Wenck
Engineers • Scientists
Business Professionals

Wenck File #2366-04

December 2014

unmatched Service
strategic Advice
technical Excellence

CLEAN WATER LAND & LEGACY AMENDMENT

North Fork Crow River TMDL Bacteria, Nutrients, and Turbidity

Prepared for:

CROW RIVER ORGANIZATION OF WATER
311 Brighton Avenue, Suite C
Buffalo, Minnesota 55313

Prepared by:

WENCK ASSOCIATES, INC.
1800 Pioneer Creek Center
P.O. Box 249
Maple Plain, Minnesota 55359-0249
763-479-4200

wq-iw8-42e

Table of Contents

Table of Contents (Cont.)

Table of Contents (Cont.)

Table of Contents (Cont.)

Table of Contents (Cont.)

TABLES

Table of Contents (Cont.)

Table of Contents (Cont.)

Table of Contents (Cont.)

FIGURES

Table of Contents (Cont.)

Table of Contents (Cont.)

TMDL Summary

EPA/MPCA Required Elements	Summary	TMDL Page Number
Location	North Fork Crow River Watershed (HUC 07010204), west central Minnesota	Section 1.2, p1-1
303(d) Listing Information	Total of 46 listings for bacteria, turbidity or lake nutrients in 40 assessment unit ID's: *See Tables 1.2 and 1.3, p1-5*	Tables 1.2 and 1.3, p1-5
Applicable Water Quality Standards/ Numeric Targets	*See Section 1.6* Bacteria: *See Section 2.4* Turbidity: *See Sections 3.5, 3.6* Lake Nutrients *See Section 4.2*	Section 1.6.1, p1-8
Loading Capacity (expressed as daily load)	Bacteria: *See Section 2.6* Turbidity: *See Section 3.8* Lake Nutrients *See Sections.4.3, 4.4, 4.5, 4.6. 4.7, & 4.8*	Bacteria Section 2.6, p2-11 Turbidity Section 3.8, p3-12 & 3-13 Lake Nutrients Section 4.3.6, p4-19 – 4-21; Section 4.4.2, p4-27 – 4-29; Section 4.5.6, p4-36 – 4-37; Section 4.6.6, p4-46 – 4-47; Section 4.7.6, p4-53 – 4-54; Section 4.8.6, p4-68 – 4-74;

TMDL Summary

EPA/MPCA Required Elements	Summary	TMDL Page Number
Waste Load Allocation	Bacteria: *See Section 2.5.3* Turbidity: *See Section 3.7.3* Lake Nutrients: *See Section.4.8.4*	Bacteria Section 2.5.3, p2-9 Turbidity Section 3.7.3, p3-10 Lake Nutrients Section 4.8.4, p4-16
Load Allocation	Bacteria: *See Section 2.6.5* Turbidity: *See Section 3.8.5* Lake Nutrients: *See Sections 4.3.6, 4.4.2, 4.5.6, 4.6.6, 4.7.6, 4.8.6*	Bacteria Section 2.6.5, p2-10 Turbidity Section 3.8.5, p3-12 Lake Nutrients Section 4.3.6, p4-19 Section 4.4.2, p4-27 Section 4.5.6, p4-35 Section 4.6.6, p4-45 Section 4.7.6, p4-53 Section 4.8.6, p4-68

TMDL Summary

EPA/MPCA Required Elements	Summary	TMDL Page Number
Margin of Safety	Bacteria: An explicit 10% 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 2.5.2* Turbidity: An explicit MOS was based on the difference between the median flow of each flow regime at the estimated 42 mg/L standard and the median flow regime at the surrogate TSS standard. The resulting value was converted to a daily load by multiplying by both TSS standard concentrations and set as the MOS for each flow category. *See Section 3.7.2* 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 4.2.6*	Bacteria Section 2.5.2, p2-9 Turbidity Section 3.7.2, p3-10 Lake Nutrients Section 4.2.6, p4-19
Seasonal Variation	Bacteria: Load duration curve methodology accounts for seasonal variations; *See Section 2.5* Turbidity: Load duration curve methodology accounts for seasonal variations; *See Section 3.7* 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 4.2.8*	Bacteria Section 2.5, p2-5 Turbidity Section 3.7, p3 -7 Lake Nutrients Section 4.2.8, p4-12

TMDL Summary

EPA/MPCA Required Elements	Summary	TMDL Page Number
Reasonable Assurance	Information is presented regarding BMP's 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 6.0.*	Section 6.0 p. 6-1
Monitoring	A general overview of follow-up monitoring is included; *See Section 6.4*	Section 6.4, p. 6-4
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. 5-1
Public Participation	Civic Engagement Meetings February 10, 2011; March 20, 2011; December 5, 2011; December 13, 2011; March 16, 2012; March 30, 2012; July 16, 2012. TMDL Lake Meetings September 26, 2012; September 27, 2012; October 2, 2012; October 10, 2012; October 23, 2012; October 25, 2012; Public Notice August 11, 2014 to September 10, 2014	Section 7.0, p. 7-1

1.0 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 this directive, the State of Minnesota has directed that a TMDL be prepared to address bacteria and turbidity exceedances as well as low dissolved oxygen in reaches located in the North Fork Crow 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 Waste Load Allocation (WLA; Point Sources)
+ Σ Load Allocation (LA; nonpoint sources)
+ Margin of Safety (MOS)

The waste load allocation (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 of the North Fork Crow River.

1.2 WATERSHED STUDY AREA

The North Fork Crow River Watershed is located in eight counties in west-central Minnesota: Wright, Meeker, Kandiyohi, Stearns, Pope, Hennepin, McLeod, and Carver (Figure 1.1). The headwaters for the North Fork Crow River are located in Pope County, at Grove Lake. The North and South Forks of the Crow River converge in Rockford, Minnesota to become the Lower Crow River. The Lower Crow River flows northeast along the borders of Wright and Hennepin Counties until it empties in to the Mississippi River at the common boundary between Otsego and Dayton. From here forward the watershed will be referred to as the North Fork Crow River.

The total watershed area of the North Fork Crow River watershed is approximately 950,000 acres. Each impaired watershed is comprised of various subwatersheds that discharge to the North Fork Crow River. The individual impairment sections of this TMDL report include a detailed map of each impaired reach/tributary. All of the project areas are located within the North Central Hardwood Forest (NCHF), where the topography ranges from nearly flat to rolling to steep sloped.

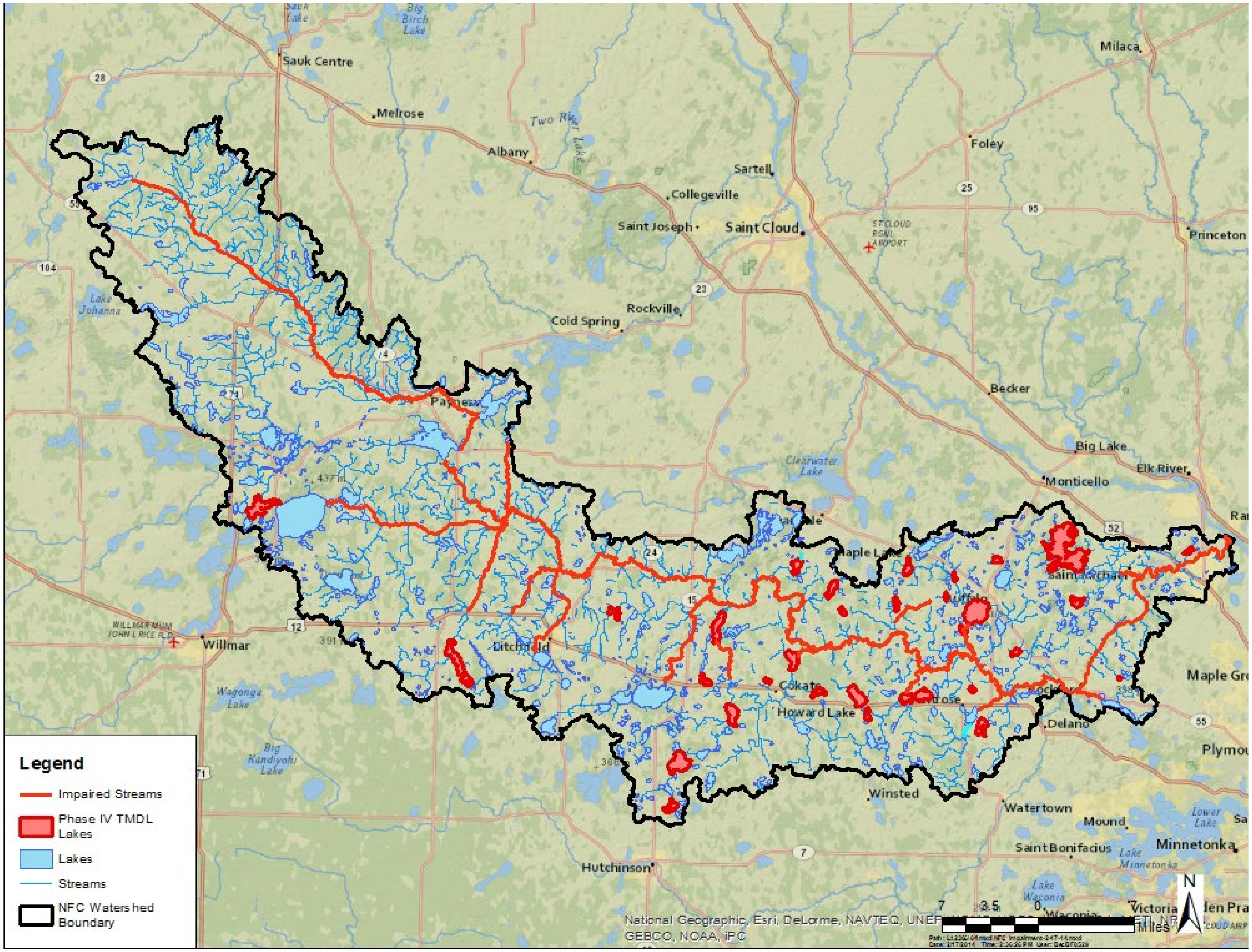


Figure 1.1. North Fork Crow River watershed impairments addressed in this TMDL study.

1.3 LAND USE SUMMARY

Land use for the North Fork Crow River watersheds was calculated using the 2009 National Agricultural Statistics Service (NASS) GIS land cover file. The dominant land uses in both watersheds are hay and pasture and row crops (Table 1.1). The North Fork River Watershed has more hay and pasture land. The remaining land area is comprised of forest and shrub land, lakes and wetlands, developed land and non-corn/soybean crops.

Table 1.1. Watershed Land use in the Crow River Watershed

Land use	Percent of Total North Fork Crow Watershed
Corn/Soybeans	35%
Hay and Pasture	32%
Wetlands and Open Water	12%
Forest and Shrubland	11%
Urban/Roads	8%
Grains and other Crops	2%

Source: 2009 NASS land cover

1.4 IMPAIRMENT SUMMARY

This TMDL report addresses eleven impairments on six reaches in the North Fork Crow River watershed as well as 34 lakes. The Minnesota Pollution Control Agency's (MPCA) projected schedule for TMDL completions, as indicated on Minnesota's 303(d) impaired waters list (as noted in Tables 1.2 and 1.3), 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 water body; 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 North Fork Crow River watershed addressed in this TMDL.

Reach Name	Description	Year Listed	Target Completion	AUID	Beneficial Use	Impairment	Class
Grove Creek	Unnamed Cr to N Fk Crow R	2010	2014	07010204-514	Aquatic Recreation	*E. coli*; Turbidity	5A
Unnamed creek	Unnamed Cr to Crow R	2010	2014	07010204-542	Aquatic Recreation	*Escherichia coli*	5A
Jewitts Creek (County Ditch 19, 18, 17)	Headwaters (Lk Ripley 47-0134-00) to N Fk Crow R	2010	2014	07010204-585	Aquatic Recreation	*Escherichia coli*	5A
Unnamed creek	Unnamed ditch to Woodland WMA wetland (86-0085-00)	2010	2014	07010204-667	Aquatic Recreation	*Escherichia coli*	5A
Mill Creek	Buffalo Lk to N Fk Crow R	2010	2014	07010204-515	Aquatic Life	Turbidity	5A
Unnamed creek	Unnamed Cr to Unnamed Cr	2008	2014	07010204-668	Aquatic life	Turbidity	5C

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

Table 1.3. Lake impairments in the North Fork Crow River watershed addressed in this TMDL.

Lake ID	Name	Year Listed	Target Completion
27-0199	HAFFTEN (Pioneer/Sarah)	2004	2014
34-0154	NEST	2010	2014
43-0073	HOOK	2008	2014
47-0015	JENNIE	2010	2014
47-0032	SPRING	2012	2014
47-0038	BIG SWAN	2010	2014
47-0082	DUNNS	2002	2014
47-0088	RICHARDSON	2002	2014
47-0177	LONG	2008	2014
47-0183	HOPE	2008	2014
86-0001	FOSTER	2008	2014
86-0023	BEEBE	2008	2014
86-0031	PELICAN	2008	2014
86-0041	DEAN	2012	2014
86-0051	CONSTANCE	2012	2014
86-0086	FOUNTAIN	2008	2014
86-0090	BUFFALO	2008	2014
86-0106	LITTLE WAVERLY	2008	2014
86-0107	DEER	2008	2014
86-0112	MALARDI	2012	2014

Lake ID	Name	Year Listed	Target Completion
86-0114	WAVERLY	2008	2014
86-0120	RAMSEY	2008	2014
86-0122	LIGHT FOOT	2012	2014
86-0127	ALBERT	2012	2014
86-0182	ROCK	2012	2014
86-0184	DUTCH	2010	2014
86-0199	HOWARD	2008	2014
86-0217	GRANITE	2008	2014
86-0221	CAMP	2008	2014
86-0250	SMITH	2010	2014
86-0263	COKATO	2008	2014
86-0264	BROOKS	2012	2014
86-0273	FRENCH	2008	2014
86-0293	COLLINWOOD	2008	2014

1.5 BENEFICIAL USE CLASSIFICATIONS

This TMDL report addresses exceedances of the state standards for bacteria, turbidity and dissolved oxygen in the North Fork Crow River Watersheds 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. ch. 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. ch. 7050.0140):

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

According to Minn. R. ch. 7050.0470, Jewitts Creek is specifically listed as a 2C water. The remaining reaches are not listed in 7050.0470 and therefore classified as 2B, 3C, 4A, 4B, 5, and 6 waters (Minn. R. ch. 7050.0430). Table 1.4 summarizes the beneficial use classifications by assessment unit ID (AUID).

Table 1.4. Beneficial Use Classifications.

Reach Name on 303(d) List/Description	Assessment Unit ID	Class
Grove Creek (Unnamed Cr to N Fk Crow R)	07010204-514	2B, 3C
Mill Creek (Buffalo Lk to N Fk Crow R)	07010204-515	2B, 3C
Regal Creek (Unnamed Cr to Crow R)	07010204-542	2B, 3C
Jewitts Creek (Headwaters (47-0134) to N Fk Crow R)	07010204-585	2C
Unnamed Creek (Woodland WMA (86-0085) to N F Crow R)	07010204-667	2B, 3C
Unnamed Creek (Unnamed Cr to Woodland WMA (86-0085))	07010204-668	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. The Minn. R. ch. 7050.0470 lists water body classifications and ch. 7050.0222 (subp. 5) lists applicable water quality standards for the impaired Class 2C reaches.

1.6.1 State of Minnesota Standards and Criteria for Listing

Nutrients. Under Minn. R.7050.0150 and 7050.0222, Subp. 4, the lakes addressed in this study are located within the NCHF ecoregion with a numeric target dependent on depth as listed in Table 1.5. Therefore, this TMDL presents load and WLAs 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* and Secchi depth standards must also be met. In developing the lake nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (Heiskary and Wilson, 2005). Clear relationships were established between the causal factor total phosphorus (TP) and the response variables chlorophyll-*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 chlorophyll-*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
Chlorophyll-*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).

***E. coli*.** The bacterial impairment listings were based on *E. coli* measurements. Under Minn. R. 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."

Turbidity. Turbidity is a measure of the cloudiness or haziness of water caused by suspended and dissolved substances in the water column. Turbidity can be caused by increased suspended soil or sediment particles, phytoplankton growth, and dissolved substances in the water column. Excess turbidity can degrade aesthetic qualities of water bodies, increase the cost of treatment for drinking water or food processing uses, and harm aquatic life. Adverse ecological impacts caused by excessive turbidity include hampering the ability of aquatic organisms to visually locate food, negative effects on gill function, and smothering of spawning beds and benthic organism habitat.

The turbidity standard found in Minn. R. 7050.0222, subp.4 for 2B waters is 25 nephelometric turbidity units (NTUs). Impairment assessment procedures for turbidity are provided by MPCA (2005). The water body is added to the impaired waters list when greater than 10% of the data points collected within the previous 10 year period exceed the 25 NTU standard (or equivalent values for total suspended solids (TSS) or transparency tube data). This TMDL is written for Class 2B waters, as this is the most protective class in these stream reaches.

Since turbidity is a measure of light scatter and adsorption, turbidity cannot be expressed as a mass load which is required for TMDLs. In May, 2011, the MPCA released a technical support document which develops river/stream TSS standards for the state of Minnesota (MPCA, 2011). The proposed TSS standard for all North Fork Crow River impaired reaches will be 30 mg/L if/when MPCA's proposed standards go into effect. Prior to these newly developed standards, MPCA protocol suggested using the relationship between lab turbidity in NTUs and TSS to determine the TSS equivalent to the 25 NTU turbidity standard. Section 4.6 provides additional detail on the development of the site specific TSS surrogate standard for the three turbidity impaired reaches. Since the MPCA's proposed TSS standards have not yet been accepted, both the proposed standard and TSS surrogate standard will be used and presented as dual end points for the turbidity TMDLs in this report.

1.7 ANALYSIS OF IMPAIRMENT

The criteria used for determining 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. 7050.0407 and Minn. R. ch. 7050.2222 (5), respectively.

1.8 IMPACT OF GROWTH ON ALLOCATIONS

For all of the TMDLs, the following applies for determining the impact of growth on allocations.

1.8.1 Point Sources

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

Current discharges can be expanded and new National Pollutant Discharge Elimination System (NPDES) discharges can be added while maintaining water quality standards provided the permitted NPDES [Permits Program] effluent concentrations remain below the in-stream targets. Given this circumstance, a streamlined process for updating TMDL WLAs to incorporate new or expanding discharges will be employed. This process will apply to the non-stormwater facilities identified in this TMDL and any new wastewater or cooling water discharge in the watershed:

I. A new or expanding discharger will file with the MPCA permit program a permit modification request or an application for a permit reissuance. The permit application information will include documentation of the current and proposed future flow volumes and TSS loads.
II. The MPCA permit program will notify the MPCA TMDL program upon receipt of the request/application, and provide the appropriate information, including the proposed discharge volumes and the TSS loads.
III. The TMDL Program staff will provide the permit writer with information on the TMDL WLAs to be published with the permit's public notice.
IV. The supporting documentation (fact sheet, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the TSS discharge requirements, noting that for TSS, the effluent limit is below the in-stream TSS target and the increased discharge will maintain the turbidity water quality standard. The public will have the opportunity to provide comments on the new proposed permit, including the TSS discharge and its relationship to the TMDL.
V. The MPCA TMDL program will notify the EPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheet (or other appropriate supporting documentation) and new TSS information to the MPCA TMDL program and the EPA TMDL program.

VI. The EPA will transmit any comments to the MPCA Permits and TMDL programs during the public comment period, typically via e-mail. The MPCA will consider any comments provided by the EPA and by the public on the proposed permit action and WLA and respond accordingly; conferring with the EPA if necessary.

VII. If, following the review of comments, the MPCA determines that the new or expanded TSS discharge, with a concentration below the in-stream target, is consistent with applicable water quality standards and the above analysis, the MPCA will issue the permit with these conditions and send a copy of the final TSS information to the EPA TMDL program. The MPCA's final permit action, which has been through a public notice period, will constitute an update of the WLA only.

VIII. The EPA will document the update to the WLA in the administrative record for the TMDL. Through this process, the EPA will maintain an up-to-date record of the applicable WLA for permitted facilities in the watershed.

1.8.2 MS4 Allocation Load Transfer and Future Growth

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

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

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

1.8.3 Agriculture Practices

The amount of land in agricultural land use in the impaired reaches watersheds is likely to remain fairly constant over the next several decades. The watershed is comprised mainly of pasture/hay and row crops (corn and soybeans) and it is possible a modest shift between these two land use categories may occur. Any such shift would likely not affect the loading capacity of the stream, since that capacity is based on long-term flow records over which time land use changes between hay/pasture and row crops have likely occurred. Thus, although the conversion of pasture and hay to row crops can lead to increased fertilizer use and higher runoff rates, minor shifts in land use should not appreciably change the magnitude of the land use runoff variability that the period of record already reflects.

2.0 Bacteria Impairments

2.1 OVERVIEW OF E. COLI IMPAIRED REACH WATERSHED

This TMDL applies to the *E. coli* bacteria impairment for four tributaries to the North Fork Crow River (NFCR) (Figure 1.1). Data from six main-stem monitoring stations in the watersheds served as the basis of the impairment determination and were used to support development of the TMDL.

2.2 WATERSHED LAND USE/LAND COVER

Land use for the watershed draining directly to the *E. coli* impaired reaches and the watersheds upstream of the impaired reaches were calculated using the 2011 NASS 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. Land use for the bacteria impaired reach watersheds.

	Percent of Total							
Land Cover	**[1]Impaired Reach Grove Creek Watershed**	**[2]Grove Creek Watershed**	**[1]Impaired Reach Jewitts Creek Watershed**	**[2]Jewitts Creek Watershed**	**[1]Impaired Reach Unnamed Creek Watershed**	**[2]Unnamed Creek Watershed**	**[1]Impaired Reach Regal Creek Watershed**	**[2]Regal Creek Watershed**
Watershed size (acres)	12,740	32,778	11,710	25,774	13,499	15,389	7,541	31,594
Corn/soybeans	73%	63%	43%	45%	57%	56%	38%	33%
Hay and Pasture	5%	6%	5%	4%	2%	2%	4%	5%
Grains and other crops	3%	3%	7%	7%	15%	15%	8%	8%
Urban/Roads	6%	5%	18%	12%	4%	4%	30%	11%
Forest and Shrubland	4%	9%	6%	8%	12%	11%	8%	12%
Wetlands and open water	9%	14%	21%	24%	10%	12%	12%	31%

[1] Only includes watershed that drains directly to impaired reach.
[2] Includes upstream subwatersheds that drain to impaired reach watershed as well as direct watershed.

2.3 DATA SOURCES

2.3.1 Water Quality Data

The *E. coli* data used for the development of this TMDL are grab samples collected by the Crow River Organization of Water (CROW) and the MPCA in 2003 and 2007 through 2009 (Table 2.2). Although data prior to this period exists, the more recent data better represent current conditions in the watershed. Samples were analyzed for fecal coliform prior to 2006 and more recently *E. coli*. All fecal coliform data were converted to *E. coli* "equivalents" using the equation outlined in the SONAR for the 2007-2008 revisions of Minn. R. ch. 7050. Figure 2.1 shows the location of the monitoring stations at which samples were collected to support this TMDL. All data were obtained through the MPCA's EQuIS online database.

Table 2.2. North Fork Crow River *E. coli* monitoring sites.

EQuIS ID	Location	Parameter	Number of Samples	Years
S000-847	Main-stem Grove Creek at CSAH 3	Fecal Coliform	1	2003
		E. coli	34	2007 – 2009
S000-897	Main-stem Grove Creek at 340th St	Fecal Coliform	None	-
		E. coli	9	2007
S000-919	Main-stem Jewitts Creek at 300th St	Fecal Coliform	None	-
		E. coli	11	2007
S001-502	Main-stem Jewitts Creek at 300th St	Fecal Coliform	1	2003
		E. coli	34	2008 – 2009
S002-030	Main-stem Regal Creek at CSAH 19	Fecal Coliform	1	2003
		E. coli	44	2007 – 2009
S001-499	Unnamed Creek at Armitage Ave	Fecal Coliform	None	-
		E. coli	21	2007 – 2009

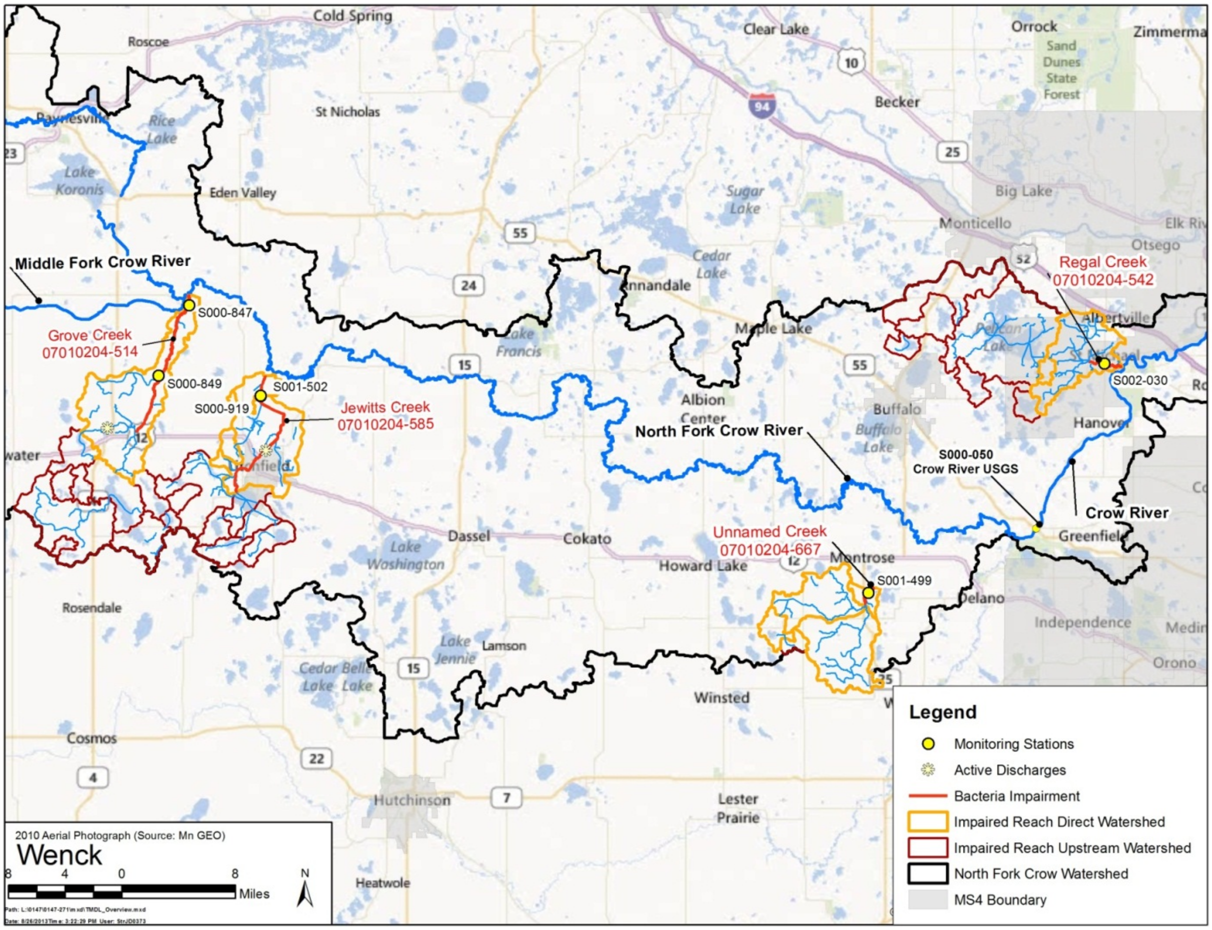


Figure 2.1.North Fork Crow River Watershed *E. Coli* impaired reach watersheds and monitoring stations.

2.3.2 Streamflow Data

Stream flow data was crucial to support development of the *E. coli* allocations for this TMDL. Streamflow data paired with *E. coli* measurements allow exceedances to be evaluated by flow regime which, in turn provides insight into potential sources.

Three of the four impaired reaches (Grove Creek – S000-847, Jewitts Creek – S001-502 and Unnamed Creek – S001-499) have recent continuous flow data (Appendix B and Figure 2.1). These stations were operated during the 2008 through 2010 sampling season from April/March through the middle of November. There is also one long-term USGS flow monitoring station located on the Crow River near Rockford (S000-050). This station began operating in 1906 and has operated year around since the early 1990s. Regression relationships between the three impaired reaches stations and the Crow River USGS station show good correlation (R^2 of 0.73-0.85) and the regression equations were used to fill data gaps and predict all winter and non-monitored flows from 2003-2012.

The fourth impaired reach (Regal Creek – S002-030) has instantaneous flow measurements collected during the sampling season in 2001. There was not enough data from this site to establish a good regression with the Crow River USGS site at Rockford. Instead, flow was calculated by multiplying the percent watershed coverage of the impaired reach by the total watershed area flowing to the Rockford USGS station.

2.4 IMPAIRMENT CRITERIA FOR IMPAIRED REACHES

To determine *E. coli* impairment, the MPCA use data collected by the MPCA and other agencies that satisfy QA/QC requirements, meet EPA guidelines, 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 water body is considered impaired if more than 10% of individual values over the 10-year period (independent of month) exceed 1,260 organisms per 100 mL (cfu/100 mL).

E. coli and *E. coli* "equivalent" data from the six main-stem 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. Figure 2.2 shows the impaired reaches' monthly *E. coli* geometric means during the bacteria index period (April-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.

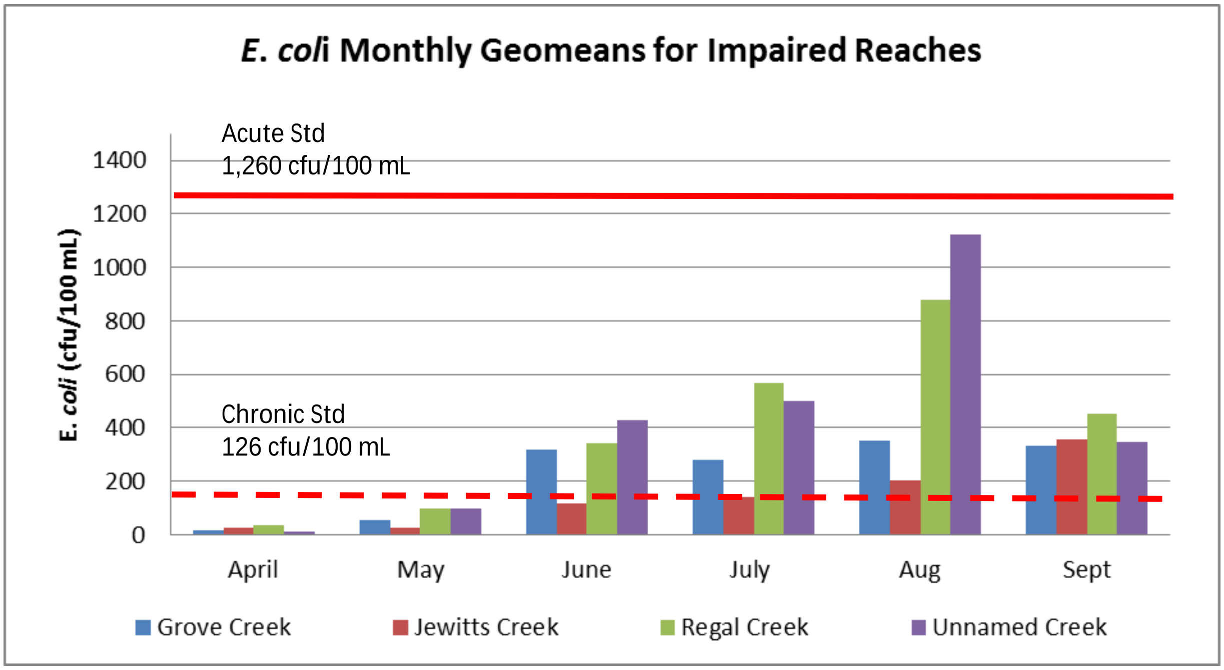


Figure 2.2. Monthly *E. coli* geometric means for each impaired reach for 2003 and 2007-2009.

Table 2.3. Individual *E. coli* acute exceedances in 2003 and 2007-2009 for the impaired reach monitoring stations.

Site	Total Samples	Acute Exceedances	Percent	Months with Acute Exceedances
Grove Creek S000-847 S000-897	44	22	50%	June (5); July (6); Aug (7); Sep (4)
Jewitts Creek S000-919 S001-502	45	21	47%	June (4); July (5); Aug (7); Sep (5)
Regal Creek S002-030	45	29	64%	May (4); June (8); July (6); Aug (7); Sep (4)
Unnamed Creek S001-499	21	14	67%	May (5); June (5); July (3); Aug (1)

2.5 ALLOCATION METHODOLOGY

2.5.1 Overview of Load Duration Curve Approach

Assimilative capacities for each reach were developed from load duration curves (Cleland 2002). Load duration curves assimilate 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 10 years (2003-2012) 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 Jewitts Creek (S001-502), the stream was at 9 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 (0-10%), high (10-40%), mid (40-60%), low (60-90%) and dry (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.

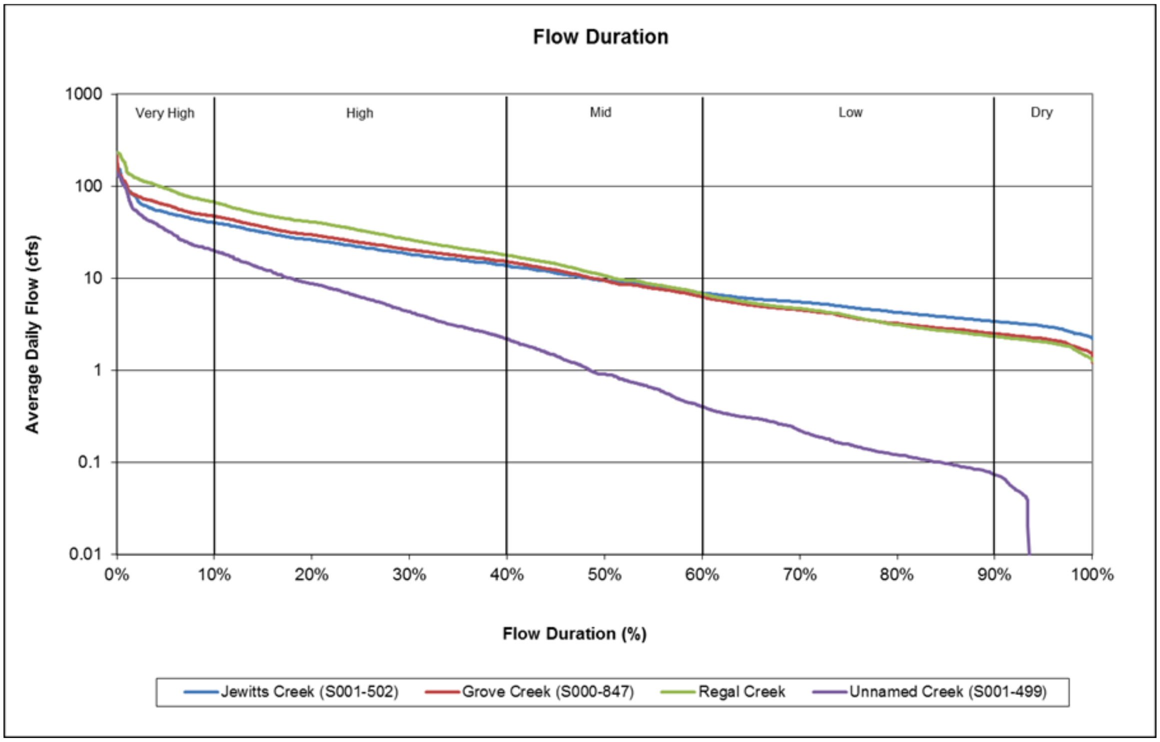


Figure 2.3. Flow duration curves for each impaired reach.

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 compared to current conditions by plotting individual load measurements (black X's in Figures 2.4 through 2.7) for each water quality sampling event. Each value that is above the TDLC line (red line) represents an exceedance of the 126 cfu/100 ml standard while those below the line are below the water quality standard. Also plotted are the geomean *E. coli* concentrations for each flow regime (blue sphere). The difference between these two provides a general percent reduction in *E. coli* that will be needed to remove each reach from the impaired waters list. The figures show Grove, Jewitts and Regal Creek reduction efforts will need to focus on the mid, low and dry flow conditions. Reductions for Unnamed Creek, on the other hand, will need to occur across all flow conditions.

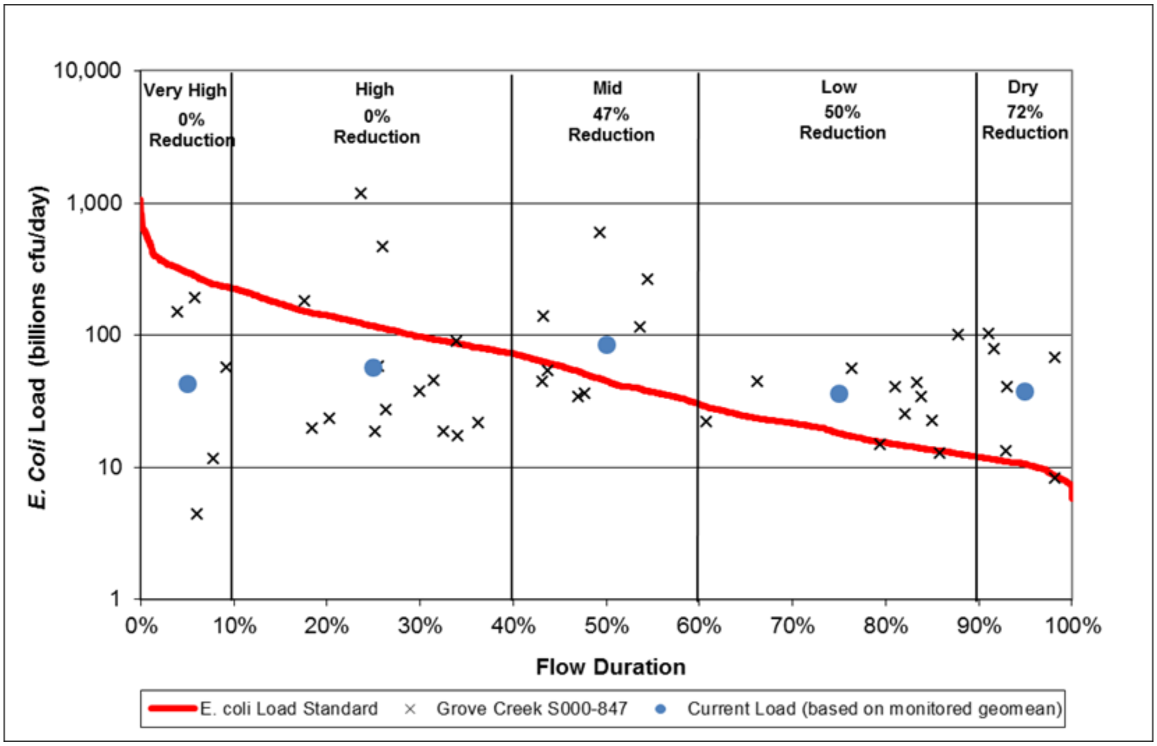


Figure 2.4. Grove Creek *E. coli* load duration curve and required load reductions by flow category.

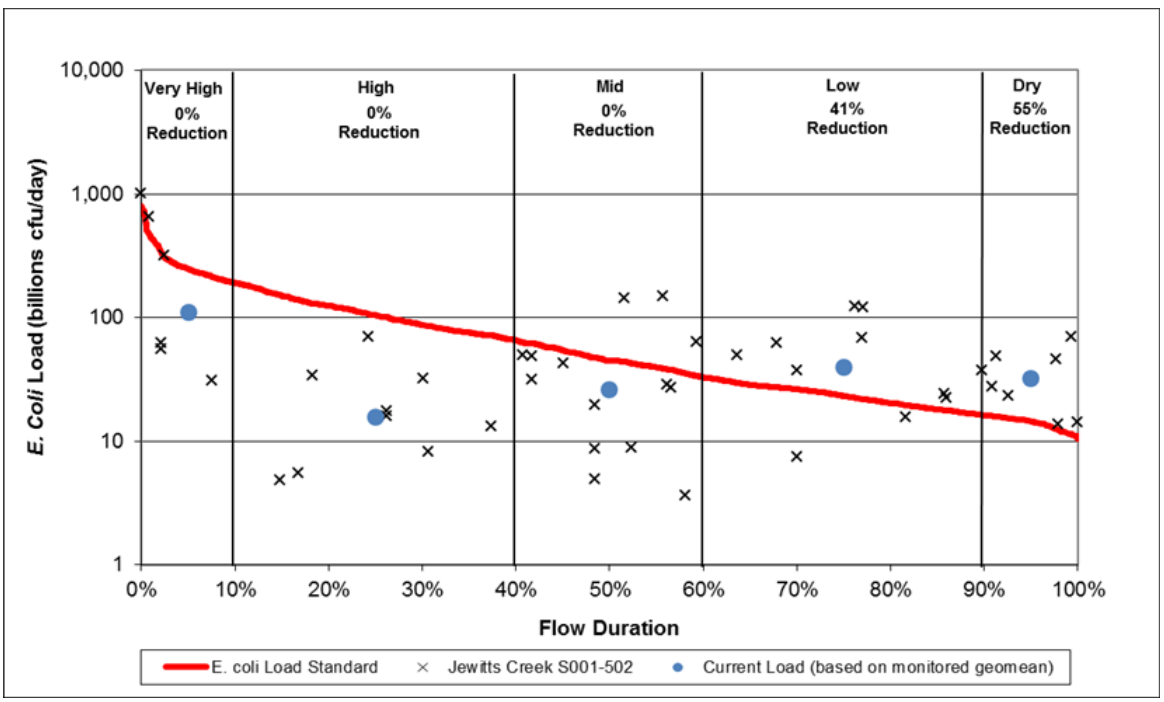


Figure 2.5. Jewitts Creek *E. coli* load duration curve and required load reduction by flow category.

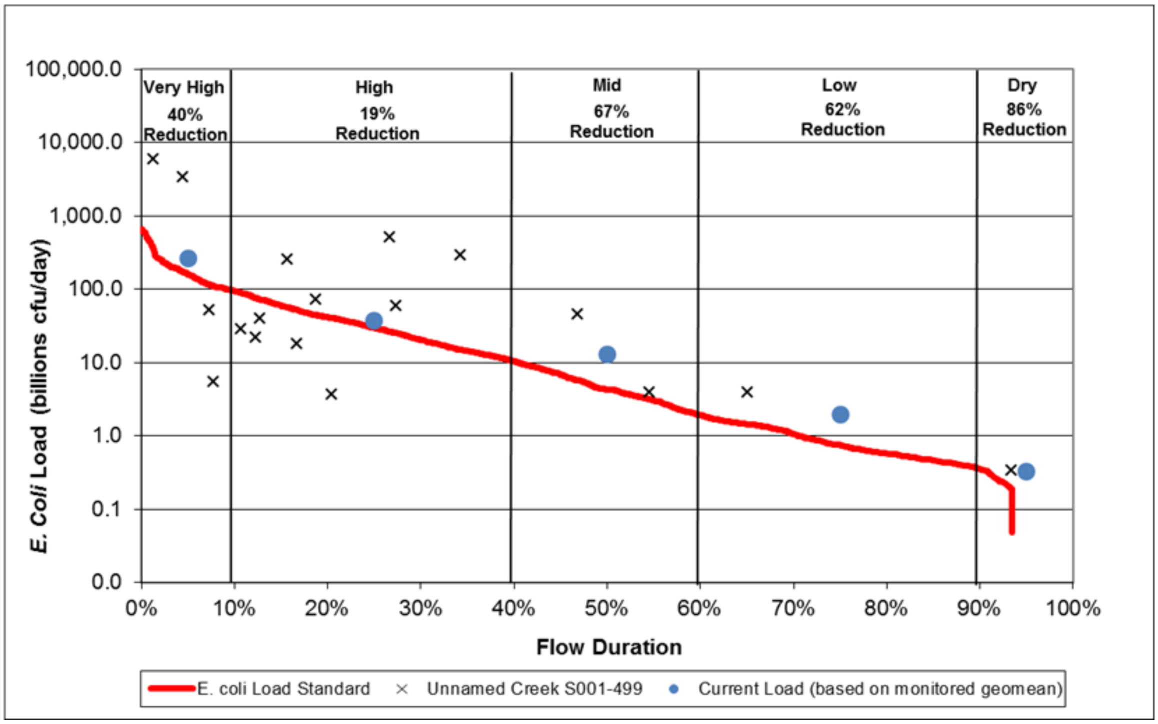


Figure 2.6. Unnamed Creek *E. coli* load duration curve and required load reduction by flow category.

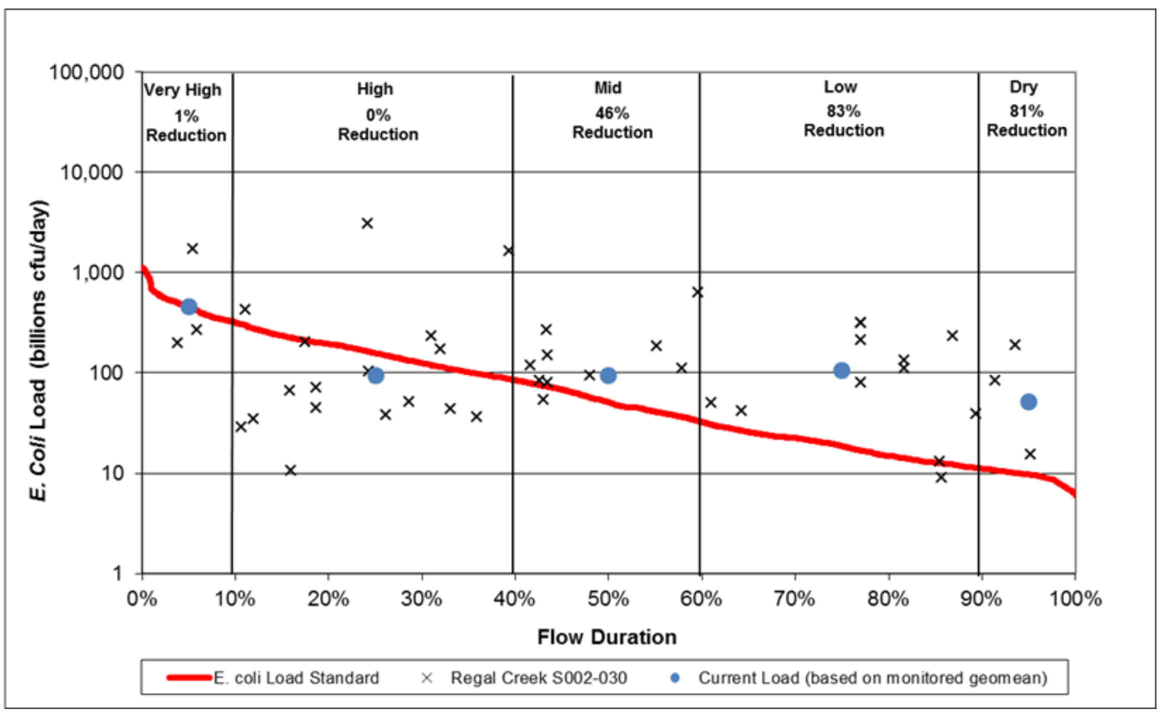


Figure 2.7. Regal Creek *E. coli* load duration curve and required load reduction by flow category.

2.5.3 Margin of Safety

The MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, waste load, 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 10% of the total load was applied whereby 10% of the loading capacity for each flow regime was subtracted before allocations were made among waste load and non-point sources. Ten 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.

2.5.4 Waste Load Allocations

The WLAs were divided into three categories: permitted point source dischargers, MS4 stormwater permits and construction and industrial stormwater permits. The following sections describe how each of these load allocations was estimated. Waste load allocations for regulated construction stormwater (permit #MNR100001) were not developed, since *E. coli* is not a typical pollutant from construction sites. Waste load allocations for regulated industrial stormwater were also not developed. Industrial stormwater must receive a waste load allocation only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired water body. There are no *E. coli* benchmarks associated with any of the industrial stormwater permit (permit #MNR050000).

2.5.4.1 NPDES Point Source Dischargers

There are two active permitted NPDES surface wastewater discharges in the impaired reaches (Table 2.4, Figure 2.1). Load allocations were calculated by multiplying the facility's wet weather design flow by the *E. coli* standard (126 cfu/100 mL). 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 wastewater treatment facility (200 organisms/100 mL) is believed to be equivalent to this TMDL's 126 organism/100 mL *E. coli* criterion. The fecal coliform-*E. coli* relationship is documented extensively in the SONAR for the 2007-2008 revisions of Minn. R. ch. 7050.

The WLA for permitted wastewater dischargers is based on facility design flow. However, the WLA often exceeds the dry flow regimes daily loading capacity because these facilities typically discharge less than their design flows. To account for this, the WLA and non-point source load allocation for this flow regime is determined by the following formula:

Allocation = (flow contribution from a given source) X (E. coli concentration limit or standard)

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

Impaired Reach	Facility Name	NPDES ID#	Location	Facility Type	Effluent Design Flow (MGD)	Allocated Load (billions organisms/day)
Grove Creek 07010204-514	Grove City WWTF	MN0023574	NFC	pond	0.13	0.6
Jewitts Creek 07010204-585	Litchfield WWTF	MN0023973	NFC	continuous	3.10	14.8

2.5.4.2 MS4

There are five MS4s that are completely within or have a portion of their municipal boundary in the impaired reach watersheds (Table 2.5; Figure 2.1). There is one additional municipality, Albertville who, according to the MPCA rules, now require NPDES permits since its population exceeded 5,000 in the 2010 census. Stormwater from Albertville and the five MS4 communities drain to two of the impaired reaches discussed in this report and are therefore assigned WLAs. MS4 allocations were calculated by multiplying the municipalities' percent watershed coverage by the total watershed loading capacity after the MOS and waste load allocation were subtracted (MPCA, 2006).

Table 2.5. Summary of permitted MS4s in the impaired reach watersheds.

Impaired Reach	MS4	Permit #	Area (acres)	*E. coli* Allocation (billions organisms/day)				
				Very High	High	Mid	Low	Dry
Jewitts Creek 07010204-585	Litchfield City MS4	MS 400253	3,435	28.8	11.3	4.0	1.3	0.2
Regal Creek 07010204-542	Albertville City MS4	None	1,486	19.2	6.7	2.0	0.7	0.4
Regal Creek 07010204-542	Buffalo City MS4	MS 400238	32	0.4	0.1	<0.1	<0.1	<0.1
Regal Creek 07010204-542	Monticello City MS4	MS 400242	77	1.0	0.3	0.1	<0.1	<0.1
Regal Creek 07010204-542	Ostego City MS4	MS 400243	149	1.9	0.7	0.2	0.1	<0.1
Regal Creek 07010204-542	St Michael City MS4	MS 400246	11,704	150.9	52.5	15.9	5.8	3.2

2.5.5 Non-point Source Load Allocation

The non-point source load allocation is the remaining load after the MOS and WLAs are subtracted from the total load capacity of each flow zone. Non-point sources include all non-permitted sources of pollution.

2.6 TOTAL MAXIMUM DAILY LOADS

Tables 2.6 through 2.9 present the total loading capacity, MOS, WLAs and the remaining non-point source load allocations for the impaired reaches. The tables also present all load allocations in terms of the percent of total loading capacity in each flow category.

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

Grove Creek 07010204-514		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		E. coli Load (billions of organisms/day)				
Total Daily Loading Capacity		298.6	117.2	45.2	18.1	10.6
Margin of Safety (MOS)		29.9	11.7	4.5	1.8	1.1
Wasteload Allocations	Grove City WWTF	0.6	0.6	0.6	0.6	0.6
	MS4 Communities	--	--	--	--	--
Load Allocation	Nonpoint source	268.1	104.9	40.1	15.7	8.9

Table 2.7. Jewitts Creek *E. coli* impaired reach TMDL for each flow zone.

Jewitts Creek 07010204-585		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		E. coli Load (billions of organisms/day)				
Total Daily Loading Capacity		248.4	104.7	44.9	23.2	14.4
Margin of Safety (MOS)		24.8	10.5	4.5	2.3	1.4
Wasteload Allocations	Permitted Point Source Dischargers	14.8	14.8	14.8	14.8	*
	Litchfield City MS4	28.4	10.8	3.5	0.8	*
Load Allocation	Nonpoint source	180.4	68.7	22.1	5.2	*

The WLA for the permitted wastewater discharger (Litchfield City WWTF) is based on facility design flow. The WLA exceeded the dry flow regimes total daily loading capacity and is denoted in the table by a "". For this flow regime, the WLA and non-point source load allocation is determined by the following formula:
Allocation = (flow contribution from a given source) X (E. coli concentration limit or standard)

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

Regal Creek 07010204-542		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		E. coli Load (billions of organisms/day)				
Total Daily Loading Capacity		452.7	157.4	47.6	17.2	9.7
Margin of Safety (MOS)		45.3	15.7	4.8	1.7	1.0
Wasteload Allocations	Permitted Point Source Dischargers	--	--	--	--	--
	Albertville City MS4	19.2	6.7	2.0	0.7	0.4
	Buffalo City MS4	0.4	0.1	<0.1	<0.1	<0.1
	Monticello City MS4	1.0	0.3	0.1	<0.1	<0.1
	Ostego City MS4	1.9	0.7	0.2	0.1	<0.1
	St. Michael City MS4	150.9	52.5	15.9	5.8	3.2
Load Allocation	Nonpoint source	234.0	81.4	24.6	8.9	5.0

Table 2.9. Unnamed Creek *E. coli* impaired reach TMDL for each flow zone.

Unnamed Creek 07010204-667		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		E. coli Load (billions of organisms/day)				
Total Daily Loading Capacity		190.81	15.23	1.09	0.14	0.03
Margin of Safety (MOS)		19.08	1.52	0.11	0.01	<0.01
Wasteload Allocations	Permitted Point Source Dischargers	--	--	--	--	--
	MS4 Communities	--	--	--	--	--
Load Allocation	Nonpoint source	171.73	13.71	0.98	0.13	0.03

2.7 POLLUTANT SOURCE ASSESSMENT

This section is intended 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 available for transport by source category for the *E. coli* impaired reach watersheds.

2.7.1 *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), and ditch sediment and water (Sadowsky et al. 2010). 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 2008-2010 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.

2.7.2 *E. coli* by Season and Flow Regime

Individual *E. coli* samples show exceedances during summer and fall and occasionally in the spring (Figures 2.8 through 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.

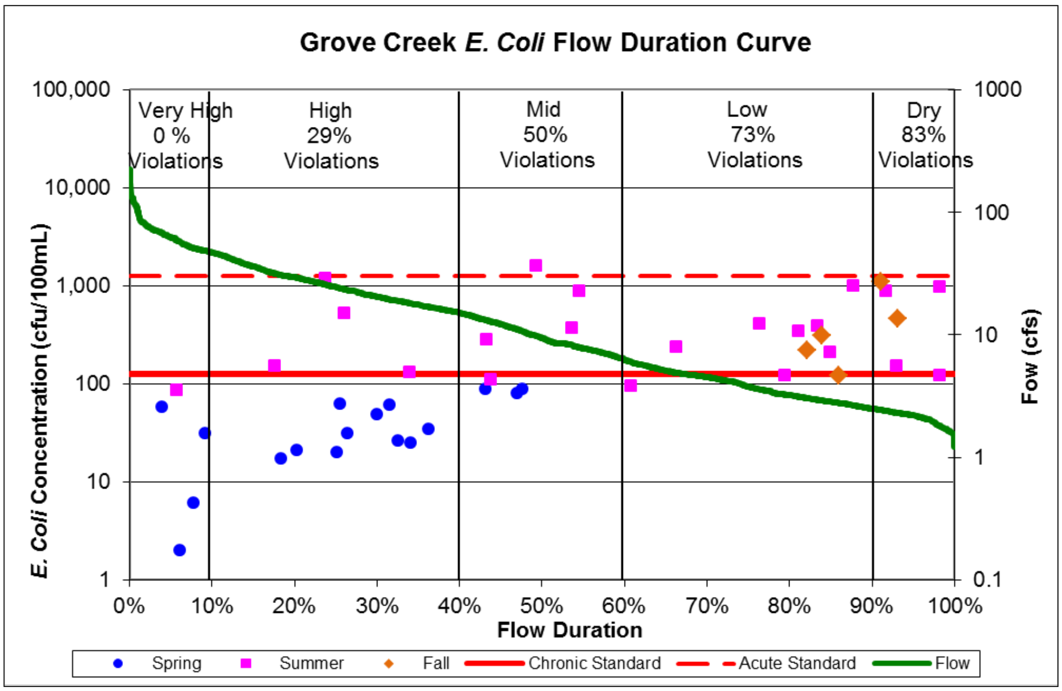


Figure 2.8. Individual *E. coli* measurements in the Grove Creek impaired reach plotted by season and flow regime.

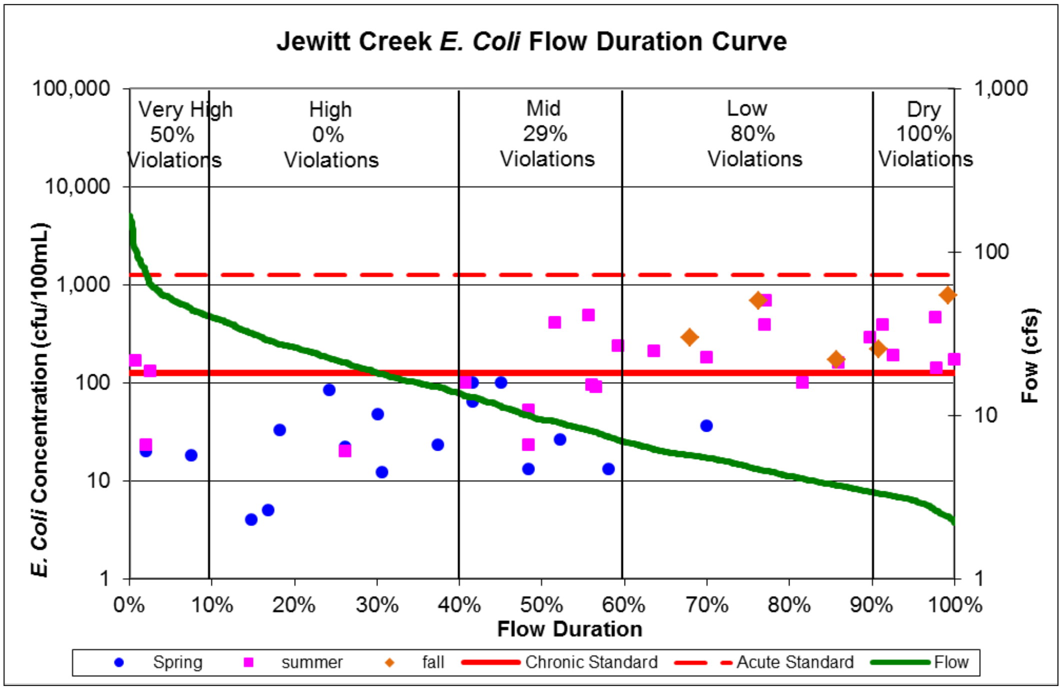


Figure 2.9. Individual *E. coli* measurements in the Jewitt Creek impaired reach plotted by season and flow regime.

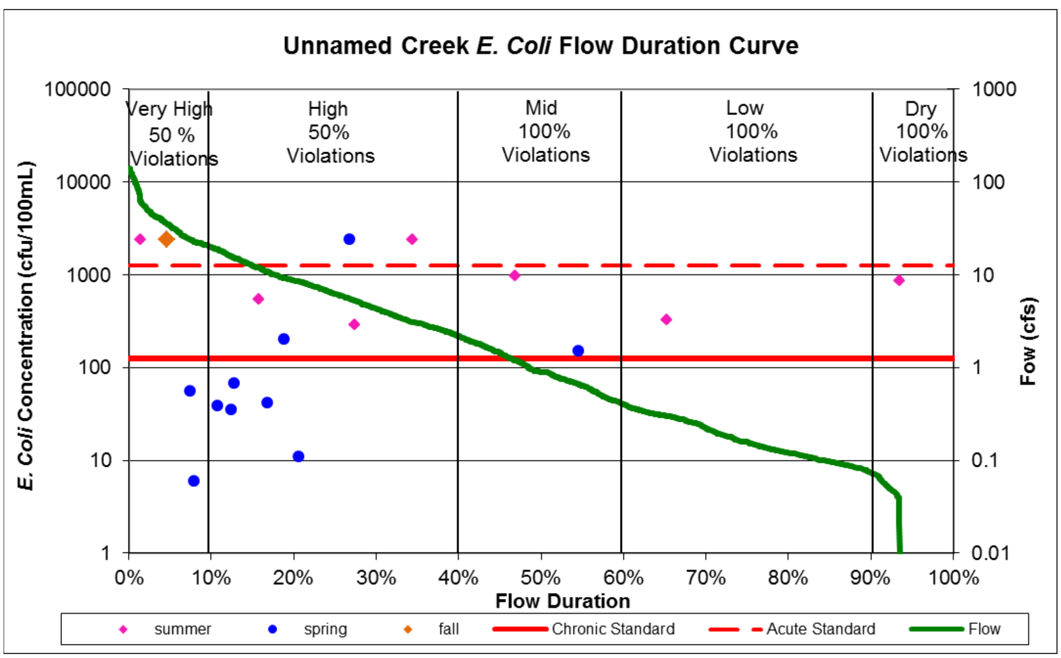


Figure 2.10. Individual *E. coli* measurements in the Unnamed Creek impaired reach plotted by season and flow regime.

