Vermillion River Watershed TMDL Report

Mississippi River – Lake Pepin Major Watershed

Minnesota Pollution Control Agency

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Vermillion River Watershed TMDL Report
Primary Authors and Contributors:

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	North Creek	07040001-670	E. coli	2010	
	Middle Creek	07040001-546	E. coli	2010	
	Middle Creek	07040001-548	E. coli	2010	
	Vermillion River	07040001-516	E. coli	2012	
	North Creek	07040001-542	Fecal coliform	2008	
	North Creek	07040001-545	Fecal coliform	2008	
	North Creek	07040001-671	Fecal coliform	2008	
	Middle Creek	07040001-668	Fecal coliform	2008	
	South Creek	07040001-527	Fecal coliform	2008	
	South Branch Vermillion River	07040001-706	Fecal coliform	2008	
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	Turbidity Impaired Reach	10 mg/L proposed TSS standard for class 2A waters not be exceeded more than 10% of the time over a multiyear data window			
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	Alimagnet Lake	Total phosphorus concentration of 60 µg/L or less, Chl-*a* concentration of 20 µg/L or less, and Secchi Disk depth of greater than 1.0 m.			
	East Lake	Total phosphorus concentration of 90 µg/L or less, Chl-*a* concentration of 0.3 µg/L or less, and Secchi Disk depth of greater than 0.7 m.			

TMDL Summary Table		
EPA/MPCA Required Elements	**Summary**	**TMDL Page #**
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Public Participation	*See Section 9* Public Comment Period: June 29, 2015 through July 29, 2015	P. 61

Acronyms

AUID	Assessment Unit ID
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
DMR	Discharge Monitoring Reports
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
DSWCD	Dakota County Soil and Water Conservation District
EPA	Environmental Protection Agency
GIS	geographic information systems
IDDE	Illicit Discharge Detection and Elimination
JPB	Joint Powers Board
LA	Load Allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LGU	Local Government Unit
m	meter
MEP	Maximum Extent Practicable
mg/L	milligrams per liter
mg/m^2-day	milligram per square meter per day
mL	milliliter
MLCCS	Minnesota Land Cover Classification System
MnDOT	Minnesota Department of Transportation
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
Minn. R.	Minnesota Rules
MS4	Municipal Separate Storm Sewer Systems
NPDES	National Pollutant Discharge Elimination System
RA	Reasonable Assurance
RR	Release rate
SONAR	Statement of Need and Reasonableness
SSTS	Subsurface Sewage Treatment Systems
SSWCD	Scott County Soil and Water Conservation District
SWPPP	Stormwater Pollution Prevention Plan
TAG	Technical Advisory Group
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	total suspended solids
µg/L	microgram per liter
USLE	Universal Soils Loss Equation
VRMN	Vermillion River Monitoring Network
VRWJPO	Vermillion River Watershed Joint Powers Organization
WLA	Waste Load Allocation
WPC	Watershed Planning Commission
WRAPS	Watershed Restoration and Protection Strategies

Executive Summary

This Total Maximum Daily Load (TMDL) study was completed for the Vermillion River Watershed, which is a subwatershed in the Mississippi River – Lake Pepin 8 digit Hydrologic Unit (HUC) located in the Lower Mississippi River Basin. The study addresses one river turbidity impairment; 12 river/stream bacteria impairments; and nutrient impairments for two lakes, Alimagnet and East Lake. The Vermillion River Watershed covers approximately 364 square miles in Scott, Dakota and Goodhue Counties. The watershed drains to the Vermillion River and ultimately the Mississippi River near Lock and Dam 3 northwest of Red Wing, Minnesota. The water bodies addressed in this study are located in the upper portion of the Vermillion River Watershed, which drains a mixture of agricultural land and developed suburban land approximately 10-15 miles south of Minneapolis and St. Paul, Minnesota. The goal of this TMDL is to quantify the pollutant reductions needed to meet State water quality standards for turbidity, *E. coli* and nutrients in the impaired streams and lakes in the upper portion of the watershed.

Flow, turbidity and total suspended solids (TSS) monitoring data recorded in the Vermillion River class 2A turbidity impaired reach (07040001-517) were used to establish a load duration curve. The curve displays the class 2A TSS numeric standard of 10 mg/L that may not be exceeded more than 10% of the time over a multiyear data window. A TMDL, waste load allocations (WLAs), and load allocations (LAs) were established for five flow categories along the flow duration curve: very high, high, mid, low, and very low flow conditions. A 45% reduction will be necessary during very high flow conditions, and an 8% reduction under high flow conditions to meet the proposed TSS concentration standard.

Similar to turbidity, flow and bacteria monitoring data recorded throughout the 12 bacteria impaired reaches were used to establish load duration curves. The curves were set up to meet the *E. coli* numeric standard of no more than 126 organisms per 100 mL as a geometric mean within any calendar month. Additionally, no more than 10% of all samples taken during any calendar month may exceed 1,260 organisms per 100 mL. The TMDL WLAs and LAs for each bacteria impaired reach were established for the five flow categories described previously.

Alimagnet and East Lake are nutrient impaired lakes located in the upper portion of the Vermillion River Watershed. Alimagnet Lake drains approximately 985 acres of land in the cities of Burnsville and Apple Valley. East Lake drains approximately 6,375 acres of land across six separate municipalities and townships: Burnsville, Eagan, Apple Valley, Lakeville, Rosemount, and Empire Township. Both Alimagnet and East Lake are defined as shallow lakes but are situated in different ecoregions. Alimagnet Lake is located in the North Central Hardwood Forest ecoregion for which the shallow lake numeric water quality standards are a summer average (June through September) total phosphorus (TP) concentration of 60 µg/L, 20 µg/L chlorophyll-*a* (Chl-*a*), and greater than 1.0 meter (m) in Secchi depth. East Lake is located in the Western Corn Belt Plain ecoregion for which numeric water quality standards for a shallow lake are a summer average TP concentration of 90 µg/L, 30 µg/L Chl-*a*, and greater than 0.7 m Secchi depth.

Nutrient budgets were developed for Alimagnet Lake and East Lake along with lake response models to set the TMDL and WLAs and LAs. Stormwater pond water quality data was available and PONDNET watershed models were developed to support nutrient budget calculations. Results indicate a nutrient wasteload reduction of 35% (60.9 pounds) and a nutrient LA reduction of 51% (106.7 pounds) will be needed for Alimagnet to meet water quality standards. For East Lake, a wasteload reduction of 36% (263.3 pounds) and a LA reduction of 56% (147.0 pounds) are required to meet water quality standards.

1. Project Overview

1.1 Purpose

This TMDL study addresses one turbidity impairment and 12 bacteria (fecal coliform and *E. coli*) impairments on several main stem and tributary reaches of the Vermillion River Watershed as shown in Figure 1.1. This TMDL also addresses nutrient impairments for two lakes in the Vermillion River Watershed. All of the impaired waterbodies are located upstream of Hastings, Minnesota in the Upper Vermillion River Watershed. The boundaries of the impaired waterbodies are located in Dakota and Scott Counties in the State of Minnesota.

The goal of this TMDL report is to quantify the pollutant reductions needed to meet State water quality standards for turbidity, bacteria and nutrients for the stream reaches and lakes listed in Table 1-1. This TMDL study is established in accordance with Section 303(d) of the Clean Water Act and provides WLAs and LAs for the watershed areas as appropriate.

There was one turbidity TMDL completed in the Vermillion River Watershed prior to this study (MPCA 2009). The Lower Vermillion River Watershed Turbidity TMDL was completed in 2009 and covered the turbidity impaired reach (07040001-504) from Hastings Minnesota, to the confluence of the Vermillion River and Mississippi River south of Lock and Dam 3. This TMDL determined turbidity WLAs and LAs for the Upper Vermillion River Watershed. However, it was concluded that no load reductions were required for the Upper Vermillion in order for the Lower Vermillion River impaired reach to meet state water quality standards. The allocations presented in this TMDL study and the implementation activities identified in the accompanied Watershed Restoration and Protection Strategy (WRAPS) report will help provide load reductions for this impairment and other downstream resources.

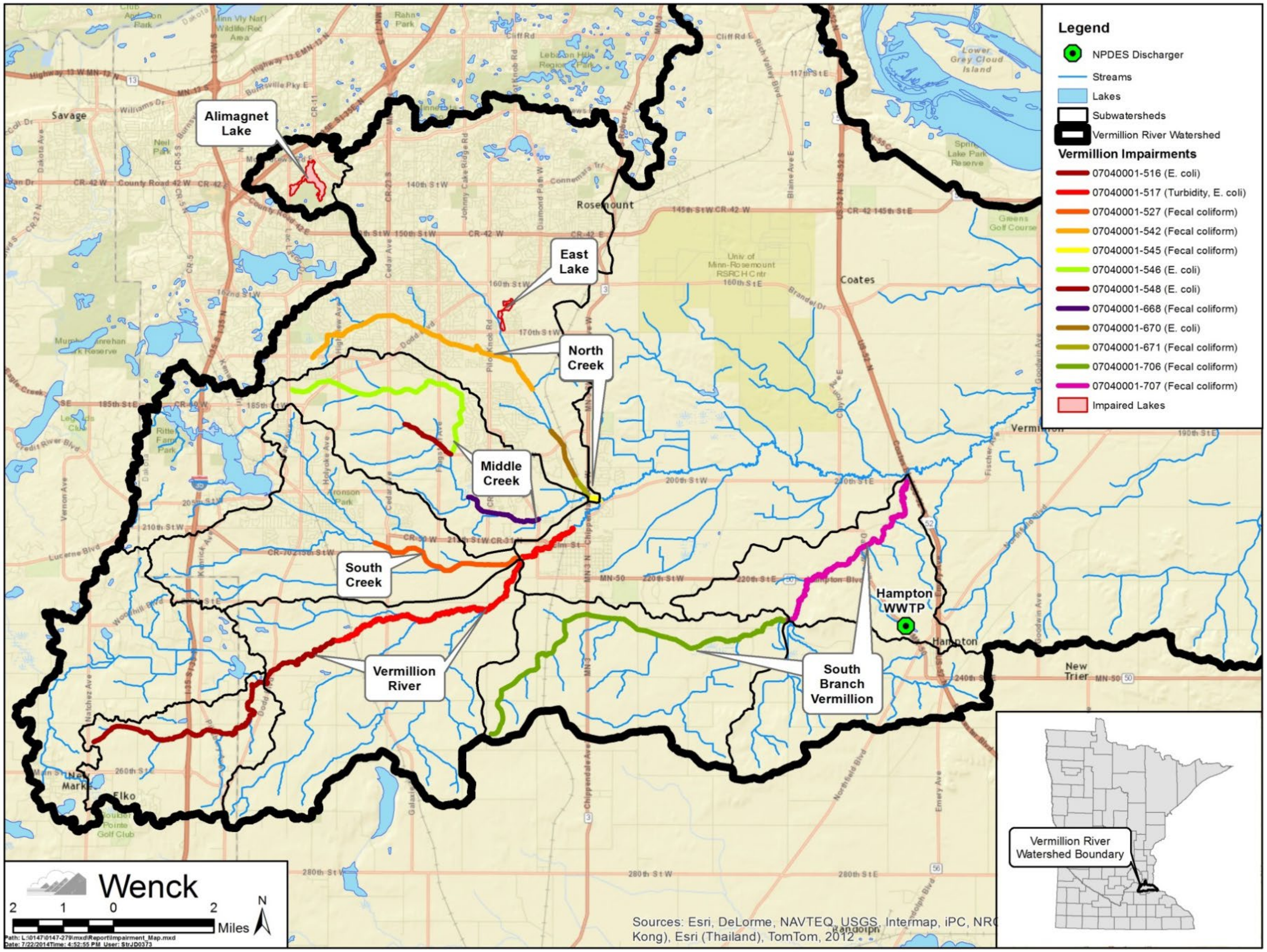

Figure 1.1. Vermillion River impaired waterbodies and drainage areas.

1.2 Identification of Waterbodies

The Vermillion River turbidity impaired reach was placed on the State of Minnesota's 303(d) list of impaired waters in 2008 as detailed in Table 1-1. The 12 bacteria impaired reaches were placed on the 303(d) list in 2008, 2010 and 2012. Alimagnet and East Lakes were placed on the 303(d) list for nutrients (TP) in 2002 and 2012, respectively. The impaired waters addressed in this TMDL are a mixture of Class 2A (cold water) and 2B (warm water) waters for which aquatic life and recreation are the protected beneficial uses.

Table 1-1. Impairments addressed in this report

Listed Water body Name	AUID#	Class	Listed Pollutant	Impaired Use	Year Placed in Impairment Inventory	303(d) List Scheduled Start & Completion Dates
Vermillion River	07040001-517	2A	Turbidity; Fecal Coliform	Aquatic life; Aquatic recreation	2008; 2008	2012/2015; 2012/2015
North Creek	07040001-670	2B	*E. coli*	Aquatic recreation	2010	2012/2015
Middle Creek	07040001-546	2B	*E. coli*	Aquatic recreation	2010	2012/2015
Middle Creek	07040001-548	2B	*E. coli*	Aquatic recreation	2010	2012/2015
Vermillion River	07040001-516	2B	*E. coli*	Aquatic recreation	2012	2012/2015
North Creek	07040001-542	2B	Fecal coliform	Aquatic recreation	2008	2012/2015
North Creek	07040001-545	2A	Fecal coliform	Aquatic recreation	2008	2012/2015
North Creek	07040001-671	2A	Fecal coliform	Aquatic recreation	2008	2012/2015
Middle Creek	07040001-668	2B	Fecal coliform	Aquatic recreation	2008	2012/2015
South Creek	07040001-527	2A	Fecal coliform	Aquatic recreation	2008	2012/2015
South Branch Vermillion River	07040001-706	2B	Fecal coliform	Aquatic recreation	2008	2012/2015
South Branch Vermillion River	07040001-707	2B	Fecal coliform	Aquatic recreation	2008	2012/2015
Alimagnet Lake	19-0021-00	NA	Nutrients	Aquatic recreation	2002	2014/2015
East Lake	19-0349-00	NA	Nutrients	Aquatic recreation	2012	2018/2022

1.3 Priority Ranking

The MPCA's projected schedule for the TMDL completions, as indicated on the 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. Ranking criteria for scheduling TMDL projects include, but are not limited to the following items:

- Impairment impacts on public health and aquatic life
- Public value of the impaired water resource
- Likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the waterbody
- Technical capability and willingness locally to assist with the TMDL
- Appropriate sequencing of TMDLs within a watershed or basin

2. Applicable Water Quality Standards and Numeric Water Quality Targets

2.1 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 portion of Vermillion River listed as impaired for turbidity is a class 2A cold water stream. The class 2A turbidity standard (Minn. R. ch. 7050.0222) that was in place at the time of the impairment assessment for this reach was 10 nephelometeric turbidity units (NTUs). The designated use that this standard protects is the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life, and their habitat. Impairment assessment procedures for turbidity are provided in the guidance manual for determination of impairment (MPCA 2007). Impairment listings occur when greater than 10% of data points collected within the previous 10-year period exceed the 10 NTU standards (or equivalent values for the TSS or transparency tube).

The aforementioned 10 NTU turbidity standard had been in place since the late 1960's. However, the standard had several weaknesses, including being a statewide standard and, since turbidity is a measure of light scatter and absorption, it is not a mass unit measurement and therefore not directly amenable to TMDLs and other load-based studies. Other issues with the previous turbidity standard included having too much variation in measurement because of particle composition in water, variation among turbidity meters, and poor quantitative documentation of what a turbidity unit is.

Although recognized earlier, these weaknesses became a significant problem when U.S. Environmental Protection Agency (EPA) and the Minnesota Pollution Control Agency's (MPCA) TMDL program became fully realized in the early 2000's. Once the TMDL studies began, it became clear that the existing standard was only indirectly related to biotic community health. In addition, the TMDL development was challenging because the studies needed to be developed using the TSS, which is measured as a mass unit (mg/L).

As a result, a committee of MPCA staff across several divisions met for over a year to develop TSS criteria to replace the current turbidity standards. These TSS criteria are regional in scope and based on a combination of both biotic sensitivity to the TSS concentrations and reference streams/least impacted streams as data allow. The results of the TSS criteria development were published by the MPCA in 2011, and propose a 10 mg/L TSS standard for Class 2A waters that may not be exceeded more than 10% of the time over a multiyear data window (MPCA 2011). The assessment season is identified as April through September. The TSS standard technical support document was placed on public notice in November, 2013, and the rules were adopted at the June 24, 2014 meeting of the MPCA Citizen's Board. The rules were approved by EPA in January 2015. For the purpose of this TMDL, the newly adopted 10 mg/L TSS standard for Class 2A waters will be used to develop the turbidity TMDL and allocations for the Vermillion River turbidity impaired reach (07040001-517).

2.2 Bacteria

The fecal coliform standard contained in Minn. R. 7050.0222, subp. 5, states that fecal coliform concentrations shall "not exceed 200 organisms per 100 milliliters as a geometric mean of not less than five samples in any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 2000 organisms per 100 milliliters. The standard applies only between April 1 and October 31." Impairment assessment is based on the procedures contained in the Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment (MPCA 2012).

With the revisions of Minnesota's water quality rules in 2008, the state changed to an *E. coli* standard because it is a superior potential illness indicator and costs for lab analysis are less (MPCA 2007). The revised standards now state:

"*E. coli* concentrations are not to exceed 126 colony forming units per 100 milliliters (cfu/100 ml) 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 cfu/100 ml. The standard applies only between April 1 and October 31."

The *E. coli* concentration standard of 126 cfu/100 ml was considered reasonably equivalent to the fecal coliform standard of 200 cfu/100 ml from a public health protection standpoint. The Statement of Need and Reasonableness (SONAR) section that supports this rationale uses a log plot that shows a good relationship between these two parameters. The following regression equation was deemed reasonable to convert fecal coliform data to *E. coli* equivalents:

E coli concentration (equivalents) = 1.80 x (Fecal Coliform Concentration)$^{0.81}$

2.3 Nutrients

Under Minn. R. chs. 7050.0150 and 7050.0222, subp. 4, the lakes addressed in this study are shallow lakes located within the North Central Hardwood Forest (Alimagnet Lake) and the Western Cornbelt Plain (East Lake) Ecoregions with numeric targets listed in Table 2-1. This TMDL presents load and WLAs and estimated load reductions assuming end points of ≤60 µg/L and ≤90 µg/L TP for Alimagnet Lake and East Lake, respectively.

In addition to meeting phosphorus limits, Chl-*a* and Secchi depth standards must also be met for the resource to be considered "fully supporting" its designated use. In developing the nutrient standards for Minnesota lakes (Minn. R. 7050), the MPCA evaluated data from a large cross-section of lakes within each of the state's ecoregions (MPCA 2005). Clear relationships were established between the causal factor TP and the response variables Chl-*a* and Secchi disk. Based on these relationships it is expected that by meeting the phosphorus targets of 60 µg/L and 90 µg/L, the Chl-*a* and Secchi standards will likewise be met.

Table 2-1. Numeric standards for lakes in the North Central and Western Corn Belt Plain Ecoregion

Parameters	North Central Hardwood Forest Standards (Shallow Lakes[1])	Western Corn Belt Plain Standards (Shallow Lakes[1])
Total Phosphorus (µg/L)	≤60	≤90
Chlorophyll-*a* (µg/L)	≤20	≤30
Secchi disk transparency (m)	≥1.0	≥0.7

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

3. Watershed and Waterbody Characterization

The Vermillion River Watershed is located in the south-central part of the Twin Cities Metropolitan Area, encompassing 364 square miles within the Upper Mississippi River Basin in portions of Dakota County (307 square miles), Goodhue County (38 square miles) and Scott County (19 square miles). The western portion of the watershed, referred to as the Upper Vermillion River, begins near New Market Township in Scott County and flows northeast through central Dakota County to the city of Hastings. In Hastings, the river drops 90 feet at Vermillion Falls Park where it is referred to as the Lower Vermillion River. East of Hastings, the Lower Vermillion River splits: one branch flows north to the Mississippi River; the other branch flows south, paralleling the Mississippi River for 20 miles through Ravenna and Welch Townships before joining the Mississippi River near the City of Red Wing in Goodhue County.

The Vermillion River supports a naturally reproducing population of brown trout. A portion of the main branch of the Upper Vermillion River and some of its tributaries, beginning in the southeast corner of Lakeville and central Eureka Township and stretching east through Farmington and Empire Township to a point just east of Highway 52 in Vermillion Township, have been designated as trout streams (class 2A waters) by the Minnesota Department of Natural Resources (DNR).

Although the Vermillion River is capable of supporting brown trout, the river's main stem and several tributaries and lakes are impaired for high levels of turbidity, bacteria and nutrients (Table 1-1). Two reaches of the Vermillion River main stem and two tributary reaches also do not meet State of Minnesota fish and macroinvertebrate standards for biotic integrity. One additional reach of the Vermillion River does not meet the fish biotic standard but does meet the macroinvertebrate standard. All of these impairments are located in the Upper Vermillion River Watershed between the headwaters and Hastings, Minnesota (Figure 1.1). Biological stressors for these impaired reaches were identified as part of the Vermillion River Watershed Stressor Identification Report (Wenck Associates, 2013). Restoration and protection efforts for these reaches are identified in the Vermillion River WRAPS Report (MPCA 2015).

3.1 Streams

The turbidity impaired reach and 12 bacteria impaired reaches of the Vermillion River Watershed are located in the upper portion of the Vermillion River Watershed (Figure 1.1). Collectively, these reaches cover approximately 50 stream miles and drain approximately 88,948 acres in Dakota and Scott Counties. Two of the impaired reaches (07040001-516 and 07040001-517) are on the main stem of the Vermillion River while the other reaches are located on four major tributaries that drain to the main stem: North Creek, Middle Creek, South Creek, and South Branch Vermillion River.

3.2 Lakes

Alimagnet and East Lake are both relatively small, nutrient impaired shallow lakes located in the far northern portion of the Upper Vermillion River Watershed. Alimagnet Lake drains approximately 985 acres of land in the cities of Burnsville and Apple Valley. East Lake drains approximately 11,579 acres of land across six separate municipalities and townships: Burnsville, Eagan, Apple Valley, Lakeville, Rosemount, and Empire Township. Lake morphometry for Alimagnet and East Lake is listed in Table 3-1.

Table 3-1. Lake morphometry for Alimagnet Lake and East Lake

Parameter	Alimagnet Lake	East Lake
Surface Area (acres)	109	42
Average Depth (ft)	5	4
Maximum Depth (ft)	9	10
Lake Volume (acre-ft)	545	162
Littoral Area (%)	100%	100%
Depth Class	Shallow	Shallow
Drainage Area (acres)	985	11,579

3.3 Subwatersheds

Figures depicting the subwatersheds and flow patterns of each impaired water body addressed in this TMDL study are included in Appendices A-C. Subwatersheds for the turbidity and bacteria impaired reaches and East Lake were determined based on a 2009 study of the Vermillion River Watershed (Barr Engineering, 2009). Subwatersheds for Alimagnet Lake were established as part of the lake's 2005 Lake Management Plan (Blue Water Science and Bonestroo, 2005).

3.4 Land Cover

Approximately 139 square miles (88,948 acres) of the Vermillion River Watershed is included in the TMDL study area (Figure 1.1). A broad range of land use and land cover exists within the study area which is summarized in Table 3-2 below. The Minnesota Land Cover Classification System (MLCCS) was used to describe all land cover for the purpose of this study. The MLCCS was first established by the DNR in 2004 and has been continually updated with the help of federal, state, regional and local government units (LGUs) (DNR 2004). The primary objective of the MLCCS is to accurately map all land cover types and to standardize land cover identification and interpretation. Figures depicting land cover for the subwatersheds draining to each impaired water body are included in Appendices A-C.

Table 3-2. Land cover in the TMDL study area

MLCCS Land Cover	Area (acres)	Percent of Study Area
Agricultural Land	32,211	36%
Medium Density Development	20,852	23%
Low Density Development	9,128	10%
Emergent Wetland	5,248	6%
Forest	5,136	6%
Maintained Tall Grasses	3,225	4%
Dry Tall Grasses	2,293	3%
High Density Development	2,118	2%
Short Grasses	1,819	2%
Tall Grasses	1,806	2%
Wetland Open Water	1,340	2%
Tree Plantation	1,044	1%
Wetland Forest	899	1%
Open Water	848	1%
Wetland Shrubs	787	1%
Shrubland	194	<1%
Mud Flat	<1	<1%
Total	**88,948**	**100%**

3.5 Current/Historic Water Quality

The Vermillion River Monitoring Network (VRMN) is a joint effort between the Vermillion River Watershed Joint Powers Organization (VRWJPO), the Dakota County Soil and Water Conservation District (DSWCD), and Scott County Soil and Water Conservation District (SSWCD). The VRMN was created to assess water quality and quantity throughout the watershed. The data collected through the VRMN includes a combination of chemical, physical and biological parameters that help local agencies determine the health of the stream and implement appropriate management strategies. The stream monitoring data set used in this TMDL study was obtained directly from the VRWJPO, the DSWCD, and the SSWCD, and supplemented from the MPCA and United States Geological Survey (USGS) databases as available. Lake monitoring data was supplied by the Cities of Burnsville, Apple Valley, and Lakeville, and from the MPCA website as necessary. Stream and lake sampling site locations are indicated on maps included in Appendices A-C.

3.5.1 Turbidity

The Dakota County SWCD and the VRWJPO staff deployed continuous turbidity loggers from 2008 through 2012 at two main stem monitoring stations along the Vermillion River. In 2012, two additional stations were equipped with turbidity loggers to determine turbidity contributions from South Creek and the reach immediately upstream of the impaired reach. Locations and descriptions of each monitoring station are summarized in Appendix A. This continuous turbidity dataset supplies an accurate depiction of daily turbidity values for a given year when compared to discrete grab samples that only represent a finite number of days. A relationship was developed between the continuous turbidity and laboratory measured TSS. A total of 186 paired turbidity/TSS samples were used to develop the relationship (Appendix A). A regression was developed and used to convert all average daily field turbidity values to average daily TSS concentrations.

Figure 3.1 shows the continuous field turbidity data for the most downstream monitoring site (VR1.3) converted to TSS equivalents and compared to flow duration. The flow duration is presented on the X-axis and divided into five flow zones including very high flows (0-10%), high flows (10-40%), mid flows (40-60%), low flows (60-90%) and very low flows (90-100%). According to the TSS standard for Class 2A waters, a stream reach is considered impaired if more than 10% of TSS samples collected April through September exceed 10 mg/L. Table 3-3 summarizes the TSS equivalent data for each site compared to the 10 mg/L TSS standard. These data suggest the TSS exceedances are most common during the very high and high flow conditions, although violations were recorded under most flow categories.

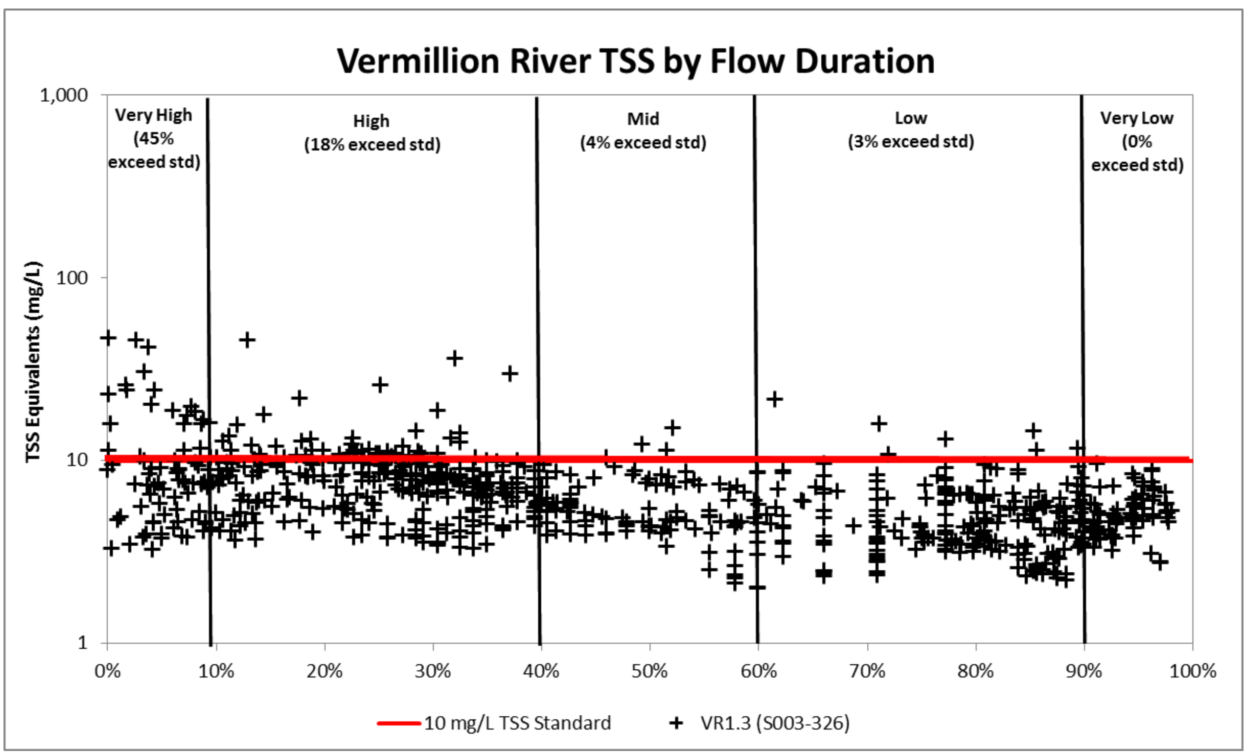

Figure 3.1. The TSS measurements (converted from continuous turbidity) by flow category in the Vermillion River. Measurements were taken downstream of South Creek at the most downstream monitoring station in the impaired reach (Refer to Appendix A for complete description of monitoring stations and data). Flow categories were established using daily flow data collected at the VR1.3 monitoring station.

Table 3-3. Summary of the TSS equivalent data at the three main stem and one tributary monitoring station within the impaired reach

	Very High			High			Mid			Low			Very Low		
Site	Observations	Average (mg/L)	% > 10 mg/L	Observations	Average (mg/L)	% > 10 mg/L	Observations	Average (mg/L)	% > 10 mg/L	Observations	Average (mg/L)	% > 10 mg/L	Observations	Average (mg/L)	% > 10 mg/L
VR 7.8 S003-338	22	15.9	32%	52	10.9	38%	53	5.8	6%	59	4.8	0%	35	4.3	0%
VR2.5 S003-325	126	15.7	52%	291	10.5	39%	186	7.7	14%	338	6.0	7%	132	3.2	1%
VR1.3 S003-326	84	10.6	45%	290	8.0	18%	108	5.6	4%	223	5.1	3%	77	5.3	0%
Cedar (South Creek tributary) S005-109	15	50.6	67%	50	4.4	12%	52	2.8	4%	57	4.1	9%	34	0.6	0%

3.5.2 Bacteria

A stream reach is placed on the 303(d) Impaired Waters List if the geometric mean (or "geomean") of the aggregated monthly *E. coli* concentrations for one or more months exceed the chronic standard of 126 cfu/100 ml. A water body is also considered impaired if more than 10% of the individual samples during any calendar year exceed the 1,260 cfu/100 ml acute standard.

Table 3-4 shows April through October monthly *E. coli* geometric means for the 12 bacteria impaired reaches in the Vermillion River Watershed. Geometric means are often used to describe bacteria data over arithmetic means as the geometric mean normalizes the ranges being averaged, using the following equation:

$$Geometric\ mean = \sqrt[n]{x_1 * \ x_2 * \ldots . x_n}$$

The reaches were grouped into five major tributaries/study areas: North Creek, Middle Creek, South Creek, Vermillion Main Stem, and South Branch Vermillion River. Available data from 2004 to 2013 was used to develop the bacteria TMDLs in this study; however, two reaches only had data collected between 1999 and 2000 (07040001-668 and 07040001-706). Fecal coliform data were converted to *E. coli* equivalents using the equation described in Section 2 for reaches where only fecal coliform was analyzed. Table 3-4 shows monthly geometric means for all impaired reaches which exceeded the 126 cfu/100 ml chronic *E. coli* standard for at least one month during the April through October index period. Additionally, individual samples exceed the 1,260 cfu/100 ml acute standard at least 10% of the time in several reaches during the April through October index period.

Table 3-4. Monthly geometric mean of *E. coli* values for the Vermillion River impaired reaches

			April			May			June			July			August			September			October			All Months		
Tributary/Study Area	**Reach**	**Data Years**	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260	n	Geo	%n > 1,260
North Creek	542	2006-2007	10	139	10%	10	453	20%	10	2,507	70%	10	2,042	70%	11	1,362	45%	10	1,811	60%	--	--	--	61	952	46%
	671	2004-2013	30	31	0%	32	110	6%	36	315	14%	28	270	7%	36	365	14%	28	217	7%	22	81	5%	212	159	8%
	670	2006-2007	10	28	0%	10	77	0%	10	102	0%	10	247	1%	11	493	18%	10	226	10%	--	--	--	61	138	7%
	545	2004-2013	21	59	0%	23	180	13%	25	483	32%	22	298	5%	29	339	17%	21	208	10%	22	221	23%	163	227	15%
Middle Creek	668	2000	--	--	--	2	1,041	0%	1	1,407	100%	1	2486	100%	6	406	17%	5	234	20%	--	--	--	15	470	27%
	546	2006-2007	10	113	0%	10	494	10%	10	1,402	50%	10	1,643	80%	11	2,429	55%	10	1,510	50%	--	--	--	61	897	41%
	548	2006-2007	10	75	30%	10	239	10%	10	885	40%	10	1674	80%	11	1,721	55%	10	820	40%	--	--	--	61	590	38%
South Creek	527	2011-2013	8	21	0%	9	105	11%	9	682	56%	7	177	0%	9	157	11%	7	87	0%	8	47	0%	57	112	12%
Vermillion River	516	2005-2011	13	66	8%	13	196	8%	15	584	33%	8	675	13%	9	1,095	56%	10	364	10%	13	171	15%	81	292	20%
	517	2004-2013	20	84	5%	23	197	13%	26	573	31%	20	458	5%	28	582	21%	19	452	21%	22	197	5%	158	314	15%
South Branch Vermillion River	706	1999-2000	--	--	--	7	113	0%	6	316	17%	7	143	0%	11	415	0%	10	165	10%	--	--	--	41	213	5%
	707	2004-2013	25	53	20%	28	127	4%	32	472	22%	27	414	15%	32	505	28%	23	320	9%	25	139	0%	192	237	13%

Notes: n = number of samples

Geo = Geometric mean in cfu/100 ml

%n > 1,260 = Percent of samples greater than 1,260 cfu/100 ml

-- no available data

3.5.3 Nutrients

The historical in-lake water quality data set from 2000 to 2013 was reviewed and considered for this TMDL study. For the purposes of developing the Alimagnet TMDL, available data from the most recent six years (2008 through 2013) was used to establish the “average” condition. Data prior to the most recent six years was not used due to improved water quality conditions in Alimagnet beginning in 2006. The improved conditions are a result of various watershed and in-lake improvement projects including winter aeration, stormwater pond barley straw treatments, curly-leaf pondweed control, and bluegill and bullhead removals (Blue Water Science 2013). For East Lake, the “average” condition focused on data from 2007-2008, and 2010-2012, as no watershed monitoring data was collected prior to 2007. Table 3-5 lists the June through September averages of TP concentration, Chl-*a* concentration, and Secchi depth for each impaired lake. The table also lists the data years which were used to calculate the “average” condition for the TMDL study.

Both Alimagnet Lake and East Lake indicate average summer growing season TP, Chl-*a* and Secchi depths are not meeting ecoregion-defined state standards. Appendix C contains detailed figures showing average annual values for each of the parameters summarized in Table 3-5. It should be noted that Alimagnet, and to a lesser extent East Lake, have demonstrated some improvement in water quality, particularly with regards to TP in recent years. However, the TP and the response variables for both lakes are still not meeting state standards.

Table 3-5. Alimagnet and East Lake summer growing season average water quality

Parameter	**Alimagnet Lake**			**East Lake**		
	“Average” Condition Calculation Years	Ecoregion Standard	Average Condition	“Average” Condition Calculation Years	Ecoregion Standard	Average Condition
TP (µg/L)	2008-2013	60	84	2007-2008, 2010-2012	90	142
Chlorophyll-*a* (µg/L)	2008-2013	20	47	2007-2008, 2010-2012	30	116
Secchi Depth (m)	2008-2013	1.0	0.9	2007-2008, 2010-2012	0.7	0.5

3.6 Pollutant Source Summary

3.6.1 Turbidity

Turbidity is a measure of the cloudiness or haziness of water caused by suspended and dissolved substances in the water column. The turbidity source assessment focused on TSS, not turbidity, since TMDL development was based on the TSS standard. Runoff from homes, buildings, roads, pastures, cropland and other areas has the potential to export TSS to surface water. Permitted sources of the TSS include construction, industrial and municipal stormwater runoff and wastewater effluent. There are no active industrial or municipal wastewater dischargers in the Vermillion River turbidity impaired reach watershed. There are six entities with NPDES/SDS Phase II permits for municipal separate storm sewer systems (MS4s) within the turbidity impaired reach watershed.

When assessing the TSS 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 sediment erosion from upland fields, tile drainage, gully erosion, livestock grazing, point source discharges and stormwater from construction sites and impervious surfaces. Internal sources of sediment and turbidity include sediment re-suspension, bank erosion and failure, and in-channel algal production.

For this study, external sources were estimated using the Universal Soils Loss Equation (USLE). The USLE provides an assessment of existing soil loss from upland sources and the potential to address sediment loading through the application of Best Management Practices (BMP). The 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. Detailed results of the USLE analysis are provided in Appendix A.

Review of Chl-*a* data within the impaired reach and a streambank assessment for the turbidity impaired reach were completed as part of this TMDL to assess potential internal sources of TSS. The Chl-*a* in the Vermillion River impaired reach is low and showed no exceedances when compared to the <35 µg/L eutrophication criteria for streams in Minnesota's Southern River Region (MPCA 2013; Appendix A).

In order to determine the TSS inputs from bank erosion, the turbidity impaired reach and one tributary reach (07040001-527) were walked, and erosion features were noted, measured and annual TSS export was estimated. A complete discussion of the streambank assessment methods and results are provided in Appendix A.

Results of the USLE analysis, Chl-*a* data review and streambank assessments for the turbidity impaired reach led to the following conclusions:

- Low average Chl-*a* concentrations throughout the year at both monitoring sites (S003-325 and S003-326) indicates that algal turbidity is not a primary source of turbidity in the impaired Vermillion River reach.
- Streambank erosion appears to deliver a small fraction of sediment to the impaired reach when compared to potential field erosion. In addition, the annual monitored in-stream TSS load is an order of magnitude larger than the annual estimated streambank soil loss. These two lines of evidence suggest that field erosion is the primary source of TSS to the impaired Vermillion River reach.

- Although the annual mass is small compared to the load from field erosion, there appears to be some excess sediment delivered to the stream from streambank erosion. Stream surveys and observations during fish and macroinvertebrate sampling suggest that streambank erosion is common in certain areas and is causing localized sediment aggradation, pool filling, and channel braiding. This suggests streambank erosion through the impaired reach may be more a source of excess sediment bedload than suspended sediment.

3.6.2 *E. coli*

Bacteria loading can occur from both permitted and non-permitted sources. Permitted sources of bacteria can include industrial wastewater effluent, municipal wastewater treatment plant effluent, and municipal stormwater runoff. Review of the Vermillion River Watershed bacteria impaired reaches addressed in this TMDL indicates that there is only one active permitted wastewater discharger in the watershed. This discharger, Hampton Wastewater Treatment Facility (WWTF), is located near the city of Hampton and discharges to the South Branch Vermillion impaired reach (07040001-707). There are also seven MS4s that have at least a portion of their boundary within one of the 12 bacteria impaired reach watersheds.

There are currently no National Pollutant Discharge Elimination System (NPDES) permitted feedlot operations in the Vermillion River Watershed. A feedlot owner is required to apply for a NPDES feedlot permit when a new or expanding facility will have a capacity of 1,000 animal units or more; or if it meets or exceeds the EPA Large Concentrated Animal Feedlot Operation (CAFO) threshold. There are several smaller, non-NPDES registered feedlot operations in the Vermillion River Watershed. Appendix B contains a series of maps showing registered feedlot locations in each *E. coli* impaired reach watershed.

Runoff from homes, pastures and other areas has the potential to transport bacteria from pets and livestock animals to surface water. Failing or nonconforming septic systems, or subsurface sewage treatment systems (SSTS) near waterways can also be a source of bacteria to streams, especially during low flow periods when these sources continue to discharge and runoff driven sources are not active. In 2006, Dakota County Water Resources received funding from the EPA's Section 319 Grant Program to target SSTS compliance in rural riparian areas in the Vermillion River watershed (Dakota County Water Resources Department 2009). Project staff conducted outreach activities to identify and inspect all pre-1996 SSTS within 300 feet of rural intermittent and perennial streams in the Dakota County portion of the Vermillion River watershed. Through this effort, 165 SSTS were inspected and 64 systems were found to be failing. Using incentive payments of $500 per household, existing low-interest loan programs available for septic system upgrades, and compliance and enforcement, the program achieved compliance for all 64 failing systems.

A bacteria accounting exercise was performed to estimate the total amount of bacteria produced within the drainage area of each impaired reach. The accounting exercise uses available livestock, geographic information systems (GIS), human and pet populations, wildlife population, septic data and literature rates from various studies/sources to estimate bacteria production in each watershed. The purpose of this exercise was to compare the number of bacteria generated by each source to aid in focusing implementation activities. Detailed results of the bacteria source accounting are presented in Appendix B. In addition to the accounting exercise, a GIS desktop survey was also performed to assess potential bacteria sources in the riparian and near-stream areas of each impaired reach. Air photos along the impaired reach corridors were investigated and notes and observations were recorded regarding several potential sources including: stream buffers, livestock operations near stream channels (<500 feet), stream buffers in urban and agricultural areas, in-channel wetlands and ponded areas, golf courses and stormwater ponds that outlet directly to the impaired reach. Detailed results of the desktop GIS survey are also presented in Appendix B. Table 3-6 below provides a general source assessment summary for each reach based on the watershed bacteria accounting exercise and the desktop GIS survey.

Table 3-6. Summary of potential *E. coli* sources in each impaired reach based on the watershed accounting exercise and near-stream desktop GIS survey

		Urban			Livestock			Rural			In-Stream			Wildlife		Upstream Sources
Tributary/ Study Area	**Reach**	Poorly buffered urban area near stream	Golf Courses	Stormwater ponds near stream	Feedlots near streams	Feedlots away from stream	Poorly buffered pastureland near stream	Poorly buffered cropland near stream	Cropland away from stream	Failing Septics (SSTS)	In-channel wetlands	In-channel ponded areas	Upstream lakes and wetlands	Waterfowl	Deer	Upstream Reaches and Impairments
North Creek	545	™		™				˜	™	™				™	™	˜
	671	™						›	›	™				™	™	˜
	670	™		˜				™	›	™	˜			™	™	˜
	542	˜	™	™				™		™	˜		™	™	™	
Middle Creek	668	™		›		˜		›	›	™	˜			™	™	˜
	546	›		˜	˜	™	›	˜	˜	™				™	™	
	548				›	™	˜	˜	˜	™	™			™	™	›
South Creek	527	›		˜		›	™	˜	˜	™			™	™	™	›
Vermillion River	516			™	›	›	›	›	›	™	˜	™	™	™	™	
	517	™		™		™		›	›	™	™	™		™	™	˜
South Branch Vermillion River	706				›	˜	™	˜	˜	™	›	™		™	™	
	707			™	›	˜	›	›	˜	™				™	™	˜

Key: ˜ = High Presence › = Moderate Presence ™ = Low Presence

3.6.3 Nutrients

A key component to developing a nutrient TMDL is understanding the sources contributing to the impairment. This section provides a brief description of the potential sources in the watershed contributing to excess nutrients in Alimagnet Lake and East Lake. Section 4.3 of this report will discuss the major pollutant sources and how they were quantified using monitoring data and water quality modeling. The information presented here and in the upcoming sections together will provide information necessary to both assess the existing contributions of pollutant sources and target pollutant load reductions. The cities of Burnsville, Apple Valley and Lakeville have also completed a number of specialized studies that will inform implementation activities.

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. Water quality in upstream lakes, stormwater ponds and other waterbodies has a direct influence on downstream lakes in the watershed. Other factors influencing TP nutrient levels in these water bodies include atmospheric nutrient loading, watershed nutrient loading, and internal phosphorus loading.

3.6.3.1 Permitted Sources

Phosphorus loading from a lake's watershed can come from a variety of sources such as fertilizer, manure, and the decay of organic matter. Wind and water action erode the soil, detaching particles and conveying them in stormwater runoff to nearby water bodies where the phosphorus becomes available for algal growth (Table 3-7). Organic material such as leaves and grass clippings can leach dissolved phosphorus into standing water and runoff or be conveyed directly to water bodies where biological action breaks down the organic matter and releases phosphorus.

Table 3-7. 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 sediment, grass clippings, leaves, and other phosphorus-containing materials to surface water through a regulated MS4 conveyance system.
Construction Stormwater NPDES/SDS General Permit	Permits for any construction activities disturbing: 1) One acre or more of soil, 2) Less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre or 3) Less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources.	The EPA estimates a soil loss of 20 to 150 tons per acre per year from stormwater runoff at construction sites. Such sites vary in the number of acres they disturb.

Permitted Source	Source Description	Phosphorus Loading Potential
Multi-sector Industrial Stormwater NPDES/SDS General Permit	Applies to facilities with Standard Industrial Classification Codes in 10 categories of industrial activity with significant materials and activities exposed to stormwater.	Significant materials include any material handled, used, processed, or generated that when exposed to stormwater may leak, leach, or decompose and be carried offsite.

3.6.3.2 Non-permitted Sources

Table 3-8 describes several phosphorus sources that are not regulated by the NPDES program. For many lakes, especially shallow lakes, internal sources can be a significant portion of the TP load. Under anoxic conditions at the lake bottom, weak iron-phosphorus adsorption bonds on sediment particles break, releasing phosphorus into the water column in a form highly available for algal uptake. In many lakes, high internal loading rates are the result of a large pool of phosphorus in the sediment that has accumulated over several decades of watershed loading to the lake. Thus, even if significant watershed load reductions have been achieved through BMPs and other efforts, internal loading from the sediment can remain high and in-lake water quality may not improve. Carp and other rough fish uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments, releasing phosphorus and increasing turbidity. Some aquatic vegetation species such as invasive curly-leaf pondweed can outcompete and suppress native vegetation species. Curly-leaf begins its growth cycle earlier in the season compared to other species and typically dies back in mid-summer. As a result, lakes with heavy curly-leaf pondweed infestation can have little or no submerged vegetation by late summer. This can cause lower dissolved oxygen (DO) levels, increased sediment re-suspension and phosphorus release from sediment. Eurasian watermilfoil, which is present in many lakes throughout Minnesota, is not a phosphorus source, but is an invasive that can also out-compete native vegetation and negatively impact recreational use of lakes.

Table 3-8. Potential non-permitted sources of phosphorus in Alimagnet Lake and East Lake

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 (see Table 3-2) creating both rural and urban stormwater runoff that does not pass through a regulated MS4 conveyance system.
Internal Phosphorus Release	Release from lake bottom sediments during periods of low DO; release from aquatic vegetation during senescence and breakdown.

3.6.3.3 Phosphorus Load Summary

A general summary of the nutrient sources to Alimagnet Lake and East Lake is provided in Table 3-9. Estimates of each source and how they were calculated are discussed in Section 4.3.

Table 3-9. Sources of phosphorus in Alimagnet and East Lake

Source Type	Source	Alimagnet Lake	East Lake	Notes
Watershed	Agriculture		○	Agricultural land no longer present in Alimagnet watershed. East Lake contains approximately 7% agricultural land, however much of this is currently being converted to residential development.
	Urban	●	●	Urban land accounts for approximately 65% and 75% of the landuse in Alimagnet and East Lake, respectively
	Upstream Lakes		○	No upstream lakes in Alimagnet watershed. East Lake watershed does have several upstream lakes (i.e. Cobblestone, Alimagnet), however outflow and nutrient loading from these lake is small relative to other sources
	Failing Septics (SSTS)			SSTS no longer exist in either watershed. Municipal wastewater in both lakesheds is treated by municipalities and discharged outside of the watershed
Internal	Sediment Release	●	○	Release of phosphorus from sediments for each lake were measured in the laboratory (refer to Section 4.3.1.4 and Appendix C)
	Historic Impacts (i.e. WWTF discharge)			No known source
	Aquatic Vegetation	Δ		Alimagnet Lake currently contains curly-leaf pondweed and is present across 50%-90% of the lake early in the summer (Blue Water Science, 2013).
	Rough Fish	Δ	Δ	Rough fish removals from 2005-2009 have successfully controlled much of the rough fish population in Alimagnet Lake (Blue Water Science, 2013). A 2010 survey of East Lake suggest fish population dominated by rough fish, including common carp (Blue Water Science, 2014).

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

4 TMDL Development

4.1 Turbidity

The data used for the development of the Vermillion River Turbidity TMDL (AUID 07040001-517) are historic turbidity and the TSS measurements by Dakota County SWCD between 2008 and 2013. SWCD staff deployed continuous field turbidity data loggers at four monitoring stations in the turbidity impaired reach watershed. All field turbidity measurements were converted to the TSS equivalents using a regression relationship between field turbidity and laboratory TSS measurements (Appendix A). Stream flow data was also important in supporting development of the turbidity TMDL. Streamflow data paired with turbidity and the TSS measurements allow exceedances to be evaluated by flow regime which, in turn, provide insight into potential sources. Continuous stream flow data is available at two locations within the impaired reach. Appendix A includes a complete description of the historic turbidity, TSS, and stream flow data within the impaired reach along with figures showing locations of all monitoring stations.

4.1.1 Loading Capacity

The TSS loading capacity for the Vermillion River turbidity impaired reach was developed from a load duration curve. Load duration curves incorporate flow and the TSS data across stream flow regimes and provide loading capacities and a means of estimating load reductions necessary to meet water quality standards. To develop the load duration curve, all average daily flow values at station VR1.3 (S003-326; Appendix A) from 2004-2013 were multiplied by the 10 mg/L standard and converted to a daily load to create a "continuous" load duration curve. For the purposes of this TMDL, the baseline year for implementation will be 2009, which represents the mid-range year of the flow record used to construct the load duration curve (See Section 8.2.1). The 10-year TSS load duration curve for the turbidity impaired reach is shown in Figure 4.1. On this figure the curve represents the loading capacity of the stream for each daily flow. The curve is divided into flow zones including very high (0-10%), high (10-40%), mid (40-60%), low (60-90%) and very low (90 to 100%) flow conditions. For simplicity, only the median (or midpoint) load of each flow zone is used to show the TMDL equation components in the TMDL tables. However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by EPA.

The TMDL load duration curve can also be compared to current conditions by plotting the measured load for each water quality sampling event (Figure 4.2). Each value that is above the curve represents an exceedance of the water quality standard while those below the line are below the water quality standard. Also plotted are the 90th percentile monitored TSS concentrations for each flow regime (solid green circle). The difference between these two provides a general percent reduction in TSS that will be needed to remove the reach from the impaired waters list. The data shows the TSS reductions in the Vermillion River impaired reach will be needed for the very high and high flow conditions.

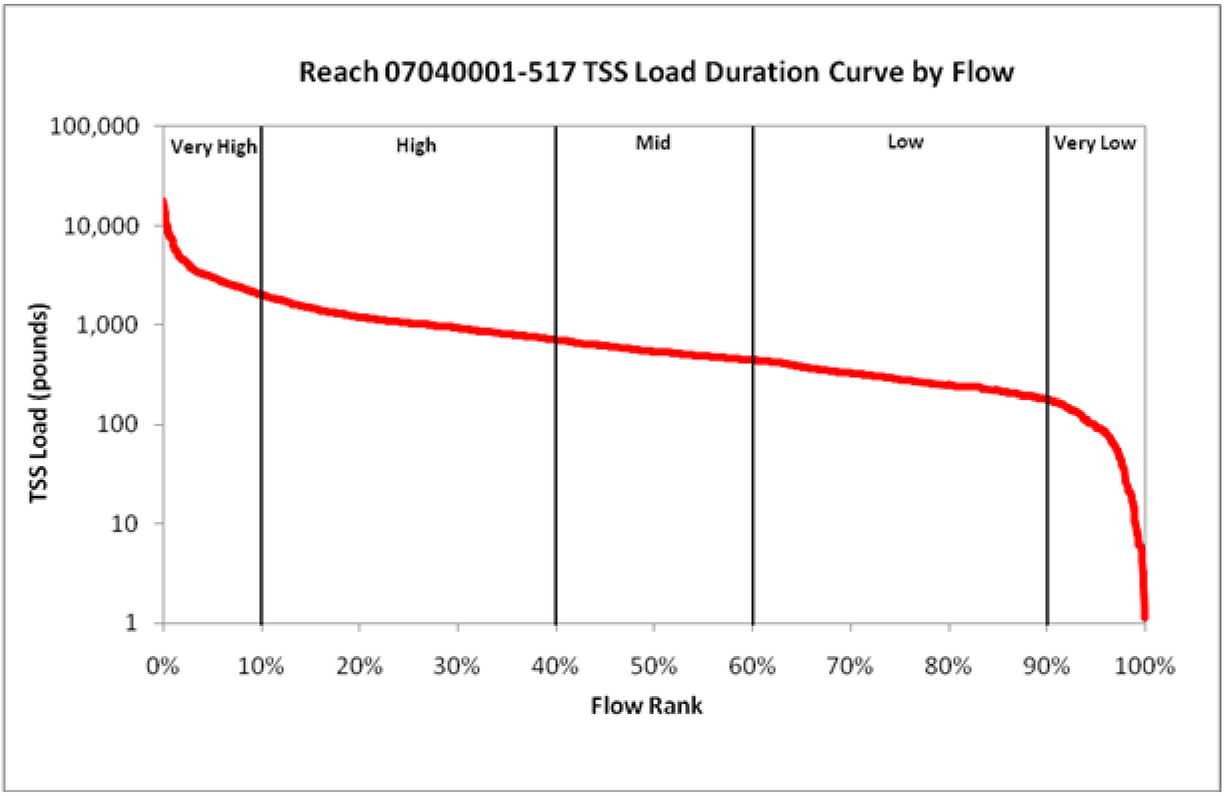

Figure 4.1. Standard TSS load duration curve for reach 07040001-517.

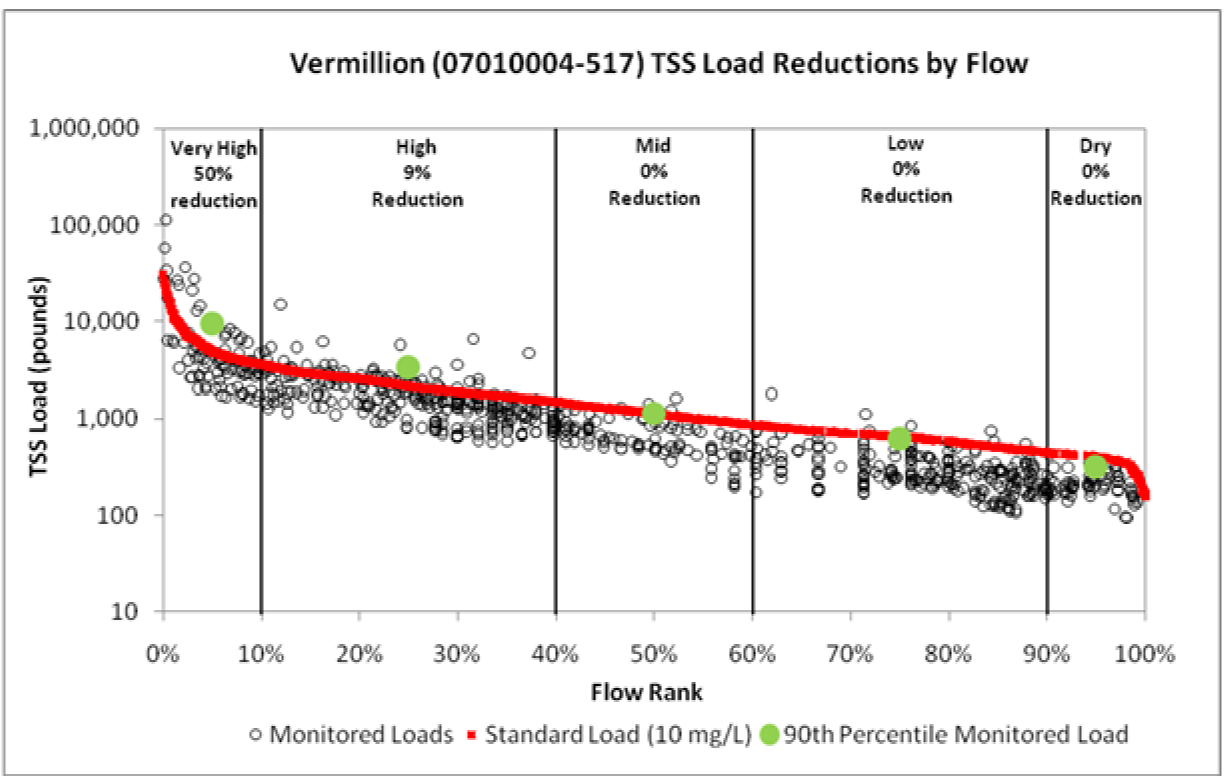

Figure 4.2. The TSS monitored loads, load standard and load reductions for Reach 07040001-517.

4.1.2 Wasteload Allocation Methodology

The WLAs for turbidity TMDLs are typically divided into three categories: NPDES point source dischargers, permitted MS4s, and construction and industrial stormwater. The following sections describe how each of these LAs was estimated.

4.1.2.1 NPDES Point Source Dischargers

There are no NPDES Point Source dischargers in the Vermillion River turbidity impaired reach watershed.

