Sauk River Bacteria and Nutrients Total Maximum Daily Load

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Prepared for:

SAUK RIVER WATERSHED DISTRICT

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EPA/MPCA Required Elements	**Summary**	**TMDL Page Number**
Margin of Safety	Bacteria: An explicit 5% MOS was used, in addition to an implicit MOS. The implicit MOS was applied as part of the WLA by assuming the point sources are always discharging at permitted limits. *See Section 2.4.2* Lake Nutrients: An explicit 5% MOS was used, in addition to an implicit MOS. The MOS is implicit by incorporating conservative model assumptions. *See Section 3.2.7*	Bacteria Section 2.4.2, p. 24 Lake Nutrients Section 3.2.7, p. 49
Seasonal Variation	Bacteria: Load duration curve methodology accounts for seasonal variations; *See Section 2.4* Lake Nutrients: Seasonal variation is accounted for through the use of annual loads and developing targets for the summer period, where the frequency and severity of nuisance algal growth will be the greatest; *See Section 3.2.9*	Bacteria Section 2.4, p. 22 Lake Nutrients Section 3.2.9, p. 49
Reasonable Assurance	Information is presented regarding BMPs to address impairments of bacteria, turbidity and lake nutrients. Since there are several sources and some common delivery pathways, most of the strategies have multiple water quality benefits in terms of load reductions through implementation. NPDES Permits provide assurances for permitted sources to comply with WLAs; *See Section 5.0.*	Section 5.0 p. 75
Monitoring	A general overview of follow-up monitoring is included; *See Section 5.4*	Section 5.4, p. 78
Implementation	This report sets forth an implementation framework, general load reduction strategies, and a rough approximation of the overall implementation cost to achieve the TMDL. A more detailed implementation section will be included in the WRAPS report. *See Section 5.0*	Section 5.0, p. 78

1 Introduction

1.1 PURPOSE

Section 303(d) of the Clean Water Act establishes a directive for developing Total Maximum Daily Loads (TMDLs) to achieve Minnesota water quality standards established for designated uses of state waterbodies. Under the Clean Water Act, the state of Minnesota has directed that a TMDL be prepared to address stream bacteria and lake nutrient exceedances located in the Sauk River Watershed. The goal of the TMDL study is to quantify the pollutant reductions needed to meet state water quality standards. This report presents the results of the study.

A TMDL is defined as the maximum quantity of a pollutant that a water body can receive and continue to meet water quality standards for designated beneficial uses. Thus, a TMDL is simply the sum of point sources and nonpoint sources in a watershed. A TMDL can be represented in a simple equation as follows:

TMDL = Σ Wasteload Allocation (WLA; Point Sources)

+ Σ Load Allocation (LA; nonpoint sources)

+ Margin of Safety (MOS)

The WLA is the sum of the loads from all point sources and the load allocation (LA) is the sum of the load from all nonpoint sources. The Margin of Safety (MOS) represents an allocation to account for variability in environmental data sets and uncertainty in the assessment of the system. Other factors that must be addressed in a TMDL include seasonal variation, future growth, critical conditions, and stakeholder participation.

This TMDL report provides WLAs, LAs and MOS needed to achieve the state standard for each parameter in each impaired reach and lake of Sauk River Watershed.

1.2 WATERSHED STUDY AREA

The Sauk River Watershed is located in west-central Minnesota and covers five counties that include Douglas, Meeker, Pope, Stearns, and Todd counties. The headwaters of the Sauk River Watershed are located in the northwest region of the watershed and flows 119 miles southeast to its confluence with the Mississippi River near St. Cloud (Figure 1.1).

The total watershed area of the Sauk River Watershed is approximately 666,899 acres. Each impaired watershed is comprised of various subwatersheds that discharge to or are on the main stem of the Sauk River. The individual impairment sections of this TMDL report include a detailed map of each impaired stream reach/tributary/lake.

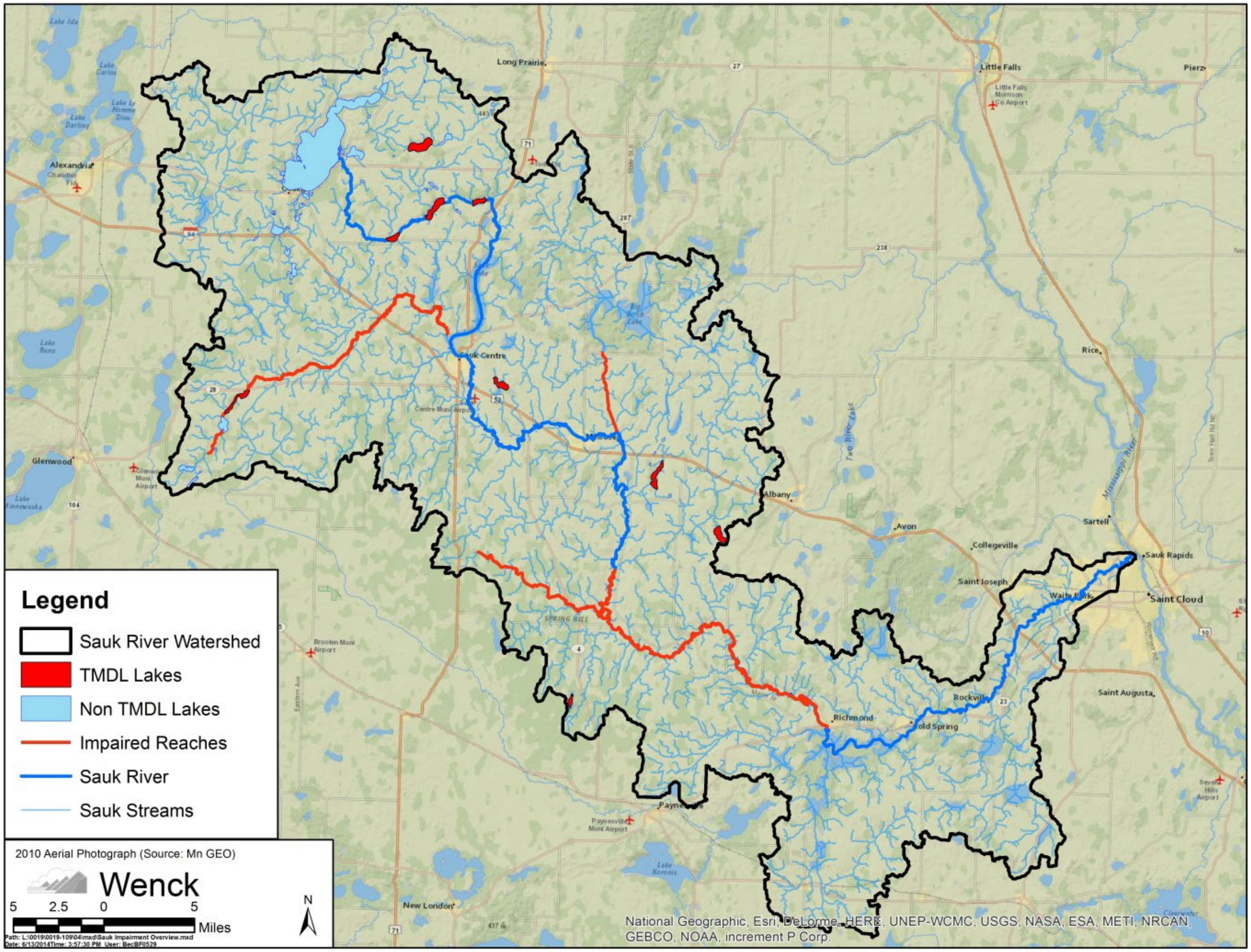


Figure 1.1. Sauk River Watershed impairments addressed in this TMDL study

1.3 LAND USE SUMMARY

Land use for the entire Sauk River Watershed was calculated using the 2011 National Agricultural Statistics Service Geographic Information System (GIS) land cover file. The dominant land use within the watershed is row crops (Table 1.1). The remaining land area is comprised of forest and shrubland, lakes and wetlands, developed land and non-corn/soybean crops.

Table 1.1. Watershed Land use in the Sauk River Watershed

Land use	Acres	Percent Total
Corn and Soybeans	274,617	42%
Grains and Other Crops	109,078	16%
Wetlands and Open Water	102,543	15%
Forest and Shrubland	76,609	11%
Grassland	60,101	9%
Urban/Roads	43,415	7%
Hay and Pasture	536	0%
Total	666,899	100%

Source: 2011 NASS land cover

1.4 IMPAIRMENT SUMMARY

This TMDL report addresses four stream reaches with bacteria impairments (Table 1.2) and nine lakes with nutrient impairments (Table 1.3) in the Sauk River Watershed. This document is organized such that bacteria impairments are addressed in section two and nutrient impairments are addressed in section three. The Minnesota Pollution Control Agency's (MPCA's) projected schedule for TMDL completions, as indicated on Minnesota's 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. 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.

Table 1.2. Stream impairments in the Sauk River Watershed addressed in this TMDL.

Reach Name	Description	Year Listed	AUID	Beneficial Use	Impairment	Class
Ashley Creek	Headwaters to Sauk Lake	2010	07010202-503	Aquatic Recreation	*Escherichia coli*	2B, 3C
Sauk River	Getchell Creek to State Highway 23	2010	07010202-508	Aquatic Recreation	*Escherichia coli*	2B, 3C
Adley Creek	Sylvia Lake to Sauk River	2010	07010202-527	Aquatic Recreation	*Escherichia coli*	2B, 3C
Stoney Creek	Headwaters to Sauk River	2008	07010202-541	Aquatic Recreation	*Escherichia coli*	2B, 3C

[1] Reaches on 2010 303(d) impaired waters list

Table 1.3. Lake nutrient impairments in the Sauk Watershed addressed in this TMDL.

Lake ID	Name	Year Listed	Beneficial Use	Impairment	Class
77-0181	Maple	2010	Aquatic Recreation	*Nutrients*	2B, 3C
77-0164	Little Sauk	2012	Aquatic Recreation	*Nutrients*	2B, 3C
77-0182	Guernsey	2012	Aquatic Recreation	*Nutrients*	2B, 3C
77-0163	Juergens	2012	Aquatic Recreation	*Nutrients*	2B, 3C
61-0029	Westport	2010	Aquatic Recreation	*Nutrients*	2B, 3C
73-0199	Sand	2010	Aquatic Recreation	*Nutrients*	2B, 3C
73-0237	Henry	2012	Aquatic Recreation	*Nutrients*	2B, 3C
73-0208	Uhlenkolts	2012	Aquatic Recreation	*Nutrients*	2B, 3C
73-0273	McCormic	2010	Aquatic Recreation	*Nutrients*	2B, 3C

1.5 BENEFICIAL USE CLASSIFICATIONS

This TMDL report addresses exceedances of the state standards for bacteria and lake nutrients in the Sauk River Watershed of Minnesota. A discussion of beneficial water use classes in Minnesota and the standards for those classes is provided in order to define the regulatory context and explain the rationale behind the environmental result of the TMDL. All waters of Minnesota are assigned classes based on their suitability for the following beneficial uses (Minn. R. 7050.0140 and 7050.0220):

1. Domestic consumption
2. Aquatic life and recreation
3. Industrial consumption
4. Agriculture and wildlife
5. Aesthetic enjoyment and navigation
6. Other uses
7. Limited resources value
    a) Cold water sport fish (trout waters), also protected for drinking water
    b) Cool and warm water sport fish, also protected for drinking water
    c) Cool and warm water sport fish, indigenous aquatic life, and wetlands, and
    d) Limited resource value waters

Classification as a 2B water is intended to protect cool and warm water fisheries, while classification as a 2C water is intended to protect indigenous fish and associated aquatic communities, a 3C classification protects water for industrial use and cooling. All surface waters classified as Class 2 are also protected for industrial, agricultural, aesthetics, navigation, and other uses (Classes 3, 4, 5, and 6, respectively). Minn. R. ch. 7050 contains general provisions, definitions of water use classes, specific standards of quality and purity for classified waters of the state, and the general and specific standards for point source dischargers to waters of the state.

The designated beneficial use for Class 2 waters (the most protective use class in the project area) is as follows (Minn. R. 7050.0140):

> **Class 2 waters, aquatic life and recreation**. Aquatic life and recreation includes all waters of the state that support or may support fish, other aquatic life, bathing, boating, or other recreational purposes and for which quality control is or may be necessary to protect aquatic or terrestrial life or their habitats or the public health, safety, or welfare.

Table 1.4 summarizes the beneficial use classifications by assessment unit ID (AUID) for the impaired streams included in this report.

Table 1.4. Beneficial Use Classifications for Impaired Stream Reaches.

Reach Name on 303(d) List/Description	Assessment Unit ID	Beneficial Use
Ashley Creek (Headwaters to Sauk Lake)	07010202-503	2B, 3C
Sauk River (Adley Creek to State Highway 23)	07010202-508	2B, 3C
Adley Creek (Sylvia Lake to Sauk River)	07010202-527	2B, 3C
Stoney Creek (Headwaters to Sauk River)	07010202-541	2B, 3C

1.6 CRITERIA USED FOR LISTING

The criteria used for determining stream reach impairments are outlined in the MPCA document Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment – 305(b) Report and 303(d) List, January 2010. The applicable water body classifications and water quality standards are specified in Minn. R. ch. 7050. Minn. R. 7050.0470 lists water body classifications.

1.6.1 State of Minnesota Standards and Criteria for Listing

***Nutrients*.** Under Minn. R. 7050.0150 and Minn. R. 7050.0222, subp. 4, the lakes addressed in this study are located within the North Central Hardwood Forest ecoregion with a numeric target dependent on depth as listed in Table 1.5. Therefore, this TMDL presents LA and WLA and estimated load reductions assuming an end point of ≤60 mg/L and ≤40 mg/L TP for shallow lakes and deep lakes, respectively.

In addition to meeting a phosphorus limit of 60 µg/L and 40 µg/L for shallow and deep lakes, chlorophyll-*a* (Chl-*a*) and Secchi depth standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. ch. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson 2005). Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi disk. Based on these relationships it is expected that by meeting the phosphorus targets of 60 µg/L and 40 mg/ for shallow and deep lakes, the Chl-*a* and Secchi standards will likewise be met.

Table 1.5. Numeric standards for lakes in the North Central Hardwood Forest Ecoregion.

Parameters	Shallow[1] Lake Standard	Deep Lake Standard
Total Phosphorus (mg/L)	**≤60**	**≤40**
Chl-*a* (mg/L)	**≤20**	**≤14**
Secchi disk transparency (meters)	**≥1.0**	**≥1.4**

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

***Escherichia coli (E. coli)*.** Each bacterium impaired reach listing was based on *E. coli* measurements. Under Minn. R. chs. 7050.0150 and 7050.0222, *E. coli* concentrations are:

> "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 10% of all samples taken during any calendar month individually exceed 1,260 organisms/100 mL. The standard applies only between April 1 and October 31."

2 Bacteria Impairments

2.1 OVERVIEW OF *E. COLI* IMPAIRED REACH WATERSHED

This TMDL applies to the *E. coli* bacteria impairment for three tributaries and one main stem reach of the Sauk River (Figure 2.1). Data from monitoring stations in the watersheds served as the basis of the impairment determination and were used to support development of the TMDLs.

2.2 *E. COLI* WATERSHED LAND USE/LAND COVER

Land use for watersheds draining directly to the *E. coli* impaired reaches were calculated using the 2011 National Land Cover Database (NLCD 2011) GIS land cover file (Table 2.1). Land use in the *E. coli* impaired reach watersheds is primarily cropland with some urban land. Other land use is comprised of hay and pasture land, lakes and wetlands and forest and shrubland.

Table 2.1. Watershed land use (Source: 2011 NLCD Land Cover)

	Percent of Total			
Land Use	**[1]Adley Creek Direct Watershed**	**[1]Ashley Creek Direct Watershed**	**[1]Sauk River Direct Impaired Watershed**	**[1]Stoney Creek Direct Watershed**
Watershed Size (acres)	14,043	80,236	83,220	16,522
Row Crops	38%	65%	64%	67%
Pasture and Hay	40%	17%	23%	22%
Forest and Shrubland	9%	4%	5%	3%
Urban/Roads	4%	4%	4%	5%
Open water and Wetlands	6%	8%	2%	2%
Grassland	3%	2%	2%	1%

[1] Only includes watershed areas that drains directly to impaired reach.

2.3 *E. COLI* DATA SOURCES

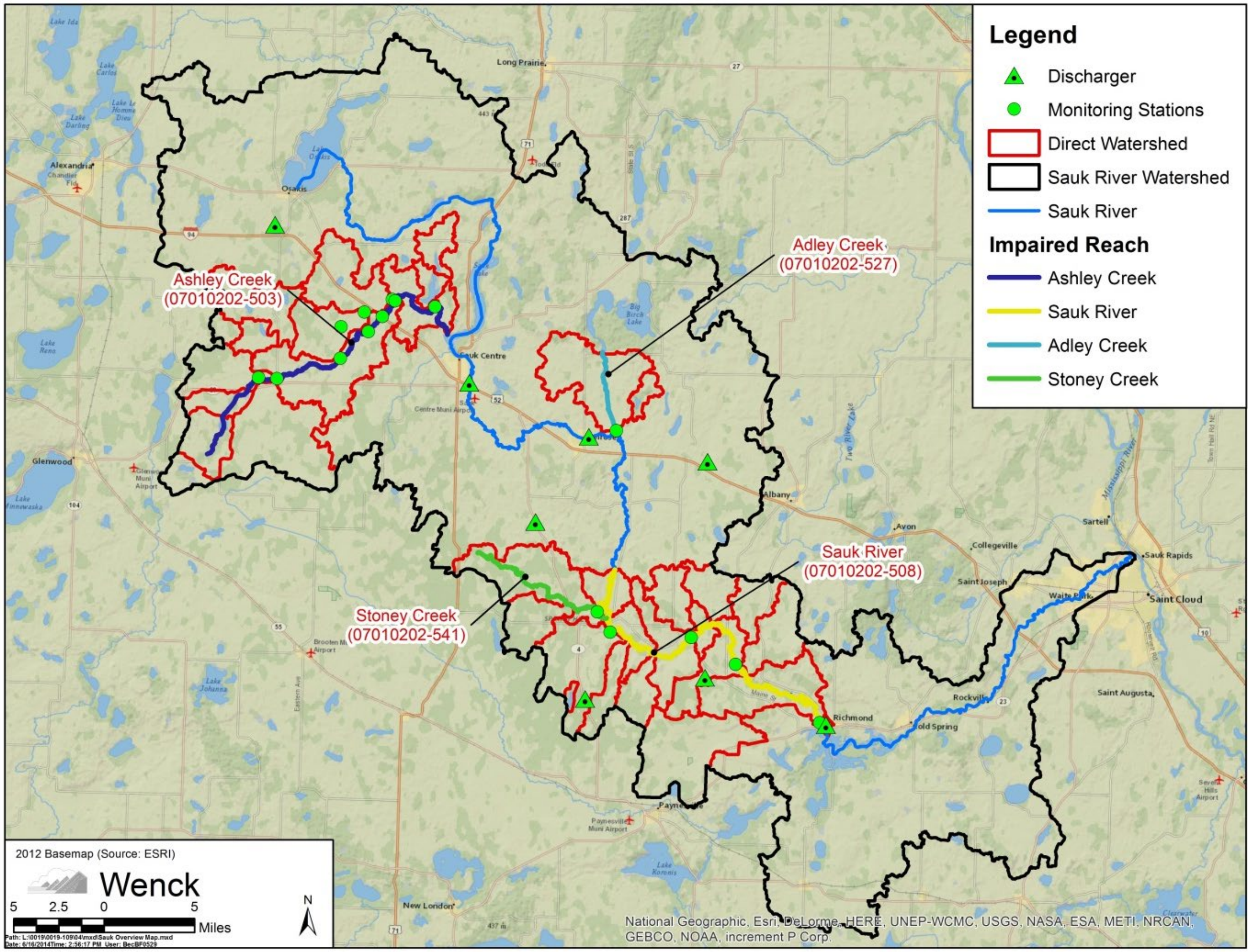
2.3.1 Water Quality Data

Bacteria data used for the development of this TMDL were grab samples collected primarily by the Sauk River Watershed District (SRWD), in addition to various other organizations (Table 2.2). The available data is displayed in Table 2.2; however, only data from the past 10 years (2003 to 2012) is used herein to assess the current water quality conditions of each impaired reach. This limited timescale approach was used since data prior to 2003 may not accurately represent the current conditions in each watershed. Data was obtained from the MPCA Environmental Quality Information System (EQuIS) database and from the SRWD.

Table 2.2 Sauk River Watershed impaired reach monitoring sites.

Watershed	Sites	Parameter	Number of Samples	Years
Adley Creek	S000-369	*E. coli*	83	2006-2012
		Fecal Coliform	4	1976-1982
	S001-389	*E. coli*	15	2007-2007
	S003-322	*E. coli*	20	2007-2009; 2012
	S006-153	*E. coli*	16	2010-2011
Ashley Creek	S003-290	*E. coli*	2	2006-2006
	S003-522	*E. coli*	37	2006-2008
	S003-870	*E. coli*	10	2008-2008
	S003-871	*E. coli*	19	2007-2008
	S003-872	*E. coli*	21	2007-2007
	S003-884	*E. coli*	19	2007-2008
	S003-885	*E. coli*	18	2007-2008
	S004-625	*E. coli*	52	2007-2012
	S005-302	*E. coli*	5	2006-2006
	S005-304	*E. coli*	5	2007-2007
Sauk River	S000-284	*E. coli*	96	2006-2012
		Fecal Coliform	65	1974-1983
	S000-517	*E. coli*	83	2006-2012
		Fecal Coliform	2	1983-1983
	S000-518	Fecal Coliform	26	1983-1983
	S000-702	*E. coli*	95	2006-2012
		Fecal Coliform	2	1983-1983
	S000-950	*E. coli*	58	2008-2012
	S003-289	*E. coli*	69	2006-2012
		Fecal Coliform	1	2005-2005
	S000-373	*E. coli*	105	2007-2012
Stoney Creek	S000-497	*E. coli*	81	2006-2012
		Fecal Coliform	2	1978-2005

Figure 2.1. Sauk River Watershed *E. Coli* impaired reach watersheds and monitoring stations.



2.3.2 Streamflow Data

Stream flow data was crucial to support development of the *E. coli* allocations for this TMDL. Paired streamflow and *E. coli* data allow exceedances to be evaluated by flow regime, which can provide insights into potential bacteria sources.

The SRWD maintains continuous flow gauging stations in all four impaired reaches (Adley Creek – S003-369, Ashley Creek – S004-625, Ashley Creek – S004-625, and Sauk River – S000-517) (Figure 2.3). These stations, however, are not maintained during the winter months. Furthermore, there are no U. S. Geological Survey (USGS) continuous gauge stations that can be used to fill data gaps during the winter season. Data relationships were developed between sites to fill any data gaps to create continuous flow records from each site from 2003 to 2012 from March to October (Appendix A).

2.3.3 Impairment Criteria for Impaired Reaches

To assess *E. coli* impairments, the MPCA uses data collected by the MPCA and other entities that meet QA/QC requirements, meet U. S. Environmental Protection Agency (EPA) guidelines, and are analyzed by an EPA approved method and entered into the MPCA's EQuIS/STORET online database. If multiple *E. coli* samples have been collected on the same assessment unit (reach), then the geometric mean of all measurements are used in the assessment analysis for that day. Then, data over the full 10-year period are aggregated by individual month (i.e. all April values for all 10 years). A minimum of five values for each month is ideal, but is not always necessary to make an impairment determination. If the geometric mean of the aggregated monthly *E. coli* concentrations for one or more months exceeds 126 organisms per 100 mL, that reach is placed on the 303(d) impaired list. Also, a waterbody is considered impaired if more than 10% of individual values over the 10-year period (independent of month) exceed the acute standard (1,260 cfu/ 100 ml).

E. coli and fecal coliform data from the monitoring stations were combined into one dataset and analyzed according to the aforementioned MPCA assessment methodology to demonstrate the level of impairment in the impaired reach. All fecal coliform data were converted to *E. coli* "equivalents" using the equation outlined in the SONAR for the 2007 and 2008 revisions of Minn. R. ch. 7050. Figure 2.2 shows the impaired reaches monthly *E. coli* geometric means during the bacteria index period (April to October). Samples were not collected in October for any of the four impaired reaches. Table 2.3 lists the acute standard exceedances for each impaired reach and months in which exceedances happened.

Each reach was exceeded the chronic *E. coli* standard from July to September, while none were exceeded in April or May. The Sauk River had consistently lower *E. coli* concentrations relative to the other three sites, but still regularly exceeded the chronic standard. The only site to have a monthly geomean greater than the acute *E. coli* standard was Stoney Creek, which regularly had the highest concentrations of the four sites in this study.

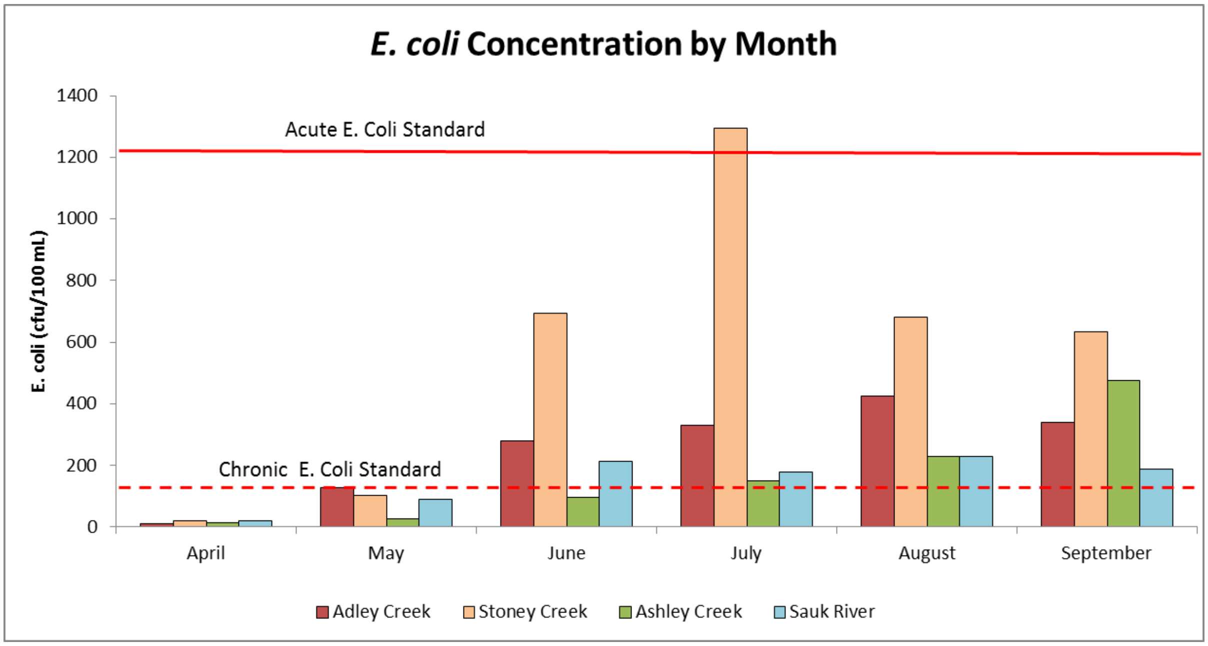


Figure 2.2. Monthly *E. coli* geometric means for each impaired reach.

Table 2.3 Individual *E. coli* acute exceedances in for the impaired reach monitoring stations.

Watershed	Monitoring Stations	Total Samples	Acute Exceedances (>1,260 cfu/100 ml)	Percent Exceedance
Adley Creek	S000-369	75	16	21%
Ashley Creek	S003-522 S003-870 S003-871 S004-625 S005-302 S005-304	72	20	27%
Sauk River	S000-517 S000-702 S000-950	109	22	20%
Stoney Creek	S000-497	71	8	11%

2.4 *E. COLI* ALLOCATION METHODOLOGY

2.4.1 Overview of Load Duration Curve Approach

Assimilative capacities for each reach were developed from load duration curves (Cleland 2002). Load duration curves combine flow and *E. coli* data across stream flow regimes and provide assimilative capacities and load reductions necessary to meet water quality standards.

A flow duration curve was developed using 8 to 10 years, depending on data availability, of continuous flow records at the furthest downstream flow station in each impaired reach. The curved line relates mean daily flow to the percent of time those values have been met or exceeded (Figure 2.3). For example, at the 50% exceedance value for Sauk River (S000-517), the stream was at 323 cubic feet per second or greater 50% of the time. The 50% exceedance is also the midpoint or median flow value. The curve is then divided into flow zones including very high (0% to 10%), high (10% to 40%), mid (40% to 60%), low (60% to 90%) and very low (90% to 100%) flow conditions. Subdividing all flow data over the past 10-years into these five categories ensures high-flow and low-flow critical conditions are accounted for in this TMDL study.

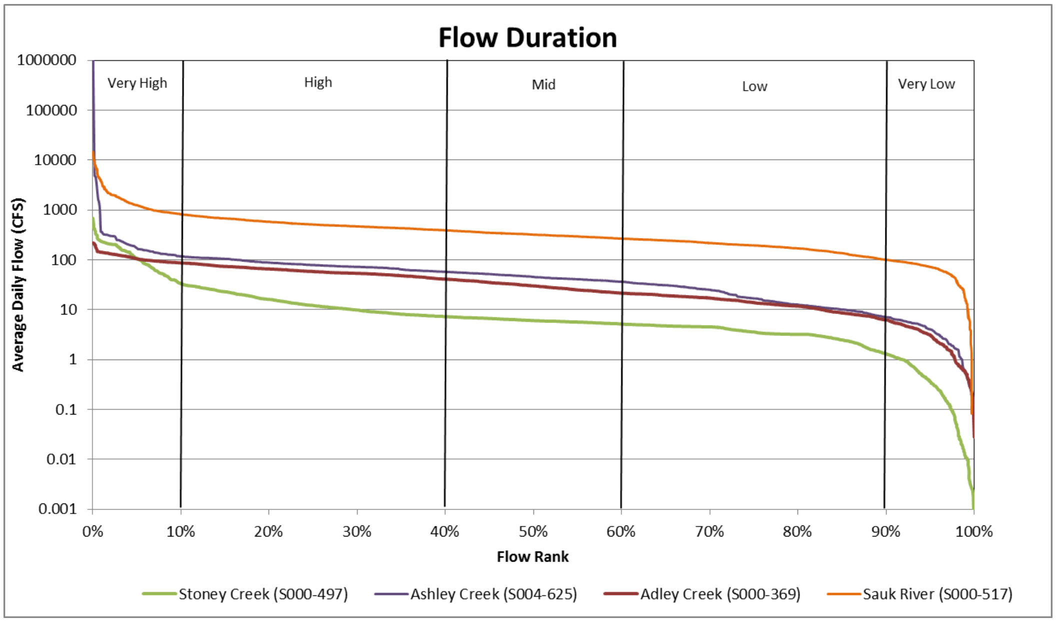


Figure 2.3. Flow duration curve for each impaired reach.

To develop a load duration curve, all average daily flow values were multiplied by the 126 cfu/100 ml standard and converted to a daily bacteria load to create a "continuous" load duration curve. Now the line represents the assimilative capacity of the stream for each daily flow. To develop the TMDL, the median load of each flow zone is used to represent the Total Daily Loading Capacity (TDLC) for that flow zone. The TDLC can also be used to determine reductions needed for each flow zone to meet *E. coli* water quality standard by plotting the monitored load for each *E. coli* sampling event (Figures 2.4 to 2.7). Each value that is above the TDLC line represents an exceedance of the water *E. coli* standard while those below the line are below the water quality standard.