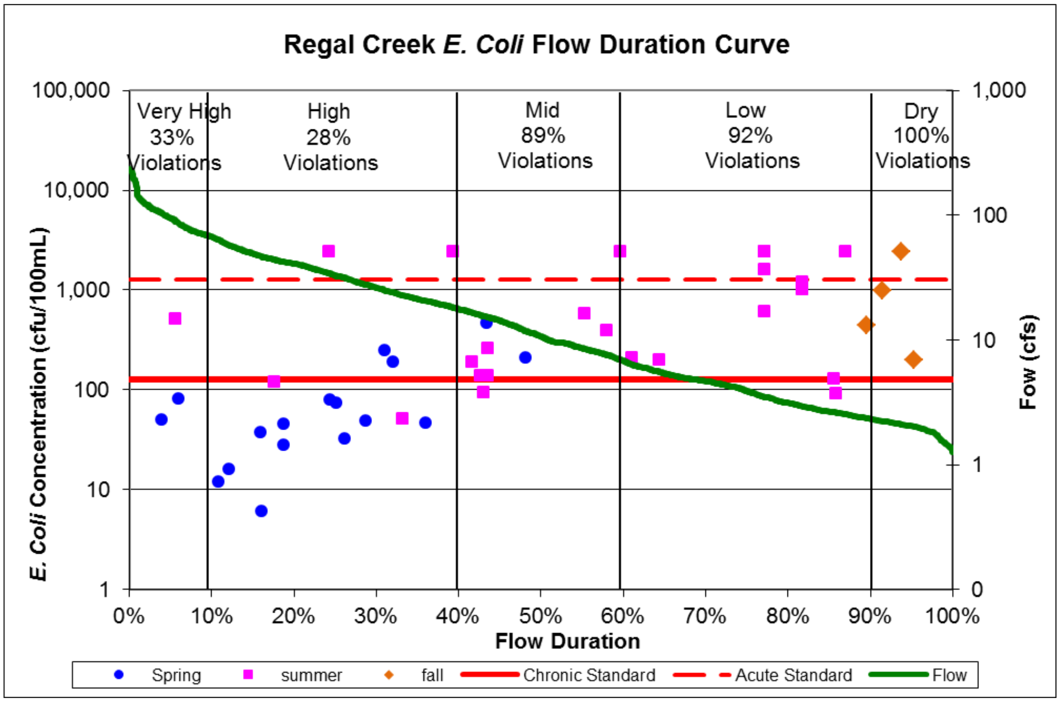


Figure 2.11. Individual *E. coli* measurements in the Regal Creek impaired reach plotted by season and flow regime.

2.7.3 Bacteria Levels in Upstream Lakes

Three of the four impaired reaches contain upstream lakes which represent boundary conditions: Grove Creek (Lund and Long Lakes), Jewitts Creek (Ripley and Chicken Lakes) and Regal Creek (Pelican and Beebe Lakes). There is currently no bacteria monitoring data available from the outlet of the upstream lakes. 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 direct watershed.

2.7.4 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.

2.7.4.1 Livestock Sources

Animal units are the standardized measurement of livestock for various agricultural purposes. Animal units 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 animal unit 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 animal units (10 animal units in shore land areas) are required to register with the MPCA. Owners with fewer than 300 animal units 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 animal units or more, and less than 1,000 animal units, a construction short form permits are required for construction/expansion activities. Feedlots greater than 1,000 animal units or specific amount of animals as defined by the Code of Federal Regulations are considered large Concentrated Animal Feedlot Operations (CAFOs) and are required to apply for a 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 animal units, 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 animal units) 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 Animal Units	Total Dairy Units	Total Beef Units	Total Swine Units	Total Poultry Units	Total Other Units
Grove Creek 07010204-514	13	1 MNG440104	2,698	251	297	540	1,549	61
Jewitts Creek 07010204-585	6	1 MNG440447	4,609	150	190	193	4,071	5
Regal Creek 07010204-542	12	0	638	350	272	14	0	2
Unnamed Creek 07010204-667	25	1 MN0064041	5,472	3,510	1,346	519	14	83

There are a number of pathways by which fecal coliform produced by livestock can reach surface waters such as runoff from feedlots, overgrazed pastures, surface application of manure and incorporated manure. Following is a description of these sources.

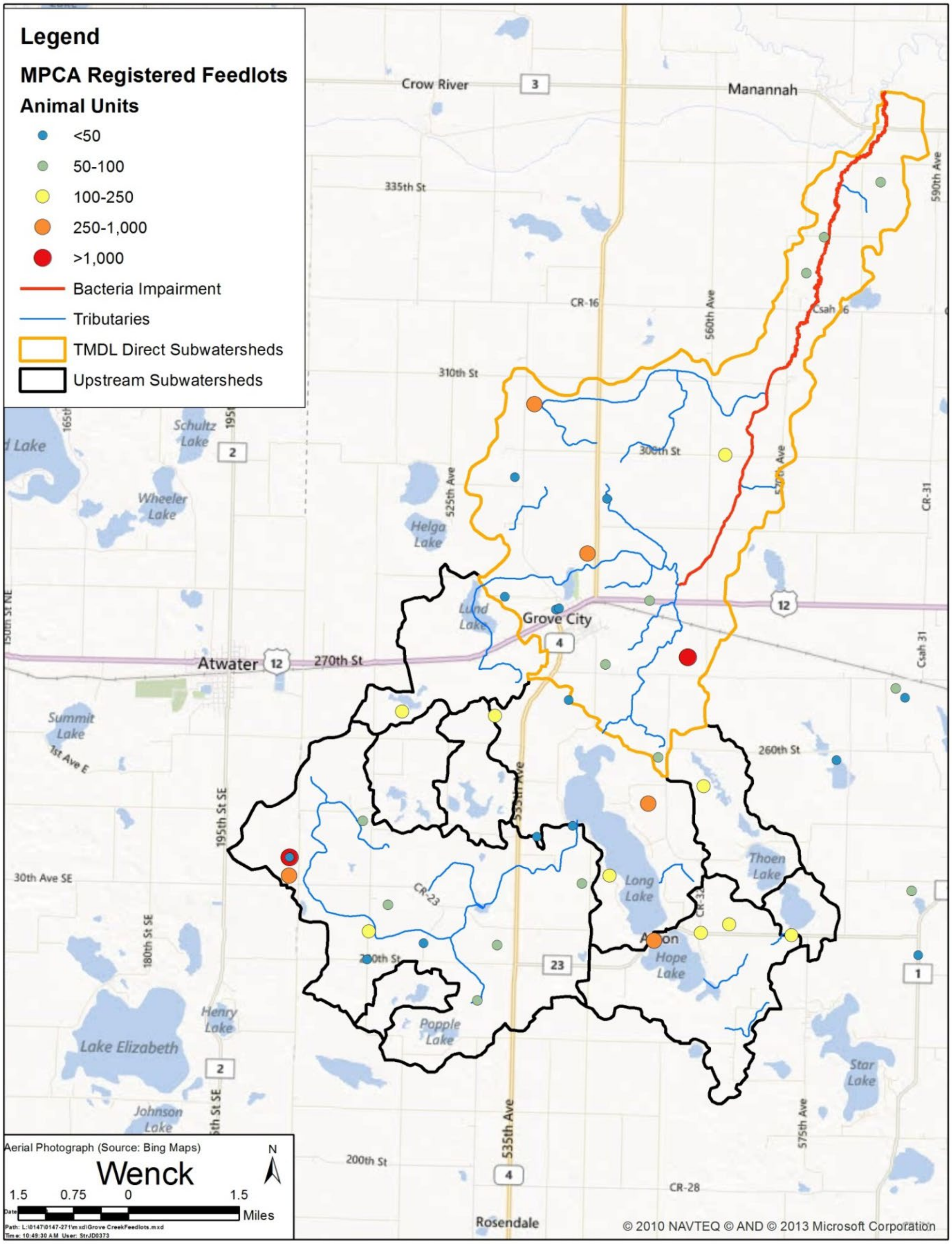


Figure 2.12. MPCA registered feedlots in the Grove Creek *E. coli* impaired watershed.

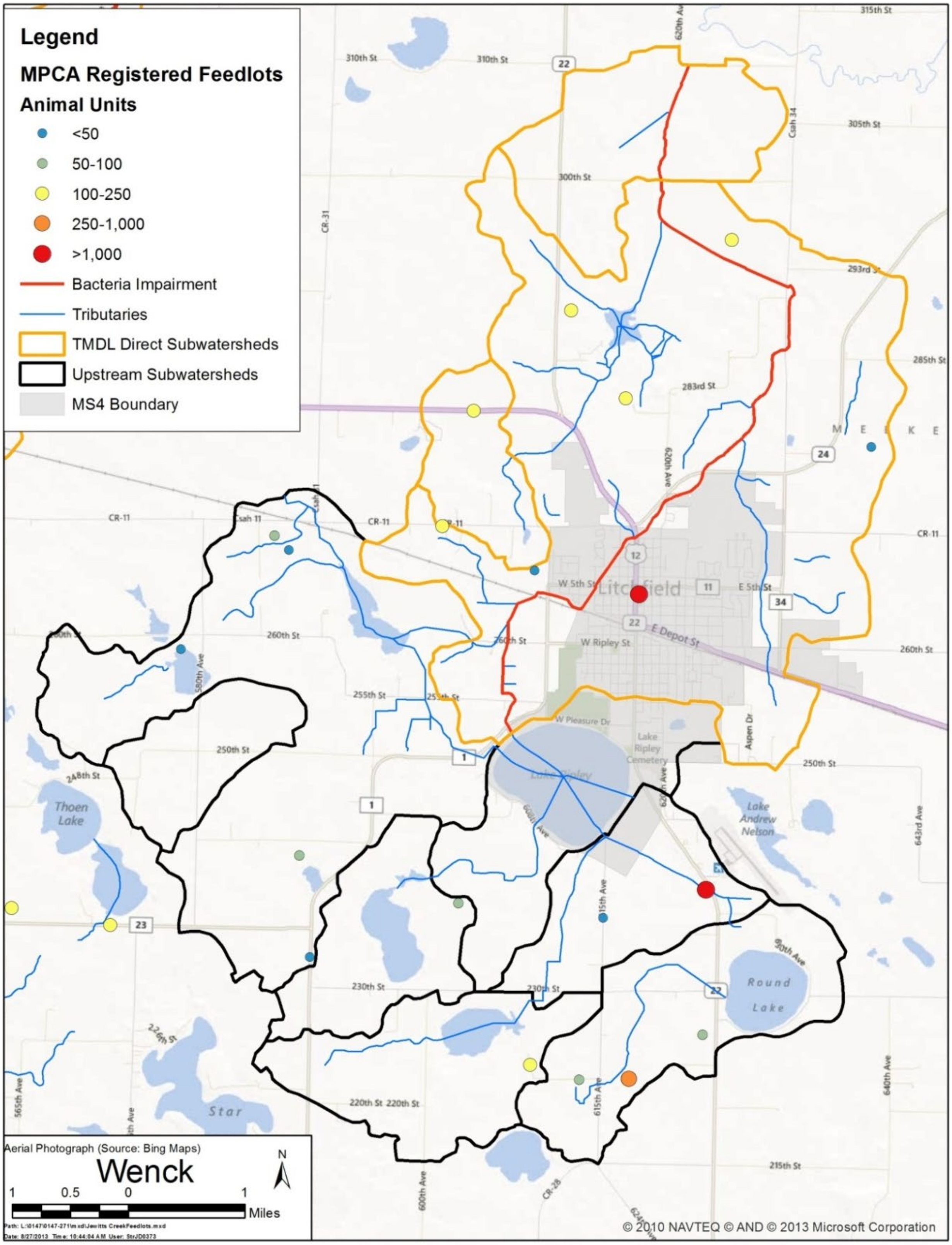


Figure 2.13. MPCA registered feedlots in the Jewitts Creek *E. coli* impaired watershed.

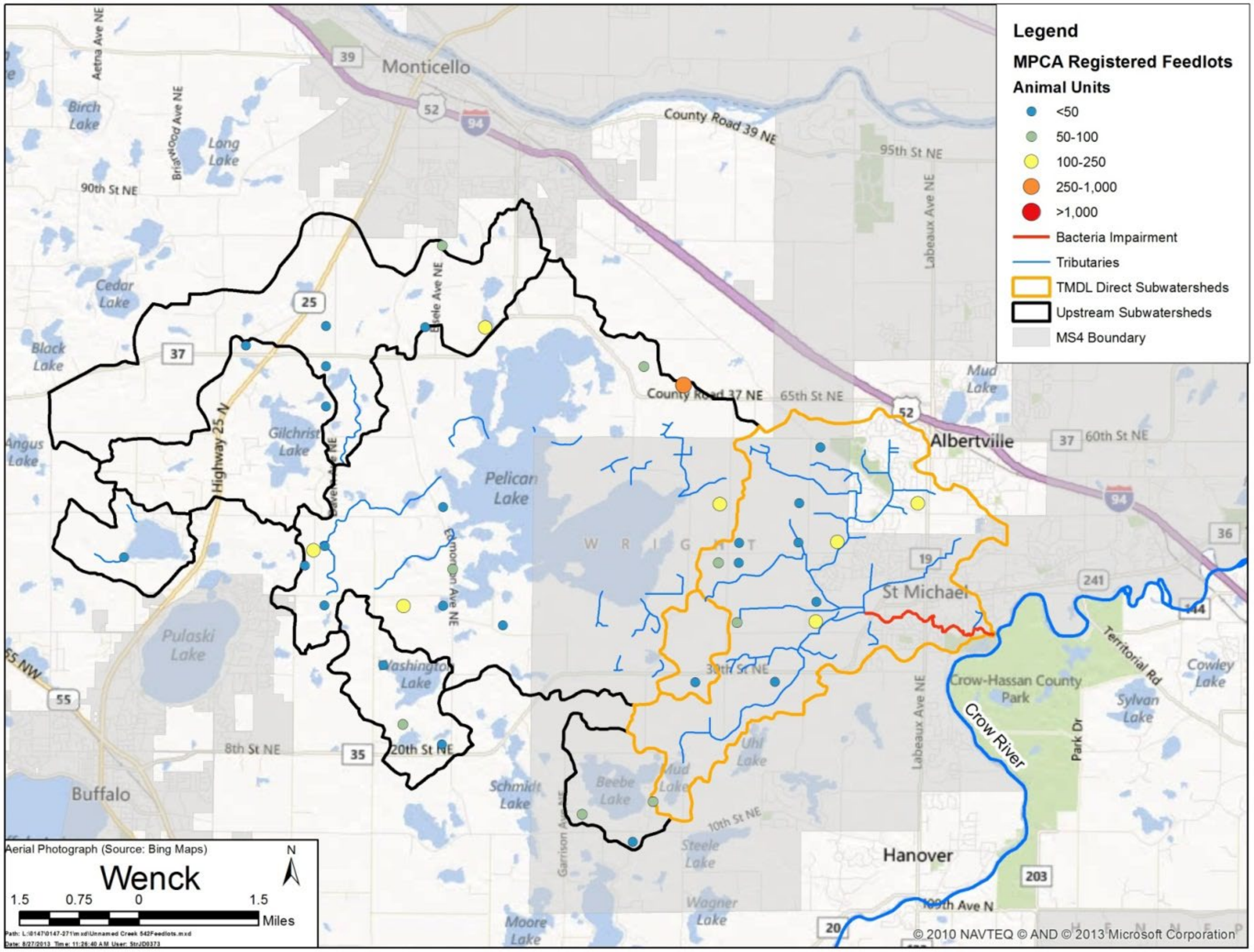


Figure 2.14. MPCA registered feedlots in the Regal Creek *E. coli* impaired watershed.

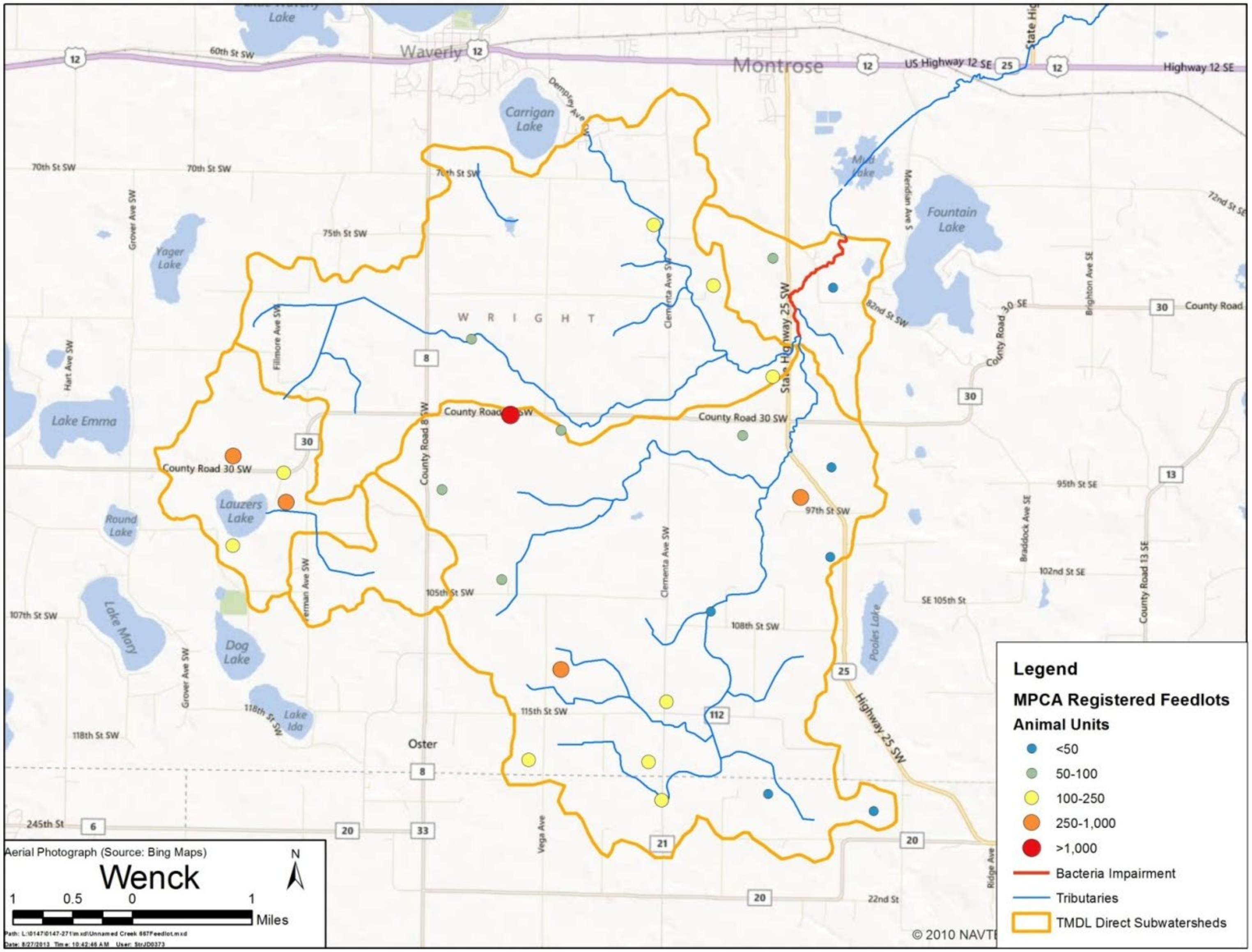


Figure 2.15. MPCA Registered feedlots in the Unnamed Creek *E. coli* impaired reach watershed

2.7.4.1.1 Manure Application

Due to the large number of feedlots and animals in the North Fork Crow River Watershed, it is likely that a significant proportion of the cropland in the impaired reaches receive 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. However, solid manure should be incorporated into the ground within 24 hours. 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.

2.7.4.1.2 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. Unnamed Creek and Regal Creek both have one feedlot (385 animal units in Unnamed Creek and 70 in Regal Creek) within 500 feet of the stream. To address overgrazed pastures, this report assumes that 1% of dairy and beef cattle are in overgrazed pastures (MPCA 2002).

2.7.4.2 Human Sources

2.7.4.2.1 Septic Systems

Failing subsurface sewage treatment systems (SSTS) can be an important source of bacteria to surface waters. Currently, the exact number and status of SSTSs in the North Fork Crow River Watershed is unknown. The MPCA's 2004 "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 North Fork Crow River Watershed (MPCA, 2004). 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 wastewater treatment facilities (WWTFs) was calculated and divided by 3 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 2004 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. A complete SSTS bacteria load summary for each impaired reach watershed is provided in Appendices A.

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

Impaired Reach	County	Rural Population	Generally Failing SSTSs	ITPHS SSTSs
Grove Creek 07010204-514	Meeker	253	10%	5%
Jewitts Creek 07010204-585	Meeker	336	10%	5%
Regal Creek 07010204-542	Wright	40	35%	5%
Unnamed Creek 07010204-667	Wright	715	35%	5%

2.7.4.2.2 NPDES-permitted Wastewater Dischargers

There are two NPDES-permitted wastewater dischargers in the impaired reach watersheds: Grove City WWTF in the Grove Creek watershed and Litchfield WWTF located in the Jewitts Creek watershed. DMRs were downloaded from the MPCA STORET database to assess effluent bacteria concentrations for each point source. According to their NPDES permits, these facilities are not to discharge treated wastewater with fecal coliform concentrations that exceed 200 organisms/100ml (126 cfu/100 ml *E. coli* concentration) as a monthly geometric mean between May 1st and October 31st. Both Grove City WWTF and Litchfield WWTF have regularly monitored effluent fecal coliform concentration since 1998 (Appendix C). Results indicate both facilities rarely exceed (less than 7% of samples) the fecal coliform permitted concentration limit and typically discharge well below the 200 organisms/100ml limit.

2.7.4.3 Wildlife

Wildlife in the impaired reaches 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 Minnesota Department of Natural Resources (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 populations were estimated assuming population densities of 2.8 geese per square mile.

2.7.4.4 Urban Stormwater Runoff

Untreated urban stormwater has demonstrated bacteria concentrations as high as or higher than grazed pasture runoff, cropland runoff, and feedlot runoff (USEPA 2001, Bannerman et al. 1993, 1996). There is a moderate amount of urban area land cover in the Crow 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.

The EPA guidance states that MS4 stormwater allocations in a TMDL must now be included in the TMDL as a WLA. The MS4 permittees must review the adequacy of their Stormwater Pollution Prevention Program (SWPPP) to meet approved WLAs and, if necessary, modify the SWPPP.

2.7.4.5 Bacteria Production

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, landuse and current conditions within the North Fork Crow impaired watersheds. Daily fecal coliform production estimates for each agricultural animal unit, 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 A provides a more complete description of the calculation and assumptions used to estimate bacteria production in each watershed.

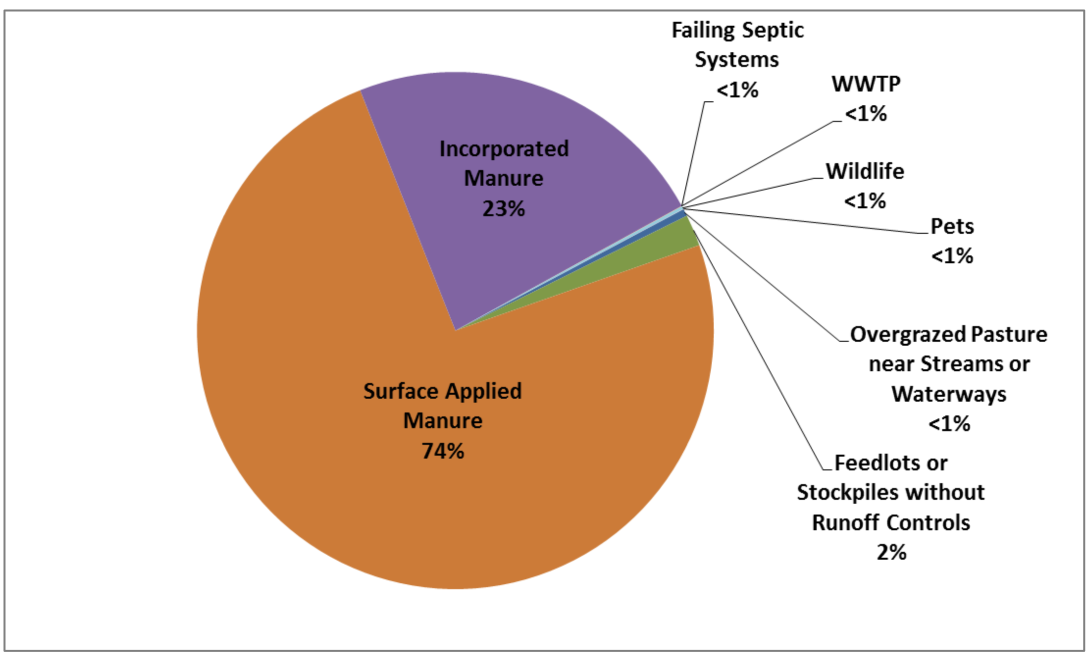


Figure 2.16. Fecal coliform production (by source) in the Grove Creek impaired reach watershed.

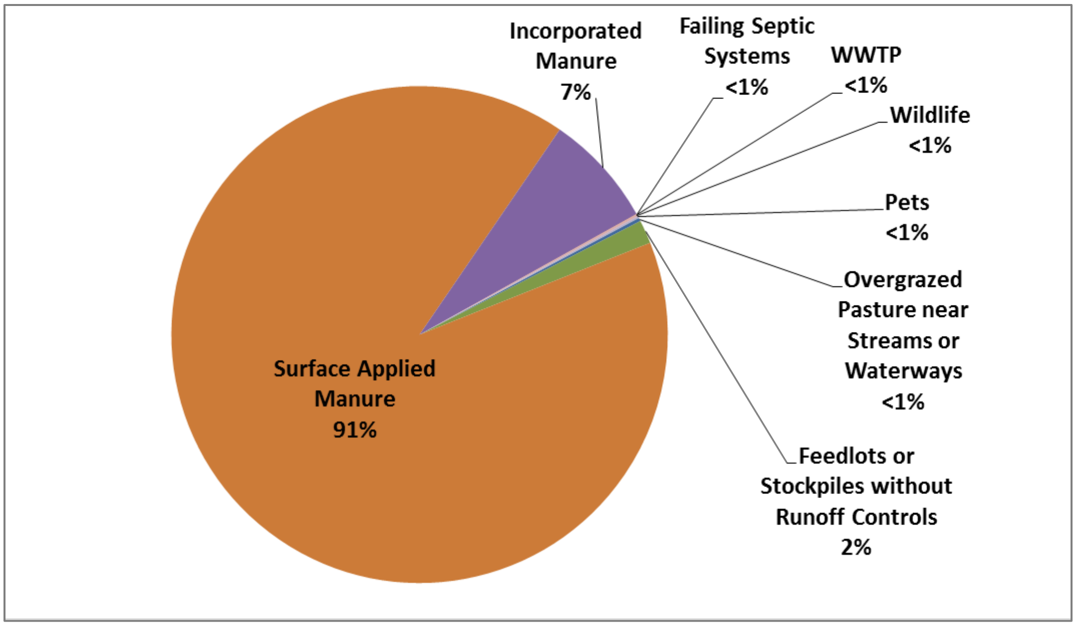


Figure 2.17. Fecal coliform production (by source) in the Jewitts Creek impaired reach watershed.

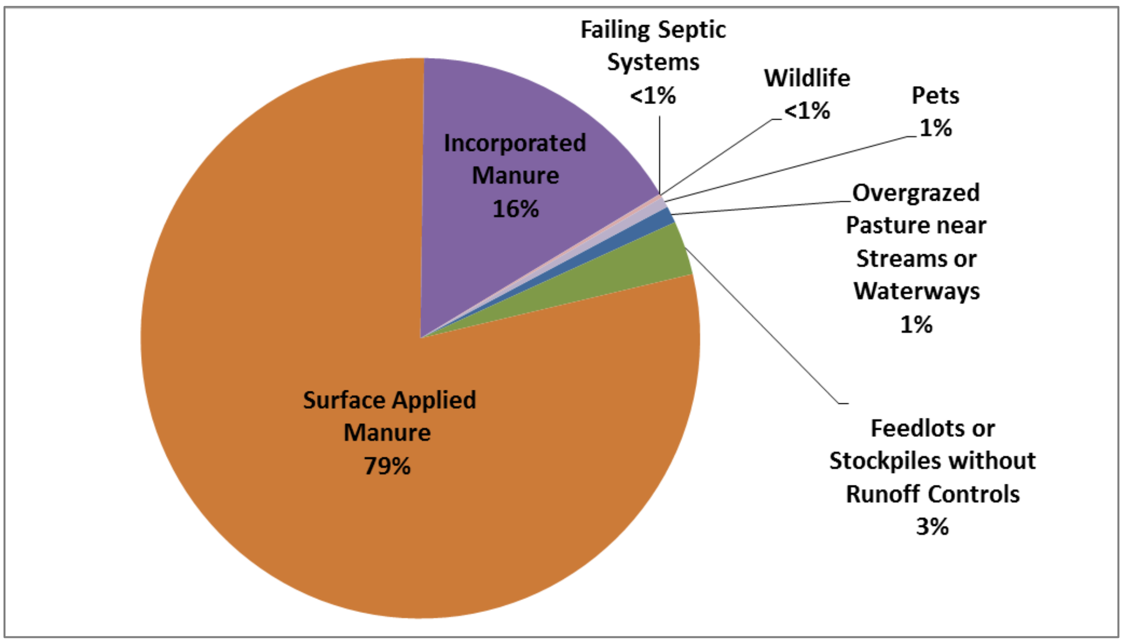


Figure 2.18. Fecal coliform production (by source) in the Regal Creek impaired reach watershed.

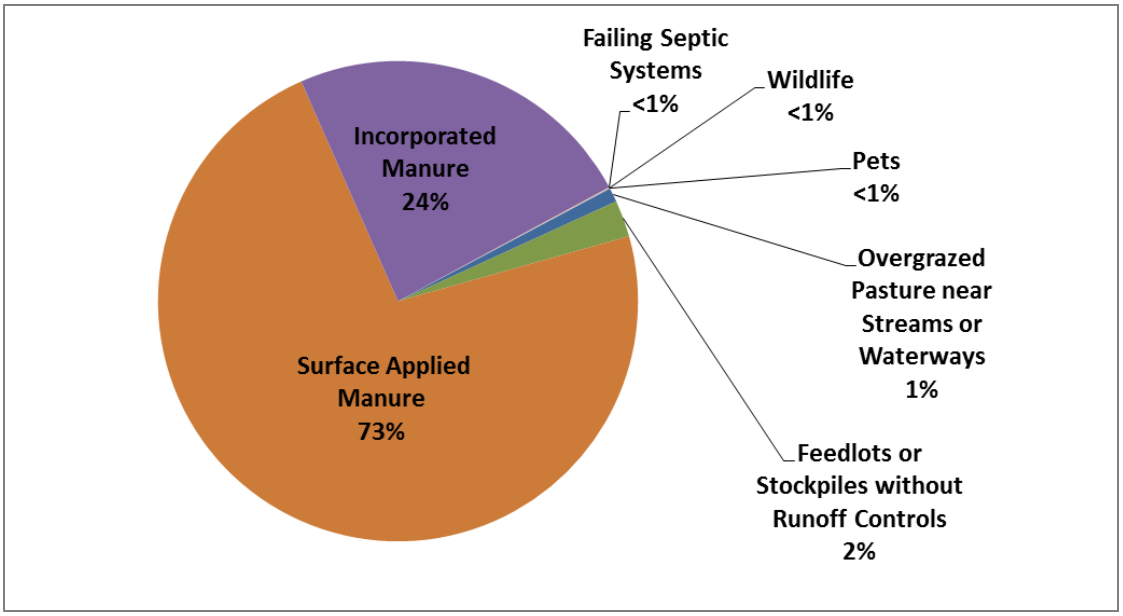


Figure 2.19. Fecal coliform production (by source) in the Unnamed Creek impaired reach watershed.

2.7.5 Pollutant Source Assessment Summary

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

- Livestock are the biggest generator of bacteria in the impaired reach watersheds.
- The largest potential sources are those activities associated with application of manure to the land. Generally speaking, mobilization of bacteria from manure spreading activities is likely to be a problem when runoff processes carry recently applied manure to receiving waters during mid, high and very high flow conditions.
- Over-grazed pastures near streams and waterways and failing septic systems/unsewered communities appear to be relatively small sources based on the small load of bacteria generated compared to livestock. However, these sources can be some of the most significant contributors to bacteria impairments during low flow conditions when dilution is minimal and bacteria from these sources are often delivered efficiently to the receiving water (as in the case of straight-pipe connections with septic systems and livestock defecating directly into a stream). Monitoring data indicates a high incidence of E. coli violations during the low and dry flow conditions. Thus, decreasing loading from septics and animals in/near streams will be crucial in achieving the *E. coli* water quality standards in these reaches.

3.0 Turbidity Impairments

3.1 OVERVIEW OF TURBIDITY IMPAIRED REACHES AND WATERSHEDS

This section includes TMDLs for three impaired reaches in the North Fork Crow River Watershed (Table 3.1). Figure 3.1 shows the locations of each impaired reach, the subwatersheds that drain directly to each impaired reach and the locations of the key monitoring stations where TSS and flow data were collected to support these TMDLs. This TMDL's turbidity source assessment and impairment assessment sections will focus on the Grove Creek, Mill Creek, and Unnamed Creek watersheds (AUID 07010204-514, 07010204-515, and 07010204-668, respectively), which are tributaries that drain directly to the North Fork Crow River.

Table 3.1. Individual reach TMDL description.

Reach Description	AUID	Year Listed	Affected Use	Pollutant/ Stressor	Target Start	Target Completion
Grove Creek	07010204-514	2010	Aquatic Life	Turbidity	2010	2013
Mill Creek	07010204-515	2010	Aquatic Life	Turbidity	2010	2013
Unnamed Creek	07010204-668	2008	Aquatic Life	Turbidity	2019	2023

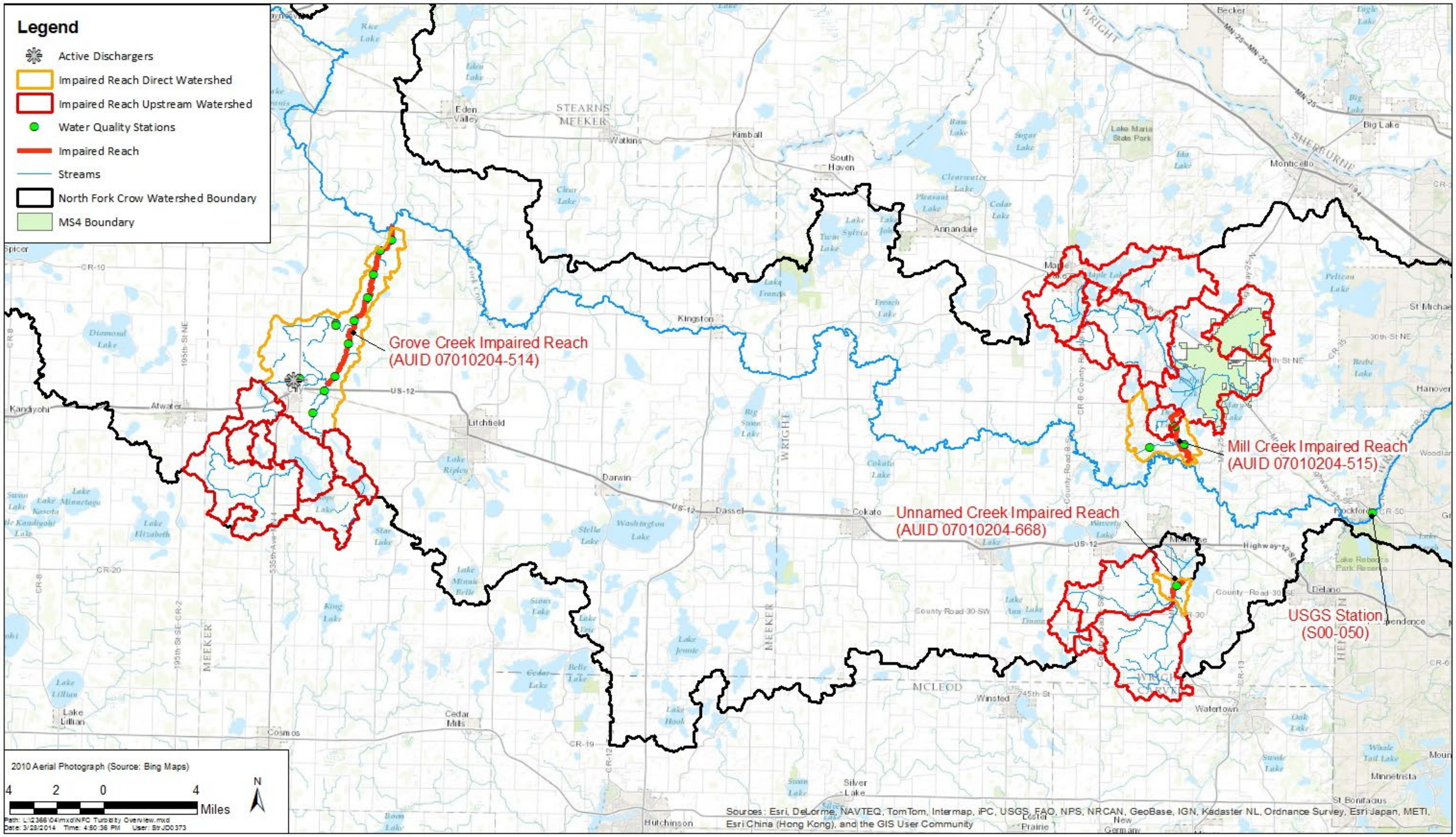


Figure 3.1. North Fork Crow turbidity impaired reaches and watersheds.

3.2 WATERSHED LAND USE

Land use for watersheds that discharge to the Mill Creek, Grove Creek, and Unnamed Creek turbidity impaired reaches were calculated using the 2009 NASS GIS land cover file (Table 3.2). Land use in each watershed is primarily corn and soybean rotation agricultural use. The remaining land area is comprised of forest and shrubland, lakes and wetlands, developed land, and non-corn/soybean crops.

Table 3.2. Turbidity impaired reach watershed land use.

Land use	Percent of Total		
	Grove Creek Impaired Watershed	Mill Creek Impaired Watershed	Unnamed Creek Impaired Watershed
Total Watershed Area	32,341	35,218	15,389
Corn/Soybeans	64%	24%	48%
Hay and Pasture	13%	29%	25%
Forest and shrubland	9%	14%	10%
Wetlands and Open Water	9%	18%	7%
Urban/Roads	5%	13%	4%
Grains and other Crops	<1%	2%	6%
Barren	<1%	<1%	<1%

3.3 TURBIDITY RELATED WATER QUALITY DATA

Three different types of measurements are typically collected to assess turbidity in surface waters. The first is a direct measure of turbidity using a field or lab turbidimeter. The second is a measure of water clarity can be made using a field transparency tube (T-tube) or Secchi tube. The third is a measure of the mass of solids in the water column measured in the lab as TSS. The CROW and the MPCA have collected turbidity, T-tube and TSS data at 13 monitoring stations in the Grove Creek impaired reach, three stations in the Mill Creek impaired reach, and one station in the Unnamed Creek impaired reach (Table 3.3).

Table 3.3. Available turbidity-related water quality measurements in the Grove Creek, Mill Creek and Unnamed Creek impaired watersheds.

Watershed	Impaired Reach	Years Monitored	Type of data	Measurements
Grove Creek	07010204-514	2001-2008	Turbidity (NTU)	17
		2007-2010	Turbidity (FNU)	57
		--	Turbidity (FNMU)	0
		2001-2009	TSS	79
		2006-2012	Transparency	69
		2008-2009	Chl-*a*	23
Mill Creek	07010204-515	2001-2008	Turbidity (NTU)	17
		2006-2010	Turbidity (FNU)	47
		2007	Turbidity (FNMU)	11
		2001-2009	TSS	81
		2007-2009	Transparency	17
		2008-2009	Chl-*a*	23
Unnamed Creek	07010204-668	2008	Turbidity (NTU)	2
		2008-2009	Turbidity (FNU)	21
		--	Turbidity (FNMU)	0
		2008-2009	TSS	15
		2000-2012	Transparency	204
		2008-2009	Chl-*a*	13

3.4 STREAMFLOW DATA

Flow data for each reach is crucial to calculate daily load allocations for each reach. Flow data were used to develop flow categories so that turbidity violations could be characterized based on whether they occurred most often during high, medium, or low flow events. This information helps provide insight on potential sources during low/base-flow as well as storm/run-off related events. There is one flow monitoring station located in each turbidity impaired reach (Table 3.4).

Table 3.4. Flow monitoring stations within the North Fork Crow impaired reaches.

Reach	STORET ID	Location	DNR ID	USGS ID	Flow Provider	Years of Operation since 2000	Flow Record Length (Days)
668	S001-499	Unnamed Creek at Armitage Rd.	18075003	N/A	MPCA	3	883
514	S000-847	Grove Creek at CSAH 3	18054001	N/A	MPCA	3	545
515	S002-018	Mill Creek at CSAH 12	18074001	N/A	MPCA	3	596
502	S000-050	Crow River at Rockford, MN	18087001	05280000	USGS	13	4,723

While turbidity, transparency and TSS samples were collected in each impaired reach over multiple years, the flow data was only available for three years at each site. The Rockford USGS station (S000-

050), located on the North Fork Crow River and has the longest and most complete flow record in the Crow River Watershed (Figure 3.1). Flow regression relationships between these stations were used to fill data gaps and create a continuous 10-year flow record for each impaired reach.

3.5 PROPOSED TSS STANDARD AND TSS SURROGATE

In May, 2011, the MPCA released the "Aquatic Life Water Quality Standards Draft Technical Support Document for TSS (Turbidity)" which develops river/stream TSS standards for the state of Minnesota. The proposed standards were developed using a combination of biotic sensitivity to TSS concentrations and reference streams/least impacted streams. The final proposed TSS standards vary throughout the state of Minnesota based on geographic location (north, central, and southern river region) and the river/stream's beneficial use classification. All three North Fork Crow River turbidity impaired reaches covered in this TMDL are considered class 2B waters in Minnesota's central river region. The TSS standard for each impaired reach will be 30 mg/L if/when the MPCA's proposed standards go into effect. Prior to the newly developed standards, the MPCA protocol suggested using the relationship between lab turbidity in NTUs and TSS to determine the TSS equivalent to the 25 NTU turbidity standard. The Grove, Mill and Unnamed Creek impaired reaches have 93 (30 lab and 63 field) paired turbidity and TSS measurements collected between 2001-2012. Since a majority of turbidity measurements taken were collected using a field turbidimeter, which reports turbidity in Formazin Nephelometric Units (FNUs), a series of conversions were used to transform the field turbidity to lab turbidity-NTUs. Unfortunately, there have been no paired field turbidity-FNU and lab turbidity-NTU data collected at any of the impaired reach sampling stations. A regression relationship of 22 paired lab turbidity reported in NTRU and field turbidity-FNU measurements from a main-stem North Fork Crow River monitoring station (S001-256) was used to convert the impaired reach field turbidity-FNUs to lab-NTRUs (Appendix D). Lab-NTRUs were then converted to lab-NTUs using the following equation developed by the MPCA (2007):

NTU = 10^(-0.0734+0.926*Log(NTRU))/1.003635

The MPCA protocol also recommends using only paired measurements with a turbidity value of 40 NTU or less and TSS values greater than 10 mg/L (MPCA 2008). A total of 42 paired turbidity/TSS samples met these criteria and indicate that the turbidity standard of 25 NTU corresponds to a surrogate TSS concentration of 42 mg/L (Figure 3.2). Initially, regression relationships were set up individually for each reach; however, differences between the two were not statistically significant and both were combined into one dataset and regression. Regression analysis between only lab turbidity-NTU (excluding converted field turbidity-FNU data points) and TSS was explored but not used in this analysis due to an unreasonable surrogate standard of 122 mg/L (Appendix D).

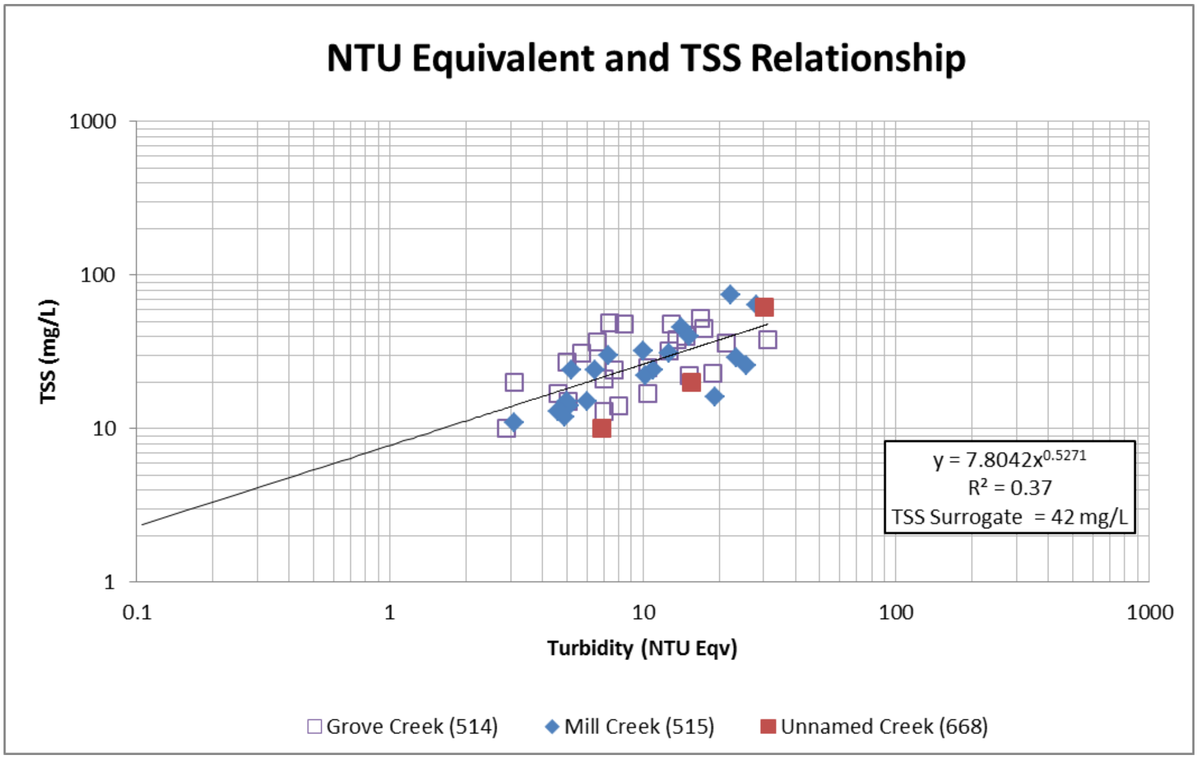


Figure 3.2. Turbidity/Total Suspended Solids Relationship for three sites within the Grove Creek, Mill Creek, and Unnamed Creek watersheds.

3.6 DEGREE OF IMPAIRMENT

The MPCA recognizes transparency and TSS as reliable surrogates for turbidity that can be used to assess impairments at sites where there are an inadequate number of turbidity observations (MPCA, 2010). For transparency, a transparency tube measurement of less than 20 centimeters indicates a violation of the 25 NTU turbidity standard.

For TSS, the central river region TSS standard of 30 mg/L will likely be implemented by the MPCA beginning sometime in 2014 (MPCA, 2011). The proposed (30 mg/L) standards will be used in this report along with the 42 mg/L TSS surrogate value to assess the degree of impairment in each stream. Up to this point, the MPCA has used turbidity measurements to determine impairments as long as an adequate amount of turbidity data exists. None of the impaired reaches in the North Fork Crow Watershed have the 20 independent turbidity (in NTUs) observations required to assess an impairment. All three (turbidity, TSS and transparency tube) parameters were evaluated for each reach in this TMDL report to investigate trends and take full advantage of the Grove Creek, Mill Creek, and Unnamed Creek dataset. In a few cases there were measurements recorded from multiple stations within the same impaired reach on the same day. To avoid double counting, data from all sites within each reach were grouped together and consolidated (averaged) by date to provide one dataset for each reach during the impairment analysis.

Table 3.5 summarizes the turbidity, transparency and TSS data collected in each reach from 2001 through 2012. These data suggest more than 10% of the transparency samples in each reach were in violation of their standard or assessment threshold. It is interesting to note that TSS (surrogate and proposed standards) and transparency had significantly higher incidence of exceedance compared to lab measured turbidity (NTUs). This is likely due to the small turbidity dataset.

Table 3.5 Turbidity related water quality exceedances in the North Fork Crow turbidity impaired reaches

Impaired Reach	Parameter	Years Monitored	Measurements	Exceedances	Percent Exceedances
Grove Creek	Turbidity	01-08	17	0	0%
	Transparency	02-12	67	8	12%
	Surrogate TSS (42 mg/L)	01-09	79	17	22%
	Proposed TSS (30 mg/L)	01-09	79	17	22%
Mill Creek	Turbidity	01-08	17	1	6%
	Transparency	07-09	17	6	35%
	Surrogate TSS (42 mg/L)	01-09	81	9	11%
	Proposed TSS (30 mg/L)	01-09	81	17	21%
Unnamed Creek	Turbidity	08	2	0	0%
	Transparency	00-12	211	43	20%
	Surrogate TSS (42 mg/L)	08-09	15	1	7%
	Proposed TSS (30 mg/L)	08-09	15	1	7%

Note: Exceedances are based on the 25 NTU turbidity standard, the 20 cm transparency surrogate assessment threshold, the 42 mg/L TSS surrogate established in this TMDL study, and the proposed 30 mg/L TSS standard. Note: Only lab measured turbidity was included in the exceedance analysis, not field turbidity converted to NTU units.

3.7 TMDL ALLOCATION METHODOLOGY

3.7.1 Overview of Load Duration Curve Approach

Assimilative capacities for the streams were developed from load duration curves (Cleland 2002). Load duration curves assimilate flow and TSS data across stream flow regimes and provide assimilative capacities from which reductions can be derived by comparing to measured loads.

Flow duration curves were developed using the flow data discussed in Section 3.5 (Figure 3.3). The curved line relates mean daily flow to the percent of time those values have been met or exceeded. For example, at the 50% exceedance value for Mill Creek, the river discharged at 26 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 (0-10%), high (10-40%), mid (40-60%), low (60-90%) and dry (90 to 100%) flow conditions.

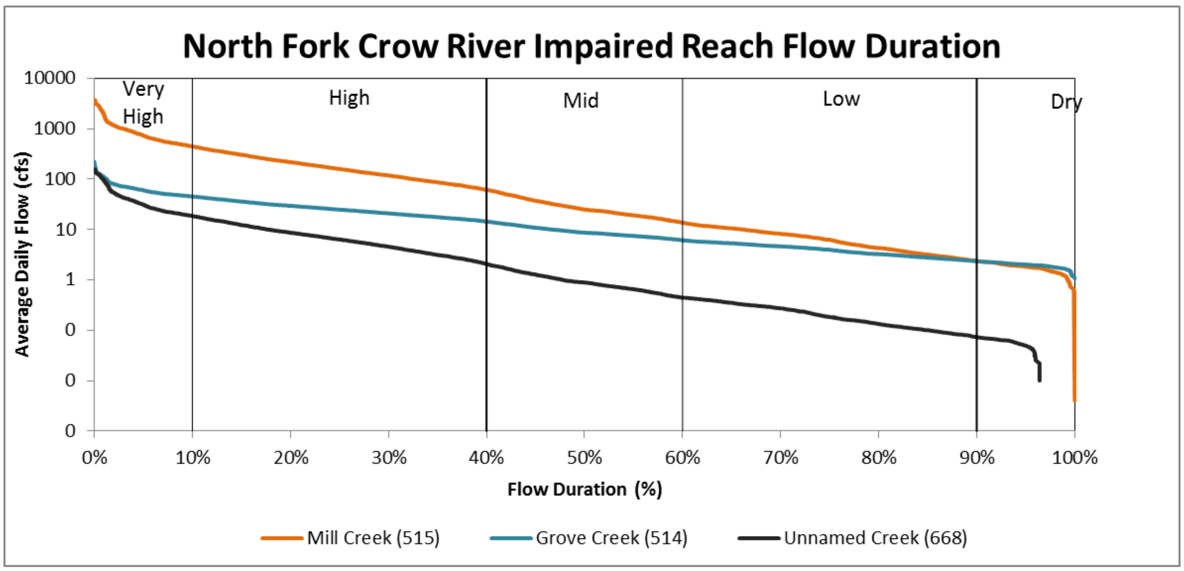


Figure 3.3. Flow duration for Grove Creek, Mill Creek, and Unnamed Creek monitoring stations.

To develop a load duration curve, all average daily flow values were multiplied by the TSS-surrogate standard and the proposed standard and then converted to a daily load to create “continuous” load duration curves. Now the lines represent 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 compared to current conditions by plotting individual load measurements (black squares in Figures 3.4 through 3.6) for each water quality sampling event. Each value that is above the TDLC lines (red line) represents an exceedance of the surrogate and proposed standards while those below the lines are below the water quality standards. Also plotted are the 90th percentile TSS monitored concentrations for each flow regime (blue circle). The difference between these two provides a general percent reduction in TSS that will be needed to remove each reach from the impaired waters list. The data shows TSS exceedances were recorded across most flow regimes in Mill and Grove Creeks. Unnamed Creek has a limited TSS dataset that suggests TSS reductions are needed only during high flow conditions to meet the 30 mg/L proposed standard. However, it is likely that the impairment listing for Unnamed Creek was performed using the robust transparency tube dataset (Table 3.5) which suggests reductions are needed across all flow conditions (Figure 3.9).

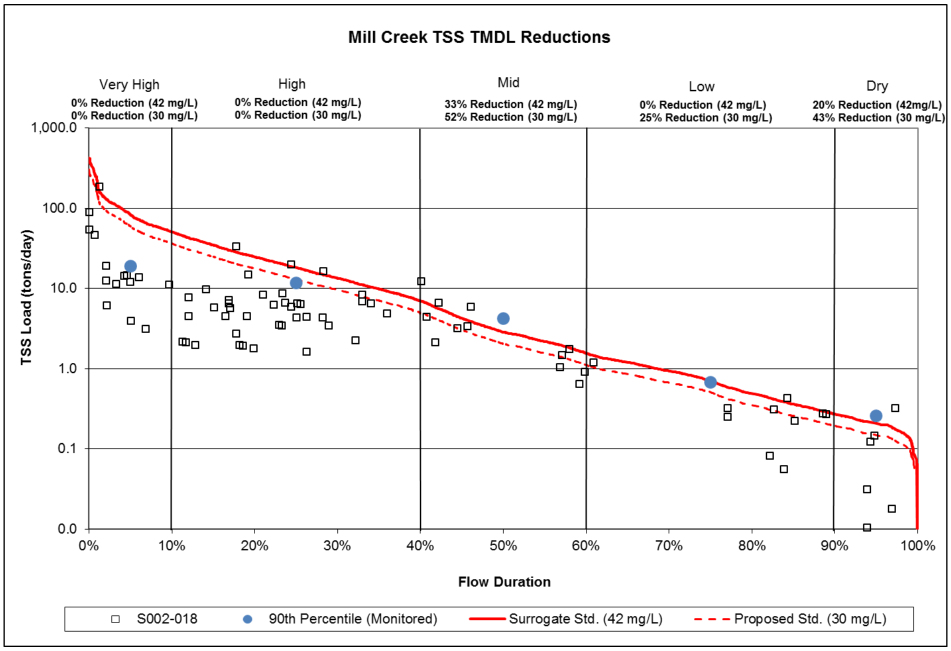


Figure 3.4. Mill Creek Impaired Reach (07010204-515) TSS standard load duration curve and necessary TSS reductions to meet TMDL.

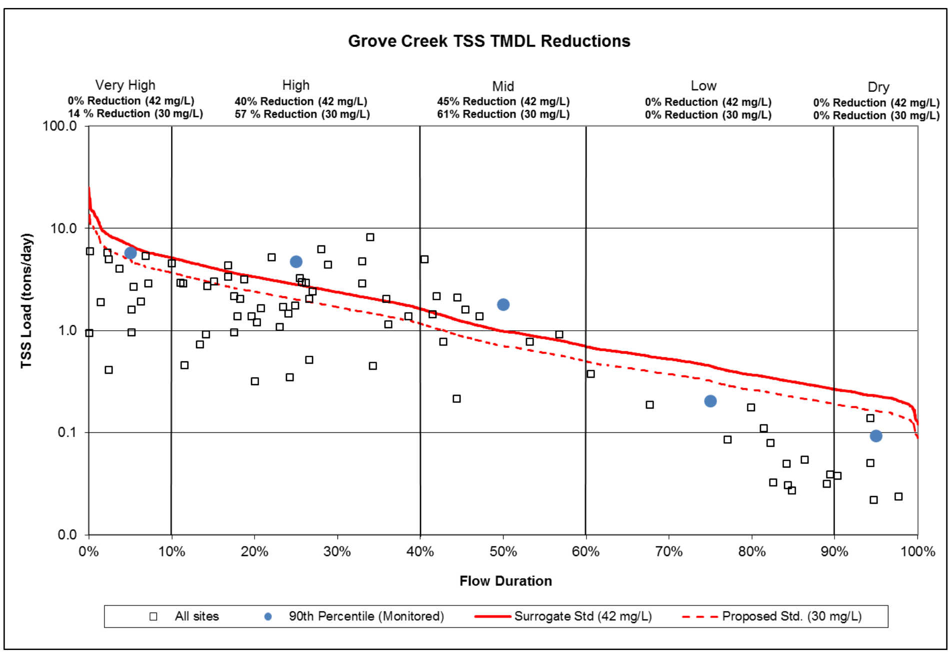


Figure 3.5. Grove Creek Impaired Reach (07010204-514) TSS standard load duration curve and necessary TSS reductions to meet TMDL.

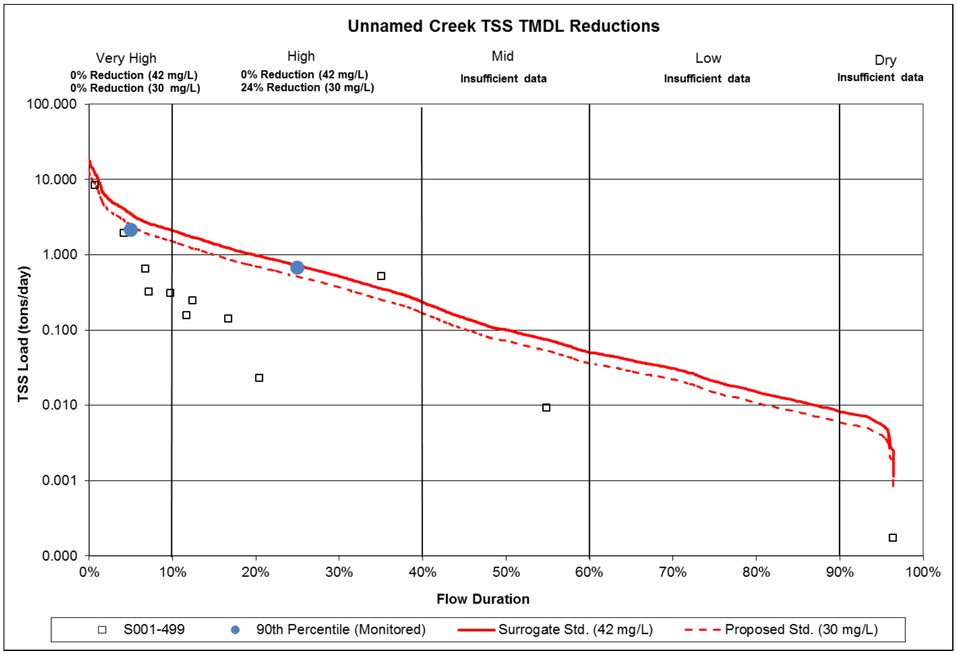


Figure 3.6. Unnamed Creek Impaired Reach (07010204-668) TSS standard load duration curve and necessary TSS reductions to meet TMDL.

3.7.2 Margin of Safety

The purpose of the MOS is to account for uncertainty that the allocations will result in attainment of water quality standards. The MOS was determined as the difference between the median flow of each flow regime and the 45th percentile flow in each zone. The resulting value was converted to a daily load by multiplying by the surrogate/proposed TSS concentration standards to establish the MOS for each flow category. This methodology accounts for variability in the data set without over protecting the high end of the flow zone and under-protecting the low end of the flow zone. The data in each flow zone are treated as a distribution and assumes any reduction efforts will affect the entire distribution.

3.7.3 Wasteload Allocations

The WLAs were divided into four primary categories including NPDES permitted wastewater dischargers, MS4 permits, and NPDES-permitted construction and industrial stormwater. Following is a description of how each load allocation was assigned.

3.7.3.1 NPDES Wastewater Dischargers

There is one active NPDES wastewater discharger in the Grove Creek Watershed that has been assigned TSS effluent limits. This facility's maximum daily effluent TSS load was established and provided by the MPCA and is a function of the facility's design flow and permitted TSS concentration limit (Table 3.6). When the design flow exceeded the stream flows, allocations are represented by an equation as described in Section 2.5.3.1.

Table 3.6 Permitted TSS Allocations for the Grove City WWTF (NPDES ID# MN0023574)

Impaired Reach Name	Reach	Facility Type	Effluent Design Flow (MGD)	Permitted TSS Concentration Limit (mg/L)	Permitted Load (tons/day)
Grove Creek	07010204-514	pond	0.13	45	0.193

3.7.3.2 MS4s

There is only one MS4s that has a portion of its municipal boundary in the Mill Creek watershed boundary (Table 3.7). The MS4 allocations were calculated by multiplying the municipalities' percent watershed coverage by the total watershed loading capacity after the MOS and WLAs were subtracted (MPCA, 2006).