4.1.2.2 Permitted MS4s

There are six permitted MS4s that are completely within or have a portion of their municipal boundary in the impaired reach watershed (Table 4-1, Appendix A). The MPCA defined and supplied the MS4 boundaries for Credit River Township, Elko New Market, Empire Township, and the City of Lakeville. At this time, it is expected that most of the land within the city and township MS4 boundaries that is currently undeveloped will undergo development within the next 10-15 years. Thus, for this TMDL study all city and township MS4s were allocated at the full extent of their jurisdictional boundary. The only Dakota County land subject to the MS4 allocations is county right of way in the 2010 United States Census Bureau urban defined area. To define Dakota County's MS4 boundary, a 60 foot buffer was applied to all Dakota County roadways in the impaired reach watershed boundary and the 2010 urban defined area. Once all MS4 boundaries were defined, individual MS4 allocations were calculated by multiplying each MS4's percent watershed coverage (determined in the GIS) by the total watershed loading capacity (determined by load duration curves) after the margin of safety (MOS) was subtracted.

Table 4-1. MS4 permittees in the Vermillion River turbidity impaired reach

MS4	
Name	**ID number**
Credit River Township MS4	MS400131
Dakota County MS4	MS400132
Elko New Market City MS4	MS400237
Empire Township MS4	MS400135
Farmington City MS4	MS400090
Lakeville City MS4	MS400099

4.1.2.3 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 Vermillion River watershed shows approximately 2.90% (1.45% construction stormwater and 1.45% industrial stormwater) of the watershed is under construction and industrial stormwater permit at any one time. Final allocations for construction and industrial stormwater were calculated by multiplying this percentage by the total watershed loading capacity.

4.1.3 Watershed Load Allocation Methodology

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

For the purposes of this study, outflow from Lake Marion (referred to as the Lake Marion Boundary Condition) was included as a separate line item in the LA. Located in the city of Lakeville, Lake Marion is a relatively large (530 acres) shallow lake that drains approximately 5,000 acres of land in Lakeville and Credit River Township. Outflow from Lake Marion enters South Creek and flows approximately six miles before discharging to the Vermillion River impaired reach near Farmington, Minnesota. Lake Marion is not currently impaired for aquatic recreation (nutrients) and is believed to be a natural sink for the TSS and therefore is not believed to contribute to elevated turbidity levels in South Creek or the main stem impaired reach. Allocations for the Lake Marion Boundary Condition were calculated by multiplying the lake watershed area to total impaired reach watershed ratio (determined in the GIS) by the total impaired reach watershed loading capacity (determined by load duration curves) after the MOS was subtracted. Since the watershed loading capacity for the impaired reach was established using the 10 mg/L TSS standard, this method assumes outflow from Lake Marion is allocated to the TSS standard. Maps showing landuse, the MS4 boundaries, and the Lake Marion Boundary Condition for the TSS impaired reach watershed are provided in Appendix A.

4.1.4 Margin of Safety

The MOS accounts for uncertainties in both characterizing current conditions and the relationship between the load, wasteload, monitored flows, and in-stream water quality to ensure the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5% of the total load was applied whereby 5% of the loading capacity for each flow regime was subtracted before allocations were made among the waste load and watershed load. Five percent was considered an appropriate MOS since the load duration curve approach minimizes a great deal of uncertainty associated with the development of TMDLs because the calculation of the loading capacity is the product of monitored flow and the TSS target concentration. Most of the uncertainty with this calculation is therefore associated with the flows in the impaired reach that were calculated based on monitored flows at VR1.3 (S003-326), which is a well-established continuous flow monitoring station with a long flow record.

4.1.5 Seasonal Variation

The TSS sampling results for each monitoring station was grouped by season and flow regime using flow and load duration curves (Appendix A). Analyzing the TSS by flow regime and season can help determine if the suspended solids are coming from algae, streambank erosion, urban runoff, or field erosion. The flow and load duration curves suggest there is no seasonal pattern to the TSS and the primary driver is flow condition. Exceedances are most common during higher flow conditions when watershed loading is high and velocities within the river are able to transport larger amounts of sediment. Any seasonal and annual variability in the TSS are accounted for by setting the TMDL across the entire observed flow record (2006-2012) using the load duration method.

4.1.6 TMDL Summary

Table 4-2 presents the total loading capacity, the MOS, the WLAs and the remaining watershed LAs for the Vermillion River turbidity impaired reach. Allocations for this TMDL were established using the 10 mg/L TSS standard for class 2A waters. All load capacities were rounded to two decimal points. The bottom line of the table shows the estimated load reduction for each flow zone. This reduction was calculated based on the difference between the 90th percentile monitored TSS concentration of each flow zone and the 10 mg/L proposed standard. At this time, there is not enough information or data available to estimate or calculate the existing (current conditions) load contribution from each of the WLA and LA sources presented in Table 4-2. Thus, the estimated load reduction for each flow zone applies to all sources. The Vermillion River WRAPS report will further investigate which sources and geographical locations within the impaired reach watershed should be targeted for turbidity/TSS BMPs and restoration activities.

Table 4-2. Vermillion River Reach 07040001-517 TSS TMDL and Allocations (based on the 10 mg/L TSS standard for class 2A waters).

		Flow Regime*				
		Very High	**High**	**Mid**	**Low**	**Very Low**
		TSS LA (lbs/day)				
Wasteload	**Total WLA**	**1,314.32**	**577.13**	**304.11**	**173.77**	**106.27**
	Credit River Township (MS400131)	*29.12*	*12.79*	*6.74*	*3.85*	*2.35*
	Dakota County ROW (MS400132)	*11.32*	*4.97*	*2.62*	*1.50*	*0.92*
	Elko New Market City (MS400237)	*167.93*	*73.74*	*38.86*	*22.20*	*13.58*
	Empire Township (MS400135)	*0.38*	*0.17*	*0.09*	*0.05*	*0.03*
	Farmington City (MS400090)	*208.96*	*91.76*	*48.35*	*27.63*	*16.90*
	Lakeville City (MS400099)	*754.64*	*331.36*	*174.60*	*99.77*	*61.01*
	Construction/ Industrial SW	*141.97*	*62.34*	*32.85*	*18.77*	*11.48*
Load	**Total LA**	**3,336.52**	**1,465.08**	**771.99**	**441.14**	**269.77**
	Lake Marion Boundary Condition	*592.07*	*259.98*	*136.99*	*78.28*	*47.87*
	Watershed LA	*2,744.45*	*1,205.10*	*635.00*	*362.86*	*221.90*
MOS		**244.78**	**107.48**	**56.64**	**32.36**	**19.79**
TOTAL LOAD (TMDL)		**4,895.62**	**2,149.69**	**1,132.74**	**647.27**	**395.83**
Existing Load (90th Percentile of observed data)		9,724.35	3,417.15	1,159.57	638.99	321.44
Estimated Load Reduction (%)		50%	9%	0%	0%	0%

* Flow data collected at station S003-326 was used to develop the flow regimes and loading capacities for this reach.

4.2 *E. coli*

The data used for the development of the bacteria TMDLs are grab samples collected by Dakota County SWCD between 2004 and 2013; however, two reaches only had data collected between 1999 and 2000 (07040001-668 and 07040001-706). Samples were analyzed for fecal coliform prior to 2007, and more recently *E. coli*. All fecal coliform data was converted to *E. coli* "equivalents" using the equation outlined in Section 2. Appendix B includes figures showing all impaired reach monitoring stations where bacteria data was collected to support this TMDL study.

Stream flow data was crucial to support development of the TMDL. Streamflow data paired with *E. coli* measurements allow exceedances to be evaluated by flow regime which, in turn, provide insight into potential sources. Stream flow was available within each reach or at a nearby downstream monitoring station. If a monitoring site was not positioned at the downstream end of the reach, stream flow records were multiplied by the percentage of total watershed area.

4.2.1 Loading Capacity Methodology

E. coli loading capacity for each reach was developed from load duration curves. Load duration curves incorporate flow and *E. coli* data across stream flow regimes. 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 load to create a "continuous" load duration curve. Flow data from various flow monitoring stations and years were used to construct the load duration curves for the 12 bacteria impaired reaches. For the purposes of this TMDL, the implementation baseline year for each impaired reach will be the mid-range year of the flow record used to construct the load duration curve (See Table 8-1 in section 8.2.1).

An example *E. coli* load duration curve for the South Creek impaired reach (07040001-527) is shown in Figure 4.3. On this figure the red curve represents the loading capacity of the stream for each daily flow. The loading capacity was divided into flow zones and the median (or midpoint) load of each flow zone was used in the TMDL equation (Table 4-5 through Table 4-16). The loading capacity can also be compared to current conditions by plotting the measured load for each water quality sampling event (black 'x's in Table 4-3). Each value that is above the curve represents an exceedance of the water quality standard while those below the line are below the water quality standard. Also plotted are the monitored *E. coli* geometric mean concentrations for each flow zone (solid green circles). The difference between the loading capacity line and monitored geometric means provide a general percent reduction in *E. coli* that will be needed to remove South Creek from the impaired waters list. The data shows *E. coli* reductions in the South Creek impaired reach should focus on the very high flow conditions. Appendix B presents *E. coli* load duration curves, observed *E. coli* loads, and required load reductions for the 12 bacteria impaired reaches in the Vermillion River Watershed.

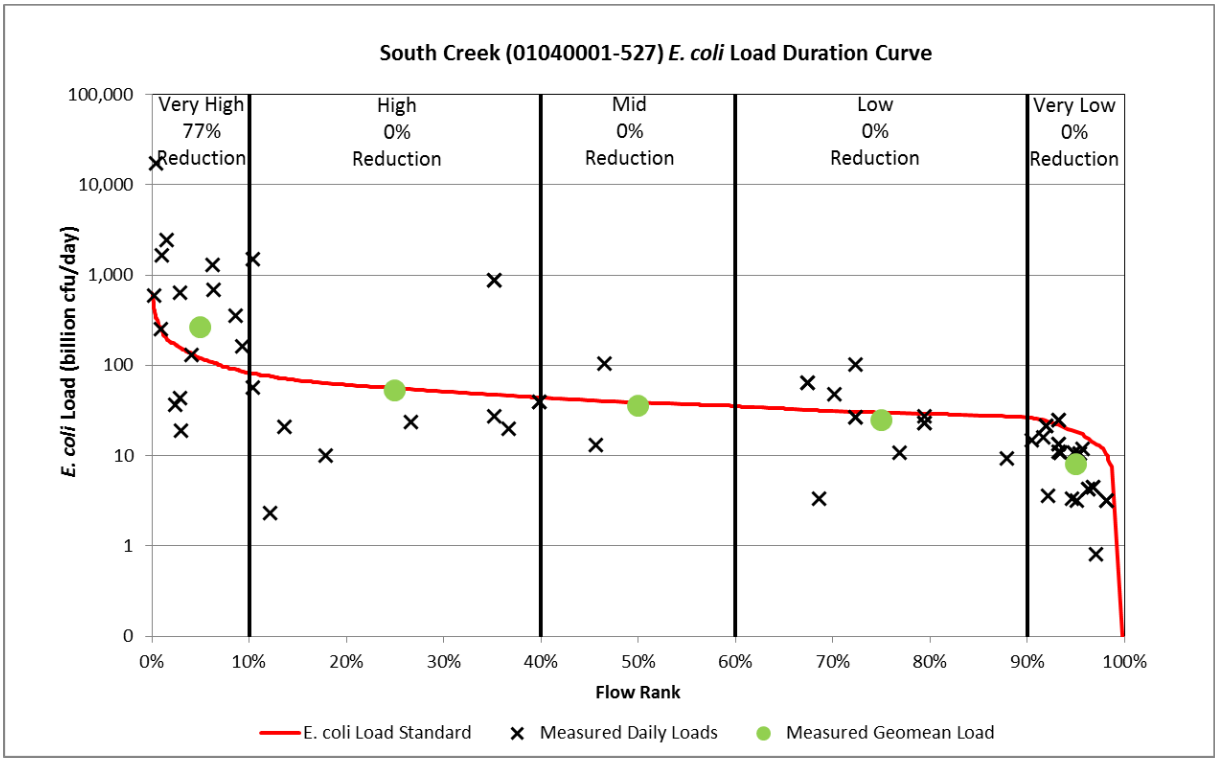

Figure 4.3. Bacteria monitored loads, load standard and load reductions for South Creek reach 07040001-527.

4.2.2 Wasteload Allocation Methodology

The WLAs for bacteria TMDLs are typically divided into three categories: permitted point source dischargers, permitted MS4s, and construction and industrial storm water. The following sections describe how each of these LAs was estimated. The WLAs for regulated construction stormwater (permit #MNR100001) were not developed, since *E. coli* is not a typical pollutant from construction sites. The WLAs for regulated industrial stormwater were also not developed. Industrial stormwater must receive a WLA only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired water body. There are no bacteria or *E. coli* benchmarks associated with any of the industrial stormwater permits (permit #MNR050000).

4.2.2.1 NPDES Point Source Dischargers

There is one active permitted NPDES point source discharger, Hampton WWTF (Facility), which discharges to the South Branch Vermillion River (Figure 1.1, Table 4-3). This Facility maintains a controlled discharge from a stabilization pond to an unnamed ditch which eventually leads to South Branch Vermillion River impaired reach 707. The Facility's maximum permitted flow rate was calculated by multiplying the stabilization pond's surface area, volume and average daily drawdown (typically 6 inches per day) during discharge. WLAs for this Facility were calculated by multiplying the maximum permitted flow rate by the E. coli standard (126 cfu/100 mL).

Discharge Monitoring Reports (DMRs) were downloaded to assess typical bacteria of the facility's effluent water (Appendix B). 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 WWTF (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 Facility's DMR records show this facility is currently meeting its effluent permit limits and state water quality standards for bacteria. Thus, no bacteria reductions or changes are needed as long as the Facility continues to employ its current treatment technologies to control bacteria in its effluent waters.

Table 4-3. Description of the NPDES Point Source discharger and *E. coli* allocations

Description	Hampton WWTF
Receiving water	Unnamed ditch to South Branch Vermillion River
Location	Hampton, Minnesota
NPDES ID#	MN0021946
Facility Type	Pond
Maximum permitted flow rate	0.407 mgd
E. coli allocated load	1.94 billion organisms/day
Average *E. coli concentration*	76 cfu / 100 mL (Fecal Coliform) 59 mpn / 100 mL (*E. coli*)

4.2.2.2 Permitted MS4s

Many of the bacteria impaired reaches partially cover, or are completely contained within one or several urban MS4 boundaries. As discussed in Section 3.6.2, bacteria in urban runoff may come from a variety of sources such as pet wastes, wildlife, golf courses and city stormwater ponds. There are seven MS4s that are completely within or have a portion of their municipal boundary in the impaired reach watersheds (Table 4-4). The MPCA defined and supplied the MS4 boundaries for Credit River Township, Elko New Market, Empire Township, Farmington and Lakeville. At this time, it is expected that most of the land within the city and township MS4 boundaries that is currently undeveloped will undergo development within the next 10-15 years. Thus, for this TMDL study all city and township MS4s were allocated at the full extent of their jurisdictional boundary. The only Minnesota Department of Transportation (MnDOT) and Dakota County land subject to the MS4 allocations is right of way within the 2010 urban defined area. The MnDOT supplied the GIS coverage files for all MnDOT right of way in the 2010 urban defined area. Dakota County's MS4 boundary was defined by applying a 60 foot buffer to all Dakota County roadways in the impaired reach watersheds and the 2010 urban defined area. Maps showing final MS4 coverage in each impaired reach watershed are included in Appendix B. Individual MS4 allocations were calculated by multiplying each MS4's percent watershed coverage (determined in the GIS) by the total watershed loading capacity (determined by load duration curves) after the MOS and the NPDES Point Source dischargers were subtracted.

Table 4-4. Permitted MS4s in the bacteria impaired reach watersheds

Trib/Study Area	Reach	MS400131 Credit River Township	MS400132 Dakota County	MS400237 Elko New Market City	MS400135 Empire Township	MS400090 Farmington City	MS400099 Lakeville City	MS400170 MnDOT
North Creek	545	No	Yes	No	Yes	Yes	Yes	Yes
	671	No	Yes	No	Yes	Yes	Yes	Yes
	670	No	Yes	No	Yes	Yes	Yes	No
	542	No	Yes	No	Yes	Yes	Yes	No
Middle Creek	668	No	Yes	No	No	Yes	Yes	No
	546	No	Yes	No	No	Yes	Yes	No
	548	No	No	No	No	Yes	Yes	No
South Creek	527	No	Yes	No	No	Yes	Yes	No
Vermillion River	516	Yes	No	Yes	No	No	Yes	No
	517	Yes	Yes	Yes	Yes	Yes	Yes	No
S. Branch Vermillion	706	No	No	No	No	Yes	No	No
	707	No	No	No	Yes	Yes	No	No

4.2.3 Watershed Load Allocation Methodology

The LA also referred to as the watershed LA, is the remaining load after the MOS and WLAs are subtracted from the total load capacity of each flow zone. The watershed LA includes all non-permitted sources such as outflow from lakes and wetlands in the watershed and runoff from agricultural land, forested land, and non-regulated MS4 residential areas. For this TMDL, the watershed LAs are primarily comprised of agricultural land outside the MS4 boundaries.

The LAs also include two upstream lake boundary conditions: Lake Marion in the South Creek and Vermillion River impaired reach watersheds, and East Lake in the North Creek impaired reach watershed. Outflow from East Lake and Lake Marion were included as separate line items in the LA for North Creek, South Creek, and the main stem Vermillion River. East Lake is a small, shallow lake located in the city of Lakeville that drains approximately 11,579 acres of land across six separate municipalities and townships: Burnsville, Eagan, Apple Valley, Lakeville, Rosemount, and Empire Township. Lake Marion is a relatively large (530 acres) shallow lake that drains approximately 5,000 acres of land in Lakeville and Credit River Township. Both Lakes are believed to be natural sinks of bacteria and therefore do not contribute to elevated bacteria levels in North Creek, South Creek and the main stem Vermillion River. *E. coli* allocations for East Lake and Lake Marion boundary conditions were calculated by multiplying each lake's watershed area to total impaired reach watershed ratio (determined in the

GIS) by the total impaired reach watershed loading capacity (determined by load duration curves) after the MOS was subtracted. Since watershed loading capacities for each impaired reach were established using the 126 cfu/100ml *E. coli* standard, the TMDL allocations assume outflow from each lake is allocated to the *E. coli* standard. Maps showing landuse, the MS4 boundaries, and lake boundary conditions in each *E. coli* impaired reach watershed are provided in Appendix B.

4.2.4 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 to ensure the TMDL allocations result in attainment of water quality standards. An explicit MOS equal to 5% of the total load was applied whereby 5% of the loading capacity for each flow regime was subtracted before allocations were made among the waste load and watershed load. Five percent was considered an appropriate MOS since the load duration curve approach minimizes a great deal of uncertainty associated with the development of TMDLs because the calculation of the loading capacity is the product of monitored flow and the target *E. coli* concentration. Most of the uncertainty with this calculation is associated with the flows in each impaired reach which were calculated using monitored flows at stations in or near each impaired reach that have a well-established, long term flow record.

4.2.5 Seasonal Variation

Geometric means for *E. coli* bacteria within the impaired reaches are often above the state chronic standard from April through October. Exceedances of the acute standard are also common in several reaches during this time period. 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 warmer summer months when stream flow is low and water temperatures are high. High *E. coli* concentrations in most of the reaches continue into the fall, which may be attributed to constant sources of *E. coli* (such as animal access to the stream) and less flow for dilution. However, this data may be skewed as more samples were collected in the summer months than in October. Seasonal and annual variations are accounted for by setting the TMDL across the entire observed flow record using the load duration method.

4.2.6 TMDL Summary

Table 4-5 through Table 4-16 present the existing load, the total loading capacity, MOS, WLA, and LA for each Vermillion River bacteria impaired reach. Allocations for these TMDLs were established using the 126 cfu/100 ml *E. coli* standard. All LAs are reported in billions of organisms/day and were rounded to two to five significant figures to prevent zero load values. The bottom line of the table shows the estimated load reduction for each flow zone. This reduction was calculated based on the difference between the monitored geometric mean *E. coli* concentration of each flow zone and the 126 cfu/100 ml standard. At this time, there is not enough information or data available to estimate or calculate the existing (current conditions) load contribution from each of the WLA and LA sources presented in Tables 4-5 through 4-16. Thus, the estimated load reduction for each flow zone applies to all sources. The

Vermillion River WRAPS report will further investigate which sources and geographical locations within the impaired reach watershed should be targeted for bacteria BMPs and restoration strategies.

4.2.6.1 North Creek

The headwaters of North Creek begin in Lakeville (reach 542) and flow to the southeast through Farmington and Empire Township before discharging to the Vermillion River. The four impaired reaches in the North Creek watershed are situated upstream to downstream in the following order: 542, 670, 671, and 545. Appendix B contains maps showing the location of each impaired reach and the MS4 boundaries within the North Creek watershed. Reach 545 begins at the confluence of North Creek and Middle Creek and therefore encompasses both major subwatersheds. TMDL allocations for all North Creek impaired reaches include the entire watershed draining to each impaired reach. For example, allocations for reach 671 includes the small watershed draining directly to reach 671, as well as the watersheds for reaches 670, 542, and the non-impaired reach between 670 and 542. The East Lake boundary condition is also included in the allocations for all North Creek *E. coli* impaired reaches. This boundary condition is included as a separate line item in the LA portion of the TMDL table and therefore does not contain the WLAs for the MS4s in the East lake watershed. Tables 4-5 through 4-8 contain the TMDL allocations for each impaired reach in the North Creek watershed, organized upstream to downstream.

Table 4-5. North Creek Reach 07040001-542 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**34.748**	**14.105**	**7.508**	**4.362**	**2.424**
	Dakota County ROW	*0.475*	*0.193*	*0.103*	*0.060*	*0.033*
	Empire Township MS4	*0.008*	*0.003*	*0.002*	*0.001*	*0.001*
	Farmington City MS4	*0.026*	*0.011*	*0.006*	*0.003*	*0.002*
	Lakeville City MS4	*34.239*	*13.898*	*7.397*	*4.298*	*2.388*
Load	**Total LA**	**85.370**	**34.653**	**18.443**	**10.717**	**5.954**
	East Lake Boundary Condition	*85.370*	*34.653*	*18.443*	*10.717*	*5.954*
MOS		**6.322**	**2.566**	**1.366**	**0.794**	**0.441**
TOTAL LOAD (TMDL)		**126.440**	**51.324**	**27.317**	**15.873**	**8.819**
Existing Load (geomean of observed data)		233.535	249.298	223.973	204.913	93.265
Estimated Reduction (%)		46%	79%	88%	92%	91%

* Flow data collected at station S003-324 was used to develop the flow regimes and loading capacities for this reach

Table 4-6. North Creek Reach 07040001-670 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**54.61**	**22.17**	**11.80**	**6.85**	**3.82**
	Dakota County ROW	*0.65*	*0.26*	*0.14*	*0.08*	*0.05*
	Empire Township MS4	*3.83*	*1.56*	*0.83*	*0.48*	*0.27*
	Farmington City MS4	*15.72*	*6.38*	*3.40*	*1.97*	*1.10*
	Lakeville City MS4	*34.41*	*13.97*	*7.43*	*4.32*	*2.40*
Load	**Total LA**	**85.37**	**34.65**	**18.44**	**10.72**	**5.95**
	East Lake Boundary Condition	*85.37*	*34.65*	*18.44*	*10.72*	*5.95*
MOS		**7.37**	**2.99**	**1.59**	**0.92**	**0.51**
TOTAL LOAD (TMDL)		**147.35**	**59.81**	**31.83**	**18.49**	**10.28**
Existing Load (geomean of observed data)		249.39	37.61	44.16	20.55	20.85
Estimated Reduction (%)		41%	0%	28%	10%	51%

* Flow data collected at station S003-324 was used to develop the flow regimes and loading capacities for this reach.

Table 4-7. North Creek Reach 07040001-671 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**55.11727**	**22.37293**	**11.90714**	**6.91913**	**3.84387**
	Dakota County ROW	*0.65206*	*0.26468*	*0.14087*	*0.08186*	*0.04547*
	Empire Township MS4	*4.33621*	*1.76013*	*0.93676*	*0.54434*	*0.30241*
	Farmington City MS4	*15.71915*	*6.38065*	*3.39584*	*1.97330*	*1.09625*
	MnDOT ROW	*0.00030*	*0.00010*	*0.00010*	*0.00004*	*0.00002*
	Lakeville City MS4	*34.40955*	*13.96737*	*7.43357*	*4.31959*	*2.39972*
Load	**Total LA**	**85.36985**	**34.65295**	**18.44264**	**10.71687**	**5.95370**
	East Lake Boundary Condition	*85.36985*	*34.65295*	*18.44264*	*10.71687*	*5.95370*
MOS		**7.39406**	**3.00136**	**1.59735**	**0.92821**	**0.51566**
TOTAL LOAD (TMDL)		**147.88118**	**60.02724**	**31.94713**	**18.56421**	**10.31323**
Existing Load (geomean of observed data)		334.32947	46.41015	33.20037	21.10593	23.33999
Estimated Reduction (%)		56%	0%	4%	12%	56%

* Flow data collected at station S003-324 was used to develop the flow regimes and loading capacities for this reach

Table 4-8. North Creek Reach 07040001-545 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**159.349**	**51.452**	**26.876**	**14.382**	**6.283**
	Dakota County ROW	*1.592*	*0.514*	*0.269*	*0.144*	*0.063*
	Empire Township MS4	*9.536*	*3.079*	*1.608*	*0.861*	*0.376*
	Farmington City MS4	*65.438*	*21.129*	*11.037*	*5.906*	*2.580*
	MnDOT ROW	*0.079*	*0.026*	*0.013*	*0.007*	*0.003*
	Lakeville City MS4	*82.704*	*26.704*	*13.949*	*7.464*	*3.261*
Load	**Total LA**	**85.370**	**34.653**	**18.443**	**10.717**	**5.954**
	East Lake Boundary Condition	*85.370*	*34.653*	*18.443*	*10.717*	*5.954*
MOS		**12.880**	**4.532**	**2.385**	**1.321**	**0.644**
TOTAL LOAD (TMDL)		**257.599**	**90.637**	**47.704**	**26.420**	**12.881**
Existing Load (geomean of observed data)		673.988	121.861	78.280	27.057	25.377
Estimated Reduction (%)		62%	26%	39%	2%	49%

* Flow data collected at station S003-323 was used to develop the flow regimes and loading capacities for this reach.

4.2.6.2 Middle Creek

The headwaters of Middle Creek begin in Lakeville (reach 546) and flow to the southeast through Farmington and Empire Township before discharging to North Creek near Chippendale Ave. The three impaired reaches in the Middle Creek watershed are situated upstream to downstream in the following order: 546, 548, and 668. Appendix B contains maps showing the location of each impaired reach and the MS4 boundaries within the Middle Creek watershed. TMDL allocations for all Middle Creek impaired reaches include the entire watershed draining to each impaired reach. For example, allocations for reach 668 includes the small watershed draining directly to reach 668, as well as the watersheds for reaches 548, 546, and the non-impaired reaches between and upstream of 548 and 546. Tables 4-9 through 4-11 contain the TMDL allocations for each *E. coli* impaired reach in the Middle Creek watershed, organized upstream to downstream.

Table 4-9. Middle Creek Reach 07040001-546 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**37.12**	**10.11**	**4.17**	**2.04**	**0.73**
	Dakota County ROW	*0.58*	*0.16*	*0.06*	*0.03*	*0.01*
	Farmington City MS4	*11.13*	*3.03*	*1.25*	*0.61*	*0.22*
	Lakeville City MS4	*25.41*	*6.92*	*2.86*	*1.40*	*0.50*
Load	**Total LA**	--	--	--	--	--
MOS		**1.95**	**0.53**	**0.22**	**0.11**	**0.04**
TOTAL LOAD (TMDL)		**39.07**	**10.64**	**4.39**	**2.15**	**0.77**
Existing Load (geomean of observed data)		--**	46.46	23.81	26.19	13.17
Estimated Reduction (%)		--**	77%	82%	92%	94%

* Flow data collected at stations S003-323 and S003-324 were used to develop the flow regimes and loading capacities for this reach

**Insufficient field data available for load reduction calculation

Table 4-10. Middle Creek Reach 07040001-548 E. coli TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**23.06**	**6.28**	**2.59**	**1.27**	**0.46**
	Farmington City MS4	**4.37**	**1.19**	**0.49**	**0.24**	**0.09**
	Lakeville City MS4	**18.69**	**5.09**	**2.10**	**1.03**	**0.37**
Load	**Total LA**	--	--	--	--	--
MOS		**1.21**	**0.33**	**0.14**	**0.07**	**0.02**
TOTAL LOAD (TMDL)		**24.27**	**6.61**	**2.73**	**1.34**	**0.48**
Existing Load (geomean of observed data)		**--****	**10.58**	**7.69**	**6.79**	**2.95**
Estimated Reduction (%)		**--****	**38%**	**65%**	**80%**	**84%**

* Flow data collected at stations S003-323 and S003-324 were used to develop the flow regimes and loading capacities for this reach

**Insufficient field data available for load reduction calculation

Table 4-11. Middle Creek Reach 07040001-668 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**92.07**	**29.65**	**15.06**	**6.41**	**1.97**
	Dakota County ROW	*0.57*	*0.18*	*0.09*	*0.04*	*0.01*
	Farmington City MS4	*85.92*	*27.67*	*14.06*	*5.98*	*1.84*
	Lakeville City MS4	*5.58*	*1.80*	*0.91*	*0.39*	*0.12*
Load	**Total LA**	**--**	**--**	**--**	**--**	**--**
MOS		**4.85**	**1.56**	**0.79**	**0.34**	**0.10**
TOTAL LOAD (TMDL)		**96.92**	**31.21**	**15.85**	**6.75**	**2.07**
Existing Load (geomean of observed data)		--**	46.43	110.32	--**	--**
Estimated Reduction (%)		--**	33%	86%	--**	--**

* Flow data collected at stations S003-324 and S003-323 were used to develop the flow regimes and loading capacities for this reach

**Insufficient field data available for load reduction calculation

4.2.6.3 South Creek

The headwaters of South Creek begin in Lakeville at the outlet of Lake Marion and flow to the east through Farmington before discharging to the Vermillion River. Reach 527 is the only *E. coli* impaired reach in the South Creek watershed. Appendix B contains maps showing the location of the impaired reach and the MS4 boundaries within the South Creek watershed. TMDL allocations for South Creek reach 527 include the entire watershed draining to the impaired reach, including the Lake Marion Boundary condition. The Lake Marion boundary condition is included as a separate line item in the LA portion of the TMDL table and therefore does not contain the WLAs for the MS4s in the Lake Marion watershed.

Table 4-12. South Creek Reach 07040001-527 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**63.06**	**29.57**	**20.46**	**15.76**	**9.83**
	Dakota County ROW	*0.61*	*0.29*	*0.20*	*0.15*	*0.09*
	Farmington City MS4	*9.44*	*4.43*	*3.06*	*2.36*	*1.47*
	Lakeville City MS4	*53.01*	*24.85*	*17.20*	*13.25*	*8.27*
Load	**Total LA**	**59.83**	**28.05**	**19.41**	**14.96**	**9.33**
	Watershed LA	*17.75*	*8.32*	*5.76*	*4.44*	*2.77*
	Lake Marion Boundary Condition	*42.08*	*19.73*	*13.65*	*10.52*	*6.56*
MOS		**6.47**	**3.03**	**2.10**	**1.62**	**1.01**
TOTAL LOAD		**129.36**	**60.65**	**41.97**	**32.34**	**20.17**
Existing Load (geomean of observed data)		567.92	53.24	35.91	25.01	8.02
Estimated Reduction (%)		77%	0%	0%	0%	0%

* Flow data collected at station S005-444 was used to develop the flow regimes and loading capacities for this reach

4.2.6.4 Vermillion River

The headwaters of the Upper Vermillion River begin near Elko New Market (reach 516) and flow to the northeast toward Farmington (Reach 517). Appendix B contains maps showing the location of the two *E. coli* impaired reaches and the MS4 boundaries within the Upper Vermillion River watershed. TMDL allocations for both Vermillion River impaired reaches include the entire watershed draining to each impaired reach. For example, allocations for reach 517 includes the watershed draining directly to reach 517, as well as the watershed for reach 516 and 527 (South Creek), and the Lake Marion Boundary Condition. Tables 4-13 through 4-14 contain the TMDL allocations for both *E. coli* impaired reaches, organized upstream to downstream.

Table 4-13. Vermillion River Reach 07040001-516 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**18.60**	**6.21**	**3.04**	**1.67**	**0.86**
	Credit River Township MS4	*2.63*	*0.88*	*0.43*	*0.24*	*0.12*
	Elko New Market City MS4	*15.17*	*5.06*	*2.48*	*1.36*	*0.70*
	Lakeville City MS4	*0.80*	*0.27*	*0.13*	*0.07*	*0.04*
Load	**Total LA**	**115.89**	**38.63**	**18.91**	**10.36**	**5.35**
	Watershed LA	*115.89*	*38.63*	*18.91*	*10.36*	*5.35*
MOS		**7.08**	**2.36**	**1.16**	**0.63**	**0.33**
TOTAL LOAD (TMDL)		**141.57**	**47.20**	**23.11**	**12.66**	**6.54**
Existing Load (geomean of observed data)		486.73	60.83	24.27	33.32	32.70
Estimated Reduction (%)		71%	22%	5%	62%	80%

* Flow data collected at station S003-325 was used to develop the flow regimes and loading capacities for this reach

Table 4-14. Vermillion Reach 07040001-517 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**100.527**	**42.427**	**21.487**	**12.714**	**8.363**
	Credit River Township MS4	*2.497*	*1.054*	*0.534*	*0.316*	*0.208*
	Dakota County ROW	*0.970*	*0.410*	*0.207*	*0.123*	*0.081*
	Elko New Market City MS4	*14.400*	*6.077*	*3.078*	*1.821*	*1.198*
	Empire Township MS4	*0.033*	*0.014*	*0.007*	*0.004*	*0.003*
	Farmington City MS4	*17.918*	*7.562*	*3.830*	*2.266*	*1.490*
	Lakeville City MS4	*64.709*	*27.310*	*13.831*	*8.184*	*5.383*
Load	**Total LA**	**291.978**	**123.228**	**62.410**	**36.928**	**24.287**
	Lake Marion Boundary Condition	*50.769*	*21.427*	*10.852*	*6.421*	*4.223*
	Watershed LA	*241.209*	*101.801*	*51.558*	*30.507*	*20.064*
MOS		**20.990**	**8.859**	**4.487**	**2.655**	**1.746**
TOTAL LOAD (TMDL)		**413.495**	**174.514**	**88.384**	**52.297**	**34.396**
Existing Load (geomean of observed data)		1527.61	265.96	212.78	117.46	119.87
Estimated Reduction (%)		73%	34%	58%	55%	71%

* Flow data collected at station S003-326 was used to develop the flow regimes and loading capacities for this reach

4.2.6.5 South Branch Vermillion River

The headwaters of the South Branch Vermillion River begin in Eureka Township (reach 706) and flows to the northeast before discharging to the Vermillion River near 200th St E. Appendix B contains maps showing the location of the two *E. coli* impaired reaches and the MS4 boundaries within the South Branch Vermillion River watershed. The TMDL allocations for the South Branch Vermillion River impaired reaches include the entire watershed draining to each impaired reach. For example, allocations for reach 707 includes the watershed draining directly to reach 707, as well as the watershed for reach 706. Tables 4-15 through 4-16 contain the TMDL allocations for both *E. coli* impaired reaches, organized upstream to downstream.

Table 4-15. South Branch Vermillion River Reach 07040001-706 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**0.48**	**0.20**	**0.10**	**0.04**	**0.01**
	Farmington City	*0.48*	*0.20*	*0.10*	*0.04*	*0.01*
Load	**Total LA**	**131.24**	**54.65**	**27.42**	**12.06**	**2.51**
	Watershed LA	*131.24*	*54.65*	*27.42*	*12.06*	*2.51*
MOS		**6.93**	**2.89**	**1.45**	**0.64**	**0.13**
TOTAL LOAD (TMDL)		**138.65**	**57.74**	**28.97**	**12.74**	**2.65**
Existing Load (geomean of observed data)		--**	113.87	40.08	--**	--**
Estimated Reduction (%)		--**	49%	28%	--**	--**

* Flow data collected at station S002-421 was used to develop the flow regimes and loading capacities for this reach
**Insufficient field data available for load reduction calculation

Table 4-16. South Branch Vermillion River Reach 07040001-707 *E. coli* TMDL and Allocations

		Flow Regime*				
		Very High	High	Mid	Low	Very Low
		E. coli in billions of organisms/day				
Wasteload	**Total WLA**	**18.48**	**8.75**	**5.74**	**4.21**	**2.12**
	Empire Township MS4	15.94	6.56	3.66	2.19	0.17
	Farmington City MS4	0.60	0.25	0.14	0.08	0.01
	Hampton WWTF	1.94	1.94	1.94	1.94	1.94
Load	**Total LA**	**199.04**	**81.89**	**45.66**	**27.33**	**2.06**
	Watershed LA	199.04	81.89	45.66	27.33	2.06
MOS		**11.45**	**4.77**	**2.70**	**1.66**	**0.22**
TOTAL LOAD (TMDL)		**228.97**	**95.41**	**54.10**	**33.20**	**4.40**
Existing Load (geomean of observed data)		506.47	124.72	84.33	73.12	--**
Estimated Reduction (%)		55%	24%	36%	55%	--**

* Flow data collected at station S002-421 was used to develop the flow regimes and loading capacities for this reach
**Insufficient field data available for load reduction calculation

4.3 Nutrients

4.3.1 Loading Capacity Methodology

The first step in developing excess nutrient TMDLs for lakes is to determine the total nutrient loading capacity for the lake. A key component for this determination is to estimate each source's current phosphorus loading for the lake. Next, lake response to phosphorus loading was modeled using the Canfield-Bachman lake equation for each impaired lake and the final loading capacity was determined. The components of this process are described below.

4.3.1.1 Watershed Loading

Watershed water and nutrient loading was estimated using a PONDNET (Walker 1989). PONDNET is a spreadsheet model that routes flow and the TP through networks of wet detention ponds. Watershed runoff is estimated using land use-based runoff coefficients and the TP load is predicted using land use specific runoff concentrations (event mean concentration). The TP removal in upstream ponds and waterbodies is predicted using an empirical TP retention function. The city of Apple Valley developed a PONDNET model as a part of its nondegradation loading assessment (Bonestroo 2007) to comply with MPCA's MS4 General Permit. The PONDNET model was extended to include areas in the Alimagnet and East Lake watersheds that are outside the city of Apple Valley. The model was then updated with the most current land use and watershed data to predict water yields and the TP loading to each lake. The model was setup to predict water yields and the TP loading on an annual time-step over a 14-year simulation period (2000-2013).

The PONDNET model was validated using storm sewer flows through lift stations and pond water quality data, where available. Model runoff coefficients were systematically adjusted to provide the best fit possible for runoff volumes at seven lift stations within the city of Apple Valley. Average modeled discharge at the seven lift stations was within 6% of the recorded discharge (Appendix C). Model TP runoff coefficients were also adjusted globally within the range of published values (Reckhow et al. 1980; MPCA 2008) to provide the best possible fit for pond TP concentrations at five monitored stormwater ponds throughout the watershed (Appendix C). Monitored flow and pond water quality data were used over modeled values for all years with a sufficient amount of monitoring data.

Once all adjustments were incorporated into PONDNET, water yields and phosphorus balances were developed for each lake including loads from major subwatersheds (Appendix C). These water and nutrient loads are directly input into the Canfield-Bachman Model for lake response analysis.

4.3.1.2 Upstream Lakes

East Lake has two upstream lakes, Alimagnet and Cobblestone, accounted for in this TMDL study. Loading contributions from these lakes were estimated by combining available water quality data with lift station data or PONDNET modeled outflow from the outlet of each lake. The TMDL for East Lake assumes water quality improvements will be made in all upstream lakes that do not currently meet state water quality standards.

4.3.1.3 Atmospheric Deposition

The atmospheric load refers to the load applied directly to the surface of the lake through atmospheric deposition. Atmospheric inputs of phosphorus from wet and dry deposition were estimated using published rates based on annual precipitation (Barr Engineering 2004). The atmospheric deposition values used for dry (< 25 inches), average, and wet precipitation years (>38 inches) are 24.9, 26.8, and 29.0 kg/km^2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds/acre/year for dry, average, and wet years, respectively.

4.3.1.4 Internal Loading

Internal phosphorus loading from lake sediments can be a major component of a lake's phosphorus budget. 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 occurs even when the overlying water column is well oxygenated. For Alimagnet Lake, temperature and DO profiles were used when available to determine the volume of 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.

No temperature or DO profiles were collected in Alimagnet Lake prior to 2010. Average annual anoxic factors for years when temperature and DO profiles were collected (2010-2013) were used to represent the anoxic factors in the unmonitored years (2008 and 2009). No temperature or DO profiles have ever been collected in East Lake. The following equation was used to estimate the anoxic factor for East Lake (Nürnberg 2005):

$$AFshallow = -354 + 44.2 \log (TP) + 0.95\ z/A^{0.5}$$

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). This equation is often used for shallow lakes as they tend to demonstrate short periods of anoxia due to instability of stratification. This instability can last a few days or even a few hours, and are often missed by periodic field measurements.

To calculate the total internal load for a lake, the anoxic factor (days) is multiplied by an estimated or measured phosphorus release rate (RR) ($mg/m^2/day$). The RR were 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 (University of Wisconsin – Stout 2014; Appendix C). As discussed in Section 3.6.3, the presence of carp and some aquatic plants can also affect lake ecosystems by changing the dynamics of internal phosphorus loading. However, not enough data is available to quantify carp and aquatic vegetation's impact on internal load in the lakes addressed in this TMDL study.

4.3.1.5 Canfield-Bachman Lake Response Model

Once the nutrient budget for a lake has been developed, the response of the lake to those nutrient loads must be established. Lake response was modeled using the Canfield-Bachman lake equation (Canfield and Bachman 1981). This equation 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. If necessary, the model parameters are adjusted appropriately to achieve an approximate match to monitored data. Once a model is 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, the nutrient inputs partitioned between sources in the lake response models were systematically reduced until the model predicted that each lake met their current TP standard of 60 µg/L for Alimagnet Lake and 90 µg/L for East Lake. Construction, calibration, and results of the Canfield-Bachman lake response model are presented in Appendix C.

Since atmospheric load is extremely difficult to control, no reduction in this source is assumed for the TMDLs. Any upstream lakes are assumed to meet water quality standards, and the resultant reductions are applied to the lake being evaluated. If 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, phosphorus export rates from certain subwatersheds are already so low that large reductions would be infeasible.

The general approach to internal load reductions is based on review of the existing sediment RR and the lake morphometry. This is accomplished by reviewing the RR versus literature values of healthy lakes. If the RRs 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.

4.3.2 Load Allocation Methodology

Table 3-8 in Section 3.6.3 summarizes the potential non-permitted nutrient sources in the East Lake and Alimagnet Lake watersheds. There are no non-regulated watershed sources of phosphorus to Alimganet Lake and East Lake since 100% of their watershed boundaries are covered by permitted MS4s. Also, there are no SSTSs in the watershed since all wastewater is treated by local municipal facilities. Thus for the East Lake and Alimagnet Lake TMDLs, the LA will include atmospheric deposition, discharge from upstream lakes, and internal loading.

4.3.3 Waste Load Allocation Methodology

The WLA is required to include all permitted sources such as construction and industrial stormwater, MS4 regulated stormwater and permitted point source discharges. Table 3-7 in Section 3.6.3 is a complete summary of potential permitted sources for lakes. The following sections describe how each permitted source was calculated for the Alimagnet Lake and East Lake TMDLs.

4.3.3.1 Construction and Industrial Stormwater

Construction and industrial stormwater WLAs were established based on estimated percentage of land in the watershed that is currently under construction or permitted for industrial use. A recent permit review across the Vermillion River watershed shows approximately 2.90% (1.45% construction stormwater and 1.45% industrial stormwater) of the watershed is under construction and industrial stormwater permit at any one time. Final allocations for construction and industrial stormwater were calculated by multiplying this percentage by the total watershed loading capacity. Once construction and industrial stormwater were calculated, the remaining watershed load for Alimagnet Lake and East Lake was distributed among the permitted MS4s in each watershed.

4.3.3.2 Permitted MS4s

There are four (Alimagnet Lake) and seven (East Lake) regulated MS4s that have a portion of their boundary in the Alimagnet and East Lake watersheds, respectively (Table 4-17). These MS4 communities were assigned the WLAs by multiplying the percent area of each MS4 by the total annual watershed phosphorus load to each lake. The MS4 percentages were calculated individually for each lake's major subwatershed, and then consolidated for presentation in the final allocation tables in Section 4.3.6. Figures depicting the MS4 permittee jurisdiction and major subwatersheds for each lakeshed are included in Appendix C.

Table 4-17. Permitted MS4s in each lakeshed.

MS4		Alimagnet Lake	East Lake
Name	ID number		
Apple Valley City MS4	MS400074	Yes	Yes
Burnsville City MS4	MS400076	Yes	--
Dakota County MS4	MS400132	Yes	Yes
Eagan City MS4	MS400014	--	Yes
Empire Township MS4	MS400135	--	Yes
Lakeville City MS4	MS400099	--	Yes
MnDOT Metro District MS4	MS400170	Yes	Yes
Rosemount City MS4	MS400117	--	Yes

4.3.3.3 NPDES Point Source Dischargers

There are no NPDES permitted point source dischargers in the Alimagnet and East Lake watersheds.

4.3.4 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 both lakes due to the quantity of watershed and in-lake monitoring data available. Stormwater pond and in-lake water quality monitoring data collected over a six year period (2008-2013) and a five year period (2007-2008 and 2010-2012) was used in the watershed and lake response models for Alimagnet Lake and East Lake, respectively.

4.3.5 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. 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.

4.3.6 TMDL Summary

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the preceding sections. The following tables 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 the 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 ≥0.1 reported in lbs/yr have been rounded to the nearest tenth of a pound.
- Values <0.1 reported in lbs/yr have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- Values ≥0.01 reported in lbs/day have been rounded to the nearest hundredth of a pound
- Values <0.01 reported in lbs/day have been rounded to enough significant digits so that the value is greater than zero and a number is displayed in the table.
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision; this is done primarily to make the arithmetic accurate.

Table 4-18 and Table 4-19 present the allocations for Alimagnet and East Lakes.

Table 4-18. Alimagnet Lake TP TMDL and Allocations

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	**176.0**	**0.48**	**115.2**	**0.32**	**60.8**	**35%**
	Construction/Industrial SW	*3.5*	*0.01*	*3.5*	*0.01*	*0*	*0%*
	Apple Valley (MS400074)	*69.9*	*0.19*	*39.1*	*0.11*	*30.8*	*44%*
	Burnsville (MS400076)	*88.0*	*0.24*	*62.4*	*0.17*	*25.6*	*29%*
	MnDOT (MS400170)	*8.6*	*0.02*	*6.0*	*0.02*	*2.6*	*30%*
	Dakota County (MS400132)	*6.0*	*0.02*	*4.2*	*0.01*	*1.8*	*30%*
Load	**Total LA**	**210.0**	**0.57**	**103.3**	**0.28**	**106.7**	**51%**
	Non-MS4 runoff	--	--	--	--	--	--
	Upstream lakes	--	--	--	--	--	--
	Atmospheric deposition	*26.1*	*0.07*	*26.1*	*0.07*	*0*	*0%*
	Internal load	*183.9*	*0.50*	*77.2*	*0.21*	*106.7*	*58%*
MOS				**11.5**	**0.03**		
Total Load		**386.0**	**1.05**	**230.0**	**0.63**	**167.5**	**43%**

[1] Net reduction from current load to TMDL is 156.0 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 156.0 + 11.5 = 167.5 lbs/yr.

Table 4-19. East Lake Phosphorus TMDL and Allocations

		Existing TP Load		Allowable TP Load		Estimated Load Reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr[1]	%
Wasteload	**Total WLA**	**723.8**	**1.98**	**460.6**	**1.26**	**263.2**	**36%**
	Construction/Industrial SW	*14.1*	*0.04*	*14.1*	*0.04*	*0*	*0%*
	Apple Valley (MS400074)	*591.7*	*1.62*	*381.0*	*1.04*	*210.7*	*36%*
	Dakota County (MS400132)	*11.9*	*0.03*	*7.4*	*0.02*	*4.5*	*38%*
	Eagan (MS400014)	*0.05*	*0.0001*	*0.05*	*0.0001*	*0*	*0%*
	Empire Township (MS400135)	*0.003*	*0.00001*	*0.003*	*0.00001*	*0*	*0%*
	Lakeville (MS400099)	*94.1*	*0.26*	*50.3*	*0.14*	*43.8*	*47%*
	MnDOT (MS400170)	*11.9*	*0.03*	*7.7*	*0.02*	*4.2*	*36%*
	Rosemount (MS400117)	*0.00002*	*0.0000001*	*0.00002*	*0.0000001*	*0*	*0%*
Load	**Total LA**	**260.8**	**0.71**	**113.8**	**0.31**	**147.0**	**56%**
	Non-MS4 runoff	--	--	--	--	--	--
	Alimagnet Lake	*82.1*	*0.22*	*54.8*	*0.15*	*27.3*	*33%*
	Cobblestone Lake	*3.5*	*0.01*	*3.5*	*0.01*	*0*	*0%*
	Atmospheric deposition	*10.2*	*0.03*	*10.2*	*0.03*	*0*	*0%*
	Internal load	*165.0*	*0.45*	*45.3*	*0.12*	*119.7*	*73%*
MOS				**30.2**	**0.08**		
Total Load (TMDL)		**984.6**	**2.69**	**604.6**	**1.65**	**410.2**	**42%**

[1] Net reduction from current load to TMDL is 380.0 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 380.0 + 30.2 (MOS) = 410.2 lbs/yr.

5 Future Growth/Reserve Capacity

For all TMDLs in the Vermillion River Watershed, the following applies for determining the impact of growth and reserve capacity on allocations.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

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

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more non-regulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
4. Expansion of a United States 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 an 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 the area weighted methodology used in setting the allocations in this TMDL. In cases where the WLA is transferred from or to a permitted MS4, the permittees will be notified of the transfer and have an opportunity to comment.

5.2 New or Expanding Wastewater

The MPCA, in coordination with the EPA Region 5, has developed a streamlined process for setting or revising the WLAs for new or expanding wastewater discharges to waterbodies with an EPA approved TMDL (MPCA 2012). This procedure will be used to update the WLAs in approved TMDLs for new or expanding wastewater dischargers whose permitted effluent limits are at or below the in-stream 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 the 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 the WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

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

6 Reasonable Assurance

Reasonable assurance (RA) activities are programs that are in place to assist in attaining the TMDL allocations and applicable water quality standards. The RA evaluation provides documentation that the TMDL's WLAs and LAs are properly calibrated and the TMDL loads will ultimately meet the applicable water quality targets. Without such calibration, a TMDL's ability to serve as an effective guidepost of water quality improvement is significantly diminished. The development of a rigorous RA demonstration includes both state and local regulatory oversight, funding, implementation strategies, follow-up monitoring, progress tracking and adaptive management. (Note: Some of these elements are described in Sections 6.0 and 7.0.)

There are two separate but complimentary frameworks in place to ensure progress toward achieving the water quality targets identified in this TMDL. The first is between the MPCA and permitted MS4s through the MPCA's Stormwater Program. The second is between the VRWJPO and LGUs in the TMDL study area through the VRWJPO's Watershed Management Plan and the LGUs' local water management plans. Both of these frameworks are described in detail below.

6.1 MPCA Stormwater Program

The MPCA is responsible for applying federal and state regulations to protect and enhance water quality within the Vermillion River Watershed. The MPCA oversees all regulated MS4 entities in stormwater management accounting activities. All regulated MS4s in the Vermillion River Watershed fall under the category of Phase II. The MS4 NPDES/SDS permits require regulated municipalities to implement BMPs to reduce pollutants in stormwater runoff to the Maximum Extent Practicable (MEP).

All owners or operators of regulated MS4s (also referred to as "permittees") are required to satisfy the requirements of the MS4 general permit. The MS4 general permit requires the permittee to develop a Stormwater Pollution Prevention Program (SWPPP) that addresses all permit requirements, including the following six minimum control measures:

- Public education and outreach
- Public participation
- Illicit Discharge Detection and Elimination (IDDE) Program
- Construction-site runoff controls;
- Post-construction runoff controls; and
- Pollution prevention and municipal good housekeeping measures

A SWPPP is a management plan that describes the MS4 permittee's activities for managing stormwater within their jurisdiction or regulated area. In the event a TMDL study has been completed, approved by the EPA prior to the effective date of the general permit, and assigns a WLA to an MS4 permittee, that permittee must document the WLA in their application and provide an outline of the BMPs to be implemented in the current permit term to address any needed reduction in loading from the MS4.

The MPCA requires applicants submit their application materials and the SWPPP document to MPCA for review. Prior to extension of coverage under the general permit, all application materials are placed on

30-day public notice by the MPCA, to ensure adequate opportunity for the public to comment on each permittee's stormwater management program. Upon extension of coverage by the MPCA, the permittees are to implement the activities described within their SWPPP, and submit annual reports to the MPCA by June 30 of each year. These reports document the implementation activities which have been completed within the previous year, analyze implementation activities already installed, and outline any changes within the SWPPP from the previous year.

The MPCA has assigned the TSS, bacteria, and nutrient loads for the Upper Watershed TMDLs to the regulated MS4s. The pollutant WLAs for each MS4 entity is outlined in Section 4.0 of the TMDL. The MS4 General Permit, which became effective August 1, 2013, requires permittees to develop compliance schedules for any TMDL that received the EPA-approval prior to the effective date of the General Permit. This schedule must identify the BMPs that will be implemented over five-year permit term, timelines for their implementation, an assessment of progress, and a long term strategy for continued progress toward ultimately achieving those WLAs. Because this Upper Watershed TMDL will be approved after the effective date of the General Permit, MS4s will not be required to report on WLAs contained in this TMDL until the effective date of the next General Permit, expected in 2018.

The RA that the WLAs calculated for the Upper Watershed TMDLs will be implemented is provided by regulatory actions. According to 40 CFR 122.44(d)(1)(vii)(B), the NPDES Permit effluent limits must be consistent with assumptions and requirements of all WLAs in an approved TMDL. The MPCA's stormwater program and its NPDES Permit program are the state programs responsible for ensuring that implementation activities are initiated and maintained, and effluent limits are consistent with the WLAs calculated from the TMDLs. The NPDES program requires construction and industrial sites to create the SWPPPs which summarize how stormwater will be minimized from construction and industrial sites.

6.2 Vermillion River Watershed Joint Powers Organization

The VRWJPO was created under the Minnesota Metropolitan Surface Water Management Act of 1982, which established requirements for preparing watershed management plans within the Twin Cities Metropolitan Area. The Act requires plans to focus on preserving and using natural water storage and retention systems through: improving water quality; preventing flooding and erosion from surface runoff; promoting groundwater recharge; protecting and enhancing fish and wildlife habitat and water recreation facilities; reducing, to the greatest practical extent, the public capital expenditures necessary to control excessive volumes and rate of runoff; and securing other benefits associated with proper management of surface water. The overall goals of restoring impaired water resources and protecting water resources from further degradation require an active partnership between the VRWJPO and the LGUs which include all the cities and townships within the VRWJPO. The VRWJPO has been actively engaged in partnering efforts with LGUs whose jurisdiction areas are within the boundaries of the VRWJPO. The VRWJPO's main role in partnering with LGUs has been establishing a consistent regulatory framework throughout the VRWJPO and through implementation efforts from the VRWJPO's Watershed Management Plan or local water resource management plans.

Prior to the development of this TMDL, the VRWJPO has pursued water quality improvement projects within the TMDL study area boundaries. These efforts include various watershed studies, establishment of consistent and protective regulations, and targeted load reduction strategies. The VRWJPO plans to continue these types of efforts, and use this TMDL study to help strengthen targeted load reduction efforts throughout the VRWJPO.

The VRWJPO undertakes projects and programs each year as it implements its Watershed Management Plan. Some recent examples pertinent to this TMDL include:

- Partnering with the city of Lakeville to establish a native plant buffer on agricultural land draining to South Creek (2011).
- Implementing the Blue Thumb Program to establish rain gardens, native gardens, and shore land stabilizations throughout the VRWJPO (Ongoing).
- Partnered with the DNR and Trout Unlimited to remeander, introduce habitat features, and establish native plantings on a straightened section of the Vermillion River within a DNR Aquatic Management Area in Empire Township (2011).
- Partnered with the DNR and University of Minnesota Extension to stabilize banks, introduce habitat features, and establish native plantings within a DNR Aquatic Management Area in Vermillion Township (2010).
- Partnered with the city of Farmington in remeandering and establishing native vegetation on a straightened section of North Creek (2009).
- Partnered with Dakota SWCD and the MPCA through a Section 319 Grant, to implement temperature reduction demonstration practices draining to South Creek (2010-2011).
- Partnered with Dakota County to purchase a conservation easement and restore a native prairie on Dakota County Ag Society land on the South Branch Vermillion River (2012)
- Partnered with Dakota SWCD and Empire Township to implement a low impact design at the Empire Township Maintenance Facility (2010).
- Operating a variety of grant programs to provide financial and technical assistance for residents, business owners, and the LGUs for water quality improvement projects such as: low impact development practices, stormwater BMPs, shoreline and streambank stabilization, replacement of failing septic systems, and environmental education/demonstration projects.
- Established a Watershed Engagement Team to develop a Communication Plan and strategies to better assist the VRWJPO in identifying actions and activities that will engage the community in understanding impaired waters, informing them on what can be done to improve impaired waters, and empowering them to take action.