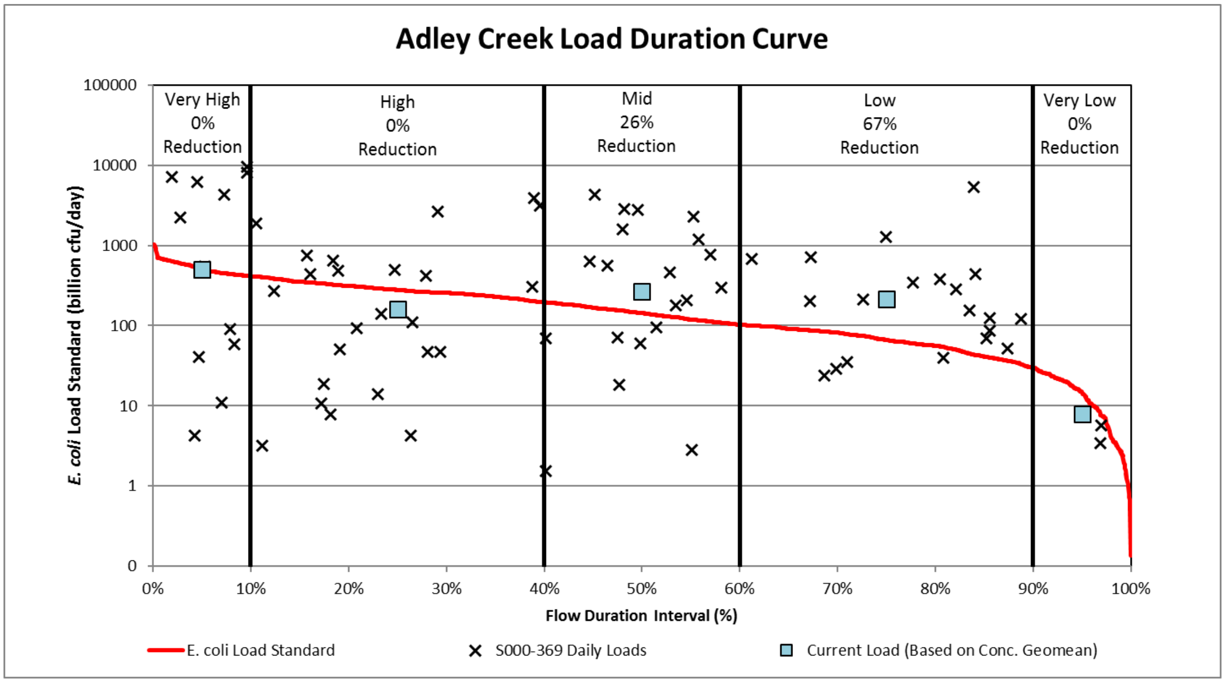


Figure 2.4. Adley Creek *E. coli* load duration curve and required load reductions by flow category.
Note: The red line represents the maximum allowable daily *E. coli* load.

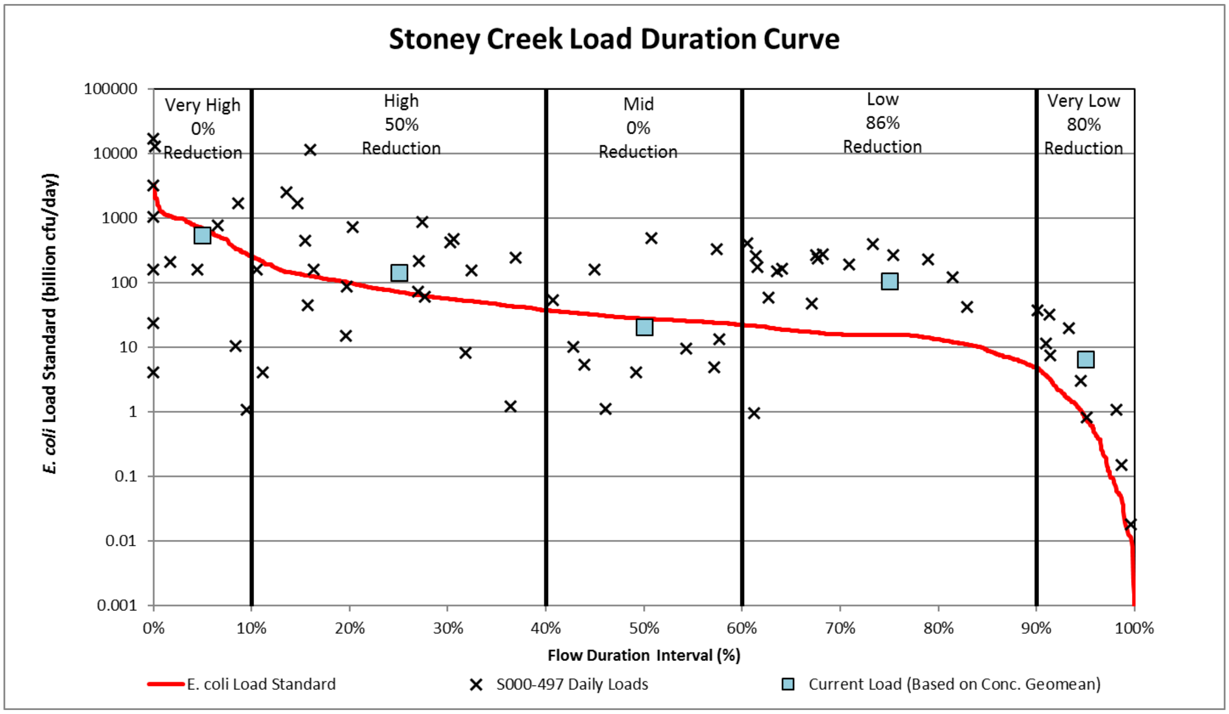
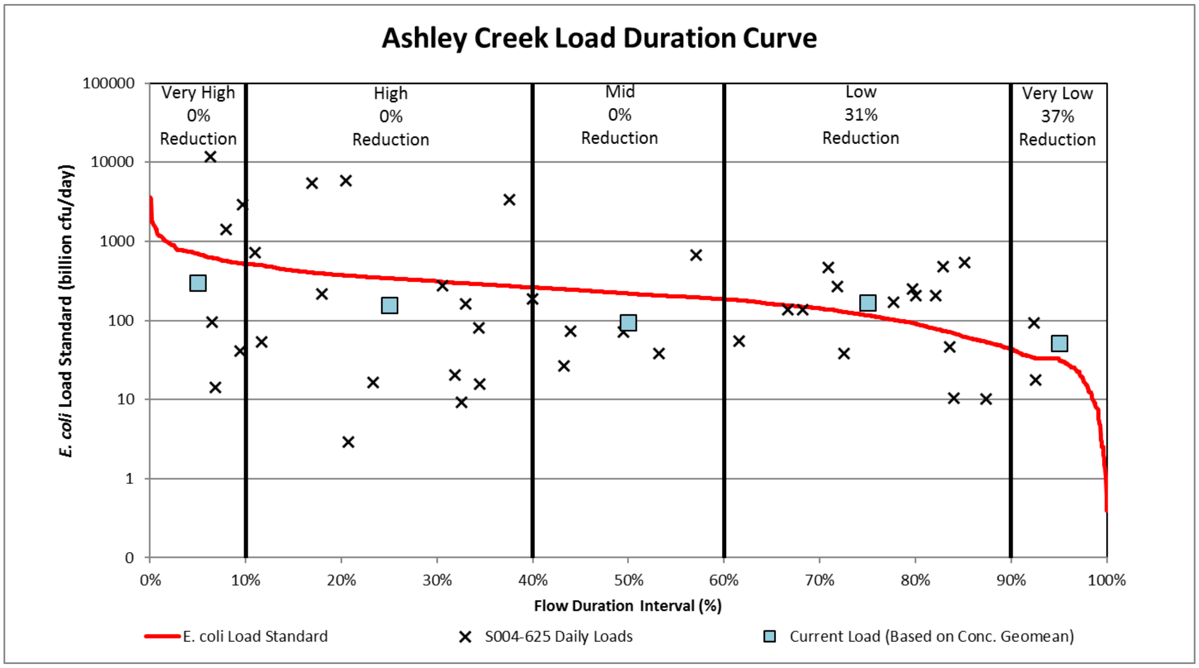


Figure 2.5. Stoney Creek *E. coli* load duration curve and required load reductions by flow category.
Note: The red line represents the maximum allowable daily *E. coli* load.

Figure 2.6. Ashley Creek *E. coli* load duration curve and required load reductions by flow category.
Note: The red line represents the maximum allowable daily *E. coli* load.



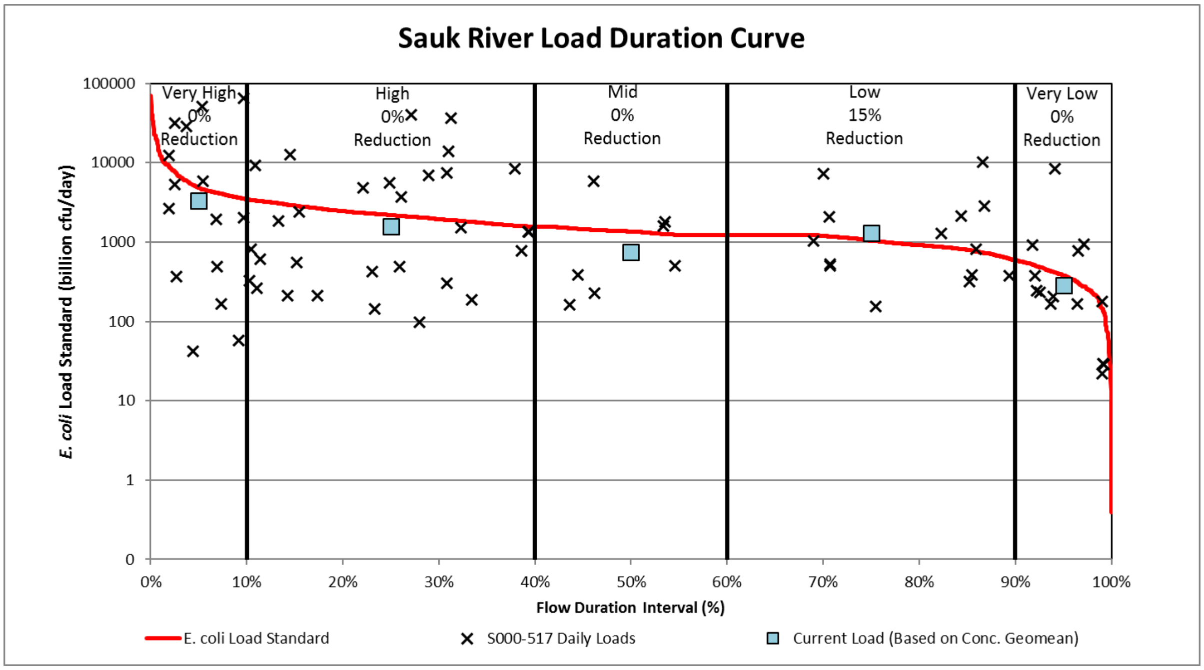


Figure 2.7. Sauk River *E. coli* load duration curve and required load reductions by flow category.
Note: The red line represents the maximum allowable daily *E. coli* load.

2.4.2 Margin of Safety

The MOS accounts for uncertainties in both current conditions and the relationship between the load, wasteload, monitored flows and in-stream water quality. The purpose of the MOS is to account for uncertainty so the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5% of the total load was applied whereby 5% of the loading capacity for each flow regime was subtracted before allocations were made among wasteload and nonpoint sources. Five percent was considered an appropriate MOS since the load duration curve approach minimizes a great deal of uncertainty associated with the development of TMDLs because the calculation of the loading capacity is simply a function of flow multiplied by the target value. Most of the uncertainty is therefore associated with the estimated flows in each assessed segment which were based on simulating a portion of the 10-year flow record at the most down-stream monitoring station.

2.4.3 Wasteload Allocations

The WLAs were divided into three categories: permitted point source dischargers, Municipal Separate Storm Sewer Systems (MS4) stormwater permits (none for this watershed), and construction and industrial stormwater permits. Industrial facilities and construction sites with stormwater permits through the MPCA are not believed to discharge the pollutant of concern and were not given *E. coli* allocations for this TMDL. The following sections describe how each of these LAs was estimated.

2.4.3.1 NPDES Point Source Dischargers

There are eight active permitted National Pollutant Discharge Elimination System (NPDES) surface wastewater discharges in the direct watershed of the impaired reaches (Table 2.4). The WLAs were calculated by multiplying the facility's design flow by the *E. coli* standard (126 cfu/100 mL). The New Munich Wastewater Treatment Plant (WWTP) was not included in the point source discharger WLA since it uses rapid infiltration basins for wastewater disposal.

Table 2.4. Description of NPDES point source dischargers and *E. coli* allocations in impaired reaches.

Impaired Reach	Facility Name	NPDES ID#	Facility Discharge Type	Effluent Design Flow (MGD)	Allocated Wasteload (billions organisms/day)
Sauk River 07010202-508	Freeport WWTP	MNG580019	Controlled	0.98	4.66
Sauk River 07010202-508	GEM Sanitary District	MNG580205	Controlled	0.61	2.92
Sauk River 07010202-508	Lake Henry WWTP	MN0020885	Continuous	0.04	0.19
Sauk River 07010202-508	Melrose WWTP	MN0020290	Continuous	3.00	14.31
Sauk River 07010202-508	Osakis WWTP	MN0020028	Controlled	4.46	21.29
Sauk River 07010202-508	Richmond WWTP	MN0024597	Continuous	0.31	1.48
Sauk River 07010202-508	Sauk Center WWTP	MN0024821	Continuous	0.89	4.24
Sauk River 07010202-508	St. Martin WWTP	MN0024783	Controlled	1.82	8.69

Discharge monitoring reports (DMRs) were downloaded to assess the typical monthly discharge values and bacteria concentrations at which each facility discharges. It should be noted that NPDES point source permit limits for bacteria are currently expressed in fecal coliform concentrations, not *E. coli*. However, the fecal coliform permit limit for each WWTP (200 organisms/100 mL) is equivalent to this TMDLs 126 organism/100 mL *E. coli* criterion. The fecal coliform - *E. coli* relationship is documented extensively in the Statement of Need and Reasonableness (SONAR) for the 2007 to 2008 revisions of Minn. R. ch. 7050.

2.4.3.2 MS4

There are no MS4s that are completely within or have a portion of their municipal boundary in the impaired reach watersheds.

2.4.4 Nonpoint Source Load Allocation

The nonpoint source LA is the remaining load after the MOS and WLAs are subtracted from the total load capacity of each flow zone. Nonpoint sources include all non-permitted sources such as outflow from lakes and wetlands in the watershed and runoff from agricultural land, forested land and non-MS4 residential areas.

2.5 *E. COLI* TOTAL MAXIMUM DAILY LOADS

Tables 2.5 through 2.8 present the total loading capacity, MOS, WLAs and the remaining nonpoint source LAs for the impaired reaches.

Table 2.5. Adley Creek *E. coli* impaired reach TMDL for each flow zone.

Adley Creek 07010202-527		**Flow Zones**				
		Very High	**High**	**Mid-Range**	**Low**	**Dry**
		***E. Coli* Load (billions of organisms/day)**				
Total Daily Loading Capacity		499.0	279.0	143.4	66.4	14.8
MOS		25.0	13.9	7.2	3.3	0.7
WLAs	Permitted Point Source Dischargers	--	--	--	--	--
LA	Nonpoint Sources	474.0	265.1	136.2	63.1	14.1

Table 2.6. Ashley Creek *E. coli* impaired reach TMDL for each flow zone.

Ashley Creek 07010202-503		**Flow Zones**				
		Very High	**High**	**Mid-Range**	**Low**	**Dry**
		***E. Coli* Load (billions of organisms/day)**				
Total Daily Loading Capacity		697.1	339.8	218.8	116.3	32.2
MOS		34.9	17.0	10.9	5.8	1.6
WLAs	Permitted Point Source Dischargers	--	--	--	--	--
LA	Nonpoint Sources	662.2	322.8	207.9	110.5	30.6

Table 2.7 Sauk River *E. coli* impaired reach TMDL for each flow zone.

Sauk River 07010202-508		**Flow Zones**				
		Very High	**High**	**Mid-Range**	**Low**	**Dry**
		***E. Coli* Load (billions of organisms/day)**				
Total Daily Loading Capacity		4,875.7	2,186.8	1,398.7	1,126.7	374.9
MOS		243.8	109.3	69.9	56.3	18.7
WLAs	Permitted Point Source Dischargers	57.8*	57.8*	57.8*	57.8*	57.8*
LA	Nonpoint Sources	4,574.1	2,019.7	1,271.0	1,012.6	298.4

*Note: Individual WWTP load allocations shown in Table 2.4

Table 2.8. Stoney Creek *E. coli* impaired reach TMDL for each flow zone.

Stoney Creek 07010202-541		**Flow Zones**				
		Very High	**High**	**Mid-Range**	**Low**	**Dry**
		***E. Coli* Load (billions of organisms/day)**				
Total Daily Loading Capacity		694.2	71.6	27.7	15.3	1.3
MOS		34.7	3.6	1.4	0.8	0.1
WLAs	Permitted Point Source Dischargers	--	--	--	--	--
LA	Nonpoint Sources	659.5	68.0	26.3	14.5	1.2

2.6 *E. COLI* POLLUTANT SOURCE ASSESSMENT

The intention of this section is to present information that is helpful in identifying the potential sources of elevated bacteria concentrations in the impaired reaches watersheds. The first section is a discussion of background levels of bacteria in streams. The next section addresses seasonal influences and looks at the relationships between elevated bacteria concentrations and flow. The third section addresses the potential influence of upstream lakes on the impaired reaches. The final section contains estimates of the potential sources of bacteria production by source category for the *E. coli* impaired reach watersheds.

2.6.1 *E. coli* Background Conditions

It has been suggested that *E. coli* bacteria has the capability to reproduce naturally in water and sediment and therefore should be taken into account when identifying bacteria sources. Two Minnesota studies describe the presence and growth of “naturalized” or “indigenous” strains of *E. coli* in watershed soils (Ishii et al. 2006), ditch sediment and water (Chadrasekaran et al. 2015). The latter study, supported with Clean Water Land and Legacy funding, was conducted in the Seven Mile Creek Watershed, an agricultural landscape in southwest Minnesota. DNA fingerprinting of *E. coli* from sediment and water samples collected in Seven Mile Creek from 2008 to 2010 resulted in the identification of 1,568 isolates comprised of 452 different *E. coli* strains. Of these strains, 63.5% were represented by a single isolate, suggesting new or transient sources of *E. coli*. The remaining 36.5% of strains were represented by multiple isolates, suggesting persistence of specific *E. coli*. Discussions with the primary author of the Seven Mile Creek study suggest that while 36% might be used as a rough indicator of “background” levels of bacteria at this site during the study period, this percentage is not directly transferable to the concentration and count data of *E. coli* used in water quality standards and TMDLs. Additionally, because the study is not definitive as to the ultimate origins of this bacteria, it would not be appropriate to consider it as “natural” background. Finally, the author cautioned about extrapolating results from the Seven Mile Creek Watershed to other watersheds without further studies.

2.6.2 *E. coli* by Season and Flow Regime

Individual *E. coli* samples show exceedances during summer and fall and less frequently in the spring (Figures 2.8 to 2.11). April was the month with the lowest bacteria concentrations even though there is little crop canopy cover and there is often significant manure application during this time. This suggests seasonality of bacteria concentrations may be influenced by stream water temperature. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during the warmer summer months when stream temperature are highest and flow is low. High *E. coli* concentrations continue into the fall, which may be attributed to failing septic systems, cattle access to stream/tributaries and/or reapplication of manure.

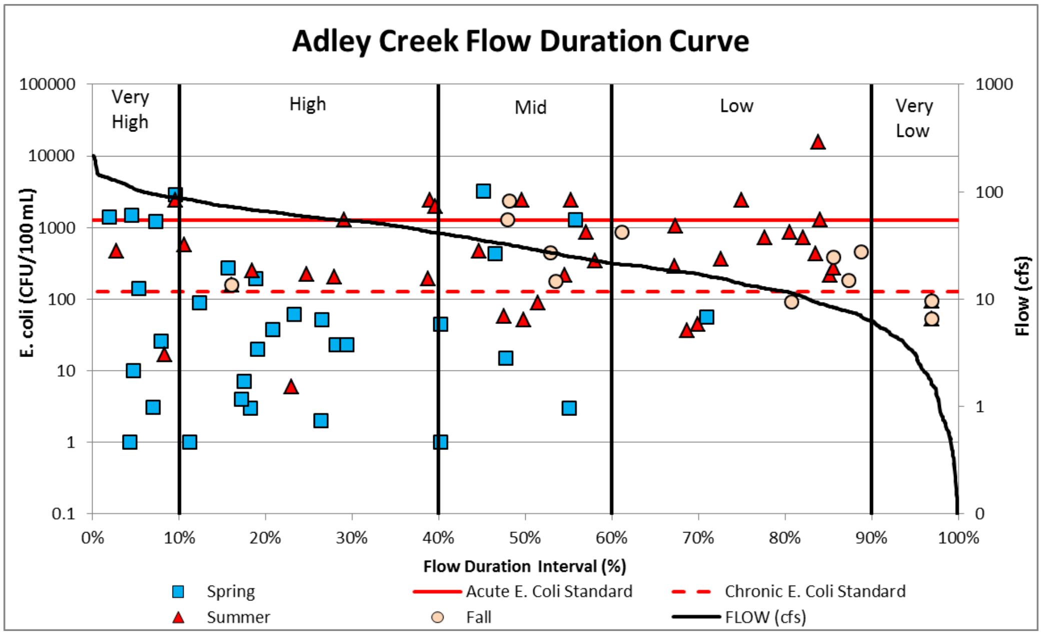


Figure 2.8. Individual *E. coli* measurements in the Adley Creek impaired reach plotted by season and flow regime.

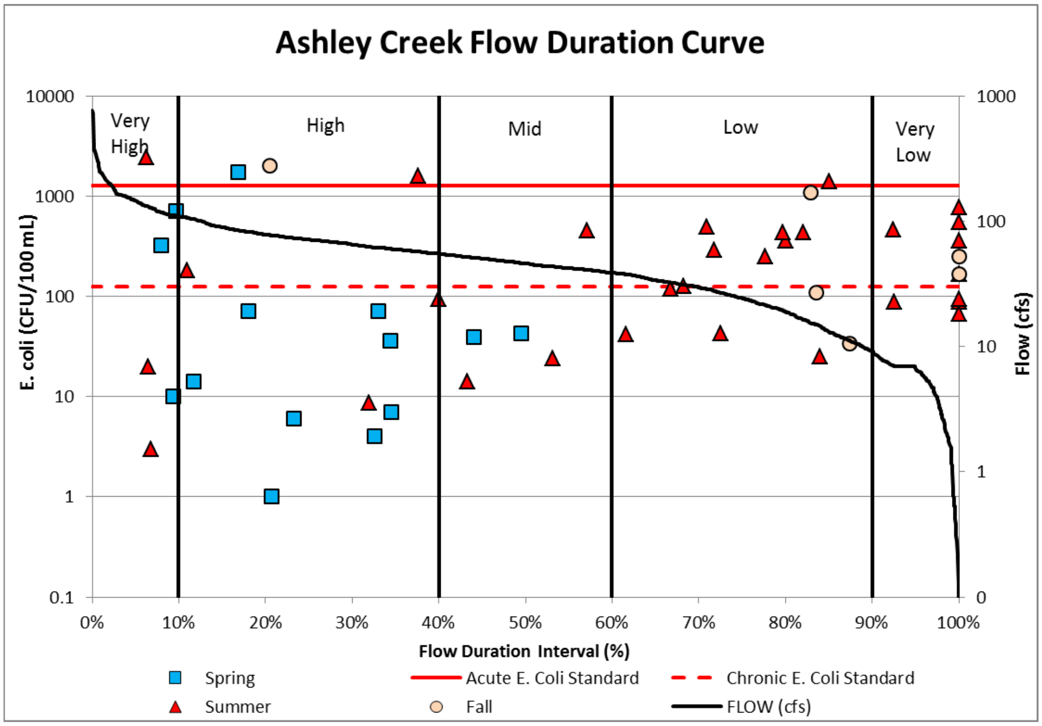


Figure 2.9. Individual *E. coli* measurements in the Ashley Creek impaired reach plotted by season and flow regime.

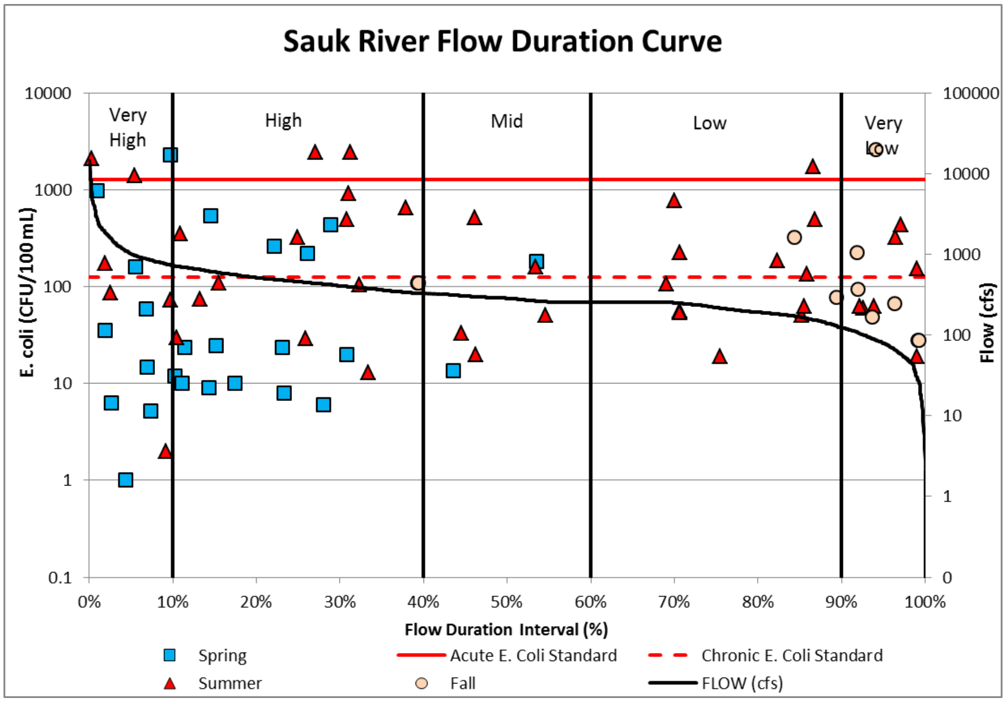


Figure 2.10. Individual *E. coli* measurements in the Sauk River impaired reach plotted by season and flow regime.

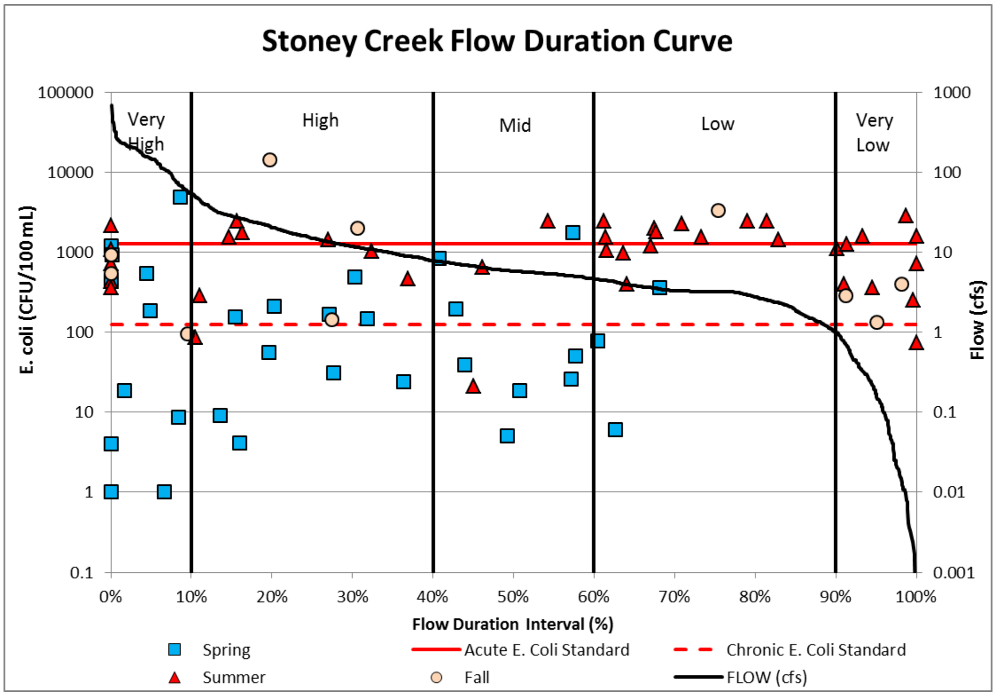


Figure 2.11. Individual *E. coli* measurements in the Stoney Creek impaired reach plotted by season and flow regime.

The relationship between flow and bacteria concentrations aids in identifying potential sources of elevated bacteria concentrations. Table 2.9 shows the conceptual relationship between flow and loading sources under various flow conditions. Under low flows, runoff processes are minimal as bacteria concentrations are primarily driven by WWTPs (if present), failing subsurface sewage treatment systems (SSTS) and animals in or near the receiving water. Conversely, at high flows, runoff from land with bacteria concentrations such as feedlots and pastures, urban areas and cropland often dominate.

Exceedances appear to occur across all flow regimes in the bacteria-listed reaches. This suggests that, at times, all of the aforementioned flow-driven sources may contribute to high bacteria concentrations observed throughout each reach.

Table 2.9 Conceptual relationship between flow regime and potential pollutant sources

Point Source Contributing Source Area	Flow Regime				
	Very High	High	Mid	Low	Dry
NPDES Permitted Treatment Facilities				M	H
Septic System w/ "Straight Pipe" connection				M	H
Livestock in receiving water				M	H
Sub-surface treatment systems			H	M	
Storm water Runoff – Impervious Areas		H	H	H	
Combined Sewer Overflows	H	H	H		
Storm water Runoff – Pervious Areas	H	H	M		
Bank Erosion	H	H	M		

Note: Potential relative importance of source areas to contribute loads under given hydrologic condition (H: High; M: Medium), based on EPA Doc. 841-B-07-006.

2.6.3 Bacteria Levels in Upstream Lakes

One of the four impaired reach contain upstream lakes that represent boundary conditions: Adley Creek (Sylvia Lake). There are currently no bacteria monitoring data available from the outlet of this upstream lake. Even if bacteria inputs to the lakes are high, the lake's volume should provide significant dilution. Thus, it is assumed a majority of the bacteria observed in the impaired reaches is produced within the impaired reach watershed.

2.6.4 Potential Bacteria Source Inventory

The purpose of the bacteria source assessment is to develop a comparison of the number of bacteria generated by the major known sources in the project area as an aid in focusing source identification activities. Only subwatersheds that drain directly to the impaired reaches and are downstream of lake boundaries were included in the source inventory (Figure 2.1). The source assessment is not directly linked to the total maximum loading capacities and allocations, which are a function of the water quality standards and stream flow (i.e. dilution capacity). Further, the inventory itself uses fecal coliform concentrations as the metric, not *E. coli*. This is because the inventory assessment is intended to evaluate the relative magnitude of bacteria loads being generated within the major source categories. The relative source comparisons are expected to be the same, regardless of whether fecal coliform or *E. coli* units are used.

