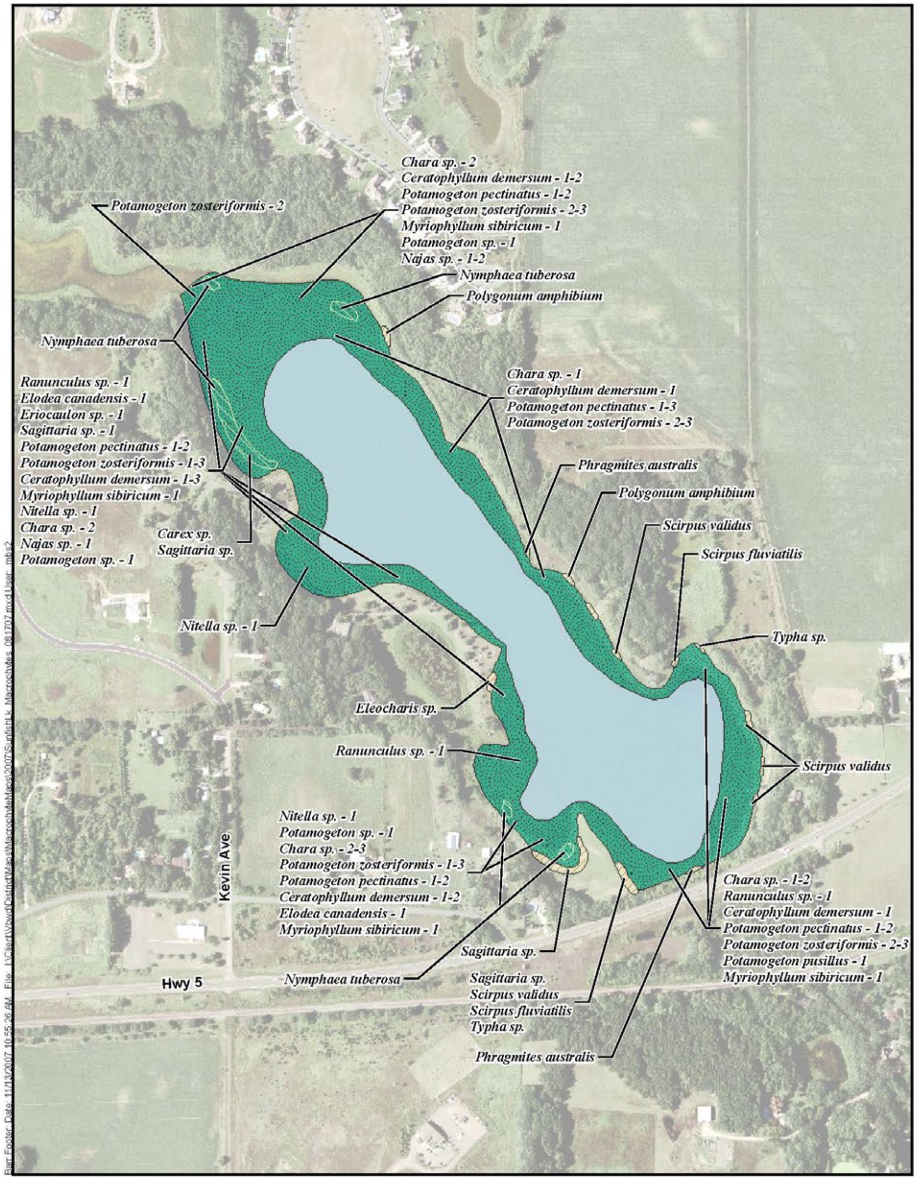
0 600 1,200
Feet

0 100 200 300 400 500
Meters

Imagery Source: 2006 AE

BARR

SUNFISH LAKE MACROPHYTE
SURVEY RESULTS
May 25, 2007
Valley Branch Watershed District



Submerged Aquatic Plants

Common Name	Scientific Name
coontail	*Ceratophyllum demersum*
muskgrass	*Chara sp.*
Canada waterweed	*Elodea canadensis*
pipewort	*Eriocaulon sp.*
northern watermilfoil	*Myriophyllum sibiricum*
bushy pondweed and naiads	*Najas sp.*
stonewort	*Nitella sp.*
sago pondweed	*Potamogeton pectinatus*
small pondweed	*Potamogeton pusillus*
pondweed	*Potamogeton sp.*
flatstem pondweed	*Potamogeton zosteriformis*
water crowfoot	*Ranunculus sp.*

Floating Leaf Plants

Common Name	Scientific Name
white waterlily	*Nymphaea tuberosa*

Emergent Plants

Common Name	Scientific Name
sedge	*Carex sp.*
spikerush	*Eleocharis sp.*
giant reed grass	*Phragmites australis*
water knotweed	*Polygonum amphibium*
arrowhead	*Sagittaria sp.*
river bulrush	*Scirpus fluviatilis*
softstem bulrush	*Scirpus validus*
cattail	*Typha sp.*

FIELD NOTES:
- Macrophyte densities estimated as follows:
  1=light; 2=moderate; 3=heavy
- Densities generally not noted for emergent and floating leaf plants
- No macrophytes found in water >9-10'
- Sporadic areas of Sagitarria sp. growing around entire lake perimeter. Dense in small areas.
- Northwest lobe dry. No aquatic vegetation.

Legend

- Emergent Plants
- Floating Leaf Plants
- Submerged Aquatic Plants
- No Aquatic Vegetation

N

0 500 1,000
Feet

0 100 200 300 400
Meters

Imagery Source: 2006 AE

BARR

SUNFISH LAKE MACROPHYTE SURVEY RESULTS
August 17, 2007
Valley Branch Watershed District