Watershed

April 2021

Final Kettle River and Upper St. Croix River Watersheds Total Maximum Daily Load Report

Watershed-wide total maximum daily loads covering *Escherichia Coli* and lake nutrient impairments in the Kettle River and Upper St. Croix River Watersheds, which are located in the St. Croix River Basin.

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

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Location: St. Croix River near Chengwatana State Forest, Minnesota.

Contents

List of tables

List of figures

Acronyms

AFO	Animal Feeding Operation
AUID	Assessment Unit Identification
BMP	best management practice
BWSR	Board of Water and Soil Resources
CAFO	Concentrated Animal Feeding Operation
cfu	colony-forming unit
Chl-*a*	chlorophyll-a
CLP	curly-leaf pondweed
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
DNR	Minnesota Department of Natural Resources
DO	dissolved oxygen
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
FTPGW	failing to protect groundwater
GIS	Geographic Information Systems
HSPF	Hydrologic Simulation Program-Fortran
HUC-8	Hydrologic Unit Code-eight digits [sub-basin level]
IBI	Index of Biotic Integrity
ITPHS	imminent threat to public health and safety
km2	square kilometer
LA	load allocation
lbs/day	pounds per day
lbs/yr	pounds per year
lb	pound
LC	loading capacity
LDC	load duration curve
LGU	Local Government Unit
LWG	local workgroup
MDA	Minnesota Department of Agriculture
mg/m2-day	milligram per square meter per day
mL	milliliter
MOS	margin of safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer System
NLCD	National Land Cover Database
NLF	Northern Lakes and Forest
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
NRS	Nutrient Reduction Strategy
PFA	Public Facilities Authority
PWP	Permanent Wetland Preserve

RIM	Reinvest in Minnesota
SAV	submerged aquatic vegetation
SID	Stressor Identification
SONAR	Statement of Need and Reasonableness
SSTS	Subsurface Sewage Treatment Systems
TMDL	total maximum daily load
TP	total phosphorus
µg/L	milligrams per liter
WASCOBs	waterways and water and sediment control basins
WLA	wasteload allocation
WRAPS	Watershed Restoration and Protection Strategy
WRP	Wetland Reserve Program

Executive Summary

Kettle River and Upper St. Croix River Watershed Approach

Intensive watershed monitoring was completed in 2016 and 2017 for the Kettle River Watershed (Hydrologic Unit Code-eight digits [sub-basin level] [HUC-8] 07030003) and the Upper St. Croix River Watershed (HUC-8 07030001), which are located in the St. Croix River Basin (MPCA 2019a and MPCA 2019b).

Stressor identification (SID) was completed during 2018 and 2019 (MPCA 2020d and MPCA 2020f). Seventy-eight river/stream reaches were assessed for their ability to support aquatic life and/or aquatic recreation. Of the assessed river/stream reaches, 57 are considered to be fully supporting of aquatic life and eight are fully supporting aquatic recreation. Of the 36 lakes assessed against the Northern Lakes and Forest (NLF) ecoregion standards for recreation use in the Kettle River and Upper St. Croix River Watersheds, 13 were determined to be impaired by nutrients, expressed as total phosphorus (TP). Rock Lake (Assessment Unit Identification [AUID] 58-0007-00) does not support aquatic recreation use, but it was determined that natural background conditions are causing the elevated concentrations of nutrients in the lake, so a total maximum daily load (TMDL) was not developed for Rock Lake. Based on previous and current monitoring assessment data, there is one total suspended solids (TSS) impaired river/stream reach, 10 bacteria impaired river/stream reaches, six macroinvertebrates Index of Biotic Integrity (IBI) impaired river/stream reaches and 10 fish IBI impaired river/stream reaches within the Kettle River and Upper St. Croix River Watersheds. For the remainder of this TMDL report, the river/stream reaches will be referred to as just “reaches”.

Overview of this TMDL

This TMDL addresses 10 bacteria impaired reaches and 12 nutrient impaired lakes in the Kettle River and Upper St. Croix River Watersheds. One TSS impaired reach, six macroinvertebrate IBI impaired reaches, and 10 fish IBI impaired reaches in the Kettle River and Upper St. Croix River Watersheds are not addressed in this TMDL and will be deferred because the water quality chemistry data was insufficient or because multiple stressors that cannot be quantified were identified. However, these reaches will be addressed through implementation of the Kettle River and Upper St. Croix River Watersheds Restoration and Protection Strategy (WRAPS) Report and local water planning efforts. Addressing multiple impairments in this TMDL is consistent with Minnesota’s Water Quality Framework that seeks to develop watershed-wide protection and restoration strategies rather than focus on individual reach impairments.

Bacteria (E. coli) Impairments

Hydrologic Simulation Program-Fortran (HSPF) simulated flow and monitored bacteria data for the bacteria impaired reaches were used to establish load duration curves (LDCs). The curves were set to meet the *E. coli* standard of no more than 126 organisms per 100 milliliter (mL). A TMDL that includes wasteload allocations (WLAs), load allocations (LAs), and margin of safety (MOS) for the bacteria impaired reach was established for the five flow zones of each reach described in the previous paragraph. Bacteria source assessment exercises for each reach indicate livestock is the largest producer of bacteria in the bacteria-impaired reaches’ watershed. However, monitoring data suggests exceedances during low-flow conditions, suggesting failing Subsurface Sewage Treatment Systems

(SSTS), livestock animals in the stream corridors, and potentially wildlife may also be important sources during certain hydrologic conditions. Implementation activities will need to focus on feedlot and pasture management best management practices (BMPs), livestock exclusion from waterways, and SSTS upgrades.

Lake Nutrient Impairments

Nutrient budgets and lake response models were developed for the 12 nutrient-impaired lakes in the Kettle River and Upper St. Croix River watersheds addressed in this TMDL. The HSPF model was used along with in-lake monitoring data to develop nutrient budgets for each lake and set up the lake response models and TMDL equations. Pollutant source assessment for these lakes indicates they will require a combination of phosphorus reductions from internal and external (watershed) sources. For some of the lakes, the models suggest internal load may be a significant source of phosphorus and therefore further investigation will be needed to evaluate these sources and the necessary in-lake management activities (e.g. rough fish management, sediment phosphorus inactivation, aquatic plant management). Watershed implementation activities will need to focus on upland BMPs to prevent phosphorus sources from getting into each lake.

1. Project Overview

1.1 Purpose

This TMDL report addresses 10 bacteria (*E. coli*) impairments on several main stem and tributary reaches in the Kettle River watershed (HUC-8 watershed 07030003) (See Figure 1). This TMDL report also addresses nutrient (phosphorus) impairments for 11 lakes in the Kettle River Watershed and one lake in the Upper St. Croix River major watershed (HUC-8 watershed 07030001). The watershed boundaries of the impaired reaches and lakes presented in this TMDL report cover portions of four counties in east-central Minnesota: Pine, Kanabec, Aitkin, and Carlton.

The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for bacteria and phosphorus for the reaches and lakes shown in Figure 2 and listed in Tables 1 and 2. This TMDL is established in accordance with Section 303(d) of the Clean Water Act and provides WLAs and LAs for the watershed areas as appropriate.

In 2012, a TMDL study was completed for Lake St. Croix near Stillwater, Minnesota—downstream of the Kettle River and Upper Croix River watersheds (MPCA and WIDNR 2012). This study determined outflow from the Kettle River accounts for approximately 23% of the Minnesota portion of the Lake St. Croix phosphorus budget, with outflow from the Minnesota portion of the Upper St. Croix River watershed accounting for approximately 12%. TMDL allocations and reductions were assigned to the St. Croix River and its tributaries, which includes the Kettle River. This TMDL calls for a 15% reduction in annual phosphorus loading (~12,000 pounds per year) for the Kettle River and for a 15% reduction in annual phosphorus loading (~3,000 pounds per year) for the portion of the Upper St. Croix River located in Minnesota. Many of the implementation activities undertaken and ongoing for the Lake St. Croix Nutrient TMDL have co-benefits that will likely have an impact on the bacteria and nutrient sources that contribute to the impairments addressed through this TMDL. Many BMPs have been implemented to date, which is discussed in greater detail in Section 6 of this report.

In 2015, a TMDL study was completed for the Mississippi River in the southern Twin Cities Metropolitan Area, downstream of the Kettle River and Upper St. Croix River watersheds (MPCA 2015b). This study addressed Total Suspended Solids (TSS) in the Mississippi River and its upstream tributaries. Overall, the study determined that the St. Croix Basin accounts for only 2% of the TSS load of the South Metro Mississippi River watershed, despite accounting for about 21% of the contributing area. The South Metro Mississippi TSS TMDL does not require reductions in TSS loading for the Kettle River and Upper St. Croix River Watersheds due to the reductions in total phosphorus, which include sediment-attached phosphorus from urban and rural portions of the basin, required by the Lake St. Croix Nutrient TMDL.

The Lake Pepin and Mississippi River Eutrophication TMDL is another large-scale TMDL effort currently underway that involves the Kettle River and Upper St. Croix River watersheds, as they are upstream of Lake Pepin and the Mississippi River. However, the allowable phosphorus loads specified in the Lake St. Croix Nutrient TMDL are protective of Lake Pepin and, therefore, the drainage area is considered a boundary condition ([BC] i.e. excluded area) in the Draft Lake Pepin TMDL (MPCA 2020a).

The Intensive Watershed Monitoring efforts for the Kettle River and Upper St. Croix River Watersheds identified 10 stream reaches that currently do not meet fish IBI standards and six stream reaches that do not meet aquatic macroinvertebrate IBI standards. SID Reports were developed for these reaches to determine the primary stressors to the biological communities (MPCA 2019). Nonpollutant stressors are not subject to load quantification and therefore do not require TMDLs. If a nonpollutant stressor is linked to a pollutant (e.g. habitat issues driven by TSS or low dissolved oxygen (DO) caused by excess phosphorus), a TMDL is required. However, in many cases habitat stressors are not linked to pollutants. The SID reports reviewed available water quality data for the impaired reaches and determined that chemical pollutants from anthropogenic sources are not a primary stressor to the fish and aquatic macroinvertebrate communities. As a result, these impairments will not be covered in this TMDL and instead will be addressed through the implementation of the Kettle and Upper St. Croix River WRAPS Report and local water planning efforts.

The intensive watershed monitoring efforts for the Kettle River and Upper St. Croix River Watersheds also identified one stream reach that currently does not meet TSS standards. This reach, Sand Creek (07030001-538), has an extensive S-TUBE dataset that provided sufficient confidence to result in an impairment listing. While Sand Creek Reach 538 was originally included in this TMDL report, the decision was made to defer TMDL development for this reach because of the lack of monitored TSS data and inconclusive results from the HSPF model on simulated TSS loads/concentrations. The Minnesota Pollution Control Agency (MPCA) will reevaluate this reach in the next impairment assessment for this watershed.

1.2 Identification of Water Bodies

The bacteria impaired reaches were placed on the Clean Water Act Section 303(d) impaired waters list (303(d) list) in 1996, 2002, 2010, and 2020 (DRAFT). The nutrient-impaired lakes were placed on the 303(d) list in 2012 and 2020. All of the impaired reaches addressed in this TMDL are Class 2B or 2C waters (warm water), except for Spring Creek Reach 550, which is a Class 2A water (cold water).

Table 1 below and Appendix A (which includes notes regarding aquatic life impairments for which TMDLs are not computed) summarize the Kettle River and Upper St. Croix River Watersheds impairments and those addressed in this TMDL.

Figure 1. Context of the Kettle River and Upper St. Croix River watersheds within the St. Croix River Basin.
Note that this study only covers the portion of the Upper St. Croix River Watershed within Minnesota.

Table 1. List of stream impairments addressed in the Kettle and Upper St. Croix River TMDL.

Affected use: Pollutant/ Stressor	Major Watershed	AUID/Lake ID	Stream Name	Location/Reach description	County(s)	Designated use class	Listing year
Aquatic Recreation: *E. coli*	Kettle	07030003-501	Grindstone River	Grindstone Reservoir to Kettle River	Pine, Kanabec	2B, 3C	1996
	Kettle	07030003-513	Split Rock River	Headwaters to Kettle River	Aitkin, Carlton, Pine	2B, 3C	2020*
	Kettle	07030003-516	South Branch Grindstone River	Headwaters to Grindstone River	Kanabec, Pine	2B, 3C	2002
	Kettle	07030003-526	Judicial Ditch 1	Headwaters to South Branch Grindstone River	Pine, Kanabec	2B, 3C	2020*
	Kettle	07030003-529	Kettle River	West Branch Kettle River to Dead Moose River	Carlton	2B, 3C	2020*
	Kettle	07030003-541	North Branch Grindstone River	Headwaters to Grindstone Lake	Pine, Kanabec	2B, 3C	2010
	Kettle	07030003-544	North Branch Grindstone River	T42 R21W S33, north line to Grindstone River	Pine, Kanabec	2B, 3C	2002
	Kettle	07030003-546	Unnamed Creek	Miller Lake to Grindstone Lake	Pine	2B, 3C	2020*
	Kettle	07030003-550	Spring Creek	Headwaters to Grindstone River	Pine	1B, 2A, 3B	2020*
	Kettle	07030003-631	Pine River	Headwaters to Pine Lake	Aitkin	2B, 3C	2020*

***2020 impairments are included on the Draft Minnesota 2020 Impaired Waters [303(d)] list, which is subject to approval by EPA.**

Table 2. List of lake impairments addressed in the Kettle and Upper St. Croix River TMDL.

Affected use: Pollutant/ Stressor	Major Watershed	AUID/Lake ID	Stream or lake name	County	Designated use class	Listing year
Aquatic Recreation: Lake Nutrients	Kettle	58-0138-00	Big Pine	Pine	2B, 3C	2020*
	Kettle	58-0126-00	Elbow	Pine	2B, 3C	2020*
	Kettle	33-0001-00	Eleven	Kanabec	2B, 3C	2020*
	Kettle	58-0102-00	Fox	Pine	2B, 3C	2020*
	Upper St. Croix	58-0029-00	Grace	Pine	2B, 3C	2020*
	Kettle	58-0123-00	Grindstone	Pine	1B, 2A, 3B	2020*
	Kettle	58-0058-00	McCormick	Pine	2B, 3C	2020*
	Kettle	09-0058-00	Merwin	Carlton	2B, 3C	2020*
	Kettle	58-0048-00	Oak	Pine	2B, 3C	2020*
	Kettle	01-0001-00	Pine	Aitkin	2B, 3C	2012
	Kettle	58-0136-00	Rhine	Pine	2B, 3C	2020*
	Kettle	09-0022-00	Twentynine	Carlton	2B, 3C	2020*

***2020 impairments are included on the Draft Minnesota 2020 Impaired Waters [303(d)] list, which is subject to approval by EPA.**

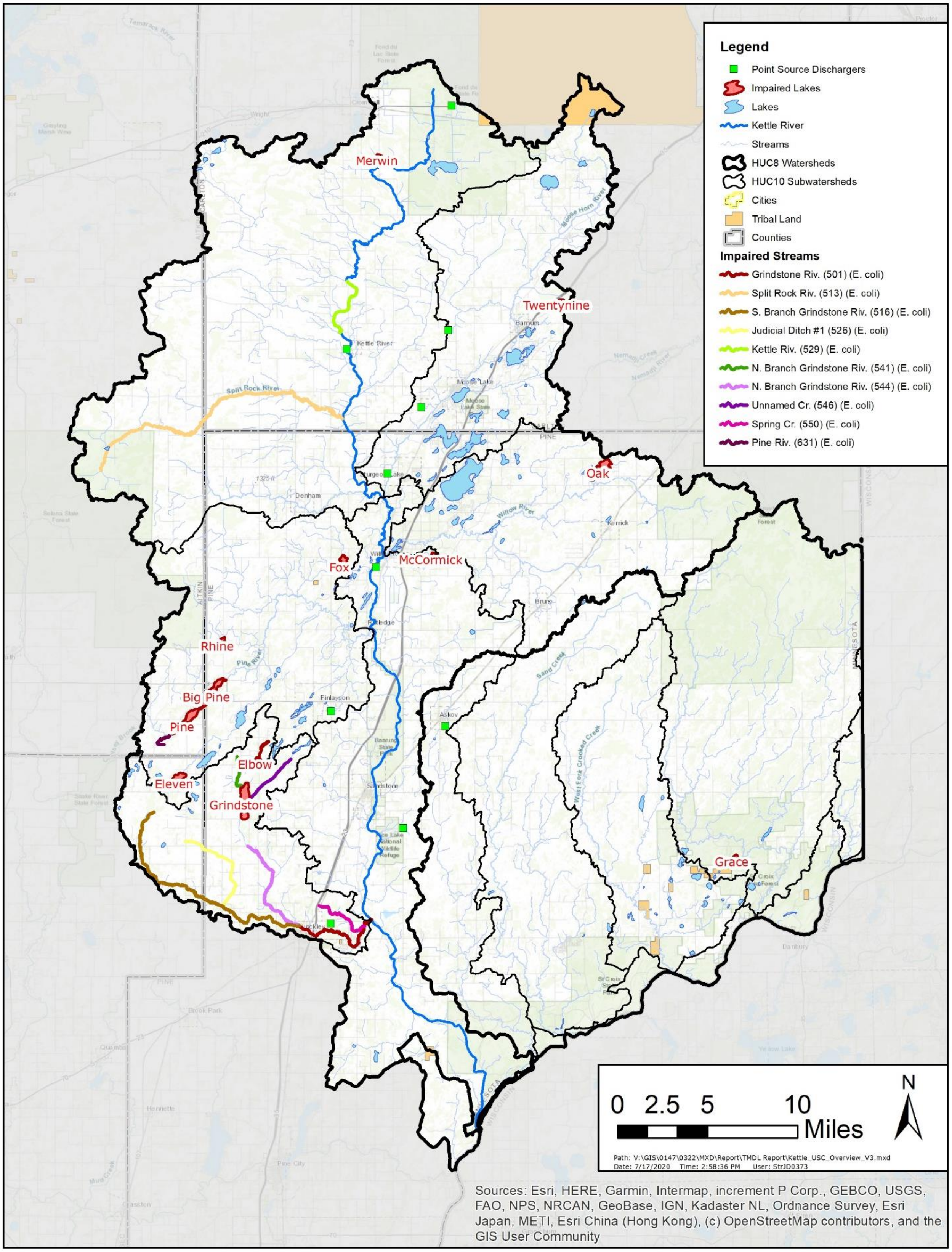


Figure 2. Overview of Kettle River and Upper St. Croix River Watersheds impairments covered in this study.

1.3 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on Minnesota's Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL report. The MPCA has aligned TMDL priorities with the watershed approach and the WRAPS cycle. The MPCA developed a state approach, Minnesota's TMDL Priority Framework Report (MPCA 2015a), to meet the needs of the U.S. Environmental Protection Agency (EPA) national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration, and Protection under the Clean Water Act Section 303(d) Program (EPA 2013). As part of these efforts, the MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. The Kettle River and Upper St. Croix River watersheds waters addressed by this TMDL report are part of that MPCA prioritization plan to meet EPA's national measure.

2. Applicable Water Quality Standards

2.1 Designated Uses

Use classifications are defined in Minn. R. 7050.0140, and water use classifications for individual water bodies are provided in Minn. R. 7050.0470, 7050.0425, and 7050.0430. The impaired lakes and streams covered in this TMDL report are classified as Class 1B, 2A or 2B, and 3B or 3C waters (Table 1). This TMDL report addresses the water bodies that do not meet the standards for Class 2 waters, which are protected for aquatic life and recreation designated uses.

Class 2A waters are protected for the propagation and maintenance of a healthy community of cold water sport or commercial fish and associated aquatic life and their habitats. Class 2B waters are protected for the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life and their habitats. Both Class 2A and 2B waters are also protected for aquatic recreation activities including swimming and bathing.

2.2 Bacteria

With the revisions of Minnesota's water quality rules in 2008, the State changed from a fecal coliform based standard to an *E. coli* based standard because it is a superior potential illness indicator and costs for lab analysis are less (MPCA 2007). The revised standard for all Class 2 waters now states:

> "*E. coli* concentrations are not to exceed 126 organisms per 100 mL (chronic standard) as a geometric mean of not less than 5 samples representative of conditions within any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 1,260 organisms per 100 mL (acute standard). The standard applies only between April 1 and October 31."

The Class 2 waters chronic *E. coli* concentration standard of 126 organisms per 100 mL was considered reasonably equivalent to the previous chronic fecal coliform standard of 200 organisms per 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 any data reported in fecal coliform to *E. coli* equivalents:

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

It should also be noted that most analytical laboratories report *E. coli* in terms of colony forming units per 100 mL colony-forming unit ([cfu]/100 mL), not organisms per 100 mL. This TMDL will present *E. coli* data in cfu/100 mL since all of the monitored data collected was reported in these units. Bacteria TMDLs were written to achieve the bacteria water quality standard of 126 orgs/100 mL as a monthly geometric mean. It is expected that by meeting the monthly geometric mean (chronic) standard, that the monthly maximum/upper 10th percentile (acute) standard will be met. The monthly geometric mean is considered a more reliable measure that is less subject to random variation (MPCA 2009), and it was determined to be appropriate and reasonable for the development of these TMDLs because the impairments are generally associated with the chronic criterion of the standard (see Table 7). That said, in order for an impaired waterbody to be removed from the impaired waters list, both the chronic standard and acute standard requirements must be met.

The MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List provides details regarding how waters are assessed for conformance to the *E. coli* standard (MPCA 2020b).

2.3 Nutrients

Under Minn. R. 7050.0150 and 7050.0222, subp. 4, the lakes addressed in this TMDL are a mixture of shallow and deep lakes located within the NLF Ecoregion. One of the lakes covered in this TMDL study, Grindstone Lake is a designated trout lake (Class 2A waterbody). All of the other lakes covered in this TMDL are protected for aquatic recreation, and are therefore designated as Class 2B waterbodies. Minnesota water quality standards for TP, chlorophyll-a (Chl-*a*) and Secchi disk transparency are listed in Table 3. It should be noted that the water quality standards for Class 2B lakes in the NLF Ecoregion apply to both shallow and deep lakes.

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

Table 3. Eutrophication standards for Class 2A and Class 2B lakes in the NLF Ecoregion.

Parameter	Water Quality Standard NLF Ecoregion Standards (Class 2A Lakes)	Water Quality Standard NLF Ecoregion Standards (Class 2B Lakes)
Total Phosphorus [µg/L]	12	30
Chlorophyll-a [µg/L]	3	9
Secchi Disk Transparency [meters]	4.8	2.0

3. Watershed and Waterbody Characterization

The Kettle River and Upper St. Croix River watersheds are major HUC-8 watersheds in the St. Croix River Basin, which covers the east-central portion of the state. The Kettle River Watershed is approximately 1,051 square-miles (672,924 acres), split between 4 counties with the majority of watershed in Pine County (53%), followed by Carlton (34%), Aitkin (10%), and Kanabec (3%) Counties. The Upper St. Croix River Watershed, is approximately 2,057 square-miles (1,316,404 acres), with the majority of the watershed located in Wisconsin. The portion of the watershed located in Minnesota is 543 square-miles (347,719 acres) and lies completely within Pine County. This TMDL only addresses impaired reaches within the Minnesota portion of the Upper St. Croix River Watershed.

Both the Kettle River and Upper St. Croix River watersheds each contain six major HUC-10 subwatersheds. Kettle River Watershed HUC-10s include: Upper Kettle River, Moose River, Willow River, Pine River, Grindstone River, and the Lower Kettle River. Upper St. Croix River Watershed HUC-10s include: Upper Tamarack River, Lower Tamarack River, Crooked Creek, Sand Creek, Bear Creek, and the Chases Brook-St. Croix River. The streams and tributaries that make up these major subwatersheds flow to the St. Croix River, which marks the boundary of Minnesota and Wisconsin.

The location of Tribal lands is included in Figure 2. Areas designated as Tribal lands within the Kettle River and Upper St. Croix River Watersheds total approximately 3,622 acres and 1,377 acres, respectively. Grindstone River Reach 501 and Grace Lake are the only impaired waterbodies in the Kettle River and Upper St. Croix River Watersheds that contain Tribal land within their immediate drainage area. There are approximately 19 acres (less than 1% of total drainage area) of Mille Lacs Band of Ojibwe land that drains to Grindstone River Reach 501 that is located near the city of Hinckley. Grace Lake contains approximately 198 acres (10% of total drainage area) of Mille Lacs Band of Ojibwe land within its drainage area. As this TMDL study did not develop any loads for Tribal lands, the load development for these two waterbodies excluded Tribal lands from their immediate drainage areas through an area-weighted approach.

3.1 Lakes

Collectively lakes and open water areas in the Kettle River and Upper St. Croix River watersheds account for approximately 2% (~23,000 acres) of the watersheds. There are 12 lakes impaired by nutrients. Oak, Grindstone, and Big Pine Lakes have TMDLs that were completed in 2007 to address mercury in fish impairments. Lake morphometry and watershed information for each impaired lake covered in this TMDL is presented in Table 4.

Table 4. Lake morphometry and characteristics.

Parameter	Big Pine	Elbow	Eleven	Fox	Grace	Grindstone	McCormick	Merwin	Oak	Pine	Rhine	Twenty-nine
County	Aitkin & Pine	Pine	Kanabec	Pine	Pine	Pine	Pine	Carlton	Pine	Aitkin	Pine	Carlton
Major Watershed	Kettle	Kettle	Kettle	Kettle	USC	Kettle	Kettle	Kettle	Kettle	Kettle	Kettle	Kettle
Lake ID	58013800	58012600	33000100	58010200	58002900	58012300	58005800	09005800	58004800	01000100	58013600	09002200
Lake Type	Deep	Deep	Shallow	Shallow	Shallow	Deep	Shallow	Shallow	Shallow	Deep	Shallow	Deep
Lake Surface Area [acres]	399	99	315	200	80	533	61	53	459	378	116	52
Ave. Depth [ft]	15	11	7	8	5	60	6	8	8	20	4	12
Max Depth [ft]	25	33	13	15	11	153	17	16	20	28	8	25
Residence Time [yrs]	0.3	0.5	1.3	0.3	0.1	2.4	0.1	0.5	0.9	0.4	0.2	0.8
Littoral Area [%]	34	73	100	100	100	13	87	94	94	25	100	64
Watershed Area[1] [acres]	16,814	2,201	1,968	4,365	1,957	13,106	2,993	628	2,460	12,855	2,282	482
Watershed Area:Surface Area	42:1	21:1	7:1	19:1	32:1	25:1	44:1	12:1	5:1	46:1	20:1	9:1

[1] Includes lake surface area and any upstream lake contributing areas

3.2 Streams

The 10 *E. coli* impaired reaches in the Kettle River (07030003) watershed addressed in this TMDL cover approximately 79 stream miles and drain approximately 191,000 acres of land across the watersheds (Table 5).

Table 5. Stream Impairments.

Major Watershed	Impaired Reach AUID#[1]	Stream Name	Impairment	Reach Length [miles]	Watershed Area [acres]	Upstream Impaired Assessment Unit(s)
Kettle	501	Grindstone River	*E. coli*	6.7	55,558	550, 544, 516, 526, 546, 541
Kettle	513	Split Rock River	*E. coli*	21.8	39,461	None
Kettle	516	South Branch Grindstone River	*E. coli*	17.3	22,757	526
Kettle	526	Judicial Ditch 1	*E. coli*	5.9	3,856	None
Kettle	529	Kettle River	*E. coli*	4.3	80,882	None
Kettle	541	North Branch Grindstone River	*E. coli*	2.1	7,153	None
Kettle	544	North Branch Grindstone River	*E. coli*	7.0	26,217	546, 541
Kettle	546	Unnamed Creek	*E. coli*	3.2	3,458	None
Kettle	550	Spring Creek	*E. coli*	3.7	2,596	None
Kettle	631	Pine River	*E. coli*	1.8	6,006	None

[1] Only the last three digits of the impaired reach AUID are shown in this table for the Kettle River (07030003) and Upper St. Croix River (07030001) impairments

3.3 Subwatersheds

The watershed boundaries of the impaired waterbodies (Figure 2) were developed using multiple data sources, starting with watershed delineations from the MPCA's HSPF model application for the Kettle River and Upper St. Croix River watersheds (RESPEC 2016). The model watershed boundaries are based on Minnesota Department of Natural Resources (DNR) Level 8 watershed boundaries and modified with a 30-meter digital elevation model. Where additional watershed breaks were needed to define the impairment watersheds, DNR Level 9 watershed boundaries and delineation using contours derived from LiDAR were used. Maps showing specific watershed boundaries for each impaired lake and reach are included in Appendices B and C.

3.4 Land use

Current land use within the Kettle River and Upper St. Croix River Watersheds is dominated by forest (primarily deciduous forest) and wetlands, followed by pasture/hay, developed, open water, and cultivated cropland (Table 6 and Figure 3). From pre-European settlement to present, land cover in the Kettle River and Upper St. Croix River watersheds shifted from upland forest cover types to upland shrub, upland grass, lowland vegetation, agriculture, and developed cover types (MFRC 2014). Of the total area in the Kettle River Watershed, approximately 24% has changed from upland forest to other cover types, which was slightly larger than the change in the percent cover in the rest of the St. Croix

River Basin. The largest change from upland forest to another cover type was to upland grass, primarily pasture/hay.

Sandstone (pop. 2,849) and Moose Lake (pop. 2,751) are the largest cities in the Kettle River Watershed. Askov (pop. 364) is the largest population center in the Upper St. Croix River Watershed and the only community that participated in the 2010 Census. There are no cities in either watershed that are subject to MPCA's Municipal Separate Storm Sewer System (MS4) Permit program.

Table 6. Summary of land use and watershed area for each impaired reach and lake (Source: NLCD 2011).

Major Watershed	Impaired Stream or Lake	AUID or Lake ID	Watershed Area [Acres]	Percent of Watershed						
				Cultivated Cropland	Pasture/Hay	Developed	Forest/Shrubland	Open Water	Wetlands	Barren/Mining
Kettle	Grindstone	501	55,558	4%	25%	5%	34%	3%	29%	<1%
Kettle	Split Rock River	513	39,461	<1%	9%	2%	45%	1%	43%	--
Kettle	South Branch Grindstone River	516	22,757	3%	28%	3%	33%	1%	31%	<1%
Kettle	Judicial Ditch 1	526	3,856	4%	21%	4%	35%	1%	35%	--
Kettle	Kettle River	529	80,882	1%	10%	2%	31%	1%	54%	<1%
Kettle	North Branch Grindstone River	541	7,153	5%	22%	4%	25%	4%	40%	--
Kettle	North Branch Grindstone River	544	26,217	4%	23%	4%	35%	4%	30%	<1%
Kettle	Unnamed Creek	546	3,458	4%	23%	4%	33%	3%	33%	--
Kettle	Spring Creek	550	2,596	9%	22%	7%	42%	<1%	19%	--
Kettle	Pine River	631	6,006	<1%	14%	2%	57%	2%	24%	--
Kettle	Big Pine	58-0138-00	3,959*	3%	13%	8%	32%	10%	34%	--
Kettle	Elbow	58-0126-00	2,201	6%	24%	6%	23%	6%	34%	--
Kettle	Eleven	33-0001-00	1,968	2%	10%	6%	23%	17%	42%	--
Kettle	Fox	58-0102-00	4,365	1%	22%	3%	40%	5%	29%	--
Upper St. Croix	Grace	58-0029-00	1,957	--	--	3%	58%	6%	33%	--
Kettle	Grindstone*	58-0123-00	10,905*	4%	21%	4%	30%	7%	34%	--
Kettle	McCormick	58-0058-00	2,993	<1%	8%	5%	41%	5%	40%	--
Kettle	Merwin	09-0022-00	628	--	35%	3%	28%	12%	22%	--
Kettle	Oak	58-0048-00	2,460	1%	15%	5%	21%	22%	36%	--
Kettle	Pine	01-0001-00	12,855	<1%	15%	3%	51%	4%	26%	--
Kettle	Rhine	58-0136-00	2,282	--	2%	1%	70%	6%	21%	--
Kettle	Twentynine	09-0022-00	482	--	11%	8%	26%	11%	45%	--
Kettle River Watershed TOTAL			672,924	2%	14%	4%	39%	3%	38%	<1%
Upper St. Croix River Watershed TOTAL			347,719	2%	8%	2%	52%	1%	34%	<1%

*Note: does not include watershed area from upstream impaired lakes (Pine and Elbow)

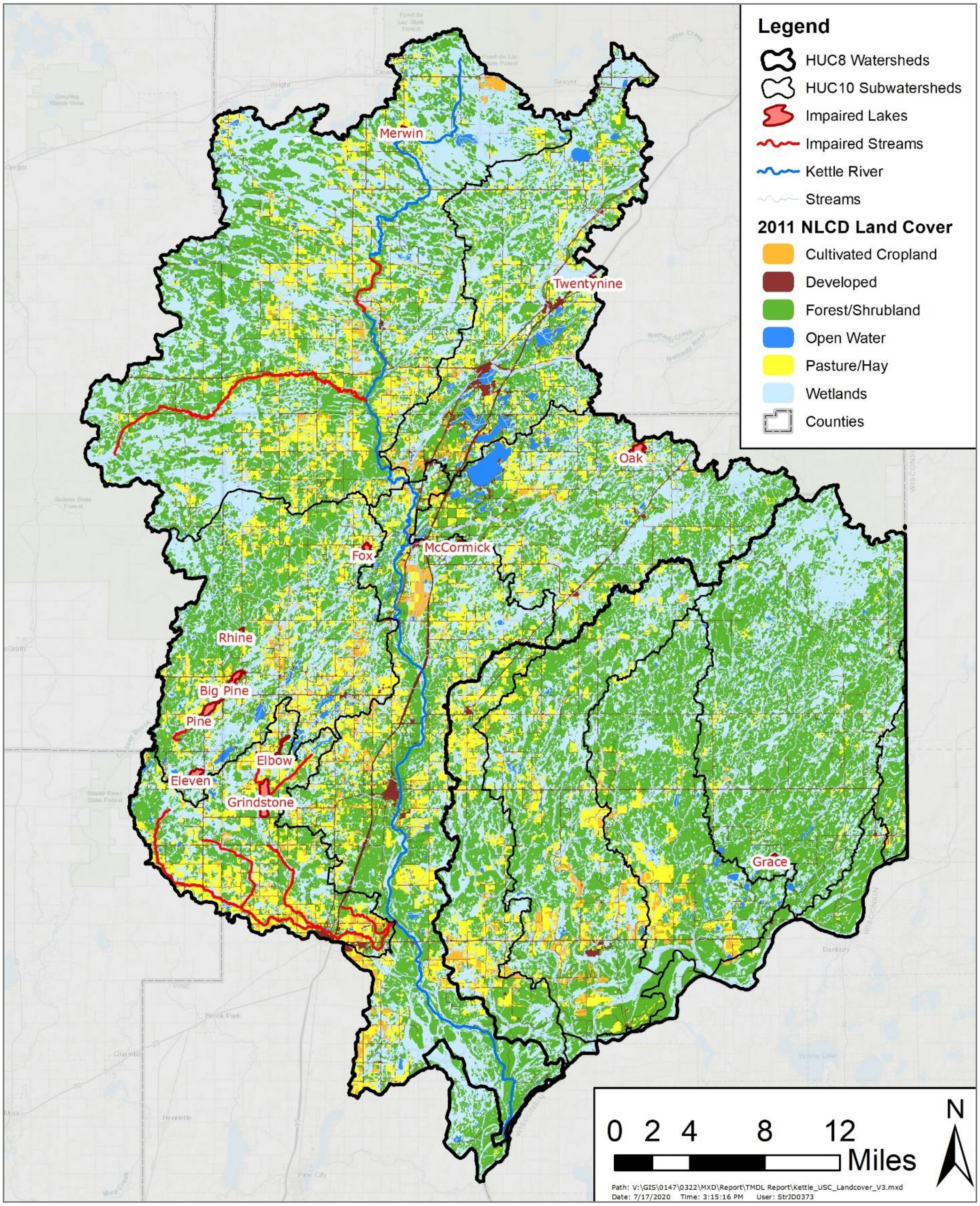


Figure 3. Kettle River and Upper St. Croix River Watersheds 2011 National Land Cover Dataset.

3.5 Current/Historical Water Quality

All data used in the development of this TMDL were collected between 2000 and 2018 by various agencies and local partners, including the MPCA, area Soil and Water Conservation Districts (SWCDs), lake associations and volunteer monitoring programs. Although data prior to 2000 exists in each of the major watersheds, the more recent data represent current conditions. Only data available through the MPCA's Environmental Quality Information System (EQuIS) through the 2018 field season were used in this TMDL.

Daily average flows were simulated using the MPCA's HSPF model for the Kettle River and Upper St. Croix River watersheds. HSPF simulated flows are available for each impaired lake and reach for model years 1995 through 2009. Kettle and Upper St. Croix River watersheds HSPF model documentation (RESPEC 2016) describes the framework of the model, the data used to develop the model and calibration/validation results. For years in which HSPF simulated flows are not available, regression relationships were established between each impaired reach/lake and the Kettle River USGS station (05336700), which has operated continuously since 1968.

3.5.1 Bacteria

Table 7 shows April through October monthly *E. coli* geometric means (2000 through 2017) for the Kettle River Watershed bacteria impaired reaches addressed in this TMDL. Geometric means are used to describe bacteria data over arithmetic means as the geometric mean normalizes the ranges being averaged, using the following equation:

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

Table 7 shows individual chronic sample exceedances, acute exceedances, and monthly geometric means for each impaired reach. Individual samples exceeded the chronic standard approximately 29% to 71% of the time from April through October. These results indicate that every reach had multiple exceedances of the monthly chronic standard (red highlighted values in Table 7). Exceedances of the monthly chronic standard were most common during the warm summer months (June through August).

Table 7. Summary of *E. coli* data for the Kettle River Watershed impaired reaches since 2000.

Month(s)	Parameter	Reach AUID#									
		501	513	516	526	529	541	544	546	550	631
Apr-Oct	Years of data	5	2	3	3	2	6	3	2	3	3
	Sample count	56	14	42	27	14	55	42	26	29	21
	Number of chronic sample exceedances	37	8	20	18	10	25	17	16	18	6
	Percent of chronic sample exceedances	66%	57%	48%	67%	71%	45%	40%	62%	62%	29%
	Number of acute sample exceedances	6	0	3	3	1	1	2	4	2	0
	Percent of acute sample exceedances	11%	0%	7%	11%	7%	2%	5%	15%	7%	0%
	Maximum (cfu/100 ml)	3,100	1,120	2,400	1,400	2,420	1,900	2,400	2,400	2,400	650

Month(s)	Parameter	Reach AUID#									
		501	513	516	526	529	541	544	546	550	631
	Geometric mean (cfu/100 ml)	202	172	104	185	232	105	86	140	121	90
Apr	Sample count	5	0	5	2	0	0	5	0	2	2
	Geometric mean (cfu/100 ml)	12	--	13	27	--	--	9	--	20	3
May	Sample count	7	0	7	4	0	7	7	3	5	2
	Geometric mean (cfu/100 ml)	54	--	68	143	--	32	48	11	35	173
Jun	Sample count	13	4	8	5	4	15	8	6	6	3
	Geometric mean (cfu/100 ml)	236	173	217	333	195	53	279	52	228	82
Jul	Sample count	11	5	6	5	5	11	6	6	5	5
	Geometric mean (cfu/100 ml)	287	329	153	624	529	210	181	530	603	194
Aug	Sample count	10	5	6	5	5	15	6	7	5	6
	Geometric mean (cfu/100 ml)	477	90	114	176	118	188	148	389	149	104
Sep	Sample count	3	0	3	2	0	7	3	4	2	2
	Geometric mean (cfu/100 ml)	606	--	91	171	--	137	200	94	122	155
Oct	Sample count	7	0	7	4	0	0	7	0	4	1
	Geometric mean (cfu/100 ml)	456	--	213	72	--	--	49	--	56	71

Note: dark red highlighted values indicate monthly geometric mean concentration exceeds the 126 organisms per 100 milliliter chronic standard with at least five samples; light red highlighted values indicate monthly geometric mean concentration exceeds the 126 organisms per 100 milliliter chronic standard with fewer than five samples. At least five samples are required per month for a reach to show exceedance of the standard—these reaches with fewer than five samples show potential exceedances of the standard.

3.5.2 Lake Phosphorus and Response Variables

In general, historical in-lake water quality data collected from 2000 through 2018 was reviewed for use in this TMDL. Table 8 lists the June through September averages for TP, Chl-*a*, and Secchi depth for each impaired lake. The table also lists the data years which were used to calculate the average condition for this TMDL. All lakes indicate average summer TP, Chl-*a* and/or Secchi depths are not meeting ecoregion-defined state standards.

Table 8. Summer growing season averages for each water quality parameter.

		In-Lake Average Condition [Calculated June – September]		
Lake Name	**Average Condition Calculation Years**	**TP Concentration [µg/L]**	**Chl-*a* Concentration [µg/L]**	**Secchi Depth [m]**
NLF Ecoregion Class 2B Lake Standards		**30**	**9**	**2.0**
Big Pine	2008, 2009, 2014, 2015, 2015, 2017	32.4	15.5	1.5
Elbow	2011, 2012	40.9	9.3	1.1
Eleven	2008, 2010, 2015, 2016	39.0	36.0	0.8
Fox	2016, 2017	52.1	32.5	1.0
Grace	2016, 2017	70.3	22.9	0.8
McCormick	2016, 2017	34.5	20.7	1.2
Merwin	2016, 2017	39.3	15.4	4.1
Oak	2011, 2012, 2016	32.8	17.0	1.4
Pine	2008, 2009, 2014, 2015, 2015, 2017	38.4	9.9	2.0
Rhine	2011, 2012	62.0	59.8	0.7
Twentynine	2016, 2017	53.4	12.3	1.9
NLF Ecoregion Class 2A Lake Standards		**12**	**3**	**4.8**
Grindstone	2008, 2016, 2017	13.0	4.7	3.4

3.6 Pollutant Source Summary

Overland Runoff/Erosion (Rural Areas)

External pollutant loads in rural areas can come from nonpermitted sources such as sediment erosion from upland fields, tile drainage (Schottler 2012), gully erosion, and livestock pastures in riparian zones. For this TMDL, nonpoint sources of TSS and phosphorus were evaluated using the Kettle and Upper St. Croix River watersheds HSPF models (RESPEC 2016). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil contaminant runoff processes, and in-stream hydraulic and sediment-chemical interactions. The results provide hourly runoff flow rates, sediment concentrations, and nutrient concentrations, along with other water quality constituents, at the outlet of any modeled subwatershed for the model time period 1995 through 2009. Model documentation contains additional details about model development and calibration (RESPEC 2016). Within each subwatershed, the upland areas are separated into multiple land use categories and are further parameterized based on hydrologic soil group. Simulated loads from upland areas represent the pollutant loads that are delivered to the modeled stream or lake; the loading rates do not represent field-scale soil loss estimates.

Overall, across the entire Kettle River HUC-8 Watershed, approximately 59% of the TSS load and 57% of the phosphorus load is from agriculture sources (i.e., cultivated crops and hay/pasture lands identified in National Land Cover Database (NLCD), in addition to loading from feedlots). Sections 3.6.1 and 3.6.2 below, contain more detailed discussion of the upland watershed source contributions for each impaired lake and stream reach.

Animal Feeding Operations

Of the 77 active feedlot facilities with approximately 26,463 livestock animal units (AUs) throughout the Kettle River and Upper St. Croix River watersheds (Table 10 and Figure 4), there are two Concentrated Animal Feeding Operations (CAFOs), neither of which are located within the drainage areas of the impaired reaches. Table 10 summarizes facility type and livestock numbers for each impaired reach, lake, and the entire watershed. CAFOs are defined by the EPA based on the number and type of animals. The MPCA currently uses the federal definition of a CAFO in its permit requirements of animal feedlots along with the definition of an AU. In Minnesota, the following types of livestock facilities are required to operate under a National Pollutant Discharge Elimination System (NPDES) permit or a state issued State Disposal System (SDS) permit: (a) all federally defined CAFOs that have had a discharge, some of which are under 1000 AUs in size; and (b) all CAFOs and non-CAFOs that have 1000 or more AUs.

CAFOs and Animal Feeding Operations (AFOs) with 1,000 or more AUs must be designed to contain all manure and manure-contaminated runoff from precipitation events of less than a 25-year, 24-hour storm event. Having and complying with an NPDES permit allows some enforcement protection if a facility discharges due to a 25-year, 24-hour precipitation event (approximately 5.3” in 24 hours) and the discharge does not contribute to a water quality impairment. Large CAFOs permitted with an SDS permit or those not covered by a permit must contain all runoff, regardless of the precipitation event. Therefore, many large CAFOs in Minnesota have chosen to have a NPDES permit, even if discharges have not occurred in the past at the facility. A current manure management plan that complies with Minn. R. 7020.2225, and the respective permit is required for all CAFOs and AFOs with 1,000 or more AUs.

CAFOs are inspected by the MPCA in accordance with the MPCA NPDES Compliance Monitoring Strategy approved by the EPA. All CAFOs (NPDES permitted, SDS permitted, and not required to be permitted) are inspected by the MPCA on a routine basis with an appropriate mix of field inspections, offsite monitoring, and compliance assistance.

For the Kettle River and Upper St. Croix River watersheds TMDL, all NPDES and SDS permitted feedlots are designed to have zero discharge, and as such they do not receive a WLA. All other non-CAFO feedlots and the land application of all manure are accounted for in the load allocation (LA) for nonpoint sources. In Minnesota, AFOs are required to register with the state if they are (1) an animal feedlot capable of holding 50 or more AUs, or a manure storage area capable of holding the manure produced by 50 or more AUs outside of shoreland; or (2) an animal feedlot capable of holding 10 or more AUs, or a manure storage area capable of holding the manure produced by 10 or more AUs, that is located within shoreland. Further explanation of registration requirements can be found in Minn. R. 7020.0350. AFOs under 1,000 AUs and those that are not federally defined as CAFOs do not operate with permits. However, the facilities must operate in compliance with applicable portions of Minn. R. 7020.

The animals raised in AFOs produce manure that is stored in pits, lagoons, tanks, and other storage devices. The manure is then applied or injected to area fields as fertilizer. When stored and applied properly, this beneficial reuse of manure provides a natural source for crop nutrition. It also lessens the need for fuel and other natural resources that are used in the production of fertilizer. AFOs, however, can pose environmental concerns; inadequately treated manure runoff from open lot feedlot facilities and improper application of manure can contaminate surface or groundwater. Based on the MPCA feedlot staff analysis of feedlot demographics, knowledge, and actual observations throughout the State of Minnesota, there is a significant amount of late winter solid manure application (before the ground thaws). During this time, the manure can be a source of nutrients and pathogens in rivers and streams, especially during precipitation events.

Short-term stockpile sites are defined in Minn. R. ch. 7020 and are considered temporary. Any stockpile kept for longer than a year must be registered with the MPCA and would be identified as part of a feedlot facility. Because of the temporary status of the short-term stockpile sites, and the fact they are usually very near or at the land application area, they are included in with the land applied manure. Incorporating manure is the preferred BMP for land application of manure and should result in less runoff losses. This TMDL does not explicitly estimate or model the contribution of manure to surface waters in the Kettle River and Upper St. Croix River watersheds. That said, since the model is calibrated to monitored in-stream water quality data at several points throughout the watershed, manure sources are implicit in the HSPF model's calculated loads for agricultural areas.

Most of the feedlots within the Kettle River and Upper St. Croix River watersheds are open lots, which are defined as uncovered lots intended for the confined feeding, breeding, raising, or holding of animals and specifically designed as confinement areas in which manure may accumulate, or where the concentration of animals is such that a vegetative cover cannot be maintained within the enclosure. In the Kettle River and Upper St. Croix River Watersheds, there are 11 registered feedlots located within 1,000 feet of a lake or 300 feet of a stream or river, an area generally defined as shoreland—all of these feedlots located within shoreland are open lots.

Feedlots data referenced and used for analysis in this report originated from the Feedlots in Minnesota resource (https://gisdata.mn.gov/dataset/env-feedlots) from the Minnesota Geospatial Commons. This data was accessed on January 14, 2020, and can be considered to represent the best data that the MPCA had available on feedlots in these watersheds (and in the state) at that time. Several definition queries and geospatial operations were performed on the data to arrive at the numbers included in Tables 9 and 10 below, and Appendix F (Table F1). These queries included: filtering by major watershed to only include feedlots located within the Kettle River and Upper St. Croix River watersheds, filtering out feedlot operations with a "last animal" date entered (meaning that the feedlot no longer holds animals), filtering out feedlots with zero and/or NULL values for animal unit counts, filtering out feedlots that do not meet the MPCA registration criteria (greater than or equal to 50 AUs or greater than or equal to 10 AUs in shoreland areas), and filtering out feedlot operations that are inactive. These operations left 77 active feedlots requiring MPCA registration in total across both watersheds.

Further filtering of feedlots to remove expired authorizations (permits or registrations), was possible at this point, but was not performed due to limited and incomplete information. None of the watersheds' four counties are delegated authority to enforce state feedlot rules, so the MPCA enforces feedlot rules in these counties (see Section 6.1.5 for greater detail). Due to limited resources, data in these counties are often updated in batches as authorizations expire and applications for reauthorizations are received. Due to the lag time associated with these administrative tasks and grace periods associated with submitting applications for reauthorization, a decision was made to include all feedlot results resulting from the filtering exercise described in the paragraph above. This decision will hopefully result in a more representative sample of the places within both watersheds were feedlot operations may be active. Although it is likely that some feedlots included in the 77 considered in this report are no longer operational, since the impairments are representative of monitoring work that was completed over the past five years, the previously-listed assumptions were considered to be valid in listing feedlot operations that may be contributing to impairments at the time water quality monitoring took place. Additionally, some limited aerial photo review to verify the locations and status (at the time of aerial photo) of operations near subwatershed boundaries confirmed that many feedlots in these watersheds with expired authorizations are likely still operating in some capacity.