2.6.4.1 Livestock Sources

Animal units (AUs) are the standardized measurement of livestock for various agricultural purposes. The AUs are used for the purpose of administering applicable state and federal regulations related to animal feedlots, manure storage areas and pastures; the most common species of livestock are assigned an AU value, which is based, in part, on the amount of manure each produces. Owners of an animal feedlot or manure storage area with 50 or more AUs (10 AUs in shore land areas) are required to register with the MPCA. Owners with fewer than 300 AUs are not required to have a permit for the construction of a new facility or expansion of an existing facility as long as construction is in accordance with the technical standards in Minn. R. ch. 7020, unless the facility is a pollution hazard. For owners with 300 AUs or more, and less than 1,000 AUs, construction short form permits are required for construction/expansion activities. Feedlots greater than 1,000 AUs or specific amount of animals as defined by the Code of Federal Regulations are considered large Concentrated Animal Feeding Operation (CAFOs) and are required to apply for an NPDES if they are discharging to waters of the United States, or a State Disposal System (SDS) Permit if they are greater than 1,000 AUs, or if they choose to obtain coverage. These operations, by law, are not allowed to discharge to waters of the state (Minn. R. 7020.2003).

Table 2.10 lists the number of feedlots present in the impaired reach watersheds according to the 2012 MPCA database and county surveys. Maps showing the approximate location (as points) and size (total AUs) of each feedlot are shown in Figures 2.12 through 2.15.

Table 2.10 Inventory of fecal coliform bacteria producers in the impaired reach direct watersheds.

Impaired Reach	# of Feedlots	# of CAFOs Permit #	Total AUs	AUs within 500 ft of stream	AUs per Acre	Total Dairy Units	Total Beef Units	Total Swine Units	Total Poultry Units	Total Other Units
Adley Creek 07010202-527	66	1	9,772	6,699	0.7	5,105	1,255	403	299	1
Ashley Creek 07010202-503	116	9	31,450	23,531	0.4	15,855	6,941	8,315	1	191
Sauk River 07010202-508	287	5	41,672	38,804	0.5	22,231	11,043	2,699	2,913	288
Stoney Creek 07010202-541	56	2	10,212	8,081	0.6	6,881	1,375	1,542	151	77

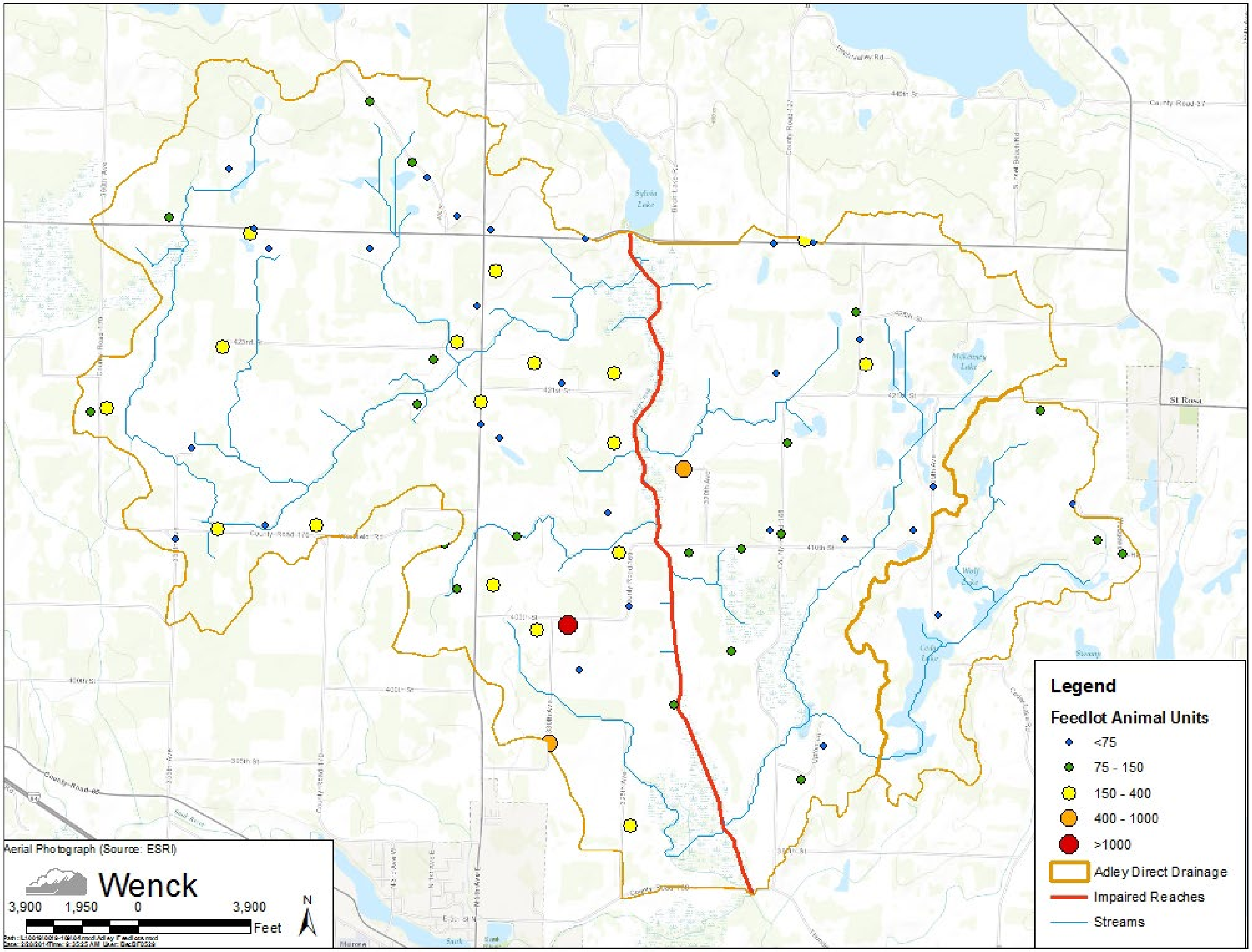


Figure 2.12. MPCA registered feedlots in the Adley Creek *E. coli* impaired watershed.

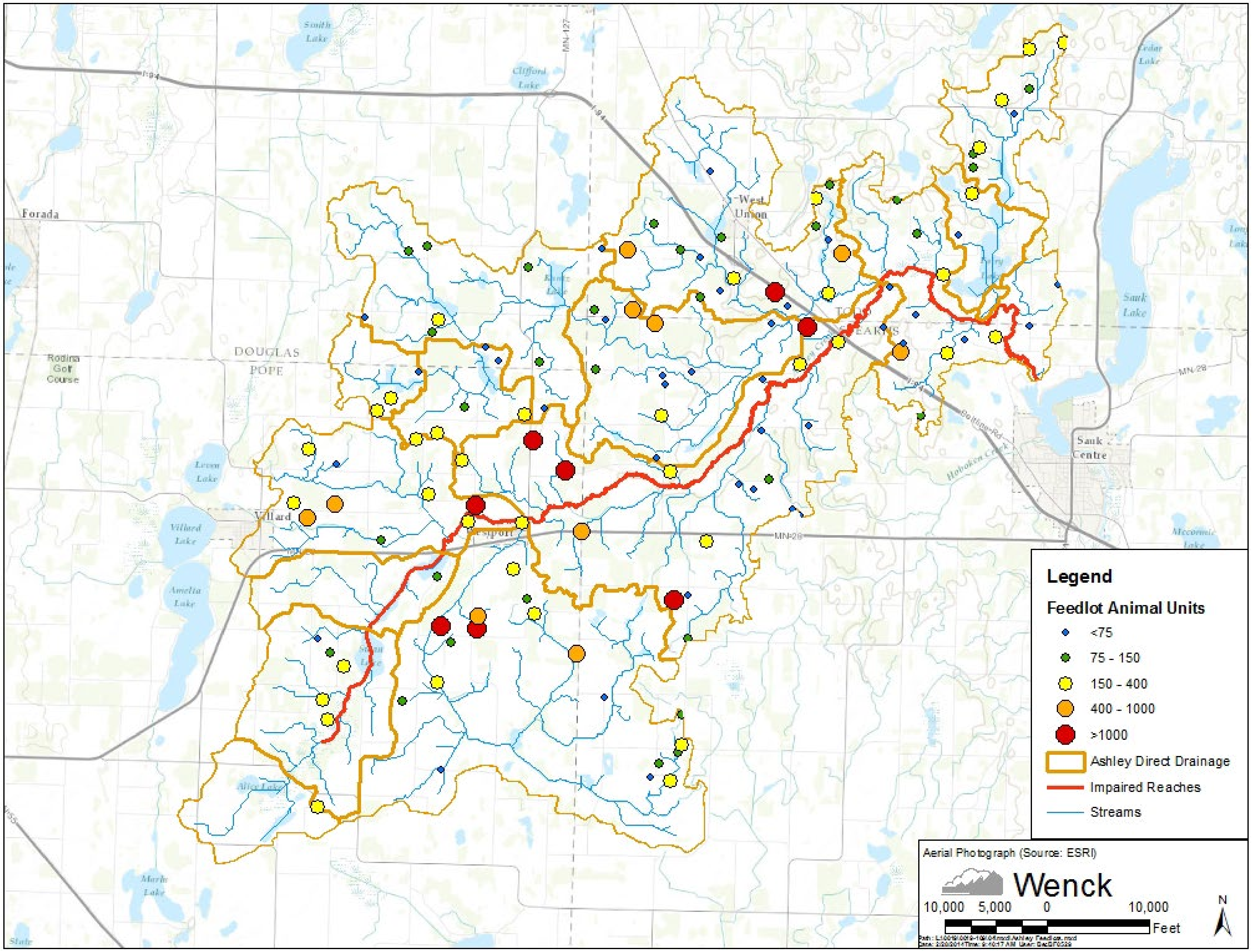


Figure 2.13. MPCA registered feedlots in the Ashley Creek *E. coli* impaired watershed.

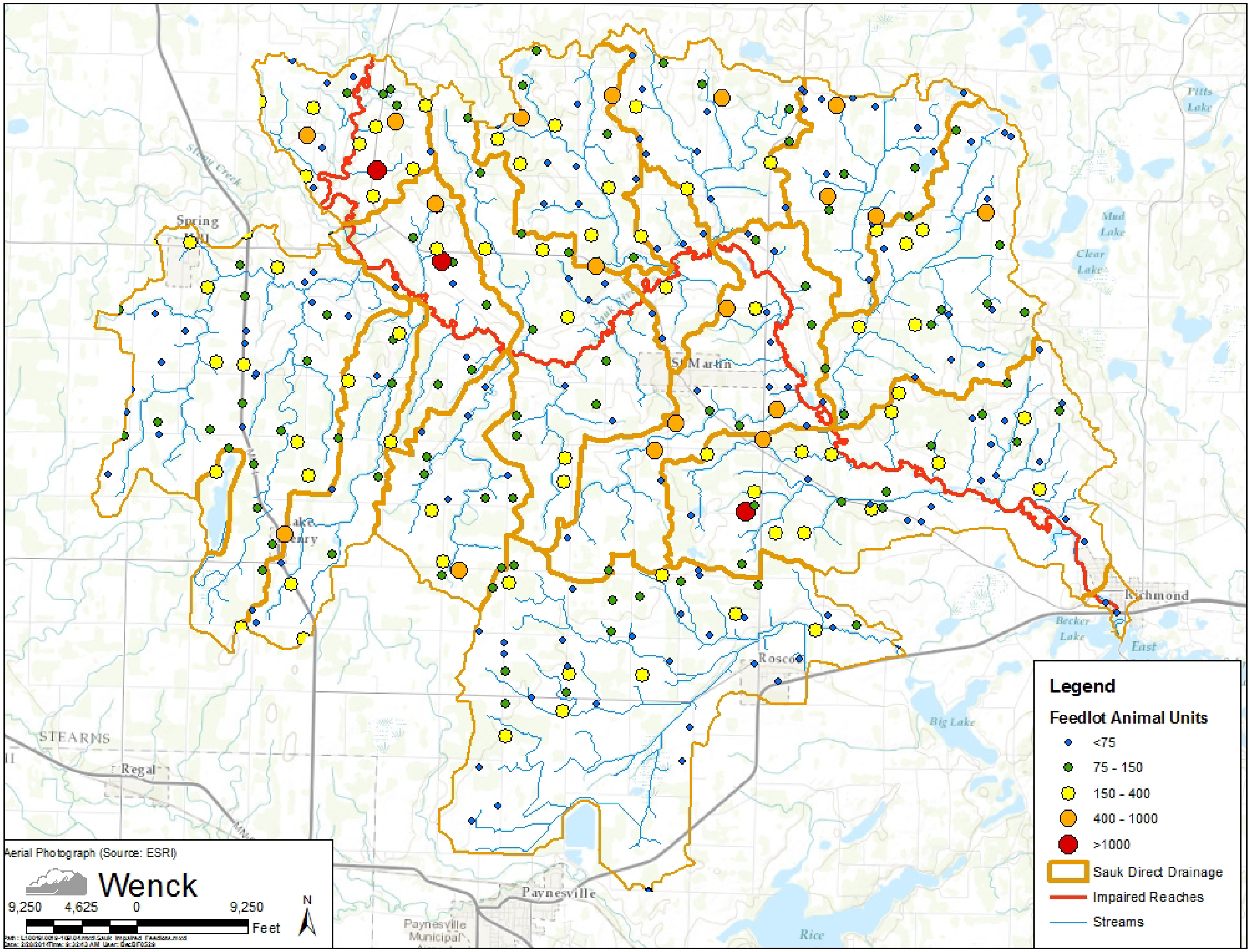


Figure 2.14. MPCA registered feedlots in the Sauk River *E. coli* impaired watershed.

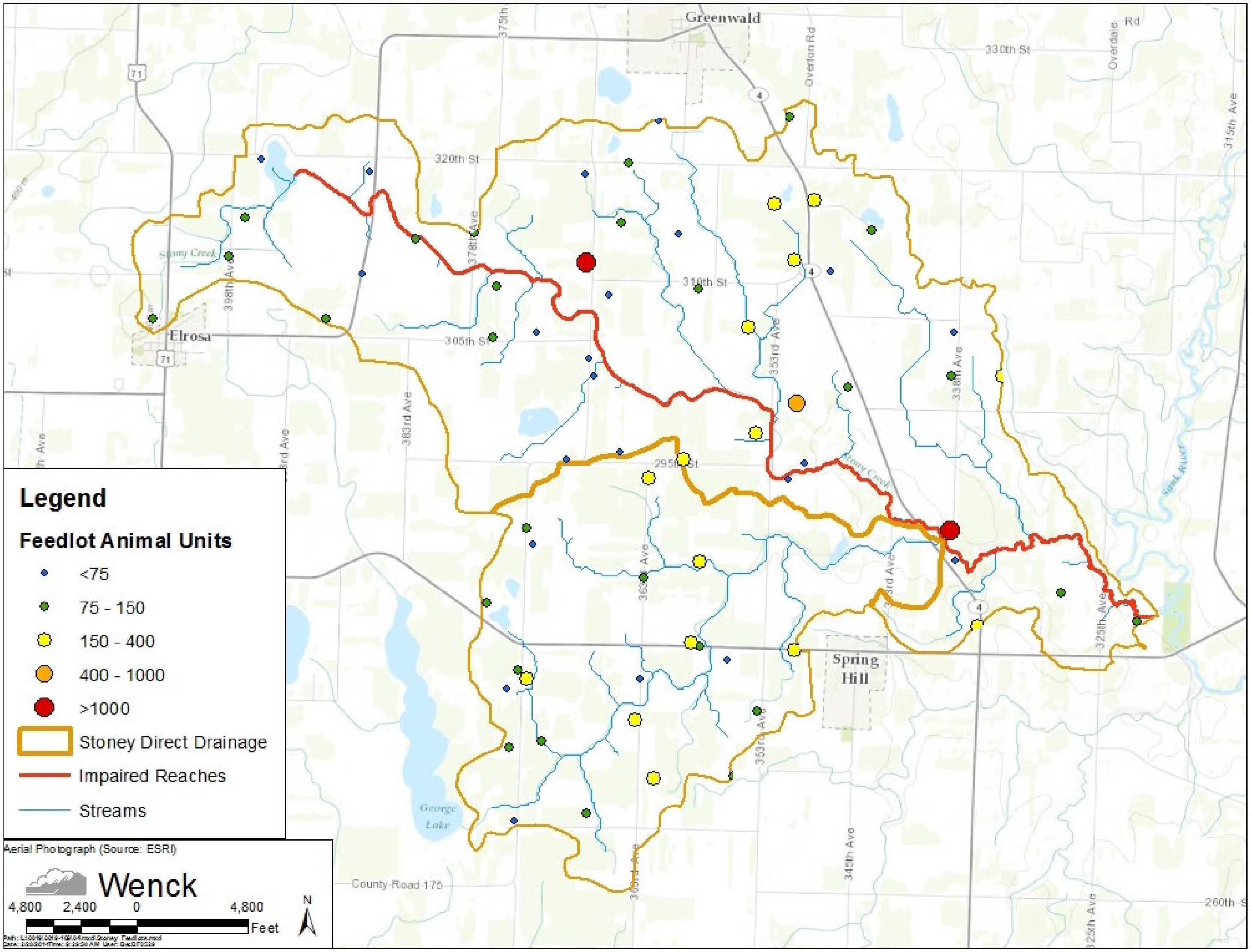


Figure 2.15. MPCA Registered feedlots in the Stoney Creek *E. coli* impaired reach watershed

2.6.5 Manure Application

A significant proportion of the cropland in the impaired reaches receives some sort of manure application. Most hog manure is applied as a liquid and is often injected directly into the soil or incorporated after surface spreading with agriculture tillage equipment. Application of incorporated manure typically occurs in the fall when liquid manure storage areas (LMSA) are full and crops have been harvested. However, some LMSAs are emptied earlier in the year if needed. When this happens, it is often done prior to spring planting although many farmers do not rely on application during this time if the top-soil is over-saturated.

Most beef and poultry manure is applied as a solid. Dairy manure is applied as both liquid and solid manure. In most cases, the larger dairy operations have LMSAs, while the smaller dairies haul manure as a solid. Most liquid manure is injected into the soil or incorporated within 24 hours. Solid manure is spread on the soil surface where it is not immediately incorporated into the ground. Again, a large portion of manure applications occur in the fall when LMSAs are emptied out. However, some farmers (especially small dairy farmers) will spread this manure year round. This source assessment assumed that 50% of the manure produced from confined animals is applied to cropland. The remaining manure application was split between upland pastures and pastures near streams depending on the number of animal units, the proximity of feedlot to streams, and the land cover within the impaired water body watershed.

2.6.6 Feedlots and Pastures Near Streams

Feedlots and open lot cattle and dairy facilities within 500 feet of a stream have a higher likelihood of animal access to the stream and therefore higher likelihood of delivering bacterial loads to the receiving water. The Sauk River, Adley Creek, Ashley Creek, and Stoney Creek impaired reaches all have multiple feedlots within 500 feet of Minnesota Department of Natural Resources (DNR) defined waters (Table 2.10). To address overgrazed pastures, this report assumes that 1% of dairy and beef cattle are in overgrazed pastures (MPCA 2002).

2.6.7 Human Sources

2.6.7.1 Septic Systems

Failing SSTS can be an important source of bacteria to surface waters. Currently, the exact number and status of SSTSs in the Sauk River Watershed is unknown. The MPCA's "2012 SSTS Annual Report: SSTS in Minnesota" report to the Minnesota Legislature includes some information regarding the performance of SSTSs in the Sauk River Watershed (MPCA 2013). This study provides county annual reports from 2002 that include estimated failure rates for each county in the state of Minnesota. The report differentiates between systems that are generally failing and those that are an imminent threat to public health and safety (ITPHS). Generally failing systems are those that do not provide adequate treatment and may contaminate groundwater. For example, a generally failing system may have a functioning, intact tank and soil absorption system, but fails to protect ground water by providing a less than sufficient amount of unsaturated soil between where the sewage is discharged and the ground water or bedrock. Systems considered ITPHS are severely failing or were never designed to provide adequate raw sewage treatment. Examples include SSTSs that discharge directly to surface water bodies such as ditches, streams, or lakes.

Total number of generally failing and ITPHS systems in each of the impaired reach watersheds was estimated in GIS using 2010 Census population data. Rural population that falls outside the boundaries of municipalities with WWTPs was calculated and divided by three people per household to estimate the total number of SSTSs in each watershed. Next, failing and ITPHS systems were estimated by multiplying the total number of SSTSs by the county failure rates from the 2012 MPCA Report (Table 2.11). Finally, annual bacteria load from failing SSTSs was calculated using the University of Minnesota Water Resource Center's 2012 version of the Septic System Improvement Estimator (SSIE). The SSIE is a spreadsheet-based model that uses published literature rates to calculate annual pollutant loads from problematic septic system. This model was setup to assume that even though generally failing systems often discharge bacteria and other pollutants to groundwater, it is unlikely that any of the bacteria from these systems makes it to surface waters. ITPHS systems, on the other hand, often discharge directly to surface waters and have extremely high delivery potentials. Thus it was assumed that none of the bacteria in ITPHS systems is removed and 100% is transported to surface waters in the impaired reach watersheds.

Table 2.11. Inventory of SSTSs in the *E. coli* impaired reach direct watersheds

Impaired Reach	County	Rural Population	Generally Failing SSTSs	ITPHS ISTSs
Adley Creek	Stearns	391	10%	2%
Ashley Creek	Douglas, Pope, Stearns, Todd	1484	10 to 20%	0 to 4%
Sauk River	Stearns	3144	10%	2%
Stoney Creek	Stearns	285	10%	2%

2.6.7.2 NPDES-permitted Wastewater Dischargers

There are eight NPDES-permitted wastewater dischargers in the impaired reach watersheds: Freeport WWTP, GEM Sanitary District, Lake Henry WWTP, Melrose WWTP, Osakis WWTP, Richmond WWTP, Sauk Center WWTP, St. Martin WWTP. The DMRs were downloaded from the MPCA STORET database to assess effluent bacteria concentrations for each point source. By rule, these facilities are not to discharge treated wastewater with fecal coliform concentrations that exceed 200 organisms/100ml (126 cfu/100 ml *E. coli* concentration). All WWTPs have regularly monitored effluent fecal coliform concentration. Results indicate each facility rarely exceeds the fecal coliform permitted concentration limit and typically discharge well below the 200 organisms/100ml limit.

2.6.7.3 Wildlife

Wildlife in the impaired reach watersheds encompasses a broad group of animals. For this assessment, deer and geese were assumed to be the main contributors while other wildlife was grouped into one separate category.

The DNR modeled deer population densities for several nearby areas. The DNR staff provided estimates of about 5 deer per square mile for most of the watershed, with up to 15 deer per square mile closer to the river valleys (Jeff Miller-DNR Wildlife Division in Willmar, personal communication). This report assumes an average deer density of 6 deer per square mile for the entire watershed.

Goose densities were estimated using the Southeast Minnesota Regional TMDL where they assumed a goose population of 20,000 individuals, which equates to a density of approximately 2.8 geese per square mile.

2.6.8 Urban Stormwater Runoff

Untreated urban stormwater has demonstrated bacteria concentrations as high as or higher than grazed pasture runoff, cropland runoff, and feedlot runoff (EPA 2001, Bannerman et al. 1993, 1996). There is very little urban area land cover in the Sauk River Watershed. Urban bacteria contributions were assumed to come exclusively from improperly managed waste from dogs and cats. Using the approach in that study, it was assumed that there were 0.58 dogs/household and 0.73 cats/household in the urban areas. Deer and geese densities in urban centers were assumed to be the same as those discussed in the previous section.

As described earlier in Section 2.6.1, *E. coli* bacteria may have the capability to reproduce naturally in water and sediment and therefore should be taken into account when identifying bacteria sources. (Sadowsky et al. 2015).

Livestock bacteria sources were assigned a percentage to predict where in the watershed livestock manure is spread and/or deposited. It is important to note that this process assumes that all bacteria produced in the watershed remain in the watershed. The assigned percentages are approximations that were developed for other bacteria TMDLs in Minnesota, and then altered to reflect GIS calculations, land use and current conditions within the Sauk River impaired watersheds. Daily fecal coliform production estimates for each agricultural AU, cat/dog and wildlife animal were derived from published values (MPCA 2002). Figures 2.16 through 2.19 summarize the total fecal coliform produced by each source as a percent of the total bacteria production in the impaired reach watershed. Appendix B provides a more complete description of the calculation and assumptions used to estimate bacteria production in each watershed.

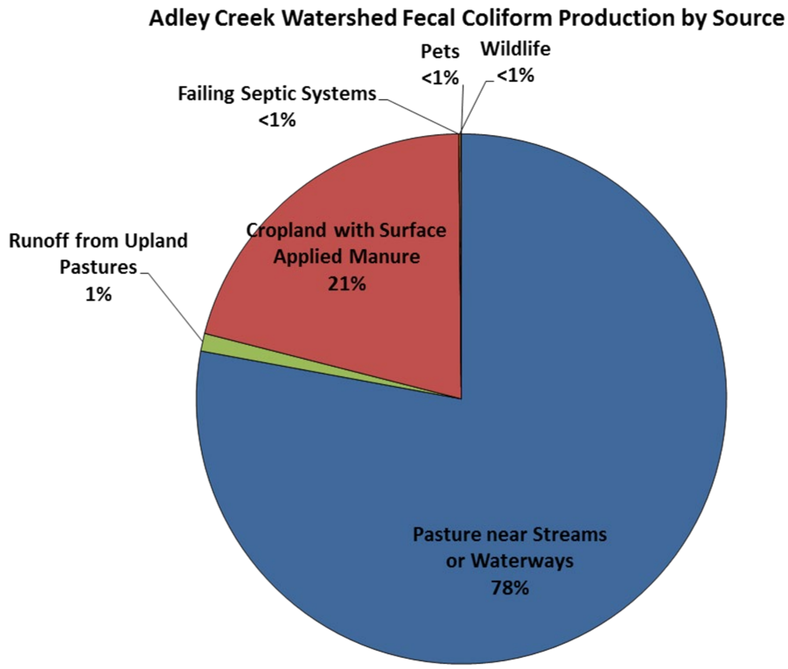


Figure 2.16. Fecal coliform available (by source) for delivery in the Adley Creek impaired reach watershed.

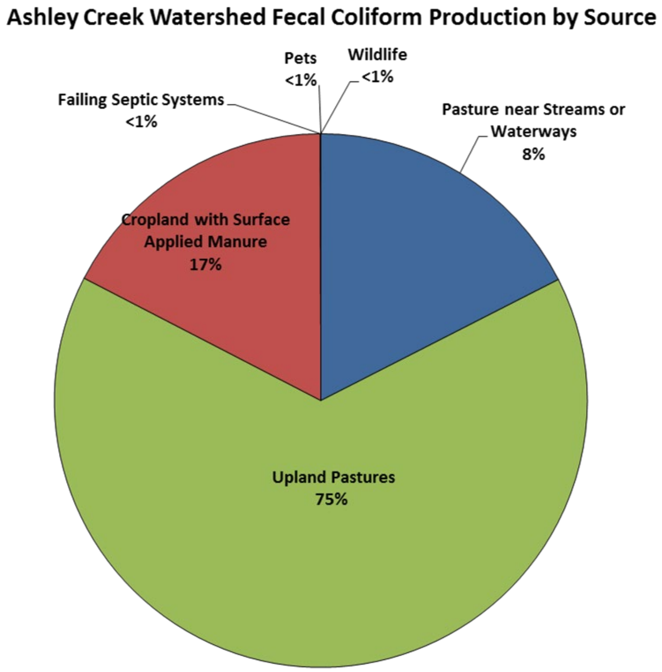


Figure 2.17. Fecal coliform available (by source) for delivery in the Ashley Creek impaired reach watershed.

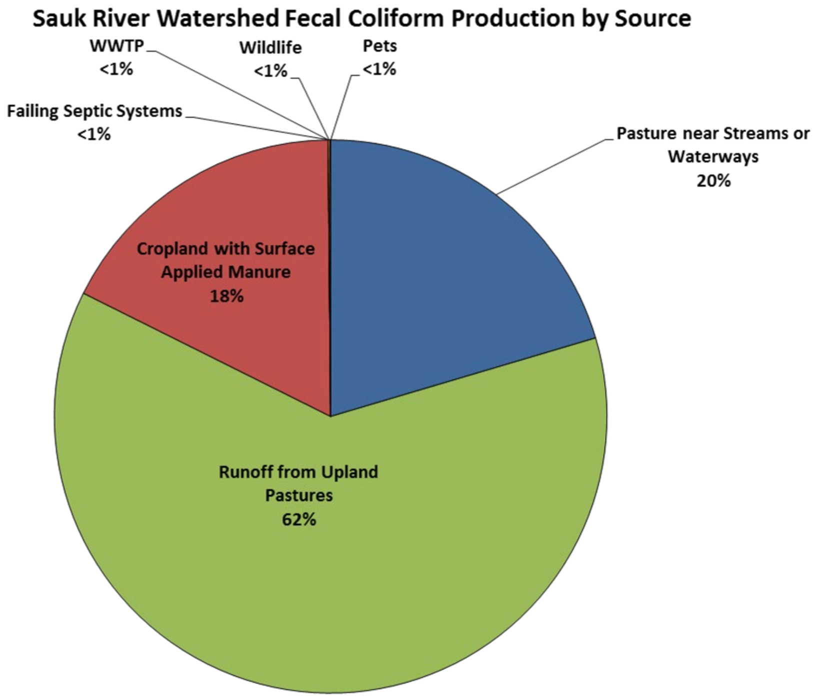


Figure 2.18. Fecal coliform available (by source) for delivery in the Sauk River impaired reach watershed.

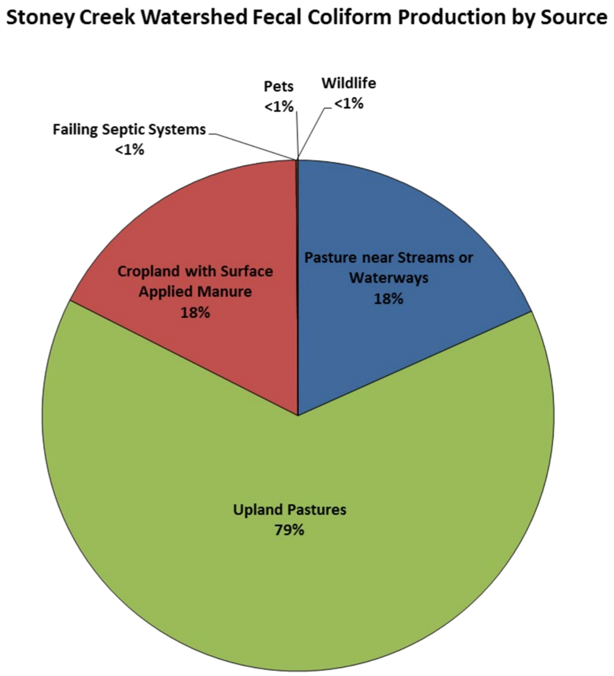


Figure 2.19. Fecal coliform available (by source) for delivery in the Stoney Creek impaired reach watershed.