With the completion of the TMDLs, the VRWJPO will serve to coordinate implementation efforts among the LGUs and help ensure progress toward the TMDL targets. Adaptations will be made by the VRWJPO and the LGUs to ensure implementation efforts are having the desired effect on water resources. The VRWJPO will take the lead role in tracking attainment of water quality standards. Reductions for the non-regulated (LA) portions of the TMDLs will also be needed. These loads include non-MS4 runoff, which includes some agricultural land as well as shoreline and streambank erosion, and internal loading.

Both the Dakota and Scott County Soil & Water Conservation Districts provide technical and financial assistance to agricultural landowners to implement conservation efforts that reduce runoff and erosion and protect water quality. The VRWJPO's capital improvement program has funded internal load reduction projects in the past, and may consider funding future projects. The VRWJPO, with assistance and cooperation from the LGUs and other groups, will take the lead on efforts to reduce loading from these non-regulated sources.

6.3 Funding

The LGU funding for water resource projects typically comes from some combination of the following sources: general tax revenue, special assessments, development fees, stormwater utility fees, and grants. The VRWJPO is funded through a special purpose tax district within Dakota and Scott Counties. This annual tax base comprises one of the main funding mechanisms for the VRWJPO sponsored implementation activities within the watershed. The VRWJPO utilizes this funding base to sponsor cost-share and grant programs to assist municipal partners with local water quality improvement projects. There are other funding mechanisms that the VRWJPO and the LGUs may apply for in the State of Minnesota. Some of these sources include: grants under the Clean Water Legacy Act (CWLA) and funding through the Clean Water Partnership program. The VRWJPO will also explore the funding mechanisms provided through the federal Section 319 grant program, which provides cost share dollars to implement voluntary activities in the watershed.

The CWLA is a statute passed in Minnesota in 2006, for the purposes of protecting, restoring, and preserving Minnesota water and providing significant funding to do so. The Act discusses how MPCA and the involved public agencies and private entities will coordinate efforts regarding land use, land management, water management, etc. Cooperation is also expected between agencies and other entities regarding planning efforts, and various local authorities and responsibilities. This would also include informal and formal agreements to jointly use technical, educational, and financial resources.

The CWLA also provides details on the overall TMDL process and follow-up implementation strategy development, and how the funding will be used. The Minnesota Board of Soil and Water Resources administers the Clean Water Fund for restoration and protection grants, and has developed a detailed grants policy explaining what is required to be eligible to receive Clean Water Fund money (FY15 Clean Water Fund Competitive Grants Policy; Minnesota Board of Soil and Water Resources 2014).

6.4 Schedule and Tracking

After the approval of the TMDL by the EPA, the VRWJPO will work with the LGUs to develop a general timeline and strategy for implementation activities to be conducted within each permit cycle and/or plan cycle. It is likely that interim goals will be established within many LGUs, as immediate changes within the watershed to fully address any one or more impairment is unlikely. The VRWJPO will adopt its 2nd Generation Watershed Plan in 2015. Within the plan, the long-term goal of removal of waters from the impaired waters list may be projected out beyond the 10-year life of the plan. Five and 10-year goals will likely be established within the implementation plan as reasonable benchmarks to achieve towards water quality standard attainment. Progress toward the TMDL targets will be assessed as part of the implementation of the 2nd Generation Watershed Plan. Future Watershed Plan revisions and updates will also look at establishing new targets to attain water quality standards, if they have not yet been met. Progress will also be assessed through the reporting requirements of the MPCA's stormwater program and the NPDES Permit requirements.

7 Monitoring Plan

Water quality sampling in the VRWJPO is conducted as part of the annual comprehensive monitoring program. The VRWJPO has monitored stream flow and quality, precipitation and other hydrologic parameters annually beginning in the early 2000's. Lake water quality sampling is typically conducted or coordinated by the local cities. The VRWJPO also began conducting annual fish and macroinvertebrate sampling in 2009, and plans to continue annual surveys. Since the mid-2000s, the VRWJPO has actively coordinated with other agencies to collect additional monitoring data.

The District's monitoring program:

- Tracks long term water quality trends,
- Quantifies pollutant loading and yields
- Performs detailed investigation of specific pollutant issues to pinpoint sources,
- Tracks attainment of water quality standards,
- Determines biotic health of stream reaches
- Tracks efficacy of the VRWJPO projects
- Provides model calibration datasets

The program is a joint collaboration between the VRWJPO, Dakota and Scott County SWCDs, the Metropolitan Council Environmental Services (MCES), United States Geological Survey (USGS), Dakota County, Scott County, the MPCA, and the DNR. In 2014, the VRWJPO monitored eight sites on the Vermillion River and tributaries for water quantity and quality, with another site monitored in cooperation with the MCES. The VRWJPO, in cooperation with the DNR and Dakota County SWCD, monitored 14 sites on stream reaches throughout the watershed for fish and macroinvertebrates. Lake water quality sampling is conducted or coordinated by each of their respective cities in cooperation with the MCES. Program data including a calculation of annual runoff, flow, pollutant loads and yields, and precipitation is published annually in the Vermillion River Watershed Monitoring Report.

Progress toward meeting TMDL goals will be measured by regularly monitoring water quality and tracking total BMPs completed. Water quality monitoring will be accomplished through the comprehensive monitoring program. It is anticipated that member cities and permitted MS4s will perform monitoring in the watershed or evaluation via other methods as applicable to the partitioned the WLA and associated correlation to each NPDES Permit.

8 Implementation Strategy Summary

8.1 Implementation Framework

The strategies described in this section are potential actions to reduce turbidity (TSS), bacteria, and nutrient loads (TP) in the Vermillion River Watershed. These actions will be further developed in a separate, more detailed WRAPS report. The Vermillion River JPO will coordinate implementation actions identified in this TMDL and the separate report.

8.2 Sources

8.2.1 MS4

The NPDES Permit requirements must be consistent with the assumptions and requirements of an approved TMDL and associated WLAs. For the purposes of this TMDL, the baseline year for implementation will be the mid-range year of the data years used for the lake response modeling (Table 8-1) and development of the TSS and bacteria load duration curves. The rationale for this is that projects undertaken recently may take a few years to influence water quality. Any waste load-reducing BMP implemented since the baseline year will be eligible to “count” toward an MS4’s load reductions. If a BMP was implemented during or just prior to the baseline year, the MPCA is open to presentation of evidence by the MS4 permit holder to demonstrate that it should be considered as a credit.

Table 8-1. Implementation baseline years

Water body	ID	Data Years Used for TMDL Development	Baseline Year
Vermillion River	07010001-517	2004-2013	2009
Vermillion River	07010001-516	2005-2013	2009
North Creek	07010001-670	2004-2013	2009
North Creek	07010001-542	2004-2013	2009
North Creek	07010001-545	2004-2013	2009
North Creek	07010001-671	2004-2013	2009
Middle Creek	07010001-546	2004-2013	2009
Middle Creek	07010001-548	2004-2013	2009
Middle Creek	07010001-668	2000-2013	2007
South Creek	07010001-527	2005-2013	2010
South Branch Vermillion	07010001-706	2000-2013	2007
South Branch Vermillion	07010001-707	2004-2013	2009
Alimagnet Lake	19-0021-00	2008-2013	2010
East Lake	19-0349-00	2007, 2008, 2010-2012	2010

8.2.2 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in the State's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the

NPDES/SDS General Stormwater Permit and properly selects, installs and maintains all BMPs required under the permit, including those related to 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. It should be noted that all local construction stormwater requirements must also be met.

8.2.3 Industrial Stormwater

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

8.2.4 Wastewater

The Hampton WWTF, which discharges to South Branch Vermillion River (07040001-707), is the only NPDES permitted wastewater discharger in the Vermillion River TMDL study area. The DMRs were downloaded from the MPCA database to assess effluent bacteria levels for this facility. By rule, the Hampton WWTF is not to discharge treated wastewater with fecal coliform concentrations that exceed 200 cfu/100ml. The DMR records show this facility is currently meeting its effluent permit limits and state water quality standards for bacteria (Appendix B). Thus, no bacteria reductions or changes are needed for the Hampton WWTF as long as the facility continues to employ its current treatment technologies to control bacteria in its effluent waters.

8.3 Strategies

8.3.1 Turbidity

Potential BMPs to reduce the TSS loads to the Vermillion River impaired reach are presented in Table 8-2. These potential BMPs, along with cost estimates, will be explored more thoroughly in the WRAPS report. Please note that loading reduced from some implementation actions listed in Table 8-2 is creditable to the LA and some to the WLA. The strategy table does not specify the applicable allocation categories.

Table 8-2. Potential TSS reduction implementation strategies

Potential BMP/Reduction Strategy
Streambank Stabilization/Buffer Enhancement – *Repair and stabilize degraded banks throughout the impaired reach. Establish vegetation (preferably native) to filter runoff from urban areas, cropland and pastures adjacent to the stream. All reaches should have at least 50 feet of buffer on both sides of the stream.*

Potential BMP/Reduction Strategy
Vegetative Practices – *Reduce sediment generation and transport through vegetative practices focusing on the establishment and protection of crop and non-crop vegetation to minimize sediment mobilization and transport. Recommended vegetative practices include grassed waterways and grass filter strips, alternative crop rotations, forest management, field windbreaks, rotational grazing, contour farming, strip cropping, cover crops, and others.*
Primary Tillage Practices – *Promote conservation tillage practices to 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 managed properly, conservation tillage can reduce soil erosion on active fields by up to two-thirds (Randall et. al. 2008).*
Urban BMPs – *promote urban BMPs such as infiltration, bioretention, increased street sweeping and others to reduce sediment runoff and transport.*
Education – *Provide educational and outreach opportunities about responsible tillage practice, vegetative management practices, and other BMPs to encourage good individual property management practices to reduce soil loss and upland erosion.*
Control Animal Access to the Stream – *Control and/or limit animal access to streambanks and areas near streams and rivers by installing fencing in pastures where access is unimpeded and installing buffer vegetation where existing fencing is directly adjacent to the stream bank.*

8.3.2 E. coli

Table 8-3 lists the BMPs that may be successful in reducing bacteria loads. These potential BMPs will be explored more thoroughly, including costs and targeting the most appropriate BMPs by location, in the accompanying WRAPS report.

Please note that loading reduced from some implementation actions listed in Table 8-3 is creditable to the LA and some to the WLA. The strategy table does not specify the applicable allocation categories.

Table 8-3. Potential *E. coli* reduction implementation strategies

Potential BMP/Reduction Strategy
Streambank Stabilization/Buffer Enhancement – *Stabilize vegetation to filter runoff from pastures adjacent to the stream. Enhancements should include at least 50 feet of buffer on both sides of the stream.*
Education – *Provide educational and outreach opportunities about proper fertilizer use, manure management, grazing management, proper pet waste disposal, and other topics to encourage good individual property management practices.*
Pasture Management –*create alternate livestock watering systems, rotational grazing, and vegetated buffer strips between grazing land and surface* water bodies.
Manure Management – *Reduction of winter spreading, eliminate spreading near open inlets, apply at agronomic rates, erosion control practices, and manure stockpile runoff controls.*
Septic System Inspection Program Review - *Although not a significant source of bacteria, Dakota and Scott County should continue to inspect and order upgrades of existing septic systems; prioritizing properties near the impaired reaches and its tributaries.*
Control Animal Access to the Stream – *Control and/or limit animal access to streambanks and areas near streams and rivers by installing fencing in pastures where access is unimpeded and installing buffer vegetation where existing fencing is directly adjacent to the stream bank.*
Pet Waste Management – *Review member cities local ordinances and associated enforcement and fines for residents who do not clean up pet waste. Increase enforcement and education about compliance with such an ordinance.*

8.3.3 Nutrients

Table 8-4 lists the BMPs that may be successful in reducing nutrient loads and managing lake water quality. Not all BMPs are necessarily appropriate or feasible for both lakes. These potential BMPs will be explored more thoroughly, including costs and targeting the most appropriate BMPs for each water body, in the accompanying WRAPS report. The VRWJPO and the MS4s have been and will continue to implement the BMPs, and have already undertaken similar projects in the lakesheds since the TMDL baseline year.

Please note that loading reduced from some implementation actions listed in Table 8-4 is creditable to the LA and some to the WLA. The strategy table does not specify the applicable allocation categories.

Table 8-4. Potential nutrient reduction strategies

Reduction Target	Potential BMP/Reduction Strategy
Watershed Load	**Education Programs –** *Provide education and outreach on low-impact lawn care practices, proper yard waste removal, and other topics to increase awareness of sources of pollutants.*
	Shoreline Restoration – *Encourage property owners to restore their shoreline with native plants and install/enhance shoreline buffers.*
	Raingarden/Bio-filtration Basins – *Encourage the use of rain gardens and similar features as a means of increasing infiltration and evapotranspiration. Opportunities may range from a single property owner to parks and open spaces.*
	Stormwater Pond Retrofits/Installation - *As opportunities arise, retrofit stormwater treatment through a variety of BMPS. Pond expansion and pre-treatment of water before it reaches the ponds may be beneficial dependent on drainage area. Also, identify target areas for new stormwater pond installation.*
	Street Sweeping Program Review/Implementation *Identify target areas for increased frequency of street sweeping and consider upgrades to traditional street sweeping equipment.*
	Agricultural BMP Implementation – *Encourage property owners to implement agricultural BMPs for nutrient load reduction. The Agricultural BMP Handbook for Minnesota (MDA 2012) provides an inventory of agricultural BMPs that address water quality in Minnesota. Several examples include conservation cover, buffer strips, grade stabilization, controlled drainage, rotational grazing, and irrigation management, among many other practices.*
Internal Load	**Technical Review –** *Prior to internal load reduction strategy implementation, a technical review is recommended to evaluate the cost and feasibility of lake management techniques such as hypolimnetic withdrawal, alum treatment, and hypolimnetic aeration to manage internal nutrient sources.*
	Alum Dosing – *If determined feasible based on technical review, chemically treat with alum to remove phosphorus from the water column as well as bind it in sediments.*
	Hypolimnetic Withdrawal or Aeration – *If determined feasible based on technical review, pump nutrient-rich water from the hypolimnion to an external location for phosphorus treatment and discharge treated water back into the lake. Or as an alternate option, aerate the hypolimnetic waters to maintain oxic condition (the anoxic condition of the hypolimnetic sediments is the contributor to the internal phosphorus load).*

Reduction Target	Potential BMP/Reduction Strategy
	Aquatic Plant Surveys/Vegetation Management – *Conduct periodic aquatic plant surveys and prepare and implement vegetation management plans.*
	Rough Fish Surveys/Management – *Consider partnership with the DNR to monitor and manage the fish population. Evaluate options to reduce rough fish populations such as installation of fish barriers to reduce rough fish access and migration.*

8.4 Adaptive Management

A list of implementation strategies in the WRAPS report that will be prepared following this TMDL assessment will focus on adaptive management (Figure 8.1). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for attaining the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDL and lay the groundwork for de-listing the impaired water bodies.

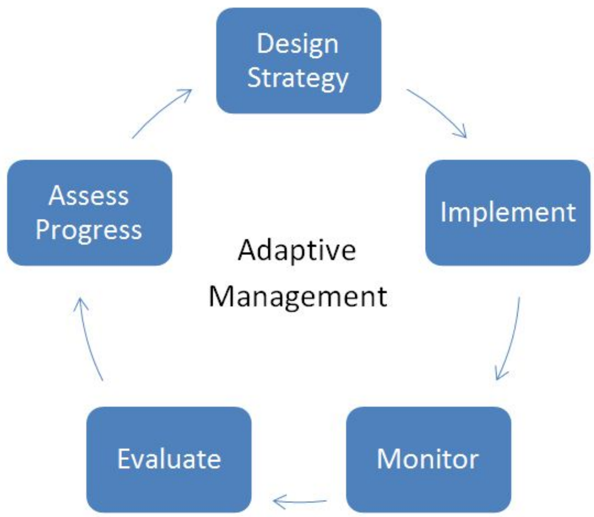

Figure 8.1. Adaptive Management.

8.5 Cost

The CWLA requires that a TMDL include an overall approximation of the cost to implement a TMDL [Minn. Stat. 2007 § 114D.25]. The initial estimate for implementing the Vermillion River WRAPS is approximately $10,000,000 for non-point source implementation and $10,000,000 for point source implementation.

9 Public Participation

A stakeholder participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the public and interested and affected agencies regarding the development of and conclusions of the TMDL. The VRWJPO's Technical Advisory Group (TAG) was convened multiple times to hear about the stressor identification and the TMDL results. The TAG consists of the VRWJPO and stakeholders from local cities, counties, state and regional agencies, consultants, soil and water conservation districts, University of Minnesota staff, and others. Monthly meetings allowed for the VRWJPO's Watershed Planning Commission (WPC), a citizen advisory group, and Joint Powers Board (JPB), the Commissioners of the Watershed, to be advised on the results of the stressor identification and TMDLs as they progressed through their development.

The stakeholder process involved meetings and other communications as tabulated below.

Table 9-1. Stakeholder communications

Date	Communication Method	Content
March 3, 2014	Meeting	Project kickoff meeting for lake TMDLs to obtain previous studies, modeling and data
March 12, 2014	Meeting	Presentation of background data, preliminary modeling results and discussion of allocation methodology
June 11, 2014	Meeting	Presentation of source assessment and preliminary TMDL allocations
July 29, 2014	Meeting	Discuss Lake TMDL allocations and implementation planning
October 22, 2014	E-mail	Pre-public notice review and comment opportunity on draft TMDL report
November 12, 2014	Meeting	Discuss draft TMDL report comments with technical stakeholders

A formal public notice period for this Vermillion River Watershed TMDL Study and WRAPS Report was held from June 29, 2015 through July 29, 2015.

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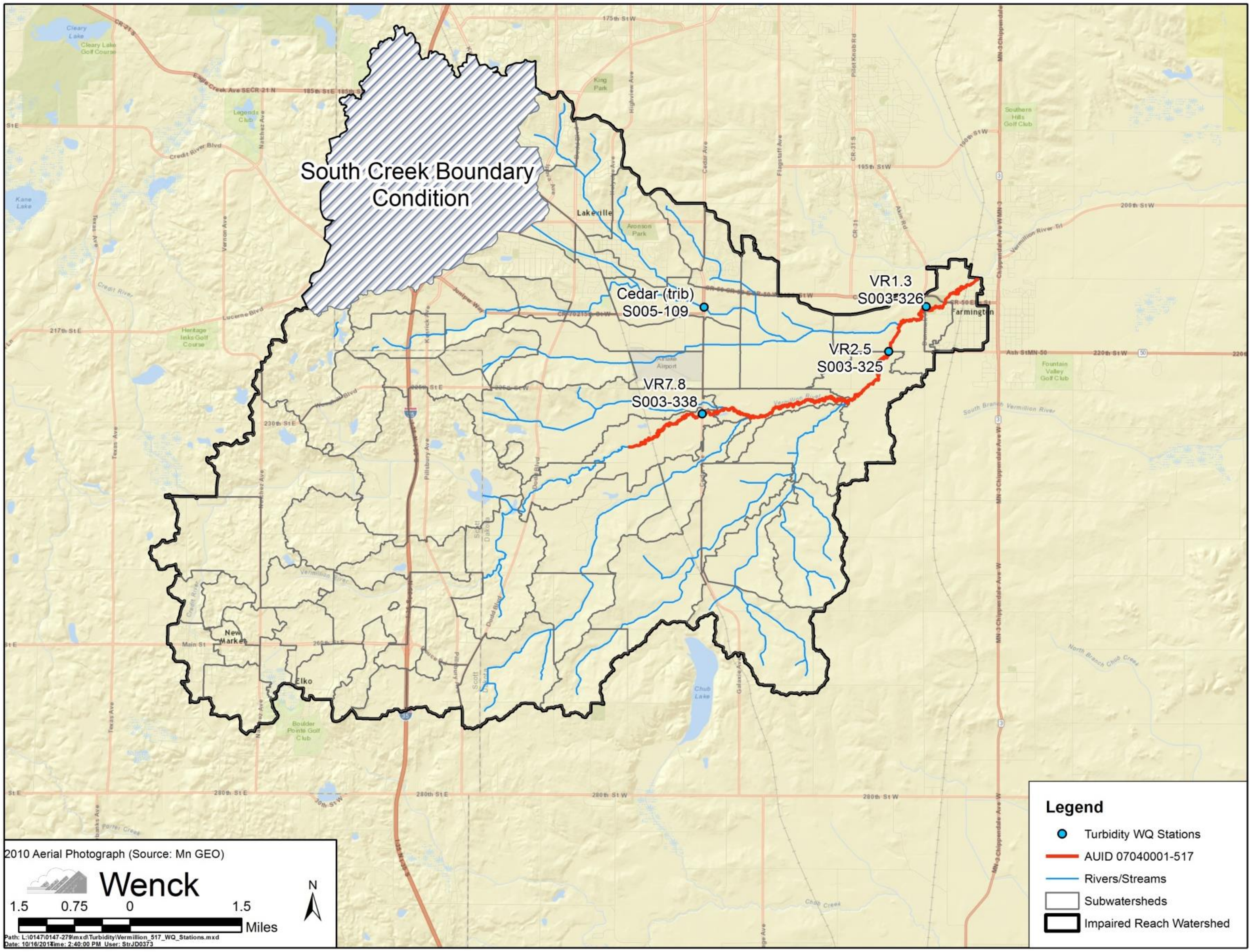
Appendices

Appendix A: Turbidity Supporting Materials

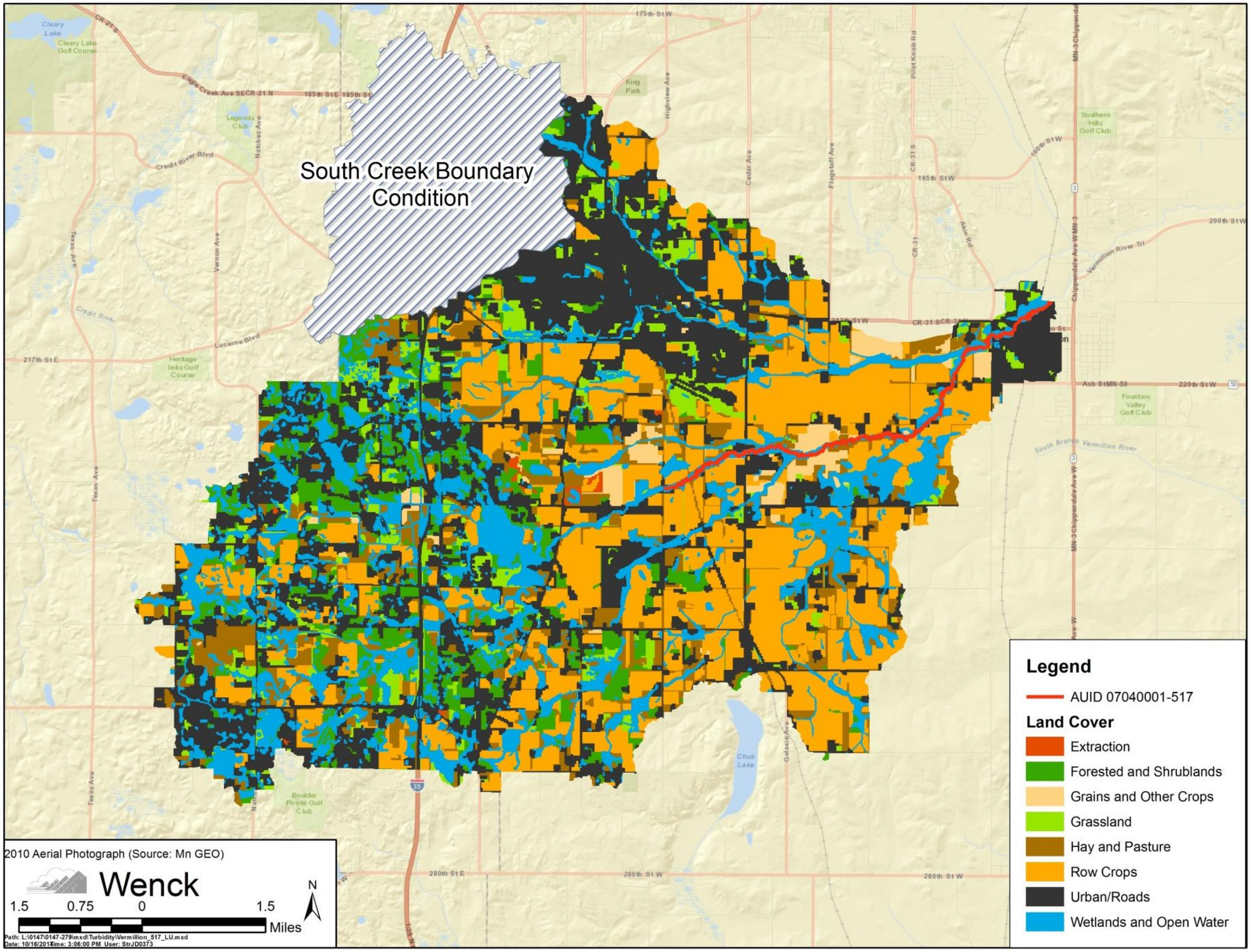
Appendix B: *E. coli* Supporting Materials

Appendix C: Lake Nutrients Supporting Materials

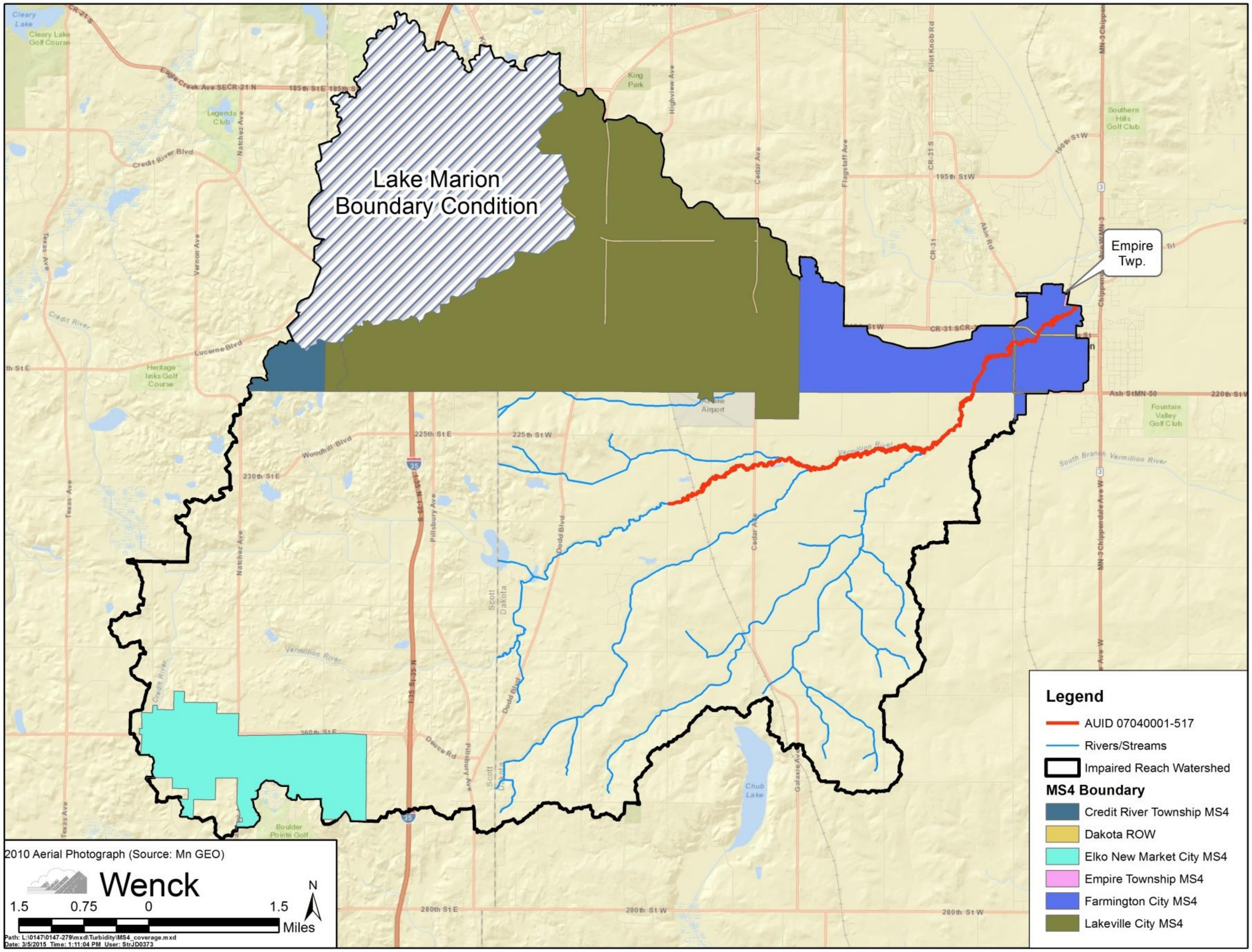
Appendix A – Turbidity TMDL Supporting Materials



Vermillion River subwatersheds and turbidity monitoring stations



Vermillion River Land Cover



Vermillion River MS4 coverage

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TECHNICAL MEMORANDUM

TO: Vermillion River Watershed JPO
Minnesota Pollution Control Agency

FROM: Jeff Strom, Jeff Madejczyk, Brian Beck

DATE: September 2014

SUBJECT: Vermillion River Impaired Reach Historic Turbidity Data Summary and Source Assessment

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This technical memorandum summarizes the historic turbidity and total suspended solid (TSS) water quality data collected throughout the Vermillion River turbidity impaired reach (AUID 07040001-517) since 2008, and provide a general TSS source assessment within the impaired reach watershed. Currently, the reach of the Vermillion River west of Farmington is listed on the 303d list of impaired waters for turbidity. To help determine the cause of the turbidity impairment, historical turbidity data from the reach was obtained from Dakota County Soil and Water Conservation District (SWCD) and Minnesota Pollution Control Agency (MPCA) database, and compared to total suspended solids (TSS), historical flow, potential upland soil loss, and stream-bank erosion. Results from this analysis demonstrated that turbidity violations occurred most frequently during elevated stream flow events.

1.0 REVIEW OF VERMILLION RIVER TURBIDITY DATA

The Dakota County Soil and Water Conservation District (SWCD) and Vermillion River Watershed Joint Powers Organization (VRWJPO) staff have deployed continuous turbidity loggers at four monitoring stations in the turbidity impaired reach watershed (Table 2-1). Three continuous turbidity monitoring stations are located along the mainstem of the river, two of which are located upstream of South Creek (VR2.5 and VR7.8) and one downstream of South Creek (VR1.3). One continuous turbidity logger was also deployed in South Creek, a tributary of the main stem impaired reach, at Cedar Ave (Cedar). The turbidity loggers at stations VR2.5 and VR1.3 were deployed from 2008-2012. Stations VR7.8 and Cedar (South Creek) were added in 2012 for the purposes of the TMDL study and therefore only have one year of turbidity data. Since the continuous turbidity probes produce readings every 15 minutes, daily averages were calculated and used herein for turbidity daily analysis. This continuous turbidity dataset supplies an accurate depiction of daily turbidity values for a given year when compared to discrete samples that only represent a finite number of days. For this reason, data from the continuous turbidity meters were used exclusively during the data analysis even though there are other sites that contain a limited number of discrete turbidity measurements.

Continuous stream flow data was available within the impaired reach at stations VR2.5 and VR 1.3. Data gaps in the flow record were filled using a regression between the two aforementioned monitoring stations (VR2.5 and VR1.3) and a continuous USGS gauge station downstream of the impaired reach in Empire Township (S000-896).

Table 1-1. Turbidity monitoring locations in the Vermillion River impaired reach.

Monitoring Station	EQuIS ID/ Reach	Location Description	Reach River Mile
VR7.8	S003-338 Reach 517	Vermillion River at Cedar Ave.	7.8
VR2.5	S003-325 Reach 517	Vermillion River at 220th Street	2.5
VR1.3	S003-326 Reach 517	Vermillion River at Denmark Avenue (CR-31)	1.3
Cedar (trib)	S005-109 Reach 527	South Creek at Cedar Ave	3.1 (trib)

1.1 Development of Field Turbidity and TSS Relationship

A relationship was developed between average daily field turbidity and laboratory measured total suspended solids (TSS). A total of 186 paired turbidity/TSS samples were used to develop the relationship (Figure 1-1). A regression was developed and used to convert all average daily field turbidity (FNU) to average daily TSS equivalent concentrations. Figure 1-2 depicts one year of continuous TSS data and the associated lab TSS measurements to demonstrate the reliability of the field turbidity-TSS relationship. The turbidity data converted to TSS equivalents are used throughout the remainder of this memo to calculate annual TSS loads and assess the TSS impairment relative to the proposed TSS standard.

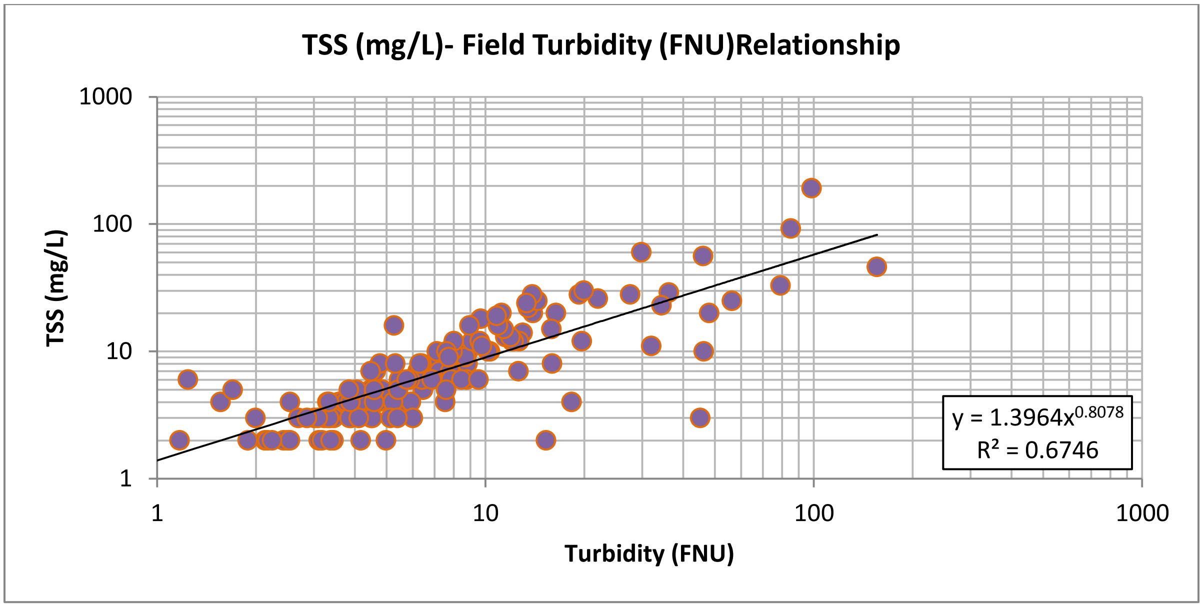


Figure 1-1. Continuous field turbidity and lab measured total suspended solids relationship for VR2.5 and VR1.5 on the impaired Vermillion Reach.

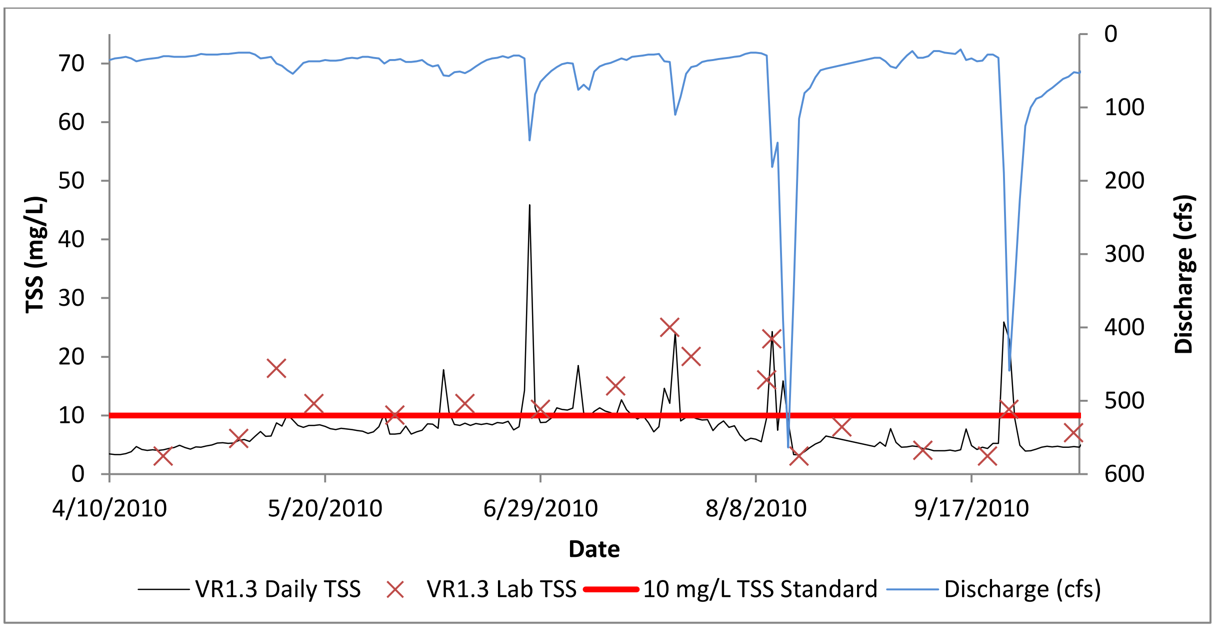


Figure 1-2. Daily Average (black line) and 15 minute interval (grey line) TSS equivalent concentrations converted from daily average field turbidity and laboratory TSS concentrations (red crosses) plotted against daily discharge. Daily average discharge presented here has been inverted to compare turbidity peaks to flow peaks. Note: Continuous TSS data was calculated using the TSS/continuous field turbidity regression presented in Figure 1-1.

1.2 Turbidity and TSS Measurements

The Vermillion River impaired reach is designated by state statute as a beneficial-use Class 2A cold water stream. For the purposes of this memo, the new TSS standard for Class 2A cold water streams of 10 mg/L will be used to assess the degree of impairment. Approximately 14%, 21%, 11%, and 11% of the daily average TSS observations collected at the VR7.8, VR2.5, VR 1.3, and Cedar monitoring stations respectively, were above the 10 mg/L TSS standard (Table 1-2). Since discrete samples are still given preference in the determination of reach impairment, this data was also used to assess the degree of impairment relative to the continuous TSS data (Table 1-3).

The South Creek tributary monitoring station had the lowest median TSS value relative to any Vermillion River impaired reach monitoring station, although it had a similar number of exceedances relative to other sites in the impaired reach. Furthermore, there was not a jump in TSS concentrations when comparing Vermillion River main-stem data upstream (VR2.5) and downstream (VR1.3) of South Creek. This suggests that South Creek is not increasing TSS concentrations in the impaired reach downstream of the confluence of South Creek and the Vermillion River.

Sediment loading at each field site was calculated using average daily flow and TSS concentration derived from the TSS/turbidity regression relationship. During winter periods, where no continuous TSS data was available, daily TSS concentration was assumed to be 4 mg/L (the final winter and initial spring measurements were, on average 4 mg/L). Annual TSS loads ranged from 27 to 274 tons/year at the VR2.5 monitoring site and 60 to 305 tons/year at the VR1.3 site (Figure 1-3).

Table 1-2. Vermillion River and South Creek turbidity monitoring stations and available TSS data converted from continuous turbidity probes.

Station	Number of Daily Average TSS Observations	Median TSS Value (mg/L)	TSS[1] Exceedances	Years[2]
VR7.8	221	5.2	8	2012
VR2.5	1,084	5.7	42	2008-2012
VR1.3	782	5.8	13	2008-2011
Cedar	209	1.8	11	2012

[1]Note: TSS data were converted from continuous turbidity meters using relationship discussed in section 1.1
[2]Note: The continuous turbidity meter at site VR1.3 was not producing reliable data during the 2012 season.

Table 1-3. Vermillion River turbidity monitoring stations and available discrete (lab) TSS data.

Study Station Name	Number of Discrete Observations	Median TSS Value (mg/L)	TSS Exceedances (10mg/L standard)	Years[1]
VR7.8	5	3	1	2012
VR2.5	174	7	60	2003-2012
VR1.3	173	8	71	2003-2012

[1]Note: Data from the past 10 years was used to assess impairment in the impaired reach although data is available prior to 2003.

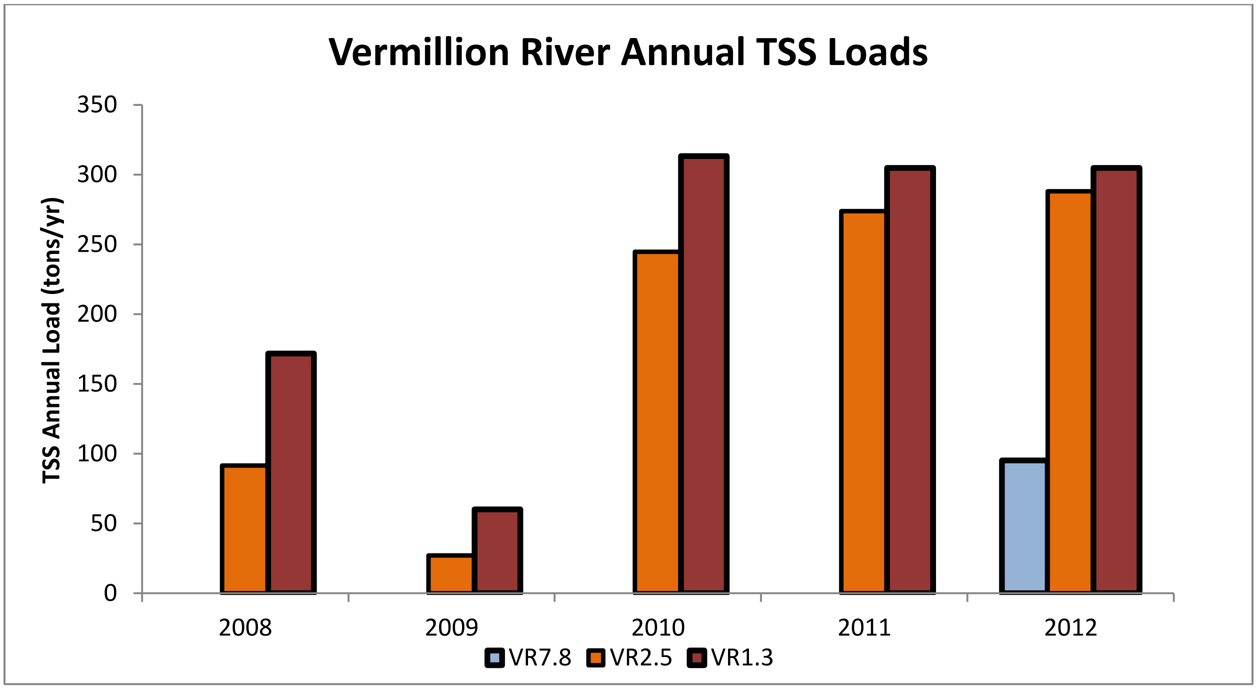


Figure 1-3. Annual monitored TSS loads at each Vermillion River impaired reach turbidity monitoring station.

1.3 TSS Relation to Flow

Average daily flow recorded at stations VR2.5 and VR1.3 were compared to the average daily TSS equivalent measurements at the four turbidity monitoring stations (Figures 1-4 through 1-7). Results indicate TSS violations occur under most flow conditions; however, the majority of exceedances occurred under higher flow conditions.

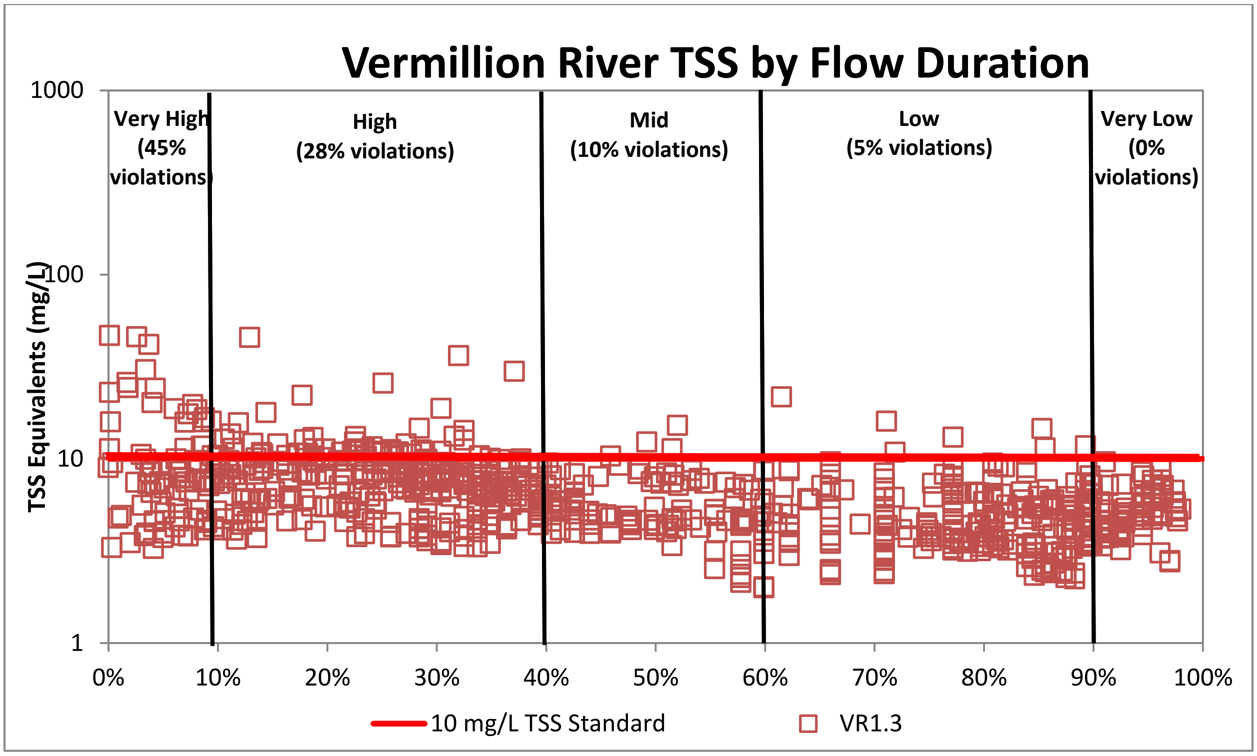


Figure 1-4. Vermillion River station VR1.3 average daily TSS by flow category.

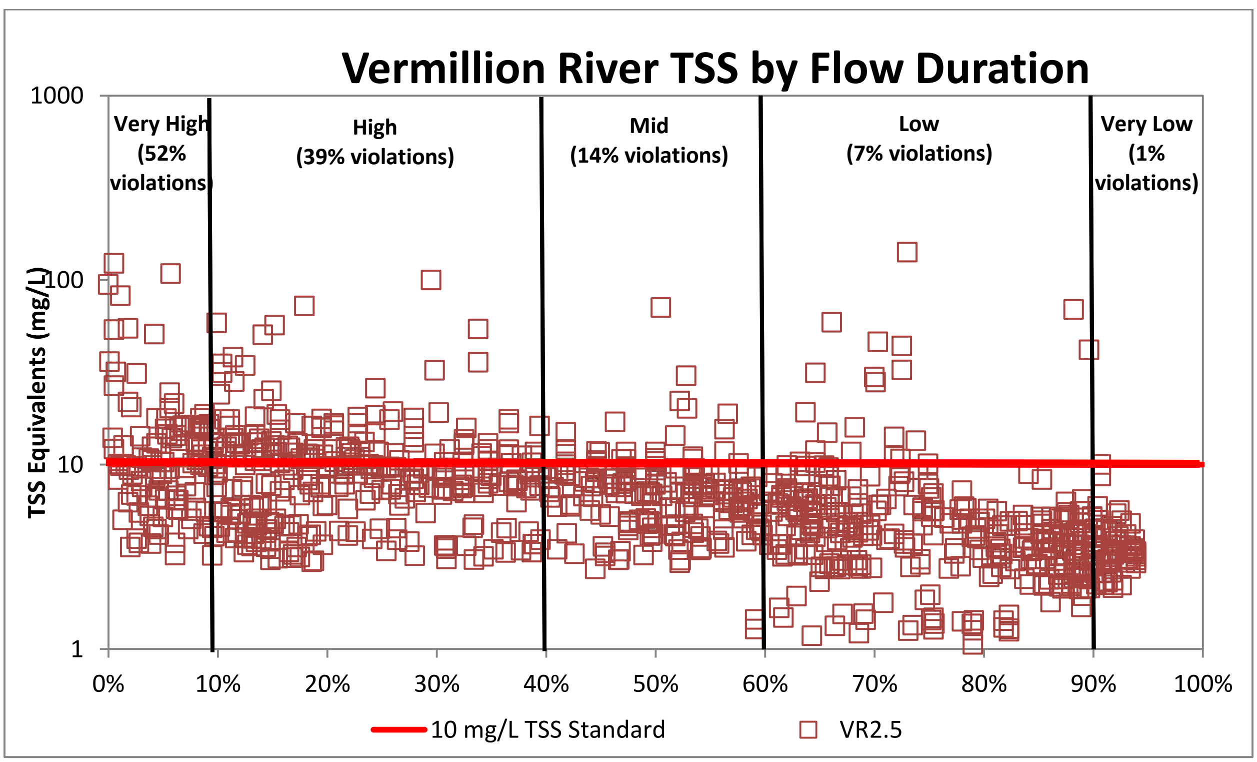


Figure 1-5. Vermillion River station VR2.5 average daily TSS by flow category.

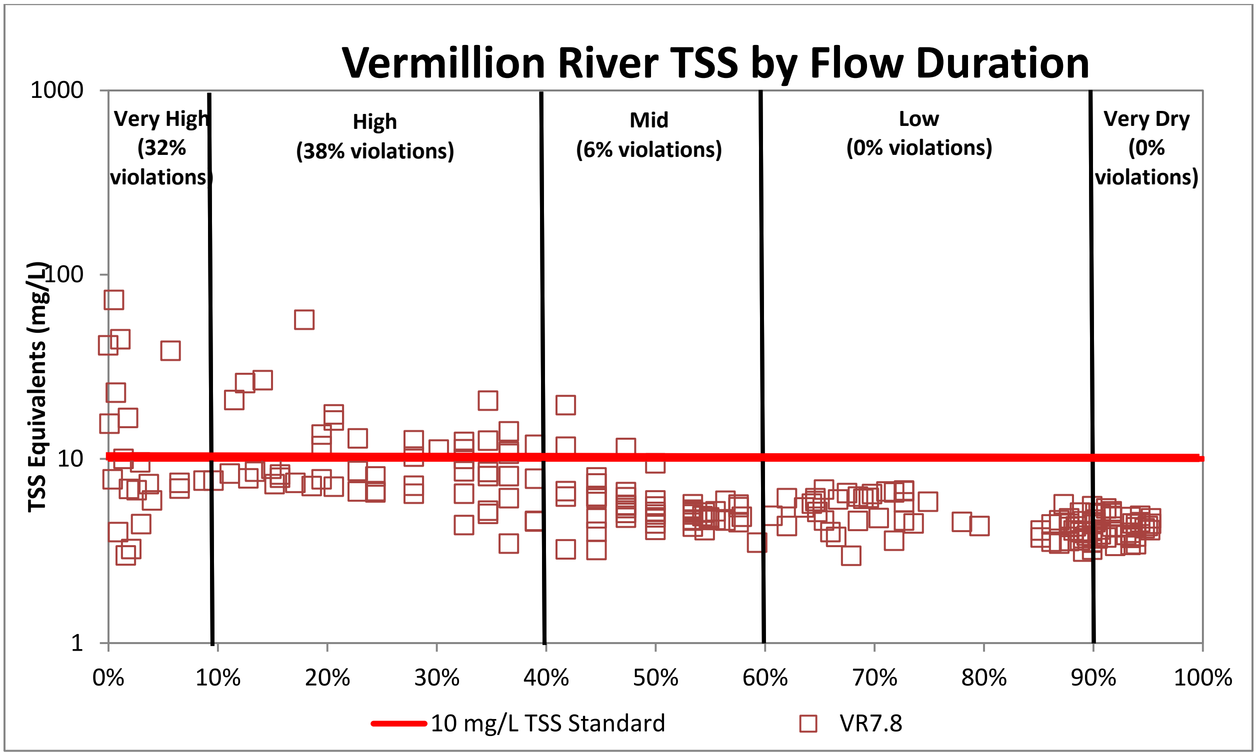


Figure 1-6. Vermillion River station 7.8 average daily TSS by flow category.

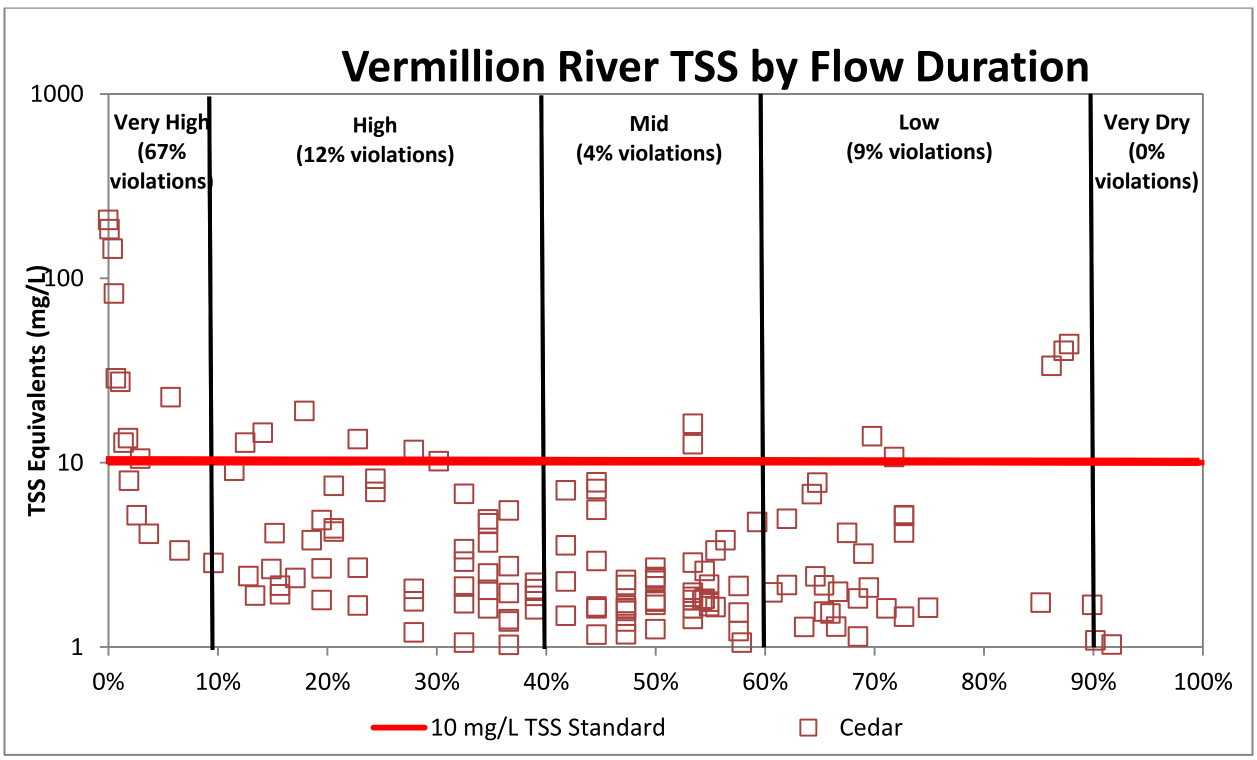


Figure 1-7. South Creek Cedar station average daily TSS by flow category.

2.0 IN-STREAM AND UPLAND SEDIMENT LOADS AND SOURCES

2.1 Algal Turbidity

In streams and rivers that receive high phosphorus loads from terrestrial sources, algal turbidity can be a major contributor to turbidity/TSS. Chlorophyll-a in the Vermillion impaired reach is relatively low and had no exceedances when compared to the proposed south river region chlorophyll-a standard of 40 mg/L (Figure 2-1). There were a few occasions in which the chlorophyll-a concentrations were elevated, although these dates were not associated with TSS exceedences. This data suggests that algal turbidity is not a primary source of turbidity in the Vermillion impaired reach.

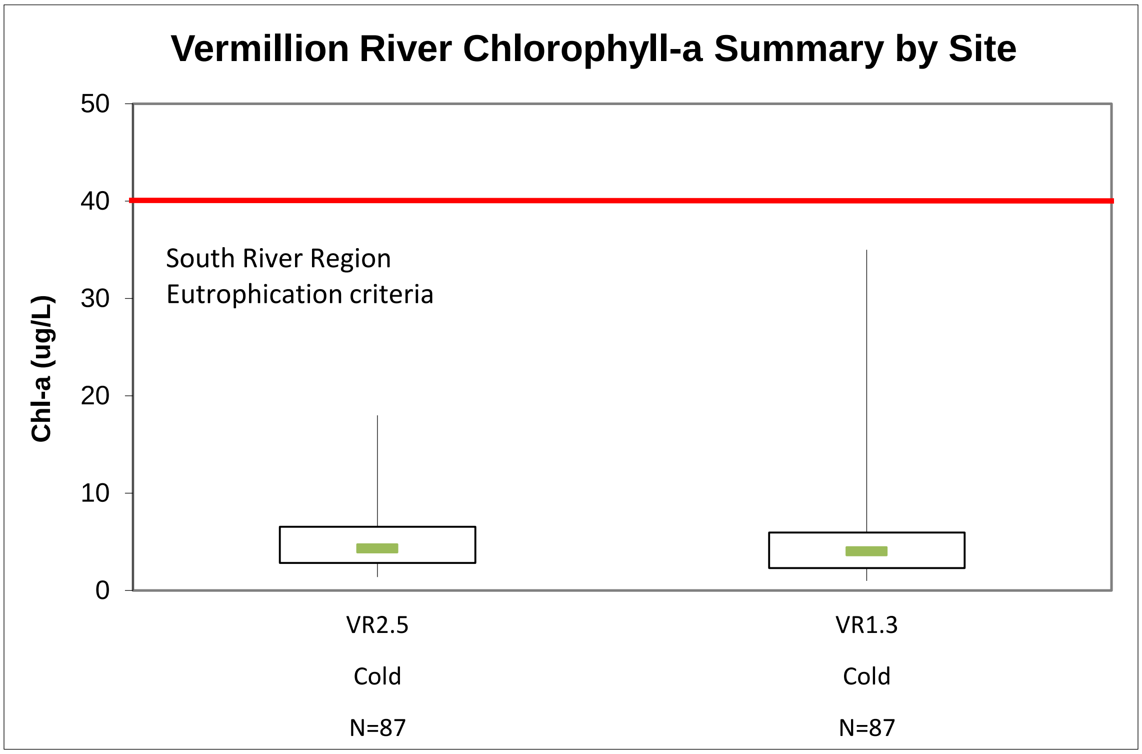


Figure 2-1. Chlorophyll-a data for the Vermillion River by monitoring station. The upper and lower edge of each box represent the 75th and 25th percentile of the data range for each site. Error bars above and below each box represent the min and max of the dataset. The green dash is the median chlorophyll-a concentration of all data collected.