Table 9 shows the total number of feedlots and AUs in each major watershed along with a simplified breakdown of number of AUs in CAFOs and in open lot feedlot operations across both watersheds. With one exception, all active feedlots identified in these watersheds are open lot operations. Table 10 breaks down the active registered feedlots located in the drainage areas of the impaired streams and lakes in both watersheds. Appendix F breaks down these numbers into additional detail by AU type, which can help to inform management strategies and tailor BMPs at the operation level.

Table 9. MPCA active registered feedlots and feedlot type by major watershed.

Major Watershed	Total Operations		CAFOs		Open Lots	
	Count	AUs	Operations	AUs	Operations	AUs
Kettle River Watershed TOTAL	**56**	**21,191**	**1**	**13,689**	**55**	**21,135**
Upper St. Croix River Watershed TOTAL	**21**	**5,272**	**1**	**995**	**21**	**5,272**

Table 10. Feedlot statistics for the drainage area to each impaired reach and lake.

Impaired Reach/Lake	Total Operations		CAFOs		Open Lots	
	Count	AUs	Operations	AUs	Operations	AUs
Grindstone River -501	10	1,653	0	--	10	1,653
Split Rock River – 513	3	246	0	--	3	246
S. Branch Grindstone R. - 516	2	266	0	--	2	266
Judicial Ditch 1 - 526	0	--	--	--	--	--
Kettle River-529	2	114	0	--	2	114
N. Branch Grindstone R - 541	2	295	0	--	2	295
N. Branch Grindstone R -544	6	1,067	0	--	6	1,067
Unnamed Creek - 546	2	513	0	--	2	513
Spring Creek - 550	0	--	--	--	--	--
Pine River - 631	1	95	0	--	1	95
Big Pine Lake 58-0138-00	0	--	--	--	--	--
Elbow Lake 58-0126-00	1	212	0	--	1	212
Eleven Lake 33-0001-00	0	--	--	--	--	--
Fox Lake 58-0102-00	1	149	0	--	1	149
Grace Lake 58-0029-00	0	--	--	--	--	--
Grindstone Lake 58-0123-00	3	596	0	--	3	596
McCormick Lake 58-0058-00	0	--	--	--	--	--

Impaired Reach/Lake	Total Operations		CAFOs		Open Lots	
	Count	AUs	Operations	AUs	Operations	AUs
Merwin Lake 09-0022-00	0	--	--	--	--	--
Oak Lake 58-0048-00	1	93	0	--	1	93
Pine Lake 01-0001-00	1	95	0	--	1	95
Rhine Lake 58-0136-00	0	--	--	--	--	--
Twentynine Lake 09-0022-00	0	--	--	--	--	--

The numbers presented in this table are for MPCA-identified feedlots in the delineated drainage areas of impaired lakes and stream reaches and do not represent all feedlots within the watersheds. See Table 9 for a breakdown of both watersheds' feedlots.

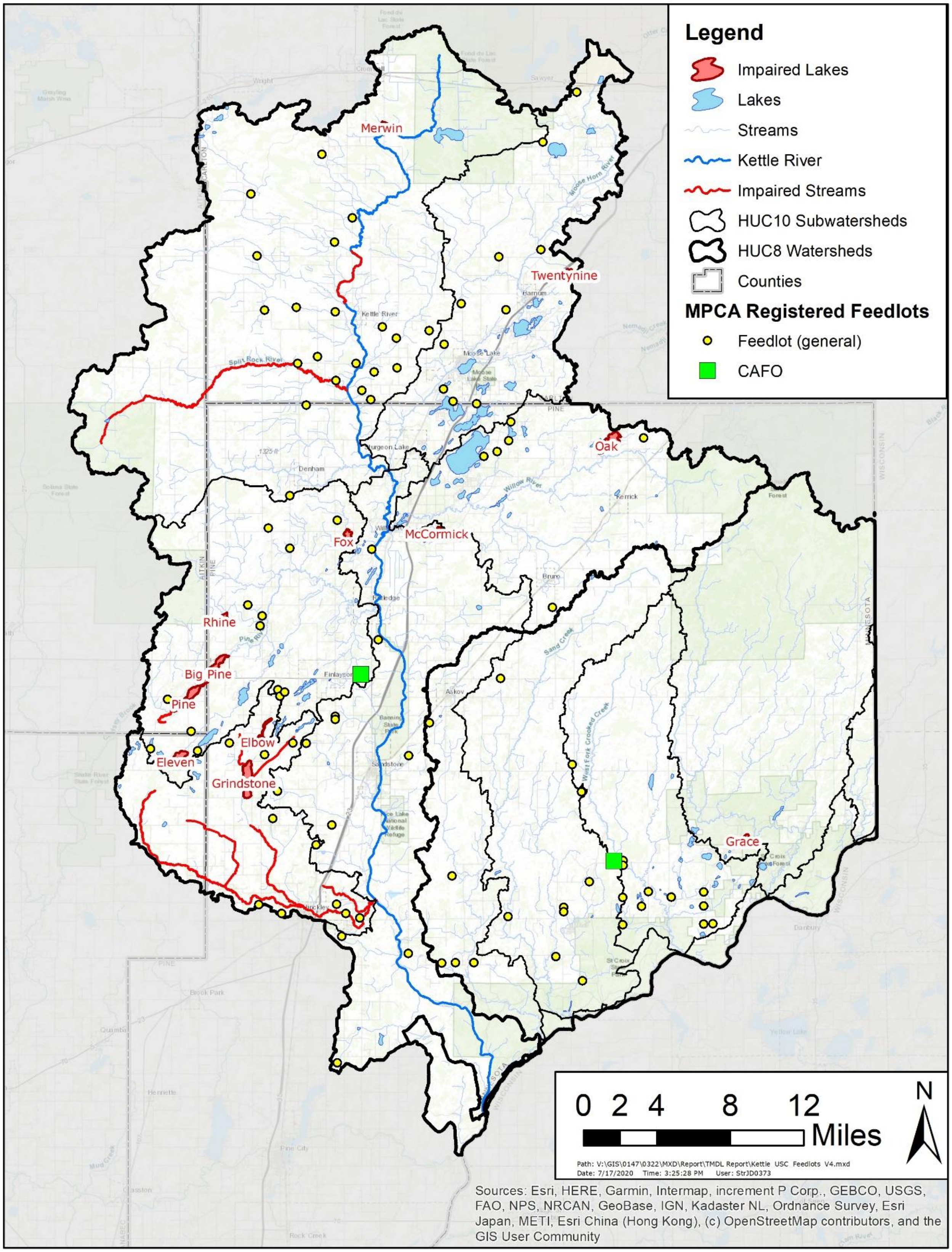


Figure 4. MPCA registered feedlots in the Kettle River and Upper St. Croix River Watersheds. Feedlots in the KUSC watersheds that are representative of those required to register under Minn. R. 7020.0350.

Urban Stormwater

Cities and developed areas can be a source of sediment, bacteria, nutrients, and chloride to surface waters through the impact of urban systems on stormwater runoff generated during precipitation events. The sources of pollutants in stormwater are many, including decaying vegetation (leaves, grass clippings, etc.), domestic and wild animal waste, soil and deposited particulates from the air, road salt, and oil and grease from vehicles.

Although land cover in the Kettle River and Upper St. Croix River Watersheds is predominantly rural, there are a few cities located throughout the watersheds. There are no communities in either watershed that are subject to the MPCA's MS4 Permit program. There are, however 13 smaller municipalities throughout the two watersheds that are not subject to MS4 permits (Table 11). As noted in Table 11, the City of Hinckley is the only municipality that contributes directly to impaired reaches addressed in this TMDL study.

Table 11. Municipalities in the Kettle River and Upper St. Croix River Watersheds.

City	County	Major Watershed	Downstream Impairment(s)	Area [acres]	Population*	Sewered (Sanitary)
Kettle River	Carlton	Kettle	None	246	180	WWTP
Barnum	Carlton	Kettle	None	646	613	WWTP
Moose Lake	Carlton	Kettle	None	2,001	2,751	WWTP
Sturgeon Lake	Pine	Kettle	None	2,447	439	WWTP
Denham	Pine	Kettle	None	845	35	Unsewered
Kerrick	Pine	Kettle	None	641	65	Unsewered
Bruno	Pine	Kettle	None	639	102	Unsewered
Willow River	Pine	Kettle	None	1,229	415	WWTP
Rutledge	Pine	Kettle	None	1,933	229	Unsewered
Finlayson	Pine	Kettle	None	1,870	315	WWTP
Sandstone	Pine	Kettle	None	3,466	2,849	WWTP
Hinckley	Pine	Ketttle	550, 501, 516, 544	1,868	1,800	WWTP
Askov	Pine	Upper St. Croix	None	816	364	WWTP

*2010 Census Population

Near-Channel Sources

Near-channel sources of sediment and nutrients are those in close proximity to the stream channel, including bluffs, banks, ravines, and the stream channel itself. Hydrologic changes in the landscape and altered precipitation patterns driven by climate change can lead to increased TSS and sediment-bound phosphorus in surface waters. Subsurface drainage tiling, channelization of waterways, land cover alteration, and increases in impervious surfaces all decrease detention time in the watershed and increase flow from fields and in streams. Draining and tiling wetland areas can decrease water storage on the landscape, which can lead to lower evapotranspiration and increased river flow (Schottler et al. 2014).

The straightening and ditching of natural rivers, streams, and waterways increases the slope of the original watercourse and moves water off the land at a higher velocity in a shorter amount of time compared to the natural watercourse condition. These changes to the way water moves through a watershed and how it makes its way into a river can lead to increases in water velocity, scouring of the river channel, and increased erosion of the river banks (Schottler et al. 2014; Lenhart et al. 2013). In the

Kettle River Watershed, 22.7% of streams have been altered, with 13% of streams altered in the Upper St. Croix River Watershed.

Near-channel TSS and TP loading from ravines, bluffs, and streambanks were estimated using the Kettle River and Upper St. Croix River watersheds' HSPF models. Model documentation (RESPEC 2016) contains additional details about the model development and calibration. HSPF model output suggests approximately 14% of the TSS load and 4% of the TP load, at the outlet of the Kettle River Watershed, comes from near-channel sources.

Internal Loading (Lakes)

For many lakes, especially shallow lakes, internal loading can represent a significant portion of the annual TP load. Internal load can come from several sources including soluble phosphorus release from the sediment, rough fish (i.e. common carp), submerged aquatic vegetation (SAV), wind resuspension, and physical disturbances such as motorized boat traffic. Under anoxic conditions at the lake bottom, weak iron-phosphorus adsorption bonds on sediment particles break, releasing phosphorus into the water column. In shallow lakes that undergo intermittent mixing of the water column throughout the growing season, the released phosphorus can mix with surface waters throughout the summer and become available for algal growth. In deeper lakes with a more stable summer stratification period, the released phosphorus has the potential to remain in the bottom water layer throughout much of the growing season until stratification breaks down in late summer or fall. In many lakes, high sediment phosphorus release rates are the result of a large pool of phosphorus in the lake bottom 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 unless in-lake phosphorus reduction practices are employed.

Common carp and other rough fish uproot aquatic macrophytes during feeding and spawning and resuspend bottom sediments, releasing phosphorus into the water column and decreasing water clarity. Grace Lake is the only impaired lake covered in this TMDL in which common carp have been observed in recent DNR fish surveys (see section 3.6.2). Additionally, wind energy and motor boat traffic in shallow depths can disturb sediment that can be mixed into the water column and represent another potential source of internal load.

Certain SAV species such as invasive curly-leaf pondweed (CLP) can outcompete and suppress native vegetation species. CLP 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 CLP infestation can have little or no submerged vegetation by late summer. This can cause lower DO levels, increased sediment resuspension and phosphorus release from sediment. Curly-leaf pondweed has been observed by the DNR in four of the impaired lakes covered in this TMDL (see section 3.6.2). Eurasian watermilfoil, which is present in many lakes throughout Minnesota, is not considered a phosphorus source during the summer growing season, but is an invasive species that can out-compete native vegetation and negatively impact recreational activity. The DNR has not observed Eurasian watermilfoil in any of the lakes covered in this TMDL.

Septic Systems (SSTS)

Failing SSTS near waterways can be a source of bacteria, phosphorus, and nitrogen to streams and lakes, especially during low flow periods when these sources continue to discharge and runoff driven sources are not active. SSTS can fail for a variety of reasons including excessive water use, poor design, physical damage, and lack of maintenance. Common limitations that contribute to failure include seasonal high water table, fine-grained soils, bedrock, and fragipan (i.e., altered subsurface soil layer that restricts water flow and root penetration). SSTS can fail hydraulically through surface breakouts or hydrologically from inadequate soil filtration.

The MPCA differentiates between systems that fail to protect groundwater and those that are an imminent threat to public health and safety (ITPHS). Generally, failing to protect groundwater (FTPGW) systems are those that do not provide adequate treatment and may contaminate groundwater. For example, a system deemed FTPGW may have a functioning, intact tank and soil absorption system, but fails to protect groundwater by providing a less than sufficient amount of unsaturated soil between where the sewage is discharged and the groundwater or bedrock. FTPGW systems can also include, but are not limited to the following:

- Seepage pits/cesspools/drywells/leaching pits
- Systems with less than the required vertical separation
- Systems not abandoned in accordance with Minn. R. 7080.2500

Systems considered ITPHS are severely failing or were never designed to provide adequate raw sewage treatment. These include SSTS and straight pipe systems that transport raw or partially treated sewage directly to a lake, stream, drainage system, or ground surface. ITPHS systems can include, but are not limited to the following:

- Straight pipes
- Sewage surfacing in the yard
- Sewage backing up into the home
- Unsafe tank lids
- Structurally unsound tanks
- Unsafe electrical conditions

Currently, the exact number and status of SSTS in the Kettle River and Upper St. Croix River watersheds is unknown. However, each year every county in the state reports estimated FTPGW and ITPHS compliance rate estimates to the MPCA. This TMDL report’s bacteria source assessment (Section 3.6.2) and lake nutrient source assessment utilizes the most recent estimated rates reported by the county to the MPCA (Table 12; MPCA personal communication 2018). It should be noted that these rates are county-wide estimates and were developed using a wide range of methods and resources and are intended for planning purposes only.

Table 12. Estimated SSTS compliance rates by county (MPCA personal communication 2018).

County	FTPGW SSTS*	IPHT SSTS*
Aitkin	11%	1%
Carlton	10%	2%
Kanabec	20%	10%
Pine	12%	5%

* Estimated compliance rates reported by county and supplied to MPCA. Intended for planning purposes only.

Municipal and Industrial Wastewater

Domestic, commercial, and industrial wastewaters are collected and treated by municipalities before being discharged to waterbodies as municipal wastewater effluent. Treated industrial wastewaters and cooling waters from industries, businesses, and other privately owned facilities may also be discharged to surface waters. Both municipal and industrial wastewater dischargers must obtain NPDES permits. While there are several wastewater treatment plants (WWTPs) located in the Kettle River Watershed (Table 13), Aitkin Agri-Peat Inc. and Hinckley WWTP are the only active permitted wastewater facilities that discharge to impaired reaches covered in this TMDL (Figure 2).

Table 13. Wastewater treatment facilities included in this TMDL study.

Facility Name	Major Watershed	NPDES ID#	Facility Type	Effluent Design Flow (MGD)	Impaired Reach(es)
Aitkin Agri-Peat Inc	Kettle	MN0055662	BMPs	4.30	529
Hinckley WWTP	Kettle	MN0023701	Continuous	0.68	501

Construction and Industrial Stormwater

Construction stormwater is regulated through an NPDES permit. Untreated stormwater that runs off construction sites often carries sediment to surface waterbodies. Because phosphorus travels adsorbed to sediment, construction sites can also be a source of phosphorus to surface waters. Phase II of the stormwater rules adopted by the EPA requires an NPDES permit for a construction activity that disturbs one-acre or more of soil; a permit is needed for smaller sites if the activity is either part of a larger development or if the MPCA determines that the activity poses a risk to water resources. Coverage under the construction stormwater general permit requires sediment and erosion control measures that reduce stormwater pollution during and after construction activities.

Industrial stormwater is regulated through an NPDES permit when stormwater discharges have the potential to come into contact with materials and activities associated with the industrial activity. It is estimated that a small percent of the project area is permitted through the industrial stormwater permit, and industrial stormwater is not considered a significant source. Currently there are only six permitted industrial stormwater sites in the Kettle River Watershed and one permitted industrial stormwater site in the Upper St. Croix River Watershed.

On average, based on watershed-wide data, less than 0.2% of the Kettle River Watershed and less than 0.1% of the Upper St. Croix River Watershed is under construction and industrial stormwater permit in any given year. Thus, construction and industrial stormwater is not considered a significant source of sediment, phosphorus or bacteria throughout either watershed.

Natural Bacterial Reproduction

Some recent studies suggest *E. coli* bacteria have the capability to reproduce naturally in water and sediment, and therefore should be taken into account when identifying bacteria sources. Two Minnesota studies describe the presence and growth of "naturalized" or "indigenous" strains of *E. coli* in watershed soils (Ishii et al. 2010), and in ditch sediment and water (Sadowsky et al. 2015). The latter study, supported with Clean Water Land and Legacy funding, was conducted in the Seven Mile Creek Watershed, an agricultural landscape in south central Minnesota. DNA fingerprinting of *E. coli* from sediment and water samples collected in Seven Mile Creek from 2008 through 2010, resulted in the identification of 1,568 isolates comprised of 452 different *E. coli* strains. Of these strains, approximately 64% were represented by a single isolate, suggesting new or transient sources of *E. coli*. The remaining 36% of strains were represented by multiple isolates, suggesting persistence of specific *E. coli*. Discussions with the primary author of the Seven Mile Creek study suggest that while 36% might be used as a rough indicator of "background" levels of bacteria at this site during the study period, this percentage is not directly transferable to the concentration and count data of *E. coli* used in water quality standards and TMDLs. Additionally, because the study is not definitive as to the ultimate origins of this bacteria, it would not be appropriate to consider it as "natural" background.

Below is a summary of other recent studies that have found the persistence of *E. coli* in soil, beach sand, and sediments throughout the year in the United States, without the continuous presence of sewage or mammalian sources.

- An Alaskan study (Adhikari et al. 2007) found that total coliform bacteria in soil were able to survive for six months in subfreezing conditions
- A study in Michigan (Marino et al. 1991) documented survival and growth of fecal coliform in stormsewer sediment
- Two studies in Maryland (Park et al. 2016; Pachpsky et al. 2016) demonstrated that release of *E. coli* from streambed sediments during baseflow periods is substantial and that water column *E. coli* concentrations are dependent on not only land management practices but also in-stream processes

3.6.1 Stream *E. coli* Source Summary

The primary *E. coli* sources considered for this TMDL include livestock, stormwater runoff from urban areas, wildlife, wastewater treatment plants, and ITPHS SSTS. Use of watershed models for estimating relative contributions of *E. coli* sources delivered to streams is difficult and generally has high uncertainty. Thus, a simpler desktop bacteria accounting exercise was conducted to provide a general estimate of the total amount of bacteria produced by each potential source within the impaired reach watershed. This exercise was done using various Geographic Information Systems (GIS) layers and other information, including: MPCA registered feedlot GIS layer, literature rates of livestock and domestic animals, 2010 census data for urban and rural areas, SSTS failure rates reported by county, and DNR wildlife population studies. Appendix B presents results of the desktop bacteria production exercise for each impaired reach watershed. Table 14 below provides a general summary of the accounting exercise, along with notes and discussion of local knowledge, data gaps, and additional information that would further refine our understanding of bacteria sources of the impaired reaches. It is important to point out that the desktop bacteria production exercise is not based on a quantitative assessment of *E. coli* loads delivered to surface waters. At this time, there is no microbial source tracking information (e.g. DNA fingerprinting) available to determine the exact source(s) of elevated bacteria observed within each impaired reach.

In general, livestock animals were by far the biggest bacteria producer (85% to 99%) in the 10 impaired reach watersheds that have at least one MPCA registered feedlot. There were two impaired reach watersheds, JD1 Reach 526 and Spring Creek Reach 550, which do not contain any MPCA registered feedlots. In both these reaches, hay/pasture accounted for a sizeable portion of the watersheds (21% and 22%, respectively), suggesting there are likely several nonregistered livestock operations in these watersheds. Further investigation by local staff may be needed to identify the location of nonregistered feedlots, and their potential to contribute to all impaired reaches in this TMDL. This could be accomplished through a combination of stakeholder outreach, windshield surveys, and investigation of high-resolution air photos.

Bacteria production for ITPHS SSTS across the 10 impaired reach watersheds was significantly low (8% or less) compared to livestock production. The production exercise estimates that the number of ITPHS SSTS range from ~25 systems in the Grindstone River Reach 501 to ~1 system in Split Rock River Reach 513, Pine River Reach 631, JD1 Reach 526, Unnamed Creek Reach 546, and Spring Creek Reach 550. Although these numbers are relatively low, ITPHS systems that discharge near the impaired reach or a major tributary may be a critical source, particularly during low flow conditions.

Review of discharge monitoring data (Appendix D) from the Hinckley WWTP that discharges to Grindstone River Reach 501, suggests *E. coli* effluent concentrations are typically well below the *E. coli* standard. Thus, this point source is not considered a source of concern for this reach. Since urban/developed land accounts for only 2% to 8% (Table 5) of the land use within the impaired reach watershed, urban sources (i.e. domestic pets) represent a small portion of the total bacteria produced in each of the impaired reach watersheds.

Wildlife, which includes deer and waterfowl, also represents a small portion of the bacteria produced in the impaired reach watersheds. Deer and waterfowl numbers in the impaired reach watersheds were estimated using areal rates reported in the Deer Population Model (DNR 2011a) and Waterfowl Breeding Population Survey (DNR and USFWS 2011) studies. Thus, these estimates do not identify or directly account for areas in which wildlife inputs may be elevated. These could include but are not limited to beaver activity and large dams, open water areas with high waterfowl densities, and lawns or golf courses near streams where geese or other waterfowl congregate.

Table 14. *E. coli* source summary for each impaired reach covered in this TMDL.

Key: ● High potential contributor ○ Moderate potential contributor - Low potential contributor X Not considered a source at this time? Limited or no information available at this time to assess

Impaired Reach	Cropland/Manure	Livestock/Pastures near Streams	Wildlife	Urban	WWTPs	SSTS	Upstream Lake(s) & Reach(es)	In-stream (sediment)	Notes
Kettle River Reach 529	-	●	?	-	X	○	X	?	• High number of exceedances during very high (100%), high (50%) and mid (83%) flow conditions. Very few samples collected during low and very low flow conditions • Wetlands (64%) and forest/shrubland (18%) are the most common land cover in riparian areas. Watershed transitions from forested/wetlands in north to mixture of hay/pasture and forest/wetland in the south • All MPCA registered livestock (114 AUs) in watershed are located in close proximity to streams/waterways
Split Rock River Reach 513	-	●	?	-	X	○	X	?	• High number of exceedances during very high (100%), high (67%) and mid (43%) flow conditions. Very few samples collected during low and very low flow conditions • Wetlands (47%), forest/shrubland (33%) and hay/pasture (15%) are the most common land cover in riparian areas. Watershed transitions from forested/wetlands in west to mixture of hay/pasture and forest/wetland in the east • Approximately two-thirds of MPCA registered livestock (156 AUs out of 246 AUs) in watershed are located in close proximity to streams/waterways
Pine River Reach 631	-	○	?	-	X	○	X	?	• Exceedances occur during high (17%), mid (50%) and low (30%) flow conditions. Very few samples collected during very high and very low flow conditions • Forest/shrubland (47%), wetlands (33%) and hay/pasture (15%) are the most common land cover in riparian areas • There is only one MPCA registered feedlot (95 AUs) in watershed and it is not located in close proximity to streams/waterways
Judicial Ditch 1 Reach 526	-	?	?	-	X	○	X	?	• Exceedances occur during high (44%), mid (78%) and low (78%) flow conditions. No samples have been collected during very high and very low flow conditions • Wetlands (61%), forest/shrubland (21%) and hay/pasture (8%) are the most common land cover in riparian areas • There are no MPCA registered livestock in this watershed. Given the amount of pastureland, there are likely several unregistered feedlots in this watershed, however no information is available at this time
S. Branch Grindstone River Reach 516	○	●	?	-	X	○	○	?	• Exceedances occur during high (46%), mid (50%), low (67%) and very low (38%) flow conditions • Wetlands (50%), forest/shrubland (20%) and hay/pasture (18%) are the most common land cover in riparian areas. There is some cropland in riparian areas in east portion of watershed near reach outlet • Approximately half of the MPCA registered livestock (134 AUs out of 266 AUs) in watershed are located in close proximity to streams/waterways

Impaired Reach	Cropland/Manure	Livestock/Pastures near Streams	Wildlife	Urban	WWTPs	SSTS	Upstream Lake(s) & Reach(es)	In-stream (sediment)	Notes
Unnamed Creek Reach 546	-	●	?	-	X	○	X	?	• Exceedances occur during mid (50%) and low (76%) flow conditions. Very few samples have been collected during very high, high, and very low flow conditions • Wetlands (42%), forest/shrubland (24%) and hay/pasture (16%) are the most common land cover in riparian areas • A majority of the MPCA registered livestock (280 AUs out of 513 AUs) in watershed are located in close proximity to streams/waterways
N. Branch Grindstone River Reach 541	-	○	?	-	X	○	?	?	• Exceedances occur during high (60%), mid (60%), low (30%) and very low (73%) flow conditions. Very few samples have been collected during very high flow conditions • Wetlands (56%), open water (17%), forest/shrubland (12%), and hay/pasture (10%) are the most common land cover in riparian areas • There are two MPCA registered feedlots (295 AUs) in the watershed, of which one (83 AUs) is located in close proximity to streams/waterways • Bacteria contribution from Elbow Lake to Reach 541 not known at this time
N. Branch Grindstone River Reach 544	-	●	?	-	X	○	?	?	• Exceedances occur during high (8%), mid (57%), low (75%) and very low (50%) flow conditions • Wetlands (41%), forest/shrubland (22%) open water (17%), and hay/pasture (14%) are the most common land cover in riparian areas • Approximately half of the MPCA registered livestock (590 AUs out of 1,067 AUs) in watershed are located in close proximity to streams/waterways • Bacteria contribution from Grindstone Lake to Reach 544 not known at this time
Spring Creek Reach 550	○	?	?	-	X	○	X	?	• Exceedances occur during high (55%), mid (63%) and low (70%) flow conditions. Very few samples have been collected during very high and very low flow conditions • Wetlands (30%), forest/shrubland (28%) and hay/pasture (28%) are the most common land cover in riparian areas • There are no MPCA registered livestock in this watershed. Given the amount of pastureland, there may be several unregistered feedlots in this watershed, however no information available at this time
Grindstone River Reach 501	○	●	?	●	-	○	●	?	• Exceedances occur during very high (50%), high (63%), mid (64%), low (65%) and very low (100%) flow conditions • Wetlands (42%), forest/shrubland (24%), hay/pasture (16%) and open water (11%) are the most common land cover in riparian areas • A majority of the MPCA registered livestock (1,130 AUs out of 1,653 AUs) in watershed are located in close proximity to streams/waterways • Approximately half of the city of Hinckley drains directly to Reach 501 • DMR data for Hinckley WWTP indicate low levels of bacteria in effluent waters discharged to Reach 501 (see Appendix D)

3.6.2 Lake Phosphorus Source Summary

Lake response models were set up for the 12 impaired lakes in the Kettle River and Upper St. Croix River watersheds to evaluate phosphorus sources and estimate annual phosphorus budgets. The lake response model selected for this exercise was 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 user-supplied lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. Model predictions are then compared to measured data to evaluate how well the model describes the lake system. If necessary, the model parameters are adjusted so that modeled predictions match monitored data.

The five major phosphorus sources defined in the lake response models are atmospheric load, loading from SSTS, watershed load, loading from upstream impaired lakes, and internal load. Methods for estimating each of these sources are described below.

Atmospheric Loads

Atmospheric inputs of phosphorus from wet and dry deposition were estimated using published rates based on annual precipitation (Barr Engineering 2007). The atmospheric deposition values used for dry (< 25 inches), average, and wet (>38 inches) precipitation years were 24.9, 26.8, and 29.0 kg P/km^2/yr, respectively. These values are equivalent to 0.22, 0.24, and 0.26 pounds (lbs) P/acre/yr for dry, average, and wet years, respectively.

SSTS Loads

Phosphorus loading from SSTS to each impaired lake were estimated using methods similar to the Lower Minnesota River Watershed TMDL (MPCA 2020e). First, the total number of people in each lakeshed was estimated by summing the number of people in: 1) households immediately adjacent to lakes; and 2) households nonadjacent to lakes. To estimate the number of people living immediately adjacent to each lake, aerial photos were used to count the number of homes/cabins. This number was then multiplied by the number of people per household (assumed to be 2.76 on average for the St. Croix River Basin; Barr Engineering 2004) and an adjustment factor to account for the assumption that half of homes/cabins adjacent to lakes are used only four months each year (adjustment factor was 2/3). To estimate the number of people living in each lakeshed, but nonadjacent to lakes, 2010 U.S. Census data was used, and the estimated number of people adjacent to each lake was subtracted from Census-estimated lakeshed numbers. Phosphorus load to SSTS was assumed to be 1.978 lbs P/person/yr (Barr Engineering 2004). This number was multiplied by the estimated number of people in the lakeshed to obtain TP loading to SSTS each year.

To determine the TP loading leaving SSTS and entering each impaired lake, loads were calculated to each of the three types of SSTS: those labeled compliant, FTPGW, or ITPHS (see SSTS discussion in Section 3.6). Because the compliance status of SSTS in each lakeshed is not known at this time, 2018 county-wide estimated compliance rates were used for this calculation (Table 12; MPCA personal communication 2018). Phosphorus removal rates for SSTS in each of these compliance groups were then applied. For SSTS adjacent to lakes, 80% removal rates were assumed for compliant systems, while 57%

removal rates were assumed for both FTPGW and ITPHS SSTS (Barr Engineering 2004). For SSTS nonadjacent to lakes, 90%, 70%, and 57% removal rates were assumed for compliant, FTPGW, and ITPHS SSTS, respectively (Barr Engineering 2004). These phosphorus removal percentages assumed for conforming and nonconforming SSTS are within the range of literature values (Viraraghavan et al. 1975; Reckhow et al. 1980; Kellogg et al. 1995; EPA 2002; ENSR 2003) as reported in Barr Engineering 2004. Finally, the sum was taken of phosphorus loading from all compliance groups and from households both adjacent and non-adjacent to lakes to obtain TP loading to each impaired lake from SSTS.

Watershed Loads

The flow and phosphorus concentrations of watershed runoff to each lake was estimated using the Kettle and Upper St. Croix River HSPF models (Appendix E), except in the case of Pine and Grindstone Lakes, where monitored rather than modeled TP concentrations were used. HSPF-predicted average annual runoff depths and TP concentrations for the impaired lakes ranged from 10.5 to 18.4 inches/year and 37 to 70 milligrams per liter (µg/L), respectively. Because the available HSPF model ran from 1996 through 2009, model output for 2010 through 2017 was estimated using regression relationships between flow data from the Kettle River USGS station and each HSPF lakeshed (1996 through 2009). These regressions were then applied to the Kettle River USGS flow data to obtain extrapolated flow data for each lakeshed for 2010 through 2017. Similarly, TP data for 2010 through 2017 was obtained by grouping TP data from 1996 through 2009 into low, medium and high precipitation years, and then using precipitation data from 2010 through 2017 to estimate TP concentration. Figure 5 shows the HSPF-predicted average annual watershed TP inputs to each impaired lake, while Appendix C contains a more detailed description of the watershed load broken down by the sub-categories described above.

Upstream Impaired Lake Loads

Big Pine and Grindstone Lakes are the only lakes in the Kettle River and Upper St. Croix River watersheds that contain impaired lakes in their drainage areas (Pine and Elbow Lakes, respectively). Outflow volumes from Pine and Elbow Lakes were estimated using the HSPF model and routed directly into Big Pine and Grindstone Lakes within the lake response models. Average annual TP loads from Pine Lake to Big Pine Lake and from Elbow Lake to Grindstone Lake were then calculated by multiplying the HSPF predicted flow volumes by the average summer growing season monitored TP concentrations for Pine and Elbow Lakes.

Internal Loads

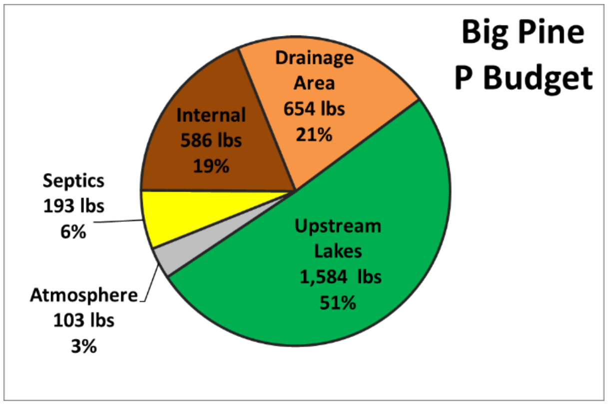
Internal loading for the impaired lakes in the Kettle River and Upper St. Croix River watersheds was estimated through a model residual approach whereby the other four phosphorus sources (atmosphere, SSTS, watershed and upstream lakes) were added to the models first, and then if necessary, additional load was added to calibrate the models. This TMDL attributes this additional load to internal phosphorus loading, which could be caused by sediment phosphorus release, rough fish (e.g. common carp), vegetation (e.g. CLP) and/or wind/boat resuspension. However, it is also possible that a portion of the additional load needed to calibrate the models is actually from one or more of the other four sources, if one or more of these sources is under-represented in the model, or from one or more loading sources that are not accounted for in the model.

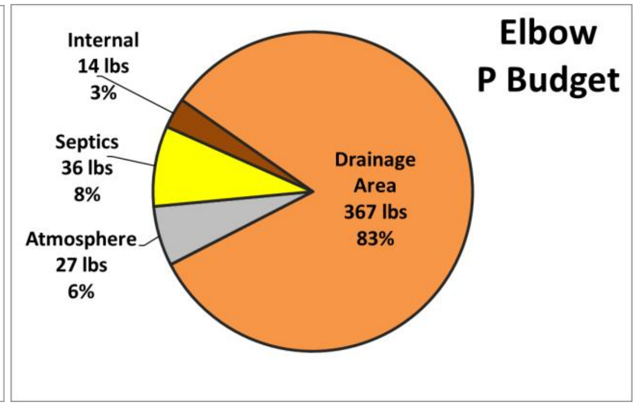
Although it can be difficult and/or cost prohibitive to directly measure phosphorus inputs from sediment phosphorus release, fish, vegetation, and wind/boat resuspension, there are ways to evaluate whether these sources have significant potential to contribute to internal load. For example, internal loading from sediment phosphorus release can be estimated by combining measured phosphorus release rates with a calculated anoxic factor (Nürnberg 2004). Sediment phosphorus release rates can be measured by collecting intact sediment cores, incubating cores in the laboratory under anoxic conditions, and determining how much phosphorus is released from the sediment core into the overlying water over time. These release rates can then be combined with the anoxic factor, which estimates the period of time that anoxia occurs over lake sediments and can be calculated using temperature and DO profiles. Sediment phosphorus release rates were not directly measured for any of the lakes in this TMDL, but should be considered in the future, at least for certain lakes that appear to have a large internal load, to further refine lake response models and understanding of these lakes.

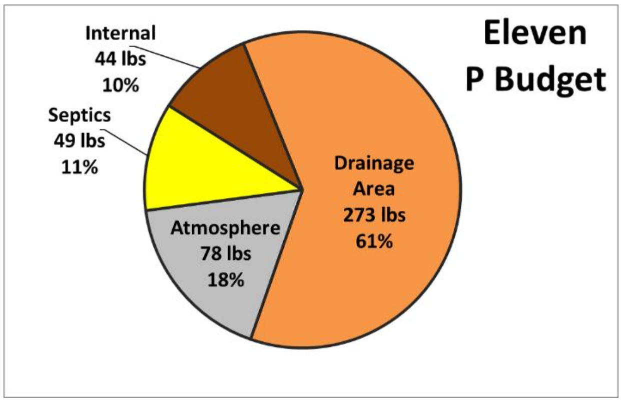
As with taking sediment cores to evaluate sediment phosphorus release, there are also ways to evaluate if rough fish have significant potential to contribute to internal load of a lake. Particularly in shallow lakes, rough fish populations—both native (e.g., black bullhead, fathead minnow) and invasive (e.g., common carp)—can have large impacts on lake water quality if they are present in high densities. Water quality degradation by rough fish is largely caused by bottom-feeding, which resuspends sediment. Common carp additionally uproot vegetation, and high carp densities can lead to increased TSS in water, reduced vegetation coverage, and lower waterfowl populations. Recent research suggests that these impacts begin to occur at common carp densities of ~100 kg of carp biomass/hectare (89 lbs/acre) (Bajer et al. 2009). Common carp population assessments have not been performed on any of the lakes in this TMDL, but assessments can be performed using standard electroshocking methods described in Bajer and Sorensen (2012). These population assessments should be considered in the future, especially if common carp are a suspected source of internal loading in a lake.

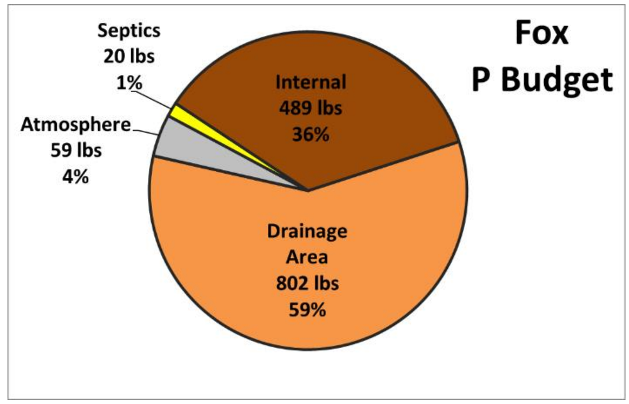
Although the lakes in this TMDL have not received formal common carp assessments, all but Merwin Lake have had their fisheries surveyed with trap and gill nets by the DNR (Table 15 and Appendix C). DNR trap and gill net surveys generally provide reliable information about the presence or absence of specific species. This presence/absence information can be used to investigate whether common carp, black bullhead, or other rough fish might be impacting water quality. Of the 11 lakes that have survey data, Grace Lake is the only lake in which common carp were captured in the trap and gill nets. The survey data indicate nearly all of the lakes contain black bullhead; however, they are generally present in low densities in most lakes. Grace, Oak, and Rhine Lakes are the only lakes with observed high black bullhead densities (233, 256, 171 catch per unit effort, respectively). While it is unclear if black bullheads are currently impacting water quality in these lakes, it may be worth investigating in the future.

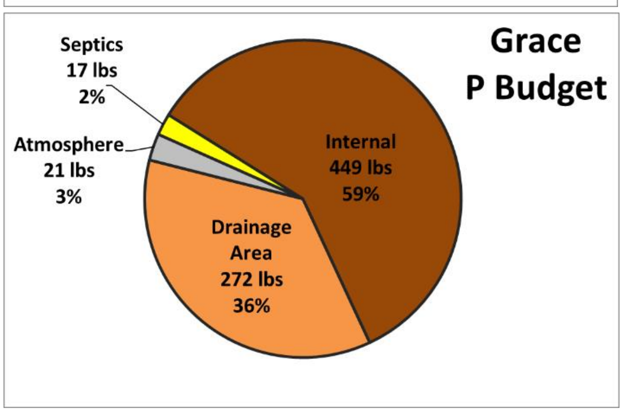
The final phosphorus source assessment results for each impaired lake are shown in Figure 5 (lbs of phosphorus per year). Table 15 provides a summary of the source categories that are of most concern for each impaired lake, based on the quantitative lake response model results (Figure 5), as well as the DNR fish surveys and anecdotal information.

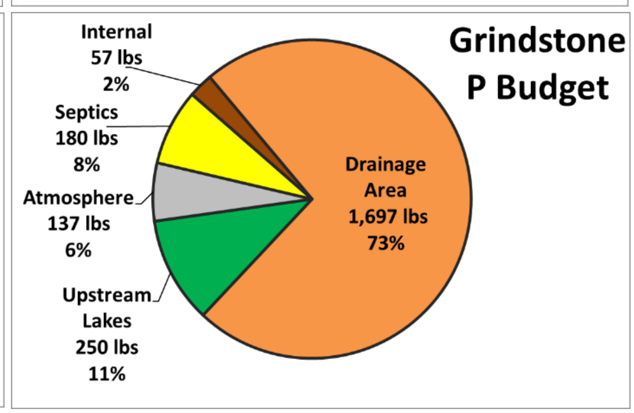

Big Pine
P Budget
Drainage
Area
654 lbs
21%
Internal
586 lbs
19%
Septics
193 lbs
6%
Atmosphere
103 lbs
3%
Upstream
Lakes
1,584 lbs
51%

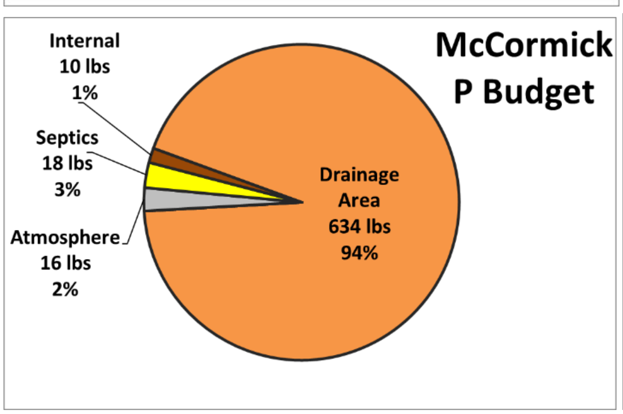

Elbow
P Budget
Internal
14 lbs
3%
Septics
36 lbs
8%
Atmosphere
27 lbs
6%
Drainage
Area
367 lbs
83%

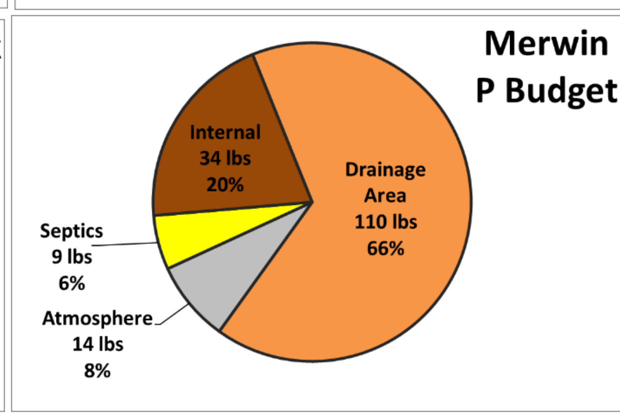

Eleven
P Budget
Internal
44 lbs
10%
Septics
49 lbs
11%
Atmosphere
78 lbs
18%
Drainage
Area
273 lbs
61%


Fox
P Budget
Septics
20 lbs
1%
Atmosphere
59 lbs
4%
Internal
489 lbs
36%
Drainage
Area
802 lbs
59%


Grace
P Budget
Septics
17 lbs
2%
Atmosphere
21 lbs
3%
Internal
449 lbs
59%
Drainage
Area
272 lbs
36%


Grindstone
P Budget
Internal
57 lbs
2%
Septics
180 lbs
8%
Atmosphere
137 lbs
6%
Upstream
Lakes
250 lbs
11%
Drainage
Area
1,697 lbs
73%


McCormick
P Budget
Internal
10 lbs
1%
Septics
18 lbs
3%
Atmosphere
16 lbs
2%
Drainage
Area
634 lbs
94%


Merwin
P Budget
Internal
34 lbs
20%
Septics
9 lbs
6%
Atmosphere
14 lbs
8%
Drainage
Area
110 lbs
66%

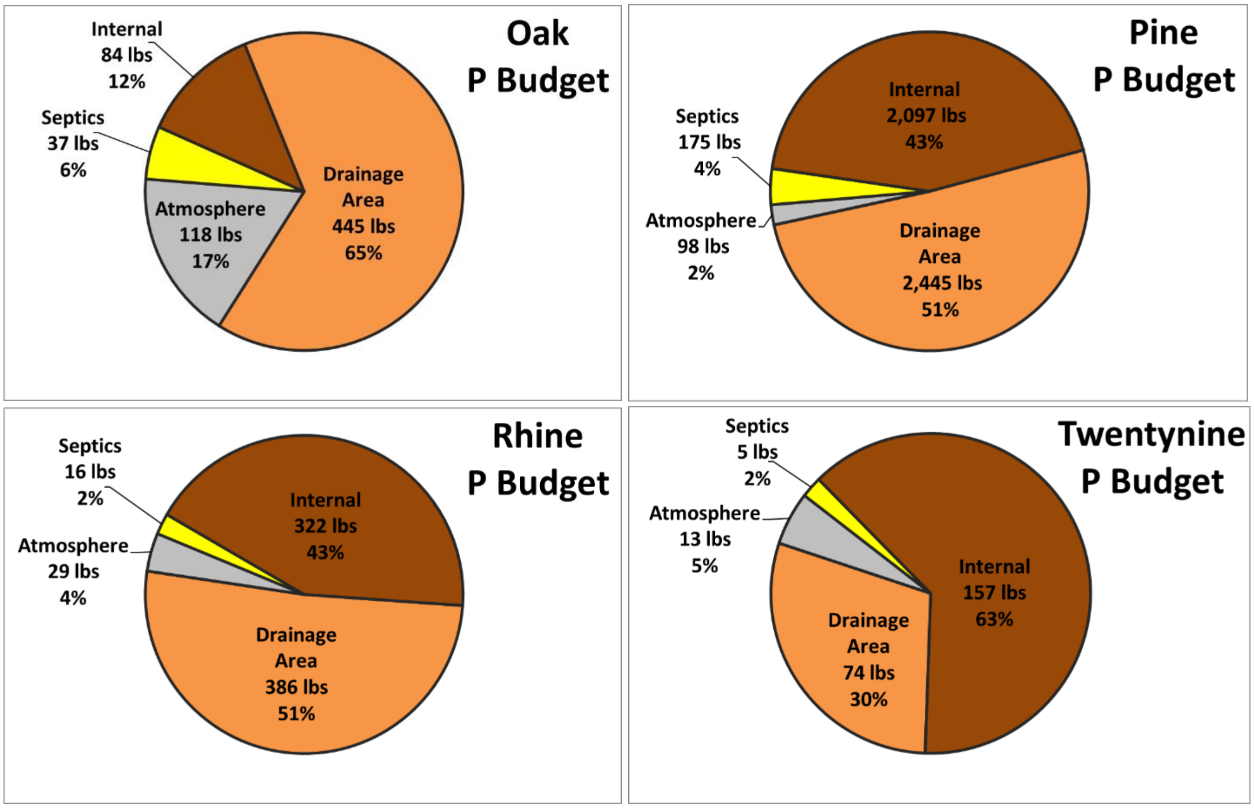


Figure 5. Average annual TP contributions by source based on HSPF and lake response modeling results.

Table 15. TP source summary for each impaired lake covered in this TMDL.