2.6.9 Pollutant Source Assessment Summary

Based on the outcome of the bacteria pollutant source inventory, the results suggest that:

- Livestock are by far the largest producer of bacteria in the impaired reach watersheds.

- The largest potential sources are those activities associated with runoff from upland pastures and pastures near waterways.
- Generally speaking, mobilization of bacteria from upland pastures is likely to be a problem when runoff processes carry recently applied manure to receiving waters during mid and high flow conditions.
- Pastures near streams and waterways may have a disproportionately large contribution of bacteria to impaired reaches during mid and low flow conditions if livestock have access to streams. Implementation activities should focus on limiting cattle access to the impaired reaches and their tributaries, and buffering runoff from pastures near streams and waterways.
- Other sources such as failing septic systems, WWTPs, wildlife, and urban runoff (pets) appear to be a small source of bacteria to the impaired reaches.

3 Lake Excess Nutrient Impairments

3.1 NUTRIENTS IN IMPAIRED LAKES

A key component to developing a nutrient TMDL is to understand the sources contributing to the impairment. This section provides a brief description of the potential sources in the watershed contributing to excess nutrients in the nine lakes addressed in this TMDL. The latter sections of this report discuss the major pollutant sources that have been quantified using monitoring data and water quality modeling. The information presented herein will provide information necessary to target pollutant load reductions.

Both permitted and non-permitted sources are present within the watershed. There are a number of factors that can influence the nutrient levels in a lake. In the case of a number of the lakes addressed in this study, water quality in upstream lakes has a direct influence on the lakes located downstream in the watershed. Other factors influencing TP nutrient levels in these water bodies to consider are atmospheric nutrient loading, watershed nutrient loading, and internal phosphorus loading in each lake.

3.1.1 Permitted Sources

Table 3.1 summarizes the potential permitted sources in the Sauk River Watershed. There are no wastewater treatment plants discharging to the impaired lakes.

Table 3.1. Potential permitted sources of phosphorus.

Permitted Source	Source Description	Phosphorus Loading Potential
Phase II Municipal Stormwater NPDES/SDS General Permit	Municipal Separate Storm Sewer Systems (MS4s)	Potential for runoff to transport grass clippings, leaves, car wash wastewater, and other phosphorus containing materials to surface water through a regulated MS4 conveyance system.
Construction Stormwater NPDES/SDS General Permit	Permits for any construction activities disturbing: 1) One acre or more of soil, 2) Less than one acre of soil if that activity is part of a “larger common plan of development or sale” that is greater than one acre or 3) Less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources.	The EPA estimates a soil loss of 20 to 150 tons per acre per year from stormwater runoff at construction sites. Such sites vary in the number of acres they disturb.
Multi-sector Industrial Stormwater NPDES/SDS General Permit	Applies to facilities with Standard Industrial Classification Codes in 10 categories of industrial activity with significant materials and activities exposed to stormwater.	Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite.

3.1.2 Non-Permitted Sources

Table 3.2 summarizes the potential non-permitted nutrients sources in Sauk River Watershed.

Table 3.2. Potential non-permitted sources of phosphorus.

Non-Permitted Source	Source Description
Atmospheric Phosphorus Loading	Precipitation and dryfall (dust particles suspended by winds and later deposited).
Watershed Phosphorus Export	Variety in land use creating both rural and urban stormwater runoff that does not pass through a regulated MS4 conveyance system.
Internal Phosphorus Release	Under anoxic conditions, weak iron-phosphorus bonds break, releasing phosphorus in a highly available form for algal uptake. Carp and other rough fish present in lakes can lead to increased nutrients in the water column as they uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments. Over-abundance of aquatic plants can limit recreation activities and invasive aquatic species such as curly-leaf pondweed can change the dynamics of internal phosphorus loading. Historical impacts, such as WWTP effluent discharge, can also affect internal phosphorus loading.
Groundwater Contribution	Groundwater can be a source or sink for water in a lake and contains varying levels of phosphorus.
SSTS (Subsurface Sewage Treatment Systems)	SSTS failures on lakeshore homes can contribute to lake nutrients impairments.

3.2 NUTRIENT TMDL METHODOLOGY

The first step in developing an excess nutrients TMDL for lakes is to determine the total nutrients loading capacity or assimilative capacity for the lake. A key component for this determination is to estimate the current phosphorus loading by the sources for each lake. Following estimation of the current loading, lake response to phosphorus loading was modeled using the BATHTUB suite of models for the impaired lakes and the loading capacity was determined. The components of this process are described below.

3.2.1 Nutrients Loading and Lake Response

3.2.1.1 Watershed Loading

A Hydrological Simulation Program-FORTRAN (HSPF) model was developed by the MPCA for the Sauk River Watershed (RESPEC 2012). All watershed loads were taken from the models and input into the spreadsheet BATHTUB models developed for this study. In the cases where watershed water quality data were available and were significantly different from model results, these data were used rather than model outputs. In all other cases, model output was used to estimate watershed loading.

It is important to note that the HSPF model uses loading rates based on hydrozones and not individual lakesheds, meaning that some resolution is lost for each of the individual lakes. For example, the same land use loading rates are used for all of the lakes in the Juergens Lake chain even though there are large differences in AUs among the lakesheds. These differences were assessed in this TMDL where data are available.

3.2.1.2 Septic System Loading

Failing or nonconforming individual SSTSs can be an important source of phosphorus to surface waters. Currently, knowledge of the exact number and status of SSTSs in the Sauk River Watershed is unclear. The MPCA's 2012 "10 Year Plan to Upgrade and Maintain Minnesota's On-site Treatment Systems" report to the Minnesota Legislature includes some information regarding the performance of SSTSs in the Sauk River Watershed (MPCA 2013). This study provides county annual reports from 2002 that include estimated failure rates for each county in the state of Minnesota. Phosphorus loading from failing SSTSs was not explicitly modeled in the Sauk River HSPF model (Reisinger, personal communication). Instead, failing SSTS contribution was estimated outside of the model according to the following methodology. The number of SSTSs contributing to each stream/lake was developed by applying equal distribution of septic systems across each county based on the SSTS numbers provided in the 2012 MPCA report. For counties with no SSTS estimates in the 2004 report, septics were estimated by calculating rural population in GIS using 2010 Census population data. Rural population that falls outside the boundaries of municipalities with WWTPs was calculated and divided by three people per household to estimate the total number of SSTS for each lake watershed. Loading from all failing SSTSs was assumed to contribute a constant per person flow of 50 gallons/day and nitrogen, phosphorus and carbonaceous biochemical oxygen demand (CBOD) pollutant concentrations of 53 mg/L, 10 mg/L and 175 mg/L, respectively. County failure rates from the 2012 MPCA Report are presented in Table 3.3.

Table 3.3. SSTS failure rates by county (MPCA 2012).

County	Percent Failing Systems
Stearns	2%
Pope	15%
Todd	4%

3.2.1.3 Upstream Lakes

Some of the lakes addressed in the TMDL have upstream lakes, which are addressed in this TMDL and prior TMDLs. Meeting water quality standards in the downstream lakes is contingent on water quality improvements in the impaired upstream lakes. For these situations, lake outflow loads from the upstream lake were routed directly into the downstream lake and were estimated using monitored lake water quality. During reduction calculations upstream lakes with current or prior TMLDs were assumed to meet state water quality standards for phosphorus concentrations.

3.2.1.4 Atmospheric Deposition

A study conducted for the MPCA, "Detailed Assessment of Phosphorus Sources to Minnesota Watersheds" (Barr Engineering 2004), estimated the atmospheric inputs of phosphorus from deposition for different regions of Minnesota. The rates vary based on the precipitation received in a given year. Precipitation received during 2005 to 2011 was within that study's average range (25 inches to 38 inches). That study's annual atmospheric deposition rate of 26.8 kg/km^2 for average precipitation years was used to calculate annual atmospheric deposition load for these lakes.

3.2.1.5 Internal Loading

Internal phosphorus loading from lake sediments is an important part of the phosphorus budgets of lakes. Internal loading is typically the result of sediment releasing phosphorus to the water column. This often occurs when anoxic conditions are present, meaning that the water in and above the sediment is devoid of oxygen. However, studies have shown that internal loading can and does occur when the overlying water column is well oxygenated. For deep lakes in this study, temperature and dissolved oxygen profiles were used to determine the volume of lake water under anoxic conditions throughout the summer growing season. This volume was then used to calculate an anoxic factor (Nürnberg 2004) normalized over the lake basin and reported as number of days.

In order to calculate total internal load for a lake, the anoxic factor (days) is multiplied by an estimated or measured phosphorus release rate (mg/m^2/day). Release rates can be obtained by collecting sediment cores in the field and incubating them in the lab under oxic and/or anoxic conditions to measure phosphorus release over time. For this project, lab determined release rates were not available any lakes. Literature values (Nürnberg 1997) and model residuals were used to determine appropriate release rates for all other lakes with no lab measurements.

3.2.2 BATHTUB Model (Lake Response)

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. Lake response to nutrient loading was modeled using the BATHTUB suite of models and the significant data set available for the impaired lakes. BATHTUB is a series of empirical eutrophication models that predict the response to phosphorus inputs for morphologically complex lakes and reservoirs (Walker 1999). Several models (subroutines) are available for use within the BATHTUB model, and the Canfield-Bachmann model was used to predict the lake response to TP loads. The Canfield-Bachmann model estimates the lake phosphorus sedimentation rate, which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom, and is used in concert with lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. These model predictions are compared to measured data to evaluate how well the model describes the lake system. Once a model is well calibrated, the resulting relationship between phosphorus load and in-lake water quality is used to determine the assimilative capacity.

To set the TMDL for each impaired lake in the study, the nutrient inputs partitioned between sources in the lake response model were then systematically reduced until the model predicted that each lake met the current TP standard of 60 mg/L as a growing season mean for shallow lakes and 40 mg/L for deep lakes. Lake response model results are included in Appendix C.

3.2.3 Phosphorus Load Summary

Table 3.4 summarizes the nutrient sources to each lake.

Table 3.4. Nutrient sources for each of the impaired lakes in the Sauk River Watershed.

		Watershed Sources							Internal Sources			Notes
Lake Chain	**Lake**	**Lake Morphology**	**Agriculture**	**Urban**	**Septics**	**Other**	**Sediment Release**	**Historic Impacts**	**Aquatic Vegetation (1)**	**Rough Fish (i.e. Carp) (2)**	**Upstream Lakes**	
Guernsey	**Maple**	**Deep**	●		○		●					Carp were not present in the most recent fish survey (2008) and only identified in one prior survey. The most recent vegetation survey indicates that coontail and filamentous algae are the most common submerged aquatic species
	Guernsey	**Shallow**	●		○		○		Δ	Δ	●	Carp comprised 10% of total biomass in most recent (2009) DNR fish survey. Recent fish and vegetation surveys indicate that poor water quality has resulted in sparse vegetation and low species diversity. Curly-leaf pondweed was observed in Guernsey lake although it is not the most abundant submerged vegetation.
	Little Sauk	**Deep**	●				○		Δ	Δ	●	Carp comprised 21% of total biomass in most recent (2009) DNR fish survey. Curly-leaf pondweed was present during August 2009 vegetation survey. Coontail and Canada waterweed most common species noted.
	Juergens	**Shallow**	●		○		○		Δ	Δ	●	Carp are present in lake but only accounted for 2% of total biomass in most recent (1990) DNR fish survey. No carp were found in the 1985 and 1957 DNR Fish surveys.
Individual	**Henry**	**Shallow**	○				●					No carp have been observed in Henry Lake although no DNR fish surveys have been conducted. Henry Lake is used as a walleye rearing pond and is stocked annually. The submergent vegetation consists primarily of duckweed, coontail, northern milfoil, sago pondweed, and bladderwort.
	McCormic	**Shallow**	●		○		○					There is not currently a DNR fish or vegetation survey available for McCormic Lake.
	Sand	**Shallow**	○		○		●		Δ	Δ		Carp comprised 5% of total biomass during recent (2012) DNR fish survey. Vegetation had moderate diversity and abundance according to the 2002 survey.
	Uhlenkolts	**Shallow**	○		○		●			Δ		Carp comprised 58% of total biomass and roughfish, including carp, comprised 98% of the total biomass of the most recent DNR fish survey (1982). There was only one submerged vegetation species, yellow waterlily, recorded during a 1976 DNR survey.
	Westport	**Shallow**	●				○			Δ		Carp comprised 20% of total biomass during the most recent (2007) DNR fish survey. Observations during the 2007 DNR fish survey suggest that it has moderate vegetation species diversity with no curly-leaf pondweed recorded.

● Primary Source
○ Secondary Source
Δ Potential Source (Unknown Level of Impact)

3.2.4 TMDL Allocation Methodology

To develop the appropriate loads under TMDL conditions, each load is evaluated sequentially to determine loads. Since atmospheric load is impossible to control on a local basis, no reduction in the source was assumed for the TMDLs. Septic discharge is not permitted, so 100% reduction is assumed. Then, any upstream lakes are assumed to meet water quality standards and the resultant reductions are applied to the lake being evaluated. If all of these reductions result in the lake meeting water quality standards, then the TMDL allocations are done. If more reductions are required, then the internal and external loads are evaluated simultaneously.

The capacity for watershed load reductions is considered first by looking at watershed loading rates and runoff concentrations compared to literature values. For example, some watershed phosphorus export rates are already so low that large reductions would be infeasible. Therefore, an internal load reduction is required to achieve water quality goals. However, in some cases, the situation was reversed and the internal load was already so low that only watershed reductions were required.

The general approach to internal load reductions was to evaluate the capacity for reducing the internal loading based on review of the modeled sediment release rates and the lake morphometry. This is accomplished by reviewing the estimated release rates versus literature values of healthy lakes. If the release rates are high, then they are reduced systematically until either a minimum of 1 $mg/m^2/day$ is reached or the lakes meet TMDL requirements. In some extreme cases, the release rate had to be reduced below 1 $mg/m^2/day$ to meet requirements. However, this is only done after all feasible watershed load reductions are included.

3.2.5 Load Allocation Methodology

The LA includes all non-permitted sources, including: atmospheric deposition, discharge from upstream lakes, watershed loading from non-regulated areas, and internal loading.

3.2.6 Wasteload Allocation Methodology

There are no MS4s that are completely within or have a portion of their municipal boundary in at least one of the impaired lake watersheds. The Juergens, Guernsey, and Little Sauk Chain do have MS4s and point sources upstream of Lake Osakis, but these have already been allocated in the Lake Osakis nutrient TMDL (Wenck 2013).

3.2.6.1 Construction and Industrial Stormwater

Construction and industrial stormwater WLAs were established based on estimated percentage of land in the watershed that is currently under construction or permitted for industrial use. A recent permit review across the entire Sauk River Watershed showed minimal construction (less than 1% of watershed area) and industrial activities (less than 0.5% of the watershed area). To account for future growth (reserve capacity), allocations in the TMDL were rounded up to 1% for construction stormwater and 0.5% for industrial stormwater. The best management practices (BMPs) and other stormwater control measures that should be implemented at the construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). 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 facility specific Individual Wastewater Permit or NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). 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 impaired waters discharges 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. Similarly, if an industrial 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. It should be noted that all local construction and industrial stormwater management requirements must also be met.

3.2.7 Margin of Safety

An explicit MOS has been included in this TMDL. Five percent of the load has been set aside to account for any uncertainty in the lake response models. The 5% MOS was considered reasonable for all of the modeled lakes due to the quantity of watershed and in-lake monitoring data available. Watershed monitoring data collected over a two-year period (2008 to 2009) was used for the majority of the lake modeling. In-lake monitoring data collected during the same two-year period was also available for the majority of the lakes.

3.2.8 Lake Response Variables

In addition to meeting phosphorus limits, Chl-*a* and Secchi transparency standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. ch. 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 transparency. Based on these relationships it is expected that by meeting the phosphorus target in each lake, the Chl-*a* and Secchi standards will likewise be met.

3.2.9 Seasonal Variation

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

3.2.10 Reserve Capacity

The amounts of land in agricultural use in the Smith Lake, Faille Lake and Osakis Lake Watersheds are likely to remain fairly constant over the next several decades. The watershed is comprised mainly of pasture and hay and row crops (corn and soybeans). While the majority of the landscape is likely to remain in an agricultural land use, it is possible a modest shift between pasture/hay and row crops may occur. Any such shift would likely not affect the loading capacity of the lakes, since that capacity is based on long-term flow records over which time land use changes have likely occurred. Thus, slight shifts in land use should not appreciably change the magnitude of the land use runoff variability that the period of record already reflects.

3.2.11 TMDL Summary

The allowable total phosphorus (TP) load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the preceding sections. The following sections summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake. In these tables the total load reduction is the sum of the required WLA reductions plus the required LA reductions; this is not the same as the net difference between the existing and allowable total loads, however, because the WLA and LA reductions must accommodate the MOS.

The following rounding conventions were used:

- Values ≥1 reported in lbs/yr have been rounded to the nearest whole number.
- Values <1 reported in lbs/yr have been rounded to the nearest tenth of a pound.
- Values reported in lbs/day have been rounded to three significant digits.

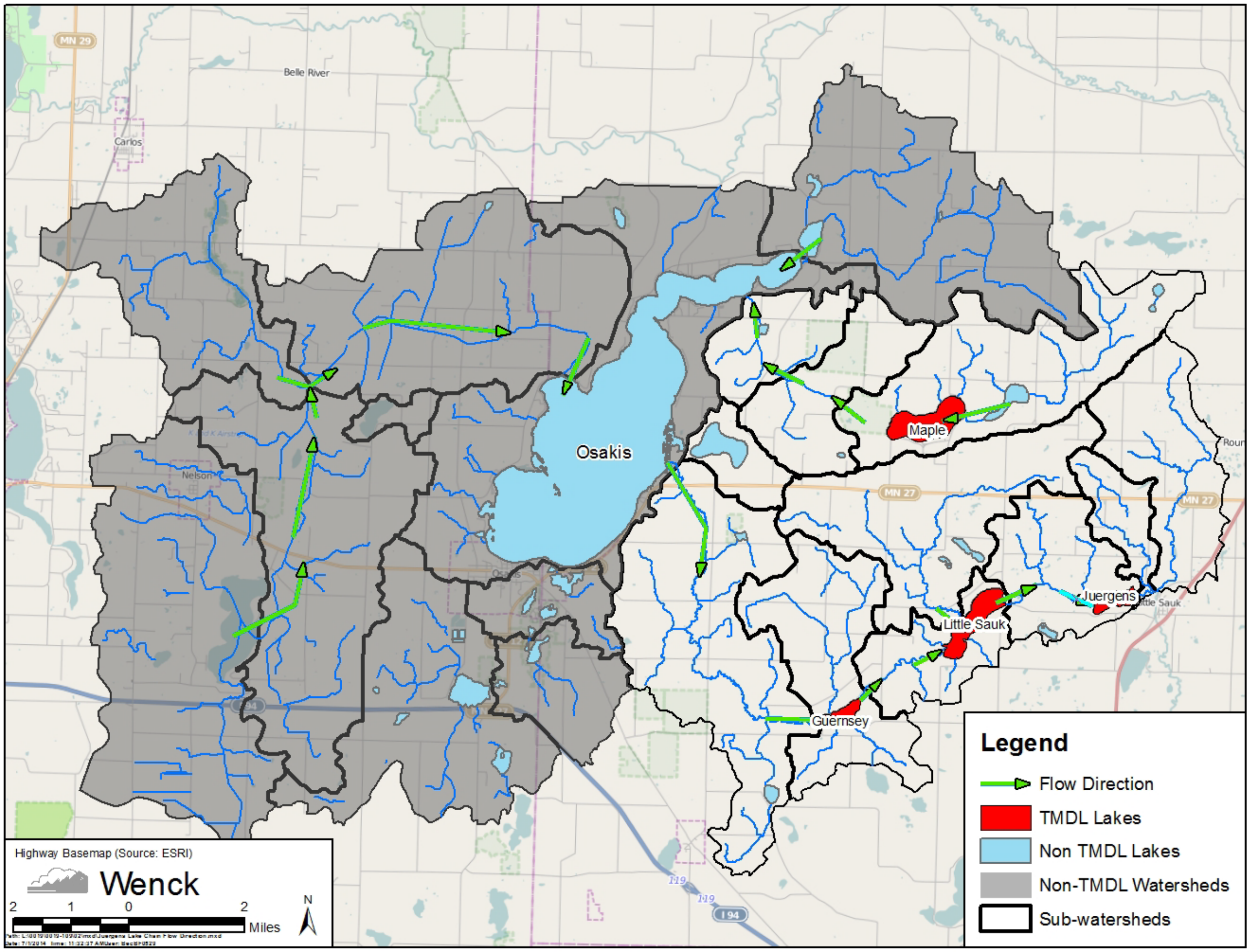
3.3 JUERGENS CHAIN OF LAKES TMDL

3.3.1 Watershed Description

Maple Lake (DNR # 77-0181), Guersney Lake (DNR # 77-0182), Little Sauk Lake (DNR # 77-0164), and Juergens Lake (DNR # 77-0163) are located in the Sauk River Headwaters 10-digit HUC (0701020201). This chain of lakes is located in the north-west portion of the Sauk River Watershed and includes portions of Todd and Douglas County (Figure 3.1).

Maple Lake is upstream of Osakis Lake and has a small watershed (6,406 acres) relative to other lakes in the Juergens Chain of Lakes. The first lake downstream of Lake Osakis, Guernsey Lake, has a relatively small watershed and receives roughly 90% of its total annual flow from the Osakis Lake Watershed. Guernsey Lake's direct watershed falls completely within Todd County although tributaries upstream of Lake Osakis receive drainage from Douglas County and Todd County. Following Guernsey Lake are Little Sauk and Juergens Lake, which both have small watersheds and receive most of their TP load and annual discharge from upstream lakes. Since Lake Osakis already has a completed nutrient TMDL (Wenck 2013), it was used as a boundary condition for the Guernsey Lake.

Figure 3.1. Flow pattern in the Jurgens Chain of Lakes TMDL study area.



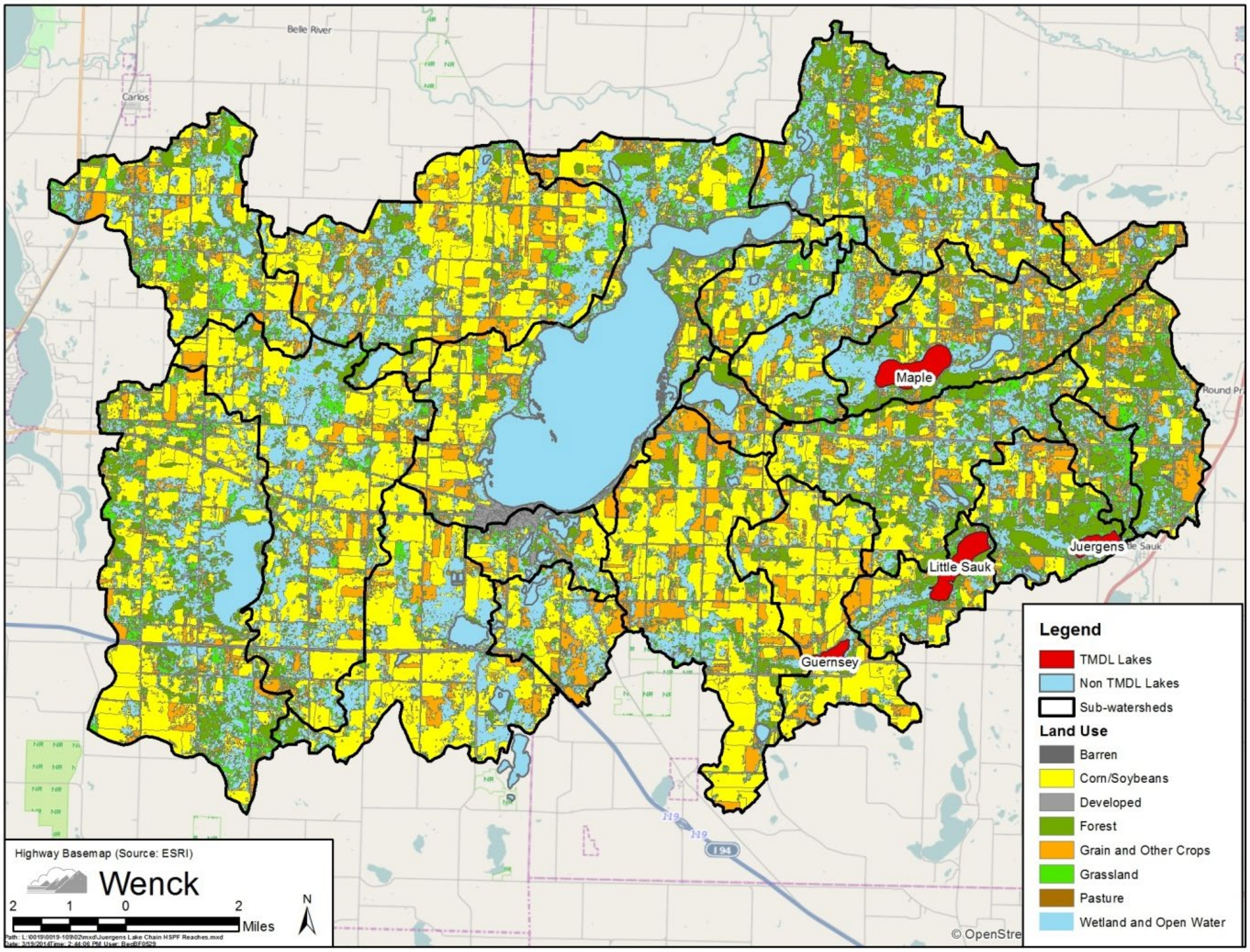


Figure 3.2. Land use in the Juergens Chain of Lakes TMDL study area.

Minn. R. 7050.0150, subp. 4, states that in order to be considered a lake/reservoir, a water body must have a hydraulic residence time of at least 14 days, which is to be determined using a flow equal to the 122-day 10-year low flow (122Q10) measured June 1st through September 30th. Although the 122Q10 was not calculated in this report, the average annual residence time for Guernsey, Little Sauk, and Juergens Lake are 7 days, 25 days, and 7 days, respectively. If necessary, these lakes may be considered reservoirs due to their extremely short residence time. The result of changing the definition of a lake to a reservoir would require site specific water quality standards for each reservoir. However, since the water quality is highly influenced by upstream TP loading, it is likely that these lakes will meet state standards for water quality if Lake Osakis water quality meets state standards.

Table 3.5. Land use in the Juergens Chain of Lakes TMDL study area

Lake		Open Water	Developed	Forest	Grassland /Scrub	Pasture	Crops	Wetlands	Total
Guernsey	Acres	169	679	880	311	3,738	7,829	618	14,224
	Percentage	3%	5%	6%	1%	24%	58%	3%	100%
Little Sauk	Acres	319	452	1,160	469	2,363	3,013	647	8,423
	Percentage	4%	5%	14%	6%	28%	35%	8%	100%
Juergens	Acres	147	150	561	284	1,043	778	142	3,105
	Percentage	5%	5%	18%	9%	33%	25%	5%	100%
Maple	Acres	399	276	995	277	2,151	1,623	682	6,403
	Percentage	6%	4%	16%	4%	34%	25%	11%	100%

3.3.2 Lake Morphometry

Guernsey and Juergens are considered shallow lakes, which means their maximum depth is less than 15 feet and/or the total area of the lake less than 15 feet deep (referred to as the littoral area) is greater than 80%. The other two lakes, Little Sauk and Maple Lake, are considered deep lakes and have maximum depths greater than 15 feet and are less than 80% littoral. Guernsey, Little Sauk and Juergens have very short residence (less than one year) due to their large upstream drainage areas. Maple Lake, on the other hand, has a smaller drainage area, which results in a much longer residence time.

Table 3.6 Lake morphometry for the Juergens Chain of Lakes

Parameter	Surface Area	Maximum Depth	Lake Volume	Residence Time	Littoral Area	Depth Class	Drainage Area
Water body	**acre**	**feet**	**ac-ft**	**years**	**%**	**--**	**acre**
Maple	388	19	3,158	1.22	53%	Deep	6,403
Guernsey	121	16	892	0.02	100%	Shallow	13,040
Little Sauk	286	25	2,747	0.07	34%	Deep	8,423
Juergens	117	16	1,070	0.02	100%	Shallow	3,105

3.3.3 Historic Water Quality

Tables 3.7 and 3.8 list the June through September averages of TP concentration, chl-*a* concentration, and Secchi depth for each impaired lake. The table also lists the data years, which were used to calculate the "average" condition for the TMDL study. In most cases, in-lake data was available from a period of 2007 to 2012.

Table 3.7. Deep lake growing season averages for water quality parameters.

		In-Lake "Average" Condition (Calculated June to September)		
Lake Name	"Average" Condition Calculation Years	TP Concentration (µg/L)	Chl-*a* Concentration (µg/L)	Secchi Depth (m)
Water Quality Standard for Deep Lakes		**40.0**	**14.0**	**1.4**
Maple	2007 to 2012	81.9	43.3	1.9
Little Sauk	2008 to 2009	55.5	47.6	1.3

Table 3.8. Shallow lake growing season averages for water quality parameters.

		In-Lake "Average" Condition (Calculated June to September)		
Lake Name	**"Average" Condition Calculation Years**	**TP Concentration (µg/L)**	**Chl-*a* Concentration (µg/L)**	**Secchi Depth (m)**
Water Quality Standard for Shallow Lakes		**60.0**	**20.0**	**1.0**
Guernsey	2008 to 2009	64.8	44.5	0.9
Juergens	2008 to 2009	68.8	44.5	1.3

3.3.4 Biological Conditions

Carp have been documented in Guernsey, Little Sauk, and Juergens lakes. These three all have large littoral areas, which may allow carp to impact water quality. Additionally, Curly-leaf pondweed has been documented in Guernsey and Little Sauk Lakes, which may exacerbate internal phosphorus loading.

Table 3.9 Aquatic vegetation and fisheries data for the Juergens Chain of Lakes.

Lake	Recent Survey Month-Year	Curly-leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Maple	2008	--	--	No	Fish biomass dominated by top predators while fish count is dominated by pan fish.
Guernsey	2009	Yes	No	Yes	Very little plant growth due to low water clarity; abundant carp population although there is still a healthy pan fish and top predator population.
Little Sauk	2009	Yes	No	Yes	Large carp (and roughfish) population. Relatively low vegetation diversity.
Juergens	1990	--	--	No	Vegetation data not available

3.3.5 Nutrient Sources

Maple Lake

Maple Lake is a deep lake in a small upstream watershed that is primarily surrounded by row crops and pasture. Carp have not been observed in in Maple Lake and its primary submergent vegetation is coontail. Nutrient loading in the lake is split between watershed runoff and internal loading; however, measuring sediment chemistry characteristics will help refine the nutrient budget for the lake.

Guernsey, Little Sauk, and Juergens Lake

Guernsey, Little Sauk, and Juergens lakes are connected lakes that receive more than 80% of their overall flow from Lake Osakis. Since these lakes receive the majority of their water from a lake with poor water quality (Lake Osakis: summer average TP 60 µg/L), their water quality will likely improve with any improvements in upstream water quality. Internal and SSTS phosphorus loading to these lakes constitutes less than 1% of the overall phosphorus budget for these lakes. Since these lakes are all relatively shallow and connected, the presence of carp and curly-leaf pondweed may contribute to poor water clarity.

Table 3.10 Nutrient Loading Sources for the Juergens Chain of Lakes.