Table 3.7. Wasteload allocations for all MS4 communities that contribute directly to or are upstream of the Mill Creek impaired reach (07010204-515).

MS4	Permit #	Area (acres)	TSS Standard	TSS Allocation (tons/day)				
				Very High	High	Mid	Low	Dry
Buffalo City MS4	MS 400238	5,427	42 mg/L	13.36	2.53	0.50	0.09	0.03
			30mg/L	9.54	1.81	0.36	0.06	0.02

3.7.3.3 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 North Fork Crow River Watershed showed minimal construction (<1% of watershed area) and industrial activities (<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 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 Permit 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.

3.7.4 Load Allocations

The non-point source load allocation is the remaining load after the MOS and all WLAs are subtracted from the total load capacity of each flow zone. Non-point source load allocations for each impaired watershed upstream was calculated by subtracting MOS and WLAs from the total daily loading capacity in each watershed.

3.8 ALLOCATION BY REACH

Tables 3.8 through 3.13 present the total loading capacity, margin of safety, WLAs and the remaining non-point source load allocations for the Mill Creek (07010204-515), Grove Creek (07010204-514), and Unnamed Creek (07010204-668) impaired reaches. TMDL allocations were established using both the 42 mg/L surrogate standard and the 30 mg/L proposed standard.

Table 3.8 Mill Creek impaired reach TSS total daily loading capacities and allocations according to the 42 mg/L surrogate standard.

Mill Creek 07010204-515		Flow Zones				
		Very High	High	Mid	Low	Dry
		TSS Load (tons/day)				
Total Daily Loading Capacity		90.77	18.35	3.55	0.67	0.23
Margin of Safety (MOS)		4.07	1.94	0.28	0.08	0.01
Wasteload Allocations	Permitted Wastewater Dischargers	--	--	--	--	--
	Buffalo City MS4	13.36	2.53	0.50	0.09	0.03
	Industrial and Construction Stormwater	1.30	0.25	0.05	0.01	<0.01
Non-point source Load Allocation	Mill Creek Watershed	72.04	13.63	2.72	0.49	0.18

Table 3.9. Mill Creek impaired reach TSS total daily loading capacities and allocations according to the 30 mg/L proposed standard.

Mill Creek 07010204-515		Flow Zones				
		Very High	High	Mid	Low	Dry
		TSS Load (tons/day)				
Total Daily Loading Capacity		64.83	13.12	2.54	0.48	0.16
Margin of Safety (MOS)		2.91	1.39	0.20	0.06	0.01
Wasteload Allocations	Permitted Wastewater Dischargers	--	--	--	--	--
	Buffalo City MS4	9.54	1.81	0.36	0.06	0.02
	Industrial and Construction Stormwater	0.93	0.18	0.04	0.01	<0.01
Non-point source Load Allocation	Mill Creek Watershed	51.45	9.74	1.94	0.35	0.13

Table 3.10. Grove Creek Impaired reach TSS total daily loading capacities and allocations according to the 42 mg/L surrogate standard.

Grove Creek 07010204-514		Flow Zones				
		Very High	High	Mid-Range	Low	Dry
		TSS Load (tons/day)				
Total Daily Loading Capacity		7.23	2.81	1.11	0.44	0.25
Margin of Safety (MOS)		0.23	0.13	0.07	0.04	<0.01
Wasteload Allocations	Grove City WWTF	0.19	0.19	0.19	0.19	0.19
	MS4 Communities	--	--	--	--	--
	Industrial & Construction Stormwater	0.10	0.04	0.01	<0.01	<0.01
Non-point-source Load Allocation	Grove Creek Watershed	6.71	2.45	0.84	0.21	0.05

Table 3.11. Grove Creek impaired reach TSS daily loading capacities and allocations according to the 30 mg/L proposed standard.

Grove Creek 07010204-514		**Flow Zones**				
		Very High	**High**	**Mid-Range**	**Low**	**Dry**
		TSS Load (tons/day)				
Total Daily Loading Capacity		5.17	2.01	0.79	0.32	0.18
Margin of Safety (MOS)		0.17	0.10	0.05	0.03	<0.01
Wasteload Allocations	Grove City WWTF	0.19	0.19	0.19	0.19	*
	MS4 Communities	--	--	--	--	--
	Industrial & Construction Stormwater	0.07	0.03	0.01	<0.01	<0.01
Non-point - source Load Allocation	Grove Creek Watershed	4.74	1.69	0.54	0.09	*

The WLA for the permitted wastewater discharger (Grove City WWTF) is based on facility design flow. The WLA exceeded the dry flow regimes total daily loading capacity and is denoted in the table by a "". For this flow regime, the WLA and non-point source load allocation is determined by the following formula:
Allocation = (flow contribution from a given source) X (TSS concentration limit or standard)

Table 3.12. Unnamed Creek impaired reach TSS total daily loading capacities and allocations according to the 42 mg/L proposed standard.

Unnamed Creek 07010204-668		**Flow Zones**				
		Very High	**High**	**Mid-Range**	**Low**	Dry
		TSS Load (tons/day)				
Total Daily Loading Capacity		4.00	0.73	0.10	0.02	0.0*
Margin of Safety (MOS)		0.30	0.07	<0.01	<0.01	0.0*
Wasteload Allocations	Permitted Wastewater Dischargers	--	--	--	--	--
	MS4 Communities	--	--	--	--	--
	Industrial and Construction Stormwater	0.06	0.01	<0.01	<0.01	0.0*
Non-point source Load Allocation	Unnamed Creek Watershed	3.64	0.65	0.10	0.02	0.0*

*There was no flow during median dry flow conditions.

Table 3.13. Unnamed Creek impaired reach TSS total daily loading capacities and allocations according to the 30 mg/L proposed standard.

Unnamed Creek 07010204-668		Flow Zones				
		Very High	**High**	**Mid-Range**	**Low**	Dry
		TSS Load (tons/day)				
Total Daily Loading Capacity		2.85	0.52	0.07	0.01	0.0*
Margin of Safety (MOS)		0.21	0.05	<0.01	<0.01	0.0*
Wasteload Allocations	Permitted Wastewater Dischargers	--	--	--	--	--
	MS4 Communities	--	--	--	--	--
	Industrial and Construction Stormwater	0.04	0.01	<0.01	<0.01	0.0*
Non-point source Load Allocation	Unnamed Creek Watershed	2.60	0.46	0.07	0.01	0.0*

*There was no flow during median dry flow conditions.

3.9 ASSESSMENT OF TURBIDITY SOURCES

When assessing turbidity in streams, the first step is to determine the relative proportions of external and internal sources. External sources include sediment loading from outside the stream channel such as field and gully erosion, point source dischargers, livestock grazing and stormwater from construction sites and impervious surfaces. Internal sources of suspended sediment and turbidity include sediment resuspension, bank erosion and failure, and in-channel algal production. Identifying turbidity sources in river and stream systems is often difficult due to complex flow patterns and interactions throughout the watershed. However, a general sense of the timing, magnitude and sources of turbidity and sediment can be developed using available data to provide a weight of evidence for potential sources. Following is a description of the methods and data used to develop a better understanding of the primary sources. It is important to note that these estimates do not affect the established TMDL allocations, which are calculated using the load duration curves for each listed reach.

3.9.1 Flow and Seasonal Variability

Sampling results for turbidity and transparency related parameters were grouped by season and flow regime using flow duration curves. Comparing turbidity parameters by flow regime and season can help determine if the suspended solids are coming from algae, streambank erosion, or field erosion. Violations in the Grove Creek impaired reach are most common during spring (February through May) and summer (June through August) high and mid flow conditions (Figure 3.7). Mill Creek exceedances occurred during high, mid, and low flow conditions, all of which were recorded during summer months (Figure 3.8). Unnamed Creek had a high incidence of transparency violations during high and low flow conditions during the summer months (Figure 3.9; note: due to turbidity data availability, t-tube data were used).

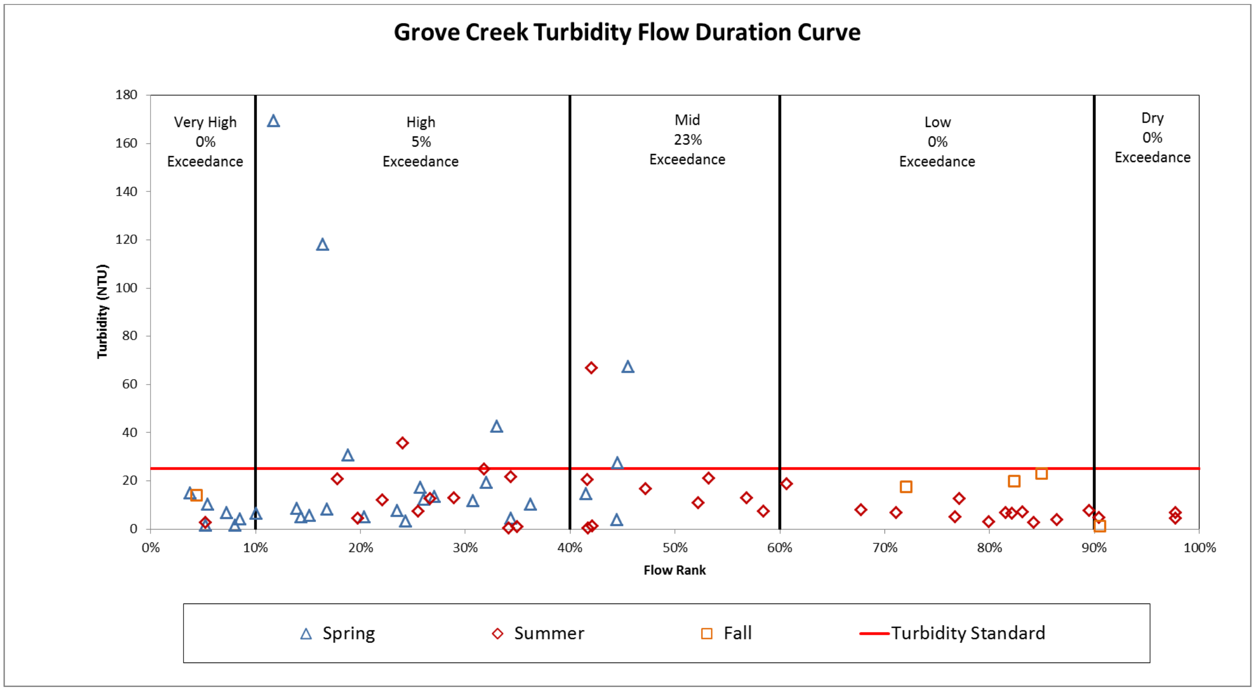


Figure 3.7. Grove Creek turbidity flow duration.
This figure includes lab measured turbidity (NTU) and field measured turbidity (FNU) that was converted to NTUs. Data from all Grove Creek water quality monitoring stations is included in this figure.

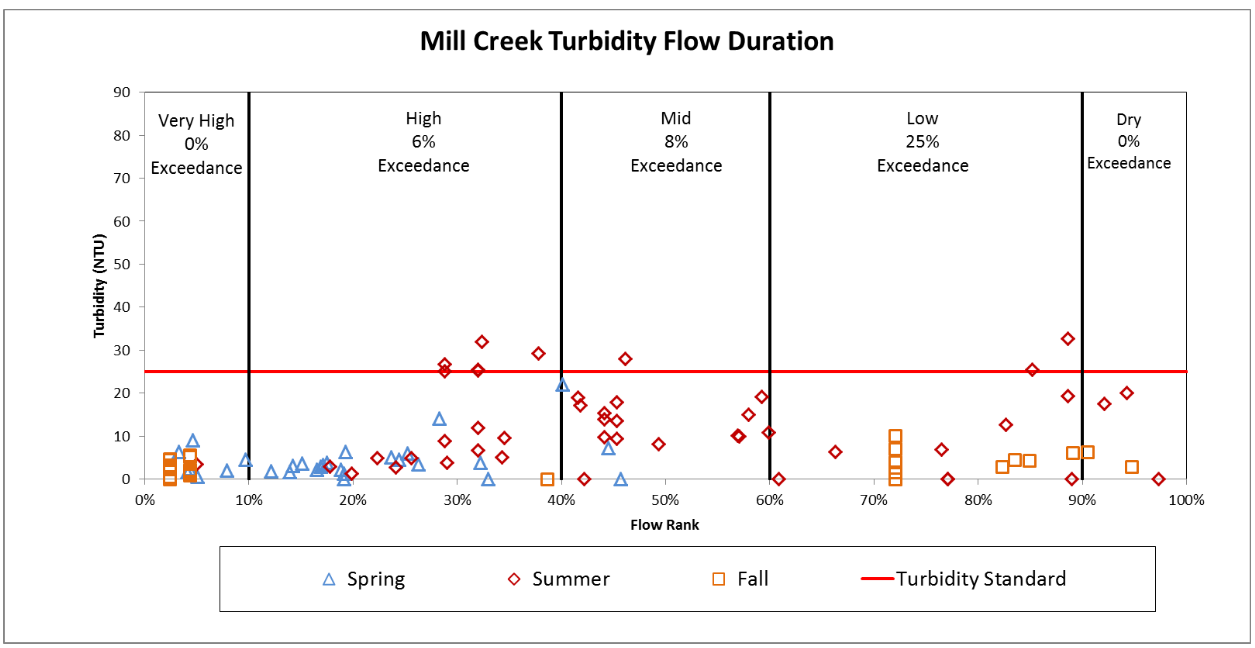


Figure 3.8. Mill Creek turbidity flow duration.
This figure includes lab measured turbidity (NTU) and field measured turbidity (FNU) that was converted to NTUs. Data from all Mill Creek water quality monitoring stations is included in this figure.

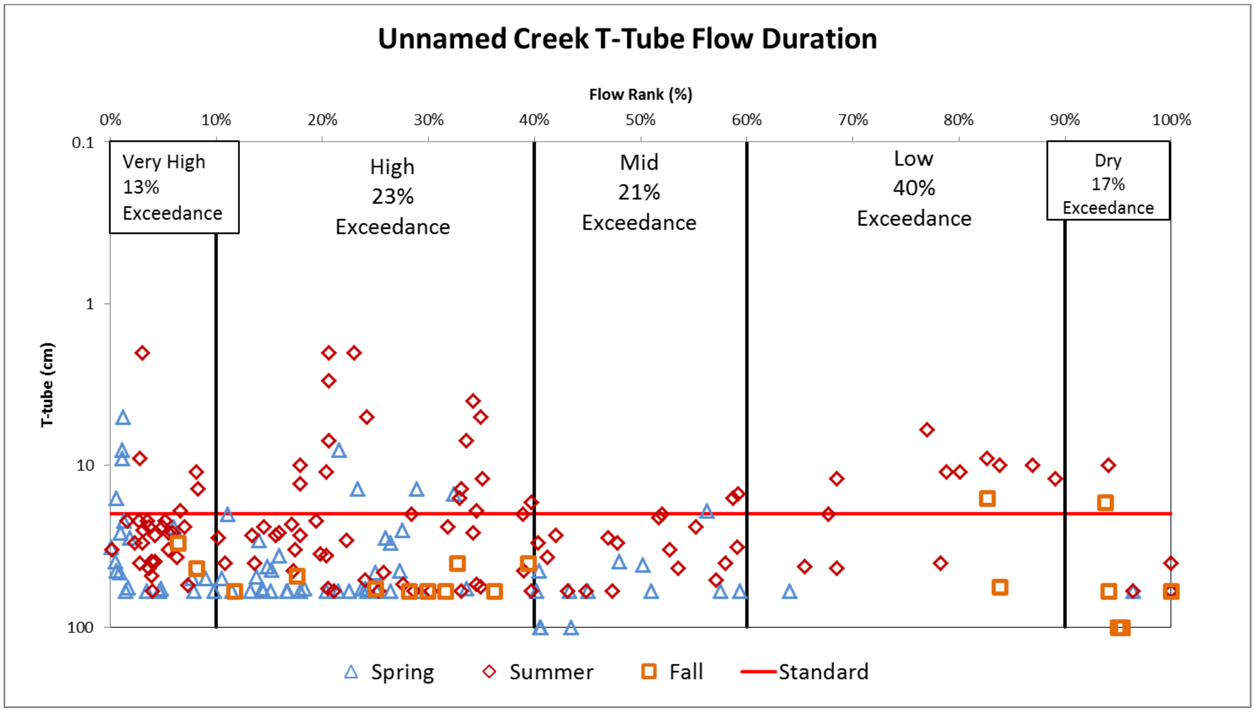


Figure 3.9. Unnamed Creek T-Tube Flow Duration Curve.

Typically, turbidity sources can be categorized by seasonality and flow regime. High flow conditions may result in bank or field erosion, which happen primarily in the spring and summer. Conversely, exceedances that occur during warm summer months and low flow conditions are usually a result of algal turbidity. Both Grove and Unnamed Creek possess exceedances that occur during spring and summer months during very high, high, and mid flow conditions. These data suggest that high flow events (i.e. summer storms and spring snowmelt) may be driving streambank or field erosion in the Grove and Unnamed Creek impaired reaches. However, Mill and Unnamed Creek contain exceedances that occur during low flow conditions in the summer and fall months, which suggests in stream algae production as a source of turbidity.

3.9.2 Field Erosion

Average upland sediment loss in the impaired reach watersheds was modeled using the Universal Soil Loss Equation (USLE). This model provides an assessment of existing soil loss from upland sources and the potential to assess sediment loading through the application of Best Management Practices (BMPs). USLE predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, land use and management practices. The general form of the USLE has been widely used in predicting field erosion and is calculated according to the following equation:

$$A = R \times K \times LS \times C \times P$$

Where A represents the potential long term average soil loss (tons/acre) and is a function of the rainfall erosivity index (R), soil erodibility factor (K), slope-length gradient factor (LS), crop/vegetation management factor (C) and the conservation/support practice factor (P). USLE only predicts soil loss from sheet or rill erosion on a single slope as it does not account for potential losses from gully, wind, tillage or streambank erosion.

For this exercise, it was assumed all agricultural practices are subject to maximum soil loss fall plow tillage methods and no support practices (P-factor = 1.00). Raster layers of each USLE factor were constructed in ArcGIS for the Grove, Mill and Unnamed Creek impaired reach watershed study areas and then multiplied together to estimate the average annual potential soil loss for each grid cell. Model results for each impaired watershed are illustrated in Figures 3.10 through 3.12. It is important to note that model results represent the maximum amount of soil loss that could be expected under existing conditions and have not been calibrated to field observations or observed/monitored data. Thus, results are intended to provide a first cut in identifying potential field erosion hot spots based on slope, land use and soil attributes. Areas with high potential erosion should be verified in the field prior to BMP planning and targeting.

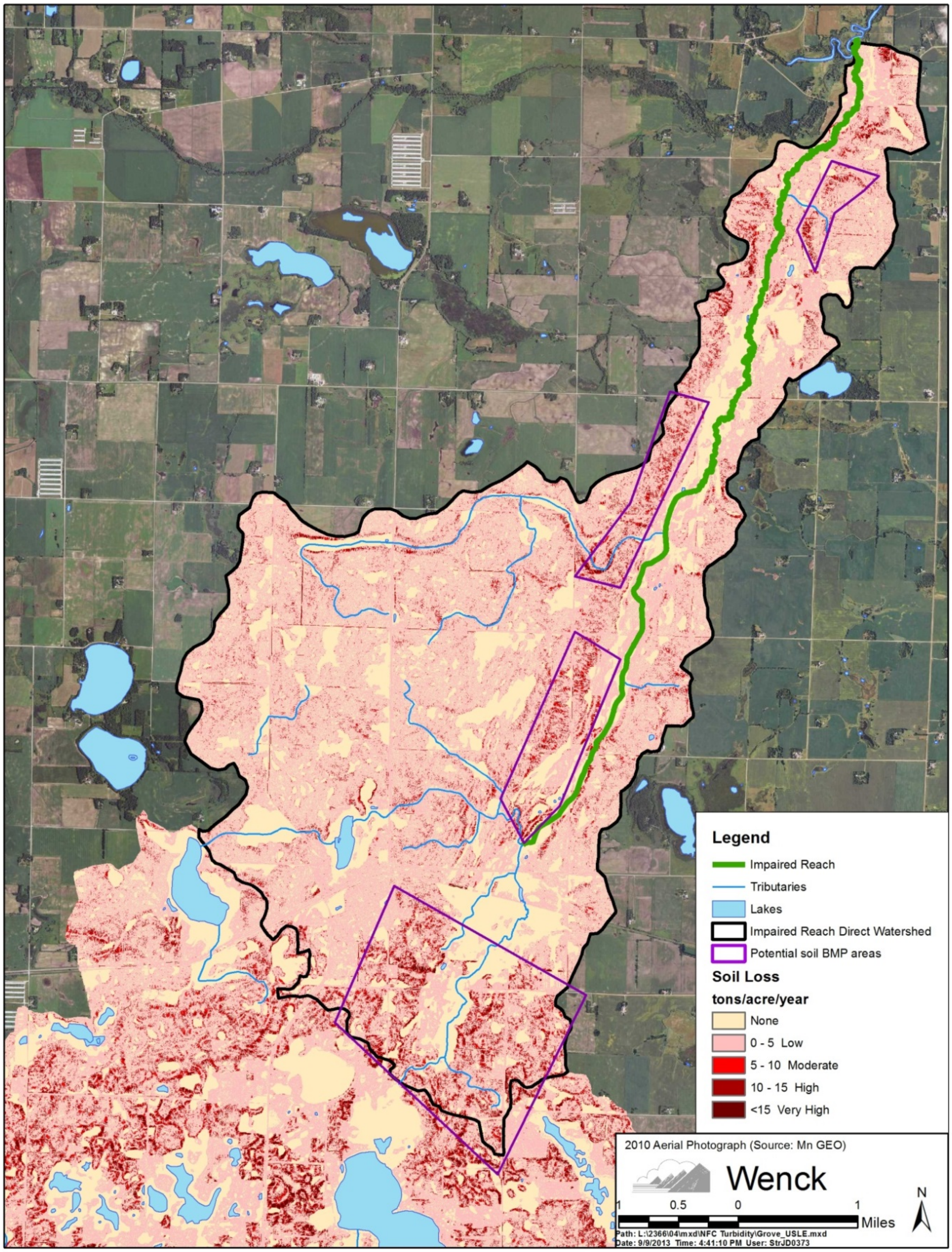


Figure 3.10. Potential soils loss in the Grove Creek impaired reach watershed.

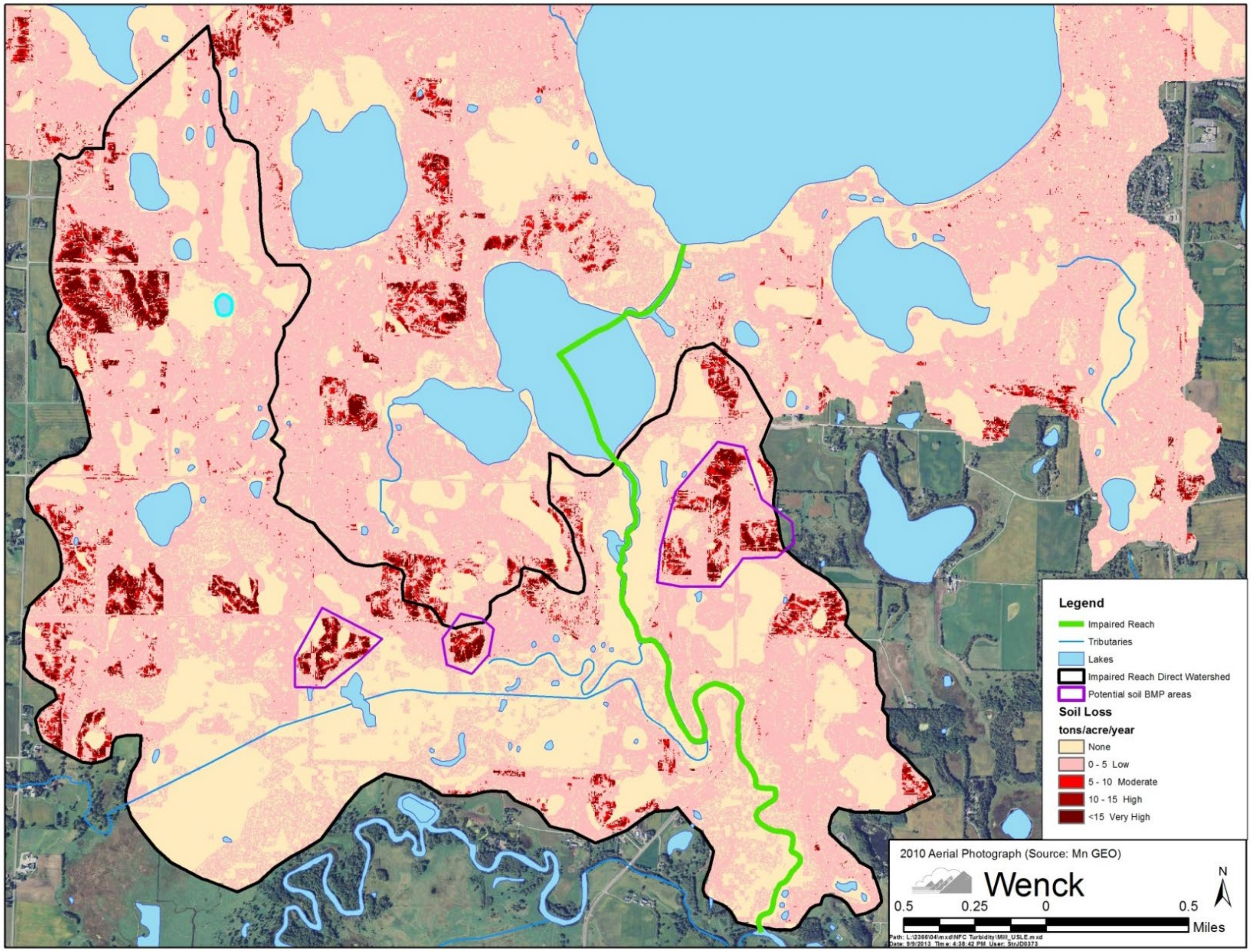


Figure 3.11. Potential soil loss in the Mill Creek impaired reach watershed.

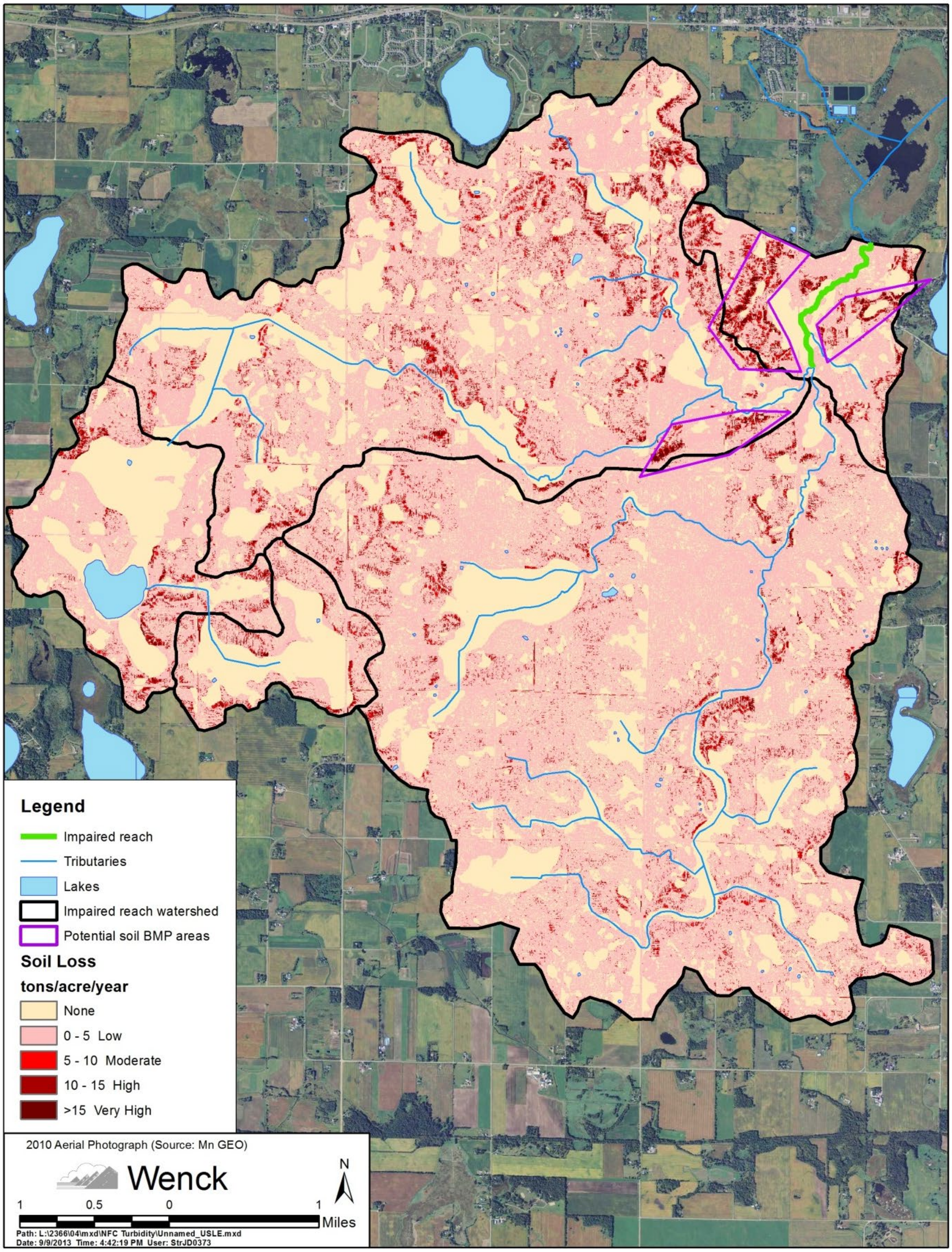


Figure 3.12. Potential soil loss in the Unnamed Creek impaired reach watershed.

3.9.3 Bank and Gully Erosion

Another potential source of TSS in streams is from detached soil particles from streambanks and gullies near streams. To date, there have been no surveys or data collected to assess the amount of streambank and gully erosion along the Grove, Mill and Unnamed Creek impaired reaches. Stream Power Index (SPI) is a GIS exercise that calculates the erosive power of overland flow which can be used to help identify potential flow erosion. The SPI takes into account both a local slope geometry and site location in the landscape and is calculated in GIS according to the following equation:

SPI = ln (A * Slope)

Where A is catchment area (flow accumulation). As catchment area and slope gradient increase, flow velocities and the amount of water contributed by upslope areas also increase leading to higher erosion potential and SPI values.

SPI was calculated in GIS for the Grove, Mill and Unnamed Creek impaired reach watersheds. Analysis of SPI results for each impaired reach focused on areas near (<500 feet) the main-stem channel and major tributary channels since flow erosion from these areas are more likely to effectively deliver sediment to the impaired reach. The SPI analysis identified a few high SPI areas in the Grove and Unnamed Creeks that could be contributing sediment through bank and/or gully erosion near the stream (Figures 3.13 and 3.14). These areas should be verified prior to any BMP planning to determine if they are failing or may be a sediment source. Despite a few potential problem areas, SPI values were generally low throughout the Grove, Mill and Unnamed Creek impaired reach stream corridor since these reaches flow through large wetland buffers (Grove and Mill Creeks) and forested areas (Unnamed Creek). Thus, stream bank and gully erosion is not believed to be a major source of sediment to the impaired reaches.

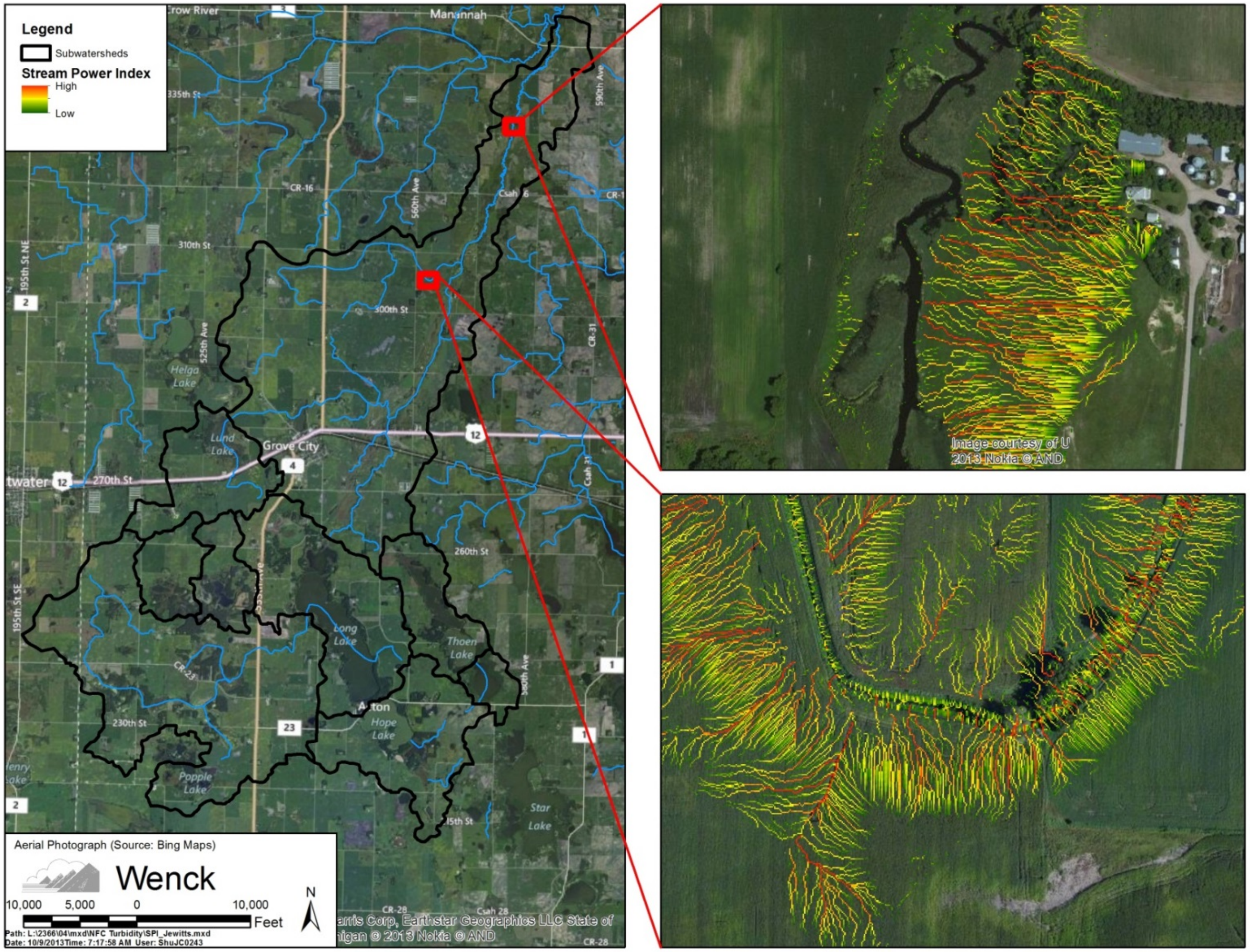


Figure 3.13. Potential streambank/gully erosion areas in the Grove Creek watershed.

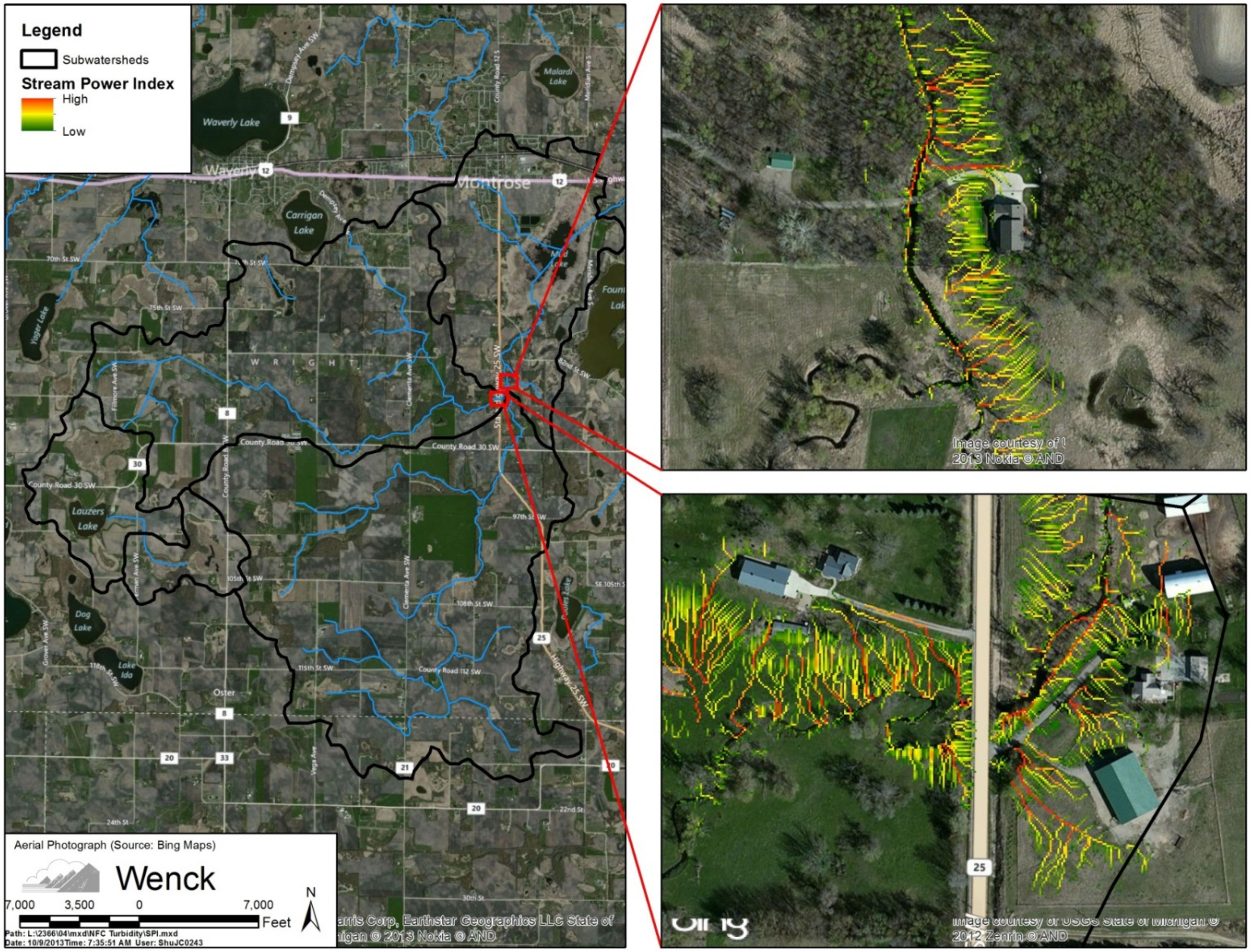


Figure 3.14. Potential streambank/gully erosion areas in the Unnamed Creek watershed.

3.9.4 Algal Turbidity

Chlorophyll-*a* measurements were collected from 2008-2009 within each impaired reach. These data can be used to assess whether turbidity impairments are being driven by mineral (i.e. sediment from bank and field erosion) or algal turbidity. Chlorophyll-*a* concentrations were plotted on a flow duration curve to assess which flow regimes resulted in high chlorophyll-*a* concentrations (Figure 3.15). In some cases, warm temperatures and low flow can provide favorable conditions for in-stream algal production. In addition to in-stream algal production, upstream impaired lakes may provide an external source of algal turbidity. Two of the three reaches, Mill and Grove Creek, contain upstream lakes that may contribute algal turbidity to the aforementioned streams. Furthermore, these watersheds (Mill and Grove Creek) contain multiple lakes that currently have nutrient impairments with chlorophyll-*a* concentrations ranging from 111 to 230 ug/L in the Grove Creek watershed and 30 to 60 ug/L in the Mill Creek watershed (Figure 3.16). It should be noted that during low flow conditions, lakes upstream of the impaired Grove Creek reach may not be discharging to Grove Creek. This insight may explain why Grove Creek has low chlorophyll-*a* concentrations during low flows, but higher chlorophyll-*a* concentrations during mid or high flows. Unnamed Creek does not have upstream lakes that are in close proximity to the impaired reach, which reduces the likelihood of upstream algal loading.

Although there is not currently a standard for chlorophyll-*a* concentrations in streams, there is a proposed 18 ug/L chlorophyll-*a* standard for rivers in the central river region. If this is taken into consideration, Mill and Grove Creek would exceed the criteria 44% and 16%, respectively. Unnamed Creek did not have any exceedances. Although the dataset is limited, it appears that algal biomass may be contributing to Mill Creek's and Grove Creek's turbidity problems. To verify that algae is a source of turbidity in Mill or Grove Creek, further sampling would be required due to the limited extent of available chorophyll-*a* data in the impaired reaches.

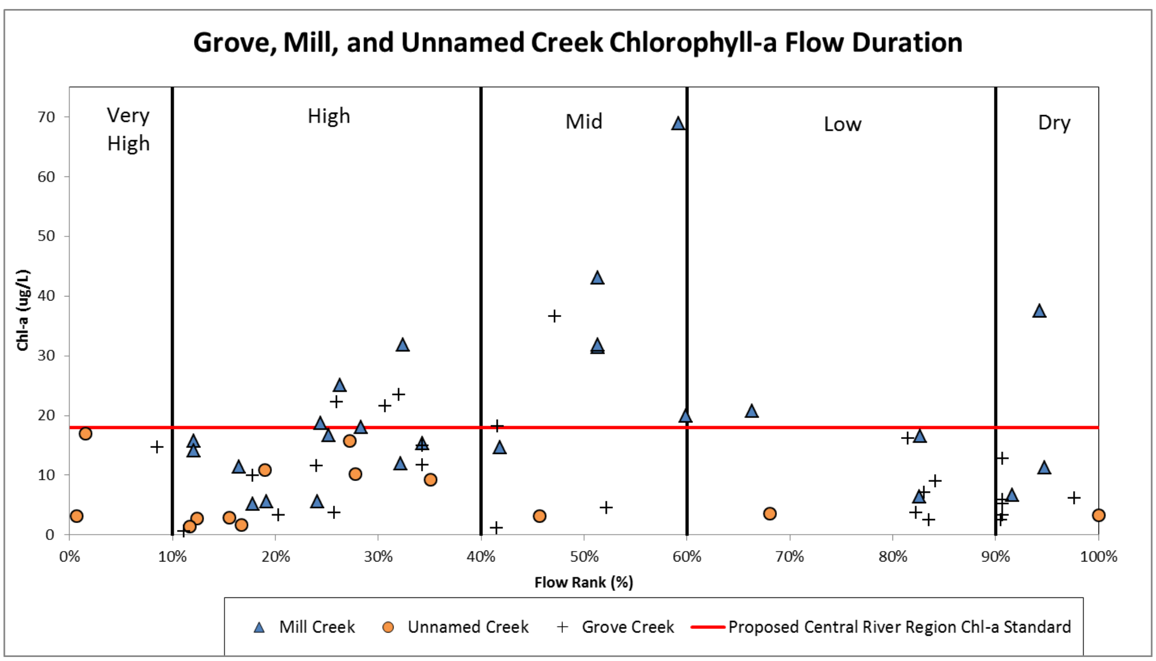


Figure 3.15 Chlorophyll-*a* flow duration curve for Grove, Mill and Unnamed Creek.

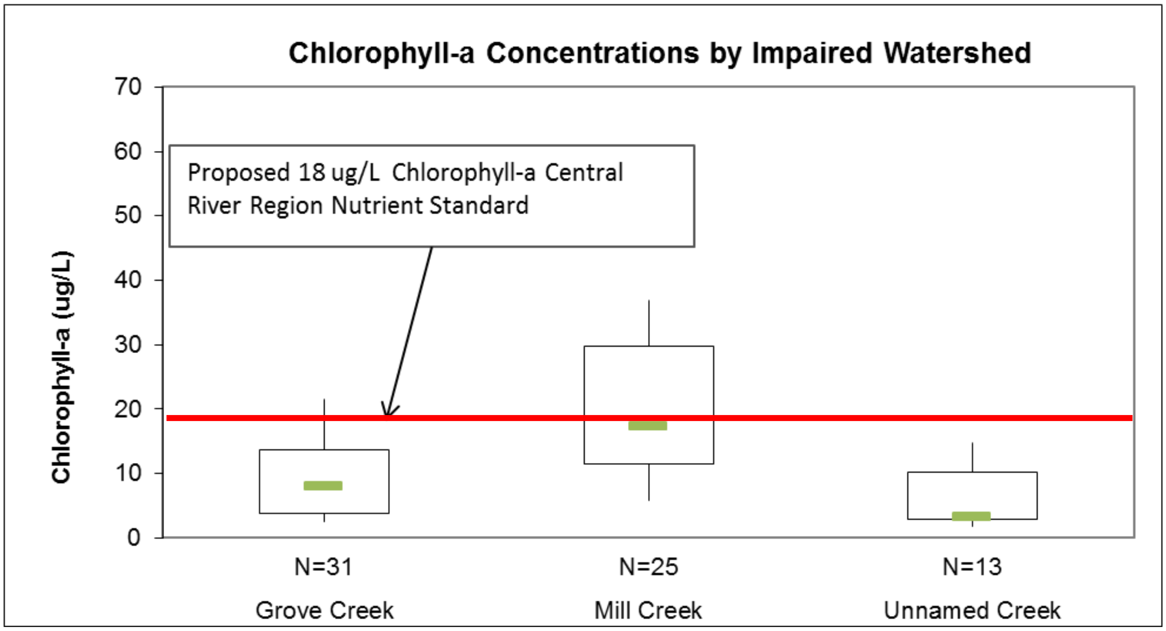


Figure 3.16. Chlorophyll-*a* concentration box plots for Grove, Mill, and Unnamed Creek.
The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. Error bars above and below each box represents the 95th and 5th percentile of the dataset. The green dash is the median chlorophyll-a concentration of all data collected.

3.9.5 Permitted WWTF Contributions

There is one NPDES wastewater discharger in the Grove Creek watershed with TSS permit limits. Discharge Monitoring Reports (DMRs) were downloaded from the MPCA's Environmental Data Access (EDA) website to assess TSS concentrations for each point source. Point source concentration limits are established in facility's individual NPDES permits. Typically, calendar monthly average TSS concentrations are not to exceed 30 mg/L as a for facilities with a continuous effluent discharge and 45 mg/L for stabilization pond facilities that discharge periodically. The Grove City WWTF, which is a stabilization pond (30 mg/L), monitoring report shows that the facility has monitored effluent TSS concentrations at least monthly since 1999 (Appendix C). The DMR results indicate this facility has had no exceedances over the past 14 years (1999-2013). The median TSS effluent concentration concentration is 7 mg/L with a minimum and maximum TSS concentration of 0.08 and 34 mg/L, respectively. Since the median concentration is low, the contribution of the Grove City WWTF is very small compared to streambank and field erosion.

3.9.6 Turbidity Source Summary

Turbidity assessments in rivers and streams are often complex due to the variety of pollutants, inputs and variables that contribute to impairment. The turbidity source assessment for this TMDL focused on three primary sources: upland field erosion, stream bank erosion and algal turbidity. These three sources were calculated and/or analyzed independently using available GIS data and monitoring data.

In all impaired watersheds exceedances were commonly observed during high flow events suggesting inputs from field erosion or streambank erosion. However, SPI analysis suggested that streambank erosion was likely a small contributor to the suspended sediment load. Low flow and mid flow exceedances were recorded at Grove and Mill Creek during the summer and early fall. Analysis of available chlorophyll-*a* data suggests that algae are likely a source of turbidity during these flow conditions. Furthermore, lakes upstream of Grove and Mill Creek are impaired for nutrients, which regularly result in high chlorophyll-*a* concentrations. Thus, implementation should focus on the following: BMPs for upland areas with high erosion potential and reducing upstream algal growth. Secondarily, stabilization of failing and sensitive streambanks will benefit the stream reaches.

4.0 Lake Excess Nutrient Impairments

4.1 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 34 lakes addressed in this TMDL. The latter sections of this report discuss the major pollutant sources that have been quantified using collected monitoring data and water quality modeling. The information presented here and in the upcoming sections together 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.

4.1.1 Permitted Sources

Table 4.1 summarizes the potential permitted sources in the Crow River watershed.

Table 4.1. 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 Environmental Protection Agency (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.

Permitted Source	Source Description	Phosphorus Loading Potential
Multi-sector Industrial Stormwater NPDES/SDS General Permit	Applies to facilities with Standard Industrial Classification Codes in ten 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.

4.1.2 Non-Permitted Sources

Table 4.2 summarizes the potential non-permitted nutrient sources in the North Fork Crow River watershed.

Table 4.2. 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 WWTF 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 nutrient impairments.

4.2 TMDL METHODOLOGY

The first step in developing an excess nutrient TMDL for lakes is to determine the total nutrient 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.

4.2.1 Nutrient Sources and Lake Response

4.2.2.1 Watershed Loading

An HSPF model was developed by the MPCA for the North Fork Crow River Watershed (RESPEC 2012). All watershed and SSTS loads for each of the lakes, was 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 Big Swan Lake chain even though there are large differences in animal units among the lakesheds. These differences were assessed in this TMDL where data are available.

4.2.2.2 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 North Fork Crow River Watershed is unclear. The MPCA's 2004 "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 North Fork Crow River Watershed (MPCA, 2004). 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 North Fork Crow 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 2004 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 WWTFs was calculated and divided by 3 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 CBOD pollutant concentrations of 53 mg/L, 10 mg/L and 175 mg/L, respectively. County failure rates from the 2004 MPCA report are presented in Table 4.3.

Table 4.3. SSTS failure rates by county (MPCA, 2004).

County	Percent Failing Systems
Carver	50%
Hennepin	25%
Kandiyohi	45%
McLeod	20%
Meeker	10%
Pope	20%
Stearns	30%
Wright	35%

4.2.2.3 Upstream Lakes

Some of the lakes addressed in the TMDL have upstream lakes which are also addressed in the TMDL. 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.

4.2.2.4 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 2005-2011 was within that study's average range (25" to 38"). 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.

4.2.2.5 Internal Loading

Internal phosphorus loading from lake sediments has been demonstrated to be an important part of the phosphorus budgets of lakes. Internal loading is typically the result of organic 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. For deep lakes where temperature and DO data have not been collected, a regression equation relating measured anoxic factors and lake morphometry was used to predict the anoxic factor:

$$AF_{deep} = -0.11\ (F/Z_{max}) + 48.49$$

Where F is fetch (ft) and Z_{max} (ft) is the maximum depth of the lake. This relationship ($R^2 = 0.61$) was developed by Wenck Associates using calculated anoxic factors for 13 deep lakes in the North Fork Crow Watershed with good temperature and oxygen profile data (Figure 4.1). It is important to note that shallow lakes can often demonstrate short periods of anoxia due to instability of stratification which can last a few days or even a few hours that are often missed by periodic field measurements. So, for all shallow lakes in this TMDL study, a different equation was used to estimate the anoxic factor (Nürnberg 2005):

$$AF_{shallow} = -35.4 + 44.2 \log (TP) + 0.95\ z/A^{0.5}$$

Where TP is the average summer phosphorus concentration of the lake, z is the mean depth (m) and A is the lake surface area (km^2).

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 available for Buffalo, Dean and Fountain Lakes. Literature values (Nürnberg 1997) and model residuals were used to determine appropriate release rates for all other lakes with no lab measurements. Selected release rates and calculated anoxic factors are provided in Appendix E.

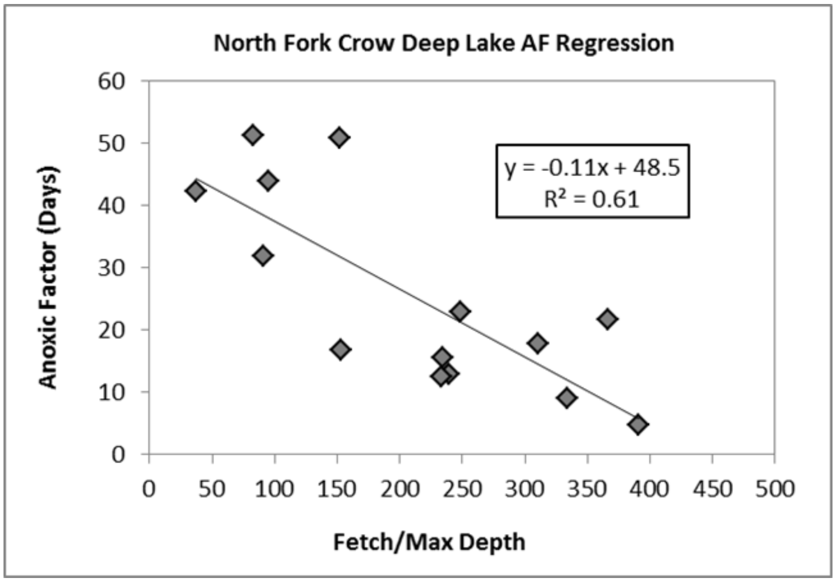


Figure 4.1. Relationship between calculated anoxic factor and lake morphometry for 13 deep lakes in the North Fork Crow River watershed.

4.2.3 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 µg/L as a growing season mean for shallow lakes and 40 µg/L for deep lakes. Lake response model results are included in Appendix E.

4.2.4 Phosphorus Load Summary

Table 4.4 summarizes the nutrient sources to each of the lakes.

Table 4.4. Nutrient sources for each of the impaired lakes in the North Fork Crow River watershed.

Lake Chain	Lake	Watershed Sources: Agriculture	Watershed Sources: Urban	Watershed Sources: SSTS	Watershed Sources: Other	Internal Sources: Sediment Release	Internal Sources: Historic Impacts (i.e. WWTF discharge)	Internal Sources: Aquatic Vegetation (1)	Internal Sources: Rough Fish (i.e. Carp) (2)	Upstream Lakes	Notes
Big Swan	**Hook**	○				●			Δ		Carp comprised 37% of total biomass in most recent (2005) DNR fish survey. Aquatic vegetation was sparse and grew only to a depth of 4 ft on August 2005 survey - coontail and sago pondweed were the only submergent species noted.
	Jennie	●				○		Δ	Δ		Carp comprised 16% of total biomass in most recent (2007) DNR fish survey. Curly-leaf pondweed is abundant during spring and early summer and has been a contentious issue in recent years. Jennie does have a good variety of native submerged species - 13 species noted during August 2007 survey
	Collinwood	●				○		Δ	Δ		Carp comprised 55% of total biomass in most recent (2006) DNR fish survey. Curly-leaf pondweed was present during July 2006 vegetation survey along with 6 native submerged species. Coontail and Canada waterweed most common species noted.
	Spring	○	○	○		●		Δ	Δ		Carp are present in lake but only accounted for 11% of total biomass in most recent (2003) DNR fish survey. Carp have accounted for as much as 46% of total biomass in 1992. Curly-leaf present in July 2003 vegetation survey and was observed growing to the surface throughout June 2004. Six native submergent vegetation species noted during July 2003 survey with Canada waterweed being the most abundant.
	Big Swan	●						Δ	Δ	○	Carp comprise 34% of total biomass in most recent (2007) DNR fish survey. Only one species (coontail) noted during July 2007 survey, and abundance was low. Fluctuating water levels likely limit most forms of submergent vegetation, making Big Swan an atypical lakeclass 24 water body. Curly-leaf pondweed had formed surface mats in some areas by mid-May, but they had broken down and were not present by early July 2007.
Deer	**Ramsey**	●		○		○		Δ	Δ		Carp are present in lake but have been relatively low historically and only 6% of total biomass in most recent (2008) DNR fish survey. Eurasian water milfoil is abundant in this lake and was found on 95% of the plant survey transects during the July 2008 survey. Curly-leaf pondweed has also been noted in the lake since at least 1998. Overall, the aquatic plant community is diverse and supported 14 native submerged species that grew to a depth of 9 feet during the July 2008 survey.
	Light Foot	●		○		●	Δ		Δ		Maple Lake WWTF discharged to Dutch Lake up until 2010. This facility is now connected to the Annandale/Maple Lake/Howard Lake WWTF (MN0066966).Carp comprised 37% of total biomass during most recent (2008) DNR fish survey. Coontail and sago pondweed were the only submerged plant species noted during a September 2008 vegetation survey. Secchi depth during this survey was 3.5 feet and submerged plants did not grow at depths greater than 2 feet.
	Albert	○				●			Δ		Carp comprised 45% of total biomass during recent (2009) DNR fish survey which is up from previous fish surveys in the 1970s and 1980s. Only one submerged vegetation species, sago pondweed, was noted growing to a maximum depth of 0.5 feet during July 2009 vegetation survey. Vegetation was more abundant and diverse during surveys conducted in the 1980s.
	Buffalo	○	○			●		Δ	Δ	●	Carp comprised 31% of total biomass during the most recent (1993) DNR fish survey. Curly-leaf pondweed was noted during the July 1993 vegetation survey along with 4 other submerged species.
	Deer					○		Δ	Δ	●	Carp comprised 12% of total biomass during the most recent (1993) DNR fish survey. Only 4 submerged plant species observed during August 1993 vegetation survey. Observations from a 1988 survey noted abundance of curly-leaf pondweed in the early summer and limited vegetation growth in late summer.

● Primary Source

○ Secondary Source

Δ Potential Source (Unknown Level of Impact)

Lake Chain	Lake	Watershed Sources				Internal Sources				Upstream Lakes	Notes
		Agriculture	Urban	SSTS	Other	Sediment Release	Historic Impacts (i.e. WWTF discharge)	Aquatic Vegetation (1)	Rough Fish (i.e. Carp) (2)		
Waverly	**Howard**	○				●		Δ	Δ		Carp were present in most recent (2006) DNR fish survey but only represented 5% of the total biomass. Carp numbers are down from 1970s and 1980s when they represented 15%-25% of total biomass. Curly-leaf pondweed and Eurasian milfoil were first noted during August 2006 survey and were the dominant vegetation species observed and considered nuisances. Five other submergent species noted in lower abundance.
	Dutch	●				●	Δ	Δ	Δ		Howard Lake WWTF discharged to Dutch Lake up until 2009. This facility is now connected to the Annandale/Maple Lake/Howard Lake WWTF (MN0066966). Carp comprised 12% of total biomass during most recent (2006) DNR fish survey, while other rough fish (primarily black bullhead) accounted for 20%. Curly-leaf pondweed was noted during the July 2006 vegetation survey and no other submerged species were noted.
	Waverly	●	○			●	Δ		Δ	○	Waverly WWTF discharged to Carrigan Lake, which is upstream of Waverly Lake, up until 2004. This facility is now connected to Montrose WWTF (MN000024228). Carp comprised 33% of total biomass during most recent (2004) DNR fish survey. There is no vegetation data available for Waverly, however Eurasian milfoil is common throughout portions of the lake.
	Little Waverly	●				○			Δ	○	Carp were present in most recent (2004) DNR fish survey but represented only 3% of the total biomass. Other rough fish, primarily black bullhead, accounted for 55% of the total biomass during the 2004 survey. No vegetation available for Little Waverly.
Individual Lakes	**Richardson**	●				●			Δ		Carp comprised 6% of total biomass during most recent (2008) DNR fish survey, while other rough fish (primarily black bullhead) accounted for 21%. Curly-leaf pondweed was observed during July 2008 vegetation survey. Sago pondweed was the only other submerged species noted.
	Dunns			○		●			Δ	○	Carp comprised 16% of total biomass in most recent (2008) DNR fish survey. Yellow water lily was the only non-emergent vegetation species noted during a July 2008 vegetation survey.
	Hope	●				●			Δ		Carp comprised 16% of total biomass in most recent (2004) DNR fish survey. Other rough fish, primarily black bullhead, also accounted for 16% of the total biomass. From 1977-1991, carp biomass ranged from 7%-34% while other rough fish ranged from 52%-90% of the total biomass. Vegetation was not abundant and only three non-emergent species were noted during a July 2004 survey: yellow water lily, coontail and sago pondweed.
	Fountain	○				●			Δ		Fountain Lake has experienced partial winterkills in the past. Low DO levels were most recently observed in 2001 when the lake was opened to unlimited fishing. Because of its connection to the Crow River, restocking is unnecessary after periods of partial winterkill. Carp comprised 24% of total biomass during most recent (2009) DNR fish survey, while other rough fish (mainly black and brown bullhead) accounted for only 29%. 2009 survey noted very little, if any submerged aquatic vegetation. With a maximum depth less than 10 feet, this lake should be able to support an abundance of submerged vegetation if water clarity improved. The only vegetation observed was floating and emergent species such as yellowy water lily, cattail and bulrush.
	Long	●				●			Δ		Long Lake has a history of winterkill, and fish populations can fluctuate greatly. Connections to Hope, North Fork Crow River and Grove Creek allow fish to migrate into and out of Long Lake during high flows. Carp comprised 9% of the total biomass in most recent (2004) DNR fish survey while other rough fish (primarily black bullhead) accounted for 29%. From 1978-1991, carp biomass ranged from 20%-61% while other rough fish ranged from 38%-56% of total biomass. Curly-leaf pondweed was observed during an August 2004 survey. The only other non-emergent vegetation species noted were coontail and sago pondweed.