Key: ● High potential contributor ○ Moderate potential contributor - Low potential contributor X Not considered a source at this time? Limited or no information available at this time to assess

Lake Name	Watershed Sources					Internal Sources			Upstream Impaired Lake(s)	Notes
	Agriculture	Developed shoreline	SSTS	WWTPs	Upstream Lakes	Sediment Release	Aquatic Vegetation	Rough Fish		
Big Pine	○	○	○	x	●	○	?	x	Pine	- DNR fish surveys observed no carp and a small presence of black bullhead. Overall the fishery had a desirable fish community that was comprised largely of insectivore and top predator fishes. (most recent survey was 2014; 8 surveys since 1980) - Sediment phosphorus release rate was estimated based on hypolimnetic TP data from 1996 and 2016 and DO data from 2016 and is moderate (5.1 mg/m2-day) - HSPF-predicted average annual watershed TP concentration (70 µg/L) exceeds 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: cropland (23%), near channel (23%), and grassland/pasture (20%) - Pine Lake is an upstream impaired lake that contributes 51% of Big Pine Lake's TP load annually - Historic DNR vegetation surveys indicate CLP is present in the lake, however no records of abundance are available. Recent DNR survey (2008) suggests a healthy SAV community that is well above FQI impairment threshold
Elbow	●	○	○	x	x	-/?	x	x	NA	- DNR fish surveys observed no carp and an abundance of bullhead species (black, brown, and yellow). The remaining fishery was relatively simple and largely comprised of 2 top carnivore species. The lake has only been surveyed once (1984). - Internal load rate based on model residual (0.4 mg/m2-day) is low - HSPF-predicted average annual watershed TP concentration (60 µg/L) exceeds 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: grassland/pasture (29%), near channel (29%), and cropland (26%) - A single vegetation survey was conducted by DNR in 1998 and indicated no CLP or other nuisance nonnative species present in the lake. The 1998 DNR survey suggests a healthy SAV community that is well above the FQI impairment threshold
Eleven	●	○	○	x	x	-/?	-	x	NA	- DNR fish surveys observed no carp and minimal black bullhead. The fishery was comprised of a diverse and balanced insectivore and top carnivore community (most recent survey was 2015; 8 surveys since 1980) - Internal load rate based on model residual (0.4 mg/m2-day) is low - HSPF-predicted average annual watershed TP concentration (60 µg/L) exceeds 50 µg/L river eutrophication standard

Lake Name	Watershed Sources: Agriculture	Watershed Sources: Developed shoreline	Watershed Sources: SSTS	Watershed Sources: WWTPs	Watershed Sources: Upstream Lakes	Internal Sources: Sediment Release	Internal Sources: Aquatic Vegetation	Internal Sources: Rough Fish	Upstream Impaired Lake(s)	Notes
										- HSPF-predicted top three watershed TP sources include: grassland/pasture (32%), cropland (29%), and forest/shrubland (14%) - Historic DNR vegetation surveys indicate CLP is present in the lake. The most recent DNR survey (2016) shows a CLP abundance of 20% in late summer sampling (July and August). Overall, the 2016 survey suggests a healthy SAV community that is well above FQI impairment threshold
Fox	●	-	-	x	x	○	x	x	NA	- DNR fish surveys have observed no carp and a significant decrease in the abundance of black bullhead. The fishery has shifted to a greater proportion of insectivore and top carnivore species (most recent survey was 2014; 5 surveys since 1993) - Internal load rate based on model residual (5.6 mg/m2-day) is moderate - HSPF-predicted average annual watershed TP concentration (50 µg/L) equals 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: grassland/pasture (51%), forest/shrubland (17%), and cropland (16%) - Historic DNR vegetation surveys show no indication of CLP or other nuisance nonnative species in the lake. The most recent DNR survey (2014) suggests a healthy SAV community that is well above the FQI impairment threshold
Grace	○	x	-	x	x	●	x	●	NA	- DNR fish surveys have observed large swings in black bullhead abundance. Adult common carp have also been observed during various surveys. - Internal load rate based on model residual (15.9 mg/m2-day) is very high - Based on local information, recent logging and timber harvesting has occurred within the watershed to Grace Lake - HSPF-predicted average annual watershed TP concentration (37 µg/L) is below 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: forest/shrubland (54%), grassland/pasture (14%), and developed (10%) - A DNR vegetation survey conducted in 1998 indicated no CLP or other nuisance nonnative species present in the lake. Species data from other survey years was not received or reviewed for this TMDL. The most recent DNR survey (2009) suggests a healthy SAV community that is well above the FQI impairment threshold
Grindstone	●	○	○	x	○	-	x	x	Elbow	- DNR fish surveys observed no carp and a significant decline in black bullhead. The lake is a coldwater fishery comprised of many trout species (most recent survey was 2016; 8 surveys since 1980)

Lake Name	Watershed Sources					Internal Sources			Upstream Impaired Lake(s)	Notes
	Agriculture	Developed shoreline	SSTS	WWTPs	Upstream Lakes	Sediment Release	Aquatic Vegetation	Rough Fish		
										- Sediment phosphorus release rate was estimated based on hypolimnetic TP data from 1993 and 2016 and DO data from 1993 and 2016 (0.1 mg/m2-day) and is extremely low because bottom waters rarely experience anoxia - HSPF-predicted average annual watershed TP concentration (47 µg/L) is below 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: grassland/pasture (29%), near channel (29%), and cropland (26%) - Elbow Lake is an upstream impaired lake (average TP concentration = 41 µg/L) that contributes approximately 11% of Grindstone's annual TP load - A DNR vegetation survey from 1976 indicated CLP presence in the lake. However, in the four subsequent DNR surveys no CLP was observed. No records of sample dates or abundance are available from the 1976 survey. The most recent DNR survey (2018) suggests a healthy SAV community that is well above FQI impairment threshold
McCormick	●	x	○	x	x	-	x	x	NA	- DNR fish surveys observed no carp and a small and declining presence of black bullhead (most recent survey was 2009; 3 surveys since 1989) - Internal load rate based on model residual (0.5 mg/m2-day) is low - HSPF-predicted average annual watershed TP concentration (61 µg/L) exceeds 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: cropland (58%), developed (16%), and grassland/pasture (11%) - Historic DNR vegetation surveys show no indication of CLP or other nuisance nonnative species in the lake. The most recent DNR survey (2009) suggests a healthy SAV community that is well above the FQI impairment threshold
Merwin	●	-	○	x	x	○	x	?	NA	- There have not been any DNR fish surveys on Merwin Lake - Internal load rate based on model residual (1.8 mg/m2-day) is low to moderate - Based on local information, a paper mill used to operate within the watershed to Merwin Lake. Additionally there is a small golf course located in the lake's watershed - HSPF-predicted average annual watershed TP concentration (46 µg/L) is below 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: grassland/pasture (58%), wetlands (15%), and forest/shrubland (13%)

Lake Name	Watershed Sources: Agriculture	Watershed Sources: Developed shoreline	Watershed Sources: SSTS	Watershed Sources: WWTPs	Watershed Sources: Upstream Lakes	Internal Sources: Sediment Release	Internal Sources: Aquatic Vegetation	Internal Sources: Rough Fish	Upstream Impaired Lake(s)	Notes
										- A DNR vegetation survey conducted in 1997 indicated no CLP or other nuisance nonnative species present in the lake. Species data from other survey years was not received or reviewed for this TMDL. The most recent DNR survey (2008) suggests a healthy SAV community that is well above the FQI impairment threshold
Oak	○	○	○	x	x	○	-	-	NA	- DNR fish surveys have not observed carp and a moderate occurrence of bullheads. (most recent survey was 2015; 9 surveys since 1980; high densities of bullhead were documented in 1990) - Internal load rate based on model residual (0.6 mg/m2-day) is low - HSPF-predicted average annual watershed TP concentration (44 µg/L) is below 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: near channel (34%), grassland/pasture (23%), and forest/shrubland (13%) - Historic DNR vegetation surveys indicate CLP is present in the lake. It was observed in 1970 and once again in a July 2010 survey. CLP had a 10% abundance in the July 2010, however, no abundance data was available for early surveys periods. The most recent DNR survey (2010) suggests a healthy SAV community that is well above FQI impairment threshold
Pine	●	○	-	x	x	●	?	x	NA	- DNR fish surveys have not observed carp and a decline of black bullhead to non-detectable levels (most recent survey was 2014; 7 surveys since 1984) - Sediment phosphorus release rate was estimated based on hypolimnetic TP data from 2016 and DO data from 1996 and 2016 (10.8 mg/m2-day) and is very high - Based on local information, a trout farm used to be located upstream of Pine Lake. This operation closed in the mid-1980s, however it was believed to be a source of phosphorus and sediment to the lake and may have created legacy effects - HSPF-predicted average annual watershed TP concentration (58 µg/L) exceeds 50 µg/L eutrophication standard - HSPF-predicted top three watershed TP sources include: grassland/pasture (49%), forest/shrubland (28%), and cropland (8%) - Historic DNR vegetation surveys indicate CLP is present in the lake, however no records of abundance are available. Recent DNR survey (2018) suggests a healthy SAV community that is well above FQI impairment threshold
Rhine	○	-	-	x	x	●	x	●	NA	- DNR fish surveys observed no carp, but high abundance and biomass of black bullhead (surveys in 1984 and 2000) - Internal load rate based on model residual (6.9 mg/m2-day) is moderate

Lake Name	Watershed Sources					Internal Sources			Upstream Impaired Lake(s)	Notes
	Agriculture	Developed shoreline	SSTS	WWTPs	Upstream Lakes	Sediment Release	Aquatic Vegetation	Rough Fish		
										- HSPF-predicted average annual watershed TP concentration (47 µg/L) is below 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: forest/shrubland (74%), grassland/pasture (16%), and wetlands (7%) - Only one DNR vegetation survey was conducted in 1998 and showed no indication of CLP or other nuisance nonnative species in the lake. This survey suggested a healthy SAV community that is slightly above the FQI impairment threshold
Twentynine	○	○	-	x	x	●	?	x	NA	- DNR fish surveys observed no carp and no black bullhead. The fishery is relatively simple and has minimal diversity (surveys in 1968 and 2001) - Internal load rate based on model residual (9.1 mg/m2-day) is high - HSPF-predicted average annual watershed TP concentration (37 µg/L) is below 50 µg/L river eutrophication standard - HSPF-predicted top three watershed TP sources include: grassland/pasture (37%), developed (22%), and wetlands (19%) - No vegetation survey data available

4. TMDL Development

4.1 TMDL Overview

A TMDL represents the total mass of a pollutant that can be assimilated by the receiving water without causing that receiving water to violate water quality standards. The TMDL is an equation with four different components, as described below:

$$\textbf{TMDL = LC = ΣWLA +Σ LA + MOS + RC}$$

Where:

LC = loading capacity; or the greatest pollutant load a waterbody can receive without violating water quality standards;

WLA = wasteload allocation; or the portion of the TMDL allocated to existing or future permitted point sources of the relevant pollutant;

LA = load allocation, or the portion of the TMDL allocated to existing or future nonpoint sources of the relevant pollutant;

MOS = margin of safety, or an accounting of uncertainty about the relationship between pollutant loads and receiving water quality. The MOS can be provided implicitly through analytical assumptions or explicitly by reserving a portion of loading capacity (LC) (EPA 1999).

RC = reserve capacity, an allocation of future growth. This is an MPCA-required element, if applicable (not applicable in this TMDL).

Per Code of Federal Regulations (40 CFR § 130.2(i)), TMDLs can be expressed in terms of mass per time, toxicity or other appropriate measures. For this TMDL, the TMDLs, allocations and margins of safety are expressed in mass/day. Each of the TMDL components is discussed in greater detail in the following sections.

4.1.1 Model Approach

The Kettle River and Upper St. Croix River Watersheds HSPF Model was used to estimate watershed runoff and pollutant loading to the impaired lakes and reaches included in this TMDL. HSPF is a comprehensive watershed model of hydrology and water quality that includes modeling land surface and subsurface hydrologic and water-quality processes, which are linked and closely integrated with corresponding stream, wetland and reservoir processes. HSPF model applications can be used to determine critical environmental conditions (e.g., low/high flows or seasons) for the impaired segments by providing continuous flow and concentration predictions throughout the system.

An HSPF model that covers the Kettle River and Upper St. Croix River watersheds was developed in 2016 to support this TMDL study and other planning and management efforts in the watershed (RESPEC 2016). The HSPF model predicts the range of flows that have historically occurred in the modeled area, the load contributions from a variety of point and nonpoint sources in a watershed, and the source contributions when paired flow and concentration data are limited. Supporting documentation is available which discusses modeling methodologies, data used, and calibration results for the Kettle River and Upper St. Croix River Watersheds HSPF Model (RESPEC 2016).

4.1.2 Load Duration Curve Approach

Pollutant load capacity (LC) for the *E. coli* impaired stream reaches were developed using LDCs. LDCs incorporate flow and water quality across the reach flow zones, and provide loading capacities and a means of estimating load reductions necessary to meet water quality standards. To develop the LDCs, HSPF simulated average daily flow values from 2000 through 2017 for each reach were multiplied by the appropriate water quality standard and converted to daily loads to create "continuous" LDCs. Because this method uses a long-term record of daily flows, virtually the full spectrum of allowable loading capacities is represented by the resulting curve.

In the TMDL equation tables of this TMDL, only five points on the entire LC curve are depicted: very high flows (0% to 10%), high flows (10% to 40%), mid flows (40% to 60%), low flows (60% to 90%) and very low flows (90% to 100%). 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 the EPA. For the purposes of this TMDL, the baseline year for implementation will be 2009, which represents the mid-range year of the HSPF flow record used to construct the LDCs (See Section 8.2.3).

4.1.3 Natural Background Consideration

Natural background was given consideration in the development of LA in this TMDL. Natural background is the landscape condition that occurs outside of human influence. Minn. R. 7050.0150, subp. 4, defines the term "natural causes" as the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a waterbody in the absence of measurable impacts from human activity or influence. The Clean Water Legacy Act (Minn. Stat. § 114D.10, subd. 10) defines natural background as "characteristics of the water body resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics that affect the physical, chemical or biological conditions in a water body, but does not include measurable and distinguishable pollution that is attributable to human activity or influence."

Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes, such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc. Natural background conditions were evaluated, where possible, within the modeling and source assessment. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, urban stormwater, failing SSTS, and other anthropogenic sources.

Based on the MPCA's waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest natural background sources are a major driver of any of the impairments addressed in this TMDL and/or affect their ability to meet state water quality standards. For all impairments addressed in this TMDL, natural background sources are implicitly included in the LA portion of the TMDL allocation tables, and TMDL reductions should focus on the major anthropogenic sources identified in the source assessment. Federal law instructs an agency to distinguish between natural and nonpoint source loads "wherever possible." 40 CFR § 130.2(g). Minnesota law does not compel the MPCA to develop a separate LA for natural background sources.

4.1.4 Loading Capacity Methodology

LDCs were used to represent the LC for the 10 *E. coli*-impaired reaches covered in this TMDL. The flow component of each LC curve is based on the HSPF simulated average daily flows from April through October (2000 through 2017), and the concentration component is the *E. coli* concentration standard of 126 cfu/100 mL. *E. coli* LDCs for each impaired reach covered in this TMDL are shown in Section 4.3.6. On these figures the red curve represents the allowable *E. coli* LC of the reach for each flow rank. The median (or midpoint) load of each flow zone was used to represent the total LC in the TMDL tables. Each reach's LC can be compared to current conditions by plotting the measured load during each individual water quality sampling event (black circles in Figures 6 through 15). Each black circle that is above the curve exceeds the 126 cfu/100 mL water quality standard while those below the line are below the standard. It is important to point out that the *E. coli* standard is not applied to individual sample points, but rather by aggregating the data by month and calculating the geometric mean. That said, plotting the individual sample points helps visualize how the individual data points relate to flow conditions and when elevated bacteria concentrations are more common.

The existing *E. coli* concentration for each impaired reach was calculated as the geometric mean of all monitoring data collected during the months that the standard applies (April through October). The overall estimated concentration-based percent reduction needed to meet the TMDL was calculated by comparing the highest observed (monitored) monthly geometric mean from the months that the standard applies to the geometric mean standard. Also plotted on the LDC figure are the monitored *E. coli* geometric mean loads for each flow zone (solid green circles). Plotting these individual loads help determine what flow zones and practices should be targeted to achieve the overall reduction goal for each impaired reach.

4.1.5 Wasteload Allocation Methodology

The WLAs for the *E. coli* TMDLs were divided into three categories: NPDES permitted wastewater dischargers, NPDES permitted MS4 stormwater, and NPDES permitted construction and industrial stormwater. This section describes how each of these WLAs were assigned. The NPDES permitted livestock CAFOs are zero discharge facilities and are given a WLA of zero and should not impact water quality in the basin as a point source. Therefore it is not necessary to put them in the *E. coli* TMDL table. Straight pipe septic systems are illegal and receive a WLA of zero. Therefore it is not necessary to put them in the *E. coli* TMDL table. In addition, no permitted CAFOS exist in the impaired reaches.

<u>NPDES Permitted Wastewater Dischargers</u>

The Hinckley WWTP is the only active NPDES permitted surface wastewater discharger that is a source of *E. coli* bacteria that discharges to an *E. coli*-impaired reach (Grindstone River Reach 501) covered in this TMDL. WLAs for Hinckley WWTP were calculated by multiplying the facility's wet-weather design flow by the *E. coli* standard (126 cfu/100 mL). DMRs for the Hinckley WWTP were downloaded to assess the typical monthly discharge values and bacteria concentrations for this facility. It should be noted that NPDES wastewater permit limits for bacteria are currently expressed in fecal coliform concentrations, not *E. coli*. However, the fecal coliform permit limit for Hinckley WWTP (200 organisms/100 mL) is intended to ensure that the facility is effectively disinfecting its effluent, and therefore does not contribute to *E. coli* standard violations in its receiving waters. The fecal coliform-*E. coli* relationship is documented extensively in the SONAR for the 2007 and 2008 revisions of Minn. R. ch. 7050. Results of the Hinckley WWTP DMRs are presented in Appendix D.

Table 16. *E. coli* allocations for NPDES permitted dischargers in the Kettle River Watershed *E. coli* impaired reaches.

Impaired Reach	Facility Name	NPDES ID#	Effluent Design Flow (MGD)	Permitted concentration (org./100 mL)	Permitted Load (billions of org./day)
501	Hinckley WWTP	MN0023701	0.68	126	3.3

NPDES Permitted MS4 Stormwater

There are no permitted MS4s located in the watersheds draining to the Kettle River *E. coli* impaired reaches covered in this TMDL.

NPDES Permitted Construction and Industrial Stormwater

WLAs for regulated construction stormwater (Permit #MNR100001) were not developed, since *E. coli* is not a typical pollutant from construction sites. Industrial stormwater receives 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) in the *E. coli* impaired reach watersheds and therefore no industrial stormwater *E. coli* WLAs were assigned.

4.1.6 Load Allocation Methodology

As stated in the governing TMDL equation, the LA, also referred to as the watershed LA, is comprised of the nonpoint source load that is allocated to an impaired AUID after the MOS and WLA are subtracted from the total LC for each flow regime. This residual load is meant to represent the watershed LA that includes all nonregulated sources *E. coli* upstream of the impaired reach, which are summarized in Section 3.6.

The relationship between bacterial sources and bacterial concentrations found in streams is complex, involving precipitation and flow, temperature, livestock management practices, wildlife activities, survival rates, land use practices, and other environmental factors. Section 3.6 discusses possible sources of bacteria found in streams and highlighted the observation that *E. coli* populations can be naturalized in the sediment and persist over an extended period of time. Chandrasekaran et. al. (2015) concluded that approximately 36% of *E. coli* strains were represented by multiple isolates, suggesting persistence of specific *E. coli*. The authors suggested that 36% might be used as a rough indicator of “background” levels of bacteria at this site during the study period. While these results may not be transferable to other locations, they do suggest the presence of background *E. coli* and a fraction of *E. coli* may be present regardless of the control measures taken by traditional implementation strategies.

4.1.7 Margin of Safety

The MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. The MOS can be either implicitly or explicitly defined as a set-aside amount. An explicit MOS was calculated as 10% of the LC for the *E. coli*-impaired reaches covered in this TMDL. Ten percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty. The LDC calculations are based on *E. coli* target concentrations and modeled flow data that has been calibrated to long-term monitored flow data. Most of the uncertainty with this calculation is therefore associated with the HSPF modeled flow output for each reach. The Kettle River HSPF model was calibrated and validated using 15 years (1995 through 2009) of flow data from two gaging stations (RESPEC 2016). Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed as a whole. See Appendix E of this TMDL for the HSPF model calibration and validation results. The individual *E. coli* LDCs were developed using HSPF modeled daily flow data from April through October (2000 through 2017). The *E. coli* TMDLs apply a MOS to each flow zone along the duration curves by subtracting 10% of the flow zone's LC.

4.1.8 Seasonal Variation

E. coli monitoring data for the bacteria-impaired reaches indicate all reaches had multiple exceedances of the monthly chronic standard (Table 7). Further, individual exceedances of the acute standard occurred in eight of the 10 impaired reaches (Table 7). 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 many of the reaches continue into the fall, which may be attributed to constant sources of *E. coli* (such as failing SSTS and animal access to the stream) and less flow for dilution. However, some of the data may be skewed as more samples were collected in the summer months than in early spring and late fall. Seasonal and annual variations are accounted for by setting the TMDL across the entire flow record using the load duration method.

4.1.9 *E. coli* TMDL Summary

The TMDL summary tables (Tables 17 through 26) for each Kettle River Watershed *E. coli*-impaired reach present the existing load, the total LC (Total Load (TMDL) in tables, MOS, WLA (Wasteload in tables), and LA (Load in tables). 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 one significant figure to prevent zero load values. The bottom line of the tables shows the estimated concentration-based percent load reduction for each reach to meet the TMDL for all flow zones. This reduction was calculated by comparing the highest observed (monitored) monthly geometric mean from the months that the standard applies to the geometric mean 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 the TMDL tables. Thus, the estimated load reduction for each flow zone applies to the waterbody as a whole. See Section 8 of this TMDL and the WRAPS report for further information on which sources and geographical locations within the impaired reach watershed should be targeted for bacteria BMPs and restoration strategies.

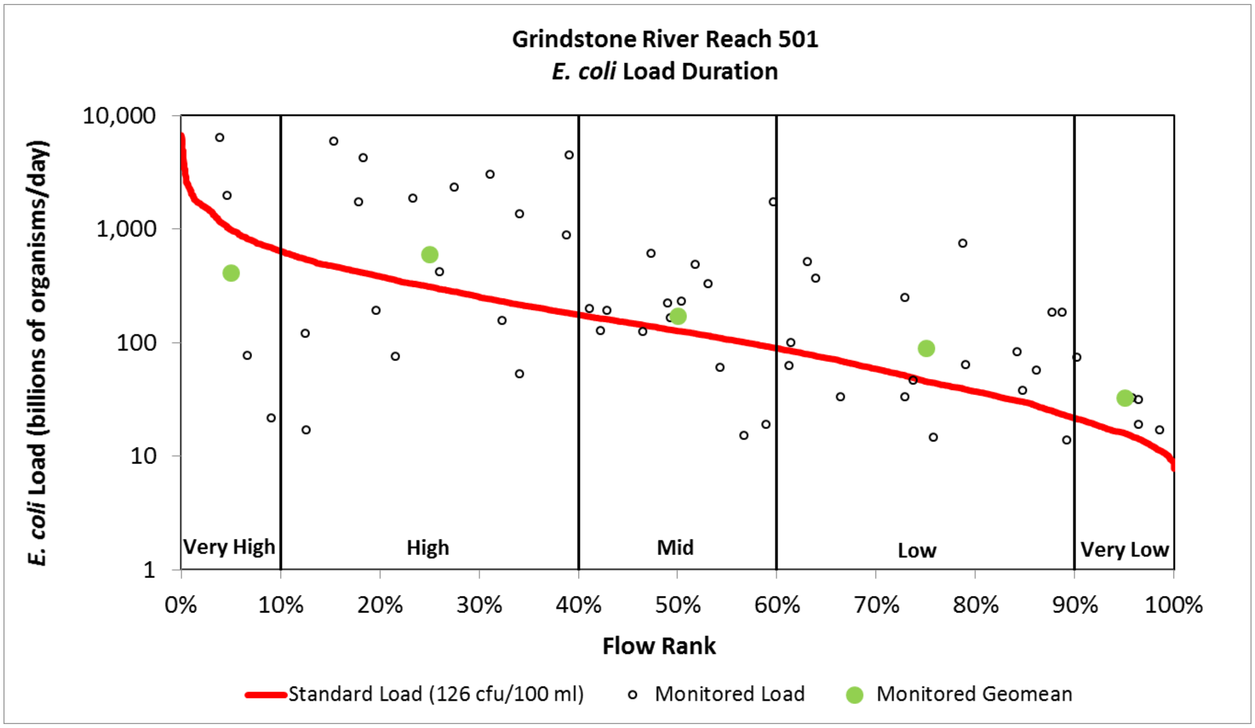


Figure 6. Grindstone River Reach 501 *E. coli* LDC and monitored loads.

Table 17. *E. coli* TMDL summary for Grindstone River Reach 501.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Hinckley WWTP (MN0023701)	3	3	3	3	3
	Total WLA	**3**	**3**	**3**	**3**	**3**
Load	**Total LA**	**880**	**277**	**111**	**38**	**11**
MOS		**98**	**31**	**13**	**5**	**2**
Total load		**981**	**311**	**127**	**46**	**16**
Existing Concentration Apr-Oct (org/100 mL)**		**202**				
Maximum Monthly Geometric Mean (org/100mL)**		**606**				
Overall Estimated Percent Reduction**		**79%**				

* Model simulated flow for HSPF reach 627 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S001-270 (years 2007-2009, 2016 and 2017)

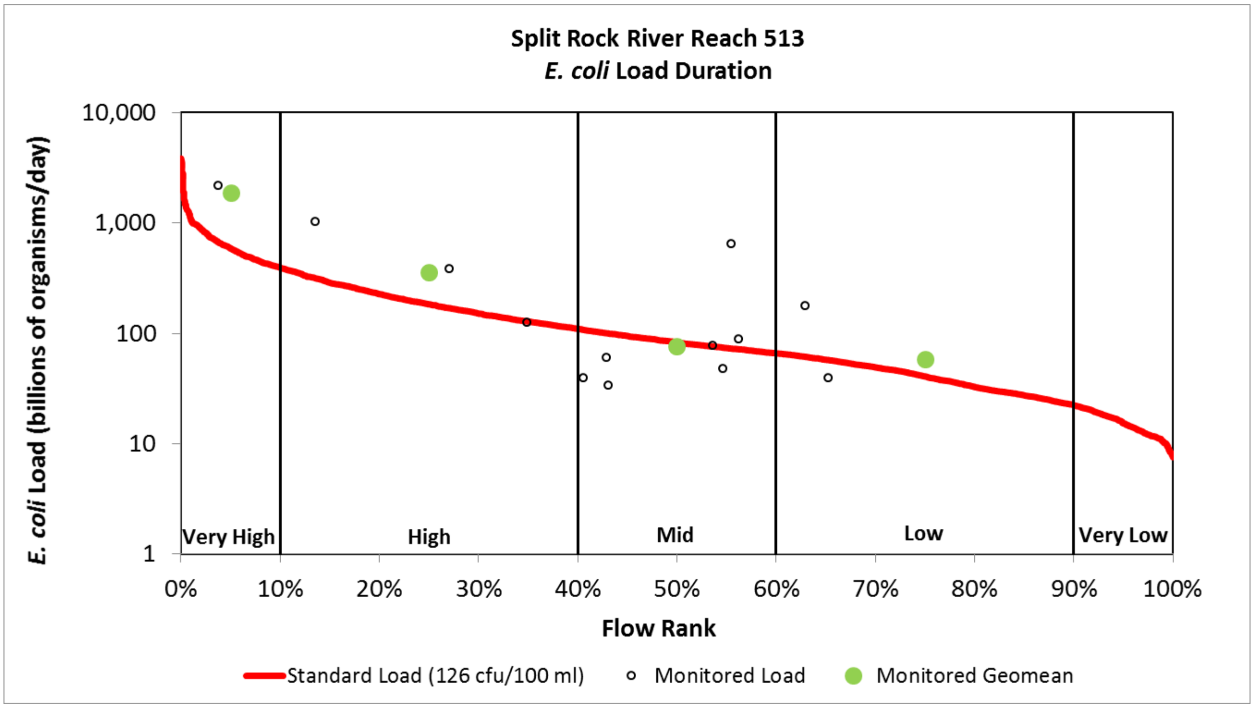


Figure 7. Split Rock River Reach 513 *E. coli* LDC and monitored loads.

Table 18. *E. coli* TMDL summary for Split Rock River Reach 513.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	526	165	74	37	14
	MOS	58	18	8	4	2
	Total load	584	183	82	41	16
	Existing Concentration Apr-Oct (org/100 mL)**	172				
	Maximum Monthly Geometric Mean (org/100mL)**	329				
	Overall Estimated Percent Reduction**	62%				

* Model simulated flow for HSPF reach 467 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S008-823 (years 2016 and 2017)

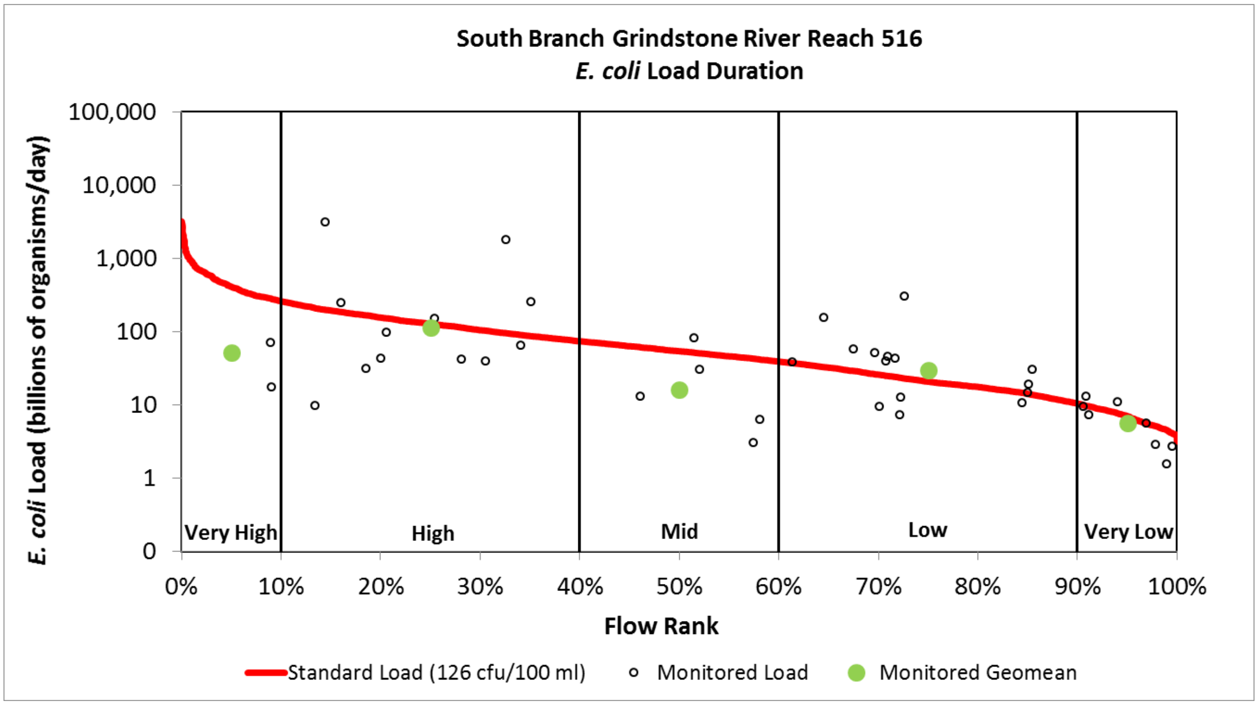


Figure 8. South Branch Grindstone River Reach 516 *E. coli* LDC and monitored loads.

Table 19. *E. coli* TMDL summary for South Branch Grindstone River Reach 516.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	367	115	49	19	6
MOS		41	13	5	2	0.7
Total load		408	128	54	21	7
Existing Concentration Apr-Oct (org/100 mL)**		104				
Maximum Monthly Geometric Mean (org/100mL)**		217				
Overall Estimated Percent Reduction**		42%				

* Model simulated flow for HSPF reach 624 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S001-263 (years 2007 through 2009)

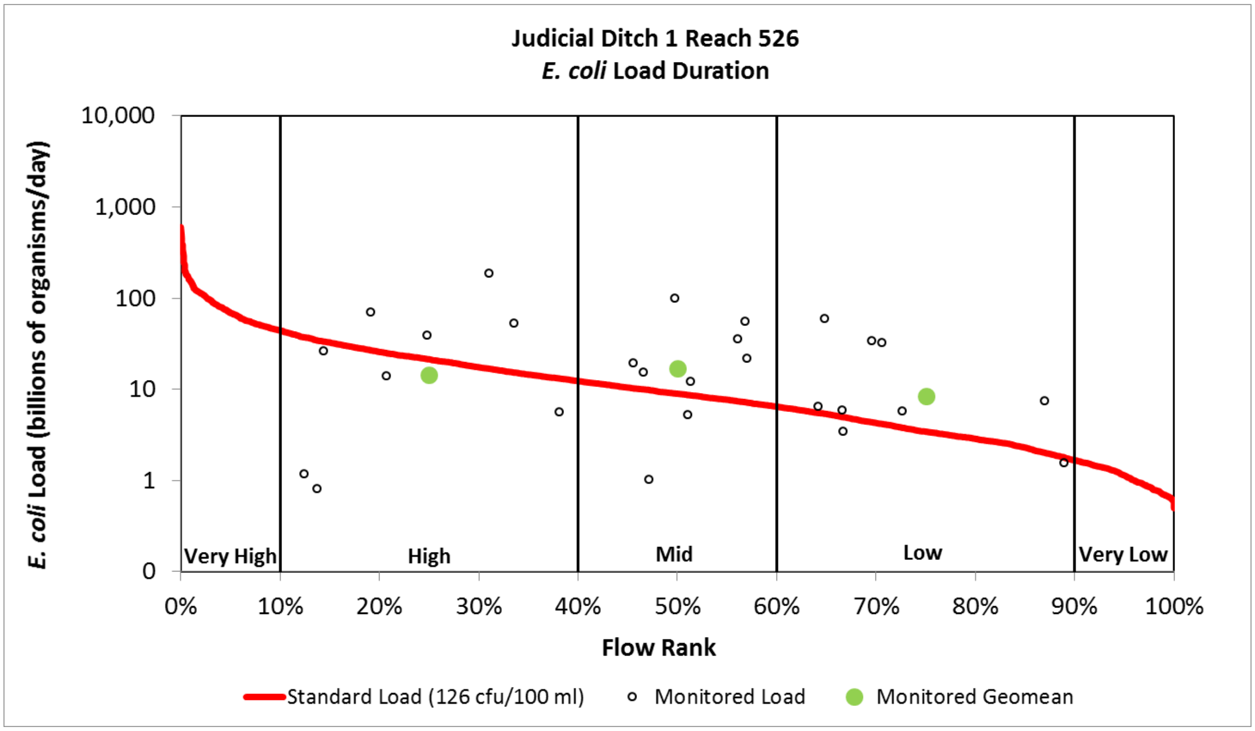


Figure 9. Judicial Ditch #1 Reach 526 *E. coli* LDC and monitored loads.

Table 20. *E. coli* TMDL summary for Judicial Ditch #1 Reach 526.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	62	19	8	3	1
	MOS	7	2	0.9	0.3	0.1
	Total load	69	21	9	3	1
	Existing Concentration Apr-Oct (org/100 mL)**	185				
	Maximum Monthly Geometric Mean (org/100mL)**	624				
	Overall Estimated Percent Reduction**	80%				

* Model simulated flow for HSPF reach 622 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S004-894 (years 2008 through 2010)

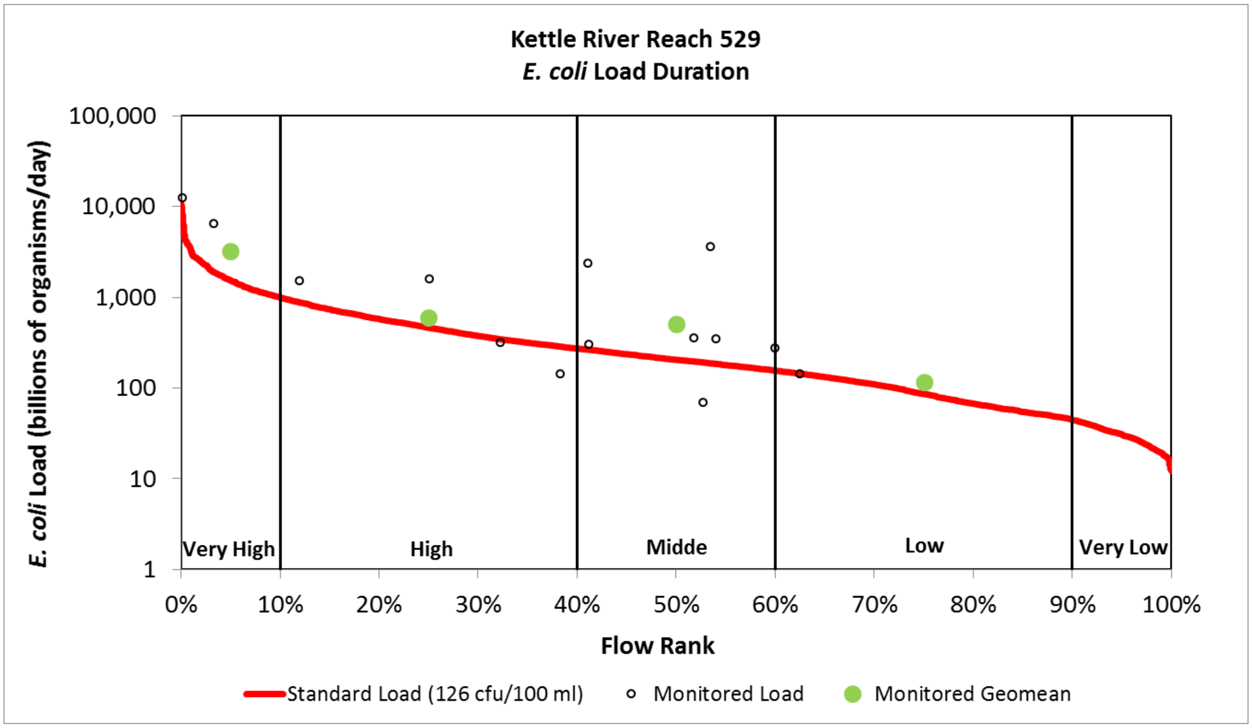


Figure 10. Kettle River Reach 529 *E. coli* LDC and monitored loads.

Table 21. *E. coli* TMDL summary for Kettle River Reach 529.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	1,377	416	184	78	27
MOS		153	46	20	9	3
Total load		1,530	462	204	87	30
Existing Concentration Apr-Oct (org/100 mL)**		232				
Maximum Monthly Geometric Mean (org/100mL)**		529				
Overall Estimated Percent Reduction**		76%				

* Model simulated flow for HSPF reach 430 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S008-822 (years 2016 and 2017)

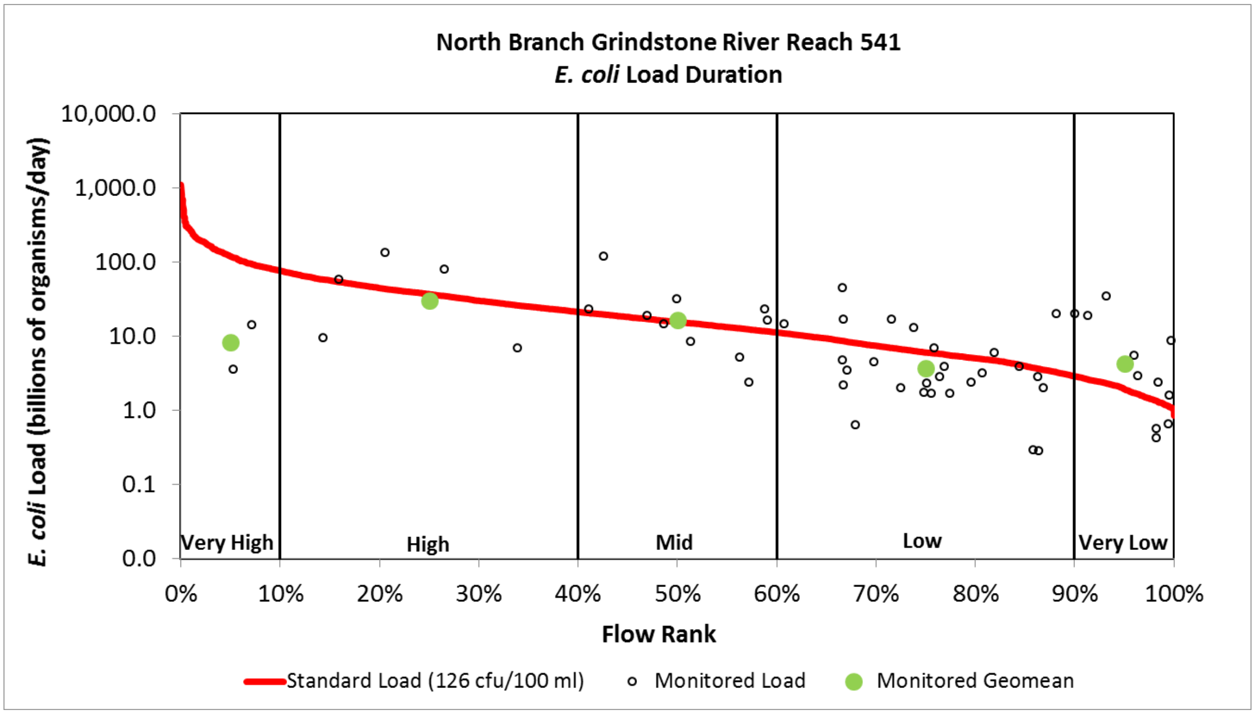


Figure 11. North Branch Grindstone River Reach 541 *E. coli* LDC and monitored loads.

Table 22. *E. coli* TMDL summary for North Branch Grindstone River Reach 541.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	107	33	14	5	2
	MOS	12	4	2	0.6	0.2
	Total load	119	37	16	6	2
	Existing Concentration Apr-Oct (org/100 mL)**	105				
	Maximum Monthly Geometric Mean (org/100mL)**	210				
	Overall Estimated Percent Reduction**	40%				

* Model simulated flow for HSPF reach 625 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S004-891 (years 2006-2009, 2016 and 2017)

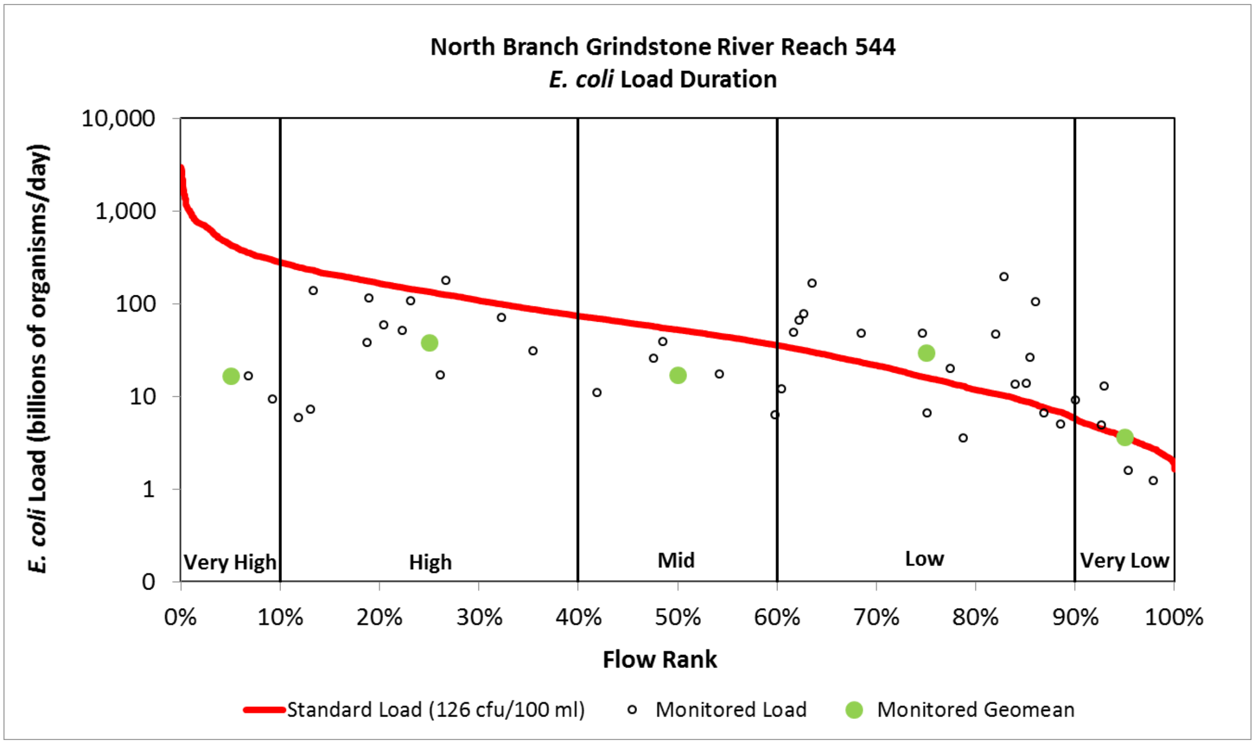


Figure 12. North Branch Grindstone River Reach 544 *E. coli* LDC and monitored loads.

Table 23. *E. coli* TMDL summary for North Branch Grindstone River Reach 544.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	386	121	47	14	3
	MOS	43	13	5	2	0.4
	Total load	429	134	52	16	3
	Existing Concentration Apr-Oct (org/100 mL)**	86				
	Maximum Monthly Geometric Mean (org/100mL)**	279				
	Overall Estimated Percent Reduction**	55%				

* Model simulated flow for HSPF reach 626 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S001-262 (years 2007 through 2009)

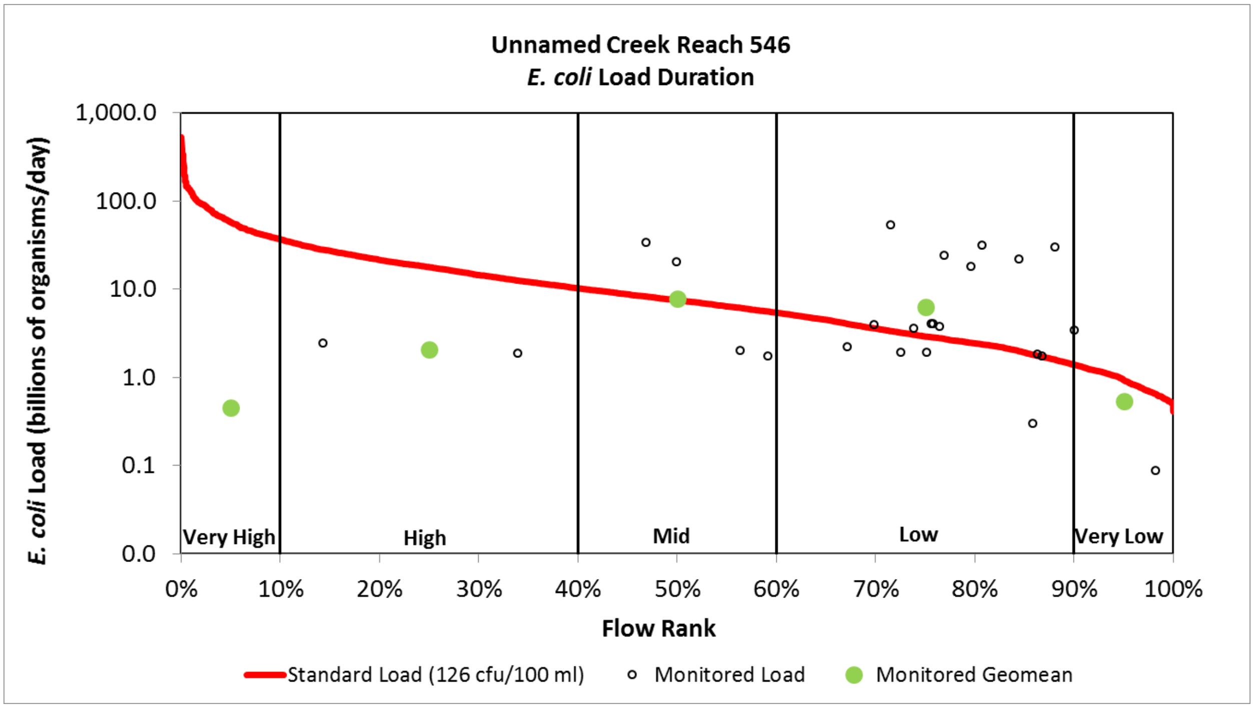


Figure 13. Unnamed Creek Reach 546 *E. coli* LDC and monitored loads.

Table 24. *E. coli* TMDL summary for Unnamed Creek Reach 546.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	52	16	7	3	0.8
	MOS	6	2	0.8	0.3	0.09
	Total load	58	18	8	3	0.9
	Existing Concentration Apr-Oct (org/100 mL)**	140				
	Maximum Monthly Geometric Mean (org/100mL)**	530				
	Overall Estimated Percent Reduction**	76%				

* Model simulated flow for HSPF reach 624 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S002-245 (years 2008 and 2009)

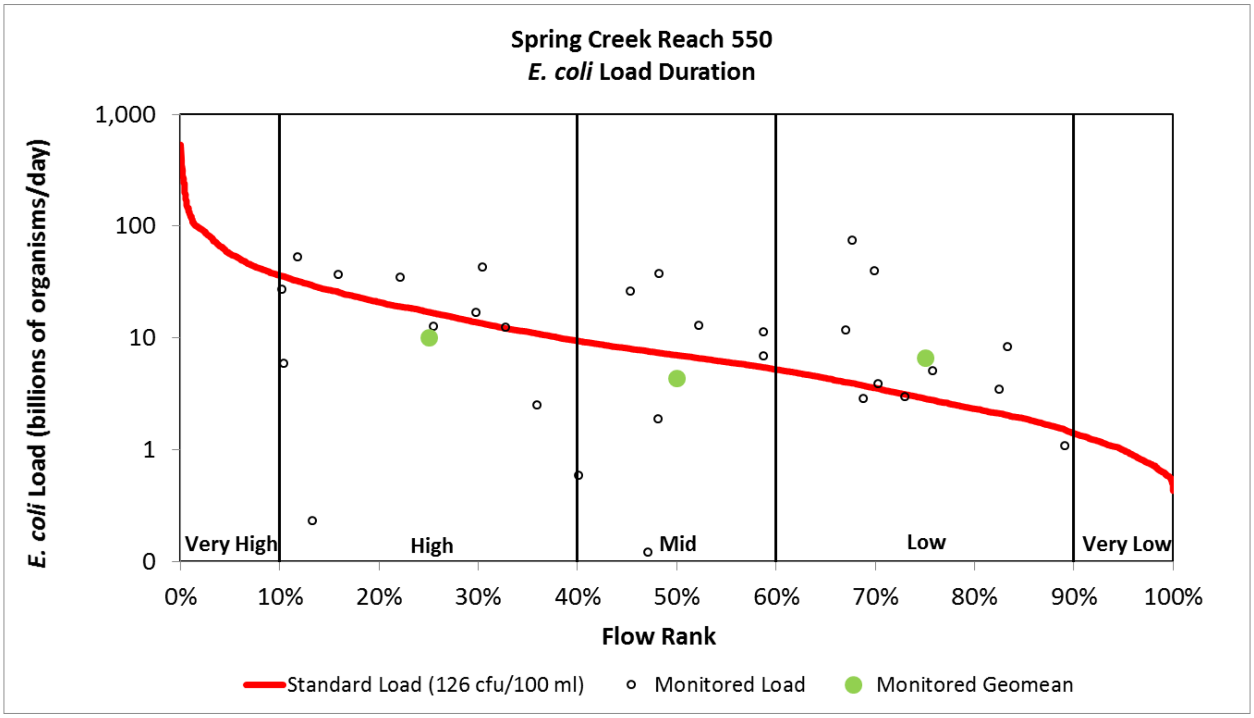


Figure 14. Spring Creek Reach 550 *E. coli* LDC and monitored loads.