Lake	Nonpoint Source Runoff	SSTS	Upstream Lakes	Atmosphere	Internal Load
Maple	42%	1%	<1%	5%	52%
Guernsey	14%	1%	81%	<1%	4%
Little Sauk	10%	<1%	87%	1%	2%
Juergens	5%	<1%	86%	<1%	9%

3.3.6 TMDL Summary

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the previous sections. Tables 3.11 through 3.14 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 3.11. TMDL allocations for Maple Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Construction and Industrial Stormwater	8	0.022	8	0.022	0	0%
Load	SSTS	9	0.024	0	0.000	9	100%
	Nonpoint Source Runoff	803	2.198	384	1.053	418	52%
	Upstream Lakes	0	0	0	0	0	0%
	Atmosphere	93	0.254	93	0.254	0	0%
	Internal Load	1,017	2.785	183	0.501	834	82%
	MOS	--	--	35	0.096	--	5%
	TOTAL	1,930	5.283	703	1.926	1,261	64%

Table 3.12. TMDL allocations for Guernsey Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Construction & Industrial Stormwater	54	0.147	54	0.147	0	0%
Load	SSTS	34	0.092	0	0.000	0	100%
	Nonpoint Source Runoff	960	2.628	960	2.628	0	0%
	Upstream Lakes	5,378	14.725	3,286	8.998	2,092	39%
	Atmosphere	29	0.079	29	0.079	0	0%
	Internal Load	260	0.712	260	0.712	0	0%
	MOS	--	--	243	0.666	--	5%
	TOTAL	6,715	18.383	4,832	13.230	2,126	28%

Table 3.13. TMDL allocations for Little Sauk Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Industrial & Construction Stormwater	70	0.192	70	0.192	0	0%
Load	SSTS	23	0.064	0	0.000	0	100%
	Nonpoint Source Runoff	862	2.359	362	0.991	500	58%
	Upstream Lakes	7,015	19.205	4,760	13.033	2,255	32%
	Atmosphere	68	0.187	68	0.187	0	0%
	Internal Load	131	0.359	131	0.359	0	0%
	MOS	----	--	285	0.780	--	5%
	TOTAL	8,169	22.366	5,676	15.542	2,778	31%

Table 3.14. TMDL allocations for Juergens Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Construction & Industrial Stormwater	75	0.206	75	0.206	0	0%
Load	SSTS	9	0.024	0	0	9	100%
	Nonpoint Source Runoff	470	1.286	470	1.286	0	0%
	Upstream Lakes	7,515	20.576	4,562	12.490	2,953	39%
	Atmosphere	28	0.076	28	0.076	0	0%
	Internal Load	777	2.126	777	2.126	0	0%
	MOS	--	--	311	0.852	--	5%
	TOTAL	8,874	24.294	6,223	17.036	2,962	30%

3.4 INDIVIDUAL LAKES TMDL

3.4.1 Watershed Description

The remaining five lakes are not contained within one HUC-12 watershed. These lakes and their watersheds are located in Pope and Stearns County in the central portion of the Sauk River Watershed (Figures 3.3 to 3.10). Of the five individual lakes, all are categorized as shallow lakes. The majority of these lakes are located in small watersheds that flow into the Sauk River. The predominant land use in the individual lake watersheds is row crops (36%), pasture (30%) and forest (13%) while all other land uses account for less than 25% of the total (Figures 3.15). There are no major cities or urban centers located in any of the individual lake watersheds.

Table 3.15. Land use in the individual lakes TMDL study area

Lake		Open Water	Developed	Forest	Grassland/ Scrub	Pasture	Crops	Wetlands	Total
Henry	Acres	206	<1	22	12	29	152	21	442
	Percentage	47%	<1%	5%	3%	7%	33%	5%	100%
McCormic	Acres	201	35	103	17	268	336	38	998
	Percentage	20%	4%	10%	2%	27%	33%	4%	100%
Sand	Acres	208	13	12	2	94	110	13	452
	Percentage	46%	3%	3%	0%	21%	24%	3%	100%
Uhlenkolts	Acres	299	190	184	21	855	1,352	27	2,928
	Percentage	10%	6%	6%	1%	29%	47%	1%	100%
Westport	Acres	583	395	553	290	895	6,220	1,199	10,135
	Percentage	6%	4%	5%	3%	9%	61%	12%	100%

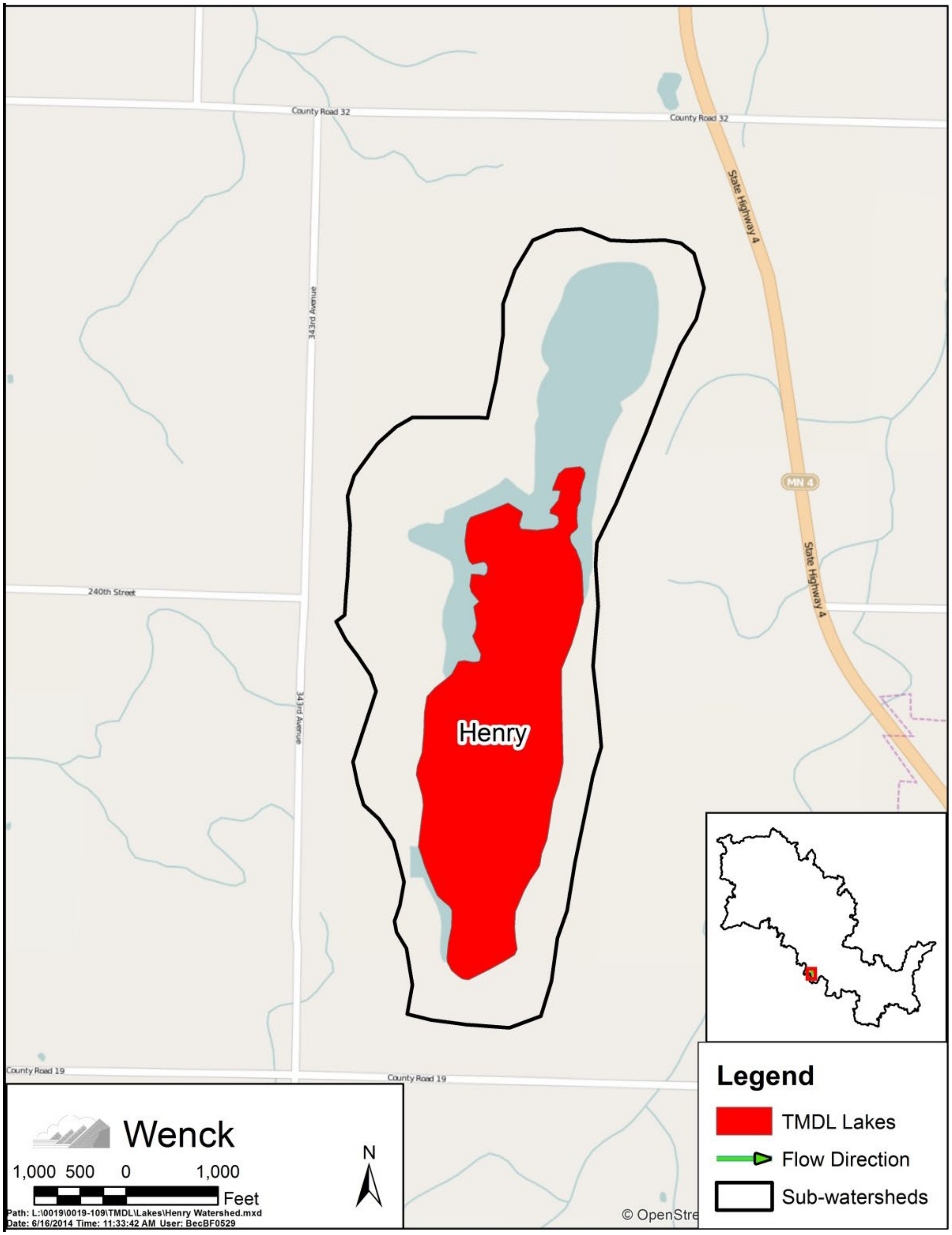


Figure 3.3. Henry Lake Watershed.

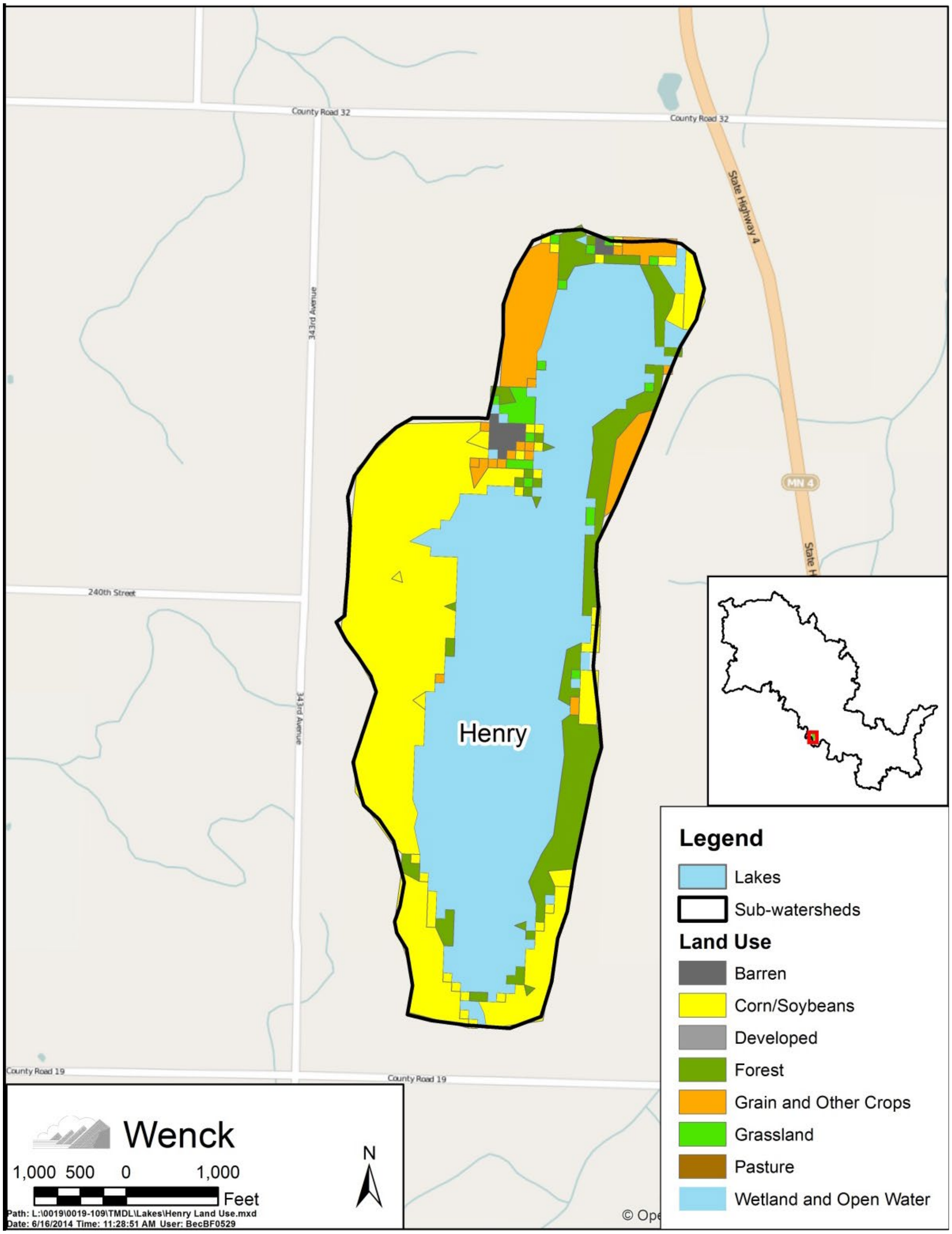


Figure 3.4. Henry Lake Watershed land use.

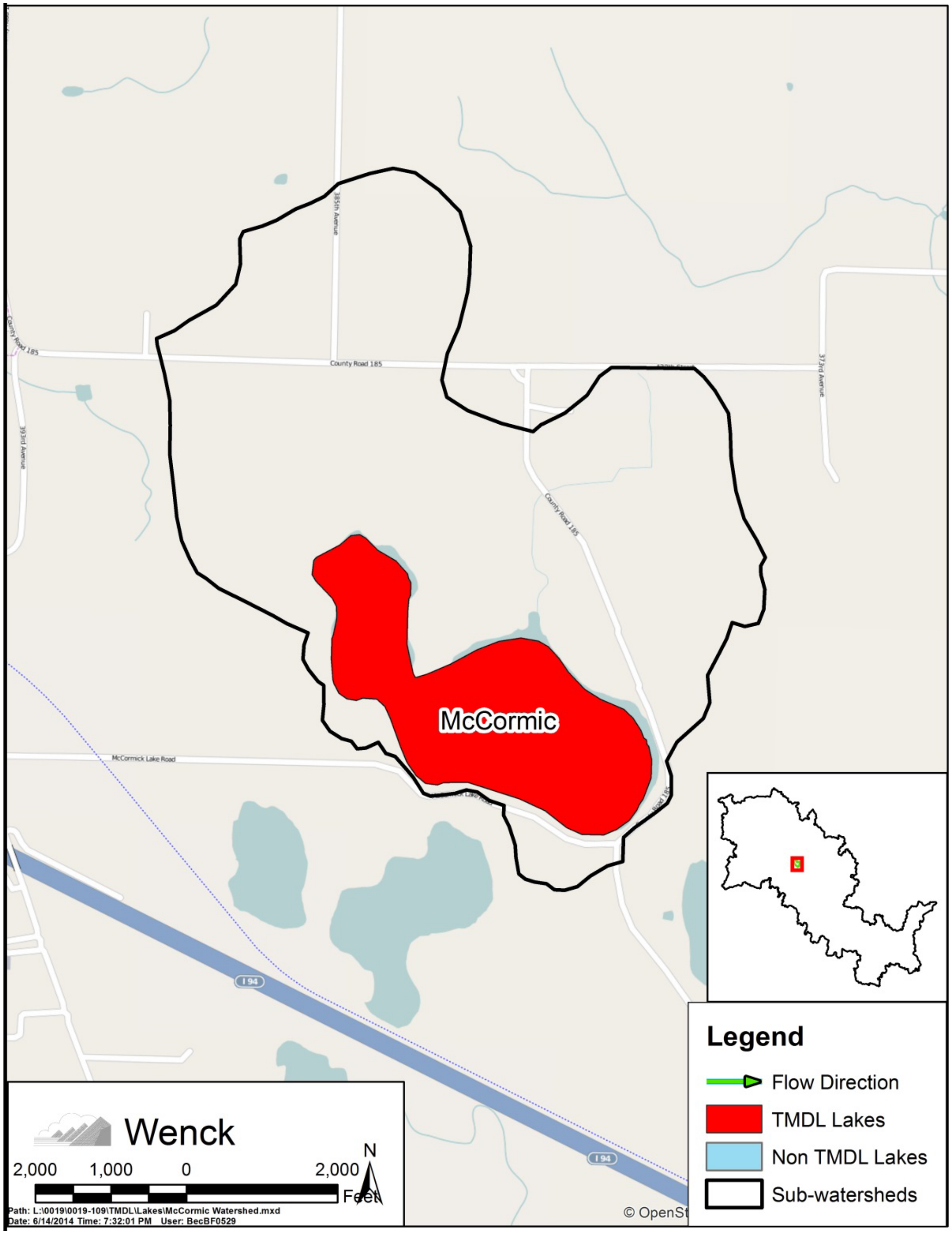


Figure 3.5. McCormic Lake Watershed.

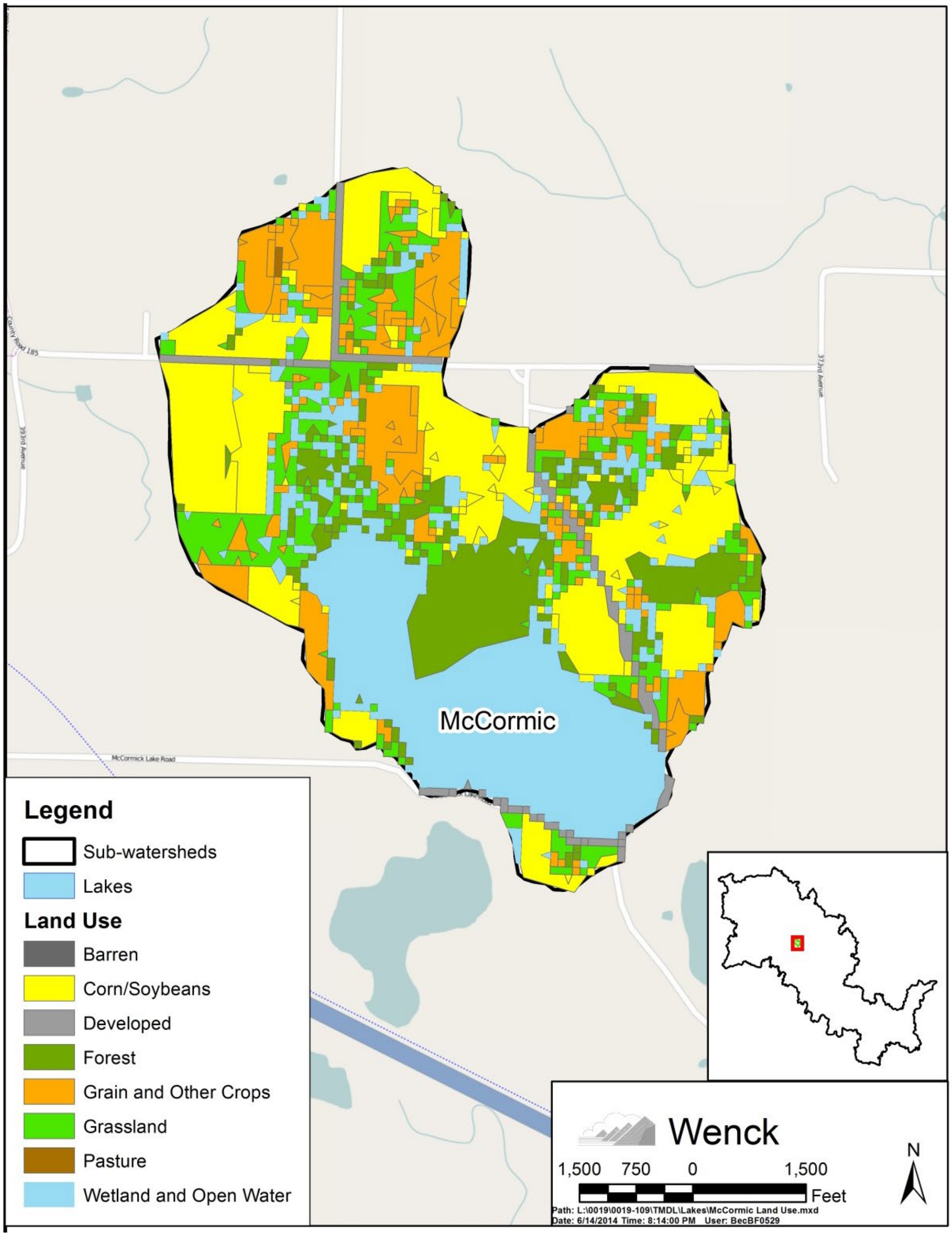


Figure 3.6. McCormic Lake Watershed land use.

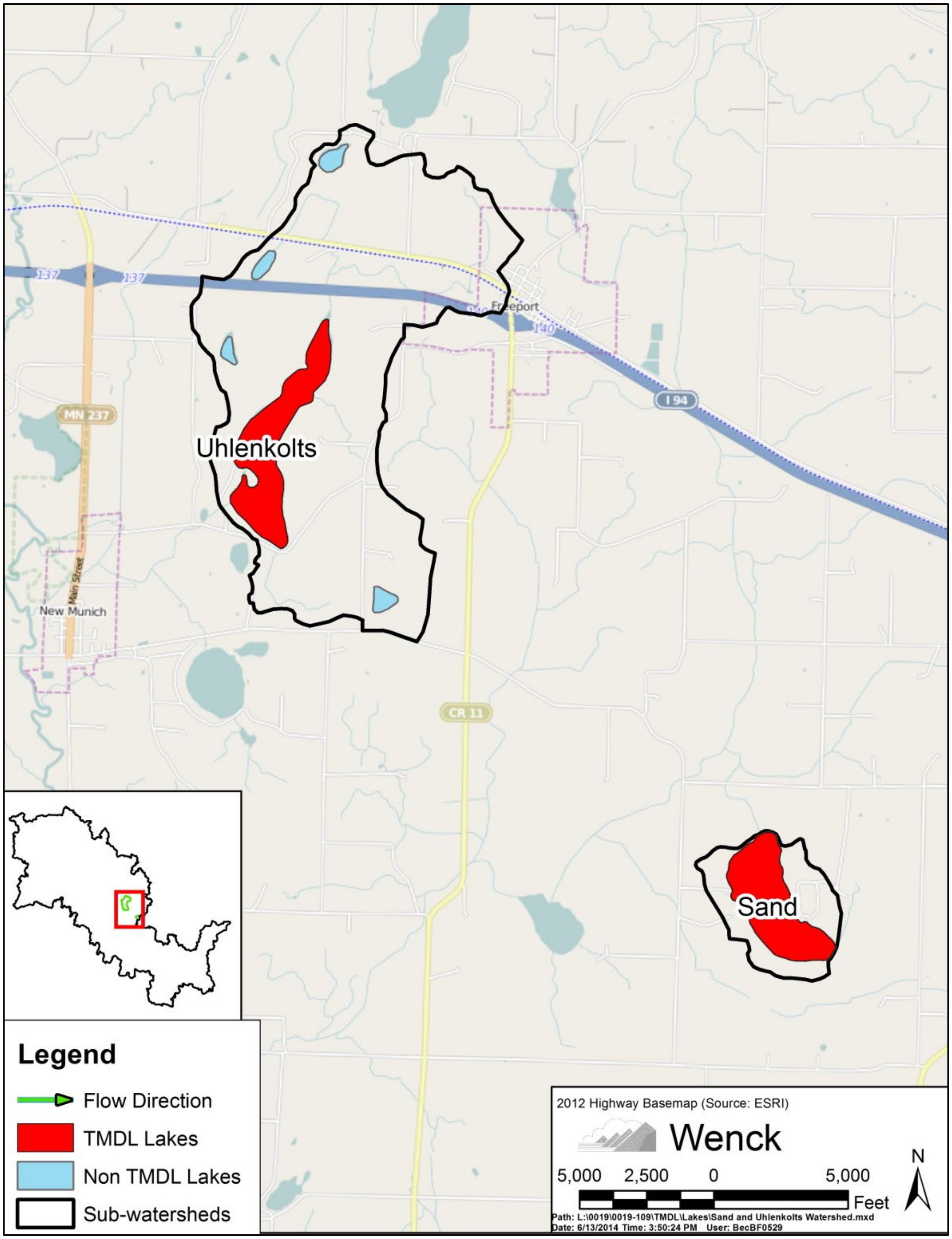


Figure 3.7. Sand and Uhlenkolts Lake Watersheds.

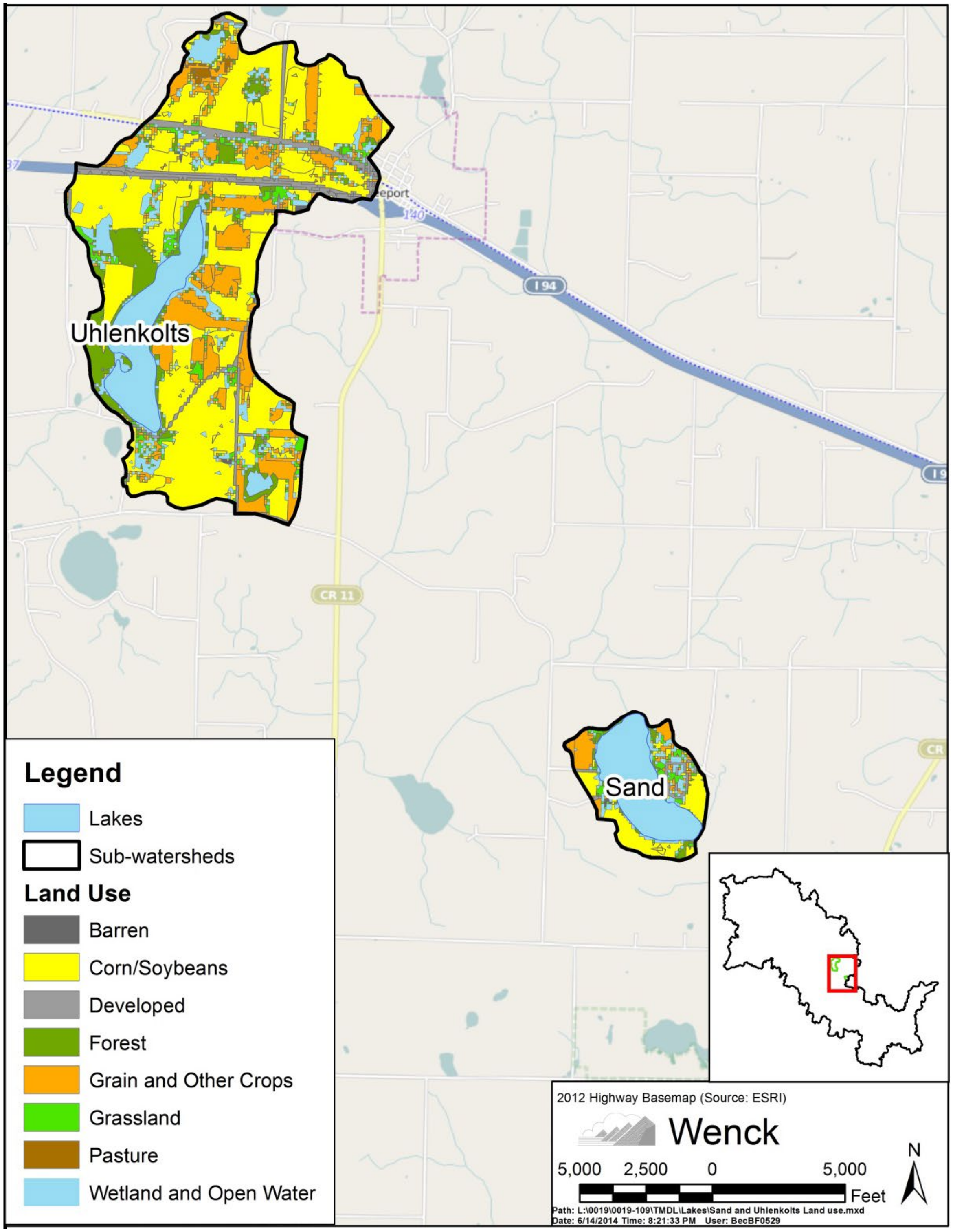


Figure 3.8. Sand and Uhlenkolts Lake Watershed land use.

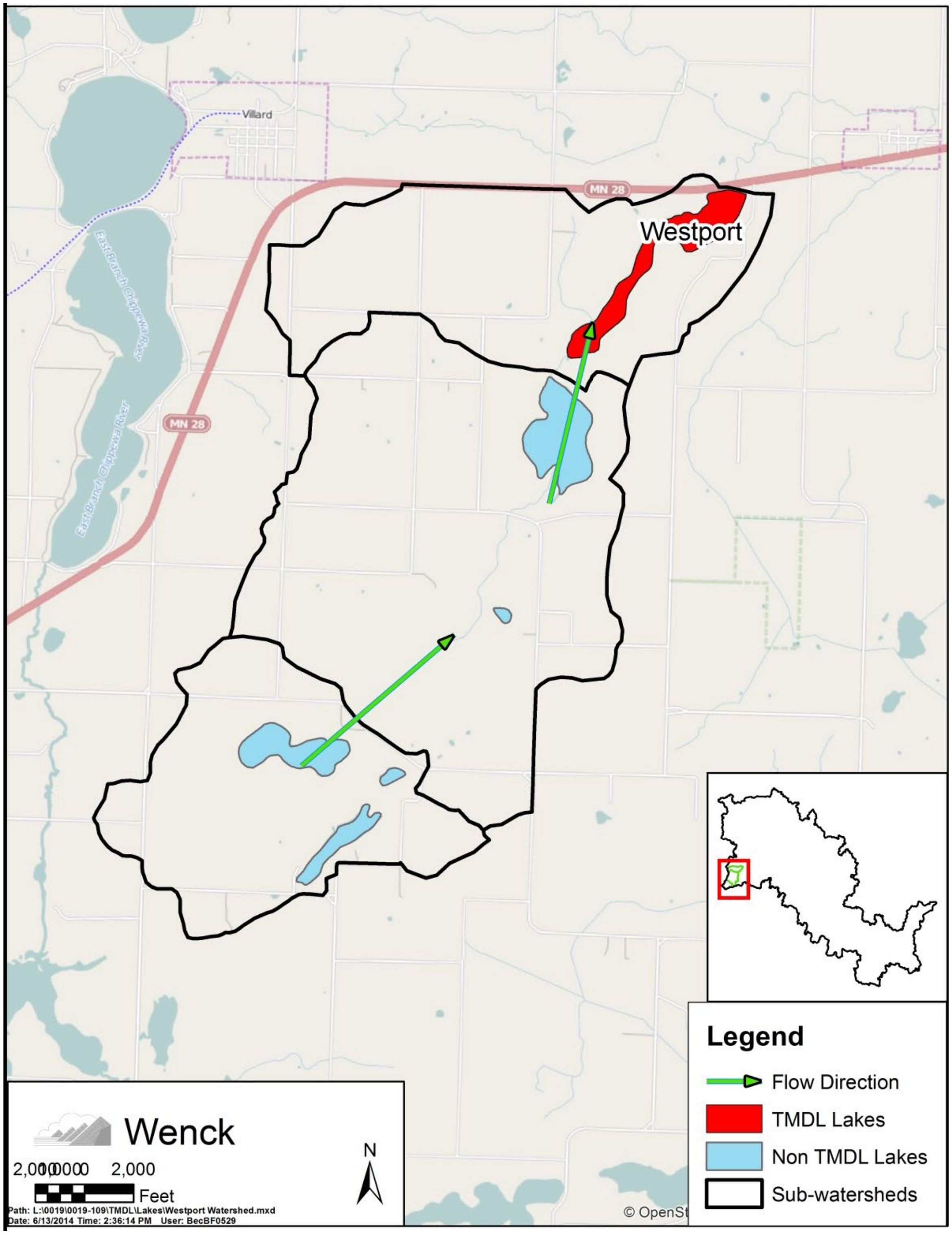


Figure 3.9. Westport Lake Watershed.