● Primary Source

○ Secondary Source

Δ Potential Source (Unknown Level of Impact)

Lake Chain	Lake	Watershed Sources				Internal Sources				Upstream Lakes	Notes
		Agriculture	Urban	SSTS	Other	Sediment Release	Historic Impacts (i.e. WWTF discharge)	Aquatic Vegetation (1)	Rough Fish (i.e. Carp) (2)		
	Nest	○				●		Δ		●	Carp were present in most recent (2008) DNR fish survey but represented only 4% of the total biomass. Other rough fish, mainly black bullhead, accounted for 17% of the total biomass during the 2008 survey. Submergent vegetation is most abundant in the shallow areas of the northeast half of the lake. Shallow bays throughout the lake typically contain curly-leaf pondweed, coontail and water lilies. Curly-leaf pondweed was first noted during the July 1996 vegetation survey. Sixteen different native submerged vegetation species were noted during the most recent (2008) vegetation survey.
	Constance	○		○		●		Δ			Constance lake has poor water quality and a history of summer and winter fish kills. No carp have been noted in any of the 5 DNR fish surveys since 1979. However, rough fish (primarily yellow bullhead) accounted for 36% of the total biomass during the most recent (2011) DNR fish survey and ranged from 17%-42% during past surveys. Curly-leaf pondweed was surveyed in early June 2011 and was found growing at or near the surface at approximately 20% of the lake area. Vegetation was surveyed again in August 2011 and 7 submergent species were noted with coontail and Canada waterweed the most common species. Submerged vegetation grew to a maximum depth of 9.5 feet.
	Pelican	○				●					There is DNR fish survey information available for Pelican Lake. The lake is listed on the DNR's Designation of Infested Waters list for Eurasian Milfoil.
	Beebe	●		○		●		Δ			Carp were present in most recent (2009) DNR fish survey but represented only 5% of the total biomass. Other rough fish, mainly yellow bullhead, accounted for 25% of the total biomass during the 2009 survey. Two point-intercept vegetation survey were completed by DNR Ecological Resources staff. The first, 22 May 2009, found curly leaf pondweed at 84% of sites less than 20 feet deep. Eurasian water milfoil (EWM) was observed at 3% of sites. The second survey, 13 July 2009, showed that curly leaf pondweed was growing at 56% of the points, while EWM was the second most common species observed at 33% of the points. Six other species of native submersed vegetation were noted, however none were common.
	Foster	●				●			Δ		Foster Lake has poor water quality and a history of summer and winter fish kills. Carp comprised 14% of total biomass during the only DNR fish survey in 1985. Other rough fish, primarily black bullhead, accounted for 39% of the total biomass during the 1985 survey. The survey noted high rough fish and carp activity, very turbid water and no submerged vegetation growing throughout the lake.
	Hafften	○				●				●	Carp were present in most recent (2005) DNR fish survey but represented only 7% of the total biomass. Other rough fish (primarily yellow and brown bullhead) accounted for 13% of the total biomass during the most recent (2005) DNR fish survey but have ranged from 15%-44% during past surveys (1963-1993). No vegetation data is available for Hafften Lake.
	Malardi	○				●					Lake Malardi is currently scheduled for a lake drawdown. According to the lake drawdown management plan, there have been no formal fish surveys conducted on the lake, however some anecdotal observations suggesting that fish assemblages are often present. However, the relative shallow depth of the lake combined with harsh winters likely suggests fish populations are stressed and prone to winterkills. Pre-drawdown, there was no way to prevent fish from migrating from the North Fork Crow River. A fish barrier is scheduled to be installed on the outlet channel as part of the drawdown project. No pre-drawdown vegetation surveys have been conducted on Malardi. However, notes from the management plan indicate abundance of plants throughout much of the lake but little species diversity.

● Primary Source

○ Secondary Source

Δ Potential Source (Unknown Level of Impact)

Lake Chain	Lake	Watershed Sources				Internal Sources				Upstream Lakes	Notes
		Agriculture	Urban	SSTS	Other	Sediment Release	Historic Impacts (i.e. WWTF discharge)	Aquatic Vegetation (1)	Rough Fish (i.e. Carp) (2)		
	Granite	●				●		Δ	Δ		Carp were present in most recent (2008) DNR fish survey but represented only 4% of the total biomass. However, other rough fish, mainly black and yellow bullhead, accounted for 52% of the total biomass during the 2008 survey. During an August 2008 survey, aquatic plants were found down to depths of 8 feet and bushy pondweed, sago pondweed and coontail were the most abundant species. Curly-leaf pondweed, first noted in 1980 in Granite Lake, was found on 22% of the lake.
	French	●		○					Δ		Carp comprised 10% of total biomass during most recent (2011) DNR fish survey, while other rough fish accounted for 12%. No vegetation survey information available for French Lake.
	Camp	●				●					No DNR fish or vegetation surveys available for Camp Lake.
	Rock	○		○		●		Δ	Δ		Carp comprised 13% of total biomass during most recent (2006) DNR fish survey, while other rough fish (mainly yellow bullhead) accounted for 38%. Curly-leaf pondweed was present in Rock Lake along with Eurasian milfoil during an August 2006 vegetation survey. There were 5 native submerged species observed during the 2006 survey, with coontail being the most abundant.
	Brooks	○		○		●		Δ			No carp have been noted in any of the 4 DNR fish surveys from 1996-2005. However, rough fish (primarily black bullhead) accounted for 7% of the total biomass during the most recent (2005) DNR fish survey and ranged from 77%-100% during past surveys. Curly-leaf pondweed was present in Brooks Lake during an August 2005 vegetation survey. There were 5 native submerged species observed during the 2005 survey, with sago pondweed being the most abundant.
	Smith	○				●					No DNR fish or vegetation surveys available for Smith Lake.
	Cokato	●		○				Δ	Δ		Carp comprised 18% of total biomass during most recent (2007) DNR fish survey, while other rough fish (mainly black bullhead) accounted for only 1%. Curly-leaf pondweed was present in Cokato Lake during an August 2007 vegetation survey. There were only three native submerged species observed during the 2007 survey as vegetation only grew to depths of 6 feet or less. Vegetation was sparse and sago pondweed being the most abundant species observed during the survey.

● Primary Source

○ Secondary Source

Δ Potential Source (Unknown Level of Impact)

4.2.5 TMDL Allocation Methodology

To develop the appropriate loads under TMDL conditions, each load is evaluated sequentially to determine appropriate 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 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 existing sediment release rates and the lake morphometry. This is accomplished by reviewing the 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.

4.2.6 Load Allocation Methodology

The LA includes all non-permitted sources, including: atmospheric deposition, septic systems, discharge from upstream lakes, watershed loading from non-regulated areas, and internal loading. Some discharges from areas geographically located in a regulated MS4 community that do not drain through a conveyance system (and therefore are not regulated sources) are also included in the LA (determined as described in the following section).

4.2.7 Wasteload Allocation Methodology

The WLAs were divided into four primary categories including NPDES permitted wastewater dischargers, MS4 permits, and NPDES-permitted construction and industrial stormwater. There are only two active NDPDES permitted wastewater dischargers located in any of lake watersheds. Following is a description of how MS4 and construction and industrial stormwater allocations were assigned.

4.2.7.1 MS4s

There are four MS4s that are completely within or have a portion of their municipal boundary in at least one of the impaired lake watersheds (Table 4.5): Monticello City (Pelican Lake), Buffalo City (Buffalo, Constance, Deer and Pelican Lakes), St. Michael City (Pelican, Beebe and Foster Lakes) and Otsego City (Foster Lake). Based on discussions with MNDOT, they do not drain to any of the lakes in this study. Furthermore, there are no County MS4s in any of the drainage areas. Runoff from these MS4 communities that drains to impaired lakes discussed in this report was assigned WLAs according to the following methodology. Within the North Fork Crow HSPF model, MS4 areas were separated from non-MS4 areas but were assigned the same land use classification and phosphorus loading rates (RESPEC, 2011). Thus, MS4 allocations were calculated by dividing HSPF model predicted MS4 average annual phosphorus load by each lake's average annual watershed (MS4 plus non-MS4 total) load. The MS4 proportion of the total watershed load was used to set both the existing MS4 load as well as the TMDL load allocation. TMDL reductions for MS4 and non-MS4 runoff were similar since land use classification loading rates were the same.

Table 4.5. Permitted MS4s in each lakeshed.

MS4 Name		Buffalo City	Monticello City	St. Michael City	Otsego City
MS4 ID Number		MS400238	MS400242	MS400246	MS400243
86-001	FOSTER	--	--	Yes	Yes
86-023	BEEBE	--	--	Yes	--
86-031	PELICAN	Yes	Yes	Yes	--
86-051	CONSTANCE	Yes	--	--	--
86-090	BUFFALO	Yes	--	--	--
86-107	DEER	Yes	--	--	--

4.2.7.2 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 North Fork Crow River Watershed showed minimal construction (<1% of watershed area) and industrial activities (<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 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 Permit 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.

4.2.8 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 7 year period (2005 to 2011) was used for the majority of the lake modeling. In-lake monitoring data collected during the same 7 year period was also available for the majority of the lakes.

4.2.9 Lake Response Variables

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

4.2.10 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.

4.2.11 TMDL Summary

The allowable 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 ≥10 reported in lbs/yr have been rounded to the nearest whole number.
- Values <10 reported in lbs/yr have been rounded to the nearest tenth of a pound.
- Values reported in lbs/day have been rounded to enough significant digits so that the value is greater than zero.

4.3 BIG SWAN CHAIN OF LAKE TMDL

4.3.1 Watershed Description

Hook Lake (DNR # 43-0073), Jennie Lake (DNR # 47-0015), Collinwood Lake (DNR # 86-0293), Spring Lake (DNR # 47-0032) and Big Swan Lake (DNR # 47-0038) are located in the Big Swan Lake 10-digit HUC (0701020405). This chain of lakes is located in the south-central portion of the North Fork Crow River Watershed and includes portions of three counties (Figure 4.2).

Hook Lake is the upper-most lake in the Big Swan Chain and has a relatively small watershed (3,354 acres) completely within McLeod County. Jennie Lake is located downstream of Hook Lake and receives flow from Hook and Todd Lakes and direct watershed runoff from rural land in Meeker County and a small portion of McLeod County. Collinwood Lake is located along the border of Meeker and Wright County and is situated downstream of Jennie Lake. Collinwood receives direct watershed runoff from

Meeker County and a small portion of Wright County. Collinwood also receives flow from two nearby lakes, Pigeon and Maple Lake, via Collinwood Creek that have several other upstream lakes including Jewitt, Long, Wolf, Jennie, Todd and Hook Lakes.

Located in the town of Dassel, Spring Lake has a small watershed (1,036 acres) that includes flow from Long Lake and direct watershed runoff from urban and rural land in Meeker County. Spring Lake is the only lake in the Big Swan Chain that is not located along the main-stem of Collinwood Creek. Big Swan Lake is located in Meeker County north of Spring and Collinwood Lakes. Big Swan is the downstream-most lake in the Big Swan Chain and receives a majority of its inflow from Collinwood Creek, which drains all of the aforementioned lakes and lakesheds. Direct runoff to Big Swan is made up of approximately 8,700 acres of rural land in Meeker and Wright Counties. Predominant land use in the Big Swan Chain is row crops (62%) and pastureland (17%) while all other land uses account for less than 10% of the total (Figure 4.3 and Table 4.6). Urban land accounts for only 6% of the land use in the Big Swan Chain. The City of Dassel, located in the Spring Lake watershed, has a population of approximately 1,500 people and is the only moderately sized urban area in the Big Swan Chain.

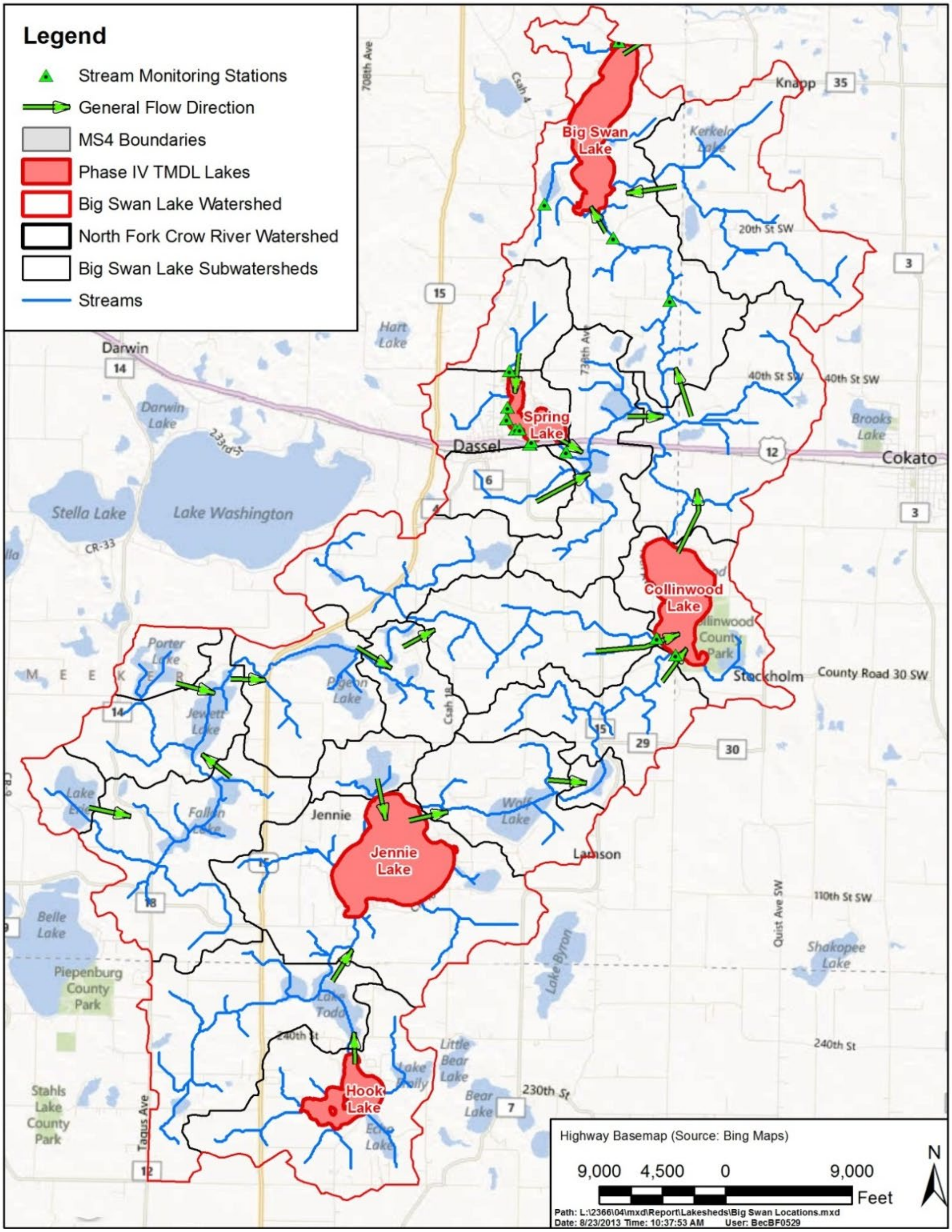


Figure 4.2. Flow pattern in the Big Swan Chain of Lakes TMDL study area.

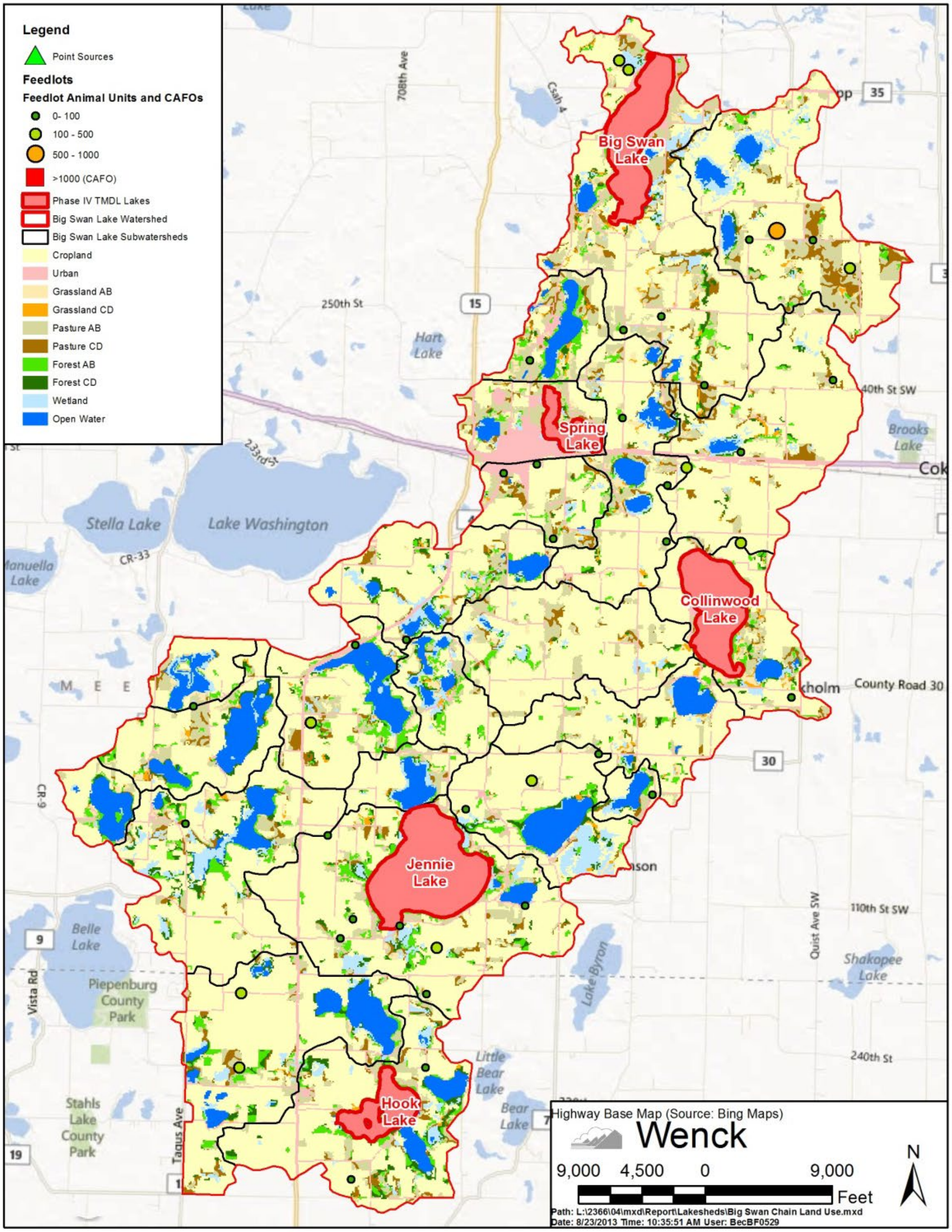


Figure 4.3. Land use in the Big Swan Chain of Lakes TMDL study area.

Table 4.6. Land use in the Big Swan Chain of Lakes TMDL study area

Lake		Urban	Forest	Cropland	Grassland	Pasture	Wetland	Feedlot	total
Big Swan	Acres	2,701	2,856	29,132	1,293	5,922	3,550	24	45,478
	Percentage	6%	6%	64%	3%	13%	8%	0%	100%
Spring	Acres	362	44	259	39	295	37	--	1,036
	Percentage	35%	4%	25%	4%	28%	4%	0%	100%
Collinwood	Acres	1,444	2,243	19,218	751	2,968	2,332	11	28,967
	Percentage	5%	8%	66%	3%	10%	8%	0%	100%
Jennie	Acres	550	882	7,070	138	1,137	882	5	10,664
	Percentage	5%	8%	67%	1%	11%	8%	0%	100%
Hook	Acres	131	300	1,906	27	360	289	1	3,014
	Percentage	4%	10%	63%	1%	12%	10%	0%	100%

Note: Lake surface land use excluded

4.3.2 Lake Morphometry

Jennie and Hook Lakes are considered shallow lakes, meaning 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 three lakes are considered deep lakes and have maximum depths greater than 15 feet and are less than 80% littoral. Collinwood and Big Swan have relatively short residence (less than 1 year) due to their large drainage areas. Spring, Jennie and Hook Lakes, on the other hand, have smaller drainage areas and residence greater than one year (Table 4.7).

Table 4.7 Lake morphometry for all impaired lakes in the study area.

Parameter	Surface Area	Average Depth	Maximum Depth	Lake Volume	Residence Time	Littoral Area	Depth Class	Drainage Area*
Water body	**acre**	**feet**	**feet**	**ac-ft**	**years**	**%**	**--**	**acre**
Big Swan	694	15	32	10,564	0.6	49	Deep	45,478
Spring	218	10	30	2,131	2.4	76	Deep	1,036
Collinwood	636	12	28	7,807	0.7	55	Deep	28,967
Jennie	1,064	8	15	8,969	2.3	99	Shallow	10,664
Hook	330	7	18	2,321	1.9	98	Shallow	3,014

*Excludes Lake Surface

4.3.3 Historic Water Quality

Tables 4.8 and 4.9 list the June through September averages of TP concentration, chlorophyll-*a* (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 some cases, in-lake data was not available for all years of the 2005 to 2011 or 2000 to 2012 data sets.

Table 4.8. Deep lake growing season averages for water quality parameters.

Lake Name	"Average" Condition Calculation Years	In-Lake "Average" Condition (Calculated June - September) TP Concentration (µg/L)	Chl-*a* Concentration (µg/L)	Secchi Depth (m)
Water Quality Standard for Deep Lakes		**40.0**	**14.0**	**1.4**
Big Swan	2006-2011	102.9	52.6	1.0
Spring	2006-2011	64.4	25.3	1.1
Collinwood	2002-2010	96.4	44.5	1.4

Table 4.9. Shallow lake growing season averages for water quality parameters.

Lake Name	"Average" Condition Calculation Years	In-Lake "Average" Condition (Calculated June - September) TP Concentration (µg/L)	Chl-*a* Concentration (µg/L)	Secchi Depth (m)
Water Quality Standard for Shallow Lakes		**60.0**	**20.0**	**1.0**
Jennie	2002-2011	53.2	26.6	1.2
Hook	2006	121.2	77.1	0.4

4.3.4 Biological Conditions

All of the lakes have carp populations with the largest in Big Swan Lake (Table 4.10). Jennie, Hook and Spring Lakes will be the most sensitive to carp infestations with reproduction likely occurring in Hook Lake due to its history of winterkills. Carp will need to be controlled in this watershed for the lakes to meet water quality standards.

Table 4.10 Aquatic vegetation and fisheries data for the Big Swan Chain of Lakes.

Lake	Recent Survey Month-Year	Curly Leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Big Swan	August-2007	Yes	No	Yes	Carp comprise 1/3 of total biomass; Large water level fluctuations may affect vegetation.
Spring	June-2003	Yes	No	Yes	Historically abundant carp populations.
Collinwood	July-2006	Yes	No	Yes	Relatively large carp population.
Jennie	June-2007	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.
Hook	Aug-2005	--	--	Yes	Lake has a history of winterkill; Most recent partial kill occurred in 1996; Vegetation is sparse and dominated by coontail.

4.3.5 Nutrient Sources

Nutrient sources to the lakes are provided in Table 4.11.

Table 4.11. Nutrient sources for the lakes in this subwatershed.

Lake	Drainage Areas	SSTS	Upstream Lakes	Atmosphere	Internal Load
Hook	15%	3%	--	4%	78%
Jennie	47%	8%	7%	9%	29%
Collinwood	53%	7%	5%	2%	33%
Spring	11%	16%	5%	7%	61%
Big Swan	53%	4%	35%	2%	6%

Hook Lake

Hook Lake is a shallow productive lake with a history of winterkills. Based on the model results, the lake is dominated by internal loading. Watershed monitoring is needed to verify model predicted runoff phosphorus concentrations. Both Echo Lake and Emily Lake should be monitored since both discharge to Hook Lake.

Jennie Lake

Jennie Lake is also a shallow lake which receives nutrient loads from Hook Lake. The HSPF model predicted slightly higher runoff concentrations to Jennie Lake which contributes around 47% of the phosphorus load to the lake. This may be a result of a large number of animal units in the watershed (over 600 dairy cows and 500 beef cattle). Load reductions to Jennie Lake need to focus on watershed loading. Although carp populations were small at the time of sampling, it is likely that carp are affecting water quality due to their large presence in the overall watershed.

Collinwood Lake

Collinwood Lake is a deep lake that receives most of its nutrients from the watershed. Nutrient reductions should focus on watershed sources although internal load reductions will be required for Collinwood Lake to meet the targeted goals.

Spring Lake

Spring Lake is a small deep Lake tributary to Big Swan Lake and receives drainage from the City of Dassel. However, loading to Spring Lake appears to be dominated by internal phosphorus loading.

Big Swan Lake

Big Swan Lake receives drainage from the entire subwatershed including the previously mentioned lakes. Therefore, reductions in phosphorus loading need to come from both the watershed and upstream lakes for Big Swan Lake to meet water quality standards. It is also important to note that a large carp population exists in the lake. Although these carp may not have a large impact on Big Swan Lake, it may serve as a refuge for carp that move throughout the watershed.

4.3.6 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 4.12 through 4.16 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 4.12. TMDL allocations for Hook 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	3	0.01	3	0.01	0	**0%**
Load	Drainage Areas	338	0.9	298	0.8	41	**12%**
	SSTS	69	0.2	0	0.0	69	**100%**
	Atmosphere	73	0.2	73	0.2	0	**0%**
	Internal Load	1,750	4.8	339	0.9	1,411	**81%**
	MOS	--	--	38	0.1	--	**--**
	TOTAL	**2,233**	**6.11**	**751**	**2.01**	**1,521**	**66%**

Table 4.13. TMDL allocations for Jennie Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction and Industrial Stormwater	14	0.04	14	0.04	0	**0%**
Load	Drainage Areas	1,402	3.8	1,271	3.5	131	**9%**
	SSTS	245	0.7	0	0.0	245	**100%**
	Upstream Lakes	193	0.5	96	0.3	98	**50%**
	Atmosphere	254	0.7	254	0.7	0	**0%**
	Internal Load	851	2.3	851	2.3	0	**0%**
	MOS	--	--	131	0.4	--	**--**
	TOTAL	**2,959**	**8.04**	**2,617**	**7.24**	**474**	**12%**

Table 4.14. TMDL allocations for Collinwood Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	47	0.1	47	0.1	0	**0%**
Load	Drainage Areas	4,702	12.9	1,531	4.2	3,171	**67%**
	SSTS	663	1.8	0	0.0	663	**100%**
	Upstream Lakes	478	1.3	478	1.3	0	**0%**
	Atmosphere	152	0.4	152	0.4	0	**0%**
	Internal Load	2,837	7.8	147	0.4	2,690	**95%**
	MOS	--	--	124	0.3	--	**--**
	TOTAL	**8,879**	**24.3**	**2,479**	**6.7**	**6,524**	**72%**

Table 4.15. TMDL allocations for Spring Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	0.9	0.002	0.9	0.002	0	**0%**
Load	Drainage Areas	87	0.2	62	0.2	26	**29%**
	SSTS	126	0.3	0	0.0	126	**100%**
	Upstream Lakes	38	0.1	38	0.1	0	**0%**
	Atmosphere	52	0.1	52	0.1	0	**0%**
	Internal Load	474	1.3	166	0.5	308	**65%**
	MOS	--	--	17	0.05	--	**--**
	TOTAL	**777.9**	**2.002**	**335.9**	**0.952**	**460**	**57%**

Table 4.16. TMDL allocations for Big Swan Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	%
Wasteload	Construction & Industrial Stormwater	38	0.1	38	0.1	0	**0%**
Load	Drainage Areas	3,750	10.3	1,194	3.3	2,556	**68%**
	SSTS	306	0.8	0	0.0	306	**100%**
	Upstream Lakes	2,526	6.9	1,059	2.9	1,466	**58%**
	Atmosphere	166	0.5	166	0.5	0	**0%**
	Internal Load	436	1.2	58	0.2	378	**87%**
	MOS	--	--	132	0.4	--	**--**
	TOTAL	**7,222**	**19.8**	**2,647**	**7.4**	**4,706**	**63%**

4.4 DEER CHAIN OF LAKES

4.4.1 Watershed Description

Ramsey Lake (DNR # 86-0120), Albert Lake (DNR # 86-0127), Light Foot Lake (DNR # 86-0122), Buffalo Lake (DNR # 86-0090) and Deer Lake (DNR # 86-010700) are located in the Mill Creek 12-digit HUC (070102040606). This chain of lakes is located completely within Wright County and is situated in the northeast portion of the North Fork Crow River Watershed (Figure 4.4).

Ramsey Lake is located south of the city of Maple Lake and is the farthest upstream impaired lake in the Deer Chain. Ramsey Lake has a relatively small drainage area (3,427 acres) that includes flow from Maple Lake and direct runoff from nearby rural and urban areas. Outflow from Ramsey Lake drains to Mill Creek, which flows southeast toward Buffalo Lake.

Albert Lake is a small lake east of the city of Buffalo. The Albert Lake has a very small watershed (304 acres) and is not located along the mainstem Mill Creek. Albert Lake outflows to the northeast to Light Foot Lake and Mill Creek. Light Foot Lake is situated downstream of Ramsey and Albert Lakes and receives a majority of its inflow from Mill Creek which drains the aforementioned impaired lake watersheds.

Buffalo Lake is located downstream of Light Foot along the western edge of the city of Buffalo. The Buffalo Lake drainage area includes outflow from Lake Pulaski to the northeast, direct runoff from the city of Buffalo and surrounding rural land and the Mill Creek watershed which enters through an inlet in the northwest corner of the lake. Outflow from Buffalo Lake is directed to a wide, slow-moving channel that flows southwest approximately 0.35 miles to Deer Lake. Deer Lake is the downstream most lake in the Mill Creek watershed and therefore receives a majority of its inflow from Buffalo Lake.

Predominant land use in the Deer Chain of Lakes is row crops (38%) and pastureland (19%). (See Figure 4.5 and Table 4.17.) Unlike other lake chains in the North Fork Crow Watershed, the Deer Lake chain has a higher percentage of urban land use (19%). The Cities of Maple Lake (population 2,088) and Buffalo (population 15,665) are the only moderately sized urban centers in the Deer Chain.

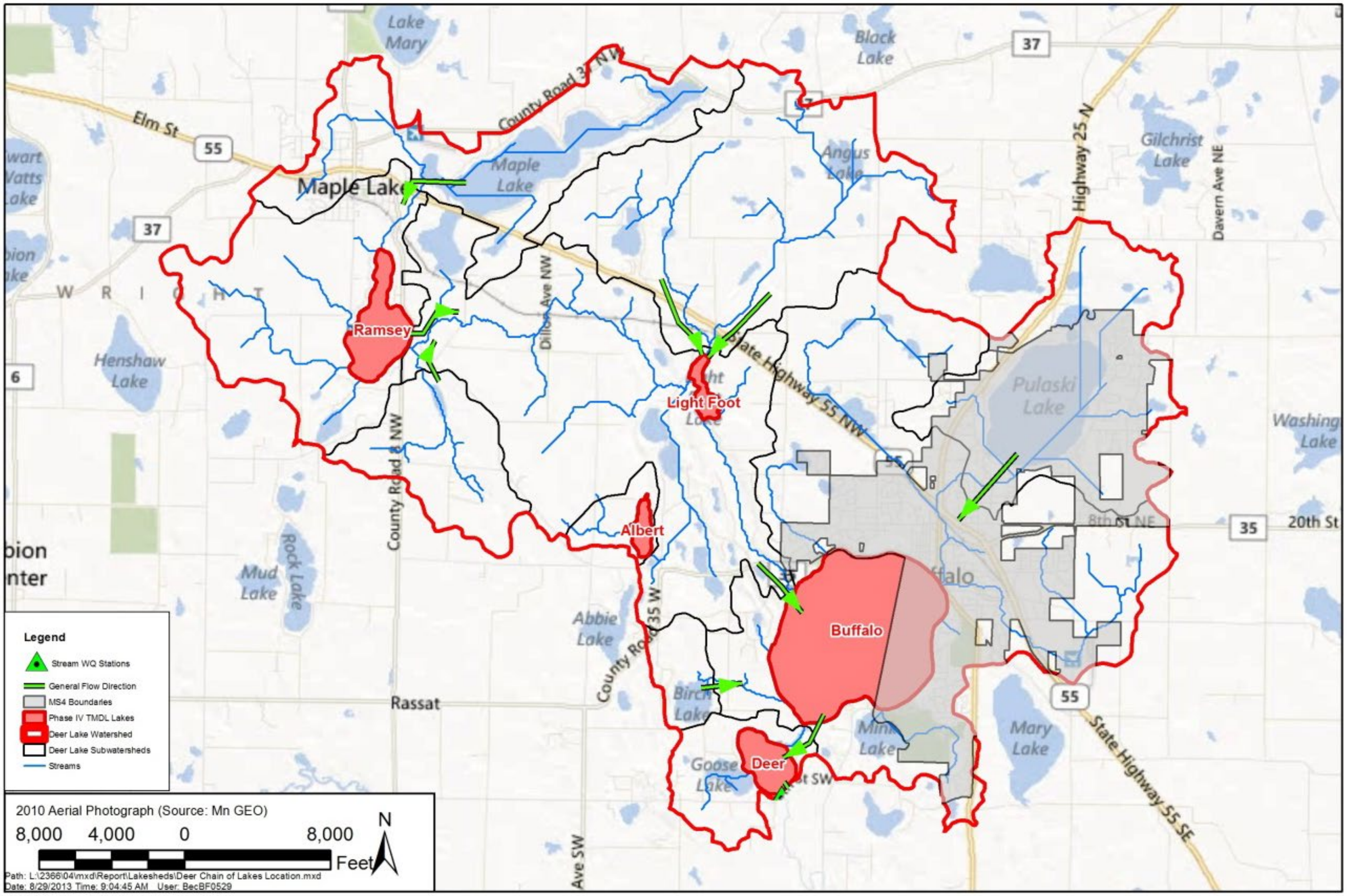


Figure 4.4. Flow pattern in the Deer Chain of Lakes TMDL study area.

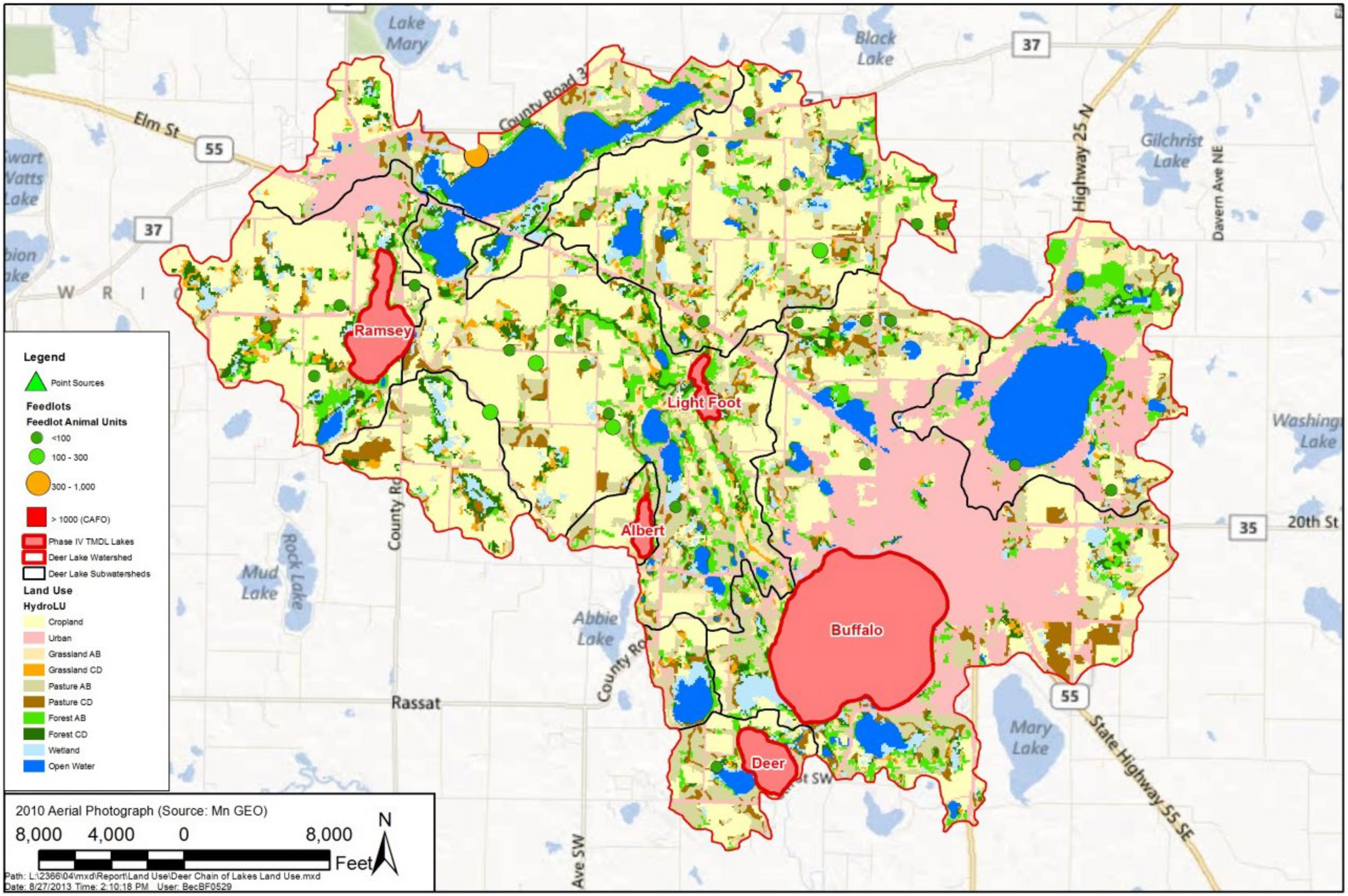


Figure 4.5. Land use in the Deer Chain of Lakes TMDL study area.

Table 4.17 Land use in the Deer Chain of Lakes TMDL study area in acres.

Lake		Urban	Forest	Cropland	Grassland	Pasture	Wetland	Feedlot	Total*
Deer	Acres	4,595	2,595	9,440	1,522	4,896	2,346	9	25,403
	Percentage	18%	10%	38%	6%	19%	9%	0%	100%
Buffalo	Acres	4,539	2,519	9,175	1,497	4,603	2,312	9	24,654
	Percentage	18%	10%	38%	6%	19%	9%	0%	100%
Light Foot	Acres	573	1,132	6,142	789	1,858	494	7	10,995
	Percentage	5%	11%	53%	8%	18%	5%	0%	100%
Ramsey	Acres	73	61	778	20	54	12	2	1,000
	Percentage	7%	6%	79%	2%	5%	1%	0%	100%
Albert	Acres	8	38	127	23	107	1	0	304
	Percentage	3%	12%	42%	8%	35%	0%	0%	100%

* Excludes Lake Surface

4.4.2 Lake Morphometry

All five impaired lakes in the Deer Chain are considered deep lakes meaning their maximum depth is greater than 15 feet and littoral area is less than 80% (Table 4.18). Light Foot and Deer Lakes have relatively short residence (less than 1 year) due to small lake volumes and relatively large drainage areas Ramsey, Albert and Buffalo Lakes, on the other hand, have smaller drainage areas and/or larger lake volumes and residence greater than one year.

Table 4.18 Lake morphometry for all impaired lakes in the study area.

Parameter	Surface Area	Average Depth	Maximum Depth	Lake Volume	Residence Time	Littoral Area	Depth Class	Drainage Area*
Water body	**acre**	**feet**	**feet**	**ac-ft**	**years**	**%**	**--**	**acre**
Deer	163	9	27	1,491	0.1	77	Deep	25,403
Buffalo	1,552	15	33	22,832	1.5	49	Deep	24,654
Light Foot	68	7	22	497	0.1	82	Deep	10,995
Ramsey	309	20	80	6,049	2.2	44	Deep	1,000
Albert	60	13	47	750	5.4	49	Deep	304

*** Excludes Lake Surface**

4.4.3 Historic Water Quality

Table 4.19 lists the June through September averages of TP concentration, chlorophyll-*a* (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 some cases, in-lake data was not available for all years of the 2002 to 2011 data sets.

Table 4.19. Deep 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 Deep Lakes		**40.0**	**14.0**	**1.4**
Ramsey	2002-2011	54.5	30.6	1.5
Light Foot	2008-2009	195.2	110.4	0.7
Albert	2002-2003	137	54	1.49
Buffalo	2006	81.8	59.3	0.7
Deer	2003-2006	79.4	53.5	1.1

4.4.4 Biological Conditions

Carp are present throughout the Deer lake chain of lakes with both Deer and Lightfoot susceptible to carp impacts (Table 4.20). Although most of these lakes are considered deep by state definitions, they all have large enough littoral areas that carp may be impacting water quality. Only minimal vegetation data are available, but Curly-leaf pondweed is present in Albert Lake.

Table 4.20. Aquatic vegetation and fisheries data for the Deer Chain of Lakes.

Lake	Recent Survey Month-Year	Curly Leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Ramsey	July-2008	--	--	Yes	Has a history of Walleye stocking; very small carp population
Light Foot	June-2008	--	No	Yes	Subject to winterkill; diverse plant population but only grew to 1.5 foot depth
Albert	July-2009	Yes	No	Yes	High abundance of carp
Buffalo	July-1993	--	--	Yes	Large rough fish population although dominated by bullheads
Deer	August-1993	--	--	Yes	Large rough fish population although dominated by bullheads

4.4.5 Nutrient Sources

The primary nutrient sources for the lakes are presented in Table 4.21.

Table 4.21. Nutrient sources for the lakes in this subwatershed.

Lake	Drainage Areas	SSTS	Upstream Lakes	Atmosphere	Internal Load
Ramsey	55%	23%	3%	3%	16%
Albert	14%	4%	--	3%	79%
Light Foot	63%	16%	6%	1%	14%
Buffalo	17%	6%	40%	3%	34%
Deer	3%	2%	75%	1%	19%

Ramsey Lake

Ramsey receives a fair amount of water from Maple Lake which has excellent water quality (summer average TP typically <25 µg/L). The SSTS load is surprisingly high despite the Maple Lake WWTF. The calculated internal release rate based on hypolimnetic mass balance suggests release rates as high as 22 mg/m^2/day, however lake data suggest that the majority of the internally released P is not making it to the epilmnion. Therefore the assumed internal release rate was 4 mg/m^2/day.

Albert Lake

Few data are available for Albert Lake and its watershed. Although the watershed is dominated by cropland, there are few animals in the watershed and runoff P concentrations are estimated to be around 200 µg/L . Internal loading is based on model residuals and the previously described regression for estimating anoxic factors. Based on the modeling, internal loading appears to be the dominant source of P to the lake, although the estimated release rate is very high at 20 mg/m^2/day. Internal release rates need to be verified prior to implementing internal load controls.

Light Foot Lake

The direct watershed (below Albert and Ramsey Lake) to Light Foot Lake has an exceptionally high number of animal units spread out in small animal feeding operations throughout the watershed. Since the HSPF model uses loading rates based on hydrozones, the additional phosphorus on the watershed from these animals is not accounted for in the estimated runoff concentrations. And since the current model results significantly under-predicted in-lake concentrations, a calibration factor of 2 was applied to watershed runoff concentrations. Internal loading, as estimated by model residual, was also relatively high comprising 43% of the P load to the lake.

Buffalo Lake

Buffalo Lake receives a large proportion of its phosphorus load from Light Foot Lake, so nutrient reductions should start there. Buffalo Lake also receives drainage from the City of Buffalo although this area represents less than 17% of the phosphorus load to the lake.

Deer Lake

Nutrient reductions to Deer Lake are almost wholly contingent upon reduced loading from Buffalo Lake. Nutrient reduction efforts need to start upstream prior to major efforts for Deer Lake. Deer Lake also appears to have a large internal phosphorus load that needs to be reduced.

4.4.6 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 4.22 through 4.26 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 4.22. TMDL allocations for Ramsey Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	%
Wasteload	Construction & Industrial Stormwater	12	0.03	12	0.03	0	**0%**
Load	Drainage Areas	1,142	3.1	756	2.1	386	**34%**
	SSTS	503	1.4	0	0.0	503	**100%**
	Upstream Lakes	72	0.2	72	0.2	0	**0%**
	Atmosphere	74	0.2	74	0.2	0	**0%**
	Internal Load	351	1.0	180	0.5	171	**49%**
	MOS	--	--	58	0.2	--	**--**
	TOTAL	**2,154**	**5.93**	**1,152**	**3.23**	**1,060**	**47%**

Table 4.23. TMDL allocations for Albert Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	1	0.002	1	0.002	0	**0%**
Load	Drainage Areas	77	0.2	32	0.1	45	**58%**
	SSTS	24	0.1	0	0.0	24	**100%**
	Atmosphere	14	0.04	14	0.04	0	**0%**
	Internal Load	434	1.2	22	0.1	412	**95%**
	MOS	--	--	4	0.01	--	**--**
	TOTAL	**550**	**1.542**	**73**	**0.252**	**481**	**87%**

Table 4.24. TMDL allocations for Light Foot Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	27	0.1	27	0.1	0	**0%**
Load	Drainage Areas	2,651	7.3	411	1.1	2,240	**84%**
	SSTS	679	1.9	0	0.0	679	**100%**
	Upstream Lakes	259	0.7	171	0.5	88	**34%**
	Atmosphere	15	0.01	15	0.01	0	**0%**
	Internal Load	578	1.6	21	0.1	557	**96%**
	MOS	--	--	33	0.1	--	**--**
	TOTAL	**4,209**	**11.61**	**678**	**1.91**	**3,564**	**84%**

Table 4.25. TMDL allocations for Buffalo Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	%
Wasteload	Construction & Industrial Stormwater	19	0.1	19	0.1	0	**0%**
	Buffalo City MS4	483	1.3	274	0.7	209	**43%**
Load	Drainage Areas	1,390	3.8	779	2.1	611	**44%**
	SSTS	613	1.7	0	0.0	613	**100%**
	Upstream Lakes	4,421	12.1	1,445	4.0	2,976	**67%**
	Atmosphere	371	1.0	371	1.0	0	**0%**
	Internal Load	3,732	10.2	643	1.8	3,090	**83%**
	MOS	--	--	186	0.5	--	**--**
	TOTAL	**11,029**	**30.2**	**3,717**	**10.2**	**7,499**	**66%**

Table 4.26. TMDL allocations for Deer Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction &Industrial Stormwater	1.6	0.004	1.6	0.004	0	**0%**
Load	Drainage Areas	153	0.4	143	0.4	11	**7%**
	SSTS	80	0.2	0	0.0	80	**100%**
	Upstream Lakes[1]	3,911	10.7	1,793	4.9	2,118	**54%**
	Atmosphere	39	0.1	39	0.1	0	**0%**
	Internal Load	1,011	2.8	220	0.6	791	**78%**
	MOS	--	--	116	0.3	--	**--**
	TOTAL	**5,195.6**	**14.204**	**2,312.6**	**6.304**	**3,000**	**55%**

1The Buffalo MS4 allocation is based on the Buffalo Lake allocation included in the upstream lake load. In other words, as long as Buffalo meets the allocation for Buffalo Lake, they meet the requirements for Deer Lake too.

4.5 WAVERLY CHAIN OF LAKES

4.5.1 Watershed Description

Howard Lake (DNR # 86-0199), Dutch Lake (DNR # 86-0184), Waverly Lake (DNR # 86-0114) and Little Waverly Lake (DNR # 86-0106) are located in the 12-Mile Creek 12-digit HUC (070102040605). This chain of lakes is located completely within Wright County in the southeast portion of the North Fork Crow River Watershed (Figure 4.6).

Howard Lake is located along the north end of the City of Howard Lake and is the furthest upstream impaired lake in the Little Waverly Chain. Dutch Lake is located less than a mile downstream of Howard Lake and has a relatively small direct watershed drainage area (3,427 acres) that includes runoff from the city of Howard Lake and nearby rural areas. A majority of the inflow to Dutch Lake is from Howard Lake and Mallard Pass, which is a small, shallow lake situated between Howard and Dutch Lakes.

Outflow from Dutch Lake drains to a small unnamed tributary that travels a short distance to 12-Mile Creek, which flows northeast toward Little Waverly Lake. Waverly Lake is a moderately sized deep lake located on the north end of the city of Waverly. Waverly Lake has a relatively small drainage area (1,674 acres) and does not receive inflow from 12-Mile Creek. The Waverly Lake watershed is comprised of outflow from Carrigan Lake to the southeast, direct runoff from the City of Waverly and surrounding rural land.

Waverly Lake outlets to a small channel on the west end of the lake, where it travels a short distance to Little Waverly Lake. Little Waverly Lake is the dowsnstream most lake in the 12-Mile Creek watershed and therefore receives a majority of its inflow from 12-Mile Creek and the aforementioned upstream lakes. Ann and Emma Lakes, located in the south central portion of the 12-Mile Creek watershed, are the only other impaired lakes in the Little Waverly Chain of Lakes.

Ann and Emma lakes were part of a separate TMDL study completed in 2012 (Wenck Associates, 2012) along the 12-Mile Creek main-stem. Predominant land use in the Little Waverly Chain of Lakes is row crops (55%), pasture (17%) and urban land (13%) while all other land uses account for less than 10% of the total (Figure 4.7 and Table 4.27). The cities of Howard Lake (population 1,962) and Waverly (population 1,356), are the only moderately sized urban centers in the Little Waverly Chain.

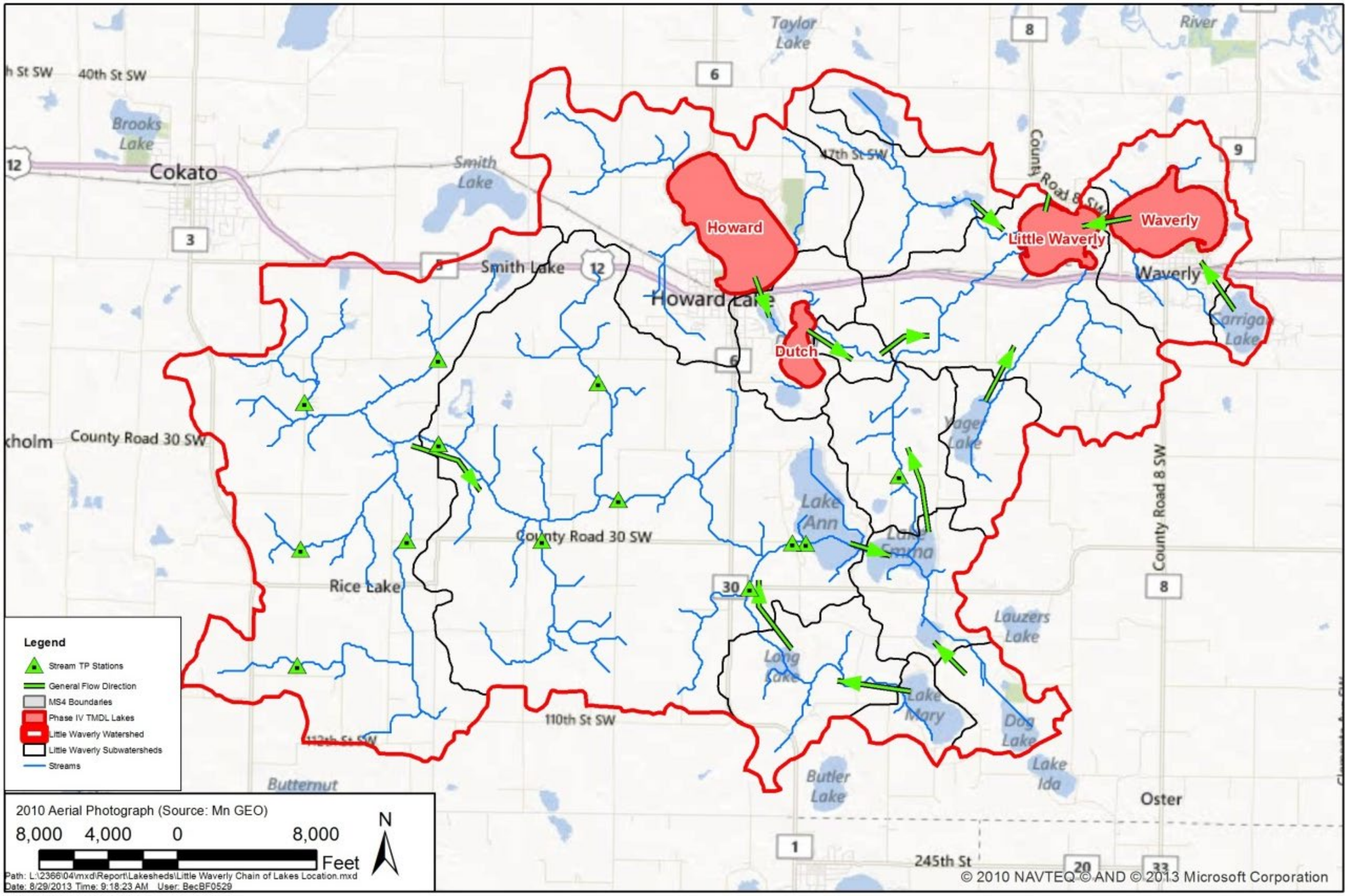


Figure 4.6. Flow pattern in the Little Waverly Chain of Lakes TMDL study area.

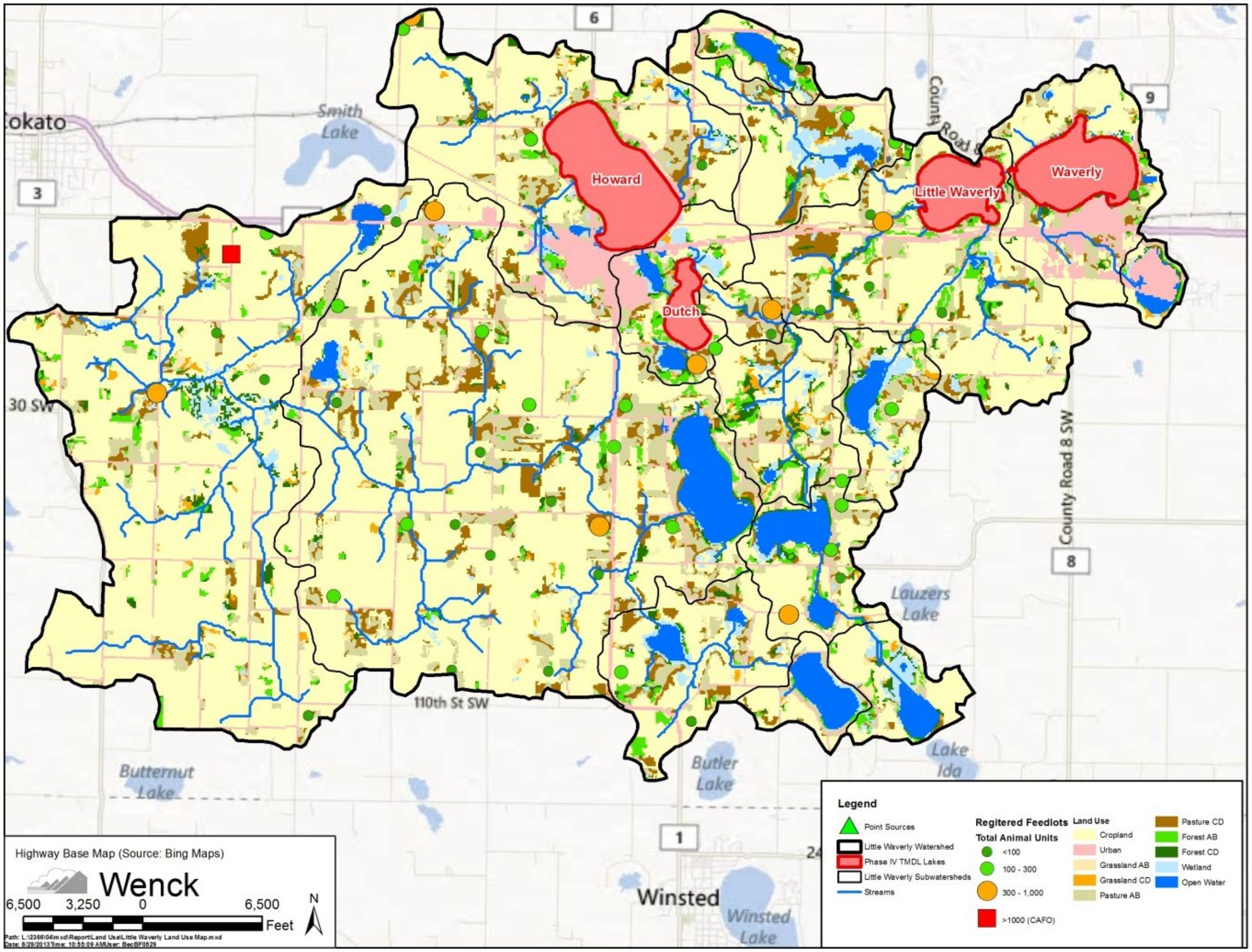


Figure 4.7. Land use in the Little Waverly Chain of Lakes TMDL study area.

Table 4.27. Land use in the Little Waverly Chain of Lakes TMDL study area in acres.

Lake		Urban	Forest	Cropland	Grassland	Pasture	Wetland	Feedlot	Total
Little Waverly	Acres	1,403	712	5,984	243	1,847	793	13	10,995
	Percentage	13%	6%	55%	2%	17%	7%	0%	100%
Waverly	Acres	484	105	735	37	246	67	0	1,674
	Percentage	29%	6%	44%	2%	15%	4%	0%	100%
Dutch	Acres	687	258	2,503	92	665	208	9	4,422
	Percentage	16%	6%	56%	2%	15%	5%	0%	100%
Howard	Acres	497	152	2,193	56	539	95	3	3,535
	Percentage	14%	4%	62%	2%	15%	3%	0%	100%

4.5.2 Lake Morphometry

Waverly, Howard and Dutch Lakes are considered deep lakes with maximum depths greater than 15 feet and littoral area is less than 80% (Table 4.28). For this TMDL, Little Waverly Lake is the only impaired shallow lake in this chain and has a maximum depth of 12 feet and is 100% littoral. Little Waverly Lake has a very short residence time of 0.2 years meaning the lake, on average flushes once every 58 days. Dutch, Howard and Waverly Lakes, on the other hand, all have residence greater than one year.

Table 4.28 Lake morphometry for all impaired lakes in the study area.

Parameter	Surface Area	Average Depth	Maximum Depth	Lake Volume	Littoral Area	Residence Time	Depth Class	Drainage Area*
Water body	**acre**	**feet**	**feet**	**ac-ft**	**%**	**years**	**--**	**acre**
Little Waverly	330	6	12	2,113	100	0.2	Shallow	10,995
Waverly	485	25	71	12,246	29	9.7	Deep	1,674
Dutch	161	10	21	1,637	69	1.1	Deep	4,422
Howard	736	16	39	12,018	43	4.5	Deep	3,535

* Excludes Lake Surface

4.5.3 Historic Water Quality

Tables 4.29 and 4.30 list the June through September averages of TP concentration, chlorophyll-*a* (chl-*a*) concentration, and Secchi depth for each impaired lake. The tables also list the data years which were used to calculate the "average" condition for the TMDL study. In some cases, in-lake data was not available for all years of the 2002 to 2011 data sets.

Table 4.29. Deep 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 Deep Lakes		**40.0**	**14.0**	**1.4**
Dutch	2004-2011	167	57.8	0.6
Howard	2002-2011	81.1	32.3	1.3
Waverly	2002-2011	41.4	18.8	2.0

Table 4.30. 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**
Little Waverly	2002-2011	410.8	63.1	0.8

4.5.4 Biological Conditions

Little Waverly is the only shallow lake in the chain and it sits at the bottom of the chain of lakes (Figure 4.6). Carp are abundant throughout the chain and are likely impacting water quality in Little Waverly Lake (Table 4.31). Curly-leaf pondweed is present throughout the chain but the relative abundance in each lake is unknown.

Table 4.31 Aquatic vegetation and fisheries data for the Waverly Chain of Lakes.

Lake	Recent Survey Month-Year	Curly Leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Little Waverly	July-2004	Yes	--	Yes	Carp are abundant
Waverly	June-2004	Yes	Yes	Yes	
Dutch	July-2006	Yes	Yes	Yes	Eurasian Milfoil discovered but was not noted in survey
Howard	Aug-2006	Yes	Yes	Yes	Carp make up a small portion of fish biomass and count

4.5.5 Nutrient Sources

Primary nutrient sources for lakes in the Waverly Chain of Lakes are presented in Table 4.32. All of the lakes have significant internal loads. Loading from SSTSs were also relatively important.

Table 4.32. Nutrient sources for lakes in the Waverly Chain of Lakes.

Lake	Drainage Areas	SSTS	Upstream Lakes	Atmosphere	Internal Load
Howard	26%	3%	--	4%	67%
Dutch	33%	8%	1%	2%	56%
Waverly	37%	15%	3%	8%	37%
Little Waverly	22%	23%	2%	1%	52%

<u>Howard Lake</u>

Nutrient loading in Howard Lake is dominated by internal loading representing 67% of the total P load to the lake. Annual TP plots demonstrate a consistent increase in surface TP at fall turnover suggesting a large mass of P accumulates in the hypolimnion.

<u>Dutch Lake</u>

Dutch Lake historically received effluent from the Howard Lake WWTF which has now been discontinued and moved to the Annandale/Maple Lake/Howard Lake WWTF (MN0066966). The discharge P load is included in the current conditions model since this was in effect through 2011, but was removed for the TMDL. Internal loading is the dominant source for Dutch Lake, likely a result of years of high external loading including effluent from the Howard Lake WWTF. Carp are also present in Dutch Lake and Mallard Pass which is likely contributing to water quality problems in the lake.

<u>Waverly Lake</u>

Waverly Lake barely exceeds the State standard for TP (40 µg/L) with a long term summer average TP around 42 µg/L. One source of P to the lake is Carrigan Lake which drains to Waverly Lake. Improving water quality in Carrigan Lake is critical to meeting water quality standards in Waverly Lake. The remaining reductions can be achieved through watershed load reductions including eliminating SSTSs.