Table 25. *E. coli* TMDL summary for Spring Creek Reach 550.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	50	15	6	3	0.9
MOS		6	2	0.7	0.3	0.1
Total load		56	17	7	3	1
Existing Concentration Apr-Oct (org/100 mL)**		121				
Maximum Monthly Geometric Mean (org/100mL)**		603				
Overall Estimated Percent Reduction**		79%				

* Model simulated flow for HSPF reach 628 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S004-895 (years 2008 through 2010)

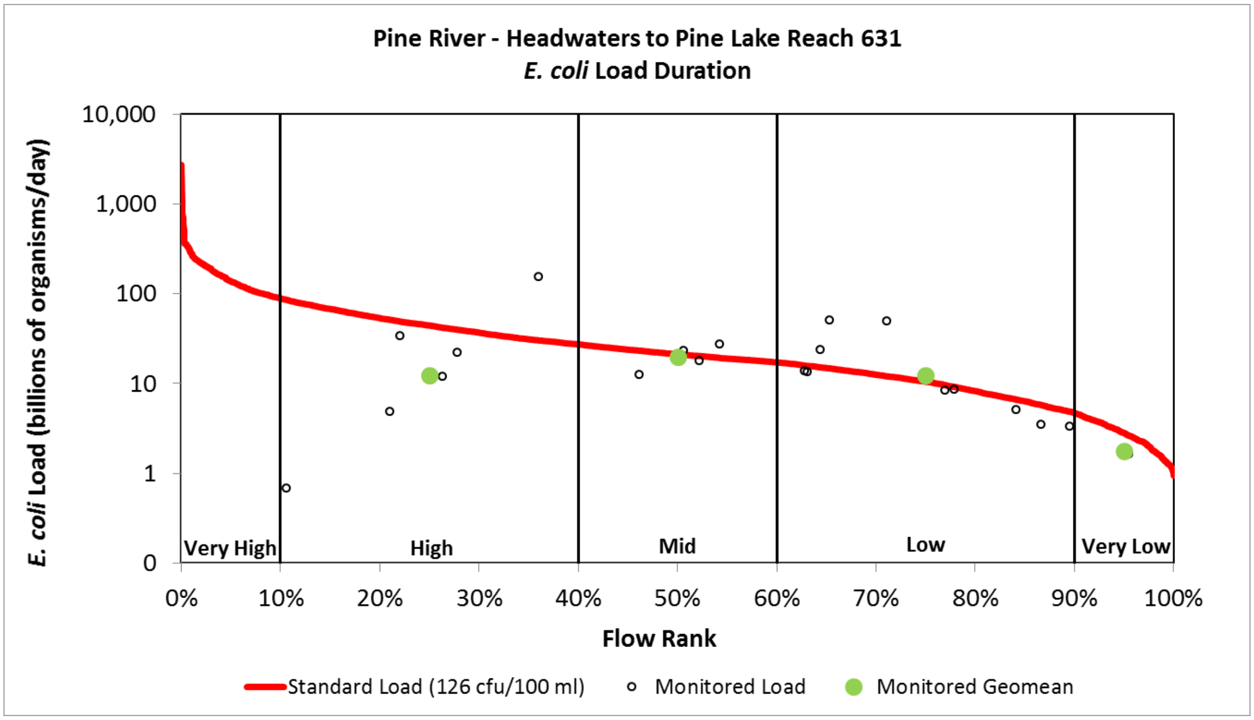


Figure 15. Pine River Reach 631 *E. coli* LDC and monitored loads.

Table 26. *E. coli* TMDL summary for Pine River Reach 631.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of org/day)				
Wasteload	Total WLA	--	--	--	--	--
Load	Total LA	124	40	19	9	3
	MOS	14	4	2	1	0.3
	Total load	138	44	21	10	3
	Existing Concentration Apr-Oct (org/100 mL)**	90				
	Maximum Monthly Geometric Mean (org/100mL)**	194				
	Overall Estimated Percent Reduction**	35%				

* Model simulated flow for HSPF reach 521 from April-October (2000-2017) was used to develop the flow zones and LCs for this reach

** Water quality monitoring station(s) used to estimate reductions: S004-889 (years 2008-2010)

4.2 Phosphorus - Lakes

4.2.1 Loading Capacity Methodology

TP LCs for each impaired lake in the Kettle River and Upper St. Croix River watersheds were developed using the Canfield Bachmann Lake Response Model. Phosphorus loading from the atmosphere, SSTS, watershed, upstream impaired lakes, and internal load were the primary sources evaluated and incorporated into the Canfield Bachman Lake Response Models. Appendix C of this TMDL provides more detail of the phosphorus source assessment and lake response model methodology. Once each of the lake response models was calibrated, the resulting relationship between phosphorus load and in-lake water quality was used to determine the assimilative capacity. To set the LC 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 its ecoregion TP standard. This process is discussed in more detail in Section 4.2.6.

4.2.2 Wasteload Allocation Methodology

The WLA were divided into three primary categories: NPDES permitted wastewater dischargers, NPDES permitted MS4 stormwater, and NPDES-permitted construction and industrial stormwater.

<u>NPDES Permitted Wastewater Dischargers</u>

There are no permitted wastewater dischargers located in the watersheds draining to the impaired lakes covered in this TMDL.

<u>NPDES Permitted MS4 Stormwater</u>

There are no permitted MS4s located in the watersheds draining to the impaired lakes covered in this TMDL.

<u>NPDES Permitted Construction and Industrial Stormwater</u>

Construction and industrial stormwater WLAs were established based on estimated percentage of land in the Kettle River and Upper St. Croix River Watersheds currently under construction or permitted for industrial use. A recent permit review across the watershed (see Section 4.2.2) showed minimal construction and industrial activities (~0.12% and ~0.06% of the Kettle River and Upper St. Croix River watersheds, respectively).

4.2.3 Load Allocation Methodology

The LA includes nonpoint sources that are not subject to NPDES permit requirements, as well as natural background sources. These include phosphorus sources such as internal load from the sediments or rough fish, soil erosion or nutrient leaching from cropland, pastureland, phosphorus-laden runoff from urban areas not covered by MS4 Permits, and streambed and streambank erosion resulting from human-induced hydrologic changes and disturbance of stream channels and riparian areas. In addition, some phosphorus may leach into the lake or its upstream tributaries from failing SSTS. The only portion of the watershed runoff not included in the LA is the small loading set aside for regulated stormwater runoff from construction and industrial sites.

Natural background sources of phosphorus include atmospheric deposition, as well as the relatively low levels of soil erosion from both stream channels and upland areas that would occur under natural conditions. Aside from atmospheric deposition, this TMDL does not attempt to quantify the natural background load as a separate component of the LA for the impaired lakes. Natural background load is likely a small part of the LA for lakes in the Kettle River Watershed. Studies indicate runoff load of nutrients and other pollutants from urban, agricultural and other developed or disturbed lands is generally at least an order of magnitude greater than runoff loads from natural landscapes (Barr Engineering 2004). Any estimate of natural background as a separate component of the LA would be of limited value, very difficult to produce, and would have a large potential for error without expensive, special studies such as paleolimnological analysis of sediment cores.

4.2.4 Margin of Safety

An explicit MOS was used for each of the impaired lake TMDLs. Ten percent of the load was set aside in the TMDL for each impaired lake to account for uncertainty in the phosphorus source assessment and the lake response models. The Kettle and Upper St. Croix River HSPF model was calibrated and validated using 15 years (1995 through 2009) of flow data from one USGS gaging station (USGS 5336700, aka., Kettle River near Sandstone). Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. See Appendix E of this TMDL for the HSPF model calibration and validation results.

4.2.5 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 is the greatest. Although the critical period is 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.

4.2.6 Phosphorus Reduction Methodology

This section provides an explanation of the steps used in the lake response models to calculate lake nutrient reductions to meet the TMDLs. The following items were taken into account: atmospheric deposition, upstream lakes, SSTS, watershed conditions, and internal load. A uniform methodology was established to assign load reductions to the various sources to meet TMDL goals. The individual LAs are provided as guidance for implementation; the individual loading goals for nonpermitted sources might change through adaptive implementation. The steps for nutrient reductions are discussed below:

- No reductions to atmospheric load were assigned since these loads were generally a small portion of the total load to the lake and the sources are extremely difficult to define and control.
- ITPHS SSTS and FTPGW SSTS are not allowed under Minnesota Rule and were not given a WLA. See Section 3.6 for more discussion on the methods used to estimate SSTS contributions and Reasonable Assurance SSTS Section 6.1.5.
- All upstream impaired lakes are expected 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.

- Watershed loading will be incrementally reduced until watershed TP concentrations meet river/stream eutrophication standards. If after this the modeled lake TP is still not meeting water quality standards, the remaining phosphorus reduction will be taken from internal loading.
- For many of the lakes in the Kettle River and Upper St. Croix River watersheds, initial model results indicate that internal load is a significant source of phosphorus and that in-lake efforts may be needed to achieve water quality standards. The general approach to internal load reduction is based on review of the potential internal loading sources (see discussion in Sections 3.6 and 8.3.5), the monitored/modeled sediment release rates and lake morphometry. This is accomplished by comparing the existing monitored/modeled release rates to literature values of non-impaired lakes (~1 milligram per square meter per day [mg/m2-day]) (Nurnberg 1997; Wenck 2011). If the estimated release rate is high, then the rate is reduced systematically until either a minimum of 1 mg/m2-day is reached or the modeled lake TP meets water quality standards.

4.2.7 Phosphorus 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 (Total load in tables), the TMDL allocations (Wasteload and Load in tables), and required reductions for each lake. In these tables the total load reduction is the sum of the required WLA reductions plus the required LA reductions; this is not the same as the net difference between the existing and allowable total loads, however, because the WLA and LA reductions must accommodate the MOS.

The following rounding conventions were used in the TMDL tables:

- Values ≥1.0 reported in pounds per year (lbs/yr) have been rounded to the nearest lb.
- Values <1.0 reported in lbs/yr have been rounded to one significant digit so that the value is greater than zero and a number is displayed in the table.
- Values ≥0.1 reported in pounds per day (lbs/day) have been rounded to the nearest tenth of a lb.
- Values <0.1 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.

Tables 27 through 38 present the allocations for the impaired lakes in the Kettle River and Upper St. Croix River watersheds.

Table 27. Big Pine Lake (58-0138-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.8**	**0.002**	**0.8**	**0.002**	**0**	**0%**
	Construction/Industrial SW	0.8	0.002	0.8	0.002	0	0%
Load	**Total LA**	**3,119**	**8.5**	**2,407**	**6.7**	**712**	**23%**
	Atmosphere	103	0.3	103	0.3	0	0%
	Drainage Area	653	1.8	512	1.4	141	22%
	Upstream Lakes (Pine)	1,584	4.3	1,239	3.4	345	22%
	Septic Systems	193	0.5	94	0.3	99	51%
	Internal Load	586	1.6	459	1.3	127	22%
MOS				**268**	**0.7**		
Total load		**3,120**	**8.5**	**2,676**	**7.4**	**712****	**21%**

* Model calibration year(s): 2008, 2009, 2014, 2015, 2016, 2017

** Net reduction from current load to TMDL is 370 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 444 + 268 = 712 lbs/yr.

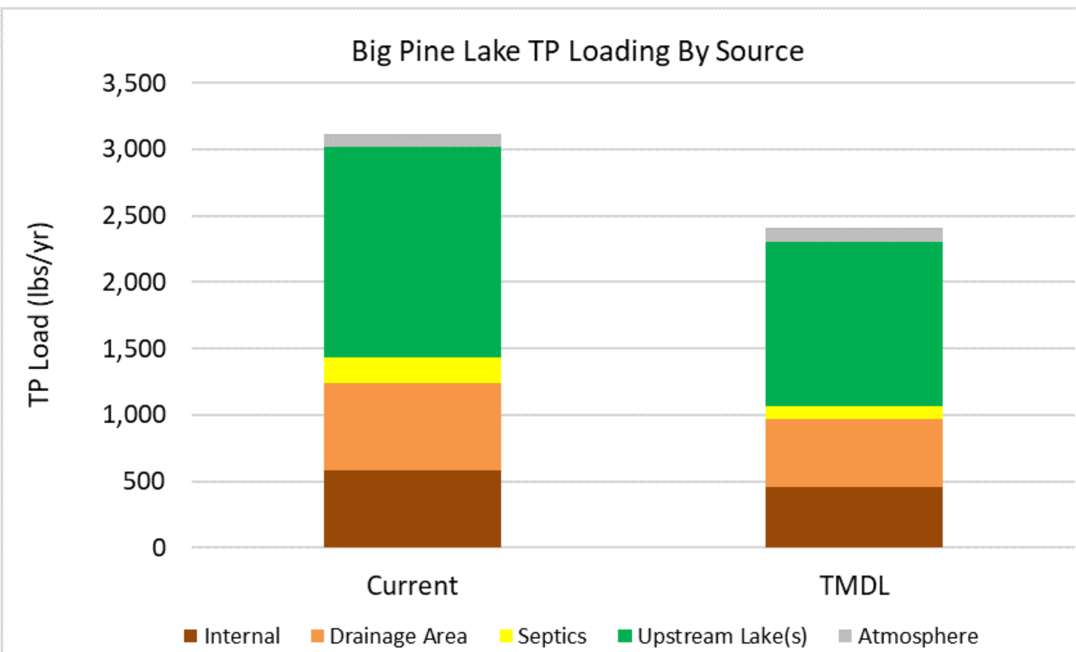


Figure 16. Big Pine Lake phosphorus source reductions to meet TMDL.

Table 28. Elbow Lake (58-0126-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.5**	**0.001**	**0.5**	**0.001**	**0**	**0%**
	Construction/Industrial SW	0.5	0.001	0.5	0.001	0	0%
Load	**Total LA**	**444**	**1.2**	**272**	**0.8**	**172**	**42%**
	Atmosphere	27	0.1	27	0.1	0	0%
	Drainage Area	367	1.0	203	0.6	164	45%
	Septic Systems	36	0.1	28	0.1	8	22%
	Internal Load	14	0.04	14	0.04	0	0%
	MOS			**30**	**0.1**		
	Total load	**445**	**1.2**	**303**	**0.9**	**172****	**39%**

* Model calibration year(s): 2011, 2012
** Net reduction from current load to TMDL is 142 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 142 + 30 = 172 lbs/yr.

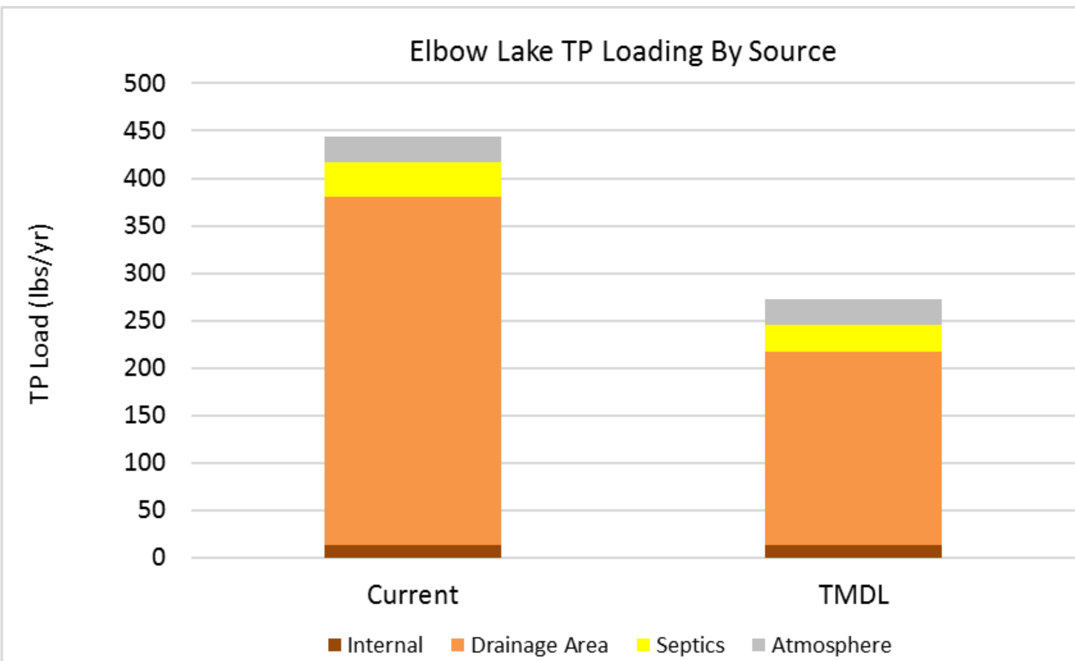


Figure 17. Elbow Lake phosphorus source reductions to meet TMDL.

Table 29. Eleven Lake (33-0001-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.3**	**0.0009**	**0.3**	**0.0009**	**0**	**0%**
	Construction/Industrial SW	0.3	0.0009	0.3	0.0009	0	0%
Load	**Total LA**	**444**	**1.2**	**279**	**0.7**	**165**	**37%**
	Atmosphere	78	0.2	78	0.2	0	0%
	Drainage Area	273	0.8	125	0.3	148	54%
	Septic Systems	49	0.1	32	0.1	17	35%
	Internal Load	44	0.1	44	0.1	0	0%
MOS				**31**	**0.1**		
Total load		**444**	**1.2**	**310**	**0.8**	**165****	**37%**

* Model calibration year(s): 2008, 2010, 2015, 2016
** Net reduction from current load to TMDL is 134 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 134 + 31 = 165 lbs/yr.

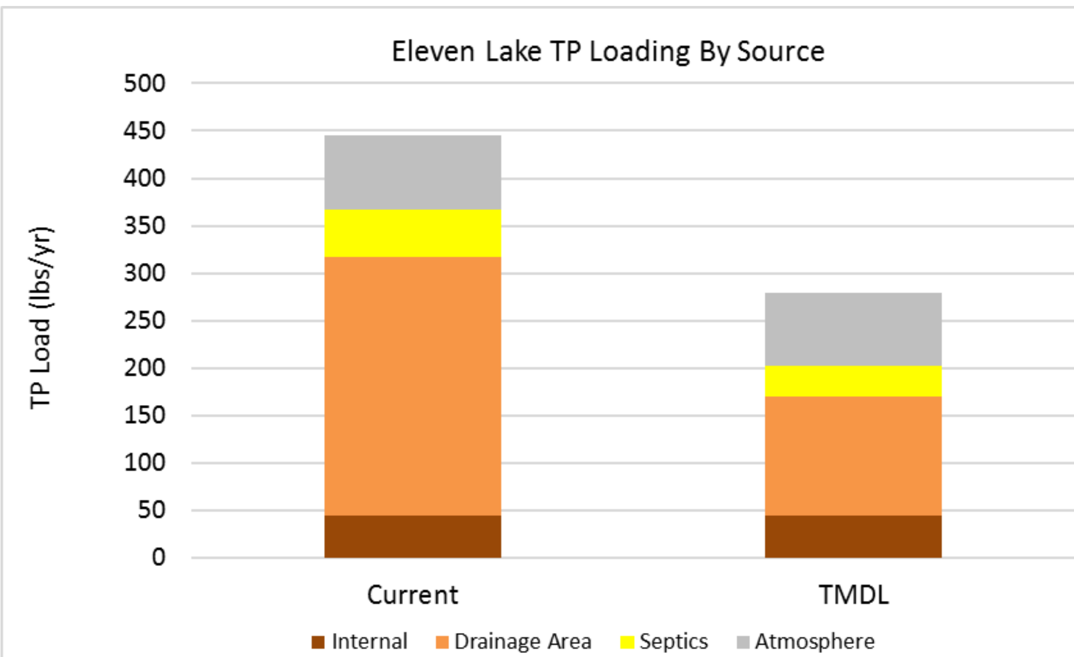


Figure 18. Eleven Lake phosphorus source reduction to meet TMDL.

Table 30. Fox Lake (58-0102-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**1**	**0.003**	**1**	**0.003**	**0**	**0%**
	Construction/Industrial SW	1	0.003	1	0.003	0	0%
Load	**Total LA**	**1,370**	**3.8**	**636**	**1.8**	**734**	**54%**
	Atmosphere	59	0.2	59	0.2	0	0%
	Drainage Area	801	2.2	547	1.5	254	32%
	Septic Systems	20	0.1	14	0.04	6	28%
	Internal Load	490	1.3	16	0.04	474	97%
MOS				**71**	**0.2**		
Total load		**1,371**	**3.8**	**708**	**2.0**	**734****	**54%**

* Model calibration year(s): 2016, 2017
** Net reduction from current load to TMDL is 663 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 661 +71 = 734 lbs/yr.

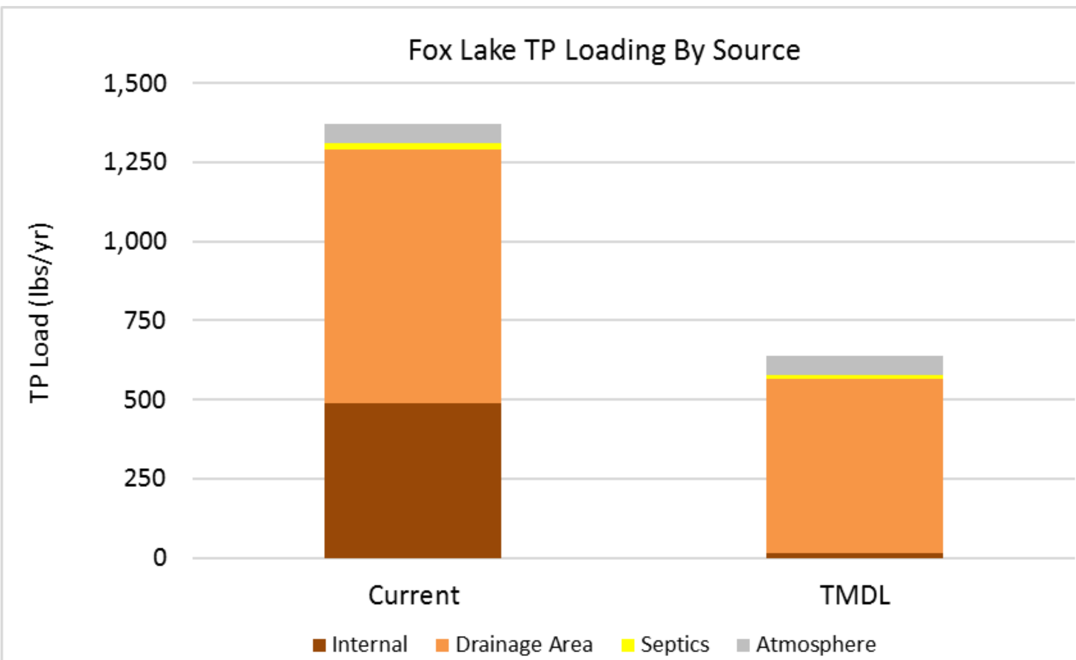


Figure 19. Fox Lake phosphorus source reductions to meet TMDL.

Table 31. Grace Lake (58-0029-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.2**	**0.0004**	**0.2**	**0.0004**	**0**	**0%**
	Construction/Industrial SW	0.2	0.0004	0.2	0.0004	0	0%
Load	**Total LA**	**732**	**2.0**	**242**	**0.6**	**490**	**67%**
	Atmosphere	21	0.06	21	0.06	0	0%
	Drainage Area	245	0.7	191	0.5	54	22%
	Septic Systems	17	0.05	12	0.03	5	29%
	Internal Load	449	1.2	18	0.05	431	96%
MOS				**27**	**0.1**		
Total Load		**732**	**2.0**	**269**	**0.7**	**490****	**66%**

* Model calibration year(s): 2016, 2017

** Net reduction from current load to TMDL is 463 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 463 + 27 = 490 lbs/yr.

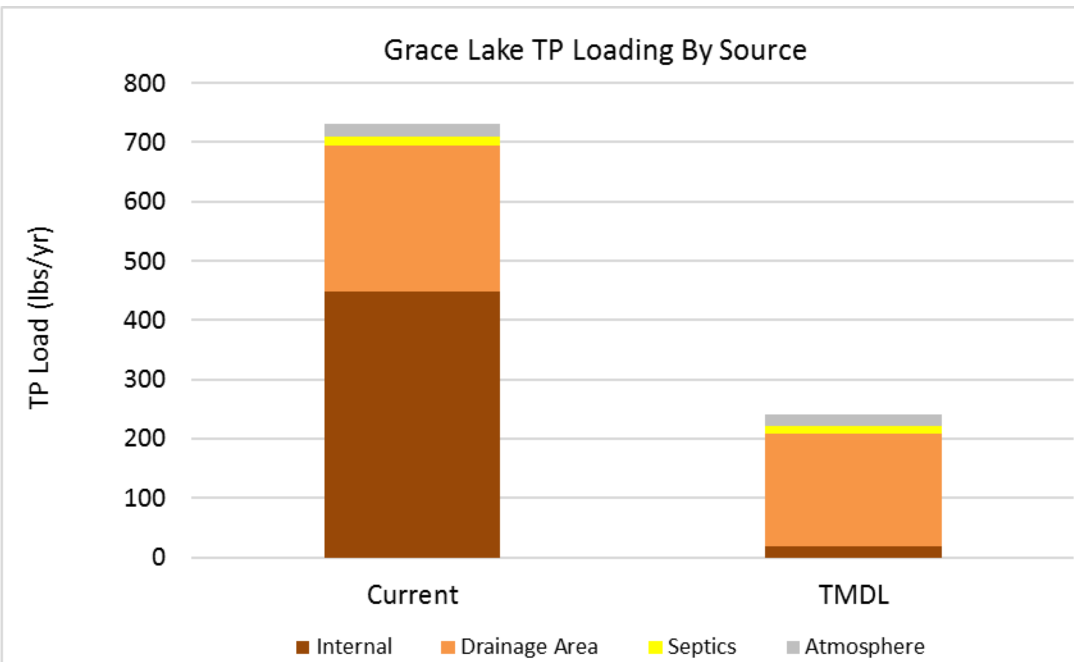


Figure 20. Grace Lake phosphorus source reductions to meet TMDL.

Table 32. Grindstone Lake (58-0123-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**2**	**0.006**	**2**	**0.006**	**0**	**0%**
	Construction/Industrial SW	2	0.006	2	0.006	0	0%
Load	**Total LA**	**2,319**	**6.4**	**1,836**	**5.1**	**483**	**21%**
	Atmosphere	137	0.4	137	0.4	0	0%
	Drainage Area	1,695	4.6	1,315	3.6	380	22%
	Upstream Lakes (Elbow)	250	0.7	184	0.5	66	27%
	Septic Systems	180	0.5	143	0.4	37	20%
	Internal Load	57	0.2	57	0.2	0	0%
MOS				**204**	**0.6**		
Total Load		**2,321**	**6.4**	**2,042**	**5.7**	**483****	**21%**

* Model calibration year(s): 2008, 2016, 2017
** Net reduction from current load to TMDL is 279 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 279 + 204 = 483 lbs/yr.

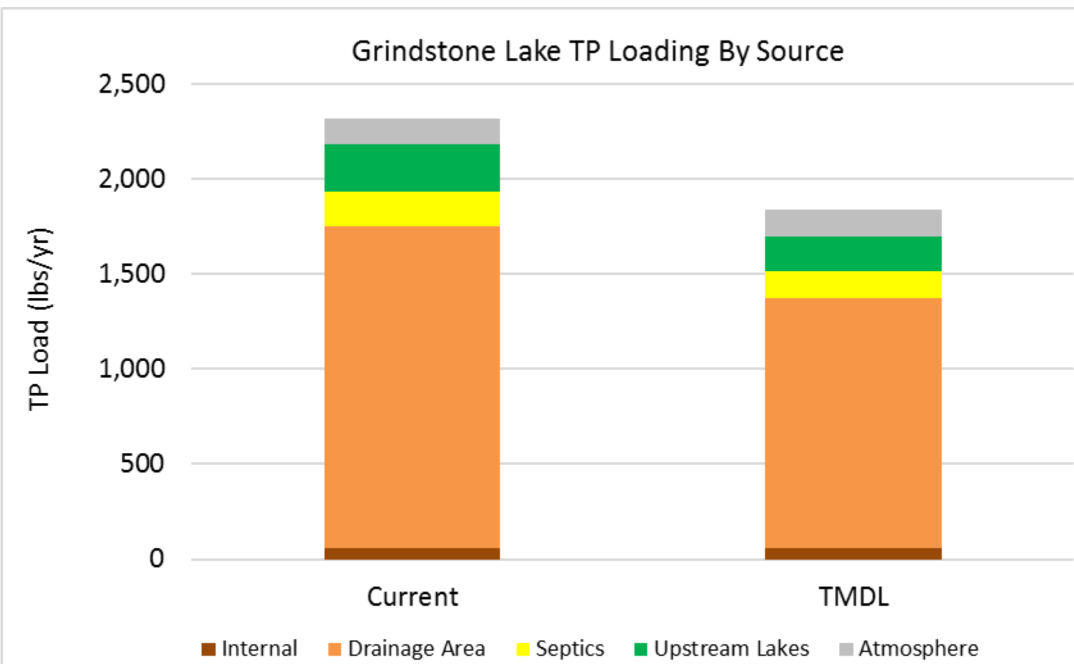


Figure 21. Grindstone Lake phosphorus source reductions to meet TMDL.

Table 33. McCormick Lake (58-0058-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.8**	**0.002**	**0.8**	**0.002**	**0**	**0%**
	Construction/Industrial SW	0.8	0.002	0.8	0.002	0	0%
Load	**Total LA**	**677**	**1.8**	**509**	**1.4**	**168**	**25%**
	Atmosphere	16	0.04	16	0.04	0	0%
	Drainage Area	633	1.7	471	1.3	162	26%
	Septic Systems	18	0.05	12	0.03	6	29%
	Internal Load	10	0.03	10	0.03	0	0%
MOS				**57**	**0.2**		
Total load		**678**	**1.8**	**567**	**1.6**	**168****	**25%**

* Model calibration year(s): 2016, 2017

** Net reduction from current load to TMDL is 111 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 111 + 57 = 168 lbs/yr.

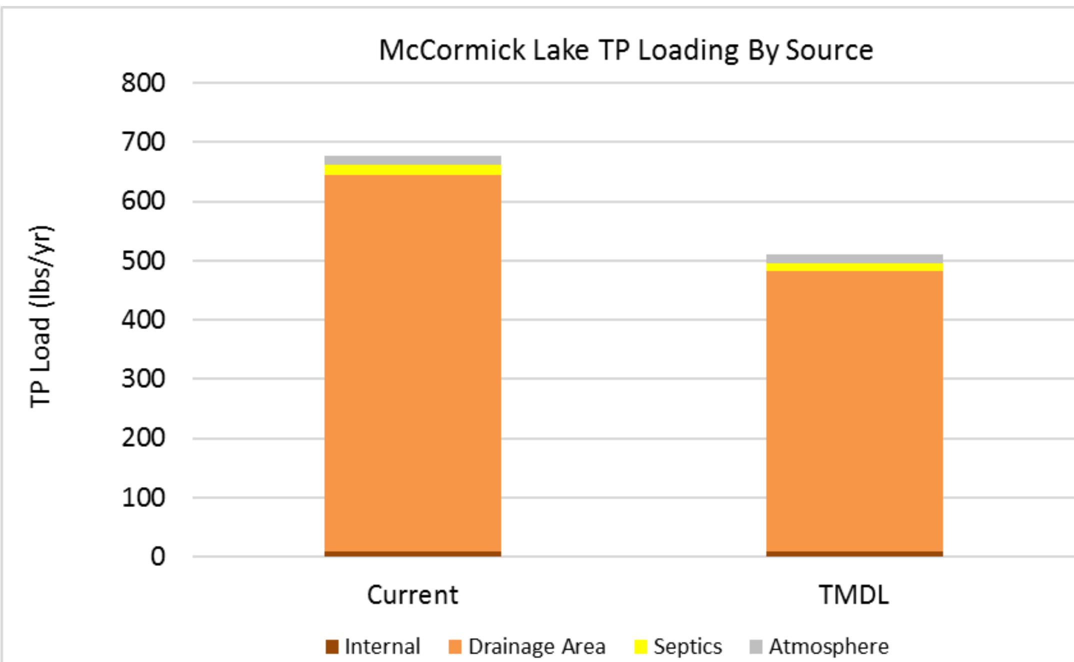


Figure 22. McCormick Lake phosphorus source reductions to meet TMDL.

Table 34. Merwin Lake (09-0058-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.1**	**0.0004**	**0.1**	**0.0004**	**0**	**0%**
	Construction/Industrial SW	0.1	0.0004	0.1	0.0004	0	0%
Load	**Total LA**	**167**	**0.5**	**108**	**0.3**	**59**	**36%**
	Atmosphere	14	0.04	14	0.04	0	0%
	Drainage Area	110	0.3	70	0.2	40	37%
	Septic Systems	9	0.03	8	0.02	1	16%
	Internal Load	34	0.1	16	0.04	18	52%
MOS				**12**	**0.03**		
Total load		**167**	**0.5**	**120**	**0.3**	**59****	**35%**

* Model calibration year(s): 2016, 2017

** Net reduction from current load to TMDL is 47 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 47 + 12 = 59 lbs/yr.

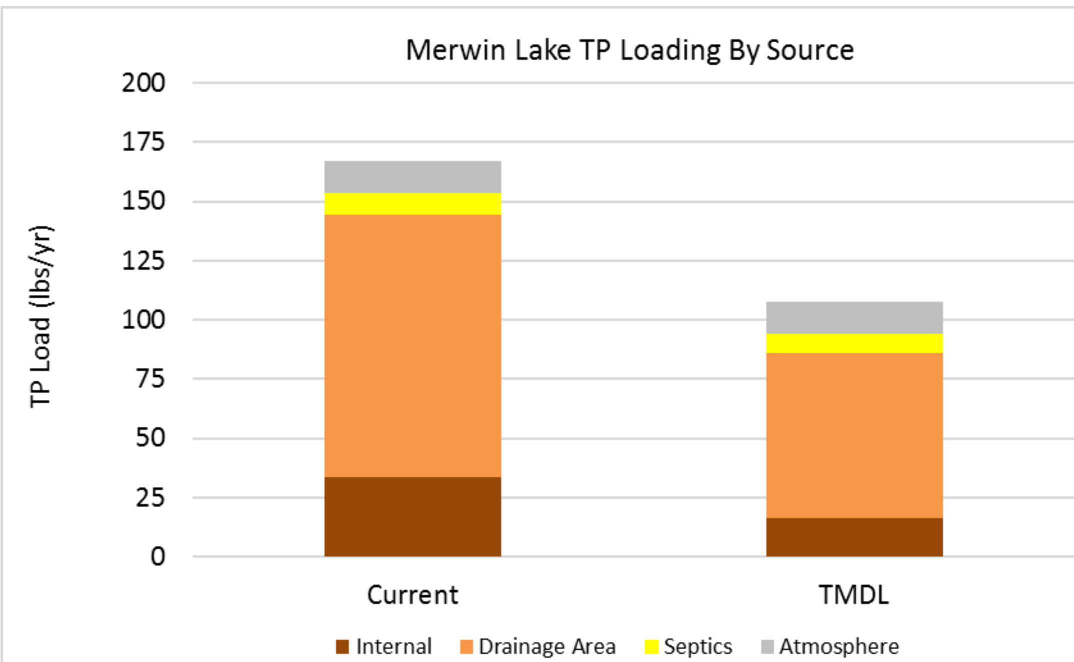


Figure 23. Merwin Lake phosphorus source reductions to meet TMDL.

Table 35. Oak Lake (58-0048-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.6**	**0.002**	**0.6**	**0.002**	**0**	**0%**
	Construction/Industrial SW	0.6	0.002	0.6	0.002	0	0%
Load	**Total LA**	**683**	**1.8**	**547**	**1.5**	**136**	**20%**
	Atmosphere	118	0.3	118	0.3	0	0%
	Drainage Area	444	1.2	316	0.9	128	29%
	Septic Systems	37	0.1	29	0.1	8	21%
	Internal Load	84	0.2	84	0.2	0	0%
MOS				**61**	**0.2**		
Total load		**684**	**1.8**	**609**	**1.7**	**136****	**20%**

* Model calibration year(s): 2011, 2012, 2016
** Net reduction from current load to TMDL is 75 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 75 + 61 = 136 lbs/yr.

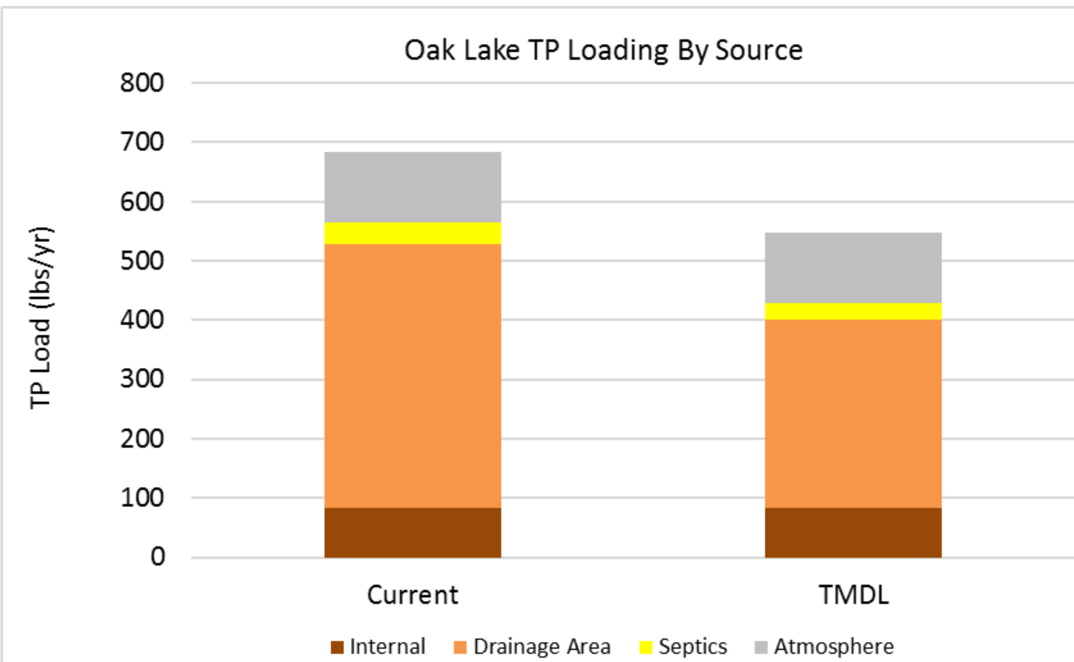


Figure 24. Oak Lake phosphorus source reductions to meet TMDL.

Table 36. Pine Lake (01-0001-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**3**	**0.008**	**3**	**0.008**	**0**	**0%**
	Construction/Industrial SW	3	0.008	3	0.008	0	0%
Load	**Total LA**	**4,812**	**13.2**	**3,046**	**8.3**	**1,766**	**37%**
	Atmosphere	98	0.3	98	0.3	0	0%
	Drainage Area	2,442	6.7	1,917	5.2	525	22%
	Septic Systems	175	0.5	143	0.4	32	18%
	Internal Load	2,097	5.7	888	2.4	1,209	58%
MOS				**339**	**0.9**		
Total load		**4,815**	**13.2**	**3,388**	**9.2**	**1,766****	**37%**

* Model calibration year(s): 2008, 2009, 2014, 2015, 2016, 2017

** Net reduction from current load to TMDL is 1,427 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 1,427 + 339 = 1,766 lbs/yr.

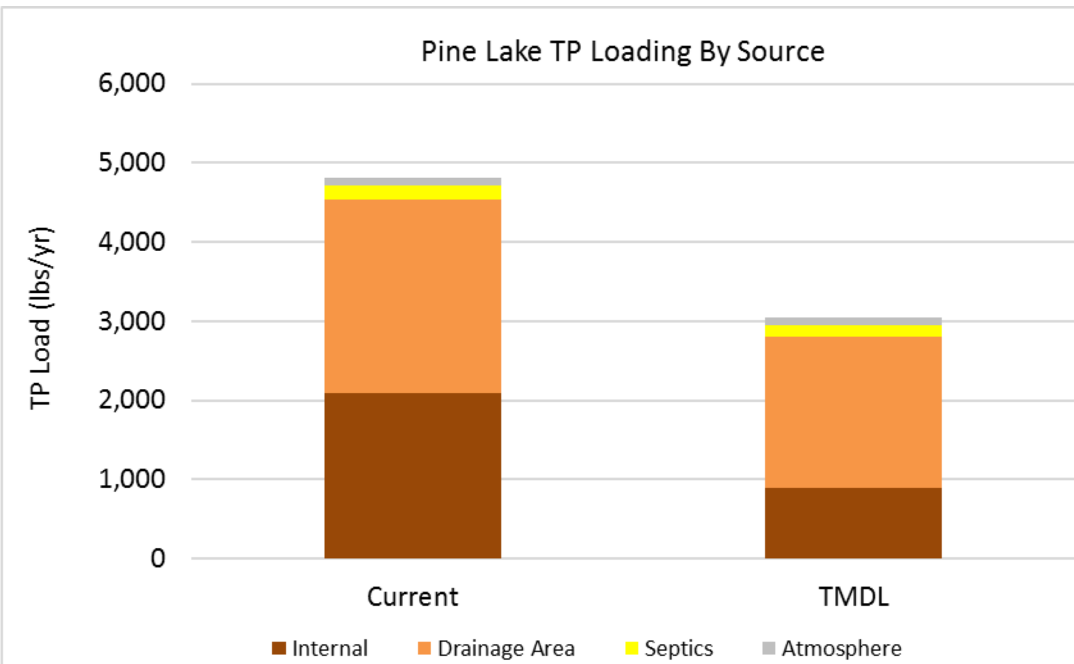


Figure 25. Pine Lake phosphorus source reductions to meet TMDL.

Table 37. Rhine Lake (58-0136-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.5**	**0.001**	**0.5**	**0.001**	**0**	**0%**
	Construction/Industrial SW	0.5	0.001	0.5	0.001	0	0%
Load	**Total LA**	**752**	**2.1**	**294**	**0.8**	**458**	**61%**
	Atmosphere	29	0.1	29	0.1	0	0%
	Drainage Area	385	1.1	220	0.6	165	43%
	Septic Systems	16	0.04	13	0.04	3	20%
	Internal Load	322	0.9	32	0.1	290	90%
MOS				**33**	**0.1**		
Total load		**753**	**2.1**	**328**	**0.9**	**458****	**61%**

* Model calibration year(s): 2011, 2012

** Net reduction from current load to TMDL is 425 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 425 + 33 = 458 lbs/yr.

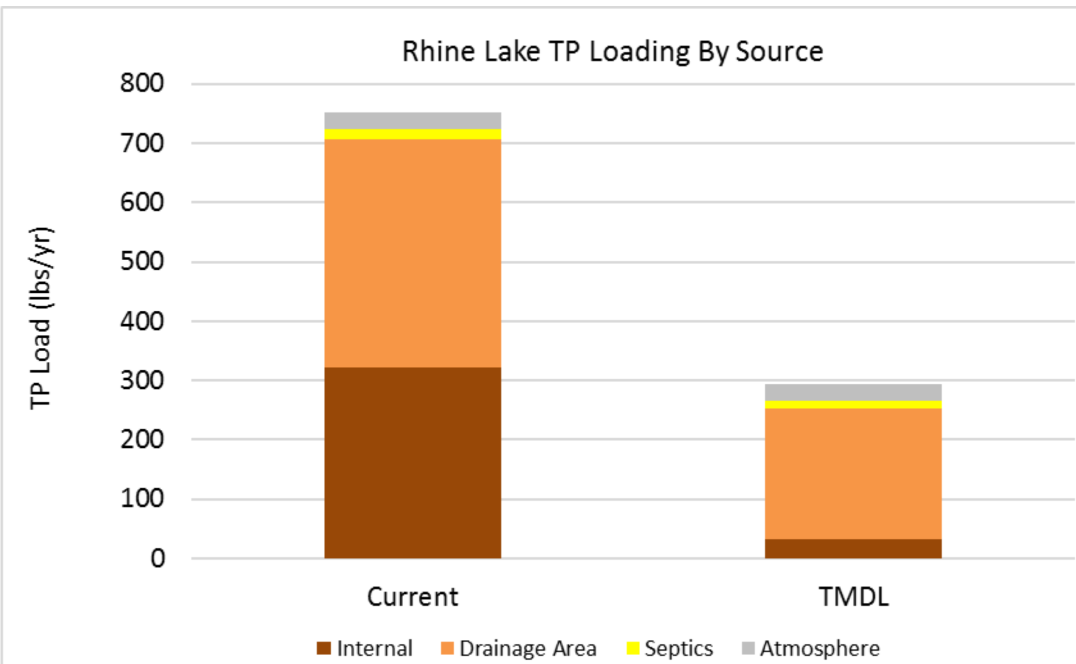


Figure 26. Rhine Lake phosphorus source reductions to meet TMDL.

Table 38. Twentynine (09-0022-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
Wasteload	**Total WLA**	**0.09**	**0.0003**	**0.09**	**0.0003**	**0**	**0%**
	Construction/Industrial SW	0.09	0.0003	0.09	0.0003	0	0%
Load	**Total LA**	**249**	**0.7**	**104**	**0.3**	**145**	**58%**
	Atmosphere	13	0.04	13	0.04	0	0%
	Drainage Area	74	0.2	70	0.2	4	5%
	Septic Systems	5	0.01	4	0.01	1	20%
	Internal Load	157	0.4	17	0.05	140	89%
MOS				**12**	**0.03**		
Total load		**249**	**0.7**	**116**	**0.3**	**145****	**58%**

* Model calibration year(s): 2016, 2017

** Net reduction from current load to TMDL is 133 lbs/yr, but the gross load reduction from all sources must also accommodate the MOS and is therefore 132 + 12 = 145 lbs/yr.

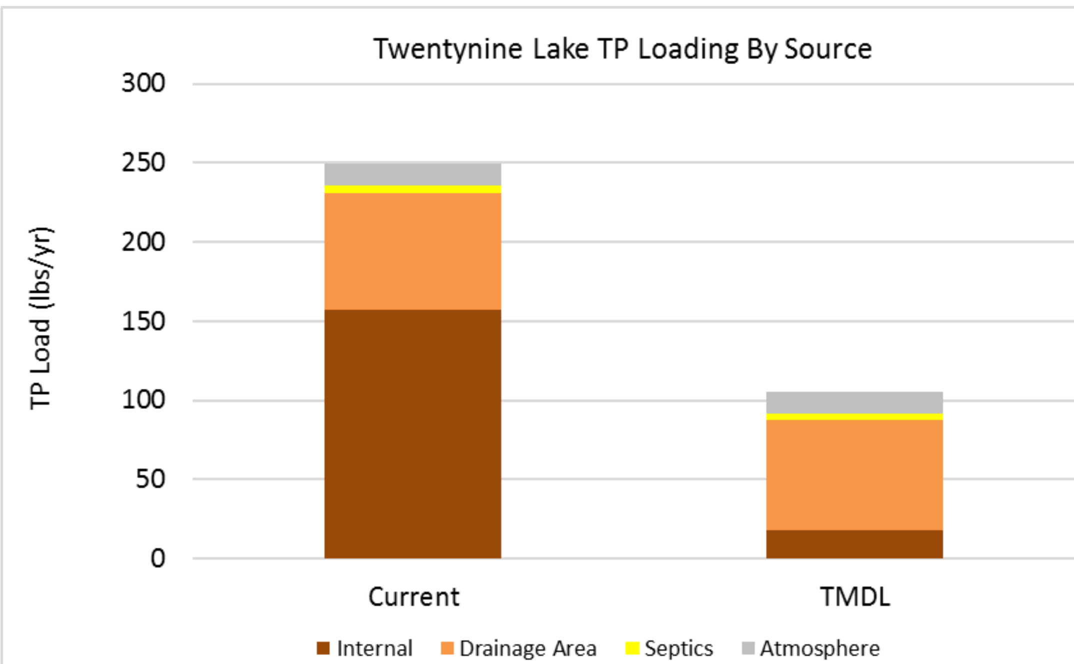


Figure 27. Twentynine Lake phosphorus source reductions to meet TMDL.