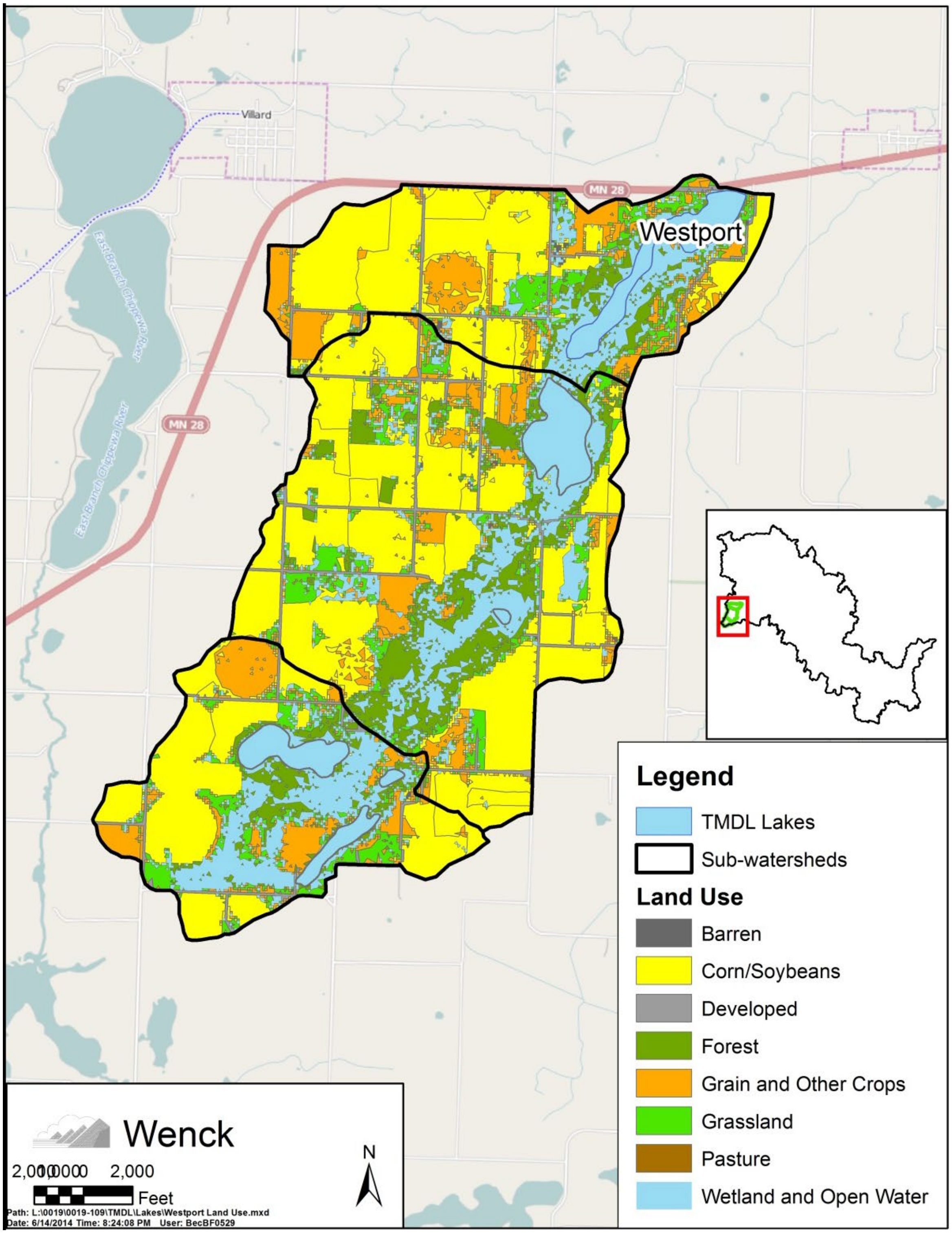


Figure 3.10. Westport Lake Watershed land use.

3.4.2 Lake Morphometry

Table 3.16 outlines the lake morphometry for the individual lakes in the Sauk River Watershed TMDL. These lakes are all considered shallow lakes with maximum depths ranging from 5 feet to 12 feet. Watershed sizes also varied from 10,135 acres to 442 acres.

Table 3.16. Morphometry in the individual lakes TMDL study area

Parameter	Surface Area (acres)	Maximum Depth (ft)	Lake Volume (acre-ft)	Residence Time (years)	Littoral Area (%)	Depth Class	Drainage Area (acres)
Henry	71	5	354	0.4	100%	Shallow	442
McCormic	206	12	1,208	3.2	100%	Shallow	998
Sand	209	12	1,415	1.7	100%	Shallow	452
Uhlenkolts	239	9	2,149	1.7	100%	Shallow	2,928
Westport	203	10	857	0.3	100%	Shallow	10,135

3.4.3 Historic Water Quality

Table 3.17 shows the June through September averages of TP concentration, chl-*a* concentration, and Secchi depth for each impaired lake. The table also lists the data years which were used to calculate the "average" condition for the TMDL study. In most cases, in-lake data was not available for all years of the 2005 to 2012 data sets.

Table 3.17. Shallow lake growing season averages for water quality parameters.

		In-Lake "Average" Condition (Calculated June – September)		
Lake Name	**"Average" Condition Calculation Years**	**TP Concentration (µg/L)**	**Chl-*a* Concentration (µg/L)**	**Secchi Depth (m)**
Water Quality Standard for Shallow Lakes		**60.0**	**20.0**	**1.0**
Henry	2008-2009	671.5	41.5	0.8
McCormic	2008-2009	88.0	79.0	1.3
Sand	2005; 2008-2009	142.0	63.5	0.7
Uhlenkolts	2008-2009	284.0	79.5	0.4
Westport	2007-2012	80.2	39.0	1.0

3.4.4 Biological Conditions

Of the individual lakes, only three have had fish surveys completed. Furthermore, Uhlenkolts Lake's most recent survey is over 30 years old. Henry and McCormic Lake are both used as walleye rearing ponds and have qualitative fisheries and vegetation information. Biological conditions in Sand, Uhlenkolts, and Westport Lake, are degraded due to the presence of roughfish and carp. Only Sand Lake had vegetation data that showed the presence of curly-leaf pondweed.

Table 3.18 Aquatic vegetation and fisheries data.

Lake	Recent Survey Month-Year	Curly-leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Henry	2013[1]	--	--	No	Lake has regular winterkills; no carp noted in the lake due to limited connectivity to other lakes. Lake used as a walleye rearing pond by the DNR.
McCormic	2010*	--	--	No	Lake has historically experience winterkills; however, high water levels have reduced winterkills in recent years. Lake is used as a walleye rearing pond by the DNR.
Sand	2012	Yes	No	Yes	Roughfish and carp comprise small portion of the total count and biomass; curly-leaf pondweed abundant; relatively diverse submerged aquatic vegetation population.
Uhlenkolts	1982	No	No	Yes	Winterkills are common due to high productivity. Roughfish and carp likely decrease water clarity due to large littoral area.
Westport	2007	No	No	Yes	Lake has a history of winterkill. Vegetation is relatively diverse and dominated by coontail, white waterlily, and yellow waterlily.

*Lake management plan available

[1] Personal Communication with DNR Fisheries biologist on the current status of fisheries in Henry Lake

3.4.5 Nutrient Sources

Nutrient sources for the individual lakes are provided in Table 3.19.

Table 3.19. Nutrient sources for lakes in the Sauk River Watershed.

Lake	Nonpoint Source Runoff	SSTS	Upstream Lakes	Atmosphere	Internal Load
Henry	3.7%	<0.1%	--	1.5%	94.8%
McCormic	90.2%	0.1%	--	5.7%	4.0%
Sand	18.1%	0.1%	--	3.6%	78.2%
Uhlenkolts	29.2%	0.4%	--	2.3%	68.1%
Westport	88.6%	<0.1%	--	2.6%	8.8%

Henry

Henry is a small, very shallow lake with a very small direct watershed. It has no upstream watersheds and is surrounded by agricultural land with the exception of a small hardwood forested area on its eastern shore. Henry Lake demonstrates extremely high in-lake TP concentrations with average TP concentrations of 671.5 µg/L. The TP budget is dominated by internal loading, which suggests that in-lake management should reduce phosphorus loading. Measuring sediment chemistry characteristics will improve the nutrient budget estimates for the lake and confirm that internal loading is the primary source of phosphorus to Lake Henry.

McCormic

McCormic Lake has the lowest TP of the five individual lakes in this TMDL (88 µg/L), which explains why the lake meets Minnesota state water clarity standards (Secchi > 1.0 m). Additionally, water clarity may be greater than other lakes in this TMDL due to the absence of carp.

Sand

Sand lake is shallow lake with a very small watershed, which results in most of the phosphorus budget coming from internal loading with only a small portion coming from watershed loading. Both carp and curly-leaf pondweed are present exacerbating poor water quality conditions. In-lake management will be necessary to improve water quality.

Uhlenkolts

Uhlenkolts Lake has poor water clarity likely driven by high algal productivity and sediment re-suspension from carp and other roughfish. Sediment phosphorus release is the primary source of phosphorus to Uhlenkolts Lake although watershed loading accounts for roughly one quarter of the phosphorus budget.

Westport

Westport is a shallow lake with two small upstream tributaries with land use that predominately consists of row crops (61%). The lake has a history of fish kills in addition to having a large population of roughfish and carp. The majority of phosphorus loading comes from watershed loading with internal loading only accounting for 9% of the TP budget.

3.4.6 TMDL Summary

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the previous sections. Tables 3.20 through 3.24 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 3.20. TMDL allocations for Henry Lake.

Allocation	**Source**	**Existing TP Load**		**TP Allocations (WLA & LA)**		**Load Reduction**	
		(lbs/year)	**(lbs/day)**	**(lbs/year)**	**(lbs/day)**	**(lbs/year)**	**%**
Wasteload	Industrial & Construction Stormwater	0.4	0.001	0.4	0.001	0.0	0%
Load	SSTS	0.3	0.001	0.0	0.000	0.3	100%
	Nonpoint Source Runoff	41.5	0.113	1.9	0.005	39.6	95%
	Upstream Lakes	0.0	0.000	0.0	0.000	0.0	0%
	Atmosphere	16.9	0.046	16.9	0.046	0.0	0%
	Internal Load	1064.5	2.914	4.5	0.012	1059.9	99%
	MOS	--	--	1.2	0.001	--	**5%**
	TOTAL	**1,123.6**	**3.1**	**24.9**	**0.065**	**1,099.8**	**98%**

Table 3.21. TMDL allocations for McCormic Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Industrial & Construction Stormwater	7	0.021	7	0.021	0	**0%**
Load	SSTS	0	0.002	0	0.000	0	**100%**
	Nonpoint Source Runoff	773	2.116	427	1.171	345	**45%**
	Upstream Lakes	0	0.000	0	0.000	0	**0%**
	Atmosphere	49	0.134	49	0.134	0	**0%**
	Internal Load	34	0.095	34	0.095	0	**0%**
	MOS			27	0.074		**5%**
	TOTAL	**864**	**2.368**	**544**	**1.495**	**346**	**37%**

Table 3.22. TMDL allocations for Sand Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Industrial & Construction Stormwater	2	0.007	2	0.007	0	0%
Load Allocation	SSTS	1	0.004	0	0.000	1	100%
	Nonpoint Source Runoff	246	0.673	28	0.077	218	89%
	Upstream Lakes	0	0	0	0	0	0%
	Atmosphere	50	0.137	50	0.137	0	0%
	Internal Load	1,071	2.932	193	0.530	878	82%
	MOS	--	--	10	0.029	--	5%
	TOTAL	**1,370**	**3.753**	**283**	**0.78**	**1,097**	**79%**

Table 3.23. TMDL allocations for Uhlenkolts Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Industrial & Construction Stormwater	8	0.021	8	0.021	0	**0%**
Load Allocation	SSTS	8	0.023	0	0	8	**100%**
	Nonpoint Source Runoff	746	2.043	199	0.544	547	**73%**
	Upstream Lakes	0	0.000	0	0.000	0	**0%**
	Atmosphere	57	0.156	57	0.156	0	**0%**
	Internal Load	1,764	4.829	113	0.309	1,651	**94%**
	MOS			19	0.000		**5%**
	TOTAL	**2,583**	**7.072**	**396**	**1.030**	**2,206**	**85%**

Table 3.24. TMDL allocations for Westport Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/day)	(lbs/year)	%
Wasteload	Industrial & Construction Stormwater	16	0.040	16	0.040	0	0%
Load Allocation	SSTS	0	0	0	0	0	0%
	Nonpoint Source Runoff	1,627	4.450	978	2.680	649	40%
	Upstream Lakes	0	0.000	0	0.000	0	0%
	Atmosphere	49	0.130	49	0.130	0	0%
	Internal Load	164	0.450	164	0.450	0	0%
	MOS	--	--	63	0.170	--	5%
	TOTAL	**1,856**	**5.070**	**1,270**	**3.47**	**649**	**36%**

4 Implementation

4.1 INTRODUCTION

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

4.2 IMPLEMENTATION FRAMEWORK

4.2.1 *E. coli* and Nutrient Load Reduction Strategies

The following is a description of potential actions for bacterial and nutrient loading to impaired bacteria reaches and nutrient impaired lakes in this TMDL. These actions were further described in the Sauk River Watershed Restoration and Protection Strategy (WRAPS) Report.

Nutrients in lakes. Implementation activities for lakes should focus primarily on watershed and internal phosphorus load reductions. All nine lake TMDLs require load reductions including upgrading all noncompliant SSTSs. Reductions specific for the Juergens Chain of Lakes includes upstream nutrient impaired lake restoration to meet water quality criteria. Reductions in watershed loading will come from land practices such as manure and livestock management. Many of the small upstream lakes, which include McCormic, Sand, Maple, Uhlenkolts, Henry, and Westport, primarily include internal nutrient reductions due to their small contributing watershed.

E. coli in streams. During higher flow events, the majority of *E. coli* appears to be coming from pastures near the streams and ditches in the watershed. During low flows, cattle access to streams is the major source of bacteria to impaired reaches. Therefore, BMPs should focus on livestock exclusions, buffers, and manure management.

4.2.2 Installation or Enhancement of Buffers

The largest potential sources of bacteria are those activities associated with pasture management. In many locations along the river, cattle grazing has denuded stream banks of stabilizing native vegetation that would otherwise filter runoff of bacteria and nutrients from pastures near streams and waterways. Secondarily, BMPs for upland pasture land should also be implemented.

4.2.3 Pasture Management

Overgrazed pastures, reduction of pastureland, and direct access of livestock to streams may contribute a significant amount of nutrients and bacteria to surface waters throughout all flow conditions. The following livestock grazing practices are for the most part economically feasible and are extremely effective measures in reducing nutrient and bacteria runoff from feedlots:

- Livestock exclusion from public waters through setback implementation and fencing
- Creating alternate livestock watering systems
- Rotational grazing
- Vegetated buffer strips between grazing land and surface water bodies

4.2.4 Manure Management

Manure Application. Minnesota feedlot rules (Minn. R. ch. 7020) now require manure management plans for feedlots greater than 300 AUs that do not employ a certified manure applicator. These plans require manure accounting and record-keeping as well as manure application risk assessment based on method, time and place of application. The following BMPs will be considered in all manure management plans, including animal operations with less than 300 AUs, to reduce potential nutrient and bacteria delivery to surface waters:

- Immediate incorporation of manure into topsoil
- Reduction of winter spreading, especially on slopes
- Eliminate spreading near open inlets and sensitive areas
- Apply at agronomic rates
- Follow setbacks in feedlot rules for spreading manure
- Erosion control through conservation tillage and vegetated buffers

Additional technologies will be evaluated including chemical addition to manure prior to field application to reduce phosphorus availability and mobility.

Manure Stockpile Runoff Controls. There are a variety of options for controlling manure stockpile runoff that reduce nonpoint source nutrient loading, including:

- Move fences or altering layout of feedlot
- Eliminate open tile intakes and/or feedlot runoff to direct intakes
- Install clean water diversions and rain gutters
- Install grass buffers
- Maintain buffer areas
- Construct solid settling area(s)
- Prevent manure accumulations
- Manage feed storage
- Manage watering devices
- Total runoff control and storage
- Install roofs
- Runoff containment with irrigation onto cropland/grassland
- Vegetated infiltration areas or tile-drained vegetated infiltration area with secondary filter strips

These practices should be applied where appropriate.

Soil Phosphorus Testing. Because the amount of manure applied in the Sauk River Watershed is high, soil testing would help manage where manure can be applied with little or no loss to surface waters. A soil phosphorus testing program will allow managers to make better decisions about where TP from manure is needed and where it may be applied in excess.

4.2.5 Septic System Inspections and Upgrades

Douglas County, Pope County, Stearns County, and Todd County should continue to inspect and order SSTS upgrades, with priority given to systems that are imminent threats to public health and safety and failing systems near streams and waterways. The counties should continue to identify and address systems that are not meeting adopted septic ordinances. Special attention shall be given to systems with high nutrient and bacteria loading potential based on proximity to the lake, streams and systems that may discharge directly to surface water.

4.2.6 Internal Nutrient Load Reductions

Internal nutrient loads need to be reduced to meet the TMDL allocations for six lakes presented in this document. There are numerous options for reducing internal nutrient loads ranging from simple chemical inactivation of sediment phosphorus to complex infrastructure techniques including hypolimnetic aeration.

Internal load reduction technical review. Prior to implementation of any strategy to reduce internal loading in each lake, a technical review needs to be completed to evaluate the cost and feasibility of the lake management techniques available to reduce or eliminate internal loading. Several options could be considered to manage internal sources of nutrients including hypolimnetic withdrawal, alum treatment, vegetation management and hypolimnetic aeration. A technical review should be completed to provide recommendations for controlling internal loading in each lake. This review will also include the potential impacts of each management option to wild rice beds and other sensitive aquatic vegetation.

4.2.7 Studies and Biological Management plans

Vegetation management. Curly-leaf pondweed is present in many of the lakes in this TMDL, and in some cases at extremely high concentrations. Senescence of curly-leaf pondweed in summer can be a source of internal phosphorus load that often results in a late summer nuisance algal bloom. Vegetation management, such as several successive years of chemical treatment, may be required to keep this exotic invasive species at non-nuisance levels.

Conduct periodic aquatic plant surveys and prepare and implement vegetation management plans. As BMPs are implemented and water clarity improves, the aquatic vegetation community will change. Surveys should be updated periodically and vegetation management plans amended to take into account appropriate management activities for that changing community.

Carp Management. One activity should be to partner with the DNR to monitor and manage the fish population to maintain a beneficial fish community. Options to reduce rough fish populations should be evaluated, and the possibility of fish barriers explored to reduce rough fish access to spawning areas and to minimize rough fish migration between lakes.

Encourage shoreline restoration. Many property owners maintain a turfed edge to the shoreline. Property owners should be encouraged to restore their shoreline with native plants to reduce erosion and capture direct runoff. Shoreline restoration can cost $30 to $65 per linear foot, depending on the width of the buffer installed. The Douglas County SWCD, Pope County SWCD, Stearns County SWCD, Todd County SWCD and SRWD will continue to work with all willing landowners to naturalize their shorelines.

4.2.8 Education

Provide educational and outreach opportunities in the watershed about proper fertilizer use, manure management, grazing management, low-impact lawn care practices, and other topics to increase awareness of sources of pollutant loadings to the lakes and encourage the adoption of good individual property management practices. Opportunities to better understand aquatic vegetation management practices and how they relate to beneficial biological communities and water quality should also be developed.

4.2.9 Adaptive Management

The allocations in this TMDL represent aggressive goals for nutrient and bacteria reductions. Consequently, implementation will be conducted using adaptive management principles (Figure 6.1). Adaptive management is appropriate because it is difficult to predict the lake response that will occur from implementing strategies with the paucity of information available to demonstrate expected reductions. Future technological advances may alter the course of actions detailed here. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategies for attaining the water quality goals established in this TMDL.

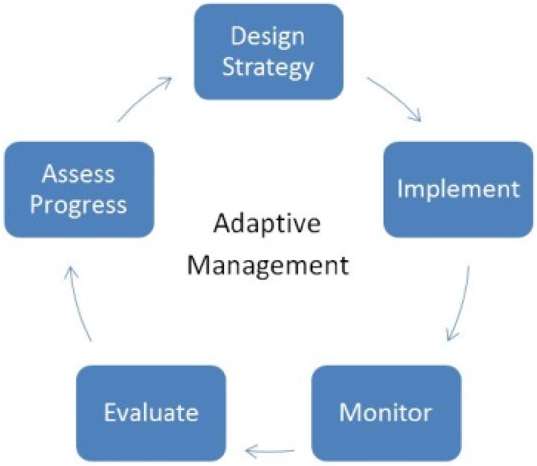


Figure 4.1. Adaptive management.

5 Reasonable Assurance

5.1 INTRODUCTION

As a requirement of TMDL studies, reasonable assurance must be provided demonstrating the ability to reach and maintain water quality endpoints. The source reduction strategies detailed in Section 4 have been shown to be effective in reducing nutrients in receiving waters. It is reasonable to expect that these measures will be widely adopted by landowners and resource managers, in part because they have already been implemented in some parts of the watershed over the last 20 years.

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

Various sources of technical assistance and funding will be used to execute measures detailed in the Sauk River Watershed Management Plan (SRWD 2013). Funding resources include a mixture of state and federal programs, including (but not limited to) the following:

- Federal Clean Water Act Section 319 Grants for watershed improvements
- Conservation Reserve Program and other federal Farm Bill conservation programs
- Funds ear-marked to support TMDL and WRAPS implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the state's citizens in November 2008.
- Local government cost-share funds
- Soil and Water Conservation Districts (SWCDs) cost-share funds

Finally, it is a reasonable expectation that existing regulatory programs such as those under NDPES will continue to be administered to control discharges from industrial, municipal, and construction sources as well as large animal feedlots that meet the thresholds identified in those regulations.

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

5.2 SAUK RIVER WATERSHED DISTRICT

The SRWD has been active in water resources management and protection since it was formed in 1986. The SRWD's 2014 through 2024 Comprehensive Watershed Management Plan identifies the following major roles for the District:

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

The SRWD's published comprehensive management plan outlines strategies and actions to improve water quality, protect groundwater resources, and guide the operation of the Watershed District.

5.3 COUNTY SOIL AND WATER CONSERVATION DISTRICTS

The purpose of the County SWCDs is to plan and execute policies, programs, and projects that conserve the soil and water resources within its jurisdictions. The SWCDs that fall within the impaired watershed of this TMDL are the Todd, Stearns, Pope, and Douglas SWCD. They are particularly concerned with erosion of soil due to wind and water. The SWCDs are heavily involved in the implementation of practices that effectively reduce or prevent erosion, sedimentation, siltation, and agricultural-related pollution in order to preserve water and soil as resources. The Districts frequently act as local sponsors for many types of projects, including grassed waterways, on-farm terracing, erosion control structures, and flow control structures.

5.4 MONITORING

Two types of monitoring are necessary to track progress toward achieving the load reduction required in the TMDL and the attainment of water quality standards. The first type of monitoring is tracking implementation of BMPs and capital projects. The SRWD and the Todd and Douglas County SWCDs will track the implementation of these projects annually. The second type of monitoring is physical and chemical monitoring of the resources. The SRWD plans to monitor the affected resources.

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

5.5 STRATEGIC EFFORTS

Collaborative efforts between the SRWD, State and County agencies and other local organizations, such as Pheasants Forever and Ducks Unlimited, has been the foundation of the success seen within the Sauk River Watershed. These partnerships continue to build as new water resource issues (i.e. AIS) arise within the SRWD.

Funding continues to be a factor in implementing conservation practices. The SRWD and its partners continues to pursue funding from state (CWF) and federal (EPA Section 319) agencies, as well as local organizations, to provide technical and financially assistance to landowners to install conservation BMPs. To maximize these funds, the SRWD subdivided the Sauk River Watershed into 10 water management units, based on land use, terrain and drainage patterns. In addition, the SRWD completed a HSPF model for the Sauk River Watershed to target and prioritize the watershed down to a HUC 12 level. Further targeting and prioritizing efforts are underway using the PTMApp program in several section of the SRWD, such as Ashley Creek and Adley Creek. Information gathered from all targeting and prioritizing efforts are shared with local partners to increase the effectiveness of available implementation dollars as well as enhance outreach efforts.

Utilizing information from targeting efforts, a detailed implementation plan will be developed for the water resources listed in this TMDL report. The plan will list action items and responsible parties as well as time lines and estimated cost. The implementation plan will address the required load reductions listed in this report.

5.6 PUBLIC PARTICIPATION

The Sauk River Watershed District held public meetings on October 27, 2011, November 30, 2011, and December 8, 2011, to discuss listed impaired waters in the Sauk River Watershed. A survey was done in November, 2011.

A smaller meeting was held on August 28, 2012.

In the summer of 2013, the Sauk River Watershed District and the Stearns County SWCD conducted “door to door” landowner visits to discuss the Sauk River and the concerns for water resources.

Public Notice for Comments

An opportunity for public comment on the draft TMDL report was provided via a public notice in the State Register from January 9, 2017 through February 8, 2017. One comment letter was received.

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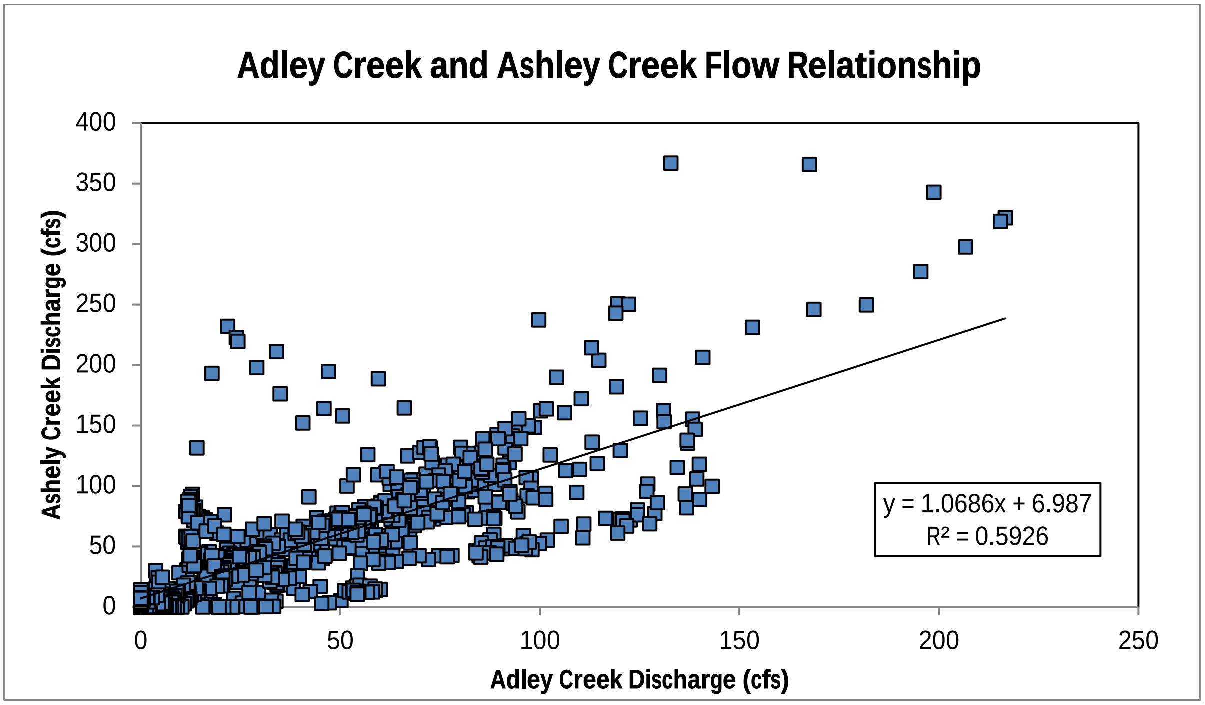
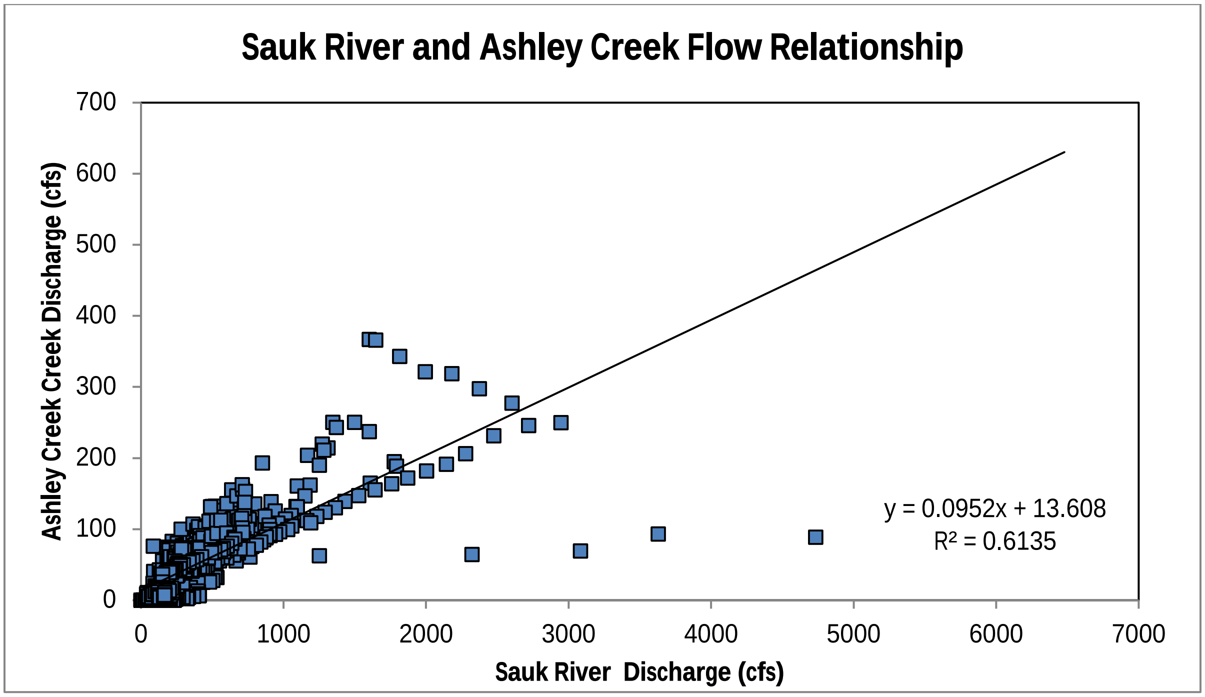
Appendix A

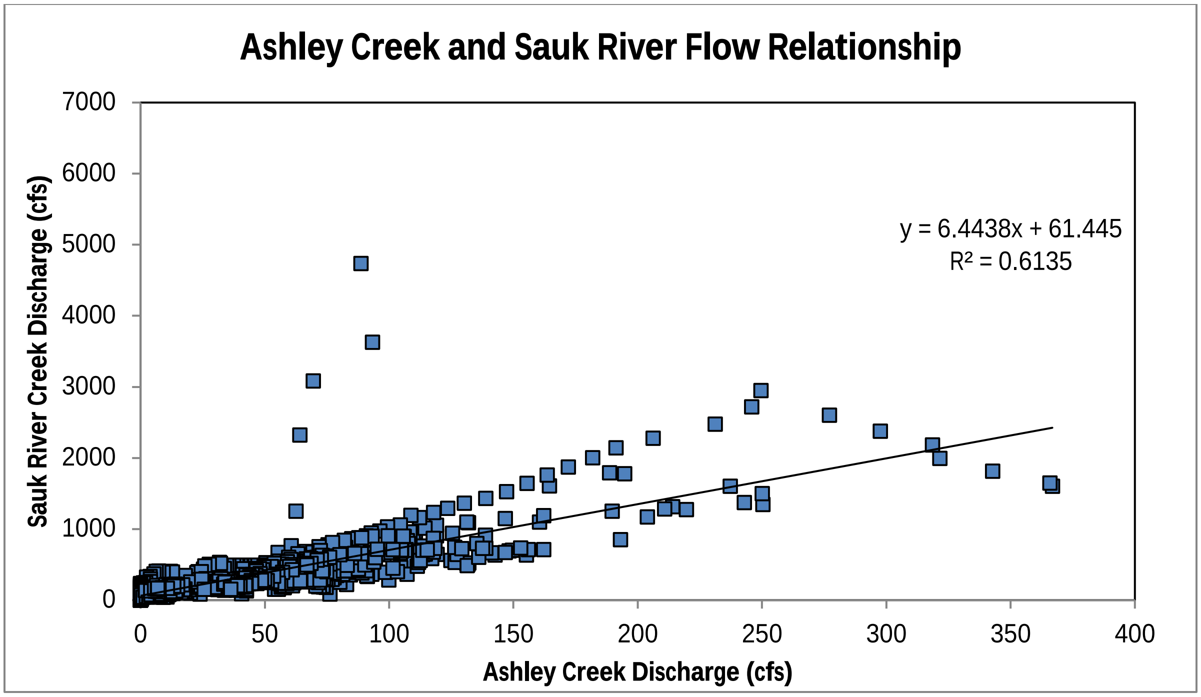
Continuous Flow Monitoring Regressions



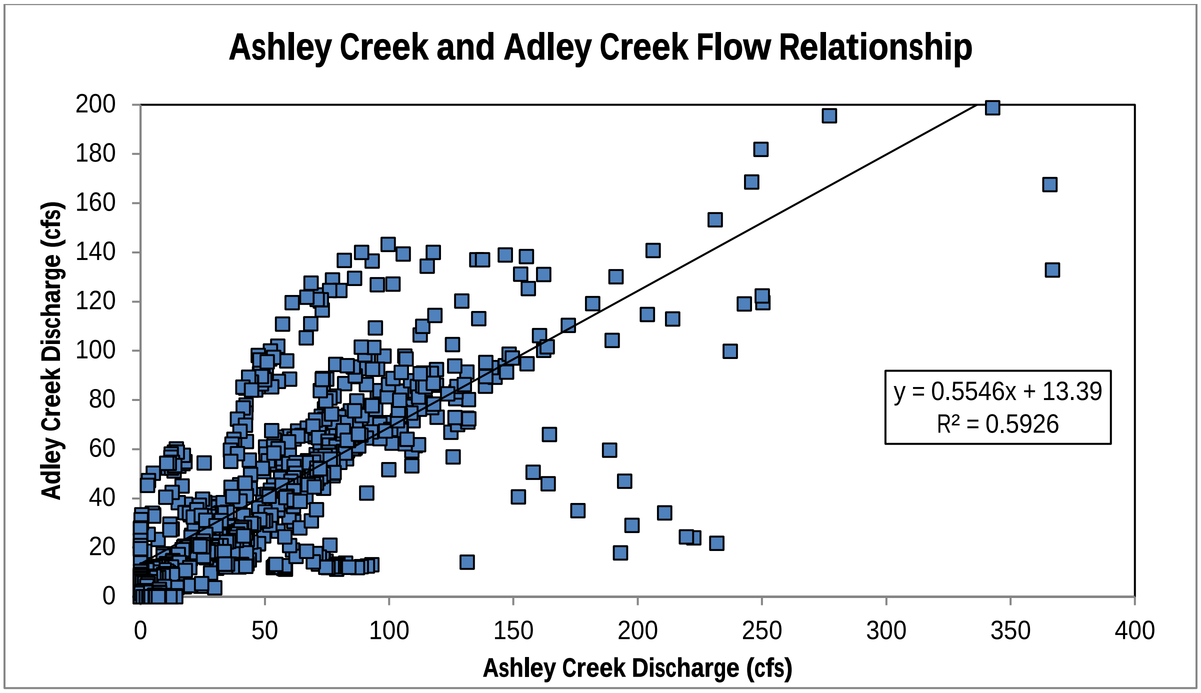
Flow regression between the Adley Creek (S000-369) and Ashley Creek (S004-625) monitoring stations.