<u>Little Waverly Lake</u>

Little Waverly Lake demonstrates extremely high in-lake TP concentrations with a long term average TP concentration of 411 µg/L as a summer average. Because the HSPF model applies loading rates across entire hydrozones, the watershed runoff concentrations are likely under-predicted for the watershed and a calibration factor was applied so that concentrations were similar to inflows to Ann Lake. Internal release rates were estimated at 30 mg/m2/day, which is extremely high even for hypereutrophic lakes. Settling in the lake was also assumed to be very small in order to get the model to predict in lake concentrations. Because of these factors, the uncertainty in the split between external and internal loads is relatively high and monitoring is needed to verify model inputs.

4.5.6 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 4.33 through 4.36 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 4.33. TMDL allocations for Howard Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	13	0.03	13	0.03	0	**0%**
Load	Drainage Areas	1,262	3.5	676	1.9	586	**46%**
	Septic Systems	166	0.5	0	0	166	**100%**
	Atmosphere	176	0.5	176	0.5	0	**0%**
	Internal Load	3,358	9.2	622	1.7	2,736	**81%**
	MOS	--	--	31	0.1	--	--
	TOTAL	**4,975**	**13.73**	**1,518**	**4.23**	**3,488**	**69%**

Table 4.34. TMDL allocations for Dutch Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	7	0.02	7	0.02	0	**0%**
Load	Drainage Areas	719[3]	2.0	75	0.2	644	**90%**
	Upstream Lakes	166	0.5	90	0.2	76	**46%**
	Septic Systems	16	0.04	0	0	16	**100%**
	Atmosphere	39	0.1	39	0.1	0	**0%**
	Internal Load	1,234	3.4	48	0.1	1,187	**96%**
	MOS	--	--	14	0.04	--	--
	TOTAL	**2,181**	**6.06**	**273**	**0.66**	**1,923**	**87%**

[3]The watershed load includes historical Howard Lake WWTF load which no longer discharges to Dutch Lake.

Table 4.35. TMDL allocations for Waverly Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	%
Wasteload	Construction & Industrial Stormwater	5	0.01	5	0.01	0	**0%**
Load	Drainage Areas	513	1.4	444	1.2	64	**13%**
	Upstream Lakes	204	0.6	123	0.3	82	**40%**
	SSTS	39	0.1	0	0	39	**100%**
	Atmosphere	116	0.3	116	0.3	0	**0%**
	Internal Load	534	1.5	534	1.5	0	**0%**
	MOS	--	--	64	0.2	--	--
	TOTAL	**1,411**	**3.91**	**1,286**	**3.51**	**185**	**9%**

Table 4.36. TMDL allocations for Little Waverly Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	33	0.1	33	0.1	0	**0%**
Load	Drainage Areas	3,245	9.0	420	1.1	2,825	**86%**
	Upstream Lakes	3,484	9.5	1,478	4.0	2,006	**58%**
	SSTS	252	0.7	0	0	252	**100%**
	Atmosphere	79	0.2	79	0.2	0	**0%**
	Internal Load	7,903	21.6	120	0.3	7,784	**98%**
	MOS	--	--	112	0.3	--	--
	TOTAL	**14,996**	**41.0**	**2,242**	**6.0**	**12,867**	**85%**

4.6 RICHARDSON/DUNNS, HOPE/LONG AND NEST LAKES

4.6.1 Watershed Description

Richardson Lake (DNR# 47-0088) and Dunns Lake (DNR# 47-0082) are located in the County Ditch #36 12-digit HUC (070102040403). These lakes and their watersheds are located completely within Meeker County in the central portion of the North Fork Crow River Watershed (Figure 4.8). Richardson Lake is a relatively small deep lake located upstream of Dunns Lake. A majority of the inflow to Richardson Lake comes from County Ditch #36 which enters the south end of the lake. Richardson has a small direct watershed that drains rural land around the lake. Dunns Lake is hydrologically connected to Richardson through a small wetland channel that flows between the two lakes and enters Dunns on the northwest corner of the lake. Similar to Richardson, Dunns has a small direct watershed (500 acres) and receives most of its inflow from Richardson Lake. Predominant land use in the Richardson/Dunns watershed is row crops (70%), pasture (12%) and urban land (5%) while all other land uses account for less than 10% of the total (Figure 4.10, Table 4.37). There are no cities or urban centers located in the Richardson/Dunns watershed.

Hope Lake (DNR# 47-0183) and Long Lake (DNR# 47-0177) are located in the Long Lake 12-digit HUC (070102040301). The Hope and Long Lake watersheds are located completely within Meeker County in the south central portion of the North Fork Crow River Watershed (Figure 4.8). Hope Lake is a small shallow lake located upstream of Long Lake. The Hope Lake drainage area includes outflow from Harold and Thoen Lakes to the northeast and direct runoff from rural area surrounding the lake. Long Lake is hydrologically connected to Hope through a small wetland between the two lakes. Inflow to Long Lake is split between flow from Hope Lake, runoff from its direct watershed and County Ditch 26 which drains approximately 9,448 acres of land west of Long Lake. Predominant land use in the Hope/Long Lake watershed is row crops (67%), forest (10%) and wetland (10%) while all other land uses account for less than 10% of the total (Figure 4.10 and Table 4.37). There are no cities or urban centers located in the Hope/Long Lake Watershed.

Nest Lake (DNR# 34-0154) has a large watershed that includes five 12-digit HUC subwatersheds: County Ditch # 37 (070102040203), County Ditch #B6 (070102040202), Middle Fork Crow River headwaters (070102040201), Mud Lake (070102040204) and Nest Lake (070102040205). Nest Lake is located completely within Kandiyohi County, but its watershed includes portions of Stearns and Pope county as well (Figure 4.9) A majority of the inflow to Nest Lake comes from Mud Lake which is located approximately 3 miles upstream of Nest Lake and is made up of a series of hydrologically connected shallow lakes, wetlands and channels. Nest Lake's watershed downstream of Mud Lake includes flow from the Middle Fork Crow River that enters the north basin of the lake, inflow from George Lake and a large wetland complex west of the lake as well as runoff from urban and rural areas in Nest Lake's direct watershed. Predominant land use in the Nest Lake watershed is row crops (48%), forest (14%) and urban land (13%) while all other land uses account for less than 10% of the total (Figure 4.11 and Table 4.37). The cities of Belgrade (population 740) and New London (population 1,251) are the only moderately sized urban centers in the Nest Lake Watershed.

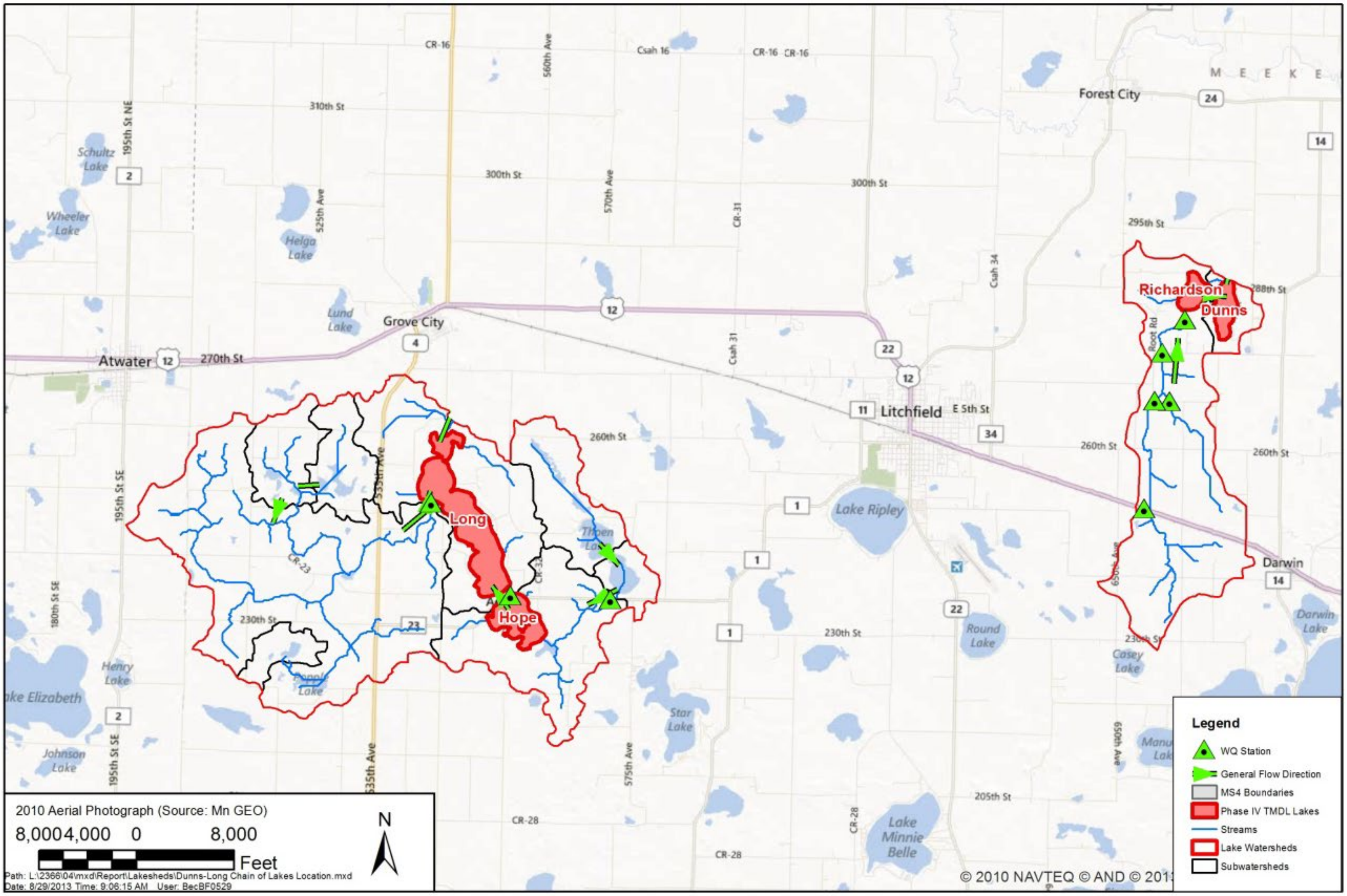


Figure 4.8. Flow patterns in the Dunns and Long Chain of Lakes study areas.

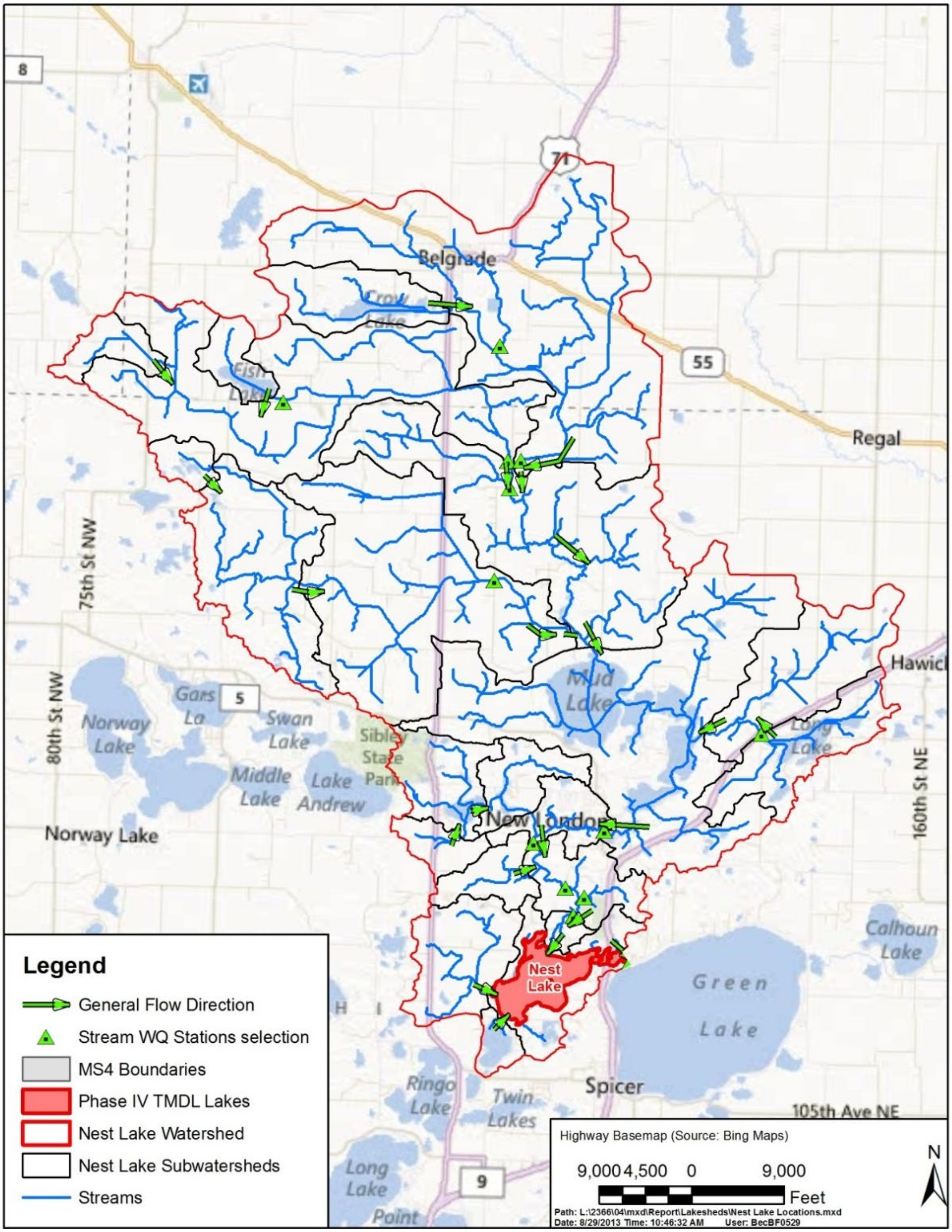


Figure 4.9. Flow pattern in the Nest Lake TMDL study area.

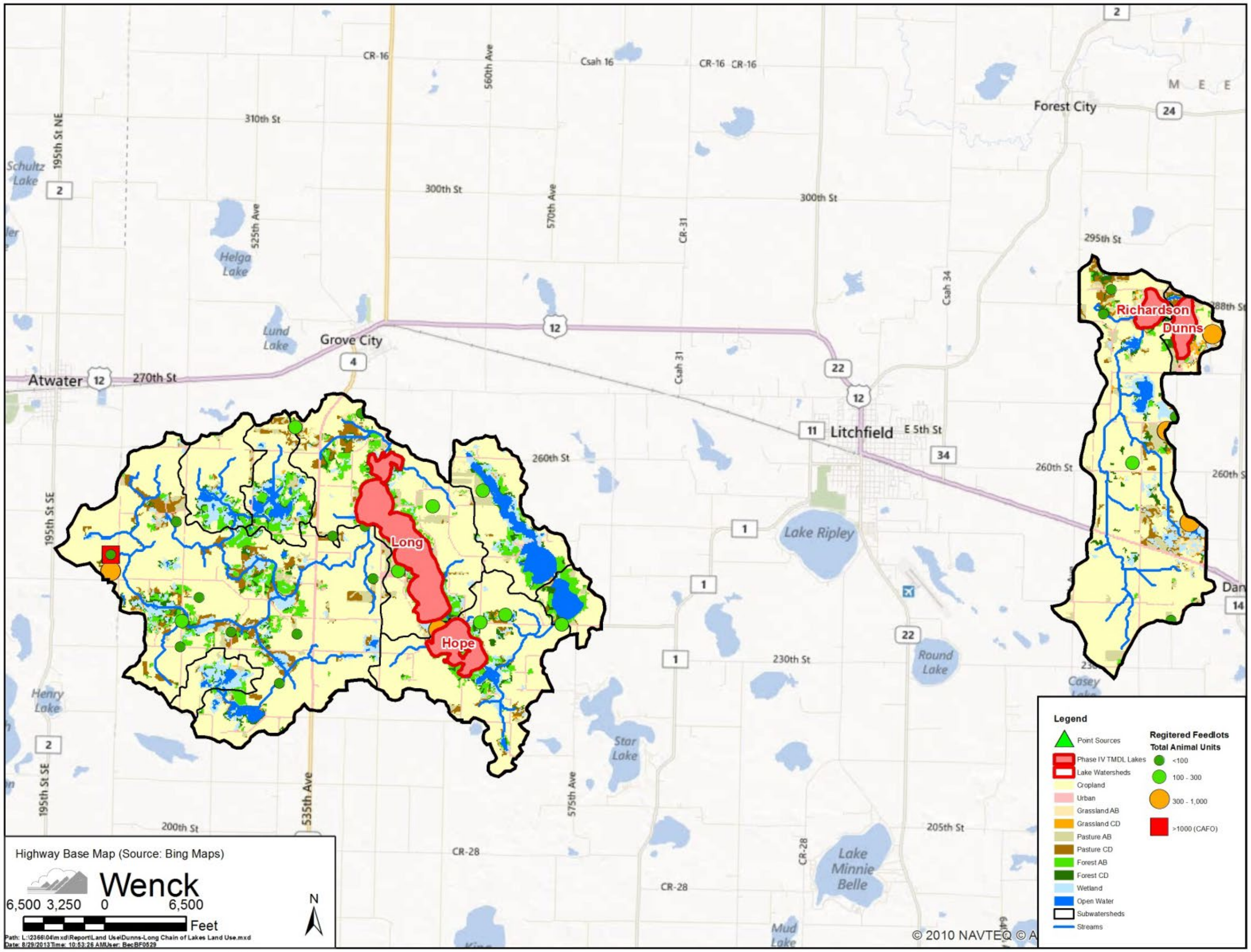


Figure 4.10. Land use in the Dunns and Long Chain of Lakes TMDL study areas.

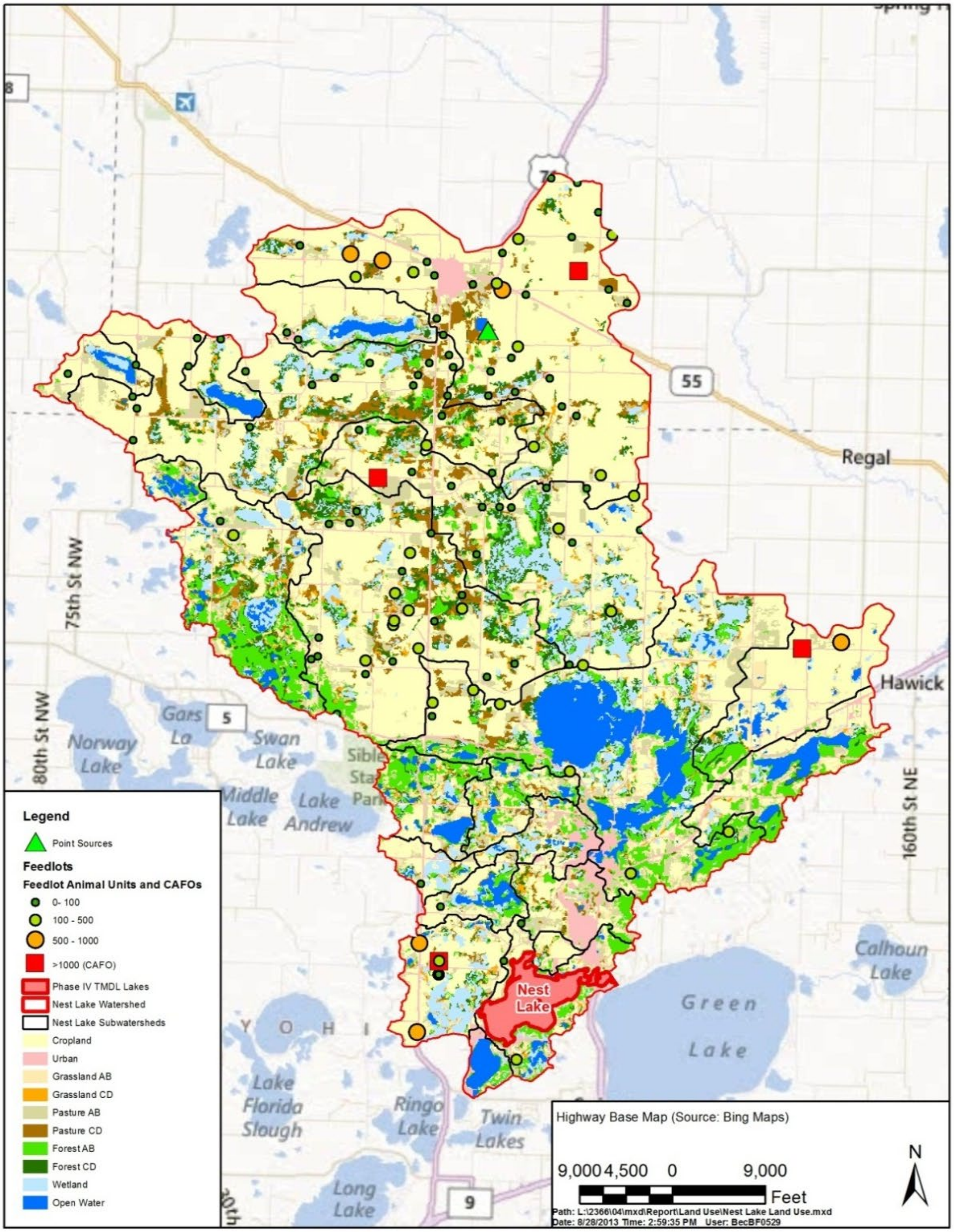


Figure 4.11. Land use in the Nest Chain of Lakes TMDL study areas

Table 4.37. Land use in the Nest Lake, Dunns and Richardson, and Hope and Long TMDL study area.

Lake		Urban	Forest	Cropland	Grassland	Pasture	Wetland	Feedlot	Total
Dunns	Acres	247	241	3,718	146	605	280	9	5,246
	Percentage	5%	5%	70%	3%	12%	5%	<1%	100%
Richardson	Acres	214	181	3,584	109	542	260	6	4,896
	Percentage	4%	4%	75%	2%	11%	5%	<1%	100%
Hope	Acres	723	1,646	11,267	164	1,418	1,680	29	16,927
	Percentage	4%	10%	67%	1%	8%	10%	<1%	100%
Long	Acres	158	446	2,754	45	236	569	5	4,213
	Percentage	4%	11%	65%	1%	6%	13%	<1%	100%
Nest	Acres	4,515	10,647	35,661	5,678	9,355	8,165	118	74,139
	Percentage	6%	14%	48%	8%	13%	11%	<1%	100%

Note: Water surface land use not included

4.6.2 Lake Morphometry

Long and Hope Lakes both have maximum depths less than 15 feet and are considered shallow lakes. Nest, Dunns and Richardson Lakes are considered deep lakes and have maximum depths over 15 feet and less than 80% littoral coverage. Hope, Long and Nest Lakes have short residence (less than 1 year) due to their large drainage areas compared to their lake volumes. Richardson and Dunns Lakes, on the other hand, are deeper lakes with relatively small drainage areas and residence greater than one year Table 4.38).

Table 4.38. Lake morphometry for all impaired lakes in the study area.

Parameter	Surface Area	Average Depth	Maximum Depth	Lake Volume	Residence Time	Littoral Area	Depth Class	Entire Lake Drainage Area*
Water body	**acre**	**feet**	**feet**	**ac-ft**	**years**	**%**	**--**	**acre**
Dunns	152	12	20	1,773	1.6	56	Deep	5,426
Richardson	116	20	47	2,343	2.2	39	Deep	4,896
Hope	250	6	10	1,466	0.6	100	Shallow	16,927
Long	771	6	11	4,637	0.3	100	Shallow	4,213
Nest	1,008	14	40	14,498	0.5	52	Deep	74,139

*** Excludes Lake Surface**

4.6.3 Historic Water Quality

Tables 4.39 and 4.40 list the June through September averages of TP concentration, chlorophyll-*a* (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 some cases, in-lake data was not available for all years of the 2000 to 2011 data sets.

Table 4.39. Deep 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 Deep Lakes		**40.0**	**14.0**	**1.4**
Richardson	2000; 2003	103.4	34.8	1.4
Dunns	2000-2003	112.2	56.0	0.7
Nest	2004-2011	41.9	20.0	1.8

Table 4.40. 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**
Hope	2006; 2008	223.5	234	0.2
Long	2003-2009	269.4	238.1	0.3

4.6.4 Biological Conditions

Carp are present in all of the lakes, but at very low densities in Nest Lake (Table 4.41). Hope and Long Lakes are the most sensitive to carp populations. Curly-leaf pondweed is present in all of the lakes except Long and Dunns.

Table 4.41. Aquatic vegetation and fisheries data.

Lake	Recent Survey Month-Year	Curly Leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Richardson	June-2006	Yes	--	Yes	One pound of fingerlings stocked bi-yearly
Dunns	June-2008	No	No	Yes	Aquatic Vegetation Sparse
Hope	June-2004	Yes	--	Yes	Impressive number of Yellow Perch in 2004 survey
Long	July-2004	--	--	Yes	Fish population highly dependent on winter fishkills; Carp present in high density back to 1978
Nest	July-2008	Yes	--	Yes	Carp population low and not captured in recent survey; Abundant vegetation population

4.6.5 Nutrient Sources

Richardson and Dunn Lake are both deep lakes and Richardson flows into Dunn (Table 4.42). Loading to Richardson is predominantly watershed loading while Dunns is highly dependent on Richardson Lake. Long and Hope are connected shallow lakes that receive loading from both external and internal sources. Nest Lake receives phosphorus from both internal and external sources, but Mud Lake upstream of Nest Lake has good water quality and protects Nest Lake.

Table 4.42. Nutrient sources for lakes in the Dunns, Hope, and Nest Lake watersheds.

Lake	Drainage Areas	Point Sources	SSTS	Upstream Lakes	Atmosphere	Internal Load
Richardson	87%	--	6%	--	2%	5%
Dunns	2%	--	22%	28%	3%	45%
Long	52%	--	1%	5%	1%	41%
Hope	39%	--	1%	--	1%	59%
Nest	21%	15%	5%	35%	3%	21%

Richardson and Dunns

Richardson and Dunns Lake are connected deep lakes, although Dunns has a large littoral area. The predominant phosphorus load for these lakes is from watershed loading upstream of Richardson Lake. There are a large amount of chicken and turkey animal units in the watershed. Manure from these operations likely end up on the watershed and may be contributing to nutrient loading.

Long and Hope

Long and Hope Lake are connected shallow lakes with a mostly agricultural watershed. There are a large number of animal units in the watershed that can produce large amounts of phosphorus in applied manure. Manure management should be investigated as well as internal loading.

Nest

Nest Lake is a deep lake with a large watershed that is a mix of wetlands and agriculture. Monitoring data show that water quality is very good down through Mud Lake and degrades as it gets closer to Nest Lake. Further source assessments should focus on the wetland to the west of Nest Lake as well as the drainage area between Mud Lake and Nest Lake. No reductions were required for the Belgrade WWTF since it drains above Mud Lake and water quality in Mud Lake is better than State water quality standards. Internal load management will likely be necessary also to meet water quality standards.

4.6.6 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 4.43 through 4.47 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 4.43. TMDL allocations for Richardson Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	12	0.03	12	0.03	0	**0%**
Load	Drainage Areas	1,180	3.2	452	1.2	728	**62%**
	SSTS	84	0.2	0	0.0	84	**100%**
	Atmosphere	26	0.1	26	0.1	0	**0%**
	Internal Load	61	0.2	61	0.2	0	**0%**
	MOS	--	--	29	0.1	--	**5%**
	TOTAL	**1,363**	**3.73**	**580**	**1.63**	**812**	**57%**

Table 4.44. TMDL allocations for Dunns Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	0.3	0.001	0.3	0.001	0	**0%**
Load	Drainage Areas	25	0.1	17	0.1	8	**33%**
	SSTS	282	0.8	0	0	282	**100%**
	Upstream Lakes	354	1.0	113	0.3	241	**68%**
	Atmosphere	34	0.1	34	0.1	0	**0%**
	Internal Load	581	1.6	157	0.4	423	**73%**
	MOS	--	--	17	0.05	--	--
	TOTAL	**1,276.3**	**3.601**	**338.3**	**0.951**	**954**	**73%**

Table 4.45. TMDL allocations for Long Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	%
Wasteload	Construction & Industrial Stormwater	152	0.4	152	0.4	0	**0%**
Load	Drainage Areas	15,029	41.1	1,936	5.3	13,093	**86%**
	SSTS	354	1.0	0	0	354	**100%**
	Upstream Lakes	1,546	4.2	361	1.0	1,185	**77%**
	Atmosphere	184	0.5	184	0.5	0	**0%**
	Internal Load	11,886	32.5	276	0.8	11,610	**98%**
	MOS	--	--	153	0.4	--	**--**
	TOTAL	**29,151**	**79.7**	**3,062**	**8.4**	**26,242**	**89%**

Table 4.46. TMDL allocations for Hope Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	165	0.5	165	0.5	0	**0%**
Load	Drainage Areas	1,483	4.1	250	0.7	1,233	**83%**
	SSTS	61	0.2	0	0	61	**100%**
	Atmosphere	60	0.2	60	0.2	0	**0%**
	Internal Load	2,587	7.1	147	0.4	2,440	**94%**
	MOS	--	--	33	0.1		**5%**
	TOTAL	**4,356**	**13.2**	**655**	**1.9**	**3,734**	**85%**

Table 4.47. TMDL allocations for Nest Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	14	0.04	14	0.04	0	**0%**
	Belgrade WWTF	1,017	2.8	1,017	2.8	0	**0%**
Load	Drainage Areas	1,430	3.9	1,280	3.5	150	**10%**
	SSTS	368	1.0	0	0.0	368	**100%**
	Upstream Lakes	2,389	6.5	2,389	6.5	0	**0%**
	Atmosphere	241	0.7	241	0.7	0	**0%**
	Internal Load	1,444	4.0	747	2.0	697	**48%**
	MOS	--	--	299	0.8	--	**--**
	TOTAL	**6,903**	**18.94**	**5,987**	**16.34**	**1,215**	**13%**

4.7 COKATO CHAIN OF LAKES

4.7.1 Watershed Description

Brooks Lake (DNR # 86-0264), Smith Lake (DNR # 86-0250) and Cokato Lake (DNR # 86-0263) are located in the Cokato Lake 12-digit HUC (070102040603). This chain of lakes is located in the south-central portion of the North Fork Crow River Watershed and includes portions of three counties (Figure 4.12). Brooks Lake is a deep lake with an extremely small watershed (215 acres) located in Wright County on the north end of the city of Cokato. Drainage to Brooks Lake is made up mostly of urban runoff from the city of Cokato and surrounding agricultural land. Smith Lake is a shallow lake located in Wright County about three miles east of Brooks Lake and the city of Cokato. Smith Lake also has a small watershed (1,337) that primarily drains surrounding agricultural land. Outflow from Brooks and Smith Lakes drain to Sucker Creek which is the primary stream/ditch that flows through the Cokato Chain of Lakes (Figure 4.12). Cokato Lake is also located in Wright County north of Brooks and Smith Lakes. Cokato Lake is the downstream most lake in the Cokato Chain and receives a majority of its inflow from Sucker Creek whose watershed drains approximately 25,000 acres of land in Meeker, McLeod and Wright Counties. Inflow from Sucker Creek includes direct runoff to the creek and outflow from Brooks, Smith, Byron and Shakopee Lakes. Byron and Shakopee are non-impaired lakes with small watersheds located near the headwaters of Sucker Creek on the boarder of Meeker/McLeod (Byron) and Wright/McLeod (Shakopee) Counties. Predominant land use in the Cokato Lake Chain is row crops (74%) and pastureland (11%) while all other land uses account for less than 10% of the total (Figure 4.13 and Table 4.48). Urban land accounts for only 7% of the land use in the Cokato Chain. The City of Cokato, located near Brooks Lake, has a population of approximately 2,694 people and is the only moderately sized urban area in the Cokato Chain.

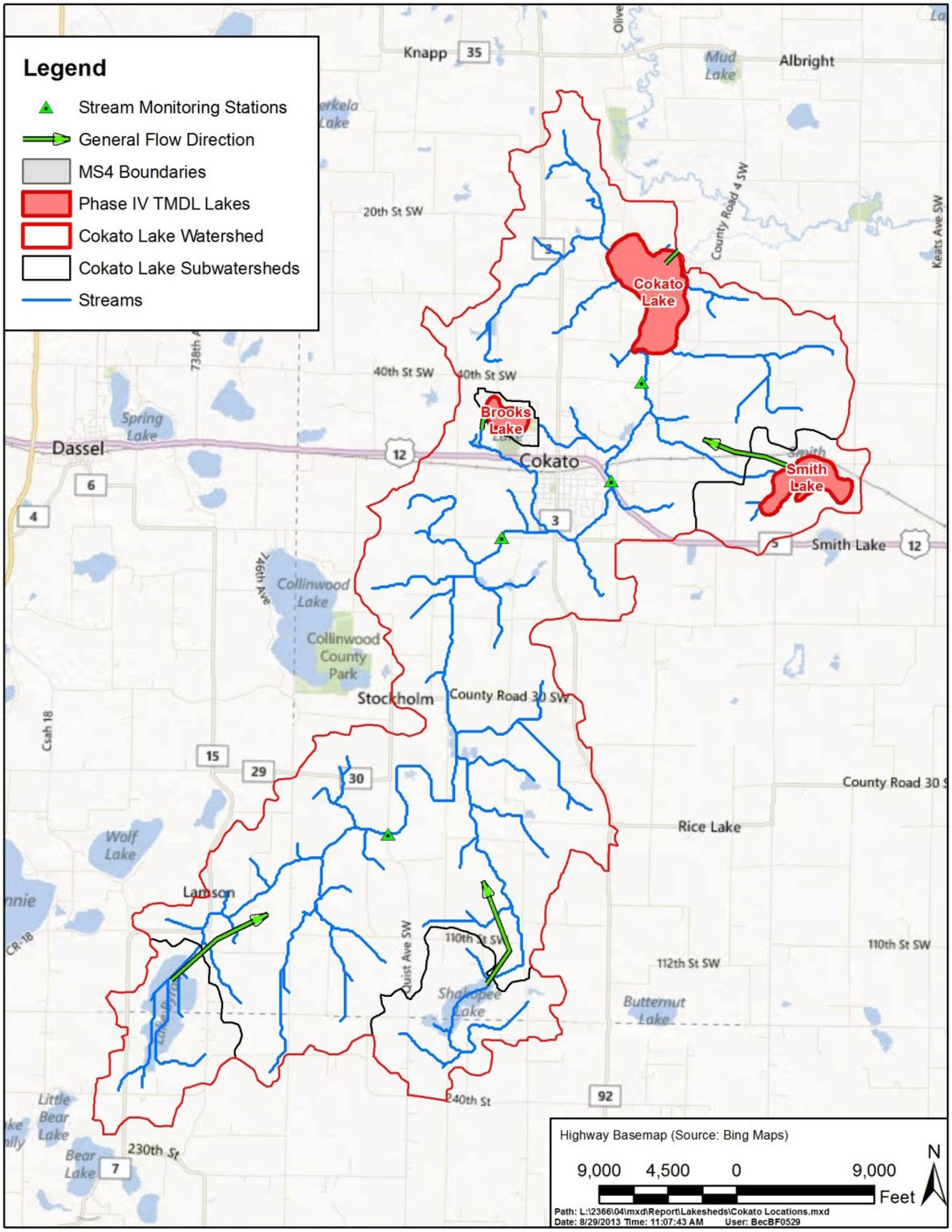


Figure 4.12. Flow pattern in the Cokato Chain of Lakes TMDL study area.

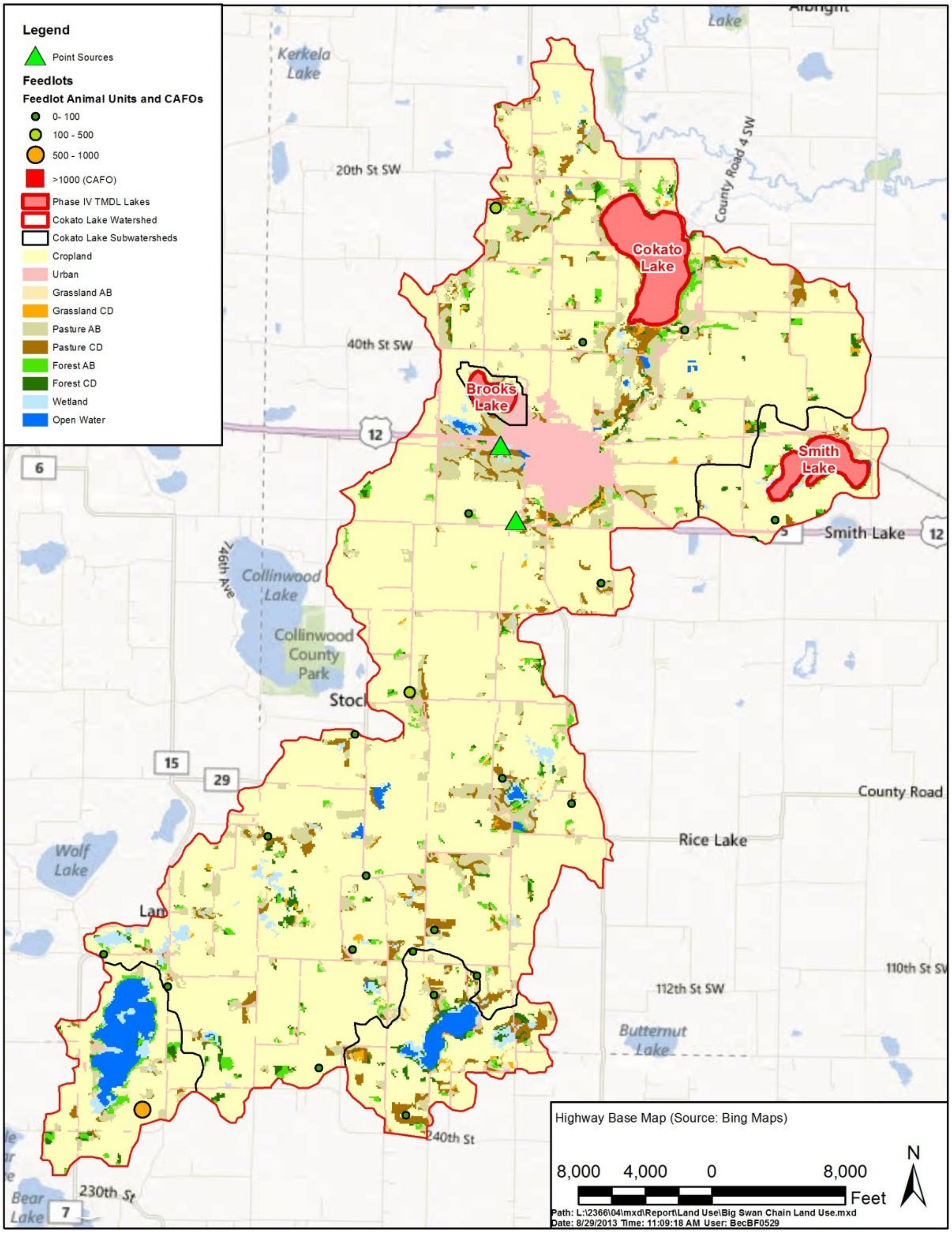


Figure 4.13. Land use in the Cokato Chain of Lakes TMDL study area.

Table 4.48 Land use in the Cokato Chain of Lakes TMDL study area in acres.

Lake		Urban	Forest	Cropland	Grassland	Pasture	Wetland	Feedlot	Total
Cokato	Acres	1,962	906	21,784	476	3,321	1,073	13	29,535
	Percentage	7%	3%	73%	2%	11%	4%	0%	100%
Brooks	Acres	43	7	39	2	21	2	0	114
	Percentage	38%	6%	34%	2%	18%	2%	0%	100%
Smith	Acres	67	44	884	10	47	53	0	1,105
	Percentage	6%	4%	80%	1%	4%	5%	0%	100%

4.7.2 Lake Morphometry

Cokato and Brooks Lakes are considered deep lakes with maximum depths greater than 15 feet and littoral area less than 80% (Table 4.49). Smith Lake, with a maximum depth of 5 feet, is the only impaired shallow lake in the Cokato Chain. Brooks Lake has a very long residence time of 23.6 years due to its depth and extremely small drainage area. Cokato and Smith Lakes, on the other hand, have residence of 1.0 and 1.5 years, respectively.

Table 4.49 Lake morphometry for all impaired lakes in the study area.

Parameter	Surface Area	Average Depth	Maximum Depth	Lake Volume	Residence Time	Littoral Area	Depth Class	Entire Watershed Drainage Area*
Water body	**acre**	**feet**	**feet**	**ac-ft**	**years**	**%**	**--**	**acre**
Cokato	545	22	52	12,122	1.0	34	Deep	29,535
Brooks	96	11	21	1,097	23.6	61	Deep	114
Smith	226	4	5	815	1.5	100	Shallow	1,105

*** Excludes Lake Surface**

4.7.3 Historic Water Quality

Tables 4.50 and 4.51 list the June through September averages of TP concentration, chlorophyll-*a* (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 some cases, in-lake data was not available for all years of the 2005 to 2011 or 2000 to 2012 data sets.

Table 4.50. Deep 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 Deep Lakes		**40.0**	**14.0**	**1.4**
Cokato	2003-2007	56.0	22.5	1.9
Brooks	2007-2011	62.8	41.9	0.8

Table 4.51. 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**
Smith	2007; 2009	186.0	337.5	0.3

4.7.4 Nutrient Sources

Smith Lake is shallow lake with a large internal load (Table 4.52). Brooks and Cokato Lake are deep lakes, with Cokato Lake at the bottom of the chain and is just above state water quality standards. Nutrient reductions for Cokato Lake should focus on watershed sources.

Table 4.52. Nutrient sources for lakes in the Cokato watershed.

Lake	Drainage Areas	Point Sources	SSTS	Upstream Lakes	Atmosphere	Internal Load
Brooks	8%	--	8%	--	9%	75%
Smith	13%	--	1%	--	2%	84%
Cokato	68%	14%	13%	2%	2%	1%

Brooks Lake

Brooks Lake is a small deep lake with a largely agricultural drainage area. According to the HSPF model, watershed loading is fairly low, attributing the poor water quality to internal loading. Nutrient reductions should focus on internal load controls with bullhead population reductions.

Smith Lake

Smith Lake is a small shallow lake that has little data. However, the Minnesota DNR conducted a whole lake drawdown in 2012 in an effort to improve submerged aquatic vegetation and improve water quality. The lake should be monitored after the drawdown to determine any changes in water quality associated with the drawdown.

Cokato Lake

Cokato Lake has a large agricultural watershed that does not drain through a lot of lakes and wetlands. The watershed also contains a large number of animal units and likely receives large quantities of applied manure on an annual basis. Manure and agricultural management should be the focus of nutrient reductions for Cokato Lake.

4.7.5 Biological Conditions

Biological conditions in the Cokato Lake watershed are degraded with an abundance of carp and roughfish as well as Curly-leaf pondweed. Carp were monitored in in Cokato Lake but not captured in Brooks Lake, although Brooks Lake is dominated by rough fish (Table 4.53).

Table 4.53. Aquatic vegetation and fisheries data.

Lake	Recent Survey Month-Year	Curly Leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Brooks	2005	Yes	No	No	History of winterkill (last recorded in 1991-1992); Dominated by rough fish
Smith	--	--	--	--	A whole lake drawdown was conducted on Smith Lake in 2012.
Cokato	2007	Yes	No	Yes	Only four species of submerged plants present, which includes Curly leaf pondweed; No recorded fish kills

4.7.6 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 4.54 through 4.56 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 4.54. TMDL allocations for Brooks Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	0.2	0.001	0.2	0.001	0	**0%**
Load	Drainage Areas	18	0.05	7	0.02	11	**61%**
	SSTS	20	0.1	0	0.00	20	**100%**
	Atmosphere	21	0.1	21	0.1	0	**0%**
	Internal Load	177	0.5	69	0.2	108	**61%**
	MOS	--	--	5	0.01	--	**--**
	TOTAL	**236.2**	**0.751**	**102.2**	**0.331**	**139**	**57%**

Table 4.55. TMDL allocations for Smith Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	3	0.01	3	0.01	0	**0%**
Load	Drainage Areas	261	0.7	87	0.2	174	**67%**
	SSTS	18	0.1	0	0.0	18	**100%**
	Atmosphere	50	0.1	50	0.1	0	**0%**
	Internal Load	1,764	4.8	133	0.4	1,631	**92%**
	MOS	--	--	14	0.04	--	**--**
	TOTAL	**2,096**	**5.71**	**287**	**0.75**	**1,823**	**86%**

Table 4.56. TMDL allocations for Cokato Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	46	0.1	46	0.1	0	0%
	Fairibault Food	884	2.4	794	2.2	90	**10%**
	Drainage Areas	4,149	11.4	2,800	7.7	1,348	**32%**
Load	SSTS	799	2.2	0	0.0	799	**100%**
	Upstream Lakes	97	0.3	30	0.1	66	**69%**
	Atmosphere	130	0.4	130	0.4	0	**0%**
	Internal Load	77	0.2	77	0.2	0	**0%**
	MOS	--	--	204	0.6	--	**--**
	TOTAL	**6,182**	**17.0**	**4,081**	**11.3**	**2,303**	**34%**

4.8 INDIVIDUAL LAKES

4.8.1 Watershed Description

The remaining lakes are not contained within one HUC-12 watershed; however, they are positioned exclusively in the most eastern two HUC-10 watersheds in the North Fork Crow Watershed (0701020406 and 0701020407). These lakes and their watersheds are located completely within Wright County in the eastern portion of the North Fork Crow River Watershed (Figures 4.14, 4.16, 4.18, 4.20, and 4.22). Of the individual lakes, four are categorized shallow while eight are considered deep. The majority of these lakes are located in small watersheds that flow into the North Fork Crow River or the Crow River, depending which HUC-10 they are located in. The average predominant land use in the individual lake watersheds is row crops (46%), pasture (21%) and forest (14%) while all other land uses account for less than 10% of the total (Figures 4.15,4.17, 4.19, 4.21, 4.23; Table 4.57). There are no cities or urban centers located in any of the individual lake watersheds.

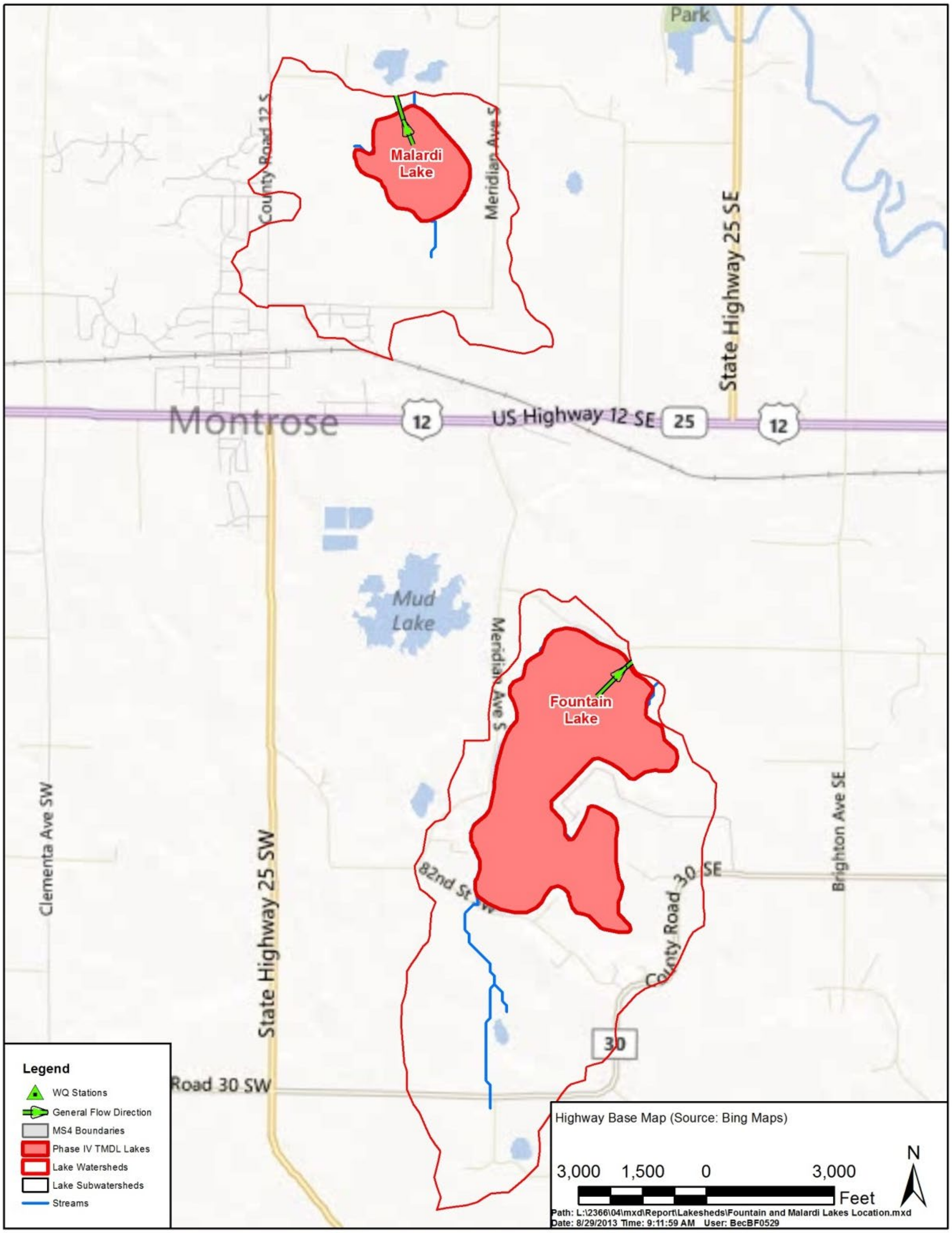


Figure 4.14. Flow pattern in the Malardi and Fountain Lake TMDL study areas.

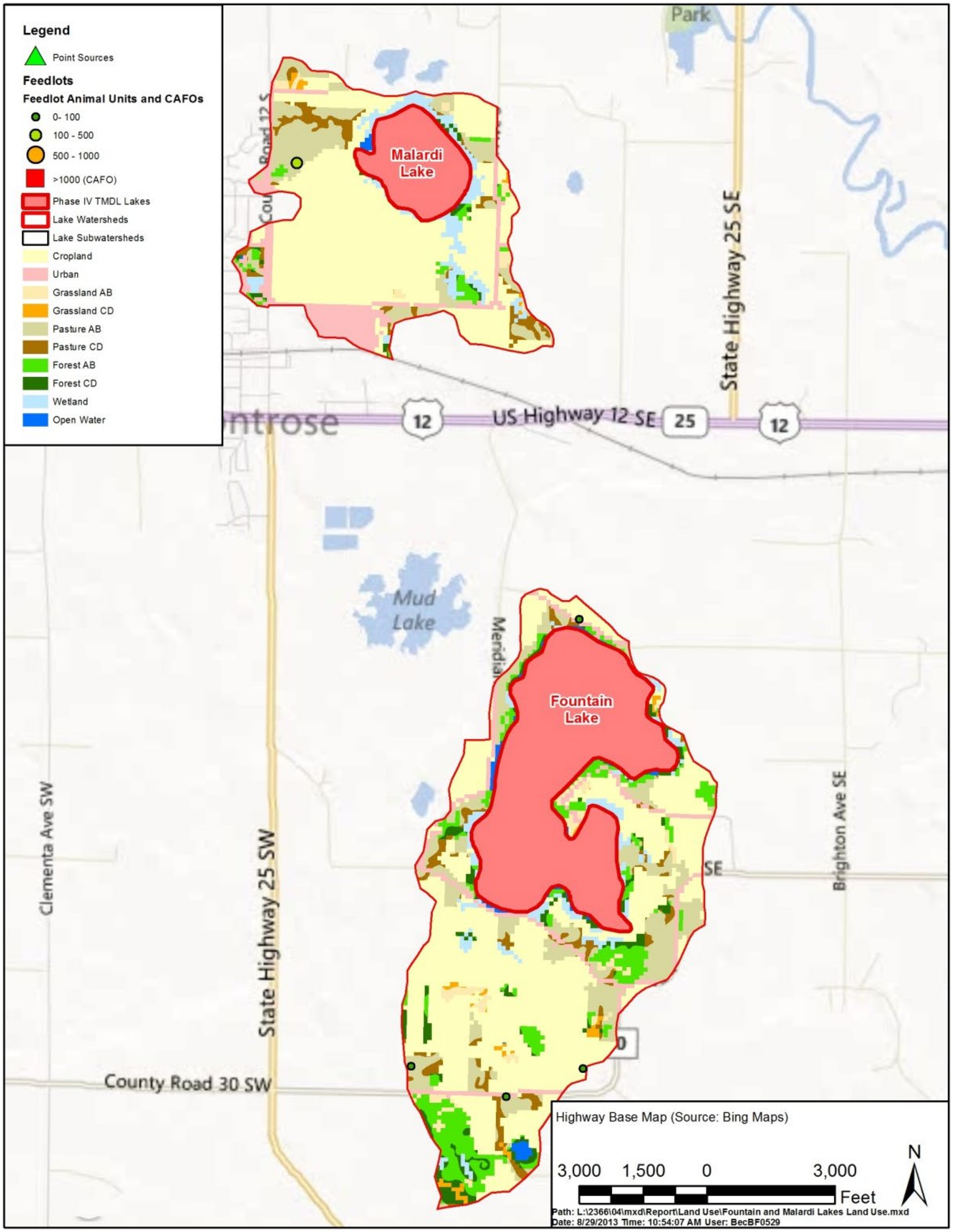


Figure 4.15. Land use in the Malardi and Fountain Lake TMDL study areas.

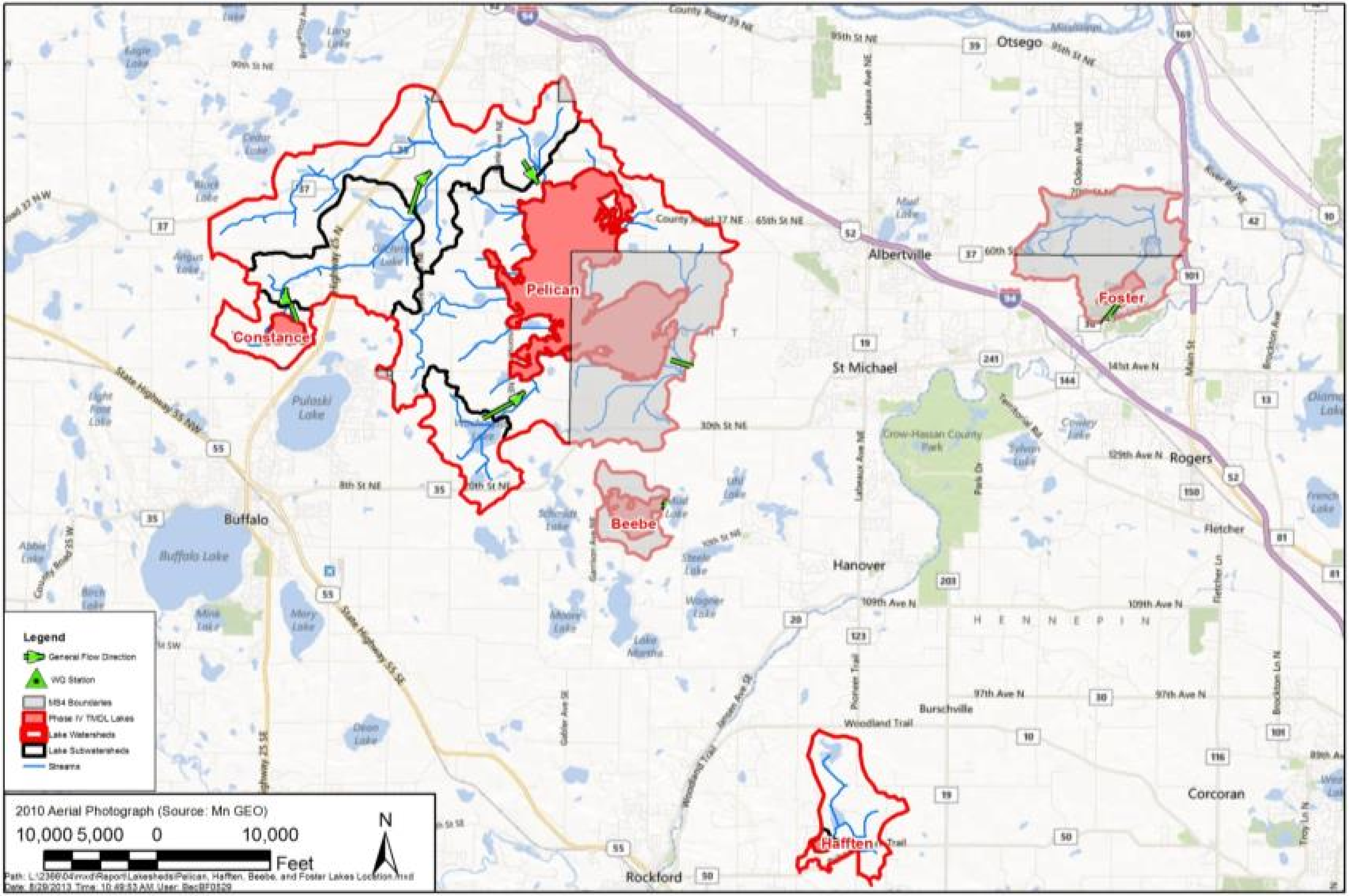


Figure 4.16. Flow pattern in the Constance, Beebe, Hafften, and Foster Lake TMDL study areas.

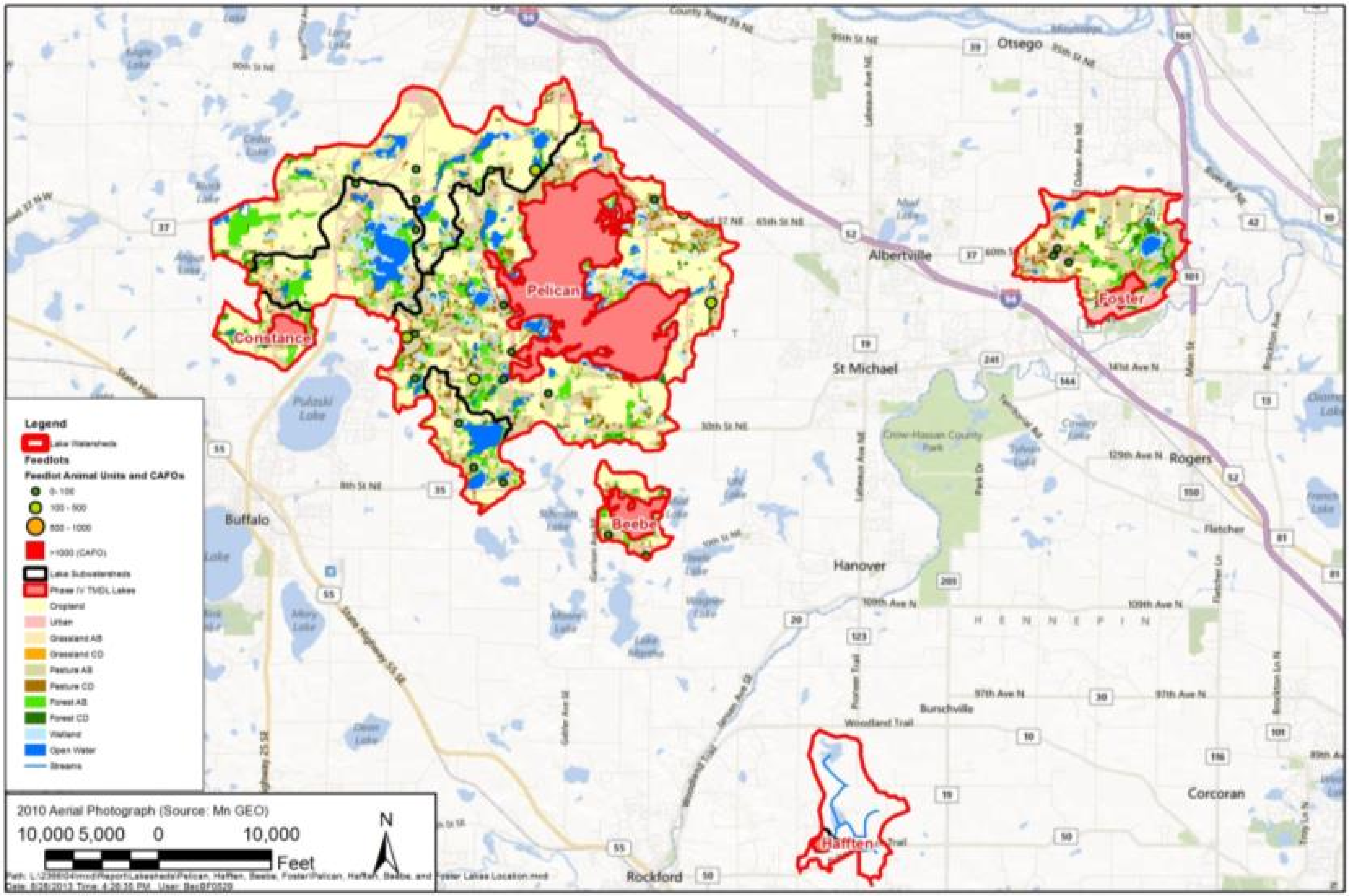


Figure 4.17. Land use in the Constance, Beebe, Hafften, and Foster Lake TMDL study areas.