5. Future Growth Considerations

According to the Minnesota State Demographic Center (Minnesota Department of Administration 2015) from 2015 to 2035, the populations of Aitkin, Kanabec, and Pine Counties are projected to decrease by 11%, 9%, and 1%, respectively. Carlton County is the only county in the Kettle River and Upper St. Croix River watersheds with a projected population increase (~3%) over the next 20 years. The overall projection for all five counties is negative 3%. The MPCA does not anticipate significant population growth within these watersheds.

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. One or more nonregulated MS4s become regulated. If this has not been accounted for in the WLA, then a transfer must occur from the LA.
2. Expansion of a U.S. Census Bureau Urban Area encompasses new regulated areas for existing permittees. An example is existing state highways that were outside an urban area at the time the TMDL was completed, but are now inside a newly expanded urban area. This will require either a WLA to WLA transfer or a LA to WLA transfer.
3. A new MS4 or other stormwater-related point source is identified and is covered under a NPDES Permit. In this situation, a transfer must occur from the LA.

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

5.2 New or Expanding Wastewater (*E. coli* TMDLs only)

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

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

6. Reasonable Assurance

A TMDL needs to provide reasonable assurance that water quality targets will be achieved through the specified combination of point and nonpoint source reductions reflected in the LAs and WLAs. According to EPA guidance (EPA 2002), "When a TMDL is developed for waters impaired by both point and nonpoint sources, and the WLA is based on an assumption that nonpoint-source load reductions will occur... the TMDL should provide reasonable assurances that nonpoint-source control measures will achieve expected load reductions in order for the TMDL to be approvable. This information is necessary for the EPA to determine that the TMDL, including the LA and WLAs, has been established at a level necessary to achieve water quality standards". Considerable reductions in nonpoint sources are required for the TMDLs presented in this report. To address these, the MPCA will:

- Evaluate existing programmatic, funding, and technical capacity to implement basin and watershed strategies.
- Identify gaps in current programs, funding, and local capacity to achieve the needed controls.
- Build program capacity for short-term and long-term goals. Demonstrate increased implementation and/or pollutant reductions.
- Commit to track/monitor/assess and report progress at set regular times.

6.1 Regulatory

6.1.1 Construction Stormwater

State implementation of the TMDL will be through action on NPDES Permits for regulated construction stormwater. To meet the WLA for construction stormwater, construction stormwater activities are required to meet the conditions of the Construction General Permit under the NPDES program and properly select, install, and maintain all BMPs required under the permit, including any applicable additional BMPs required the construction general permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the state general permit.

6.1.2 Industrial Stormwater

To meet the WLA for industrial stormwater, industrial stormwater activities are required to meet the conditions of the Industrial Stormwater General Permit or Nonmetallic Mining & Associated Activities general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

6.1.3 Wastewater NPDES and SDS Permits

The MPCA issues permits for WWTPs or industrial facilities that discharge into waters of the state. The permits have site specific limits on bacteria, TSS, chloride and other parameters that are based on water quality standards. Permits regulate discharges with the goals of, 1) protecting public health and aquatic life, and 2) assuring that every facility treats wastewater. In addition, NPDES and SDS Permits set limits and establish controls for land application of waste and byproducts. Permits issued under the NPDES program are required to have effluent limits consistent with the assumptions and requirements of the WLAs in this TMDL. Compliance with the WLAs, as developed and presented in this TMDL, is assumed to ensure meeting the water quality standards for Grindstone River Reach 501, which is the only impairment with a permitted NPDES wastewater discharger. The permitted discharger in this reach, Hinckley WWTP, did not require any changes to their discharge permit limits due to the WLAs calculated in this TMDL report.

6.1.4 SSTS Program

SSTS, commonly known as septic systems, are regulated by Minn. Stat. §§ 115.55 and 115.56. Counties and other local government units (LGUs) that regulate SSTS must meet the requirements for local SSTS programs in Minn. R. ch. 7082. Counties and other LGUs must adopt and implement SSTS ordinances in compliance with Minn. R. chs. 7080 through 7083.

These regulations detail:

- Minimum technical standards for individual and mid-size SSTS;
- A framework for LGU to administer SSTS programs and;
- Statewide licensing and certification of SSTS professionals, SSTS product review and registration, and establishment of the SSTS Advisory Committee.

Counties and other LGUs enforce Minn. R. chs. 7080 through 7083 through their local SSTS ordinance and issue permits for systems designed with flows up to 10,000 gallons per day. There are approximately 200 LGUs with SSTS programs across Minnesota, and depending on the location an LGU may be a county, city, township, or sewer district. LGU SSTS ordinances vary across the state. Some require SSTS compliance inspections prior to property transfer, require permits for SSTS repair and septic tank maintenance, and may have other requirements that are stricter than the state regulations.

Compliance inspections by Counties and other LGUs are required by Minnesota Rule for all new construction and for existing systems if the LGU issues a permit for the addition of a bedroom. In order to increase the number of compliance inspections, the MPCA has developed and administers several grants to LGUs for specific actions outlined in various ordinances. Additional grant dollars are awarded to counties that have additional provisions in their ordinance above the minimum program requirements. The MPCA has worked with counties through the SSTS Implementation and Enforcement Task Force to identify the most beneficial way to use these funds to accelerate SSTS compliance statewide. Current information from the grants to date:

- Compliance inspection for property transfer – $123,000 awarded
- Compliance inspection for any (all) permit-countywide – $27,000 awarded
- Plan to improve compliance, like records catalog or inventory (past, ongoing or future) – $32,500 awarded
- Plan to address unsewered areas – $12,500 awarded

The MPCA staff keep a statewide database of known ITPHS systems that include “straight pipe systems”. These straight pipe systems are reported to the counties or the MPCA by the public. Upon confirmation of a straight pipe system, the county sends out a notification of non-compliance, which starts a 10-month deadline to fix the system and bring it into compliance. There were seven straight pipe systems in this region that were fixed under Minn. Stat. § 115.55, subd. 1, from 2006 to 2017. Six systems were fixed in Carlton County and one was fixed in Pine County. No systems were found in Aitkin and Kanabec counties.

Since 2013, the MPCA wastewater program has been providing grant funds to counties to fix noncompliant SSTS for low-income individuals. From 2013 through 2019, a combined total of $526,358 has been awarded to Aitkin, Carlton, Kanabec, and Pine counties. Since these funds are awarded on a county-wide basis, they are not specific to any given watershed. From 2008 to 2016, an average of 210 systems have been repaired or replaced annually in the counties of the Kettle River and Upper St. Croix River watersheds (Figure 28).

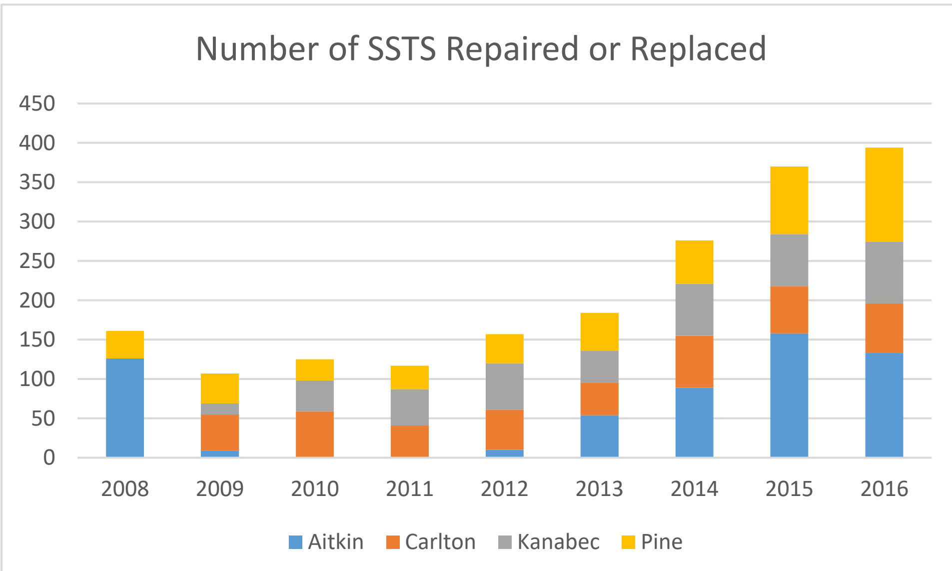


Figure 28. Number of SSTS repaired or replaced annually, 2008-2016, at the county level (not specific to the Kettle River and Upper St. Croix River watersheds)

6.1.5 Feedlot Program

All feedlots in Minnesota are regulated by Minn. R. ch. 7020. The MPCA has regulatory authority of feedlots but counties may choose to participate in a delegation of the feedlot regulatory authority to the local unit of government. Delegated counties are then able to enforce Minn. R. ch. 7020 (along with any other local rules and regulations) within their respective counties for facilities that are under the CAFO threshold. All four of the counties in the Kettle River and Upper St. Croix River watersheds are nondelegated counties, and therefore the MPCA will continue to implement the feedlot program and work with producers on manure management plans.

The MPCA regulates the collection, transportation, storage, processing, and disposal of animal manure and other livestock operation waste. The MPCA feedlot program implements rules governing these activities and provides assistance to counties and the livestock industry. The feedlot rules apply to most aspects of livestock waste management including the location, design, construction, operation and management of feedlots and manure handling facilities.

There are two primary concerns about feedlots in protecting water:

- Ensuring that manure on a feedlot or manure storage area does not run into water.

- Ensuring that manure is applied to cropland at a rate, time and method that prevents bacteria and other possible contaminants from entering streams, lakes and ground water.

Since 2012, there have been four facility inspections in the Kettle River and Upper St. Croix River Watersheds. Both of the CAFO facilities located in the watersheds have been inspected.

6.1.6 Buffers and Shoreland

The Buffer Law signed by Governor Dayton in June 2015 was amended on April 25, 2016, and further amended by legislation signed by Governor Dayton on May 30, 2017. The Buffer Law requires the following:

- For all public waters, the more restrictive of:
  - a 50-foot average width, 30-foot minimum width, continuous buffer of perennially rooted vegetation, or
  - the state shoreland standards and criteria.
- For public drainage systems established under Minn. Stat. ch. 103E, a 16.5-foot minimum width continuous buffer.

Alternative practices are allowed in place of a perennial buffer in some cases. The amendments enacted in 2017 clarify the application of the buffer requirement to public waters, provide:

- additional statutory authority for alternative practices,
- address concerns over the potential spread of invasive species through buffer establishment,
- establish a riparian protection aid program to fund local government buffer law enforcement and implementation, and
- allowed landowners to be granted a compliance waiver until July 1, 2018, when they filed a compliance plan with the SWCD.

The Board of Water and Soil Resources (BWSR) provides oversight of the buffer program, which is primarily administered at the local level; compliance with the Buffer Law in the state is displayed at the Buffer Program Update webpage. As of January 2020, reported rates of compliance for all four counties in the Kettle River and Upper St. Croix River Watersheds are between 95% and 100% (BWSR website). Most of the private lands in the Kettle River and Upper St. Croix River Watersheds contain well vegetated buffers along ditches, lakes and streams.

Buffers are critical to protecting and restoring water quality and healthy aquatic life, natural stream functions and aquatic habitat due to their immediate proximity to the water.

Other nonpoint source statutes/rules include:

- Protecting highly erodible land within the 300-foot shoreland district (Minn. Stat. § 103F.201).
- Excessive soil loss statute (Minn. Stat. § 103F.415)
- Nuisance nonpoint source pollution (Minn. R. 7050.0210, subp. 2)

6.1.7 National and State Wild and Scenic River and Outstanding Resource Value Water Status

Worried that continued development and other urban stressors would put the natural resources of the St. Croix River watershed at risk, concerned citizens and legislators during the 1960s pushed for the St. Croix to be included in the original National Wild and Scenic Rivers Act. The St. Croix National Scenic Riverway, which includes the Namekagon River in Wisconsin and the upper portion of the St. Croix, was established as part of that original Act in 1968. The Lower St. Croix National Scenic Riverway was added in 1972 (MPCA and WIDNR 2012).

The National Wild and Scenic Rivers Act defines Scenic Rivers as "those rivers or sections of rivers that are free of impoundments, with shorelines or watersheds still largely primitive and shorelines largely undeveloped, but accessible in places by roads" (Interagency Wild and Scenic Rivers Coordinating Council 2020).

At the state level, the Minnesota State Wild and Scenic Rivers Program was established in 1973 to "protect rivers which have outstanding natural, scenic, geographic, historic, cultural, and recreational values" (DNR 2020a). The state program defines Wild Rivers as those that exist in a free-flowing state with excellent water quality and with adjacent lands that are essentially primitive. Wild Rivers should not be paralleled by conspicuous and well-traveled roads or railroads. Scenic Rivers are those rivers that exist in a free-flowing state and with adjacent lands that are largely undeveloped (i.e., adjacent lands still present an overall natural character, but in places may have been developed for agricultural, residential, or other land uses (DNR 2020b).

In 1975, the Kettle River was designated as both a Scenic (from the Carlton-Pine County line downstream to the [former] Kettle River dam site at Sandstone) and a Wild (from the [former] dam site downstream to its confluence with the Saint Croix River) River. These designations ensure preservation and restoration of continuous natural vegetation within the river's riparian corridor and the preservation of floodplains, which is critical to protecting and preserving wildlife, water quality, flood abatement and the scenic nature of the river.

In addition, both Minnesota and Wisconsin have created further protective designations in the St. Croix River Basin. Minnesota has designated the entire St. Croix and Kettle River tributary as Outstanding Resource Value Waters (ORVW). Wisconsin has designated portions of the St. Croix as an Exceptional Resource Water and the remainder as an Outstanding Resource Water.

Under Minnesota Law, ORVW designation means that no new or expanded discharge of any sewage, industrial waste, or other waste is allowed unless there is no prudent, feasible alternative to the discharge. If allowed, the discharge is restricted to the extent necessary, to preserve the existing high quality, or to preserve the wilderness, scientific, recreational, or other special characteristics that make the water an ORVW (MPCA and WIDNR 2012).

6.2 Nonregulatory

6.2.1 Pollutant Load Reduction

Reliable means of reducing nonpoint source pollutant loads are fully addressed in the WRAPS report (MPCA 2020c), a document that is written to be a companion to this TMDL. In order for the impaired waters to meet water quality standards, all of the pollutant reductions in the Kettle River and Upper St. Croix River watersheds will need to come from nonpoint sources. Agricultural drainage and surface runoff are major contributors of nutrients, bacteria, sediment, and increased flows throughout the watershed. As described in the WRAPS report, the BMPs identified for restoration have all been demonstrated to be effective in reducing transport of pollutants to surface water. The combinations of BMPs discussed throughout the WRAPS process were derived from Minnesota's Nutrient Reduction Strategy (NRS) (MPCA 2014a) and related tools. As such, they were vetted by a statewide engagement process prior to being applied in the Kettle River and Upper St. Croix River watersheds.

Selection of sites for BMPs will be led by LGUs, county SWCDs, watershed management organizations, and county planning and zoning, with support from state and federal agencies. These BMPs are supported by programs administered by the SWCDs and the Natural Resource Conservation Service (NRCS). Local resource managers are well-trained in promoting, placing, and installing these BMPs. Some counties within the basin have shown significant levels of adoption of these practices. State and local agencies will need to work with landowners to identify priority areas for BMPs and practices that will help reduce nutrient runoff, as well as streambank and overland erosion. Agencies, organizations, LGUs, and citizens alike need to recognize that resigning waters to an impaired condition is not acceptable. Throughout the course of the WRAPS and TMDL meetings, local stakeholders endorsed the BMPs selected in the WRAPS report. These BMPs reduce pollutant loads from runoff (i.e. phosphorus, sediment and pathogens) and loads delivered through drainage tiles or groundwater flow (e.g. nitrates).

To help achieve nonpoint source reductions, a large emphasis has been placed on public participation, where the citizens and communities that hold the power to improve water quality conditions are involved in discussions and decision-making. The watershed's citizens and communities will need to voluntarily adopt the practices at the necessary scale and rates to achieve the 10-year targets presented in Tables 17-28 of the WRAPS report. These tables also present the allocations of the pollutant/stressor goals and targets to the primary sources and the estimated years to meet the goal developed by the WRAPS local workgroup (LWG). The strategies identified and relative adoption rates developed by the WRAPS LWG were used to calculate the adoption rates needed to meet the pollutant/stressor 10-year targets. In addition to public participation, several government programs are in place to support a political and social infrastructure that aims to increase the adoption of strategies that will improve watershed conditions and reduce loading from nonpoint sources.

Agricultural Water Quality Certification Program

The Minnesota Agricultural Water Quality Certification Program (MAWQCP) is a voluntary opportunity for farmers and agricultural landowners to take the lead in implementing conservation practices that protect waters. Those who implement and maintain approved farm management practices are certified, and in turn obtain regulatory certainty for a period of 10 years.

Through this program, certified producers receive:

Regulatory certainty: Certified producers are deemed to be in compliance with any new water quality rules or laws during the period of certification

Recognition: Certified producers may use their status to promote their business as protective of water quality

Priority for assistance: Producers seeking certification can obtain specially designated technical and financial assistance to implement practices that promote water quality.

Through this program, the public receives assurance that certified producers are using conservation practices to protect Minnesota's lakes, rivers, and streams. As of September 2020 there were 497 acres in Kettle River Watershed and 398 acres in the Upper St. Croix River Watershed enrolled in MAWQCP. Since the start of the program in 2014, the Ag Water Quality Certification Program has statewide:

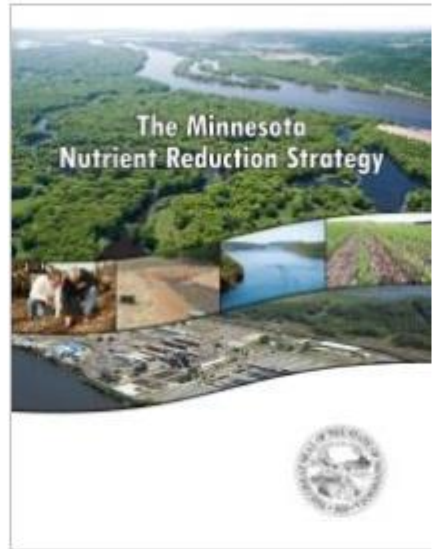
- Enrolled 699,579 acres;
- Included 955 producers;
- Added 1,969 new conservation practices;
- Kept over 66 million lbs of sediment out of Minnesota rivers;
- Saved 163 million lbs of soil and 47,101 lbs of phosphorus on farms; and
- Reduced nitrogen losses by up to 49%.

Minnesota Nutrient Reduction Strategy

The Minnesota NRS (MPCA 2014a) guides activities that support nitrogen and phosphorus reductions in Minnesota waterbodies and those downstream of the state (e.g., Lake Winnipeg, Lake Superior, and the Gulf of Mexico). The NRS was developed by an interagency coordination team with help from public input. Fundamental elements of the NRS include:

- Defining progress with clear goals
- Building on current strategies and success
- Prioritizing problems and solutions
- Supporting local planning and implementation
- Improving tracking and accountability

Included within the strategy discussion are alternatives and tools for consideration by drainage authorities, information on available tools and approaches for identifying areas of phosphorus and nitrogen loading and tracking efforts within a watershed, and additional research priorities. The NRS is focused on incremental progress and provides meaningful and achievable nutrient load reduction milestones that allow for better understanding of incremental and adaptive progress toward final goals. It has set a reduction of 45% for both phosphorus and nitrogen in the Mississippi River, downstream of the Upper St. Croix River and Kettle River watersheds.



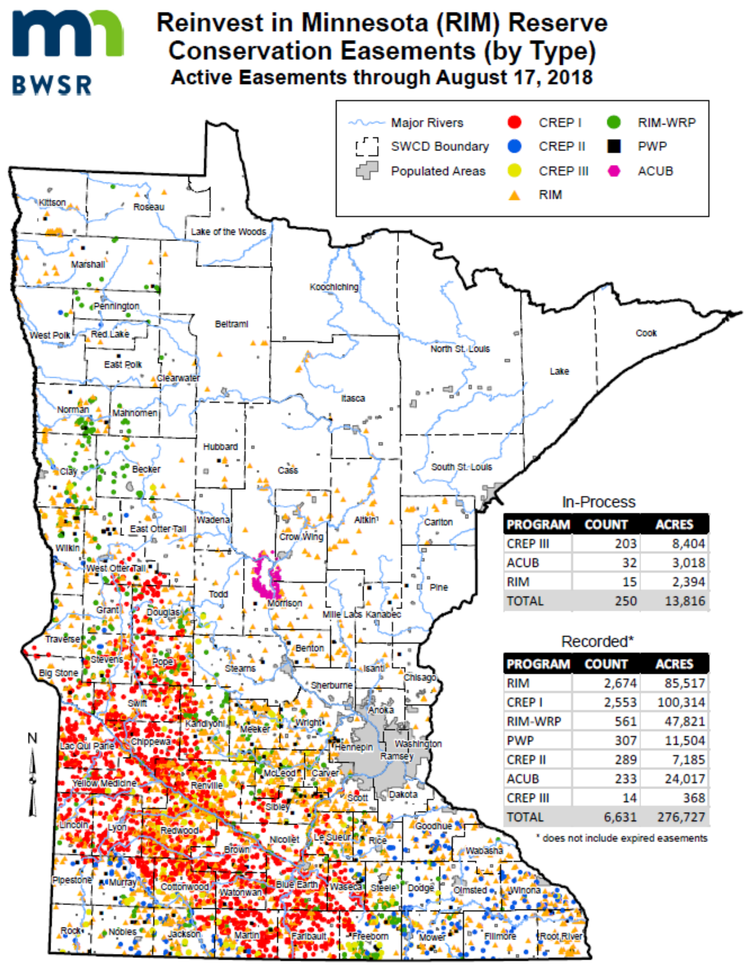
Successful implementation of the NRS will require broad support, coordination, and collaboration among agencies, academia, local government, and private industry. The MPCA is implementing a framework to integrate its water quality management programs on a major watershed scale, a process that includes:

- Intensive watershed monitoring
- Assessment of watershed health
- Development of WRAPS reports and local water plans
- Management of NPDES and other regulatory and assistance programs

This framework will result in nutrient reduction for the basin as a whole and the major watersheds within the basin.

Conservation Easements

Conservation easements are a critical component of the state's efforts to improve water quality by reducing soil erosion, phosphorus and nitrogen loading, and improving wildlife habitat and flood attenuation on private lands. Easements protect the state's water and soil resources by permanently restoring wetlands, adjacent native grassland wildlife habitat complexes and permanent riparian buffers. In cooperation with county SWCDs and the USDA NRCS, BWSR's programs compensate landowners for granting conservation easements and establishing native vegetation habitat on economically marginal, flood-prone, environmentally sensitive or highly erodible lands. These easements vary in length of time from 10 years to permanent/perpetual easements. Types of conservation easements in Minnesota include: Conservation Reserve Program (CRP); Conservation Reserve Enhancement Program (CREP); Reinvest in Minnesota (RIM); and the Wetland Reserve Program (WRP) or Permanent Wetland Preserve (PWP). As of August 2020, in Aitkin, Carlton, Kanabec, and Pine counties there was 313 acres of short-term conservation easements such as CRP and 3,449 acres of long term or permanent easements (RIM, WRP).



In-Process

PROGRAM	COUNT	ACRES
CREP III	203	8,404
ACUB	32	3,018
RIM	15	2,394
TOTAL	250	13,816

Recorded*

PROGRAM	COUNT	ACRES
RIM	2,674	85,517
CREP I	2,553	100,314
RIM-WRP	561	47,821
PWP	307	11,504
CREP II	289	7,185
ACUB	233	24,017
CREP III	14	368
TOTAL	6,631	276,727

* does not include expired easements

Figure 29. Conservation easements in Minnesota.

6.2.2 Prioritization

The WRAPS report details a number of tools that provide means for identifying priority pollutant sources and implementation work in the watershed. Further, LGUs in the Kettle River and Upper St. Croix River watersheds often employ their own local analysis for determining priorities for work.

6.2.3 Funding

On November 4, 2008, Minnesota voters approved the Clean Water, Land and Legacy Amendment to the constitution to:

- Protect drinking water sources;
- Protect, enhance, and restore wetlands, prairies, forests, and fish, game, and wildlife habitat;

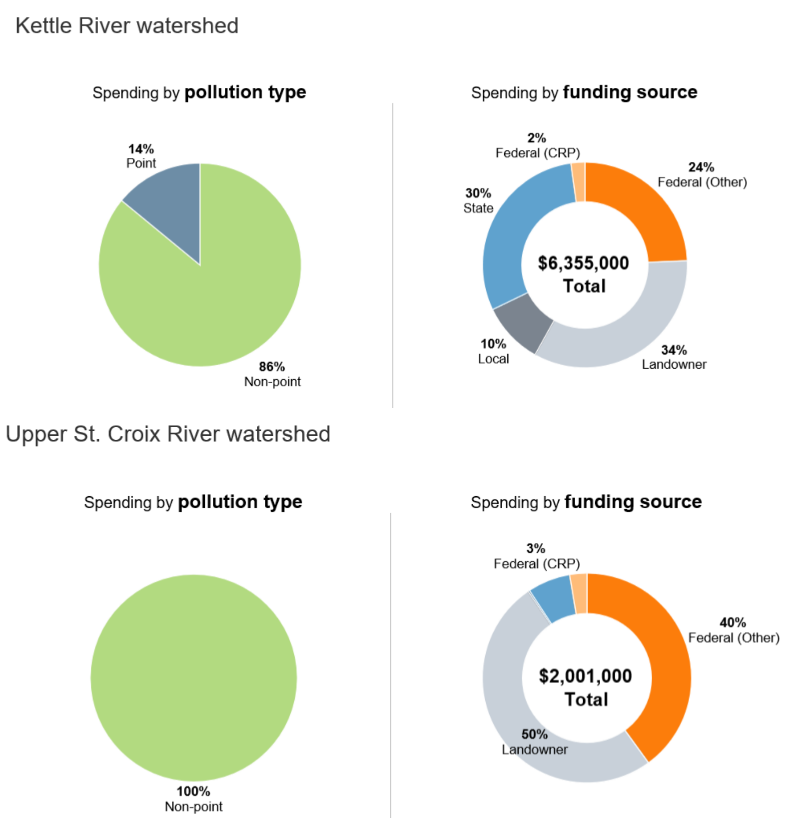
- Preserve arts and cultural heritage;
- Support parks and trails; and
- Protect, enhance, and restore lakes, rivers, streams, and groundwater.

This is a secure funding mechanism with the explicit purpose of supporting water quality improvement projects.

Other funding sources for nonpoint pollutant reduction work include but are not limited to; Clean Water Act Section 319 grant programs, BWSR Clean Water Fund Grants, the Clean Water Partnership and the Agricultural BMP loan programs, and NRCS incentive programs. Programs and activities are also occurring at the local government level, where county staff, commissioners, and residents work together to address water quality issues. In the past, several state Clean Water Partnership loan and federal Section 319 grants have been utilized to implement nonpoint source BMPs.

Since 2004, over $6.3 million has been spent addressing water quality concerns in the Kettle River Watershed and over $2 million in the Upper St. Croix Watershed (Figure 30). See the *Spending for watershed implementation projects* (https://www.pca.state.mn.us/water/spending-watershed-implementation-projects) section of the *Healthier watersheds: Tracking the actions taken* webpage for additional details.

Figure 30. Spending for watershed implementation projects in the Kettle River and Upper St. Croix River Watersheds.



6.2.4 Planning and Implementation

The WRAPS, TMDLs, and all the supporting documents provide a foundation for planning and implementation. Subsequent planning, including future development of a "One Watershed, One Plan" for the Kettle River and Upper St. Croix River watersheds, will draw on the goals, technical information, and tools to describe in detail strategies for implementation. For the purposes of reasonable assurance, the WRAPS document is sufficient in that it provides strategies for achieving pollutant reduction goals. However, many of the goals outlined in this TMDL are very similar to objectives outlined in the individual county water plans. Some general goals and themes in the individual county water plans are consistent such as:

- Protect, manage and improve surface waters
- Target landscapes and sites for increased conservation practices and reduction in feedlot and septic pollutants
- Reduce erosion, and sediment and nutrient loading
- Identify, design and improve drainage management, water retention and concentrated flow
- Protect groundwater resources

These county plans have the same goal of removing streams and lakes from the 303(d) Impaired Waters List. These plans provide watershed specific strategies for addressing water quality and quantity issues. In addition, the commitment and support from the local governmental units will ensure that this TMDL project is carried successfully through implementation.

6.2.5 Tracking Progress

Water monitoring efforts within the Kettle River and Upper St. Croix River Watersheds are diverse and constitute a sufficient means for tracking progress and supporting adaptive management. See Chapter 7 for more information on monitoring efforts and programs in both watersheds.

Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites notes that sites across Minnesota, including the Kettle and Upper St. Croix Rivers, show long-term reductions in TSS, TP, ammonia and biochemical oxygen demand (MPCA 2014b). *The Minnesota NRS* documented a 33% reduction of the phosphorus load leaving the state via the Mississippi River from the pre-2000 baseline to current (MPCA 2014a). These reports generally agree that while further reductions are needed, municipal and industrial phosphorus loads as well as loads of runoff-driven pollutants (i.e. TSS) are decreasing; a conclusion that lends assurance that the Kettle and Upper St. Croix River WRAPS and TMDL goals and strategies are reasonable and that long-term, enduring efforts to decrease erosion and nutrient loading to surface waters have the potential to reduce pollutant loads.

In addition, the MPCA maintains the Healthier Watersheds webpage, which is an online database of BMPs implemented by major watershed between 2004 and 2019 that were reported through federal, state, and locally funded programs and grants: https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. From 2004 through 2019, 1,027 BMPs have been installed in the Kettle and Upper St. Croix watersheds (Figure 31 and Table 39). The three most common strategies used were related to pastures. There were 65 prescribed grazing practices, 120 access control/fencing practices, and 56 livestock watering practices.

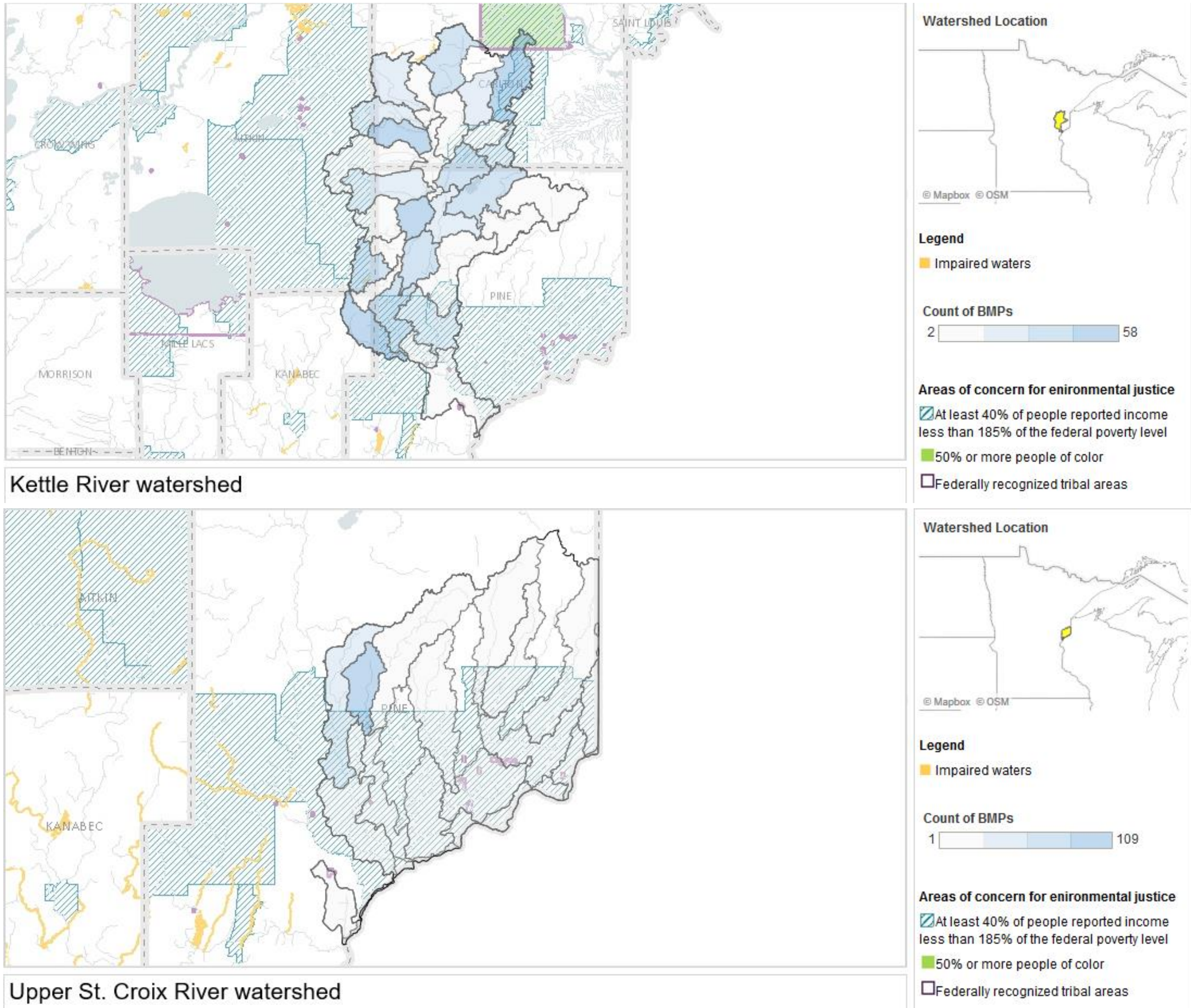


Figure 31. BMPs implemented by watershed in the Kettle River and Upper St. Croix River watersheds.

Table 39. Reported BMPs in the Kettle River and Upper St. Croix River Watersheds by BMP type (2004-2019)

BMP Strategy Type	Total BMPs	
	Kettle	Upper St. Croix
Designed Erosion Control	1	3
Nutrient Management (Cropland)	26	23
Tillage/residue Management	1	2
Buffers and Filters	4	--
Stream Banks, Bluffs, and Ravines	29	--
Converting Land to Perennials	51	18
Tile Inlet Improvements	8	6
Living Cover to Crops in Fall/Spring	2	1
Drainage Ditch Modifications	4	--
Septic System Improvements	24	--
Pasture Management	58	13
Tile Drainage Treatment/Storage	3	--
Habitat and Stream Connectivity	72	19
Feedlot Runoff Controls	2	4
Other BMPs	452	201

6.2.6 Reasonable Assurance Summary

In summary, significant time and resources have been devoted to identifying the best BMPs and supporting their implementation via state initiatives and dedicated funding in in the Kettle River and Upper St. Croix River watersheds.

The WRAPS and TMDL process engaged partners to arrive at reasonable examples of BMP combinations that achieve pollutant reduction goals. Minnesota is a leader in watershed planning, monitoring, and tracking progress toward water quality goals. Finally, examples cited herein confirm that BMPs and restoration projects have proven to be effective over time and as stated in A15-1622 MCEA vs MPCA and MCES (Minnesota Court of Appeals 2016):

> *"We conclude that substantial evidence exists to conclude that voluntary reductions from nonpoint sources have occurred in the past and can be reasonably expected to occur in the future. The Nutrient Reduction Strategy (NRS) […] provides substantial evidence of existing state programs designed to achieve reductions in nonpoint source pollution as evidence that reductions in nonpoint pollution have been achieved and can reasonably be expected to continue to occur."*

7. Monitoring Plan

Several types of monitoring are necessary to track progress toward achieving the load reductions required for the TMDLs and the achievement of water quality standards. Water monitoring combined with tracking implementation of BMPs on the ground is critical in the adaptive management approach to implementing TMDLs. The LGUs will track the implementation of BMPs annually through BWSR's e-LINK system. Monitoring results will identify progress toward obtainable benchmark goals as well as shape the next course of action for implementation through adaptive management. Data from water quality monitoring programs enables water quality condition assessment and creates a long-term data set to track progress towards water quality goals. These programs will continue to collect and analyze data in the Kettle River and Upper St. Croix River watersheds as part of Minnesota's Water Quality Monitoring Strategy (MPCA 2011). Data needs are considered by each program and additional monitoring is implemented when deemed necessary and feasible. These monitoring programs are summarized as follows:

- Intensive Watershed Monitoring collects water quality and biological data for two years at established stream and lake monitoring stations across the Kettle River and Upper St. Croix River watersheds every 10 years. The MPCA, with assistance from LGUs, will revisit and reassess a subset of these monitoring stations, as well as have capacity to visit new sites in areas with BMP implementation activity, scheduled to begin in 2026. It is expected that funding for monitoring and analysis will be available through the MPCA.
- Watershed Pollutant Load Monitoring Network data provides a continuous and long-term record of water quality conditions at the major watershed and subwatershed scale. This program collects pollutant samples and flow data to calculate continuous daily flow, sediment, and nutrient loads. There are two sites in the Kettle River Watershed with data that vary by site.
- Citizen Stream and Lake Monitoring Program data provide a continuous record of waterbody transparency throughout much of the basin. This program relies on a network of private citizen volunteers who make monthly stream and lake measurements annually. There is currently a limited number of citizens doing monitoring within the Kettle River and Upper St. Croix River watersheds. The MPCA will seek more citizen monitors to track trends of water quality transparency for impaired waters within the basin.

8. Implementation Strategy Summary

8.1 Implementation Framework

The strategies described in this section are potential actions to reduce bacteria and nutrient (TP) loads in the Kettle River and Upper St. Croix River watersheds. These actions are further developed in a separate, more detailed WRAPS report.

8.2 Permitted Sources

8.2.1 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 Minnesota'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 the Construction Stormwater General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local construction stormwater requirements must also be met.

8.2.2 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 Minnesota's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS General Permit for Construction Sand and Gravel, Rock Quarrying and Hot Mix Asphalt Production facilities (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS Permit and properly selects, installs, and maintains all BMPs required under the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. All local stormwater management requirements must also be met.

8.2.3 Wastewater

The MPCA issues permits for WWTP that discharge into waters of the state. The permits have site specific limits that are based on water quality standards. Permits regulate discharges with the goals of protecting public health and aquatic life and assuring that every facility treats wastewater. In addition, SDS permits set limits and establish controls for land application of sewage. For Grindstone River Reach 501, which is the only impaired reach with a permitted WWTP (Hinckley WWTP), the WLAs calculated in this TMDL do not require any changes to the WWTP discharge permit limits.

8.3 Nonpermitted Sources

Implementation of the Kettle River and Upper St. Croix River watersheds TMDL will require BMPs that address the various pollutants in the watershed. This section provides an overview of example BMPs that may be used for implementation. The BMPs included in this section are not exhaustive, and the list may be amended after the development of future watershed plans and studies. Other reports and studies have evaluated implementation strategies in the Kettle River and Upper St. Croix River watersheds, such as the Kettle River Watershed SID Report (MPCA 2020d), Upper St. Croix River Watershed SID Report (MPCA 2020f), and the Kettle River and Upper St. Croix River WRAPS Report (MPCA 2020c).

Agricultural sources such as pasture management and runoff from cropland, stormwater runoff from developed areas, human wastewater sources such as ITPHS septic systems, near-channel sources of sediment, and internal lake phosphorus loading were identified as substantial pollutant sources.

8.3.1 Agricultural Sources

Several different agricultural BMPs can be used to target priority sources and their associated pollutants. Table 40 provides a summary of agricultural BMPs, their NRCS code, and their targeted pollutants. Descriptions of each BMP are provided below. More information on agricultural BMPs in the State of Minnesota can be found in the Agricultural BMP Handbook for Minnesota (Lenhart et al. 2017)

Table 40. Summary of agricultural BMPs for agricultural sources and their primary targeted pollutants.

BMP (NRCS standard)	Targeted pollutant(s)			
	Phosphorus	TSS	*E. coli*	Chloride
Conservation cover (327)	X	X		
Conservation/reduced tillage (329 & 345)	X	X		
Cover crops (340)	X	X		
Filter strips (636)	X	X	X	
Riparian buffers (390)	X	X	X	
Clean water diversion (362)	X		X	
Access control/fencing (472 & 382)	X	X	X	
Waste storage facilities (313) and nutrient management (590)	X		X	X
Drainage water management (554)	X	X		
Alternative tile intakes (606)	X	X		
Grassed waterways (412)	X	X		
Water and sediment control basins (638)	X	X		
Wetland restorations (657)	X	X		

Conservation Cover (327), Conservation/Reduced Tillage (329 and 345), and Cover Crops (340)

Conservation cover, conversation/reduced tillage, and cover crops are all on-field agricultural BMPs that aim to reduce erosion and nutrient loss by increasing and/or maintaining vegetative cover and root structure. Conservation cover is the process of converting previously row crop agricultural fields to permanent perennial vegetation. Conservation or reduced tillage can mean any tillage practice that leaves additional residue on the soil surface; 30% or more cover is typically considered conservation tillage. In addition to reducing erosion, conservation tillage preserves soil moisture. Cover crops refer to "the use of grasses, legumes, and forbs planted with annual cash crops to provide seasonal soil cover on cropland when the soil would otherwise be bare" (Lenhart et al. 2017).

Filter Strips (636) and Riparian Buffers (390)

Feedlot/wastewater filter strips are defined as “a strip or area of vegetation that receive and reduce sediment, nutrients, and pathogens in discharge from a setting basin or the feedlot itself. In Minnesota, there are five levels of runoff control, with level one being the strictest and for the largest operations” (Lenhart et al. 2017). Riparian buffers are composed of a mix of grasses, forbs, sedges, and other vegetation that serves as an intermediate zone between upland and aquatic environments (Lenhart et al. 2017). The vegetation is tolerant of intermittent flooding and/or saturated soils that are prone to occur in intermediate zones.

Riparian buffers and filter strips that include perennial vegetation and trees can filter runoff from adjacent cropland, provide shade and habitat for wildlife, and reinforce streambanks to minimize erosion. The root structure of the vegetation uses enhanced infiltration of runoff and subsequent trapping of pollutants. Both, however, are only effective in this manner when the runoff enters the BMP as a slow moving, shallow “sheet”; concentrated flow in a ditch or gully will quickly pass through the vegetation offering minimal opportunity for retention and uptake of pollutants. Similarly, tile lines can often allow water to bypass a buffer or filter strip, thus reducing its effectiveness.

Clean Water Diversions (362)

Clean runoff water diversion “involves a channel constructed across the slope to prevent rainwater from entering the feedlot area or the farmstead to reduce water pollution” (Lenhart et al. 2017). Clean water diversions can take many forms including roof runoff management, grading, earthen berms, and other barriers that direct uncontaminated runoff from areas that may contain high levels of *E. coli* and nutrients.

Access Control/Fencing (472 and 382)

Fencing can be used with controlled stream crossings to allow livestock to cross a stream while minimizing disturbance to the stream channel and streambanks. Providing alternative water supplies for livestock allows animals to access drinking water away from the stream, thereby minimizing the impacts to the stream and riparian corridor. Some researchers have studied the impacts of providing alternative watering sites without structural exclusions and found that cattle spend 90% less time in the stream when alternative drinking water is furnished (EPA 2003).

Waste Storage Facilities (313) and Nutrient Management (590)

Manure management strategies depend on a variety of factors. A pasture or open lot system with a relatively low density of animals (one to two head of cattle per acre [EPA 2003]) may not produce manure in quantities that require management for the protection of water quality. For mid-size and large facilities, additional waste storage is needed. A waste storage facility is “an impoundment created by excavating earth or a structure constructed to hold and provide treatment to agricultural waste” (Lenhart et al. 2017). Waste storage facilities hold and treat waste directly from animal operations, process wastewater, or contaminated runoff.

Dairies in the watersheds store and handle manure in both liquid and solid form to be land applied at a later date. Many small dairy operations have limited to no manure storage. Other potential sources of wastewater include process wastewater such as parlor wash down water, milk-house wastewater, silage leachate, and runoff from outdoor silage feed storage areas. There are potential runoff problems associated with these wastewater sources if not properly managed. Most poultry manure is handled as a dry solid in the state; however, the poultry CAFO facility located in Kettle River Watershed handles the manure as a liquid. Improperly stockpiled poultry manure or improper land application can pose runoff issues.

Final disposal of waste usually involves land application on the farm or transportation to another site. Minn. R. 7020.2225 contains several requirements for land application of manure. These requirements vary depending on feedlot size and include provisions on manure nutrient testing, nutrient application rates (based on determination of crop needs and phosphorus soil testing), manure management plans, recordkeeping, and various limitations in certain areas or near environmentally-sensitive areas. Manure is typically applied to the land once or twice per year. To maximize the amount of nutrients and organic material retained in the soil, application should not occur on frozen ground or when precipitation is forecast during the next several days.

The Minnesota Department of Agriculture (MDA) has recently developed an interactive model to assist livestock producers to evaluate the potential runoff risk for manure applications, based on weather forecasts for temperature and precipitation along with soil moisture content. The model can be customized to specific locations. It is advised that all producers applying manure utilize the model to determine the runoff risk, and use caution when the risk is "medium" and avoid manure application during "high" risk times. For more information and to sign up for runoff risk alerts from the MDA Runoff Risk Advisory Forecast, please see the MDA website.

Drainage water management (554)

Drainage water management, or controlled drainage, is a BMP in which a water control structure such as stop logs or floating mechanisms are placed at or near the outlet of a drainage system to manage the water table beneath an agricultural field. Storing excess water through the use of a controlled drainage system reduces the volume of agricultural drainage flow to surface water and the nutrients and sediment it carries.

Alternative tile intakes (606)

This BMP replaces open intakes that are flush with the ground surface that provide a direct conduit for sediment and nutrients to enter the tile system. Alternative options include perforated riser pipes, gravel/rock inlets, dense pattern tile and vegetated buffers surrounding the inlet. These alternatives increase sediment trapping efficiency and reduce the velocity of flow into the inlet.

Grassed Waterways (412) and Water and Sediment Control Basins (638)

Grassed waterways and water and sediment control basins (WASCOBs) are both agricultural BMPs that aim to slow water flow off agricultural fields. Grassed waterways are areas of vegetative cover that are placed in line with high flow areas on a field. WASCOBs are vegetative embankments that are placed perpendicular to water's flow path to pool and slowly release water. Both practices reduce erosion and sediment and phosphorus loss from agricultural fields.

Wetland Restoration (657)

Wetland restoration refers to the restoration of former or degraded wetlands to the hydrological, vegetative, and soil conditions that existed before modification from activities such as farming or draining. Wetlands are natural storage features that slow and filter water, reducing downstream flooding events. Wetland restoration can reduce fecal bacteria, nutrient, and sediment loading to nearby waterways in addition to providing habitat for plants and wildlife (Lenhart et al 2017).

8.3.2 Stormwater Runoff

Implementation strategies to address urban stormwater management are detailed in the Minnesota Stormwater Manual. Practices can be construction-related, post-construction, pretreatment, nonstructural, and structural. Implementation in the more urban areas will likely require retrofits, while practices in the more rural residential areas can target open areas and runoff from lawns and impervious surfaces associated with development.

8.3.3 Subsurface Sewage Treatment Systems

SSTS Assessments

There are state-sponsored funding programs available for community-wide septic system assessments. The Public Facilities Authority (PFA) administers the Small Community Wastewater Treatment Program, which provides grants of up to $60,000 to LGUs to "conduct preliminary site evaluations and prepare feasibility reports, provide advice on possible SSTS alternatives, and help develop the technical, managerial, and financial capacity to build, operate, and maintain SSTS systems" (PFA website). These studies assess current SSTS compliance status as well as potential future individual and/or community SSTS solutions.

Also, BWSR has provided grant funds in the past to local governments for large-scale SSTS compliance inspection projects. These projects typically involve riparian communities on impaired waterbodies.

SSTS Upgrades/Replacement

When a straight pipe system or other ITPHS location is confirmed, the local SSTS LGU will send a Notice of Noncompliance to the owner that includes a replacement or repair timeline. State rules mandate a 10-month deadline for the system to be brought into compliance, but an LGU can choose to set a more restrictive timeline. The reductions in loading resulting from upgrading or replacing failing systems in the watershed depend on the level of failure present in the watershed.

An SSTS doesn't need to be a straight pipe or other ITPHS to be a threat to surface water quality. Leaking tanks or a drainfield without adequate separation from groundwater can result in the transport of pathogens or excess nutrients to nearby surface waters through the groundwater. This is of particular concern for water-front properties. Shoreland rules in every county require proof of a compliant SSTS prior to issuance of a building permit for dwelling additions or rebuilds, and most county-level SSTS LGU also require proof of a compliant SSTS for property transfers.

Many counties and SWCDs offer low interest loan programs for SSTS upgrades or replacement. The PFA Small Community Wastewater Program offers grant and loan packages of up to $2,000,000 for the construction of publicly owned community SSTS. The State of Minnesota offers the Clean Water Partnership 0% interest loan program for individual SSTS upgrades and compliance.

SSTS Maintenance

The most cost-effective BMP for managing loads from SSTS is regular maintenance. EPA recommends that septic tanks be pumped every three to five years depending on the tank size and number of residents in the household (EPA 2002). When not maintained properly, SSTS can cause the release of pathogens and excess nutrients into surface water. Annual inspections, in addition to regular maintenance, ensure that systems function properly. Compliance with state and county code is essential to reducing *E. coli* and phosphorus loading from SSTS. SSTS are regulated under Minn. Stats. §§ 115.55 and 115.56. Counties must enforce ordinances in Minn. R. ch. 7080 to 7083.

Public Education

Education is another crucial component of reducing pollutant loading from SSTS. Education can occur through public meetings, routine SSTS service provider home visits, mass mailings, and radio and television advertisements. An inspection program can also help with public education because inspectors can educate owners about proper operation and maintenance during inspections.