2.2 Upland Sediment Loading

Average upland sediment loss in the impaired reach watershed 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 Vermillion River impaired reach watershed study area and then multiplied together to estimate the average annual potential soil loss for each grid cell. 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, landuse and soil attributes. Areas with high potential erosion should be verified in the field prior to BMP planning and targeting.

Since this model does not take into account a stream's ability to transport suspended sediment, a sediment delivery ratio (SDR) (Vanoni 1975) was used to estimate how much upland soil loss may be delivered downstream:

$$SDR = 0.451(b)^{-0.298}$$

Where b = watershed size in square kilometers

Even with the SDR, field sediment delivery to the stream channel may still be over-estimated since the USLE model and the SDR do not take into account wetlands, lakes, and other areas of depressed storage.The USLE predicts a gross average annual soil delivery of 2,887 tons after the soil delivery ratio has been applied, which is an order of magnitude larger than the load calculated at the VR1.3 station (300 tons/yr). The estimated soil delivery calculation likely an overestimate for the reasons listed above; however, the USLE does show that the majority of the watershed has a low potential for field erosion (<1 ton/acre/year). Furthermore, most potential hotspots are located away from the main stem impaired reach in subwatersheds of upstream tributaries (Reach 527, Reach 702, and Reach 666) (Figure 2-2).

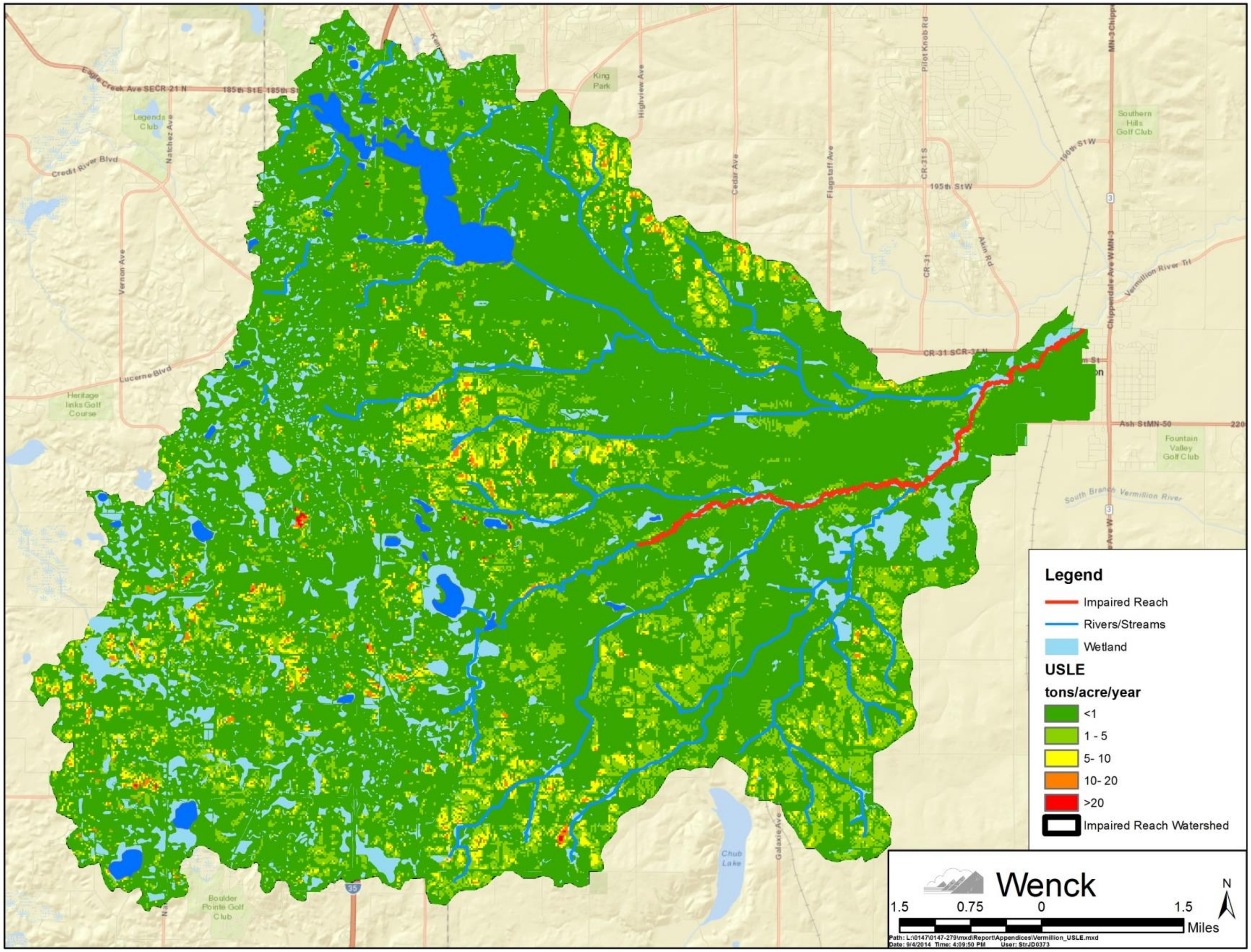


Figure 2-2. Potential upland soil loss in the impaired reach of the Vermillion River calculated using the USLE.

2.3 Streambank Sediment Loading

Landcover changes in the riparian zone may weaken streambanks by reducing or eliminating long-rooted native vegetation that strengthens and stabilizes the banks. Changes in flow regime may also destabilize streambanks that are exposed to prolonged periods of wetting or wet-dry cycles. A streambank assessment was completed to assess bank conditions as a potential source of turbidity. Reaches 517 and 527 and part of Reach 507 were walked, and erosion features were noted and measured. This data will be used to estimate the annual streambank soil loss for the turbidity TMDL.

Streambank conditions were variable, with some banks relatively stable, and others with significant slumping and sloughing, especially on outer bends. Stream bottom sediments ranged from very fine muck to small gravel, often within the same subreach. Some pools that had been observed in previous years' fish monitoring were found to be filled with sediment, and conversely, some previously filled pools were found in later years to be scoured. Aggradation, deposition, and braiding was observed on the stream walking survey, but in most locations that were assessed appeared to be associated with either bank sloughing or mass wasting or with deadfall, leaf pack, or other accumulated debris causing flow to be slowed or diverted and sediment to be deposited. To evaluate whether soil loss from streambank erosion may be contributing significantly to sediment load, South Creek Reach 527 and Reach 517 of the Vermillion were evaluated for stability and amount of observed soil loss by severity. The annual soil loss by mile by stream order was estimated, and the results extrapolated to the whole stream.

The annual soil loss was estimated using field collected data and a method developed by the Natural Resources Conservation Service referred to as the "NRCS Direct Volume Method," or the "Wisconsin method," (Wisconsin NRCS 2003). Soil loss is calculated by:

1. measuring the amount of exposed streambank in a known length of stream;
2. multiplying that by a rate of loss per year;
3. multiplying that volume by soil density to obtain the annual mass for that stream length; then
4. converting that mass into a mass per stream mile.

The Direct Volume Method is summarized in the following equation:

$$\frac{\text{(eroding area) (lateral recession rate) (density)}}{\text{2,000 lbs/ton}} = \text{erosion in tons/year}$$

Data were compiled into a spreadsheet database that summarized stream length, total eroding area, Bank Condition Severity Rating, and soil texture. The estimated recession rate was multiplied by the total eroding area to obtain the estimated total annual volume of soil loss (Table 3-1). To convert this soil loss to mass, soil texture was used to establish a volume weight for the soil. The total estimated volume of soil was multiplied by the assumed volume weight and converted into annual tons.

Table 2-1. Reaches 517 and 527 estimated streambank soil loss per year.

Reach	Survey Segment	Eroding Bank Length (feet)	Eroding Bank Height (feet)	Area of Eroding Stream-bank (ft^2)	Lateral Recession Rate (Est.) (ft/yr)	Estimated Volume (ft^3) Eroded Annually	Soil Texture	Approx. Pounds of Soil per ft^3	Est. Soil Loss (tons/ year)
517	1	250	2	500	0.08	40	Silty clay loam	80	1.60
517	1	50	4	200	0.08	16	Silty clay loam	80	0.64
517	1	10	2	20	0.10	2	Silty clay loam	80	0.08
517	1	65	2.5	162.5	0.20	32.5	Silty clay loam	80	1.30
517	1	40	2	80	0.15	12	Silty clay loam	80	0.48
517	2	18	4	72	0.10	7.2	Silt loam	85	0.31
517	2	26	2	52	0.15	7.8	Silty clay loam	80	0.31
517	2	50	2	100	0.15	15	Silty clay loam	80	0.60
517	2	70	2.5	175	0.10	17.5	Silty clay loam	80	0.70
517	2	30	1.5	45	0.20	9	Silt loam	85	0.38
517	2	40	4	160	0.20	32	Silty clay loam	80	1.28
517	2	50	2	100	0.15	15	Silt loam	85	0.64
517	2	50	3	150	0.15	22.5	Silt loam	85	0.96
517	2	75	3	225	0.15	33.75	Silt loam	85	1.43
517	3	80	3	240	0.15	36	Silt loam	85	1.53
517	4	60	5	300	0.15	45	Silt loam	85	1.91
517	4	70	3	210	0.20	42	Silt loam	85	1.79
527	1	20	3	60	0.20	12	Silty clay	70	0.42
527	1	58	4	232	0.20	46.4	Clay loam	75	1.74
527	1	50	5	250	0.20	50	Clay loam	75	1.88
527	1	22	4	88	0.30	26.4	Sandy clay	70	0.92
Total Surveyed		1,084		3,421.5		520.05		Total	20.90

Streams do experience some sediment loss per year from natural processes. According to the Wisconsin NRCS and based on their surveys of a number of streams throughout Wisconsin, a stream that is relatively undisturbed and at low risk for erosion typically experiences lateral recession of 0.01 - 0.05 feet per year. Assuming the surveyed sections detailed above were stable and experiencing 0.025 feet erosion loss per year, the total annual soil loss for those locations would be estimated as 3.46 tons per year compared to the current rate of 20.9 tons per year. The difference, or 17.44 tons per year, could be considered "excess" sediment load from streambanks in the two reaches. While this is small compared to the potential load from the watershed as described above, there appear to be localized occurrences of aggradation and braiding, pool filling and scouring. Sediment from streambank erosion may pose more of a bedded sediment issue than a significant source of excess suspended solids in the water column.

2.4 TSS Loading Conclusions

- Turbidity and TSS exceedances were greatest during very high and high flow conditions suggesting that high flow events are a primary cause streambed or field erosion; however, mid and low flow exceedances do occur throughout the dataset.

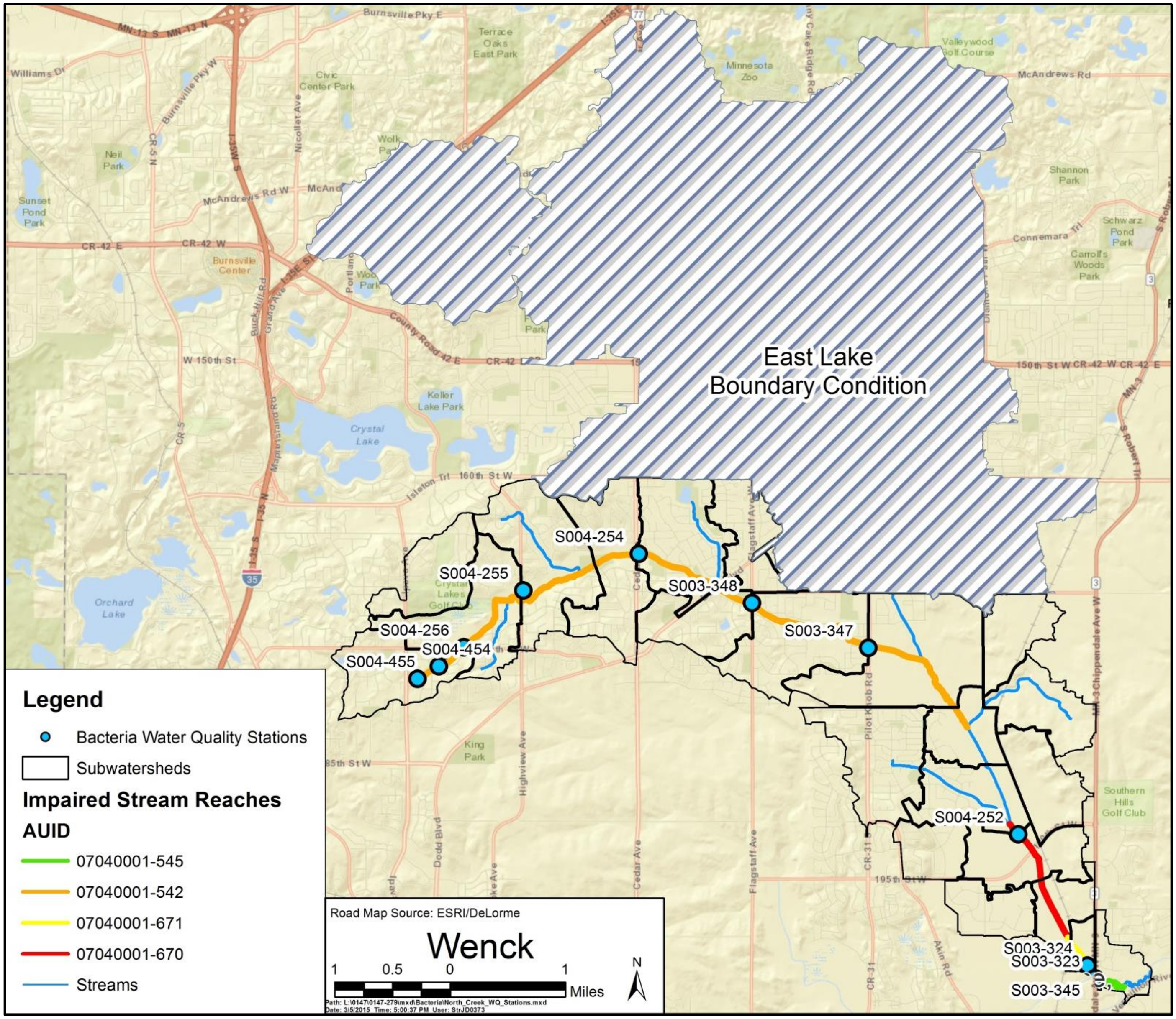
- Low average chlorophyll-a concentrations throughout the year at VR2.5 and VR1.3 indicate algal turbidity is not a primary source of turbidity in the impaired Vermillion River reach.

- South Creek has the lowest median TSS concentration of the four reaches analyzed, although it does contain a small number of exceedances. There was not a jump in TSS concentrations when comparing Vermillion River main-stem data upstream (VR2.5) and downstream (VR1.3) of South Creek. This analysis suggests that South Creek does contribute TSS to the Vermillion River impaired reach, but cannot be considered the primary source relative to the other tributaries.

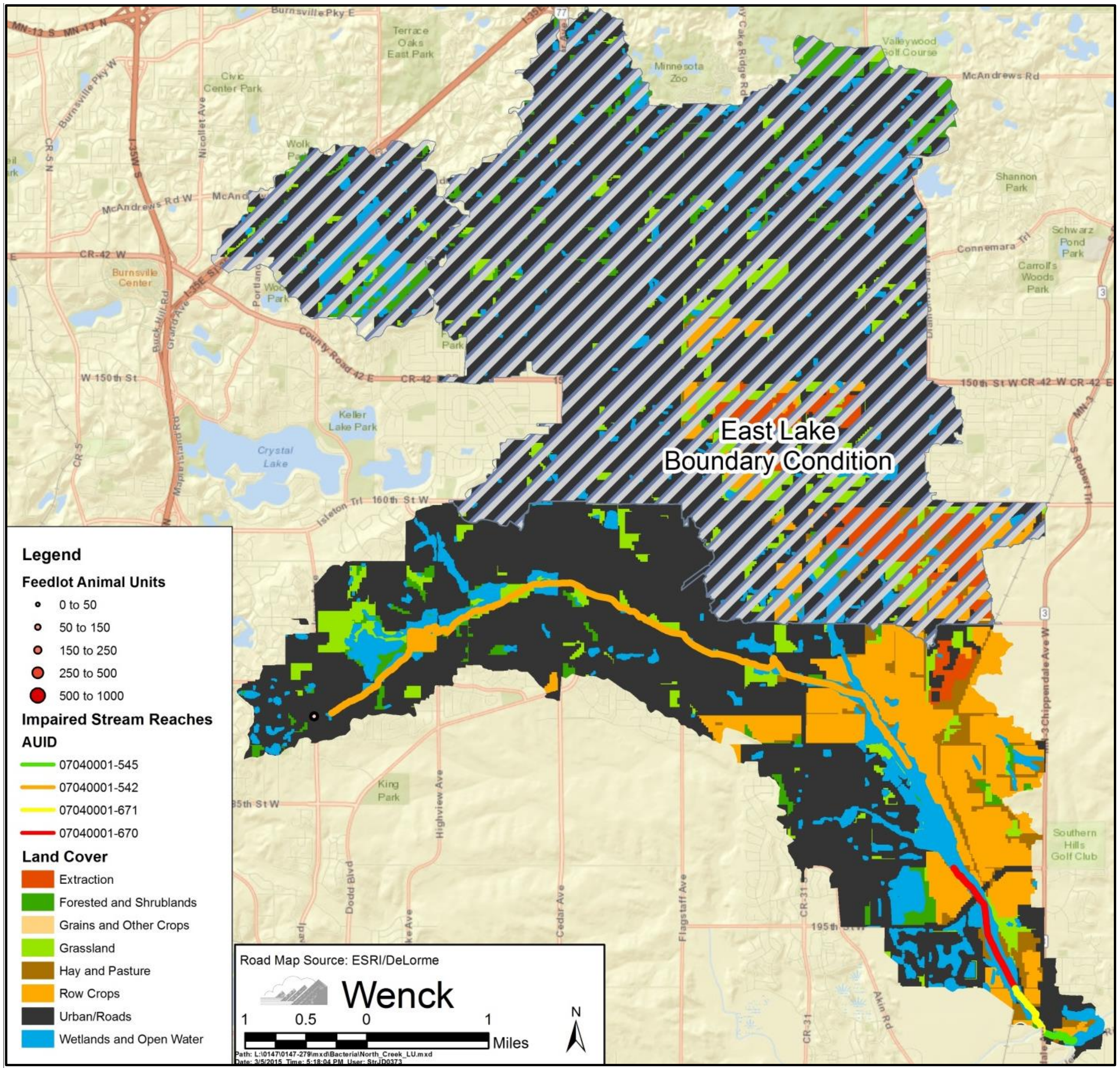
- Streambank erosion appears to deliver a small fraction of sediment to the impaired reach when compared to field erosion predicted by the USLE. In addition, the actual in-stream TSS load is an order of magnitude larger than the estimated streambank soil loss. These two lines of evidence suggest that field erosion may be the primary source of TSS to the impaired Vermillion River reach.

- There appears to be some excess sediment delivered to the stream from streambank erosion, but the annual mass is small compared to the potential load from the watershed. A stream survey and observations during fish and macroinvertebrate sampling suggest that streambank erosion appears to be associated with localized sediment aggradation, pool filling, and braiding and may be more a source of excess sediment bedload than suspended sediment.

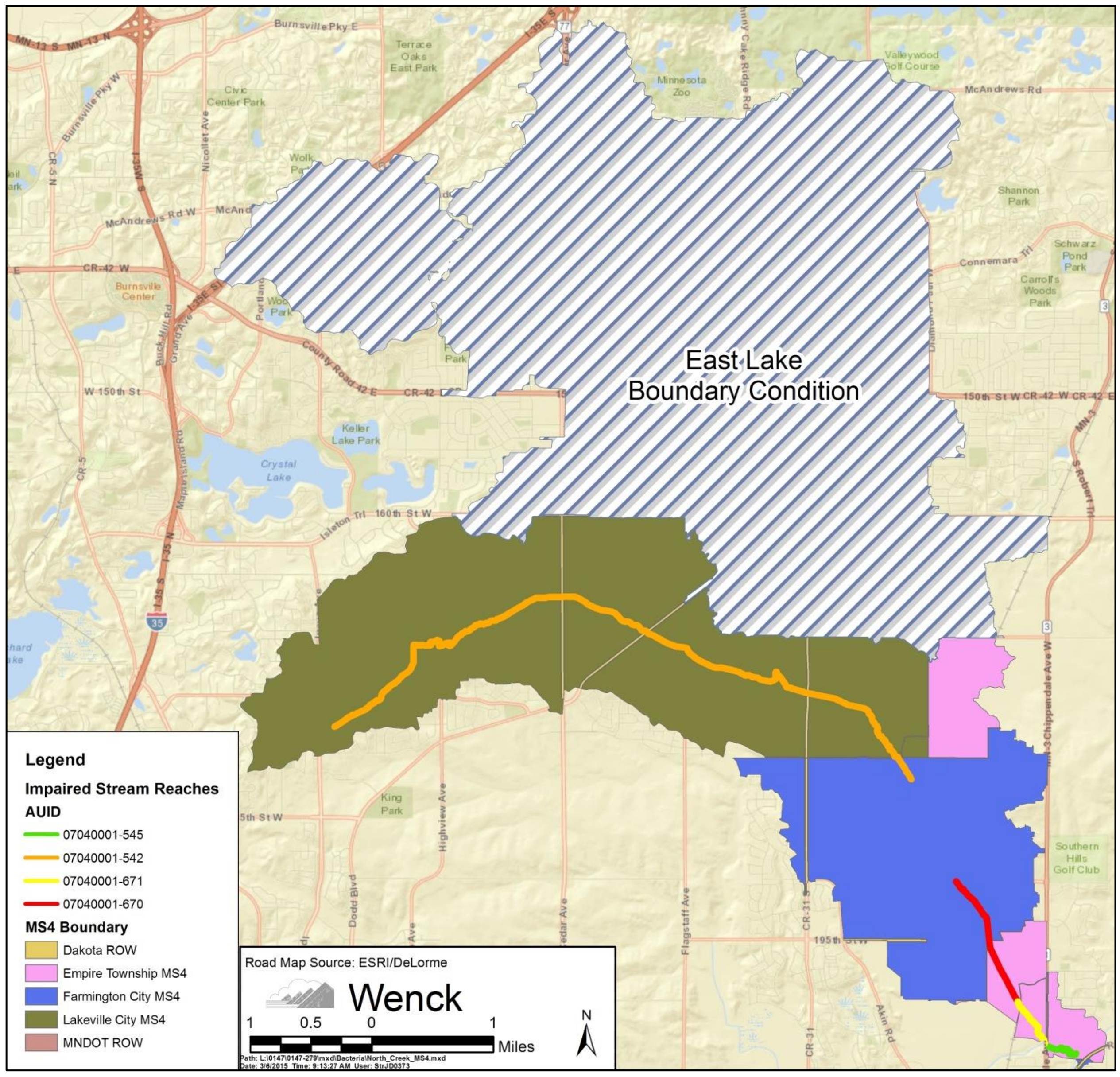
Appendix B – *E. coli* TMDL Supporting Materials



North Creek Water Quality Stations and Subwatersheds

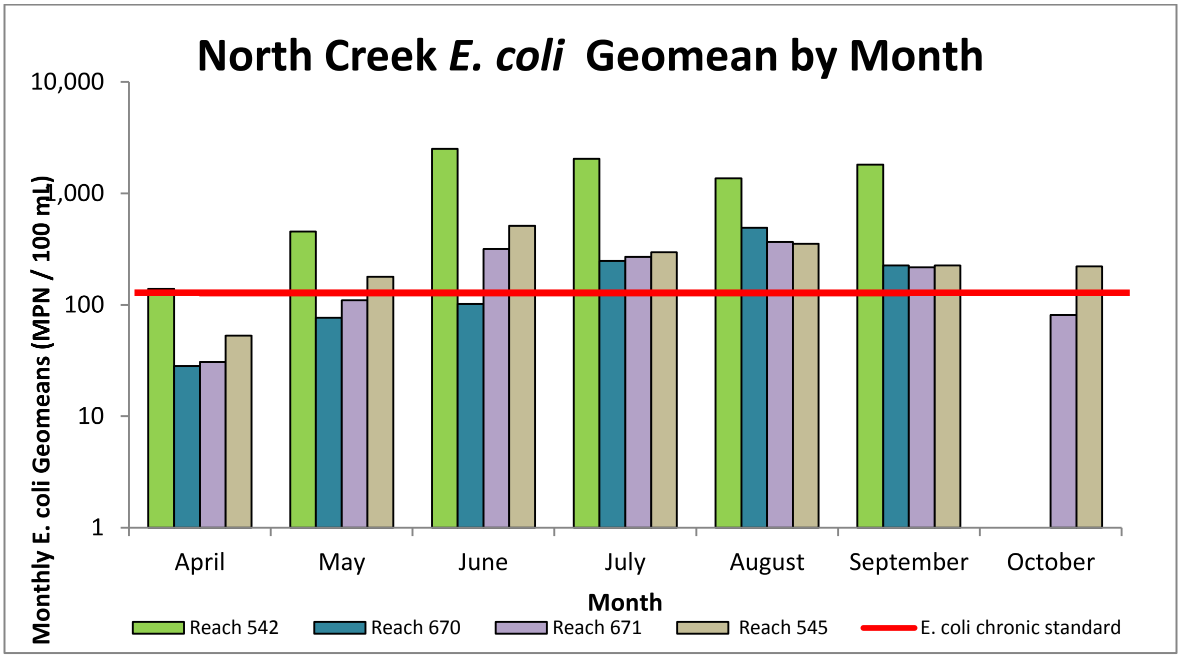


North Creek Land Cover and Feedlot Locations

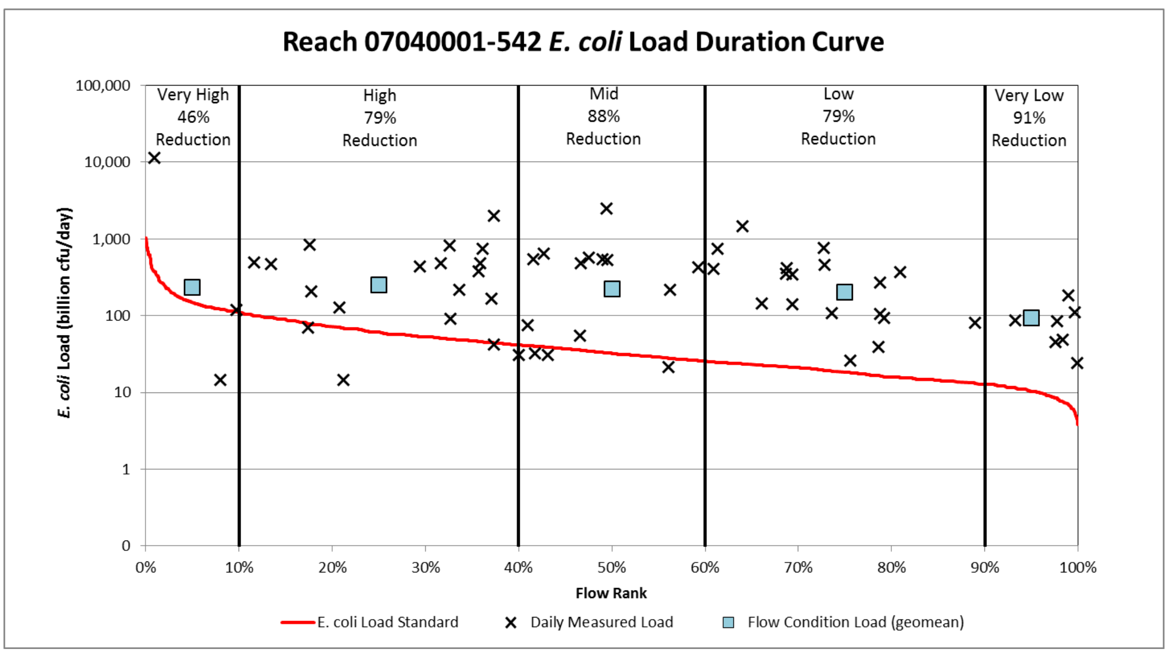


North Creek MS4 Coverage

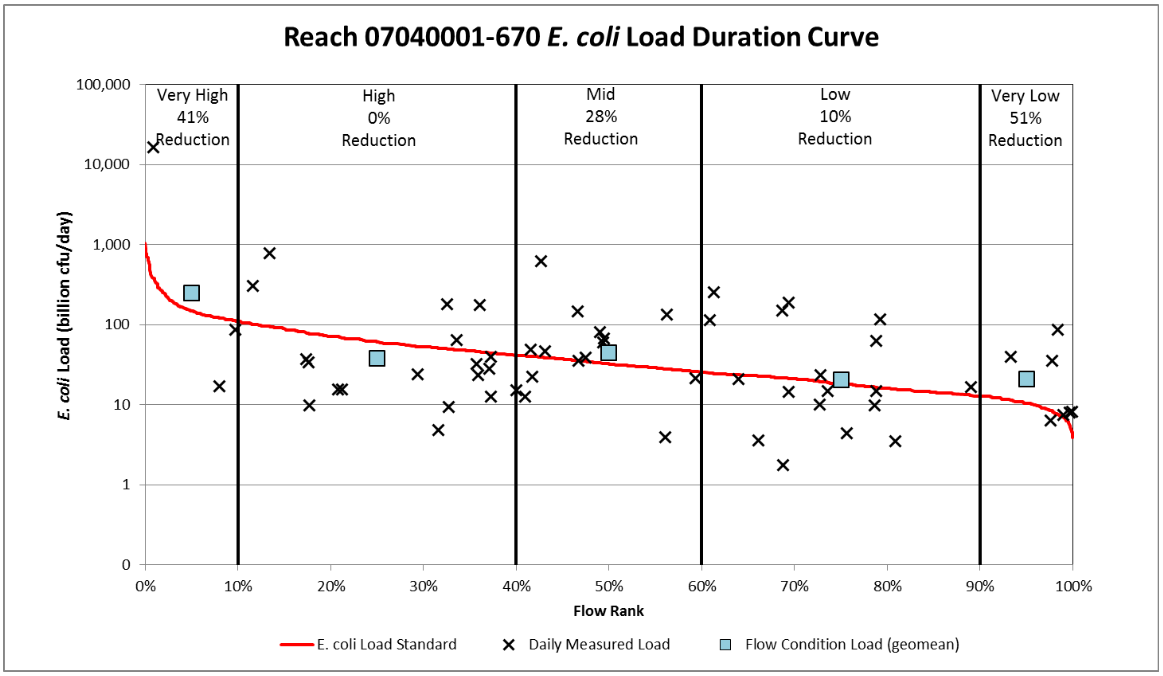
<u>North Creek *E. coli* Data</u>



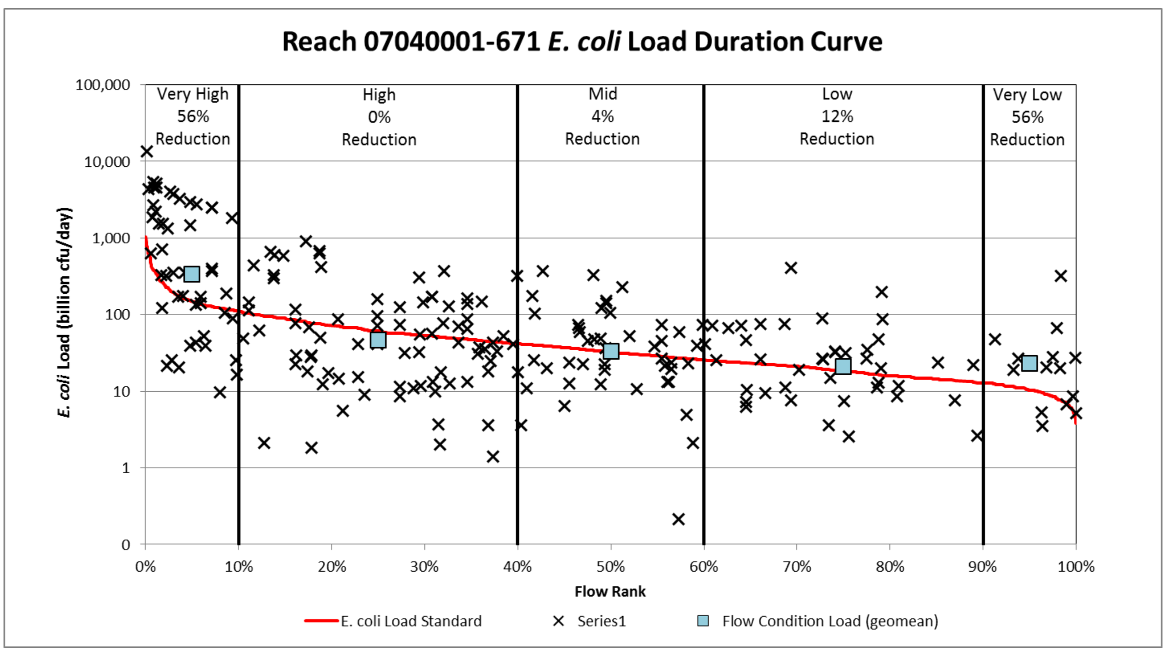
North Creek monthly geometric means relative to the chronic *E. coli* standard (126 MPN / 100 mL)



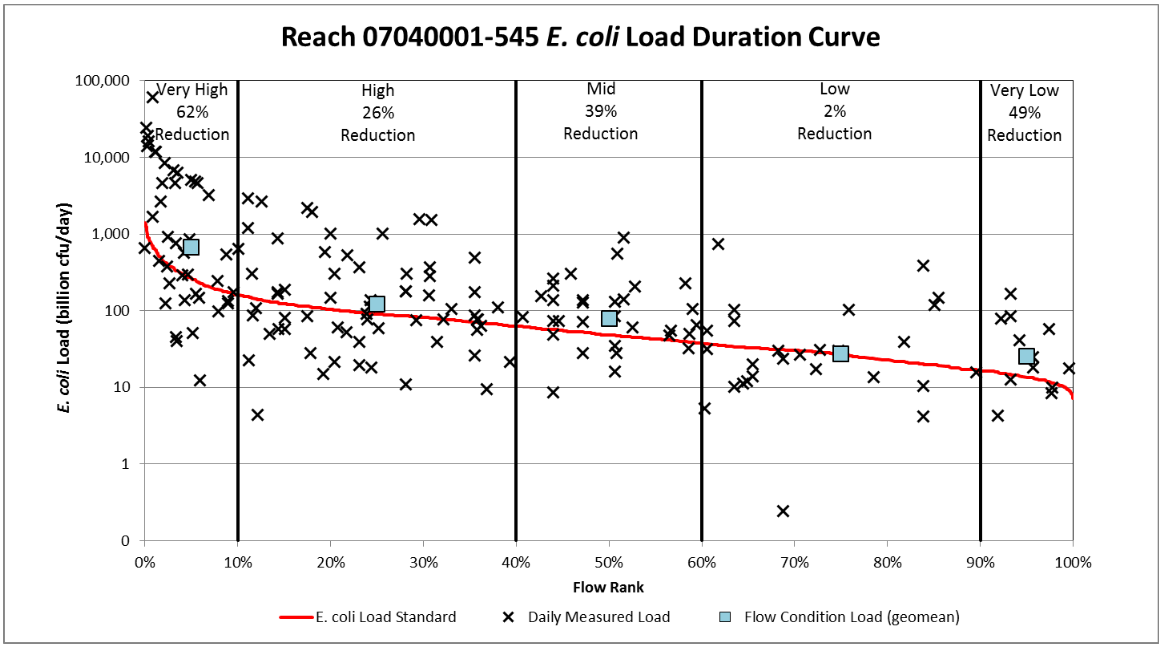
North Creek reach 07040001-542 *E. coli* load duration curve and reductions.



North Creek reach 07040001-670 *E. coli* load duration curve and reductions.



North Creek reach 07040001-671 *E. coli* load duration curve and reductions.



North Creek reach 07040001-545 *E. coli* load duration curve and reductions.

North Creek Bacteria Source Inventory

North Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/year)
Non-Failing	82	0
Failure to protect groundwater	20	0
Imminent threat to public health	3	34
Total	105	34

North Creek Fecal Coliform Production Inventory

Category	**Sub-Category**	**Animal Units or Individuals**
Livestock	Dairy	98 animal units
	Beef	0 animal units
	Swine	0 animal units
	Poultry	0 animal units
	Other (Horses & Sheep)	0 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	3 systems
	Total systems that do not discharge to surface water	102 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	262 deer
	Waterfowl (average 10 per square mile)	238 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	740 dogs and cats

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

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

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

North Creek Bacteria Delivery Assumptions

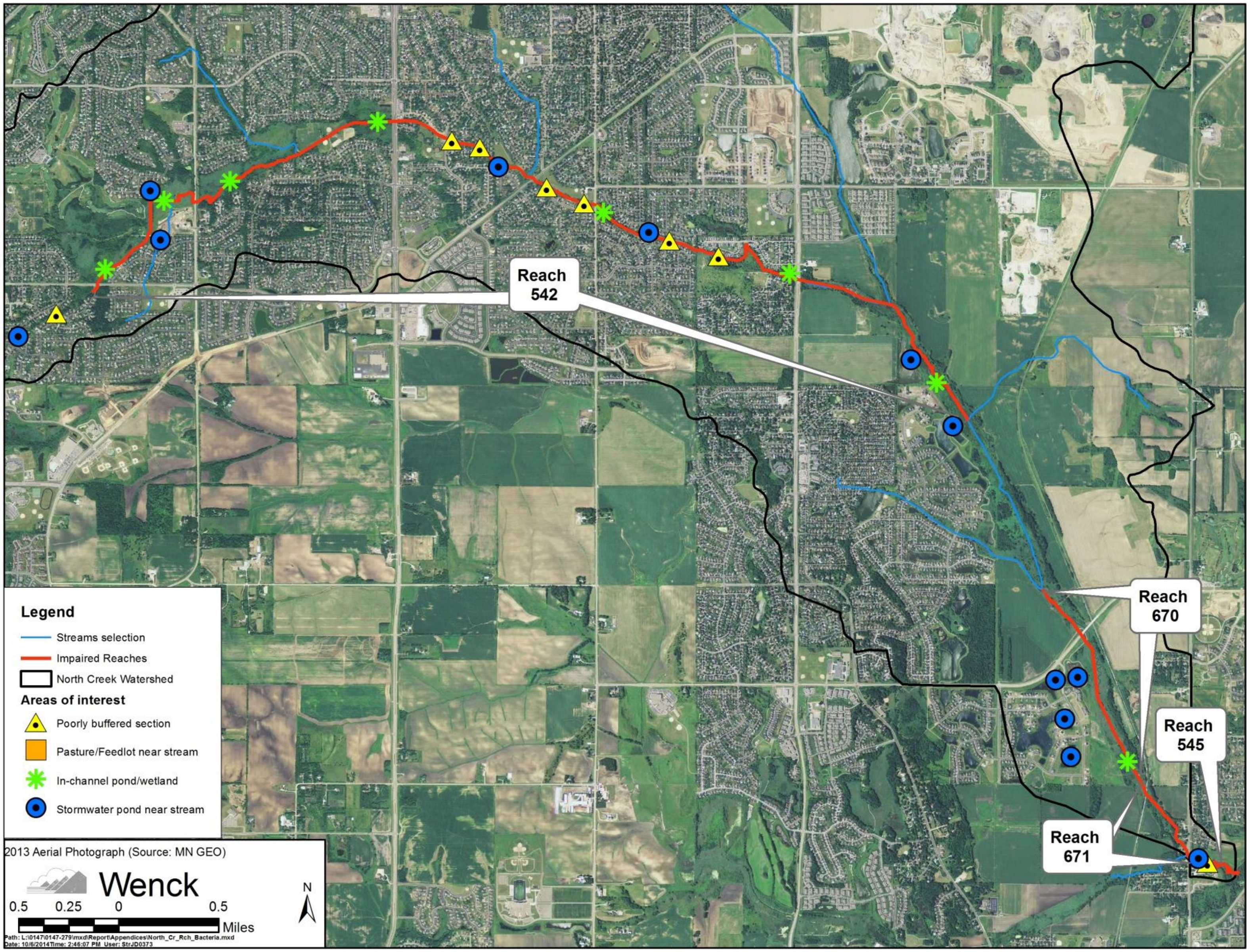
Category	**Source**	**Assumption**
Livestock	Pastures near streams or waterways	18% total of beef, dairy and other
	Runoff from Upland Pastures	49% total of beef, dairy and other
	Surface applied manure	33% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

North Creek Fecal Coliform Available for Delivery

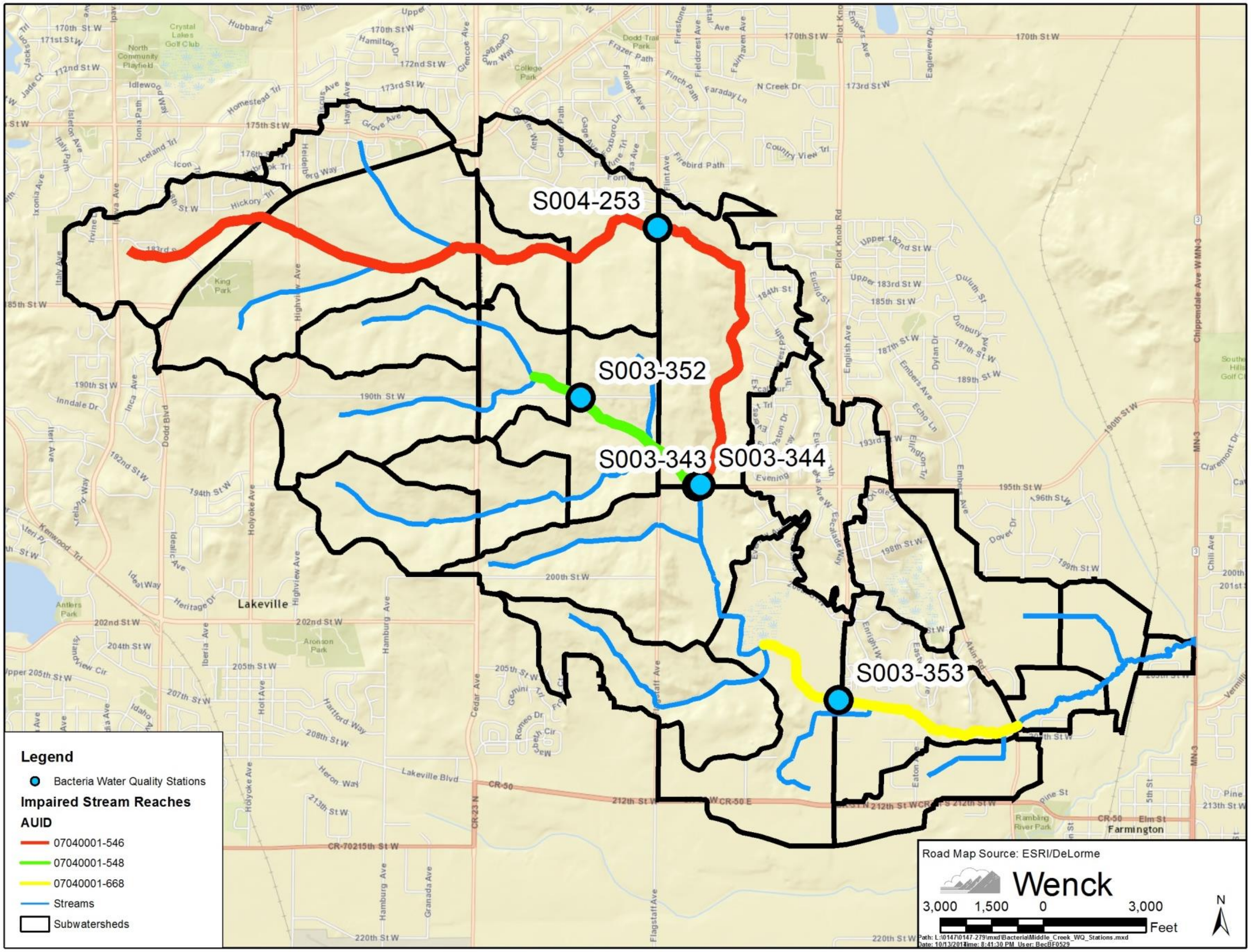
Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	1,035	1,035 (11%)
		Beef Animal Units	0	
		Other Animal Units	0	
	Runoff from Upland Pastures	Dairy Animal Units	2,767	2,767 (30%)
		Beef Animal Units	0	
		Other Animal Units	0	
	Cropland with Surface Applied Manure	Dairy Animal Units	1,901	1,901 (21%)
		Beef Animal Units	0	
		Other Animal Units	0	
Human	ITPHS septic systems and unsewered communities	Systems	34	34 (<1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	131	226 (<1%)
	Waterfowl	Geese and ducks	95	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	3,329	3,329 (35.8%)
Total				**9,292**

North Creek Bacteria Source GIS Survey

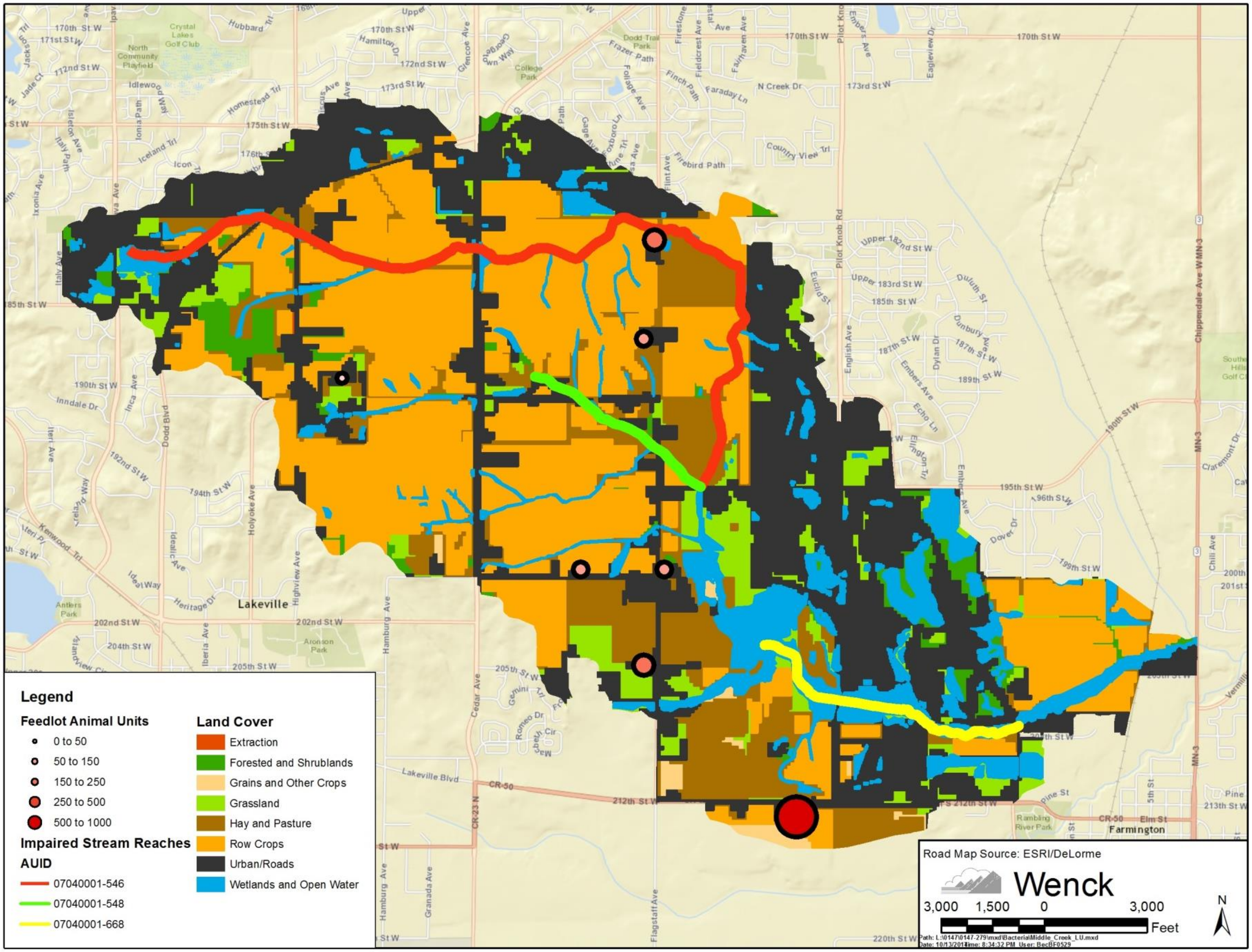
Reach	Subreach	WQ data trends	Tributaries	Adjacent Landuse					In-stream Physical Features				Overall Bacteria Loading Potential
				Golf Courses	Feedlots/ Pastures	Cropland	Urban	Stormwater Ponds	Shading	In-channel wetlands	Off-channel wetlands/lakes	Ditching	
545	Upstream start (Chippendale Ave) to end of reach (Vermillion River)	Upstream reach 542 appears to have the highest bacteria concentrations of the four North Creek Reaches. Exceedences are most frequent at very high and very low flow regimes.	None	NA	None near stream	High: poorly buffered cropland near stream on north side	Med.: Roads and houses near stream	Yes: one small pond near stream	Low: ~25% shaded	None in subreach	None near stream	Low: meandering and mostly naturally flowing	Med. Potential
671	Upstream start (railroad) to end of reach (Chippendale Ave)		None	NA	None near stream	Med.: cropland close to stream approx. 50 ft buffer on both sides	Low: low density residential nearby	None near stream	Med: ~50% shaded	None in subreach	None near stream	Low: meandering and mostly naturally flowing	Low Potential
670	Upstream start to end of reach (railroad)		None	NA	None near stream	Med.: cropland near stream but fairly well buffered	Low: low density residential nearby	Yes: 4 large ponds near stream	Low: <5% shaded	Yes: riparian wetland throughout subreach	None near stream	High: completely ditched	Med. potential
542	Pilot Knob Rd to end of reach		Tributary entering from East Lake	NA	None near stream	High: cropland near stream on both sides throughout subreach	Med.: neighborhoods nearby	Yes: 2-4 large ponds near stream	Low: no shading	Yes: riparian wetland throughout subreach	Trib from East Lake enters from north	High: completely ditched	High Potential
542	Flagstaff Ave to Pilot Knob Rd		None	NA	None near stream	No cropland near stream	High: newer homes near stream throughout subreach	Yes: a few smaller ponds near stream	Low: ~25% shaded	Yes: 2 in-channel wetlands in subreach	None near stream	High: completely ditched	Med.-Low Potential
542	Dodd Blvd to Flagstaff Ave		None	NA	None near stream	No cropland near stream	High: mostly urban and parkland near stream, poorly buffered	None near stream	Low: ~25% shaded	None in subreach	None near stream	High: completely ditched	Med. Potential
542	Cedar Ave to Dodd Blvd		Small (intermittent) trib near Dodd Blvd	NA	None near stream	No cropland near stream	High: mostly urban and parkland near stream, poorly buffered	Yes: one pond near stream	Low: ~25% shaded	None in subreach	None near stream	High: completely ditched	Med. Potential
542	Highview Ave to Cedar Ave		A couple small ditches entering subreach	NA	None near stream	No cropland near stream	Med.: mostly urban near stream, well buffered	None near stream	Low: ~25% shaded	Yes: 2 large in-channel wetlands in subreach	None near stream	High: ditched and flows through wetlands	Med.-Low Potential
542	Upstream start to Highview Ave		None	Yes, Crystal Lakes Golf Club	None near stream	Low: some cropland near stream	Med.: mostly urban near stream, well buffered	Yes: a few small ponds near stream	Low: ~10% shaded	Yes: several large wetland complexes throughout subreach	None near stream	High: completely ditched	Med.-High Potential



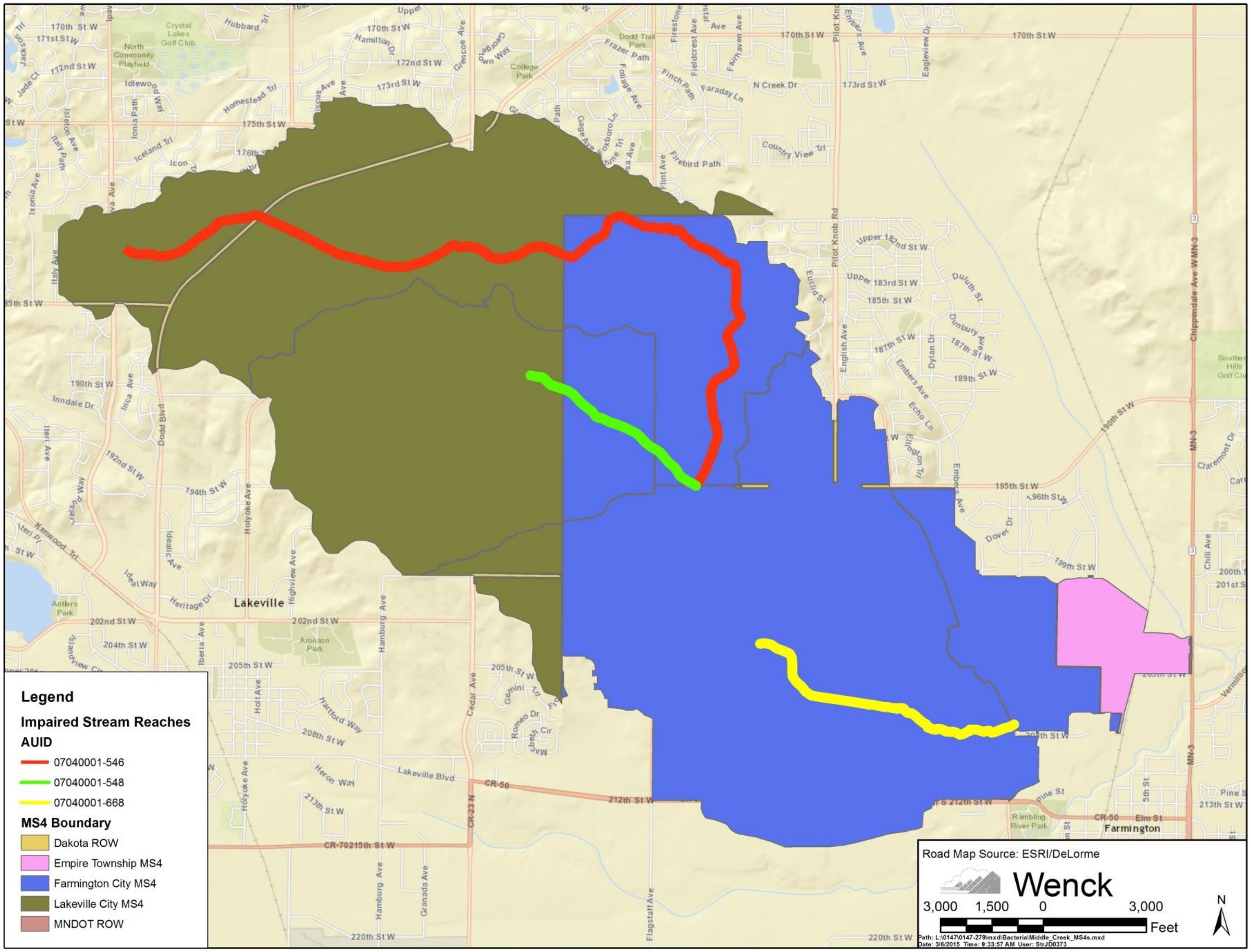
North Creek Bacteria Source GIS Survey Results