Flow regression between the Ashley Creek (S004-625) and Sauk River (S000-517) monitoring stations.



Flow regression between the Ashley Creek (S000-369) and Sauk River (S000-517) monitoring stations.



Flow regression between the Ashley Creek (S004-625) and Adley Creek (S000-369) monitoring stations.

Appendix B

Watershed Bacteria Production

Adley Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	114	0
Failure to protect groundwater	13	0
Imminent threat to public health	3	30
Total	130	30

Adley Creek Fecal Coliform Production Inventory

Category	**Sub-Category**	**Animal Units or Individuals**
Livestock	Dairy	5,105 animal units
	Beef	1,255 animal units
	Swine	403 animal units
	Poultry	299 animal units
	Other (Horses & Sheep)	30 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	3 systems
	Total systems that do not discharge to surface water	111 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	241 deer
	Waterfowl (average 10 per square mile)	219 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	183 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates

[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory

[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

Adley Creek Bacteria Production Assumptions

Category	**Source**	**Assumption**
Livestock	Pastures near streams or waterways	66% total of beef, dairy and other
	Runoff from Upland Pastures	1% of dairy, 1% of beef, 1% of other
	Surface applied manure	17% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

Adley Creek Fecal Coliform Available for Delivery

Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	195,369	269,855 (78%)
		Beef Animal Units	73,529	
		Other Animal Units	957	
	Runoff from Upland Pastures	Dairy Animal Units	2,705	3,736 (1%)
		Beef Animal Units	1,018	
		Other Animal Units	13	
	Cropland with Surface Applied Manure	Dairy Animal Units	49,519	72,307 (21%)
		Beef Animal Units	18,637	
		Other animal Units	4,152	
Human	ITPHS septic systems and unsewered communities	Systems	30	30 (<1%)
	Municipal wastewater treatment facilities	People	None	
Wildlife	Deer	Deer	241	417 (<1%)
	Waterfowl	Geese and ducks	176	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	82	82 (<1%)
Total				**346,427**

Ashley Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	495	0
Failure to protect groundwater	80	0
Imminent threat to public health	11	124
Total		12

Ashley Creek Fecal Coliform Production Inventory

Category	Sub-Category	Animal Units or Individuals
Livestock	Dairy	15,855 animal units
	Beef	6,941 animal units
	Swine	8,315 animal units
	Poultry	0 animal units
	Other (Horses & Sheep)	148 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	11 systems
	Total systems that do not discharge to surface water	484 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	106 deer
	Waterfowl (average 10 per square mile)	96 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	695 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates

[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory

[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

Ashley Creek Bacteria Production Assumptions

Category	Source	Assumption
Livestock	Pastures near streams or waterways	17% total of beef, dairy and other
	Runoff from Upland Pastures	62% total of beef, dairy and other
	Surface applied manure	17% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

Ashley Creek Fecal Coliform Available for Delivery

Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	154,796	295,605 (18%)
		Beef Animal Units	103,745	
		Other Animal Units	1,064	
	Runoff from Upland Pastures	Dairy Animal Units	575,488	965,139 (65%)
		Beef Animal Units	385,695	
		Other Animal Units	3,956	
	Cropland with Surface Applied Manure	Dairy Animal Units	153,796	257,929 (17%)
		Beef Animal Units	103,075	
		Other Animal Units	1,057	
Human	ITPHS septic systems and unsewered communities	Systems	121	121 (<1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	106	183 (<1%)
	Waterfowl	Geese and ducks	77	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	313	313 (<1%)
Total				**502,685**

Sauk River Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	922	0
Failure to protect groundwater	105	0
Imminent threat to public health	21	238
Total	1048	238

Sauk River Fecal Coliform Production Inventory

Category	**Sub-Category**	**Animal Units or Individuals**
Livestock	Dairy	22,231 animal units
	Beef	11,043 animal units
	Swine	2,699 animal units
	Poultry	2,913 animal units
	Other (Horses & Sheep)	297 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	21 systems
	Total systems that do not discharge to surface water	1027 systems
	Municipal Wastewater Treatment Facilities	See table 2.4
Wildlife[3]	Deer (average 11 per square mile)	1,430 deer
	Waterfowl (average 10 per square mile)	1,300 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	1,471 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates

[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory

[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

Sauk River Bacteria Production Assumptions

Category	**Source**	**Assumption**
Livestock	Pastures near streams or waterways	20% total of beef, dairy and other
	Runoff from Upland Pastures	59% total of beef, dairy and other
	Surface applied manure	17% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

Sauk River Fecal Coliform Available for Delivery

Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	251,722	445,666 (20%)
		Beef Animal Units	191,431	
		Other Animal Units	2,514	
	Runoff from Upland Pastures	Dairy Animal Units	763,551	1,351,846 (62%)
		Beef Animal Units	580,669	
		Other Animal Units	7,625	
	Cropland with Surface Applied Manure	Dairy Animal Units	215,641	381,786 (18%)
		Beef Animal Units	163,992	
		Other Animal Units	2,153	
Human	ITPHS septic systems and unsewered communities	Systems	238	238 (<1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	1,430	2,471 (<1%)
	Waterfowl	Geese and ducks	1,040	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	662	662 (<1%)
Total				**502,685**

Stoney Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	83	0
Failure to protect groundwater	10	0
Imminent threat to public health	2	22
Total	95	22

Stoney Creek Fecal Coliform Production Inventory

Category	Sub-Category	Animal Units or Individuals
Livestock	Dairy	6,881 animal units
	Beef	1,375 animal units
	Swine	1,542 animal units
	Poultry	151 animal units
	Other (Horses & Sheep)	187 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	2 systems
	Total systems that do not discharge to surface water	93 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	284 deer
	Waterfowl (average 10 per square mile)	258 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	133 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates

[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory

[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

Stoney Creek Bacteria Production Assumptions

Category	Source	Assumption
Livestock	Pastures near streams or waterways	18% total of beef, dairy and other
	Runoff from Upland Pastures	61% total of beef, dairy and other
	Surface applied manure	17% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

Stoney Creek Fecal Coliform Available for Delivery

Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	70,150	91,976 (18%)
		Beef Animal Units	21,459	
		Other Animal Units	367	
	Runoff from Upland Pastures	Dairy Animal Units	246,056	322,613 (64%)
		Beef Animal Units	75,270	
		Other Animal Units	1,287	
	Cropland with Surface Applied Manure	Dairy Animal Units	66,749	87,517 (17%)
		Beef Animal Units	20,419	
		Other Animal Units	349	
Human	ITPHS septic systems and unsewered communities	Systems	22	22 (<1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	284	490 (<1%)
	Waterfowl	Geese and ducks	207	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	60	60 (<1%)
Total				**502,677**

Appendix C

Lake Response Models

Average Loading Summary for Guernsey

Inflow from Drainage Areas

	Water Budgets				Phosphorus Loading		
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct Watershed	4,653	10.5	4,070	87	1.0	960
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*4,653*	*11*	*4,070*			*959.8*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Total Watershed	114.6666667	0.2	39	0.2		33.527
2					0.2		
3					0.2		
4					0.2		
5					0.2		
	Summation	*115*	*0*	*39.0*			*33.5*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Osakis			32,931	60.0	1.0	5,378
2					-	1.0	
3					-	1.0	
	Summation			*32,931*	*60.0*		*5,378*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
121	27.9	27.9	0.00	0.239	1.0	28.9
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
121	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.49			Oxic		1.0	
0.49	48.2		Anoxic	5.0	1.0	260
Summation						260
		Net Discharge [ac-ft/yr] =	**37,039**		**Net Load [lb/yr] =**	**6,661**

Average Lake Response Modeling for Guernsey

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.14	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,021	[kg/yr]
		Q (lake outflow) =	45.7	[10^6 m^3/yr]
		V (modeled lake volume) =	1.1	[10^6 m^3]
		T = V/Q =	0.02	[yr]
		P_i = W/Q =	66	[µg/l]
Model Predicted In-Lake [TP]			**64.8**	**[ug/l]**
Observed In-Lake [TP]			**64.8**	**[ug/l]**

Guernsey Lake Current Conditions BATHTUB Lake Response Model

eductions Loading Summary for Guernsey

	Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Direct Watershed	4,653	10.5	4,070	87	1.0	960
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*4,653*	*11*	*4,070*			*959.8*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Total Watershed	114.6666667	0.2	39	0.2		33.527
2					0.2		
3					0.2		
4					0.2		
5					0.2		
	Summation	*115*	*0*	*39.0*			*33.5*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Osakis			32,931	60.0	1.0	5,378
2					-	1.0	
3					-	1.0	
	Summation			*32,931*	*60.0*		*5,378*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
121	27.9	27.9	0.00	0.239	1.0	28.9
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
121	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.49			Oxic		1.0	
0.49	48.2		Anoxic	5.0	1.0	260
Summation						260

Net Discharge [ac-ft/yr] =	**37,039**	**Net Load [lb/yr] =**	**6,661**

Reductions Lake Response Modeling for Guernsey

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.14	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,021	[kg/yr]
		Q (lake outflow) =	45.7	[10^6 m^3/yr]
		V (modeled lake volume) =	1.1	[10^6 m^3]
		T = V/Q =	0.02	[yr]
		P_i = W/Q =	66	[µg/l]
Model Predicted In-Lake [TP]			**64.8**	**[ug/l]**
Observed In-Lake [TP]			**64.8**	**[ug/l]**

Guernsey Lake TMDL BATHTUB Lake Response Model

Average Loading Summary for Henry

Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct	445	1.8	65	237	1.0	42
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*445*	*2*	*65*			*41.9*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1		2.666666667	0.1	0.02	0.1		0.3902943
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*3*	*0*	*0.0*			*0.4*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	71	27.9	27.9	0.00	0.239	1.0	16.9
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
71	0.0		0.00	0	1.0	0

Internal

	Lake Area [km²]	Anoxic Factor [days]			Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
	0.29	122		Oxic		1.0	
	0.29	92.7		Anoxic	18.2	1.0	1,065
	Summation						1,065
		Net Discharge [ac-ft/yr] =		**65**	**Net Load [lb/yr] =**		**1,124**

Average Lake Response Modeling for Henry

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.38	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	510	[kg/yr]
		Q (lake outflow) =	0.1	[10^6 m^3/yr]
		V (modeled lake volume) =	0.4	[10^6 m^3]
		T = V/Q =	5.42	[yr]
		P_i = W/Q =	6338	[µg/l]
Model Predicted In-Lake [TP]			**671.5**	**[ug/l]**
Observed In-Lake [TP]			**671.5**	**[ug/l]**

Henry Lake Current Conditions BATHTUB Lake Response Model

Reductions Loading Summary for Henry

	Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct	445	1.8	65	13	0.1	2
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*445*	*2*	*65*			*2.3*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1		2.666666667	0.1	0.02	0.1	0	0
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*3*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	71	27.9	27.9	0.00	0.239	1.0	16.9

Dry-year total P deposition = 0.222

Average-year total P deposition = 0.239

Wet-year total P deposition = 0.259

(Barr Engineering 2004)

Groundwater

	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	71	0.0		0.00	0	1.0	0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.29	122		Oxic		1.0	
	0.29	92.7		Anoxic	18.2	1.0	6
	Summation						6
		Net Discharge [ac-ft/yr] =		**65**	**Net Load [lb/yr] =**		**25**

Reductions Lake Response Modeling for Henry

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.35	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	11	[kg/yr]
		Q (lake outflow) =	0.1	[10^6 m^3/yr]
		V (modeled lake volume) =	0.4	[10^6 m^3]
		T = V/Q =	5.42	[yr]
		P_i = W/Q =	141	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Henry Lake TMDL BATHTUB Lake Response Model

Average Loading Summary for Juergens Lake

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct Watershed	3,108	10.3	2,660	65	1.0	470
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*3,108*	*10*	*2,660*			*469.7*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	3	0.2	10	0.2		8.726
2					0.2		
3					0.2		
4					0.2		
5					0.2		
	Summation	*3*	*0*	*10.0*			*8.7*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Little Sauk			43,724	63.2	1.0	7,515
2					-	1.0	
3					-	1.0	
	Summation			*43,724*	*63.2*		*7,515*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	117	27.9	27.9	0.00	0.239	1.0	27.9
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	117	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.47	122		Oxic		1.0	0
	0.47	50.1		Anoxic	14.9	1.0	777
	Summation						777
			Net Discharge [ac-ft/yr] =	**46,395**		**Net Load [lb/yr] =**	**8,798**

Average Lake Response Modeling for Juergens Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.09	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,991	[kg/yr]
		Q (lake outflow) =	57.2	[10^6 m^3/yr]
		V (modeled lake volume) =	1.3	[10^6 m^3]
		T = V/Q =	0.02	[yr]
		P_i = W/Q =	70	[µg/l]
Model Predicted In-Lake [TP]			**68.8**	**[ug/l]**
Observed In-Lake [TP]			**68.8**	**[ug/l]**

Juergens Lake Current Conditions BATHTUB Lake Response Model

eductions Loading Summary for Juergens Lake

	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct Watershed	3,108	10.3	2,660	65	1.0	470
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*3,108*	*10*	*2,660*			*469.7*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	3	0.2	10	0.2	0	0
2					0.2		
3					0.2		
4					0.2		
5					0.2		
	Summation	*3*	*0*	*10.0*			*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Little Sauk			43,724	41.6	1.0	4,948
2					-	1.0	
3					-	1.0	
	Summation			*43,724*	*41.6*		*4,948*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	117	27.9	27.9	0.00	0.239	1.0	27.9
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	117	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.47	122		Oxic		1.0	0
	0.47	50.1		Anoxic	14.9	1.0	777
	Summation						777
		Net Discharge [ac-ft/yr] =		**46,395**	**Net Load [lb/yr] =**		**6,223**

Reductions Lake Response Modeling for Juergens Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.09	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,823	[kg/yr]
		Q (lake outflow) =	57.2	[10^6 m^3/yr]
		V (modeled lake volume) =	1.3	[10^6 m^3]
		T = V/Q =	0.02	[yr]
		P_i = W/Q =	49	[µg/l]
Model Predicted In-Lake [TP]			**48.7**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Juergens Lake TMDL BATHTUB Lake Response Model

Average Loading Summary for Little Sauk

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Northern Trib	6,105	7.5	3,827	76	1.0	796
2	Direct	2,323	1.9	371	65.6	1.0	66
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*8,427*	*9*	*4,197*			*861.8*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	80	0.04	27	0.04		23.432
2					0.04		
3					0.04		
4					0.04		
5					0.04		
	Summation	*80*	*0*	*27.0*			*23.4*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Guernsey			39,669	65.0	1.0	7,015
2					-	1.0	
3					-	1.0	
	Summation			*39,669*	*65.0*		*7,015*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	286	27.9	27.9	0.00	0.239	1.0	68.4
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			

Groundwater

	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	286	0.0		0.00	0	1.0	0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.16	122		Oxic		1.0	
	1.16	27.9		Anoxic	1.8	1.0	131
	Summation						131
			Net Discharge [ac-ft/yr] =	**43,893**		**Net Load [lb/yr] =**	**8,099**

Average Lake Response Modeling for Little Sauk

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.89	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,674	[kg/yr]
		Q (lake outflow) =	54.1	[10^6 m^3/yr]
		V (modeled lake volume) =	3.4	[10^6 m^3]
		T = V/Q =	0.06	[yr]
		P_i = W/Q =	68	[µg/l]
Model Predicted In-Lake [TP]			**55.5**	**[ug/l]**
Observed In-Lake [TP]			**55.5**	**[ug/l]**

Little Sauk Lake Current Conditions BATHTUB Lake Response Model

Reduction Loading Summary for Little Sauk

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Northern Trib	6,105	7.5	3,827	32	0.4	334
2	Direct	2,323	1.9	371	27.5	0.4	28
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*8,427*	*9*	*4,197*			*362.0*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	80	0.04	27	0.04		23.432
2					0.04		
3					0.04		
4					0.04		
5					0.04		
	Summation	*80*	*0*	*27.0*			*23.4*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Guernsey			39,669	47.4	1.0	5,115
2					-	1.0	
3					-	1.0	
	Summation			*39,669*	*47.4*		*5,115*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
286	27.9	27.9	0.00	0.239	1.0	68.4

Dry-year total P deposition = 0.222

Average-year total P deposition = 0.239

Wet-year total P deposition = 0.259

(Barr Engineering 2004)

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
286	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
1.16	122		Oxic		1.0	
1.16	27.9		Anoxic	1.8	1.0	131
Summation						131

Net Discharge [ac-ft/yr] = 43,893 | **Net Load [lb/yr] = 5,700**

Reduction Lake Response Modeling for Little Sauk

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.89	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,575	[kg/yr]
		Q (lake outflow) =	54.1	[10^6 m^3/yr]
		V (modeled lake volume) =	3.4	[10^6 m^3]
		T = V/Q =	0.06	[yr]
		P_i = W/Q =	48	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Little Sauk Lake TMDL BATHTUB Lake Response Model

Average Loading Summary for Maple Lake

	Water Budgets				Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct	6,406	7.0	3,710	80	1.0	811
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*6,406*	*7*	*3,710*			*810.9*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	59.66666667	6	0.4	0.1		8.704387661
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*60*	*6*	*0.4*			*8.7*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Mud				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	388	27.9	27.9	0.00	0.239	1.0	92.8

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

Groundwater

	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	388	0.0		0.00	0	1.0	0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.57	122		Oxic	0.5	1.0	0
	1.57	52.9		Anoxic	5.6	1.0	1,025
	Summation						1,025
			Net Discharge [ac-ft/yr] =	**3,710**		**Net Load [lb/yr] =**	**1,938**

Average Lake Response Modeling for Maple Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.72	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	879	[kg/yr]
		Q (lake outflow) =	4.6	[10^6 m^3/yr]
		V (modeled lake volume) =	3.9	[10^6 m^3]
		T = V/Q =	0.85	[yr]
		P_i = W/Q =	192	[µg/l]
Model Predicted In-Lake [TP]			**88.0**	**[ug/l]**
Observed In-Lake [TP]			**88.0**	**[ug/l]**

Maple Lake Current Conditions BATHTUB Lake Response Model

Reductions Loading Summary for Maple Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct	6,406	7.0	3,710	42	0.5	428
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*6,406*	*7*	*3,710*			*427.8*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	59.66666667	6	0.4	0.1	0	0
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*60*	*6*	*0.4*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Mud				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
388	27.9	27.9	0.00	0.239	1.0	92.8

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

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
388	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
1.57	122		Oxic	0.5	1.0	0
1.57	52.9		Anoxic	5.6	1.0	183
Summation						183

Net Discharge [ac-ft/yr] = 3,710 | **Net Load [lb/yr] = 704**

Reductions Lake Response Modeling for Maple Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.72	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	319	[kg/yr]
		Q (lake outflow) =	4.6	[10^6 m^3/yr]
		V (modeled lake volume) =	3.9	[10^6 m^3]
		T = V/Q =	0.85	[yr]
		P_i = W/Q =	70	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Maple Lake TMDL BATHTUB Lake Response Model

Average Loading Summary for McCormic Lake

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct	1,001	4.6	383	749	1.0	781
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*1,001*	*5*	*383*			*781.0*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	5.333333333	1	0.04	0.1		0.779904788
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*5*	*1*	*0.0*			*0.8*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	206	27.9	27.9	0.00	0.239	1.0	49.3
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	206	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.83	122		Oxic		1.0	
	0.83	6.9		Anoxic	2.8	1.0	35
	Summation						35
			Net Discharge [ac-ft/yr] =	**383**		**Net Load [lb/yr] =**	**866**

Average Lake Response Modeling for McCormic Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.29	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	393	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	3.15	[yr]
		P_i = W/Q =	830	[µg/l]
Model Predicted In-Lake [TP]			**88.0**	**[ug/l]**
Observed In-Lake [TP]			**88.0**	**[ug/l]**

McCormic Lake Current Conditions BATHTUB Lake Response Model

Reductions Loading Summary for McCormic Lake

Water Budgets	Phosphorus Loading

Inflow from Drainage Areas

		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)^1	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct	1,001	4.6	383	444	0.6	463
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*1,001*	*5*	*383*			*463.1*

Point Source Dischargers

				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)^1	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	5.333333333	1	0.04	0.1		0
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*5*	*1*	*0.0*			*0.0*

Inflow from Upstream Lakes

				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

	Lake Area	Precipitation	Evaporation	Net Inflow	Aerial Loading Rate	Calibration Factor	Load
	[acre]	[in/yr]	[in/yr]	[ac-ft/yr]	[lb/ac-yr]	[--]	[lb/yr]
	206	27.9	27.9	0.00	0.239	1.0	49.3
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					

Groundwater

	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	206	0.0		0.00	0	1.0	0

Internal

	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.83	122		Oxic		1.0	
	0.83	6.9		Anoxic	2.8	1.0	35
	Summation						35
		Net Discharge [ac-ft/yr] =		**383**	**Net Load [lb/yr] =**		**547**

Reductions Lake Response Modeling for McCormic Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.46	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	248	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	1.5	[10^6 m^3]
		T = V/Q =	3.15	[yr]
		P_i = W/Q =	525	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

McCormic Lake TMDL BATHTUB Lake Response Model

eductions Loading Summary for Sand Lake

Inflow from Drainage Areas

			Water Budgets		Phosphorus Loading		
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Direct	455	4.4	168	100	0.2	46
2				0	0.0	1.0	0
3				0	0.0	1.0	0
4				0	0.0	1.0	0
5				0	0.0	1.0	0
	Summation	*455*	*4*	*168*			*45.7*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	No WWTF			0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	8.92319892	1	0.06	0.1		0
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*9*	*1*	*0.1*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
209	27.6	27.6	0.00	0.239	1.0	50.0
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
209	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.85			Oxic		1.0	
0.85	62.3		Anoxic	9.2	1.0	209
Summation						209
		Net Discharge [ac-ft/yr] =	**168**		**Net Load [lb/yr] =**	**304**

Average Lake Response Modeling for Sand Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	622	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	1.7	[10^6 m^3]
		T = V/Q =	8.42	[yr]
		P_i = W/Q =	2998	[µg/l]
Model Predicted In-Lake [TP]			**142.0**	**[ug/l]**
Observed In-Lake [TP]			**142.0**	**[ug/l]**

Sand Lake current conditions BATHTUB Lake Response Model

eductions Loading Summary for Sand Lake

Water Budgets					Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Direct	455	4.4	168	100	0.2	46
2				0	0.0	1.0	0
3				0	0.0	1.0	0
4				0	0.0	1.0	0
5				0	0.0	1.0	0
	Summation	*455*	*4*	*168*			*45.7*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	No WWTF			0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	8.92319892	1	0.06	0.1		0
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*9*	*1*	*0.1*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
209	27.6	27.6	0.00	0.239	1.0	50.0
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
209	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.85			Oxic		1.0	
0.85	62.3		Anoxic	9.2	1.0	209
Summation						209
		Net Discharge [ac-ft/yr] =	**168**		**Net Load [lb/yr] =**	**304**

Reductions Lake Response Modeling for Sand Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	138	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	1.7	[10^6 m^3]
		T = V/Q =	8.42	[yr]
		P_i = W/Q =	666	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Sand Lake TMDL BATHTUB Lake Response Model

Average Loading Summary for Uhlenkolts Lake

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Uhlenkolts Direct	2,931	5.7	1,396	199	1.0	754
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*2,931*	*6*	*1,396*			*753.7*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	57.33333333	5.71687892	0.38	0.1		8.3587365
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*57*	*6*	*0.4*			*8.4*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
239	27.9	27.9	0.00	0.239	1.0	57.1
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
239	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.97			Oxic		1.0	
0.97	73.5		Anoxic	11.3	1.0	1,764
Summation						1,764
		Net Discharge [ac-ft/yr] =	**1,396**		**Net Load [lb/yr] =**	**2,583**

Average Lake Response Modeling for Uhlenkolts Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$\boxed{P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.43	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,172	[kg/yr]
		Q (lake outflow) =	1.7	[10^6 m^3/yr]
		V (modeled lake volume) =	2.7	[10^6 m^3]
		T = V/Q =	1.54	[yr]
		P_i = W/Q =	680	[µg/l]
Model Predicted In-Lake [TP]			**248.0**	**[ug/l]**
Observed In-Lake [TP]			**248.0**	**[ug/l]**

Uhlenkolts Lake current conditions BATHTUB Lake Response Model

Reductions Loading Summary for Uhlenkolts Lake

Water Budgets					Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Uhlenkolts Direct	2,931	5.7	1,396	60	0.3	226
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*2,931*	*6*	*1,396*			*226.1*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	Direct	57.33333333	5.71687892	0.38	0.1		0
2					0.1		
3					0.1		
4					0.1		
5					0.1		
	Summation	*57*	*6*	*0.4*			*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	No Upstream Lake				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*
Atmosphere							
	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	239	27.9	27.9	0.00	0.239	1.0	57.1
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	239	0.0		0.00	0	1.0	0
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.97			Oxic		1.0	
	0.97	73.5		Anoxic	11.3	1.0	113
	Summation						113
		Net Discharge [ac-ft/yr] =		**1,396**		**Net Load [lb/yr] =**	**396**

Reductions Lake Response Modeling for Uhlenkolts Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.43	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	180	[kg/yr]
		Q (lake outflow) =	1.7	[10^6 m^3/yr]
		V (modeled lake volume) =	2.7	[10^6 m^3]
		T = V/Q =	1.54	[yr]
		P_i = W/Q =	104	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Uhlenkolts Lake TMDL BATHTUB Lake Response Model

Average Loading Summary for Westport Lake

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1	Total Watershed			3,098	195	1.0	1,644
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*0*	*0*	*3,098*			*1,643.6*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)^1 [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Swan				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

	Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
	203	27.9	27.9	0.00	0.239	1.0	48.6
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	203	0.0		0.00	0	1.0	0

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.82			Oxic		1.0	
	0.82	50.2		Anoxic	1.8	1.0	164
	Summation						164
			Net Discharge [ac-ft/yr] =	**3,098**	**Net Load [lb/yr] =**		**1,856**

Average Lake Response Modeling for Westport Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.88	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	842	[kg/yr]
		Q (lake outflow) =	3.8	[10^6 m^3/yr]
		V (modeled lake volume) =	1.1	[10^6 m^3]
		T = V/Q =	0.28	[yr]
		P_i = W/Q =	220	[µg/l]
Model Predicted In-Lake [TP]			**78.7**	**[ug/l]**
Observed In-Lake [TP]			**78.7**	**[ug/l]**

Westport Lake current conditions BATHTUB Lake Response Model

Reductions Loading Summary for Westport Lake

Water Budgets					Phosphorus Loading		

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Total Watershed			3,098	126	0.6	1,058
2				0		1.0	0
3				0		1.0	0
4				0		1.0	0
5				0		1.0	0
	Summation	*0*	*0*	*3,098*			*1,057.6*

Point Source Dischargers

	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1				0		1.0	
2				0		1.0	
3				0		1.0	
4				0		1.0	
5				0		1.0	
	Summation			*0*			*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Swan				-	1.0	
2					-	1.0	
3					-	1.0	
	Summation			*0*	-		*0*

Atmosphere

Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
203	27.9	27.9	0.00	0.239	1.0	48.6
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
203	0.0		0.00	0	1.0	0

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.82			Oxic		1.0	
0.82	50.2		Anoxic	1.8	1.0	164
Summation						164