8.3.4 Near Channel Sources of Sediment

Both direct and indirect controls for reducing near-channel sediment can be used in the Kettle River and Upper St. Croix River watersheds.

Direct Sediment Controls

Streambank stabilization and restoration should be implemented to address eroding banks and areas of instability in stream channels. Activities should be focused in priority areas as defined in stream-specific assessments.

The natural vegetation along stream corridors should be preserved. Buffers can mitigate pollutant loading associated with human disturbances and help to stabilize streambanks and improve infiltration. Minnesota's buffer law requires establishment of up to 50 feet of perennial vegetation along rivers, streams, and public ditches. Additional value could be added by working with landowners and residents to also install fencing or stream crossings to limit access to streams and ensuring enforcement of Minnesota's Shoreland Management Act.

Indirect Controls

Indirect controls for sediment loss typically involve land management practices and structural practices designed to temporarily store water or shift runoff patterns by increasing evapotranspiration at critical times of the year. The temporary storage of water and a shift in runoff patterns are needed to reduce peak flows and extend the length of storm hydrographs, which in turn will reduce the erosive power of streamflow on streambanks and bluffs.

8.3.5 Internal Loading in Lakes

Implementation strategies for internal loading reduction include water level drawdown, sediment phosphorus immobilization or chemical treatment (e.g., alum), management of aquatic vegetation, and biomanipulation (e.g., carp management).

Sequencing of in-lake management strategies both relative to each other, as well as relative to external load reduction, is important to evaluate and consider. In general, external loading, if moderate to high, should be the initial priority for reduction efforts. Biomanipulation may also be an early priority. However, it is generally believed that further in-lake management efforts involving chemical treatment (e.g., alum) should follow after substantial progress has been made toward achieving external load reduction goals. The success of alum treatments depends on several factors including lake morphometry, water residence time, alum dose used, and presence/abundance of benthic-feeding fish (Huser et al. 2016).

The MPCA recommends feasibility studies for any lakes in which water level drawdown or chemical treatment is considered.

8.4 Education

Education is a crucial component of reducing pollutant sources in the Kettle River and Upper St. Croix River watersheds and is important to increasing public buy-in of residents, businesses, and organizations. Education can occur through public meetings, mass mailings, radio and television advertisements, and other media.

8.5 Cost

TMDLs are required to include an overall approximation of implementation costs (Minn. Stat. § 114D.25). It is estimated that the costs to implement the activities outlined in the strategy document are approximately $8 to $10 million dollars over the next 20 years. This value is considered a rough estimate at this time as there is a level of uncertainty in the generalized cost estimate numbers used here as well as the source assessment and TMDL allocations presented in this report. The individual cost estimate exercises include: BMPs commonly implemented to address upland TSS and TP sources, livestock BMPs, ITPHS system repairs/replacements, and lake internal load projects. Required buffer installation, replacement of FTPGW systems, and SSTS maintenance are not included in the cost estimate at this time.

8.6 Adaptive Management

Adaptive management is an iterative implementation process that makes progress toward achieving water quality goals while using new data and information to reduce uncertainty and adjust implementation activities. The State of Minnesota has a unique opportunity to adaptively manage water resource plans and implementation activities, keying off intensive watershed monitoring every 10 years and other information. This opportunity resulted from a voter-approved tax increase to improve state waters. The resulting interagency coordination effort is referred to as the Minnesota Water Quality Framework, which works to monitor and assess Minnesota's major watersheds every 10 years. This framework supports ongoing implementation and adaptive management of conservation activities and watershed-based local planning efforts utilizing regulatory and nonregulatory means to achieve water quality standards.

Implementation of TMDL-related activities can take many years, and water quality benefits associated with these activities can also take many years. As the pollutant source dynamics within the watershed are better understood, implementation strategies and activities will be adjusted and refined to efficiently meet the TMDL and lay the groundwork for delisting the impaired reaches and lakes. The follow-up water monitoring program outlined in Section 7 will be integral to the adaptive management approach, providing assurance that implementation measures are succeeding in achieving water quality standards. Adaptive management does not include changes to water quality standards or LC. Any changes to water quality standards or LC must be preceded by appropriate administrative processes, including public notice and an opportunity for public review and comment.

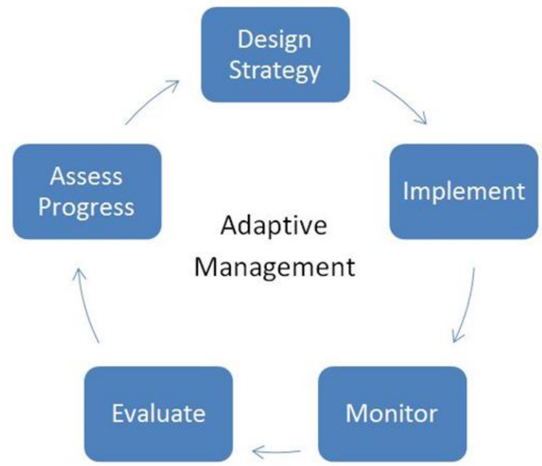


Figure 32. Adaptive management

The list of implementation strategies in the WRAPS report—prepared in conjunction with this TMDL—focuses on adaptive management (Figure 32). Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for achieving the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDLs and lay the groundwork for de-listing the impaired waterbodies.

9. Public Participation

A stakeholder participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the general public and a LWG that consisted of staff from county environmental services departments, SWCDs, MPCA, DNR, BWSR, MDA, Department of Health, lake associations, and other interested and affected citizens, LGUs, and agencies. The LWG convened multiple times to discuss and review TMDL results and provide input and feedback on the development of the Kettle River and Upper St. Croix River Watersheds SID studies, TMDLs and WRAPS. The entire public stakeholder process involved meetings and other forms of communication as described in Table 41.

Table 41. Summary of stakeholder meetings/events held during the development of the Kettle River and Upper St. Croix River Watersheds TMDL/WRAPS.

Date	Description
8/29/2018	LWG TMDL and WRAPS Kickoff Meeting at Audubon Center of the North Woods - Grindstone Lake, MN
6/11/2019	LWG Meeting to discuss TMDL and SID results at Audubon Center of the North Woods - Grindstone Lake, MN
8/29/2019	LWG Meeting to discuss draft TMDL report comments and WRAPS brainstorming at Audubon Center of the North Woods - Grindstone Lake, MN

Public notice

An opportunity for public comment on the draft TMDL was provided via a public notice in the State Register from January 11, 2021, through February 10, 2021. There were no comment letters received during the public comment period.

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Appendices

Appendix A – Assessed Streams and Lakes in the Kettle and Upper St. Croix River Watersheds

Table A-1. Stream Assessments in the Kettle River Watershed

HUC-10 Subwatershed	AUID (Last 3 digits)	River	Reach description	Aquatic life				Aq rec
				Fish Index of biotic integrity	Macroinvertebrate index of biotic integrity	Dissolved oxygen	Turbidity/TSS	Bacteria
Upper Kettle River	506	Kettle River	Birch Cr to Moose Horn R	NA	NA	NA	NA	NA
	509	Gillespie Brook	Headwaters to Kettle R	Sup	Sup	IF	IF	NA
	510	Kettle River	Dead Moose R to Gillespie Bk	Sup	Sup	IF	IF	NA
	510	Kettle River	Dead Moose R to Gillespie Bk	NA	NA	NA	NA	NA
	511	Kettle River	Headwaters to W Br Kettle R	Imp	Sup	IF	IF	NA
	512	Kettle River, West Branch	Headwaters (Section One Lk 09-0069-00) to Kettle R	Sup	Sup	IF	IF	NA
	513	Split Rock River	Headwaters to Kettle R	Sup	Imp	IF	IF	Imp
	514	Birch Creek	Headwaters to Kettle R	Sup	Sup	IF	IF	NA
	518	Unnamed creek	Unnamed cr to Dead Moose R	NA	NA	NA	NA	NA
	529	Kettle River	W Br Kettle R to Dead Moose R	Sup	Sup	IF	IF	Imp
	537	Dead Moose River	Headwaters to Kettle R	Sup	Sup	IF	IF	NA
	540	County Ditch 2	Headwaters to Kettle Lk	NA	NA	NA	NA	NA
	552	Kettle River	Carlton/Pine County line to Birch Cr	Sup	Sup	IF	IF	Sup

	569	Unnamed creek	Unnamed ditch to Birch Cr	NA	NA	NA	NA	NA
	592	Silver Creek	Unnamed cr to Unnamed cr	Sup	Sup	IF	IF	NA
	598	Unnamed creek	Headwaters to Split Rock R	NA	NA	NA	NA	NA
	604	Unnamed creek	Unnamed cr to Brich Cr	NA	NA	NA	NA	NA
	615	Unnamed ditch	Unnamed ditch to Kettle R	Sup	Sup	IF	IF	NA
	616	Heikkila Creek	Unnamed cr to Kettle R	IF	IF	IF	IF	NA
Moose River	521	Moose Horn River	W Br Moose Horn R to Hanging Horn Lk	Sup	Sup	IF	IF	NA
	523	Unnamed creek	Headwaters to Little Hanging Horn Lk	NA	NA	NA	NA	NA
	531	Moose Horn River	Hanging Horn Lk to Kettle R	Sup	Sup	Sup	Sup	Sup
	535	Moose Horn River	Headwaters (Wild Rice Lk 09-0023-00) to T48 R18W S34, south line	Sup	Sup	IF	IF	NA
	535	Moose Horn River	Headwaters (Wild Rice Lk 09-0023-00) to T48 R18W S34, south line	NA	NA	NA	NA	NA
	547	King Creek	Headwaters to Moose Horn R	Sup	Sup	IF	IF	NA
	547	King Creek	Headwaters to Moose Horn R	NA	NA	NA	NA	NA
	628	Moose Horn River, West Branch	Unnamed cr to Moose Horn R	Sup	Sup	NA	NA	NA
	629	Moose Horn River	T47 R18W S4, north line to Unnamed cr	Sup	Sup	IF	IF	NA

	630	Moose Horn River	Unnamed cr to W Br Moose Horn R	Sup	Sup	IF	IF	NA
Willow River	548	Larsons Creek	T44 R17W S5, south line to Willow River	NA	Sup	IF	IF	NA
	548	Larsons Creek	T44 R17W S5, south line to Willow River	NA	NA	NA	NA	NA
	575	Little Willow River	Unnamed cr to Unnamed cr	Sup	Sup	IF	IF	NA
	619	Hay Creek	Headwaters to Willow R	Imp	Sup	IF	IF	NA
	621	Willow River	Headwaters to Big Slough Lk outlet	Sup	Sup	IF	Sup	Sup
	622	Willow River	Big Slough Lk outlet to Kettle R	Sup	Sup	IF	IF	NA
Pine River	520	Unnamed creek	Headwaters to Bremen Cr	NA	NA	NA	NA	NA
	560	Little Pine Creek	Little Pine Lk to Pine R	Sup	Imp	IF	IF	NA
	564	Unnamed creek	Bass Lk to Unnamed cr	NA	NA	NA	NA	NA
	566	Little Bremen Creek	Unnamed cr to Bremen Cr	NA	NA	NA	NA	NA
	568	Bremen Creek	Unnamed cr to Unnamed cr	Sup	Sup	IF	IF	NA
	602	Unnamed creek	Unnamed cr to Pine Lk	NA	NA	IF	IF	Sup
	609	Rhine Creek	Unnamed cr to Pine R	Sup	Sup	IF	IF	NA
	620	Bremen Creek	Headwaters to Little Bremen Cr	Sup	Imp	IF	IF	NA
	623	Pine River	Headwaters to Bremen Cr	Sup	Imp	IF	IF	Imp
	624	Pine River	Bremen Cr to Kettle R	Sup	Sup	IF	Sup	Sup

	631	Pine River	Headwaters to Pine Lk	NA	NA	NA	NA	NA
	631	Pine River	Headwaters to Pine Lk	NA	NA	IF	IF	Imp
	633	Pine River	Big Pine Lk to Little Pine Cr	NA	NA	NA	NA	NA
	633	Pine River	Big Pine Lk to Little Pine Cr	Sup	Imp	IF	IF	NA
	634	Pine River	Little Pine Cr to Bremen Cr	NA	NA	NA	NA	NA
	634	Pine River	Little Pine Cr to Bremen Cr	Sup	Imp	IF	IF	NA
Grindstone River	501	Grindstone River	Grindstone Reservoir to Kettle R	Sup	Sup	IF	Sup	Imp
	501	Grindstone River	Grindstone Reservoir to Kettle R	NA	NA	NA	NA	NA
	516	Grindstone River, South Branch	Headwaters to Grindstone R	Imp	Sup	IF	Sup	Imp
	516	Grindstone River, South Branch	Headwaters to Grindstone R	NA	NA	NA	NA	NA
	526	Judicial Ditch 1	Headwaters to S Br Grindstone R	NA	NA	NA	NA	Imp
	541	Grindstone River, North Branch	Headwaters to Grindstone Lk	NA	NA	NA	NA	IF
	543	Grindstone River, North Branch	Grindstone Lk to T42 R21W S28, south line	Imp	Imp	NA	NA	NA
	543	Grindstone River, North Branch	Grindstone Lk to T42 R21W S28, south line	Sup	Sup	NA	NA	NA
	544	Grindstone River, North Branch	T42 R21W S33, north line to Grindstone R	Sup	Sup	IF	Sup	Imp

	546	Unnamed creek	Miller Lk to Grindstone Lk	NA	NA	NA	NA	Imp
	550	Spring Creek	Headwaters to Grindstone R	Imp	Imp	Imp	IF	Imp
	550	Spring Creek	Headwaters to Grindstone R	IF	IF	IF	IF	NA
	599	Unnamed creek	Headwaters to N Br Grindstone R	NA	NA	IF	IF	IF
	601	Unnamed creek	Headwaters to Grindstone Lk	NA	NA	NA	NA	IF
	611	Unnamed creek	Headwaters to Grindstone R	NA	NA	IF	NA	NA
	612	Unnamed creek	Headwaters to Grindstone R	NA	NA	IF	IF	IF
	614	Unnamed creek	Unnamed ditch to N Br Grindstone R	NA	NA	NA	NA	NA
Lower Kettle River	502	Kettle River	Grindstone R to St Croix R	Sup	Sup	IF	Sup	Sup
	503	Kettle River	Willow R to Pine R	Sup	Sup	IF	Imp	NA
	505	Kettle River	Moose Horn R to Willow R	Sup	Sup	IF	IF	Sup
	517	Kettle River	Skunk Cr to Grindstone R	NA	NA	NA	NA	NA
	522	Deer Creek	Headwaters to Kettle R above Grindstone R	NA	NA	NA	NA	NA
	524	Wolf Creek	Headwaters to Kettle R	NA	NA	NA	NA	NA
	525	Cane Creek	Headwaters to Kettle R	Sup	Imp	IF	IF	NA
	528	Kettle River	Pine R to former Dam (at Sandstone)	Sup	Sup	IF	Sup	Sup
	528	Kettle River	Pine R to former Dam (at Sandstone)	NA	NA	NA	NA	NA

539	Unnamed creek	Headwaters to Cane Cr	NA	NA	NA	NA	NA
562	Unnamed creek	Headwaters to Unnamed cr	NA	NA	NA	NA	NA
617	Friesland Ditch	RR tracks to Kettle River	Imp	Imp	IF	IF	NA
618	Skunk Creek	Unnamed creek to Kettle R	Imp	Sup	IF	IF	NA
625	Unnamed creek	Headwaters to Kettle R	NA	NA	NA	NA	NA
626	Unnamed creek	Headwaters to Kettle R	NA	NA	NA	NA	NA

Sup = found to meet the water quality standard, Imp = does not meet the water quality standard and, therefore, is impaired, IF = the data collected was insufficient to make a finding, NA = not assessed, IC = Inconclusive

Table A-2. Lake Assessments in the Kettle River Watershed

HUC-10 Subwatershed	Lake ID	Lake	Aquatic recreation	Aquatic life
Upper Kettle River	09-0049-00	Kettle	IF	IF
	09-0058-00	Merwin	Imp	IF
Moose River	09-0022-00	Twentynine	Imp	IF
	09-0023-00	Wild Rice	IF	IF
	09-0023-00	Wild Rice	NA	NA
	09-0026-00	Bob	Sup	IF
	09-0029-00	Park	Sup	Sup
	09-0034-00	Bear	Sup	IF
	09-0035-00	Little Hanging Horn	Sup	IF
	09-0038-00	Hanging Horn	IF	Sup
	09-0039-00	Eddy	IF	NA
	09-0041-00	Moosehead	IF	IF
	09-0043-00	Moose	Sup	IF
	09-0044-00	Echo	Sup	IF
	09-0045-00	Coffee	Sup	IF
	58-0062-00	Island	Sup	Sup
	58-0081-00	Sand	Sup	IF
Willow River	58-0048-00	Oak	Imp	Imp
	58-0067-00	Sturgeon	Sup	Sup
	58-0068-00	Eleven	Sup	NA
	58-0073-00	Dago	Sup	NA
	58-0076-00	Passenger	IF	IF
	58-0076-00	Passenger	Sup	IF
	58-0078-00	Rush	IF	NA

	58-0111-00	Stanton	IF	IF
Pine River	01-0001-00	Pine	Imp	IF
	33-0001-00	Eleven	Imp	Sup
	58-0102-00	Fox	Imp	Sup
	58-0128-00	Bass	Sup	NA
	58-0129-00	Little Pine	IF	NA
	58-0130-00	Upper Pine	Sup	Sup
	58-0132-00	Indian	IF	NA
	58-0136-00	Rhine	Imp	NA
	58-0137-00	Bass	Sup	IF
	58-0138-00	Big Pine	Imp	IF
Grindstone River	33-0003-00	Five	Sup	IF
	58-0123-00	Grindstone	Imp	Sup
	58-0123-00	Grindstone	NA	NA
	58-0126-00	Elbow	Imp	NA
	58-0135-00	Miller	IF	IF
Lower Kettle River	58-0058-00	McCormick	Imp	IF
	58-0106-00	Little Mud	NA	IF
	58-0107-00	Long	IF	IF

Sup = found to meet the water quality standard, Imp = does not meet the water quality standard and, therefore, is impaired, IF = the data collected was insufficient to make a finding, NA = not assessed, IC = Inconclusive

Table A-3. Stream Assessments in the Upper St. Croix River Watershed

HUC-10 Subwatershed	AUID (Last 3 digits)	River	Reach description	Aquatic life: Fish Index of biotic integrity	Aquatic life: Macroinvertebrate index of biotic integrity	Aquatic life: Dissolved oxygen	Aquatic life: Turbidity/TSS	Aq rec: Bacteria
Bear Creek	518	Bear Creek	Headwaters to St Croix R	Sup	Sup	IF	IF	IF
	579	Little Bear Creek	Headwaters to Unnamed cr	NA	NA	NA	NA	NA
	581	Little Bear Creek	Unnamed cr to Bear Cr	Sup	Sup	IF	IF	NA
Sand Creek	538	Sand Creek	Headwaters to T44 R18W S27, south line	NA	NA	NA	NA	NA
	546	Hay Creek	Headwaters to Lk Clayton	Imp	Imp	IF	IF	NA
	546	Hay Creek	Headwaters to Lk Clayton	NA	NA	NA	NA	NA
	552	Partridge Creek	Headwaters to Unnamed cr	NA	NA	NA	NA	NA
	553	Partridge Creek	Unnamed cr to Sand Cr	Sup	IF	IF	IF	NA
	554	Little Sand Creek	Unnamed cr to Sand Cr	Imp	Sup	IF	IF	NA
	555	Little Sand Creek	Zimbrick Cr to Unnamed cr	NA	NA	NA	NA	NA
	604	Sand Creek	T44 R18W S34, north line to Unnamed cr	Imp	Sup	IF	IF	NA
	604	Sand Creek	T44 R18W S34, north line to Unnamed cr	NA	NA	NA	NA	NA
	605	Sand Creek	Unnamed cr to Pickle Cr	Sup	Sup	IF	IF	NA
	605	Sand Creek	Unnamed cr to Pickle Cr	NA	NA	NA	NA	NA
	606	Sand Creek	Pickle Cr to T43 R19W S24, south line	Imp	Sup	IF	IF	NA
	606	Sand Creek	Pickle Cr to T43 R19W S24, south line	NA	NA	NA	NA	NA

	617	Sand Creek	T43 R19W S25, north line to Unnamed cr	Sup	Sup	IF	IF	NA
	618	Sand Creek	Unnamed cr to St Croix R	Sup	Imp	IF	IF	IF
	902	Little Hay Creek	Headwaters to Hay Cr	Sup	IF	IF	IF	NA
	902	Little Hay Creek	Headwaters to Hay Cr	NA	NA	NA	NA	NA
Crooked Creek	522	Crooked Creek	Confluence of E & W Fk to T41 R17W S29, south line	Sup	Sup	IF	IF	IF
	522	Crooked Creek	Confluence of E & W Fk to T41 R17W S29, south line	NA	NA	NA	NA	NA
	533	Crooked Creek, East Fork	Unnamed cr to Crooked Cr	Sup	Sup	IF	IF	NA
	533	Crooked Creek, East Fork	Unnamed cr to Crooked Cr	NA	NA	NA	NA	NA
	535	Crooked Creek, West Fork	T43 R18W S27, east line to T42 R18W S16, south line	NA	NA	NA	NA	NA
	537	Crooked Creek, West Fork	T41 R18W S11, north line to Crooked Cr	Sup	Sup	IF	IF	NA
	537	Crooked Creek, West Fork	T41 R18W S11, north line to Crooked Cr	NA	NA	NA	NA	NA
	541	Crooked Creek	T41 R17W S32, north line to St Croix R	Sup	Sup	IF	IF	NA
	545	Bangs Brook	T41 R17W S15, east line to Crooked Cr	IF	Sup	IF	IF	NA
	545	Bangs Brook	T41 R17W S15, east line to Crooked Cr	NA	NA	NA	NA	NA
	548	Wolf Creek	T43 R18W S32, north line to Crooked Cr	Sup	Imp	IF	IF	NA
	548	Wolf Creek	T43 R18W S32, north line to Crooked Cr	NA	NA	NA	NA	NA
	562	Kenney Brook	T41 R17W S20, north line to Crooked Cr	Sup	Sup	IF	IF	NA

	562	Kenney Brook	T41 R17W S20, north line to Crooked Cr	NA	NA	NA	NA	NA
	611	Bangs Brook	Headwaters to T41 R17W S14, west line	NA	NA	NA	NA	NA
	615	Crooked Creek, East Fork	Headwaters to CSAH 32	NA	NA	NA	NA	NA
	616	Crooked Creek, East Fork	CSAH 32 to T42 R18W S36, east line	NA	NA	NA	NA	NA
Lower Tamarack River	510	Lower Tamarack River	Hay Cr to St Croix R	Sup	Sup	IF	IF	IF
	510	Lower Tamarack River	Hay Cr to St Croix R	NA	NA	NA	NA	NA
	511	Hay Creek	MN/WI State border to Lower Tamarack R	Sup	Sup	IF	IF	IF
	511	Hay Creek	MN/WI State border to Lower Tamarack R	NA	NA	NA	NA	NA
	512	Lower Tamarack River	McDermott Cr to Hay Cr	Sup	Sup	IF	IF	NA
	513	McDermott Creek	Headwaters to Lower Tamarack R	Sup	Sup	IF	IF	IF
	514	Lower Tamarack River	Headwaters to McDermott Cr	Sup	Sup	IF	IF	NA
	528	Squib Creek	Headwaters to McDermott Cr	Sup	Imp	IF	IF	NA
	529	Keene Creek	Headwaters to Unnamed cr	NA	NA	NA	NA	NA
	531	Keene Creek	Unnamed cr to Little Ox Cr	NA	NA	IF	IF	NA
	532	Keene Creek	Little Ox Cr to Lower Tamarack R	Sup	Sup	NA	NA	NA
Upper Tamarack River	613	Upper Tamarack River	MN/WI State border to Unnamed cr	Sup	Imp	IF	IF	NA
	613	Upper Tamarack River	MN/WI State border to Unnamed cr	NA	NA	NA	NA	NA

	614	Upper Tamarack River	Unnamed cr to St Croix R	Sup	Sup	IF	IF	IF
	614	Upper Tamarack River	Unnamed cr to St Croix R	NA	NA	NA	NA	NA

Sup = found to meet the water quality standard, Imp = does not meet the water quality standard and, therefore, is impaired, IF = the data collected was insufficient to make a finding, NA = not assessed, IC = Inconclusive

Table A-4. Lake Assessments in the Upper St. Croix River Watershed

HUC-10 Subwatershed	Lake ID	Lake	Aquatic recreation	Aquatic life
Sand Creek	58-0045-00	Wilbur	IF	IF
	58-0045-00	Wilbur	NA	NA
Crooked Creek	58-0010-00	Razor	Sup	IF
	58-0013-00	Greigs	NA	IF
	58-0013-00	Greigs	NA	NA
	58-0024-00	Tamarack	Sup	IF
Lower Tamarack River	58-0005-00	Hay Creek Flowage	NA	NA
	58-0007-00	Rock	Imp	IF
	58-0029-00	Grace	Imp	IF

Sup = found to meet the water quality standard, Imp = does not meet the water quality standard and, therefore, is impaired, IF = the data collected was insufficient to make a finding, NA = not assessed, IC = Inconclusive

Appendix B - Stream Impairment Supporting Items

Supporting Items for Grindstone River Bacteria Impaired Reach (07030003-501)

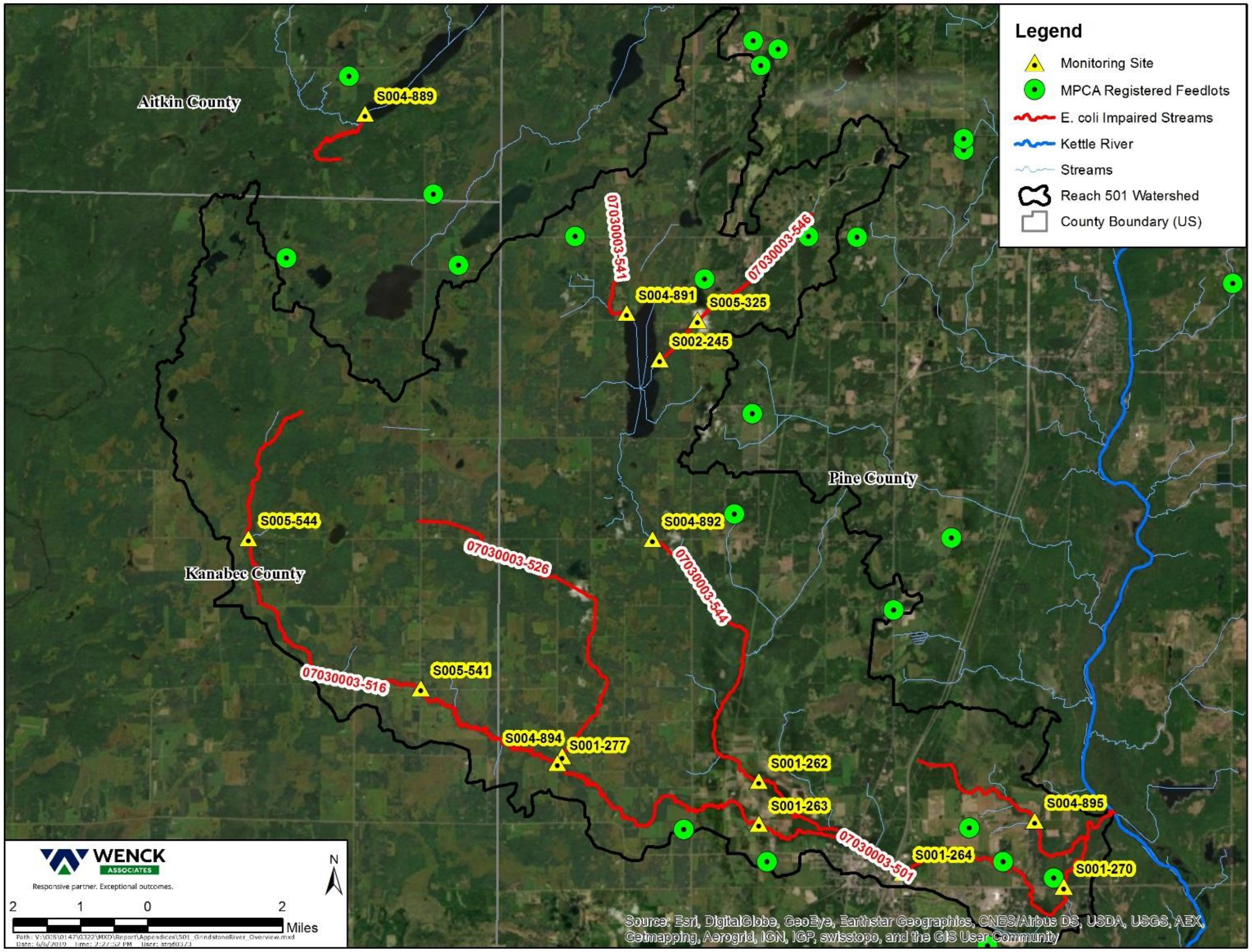


Figure B-1. Grindstone River Reach 501 Overview.

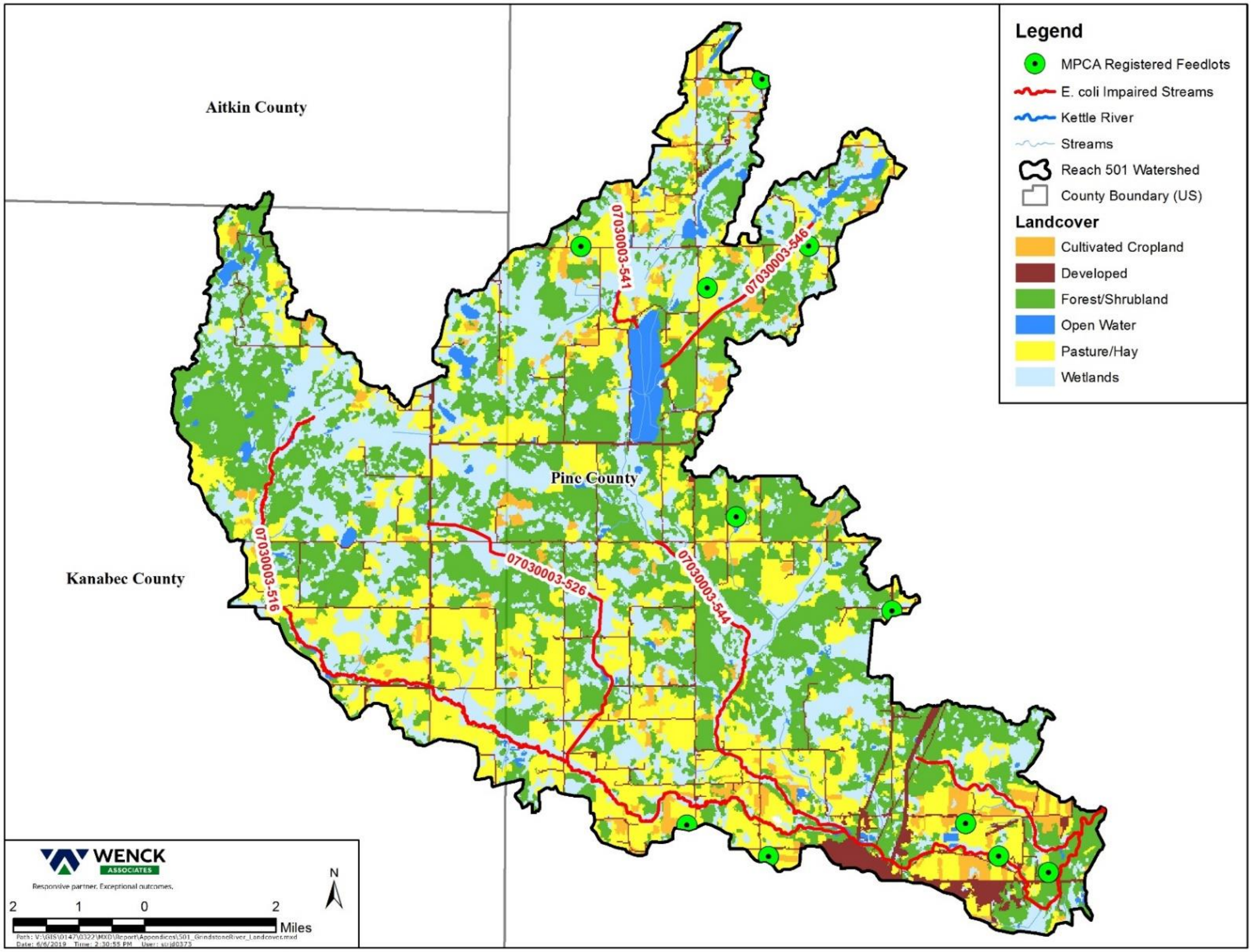


Figure B-2. Grindstone River Reach 501 Landcover.

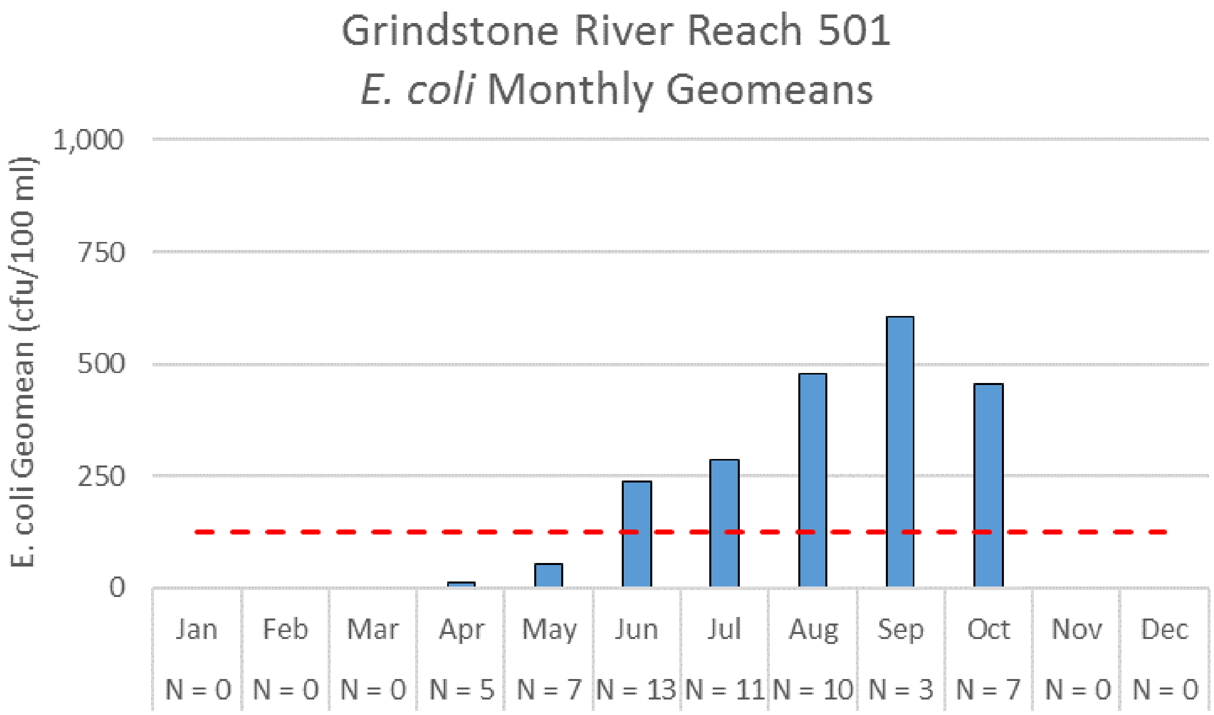


Figure B-3. Grindstone River Reach 501 E. coli Monthly Geomeans.

Table B-1. Grindstone River Reach 501 Bacteria Production Exercise.

Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Horse*	2	58.2	116	96,810	97.80%
Swine*	-	-	-		
Bovine*	1,661	58.2	96,693		
Poultry*	0.0	20.5	0		
Other Livestock*,[9]	0	-	-		
Deer [3]	434	0.5	217	564	0.57%
Waterfowl [4]	868	0.4	347		
Failing Septic Systems [5]	25	5.7	140	141	0.14%
WWTP effluent [6]	1	0.9	1		
Improperly Managed Pet Waste [7]	2,374	0.6	1,471	1,471	1.49%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Supporting Items for Split Rock River Bacteria Impaired Reach (07030003-513)

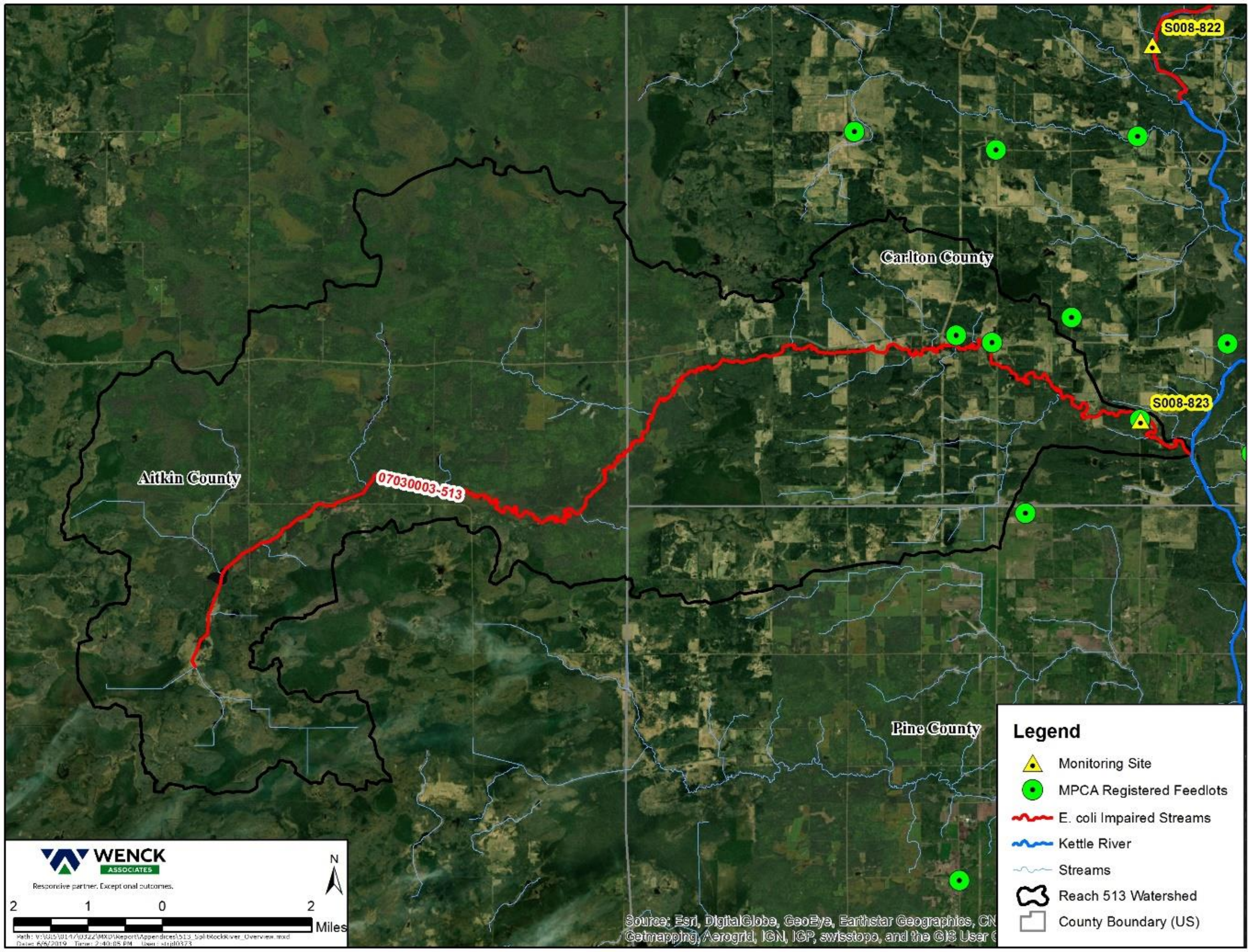


Figure B-4. Split Rock River Reach 513 Overview.

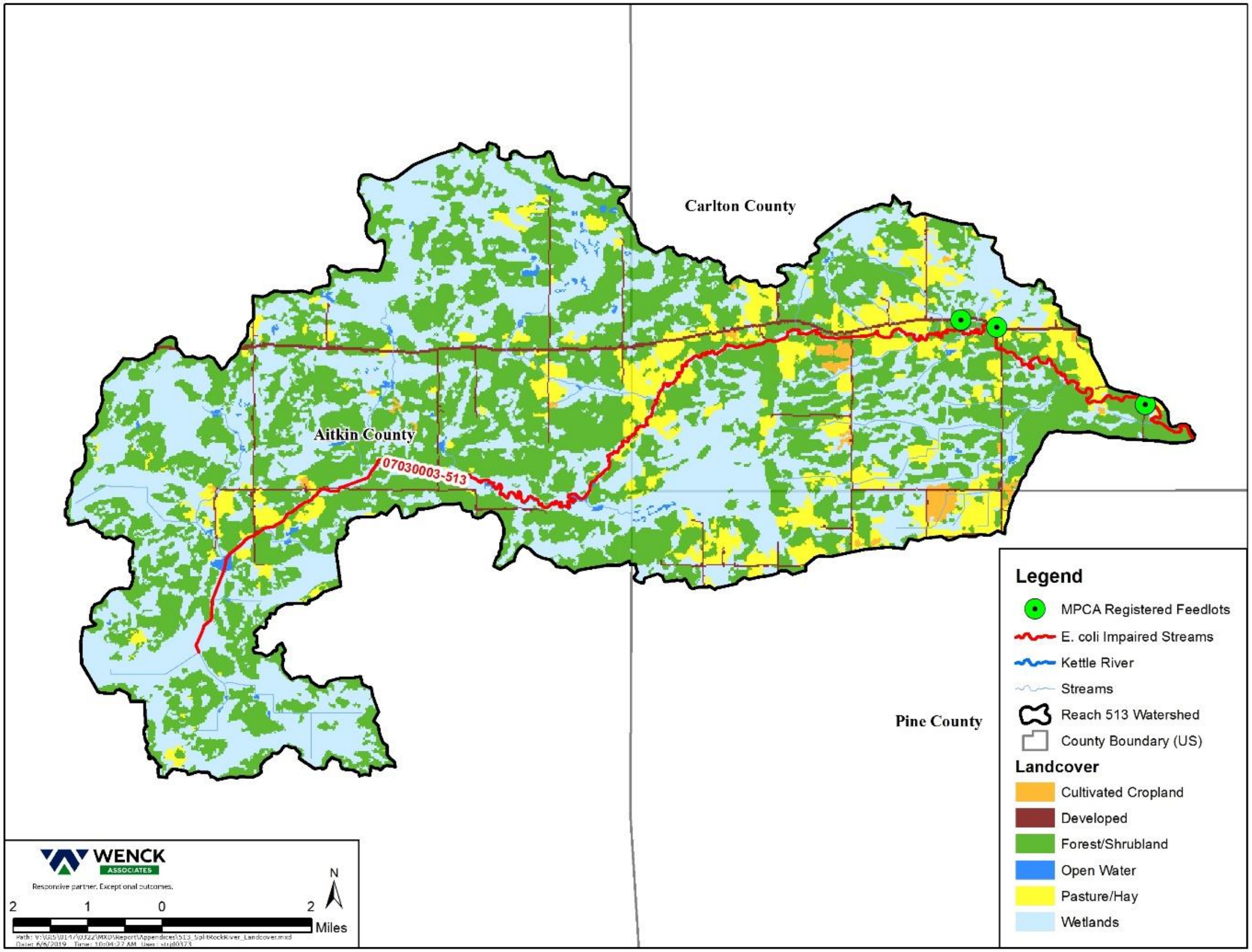


Figure B-5. Split Rock River Reach 513 Landcover.

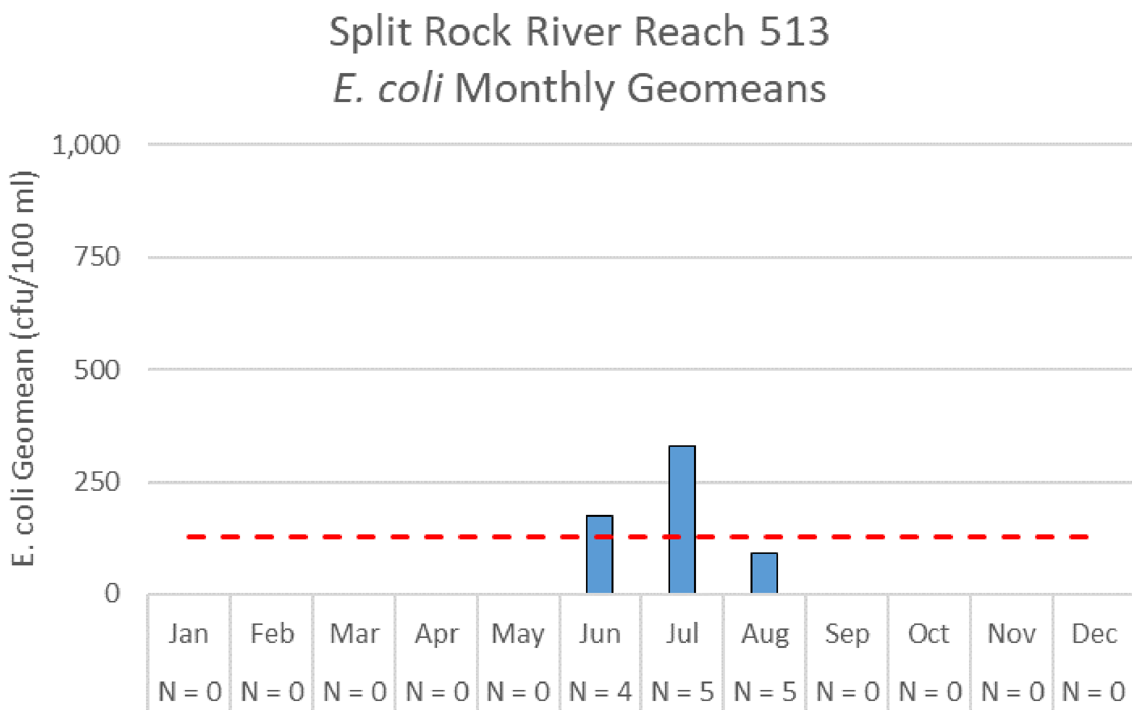


Figure B-6. Split Rock River Reach 513 E. coli Monthly Geomeans.

Table B-2. Split Rock River Reach 513 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) [1]	Horse*	-	-	-	3,096	85.51%
	Swine*	-	-	-		
	Bovine*	53	58.2	3,096		
	Poultry*	-	-	-		
	Other Livestock*,[9]	0	-	-		
Wildlife	Deer [3]	308	0.5	154	401	11.07%
	Waterfowl [4]	617	0.4	247		
Human	Failing Septic Systems [5]	1	5.7	6	6	0.17%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	21	5.6	118	118	3.26%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Supporting Items for South Branch Grindstone River Bacteria Impaired Reach (07030003-516)

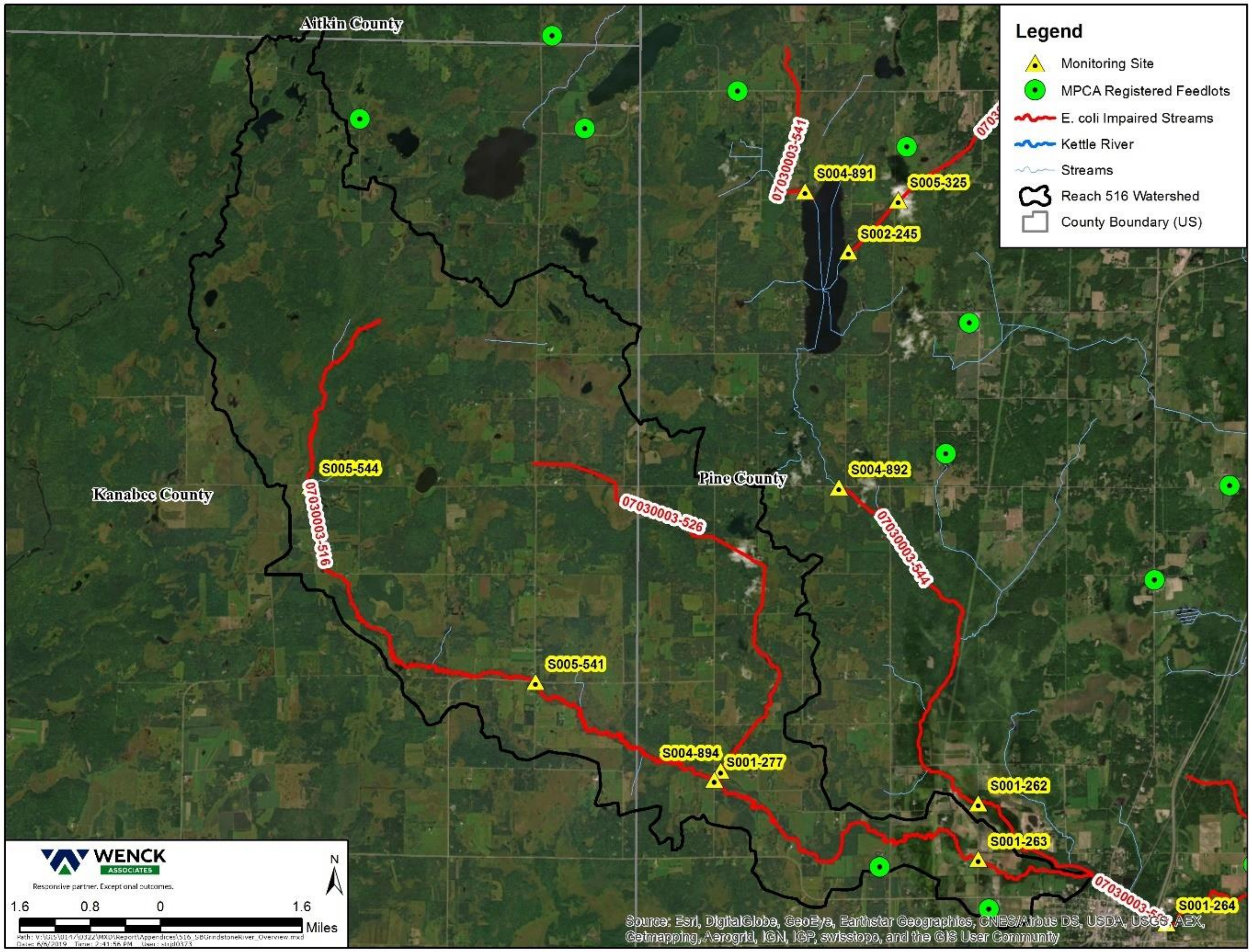


Figure B-7. South Branch Grindstone River Reach 516 Overview.