Middle Creek Water Quality Stations and Subwatersheds

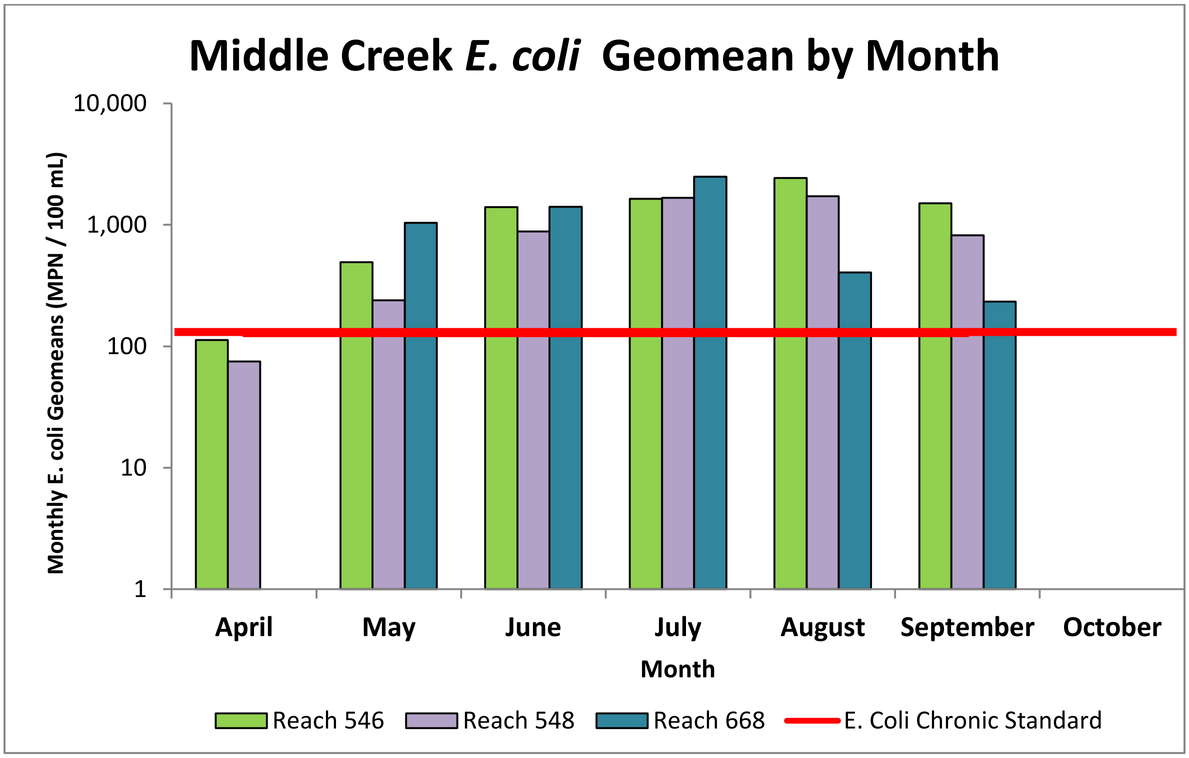


Middle Creek Land Cover and Feedlot Locations

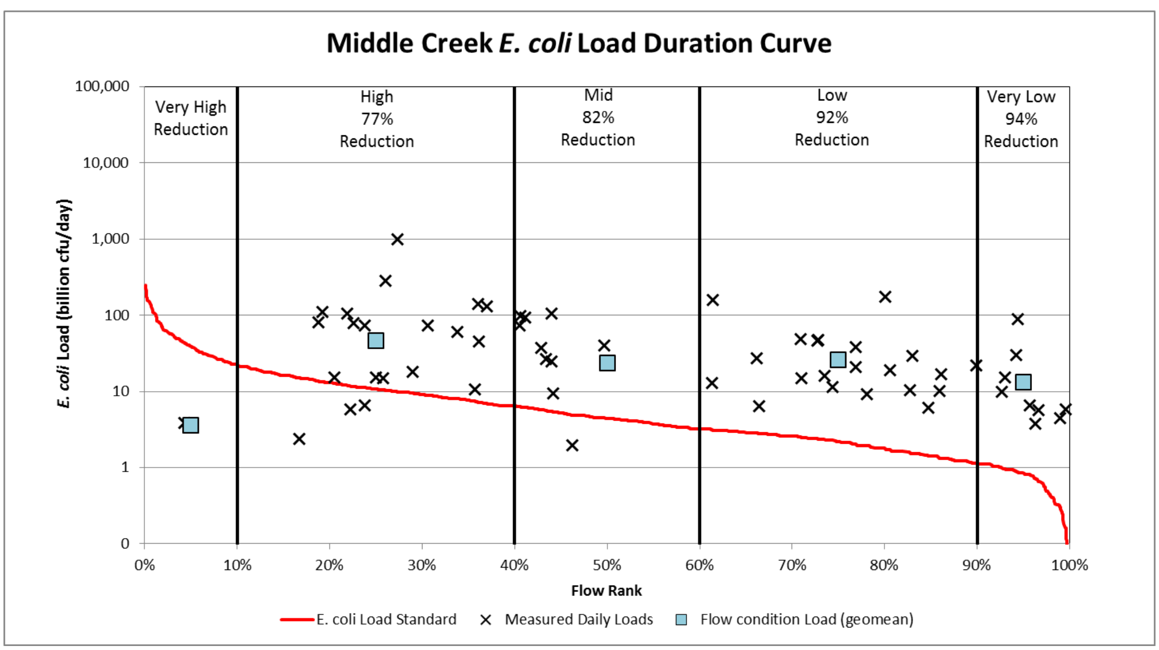


Middle Creek MS4 Coverage

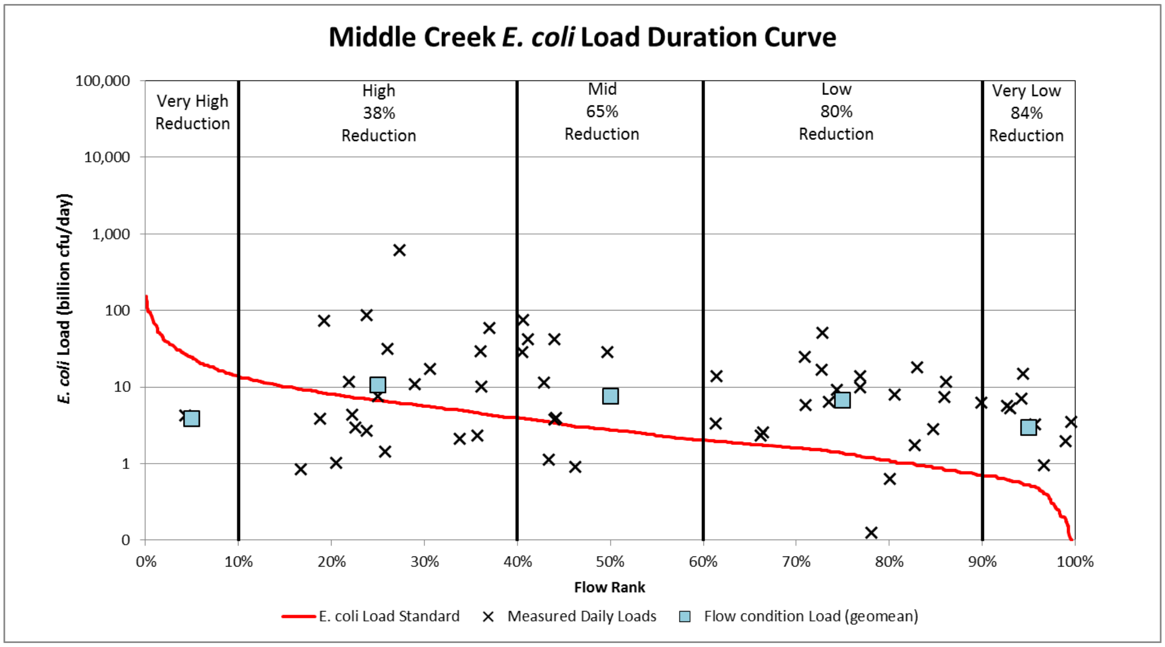
Middle Creek *E. coli* Data



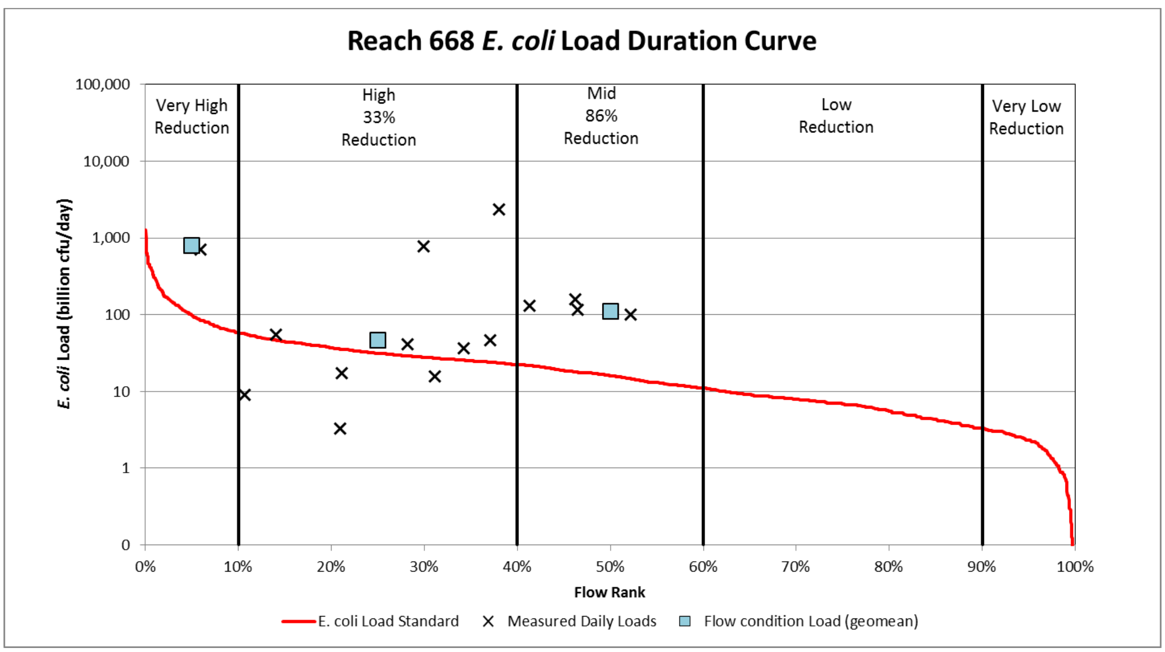
Middle Creek monthly geometric means relative to the chronic *E. coli* standard (126 MPN / 100 mL)



Middle Creek reach 07040001-546 *E. coli* load duration curve and reductions.



Middle Creek reach 07040001-548 *E. coli* load duration curve and reductions.



Middle Creek reach 07040001-668 *E. coli* load duration curve and reductions.

Middle Creek Bacteria Source Inventory

Middle Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/year)
Non-Failing	78	0
Failure to protect groundwater	14	0
Imminent threat to public health	2	25
Total	94	25

Middle Creek Fecal Coliform Production Inventory

Category	**Sub-Category**	**Animal Units or Individuals**
Livestock	Dairy	225 animal units
	Beef	1,440 animal units
	Swine	0 animal units
	Poultry	0 animal units
	Other (Horses & Sheep)	43 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	2 systems
	Total systems that do not discharge to surface water	78 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	135 deer
	Waterfowl (average 10 per square mile)	122 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	8039 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory
[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

Middle Creek Bacteria Delivery Assumptions

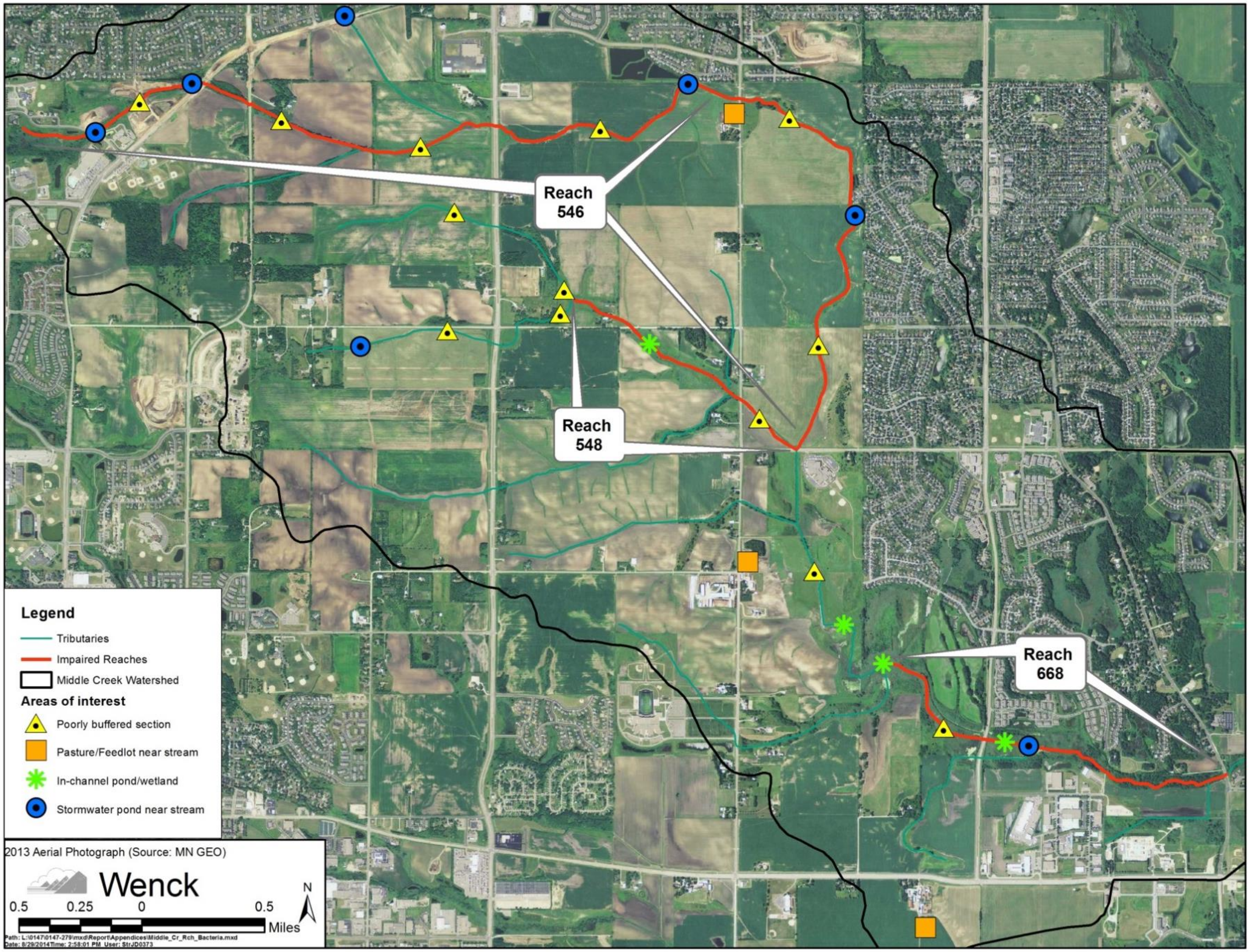
Category	**Source**	**Assumption**
Livestock	Pastures near streams or waterways	5% total of beef, dairy and other
	Runoff from Upland Pastures	61% total of beef, dairy and other
	Surface applied manure	33% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

Middle Creek Fecal Coliform Available for Delivery

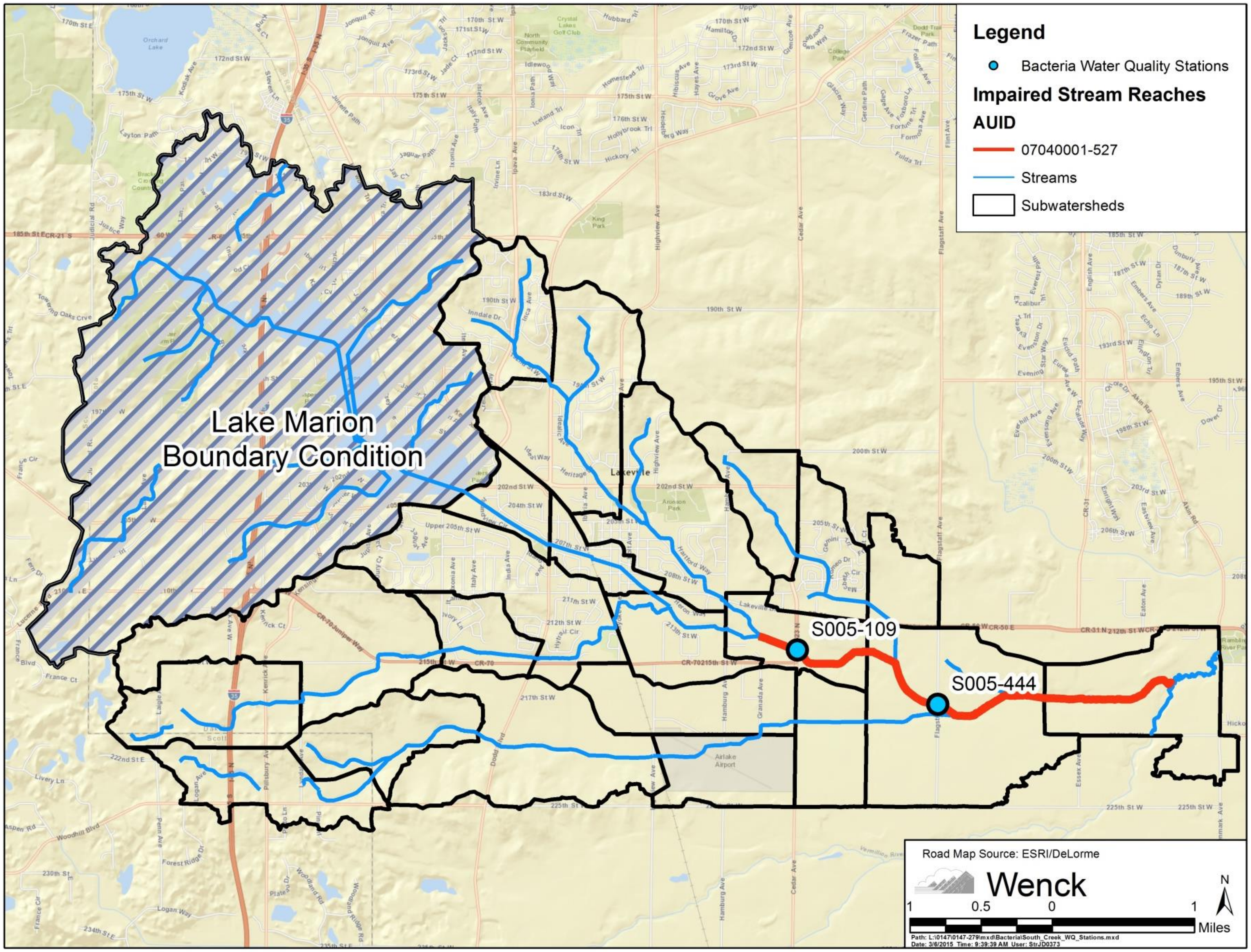
Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	692	7,599 (5%)
		Beef Animal Units	6,775	
		Other Animal Units	132	
	Runoff from Upland Pastures	Dairy Animal Units	8,038	88,335 (60%)
		Beef Animal Units	78,761	
		Other Animal Units	1,536	
	Cropland with Surface Applied Manure	Dairy Animal Units	4,365	47,967 (33%)
		Beef Animal Units	42,768	
		Other Animal Units	834	
Human	ITPHS septic systems and unsewered communities	Systems	25	25 (<1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	135	232 (<1%)
	Waterfowl	Geese and ducks	98	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	3,618	3,618 (2%)
Total				**147,776**

Middle Creek Bacteria Source GIS Survey

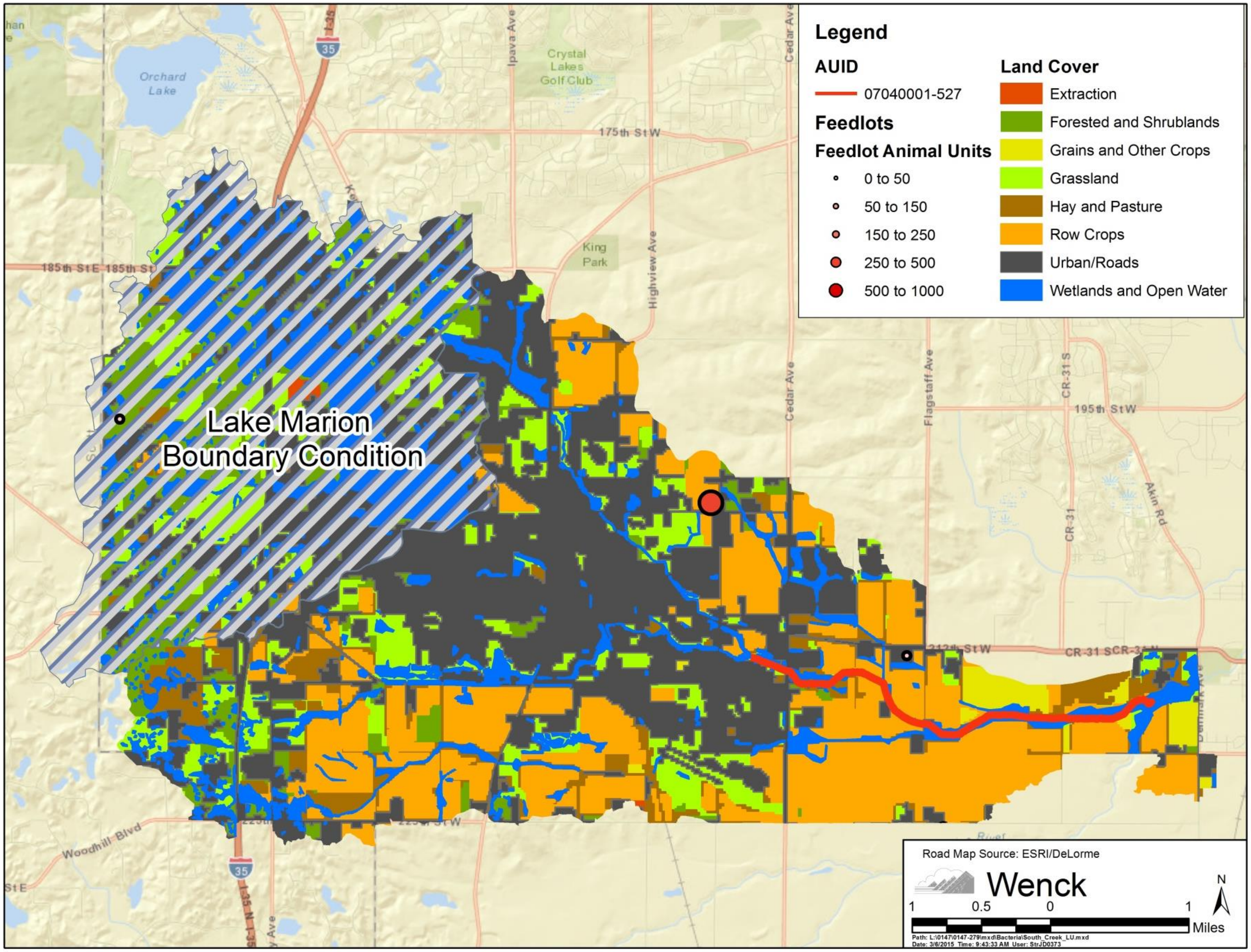
Reach	Subreach	WQ data trends	Tributaries	Adjacent Landuse					In-stream Physical Features				Overall Bacteria Loading Potential
				Golf Courses	Feedlots/ Pastures	Cropland	Urban	Stormwater Ponds	Shading	In-channel wetlands	Off-channel wetlands/lakes	Ditching	
548	Flagstaff Ave to end of reach (195th St)	All reaches had similar *E. coli* concentrations. Exceedances occurred most often during mid to very-low flow regimes.	No major tribs	NA	High: Small feedlot just north of stream, poorly buffered	High: cropland on both sides of stream, ~20 ft buffer	Low: some roadways near reach	None near stream	Low: no shading	None	None near stream	Yes: heavily ditched	High Potential
548	Upstream start to Flagstaff Ave		No major tribs	NA	High: hay/pasture near stream, poorly buffered	Med.: cropland on both sides of stream, hay/pasture and wetland buffer	Low: some roads and farmsteads near stream	None near stream	Low: no shading	Yes: small in-channel emergent wetlands near 190th St	None near stream	Yes: heavily ditched	High Potential
548	Drainage area upstream of impaired reach		A few small tribs	NA	High: Large pasture near stream	High: cropland on both sides of stream	Low: some roads and farmsteads near stream	None near stream	Low: ~10 shaded	None	None near stream	Yes: heavily ditched	High Potential
546	Flagstaff Ave to end of reach (195th St)		No major tribs	NA	None near stream	High: cropland and hay fields on both sides of stream, poorly buffered	Med.: new development ~500 east of stream	Yes: 3-4 SW ponds near stream	Low: no shading	None	None near stream	Yes: heavily ditched	Med.-High Potential
546	Cedar Ave to Flagstaff Ave		No major tribs	NA	High: large feedlot near stream (Flagstaff Ave)	High: cropland near stream throughout reach, poorly buffered	Med.: new development near stream	Yes: a few large SW ponds near stream	Low: no shading	None	None near stream	Yes: heavily ditched	High Potential
546	Highview Ave to Cedar Ave		Trib from north drains urban land and SW ponds	NA	None near stream	High: cropland near stream throughout reach, poorly buffered	Low: none near stream, tribs draining urban land from north	None near stream	Low: <10% shading	None	None near stream	Yes: heavily ditched	Med. Potential
546	Upstream start to Highview Ave		No major tribs	NA	None near stream	High: cropland and hay fields on both sides of stream, poorly buffered	High: development near stream	Yes: numerous SW ponds near stream	Low: 10-20% shaded	None	None near stream	Yes: heavily ditched	Med.-Hgh Potential
668	Pilot Knob Rd to end of reach (Akin Rd)		Small trib from south draining ag. land	NA	None near stream	Med.: Small area of row crops south of stream	Med.: moderate development near stream	Yes: numerous SW ponds near stream	Med.: 40-60% shaded	Yes: small in-channel wetland	None near stream	Yes: heavily ditched	Med. Potential
668	Upstream start to Pilot Knob Rd		A few small ditches entering subreach	NA	High: large feedlot near trib, poorly buffered	Med.: cropland in areas near stream, poorly buffered	Low: some development in area, but not near stream	Yes: a few SW ponds near stream	Low: <10% shading	Yes: large in-channel wetland	None near stream	Yes: heavily ditched	High Potential



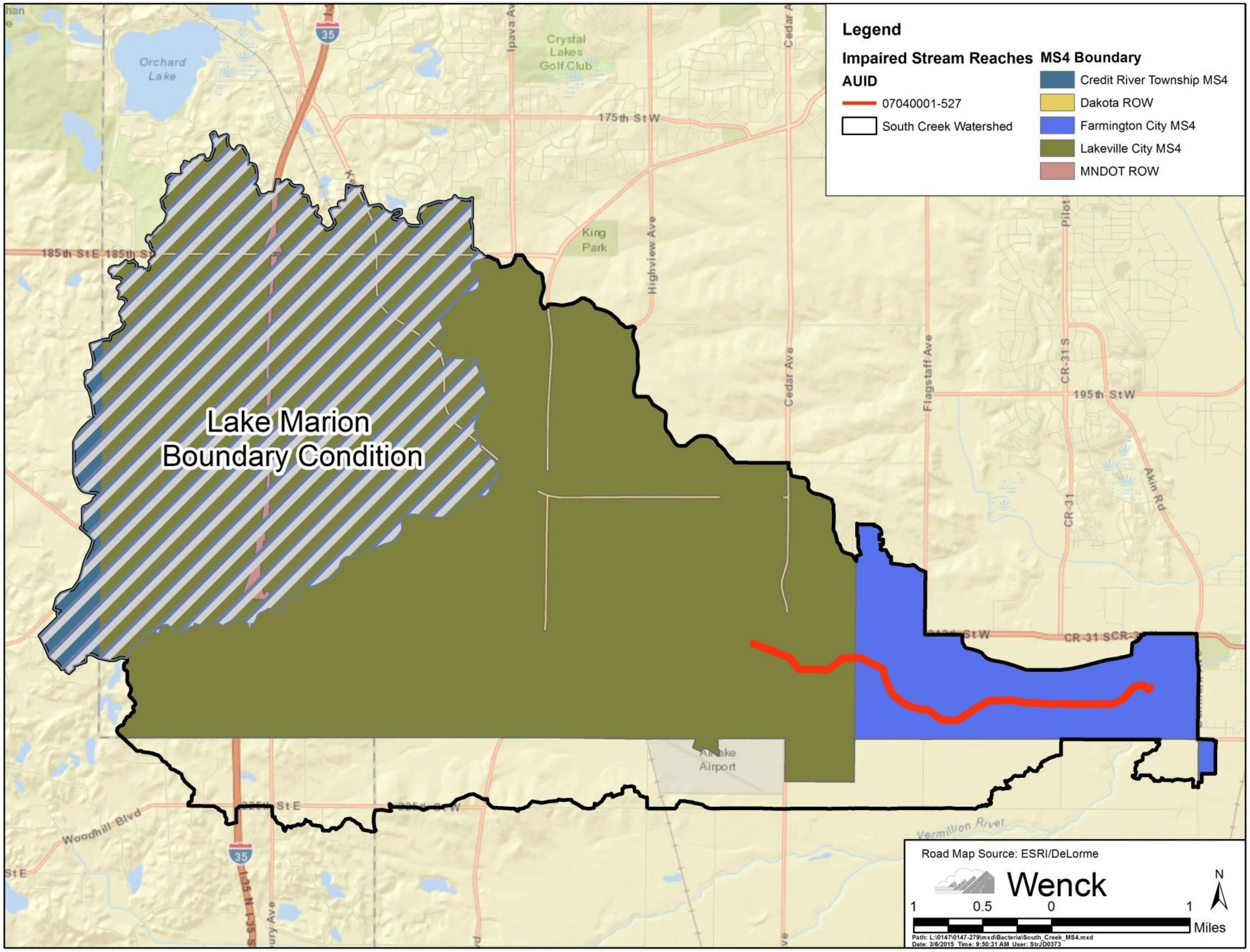
Middle Creek Bacteria Source GIS Survey Results.



South Creek Water Quality Stations and Subwatersheds

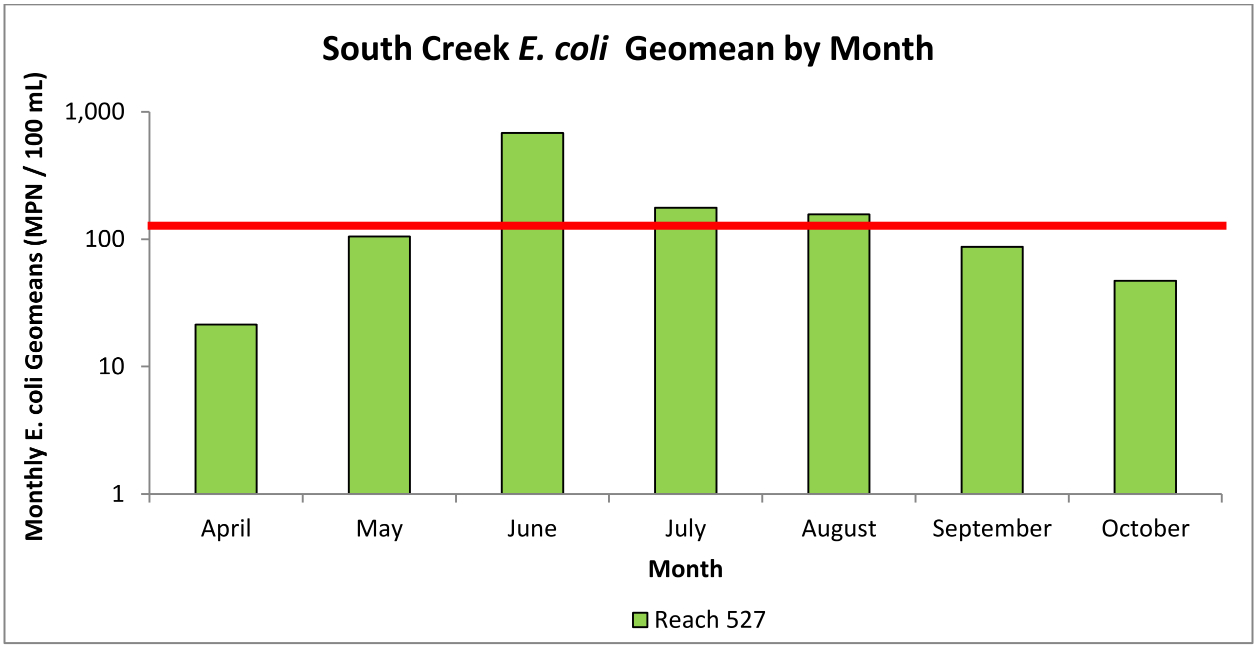


South Creek Land Cover and Feedlot Locations

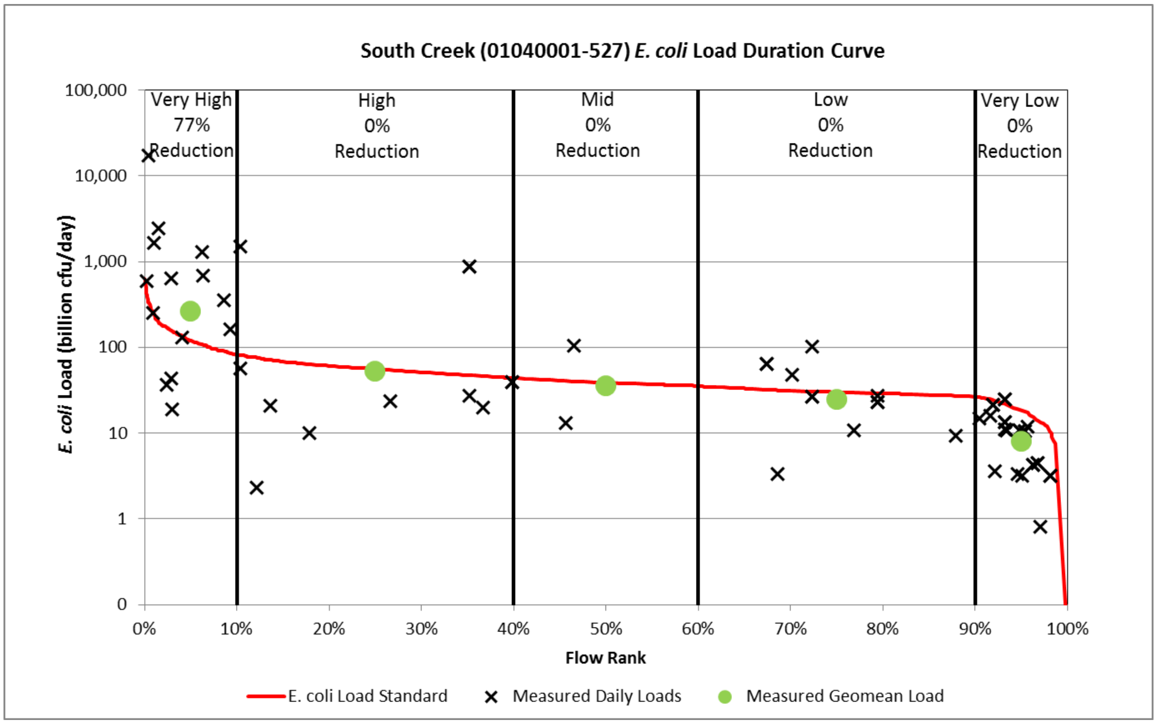


South Creek MS4 Coverage

<u>South Creek *E. coli* Data</u>



South Creek monthly geometric means relative to the chronic *E. coli* standard (126 MPN / 100 mL)



South Creek reach 07040001-527 *E. coli* load duration curve and reductions.

South Creek Bacteria Source Inventory

South Creek Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/year)
Non-Failing	216	0
Failure to protect groundwater	53	0
Imminent threat to public health	9	102
Total	278	102

South Creek Fecal Coliform Production Inventory

Category	**Sub-Category**	**Animal Units or Individuals**
Livestock	Dairy	254 animal units
	Beef	0 animal units
	Swine	0 animal units
	Poultry	0 animal units
	Other (Horses & Sheep)	49 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	9 systems
	Total systems that do not discharge to surface water	225 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	252 deer
	Waterfowl (average 10 per square mile)	229 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	8,274 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory
[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

South Creek Bacteria Delivery Assumptions

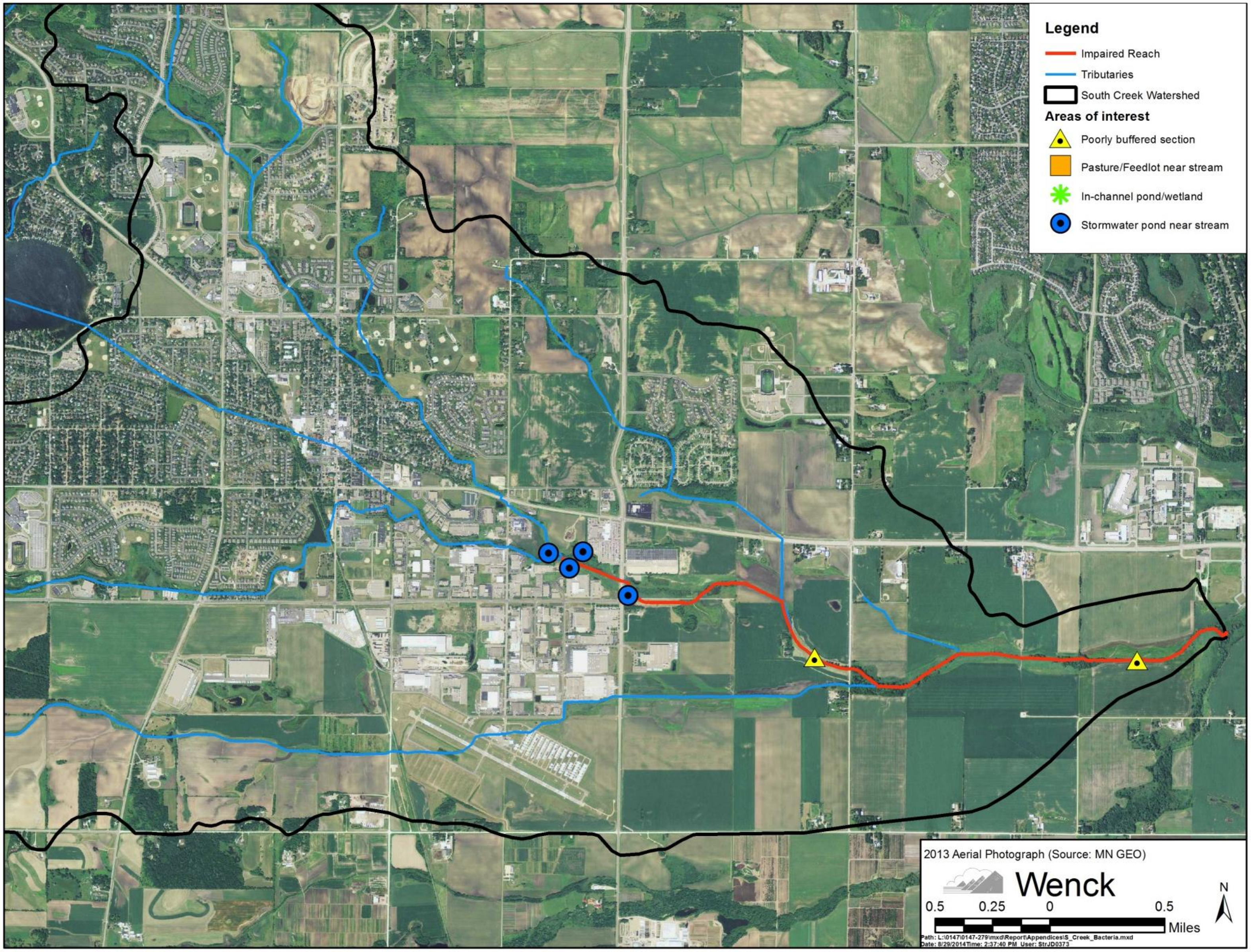
Category	**Source**	**Assumption**
Livestock	Pastures near streams or waterways	2% total of beef, dairy and other
	Runoff from Upland Pastures	65% total of beef, dairy and other
	Surface applied manure	33% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

South Creek Fecal Coliform Available for Delivery

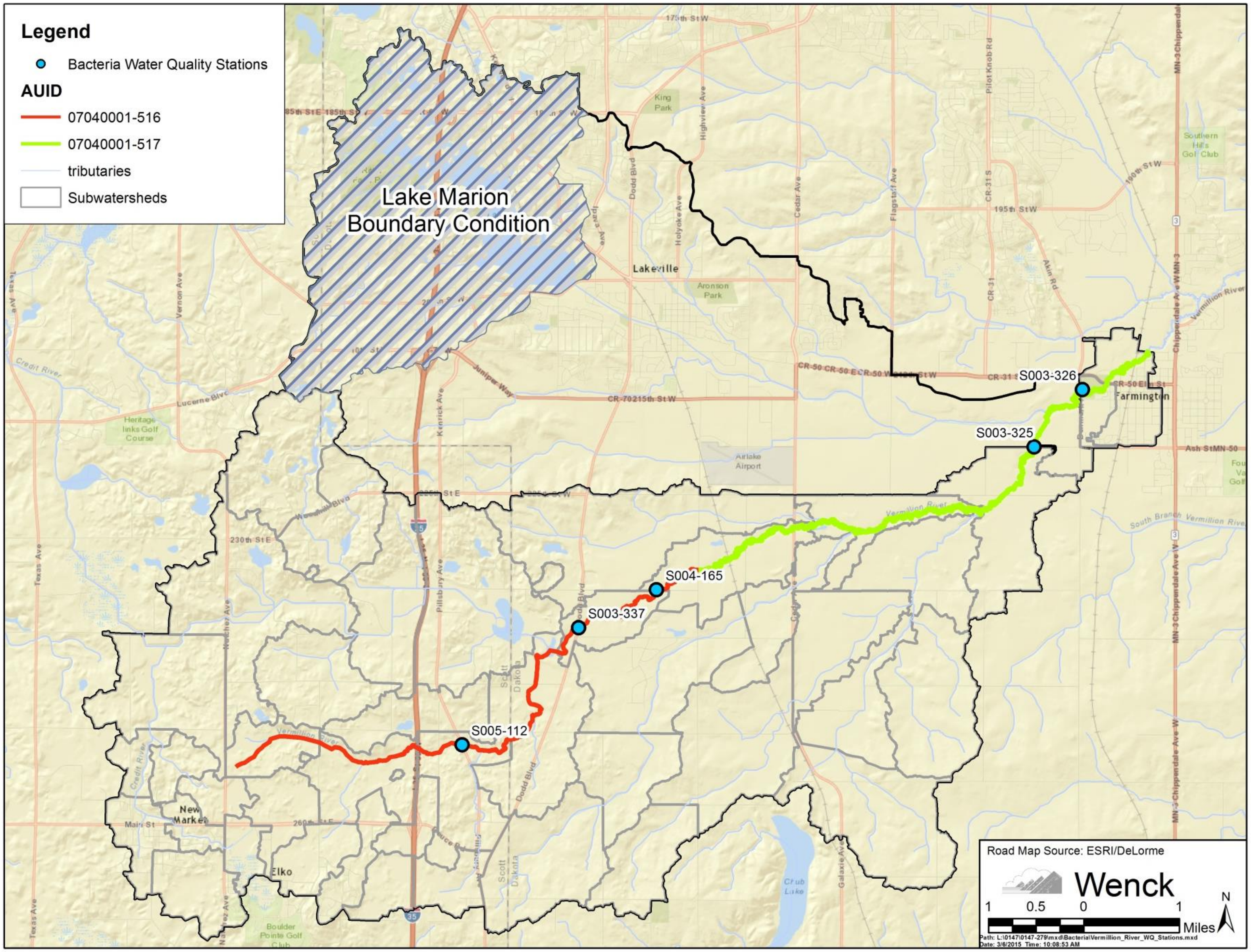
Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	108	108 (1%)
		Beef Animal Units	0	
		Other Animal Units	0	
	Runoff from Upland Pastures	Dairy Animal Units	3,694	3,694 (37%)
		Beef Animal Units	0	
		Other Animal Units	0	
	Cropland with Surface Applied Manure	Dairy Animal Units	1,901	1,901 (19%)
		Beef Animal Units	0	
		Other Animal Units	0	
Human	ITPHS septic systems and unsewered communities	Systems	102	102 (1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	252	436 (4%)
	Waterfowl	Geese and ducks	184	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	3,723	3,723 (37%)
Total				**9,964**

South Creek Bacteria Source GIS Survey

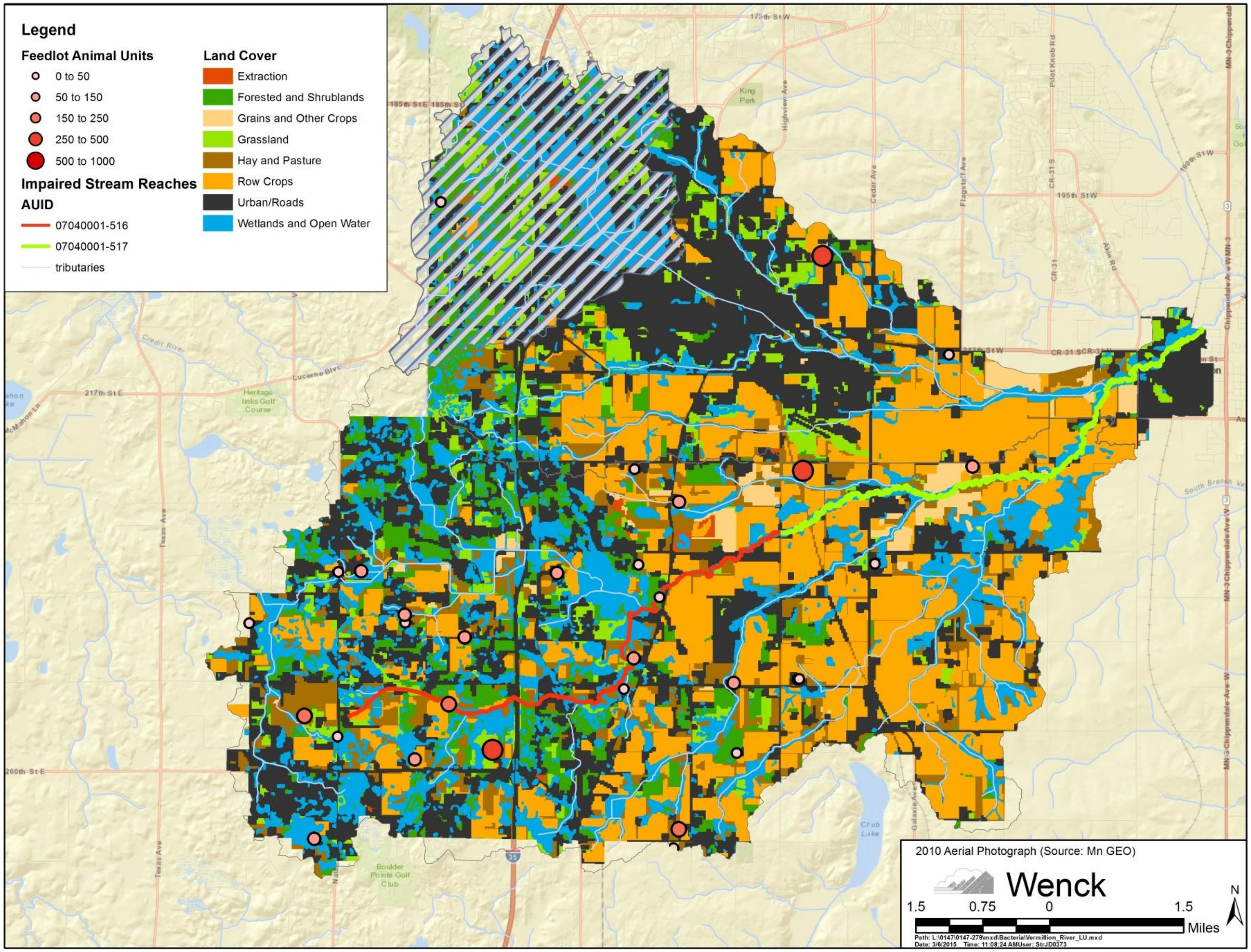
Reach	Subreach	WQ data	Tributaries	Adjacent Landuse					In-stream Physical Features				Overall Bacteria Loading Potential
				Golf Courses	Feedlots/ Pastures	Cropland	Urban	Stormwater Ponds	Shading	In-channel wetlands	Off-channel wetlands/lakes	Ditching	
527	Entire impaired reach	Exceedances occurred primarily during high flow regimes.	3 entering impaired reach draining mix of industrial and cropland	NA	Med.: large feedlot north of impaired reach	High: Cropland near stream throughout entire subreach	Med.: transitions from urban (upstream) to agriculture (downstream)	Med.: several ponds in upper part of subreach	Low: ~15% shaded	None in subreach	None in subreach	High: heavily ditched	High Potential



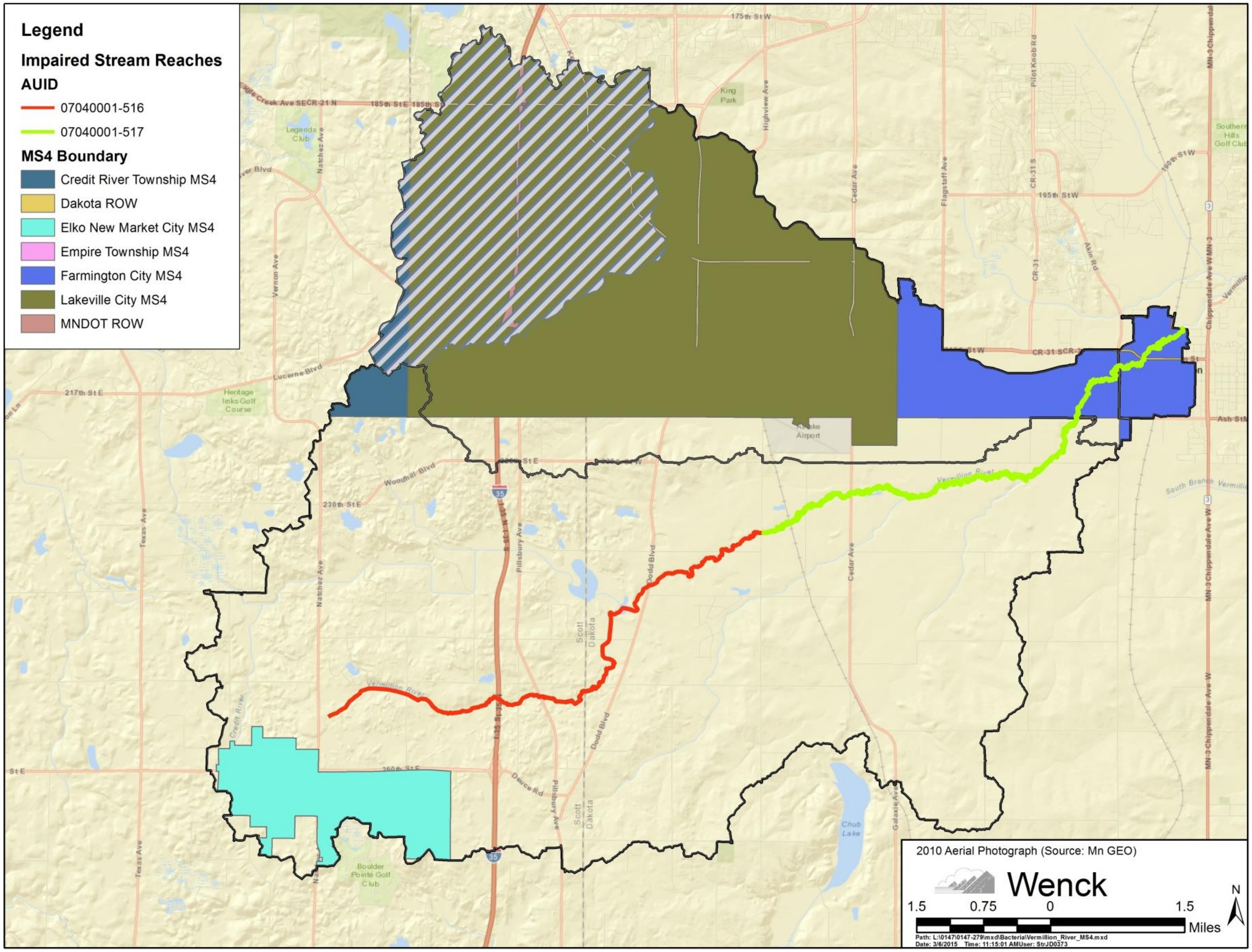
South Creek Bacteria Source GIS Survey Results.



Vermillion River Water Quality Stations and Subwatersheds

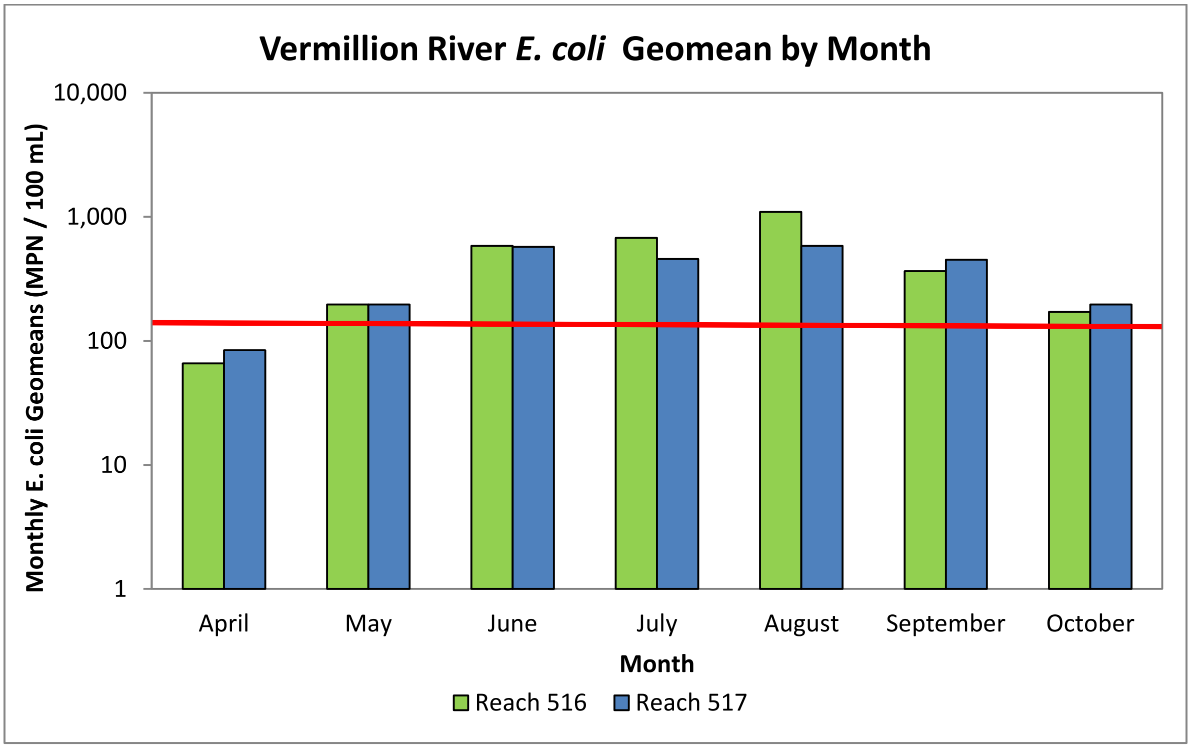


Vermillion River Land Cover and Feedlot Location

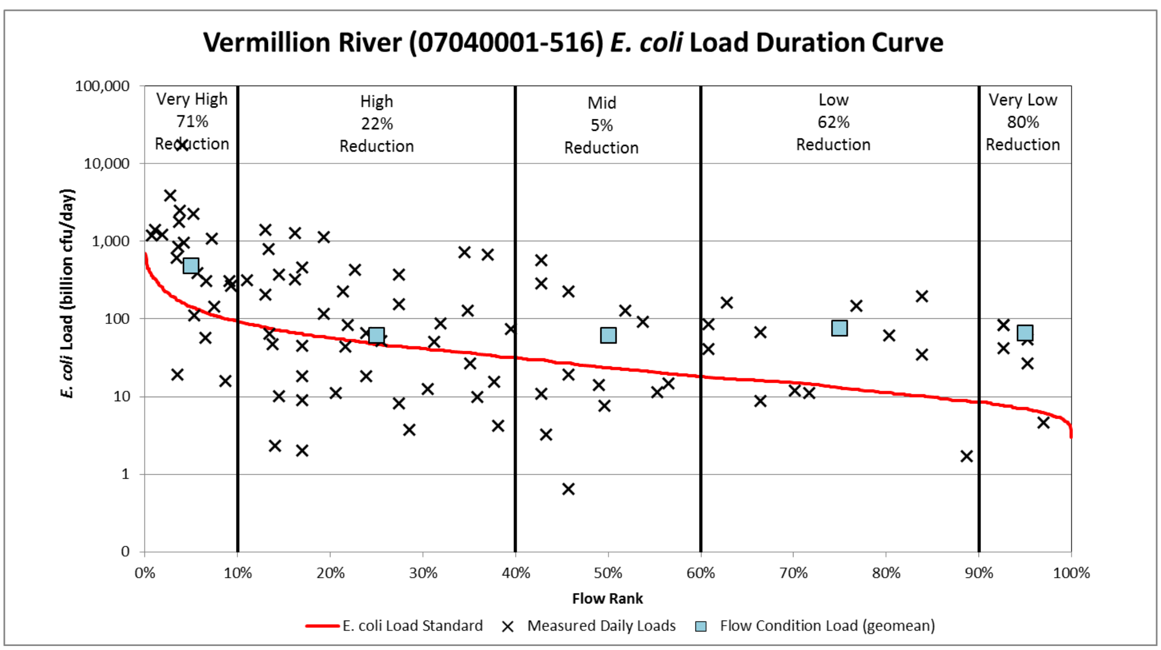


Vermillion River MS4 Coverage

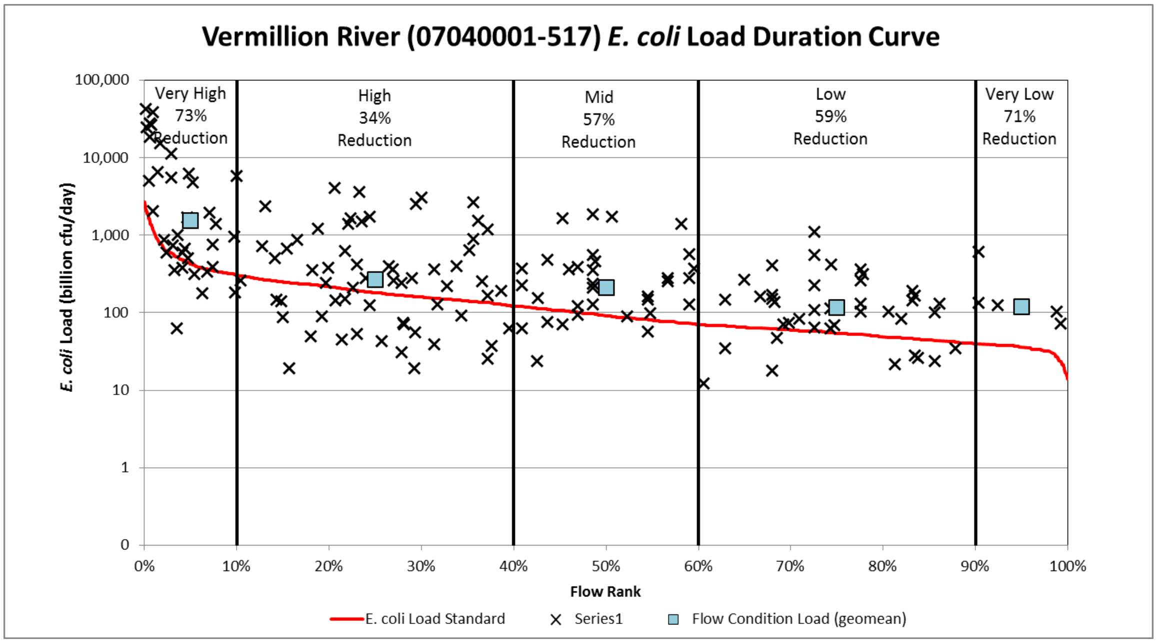
Vermillion River *E. coli* Data



Vermillion River monthly geometric means relative to the chronic *E. coli* standard (126 MPN / 100 mL)



Vermillion River reach 07040001-516 *E. coli* load duration curve and reductions.