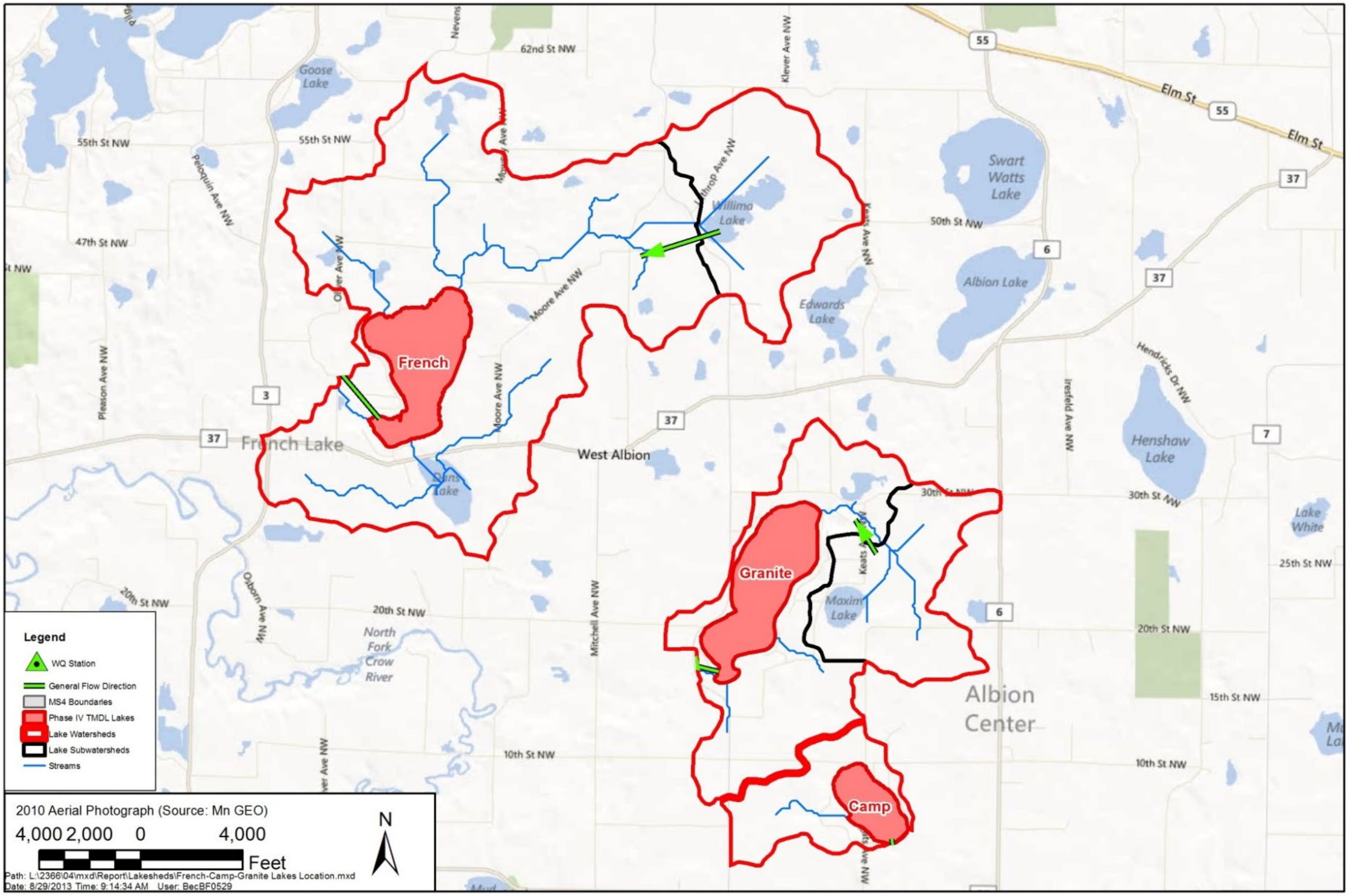


Figure 4.18. Flow pattern in the French, Granite, and Camp Lake TMDL study areas.

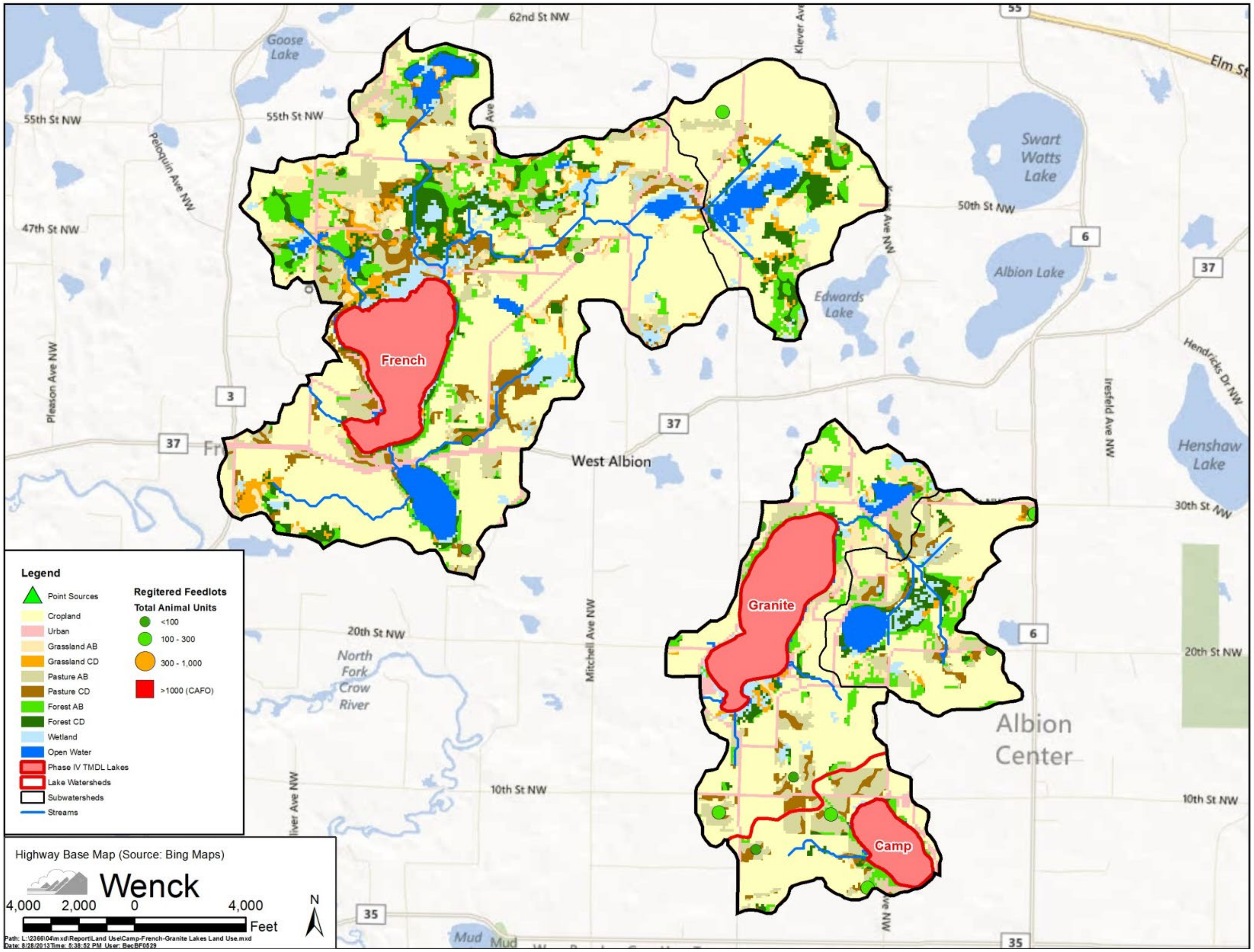


Figure 4.19. Land use in the French, Granite, and Camp Lake TMDL study areas.

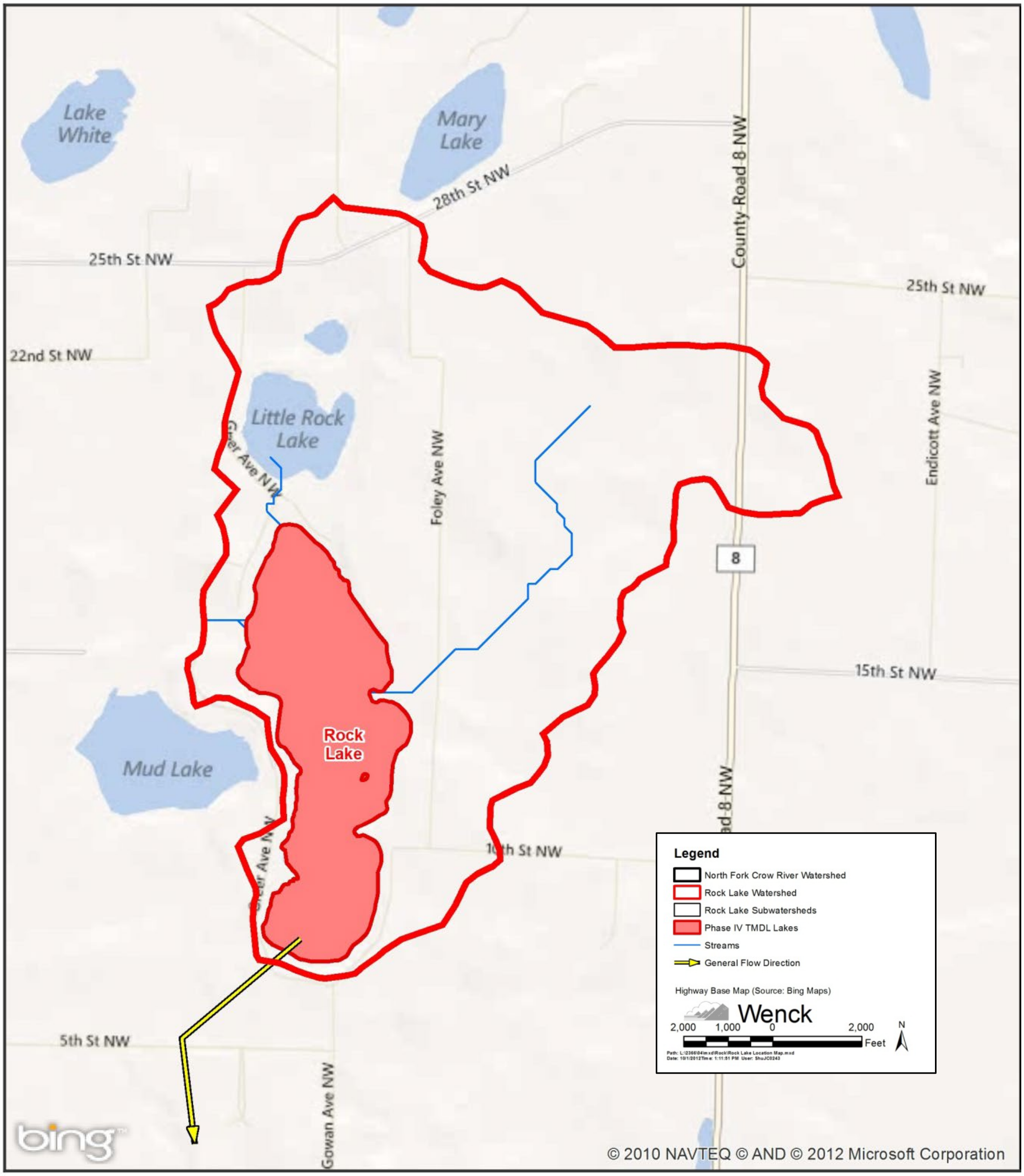


Figure 4.20. Flow Pattern in Rock Lake TMDL study area.

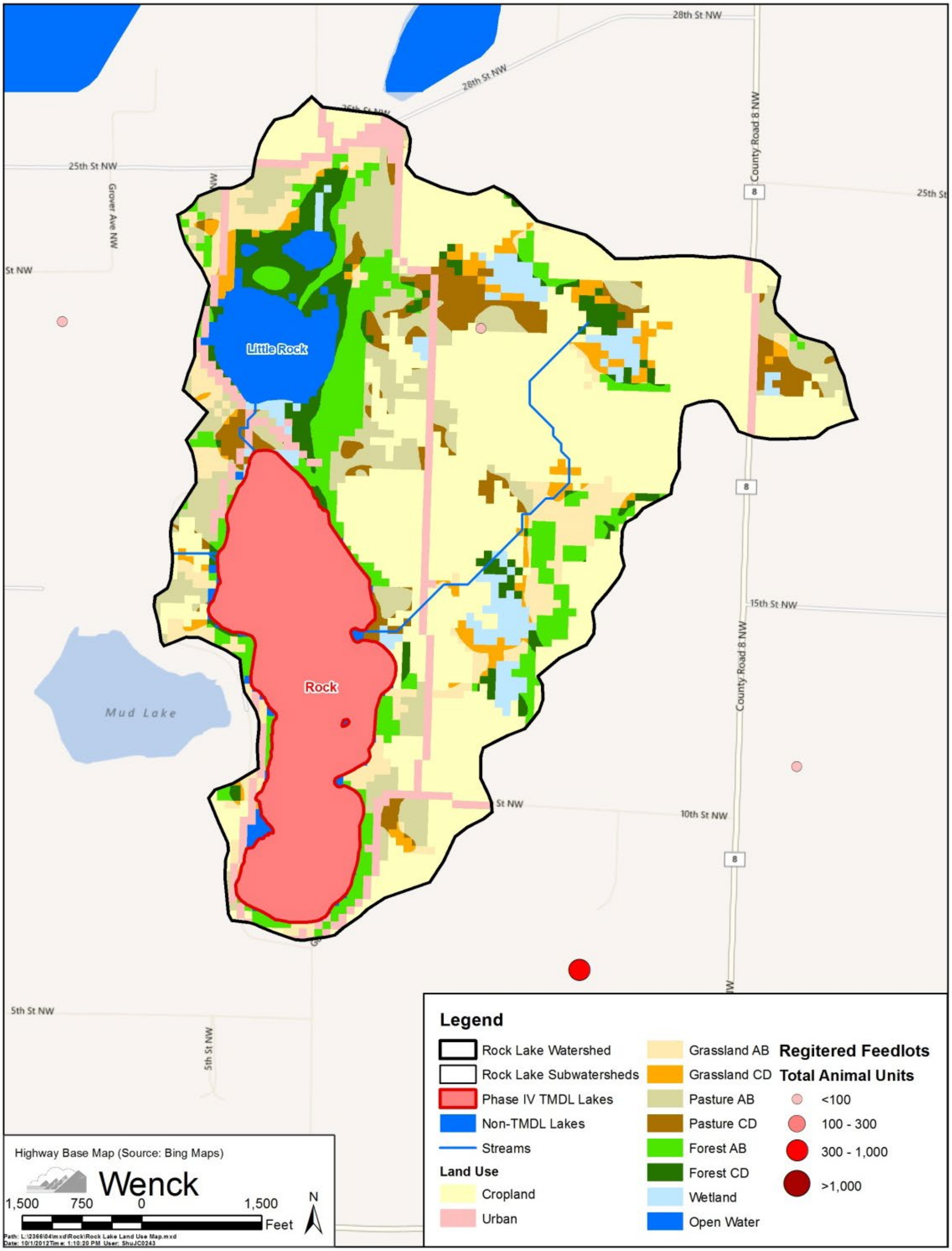


Figure 4.21. Land use in Rock Lake TMDL study area.

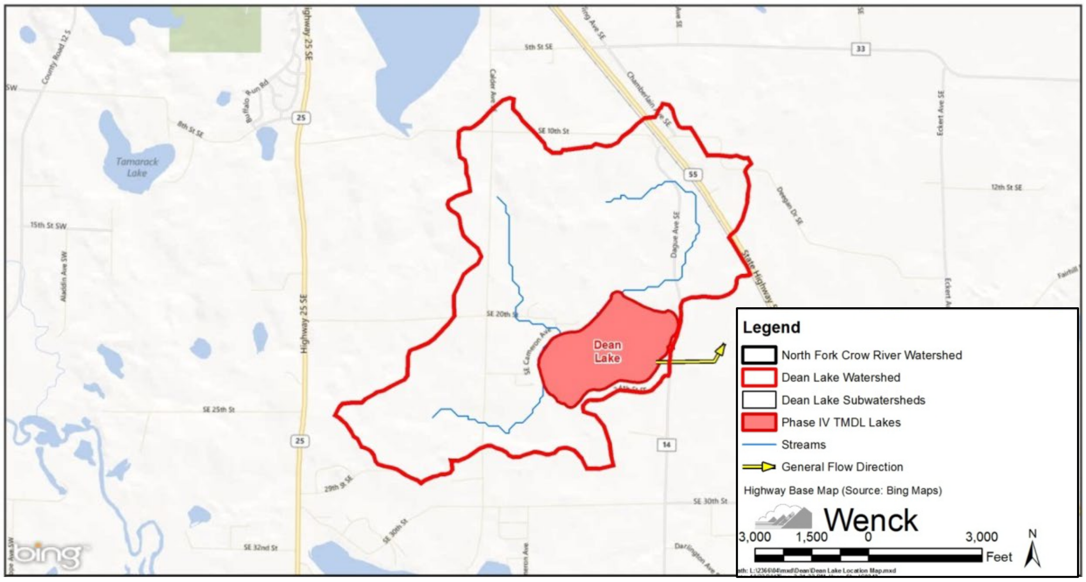


Figure 4.22. Flow Pattern in Dean Lake TMDL study area.

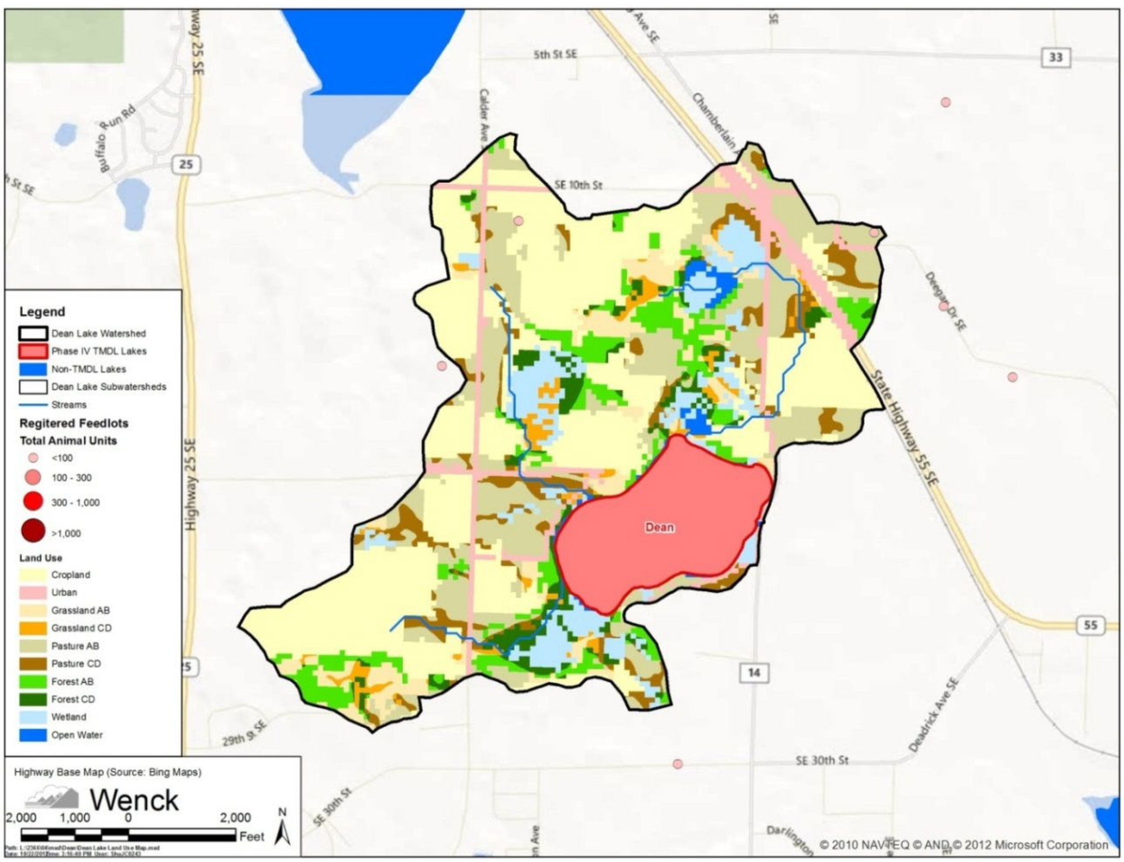


Figure 4.23. Land use in Dean Lake TMDL study area.

Table 4.57. Land use for all impaired lakes in the TMDL study area in acres.

Lake		Urban	Forest	Cropland	Grassland	Pasture	Wetland	Feedlot	total
Fountain	Acres	60	159	574	38	195	58	2	1,086
	Percentage	6%	15%	53%	3%	18%	5%	0%	100%
Constance	Acres	46	163	343	48	138	15	-	753
	Percentage	6%	22%	46%	6%	18%	2%	0%	100%
Pelican	Acres	1,203	2,155	8,471	1,073	3,988	2,160	10	19,060
	Percentage	6%	11%	45%	6%	21%	11%	0%	100%
Beebe	Acres	43	110	305	34	151	12	0	655
	Percentage	7%	17%	46%	5%	23%	2%	0%	100%
Foster	Acres	427	391	740	69	982	240	1	2,850
	Percentage	15%	14%	27%	2%	34%	8%	0%	100%
Hafften	Acres	55	233	526	82	439	226	0	1,561
	Percentage	4%	15%	33%	5%	28%	15%	0%	100%
Malardi	Acres	82	23	399	13	122	60	1	700
	Percentage	12%	3%	57%	2%	17%	9%	0%	100%
Granite	Acres	141	237	1,094	143	280	157	2	2,054
	Percentage	7%	12%	52%	7%	14%	8%	0%	100%
French	Acres	216	693	2,545	435	701	462	3	5,055
	Percentage	4%	14%	50%	9%	14%	9%	0%	100%
Camp	Acres	32	43	263	2	132	3	1	476
	Percentage	7%	9%	55%	0%	28%	1%	0%	100%
Rock	Acres	63	148	414	97	143	78	0	943
	Percentage	7%	16%	44%	10%	15%	8%	0%	100%
Dean	Acres	96	174	572	127	383	122	0	1,474
	Percentage	7%	12%	38%	9%	26%	8%	0%	100%

4.8.2 Lake Morphometry

Table 4.58 outlines the lake morphometry for the individual lakes in the North Fork Crow River Watershed. These lakes are a mixture of shallow and deep lakes with maximum depths ranging from 4 feet to 52 feet. Watershed sizes also varied from rather large at 19,060 acres to very small at 476 acres.

Table 4.58. Lake morphometry for all impaired lakes in the study area.

Parameter	Surface Area	Average Depth	Maximum Depth	Lake Volume	Residence Time	Littoral Area	Depth Class	Drainage Area*
Water body	**acre**	**feet**	**feet**	**ac-ft**	**years**	**%**	**--**	**acre**
Fountain	428	6.1	10	2,616	4.3	100	Shallow	1,086
Constance	175	12	23	2,016	6.6	50	Deep	753
Pelican	3,460	6	10	19,094	3.0	100	Shallow	19,060
Beebe	296	12	27	3,616	9.8	46	Deep	655
Foster	121	6	10	669	0.6	100	Shallow	2,850
Hafften	43	11	44	481	0.6	60	Deep	1,561
Malardi	117	2.9	4	339	1.2	100	Shallow	700
Granite	353	18	34	6,390	5.8	31	Deep	2,054
French	346	17	50	5,812	2.6	45	Deep	5,055
Camp	108	21	52	2,303	8.4	38	Deep	476
Rock	183	13	37	2,433	8.3	54	Deep	943
Dean	176	10	20	1,803	2.4	71%	Deep	1,474

* Excludes Lake Surface

4.8.3 Historic Water Quality

Tables 4.59 and 4.60 list the June through September averages of TP concentration, chlorophyll-*a* (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 some cases, in-lake data was not available for all years of the 2005 to 2011 or 2000 to 2012 data sets.

Table 4.59. Deep 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 Deep Lakes		**40.0**	**14.0**	**1.4**
Constance	2008-2009	91.1	73.8	1.4
Beebe	2002-2009	59.6	40.3	1.3
Hafften	2000-2001;2004-2006; 2010	51.7	26.9	1.5
Granite	2002-2009	60.8	36.4	1.5
French	2003-2009	40.9	19.2	1.4
Camp	2002-2009	112.1	49.5	1.6
Rock	2008-2009	55.6	31.5	1.2
Dean	2008-209	211	82	0.61

Table 4.60. 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**
Fountain	2005-2009	312.0	163.5	0.3
Pelican	2003;2005	137.3	67.7	0.5
Foster	2003-2009	263.8	129.7	0.5
Malardi	2007-2011	500.2	298.3	0.2

4.8.4 Biological Conditions

Data is limited for many of the lakes in the North Fork Crow River Watershed. Of the shallow lakes, only Foster Lake had a fish survey completed which showed high numbers of carp (Table 4.61). Fish surveys are needed in Fountain, Pelican and Malardi Lakes. Carp are present in many of the deep lakes suggesting that they are abundant watershed-wide and likely in many of the lakes in the watershed. Only Granite Lake had vegetation data which showed the presence of Curly-leaf pondweed.

Table 4.61 Aquatic vegetation and fisheries data.

Lake	Recent Survey Month-Year	Curly Leaf Pondweed Present?	Eurasian Water Milfoil Present?	Carp Present?	Notes
Fountain	No Data	--	--		
Constance	August-2011	--	--	No	Has experienced summer and winter kills and is managed for largemouth bass and northern pike.
Pelican	No Data	--	--		
Beebe	July-2009	--	--	Yes	Walleye Stocked bi-yearly.
Foster	June-1985	--	--	Yes	Winterkills occur frequently with high carp activity. Water is turbid and lacks submerged vegetation
Hafften	July 2005	--	--	Yes	
Malardi	No Data	--	--		
Granite	August-2006	Yes	No	Yes	Regularly stocked with walleye
French	No Data	--	--		
Camp	No Data	--	--	--	Managed primarily for northern pike and largemouth bass.
Rock	August-2006	--	--	Yes	Walleye Stocked bi-yearly.
Dean	No Data	--	--	--	--

4.8.5 Nutrient Sources

Nutrient sources for the individual lakes are provided in Table 4.62.

Table 4.62. Nutrient sources for lakes in the Individual lakes watersheds.

Lake	MS4 Drainage	Drainage Areas	SSTS	Upstream Lakes	Atmosphere	Internal Load
Constance	--	10%	9%	--	4%	77%
Beebe	--	25%	11%	--	9%	55%
Hafften	--	7%	1%	40%	4%	48%
Granite	--	28%	6%	--	5%	61%
French	--	69%	13%	--	8%	10%
Camp	--	24%	1%	--	2%	73%
Rock	--	17%	20%	--	9%	54%
Dean	--	38%	7%	--	2%	53%
Fountain	--	38%	2%	--	2%	58%
Pelican	3%	12%	6%	1%	4%	74%
Foster	17%		9%	<1%	1%	73%
Malardi	--	10%	7%	--	1%	82%

<u>Constance</u>

Constance Lake is a deep lake with a small watershed that is predominantly agriculture. The lake has a history of fish kills although carp have not been captured in the lake. Water quality is driven primarily by internal loading although it is possible that a degraded wetland is contributing phosphorus to the lake. Monitoring should be conducted on the major inflow to the lake.

<u>Beebe</u>

Beebe Lake is a deep lake with water quality relatively close to state water quality standards. Carp are present in the lake but do not appear to be overly abundant. There are very few animal units in the watershed although it is predominantly agricultural. Reductions in both internal and external load are required to meet water quality standards.

<u>Hafften</u>

Hafften Lake is a small deep lake that receives most of its drainage through Schendel Lake. No water quality data are available for Schendel Lake. Nutrient loading appears to be dominated by internal loading. Monitoring Schendel Lake and sediment chemistry in Hafften will improve the nutrient budget for the lake.

<u>Granite</u>

Granite Lake is a deep lake that is dominated by internal loading. The watershed is predominantly agricultural with only a relatively small number of animals (around 300 cows).

French

Water quality in French Lake is only slightly above state water quality standards so only small reductions in phosphorus are needed. Most of the required reductions can be achieved by upgrading failing septic systems in the watershed.

Camp

Camp Lake is a small, deep lake with a predominantly agricultural watershed. Most of the loading to Camp Lake is from internal phosphorus release from the sediments. However, significant reductions are needed in both internal and watershed loading for the lake to meet water quality standards.

Rock

Rock Lake is a small, deep lake with a predominantly agricultural watershed. The lake is dominated by internal loading and SSTS sources, both of which need to be reduced or eliminated to meet water quality standards.

Dean

Dean Lake is a small, deep lake with a moderately sized watershed. Although Dean Lake is classified as a deep lake, it has a large littoral area with over 70% of the lake less than 15 feet in depth. Large reductions in both internal and external nutrient loads are needed to meet water quality standards.

Fountain

Fountain Lake is a small, very shallow lake with a predominantly agricultural watershed. Modeling suggests that internal loading is an important source of phosphorus to the lake, however internal release measurements were very low, almost zero. Watershed loading is most likely significantly underestimated in the model which has a high level of uncertainty. Watershed monitoring is necessary to further understand phosphorus sources from the watershed.

Pelican

Pelican Lake is a large shallow lake with a mostly agricultural watershed. There are a number of animal units in the watershed including almost 1,500 cows. However, internal loading appears to be the greatest source of phosphorus to the lake. Nutrient reductions are needed from both watershed and internal phosphorus sources.

Foster

Foster Lake is a small shallow lake with a predominantly agricultural watershed. Nutrient loading is dominated by internal phosphorus sources. The lake has a large rough fish population that needs to be controlled to improve water quality.

Malardi

Malardi Lake is a small shallow lake with a predominantly agricultural watershed. Significant load reductions are required in both watershed and internal loading to meet water quality standards. It is important to note that the Minnesota DNR recently conducted a whole lake drawdown on the lake. Water quality should be measured on the lake to determine the drawdowns effects on water quality.

4.8.6 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 4.63 through 4.74 summarize the existing and allowable TP loads, the TMDL allocations, and required reductions for each lake.

Table 4.63. TMDL allocations for Constance Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	0.9	0.003	0.9	0.003	0	**0%**
	City of Buffalo	0.5	0.001	0.34	0.001	0.1	**29%**
Load	Drainage Areas	93	0.3	54.3	0.1	39	**42%**
	SSTS	86	0.2	0	0	86	**100%**
	Atmosphere	39	0.1	39	0.1	0	**0%**
	Internal Load	703	1.9	125	0.3	578	**82%**
	MOS	--	--	11	0.03	--	**--**
	TOTAL	**922.4**	**2.504**	**230.54**	**0.534**	**703.1**	**75%**

Table 4.64. TMDL allocations for Pelican Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	29	0.08	29	0.08	0.0	**0%**
	City of Monticello	9.8	0.03	4.6	0.01	5	**53%**
	City of St. Michael	505	1.4	237	0.7	267	**53%**
	City of Buffalo	3	0.01	1	<0.01	2	**53%**
Load	Drainage Areas	2,399	8	1,129	3.8	1,270	**53%**
	SSTS	1,170	3.2	0	0.0	1,170	**100%**
	Upstream Lakes	104	0.3	69	0.2	36	**34%**
	Atmosphere	827	2.3	827	2.3	0	**0%**
	Internal Load	15,016	41	2,678	7	12,338	**82%**
	MOS	**--**	**--**	260	0.7	--	**--**
	TOTAL	**20,062.7**	**56.32**	**5,235**	**14.79**	**15,088**	**74%**

Table 4.65. TMDL allocations for Beebe Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	2	0.005	2	0.005	0	0%
	City of St. Michael	180	0.5	78	0.2	103	57%
Load	SSTS	80	0.2	0	0.0	80	**100%**
	Atmosphere	66	0.2	66	0.2	0	**0%**
	Internal Load	400	1.1	214	0.6	186	**46%**
	MOS	--	--	19	0.1	--	**--**
	TOTAL	**728**	**2.005**	**379**	**1.105**	**369**	**48%**

Table 4.66. TMDL allocations for Hafften Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	0.2	0.001	0.2	0.001	0	**0%**
Load	Drainage Areas	17	0.05	12	0.03	4	**25%**
	SSTS	3	0	0	0	3	**100%**
	Upstream Lakes	101	0.3	101	0.3	0	**0%**
	Atmosphere	10	0	10	0	0	**0%**
	Internal Load	125	0.3	38	0.1	87	**70%**
	MOS	--	--	9	0.02	--	**5%**
	TOTAL	**256.2**	**0.651**	**170.2**	**0.451**	**94**	**34%**

Table 4.67. MDL allocations for Granite Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	4	0.01	4	0.01	0	**0%**
Load	Drainage Areas	414	1.1	357	1.0	57	**14%**
	SSTS	85	0.2	0	0.0	85	**100%**
	Atmosphere	78	0.2	78	0.2	0	**0%**
	Internal Load	920	2.5	296	0.8	624	**68%**
	MOS	--	--	15	0.04	--	**--**
	TOTAL	**1,501**	**4.01**	**750**	**2.05**	**766**	**50%**

Table 4.68. TMDL allocations for French Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	7	0.02	7	0.02	0	**0%**
Load	Drainage Areas	720	2.0	674	1.8	46	**6%**
	SSTS	142	0.4	0	0.0	142	**100%**
	Atmosphere	83	0.2	83	0.2	0	**0%**
	Internal Load	105	0.3	105	0.3	0	**0%**
	MOS	--	--	46	0.1	--	**--**
	TOTAL	**1,057**	**2.92**	**915**	**2.42**	**188**	**13%**

Table 4.69. TMDL allocations for Camp Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
	Construction & Industrial Stormwater	3	0.01	3	0.01	0	**0%**
	Drainage Areas	336	0.9	128	0.3	209	**62%**
	SSTS	16	0.0	0	0.0	16	**100%**
	Atmosphere	26	0.1	26	0.1	0	**0%**
	Internal Load	1,030	2.8	248	0.7	781	**76%**
	MOS			12	0.03	--	**--**
	TOTAL	**1,411**	**3.81**	**417**	**1.14**	**1,006**	**70%**

Table 4.70. TMDL allocations for Rock Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	1	0.002	1	0.002	0	**0%**
Load	Drainage Areas	81	0.2	66	0.2	16	**19%**
	SSTS	93	0.3	0	0.0	93	**100%**
	Atmosphere	41	0.1	41	0.1	0	**0%**
	Internal Load	253	0.7	148	0.4	105	**41%**
	MOS	--	--	7	0.03	--	**--**
	TOTAL	**469**	**1.302**	**263**	**0.732**	**214**	**44%**

Table 4.71. TMDL allocations for Dean Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	8	0.02	8	0.02	0	**0%**
Load	Drainage Areas	773	2.1	75	0.2	698	**90%**
	SSTS	146	0.4	0	0.0	146	**100%**
	Atmosphere	42	0.1	42	0.1	0	**0%**
	Internal Load	1,083	3.0	47	0.1	1,036	**96%**
	MOS	--	--	9	0.02	--	**--**
	TOTAL	**2,052**	**5.62**	**181**	**0.44**	**1,880**	**91%**

Table 4.72. TMDL allocations for Fountain Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	18	0.1	18	0.1	0	**0%**
Load	Drainage Areas	1,820	5.0	130	0.4	1,690	**93%**
	SSTS	86	0.2	0	0.0	86	**100%**
	Atmosphere	102	0.3	102	0.3	0	**0%**
	Internal Load	2,769	7.6	362	1.0	2,407	**87%**
	MOS	--	--	32	0.1	--	**--**
	TOTAL	**4,795**	**13.2**	**644**	**1.9**	**4,183**	**87%**

Table 4.73. TMDL allocations for Foster Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	8.5	0.02	8.5	0.02	0	**0%**
	City of Otsego	547	1.5	143	0.4	404	**74%**
	City of St. Michael	294	0.8	77	0.2	217	**74%**
Load	SSTS	1	0.0	0	0.0	1	**100%**
	Atmosphere	27	0.1	27	0.1	0	**0%**
	Internal Load	2,312	6.3	135	0.4	2,177	**94%**
	MOS	--	--	20	0.1	--	**--**
	TOTAL	**3,189.5**	**8.72**	**410.5**	**1.22**	**2,799**	**88%**

Table 4.74. TMDL allocations for Malardi Lake.

Allocation	Source	Existing TP Load		TP Allocations (WLA & LA)		Load Reduction	
		(lbs/year)	(lbs/day)	(lbs/year)	(lbs/year)	(lbs/day)	(lbs/year)
Wasteload	Construction & Industrial Stormwater	2.7	0.01	2.7	0.01	0	**0%**
Load	Drainage Areas	263	0.7	53	0.1	210	**80%**
	SSTS	176	0.5	0	0.0	176	**100%**
	Atmosphere	26	0.1	26	0.1	0	**0%**
	Internal Load	2,138	5.9	43	0.1	2,095	**98%**
	MOS	--	--	7	0.02	--	**--**
	TOTAL	**2,605.7**	**7.21**	**131.7**	**0.3**	**2,481**	**95%**

5.0 Implementation

5.1 SUMMARY BY ECOREGIONS, AGROECOREGIONS AND LAND COVER

The majority of the watershed lies in the NCHF ecoregion, characterized by varying landscapes of rolling hills and smaller plains (Figure 5.1). The uplands are forested by hardwoods and conifers, and the plains are livestock pastures, hay fields, and row crops. Six percent is Western Corn Belt Plains (WCP) ecoregion, characterized by fertile soils, and extensive cultivation for row crops.

An ecoregion is a geographical area where the land use (agriculture, forest, prairie, etc.), underlying geology, potential native plant community, and soils are relatively similar. Ecoregion divisions are relatively coarse with seven ecoregions covering the entire state of Minnesota.

Advancement in land management research suggests

> "…that watershed management in highly agricultural watersheds will be most effective when hydrologic watersheds are used as a framework that is complemented by agroecoregions to identify, and target regions where specific combinations of BMPs for agricultural sediment and phosphorus abatement are most appropriate." (Hatch et. al., 2001)

The concept of agroecoregions arose out of discussions organized and funded by the Minnesota Department of Agriculture beginning in 1995 (Mulla, 2002). According to Mulla,

> "Agroecoregions are zones having unique soil, landscape, and climatic characteristics which confer unique limitations and potentials for crop and animal production. Each agroecoregion contains unique physiographic factors that influence the potential for production of nonpoint source pollution and the potential for adoption of farm management practices."

The North Fork Crow River Watershed is predominantly comprised of three agroecoregions, Rolling Moraine, Steep Dryer Moraine, and Alluvium & Outwash (Figure 5.2). Table 5.1 summarizes the percentage acres by agroecoregion within the project area watershed.

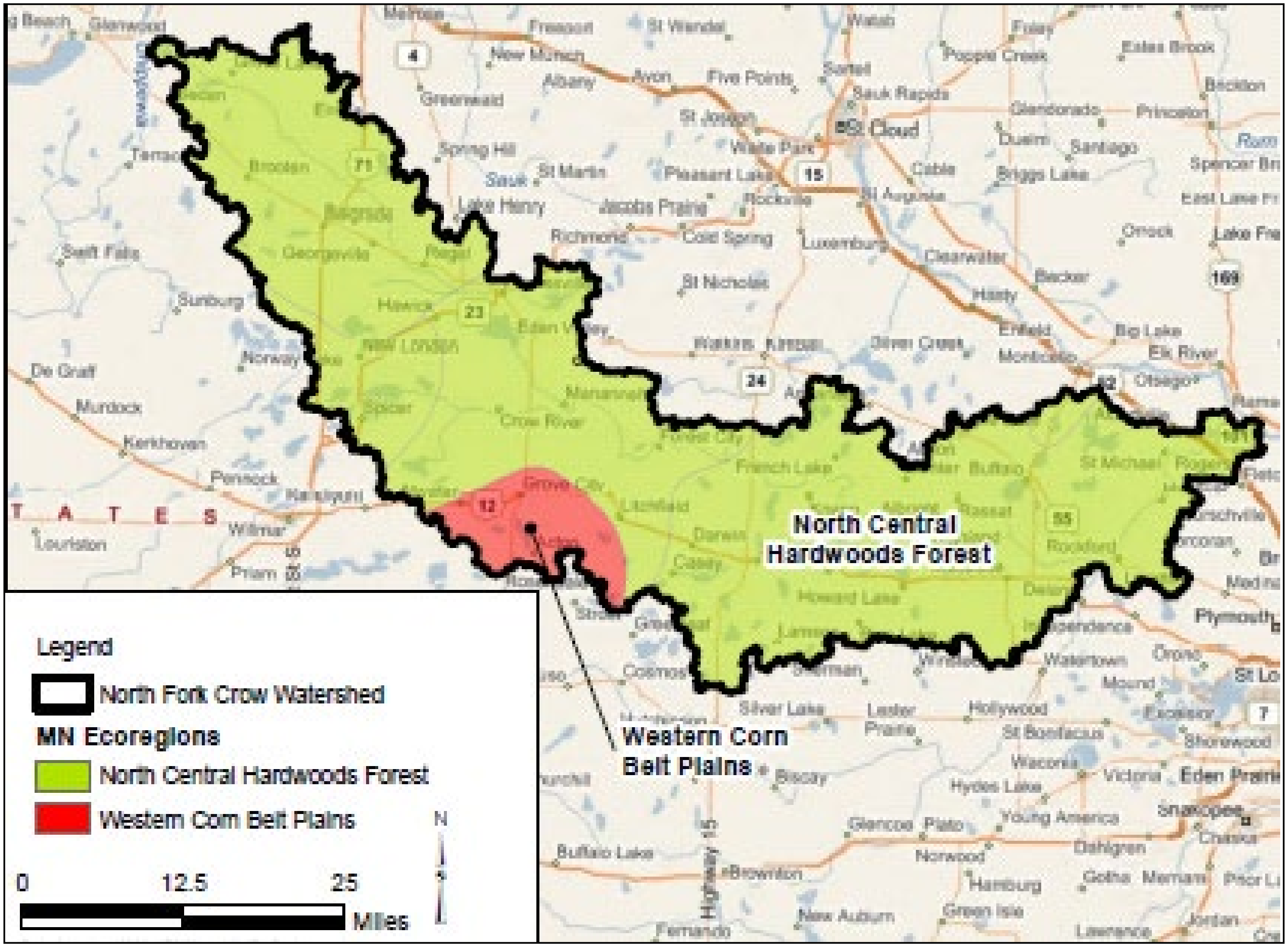


Figure 5.1. Ecoregions in the North Fork Crow River Watershed.

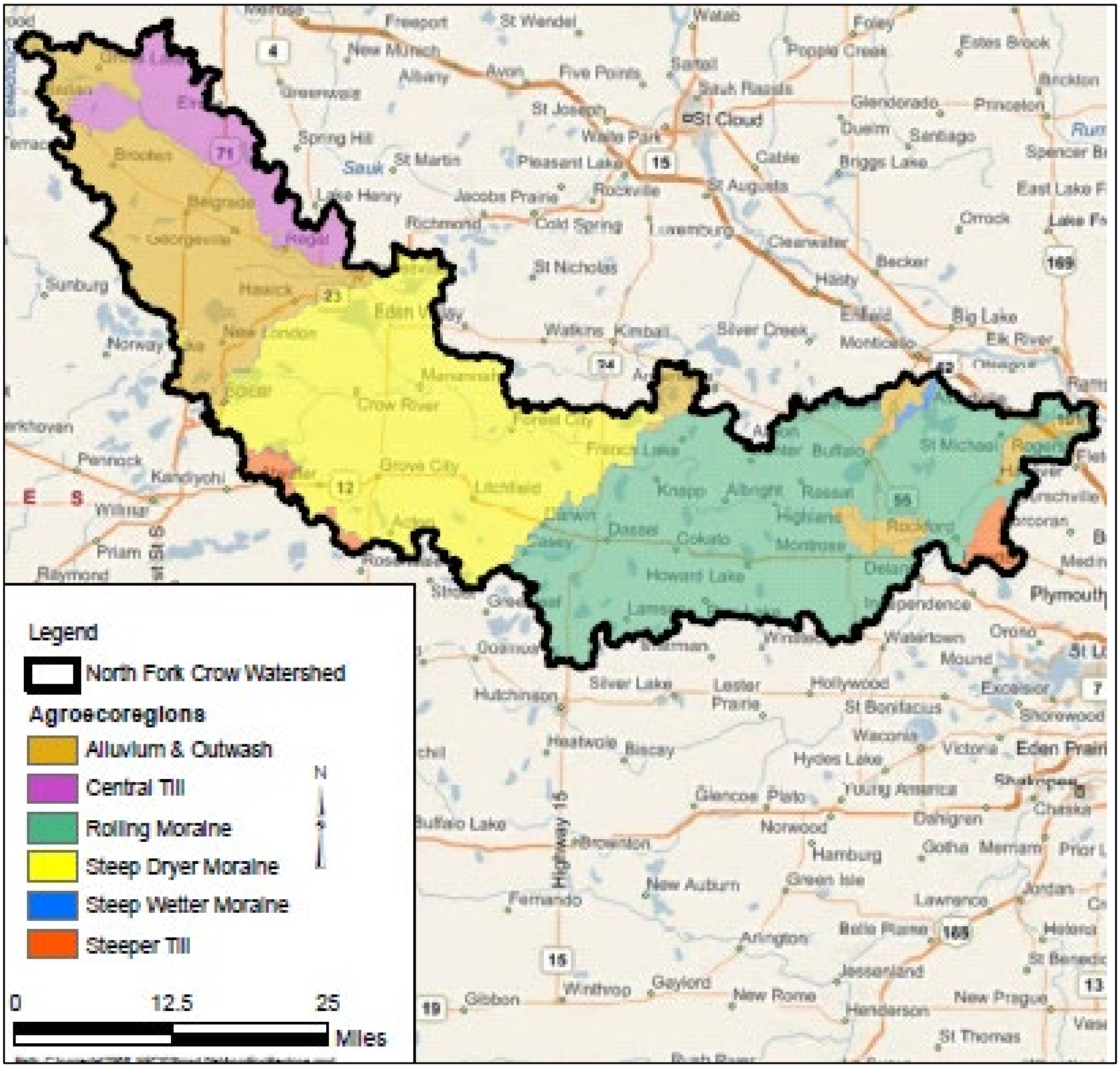


Figure 5.2. Agroecoregions in the North Fork Crow River Watershed.

Table 5.1. North Fork Crow River Watershed Agroecoregions Summary.

Agroecoregion Type	Percentage of Type
Alluvium & Outwash	21.7%
Central Till	7.7%
Rolling Moraine	37.0%
Steep Dryer Moraine	31.1%
Steep Wetter Moraine	0.3%
Steeper Till	2.2%
TOTAL	100.0%

The Alluvium & Outwash agroecoregion is located primarily in the upper reaches of the North Fork Crow River Watershed. Soils are either fine-textured alluvium or coarse-textured outwash, located on flat to moderately steep slopes and generally well drained. Water erosion rates can be severe, while wind erosion can be high to severe.

The Steep Dryer Moraine agroecoregion covers the middle portions of the North Fork Crow River Watershed. Most of the landscape developed from glacial moraines. Soils are predominantly loamy, on very steep slopes and well drained. Water erosion rates can be severe to extreme, while wind erosion can be moderate to severe.

The Rolling Moraine agroecoregion covers the bottom third of the North Fork Crow River Watershed and is characterized by fine textured soils (loamy or sandy). The soils are well-drained located on steep to very steep slopes, having severe to extreme water erosion potential and moderate wind erosion rates.

Based on 50 years of precipitation values available from Minnesota State Climatologist for Buffalo, Minnesota, near the center of the study area, the average annual precipitation is 29.16 inches. The average monthly distribution of precipitation is shown in Figure 5.3.

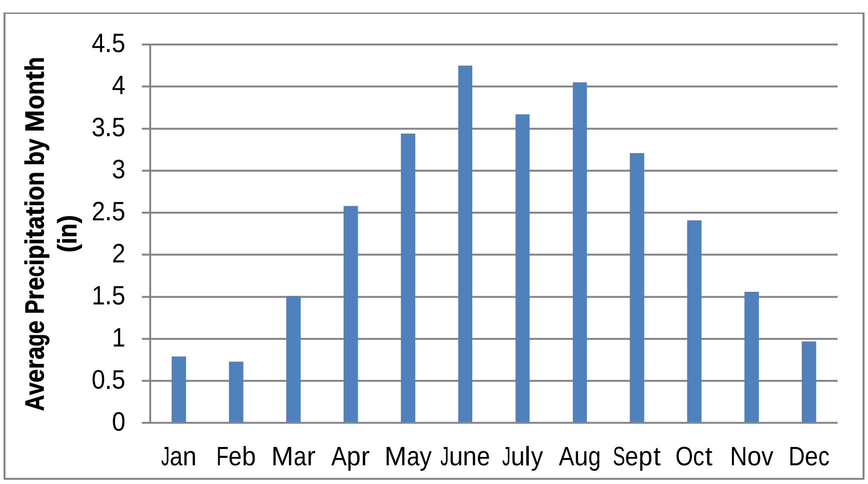


Figure 5.3. Average Monthly Distribution of Precipitation at Buffalo, MN.

A matrix has been developed by Dr. David Mulla of the University of Minnesota to provide general planning-level guidance on the application of BMPs within each agroecoregion (Mulla 2002). The BMPs were developed through a focus group process that included experts from the University of Minnesota, MPCA, Minnesota Department of Agriculture, and the Minnesota Board of Water and Soil Resources. Four broad categories of management practices discussed include nutrient management, vegetative practices, tillage practices, and structural practices (Miller et al. 2012). Selection of appropriate management practices for the pollutant(s) of concern depends on site-specific conditions, stakeholder attitudes and knowledge, and on economic factors. This information is intended to be used as a starting point in the development of a custom set of BMPs to reduce sources of pollution generation and transport through improved management of uplands and riparian land within the TMDL project area. Reducing sediment generation and transport will also lead to decreases in turbidity and bacteria concentrations in downstream reaches.

Vegetative Practices

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

Primary Tillage Practices

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

Structural Practices

- Wetland restoration
- Livestock exclusion
- Liquid manure waste facilities

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

5.1.1 Vegetative Management Practices

Vegetative practices include those focusing on the establishment and protection of crop and non-crop vegetation to minimize sediment mobilization from agricultural lands and decrease sediment transport to receiving waters. The recommended cropping practices are designed in part to slow the speed of runoff over bare soil to minimize its ability to entrain sediment. Grassed waterways and grass filter strips provide settling of entrained sediment which gets incorporated into both the soil and vegetation. Other practices, such as alternative crop rotations, forest management, and field windbreaks are designed to minimize exposure of bare soils to wind and water which can transport soil off-site. Pasture management often emphasizes rotational grazing techniques, where pastures are divided into paddocks, and the livestock moved from one paddock to another before forage is over-grazed. As livestock are moved frequently, forage is able to survive. Maintaining the vegetation, as opposed to bare soil, allows for greater water infiltration, reducing runoff and associated sediment transport.

There are a number of programs available to compensate land owners for moving environmentally sensitive cropland out of production for varying periods of time. These include the CRP, Re-Invest in Minnesota (RIM) Reserve Program, and the CREP-II. Anticipated benefits in reducing soil erosion and improving water quality are key considerations in deciding what lands can be enrolled in each program

5.1.2 Primary Tillage Practices

Certain kinds of tillage practices can significantly reduce the generation and transport of soil from fields. Conservation tillage techniques emphasize the practice of leaving at least some vegetation cover or crop residue on fields as a means of reducing the exposure of the underlying soil to wind and water which leads to erosion. If it is managed properly, conservation tillage can reduce soil erosion on active fields by up to two-thirds (Randall et. al. 2008).

5.1.3 Structural Practices

Structural practices emphasize elements that generally require a higher level of site-specific planning and engineering design. Most structural practices focus on watershed improvements to decrease sediment loading to the receiving water. For example, restoration of wetlands can create a natural method of slowing overland runoff and storing runoff water, which can both reduce channel instability and flooding downstream. In addition, the quiescent conditions of a wetland mean that they can be effective at settling out sediment particles in the runoff that reaches them, although accumulation of too much sediment too rapidly can compromise other important functions of the wetland. Livestock exclusion involves fencing or creating other structural barriers to limit or eliminate access to streams by livestock, and may involve directing livestock to an area that is better designed to provide limited access with minimal impact.

5.1.3.1 Feedlot Runoff Reduction

This strategy is regulated under Minn. R. ch. 7020. Prior to 2010, the feedlot program had many feedlots operating within the Open Lot Agreement (OLA), this is no longer an option and all deadlines for this program have since passed. The agricultural producers that have not completed all requirements in their expired OLA now must comply with the “Feedlot Rule OLA – Memorandum of Understanding” in order to continue to correct their open lot runoff problems in order to receive a conditional waiver from enforcement penalties. All other facilities not in this category must comply with state rules and statutes to meet effluent limitations and maintain compliance. Additional assistance with the below list of BMPs may be obtained through a Soil and Water Conservation District (SWCD) or Natural Resource Conservation Services (NRCS) offices

- Move Fences/Change Lot Area
- Eliminate Open Tile Intakes and/or Feedlot Runoff to the Intake
- Install Clean Water Diversions and Rain Gutters
- Install Grass Buffers
- Maintain Buffer Areas
- Construct a Solids Settling Area(s)

- Prevent Manure Accumulations
- Manage Feed Storage
- Manage Watering Devices
- Total Runoff Control and Storage
- Roofs
- Runoff Containment with Irrigation onto Cropland/Grassland
- Vegetated Infiltration Area
- Tile-Drained Vegetated Infiltration Area with Secondary Vegetated Filter Strip
- Sunny Day Release on to Vegetated Infiltration Area or Filter Strip
- Vegetated Filter Strip

5.1.3.2 Manure Management Planning

Continued cooperation and communication with the MPCA and delegated county programs to facilitate appropriate education and assistance to agricultural producers may increase compliance with state rule requirements in Minn. R. ch. 7020.2225. The NRCS offices or SWCD facilitate Environmental Quality Incentives Program (EQIP) or other cost-share programs to put BMPs into place as well as comprehensive nutrient management plans (CNMP). The CNMP and Manure Management Plans (MMP) can be used interchangeably to address land application of manure. The development, implementation, and updating of CNMPs or MMPs can ensure the manure is being utilized and aid in prevention of bacteria runoff. It is also key in preventing additional inputs of phosphorus and nitrogen leaching.

5.2 WASTE WATER TREATMENT FACILITIES

Counties, Regional Development Commissions and the MPCA staff will work with WWTFs to ensure continued compliance.

5.3 SUBSURFACE SEWAGE TREATMENT SYSTEMS (SSTS)

Low interest loan dollars are available to aid landowners in upgrading SSTS.

5.3.1 North Fork Crow River Watershed Restoration and Protection Strategy (WRAPS)

The CROW, the North Fork Crow Watershed District, and the Middle Fork Crow Watershed District have partnered with the MPCA to develop the North Fork Crow River Watershed Restoration and Protection Strategy (NFC WRAPS). The purpose of this plan is to address all impairments in the North Fork Crow River Watershed not included in this TMDL study. The NFC WRAPS will include nutrient TMDLs for 34 lakes in the North Fork Crow River Watershed. It is assumed the nutrient reduction goals and implementation plans presented in these TMDLs will help reduce TP, chlorophyll-a (algal turbidity) and $CBOD_5$ in the turbidity impaired reaches and many of the dissolved oxygen impaired reaches addressed in other TMDL studies.

5.4 ADAPTIVE MANAGEMENT

The WRAPS will include a more detailed implementation plan focused on adaptive management (Figure 5.4). As the water quality dynamics within the watershed are better understood, management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired reaches.

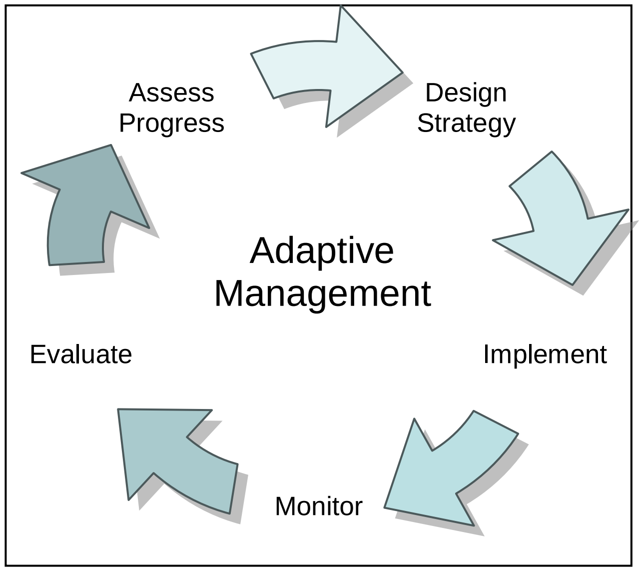


Figure 5.4. Adaptive Management.

6.0 Reasonable Assurance

6.1 INTRODUCTION

When establishing a TMDL, reasonable assurances must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurance, including a thorough knowledge of the ability to implement BMPs as well as the overall effectiveness of the BMPs. This TMDL establishes aggressive goals for the reduction of turbidity, nutrient, and *E. coli* loads to the North Fork Crow River Watershed.

Many of the goals outlined in this TMDL study are consistent with objectives outlined in the Meeker and Wright County 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 this TMDL effort as well as the broader planning efforts mentioned previously have generated commitment and support from the local government units affected by this TMDL and will help ensure that this TMDL project is carried successfully through implementation.

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

- Federal Section 319 Grants for watershed improvements
- Funds ear-marked to support TMDL implementation from the Clean Water, Land, and Legacy constitutional amendment, approved by the state's citizens in November 2008.
- Watershed District cost-share funds
- Local government funds
- Soil and Water Conservation Districts cost-share funds
- NRCS cost-share funds
- Local Lake Association 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.

6.2 REGULATORY APPROACHES

NPDES Phase II MS4 stormwater permits are in place for the cities draining to the North Fork of the Crow River, and the main stem of the Crow River. Under the stormwater program, permit holders are required to develop and implement a Stormwater Pollution Prevention Plan (SWPPP; MPCA, 2004). The SWPPP must cover six minimum control measures:

- Public education and outreach;

- Public participation/involvement;
- Illicit discharge, detection and elimination;
- Construction site runoff control;
- Post-construction site runoff controls;
- Pollution prevention/good housekeeping

The permit holder must identify BMPs and measurable goals associated with each minimum control measure.

The MPCA's MS4 general permit requires MS4 permittees to provide reasonable assurances that progress is being made toward achieving all SLAs in TMDL's approved by EPA prior to the effective date of the permit. In doing so, they must determine if they are currently meeting their WLA(s). If the WLA is not being achieved at the time of application, a compliance schedule is required that includes interim milestones, expressed as best management practices, that will be implemented over the current five-year permit term to reduce loading of the pollutant of concern in the TMDL. Additionally, a long-term implementation strategy and target date for fully meeting the WLA must be included.

6.3 LOCAL MANAGEMENT

6.3.1 Crow River Organization of Water

Portions of ten counties in Central Minnesota make up the Crow River Watershed which includes both the North Fork and South Fork Crow Rivers. From the perspective of the Upper Mississippi River Basin, the Crow River is one of its major tributaries to the Mississippi River. The effects of rapid urban growth, new and expanding wastewater facilities and erosion from agricultural lands have been common concerns of many citizens, local, state and regional governments in Central Minnesota. As a result, many groups began meeting in 1998 to discuss management of the Crow River basin consisting of the North Fork and South Fork. The CROW was formed in 1999 as a result of heightened interest in the Crow River. A Joint Powers Agreement has been signed between all ten of the Counties with land in the Crow River Watershed. The CROW Joint Powers Board is made up of one representative from each of the County Boards who signed the agreement. The Counties involved in the CROW Joint Powers include Carver, Hennepin, Kandiyohi, McLeod, Meeker, Pope, Renville, Sibley, Stearns and Wright. The CROW currently focuses on identifying and promoting the following:

- Protecting water quality and quantity
- Protecting and enhancing fish and wildlife habitat and water recreation facilities
- Public education & awareness
- BMP implementation

In the summer of 2010, the CROW and local partners began working with the MPCA's new Major WRAPS approach in the North Fork Crow River Watershed. The idea behind the watershed approach is to provide a more complete assessment of water quality and facilitate data collection for the development of a TMDLs and protection strategies. In the watershed approach, the streams and lakes within a major watershed are intensively monitored to determine the overall health of the water resources, identify impaired waters, and identify those waters in need of additional protection efforts to prevent impairments. This process is different from the past approach because previously, monitoring efforts were concentrated in a defined area (a lake or stream reach) to address one impairment. Under the WRAPS approach, all impairments are addressed at the same time. This process provides a communication tool that can inform stakeholders, engage volunteers, and help coordinate local/state/federal monitoring efforts so the data necessary for effective water resources planning is available, citizens and stakeholders are engaged in the process, and citizens and governments across Minnesota can evaluate the progress.

6.3.2 Local Comprehensive Water Management Plans

The North Fork TMDL project area is comprised of areas of Meeker, Wright and Hennepin Counties. Meeker and Wright Counties have each adopted a county water plan that articulates goals and objectives for water and land-related resource management initiatives. Meeker County's Water Plan was created in 2003 and will expire in 2012. The Wright County Water Plan runs from 2006 through 2015. The area of Hennepin County that impacts the project area for this TMDL project is covered by the Pioneer Sarah Water Management Commission. The Pioneer Sarah WMC has adopted a watershed management plan for the Pioneer-Sarah Creek Watershed, and is currently undergoing an amendment process for the plan.

Addressing impaired waters and assisting in TMDL projects are top priorities in all of these plans. In addition, the implementation section of the plans focus on a number of areas important in restoring impaired waters to a non-impaired status. The following are examples of some of the implementation goals found in the water and watershed management plans.