			Net Discharge [ac-ft/yr] =	**3,098**		**Net Load [lb/yr] =**	**1,270**

Reductions Lake Response Modeling for Westport Lake

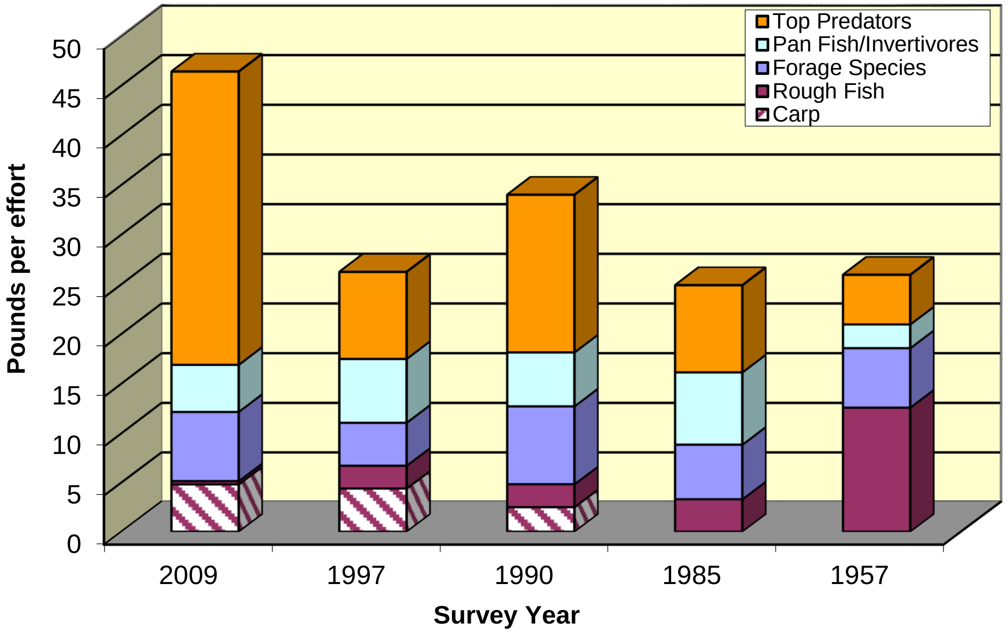
Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.88	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	576	[kg/yr]
		Q (lake outflow) =	3.8	[10^6 m^3/yr]
		V (modeled lake volume) =	1.1	[10^6 m^3]
		T = V/Q =	0.28	[yr]
		P_i = W/Q =	151	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Westport Lake TMDL BATHTUB Lake Response Model

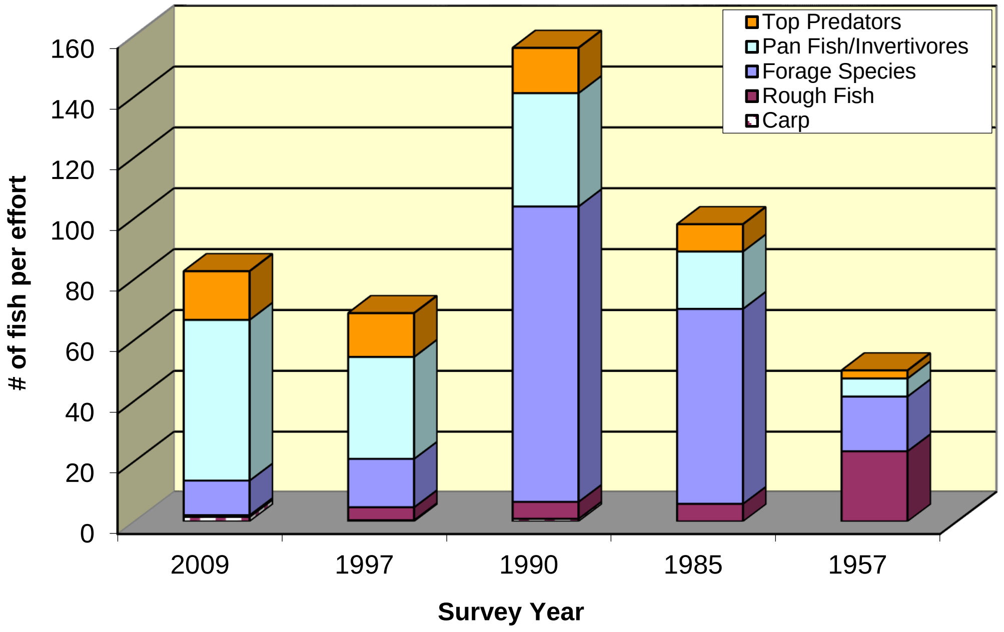
Appendix D

Fish Population Data

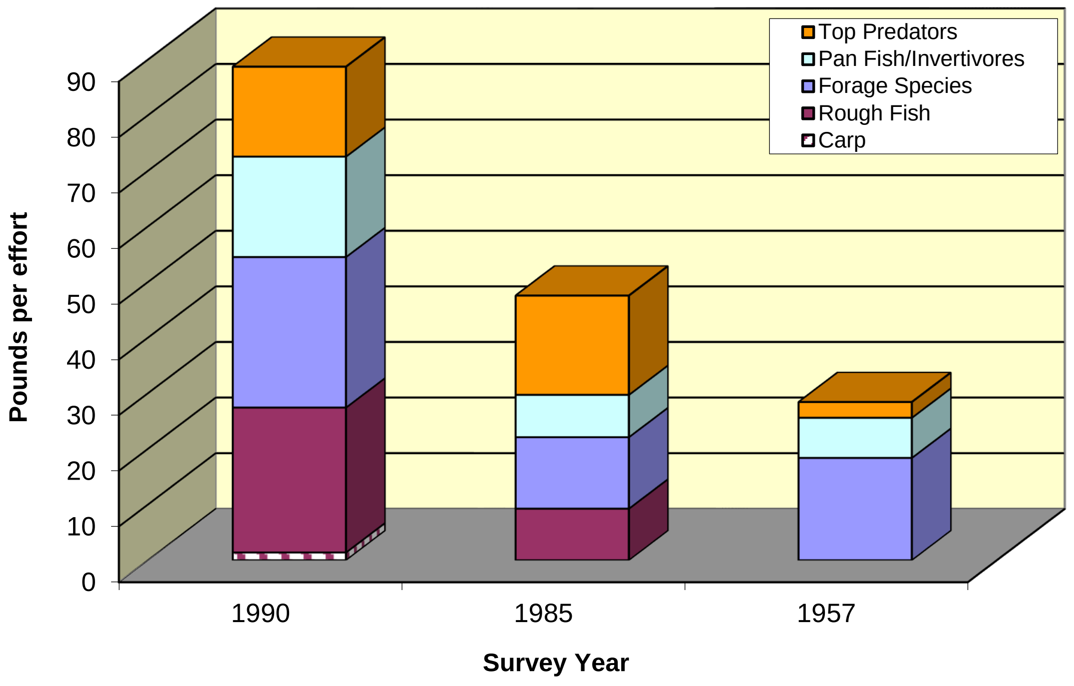
Guernsey Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



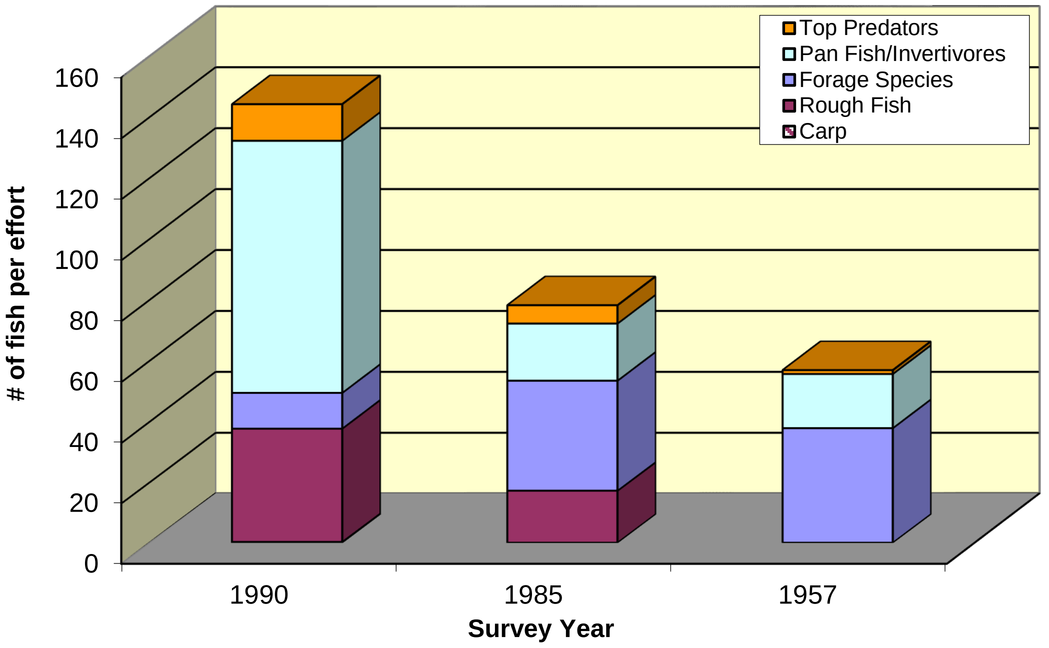
Guernsey Lake Trophic Group
Historical Catch Summary for DNR Surveys



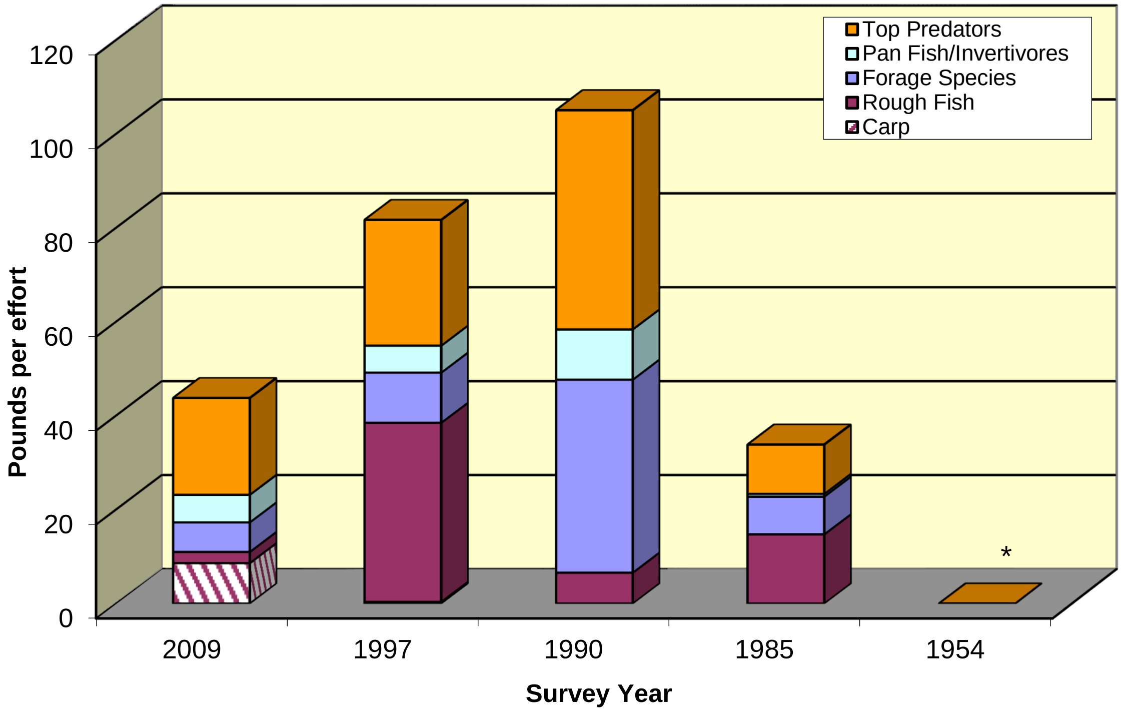
Juergens Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Juergens Lake Trophic Group
Historical Catch Summary for DNR Surveys

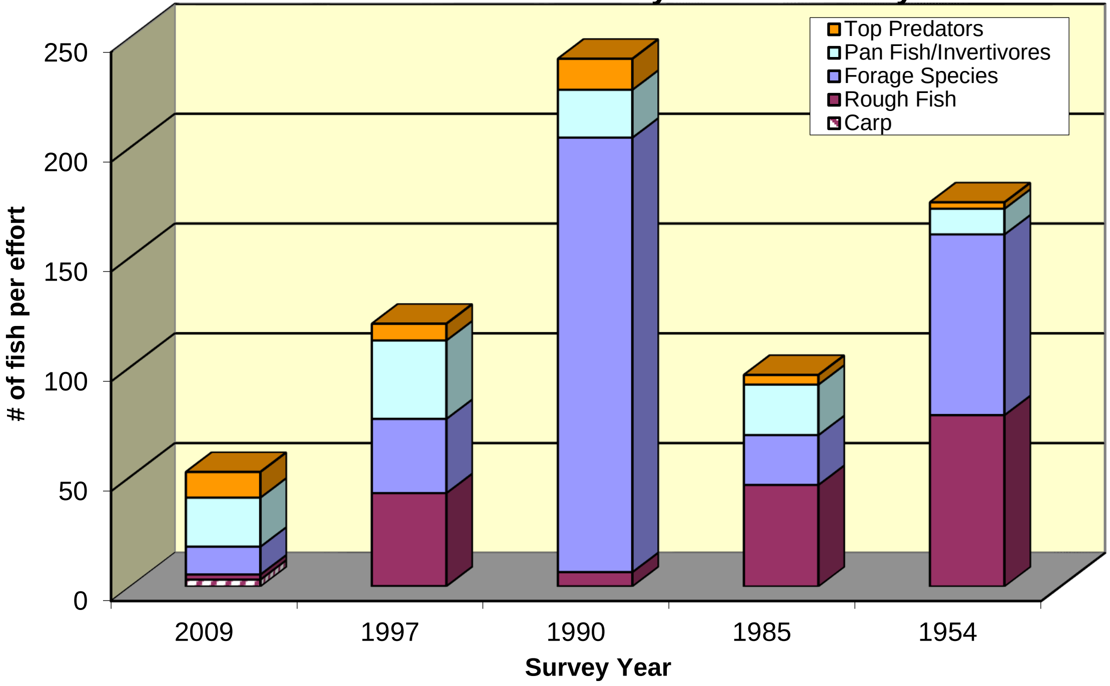


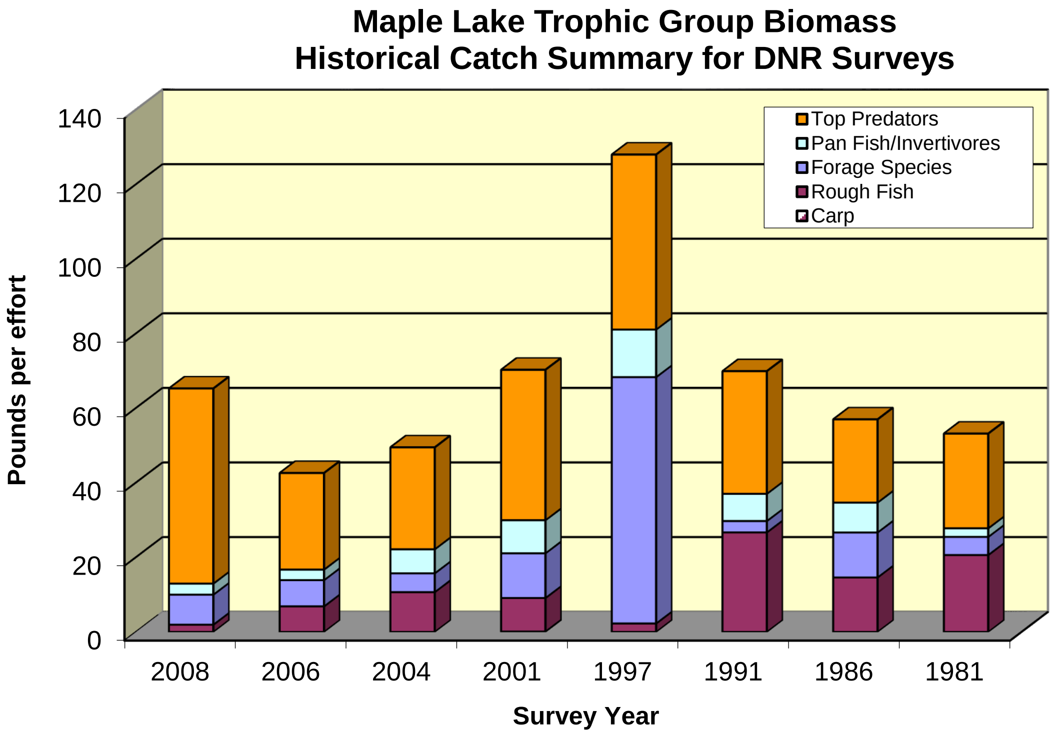
Little Sauk Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys

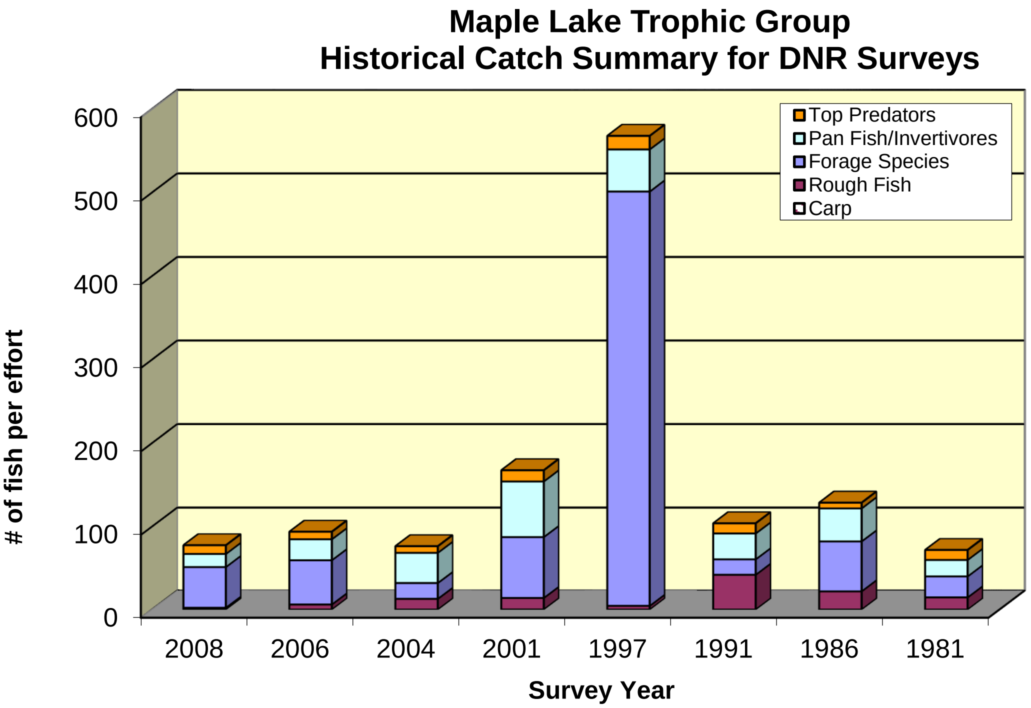


*Mass was not recorded during survey

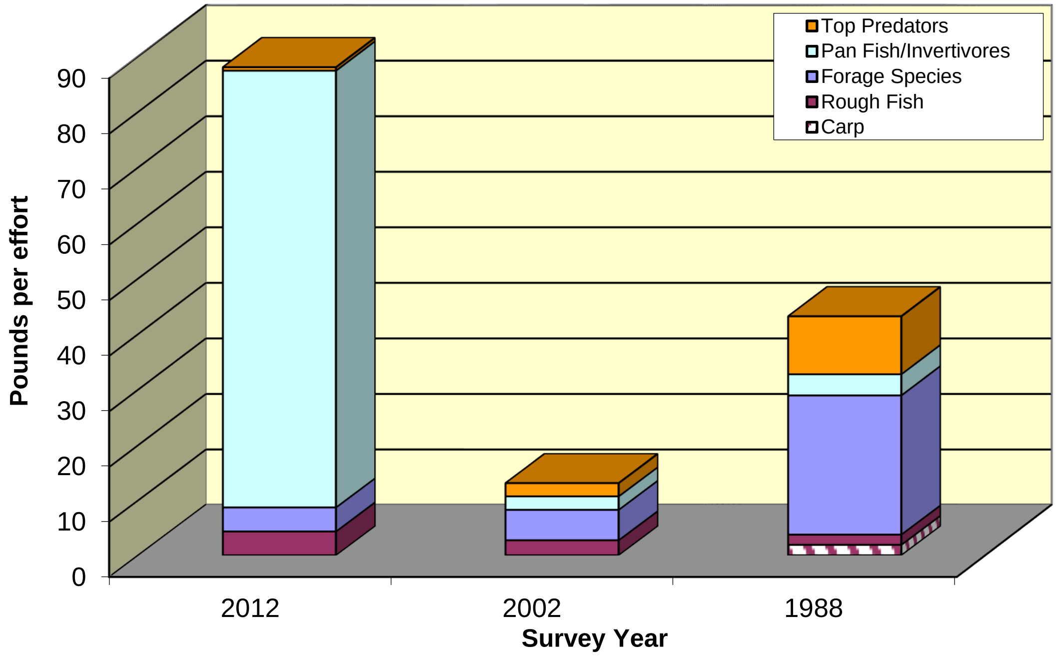
Little Sauk Lake Trophic Group
Historical Catch Summary for DNR Surveys



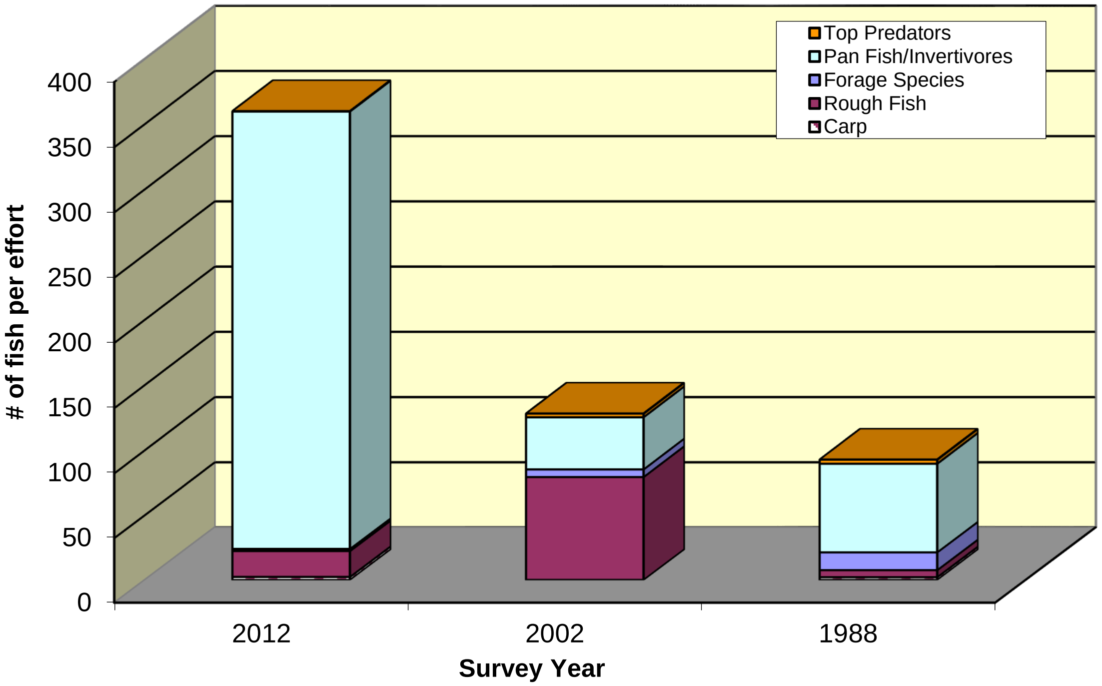

Maple Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys
Pounds per effort
140
120
100
80
60
40
20
0
2008
2006
2004
2001
1997
1991
1986
1981
Survey Year
Top Predators
Pan Fish/Invertivores
Forage Species
Rough Fish
Carp


Maple Lake Trophic Group
Historical Catch Summary for DNR Surveys
# of fish per effort
600
500
400
300
200
100
0
2008
2006
2004
2001
1997
1991
1986
1981
Survey Year
Top Predators
Pan Fish/Invertivores
Forage Species
Rough Fish
Carp

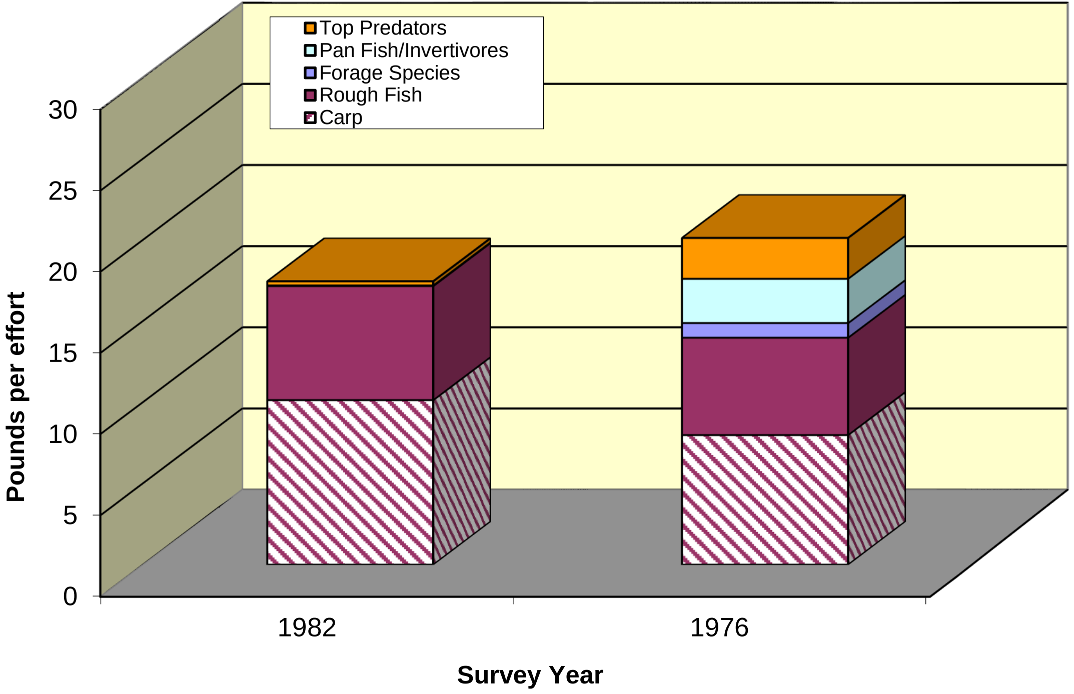
Sand Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



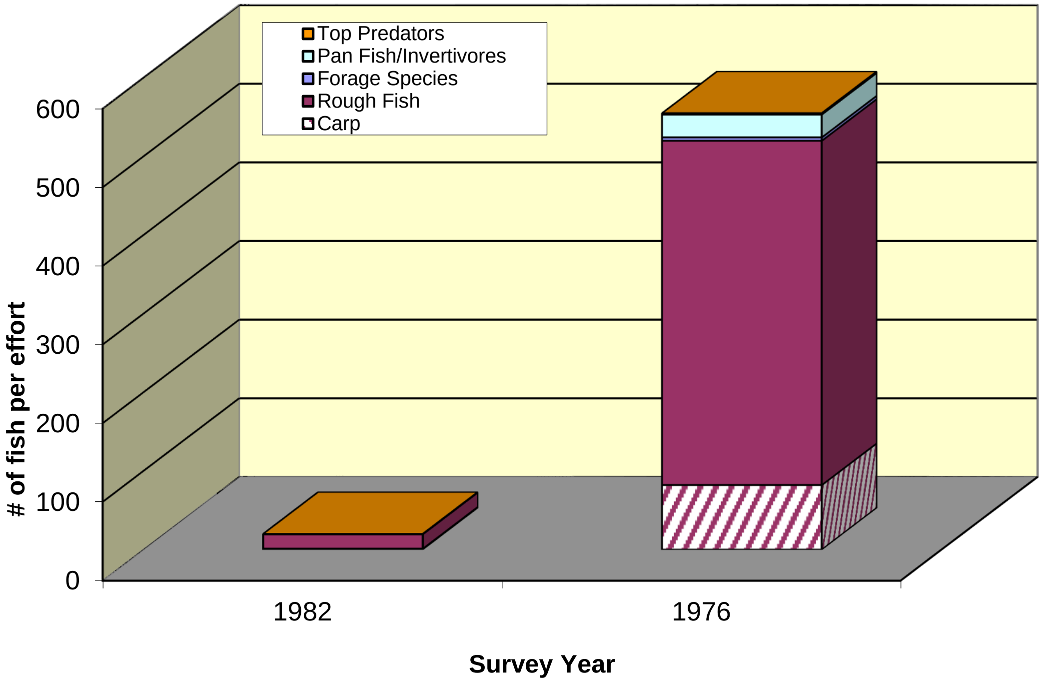
Sand Lake Trophic Group
Historical Catch Summary for DNR Surveys



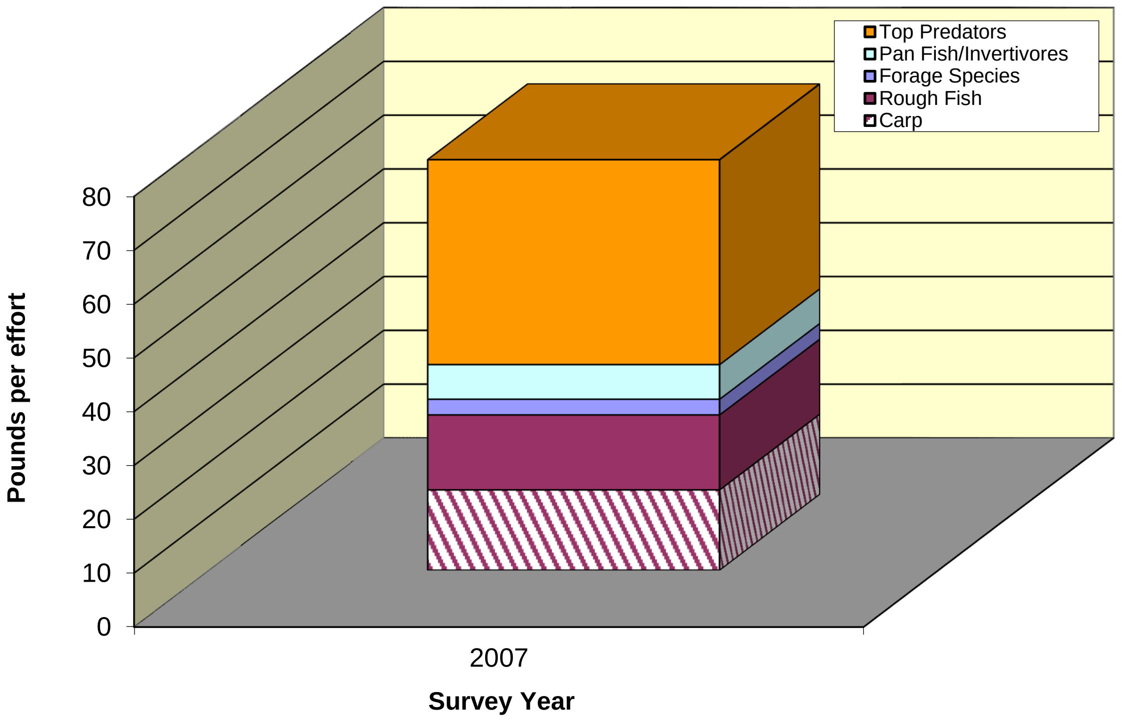
Uhlenkolts Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Uhlenkolts Lake Trophic Group
Historical Catch Summary for DNR Surveys



Westport Lake Trophic Group Biomass
Historical Catch Summary for DNR Surveys



Westport Lake Trophic Group
Historical Catch Summary for DNR Surveys