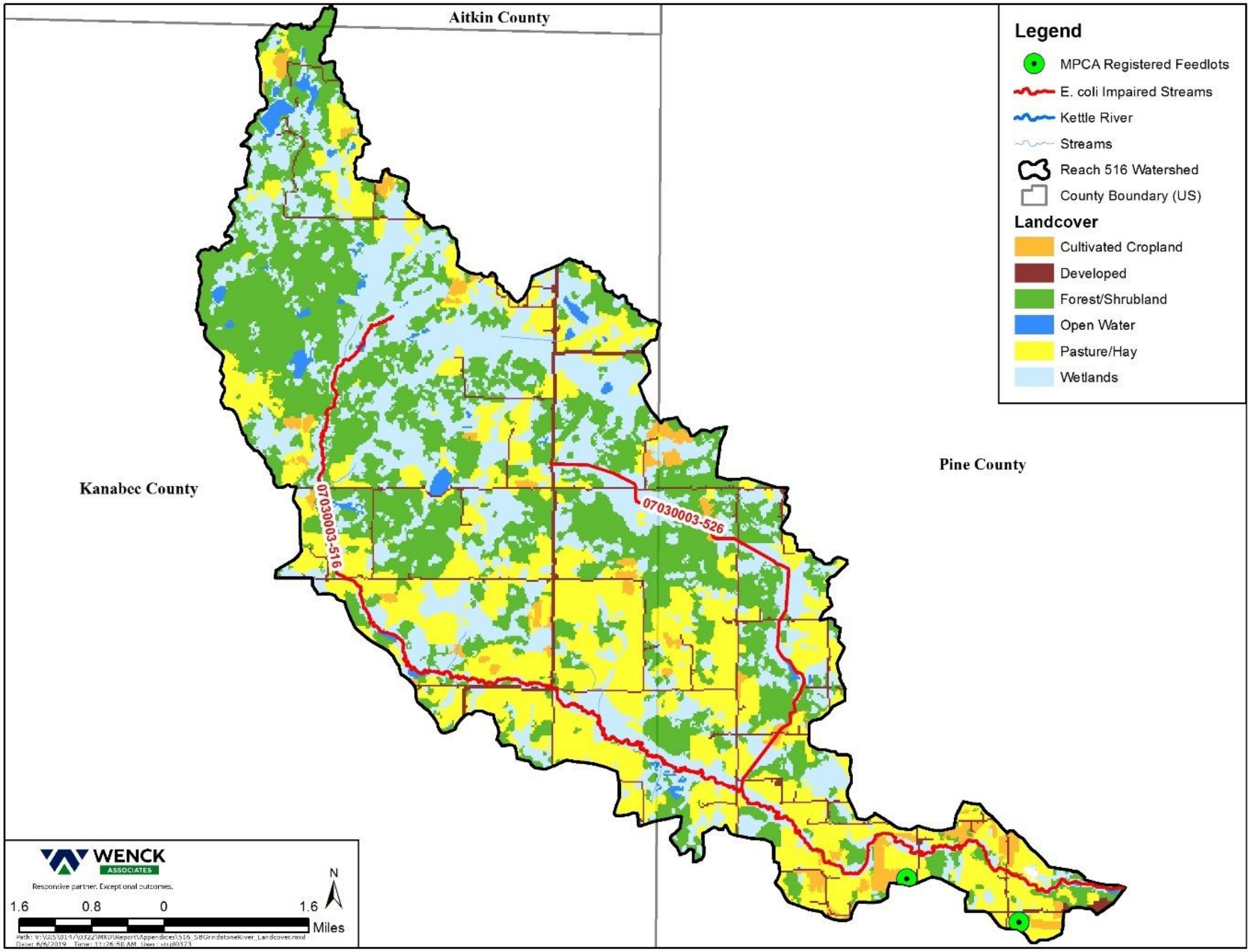


Figure B-8. South Branch Grindstone River Reach 516 Landcover.

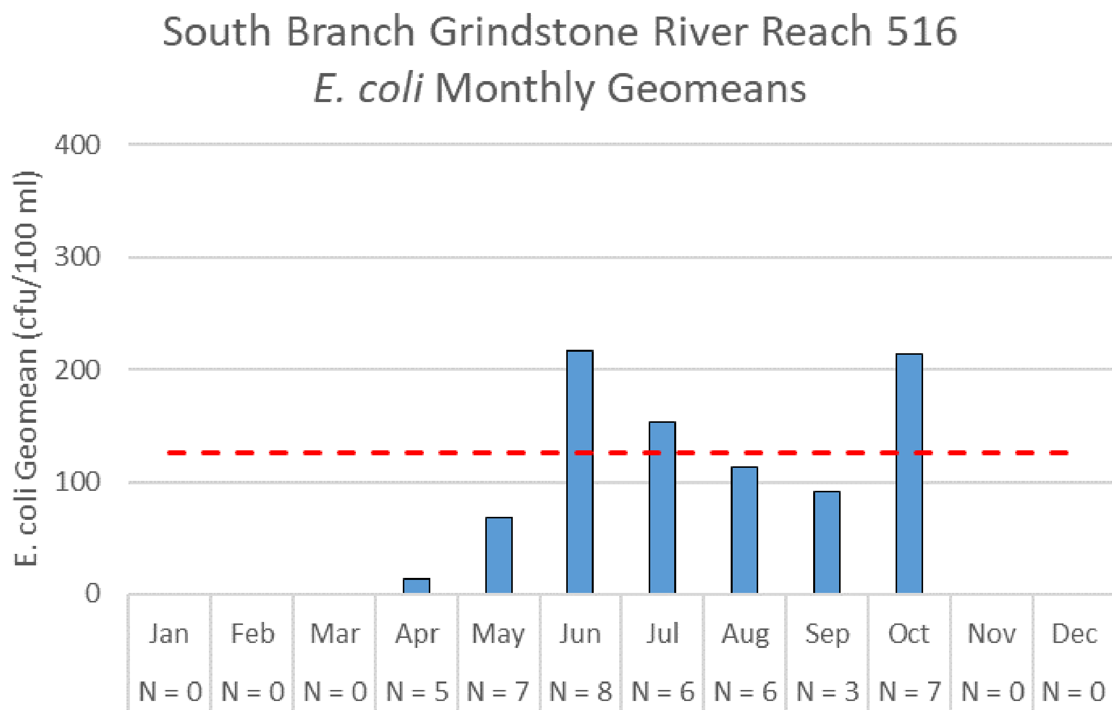


Figure B-9. South Branch Grindstone River Reach 516 E. coli Monthly Geomeans.

Table B-3. South Branch Grindstone River Reach 516 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) [1]	Horse*	-	-	-	15,481	96.30%
	Swine*	-	-	-		
	Bovine*	266	58.2	15,481		
	Poultry*	-	-	-		
	Other Livestock*,[9]	0	-	-		
Wildlife	Deer [3]	280	0.5	140	364	2.27%
	Waterfowl [4]	560	0.4	224		
Human	Failing Septic Systems [5]	6	5.7	32	32	0.20%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	262	0.8	198	198	1.23%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Supporting Items for Judicial Ditch 1 Bacteria Impaired Reach (07030003-526)

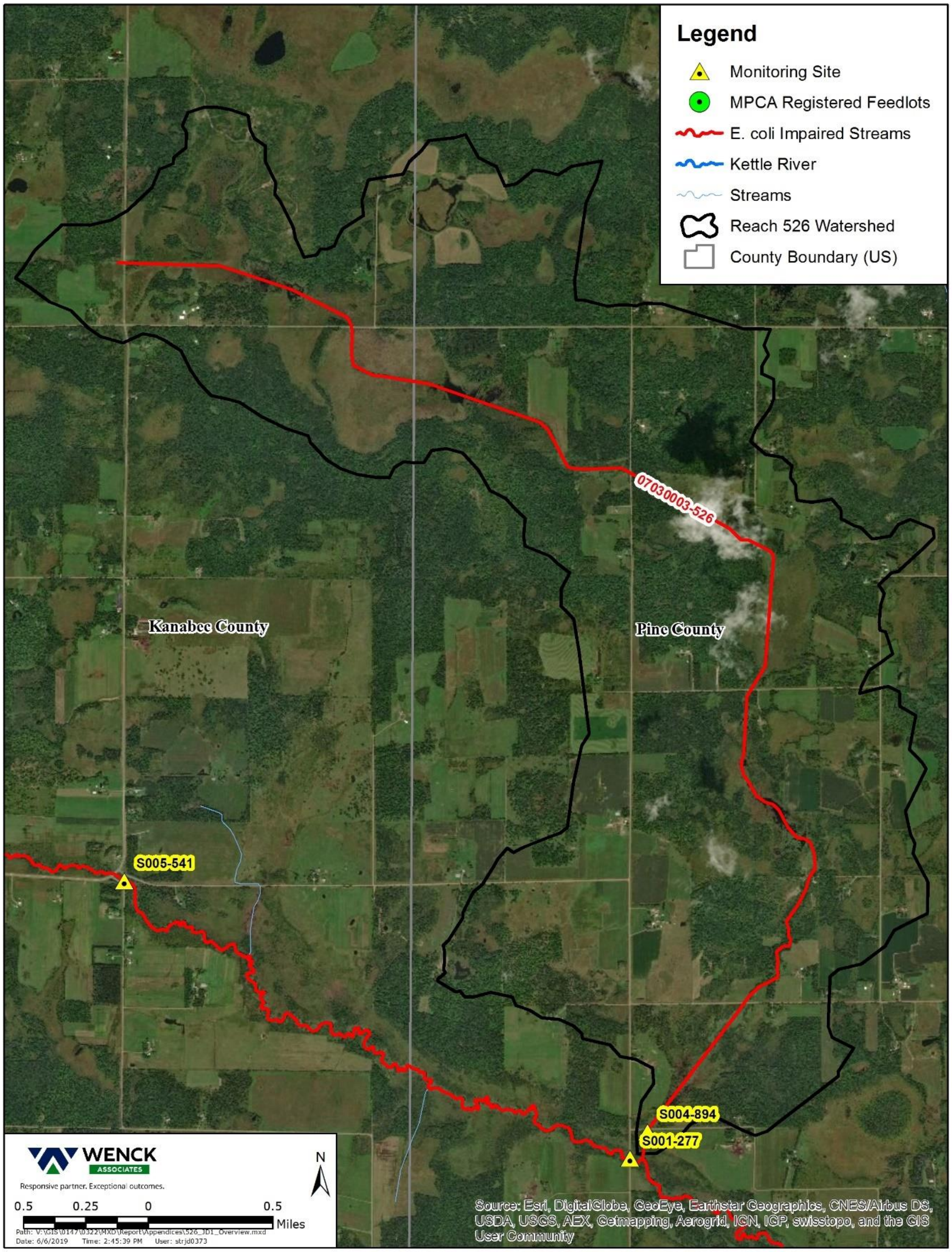


Figure B-10. Judicial Ditch 1 Reach 526 Overview.

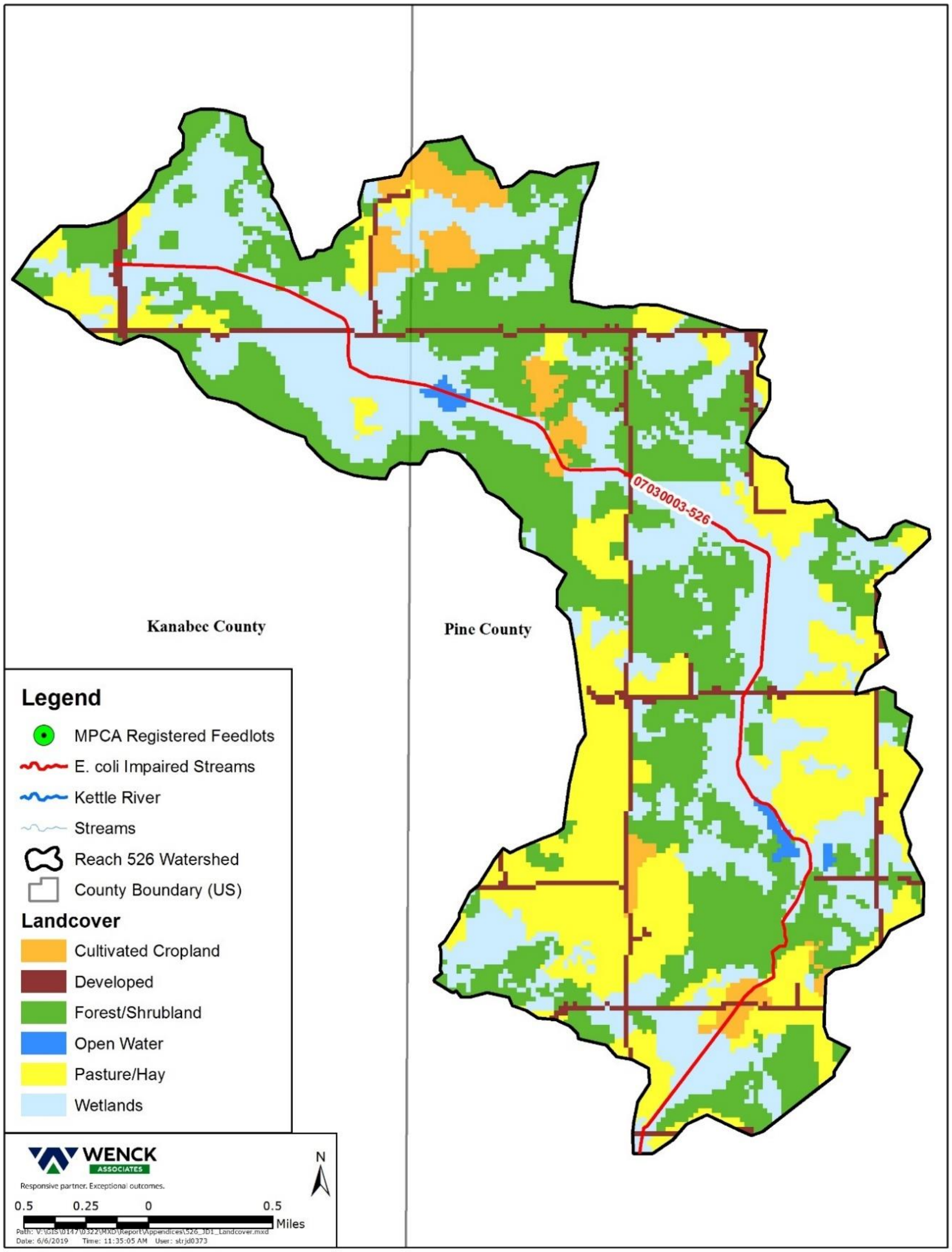


Figure B-11. Judicial Ditch 1 Reach 526 Landcover.

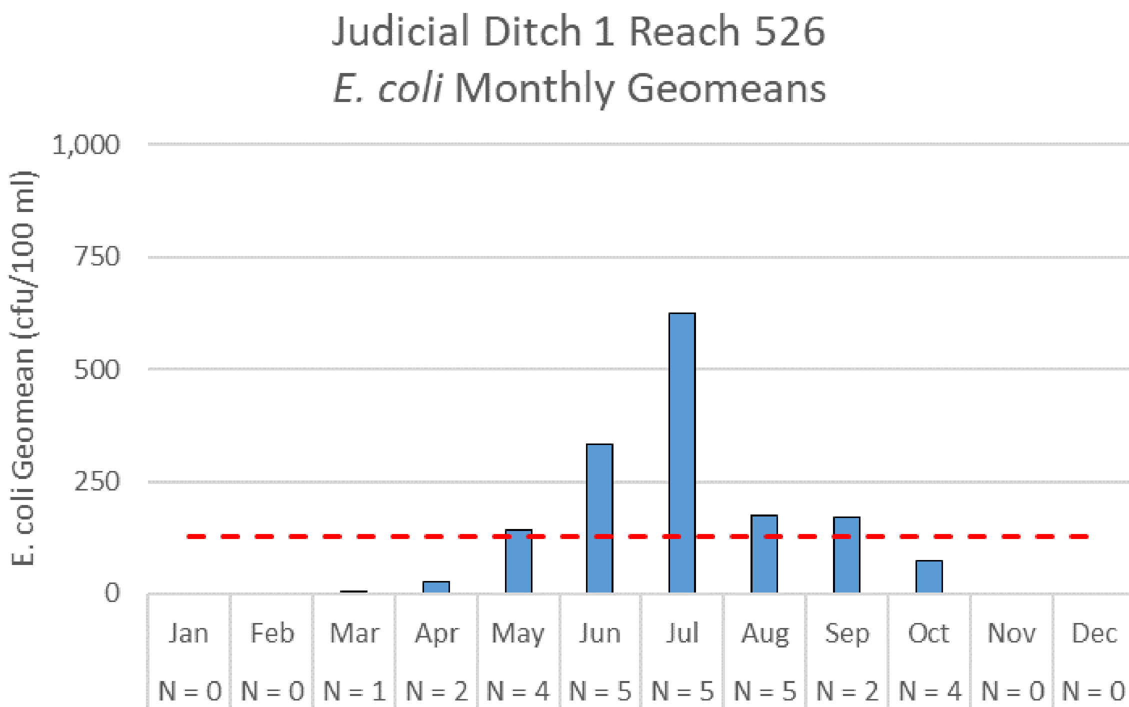


Figure B-12. Judicial Ditch 1 Reach 526 E. coli Monthly Geomeans.

Table B-4. Judicial Ditch 1 Reach 526 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.][8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure)[1]	Horse*	-	-	-	-	0.00%
	Swine*	-	-	-		
	Bovine*	-	-	-		
	Poultry*	-	-	-		
	Other Livestock*,[9]	0	-	-		
Wildlife	Deer[3]	30	0.5	15	39	39.25%
	Waterfowl[4]	60	0.4	24		
Human	Failing Septic Systems[5]	1	5.7	8	8	7.59%
	WWTP effluent[6]	-	-	-		
Domestic Animals[2]	Improperly Managed Pet Waste[7]	84	0.6	53	53	53.17%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Supporting Items for Kettle River Bacteria Impaired Reach (07030003-529)

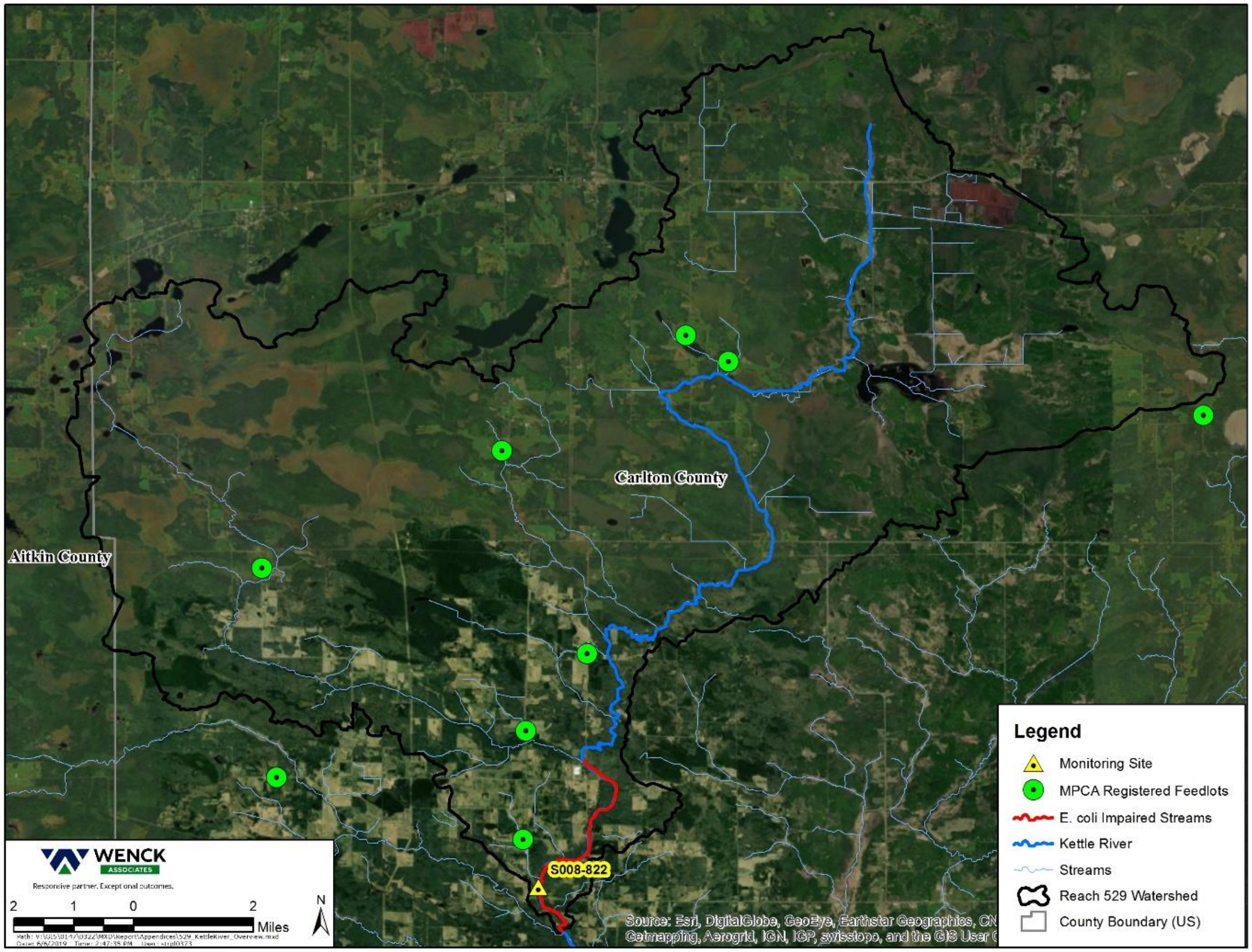


Figure B-13. Kettle River Reach 529 Overview.

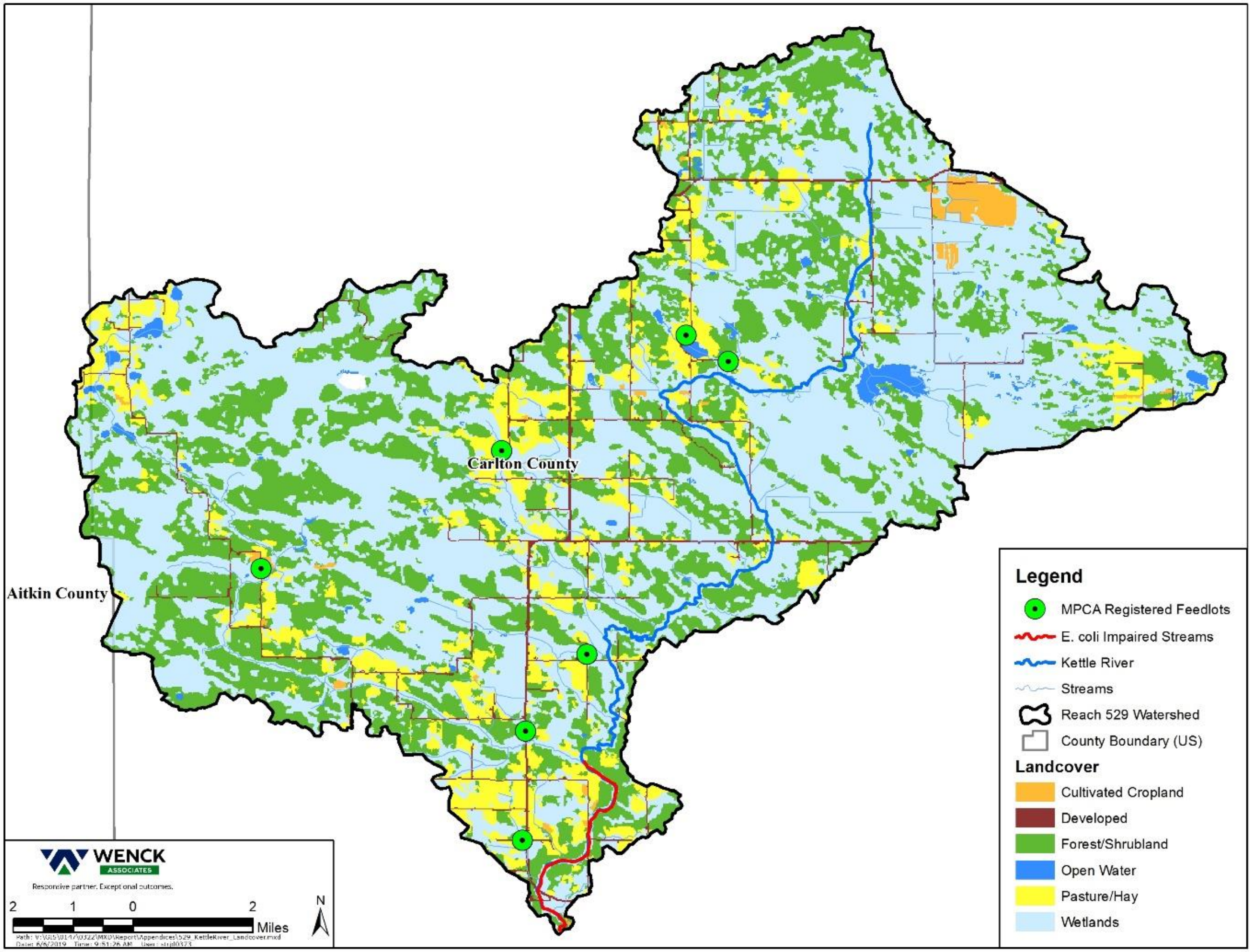


Figure B-14. Kettle River Reach 529 Landcover.

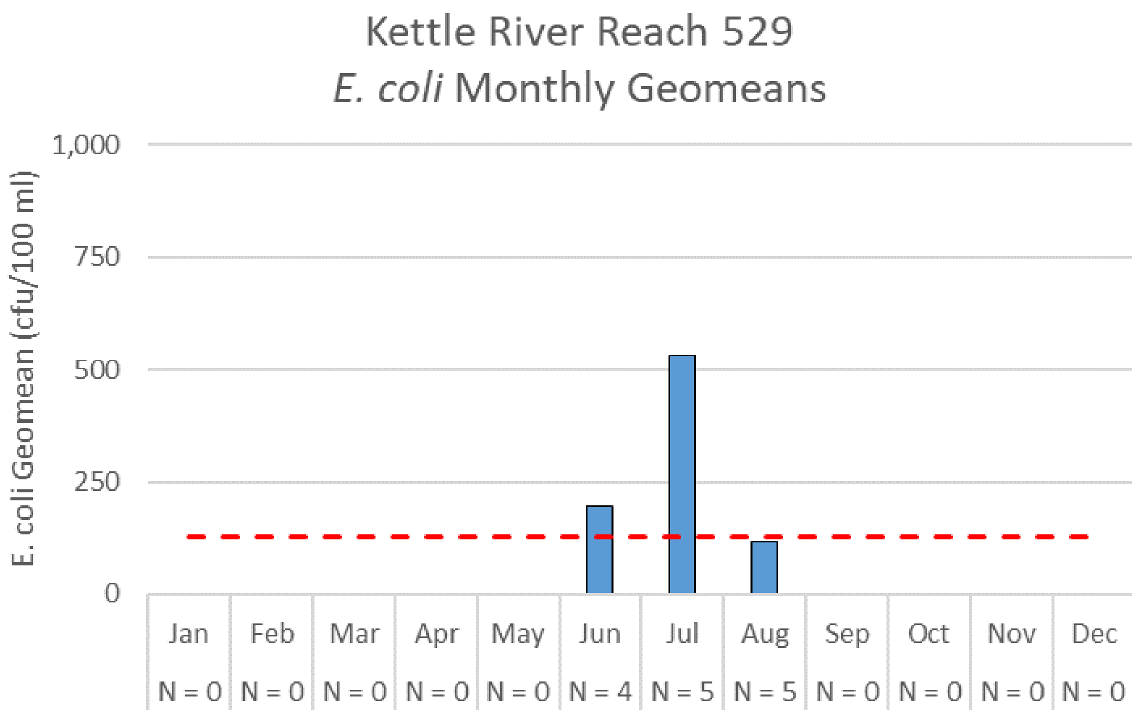


Figure B-15. Kettle River Reach 529 E. coli Monthly Geomeans.

Table B-5. Kettle River Reach 529 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) [1]	Horse*	4	58.2	233	17,204	91.88%
	Swine*	-	-	-		
	Bovine*	290	58.2	16,890		
	Poultry*	-	-	-		
	Other Livestock*,[9]	3	32.7	82		
Wildlife	Deer [3]	632	0.5	316	821	4.39%
	Waterfowl [4]	1,264	0.4	506		
Human	Failing Septic Systems [5]	6	5.7	34	34	0.18%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	-	-	665	665	3.55%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Supporting Items for North Branch Grindstone River Bacteria Impaired Reach (07030003-541)

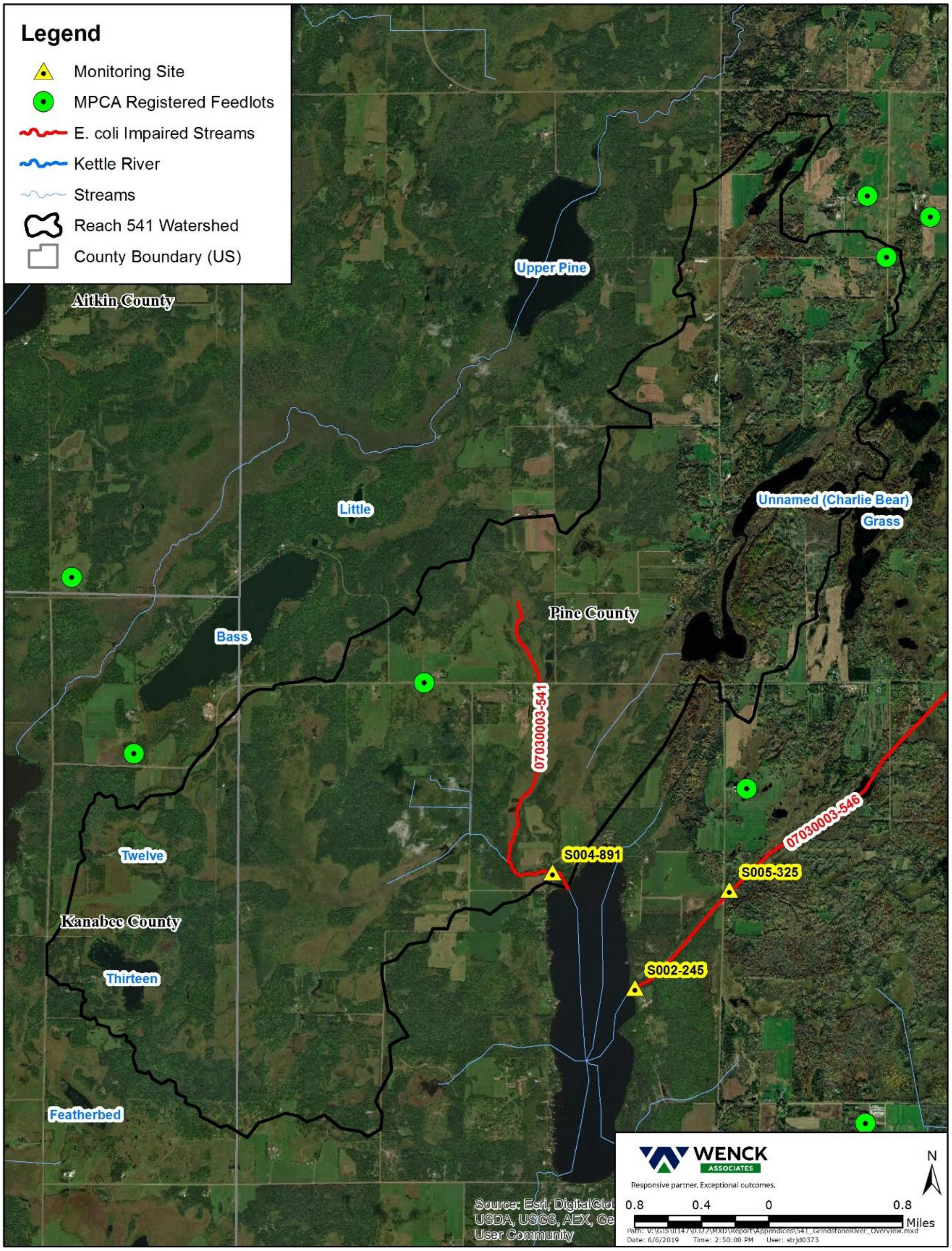


Figure B-16. North Branch Grindstone River Reach 541 Overview.

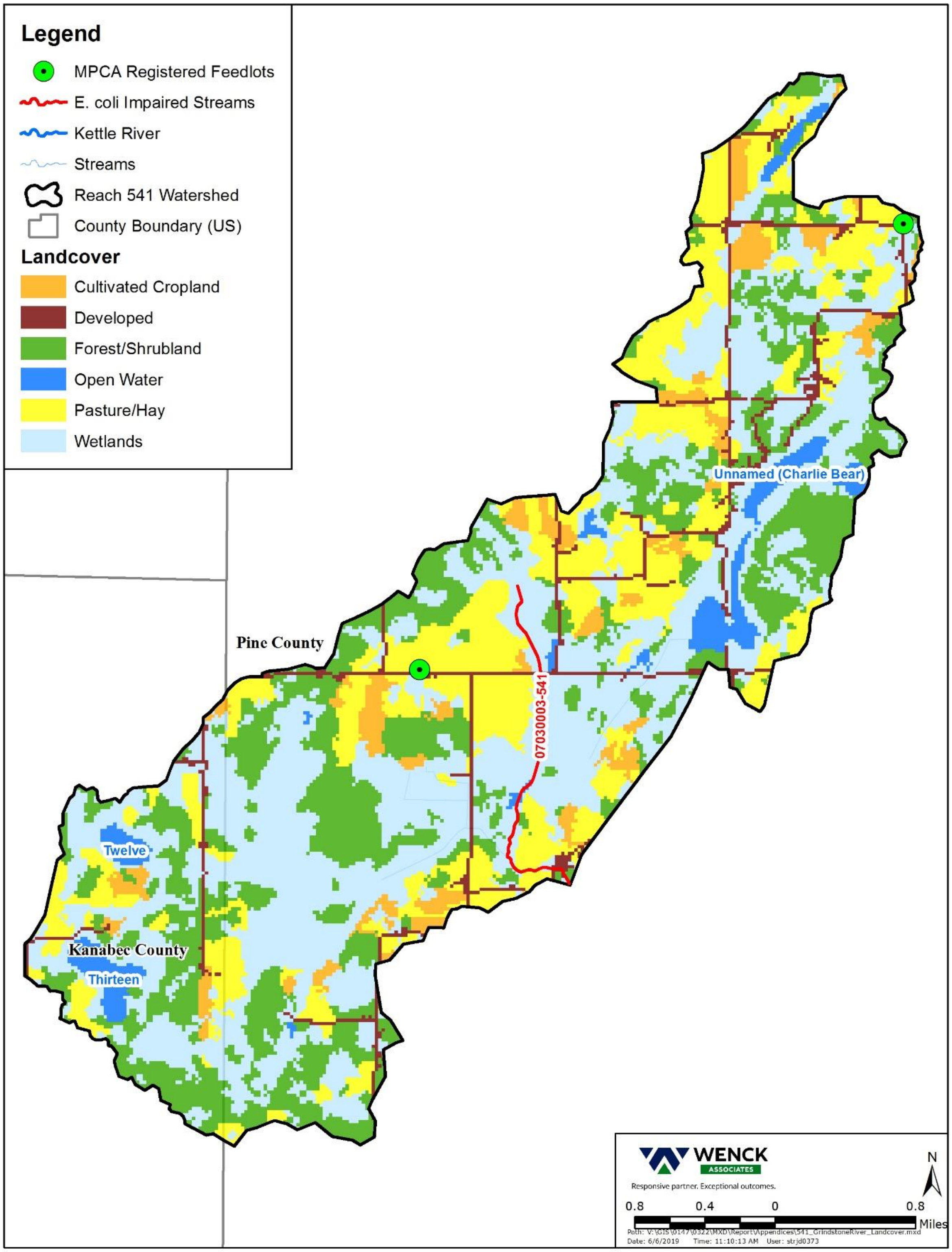


Figure B-17. North Branch Grindstone River Reach 541 Landcover.

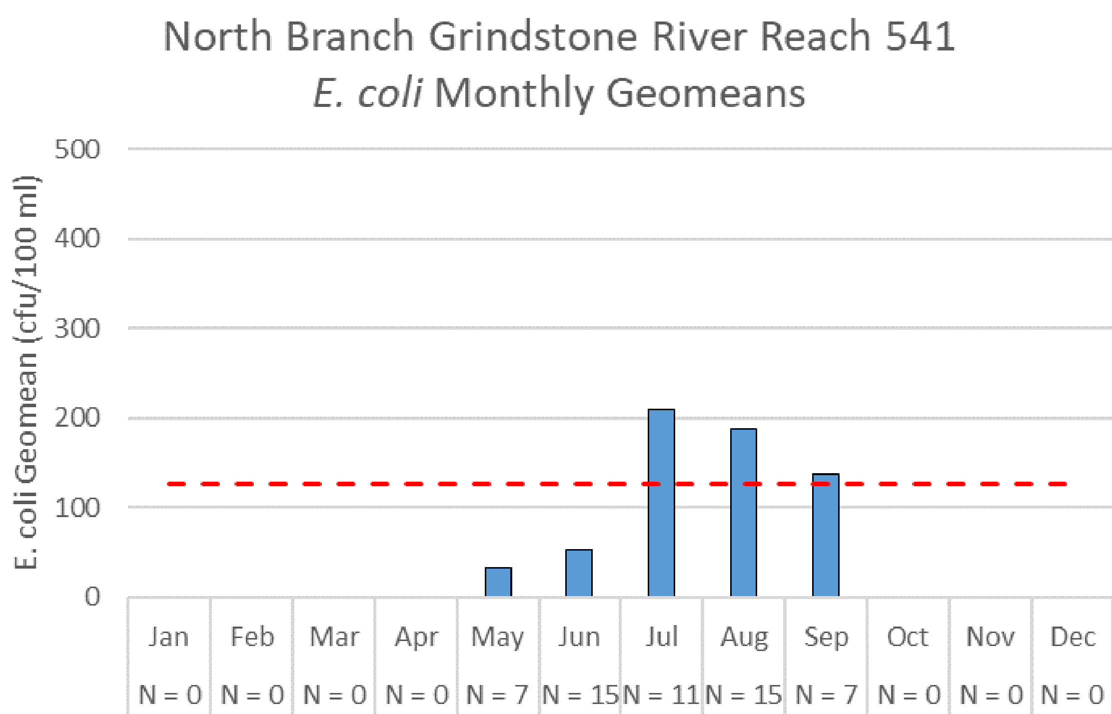


Figure B-18. North Branch Grindstone River Reach 541 E. coli Monthly Geomeans.

Table B-6. North Branch Grindstone River Reach 541 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) [1]	Horse*	-	-	-	17,152	98.97%
	Swine*	-	-	-		
	Bovine*	295	58.2	17,152		
	Poultry*	-	-	-		
	Other Livestock*,[9]	0	-	-		
Wildlife	Deer [3]	56	0.5	28	73	0.42%
	Waterfowl [4]	112	0.4	45		
Human	Failing Septic Systems [5]	2	5.7	13	13	0.07%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	156	0.6	93	93	0.54%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Supporting Items for North Branch Grindstone River Bacteria Impaired Reach (07030003-544)

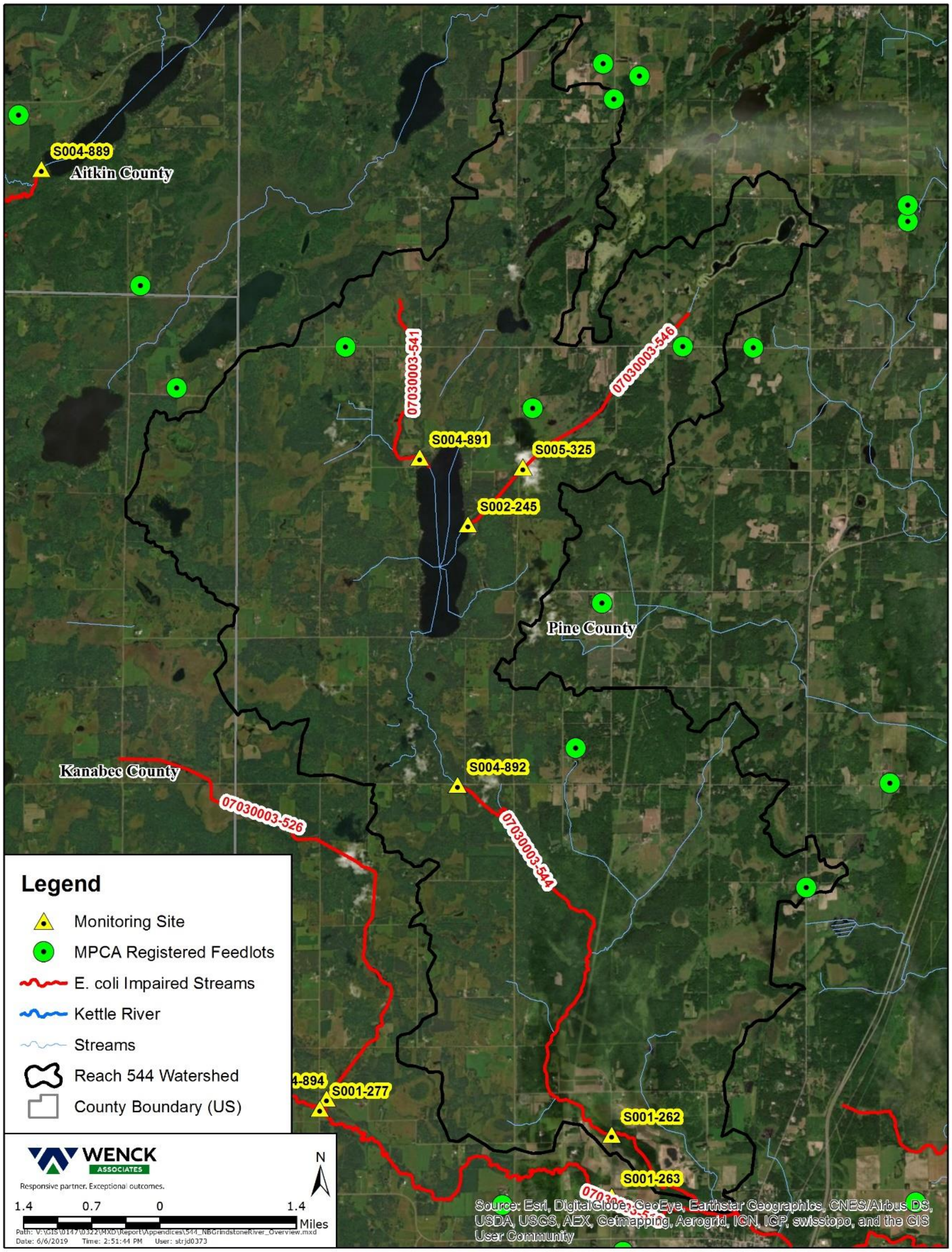


Figure B-19. North Branch Grindstone River Reach 544 Overview.

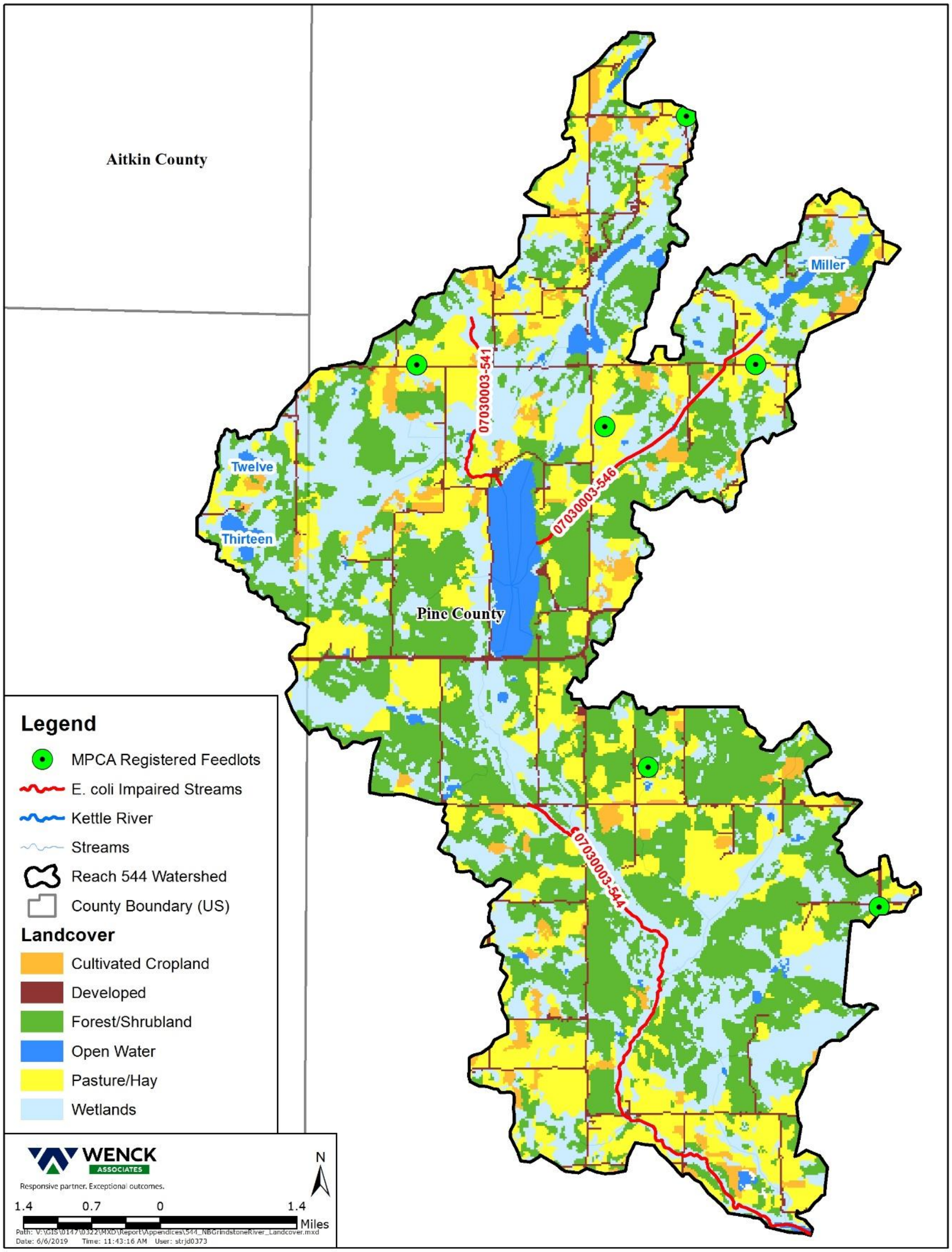


Figure B-20. North Branch Grindstone River Reach 544 Landcover.