1.) Provide education and incentives to lake, river riparian and wetland owners to retain or restore native vegetation
2.) Utilize local, state and federal cost share programs for high priority erosion sites
3.) Promote BMP's and provide incentives for buffers
4.) Adopt ordinances to limit erosion and sedimentation from construction, and limit the rate and volume of storm water runoff
5.) Promote rain garden programs
6.) Promote setbacks, fencing and other means of excluding livestock from area surface waters
7.) Conduct annual manure management forum
8.) Continue SSTS low interest loan and inspection programs

6.3.3 County Soil and Water Conservation Districts

The purpose of the County SWCDs is to plan and execute policies, programs, and projects which conserve the soil and water resources within its jurisdictions. 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. The CROW has established close working relationships with the SWCDs on a variety of projects. One example is the conservation buffer strip cash incentives program that provides cash incentives to create permanent grass buffer strips adjacent to water bodies and water courses on land in agricultural use.

6.3.4 Watershed Districts

The North Fork Crow River basin has two watershed districts: North Fork and Middle Fork Crow River. Goals for each district include: to improve and enhance water quality, to control water flow, protect groundwater quality, to protect and restore critical areas, to promote wise public, private and natural use of water while maintaining, promoting wise land use management, enhancing and preserving public and private drainage for present and future residents while engaging residents in water resource management.

The District's primary purpose is the conservation of the quality and quantity of water within the Watershed District boundaries. A watershed is the area within the geographic boundaries of land that drains into a surface water feature such as a stream, river, or lake and contributes to the recharge of ground water. Due to the continuous movement of water within a watershed, it is difficult to manage based upon linear public boundaries. As a result, a Watershed District consists of a local unit of government that assists in the management of water quality and water quantity issues residing within the boundaries of a watershed district. A Watershed District is a local unit of government that is used to help prevent and solve water-related problems. CROW works with the watershed districts to implement conservation programs and educational outreach. Each watershed district has a management plan to address water quality concerns.

6.4 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 on the ground. The CROW and the SWCDs will track the implementation of these projects annually. The second type of monitoring is physical and chemical monitoring of the resource. The CROW plans to monitor the affected resources on a ten year cycle in conjunction with the North Fork Crow River WRAPS process.

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.

7.0 Public Participation

7.1 PUBLIC PARTICIPATION PROCESS

Public participation opportunities were provided during the project in the form of public meetings, electronic newsletters and CROW's website. A display board was developed to be taken to county fairs, DNR "Our Waters Our Choice" presentations in counties in the watershed. CROW staff attended local partner meetings to review the TMDL process and receive input on the project. The CROW's Technical Committee is comprised of 10 counties within the Crow River Watershed and the following local agencies: SWCD, NRCS, Water Planners, BWSR, MN DNR, USFWS, Metropolitan Council and Cities. The Technical Committee and citizens reviewed project activities and provided comments. The CROW has presented information regarding the TMDL project during its regular scheduled Joint Powers Board and Technical Committee meetings.

7.2 CIVIC ENGAGEMENT MEETINGS

On February 10, 2011, local partners met to review the grant contract and watershed information, discussed the civic engagement process, identified core and peripheral partners and discussed potential locations and times for upcoming informational meetings.

On March 10, 2011, core civic engagement partners met and developed a situation statement and a draft logic model.

On December 5, 2011, local partners met to discuss the civic engagement process, review project timeline, logic model, and list of peripheral partners. The group determined a meeting for local government partners was needed to help provide background information on the North Fork WRAPS project, review project timeline, and create an active discussion on the projects civic engagement strategy

On December 13, 2011, local partners attended a civic engagement workshop held by the MPCA staff in Brainerd. The workshop provided a base knowledge for civic engagement and how to implement it.

On March 16, 2012, local partners attended a civic engagement workshop held by the MPCA staff in Brainerd. The workshop reviewed a variety of strategic planning models. The partners decided to start over on the North Fork strategic plan and use the Appreciative Inquire model instead of the Logic model. The Appreciative Inquire model focused on what is working, rather than what is not in the basin.

On March 30, 2012, local partners meet and finished the civic engagement strategic plan. A draft plan was submitted and reviewed by the MPCA in April. July 16, 2012, will be the first "check-in" meeting for the partners to review goals/tasks set for the meeting.

July 16 2012, Civic Engagement Team met in Hutchinson to discuss 2012/2013 activities. The group planned on conducting a canoe paddle to assess the river; however it was canceled due to low water levels. The paddle was rescheduled for late spring/early summer.

7.2.1 TMDL Lake Meetings

The North Fork Crow Watershed Civic Engagement Team held several meetings throughout the watershed as part of a large process of evaluating water quality conditions and establishing water quality improvement goals and priorities. A total of 34 lakes were reviewed and discussed throughout the watershed. Lake data results were provided and discussed. Wenck reviewed existing conditions of the water resource and land uses that influence the water quality for each lake. Projects or strategies were identified to improve water quality at each meeting for each lake. The end goal of this process was to provide the information to communities and stakeholders around the lakes to enable them to take actions designed to restore and protect water quality in the North Fork Crow River Watershed.

All meetings were held from 6:00 pm – 8:00 pm in the following communities:

Sept 26, 2012 – Howard Lake City Hall in Howard Lake. Lakes reviewed were: Howard, Dutch, Little Waverly and Big Waverly. A total of 16 people attended the meeting. CROW was contacted through a series of phone calls and emails requesting additional information or requesting to be placed on a contact list for project updates.

Sept 27, 2012 – Meeker County Courthouse in Litchfield. Lakes reviewed were: Richardson, Dunns, Long, Hope and Nest. A total of 10 people attended the meeting. CROW was contacted through a series of phone calls and emails requesting additional information or requesting to be placed on a contact list for project updates.

Oct 2, 2012 – Cokato City Hall in Cokato. Lakes reviewed were: French, Granite, Camp, Rock, Brooks, Cokato and Smith. A total of 21 people attended the meeting. CROW was contacted through a series of phone calls and emails requesting additional information or requesting to be placed on a contact list for project updates.

Oct 10, 2012 – City Hall in St. Michael. Lakes reviewed were: Pelican, Beebe, Foster and Hafften Lakes. A total of 32 people attended the meeting. CROW was contacted through a series of phone calls and emails requesting additional information or requesting to be placed on a contact list for project updates.

Oct 23, 2012 – Wright County Courthouse in Buffalo. Lakes reviewed were: Constance, Buffalo, Deer, Lightfoot, Albert, Ramsey, Dean, Malardi and Fountain. A total of 28 people attended the meeting. CROW was contacted through a series of phone calls and emails requesting additional information or requesting to be placed on a contact list for project updates. The meeting discussed the need for additional data on Dean, Malardi and Fountain lakes. The collection of lake core samples will aid in the completion of lake TMDLs for Dean, Malardi and Fountain lakes and enable completing project tasks in the North Fork Crow River WRPP. The cores were collected in 2013.

Oct 25, 2012 – Dassel Historic Society in Dassel. Lakes reviewed were: Hook, Jennie, Collinwood, Spring and Big Swan. A total of 29 people attended the meeting. CROW was contacted through a series of phone calls and emails requesting additional information or requesting to be placed on a contact list for project updates.

8.0 References

Bannerman, R., A. Legg and S. Greb. 1996. *Quality of Wisconsin Stormwater 1989-1994*. USGS Open File Report 96-458. U.S. Geological Survey, Reston, VA.

Bannerman, R., D. Owens, R. Dodds, and N. Hornewer. 1993. *Sources of Pollutants in Wisconsin Stormwater*. Water Science and Technology 28(3-5):241-259.

Cleland, B.R. 2002. *TMDL Development From the "Bottom Up" – Part II: Using Duration Curves to Connect the Pieces*. National TMDL Science and Policy – WEF Specialty Conference. Phoenix, AZ.

Duan, N., 1983, *Smearing estimate -- a nonparametric retransformation method*: Journal of the American Statistical Association, 78, 383, p. 605-610

Hatch, L.K., A.P. Mallawatantri, D. Wheeler, A. Gleason, D.J. Mulla, J.A. Perry, K.W. Easter, P. Brezonik, R. Smith, and L. Gerlach. 2001. *Land Management at the major watershed – agroecoregion intersection*. J. Soil Water Conservation. 56:44-51.

Miller, T. P. , J. R. Peterson, C. F. Lenhart, and Y. Nomura. 2012. The Agricultural BMP Handbook for Minnesota. Minnesota Department of Agriculture.

Minnesota Pollution Control Agency. 2002. *Regional Total Maximum Daily Load Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota*. October 2002.

Minnesota Pollution Control Agency (MPCA). 2004. *10-Year Plan to Upgrade and Maintain Minnesota's On-site (ISTS) Treatment Systems.* Report to the Legislature. February 2004.

Minnesota Pollution Control Agency. 2005. *The Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment*. <<http://www.pca.state.mn.us/publications/manuals/tmdl-guidancemanual04.pdf>>

MPCA 2005. Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, 3rd Edition. September 2005.

Minnesota Pollution Control Agency. 2006. *Revised Regional Total Maximum Daily Load Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota.*

Minnesota Pollution Control Agency. 2007. *Statement of Need and Reasonableness (SONAR) in the Matter of Proposed Revisions of Minnesota Rules Chapter 7050, Relating to the Classification and Standards for Waters of the State*. Book III of III. July 2007.

Minnesota Pollution Control Agency. 2007. *Turbidity TMDL Protocols and Submittal Requirements*. <http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/project-resources/tmdl-policy-and-guidance.html>

Minnesota Pollution Control Agency. 2007. *Bacteria TMDL Protocols and Submittal Requirements*. <http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/project-resources/tmdl-policy-and-guidance.html>

Minnesota Pollution Control Agency. 2008. *Pipestone Creek Fecal Coliform Bacteria and Turbidity Total Maximum Daily Load Report*.

Minnesota Pollution Control Agency. 2008. *Minnesota Stormwater Manual*. Version 2, January 2008.

Minnesota Pollution Control Agency (unpublished) 2008. *Development of Total Suspended Solids (TSS) Surrogates in the Minnesota River Basin*. 10/28/2008 draft by E. Campbell, L. Ganske, and G. Johnson. 19 pgs.

Minnesota Pollution Control Agency. 2010. *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List. 2010 Assessment Cycle*. <http://www.pca.state.mn.us/publications/wq-iw1-04.pdf>.

Minnesota Pollution Control Agency. 2011. *Aquatic Life Water Quality Standards Draft Technical Support Document for Total Suspended Solids (Turbidity).* Draft May 2011. <http://www.pca.state.mn.us/index.php/view-document.html?gid=14922>

Minnesota Pollution Control Agency. 2012. Zumbro Watershed Turbidity Total Maximum Daily Load, Section 3.7.1 New and Expanding Discharges. January 2012. <http://www.pca.state.mn.us/index.php/view-document.html?gid=17902>

Mulla, D.J. 2002. *Relationship between Agro-ecoregions and Water Quality.* Minnesota River Research Forum presentation.

Randall, G. Wagar, T., Senjem, N., Busman, L., and Moncrief, J. 2008. *Tillage Best Management Practices for Water Quality Protection in Southeastern Minnesota*, University of Minnesota Extension Service, St. Paul, Revised 2000, Order# WW-07694. http://www.extension.umn.edu/distribution/cropsystems/DC7694.html

RESPEC 2010. *Fingerprinting Sources of Sediment in Large Agricultural River Systems*. St Croix Watershed Research Station.

Sadowsky, M. and S. Matteson. 2010. *Growth, Survival, and Genetic Structure of E. coli Found in Ditch Sediments and Water at the Seven Mile Creek Watershed*. Minnesota Department of Agriculture, St. Paul. http://www.mda.state.mn.us/protecting/cleanwaterfund/research/~/media/Files/protecting/cwf/ecoliditch7milecreek.ashx

U. S. Environmental Protection Agency. 2001. *Protocol for Developing Pathogen TMDLs*. EPA 841-R-00-002. Office of Water (4503F). United States Environmental Protection Agency, Washington, D.C.

Appendix A

Watershed Bacteria Production

Grove Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	72	0
Failure to protect groundwater	8	0
Imminent threat to public health	4	11
Total	84	11

Grove Creek Fecal Coliform Production Inventory

Category	**Sub-Category**		**Animal Units or Individuals**
Livestock	The Basin contains an estimated 13 registered livestock facilities ranging in size from less than 50 animal units to several hundred	Dairy	251 animal units
		Beef	297 animal units
		Swine	540 animal units
		Poultry	1,549 animal units
		Other (Horses & Goats)	51 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]		4 systems
	Total systems that do not discharge to surface water		241 systems
	Municipal Wastewater Treatment Facilities		Grove City
Wildlife[3]	Deer (average 11 per square mile)		119 deer
	Waterfowl (average 10 per square mile)		56 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]		702 dogs and cats

[1] Based on Meeker County SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on Meeker 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 2002).

Grove Creek Bacteria Production Assumptions

Category	**Source**	**Assumption**
Livestock	Overgrazed pastures near streams or waterways	1% total of beef, dairy and horse production
	Feedlots or stockpiles without runoff controls	1% of dairy, 5% of beef, 1% of poultry
	Surface applied manure	64% of dairy, 94% of beef, 10% of swine, 99% of poultry
	Incorporated manure	34% of dairy, 90% of swine
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	Grove City WWTF DMR reported bacteria effluent
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

Grove 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	Overgrazed pastures near streams or waterways	Dairy Animal Units	146	410 (<1%)
		Beef Animal Units	264	
	Feedlots or stockpiles without runoff controls	Dairy Animal Units	146	1,785 (2%)
		Beef Animal Units	1,321	
		Poultry Animal Units	318	
	Surface applied manure	Dairy Animal Units	9.349	67,385 (74%)
		Beef Animal Units	24,833	
		Swine Animal Units	1,766	
		Poultry Animal Units	31,437	
	Incorporated manure	Dairy Animal Units	4,967	20,859 (23%)
		Swine Animal Units	15,892	
Human	ITPHS septic systems and unsewered communities	Systems	11	11 (<1%)
	Municipal wastewater treatment facilities	People	<1	
Wildlife	Deer	Deer	119	164 (<1%)
	Waterfowl	Geese and ducks	45	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	19	19 (<1%)
Total				**90,633**

Jewitts Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	95	0
Failure to protect groundwater	11	0
Imminent threat to public health	6	14
Total	112	14

Jewitts Creek Fecal Coliform Production Inventory

Category	Sub-Category		Animal Units or Individuals
Livestock	The Basin contains an estimated 8 registered livestock facilities ranging in size from less than 50 animal units to several hundred	Dairy	150 animal units
		Beef	190 animal units
		Swine	193 animal units
		Poultry	4,071 animal units
		Other (Horses & Goats)	5 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]		6 systems
	Total systems that do not discharge to surface water		106 systems
	Municipal Wastewater Treatment Facilities		Litchfield WWTP
Wildlife[3]	Deer (average 11 per square mile)		110 deer
	Waterfowl (average 10 per square mile)		51 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]		3,357 dogs and cats

[1] Based on Meeker County SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on Meeker 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 2002).

Jewitts Creek Bacteria Production Assumptions

Category	Source	Assumption
Livestock	Overgrazed pastures near streams or waterways	1% total of beef, dairy and horse production
	Feedlots or stockpiles without runoff controls	1% of dairy, 5% of beef, 1% of poultry
	Surface applied manure	64% of dairy, 94% of beef, 10% of swine, 99% of poultry
	Incorporated manure	34% of dairy, 90% of swine
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	Litchfield WWTF DMR reported bacteria effluent
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

Jewitts 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	Overgrazed pastures near streams or waterways	Dairy Animal Units	87	256 (<1%)
		Beef Animal Units	169	
	Feedlots or stockpiles without runoff controls	Dairy Animal Units	87	1,765 (2%)
		Beef Animal Units	844	
		Poultry Animal Units	834	
	Surface applied manure	Dairy Animal Units	5,569	104,685 (91%)
		Beef Animal Units	15,871	
		Swine Animal Units	631	
		Poultry Animal Units	82,614	
	Incorporated manure	Dairy Animal Units	2,958	8,535 (7%)
		Swine Animal Units	5,577	
Human	ITPHS septic systems and unsewered communities	Systems	14	15 (<1%)
	Municipal wastewater treatment facilities	People	1	
Wildlife	Deer	Deer	110	151 (<1%)
	Waterfowl	Geese and ducks	41	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	151	151 (<1%)
Total				**115,558**

Regal Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	7	0
Failure to protect groundwater	5	0
Imminent threat to public health	1	2
Total	13	2

Regal Creek Fecal Coliform Production Inventory

Category	Sub-Category		Animal Units or Individuals
Livestock	The Basin contains an estimated 14 registered livestock facilities ranging in size from less than 50 animal units to several hundred	Dairy	350 animal units
		Beef	272 animal units
		Swine	14 animal units
		Poultry	0 animal units
		Other (Horses & Goats)	2 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]		1 systems
	Total systems that do not discharge to surface water		12 systems
	Municipal Wastewater Treatment Facilities		None
Wildlife[3]	Deer (average 11 per square mile)		71 deer
	Waterfowl (average 10 per square mile)		33 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]		6,191 dogs and cats

[1] Based on Wright County SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on Wright 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 2002).

Regal Creek Bacteria Production Assumptions

Category	Source	Assumption
Livestock	Overgrazed pastures near streams or waterways	1% total of beef, dairy and horse production
	Feedlots or stockpiles without runoff controls	1% of dairy, 5% of beef, 1% of poultry
	Surface applied manure	64% of dairy, 94% of beef, 10% of swine, 99% of poultry
	Incorporated manure	34% of dairy, 90% of swine
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None in watershed
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

Regal 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	Overgrazed pastures near streams or waterways	Dairy Animal Units	204	446 (1%)
		Beef Animal Units	242	
	Feedlots or stockpiles without runoff controls	Dairy Animal Units	204	1,414 (3%)
		Beef Animal Units	1,210	
		Poultry Animal Units	--	
	Surface applied manure	Dairy Animal Units	13,052	35,840 (79%)
		Beef Animal Units	22,739	
		Swine Animal Units	46	
		Poultry Animal Units	3	
	Incorporated manure	Dairy Animal Units	6,934	7,346 (16%)
		Swine Animal Units	412	
Human	ITPHS septic systems and unsewered communities	Systems	2	2 (<1%)
	Municipal wastewater treatment facilities	People	--	
Wildlife	Deer	Deer	71	97 (<1%)
	Waterfowl	Geese and ducks	26	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	279	279 (<1%)
Total				**45,424**

Unnamed Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/day)
Non-Failing	143	0
Failure to protect groundwater	83	0
Imminent threat to public health	12	30
Total	238	30

Unnamed Creek Fecal Coliform Production Inventory

Category	Sub-Category		Animal Units or Individuals
Livestock	The Basin contains an estimated 26 registered livestock facilities ranging in size from less than 50 animal units to several hundred	Dairy	3,510 animal units
		Beef	1,516 animal units
		Swine	519 animal units
		Poultry	14 animal units
		Other (Horses & Goats)	82 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]		12 systems
	Total systems that do not discharge to surface water		226 systems
	Municipal Wastewater Treatment Facilities		None
Wildlife[3]	Deer (average 11 per square mile)		138 deer
	Waterfowl (average 10 per square mile)		65 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]		347 dogs and cats

[1] Based on Wright County SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on Wright County 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 2002).

Unnamed Creek Bacteria Production Assumptions

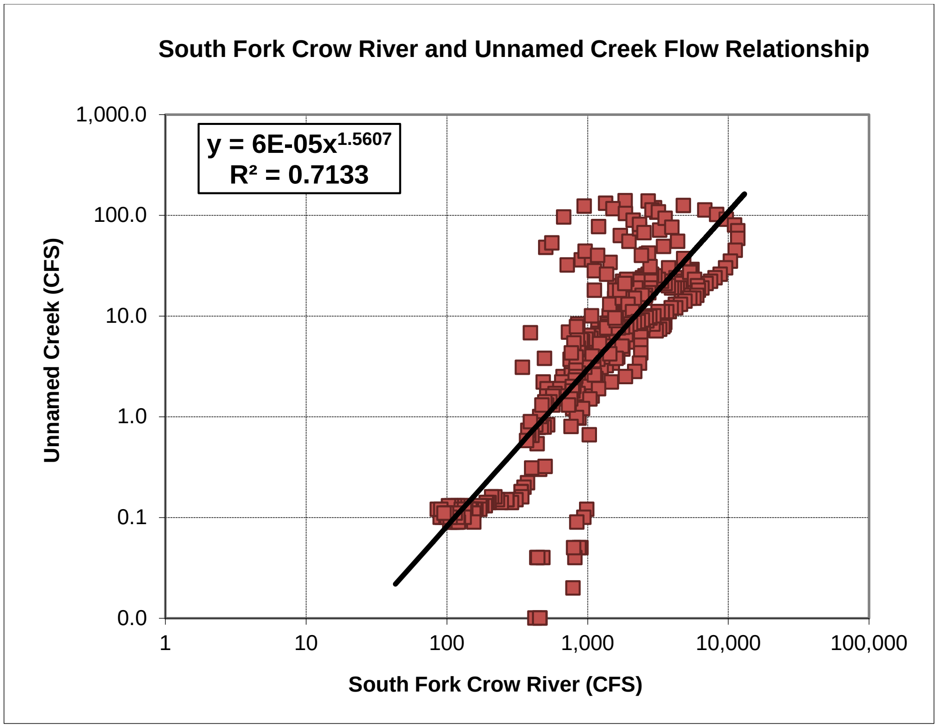
Category	Source	Assumption
Livestock	Overgrazed pastures near streams or waterways	1% total of beef, dairy and horse production
	Feedlots or stockpiles without runoff controls	1% of dairy, 5% of beef, 1% of poultry
	Surface applied manure	64% of dairy, 94% of beef, 10% of swine, 99% of poultry
	Incorporated manure	34% of dairy, 90% of swine
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None in watershed
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

Unnamed Creek Fecal Coliform Available for Delivery

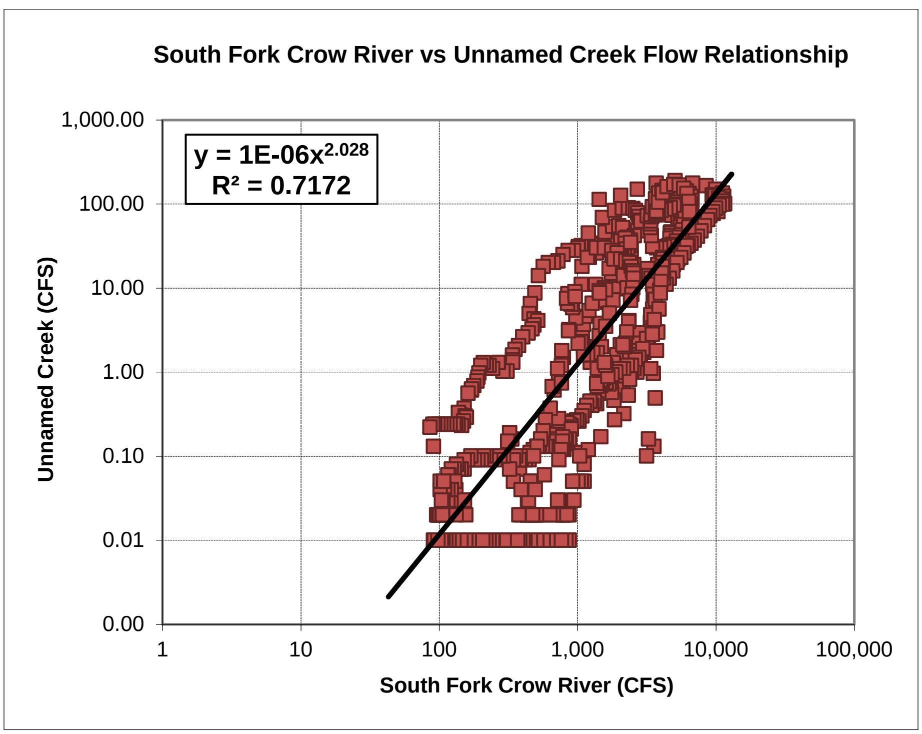
Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Overgrazed pastures near streams or waterways	Dairy Animal Units	2,043	3,394 (1%)
		Beef Animal Units	1,351	
	Feedlots or stockpiles without runoff controls	Dairy Animal Units	2,043	8,800 (2%)
		Beef Animal Units	6,754	
		Poultry Animal Units	3	
	Surface applied manure	Dairy Animal Units	130,740	259,692 (73%)
		Beef Animal Units	126,971	
		Swine Animal Units	1,697	
		Poultry Animal Units	284	
	Incorporated manure	Dairy Animal Units	69,456	84,730 (24%)
		Swine Animal Units	15,274	
Human	ITPHS septic systems and unsewered communities	Systems	30	30 (<1%)
	Municipal wastewater treatment facilities	People	--	
Wildlife	Deer	Deer	69	95 (<1%)
	Waterfowl	Geese and ducks	26	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	16	16 (<1%)
Total				**356,757**

Appendix B

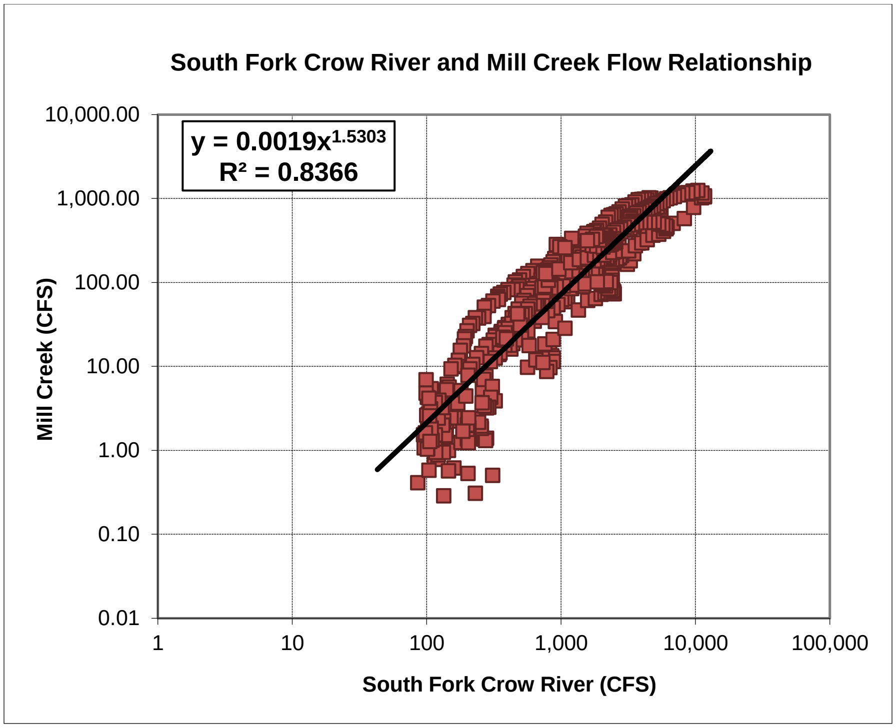
Continuous Flow Monitoring Regressions



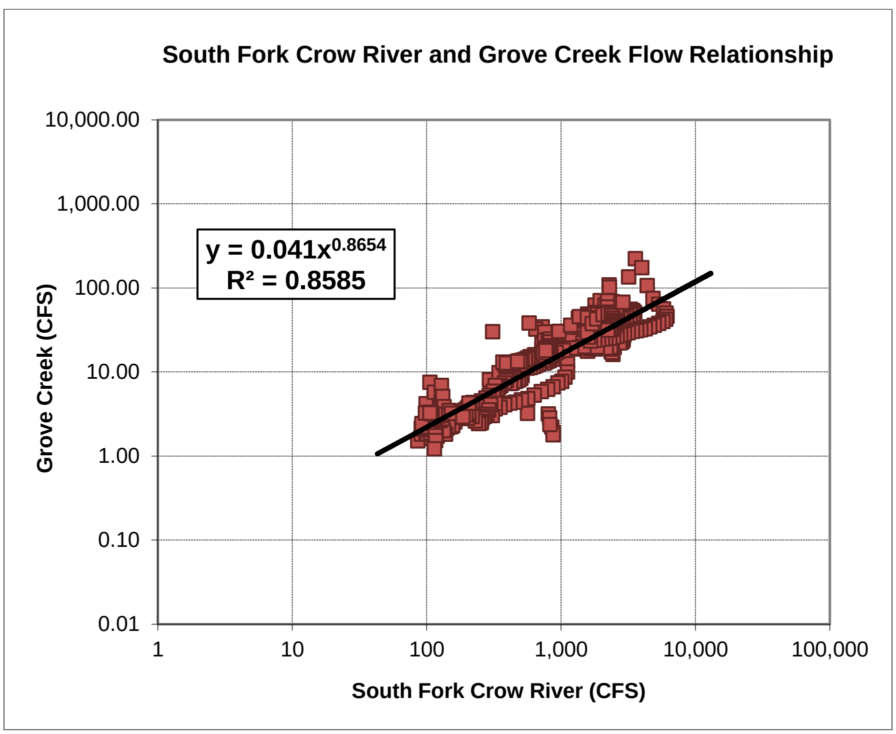
Flow regression between the South Fork Crow River (S000-050) and Unnamed Creek (S001-499) monitoring stations.



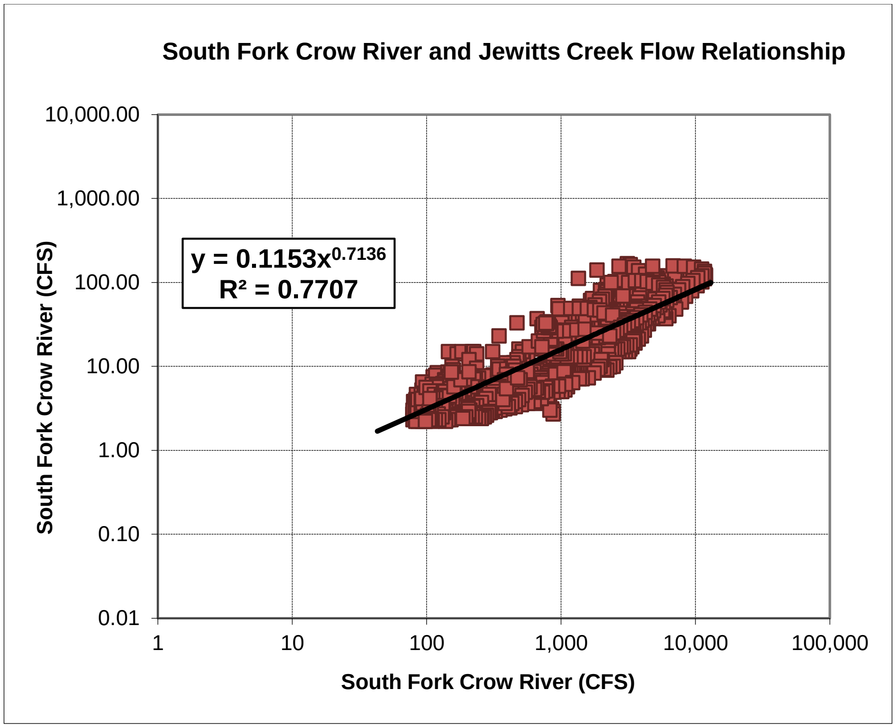
Flow regression between the South Fork Crow River (S000-050) and Unnamed Creek (S005-836) monitoring stations.



Flow regression between the South Fork Crow River (S000-050) and Mill Creek (S002-018) monitoring stations.



Flow regression between the South Fork Crow River (S000-050) and Grove Creek (S000-847) monitoring stations.



Flow regression between the South Fork Crow River (S000-050) and Jewitts Creek (S001-502) monitoring stations.

Note:

The regression relationships above, which correlated well in each reach ($R^2 > 0.7$), were used to fill data gaps in the flow record for each impaired reach.

Appendix C

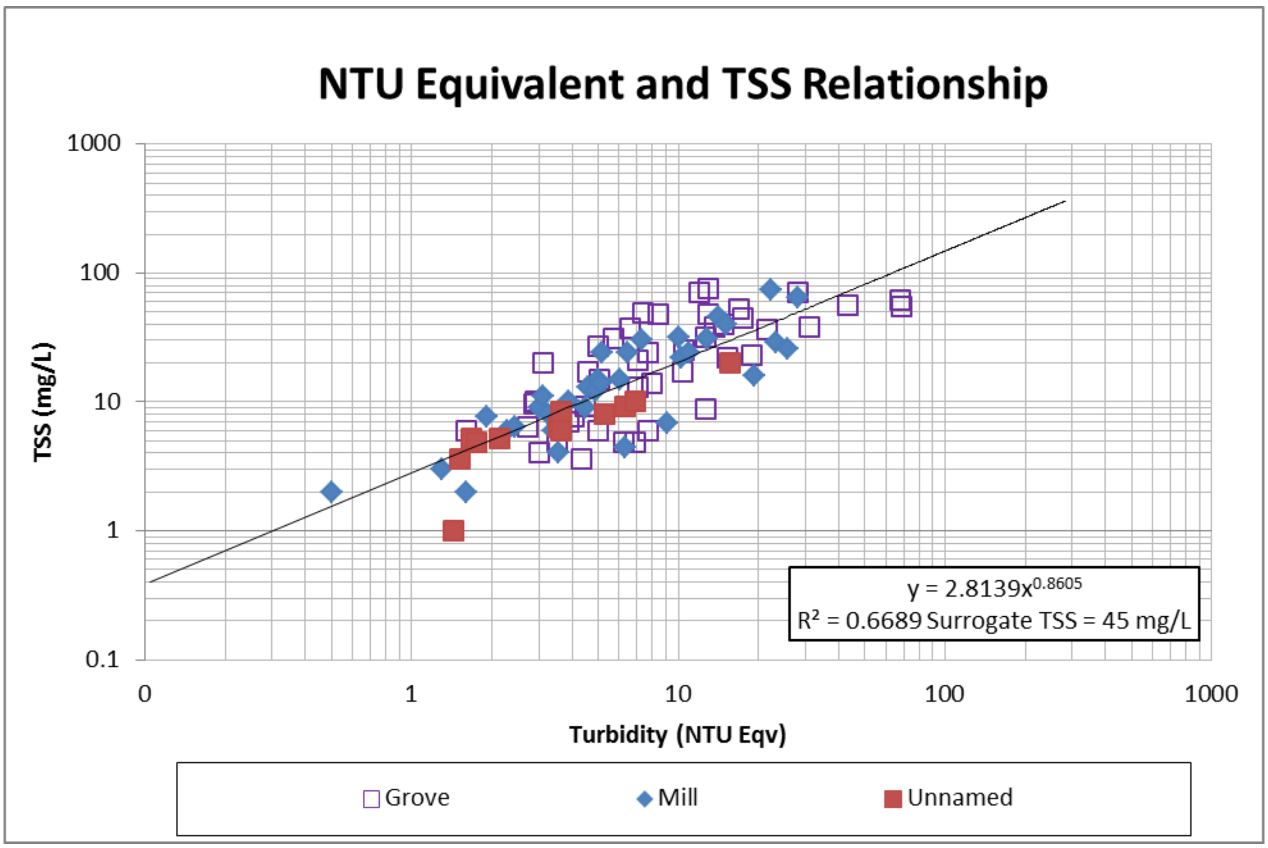
NPDES Permitted Point Source Fecal Coliform and Total Suspended Solids DMR Summary

Facility	Location	Months Sampled	Individual Exceedances	Fecal Coliform Average of Monitored Geomeans since 1999 to present (organisms/100 mL)											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Grove City WWTP	NFC	90	4					23	19	26	27	22	35		
Litchfield WWTP	NFC	93	4				28	30	33	18	25	27	29		

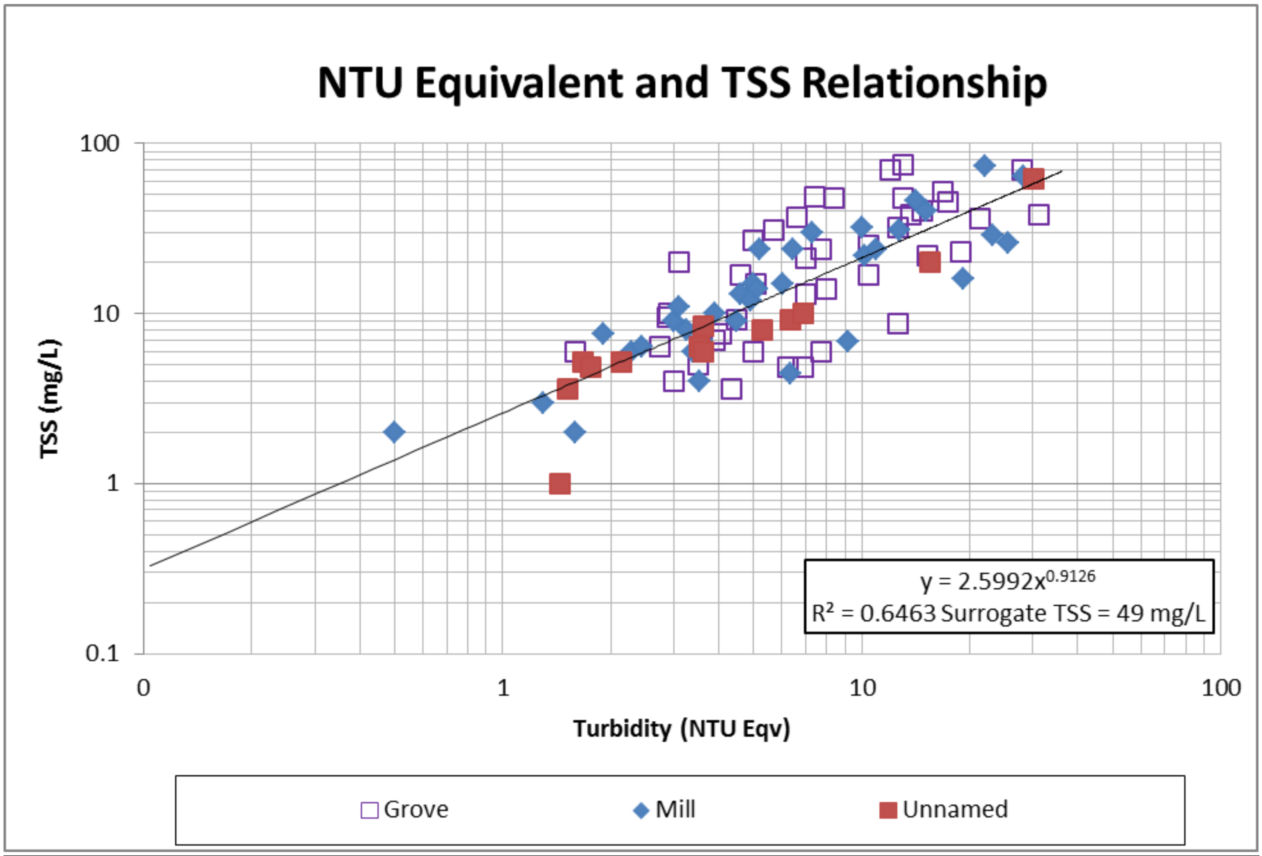
Facility	Location	Months Sampled	Individual Exceedances	TSS Average of Monitored Averages since 1999 to present (mg/L)											
				Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Grove City WWTP	NFC	161	0	32	32	31	28	40	38	36	38	42	47	36	39

Appendix D

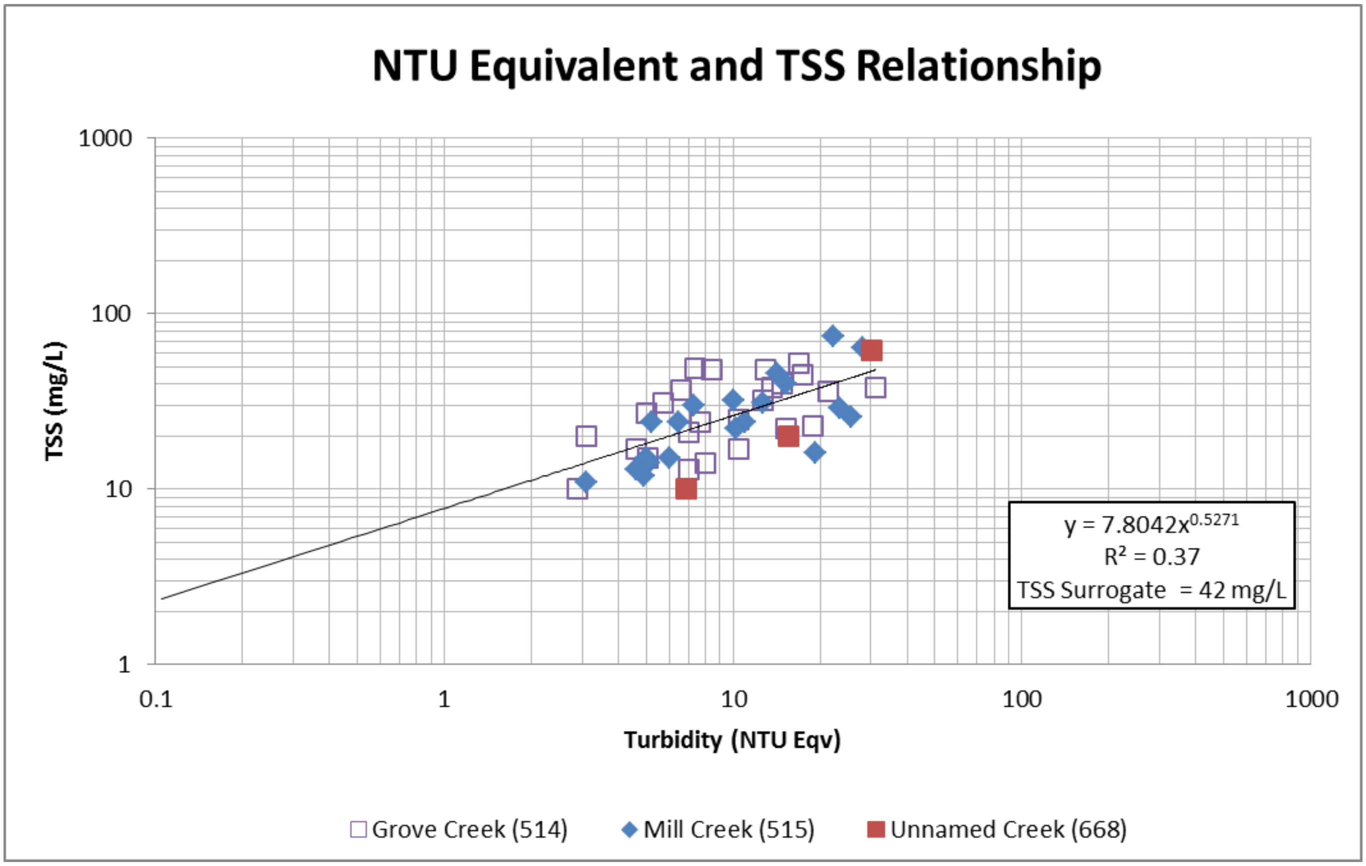
TSS-NTU Regression Relationships Used to Develop TSS Surrogate Standard



The NTU and TSS data relationship was plotted including all data points from each impaired reach.



All data points with NTU measurements greater than 40 NTU were removed as recommended by the MPCA (MPCA, 2008)



All data points with TSS measurements less than 10 mg/L were removed as recommended by the MPCA (MPCA, 2008). This is the regression used to calculate the surrogate TSS standard used in the TMDL analysis.

Appendix E

Lake Response Models

Lake	Depth Class	Anoxic Release Rate (mg/m2/d)	Anoxic Factor (days)	Oxic Release Rate (mg/m2/d)	Oxic Factor (days)	Annual Load (lbs)
Big Swan	Deep	15.0	4.7	--	--	436
Collinwood	Deep	23.2	21.6	--	--	2,837
Hook	Shallow	10.1	58.9*	--	--	1,750
Jennie	Shallow	2.0	44.8*	--	--	851
Spring	Deep	4.8	50.8	--	--	474
Brooks	Deep	6.4	32.5*	--	--	177
Cokato	Deep	0.5	31.6	--	--	77
Smith	Shallow	12.6	69.2*	--	--	1,764
Albert	Deep	20.0	40.7	--	--	434
Buffalo	Deep	10.5	23.8	0.2	98.2	3,732
Deer	Deep	22.0	31.6	--	--	1,011
Light Foot	Shallow	13.6	70.3*	--	--	578
Ramsey	Deep	4.0	31.8	--	--	351
Richardson	Deep	1.0	59	--	--	61
Dunns	Deep	7.0	61.2*	--	--	581
Dutch	Deep	12.0	66.4*	0.5	122	1,235
Howard	Deep	15.5	33	--	--	3,358
Little Waverly	Shallow	30.0	81.3*	2.0	122	7,903

Lake	Depth Class	Anoxic Release Rate (mg/m2/d)	Anoxic Factor (days)	Oxic Release Rate (mg/m2/d)	Oxic Factor (days)	Annual Load (lbs)
Waverly	Deep	2.8	43.9	--	--	534
Hope	Shallow	15.0	73.2*	0.5	122	2,587
Long	Shallow	20.0	80.3*	1.0	122	11,886
Constance	Deep	14.0	30.2	0.5	61	703
Pelican	Shallow	7.1	59.9*	0.5	122	15,016
Camp	Deep	26	41.1	--	--	1,030
Dean	Shallow	8.0	71.4*	1.0	122	1,083
Foster	Shallow	27.3	74*	1.0	122	2,312
Fountain	Shallow	10.0	68*	0.9	54	2,769
French	Deep	1	34	--	--	105
Granite	Deep	12.7	23	--	--	920
Hafften	Deep	7.7	42.2	--	--	125
Malardi	Shallow	23.6	81.5*	1	122	2,138
Nest	Deep	9.5	16.9	--	--	1,444
Rock	Deep	5.0	31	--	--	253

* Shallow Lake Anoxic Factor from Nurnberg 2005

Hook Lake Current Conditions BATHTUB Lake Response Model

	Average Loading Summary for Hook						
	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	Reach 374 near lal	3,356	4.5	1,244	101	1.0	342
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*3,356*	*4*	*1,244*			*342*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	374		106	5.941	43%		69.5
2							
3							
4							
5							
	Summation			*5.9*			*69*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	330	23.8	23.8	0.00	0.22	1.0	73
		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]
	330	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]
	1.33			Oxic		1.0	
	1.33	58.9		Anoxic	6.2	1.0	1,750
	Summation						1,750
		Net Discharge [ac-ft/yr] =		**1,250**	**Net Load [lb/yr] =**		**2,235**

Average Lake Response Modeling for Hook				
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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,014	[kg/yr]
		Q (lake outflow) =	1.5	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	1.86	[yr]
		P_i = W/Q =	657	[µg/l]
Model Predicted In-Lake [TP]			**121.2**	**[ug/l]**
Observed In-Lake [TP]			**121.2**	**[ug/l]**

Hook Lake TMDL BATHTUB Lake Response Model

TMDL Loading Summary for Hook

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	Reach 374 near lal	3,356	4.5	1,244	100	1.0	338
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*3,356*	*4*	*1,244*			*338*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	374		106	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*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]
	330	23.8	23.8	0.00	0.22	1.0	73
		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]
	330	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]
	1.33			Oxic		1.0	
	1.33	58.9		Anoxic	6.2	1.0	339
	Summation						339
			Net Discharge [ac-ft/yr] =	**1,244**		Net Load [lb/yr] =	**750**

TMDL Lake Response Modeling for Hook

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	341	[kg/yr]
		Q (lake outflow) =	1.5	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	1.87	[yr]
		P_i = W/Q =	222	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Jennie Lake Current Conditions BATHTUB Lake Response Model

	Average Loading Summary for	*Jennie*					
	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	Reach 376 tributar	6,790	2.6	1,471	223	1.0	891
2	Reach 376 near lal	5,573	4.0	1,853	104.1	1.0	525
3						1.0	
4						1.0	
5						1.0	
	Summation	*12,364*	*7*	*3,324*			*1416*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1804602		107	6.017	43%		70.4
2	1804603		267	14.975	43%		175.1
3							
4							
5							
	Summation			*21.0*			*245*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Hook			586	121.2	1.0	193
2					-	1.0	
3					-	1.0	
	Summation			*586*	*121.2*		*193*
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]
	1064	26.6	26.6	0.00	0.24	1.0	254
		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]
	1064	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	4.31			Oxic		1.0	
	4.31	44.8		Anoxic	2.0	1.0	851
	Summation						851
		Net Discharge [ac-ft/yr] =		**3,931**	**Net Load [lb/yr] =**		**2,959**

Average Lake Response Modeling for	*Jennie*			
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 =	1.08	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,343	[kg/yr]
		Q (lake outflow) =	4.9	$[10^6 m^3/yr]$
		V (modeled lake volume) =	11.1	$[10^6 m^3]$
		T = V/Q =	2.28	[yr]
		P_i = W/Q =	277	[µg/l]
Model Predicted In-Lake [TP]			**60.1**	**[ug/l]**
Observed In-Lake [TP]			**60.1**	**[ug/l]**

Jennie Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Jennie

	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	Reach 376 tributar	6,790	2.6	1,471	223	1.0	891
2	Reach 376 near lal	5,573	4.0	1,853	104.1	1.0	525
3						1.0	
4						1.0	
5						1.0	
	Summation	*12,364*	*7*	*3,324*			*1,416*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1804602		107	0.000	43%	0.0	0.0
2	1804603		267	0.000	43%	0.0	0.0
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Hook			586	60.0	0.5	96
2					-	1.0	
3					-	1.0	
	Summation			*586*	*60.0*		*96*
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]
	1064	26.6	26.6	0.00	0.24	1.0	254
		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]
	1064	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]
	4.31			Oxic		1.0	
	4.31	44.8		Anoxic	2.0	1.0	851
	Summation						851
		Net Discharge [ac-ft/yr] =		**3,910**	**Net Load [lb/yr] =**		**2,617**

TMDL Lake Response Modeling for Jennie

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 =	1.08	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,187	[kg/yr]
		Q (lake outflow) =	4.8	[10^6 m^3/yr]
		V (modeled lake volume) =	11.1	[10^6 m^3]
		T = V/Q =	2.29	[yr]
		P_i = W/Q =	246	[µg/l]
Model Predicted In-Lake [TP]			**55.6**	**[ug/l]**
Observed In-Lake [TP]			**55.6**	**[ug/l]**

Collinwood Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Collinwood							
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	Reach 379 (West)	13,895	5.3	6,175	187	1.0	3,135
2	Reach 377 (South)	4,265	5.2	1,833	279.9	1.0	1,396
3	Direct Watershed (	2,075	3.9	680	118.4	1.0	219
4						1.0	
5						1.0	
	Summation	*20,234*	*14*	*8,689*			*4,750*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	377		345	19.336	43%		226.1
2	1801701 (Direct WS)		114	6.370	43%		74.5
3	Reach 379 (HUIDs)		553	30.994	43%		362.4
4							
5							
	Summation			*56.7*			*663*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Jennie			2,926	60.1	1.0	478
2					-	1.0	
3					-	1.0	
	Summation			*2,926*	*60.1*		*478*
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]
	636	30.0	30.0	0.00	0.24	1.0	152.0
		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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	636	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]
	2.57			Oxic		1.0	
	2.57	21.6		Anoxic	23.2	1.0	2,837
	Summation						2,837
		Net Discharge [ac-ft/yr] =		**11,671**	**Net Load [lb/yr] =**		**8,880**

Average Lake Response Modeling for Collinwood				
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.) =	4,028	[kg/yr]
		Q (lake outflow) =	14.4	[10^6 m^3/yr]
		V (modeled lake volume) =	9.6	[10^6 m^3]
		T = V/Q =	0.67	[yr]
		P_i = W/Q =	280	[µg/l]
Model Predicted In-Lake [TP]			**102.8**	**[ug/l]**
Observed In-Lake [TP]			**102.8**	**[ug/l]**

Collinwood Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Collinwood

	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	Reach 379 (West)	13,895	5.3	6,175	73	0.4	1,222
2	Reach 377 (South)	4,265	5.2	1,833	70.0	0.3	349
3	Direct Watershed (	2,075	3.9	680	71.0	0.6	131
4						1.0	
5						1.0	
	Summation	*20,234*	*14*	*8,689*			*1,703*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	377		345	0.000	43%	0.0	0.0
2	1801701 (Direct WS)		114	0.000	43%	0.0	0.0
3	Reach 379 (HUIDs)		553	0.000	43%	0.0	0.0
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Jennie			2,926	60.1	1.0	478
2					-	1.0	
3					-	1.0	
	Summation			*2,926*	*60.1*		*478*
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]
	636	30.0	30.0	0.00	0.24	1.0	152.0
				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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	636	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]
	2.57			Oxic		1.0	
	2.57	21.6		Anoxic	23.2	1.0	147
	Summation						147
			Net Discharge [ac-ft/yr] =	**11,614**		Net Load [lb/yr] =	**2,480**

TMDL Lake Response Modeling for Collinwood

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.) =	1,125	[kg/yr]
		Q (lake outflow) =	14.3	[$10^6\ m^3/yr$]
		V (modeled lake volume) =	9.6	[$10^6\ m^3$]
		T = V/Q =	0.67	[yr]
		P_i = W/Q =	78	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Spring Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Spring

	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	Reach 378 near lal	1,252	4.7	488	66	1.0	88
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,252*	*5*	*488*			*88*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1801704		192	10.775	43%		126.0
2							
3							
4							
5							
	Summation			*10.8*			*126*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Long Lake			377	37.0	1.0	38
2					-	1.0	
3					-	1.0	
	Summation			*377*	*37.0*		*38*
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]
	218	28.3	28.3	0.00	0.24	1.0	52
				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]
	218	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	0.88			Oxic		1.0	
	0.88	50.8		Anoxic	4.8	1.0	474
	Summation						474
			Net Discharge [ac-ft/yr] =	875		Net Load [lb/yr] =	778

Average Lake Response Modeling for Spring

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	353	[kg/yr]
		Q (lake outflow) =	1.1	[10^6 m^3/yr]
		V (modeled lake volume) =	2.6	[10^6 m^3]
		T = V/Q =	2.43	[yr]
		P_i = W/Q =	327	[µg/l]
Model Predicted In-Lake [TP]			**69.3**	**[ug/l]**
Observed In-Lake [TP]			**69.3**	**[ug/l]**

Spring Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for			***Spring***			
	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	Reach 378 near lal	1,252	4.7	488	60	0.9	79
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,252*	*5*	*488*			*79*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1801704		192	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Long Lake			377	37.0	1.0	38
2					-	1.0	
3					-	1.0	
	Summation			*377*	*37.0*		*38*
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]
	218	28.3	28.3	0.00	0.24	1.0	52.1
		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	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	218	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	0.88			Oxic		1.0	
	0.88	50.8		Anoxic	4.8	1.0	166
	Summation						166
		Net Discharge [ac-ft/yr] =		**865**	**Net Load [lb/yr] =**		**335**

TMDL Lake Response Modeling for		***Spring***		
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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	152	[kg/yr]
		Q (lake outflow) =	1.1	[10^6 m³/yr]
		V (modeled lake volume) =	2.6	[10^6 m³]
		T = V/Q =	2.46	[yr]
		P_i = W/Q =	143	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Big Swan Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Big Swan

	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	Reach 384 Tributar	13,632	4.9	5,519	228	1.0	3,424
2	Reach 384 Near La	3,466	4.5	1,290	103.7	1.0	364
3						1.0	
4						1.0	
5						1.0	
	Summation	*17,098*	*9*	*6,809*			*3,788*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 384		467	26.173	43%		306.0
2							
3							
4							
5							
	Summation			*26.2*			*306*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Collinwood Lake			9,241	96.8	1.0	2,433
2	Spring Lake			494	69.3	1.0	93
3					-	1.0	
	Summation			*9,735*	*83.0*		*2,526*
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]
	694	25.6	25.6	0.00	0.24	1.0	166
		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]
	694	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]
	2.81			Oxic		1.0	
	2.81	4.7		Anoxic	15.0	1.0	436
	Summation						436
		Net Discharge [ac-ft/yr] =		**16,570**	**Net Load [lb/yr] =**		**7,222**

Average Lake Response Modeling for Big Swan

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 =	0.57	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,276	[kg/yr]
		Q (lake outflow) =	20.4	[10^6 m^3/yr]
		V (modeled lake volume) =	13.0	[10^6 m^3]
		T = V/Q =	0.64	[yr]
		P_i = W/Q =	160	[µg/l]
Model Predicted In-Lake [TP]			**91.8**	**[ug/l]**
Observed In-Lake [TP]			**91.8**	**[ug/l]**

Big Swan Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Big Swan

		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	Reach 384 Tributai	13,632	4.9	5,519	74	0.3	1,109
2	Reach 384 Near La	3,466	4.5	1,290	72.6	0.7	255
3						1.0	
4						1.0	
5						1.0	
	Summation	*17,098*	*9*	*6,809*			*1364*
Failing Septic Systems							
	Name	Area [ac]	' people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 384		467	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Collinwood Lake			9,241	40.0	0.4	1,006
2	Spring Lake			494	40.0	0.6	54
3					-	1.0	
	Summation			*9,735*	*40.0*		*1,059*
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]
	694	25.6	25.6	0.00	0.24	1.0	166
		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]
	694	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]
	2.81			Oxic		1.0	
	2.81	4.7		Anoxic	15.0	1.0	58
	Summation						58
		Net Discharge [ac-ft/yr] =		**16,544**	**Net Load [lb/yr] =**		**2,647**

TMDL Lake Response Modeling for Big Swan

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 =	0.57	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,201	[kg/yr]
		Q (lake outflow) =	20.4	[10^6 m^3/yr]
		V (modeled lake volume) =	13.0	[10^6 m^3]
		T = V/Q =	0.64	[yr]
		P_i = W/Q =	59	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Ramsey Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Ramsey

	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	Reach 492 near lal	3,427	5.0	1,433	296	1.0	1,154
2							
3							
4							
5							
	Summation	*3,427*	*5*	*1,433*			*1,154*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1801401		476	26.663	43%		311.7
2	1801402		292	16.361	43%		191.3
3							
4							
5							
	Summation			*43.0*			*503*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Upper Maple			1,232	21.4	1.0	72
2					-	1.0	
3					-	1.0	
	Summation			*1,232*	*21.4*		*72*
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]
	309	29.6	29.6	0.00	0.24	1.0	74
		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]
	309	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]
	1.25			Oxic		1.0	
	1.25	31.8		Anoxic	4.0	1.0	351
	Summation						351
		Net Discharge [ac-ft/yr] =		**2,708**	**Net Load [lb/yr] =**		**2,154**

Average Lake Response Modeling for Ramsey

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 =	1.15	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	977	[kg/yr]
		Q (lake outflow) =	3.3	[10^6 m^3/yr]
		V (modeled lake volume) =	7.5	[10^6 m^3]
		T = V/Q =	2.23	[yr]
		P_i = W/Q =	292	[µg/l]
Model Predicted In-Lake [TP]			**59.8**	**[ug/l]**
Observed In-Lake [TP]			**59.8**	**[ug/l]**

Ramsey Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for			***Ramsey***			
	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	Reach 492 near lal	3,427	5.0	1,433	212	0.7	825
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*3,427*	*5*	*1,433*			*825*
Failing Septic Systems							
	Name	Area [ac]	' people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1801401		476	0.000	43%	0.0	0.0
2	1801402		292	0.000	43%	0.0	0.0
3							
4							
5							
	Summation			*0.0*			*0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Upper Maple			1,232	21.4	1.0	72
2					-	1.0	
3					-	1.0	
	Summation			*1,232*	*21.4*		*72*
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]
	309	29.6	29.6	0.00	0.24	1.0	74
		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]
	309	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]
	1.25			Oxic		1.0	
	1.25	31.8		Anoxic	4.0	1.0	180
	Summation						180
		Net Discharge [ac-ft/yr] =		**2,665**	**Net Load [lb/yr] =**		**1,151**

TMDL Lake Response Modeling for		***Ramsey***		
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 =	1.15	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	522	[kg/yr]
		Q (lake outflow) =	3.3	[10^6 m^3/yr]
		V (modeled lake volume) =	7.5	[10^6 m^3]
		T = V/Q =	2.27	[yr]
		P_i = W/Q =	159	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Albert Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Albert

	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 Albert Lake Waters	304	5.4	137	209	1.0	78
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*304*	*5*	*137*			*78*
Failing Septic Systems						
Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1 Albert		37	2.072	43%		24.2
2						
3						
4						
5						
Summation	*0*		*2.1*			*24*
Inflow from Upstream Lakes						
			Discharge	Estimated P Concentration	Calibration Factor	Load
Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				-	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]
60	30.1	30.1	0.00	0.24	1.0	14
	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]
60	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]
0.24			Oxic		1.0	
0.24	40.7		Anoxic	20.0	1.0	434
Summation						434
	Net Discharge [ac-ft/yr] =		**139**		**Net Load [lb/yr] =**	**550**

Average Lake Response Modeling for Albert

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	0.85	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	250	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.9	[10^6 m^3]
		T = V/Q =	5.40	[yr]
		P_i = W/Q =	1456	[µg/l]
Model Predicted In-Lake [TP]			**137.0**	**[ug/l]**
Observed In-Lake [TP]			**137.0**	**[ug/l]**

Albert Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for			***Albert***			
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	Albert Lake Waters	304	5.4	137	98	0.5	36
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*304*	*5*	*137*			*36*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Albert		37	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation	*0*		*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	60	30.1	30.1	0.00	0.24	1.0	14
		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]
	60	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]
	0.24			Oxic		1.0	
	0.24	40.7		Anoxic	20.0	1.0	22
	Summation						22
		Net Discharge [ac-ft/yr] =		**137**	**Net Load [lb/yr] =**		**72**