Vermillion River reach 07040001-517 *E. coli* load duration curve and reductions.

Vermillion River Bacteria Source Inventory

Vermillion River Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/year)
Non-Failing	1,107	0
Failure to protect groundwater	126	0
Imminent threat to public health	25	286
Total	1,258	286

Vermillion River Fecal Coliform Production Inventory

Category	Sub-Category	Animal Units or Individuals
Livestock	Dairy	918 animal units
	Beef	543 animal units
	Swine	30 animal units
	Poultry	0 animal units
	Other (Horses & Sheep)	63 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	25 systems
	Total systems that do not discharge to surface water	1234 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	228 deer
	Waterfowl (average 10 per square mile)	208 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	3,628 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory
[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

Vermillion River Bacteria Delivery Assumptions

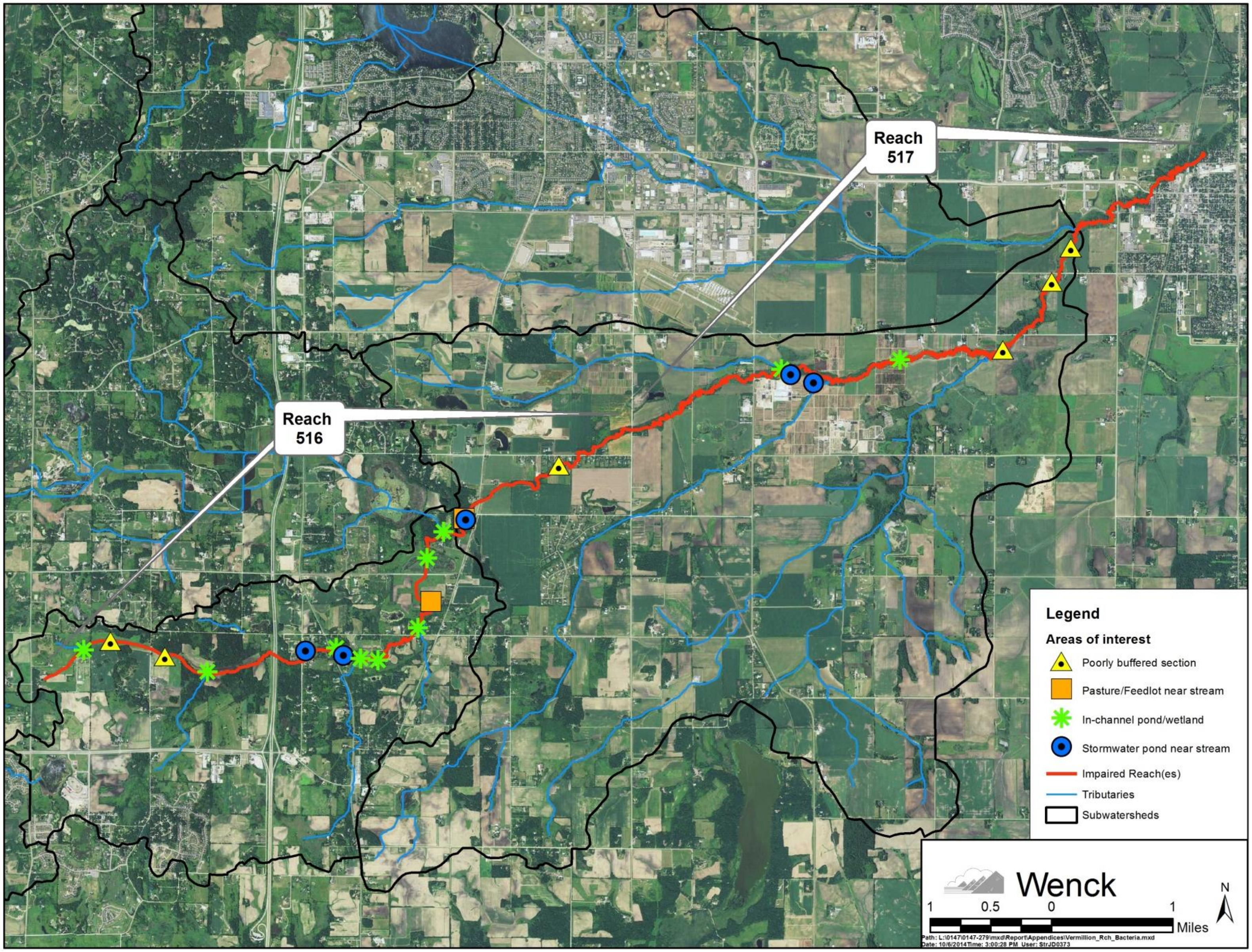
Category	Source	Assumption
Livestock	Pastures near streams or waterways	21% total of beef, dairy and other
	Runoff from Upland Pastures	46% total of beef, dairy and other
	Surface applied manure	33% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

Vermillion River Fecal Coliform Available for Delivery

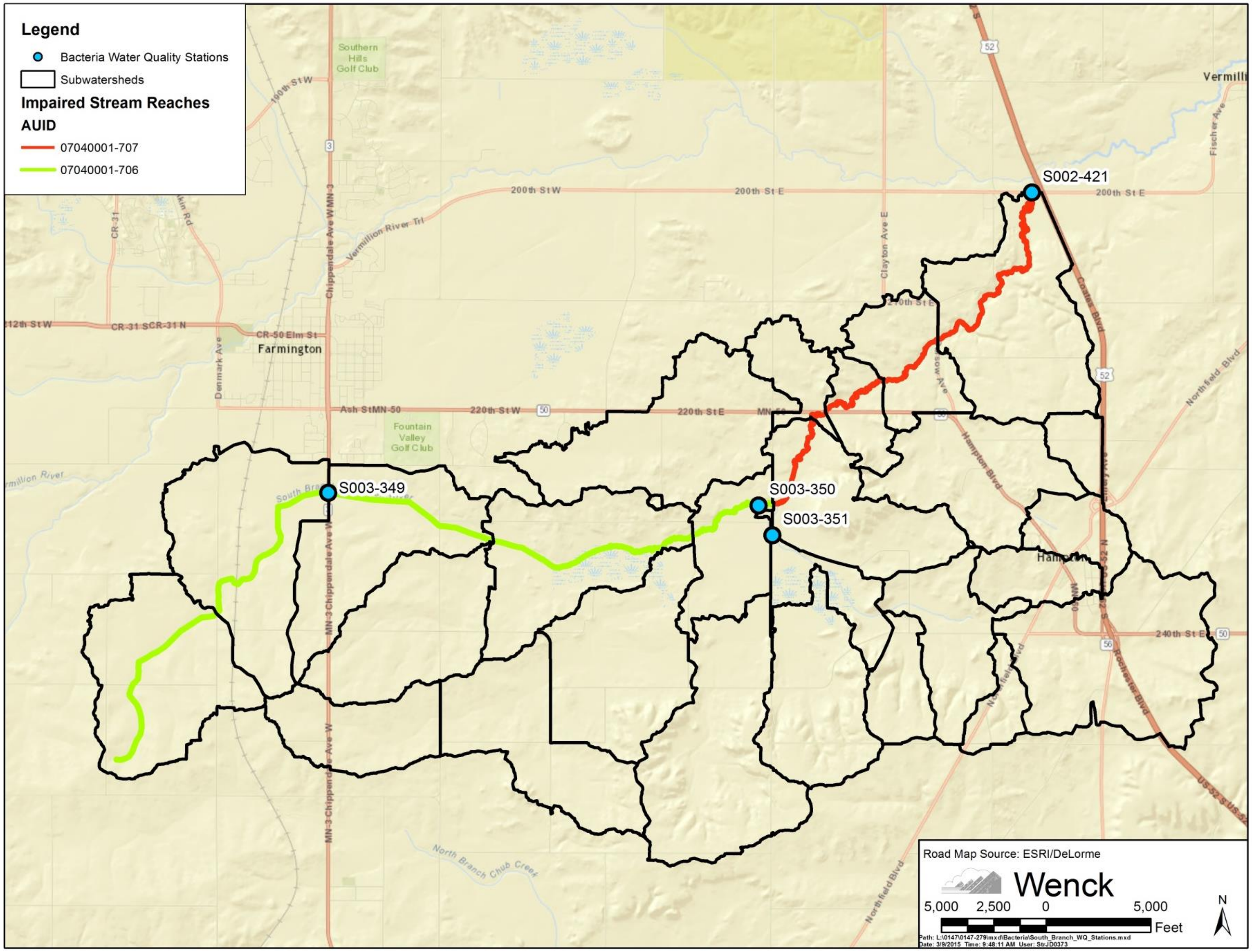
Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	11,299	22,112 (21%)
		Beef Animal Units	10,235	
		Other Animal Units	578	
	Runoff from Upland Pastures	Dairy Animal Units	24,327	47,610 (44%)
		Beef Animal Units	22,037	
		Other Animal Units	1,245	
	Cropland with Surface Applied Manure	Dairy Animal Units	17,813	35,449 (33%)
		Beef Animal Units	16,136	
		Other Animal Units	1,500	
Human	ITPHS septic systems and unsewered communities	Systems	286	286 (<1%)
	Municipal wastewater treatment facilities	People	0	
Wildlife	Deer	Deer	228	394 (<1%)
	Waterfowl	Geese and ducks	166	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	1,633	1,633 (2%)
Total				**107,484**

Vermillion River Bacteria Source GIS Survey

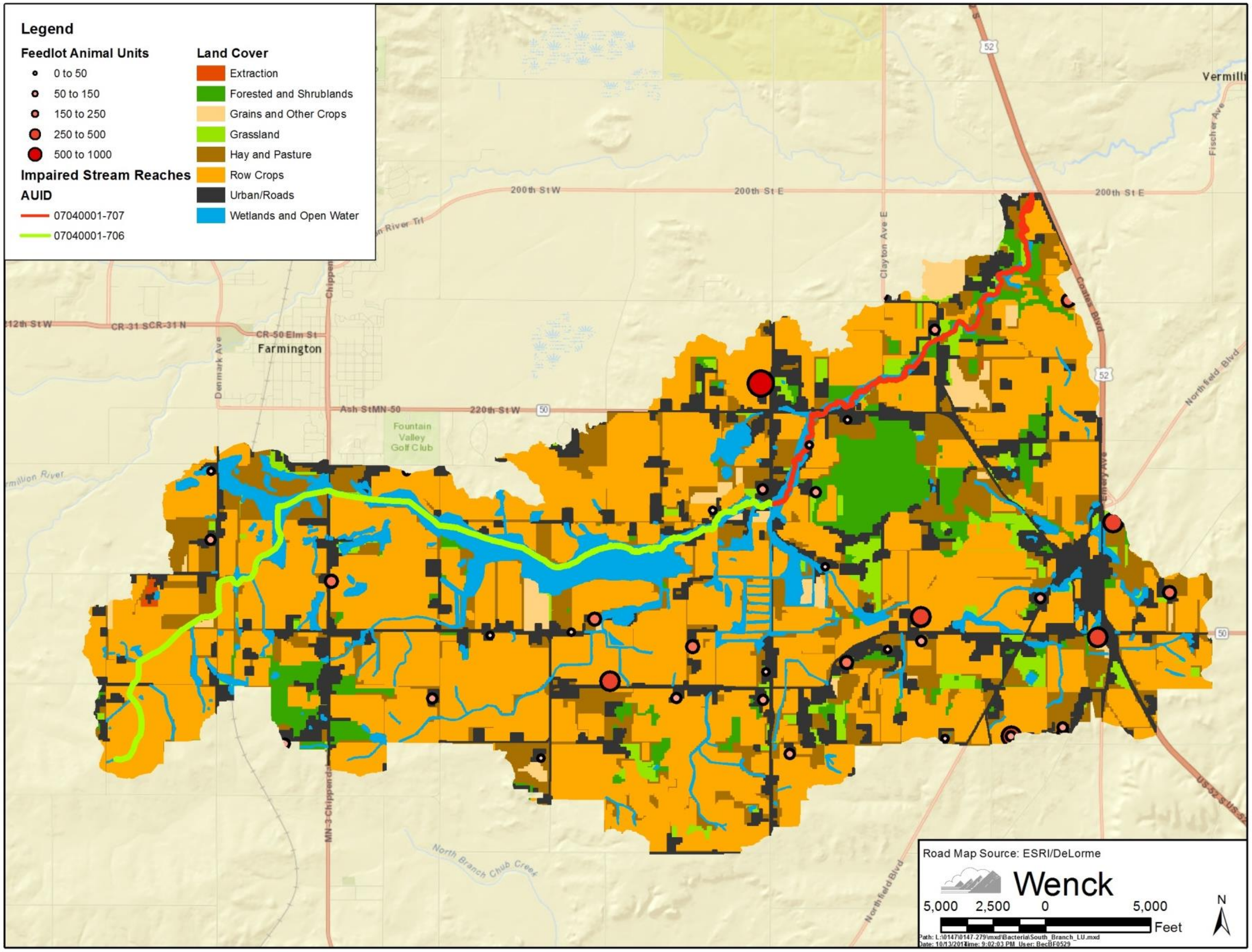
Reach	Subreach	WQ data	Tributaries	Adjacent Landuse					In-stream Physical Features				Overall Bacteria Loading Potential
				Golf Courses	Feedlots/ Pastures	Cropland	Urban	Stormwater Ponds	Shading	In-channel wetlands	Off-channel wetlands/lakes	Ditching	
516	Upstream start of reach to I-35W	No *E. coli* trends from upstream to downstream. Exceedances occur under all flow regimes.	2 tribs entering subreach	NA	Low: small feedlot but not near stream	High: poorly buffered cropland near stream in some areas	None near stream	Low: WWTF ponds near stream	Low-Med: upper subreach ~20% shaded, lower subreach ~65%	Yes: large riparian wetlands in several places	None in subreach	High: heavily ditched	Med.-High Potential
516	I-35W to 250th St		1 trib entering subreach	NA	None near stream	Med.: some cropland near stream	None near stream	High: several farm ponds near stream in subreach	Med: 20-50% shaded	Yes: large riparian wetlands in several places	None in subreach	Med: ditched and naturally flowing	Med. Potential
516	250th St to Dodd Blvd		1 trib entering subreach from Rice Lake	NA	High: 2 poorly buffered feedlots located near stream	Med.: some cropland near stream	None near stream	Med: a few farm ponds near stream throughout subreach	Low: <10% shaded	Yes: large wetland complex throughout subreach	Rice Lake flows to subreach upstream of Dodd Blvd	Low: flows through wetland complex	High Potential
516	Dodd Blvd to end of reach		None	NA	None near stream	Med.: poorly buffered cropland near stream in some areas	Low: very little near stream	None near stream	High: ~75% shaded	Yes: a few smaller in-channel wetlands	None in subreach	Low: flows through forested buffer	Med.-Low Potential
517	Upstream start of reach (Highview Ave) to Cedar Ave		None	NA	None near stream	Med.: areas of cropland near stream, mostly buffered	None near stream	None near stream	Med: ~60% shaded	None in subreach	None in subreach	Low: flows through forested buffer	Med.-Low Potential
517	Cedar Ave to 225th Ave		3 tribs entering subreach	NA	None near stream	Med.: cropland close to stream in areas, some areas poorly buffered	None near stream	Med: a few farm/nursery ponds near stream	Med: wetland area 0% shaded, rest of subreach 75% shaded	Yes: a few in-channel wetlands	None in subreach	Low: flows through forested buffer	Med. Potential
517	225th Ave to Denmark Ave		1 trib entering subreach – South Creek	NA	None near stream	High: moderate amount of cropland near stream, poorly buffered	Low: some farmsteads and houses near stream	None near stream	Med: 30-60% shaded	None in subreach	None in subreach	Low: flows through forested buffer	Med. Potential
517	Denmark Ave to end of reach		None	NA	None near stream	Low: no cropland near stream	Med.: Urban and parkland near stream	Med: a few small stormwater ponds near stream	High: ~65% shaded	Yes: a few riparian wetlands near stream	None in subreach	Low: flows through forested buffer	Med.-Low Potential



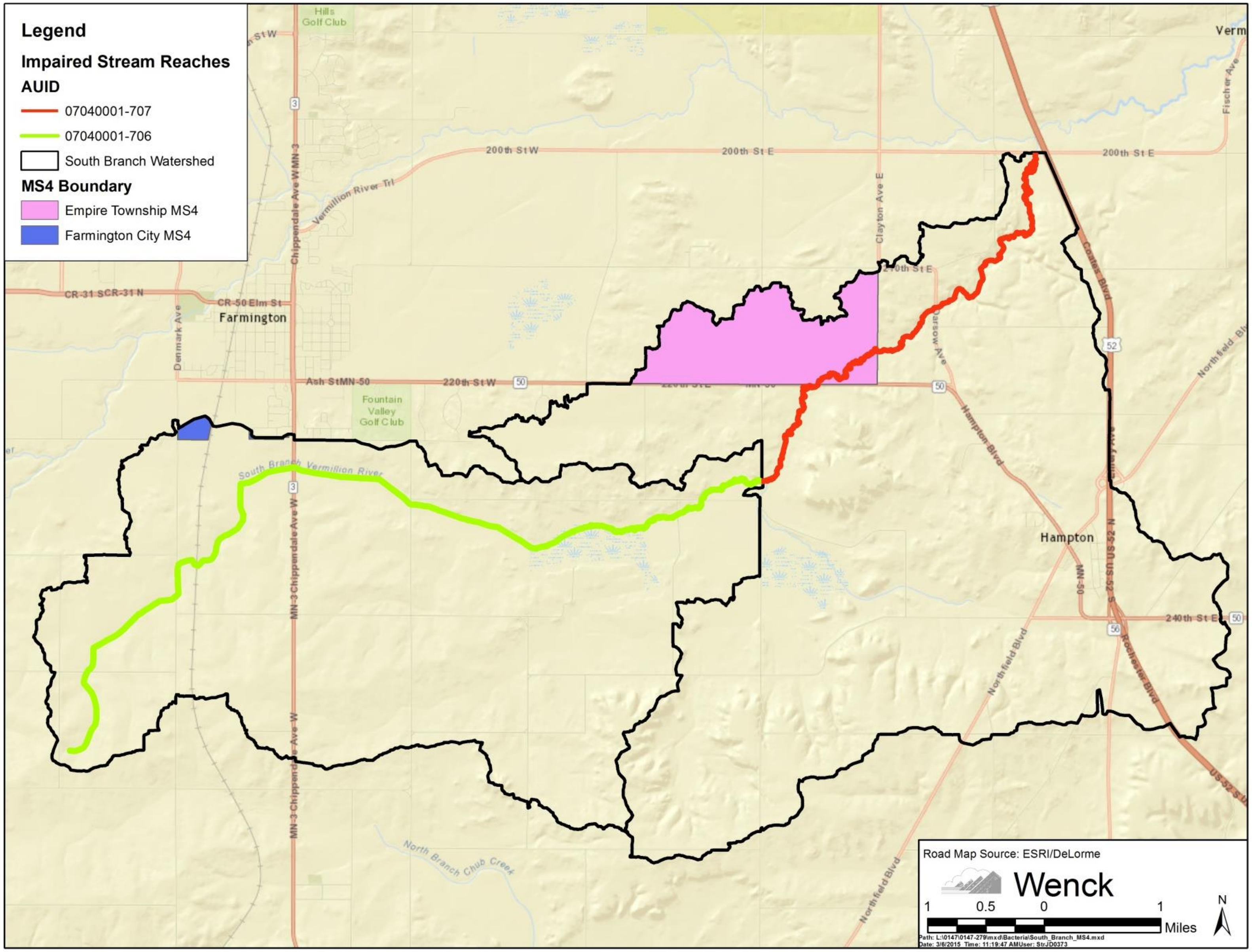
Vermillion River Bacteria Source GIS Survey Results.



South Branch Vermillion River Water Quality Stations and Subwatersheds

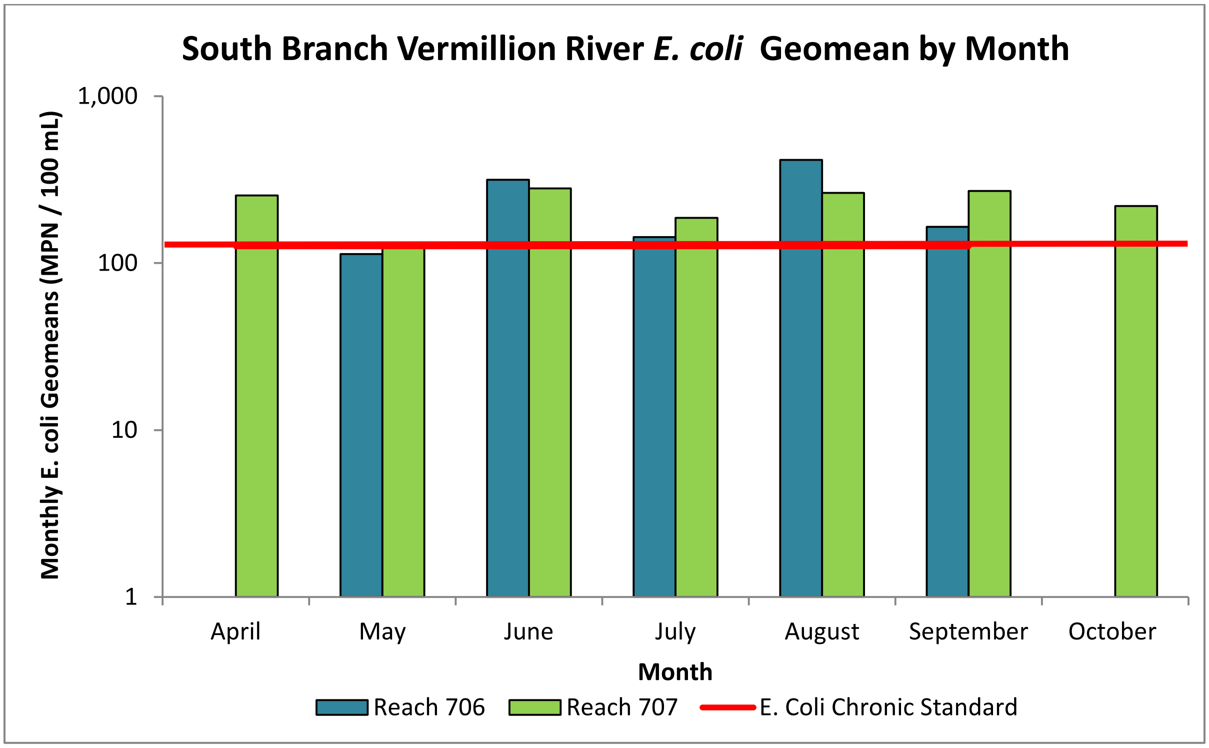


South Branch Vermillion River Land Cover and Feedlot Location

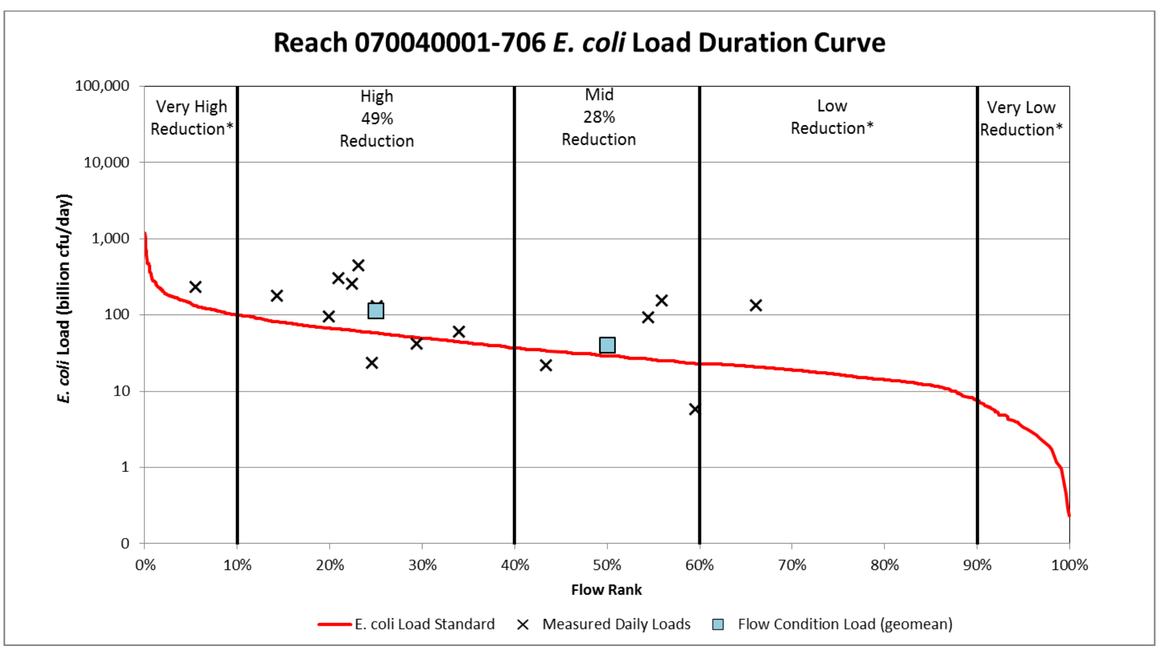


South Branch Vermillion River MS4 Coverage

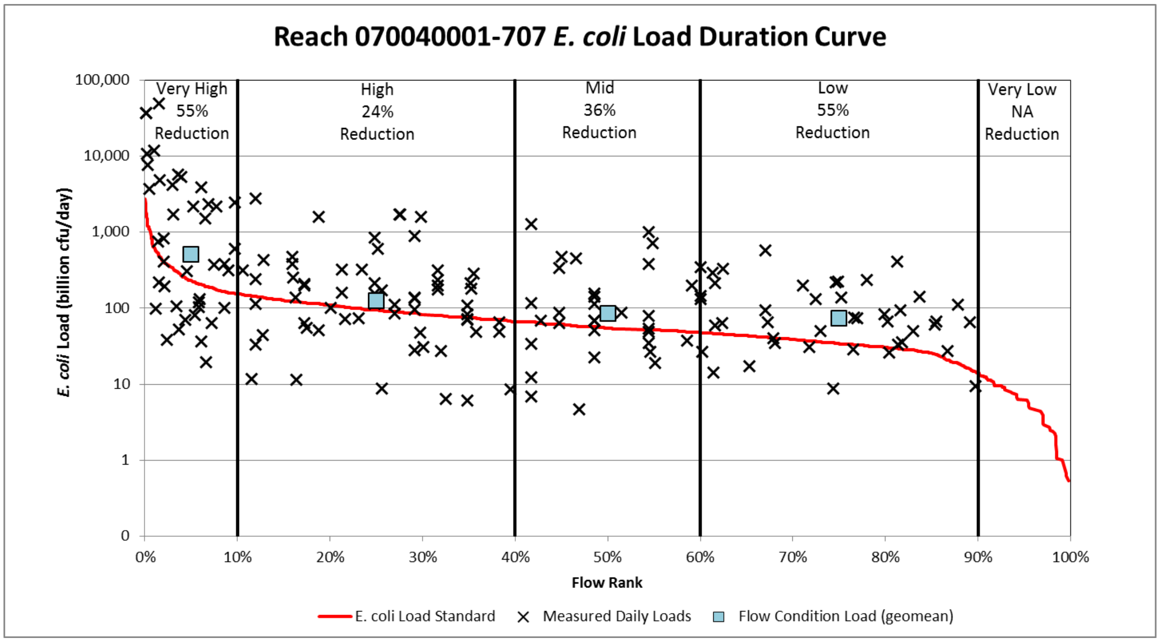
South Branch Vermillion River *E. coli* Data



South Branch monthly geometric means relative to the chronic *E. coli* standard (126 MPN / 100 mL)



South Branch reach 07040001-706 *E. coli* load duration curve and reductions.



South Branch reach 07040001-707 *E. coli* load duration curve and reductions.

Monthly Discharge Monitoring Report (DMR) data from the Hampton Waste Water Treatment Plant

	Fecal Coliform Concentration (CFU / 100 mL)					
Year	**April**	**May**	**June**	**August**	**September**	**October**
2000	--	--	70	--	--	10
2001	--	16	10	--	--	10
2002	--	10	55	--	83	170
2003	--	--	147	95	--	145
2004	--	25	200	--	--	120
2005	--	25	166	--	--	12
2006	--	10	--	--	--	85
2007	--	136	--	--	--	85
2008	--	145	--	--	--	193
2009	--	15	--	--	--	143
2010	--	134	--	--	--	55
2011	29	37	--	--	63	53
2012	--	48	--	--	--	22
2013	--	56	10	--	--	131

South Branch Vermillion River Bacteria Source Inventory

South Branch Failing Septic System Bacteria Loading Summary

System Type	Count	Bacteria Contribution (10^9 organisms/year)
Non-Failing	549	0
Failure to protect groundwater	37	0
Imminent threat to public health	8	89
Total	594	89

South Branch Fecal Coliform Production Inventory

Category	**Sub-Category**	**Animal Units or Individuals**
Livestock	Dairy	924 animal units
	Beef	2469 animal units
	Swine	1273 animal units
	Poultry	7 animal units
	Other (Horses & Sheep)	161 animal units
Human[1]	Total systems with inadequate wastewater treatment[2]	8 systems
	Total systems that do not discharge to surface water	586 systems
	Municipal Wastewater Treatment Facilities	None
Wildlife[3]	Deer (average 11 per square mile)	345 deer
	Waterfowl (average 10 per square mile)	313 geese/ducks
Pets	Dogs and Cats in Urban Areas[3]	833 dogs and cats

[1] Based on county SSTS inventory (failure rates) and rural population estimates
[2] Assumes 3.0 people per household (USEPA 2002) and ITPHS failure rate based on county SSTS inventory
[3] Calculated based on # of households in watershed (SSTS inventory) multiplied by 0.58 dogs/household and 0.73 cats/household according to the Southeast Minnesota Regional TMDL (MPCA 2012).

South Branch Bacteria Delivery Assumptions

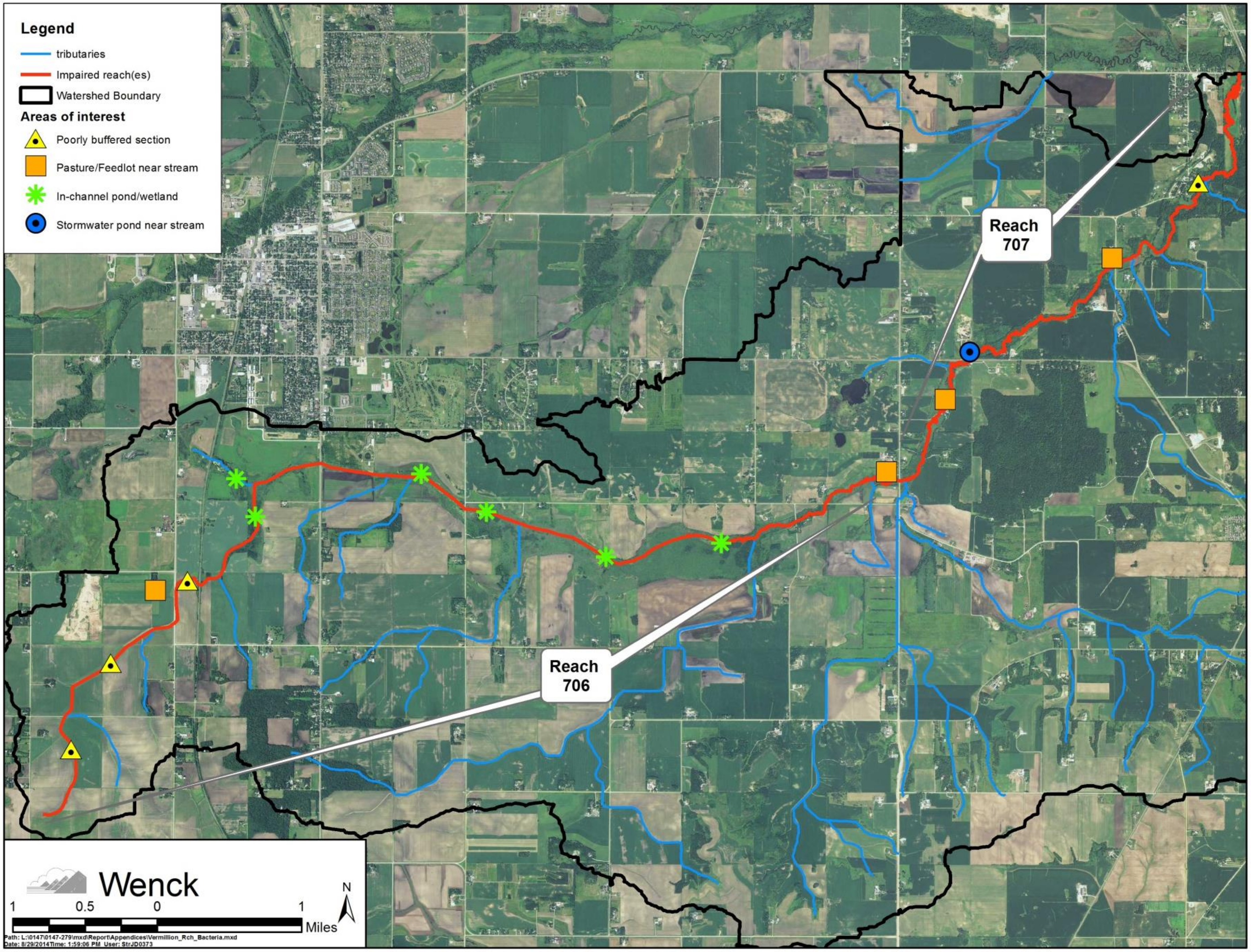
Category	**Source**	**Assumption**
Livestock	Pastures near streams or waterways	17% total of beef, dairy and other
	Runoff from Upland Pastures	50% total of beef, dairy and other
	Surface applied manure	33% of dairy, beef, and other
Human	ITPHS septic systems and unsewered communities	All waste from failing septic systems and unsewered communities
	Municipal wastewater treatment facilities	None
Wildlife	Deer	All fecal matter produced by deer in basin
	Waterfowl	All fecal matter produced by geese and ducks in basin
	Other wildlife	The equivalent of all fecal matter produced by deer and waterfowl in basin
Urban Stormwater Runoff	Improperly managed waste from dogs and cats	10% of waste produced by estimated number of dogs and cats in basin

South Branch Fecal Coliform Available for Delivery

Category	Source	Animal Type	Total Fecal Coliform Available(10^9)	Total Fecal Coliform Available by Source(10^9 per day) (% of total watershed bacteria production)
Livestock	Pasture near Streams or Waterways	Dairy Animal Units	8,821	46,404 (17%)
		Beef Animal Units	36,084	
		Other Animal Units	1,499	
	Runoff from Upland Pastures	Dairy Animal Units	27,030	142,198 (50%)
		Beef Animal Units	110,575	
		Other Animal Units	4,593	
	Cropland with Surface Applied Manure	Dairy Animal Units	17,926	94,301 (33%)
		Beef Animal Units	73,329	
		Other Animal Units	3,046	
Human	ITPHS septic systems and unsewered communities	Systems	89	89 (<1%)
	Municipal wastewater treatment facilities	People	0.2	
Wildlife	Deer	Deer	172	298 (<1%)
	Waterfowl	Geese and ducks	125	
Urban Sources	Improperly managed waste from dogs and cats	Dogs and cats	375	375 (<1%)
Total				**283,665**

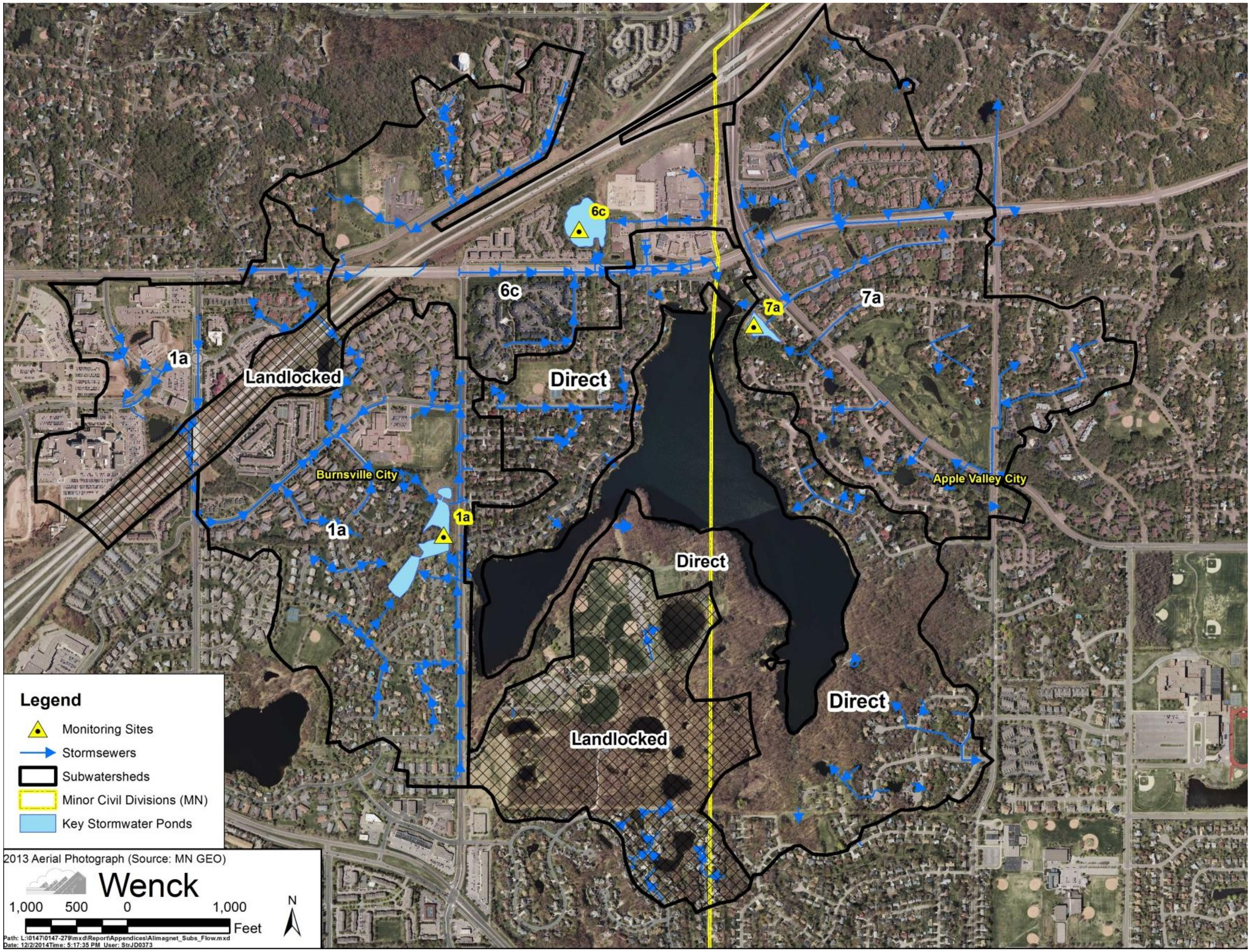
South Branch Vermillion River Bacteria Source GIS Survey

Reach	Subreach	WQ data trends	Tributaries	Adjacent Landuse					In-stream Physical Features				Overall Bacteria Loading Potential
				Golf Courses	Feedlots/ Pastures	Cropland	Urban	Stormwater Ponds	Shading	In-channel wetlands	Off-channel wetlands/lakes	Ditching	
706	Upstream start of reach to Denmark Ave	No bacteria trends from upstream to downstream. Exceedances occur during most flow regimes.	4-5 small ditches entering subreach	NA	Med.: one feedlot located near stream	High: predominately cropland near subreach, poorly buffered	None near stream	None near stream	Low: <10%	None in subreach	None in subreach	High: 100% ditched	High Potential
706	Denmark Ave to Biscayne Ave		A few small ditches entering subreach	NA	Low: none near stream	High: Cropland near stream	None near stream	None near stream	Low: 0-40% shading	Yes: a few areas of riparian wetland	None in subreach	High: 100% ditched	Medium Potential
706	Biscayne Ave to Blaine Ave (end of reach)		A few ditches entering subreach	NA	Med.: One feedlot and pasture near stream	Med.: Cropland near stream	None near stream	None near stream	Low: 0-20% shading	Yes: large in-channel wetland complex through subreach	None in subreach	High: 100% ditched	Medium Potential
707	Blaine Ave to Darsow Ave		A few ditches entering subreach	NA	Med.: Two feedlots and farmsteds near stream	Med.: Cropland near stream	None near stream	Low: a couple ponds near stream	High: 50-75% shading	None in subreach	None in subreach	Low: more naturally flowing	Medium-Low Potential
707	Darsow Ave to 200th St E (end of reach)		One tributary and a few small ditches entering subreach	NA	None near stream	Med.: Cropland near stream, some poorly buffered	None near stream	None near stream	High: 50-75% shading	None in subreach	None in subreach	Low: more naturally flowing	Medium-Low Potential



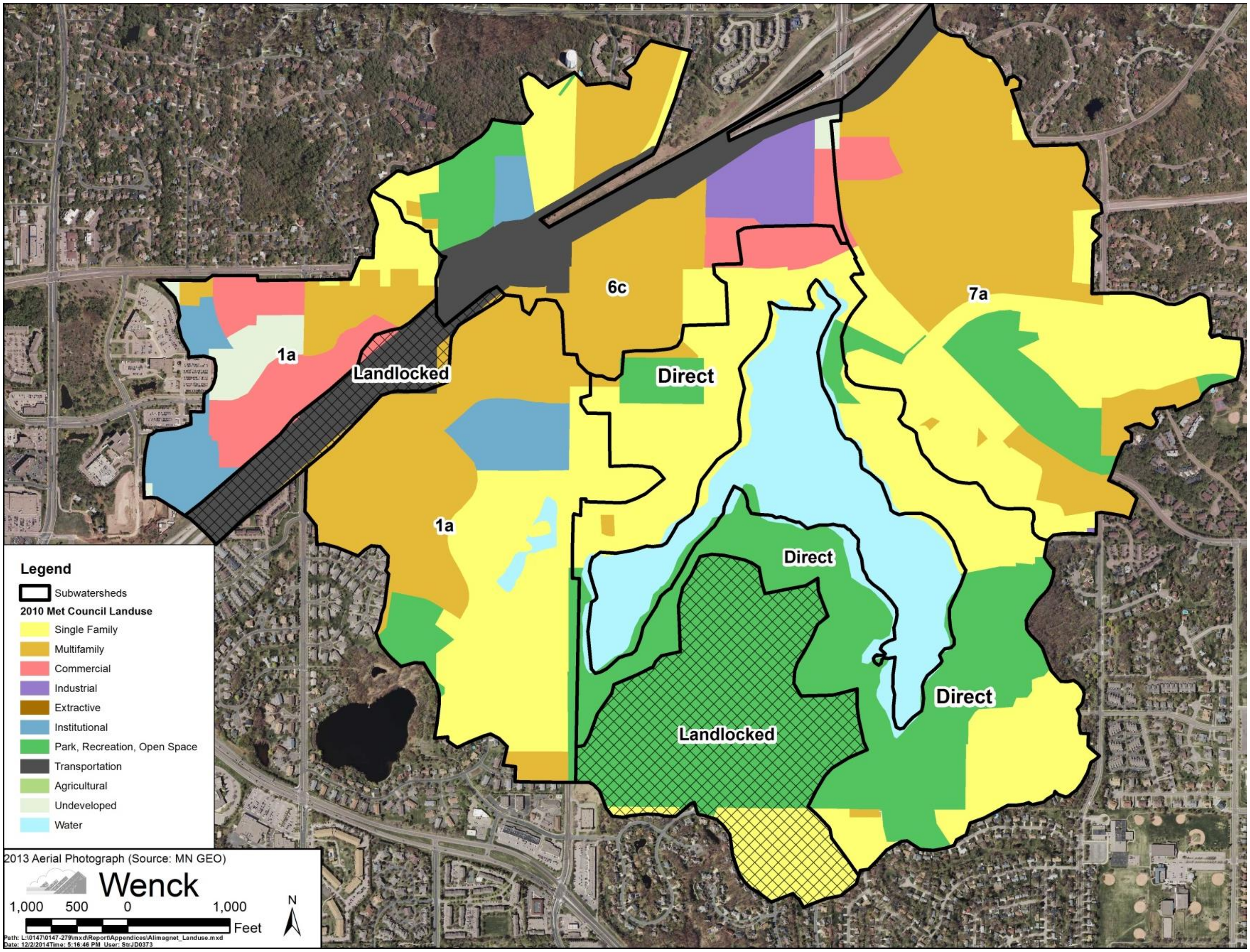
South Branch Vermillion River Bacteria Source GIS Survey Results.

Appendix C – Nutrient TMDLs Supporting Materials



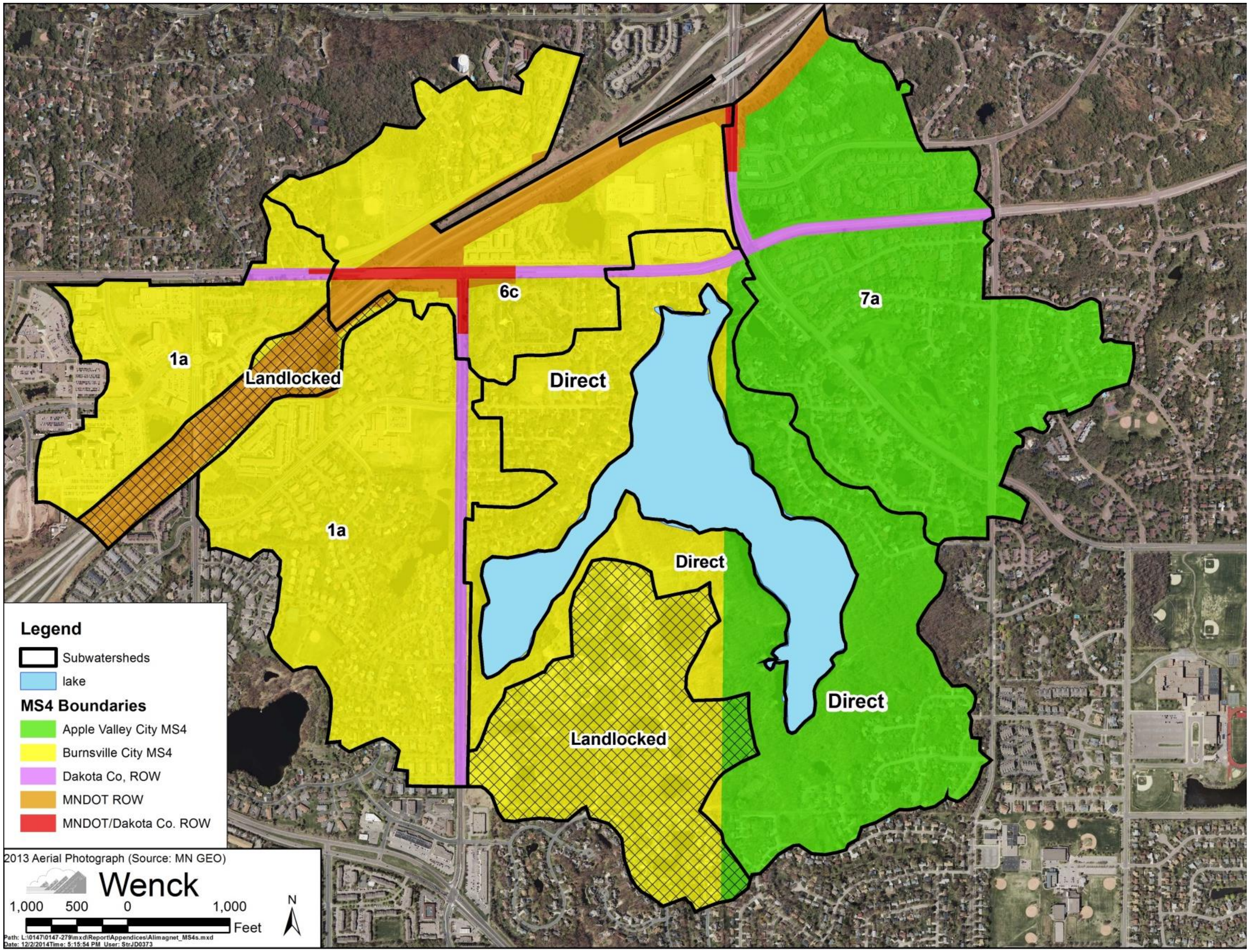
Alimagnet Lake subwatersheds, flow patterns and sampling locations.

Note: Areas labeled "landlocked" do not drain to the lake and were not included in the TMDL model analysis



Alimagnet Lake Watershed Landuse

Note: Areas labeled "landlocked" do not drain to the lake and were not included in the TMDL model analysis



Alimagnet Lake MS4 coverage

Note: Areas labeled "landlocked" do not drain to the lake and were not included in the TMDL model analysis

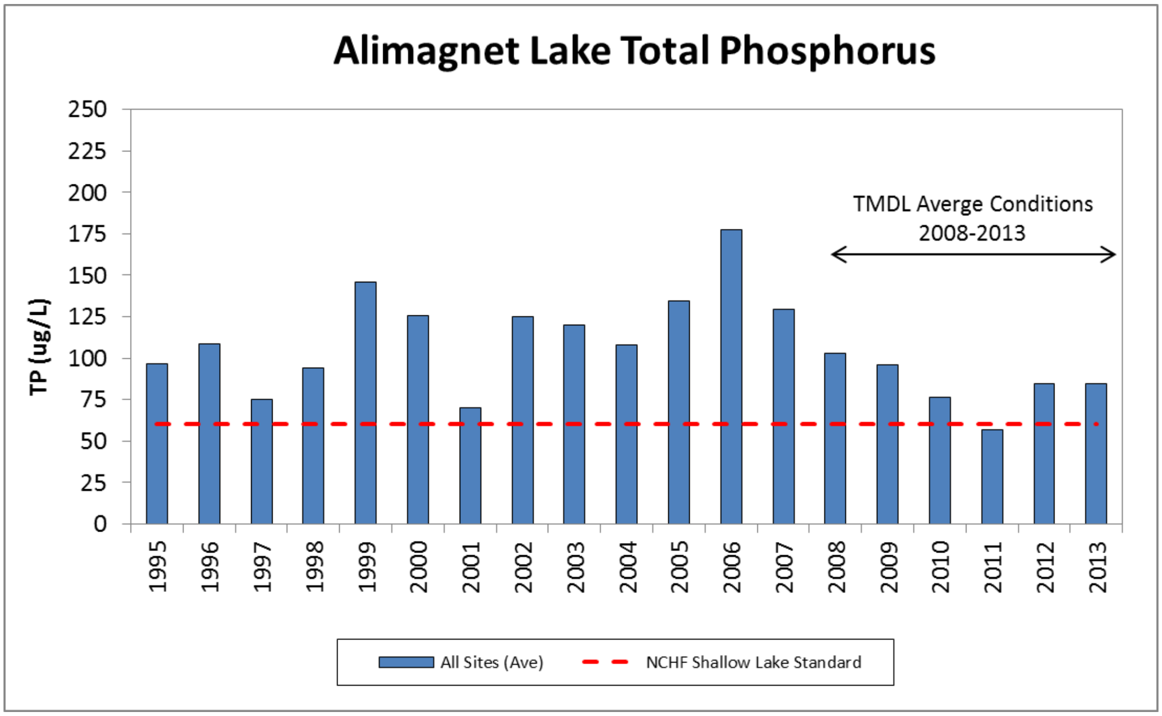
Alimagnet Lake Data

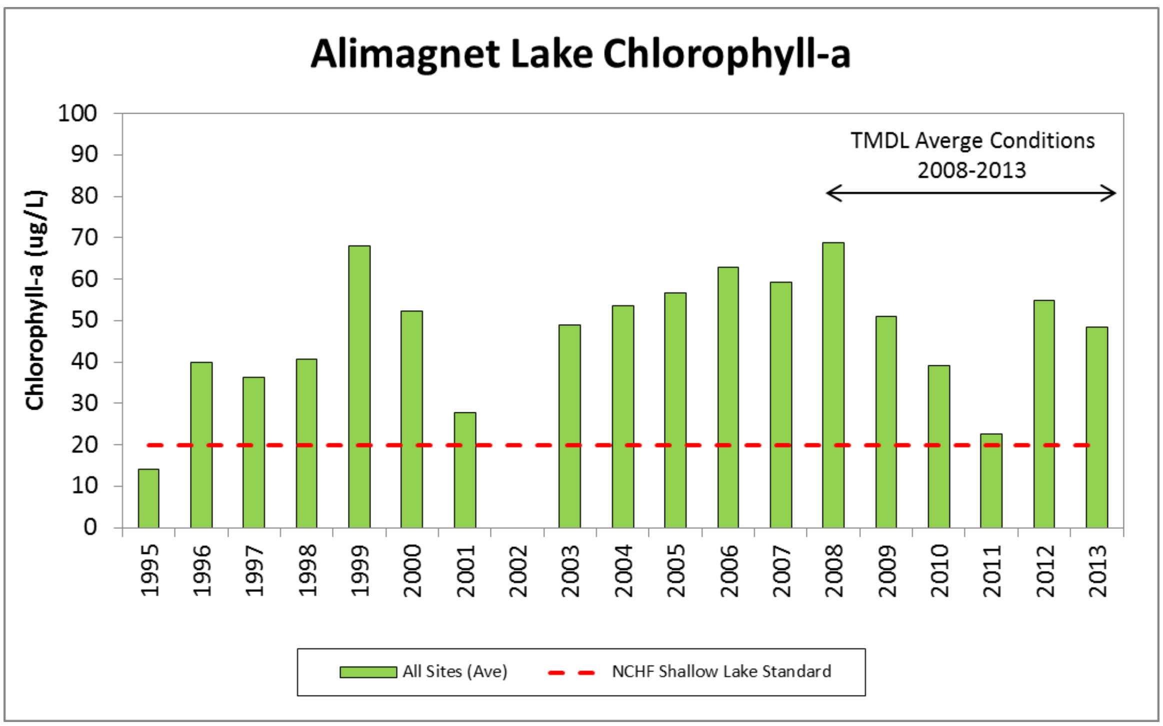
Alimagnet Lake Historic Water Quality Sampling

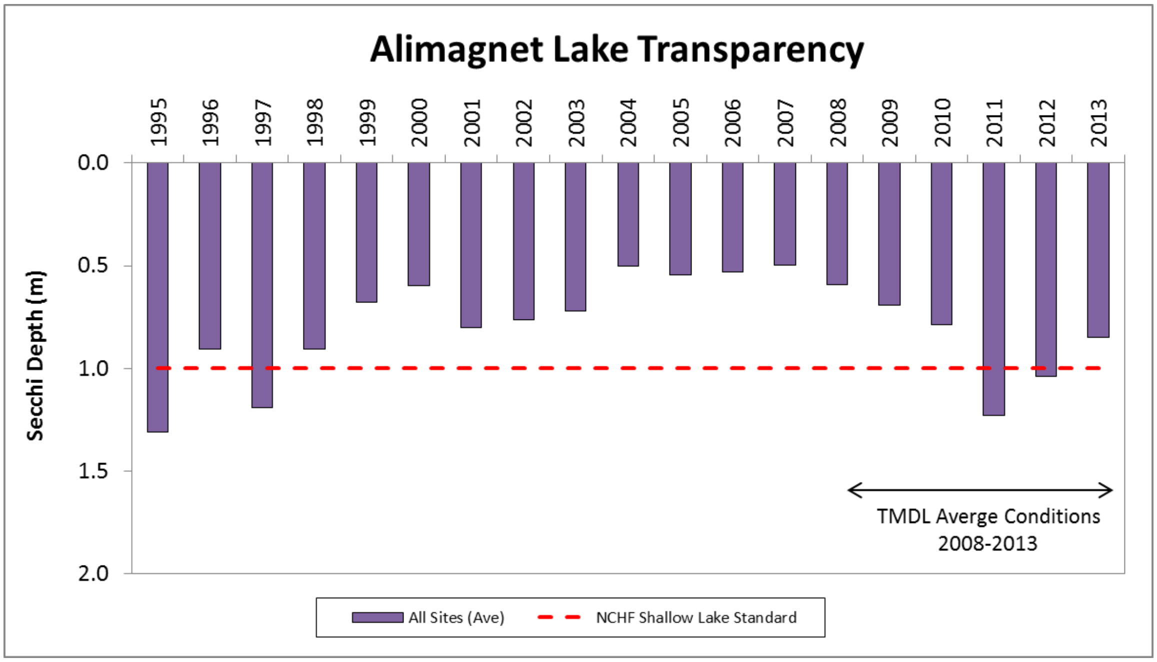
Year	Total Phosphorus (ug/L)		Chlorophyll-a (ug/L)		Secchi (m)	
	N	Ave	N	Ave	N	Ave
1995	9	97	9	14	9	1.31
1996	6	108	6	40	10	0.91
1997	6	75	6	36	12	1.19
1998	5	94	5	41	7	0.90
1999	7	146	7	68	10	0.68
2000	7	126	7	52	13	0.60
2001	5	70	5	28	9	0.80
2002	7	125	--	--	13	0.76
2003	8	120	7	49	8	0.72
2004	6	108	6	54	7	0.50
2005	6	135	5	57	10	0.55
2006	6	178	6	63	9	0.53
2007	6	129	6	59	10	0.50
2008	5	103	5	69	9	0.59
2009	6	96	6	51	13	0.69
2010	12	76	8	39	14	0.79
2011	12	57	8	23	13	1.23
2012	10	84	10	55	12	1.04
2013	4	85	4	48	4	0.85

Notes: Only June 1 through September 30 sample events presented

Only data from the past 6 years (2008-2013) were used to represent current conditions in TMDL

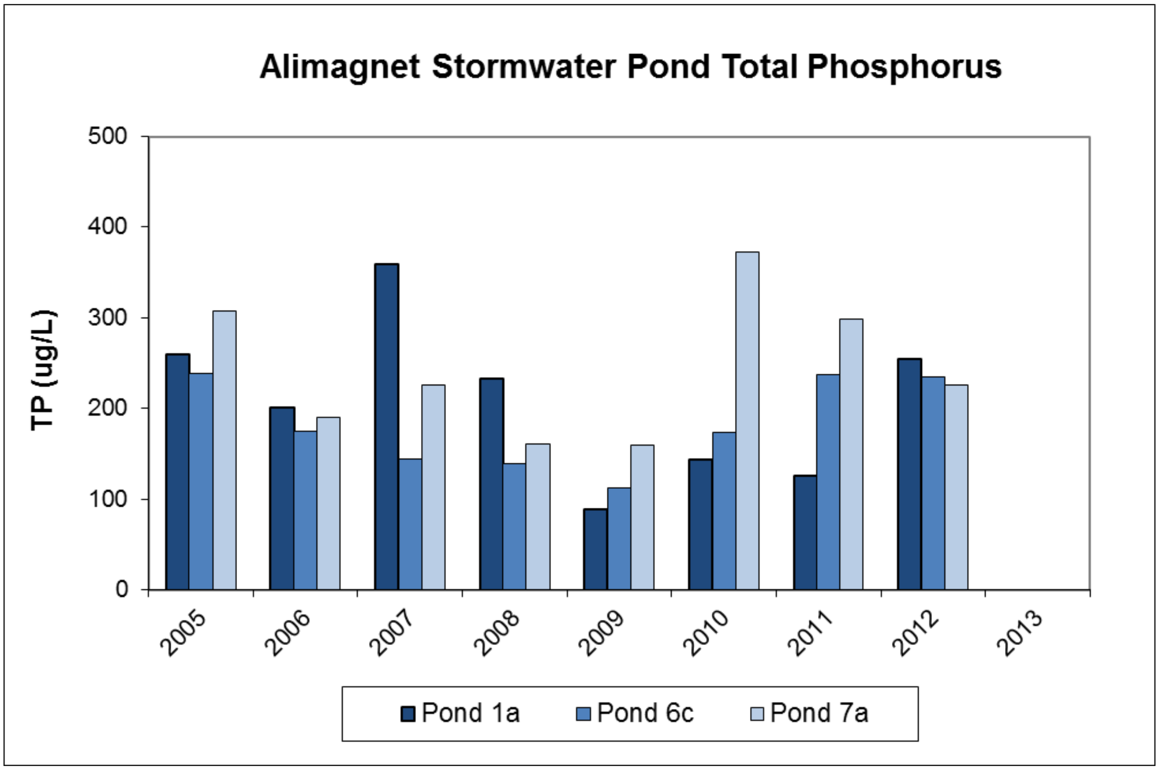

Alimagnet Lake Total Phosphorus
TP (ug/L)
250
225
200
175
150
125
100
75
50
25
0
TMDL Averge Conditions
2008-2013
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
All Sites (Ave)
NCHF Shallow Lake Standard


Alimagnet Lake Chlorophyll-a
Chlorophyll-a (ug/L)
100
90
80
70
60
50
40
30
20
10
0
TMDL Averge Conditions
2008-2013
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
All Sites (Ave)
NCHF Shallow Lake Standard

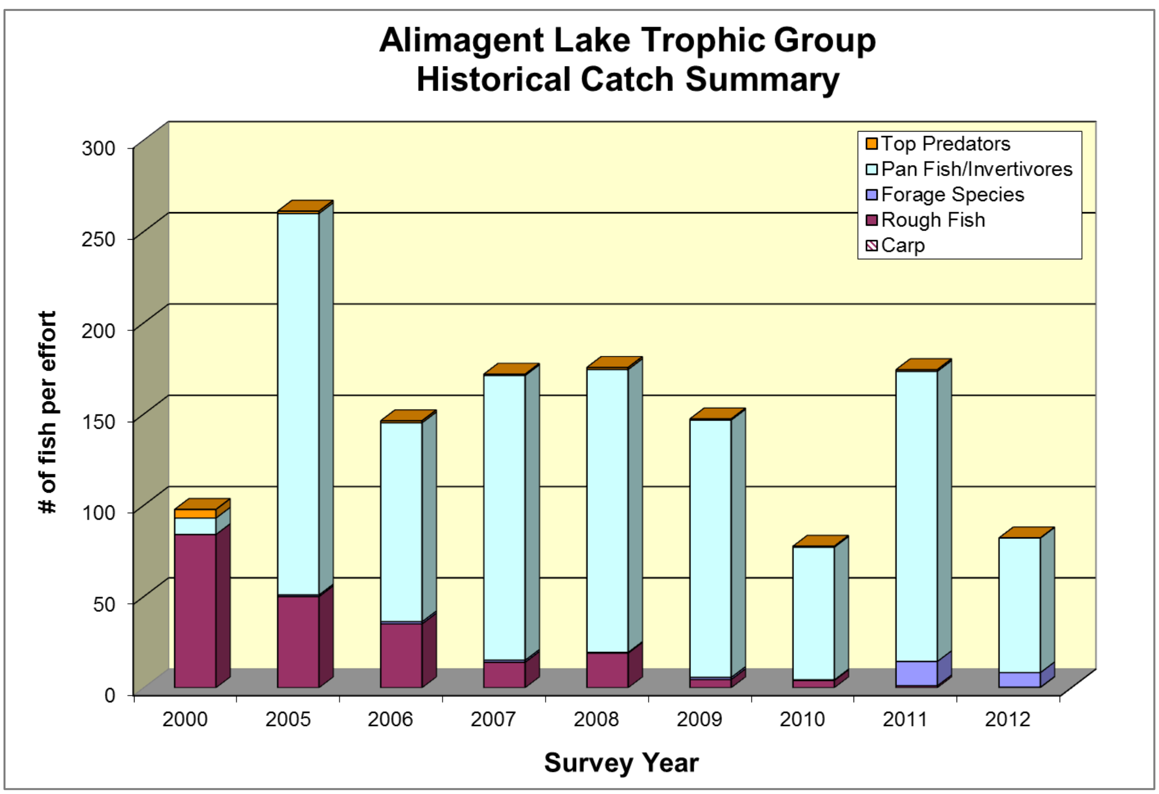


Alimagnet Stormwater Pond TP Monitoring Data

Year	Pond 1a		Pond 6c		Pond 7a	
	N	TP Ave (µg/L)	N	TP Ave (µg/L)	N	TP Ave (µg/L)
2005	3	259	3	238	3	307
2006	5	200	5	175	5	190
2007	4	359	4	144	4	226
2008	4	232	4	139	4	160
2009	4	89	4	113	4	160
2010	4	144	4	174	4	373
2011	4	126	4	238	4	298
2012	4	255	4	235	4	226
2013	--	--	--	--	--	--

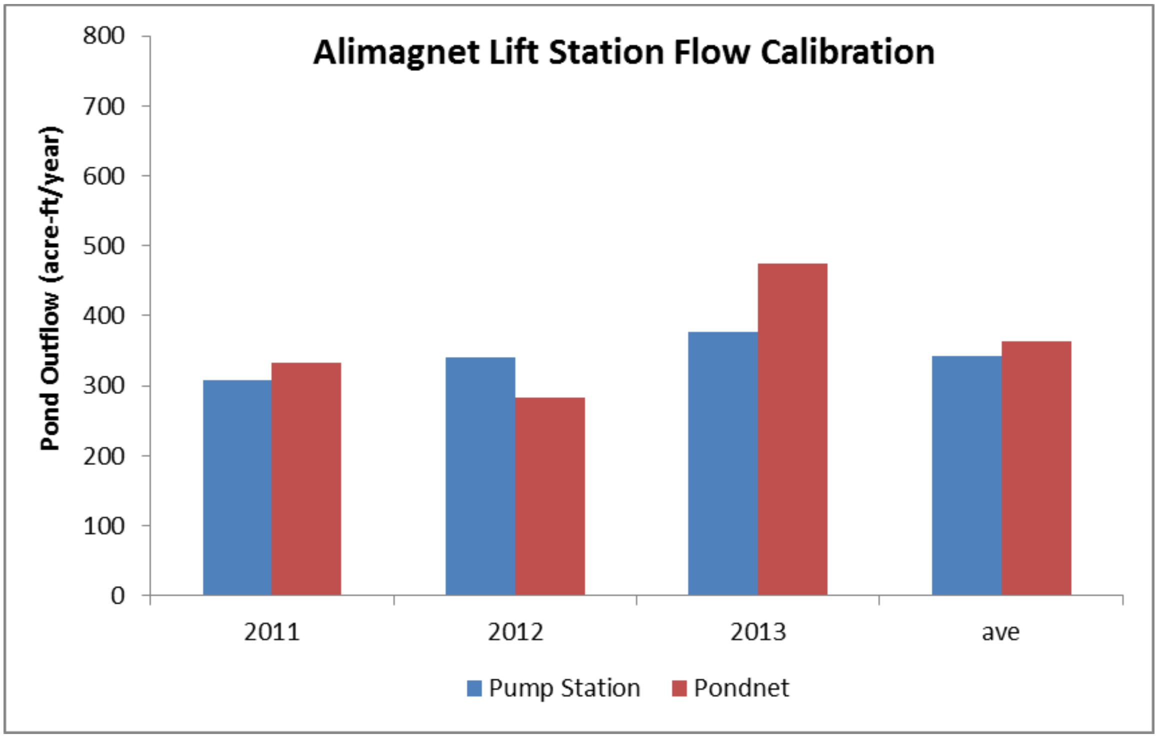


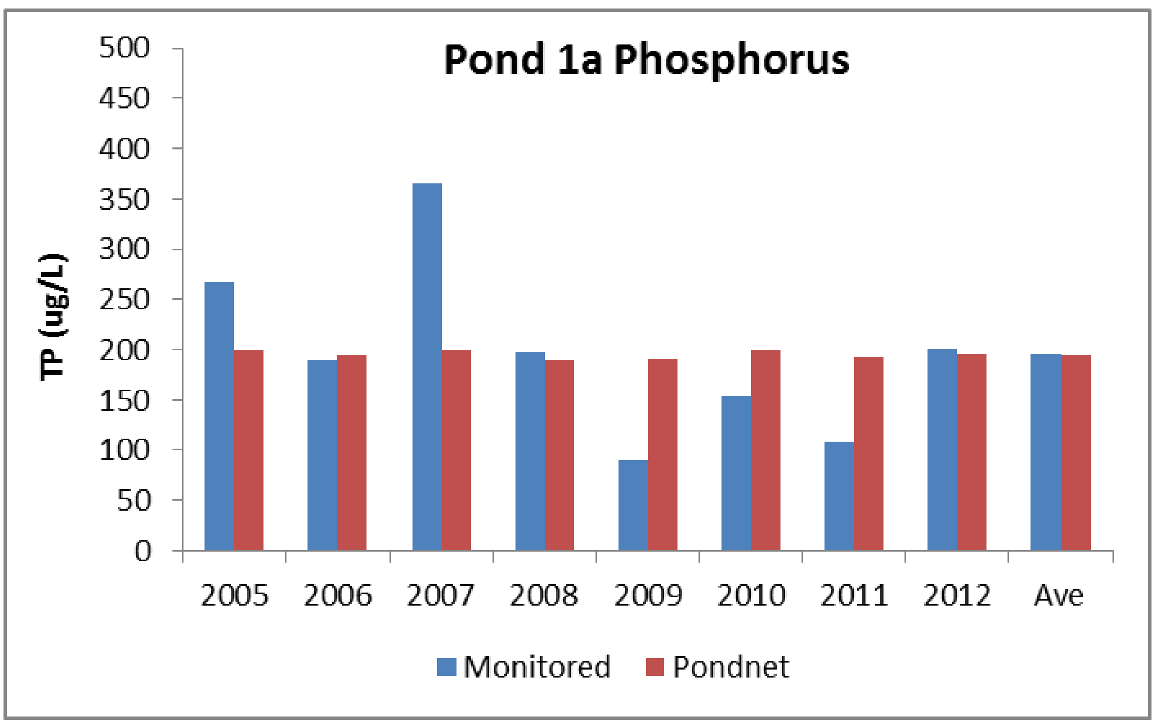
Alimagnet Lake Fish Surveys by Trophic Group

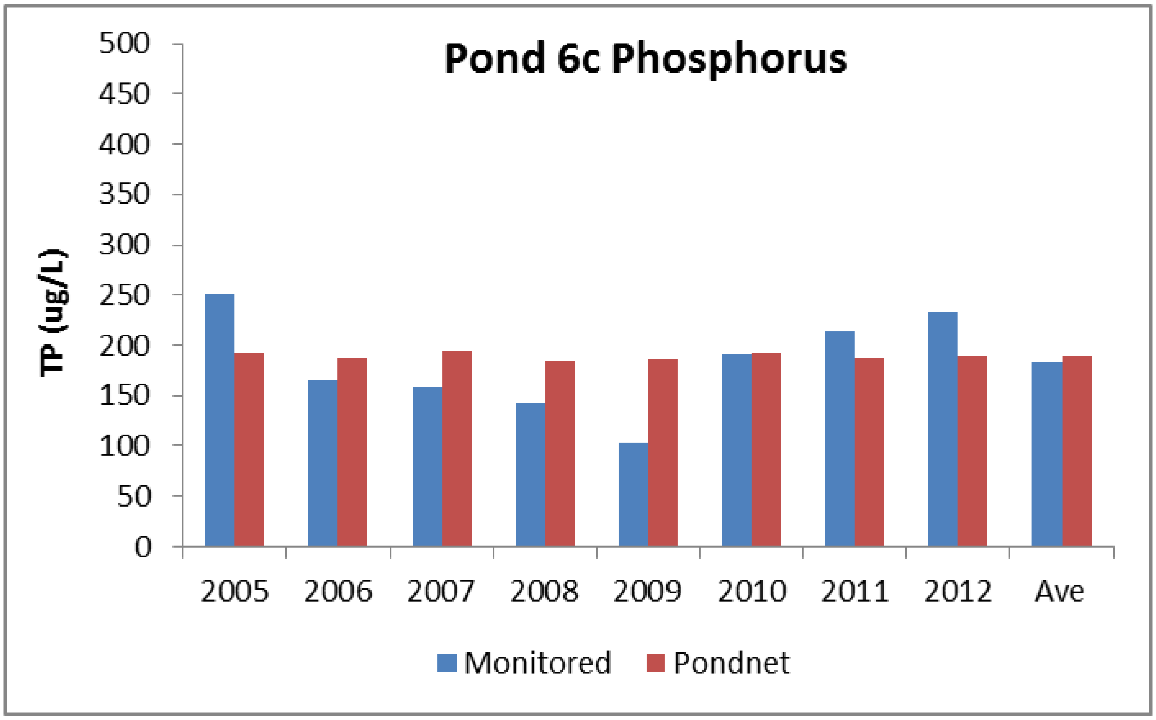


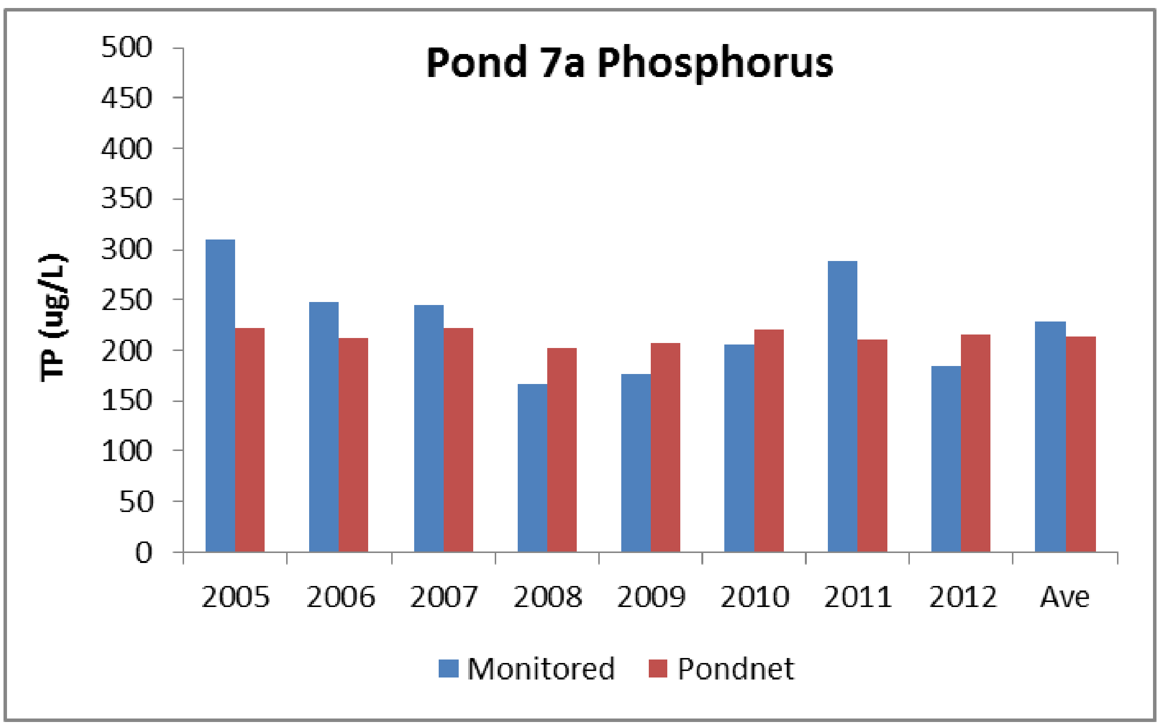
Alimagnet Modeling

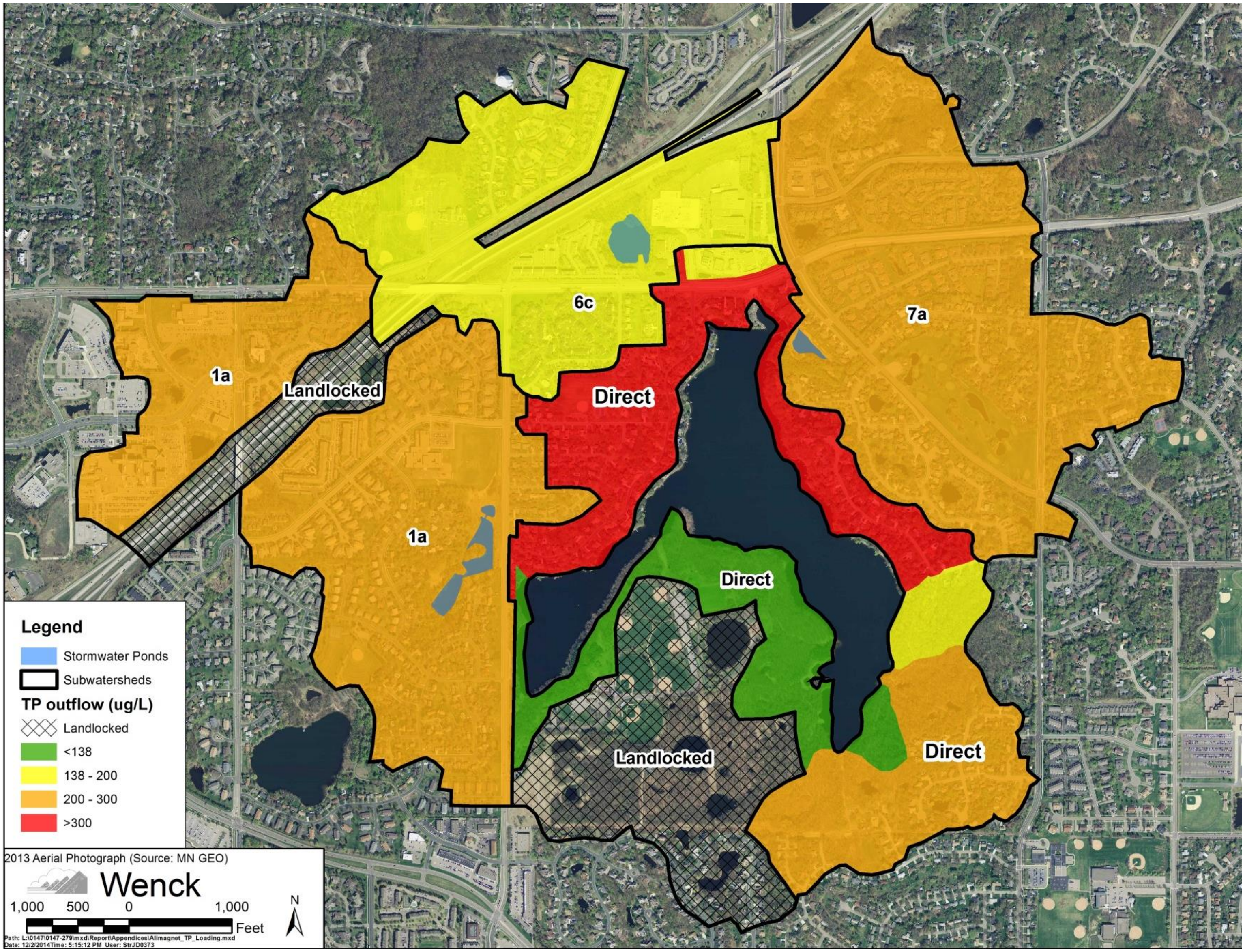
Alimagnet Lake Watershed PONDNET Model Performance






Pond 6c Phosphorus
TP (ug/L)
500
450
400
350
300
250
200
150
100
50
0
2005
2006
2007
2008
2009
2010
2011
2012
Ave
Monitored
Pondnet

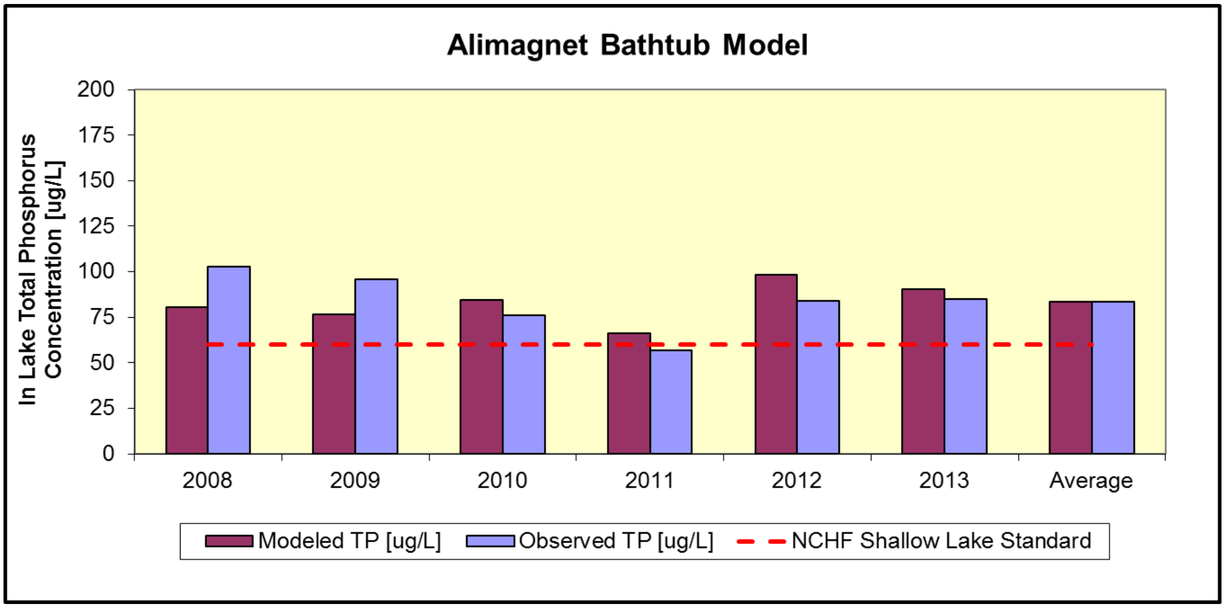

Pond 7a Phosphorus
TP (ug/L)
500
450
400
350
300
250
200
150
100
50
0
2005
2006
2007
2008
2009
2010
2011
2012
Ave
Monitored
Pondnet



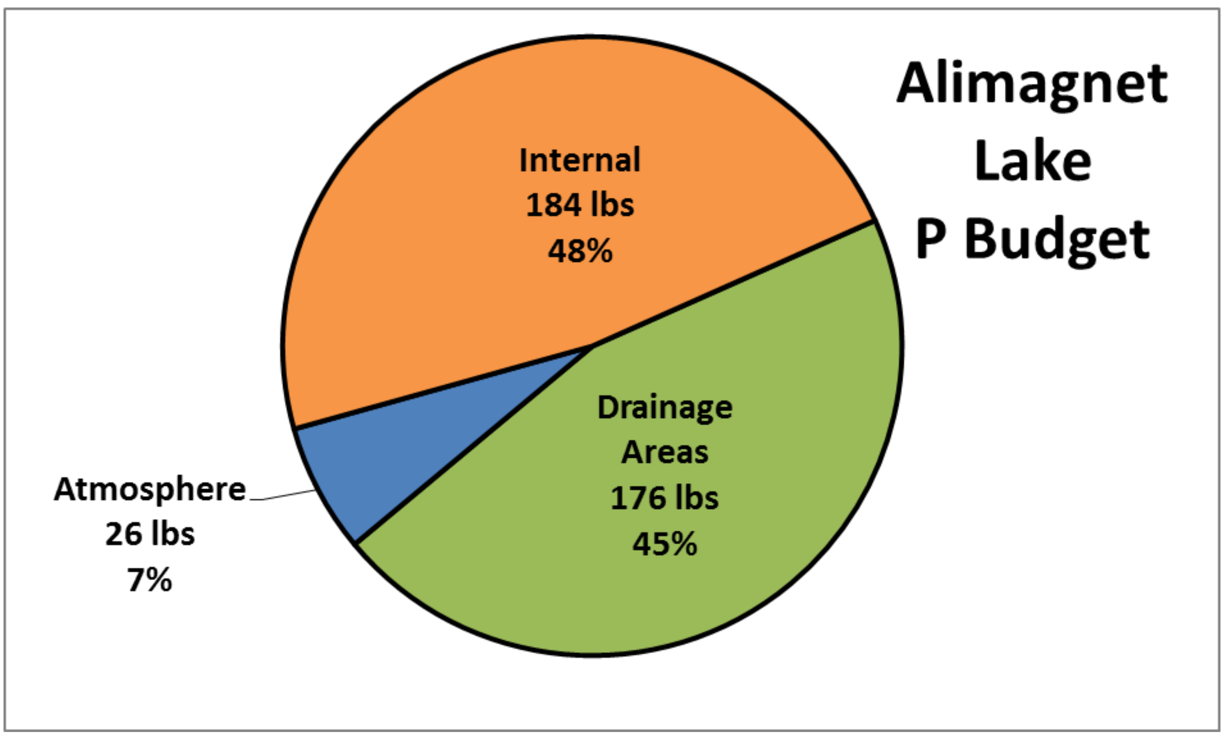
Alimagnet Lake Watershed PONDNET Model Results by Subwatershed

Note: Areas labeled "landlocked" do not drain to the lake and were not included in the TMDL model analysis

Alimagnet Lake BATHTUB Lake Response Model Performance



Alimagnet Lake Current Conditions Phosphorus Budget



Alimagnet Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for Alimagnet Lake

	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	1.1a.3	284.30	4.50	106.57	160	1.0	46.28
2	6.6c.1	175.16	5.01	73.16	183	1.0	36.43
3	7.7a.1	256.75	4.06	86.74	208	1.0	49.19
4	Burnsville Outfalls	115.57	2.53	24.35	268	1.0	17.77
5	Apple Valley Outfalls	153.56	2.45	31.38	309	1.0	26.35
	Summation	*985.33*	*18.55*	*322.20*			*176.01*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1				0	0		0
2				0	0.0		0
3				0	0.0		0
4				0	0.0		0
5				0	0.0		0
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
				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]
	109.00	28.24	28.24	0.00	0.24	1.0	26.1
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.44	336.95		Oxic	0.17	1.0	55.71
	0.44	28.05		Anoxic	4.70	1.0	128.21
	Summation						183.92
		Net Discharge [ac-ft/yr] =		**322.20**	**Net Load [lb/yr] =**		**385.99**

Average Lake Response Modeling for Alimagnet Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	1.22	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	175	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	0.7	[10^6 m^3]
		T = V/Q =	1.69	[yr]
		P_i = W/Q =	440	[µg/l]
Model Predicted In-Lake [TP]			**83.5**	**[ug/l]**
Observed In-Lake [TP]			**83.5**	**[ug/l]**

Alimagnet Lake TMDL Conditions Canfield-Bachman Lake Response Model

TMDL Loading Summary for Alimagnet Lake

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF) [--]	Load [lb/yr]
	Water Budgets				**Phosphorus Loading**		
	Inflow from Drainage Areas						
1	1.1a.3	284.30	4.50	106.57	138	1.0	40.02
2	6.6c.1	175.16	5.01	73.16	138	1.0	27.47
3	7.7a.1	256.75	4.06	86.74	138	1.0	32.56
4	Burnsville Outfalls	115.57	2.53	24.35	138	1.0	9.14
5	Apple Valley Outfalls	153.56	2.45	31.38	138	1.0	11.78
	Summation	*985.33*	*18.55*	*322.20*			*120.97*

Point Source Dischargers

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

Failing Septic Systems

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

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

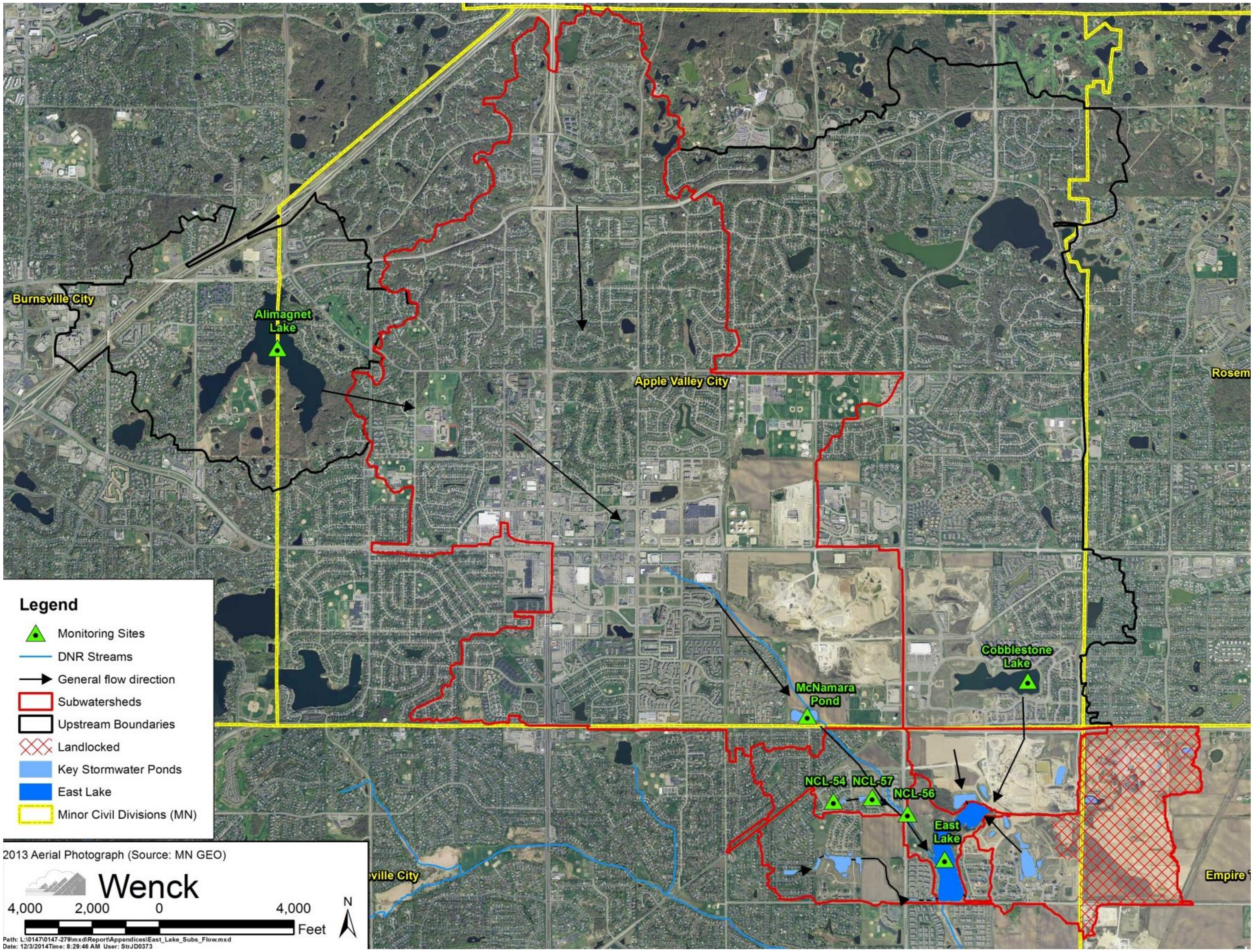
Lake Area [acre]	Precipitation [in/yr]	Evaporation [in/yr]	Net Inflow [ac-ft/yr]	Aerial Loading Rate [lb/ac-yr]	Calibration Factor [--]	Load [lb/yr]
109.00	28.24	28.24	0.00	0.24	1.0	26.06
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.44	336.95		Oxic	0.17	1.0	55.71
0.44	28.05		Anoxic	1.00	1.0	27.28
Summation						82.98
		Net Discharge [ac-ft/yr] =	**322.20**		**Net Load [lb/yr] =**	**230.01**

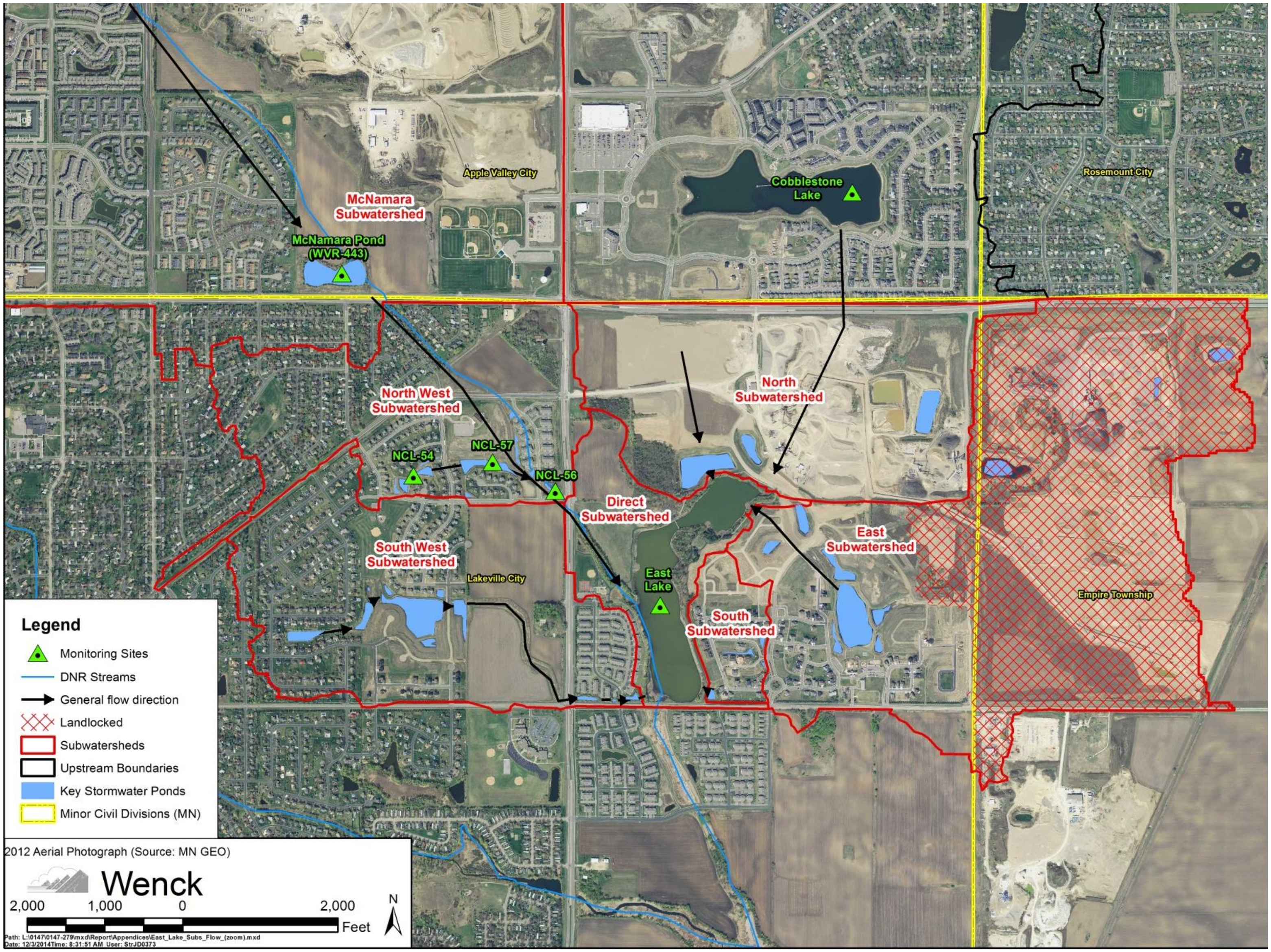
TMDL Lake Response Modeling for Alimagnet Lake

Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.22	[--]
		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) =	0.7	[10^6 m^3]
		T = V/Q =	1.69	[yr]
		P_i = W/Q =	262	[µg/l]
Model Predicted In-Lake [TP]			**60.0**	**[ug/l]**
[TP] Water Quality Standard			**60.0**	**[ug/l]**



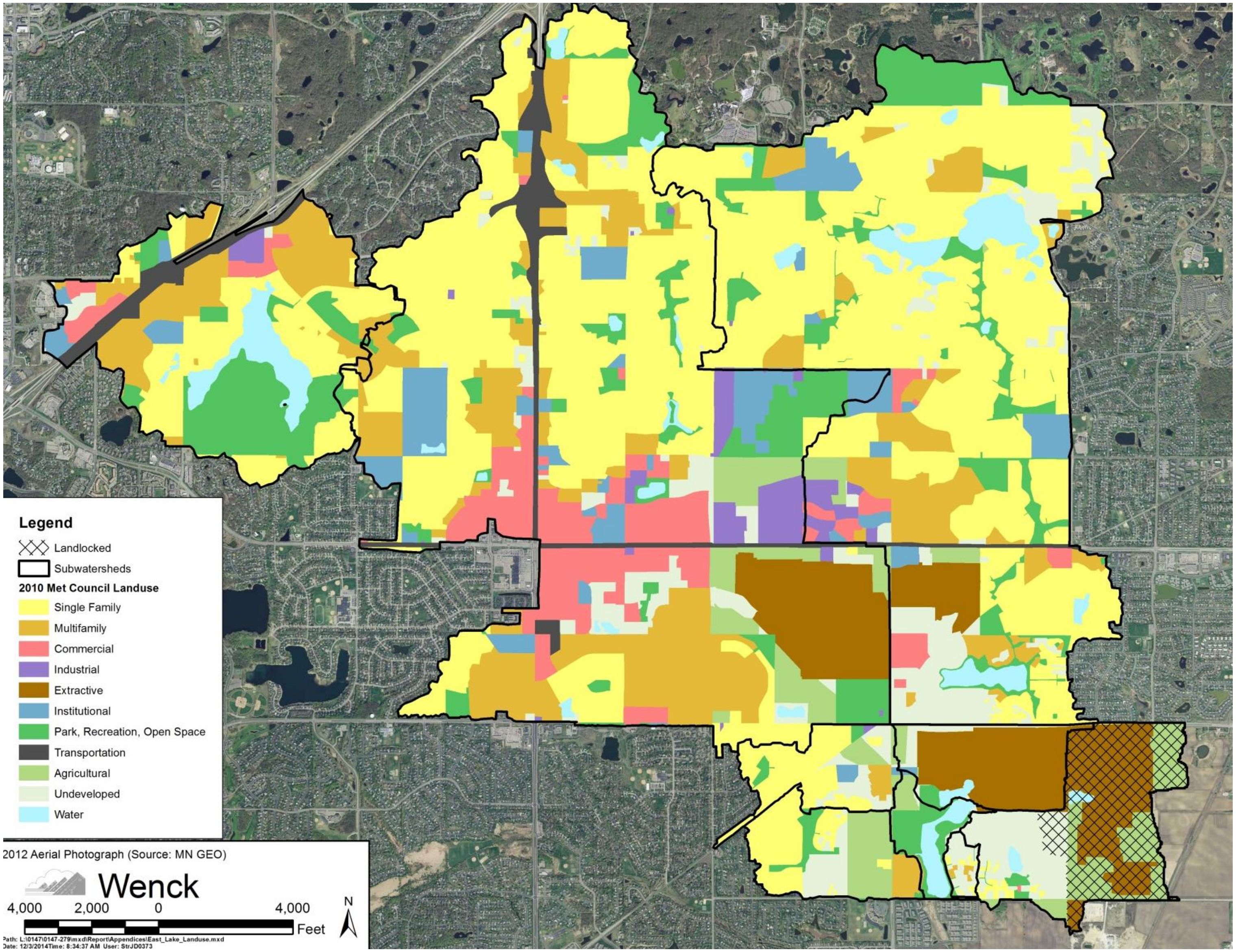
East Lake Subwatersheds, Flow Patterns and Sampling Locations

Note: Area labeled "landlocked" does not drain to the lake and is not included in the TMDL model analysis



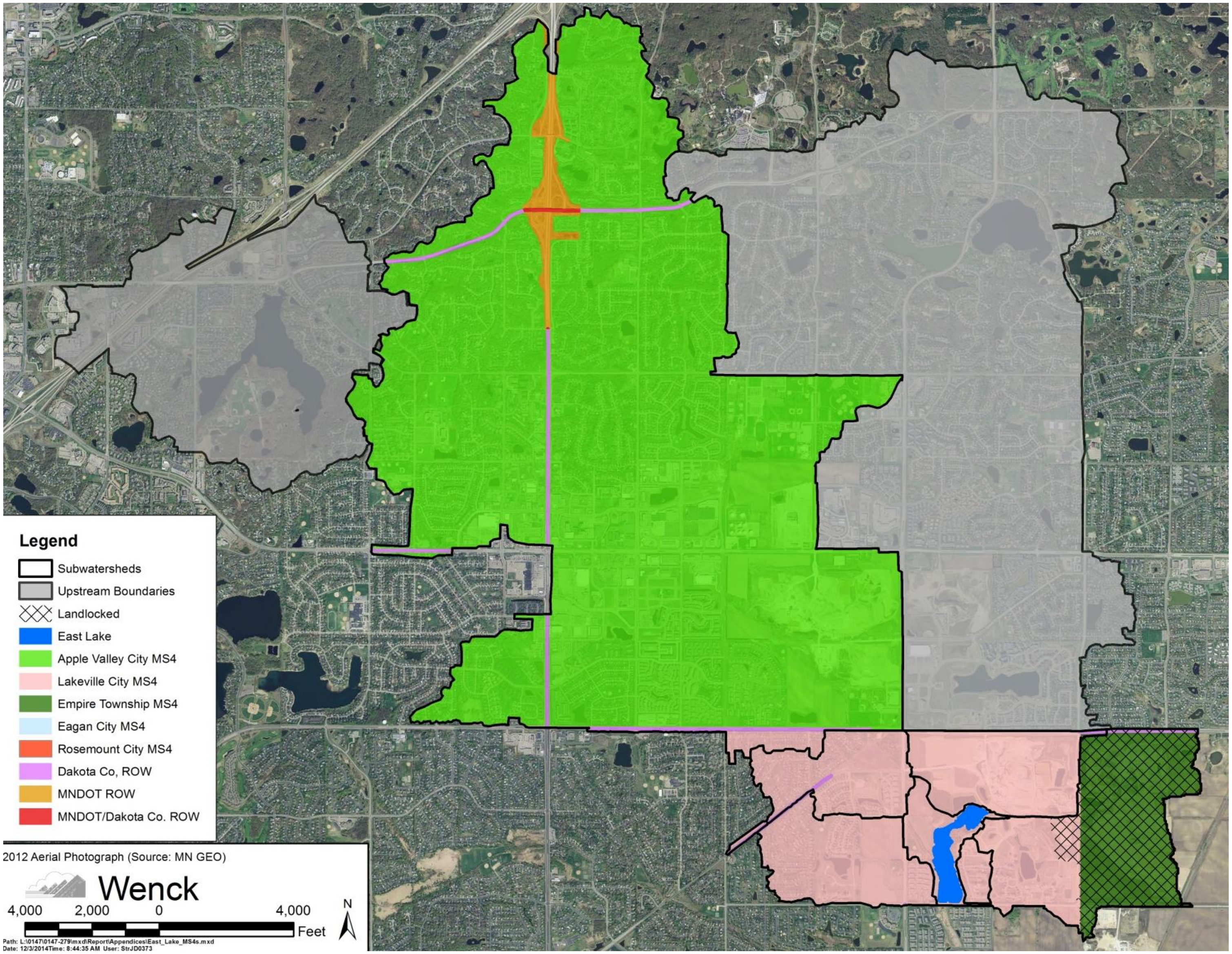
East Lake Subwatersheds, Flow Patterns and Sampling Locations (zoomed in)

Note: Area labeled "landlocked" does not drain to the lake and is not included in the TMDL model analysis



East Lake Watershed Landuse

Note: Area labeled "landlocked" does not drain to the lake and is not included in the TMDL model analysis



East Lake MS4 Coverage

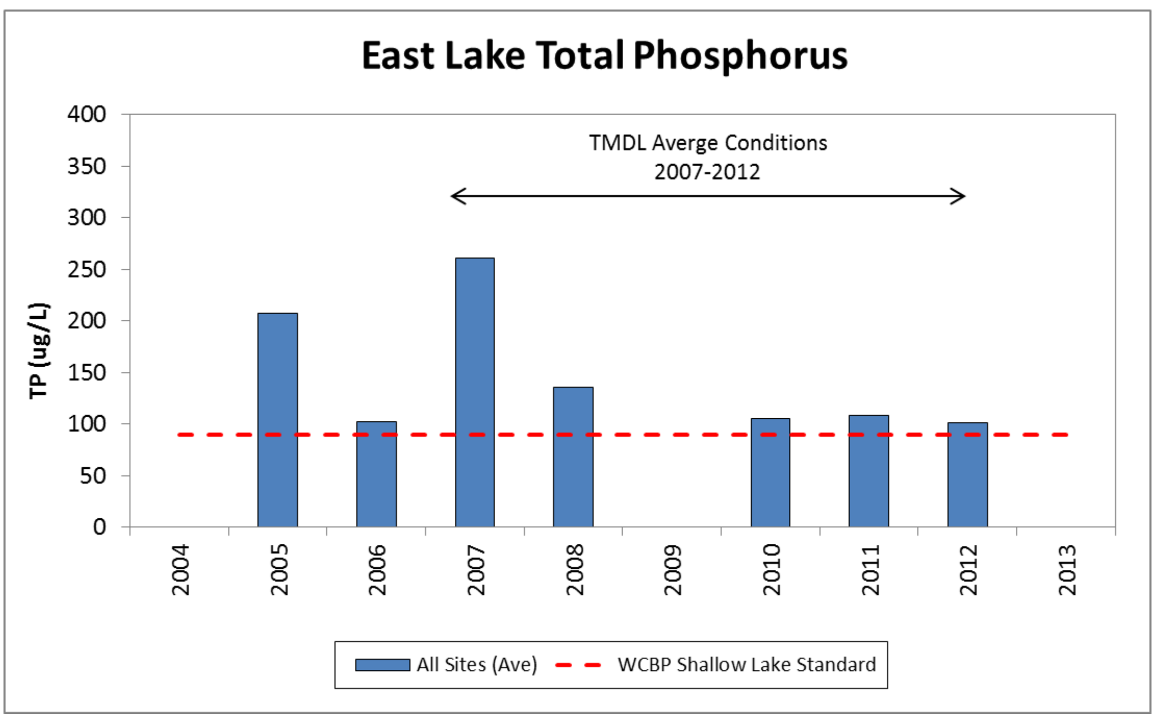
Note: Area labeled "landlocked" does not drain to the lake and is not included in the TMDL model analysis

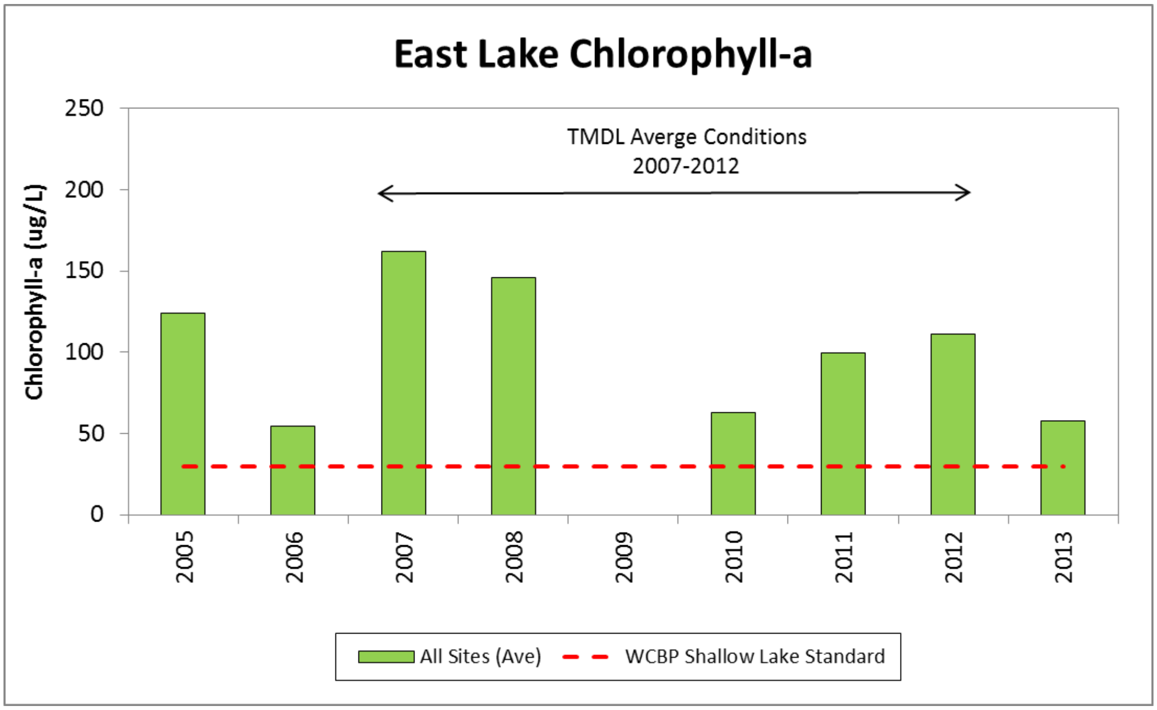
East Lake Data

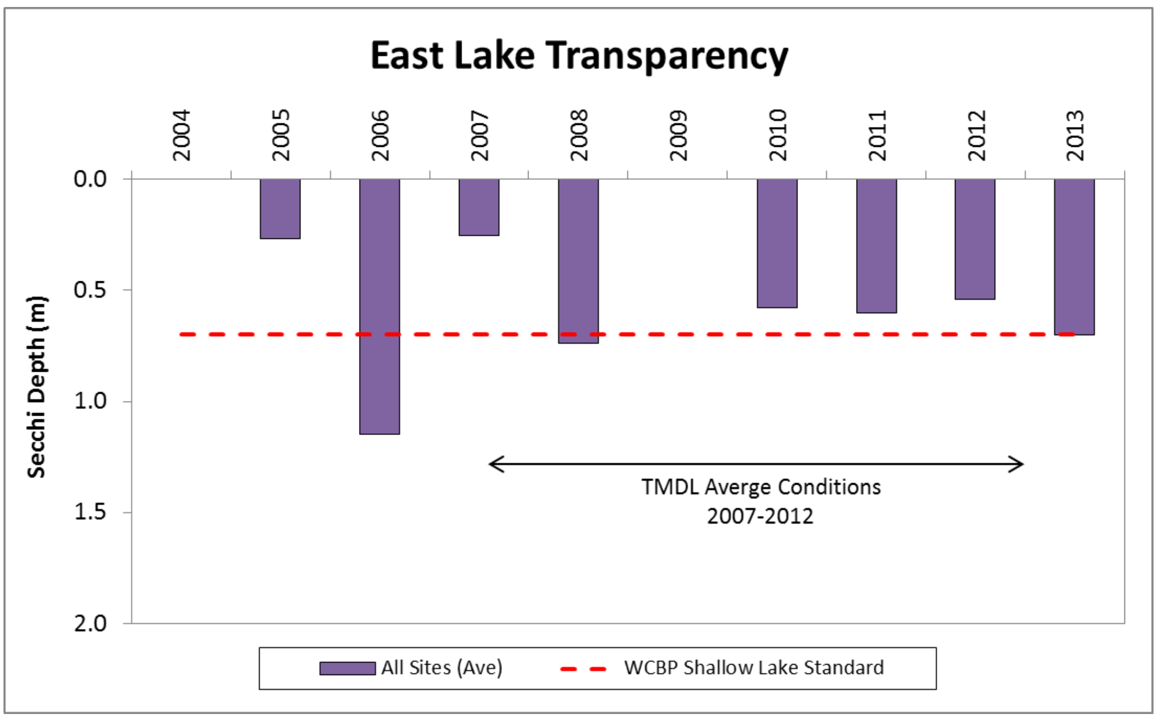
East Lake Historic Water Quality Sampling

Year	Total Phosphorus (ug/L)		Chlorophyll-a (ug/L)		Secchi (m)	
	N	Ave	N	Ave	N	Ave
2005	9	208	9	124	9	0.27
2006	4	103	4	55	4	1.15
2007	8	261	8	162	8	0.26
2008	8	136	8	146	8	0.74
2009	--	--	--	--	--	--
2010	9	106	9	63	9	0.58
2011	7	108	8	99	8	0.60
2012	8	101	7	111	8	0.54
2013	--	--	8	58	8	0.70

Notes: Only June 1 through September 30 sample events presented
Only data from the past 6 years (2008-2013) were used to represent current conditions in TMDL

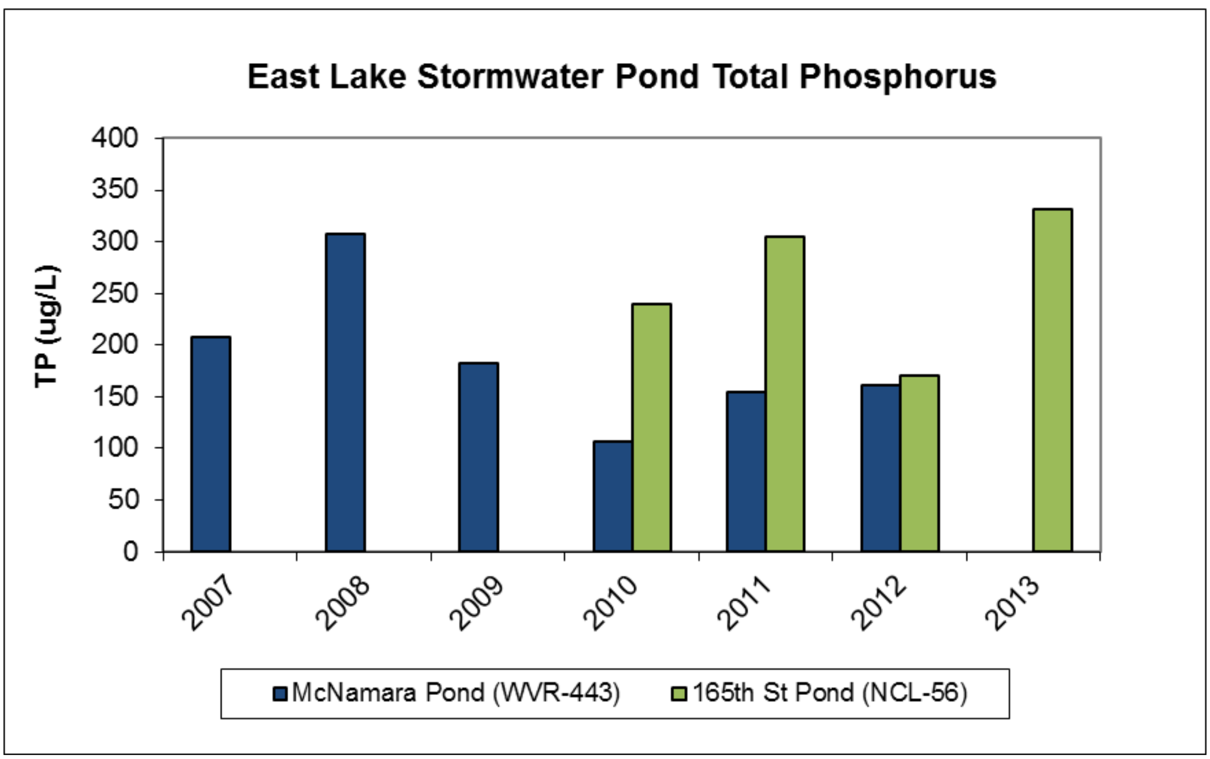



East Lake Chlorophyll-a
TMDL Averge Conditions
2007-2012
Chlorophyll-a (ug/L)
250
200
150
100
50
0
2005
2006
2007
2008
2009
2010
2011
2012
2013
All Sites (Ave)
WCBP Shallow Lake Standard