TMDL Lake Response Modeling for		***Albert***		
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 =	0.85	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	33	[kg/yr]
		Q (lake outflow) =	0.2	[10^6 m^3/yr]
		V (modeled lake volume) =	0.9	[10^6 m^3]
		T = V/Q =	5.48	[yr]
		P_i = W/Q =	195	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Light Foot Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for			***Light Foot***				
	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	Reach 496 tributar	4,568	3.8	1,450	427	2.0	1,683
2	Reach 496 near lal	5,219	3.7	1,598	222.8	2.0	969
3						1.0	
4						1.0	
5						1.0	
	Summation	*9,788*	*7*	*3,049*			*2651*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1801400		557	31.215	43%		365.0
2	1801403		69	3.864	43%		45.2
3	1808100		410	22.982	43%		268.7
4							
5							
	Summation			*58.1*			*679*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Ramsey			1,448	54.0	1.0	213
2	Albert			125	137.0	1.0	47
3					-	1.0	
	Summation			*1,573*	*95.5*		*259*
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]
	68	22.4	22.4	0.00	0.22	1.0	15
		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]
	68	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]
	0.27	122		Oxic	2.0	1.0	0
	0.27	70.3		Anoxic	36.0	1.0	578
	Summation						578
		Net Discharge [ac-ft/yr] =		**4,680**	**Net Load [lb/yr] =**		**4,182**

Average Lake Response Modeling for ***Light Foot***			
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.) =	1,897	[kg/yr]
	Q (lake outflow) =	5.8	[10^6 m^3/yr]
	V (modeled lake volume) =	0.6	[10^6 m^3]
	T = V/Q =	0.11	[yr]
	P_i = W/Q =	329	[µg/l]
Model Predicted In-Lake [TP]		**195.2**	**[ug/l]**
Observed In-Lake [TP]		**195.2**	**[ug/l]**

Light Foot Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Light Foot

	Name	Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Water Budgets				**Phosphorus Loading**		
	Inflow from Drainage Areas						
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Reach 496 tributar	4,568	3.8	1,450	427	2.0	1,683
2	Reach 496 near lal	5,219	3.7	1,598	222.8	2.0	969
3						1.0	
4						1.0	
5						1.0	
	Summation	*9,788*	*7*	*3,049*			*2651*
	Failing Septic Systems						
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1801400		557	31.215	43%		365.0
2	1801403		69	3.864	43%		45.2
3	1808100		410	22.982	43%		268.7
4							
5							
	Summation			*58.1*			*679*
	Inflow from Upstream Lakes						
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Ramsey			1,448	54.0	1.0	213
2	Albert			125	137.0	1.0	47
3					-	1.0	
	Summation			*1,573*	*95.5*		*259*
	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]
	68	22.4	22.4	0.00	0.22	1.0	15
		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]
	68	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]
	0.27	122		Oxic	2.0	1.0	0
	0.27	70.3		Anoxic	36.0	1.0	578
	Summation						578
		Net Discharge [ac-ft/yr] =		**4,680**	**Net Load [lb/yr] =**		**4,183**

TMDL Lake Response Modeling for Light Foot

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	296	[kg/yr]
		Q (lake outflow) =	5.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.6	[10^6 m^3]
		T = V/Q =	0.11	[yr]
		P_i = W/Q =	52	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Buffalo Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Buffalo

		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	Reach 498 tributar	2,212	5.9	1,094	160	1.0	475
2	Reach 498 near lal	9,405	4.5	3,536	147.4	1.0	1,418
3						1.0	
4						1.0	
5						1.0	
	Summation	*11,617*	*10*	*4,630*			*1892*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800700		936	52.448	43%		613.2
2							
3							
4							
5							
	Summation			*52.4*			*613*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Light Foot			7,978	195.2	1.0	4,235
2	Albert			163	137.0	1.0	61
3	Pulaski			2,417	19.0	1.0	125
	Summation			*10,558*	*117.1*		*4,421*
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]
	1552	35.7	35.7	0.00	0.24	1.0	371
		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]
	1552	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]
	6.28	98.2		Oxic		1.0	272
	6.28	23.8		Anoxic	10.5	1.0	3,460
	Summation						3,732
		Net Discharge [ac-ft/yr] =		**15,240**	**Net Load [lb/yr] =**		**11,029**

Average Lake Response Modeling for Buffalo

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	0.79	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	5,003	[kg/yr]
		Q (lake outflow) =	18.8	[10^6 m^3/yr]
		V (modeled lake volume) =	28.2	[10^6 m^3]
		T = V/Q =	1.50	[yr]
		P_i = W/Q =	266	[µg/l]
Model Predicted In-Lake [TP]			**87.3**	**[ug/l]**
Observed In-Lake [TP]			**87.3**	**[ug/l]**

Buffalo Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Buffalo

	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	Reach 498 tributar	2,212	5.9	1,094	100	0.6	297
2	Reach 498 near lal	9,405	4.5	3,536	99.9	0.7	961
3						1.0	
4						1.0	
5						1.0	
	Summation	*11,617*	*10*	*4,630*			*1,258*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800700		936	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Light Foot			7,978	60.0	0.3	1,302
2	Albert			163	40.0	0.3	18
3	Pulaski			2,417	19.0	1.0	125
	Summation			*10,558*	*39.7*		*1,445*
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]
	1552	35.7	35.7	0.00	0.24	1.0	371
		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]
	1552	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	6.28	98.2		Oxic		1.0	272
	6.28	23.8		Anoxic	10.5	1.0	371
	Summation						643
		Net Discharge [ac-ft/yr] =		**15,188**	**Net Load [lb/yr] =**		**3,717**

TMDL Lake Response Modeling for Buffalo

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 =	0.79	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,686	[kg/yr]
		Q (lake outflow) =	18.7	[10^6 m^3/yr]
		V (modeled lake volume) =	28.2	[10^6 m^3]
		T = V/Q =	1.50	[yr]
		P_i = W/Q =	90	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Deer Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Deer

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	Reach 502	962	6.6	529	108	1.0	155
2	0			0	0.0		0
3	0			0	0.0		0
4	0			0	0.0		0
5	0			0	0.0		0
	Summation	*962*	*7*	*529*			*155*

Failing Septic Systems

	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1807401		123	6.866	43%		80.3
2							
3							
4							
5							
	Summation			*6.9*			*80*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Buffalo Lake			16,477	87.3	1.0	3,911
2					-	1.0	
3					-	1.0	
	Summation			*16,477*	*87.3*		*3911*

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]
	163	31.0	31.0	0.00	0.24	1.0	39
				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]
	163	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]
	0.66			Oxic		1.0	
	0.66	31.6		Anoxic	22.0	1.0	1,011
	Summation						1,011
			Net Discharge [ac-ft/yr] =	**17,013**		**Net Load [lb/yr] =**	**5,196**

Average Lake Response Modeling for Deer

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 =	0.96	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,357	[kg/yr]
		Q (lake outflow) =	21.0	[10^6 m^3/yr]
		V (modeled lake volume) =	1.8	[10^6 m^3]
		T = V/Q =	0.09	[yr]
		P_i = W/Q =	112	[µg/l]
Model Predicted In-Lake [TP]			**82.5**	**[ug/l]**
Observed In-Lake [TP]			**82.5**	**[ug/l]**

Deer Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for	***Deer***					
	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	Reach 502	962	6.6	529	100	0.9	144
2	0			0	0.0		0
3	0			0	0.0		0
4	0			0	0.0		0
5	0			0	0.0		0
	Summation	*962*	*7*	*529*			*144*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1807401		123	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Buffalo Lake			16,477	40.0	0.5	1,793
2					-	1.0	
3					-	1.0	
	Summation			*16,477*	*40.0*		*1,793*
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]
	163	31.0	31.0	0.00	0.24	1.0	39
		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]
	163	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]
	0.66			Oxic		1.0	
	0.66	31.6		Anoxic	22.0	1.0	335
	Summation						335
			Net Discharge [ac-ft/yr] =	**17,006**		**Net Load [lb/yr] =**	**2,311**

TMDL Lake Response Modeling for	***Deer***		
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 =	0.96 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	1,049 [kg/yr]
		Q (lake outflow) =	21.0 [10^6 m^3/yr]
		V (modeled lake volume) =	1.8 [10^6 m^3]
		T = V/Q =	0.09 [yr]
		P_i = W/Q =	50 [µg/l]
Model Predicted In-Lake [TP]			**40.0 [ug/l]**
Observed In-Lake [TP]			**40.0 [ug/l]**

Howard Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Howard

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	Reach 474 near lal	3,535	9.0	2,650	177	1.0	1,275
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*3,535*	*9*	*2,650*			*1,275*

Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 474 near lal	3,535	253	14.2	43%		166.0
2							
3							
4							
5							
	Summation	*3,535*	*253*	*14.2*			*166*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	736	32.4	32.4	0.00	0.24	1.0	176
		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]
	736	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]
	2.98			Oxic		1.0	
	2.98	33.0		Anoxic	15.5	1.0	3,358
	Summation						3,358
		Net Discharge [ac-ft/yr] =		**2,665**	**Net Load [lb/yr] =**		**4,975**

Average Lake Response Modeling for Howard

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.) =	2,256	[kg/yr]
		Q (lake outflow) =	3.3	[10^6 m^3/yr]
		V (modeled lake volume) =	14.8	[10^6 m^3]
		T = V/Q =	4.51	[yr]
		P_i = W/Q =	686	[µg/l]
Model Predicted In-Lake [TP]			**82.7**	**[ug/l]**
Observed In-Lake [TP]			**82.6**	**[ug/l]**

Howard Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Howard

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	Reach 474 near lal	3,535	9.0	2,650	100	0.6	720
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*3,535*	*9*	*2,650*			*720*

Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 474 near lal	3,535	253	14.2	43%		0.0
2							
3							
4							
5							
	Summation	*3,535*	*253*	*14.2*			*0.0*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	736	32.4	32.4	0.00	0.24	1.0	176
			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]
	736	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]
	2.98			Oxic		1.0	
	2.98	33.0		Anoxic	2.9	1.0	622
	Summation						622
		Net Discharge [ac-ft/yr] =		**2,665**	**Net Load [lb/yr] =**		**1,518**

TMDL Lake Response Modeling for Howard

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	689	[kg/yr]
		Q (lake outflow) =	3.3	[10^6 m^3/yr]
		V (modeled lake volume) =	14.8	[10^6 m^3]
		T = V/Q =	4.51	[yr]
		P_i = W/Q =	209	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Dutch Lake Current Conditions BATHTUB Lake Response Model

	Average Loading Summary for	***Dutch***					
	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	Reach 476 near lake inflow	887	6.1	451	367	3.0	449
2	Howard Lake WWTF (MN(	NA		227	448.6	1.0	276
3						1.0	
4						1.0	
5						1.0	
	Summation	*887*	*6*	*677*			*726*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 476 (HUID 1807802	887	24	1.3	43%		15.5
2							
3							
4							
5							
	Summation	*887*	*24*	*1.3*			*16*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Howard Lake (Reach 474)			825	74.0	1.0	166
2					-	1.0	
3					-	1.0	
	Summation			*825*	*74.0*		*166*
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]
	161	30.1	30.1	0.00	0.24	1.0	39
		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]
	161	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]
	0.65	122		Oxic	0.5	1.0	88
	0.65	66.4		Anoxic	12.0	1.0	1,147
	Summation						1,234
		Net Discharge [ac-ft/yr] =		**1,504**	**Net Load [lb/yr] =**		**2,181**

Average Lake Response Modeling for	***Dutch***		
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 =	0.70 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	989 [kg/yr]
		Q (lake outflow) =	1.9 [10^6 m^3/yr]
		V (modeled lake volume) =	2.0 [10^6 m^3]
		T = V/Q =	1.09 [yr]
		P_i = W/Q =	533 [µg/l]
Model Predicted In-Lake [TP]			**171.6 [ug/l]**
Observed In-Lake [TP]			**172.5 [ug/l]**

Dutch Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for			***Dutch***			
	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	Reach 476 near lal	887	6.1	451	78	0.6	96
2	Howard Lake WW	NA				0.0	0
3						1.0	
4						1.0	
5						1.0	
	Summation	*887*	*6*	*451*			*96*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]	Loading Calibration Factor (CF)[1]	[lb/yr]
1	Reach 476 (HUID	887	24	1.3	43%	0.0	0.0
2							
3							
4							
5							
	Summation	*887*	*24*	*1.3*			*0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Howard Lake (Rea			825	40.0	0.5	90
2					-	1.0	
3					-	1.0	
	Summation			*825*	*40.0*		*90*
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]
	161	30.1	30.1	0.00	0.24	1.0	39
		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]
	161	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]
	0.65	122		Oxic	0.0	1.0	0
	0.65	66.4		Anoxic	0.5	1.0	48
	Summation						48
		Net Discharge [ac-ft/yr] =		**1,277**	**Net Load [lb/yr] =**		**273**

TMDL Lake Response Modeling for		***Dutch***		
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 =	0.70	[–]
		C_{CB} =	0.162	[–]
		b =	0.458	[–]
		W (total P load = inflow + atm.) =	123	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	2.0	[10^6 m^3]
		T = V/Q =	1.28	[yr]
		P_i = W/Q =	78	[μg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Waverly Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Waverly

	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	Reach 482 near lal	1,674	7.9	1,103	171	1.0	513
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,674*	*8*	*1,103*			*513*
Failing Septic Systems							
	Name	Area [ac]	' people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	482 (HUID 1801206)		54	3.0	43%		35.5
2	482 (HUID 1801205)		6	0.3	43%		3.8
3							
4							
5							
	Summation	*0*	*60*	*3.4*			*39*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Carrigan			150	500.0	1.0	204
2					-	1.0	
3					-	1.0	
	Summation			*150*	*500.0*		*204*
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]
	485	32.6	32.6	0.00	0.24	1.0	116.0
				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]
	485	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]
	1.96			Oxic		1.0	
	1.96	43.9		Anoxic	2.8	1.0	534
	Summation						534
			Net Discharge [ac-ft/yr] =	**1,253**		**Net Load [lb/yr] =**	**1,406**

Average Lake Response Modeling for Waverly

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	638	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	15.1	[10^6 m^3]
		T = V/Q =	9.74	[yr]
		P_i = W/Q =	411	[µg/l]
Model Predicted In-Lake [TP]			**42.1**	**[ug/l]**
Observed In-Lake [TP]			**42.1**	**[ug/l]**

Waverly Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Waverly

	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	Reach 482 near lal	1,674	7.9	1,103	171	1.0	513
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,674*	*8*	*1,103*			*513*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	482 (HUID 1801206)		54	3.0	43%	0.0	0.0
2	482 (HUID 1801205)		6	0.3	43%	0.0	0.0
3							
4							
5							
	Summation	*0*	*60*	*3.4*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Carrigan			150	300.0	0.6	123
2					-	1.0	
3					-	1.0	
	Summation			*150*	*300.0*		*123*
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]
	485	32.6	32.6	0.00	0.24	1.0	116
		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]
	485	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]
	1.96			Oxic		1.0	
	1.96	43.9		Anoxic	2.8	1.0	534
	Summation						534
		Net Discharge [ac-ft/yr] =		**1,253**	**Net Load [lb/yr] =**		**1,286**

TMDL Lake Response Modeling for Waverly

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.) =	583	[kg/yr]
		Q (lake outflow) =	1.6	[10^6 m^3/yr]
		V (modeled lake volume) =	15.1	[10^6 m^3]
		T = V/Q =	9.74	[yr]
		P_i = W/Q =	376	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Little Waverly Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Little Waverly

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	12-Mile Creek Bel(	2,480	5.0	1,041	340	1.3	963
2	Little Waverly Dire(	4,899	6.1	2,503	339.9	2.4	2,315
3							
4							
5							
	Summation	*7,379*	*11*	*3,544*			*3278*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	484 (HUID 1801202)		43	2.4	43%		27.9
2	484 (HUID 1801203)		34	1.9	43%		22.1
3	479+484 (HUID 1801204)		235	13.2	43%		154.1
4	473 (HUID 1807700)		64	3.6	43%		41.7
5	477 (HUID 1807800)		10	0.5	43%		6.4
	Summation	*0*	*385*	*21.6*			*252*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Emma Lake			7,317	116.8	1.0	2,324
2	Dutch Lake			2,130	190.7	1.0	1,105
3	Big Waverly			472	42.1	1.0	54
	Summation			*9,920*	*116.5*		*3,484*
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]
	330	29.5	29.5	0.00	0.24	1.0	79
		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]
	330	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]
	1.34	122		Oxic	2.0	1.0	718
	1.34	81.3		Anoxic	30.0	1.0	7,185
	Summation						7,903
		Net Discharge [ac-ft/yr] =		**13,486**	**Net Load [lb/yr] =**		**14,996**

Average Lake Response Modeling for Little Waverly

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 =	0.04	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	6,802	[kg/yr]
		Q (lake outflow) =	16.6	[10^6 m^3/yr]
		V (modeled lake volume) =	2.6	[10^6 m^3]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	409	[µg/l]
Model Predicted In-Lake [TP]			**393.7**	**[ug/l]**
Observed In-Lake [TP]			**393.9**	**[ug/l]**

Little Waverly Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Little Waverly

		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	12-Mile Creek Belo	2,480	5.0	1,041	58	0.2	163
2	Little Waverly Dire	4,899	6.1	2,503	59.0	0.4	402
3							
4							
5							
	Summation	*7,379*	*11*	*3,544*			*565*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]	Loading Calibration Factor (CF)[1]	[lb/yr]
1	484 (HUID 1801202)		43	2.4	43%	0.0	0.0
2	484 (HUID 1801203)		34	1.9	43%	0.0	0.0
3	479+484 (HUID 1801204)		235	13.2	43%	0.0	0.0
4	473 (HUID 1807700)		64	3.6	43%	0.0	0.0
5	477 (HUID 1807800)		10	0.5	43%	0.0	0.0
	Summation	*0*	*385*	*21.6*			*0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Emma Lake			7,317	60.0	0.5	1,194
2	Dutch Lake			2,130	40.0	0.2	232
3	Big Waverly			472	40.0	0.9	51
	Summation			*9,920*	*46.7*		*1,478*
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]
	330	29.5	29.5	0.00	0.24	1.0	79
			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]
	330	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]
	1.34	122		Oxic	0.0	1.0	0
	1.34	81.3		Anoxic	0.5	1.0	120
	Summation						120
		Net Discharge [ac-ft/yr] =		**13,486**		**Net Load [lb/yr] =**	**2,242**

TMDL Lake Response Modeling for Little Waverly

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 =	0.04	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,017	[kg/yr]
		Q (lake outflow) =	16.6	[10^6 m^3/yr]
		V (modeled lake volume) =	2.6	[10^6 m^3]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	61	[µg/l]
Model Predicted In-Lake [TP]			**60.1**	**[ug/l]**
Observed In-Lake [TP]			**60.1**	**[ug/l]**

Richardson Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Richardson

	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	CD-35 and Direct v	5,087	2.5	1,041	421	1.0	1,192
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*5,087*	*2*	*1,041*			*1192*
Failing Septic Systems							
	Name	Area [ac]	‘ people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	CD-35 and Direct v	5,087	128	7.2	43%		83.9
2							
3							
4							
5							
	Summation	*5,087*	*128*	*7.2*			*84*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	116	20.3	20.3	0.00	0.22	1.0	26
		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]
	116	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]
	0.47			Oxic		1.0	
	0.47	59.0		Anoxic	1.0	1.0	61
	Summation						61
		Net Discharge [ac-ft/yr] =		**1,048**		**Net Load [lb/yr] =**	**1,363**

Average Lake Response Modeling for Richardson

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 =	1.43	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	618	[kg/yr]
		Q (lake outflow) =	1.3	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	2.24	[yr]
		P_i = W/Q =	478	[µg/l]
Model Predicted In-Lake [TP]			**67.8**	**[ug/l]**
Observed In-Lake [TP]			**67.8**	**[ug/l]**

Richardson Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Richardson

	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	CD-35 and Direct v	5,087	2.5	1,041	174	0.4	492
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*5,087*	*2*	*1,041*			*492*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	CD-35 and Direct v	5,087	128	0.0	43%	0.0	0.0
2							
3							
4							
5							
	Summation	*5,087*	*128*	*0.0*			*0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	116	20.3	20.3	0.00	0.22	1.0	26
		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]
	116	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	0.47			Oxic		1.0	
	0.47	59.0		Anoxic	1.0	1.0	61
	Summation						61
			Net Discharge [ac-ft/yr] =	**1,041**		Net Load [lb/yr] =	**579**

TMDL Lake Response Modeling for Richardson

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 =	1.43	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	263	[kg/yr]
		Q (lake outflow) =	1.3	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	2.25	[yr]
		P_i = W/Q =	205	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Dunns Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Dunns							
		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 Watershed	350	2.0	57	164	1.0	25
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*350*	*2*	*57*			*25*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	368 near-lake septics		431	24.2	43%		282.4
2							
3							
4							
5							
	Summation	*0*	*431*	*24.2*			*282*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Richardson			1,041	125.0	1.0	354
2					-	1.0	
3					-	1.0	
	Summation			*1,041*	*125.0*		*354*
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]
	152	20.3	20.3	0.00	0.22	1.0	34
			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]
	152	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]
	0.61			Oxic	1.0	1.0	
	0.61	61.2		Anoxic	7.0	1.0	581
	Summation						581
		Net Discharge [ac-ft/yr] =		**1,122**	**Net Load [lb/yr] =**		**1,276**

Average Lake Response Modeling for Dunns				
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.) =	579	[kg/yr]
		Q (lake outflow) =	1.4	[10^6 m^3/yr]
		V (modeled lake volume) =	2.2	[10^6 m^3]
		T = V/Q =	1.58	[yr]
		P_i = W/Q =	418	[µg/l]
Model Predicted In-Lake [TP]			**97.4**	**[ug/l]**
Observed In-Lake [TP]			**97.3**	**[ug/l]**

Dunns Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for	***Dunns***					
	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 Watershed ı	350	2.0	57	164	1.0	25
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*350*	*2*	*57*			*25*
Failing Septic Systems							
				Discharge			
	Name	Area [ac]	f people on sep	[ac-ft/yr]	Failure [%]		[lb/yr]
1	368 near-lake septics		431	0.0	43%	0.0	0.0
2							
3							
4							
5							
	Summation	*0*	*431*	*0.0*			*0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Richardson			1,041	40.0	0.3	113
2					-	1.0	
3					-	1.0	
	Summation			*1,041*	*40.0*		*113*
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]
	152	20.3	20.3	0.00	0.22	1.0	34
			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]
	152	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]
	0.61			Oxic	0.5	1.0	
	0.61	61.2		Anoxic	2.0	1.0	166
	Summation						166
			Net Discharge [ac-ft/yr] =	**1,098**		**Net Load [lb/yr] =**	**338**

TMDL Lake Response Modeling for	***Dunns***			
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	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.) =	153	[kg/yr]
		Q (lake outflow) =	1.4	[10^6 m^3/yr]
		V (modeled lake volume) =	2.2	[10^6 m^3]
		T = V/Q =	1.61	[yr]
		P_i = W/Q =	113	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Long Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Long

	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	Co Ditch #26	9,820	12.0	9,851	483	2.0	12,956
2	Reach 324 near lal	2,894	7.1	1,708	478.9	3.5	2,225
3							
4							
5							
	Summation	*12,714*	*19*	*11,558*			*15180*

Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	323 (Co Ditch #26)		488	27.4	43%		319.8
2	324 (Long Direct)		52	2.9	43%		34.1
3							
4							
5							
	Summation	*0*	*540*	*30.3*			*354*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Hope Lake			2,211	257.0	1.0	1,546
2							
3							
	Summation			*2,211*	*257.0*		*1,546*

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]
	771	27.8	27.8	0.00	0.24	1.0	184
		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]
	771	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]
	3.12	122		Oxic	1.0	1.0	839
	3.12	80.3		Anoxic	20.0	1.0	11,047
	Summation						11,886
		Net Discharge [ac-ft/yr] =		**13,799**	**Net Load [lb/yr] =**		**29,150**

Average Lake Response Modeling for Long

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 =	0.54	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	13,222	[kg/yr]
		Q (lake outflow) =	17.0	[10^6 m^3/yr]
		V (modeled lake volume) =	5.7	[10^6 m^3]
		T = V/Q =	0.34	[yr]
		P_i = W/Q =	776	[µg/l]
Model Predicted In-Lake [TP]			**385.4**	**[ug/l]**
Observed In-Lake [TP]			**385.4**	**[ug/l]**

Long Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for	***Long***					
	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	Co Ditch #26	9,820	12.0	9,851	74	0.3	1,976
2	Reach 324 near lal	2,894	7.1	1,708	57.0	0.4	265
3							
4							
5							
	Summation	*12,714*	*19*	*11,558*			*2,241*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	323 (Co Ditch #26)		488	0.0	43%	0.0	0.0
2	324 (Long Direct)		52	0.0	43%	0.0	0.0
3							
4							
5							
	Summation	*0*	*540*	*0.0*			*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Hope Lake			2,211	60.0	0.2	361
2					-	1.0	
3					-	1.0	
	Summation			*2,211*	*60.0*		*361*
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]
	771	27.8	27.8	0.00	0.24	1.0	184
		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]
	771	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]
	3.12	122		Oxic	1.0	1.0	0
	3.12	80.3		Anoxic	20.0	1.0	276
	Summation						276
		Net Discharge [ac-ft/yr] =		**13,769**	**Net Load [lb/yr] =**		**3,062**

TMDL Lake Response Modeling for		***Long***		
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 =	0.54	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,389	[kg/yr]
		Q (lake outflow) =	17.0	[10^6 m^3/yr]
		V (modeled lake volume) =	5.7	[10^6 m^3]
		T = V/Q =	0.34	[yr]
		P_i = W/Q =	82	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Hope Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Hope

	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	Reach 322 near lal	4,213	6.9	2,412	251	1.8	1,648
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*4,213*	*7*	*2,412*			*1648*
Failing Septic Systems							
	Name	Area [ac]	ᶠ people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	322		93	5.2	43%		60.9
2							
3							
4							
5							
	Summation	*0*	*93*	*5.2*			*61*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	250	27.8	27.8	0.00	0.24	1.0	60
		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]
	250	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	1.01	122		Oxic	0.5	1.0	136
	1.01	73.2		Anoxic	15.0	1.0	2,451
	Summation						2,587
		Net Discharge [ac-ft/yr] =		**2,417**	**Net Load [lb/yr] =**		**4,356**

Average Lake Response Modeling for Hope

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		C_P =	0.65	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,976	[kg/yr]
		Q (lake outflow) =	3.0	[10^6 m³/yr]
		V (modeled lake volume) =	1.8	[10^6 m³]
		T = V/Q =	0.61	[yr]
		P_i = W/Q =	662	[µg/l]
Model Predicted In-Lake [TP]			**257.0**	**[ug/l]**
Observed In-Lake [TP]			**257.0**	**[ug/l]**

Hope Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for	***Hope***					
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	Reach 322 near lal	4,213	6.9	2,412	68	0.5	448
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*4,213*	*7*	*2,412*			*448*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	322		93	0.0	43%	0.0	0.0
2							
3							
4							
5							
	Summation	*0*	*93*	*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]
	250	27.8	27.8	0.00	0.24	1.0	60
			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]
	250	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]
	1.01	122		Oxic	0.5	1.0	0
	1.01	73.2		Anoxic	0.9	1.0	147
	Summation						147
			Net Discharge [ac-ft/yr] =	**2,412**		**Net Load [lb/yr] =**	**655**

	TMDL Lake Response Modeling for	***Hope***		
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 =	0.65	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	297	[kg/yr]
		Q (lake outflow) =	3.0	[10^6 m^3/yr]
		V (modeled lake volume) =	1.8	[10^6 m^3]
		T = V/Q =	0.61	[yr]
		P_i = W/Q =	100	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Nest Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Nest

	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	Middle Fork Crow I	7,373	5.6	3,461	108	1.1	1,013
2	Nest Lake Direct (I	4,313	5.6	2,022	78.3	1.0	431
3	Belgrade WWTF		0.0	187	1998.9	1.0	1,017
4						1.0	
5						1.0	
	Summation	*11,686*	*11*	*5,671*			*2462*

Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 190 (Middle Fork)		194	10.9	43%		127.1
2	Reach 210 (Middle Fork)		95	5.3	43%		62.3
3	Reach 220 (Nest Direct)		272	15.2	43%		178.2
4							
5							
	Summation	*0*	*561*	*31.4*			*368*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Mud Lake			25,919	33.9	1.0	2,389
2					-	1.0	
3					-	1.0	
	Summation			*25,919*	*33.9*		*2389*

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]
	1008	29.3	29.3	0.00	0.24	1.0	241
		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]
	1008	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]
	4.08			Oxic		1.0	
	4.08	16.9		Anoxic	9.5	1.0	1,444
	Summation						1,444
			Net Discharge [ac-ft/yr] =	**31,622**		**Net Load [lb/yr] =**	**6,904**

Average Lake Response Modeling for Nest

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	3,131	[kg/yr]
		Q (lake outflow) =	39.0	[10^6 m^3/yr]
		V (modeled lake volume) =	17.9	[10^6 m^3]
		T = V/Q =	0.46	[yr]
		P_i = W/Q =	80	[µg/l]
Model Predicted In-Lake [TP]			**44.8**	**[ug/l]**
Observed In-Lake [TP]			**44.8**	**[ug/l]**

Nest Lake TMDL Conditions BATHTUB Lake Response Model

Average Loading Summary for Nest

	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	Middle Fork Crow I	7,373	5.6	3,461	108	1.1	1,013
2	Nest Lake Direct (I	4,313	5.6	2,022	78.3	1.0	431
3	Belgrade WWTF		0.0	187	1998.9	1.0	1,017
4						1.0	
5						1.0	
	Summation	*11,686*	*11*	*5,671*			*2462*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 190 (Middle Fork)		194	10.9	43%	0.0	0.0
2	Reach 210 (Middle Fork)		95	5.3	43%	0.0	0.0
3	Reach 220 (Nest Direct)		272	15.2	43%	0.0	0.0
4							
5							
	Summation	*0*	*561*	*31.4*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Mud Lake			25,919	33.9	1.0	2,389
2					-	1.0	
3					-	1.0	
	Summation			*25,919*	*33.9*		*2389*
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]
	1008	29.3	29.3	0.00	0.24	1.0	241
		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]
	1008	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]
	4.08			Oxic		1.0	
	4.08	16.9		Anoxic	16.0	1.0	897
	Summation						897
		Net Discharge [ac-ft/yr] =		**31,622**	**Net Load [lb/yr] =**		**5,989**

Average Lake Response Modeling for Nest

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,716	[kg/yr]
		Q (lake outflow) =	39.0	[10^6 m^3/yr]
		V (modeled lake volume) =	17.9	[10^6 m^3]
		T = V/Q =	0.46	[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]**

Brooks Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Brooks							
	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	Brooks Lake Direc	114	4.7	45	148	1.0	18
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*114*	*5*	*45*			*18*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	NA (1801605)		31	1.713	43%		20.0
2							
3							
4							
5							
	Summation			*1.7*			*20*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	96	0.0	0.0	0.00	0.22	1.0	21
		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]
	96	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]
	0.39			Oxic		1.0	
	0.39	32.5		Anoxic	6.4	1.0	177
	Summation						177
		Net Discharge [ac-ft/yr] =		**46**	**Net Load [lb/yr] =**		**236**

Average Lake Response Modeling for Brooks				
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.) =		107	[kg/yr]
	Q (lake outflow) =		0.1	[10^6 m^3/yr]
	V (modeled lake volume) =		1.4	[10^6 m^3]
		T = V/Q =	23.63	[yr]
		P_i = W/Q =	1872	[µg/l]
Model Predicted In-Lake [TP]			**63.8**	**[ug/l]**
Observed In-Lake [TP]			**63.8**	**[ug/l]**

Brooks Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Brooks

	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	Brooks Lake Direc	114	4.7	45	101	0.7	12
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*114*	*5*	*45*			*12*
Failing Septic Systems							
				Discharge			
	Name	Area [ac]	people on sep	[ac-ft/yr]	Failure [%]		[lb/yr]
1	NA (1801605)		31	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	96	0.0	0.0	0.00	0.22	1.0	21
			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]
	96	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]
	0.39			Oxic		1.0	
	0.39	32.5		Anoxic	6.4	1.0	69
	Summation						69
			Net Discharge [ac-ft/yr] =	**45**		**Net Load [lb/yr] =**	**102**

TMDL Lake Response Modeling for Brooks

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.) =	47	[kg/yr]
		Q (lake outflow) =	0.1	[10^6 m^3/yr]
		V (modeled lake volume) =	1.4	[10^6 m^3]
		T = V/Q =	24.54	[yr]
		P_i = W/Q =	844	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Smith Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for				***Smith***			
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	Reach 442 near lal	1,337	4.8	531	182	1.0	263
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,337*	*5*	*531*			*263*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	442 (1801604)		28	1.574	43%		18.4
2							
3							
4							
5							
	Summation			*1.574*			*18*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	226	21.0	21.0	0.00	0.22	1.0	50
		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]
	226	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]
	0.91			Oxic		1.0	
	0.91	69.2		Anoxic	12.6	1.0	1,764
	Summation						1,764
		Net Discharge [ac-ft/yr] =		**532**	**Net Load [lb/yr] =**		**2,095**

Average Lake Response Modeling for ***Smith***			
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.) =	951	[kg/yr]
	Q (lake outflow) =	0.7	[10^6 m^3/yr]
	V (modeled lake volume) =	1.0	[10^6 m^3]
	T = V/Q =	1.53	[yr]
	P_i = W/Q =	1447	[µg/l]
Model Predicted In-Lake [TP]		**215.4**	**[ug/l]**
Observed In-Lake [TP]		**215.0**	**[ug/l]**

Smith Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Smith

	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	Reach 442 near lal	1,337	4.8	531	72	0.4	104
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,337*	*5*	*531*			*104*

Failing Septic Systems							
	Name	Area [ac]	' people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	442 (1801604)		28	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.000*			*0.0*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
226	21.0	21.0	0.00	0.22	1.0	50
		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]
226	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]
0.91			Oxic		1.0	
0.91	69.2		Anoxic	12.6	1.0	133
Summation						133
		Net Discharge [ac-ft/yr] =	**531**		**Net Load [lb/yr] =**	**287**

TMDL Lake Response Modeling for Smith

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	130	[kg/yr]
		Q (lake outflow) =	0.7	[10^6 m^3/yr]
		V (modeled lake volume) =	1.0	[10^6 m^3]
		T = V/Q =	1.54	[yr]
		P_i = W/Q =	199	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Cokato Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Cokato

	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	Reach 444 tributar	28,918	4.8	11,576	133	1.0	4,184
2	Faribault Foods - (			365	891.0	1.0	884
3	Cokato WWTF Eq			381	10.0	1.0	10
4						1.0	
5						1.0	
	Summation	*28,918*	*5*	*12,322*			*5,078*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	444+443 (1801603)		1219	68.307	43%		798.6
2							
3							
4							
5							
	Summation			*68.3*			*799*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Brooks			51	60.5	1.0	8
2	Smith			151	215.0	1.0	88
3					-	1.0	
	Summation			*202*	*137.8*		*97*
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]
	545	27.4	27.4	0.00	0.24	1.0	130
				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]
	545	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	2.21			Oxic		1.0	
	2.21	31.6		Anoxic	0.5	1.0	77
	Summation						77
			Net Discharge [ac-ft/yr] =	**12,592**		**Net Load [lb/yr] =**	**6,181**

Average Lake Response Modeling for Cokato

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 =	1.40	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,804	[kg/yr]
		Q (lake outflow) =	15.5	[10^6 m^3/yr]
		V (modeled lake volume) =	15.0	[10^6 m^3]
		T = V/Q =	0.96	[yr]
		P_i = W/Q =	180	[µg/l]
Model Predicted In-Lake [TP]			**53.1**	**[ug/l]**
Observed In-Lake [TP]			**49.2**	**[ug/l]**

Cokato Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Cokato

	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	Reach 444 tributar	28,918	4.8	11,576	97	0.7	3,040
2	Faribault Foods - (			365	800.0	1.0	794
3	Cokato WWTF Eq			381	10.0	0.8	10
4						1.0	
5						1.0	
	Summation	*28,918*	*5*	*12,322*			*3844*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	444+443 (1801603)		1219	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Brooks			51	40.0	0.7	6
2	Smith			151	60.0	0.3	25
3					-	1.0	
	Summation			*202*	*50.0*		*30*
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]
	545	27.4	27.4	0.00	0.24	1.0	130
		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]
	545	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	2.21			Oxic		1.0	
	2.21	31.6		Anoxic	0.5	1.0	77
	Summation						*77*
		Net Discharge [ac-ft/yr] =		**12,524**	**Net Load [lb/yr] =**		**4,081**

TMDL Lake Response Modeling for Cokato

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	1.40	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,851	[kg/yr]
		Q (lake outflow) =	15.5	[10^6 m^3/yr]
		V (modeled lake volume) =	15.0	[10^6 m^3]
		T = V/Q =	0.97	[yr]
		P_i = W/Q =	120	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Constance Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Constance

	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	HUID 1807302	753	4.8	299	116	1.0	94
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*753*	*5*	*299*			*94*

Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1807302		131	7.356	43%		86.0
2							
3							
4							
5							
	Summation			*7.4*			*86*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	175	0.0	0.0	0.00	0.22	1.0	39
		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]
	175	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]
	0.71	122		Oxic	1.0	1.0	190
	0.71	30.2		Anoxic	10.9	1.0	512
	Summation						702
		Net Discharge [ac-ft/yr] =		**307**	**Net Load [lb/yr] =**		**921**

Average Lake Response Modeling for Constance

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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	418	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	2.5	[10^6 m^3]
		T = V/Q =	6.57	[yr]
		P_i = W/Q =	1105	[µg/l]
Model Predicted In-Lake [TP]			**91.1**	**[ug/l]**
Observed In-Lake [TP]			**91.1**	**[ug/l]**

Constance Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for			***Constance***			
	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	HUID 1807302	753	4.8	299	99	0.9	80
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*753*	*5*	*299*			*80*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1807302		131	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	175	0.0	0.0	0.00	0.22	1.0	39
		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]
	175	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]
	0.71	122		Oxic	1.0	1.0	190
	0.71	30.2		Anoxic	10.9	1.0	141
	Summation						331
		Net Discharge [ac-ft/yr] =		**299**	**Net Load [lb/yr] =**		**450**

Average Lake Response Modeling for Constance

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.) =	104	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	2.5	[10^6 m^3]
		T = V/Q =	6.57	[yr]
		P_i = W/Q =	276	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Pelican Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Pelican

	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	Reach 982 near lal	23,107	3.1	5,959	182	1.0	2,945
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*23,107*	*3*	*5,959*			*2,945*

Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1807300	23,107		38		0.0	441.3
2	1807301			27			312.7
3	1808601			32			370.1
4	1808603			4			46.3
5							
	Summation	*23,107*	*0*				*1,170*

Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Constance			420	91.1	1.0	104
2					-	1.0	
3					-	1.0	
	Summation			*420*	*91.1*		*104*

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]
	3460	31.5	31.5	0.00	0.24	1.0	827
				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]
	3460	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]
	14.00	122		Oxic	0.5	1.0	1,883
	14.00	59.9		Anoxic	7.1	1.0	13,133
	Summation						15,016
			Net Discharge [ac-ft/yr] =	**6,378**		Net Load [lb/yr] =	**20,063**

Average Lake Response Modeling for Pelican

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.) =	9,100	[kg/yr]
		Q (lake outflow) =	7.9	[10^6 m^3/yr]
		V (modeled lake volume) =	23.6	[10^6 m^3]
		T = V/Q =	2.99	[yr]
		P_i = W/Q =	1156	[µg/l]
Model Predicted In-Lake [TP]			**137.3**	**[ug/l]**
Observed In-Lake [TP]			**137.3**	**[ug/l]**

Pelican Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Pelican

	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	Reach 982 near lal	23,107	3.1	5,959	93	0.5	1,502
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*23,107*	*3*	*5,959*			*1,502*
Failing Septic Systems							
	Name	Area [ac]	' people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1807300	23,107		0		0.0	0.0
2	1807301			0		0.0	0.0
3	1808601			0		0.0	0.0
4	1808603			0		0.0	0.0
5							
	Summation	*23,107*	*0*				*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Constance			420	60.0	0.7	69
2					-	1.0	
3					-	1.0	
	Summation			*420*	*60.0*		*69*
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]
	3460	31.5	31.5	0.00	0.24	1.0	827
				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]
	3460	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]
	14.00	122		Oxic	0.5	1.0	1,883
	14.00	59.9		Anoxic	7.1	1.0	925
	Summation						2,808
			Net Discharge [ac-ft/yr] =	**6,378**		**Net Load [lb/yr] =**	**5,206**

TMDL Lake Response Modeling for Pelican

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.) =	2,361	[kg/yr]
		Q (lake outflow) =	7.9	[10^6 m^3/yr]
		V (modeled lake volume) =	23.6	[10^6 m^3]
		T = V/Q =	2.99	[yr]
		P_i = W/Q =	300	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Beebe Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Beebe							
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	Reach 984 Near La	964	4.5	361	185	1.0	182
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*964*	*5*	*361*			*182*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1808604 (Reach 984)		122	6.835	43%		79.9
2							
3							
4							
5							
	Summation			*6.8*			*80*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	296	0.0	0.0	0.00	0.22	1.0	66
		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]
	296	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]
	1.20			Oxic		1.0	
	1.20	27.0		Anoxic	5.6	1.0	400
	Summation						400
		Net Discharge [ac-ft/yr] =		**368**	**Net Load [lb/yr] =**		**728**

Average Lake Response Modeling for Beebe				
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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	330	[kg/yr]
		Q (lake outflow) =	0.5	[10^6 m^3/yr]
		V (modeled lake volume) =	4.5	[10^6 m^3]
		T = V/Q =	9.82	[yr]
		P_i = W/Q =	726	[µg/l]
Model Predicted In-Lake [TP]			**58.5**	**[ug/l]**
Observed In-Lake [TP]			**58.3**	**[ug/l]**

Beebe Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for	*Beebe*						
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	Reach 984 Near La	964	4.5	361	100	0.5	98
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*964*	*5*	*361*			*98*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1808604 (Reach 984)		122	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	296	0.0	0.0	0.00	0.22	1.0	66
		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]
	296	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]
	1.20			Oxic		1.0	
	1.20	27.0		Anoxic	5.6	1.0	214
	Summation						214
		Net Discharge [ac-ft/yr] =		**361**	**Net Load [lb/yr] =**		**378**

TMDL Lake Response Modeling for			*Beebe*		
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 =	1.00	[--]
			C_{CB} =	0.162	[--]
			b =	0.458	[--]
			W (total P load = inflow + atm.) =	172	[kg/yr]
			Q (lake outflow) =	0.4	[10^6 m^3/yr]
			V (modeled lake volume) =	4.5	[10^6 m^3]
			T = V/Q =	10.01	[yr]
			P_i = W/Q =	385	[µg/l]
Model Predicted In-Lake [TP]				**40.0**	**[ug/l]**
Observed In-Lake [TP]				**40.0**	**[ug/l]**

Hafften Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for	*Hafften*					
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 Reach 962 near lal	213	5.0	89	70	1.0	17
2					1.0	
3					1.0	
4					1.0	
5					1.0	
Summation	*213*	*5*	*89*			*17*
Failing Septic Systems						
Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1 Reach 962		4	0.224	43%	1.0	2.6
2						
3						
4						
5						
Summation			*0.2*			*3*
Inflow from Upstream Lakes						
			Discharge	Estimated P Concentration	Calibration Factor	Load
Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1 Schandell			753	49.3	1.0	101
2				-	1.0	
3				-	1.0	
Summation			*753*	*49.3*		*101*
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]
43	28.9	28.9	0.00	0.24	1.0	10
		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]
43	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]
0.17			Oxic		1.0	
0.17	42.2		Anoxic	7.7	1.0	125
Summation						125
		Net Discharge [ac-ft/yr] =	**842**		**Net Load [lb/yr] =**	**256**

Average Lake Response Modeling for		*Hafften*			
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 =	1.00	[--]
			C_{CB} =	0.162	[--]
			b =	0.458	[--]
			W (total P load = inflow + atm.) =	116	[kg/yr]
			Q (lake outflow) =	1.0	[10^6 m^3/yr]
			V (modeled lake volume) =	0.6	[10^6 m^3]
			T = V/Q =	0.57	[yr]
			P_i = W/Q =	112	[µg/l]
Model Predicted In-Lake [TP]				**54.8**	**[ug/l]**
Observed In-Lake [TP]				**54.7**	**[ug/l]**

Hafften Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for Hafften						
	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	Reach 962 near lal	213	5.0	89	70	1.0	17
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*213*	*5*	*89*			*17*
Failing Septic Systems							
	Name	Area [ac]	ᶠ people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	Reach 962		4	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Schandell			753	49.3	1.0	101
2					-	1.0	
3					-	1.0	
	Summation			*753*	*49.3*		*101*
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]
	43	28.9	28.9	0.00	0.24	1.0	10
				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]
	43	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]
	0.17			Oxic		1.0	
	0.17	42.2		Anoxic	7.7	1.0	42
	Summation						42
			Net Discharge [ac-ft/yr] =	**842**		**Net Load [lb/yr] =**	**170**

TMDL Lake Response Modeling for Hafften				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	77	[kg/yr]
		Q (lake outflow) =	1.0	[10^6 m^3/yr]
		V (modeled lake volume) =	0.6	[10^6 m^3]
		T = V/Q =	0.57	[yr]
		P_i = W/Q =	74	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Granite Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for				***Granite***			
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	Reach 422 near lal	2,418	5.4	1,087	141	1.0	418
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*2,418*	*5*	*1,087*			*418*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
	422 (1808201)		38	2.104	43%		24.6
	422 (1808202)		92	5.142	43%		60.1
				7.2			*85*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	353	0.0	0.0	0.00	0.22	1.0	78
				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]
	353	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]
	1.43			Oxic		1.0	
	1.43	23.0		Anoxic	12.7	1.0	920
	Summation						920
			Net Discharge [ac-ft/yr] =	**1,094**		**Net Load [lb/yr] =**	**1,501**

Average Lake Response Modeling for		***Granite***		
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.) =	681	[kg/yr]
		Q (lake outflow) =	1.4	[10^6 m^3/yr]
		V (modeled lake volume) =	7.9	[10^6 m^3]
		T = V/Q =	5.84	[yr]
		P_i = W/Q =	504	[µg/l]
Model Predicted In-Lake [TP]			**60.8**	**[ug/l]**
Observed In-Lake [TP]			**60.8**	**[ug/l]**

Granite Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for			***Granite***			
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	Reach 422 near lal	2,418	5.4	1,087	127	0.9	376
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*2,418*	*5*	*1,087*			*376*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
	422 (1808201)		38	2.104	43%	0.0	0.0
	422 (1808202)		92	5.142	43%	0.0	0.0
				7.2			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	353	0.0	0.0	0.00	0.22	1.0	78
		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]
	353	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]
	1.43			Oxic		1.0	
	1.43	23.0		Anoxic	12.7	1.0	296
	Summation						296
		Net Discharge [ac-ft/yr] =		**1,094**	**Net Load [lb/yr] =**		**750**

TMDL Lake Response Modeling for		***Granite***			
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.) =	341	[kg/yr]
			Q (lake outflow) =	1.3	[10^6 m^3/yr]
			V (modeled lake volume) =	7.9	[10^6 m^3]
			T = V/Q =	5.88	[yr]
			P_i = W/Q =	254	[µg/l]
Model Predicted In-Lake [TP]				**40.0**	**[ug/l]**
Observed In-Lake [TP]				**40.0**	**[ug/l]**

French Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for French

	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	Reach 402 near lal	5,447	4.9	2,204	121	1.0	727
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*5,447*	*5*	*2,204*			*727*
Failing Septic Systems							
	Name	Area [ac]	' people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	402 (1801901)		35	1.989	43%		23.3
2	402 (1801902)		181	10.139	43%		118.5
3							
4							
5							
	Summation			*12.1*			*142*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	346	26.7	26.7	0.00	0.24	1.0	83
		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]
	346	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]
	1.40			Oxic		1.0	
	1.40	34.0		Anoxic	1.0	1.0	105
	Summation						105
		Net Discharge [ac-ft/yr] =		**2,216**	**Net Load [lb/yr] =**		**1,057**

Average Lake Response Modeling for French

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	as f(W,Q,V) from Canfield & Bachmann (1981)			
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		C_P =	1.13	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	479	[kg/yr]
		Q (lake outflow) =	2.7	[10^6 m^3/yr]
		V (modeled lake volume) =	7.2	[10^6 m^3]
		T = V/Q =	2.62	[yr]
		P_i = W/Q =	175	[µg/l]
Model Predicted In-Lake [TP]			**40.9**	**[ug/l]**
Observed In-Lake [TP]			**40.9**	**[ug/l]**

French Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for French						
	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	Reach 402 near lal	5,447	4.9	2,204	121	1.0	727
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*5,447*	*5*	*2,204*			*727*
Failing Septic Systems							
				Discharge			
	Name	Area [ac]	# people on sep	[ac-ft/yr]	Failure [%]		[lb/yr]
1	402 (1801901)		35	0.000	43%	0.0	0.0
2	402 (1801902)		181	0.000	43%	0.0	0.0
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	346	26.7	26.7	0.00	0.24	1.0	83
		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]
	346	0.0		0.00	0	1.0	0
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km²]	[days]			[mg/m²-day]	[--]	[lb/yr]
	1.40			Oxic		1.0	
	1.40	34.0		Anoxic	1.0	1.0	105
	Summation						105
		Net Discharge [ac-ft/yr] =		**2,204**	**Net Load [lb/yr] =**		**915**

TMDL Lake Response Modeling for French				
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 =	1.13	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	415	[kg/yr]
		Q (lake outflow) =	2.7	[10^6 m^3/yr]
		V (modeled lake volume) =	7.2	[10^6 m^3]
		T = V/Q =	2.64	[yr]
		P_i = W/Q =	153	[µg/l]
Model Predicted In-Lake [TP]			**37.2**	**[ug/l]**
Observed In-Lake [TP]			**37.2**	**[ug/l]**

Camp Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Camp

	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	Reach 446 Near La	594	5.5	272	460	1.0	340
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*594*	*5*	*272*			*340*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	446 (1807901)		25	1.385	43%		16.2
2							
3							
4							
5							
	Summation			*1.4*			*16*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	108	28.6	28.6	0.00	0.24	1.0	26
			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]
	108	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]
	0.44			Oxic		1.0	
	0.44	41.1		Anoxic	26.0	1.0	1,030
	Summation						1,030
			Net Discharge [ac-ft/yr] =	**273**		**Net Load [lb/yr] =**	**1,412**

Average Lake Response Modeling for Camp

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.) =	640	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m^3/yr]
		V (modeled lake volume) =	2.8	[10^6 m^3]
		T = V/Q =	8.44	[yr]
		P_i = W/Q =	1900	[µg/l]
Model Predicted In-Lake [TP]			**109.6**	**[ug/l]**
Observed In-Lake [TP]			**110.5**	**[ug/l]**

Camp Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for			*Camp*			
	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	Reach 446 Near La	594	5.5	272	194	0.4	143
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*594*	*5*	*272*			*143*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	446 (1807901)		25	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*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]
	108	28.6	28.6	0.00	0.24	1.0	26
		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]
	108	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]
	0.44			Oxic		1.0	
	0.44	41.1		Anoxic	26.0	1.0	79
	Summation						79
		Net Discharge [ac-ft/yr] =		**272**	**Net Load [lb/yr] =**		**248**

TMDL Lake Response Modeling for		*Camp*		
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 =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	113	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m^3/yr]
		V (modeled lake volume) =	2.8	[10^6 m^3]
		T = V/Q =	8.48	[yr]
		P_i = W/Q =	336	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Rock Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for	***Rock***						
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	Reach 462 near lal	1,123	3.1	285	106	1.0	82
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,123*	*3*	*285*			*82*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	462 (1808002)		141	7.9	43%		92.6
2							
3							
4							
5							
	Summation			*7.9*			*93*
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]
	183	22.4	22.4	0.00	0.22	1.0	41
		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]
	183	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]
	0.74			Oxic		1.0	
	0.74	31.0		Anoxic	5.0	1.0	253
	Summation						253
		Net Discharge [ac-ft/yr] =		**293**	**Net Load [lb/yr] =**		**469**

Modeled Parameter	Equation	Parameters	Value	[Units]
Average Lake Response Modeling for ***Rock***				
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	212	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	3.0	[10^6 m^3]
		T = V/Q =	8.29	[yr]
		P_i = W/Q =	587	[µg/l]
Model Predicted In-Lake [TP]			**56.2**	**[ug/l]**
Observed In-Lake [TP]			**55.6**	**[ug/l]**

Rock Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Rock

	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	Reach 462 near lal	1,123	3.1	285	95	0.9	74
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,123*	*3*	*285*			*74*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	462 (1808002)		141	0.0	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*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]
	183	22.4	22.4	0.00	0.22	1.0	41
		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]
	183	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]
	0.74			Oxic		1.0	
	0.74	31.0		Anoxic	5.0	1.0	148
	Summation						148
			Net Discharge [ac-ft/yr] =	**285**		**Net Load [lb/yr] =**	**263**

TMDL Lake Response Modeling for Rock

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.) =	119	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	3.0	[10^6 m^3]
		T = V/Q =	8.52	[yr]
		P_i = W/Q =	338	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Dean Lake Current Conditions BATHTUB Lake Response Model

	Average Loading Summary for Dean						
		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	Dean (1800502)	1,475	6.0	734	387	3.0	773
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,475*	*6*	*734*			*773*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800502		223	12.495	43%		146.1
2							
3							
4							
5							
	Summation			*12.5*			*146*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	176	25.5	25.5	0.00	0.24	1.0	42
		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]
	176	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]
	0.71	122		Oxic	1.0	1.0	188
	0.71	71.4		Anoxic	8.0	1.0	895
	Summation						1,083
		Net Discharge [ac-ft/yr] =		**746**	**Net Load [lb/yr] =**		**2,044**

Average Lake Response Modeling for Dean				
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 =	0.61	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	927	[kg/yr]
		Q (lake outflow) =	0.9	[10^6 m^3/yr]
		V (modeled lake volume) =	2.2	[10^6 m^3]
		T = V/Q =	2.42	[yr]
		P_i = W/Q =	1007	[µg/l]
Model Predicted In-Lake [TP]			**211.3**	**[ug/l]**
Observed In-Lake [TP]			**211.3**	**[ug/l]**

Dean Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for	***Dean***						
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	Dean (1800502)	1,475	6.0	734	46	0.4	91
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*1,475*	*6*	*734*			*91*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800502		223	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*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]
	176	25.5	25.5	0.00	0.24	1.0	42
		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]
	176	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]
	0.71	122		Oxic		1.0	19
	0.71	71.4		Anoxic	8.0	1.0	28
	Summation						47
		Net Discharge [ac-ft/yr] =		**734**	**Net Load [lb/yr] =**		**180**

TMDL Lake Response Modeling for	***Dean***			
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 =	0.61	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	82	[kg/yr]
		Q (lake outflow) =	0.9	[10^6 m^3/yr]
		V (modeled lake volume) =	2.2	[10^6 m^3]
		T = V/Q =	2.46	[yr]
		P_i = W/Q =	90	[µg/l]
Model Predicted In-Lake [TP]			**40.0**	**[ug/l]**
Observed In-Lake [TP]			**40.0**	**[ug/l]**

Fountain Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Fountain

	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	Reach 522 Near La	1,511	4.8	605	1117	8.2	1,839
2							
3							
4							
5							
	Summation	*1,511*	*5*	*605*			*1,839*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800902		131	7.365	43%		86.1
2							
3							
4							
5							
	Summation			*7*			*86*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	428	31.7	31.7	0.00	0.24	1.0	102
		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]
	428	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]
	1.73	54.29443521		Oxic	0.9	1.0	184
	1.73	67.7		Anoxic	10.0	1.0	2,585
	Summation						2,769
		Net Discharge [ac-ft/yr] =		**612**	**Net Load [lb/yr] =**		**4,796**

Average Lake Response Modeling for Fountain

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION	as f(W,Q,V) from Canfield & Bachmann (1981)			
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,176	[kg/yr]
		Q (lake outflow) =	0.8	[10^6 m^3/yr]
		V (modeled lake volume) =	3.2	[10^6 m^3]
		T = V/Q =	4.27	[yr]
		P_i = W/Q =	2879	[µg/l]
Model Predicted In-Lake [TP]			**196.3**	**[ug/l]**
Observed In-Lake [TP]			**196.3**	**[ug/l]**

Fountain Lake TMDL Conditions BATHTUB Lake Response Model

	TMDL Loading Summary for	**Fountain**					
	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	Reach 522 Near La	1,511	4.8	605	110	0.8	180
2							
3							
4							
5							
	Summation	*1,511*	*5*	*605*			*180*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800902		131	7.365	43%		0.0
2							
3							
4							
5							
	Summation			*7.4*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	428	31.7	31.7	0.00	0.24	1.0	102
		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]
	428	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]
	1.73	54.29443521		Oxic	0.5	1.0	104
	1.73	67.7		Anoxic	10.0	1.0	258
	Summation						362
		Net Discharge [ac-ft/yr] =		**612**	**Net Load [lb/yr] =**		**644**

TMDL Lake Response Modeling for	**Fountain**			
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.) =	293	[kg/yr]
		Q (lake outflow) =	0.8	[10^6 m^3/yr]
		V (modeled lake volume) =	3.2	[10^6 m^3]
		T = V/Q =	4.27	[yr]
		P_i = W/Q =	387	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Foster Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Foster

	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	Reach 988 Near La	3,003	4.9	1,215	257	1.0	849
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*3,003*	*5*	*1,215*			*849*
Failing Septic Systems							
	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	988		1	0.056	43%		0.7
2							
3							
4							
5							
	Summation			*0.1*			*1*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	121	24.6	24.6	0.00	0.22	1.0	27
		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]
	121	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]
	0.49	122		Oxic	1.0	1.0	132
	0.49	74.0		Anoxic	27.3	1.0	2,180
	Summation						2,312
		Net Discharge [ac-ft/yr] =		**1,215**	**Net Load [lb/yr] =**		**3,189**

Average Lake Response Modeling for Foster

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.) =	1,446	[kg/yr]
		Q (lake outflow) =	1.5	[10^6 m^3/yr]
		V (modeled lake volume) =	0.8	[10^6 m^3]
		T = V/Q =	0.55	[yr]
		P_i = W/Q =	965	[µg/l]
Model Predicted In-Lake [TP]			**258.8**	**[ug/l]**
Observed In-Lake [TP]			**258.8**	**[ug/l]**

Foster Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Foster

	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	Reach 988 Near La	3,003	4.9	1,215	72	0.3	238
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*3,003*	*5*	*1,215*			*238*
Failing Septic Systems							
	Name	Area [ac]	f people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	988		1	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	121	24.6	24.6	0.00	0.22	1.0	27
			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]
	121	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]
	0.49	122		Oxic	1.0	1.0	66
	0.49	74.0		Anoxic	27.3	1.0	79
	Summation						145
			Net Discharge [ac-ft/yr] =	**1,215**		**Net Load [lb/yr] =**	**410**

TMDL Lake Response Modeling for Foster

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$		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.) =	186	[kg/yr]
		Q (lake outflow) =	1.5	[10^6 m^3/yr]
		V (modeled lake volume) =	0.8	[10^6 m^3]
		T = V/Q =	0.55	[yr]
		P_i = W/Q =	124	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**

Malardi Lake Current Conditions BATHTUB Lake Response Model

Average Loading Summary for Malardi

	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	Reach 508 near lal	791	4.1	273	358	3.0	265
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*791*	*4*	*273*			*265*

Failing Septic Systems

	Name	Area [ac]	people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800801		268	15.031	43%		175.7
2							
3							
4							
5							
	Summation			*15.0*			*176*

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]
	117	0.0	0.0	0.00	0.22	1.0	26
		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 [km²]	Anoxic Factor [days]			Release Rate [mg/m²-day]	Calibration Factor [--]	Load [lb/yr]
	0.48	122		Oxic	1.0	1.0	128
	0.48	81.5		Anoxic	23.6	1.0	2,010
	Summation						2,138
		Net Discharge [ac-ft/yr] =		**288**	**Net Load [lb/yr] =**		**2,605**

Average Lake Response Modeling for Malardi

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 =	0.99	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,182	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	0.4	[10^6 m^3]
		T = V/Q =	1.18	[yr]
		P_i = W/Q =	3329	[µg/l]
Model Predicted In-Lake [TP]			**404.9**	**[ug/l]**
Observed In-Lake [TP]			**404.9**	**[ug/l]**

Malardi Lake TMDL Conditions BATHTUB Lake Response Model

TMDL Loading Summary for Malardi

	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	Reach 508 near lal	791	4.1	273	83	0.7	62
2						1.0	
3						1.0	
4						1.0	
5						1.0	
	Summation	*791*	*4*	*273*			*62*
Failing Septic Systems							
	Name	Area [ac]	# people on sep	Discharge [ac-ft/yr]	Failure [%]		[lb/yr]
1	1800801		268	0.000	43%	0.0	0.0
2							
3							
4							
5							
	Summation			*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					-	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]
	117	0.0	0.0	0.00	0.22	1.0	26
		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]
	117	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]
	0.48	122		Oxic	1.0	1.0	0
	0.48	81.5		Anoxic	23.6	1.0	43
	Summation						43
		Net Discharge [ac-ft/yr] =		**273**	**Net Load [lb/yr] =**		**131**

TMDL Lake Response Modeling for Malardi

$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.99	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	59	[kg/yr]
		Q (lake outflow) =	0.3	[10^6 m^3/yr]
		V (modeled lake volume) =	0.4	[10^6 m^3]
		T = V/Q =	1.24	[yr]
		P_i = W/Q =	176	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
Observed In-Lake [TP]			**60.0**	**[ug/l]**