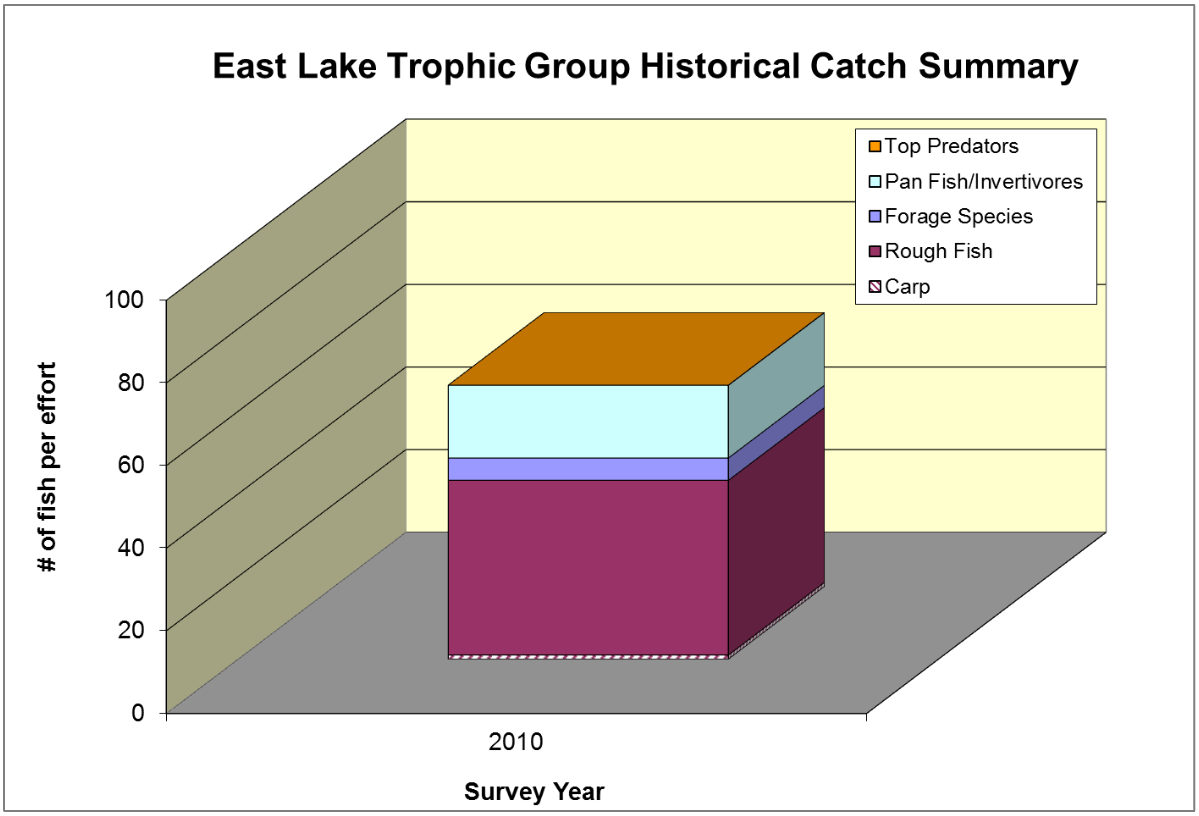

East Lake Transparency
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Secchi Depth (m)
0.0
0.5
1.0
1.5
2.0
TMDL Averge Conditions
2007-2012
All Sites (Ave)
WCBP Shallow Lake Standard

East Lake Watershed Stormwater Pond TP Monitoring Data

Year	McNamara Pond (WVR-443)		165th St Pond (NCL-56)	
	N	TP Ave (µg/L)	N	TP Ave (µg/L)
2007	4	208	--	--
2008	4	308	--	--
2009	4	183	--	--
2010	4	107	--	--
2011	4	154	5	305
2012	4	161	4	170
2013	--	--	5	332

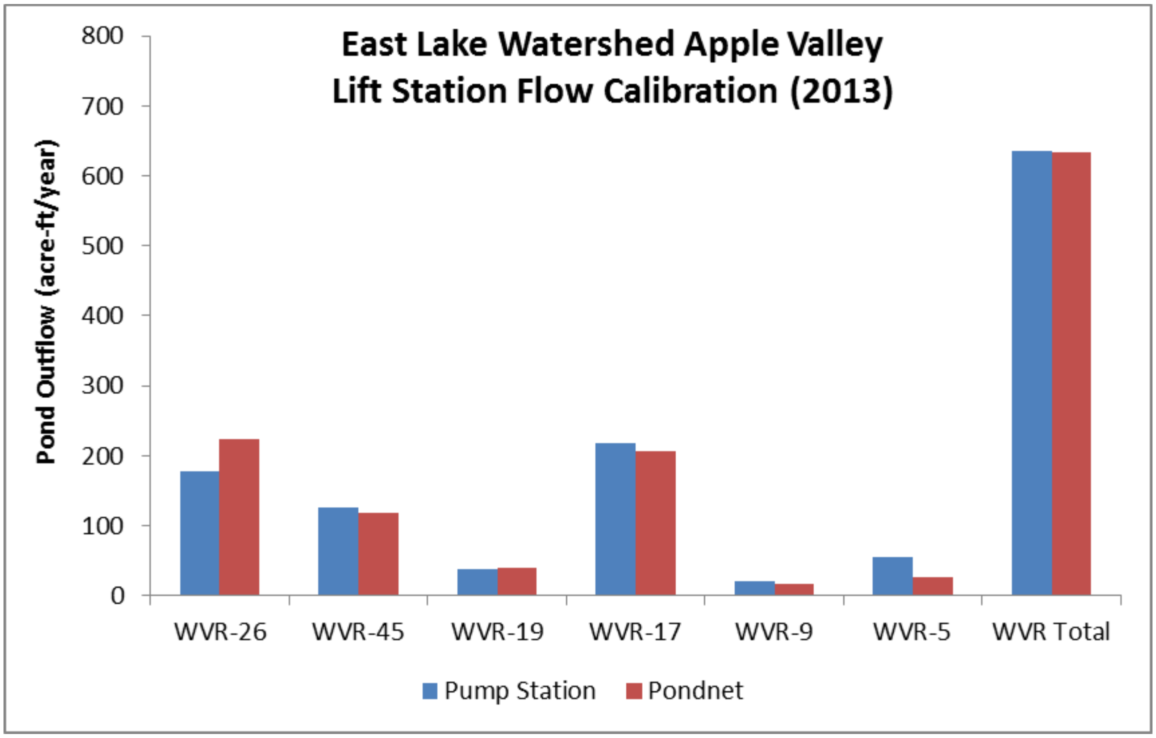


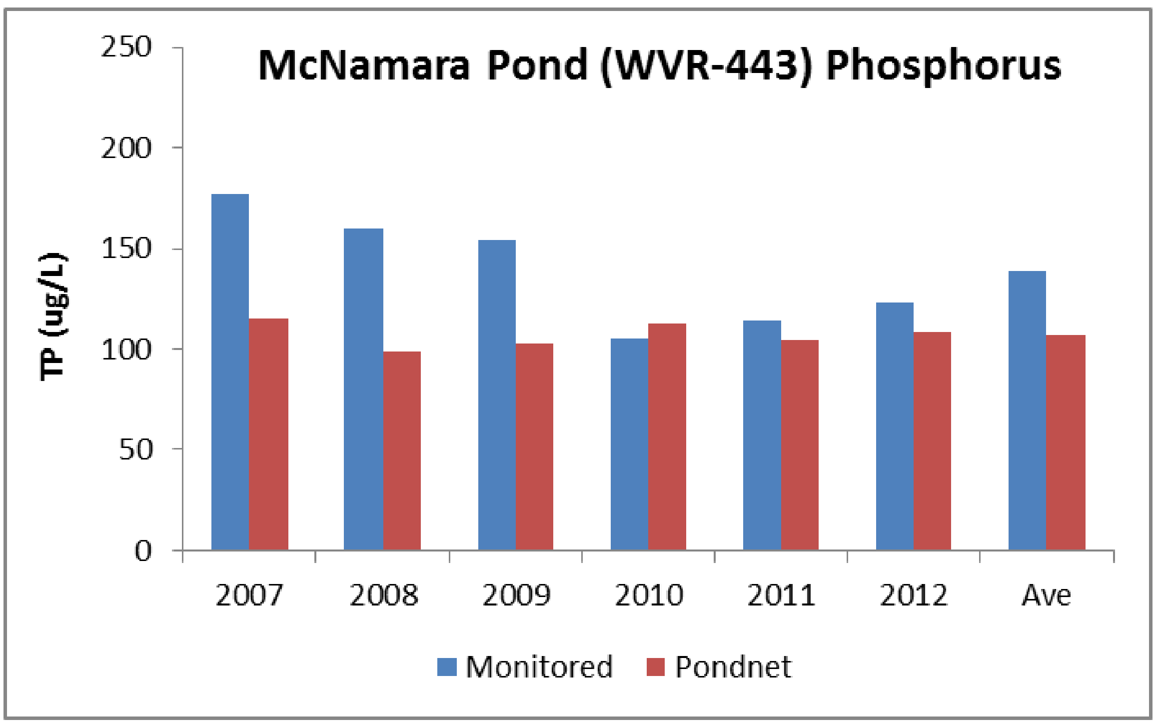
East Lake Fish Surveys by Trophic Group

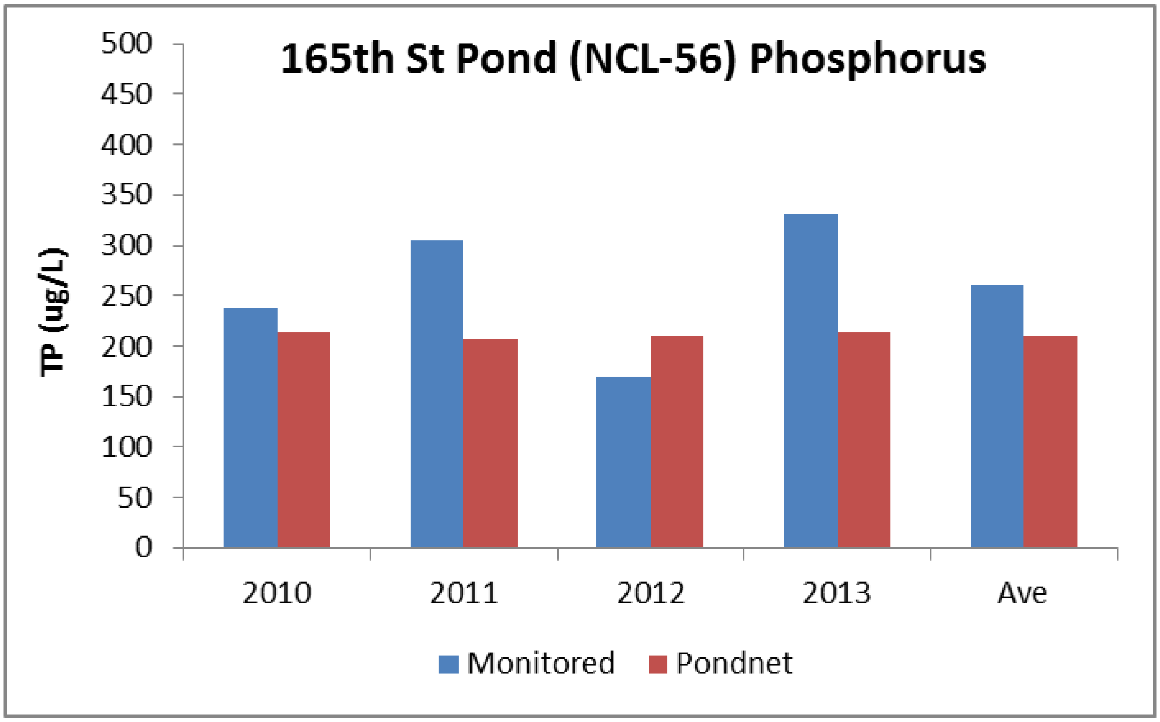


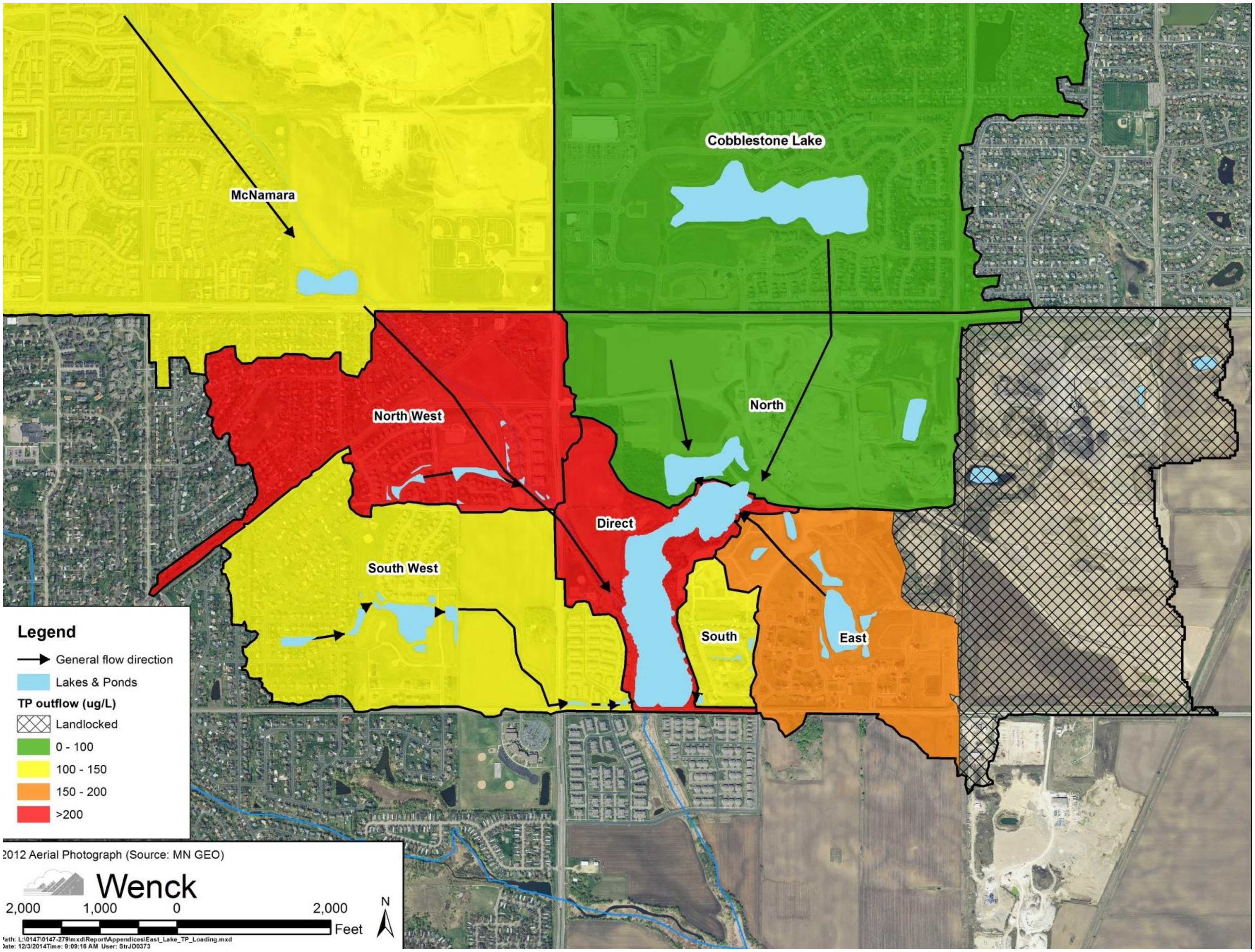
East Lake Modeling

East Lake PONDNET Model Performance





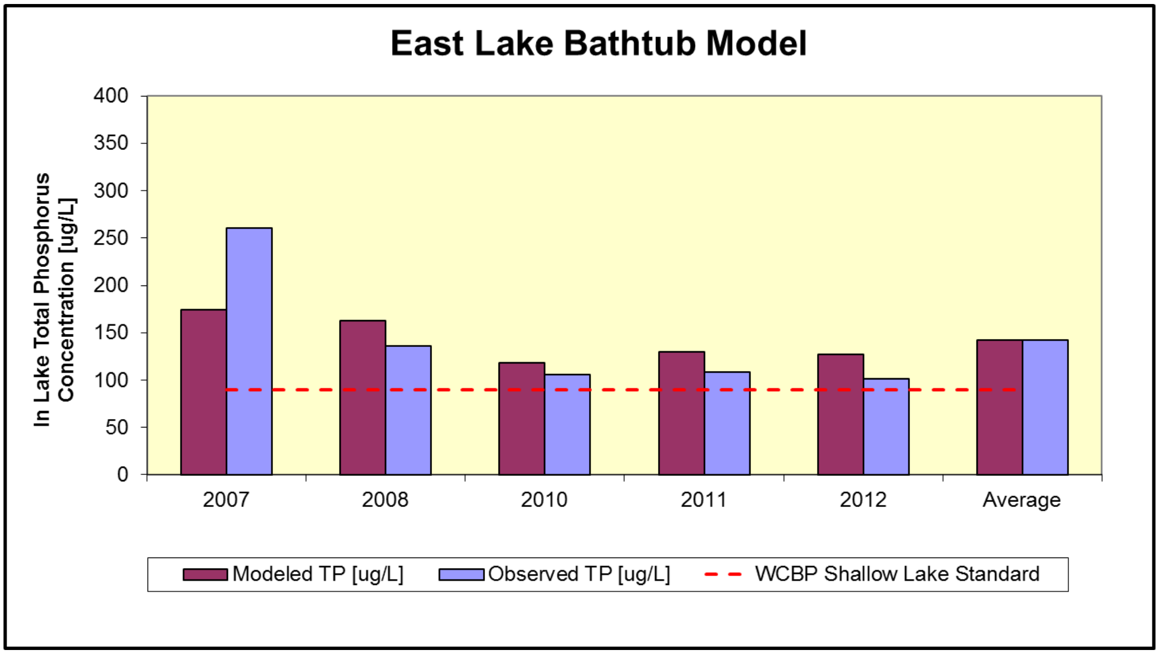

165th St Pond (NCL-56) Phosphorus
TP (ug/L)
500
450
400
350
300
250
200
150
100
50
0
2010
2011
2012
2013
Ave
Monitored
Pondnet



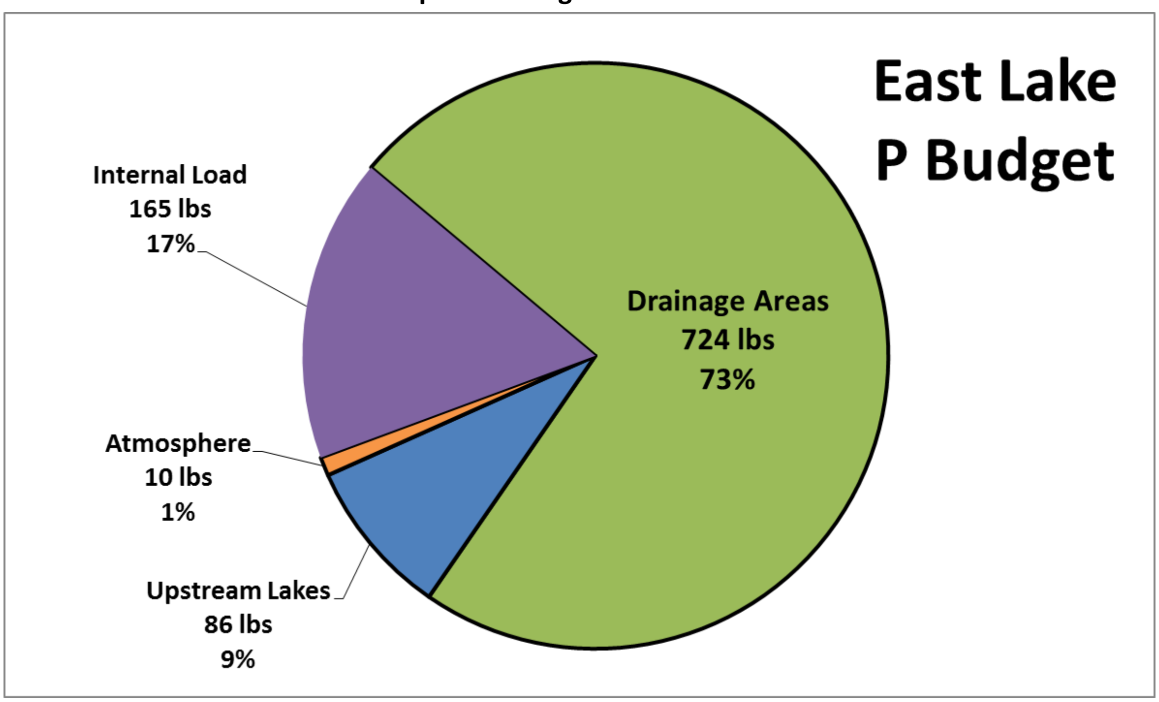
East Lake PONDNET Model Results by Subwatershed

Note: Area labeled "landlocked" does not drain to the lake and is not included in the TMDL model analysis

East Lake BATHTUB Lake Response Model Performance



East Lake Current Conditions Phosphorus Budget



East Lake Current Conditions Canfield-Bachman Lake Response Model

Average Loading Summary for East Lake

		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Calibration Factor	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	WVR-P443 Outflow	4,873.92	3.95	1,604.61	145	1.0	632.47
2	NCL-56	230.39	3.09	59.32	226	1.0	36.41
3	NCL-77	281.62	2.74	64.35	146	1.0	25.64
4	NCL-80a.1	157.41	3.52	46.21	157	1.0	19.69
5	NCL-79	275.19	0.27	6.18	56	1.0	0.94
6	NCL-81	35.43	1.69	4.98	149	1.0	2.02
7	NCL-78	70.29	1.94	11.39	213	1.0	6.58
	Summation	*5,924.26*		*1,797.03*			*723.76*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1							
2							
3							
4							
5							
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Alimagnet			335.82	90	1.0	82.11
2	Cobblestone Lake			27.37	47	1.0	3.52
3					-	1.0	
	Summation			*363.18*	*69*		*85.63*
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]
	42.45	29.23	29.23	0.00	0.24	1.0	10.15
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.17	303		Oxic	0.24	1.0	27.59
	0.17	62		Anoxic	5.90	1.0	137.44
	Summation						165.03
		Net Discharge [ac-ft/yr] =		**2,160.21**	**Net Load [lb/yr] =**		**984.56**

Average Lake Response Modeling for East Lake

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	0.43	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	447	[kg/yr]
		Q (lake outflow) =	2.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.08	[yr]
		P_i = W/Q =	168	[µg/l]
Model Predicted In-Lake [TP]			**142.2**	**[ug/l]**
Observed In-Lake [TP]			**142.2**	**[ug/l]**

East Lake TMDL Conditions Canfield-Bachman Lake Response Model

	TMDL Loading Summary for	*East Lake*					
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	WVR-P443 Outflow	4,873.92	3.95	1,604.61	99	1.0	433.78
2	NCL-56	230.39	3.09	59.32	99	1.0	16.03
3	NCL-77	281.62	2.74	64.35	99	1.0	17.41
4	NCL-80a.1	157.41	3.52	46.21	99	1.0	12.49
5	NCL-79	275.19	0.27	6.18	56	1.0	0.94
6	NCL-81	35.43	1.69	4.98	99	1.0	1.35
7	NCL-78	70.29	1.94	11.39	99	1.0	3.08
	Summation	*5,924.26*		*1,797.03*			*485.08*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1							
2							
3							
4							
5							
	Summation			*0*			*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1							
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*			*0.0*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Alimagnet			335.82	60	0.7	54.85
2	Cobblestone Lake			27.37	47	1.0	3.52
3					-	1.0	
	Summation			*363.18*	*54*		*58.37*
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]
	42.45	29.23	29.23	0.00	0.24	1.0	10.15
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.17	303		Oxic	0.24	1.0	27.59
	0.17	62		Anoxic	1.00	1.0	23.29
	Summation						50.88
		Net Discharge [ac-ft/yr] =		**2,160.21**	**Net Load [lb/yr] =**		**604.48**

TMDL Lake Response Modeling for	*East Lake*			
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	0.43	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	274	[kg/yr]
		Q (lake outflow) =	2.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.2	[10^6 m^3]
		T = V/Q =	0.08	[yr]
		P_i = W/Q =	103	[µg/l]
Model Predicted In-Lake [TP]			**90.0**	**[ug/l]**
[TP] Water Quality Standard			**90.0**	**[ug/l]**

Internal Phosphorus Loading and Sediment Phosphorus Fractionation Analysis for Alimagnet and East Lakes, Minnesota

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26 March, 2014

OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled aerobic and anaerobic conditions and to quantify biologically-labile (i.e., subject to recycling) and refractory (i.e., biologically inert and subject to burial) P fractions for sediment collected in Alimagnet and East Lake, Minnesota.

APPROACH

Laboratory-derived rates of P release from sediment under anaerobic conditions: Sediment cores were collected by Wenck Associates from a centrally-located station in each lake in November, 2013, for determination of rates of P release from sediment under aerobic and anaerobic conditions. Cores were drained of overlying water and the upper 10 cm of sediment was transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling nitrogen (anaerobic conditions) or air (aerobic conditions) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 µm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of

P release from the sediment (mg/m^2 d) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry: The upper 10 cm of an additional core was sectioned for analysis of moisture content (%), sediment density (g/cm^3), loss on ignition (i.e., organic matter content, %), loosely-bound P, iron-bound P, aluminum-bound P, calcium-bound P, labile and refractory organic P, total P, total iron (Fe) and total manganese (Mn; all expressed at mg/g). A known volume of sediment was dried at 105 ^oC for determination of moisture content and sediment density and burned at 500 ^oC for determination of loss-on-ignition organic matter content (Håkanson and Jansson 2002). Additional sediment was dried to a constant weight, ground, and digested for analysis of total P, Fe, and Mn using standard methods (Anderson 1976, APHA 2005 method 4500 P.f., EPA method 3050B).

Phosphorus fractionation (Table 1) was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), sodium hydroxide-extractable P (i.e., aluminum-bound P), and hydrochloric acid-extractable P (i.e., calcium-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Refractory organic P was estimated as the difference between total P and the sum of the other fractions.

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that result in desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström 1984, Nürnberg 1988). The sum of the loosely-bound and iron-bound P fractions represent redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988; Gächter and Meyer 1993; Hupfer et al. 1995). The sum of redox-sensitive P and labile organic P collectively represent biologically-labile P. This fraction is generally active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound, calcium-bound, and refractory organic P fractions are more chemically inert and subject to burial rather than recycling.

RESULTS AND INTERPRETATION

P mass and concentration increased rapidly and linearly in the overlying water column of sediment systems maintained under anaerobic conditions (Figure 1). The mean P concentration maximum in the overlying water was high at 0.450 mg/L (± 0.042 standard error; SE) and 0.593 mg/L (± 0.019 SE) for Alimagnet and East sediment core incubation systems at the end of the incubation period (Table 2). The mean rate of P release under anaerobic conditions was relatively high at 4.7 mg/m^2 d (± 0.4 SE) for Alimagnet Lake and 5.9 mg/m^2 d (± 0.2 SE) for East Lake (Table 2), indicative of eutrophic conditions (Nürnberg 1988). When compared to linear regression relationships developed between redox-sensitive P (i.e., loosely-bound P and iron-bound P) versus the anaerobic P release rate for other lakes in the region, Alimagnet and East Lakes fell within the overall range of values (Figure 2), suggesting that iron-phosphorus oxidation-reduction chemistry was playing a role in anaerobic P release. Overall, the mean anaerobic P release rate for each lake sediment fell near the median compared to lakes in the regional area (Figure 3).

Soluble phosphorus accumulation in the overlying water column was much lower for sediment cores incubated under aerobic conditions (Figure 4). The mean aerobic P release rate was low at 0.17 mg/m^2 d (± 0.01 SE) and 0.24 mg/m^2 d (± 0.04 SE) for sediment cores collected in Alimagnet and East Lake, respectively (Table 2). The maximum P concentration attained in the overlying water column toward the end of the incubation period was also moderately low at only 0.017 mg/L (± 0.002 SE) for Alimagnet Lake aerobic system incubations and 0.034 mg/L (±0.011 SE) for East Lake aerobic system incubations (Table 2). The mean aerobic P release rates fell within the lower 25% quartile compared to other lakes in the region (Figure 3). Typically, rates of P release are much higher under anaerobic versus aerobic conditions, due to binding of P onto Fe~(OOH) in the sediment oxidized microzone under the latter condition and suppression of diffusive flux into the overlying water column.

The upper 10-cm sediment layer in each lake exhibited a moderately low moisture content and high bulk density (Figure 5 and 6; Table 3). These physical characteristics suggested fine-grained compacted sediment accumulation in these shallow basins, which could be related to watershed urban development and runoff of predominantly inorganic particles. Organic matter content of sediments in each lake was also moderately low, ranging between ~17% and 19%. Concentrations of biologically-labile (i.e., subject to recycling back to the overlying water column; loosely-bound P, iron-bound P, and labile organic P) and refractory (i.e., aluminum-bound, calcium-bound, and refractory organic P) P concentrations were moderately low and fell within the lower 25% quartile compared to other lakes in the region (Table 4 and Figure 7). Biologically-labile P represented ~ 32% while biologically-refractory P accounted for 68% of the sediment total P concentration for both lake sediments (Table 5 and Figure 8).

The redox-sensitive P concentration (i.e., the sum of loosely-bound and iron-bound P) of sediment in both lakes was composed primarily of the iron-bound P fraction and concentrations were relatively low, falling within the lower 25% quartile, versus other lakes in the region (Figure 7). Iron-bound P accounted for ~ 51% and 54% of the biologically-labile P fraction in Alimagnet and East Lake sediments, respectively. Labile organic P, which can be recycled to the water column as a result of bacterial metabolic processes, also represented a significant portion of the biologically-labile P pool at ~42% for each lake. The loosely-bound P fraction was relatively low and only accounted for ~ 5% of the biologically-labile P and 10% of the redox-sensitive P. Loosely-bound P typically represents P in interstitial water and concentrations are usually low relative to other sediment P fractions. Aluminum-bound, calcium-bound P (i.e., P associated with apatite minerals), and refractory organic P each represented ~ 16%, 28%, and 56% of the biologically-refractory P for each lake (Figure 8). The sediment total P concentration was moderately low at 0.862 mg/g and 0.774 mg/g for both Alimagnet and East Lake sediments, respectively (Table 5), falling within or slightly below the lower 25% quartile versus other lakes in the region (Figure 7).

The total sediment Fe concentration was moderately high in both lake sediments (Table 6). The Fe concentration was also high relative to the concentration of total sediment P, resulting in an Fe:P ratio (mass:mass) of ~39:1. Ratios greater than 10:1 to 15:1 have been associated with regulation of P release from sediments under oxic (aerobic) conditions due to efficient binding of P onto iron oxyhydroxides in the sediment oxic microzone (Jensen et al. 1992). Complete binding efficiency for P at these higher relative concentrations of Fe are suggested explanations for patterns reported by Jensen et al. At lower Fe:P ratios, Fe binding sites become increasingly saturated with P, allowing for diffusion of excess porewater P into the overlying water column, even in the presence of a sediment oxic microzone. Indeed, P release rates for Alimagnet and East Lake sediments were low under aerobic conditions, a pattern that could be attributed to the Jensen et al. model. The total sediment Mn concentrations for sediments collected in each lake were relatively low. Similar to iron, Mn can play a role in P recycling between the sediment and overlying water column via oxidation-reduction reactions.

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Table 1. Sequential phosphorus (P) fractionation scheme, extractants used, and definitions of recycling potential.

Variable	Extractant	Recycling Potential
Loosely-bound P	1 M Ammonium Chloride	Biologically labile; Soluble P in interstitial water and adsorbed to $CaCO_3$; Recycled via direct diffusion, eH and pH reactions, and equilibrium processes
Iron-bound P	0.11 M Sodium Bicarbonate-dithionate	Biologically labile; P adsorbed to iron oxyhydroxides (Fe(OOH); Recycled via eH and pH reactions and equilibrium processes
Labile organic P	Persulfate digestion of the NaOH extraction	Biologically labile; Recycled via bacterial mineralization of organic P and mobilization of polyphosphates stored in cells
Aluminum-bound P	0.1 N Sodium Hydroxide	Biologically refractory; Al-P minerals with a low solubility product
Calcium-bound P	0.5 N Hydrochloric Acid	Biologically refractory; Represents Ca-P minerals such as apatite with a low solubility product
Refractory organic P	Determined by subtraction of other forms from total P	Biologically refractory; Organic P that isresistant to bacterial breakdown

Table 2. Mean (1 standard error in parentheses; n = 3) rates of phosphorus (P) release under aerobic and anaerobic conditions and mean P concentration (n = 3) in the overlying water column near the end of the incubation period for intact sediment cores collected in Alimagnet and East Lake.

Station	Diffusive P Flux			
	Aerobic		Anaerobic	
	(mg/m^2 d)	(mg/L)	(mg/m^2 d)	(mg/L)
Alimagnet	0.17 (0.01)	0.017 (0.002)	4.7 (0.4)	0.450 (0.042)
East	0.24 (0.04)	0.034 (0.011)	5.9 (0.2)	0.593 (0.019)

Table 3. Textural characteristics for sediments collected in Alimagnet and East Lake.

Station	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Loss-on-ignition (%)
Alimagnet	86.4	1.308	0.148	16.9
East	76.4	1.134	0.275	18.6

Table 4. Concentrations of biologically labile and refractory phosphorus (P) for sediments collected in Alimagnet and East Lake. DW = dry mass, FW = fresh mass.

Station	Redox-sensitive and biologically labile P				Refractory P		
	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (ug/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)	Calcium-bound P (mg/g DW)	Refractory organic P (mg/g DW)
Alimagnet	0.017	0.132	19	0.112	0.090	0.189	0.324
East	0.011	0.139	33	0.108	0.090	0.127	0.300

Table 5. Concentrations of sediment total phosphorus (P), redox-sensitive P (Redox P; the sum of the loosely-bound and iron-bound P fraction), biologically-labile P (Bio-labile P; the sum of redox-P and labile organic P), and refractory P (the sum of the aluminum-bound, calcium-bound, and refractory organic P fractions) for sediments collected in Alimagnet and East Lake. DW = dry mass.

Station	Total P	Redox P		Bio-labile P		Refractory P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Alimagnet	0.862	0.149	17.3%	0.261	30%	0.603	70%
East	0.774	0.150	19.4%	0.258	33%	0.517	67%

Table 6. Concentrations of sediment total iron (Fe), manganese (Mn), and the Fe:P ratio for sediments collected in Alimagnet and East Lake. DW = dry mass.

Station	Total Fe (mg/g DW)	Total Mn (mg/g DW)	Fe:P
Alimagnet	32.74	0.21	38.0
East	30.23	0.33	39.1

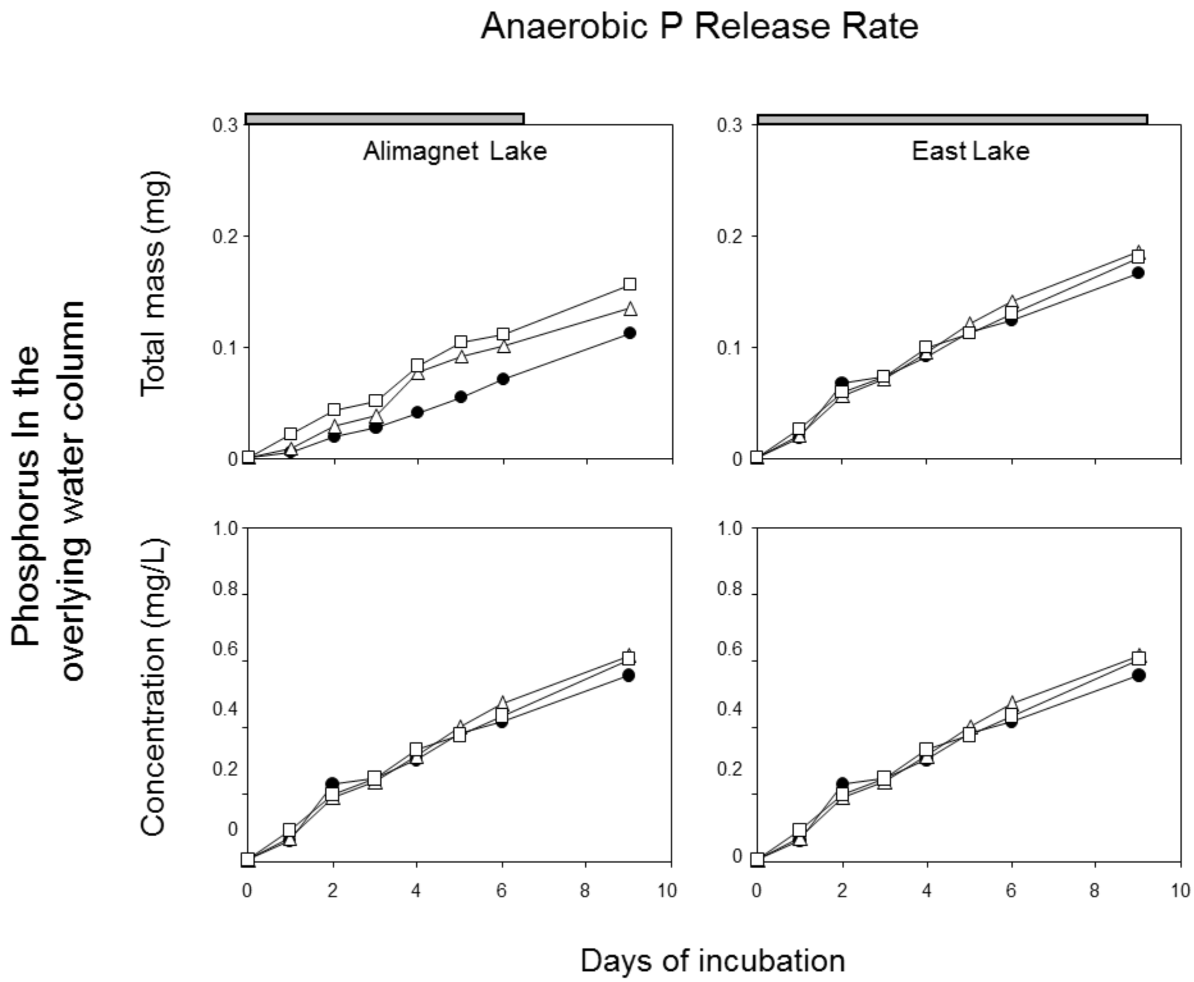


Figure 1. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under anaerobic conditions versus time for sediment cores collected in Alimagnet and East Lake. Gray horizontal bar denotes the time period used for rate estimation.

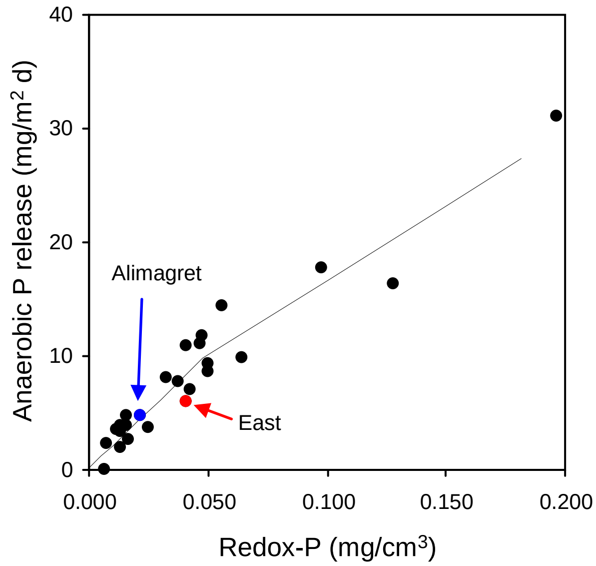


Figure 2. Relationships between redox-sensitive phosphorus (P; mg/cm^3 dry bulk density) and rates of P release from sediments under anaerobic conditions for various lakes in the region.

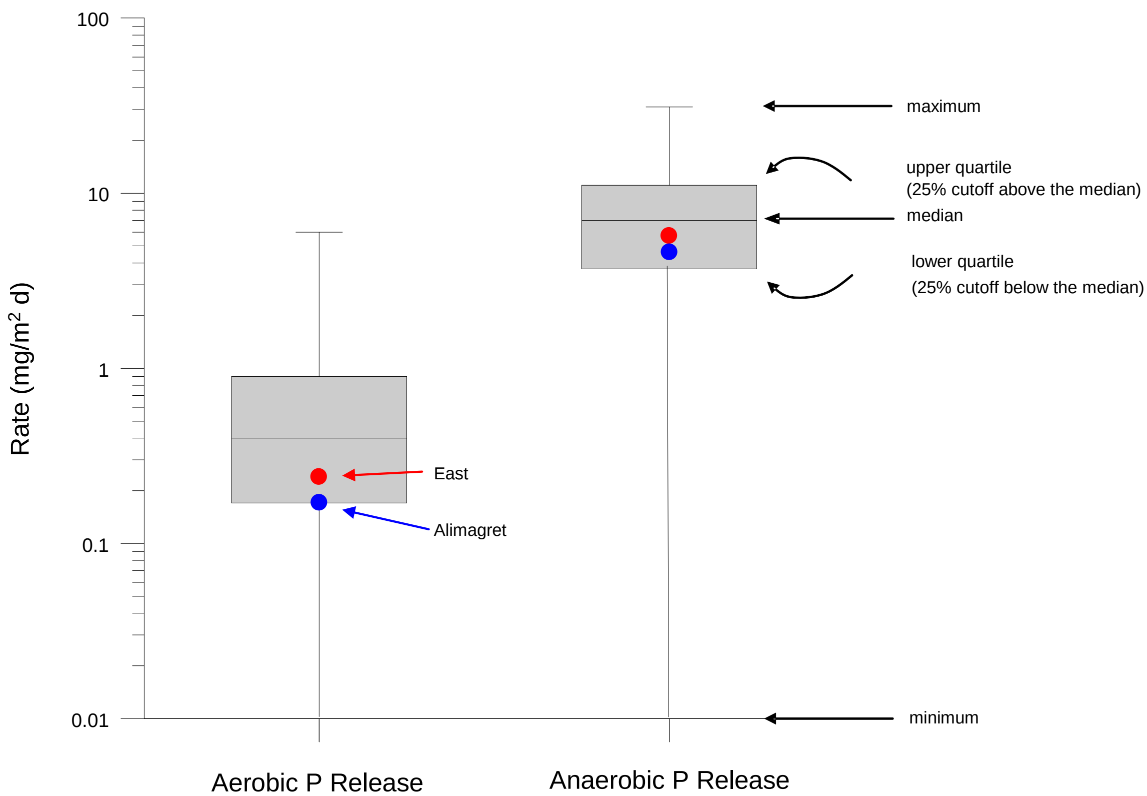


Figure 3. Box and whisker plot comparing the aerobic and anaerobic phosphorus (P) release rates measured for Alimagnet (blue circle) and East Lake (red circle) with statistical ranges for lakes in the region.

Aerobic P Release Rate

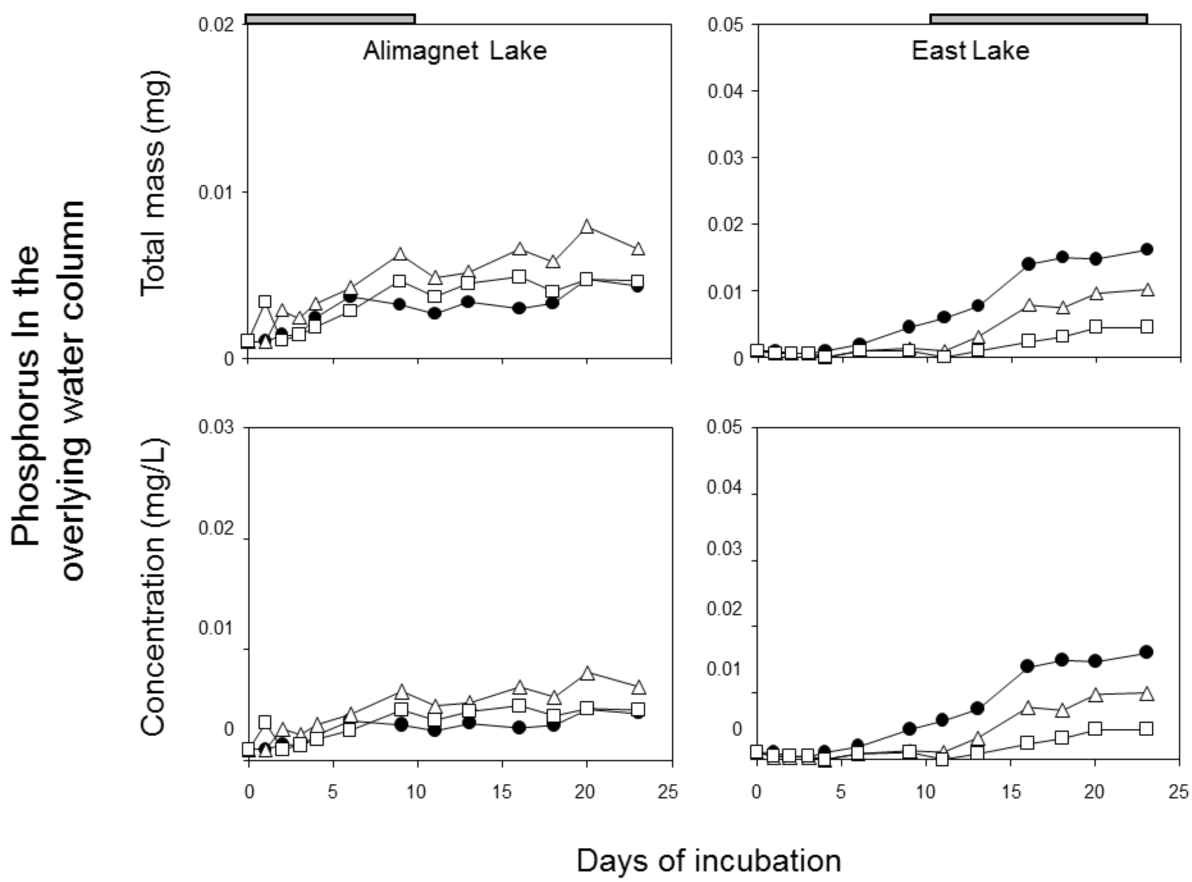


Figure 4. Changes in soluble reactive phosphorus mass (upper panels) and concentration (lower panels) in the overlying water column under aerobic conditions versus time for sediment cores collected in Alimagnet and East Lake. Gray horizontal bar denotes the time period used for rate estimation.

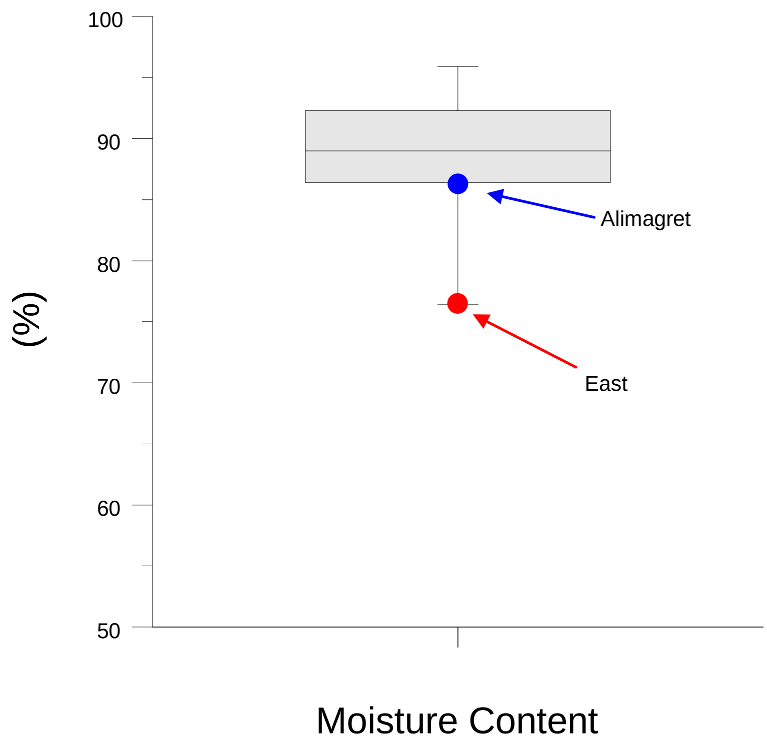
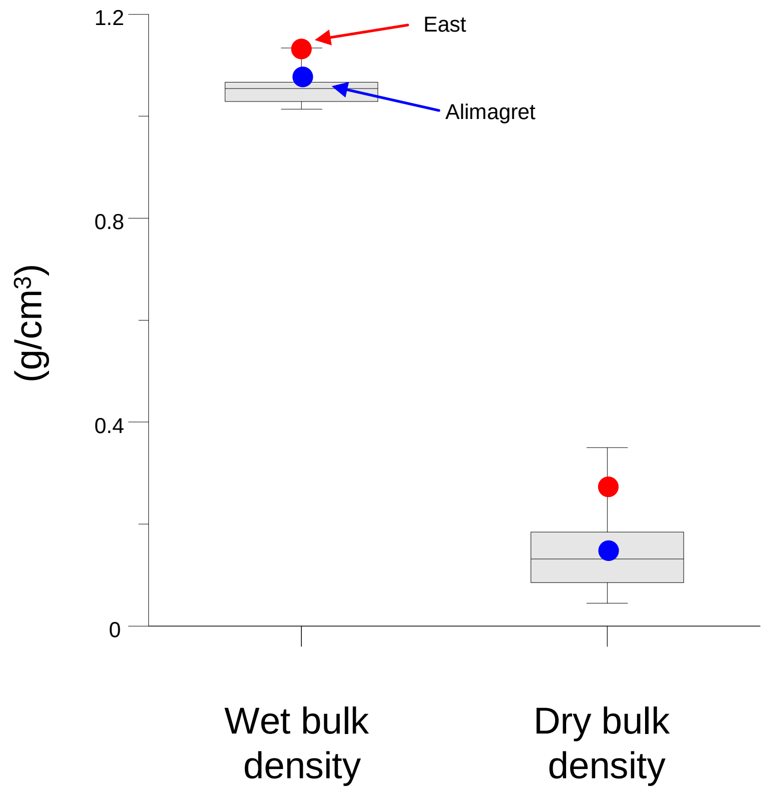


Figure 5. Box and whisker plot comparing sediment moisture content measured for Alimagnet (blue circle) and East Lake (red circle) with statistical ranges for lakes in the region.



6. Box and whisker plot comparing sediment bulk density characteristics measured for Alimagnet (blue circle) and East Lake (red circle) with statistical ranges for lakes in the region.

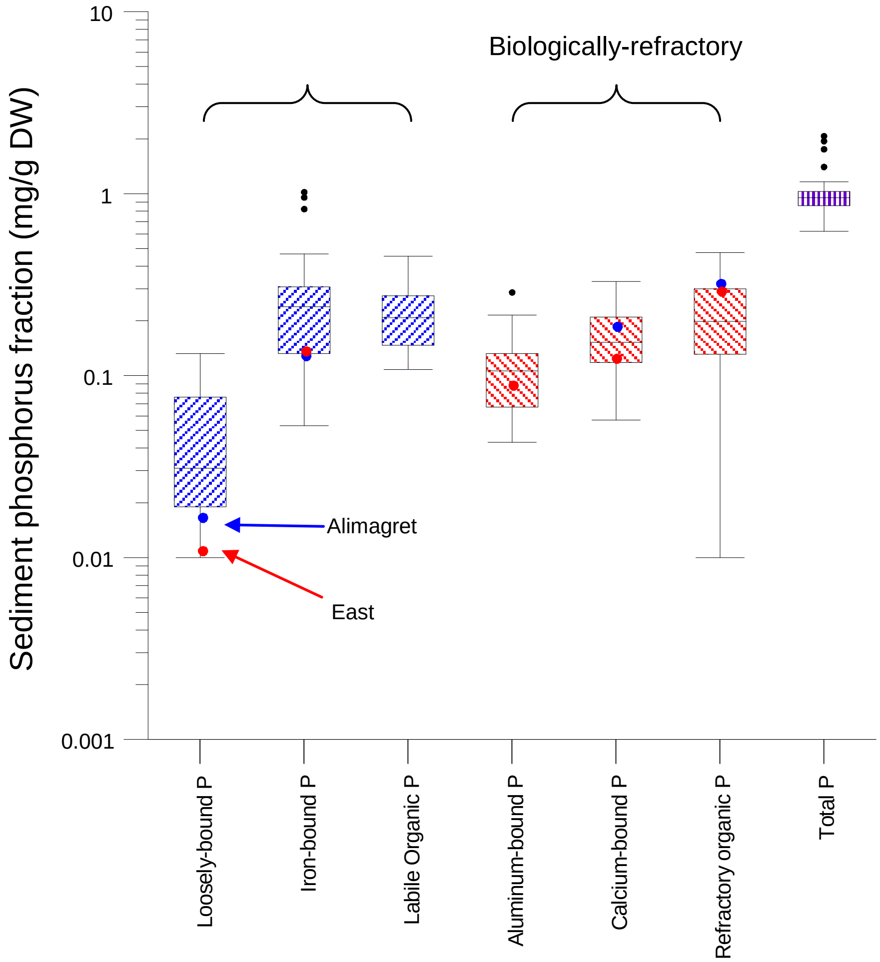


Figure 7. Box and whisker plot comparing various sediment phosphorus (P) fractions measured for Alimagnet (blue circle) and East Lake (red circle) with statistical ranges for lakes in the region. Loosely-bound, iron-bound, and labile organic P are biologically-labile (i.e., subject to recycling) and aluminum-bound, calcium-bound, and refractory organic P are more are more inert to transformation (i.e., subject to burial). Please note the logarithmic scale.

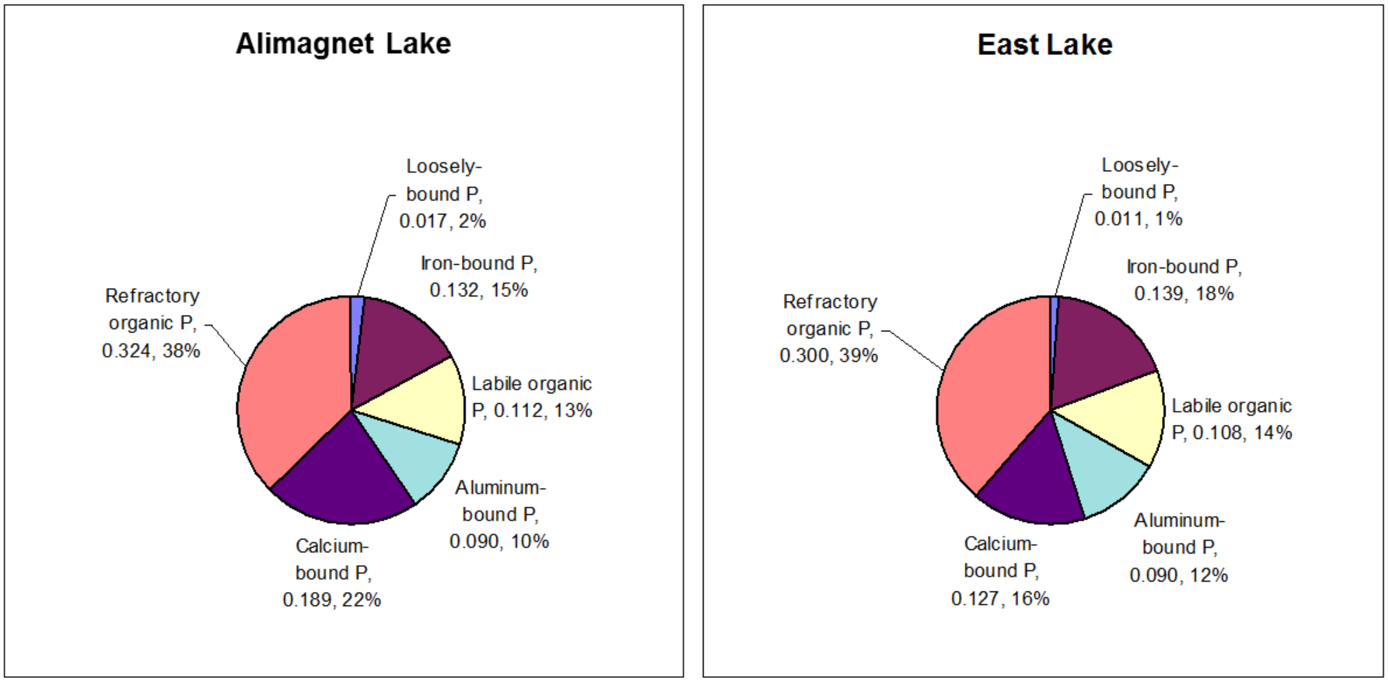


Figure 8. Total phosphorus (P) composition for sediment collected in Alimagnet and East Lake. Loosely-bound, iron-bound, and labile organic P are biologically reactive (i.e., subject to recycling) while aluminum-bound, calcium-bound, and refractory organic P are more inert to transformation (i.e., subject to burial). Values next to each label represent concentration (mg/g).