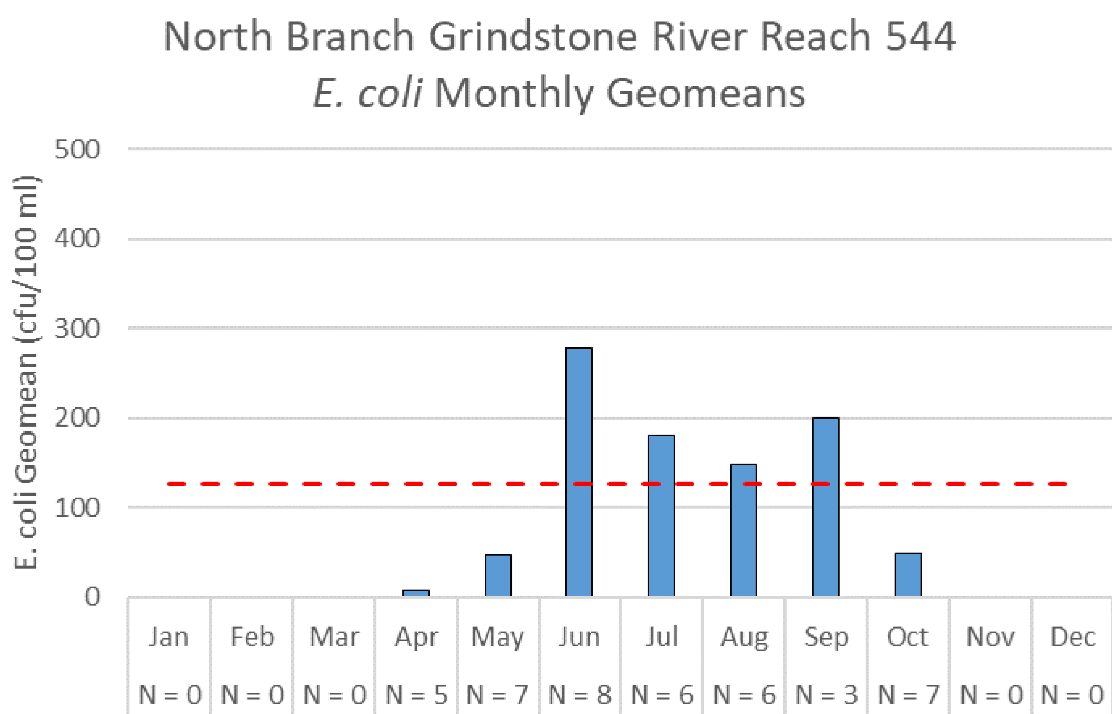


Figure B-21. North Branch Grindstone River Reach 544 E. coli Monthly Geomeans.

Table B-7. North Branch Grindstone River Reach 544 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) [1]	Horse*	-	-	-	62,099	98.66%
	Swine*	-	-	-		
	Bovine*	1,067	58.2	62,099		
	Poultry*	-	-	-		
	Other Livestock*,[9]	0	-	-		
Wildlife	Deer [3]	205	0.5	102	266	0.42%
	Waterfowl [4]	410	0.4	164		
Human	Failing Septic Systems [5]	12	5.7	67	67	0.11%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	904	0.6	514	514	0.82%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Supporting Items for Unnamed Creek Bacteria Impaired Reach (07030003-546)

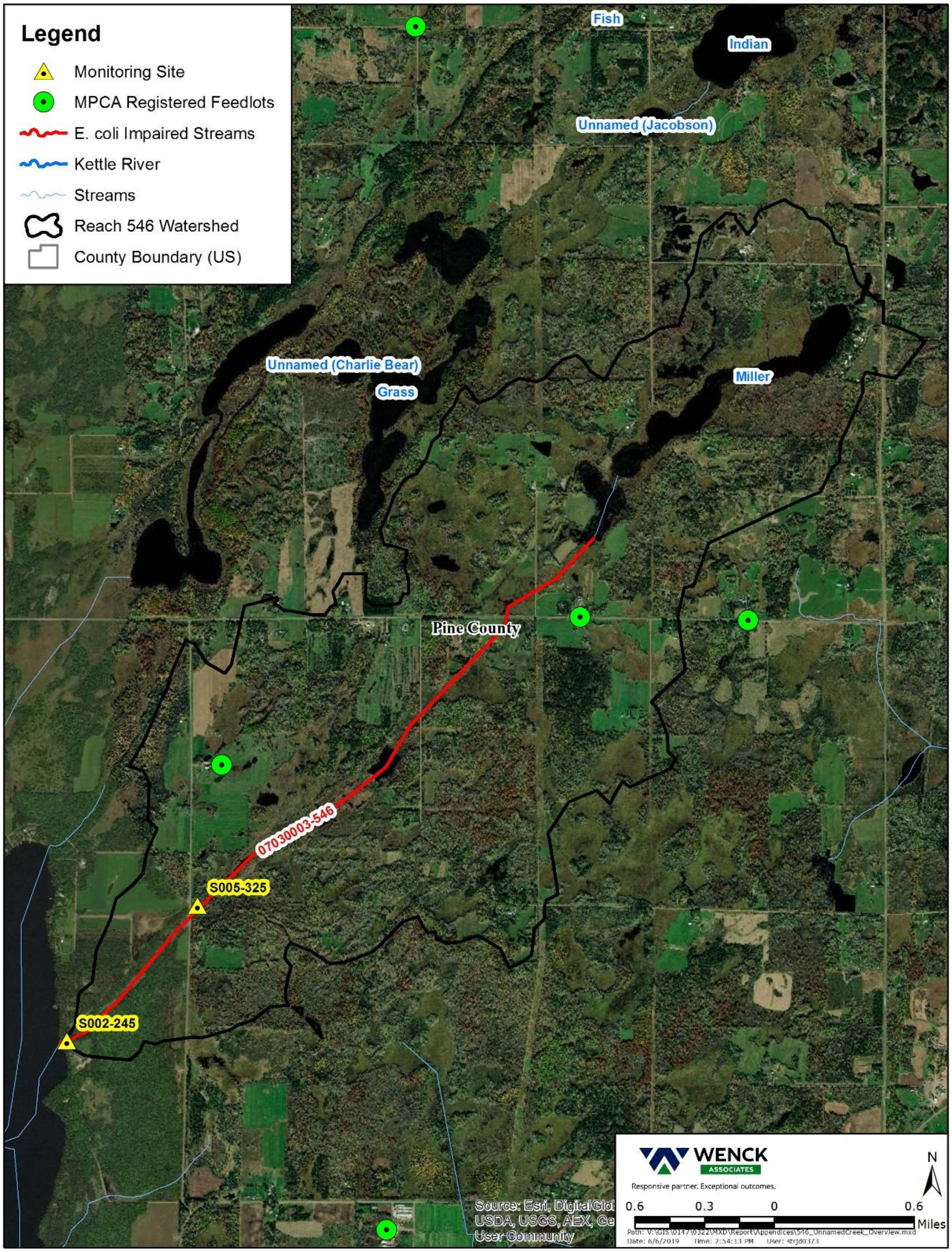


Figure B-22. Unnamed Creek Reach 546 Overview.

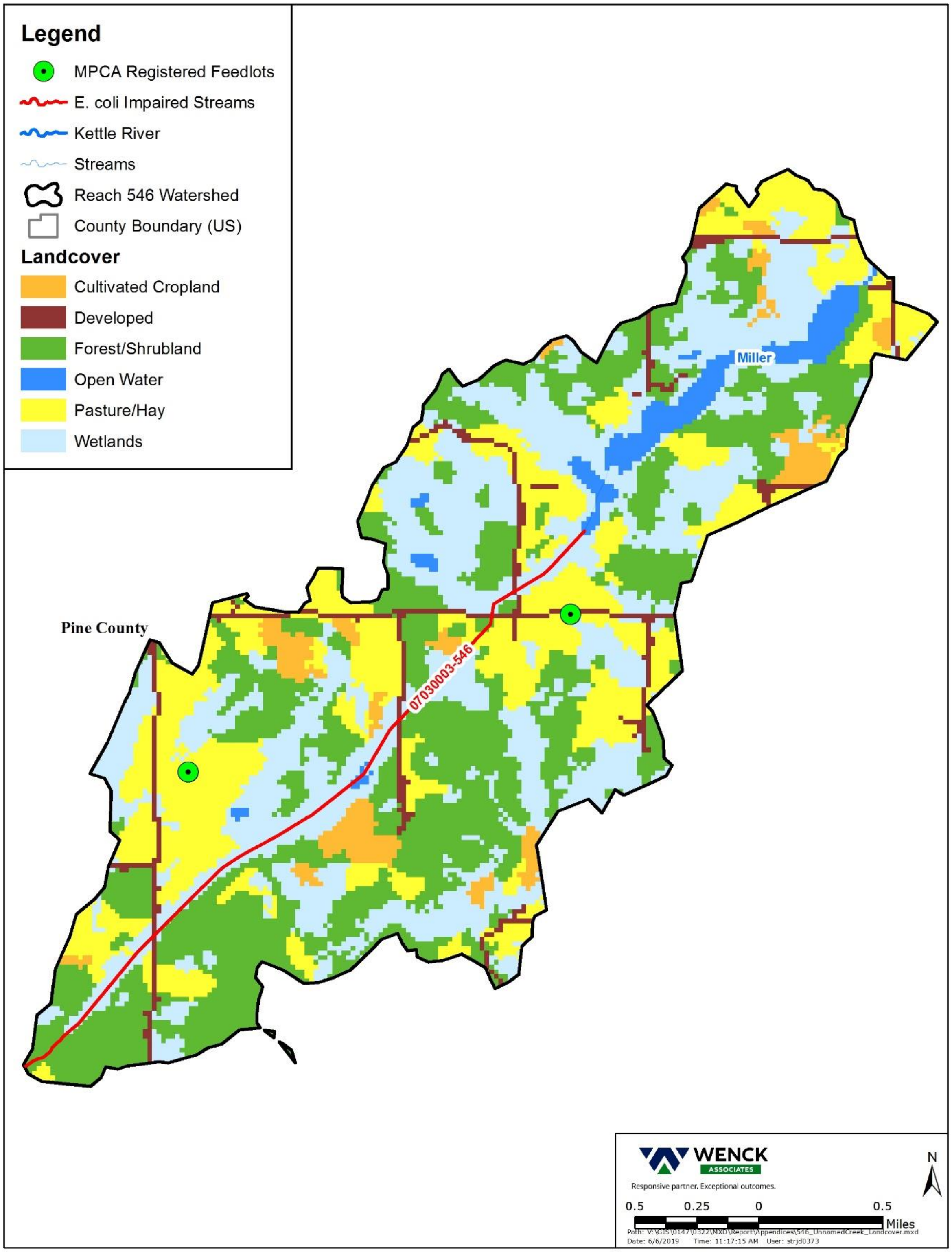


Figure B-23. Unnamed Creek Reach 546 Landcover.

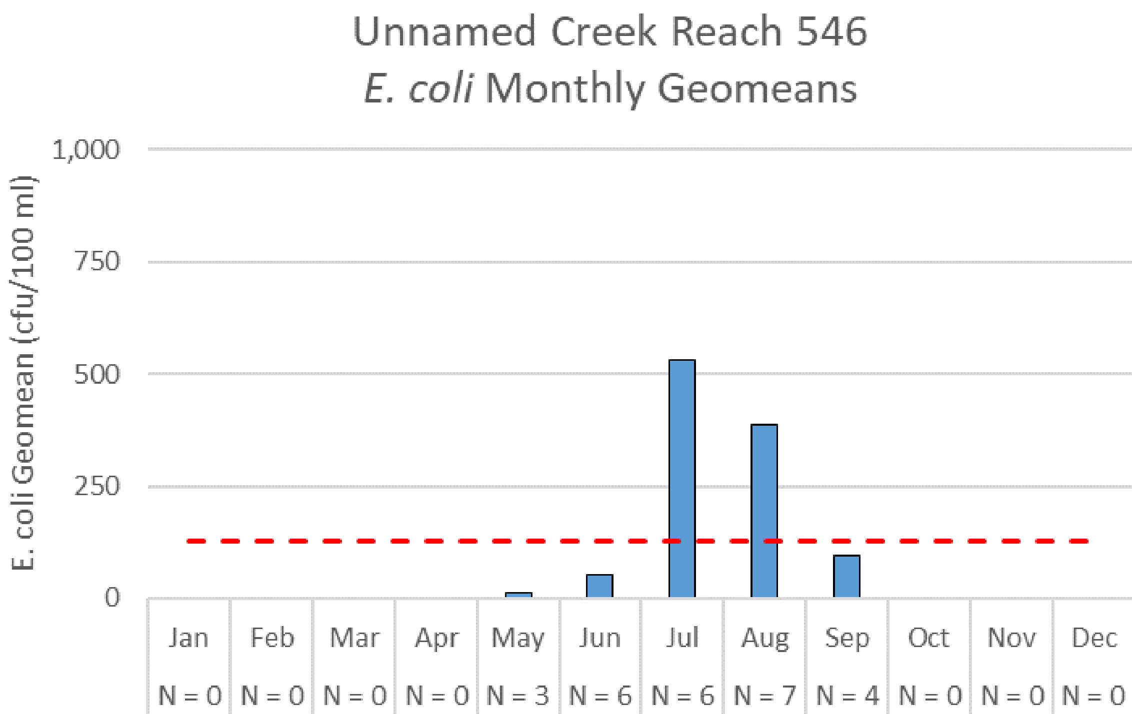


Figure B-24. Unnamed Creek Reach 546 E. coli Monthly Geomeans.

Table B-8. Unnamed Creek Reach 546 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) [1]	Horse*	-	-	-	29,828	99.71%
	Swine*	-	-	-		
	Bovine*	513	58.2	29,828		
	Poultry*	-	-	-		
	Other Livestock*,[9]	0	-	-		
Wildlife	Deer [3]	27	0.5	14	35	0.12%
	Waterfowl [4]	54	0.4	22		
Human	Failing Septic Systems [5]	1	5.7	6	6	0.02%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	83	0.6	46	46	0.16%

* Values reported as Animal Units.
[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).
[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)
[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)
[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)
[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.
[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)
[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)
[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.
[9] Other cattle include llama, goat, and sheep.

Supporting Items for Spring Creek Bacteria Impaired Reach (07030003-550)

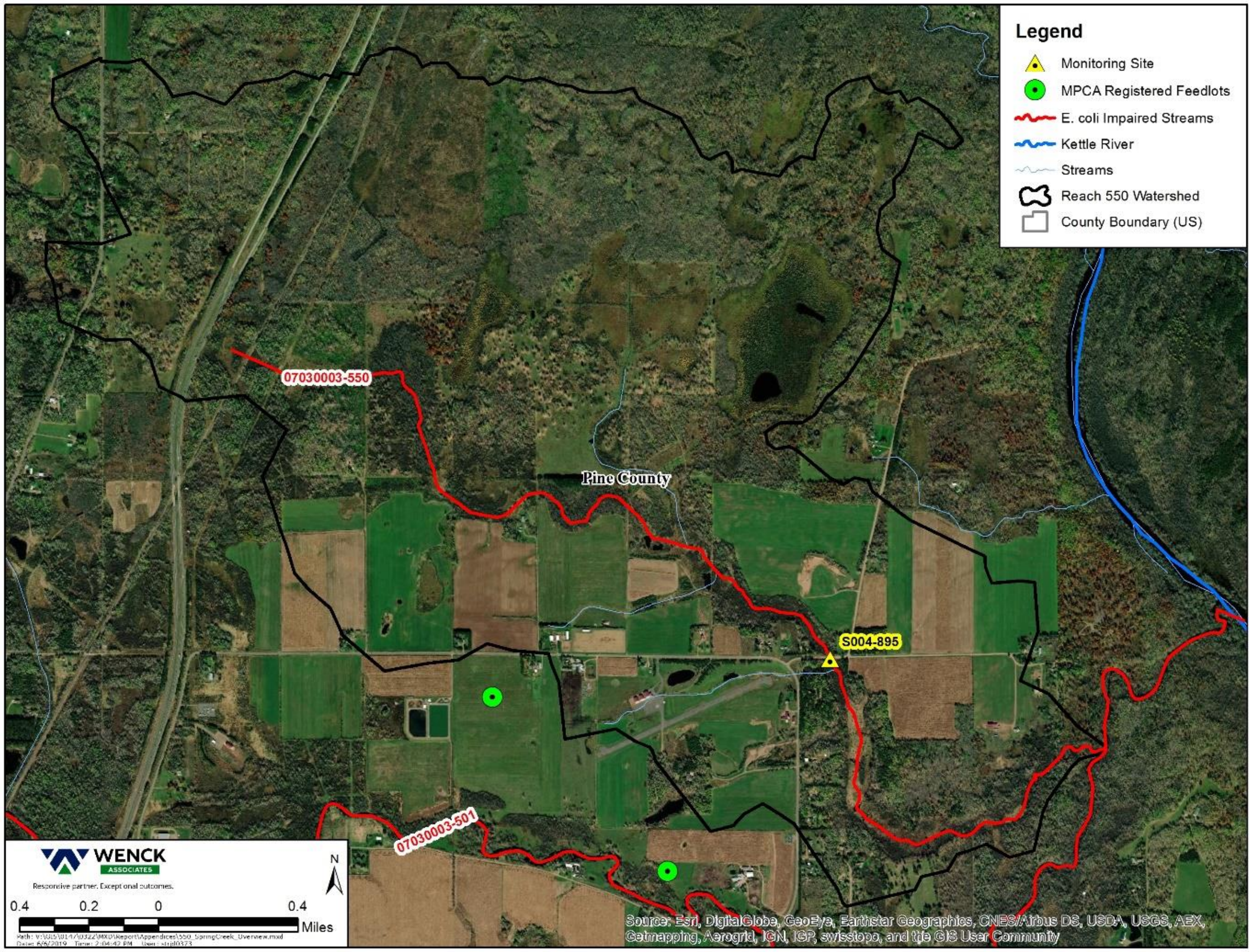


Figure B-25. Spring Creek Reach 550 Overview.

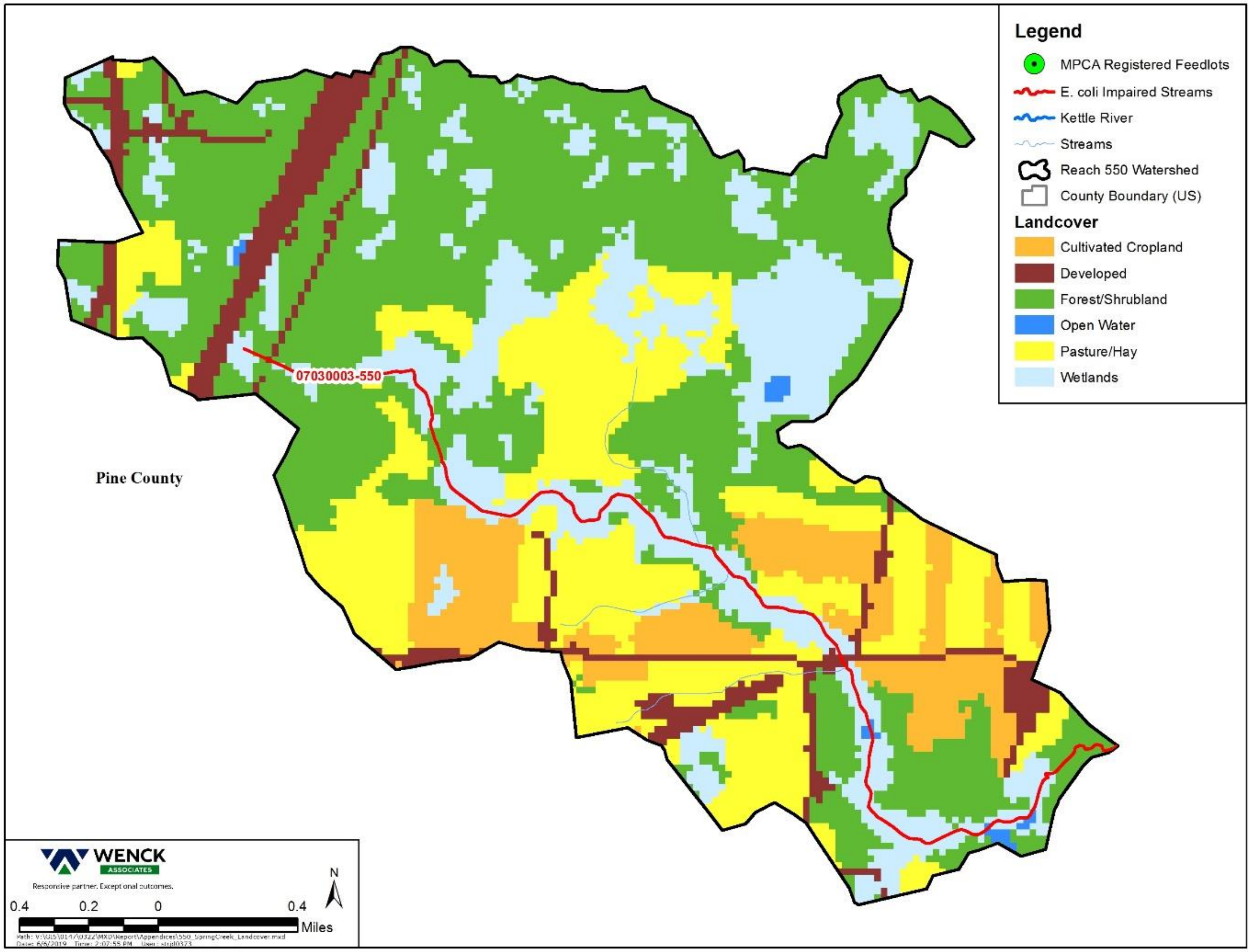


Figure B-26. Spring Creek Reach 550 Landcover.

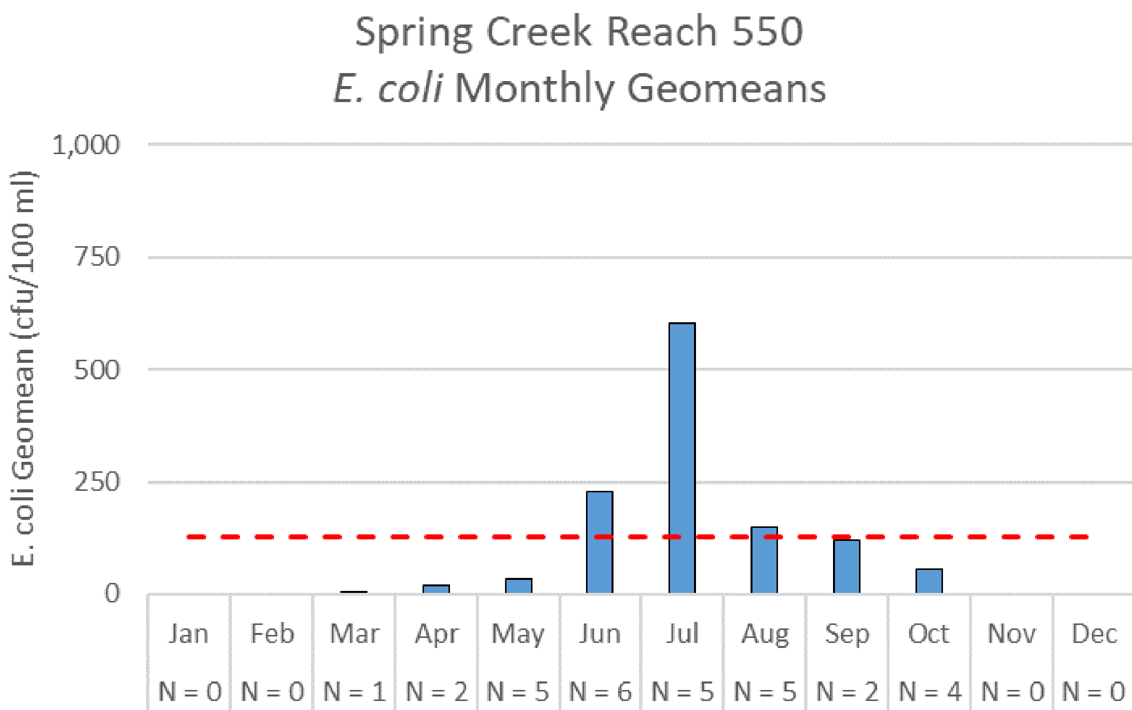


Figure B-27. Spring Creek Reach 550 E. coli Monthly Geomeans.

Table B-9. Spring Creek Reach 550 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] 8	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) 1	Horse*	-	-	-	-	0.00%
	Swine*	-	-	-		
	Bovine*	-	-	-		
	Poultry*	-	-	-		
	Other Livestock*,9	0	-	-		
Wildlife	Deer 3	20	0.5	10	26	33.02%
	Waterfowl 4	41	0.4	16		
Human	Failing Septic Systems 5	1	5.7	6	6	6.99%
	WWTP effluent 6	-	-	-		
Domestic Animals 2	Improperly Managed Pet Waste 7	85	0.6	48	48	59.99%

* Values reported as Animal Units.

1 Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

2 # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

3 Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

4 Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

5 based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

6 Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

7 Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

8 Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

9 Other cattle include llama, goat, and sheep.

Supporting Items for Pine River Bacteria Impaired Reach (07030003-631)

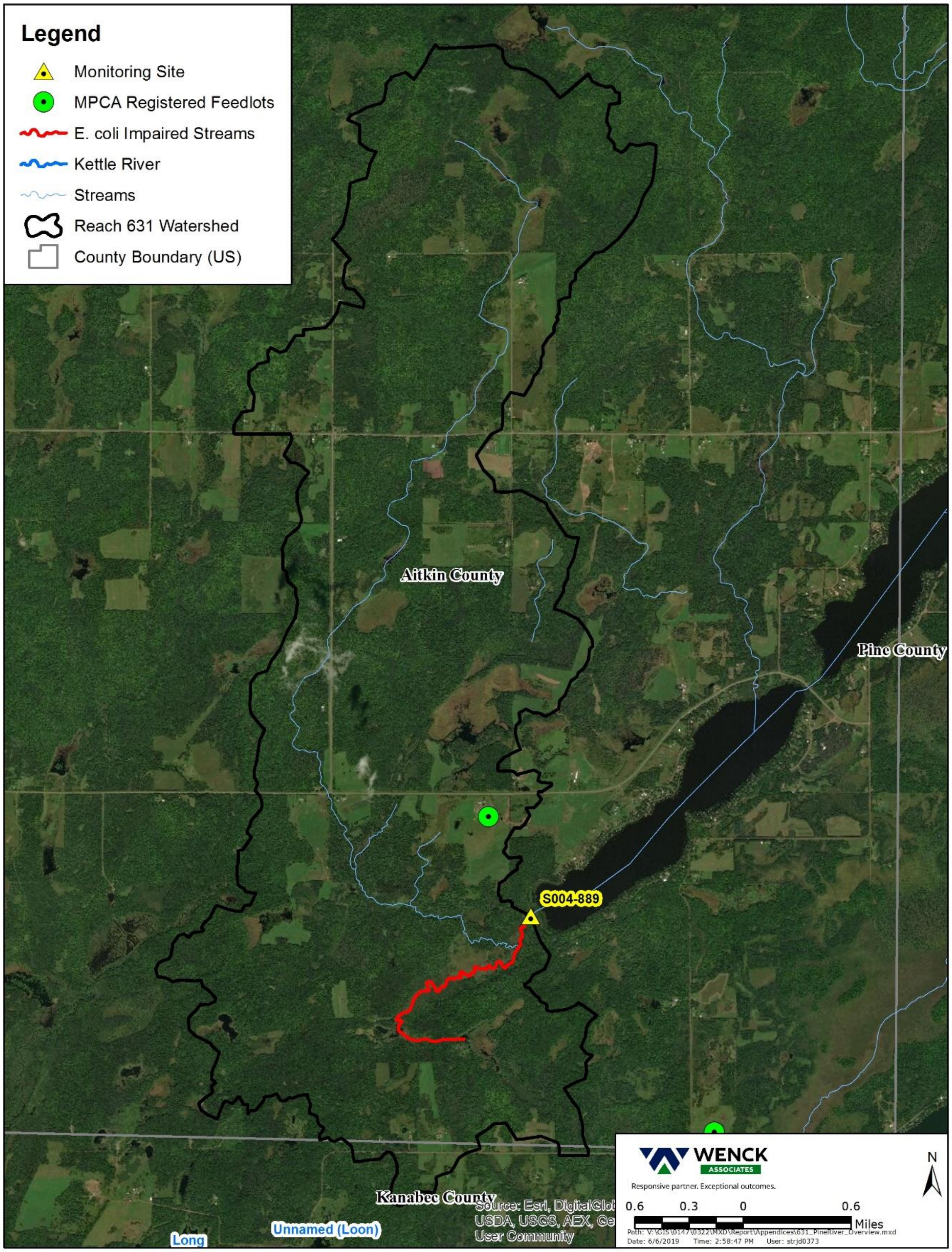


Figure B-28. Pine River Reach 631 Overview.

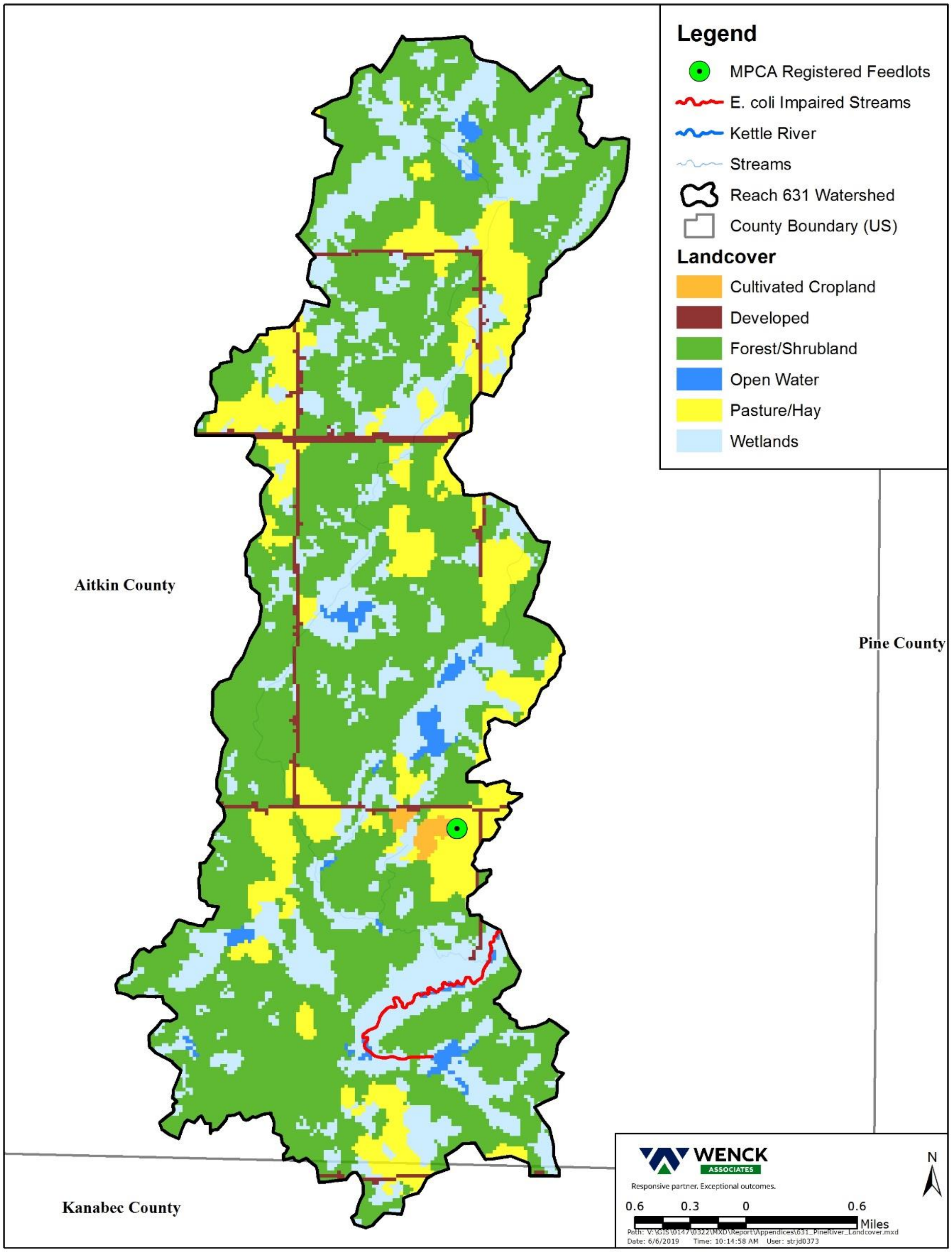


Figure B-29. Pine River Reach 631 Landcover.

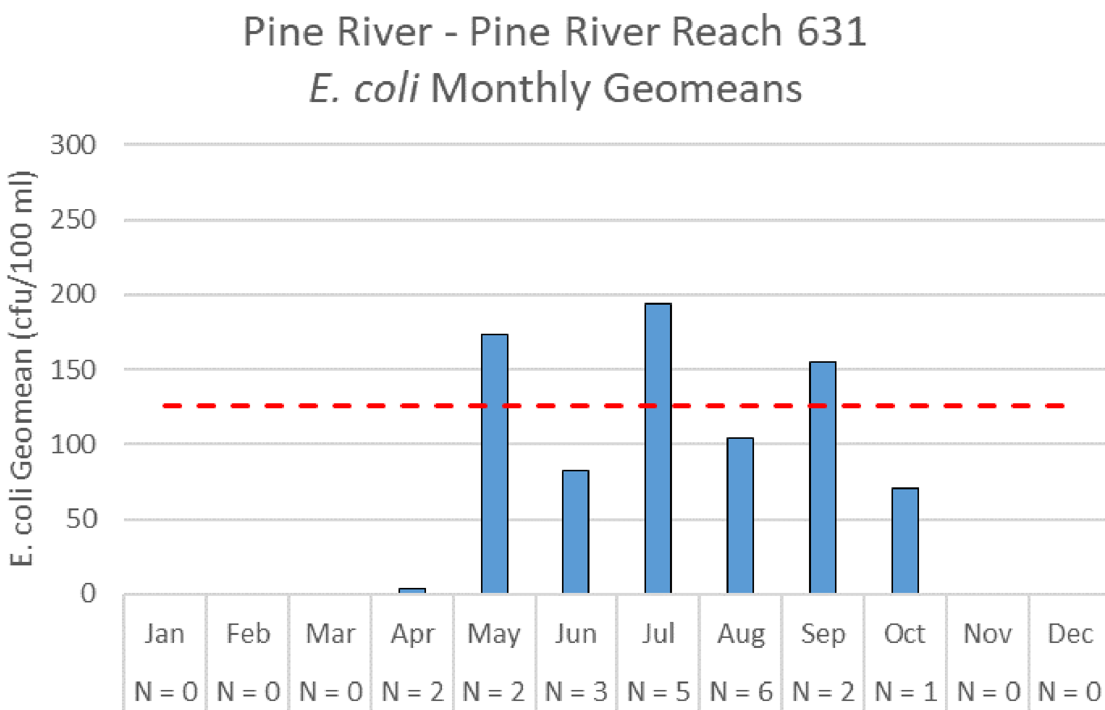


Figure B-30. Pine River Reach 631 E. coli Monthly Geomeans.

Table B-10. Pine River Reach 631 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8]	Total Fecal Bacteria Produced Per Day [Billions of Org.]	Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.]	Percent by Category
Livestock (Surface Applied Manure) [1]	Horse*	8	58.2	466	5,546	98.09%
	Swine*	-	-	-		
	Bovine*	87	58.2	5,081		
	Poultry*	-	-	-		
	Other Livestock*,[9]	0	-	-		
Wildlife	Deer [3]	47	0.5	23	61	1.08%
	Waterfowl [4]	94	0.4	38		
Human	Failing Septic Systems [5]	0	5.7	1	1	0.02%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	-	-	46	46	0.81%

* Values reported as Animal Units.

[1] Livestock animal units estimated based on MPCA registered feedlot database with animal units converted based on MN Dept. of Ag conversion units (http://www.mda.state.mn.us/animals/feedlots/feedlot-dmt/feedlot-dmt-animal-units.aspx).

[2] # of households in watershed multiplied by 0.58 dogs/ household and 0.73 cates/household according to the SE MN Regional TMDL (MPCA, 2002)

[3] Assumes average deer density of .0078 deer/acre from Monitoring Population Trends of White-tailed Deer in Minnesota (Minnesota DNR, 2013)

[4] Estimated from the MN DNR and US Fish & Wildlife Service 2018 Waterfowl Breeding Population Survey (Minnesota DNR, 2018)

[5] based on county SSTS inventory failure rates reported to MPCA (MPCA personal communication, 2018) and rural population estimates (3 persons/ septic) based on 2010 Census blocks.

[6] Reported as # of facilities with production based on WWTP effluent data from facility discharge monitoring reports (DMRs)

[7] Estimated that 35% of the bacteria produced per month attributed to pet waste is improperly managed and available for runoff (CWP, 1999)

[8] Derived from literature rates in Metcalf and Eddy (1991), Horsley and Witten (1996), Alderisio and De Luca (1999), ASAE Standards (1998) and the Southeast Minnesota Regional TMDL (MPCA, 2002). Values have been reported to two significant digits.

[9] Other cattle include llama, goat, and sheep.

Appendix C - Lake Impairment Supporting Items

Supporting Items for Big Pine Lake (58-0138-00)

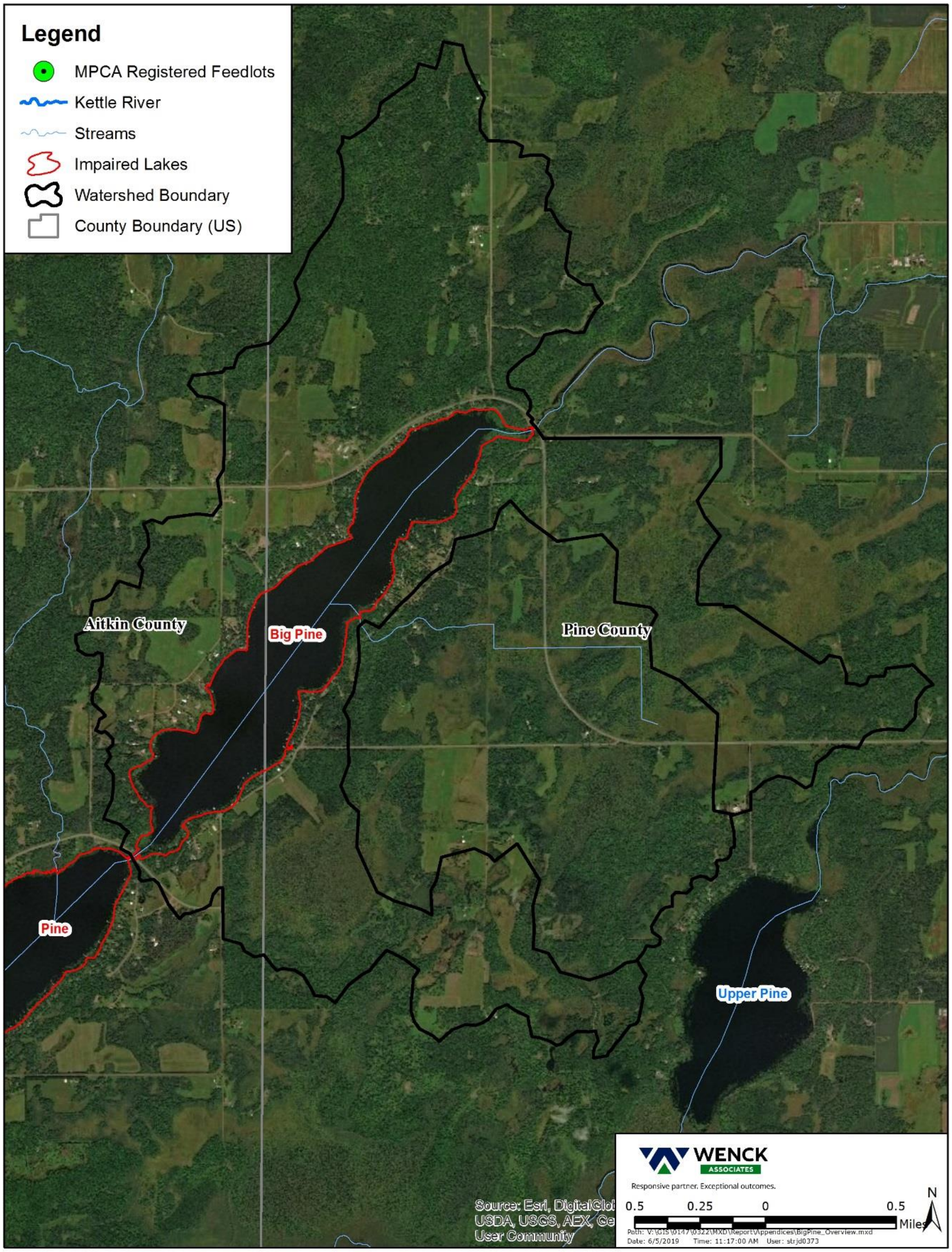


Figure C-1. Big Pine Lake Overview.

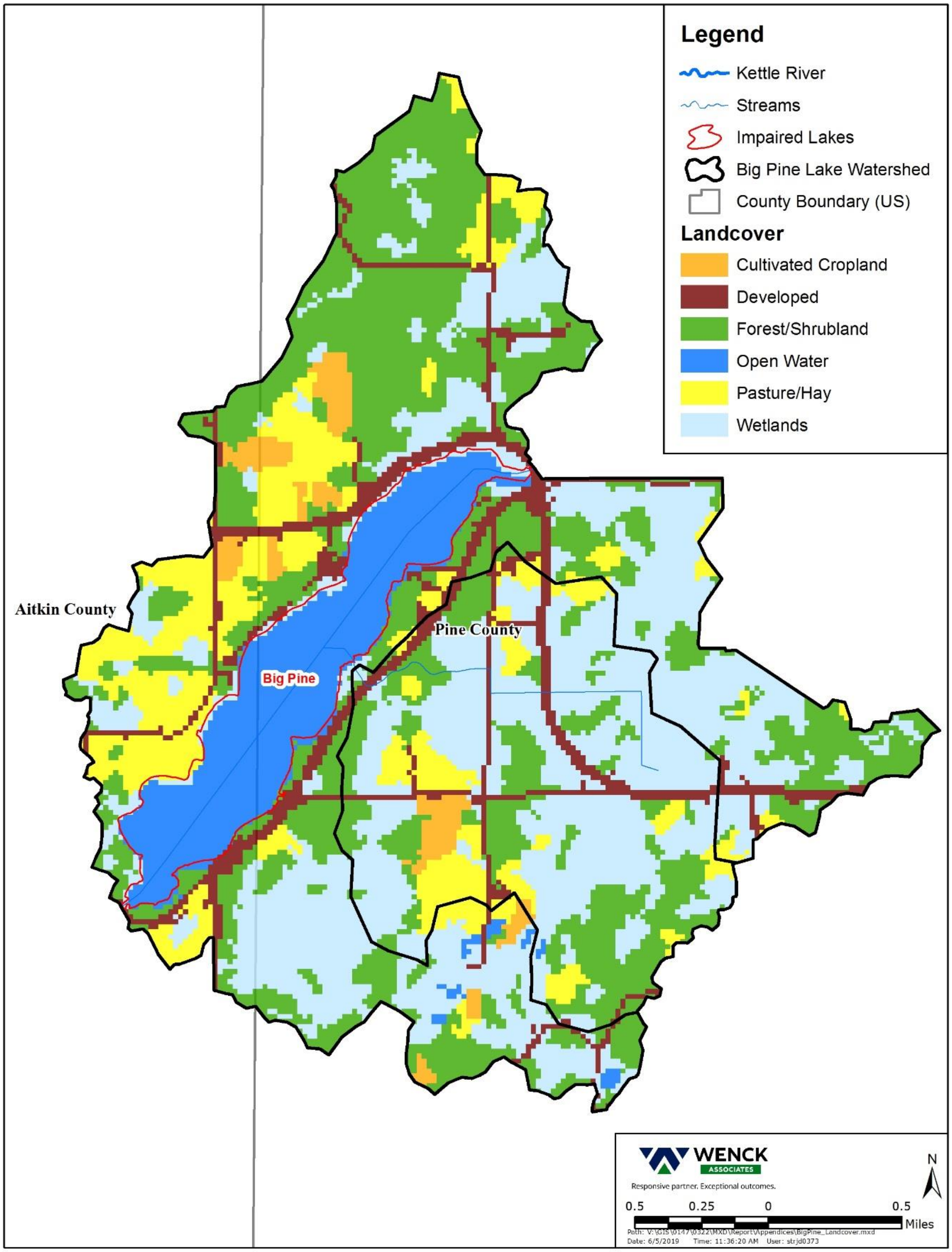
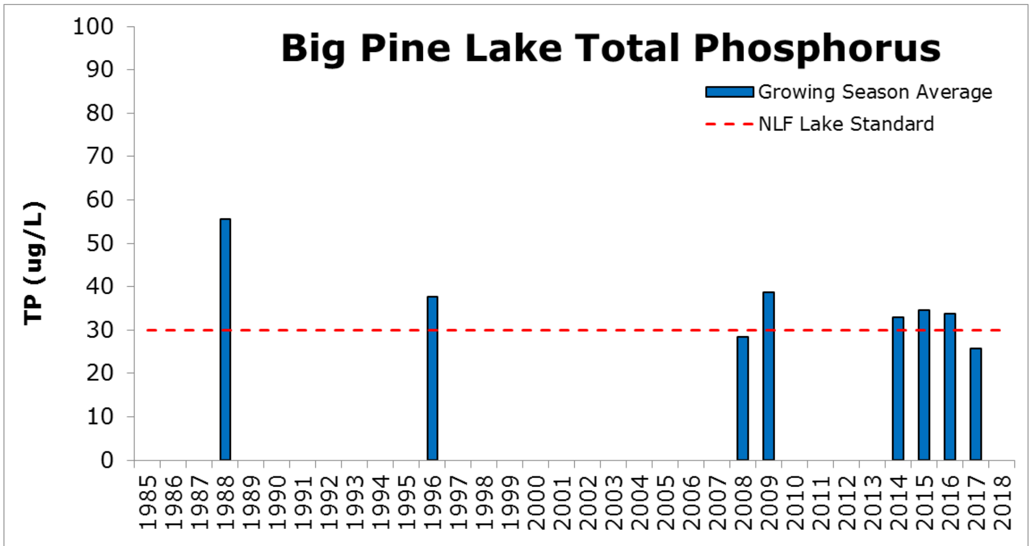
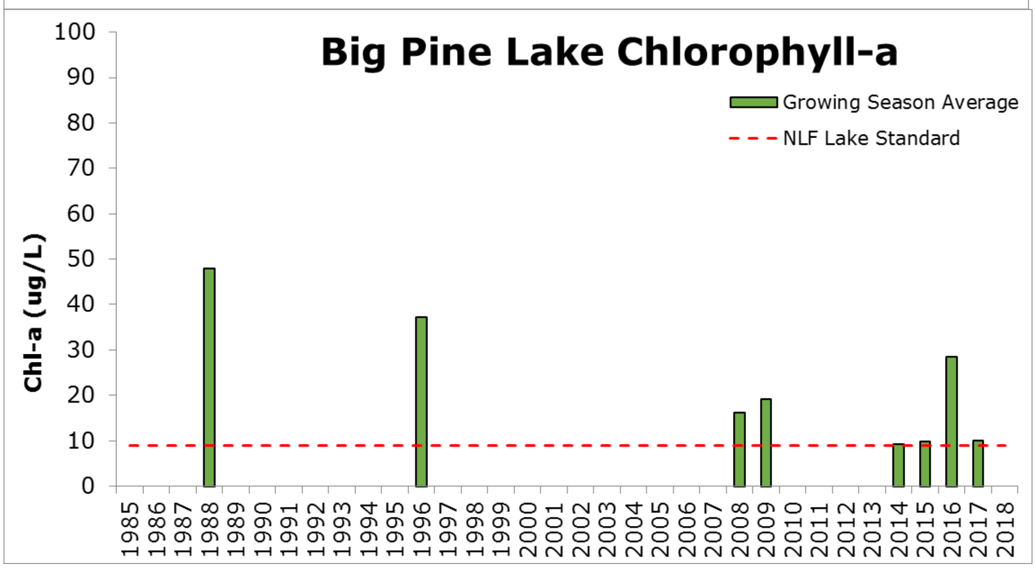


Figure C-2. Big Pine Lake Landcover.





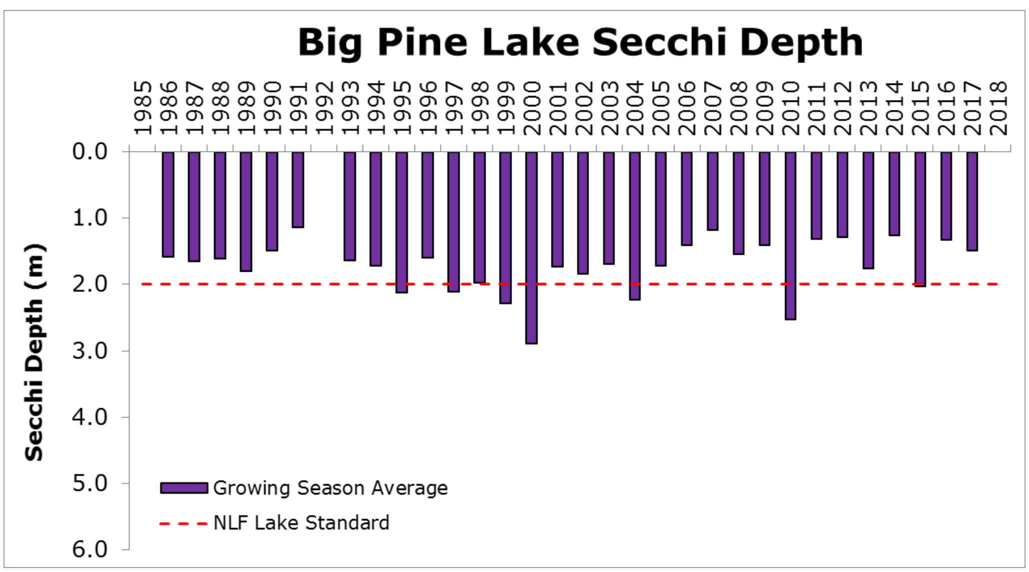


Figure C-3. Big Pine Lake Historic Water Quality.

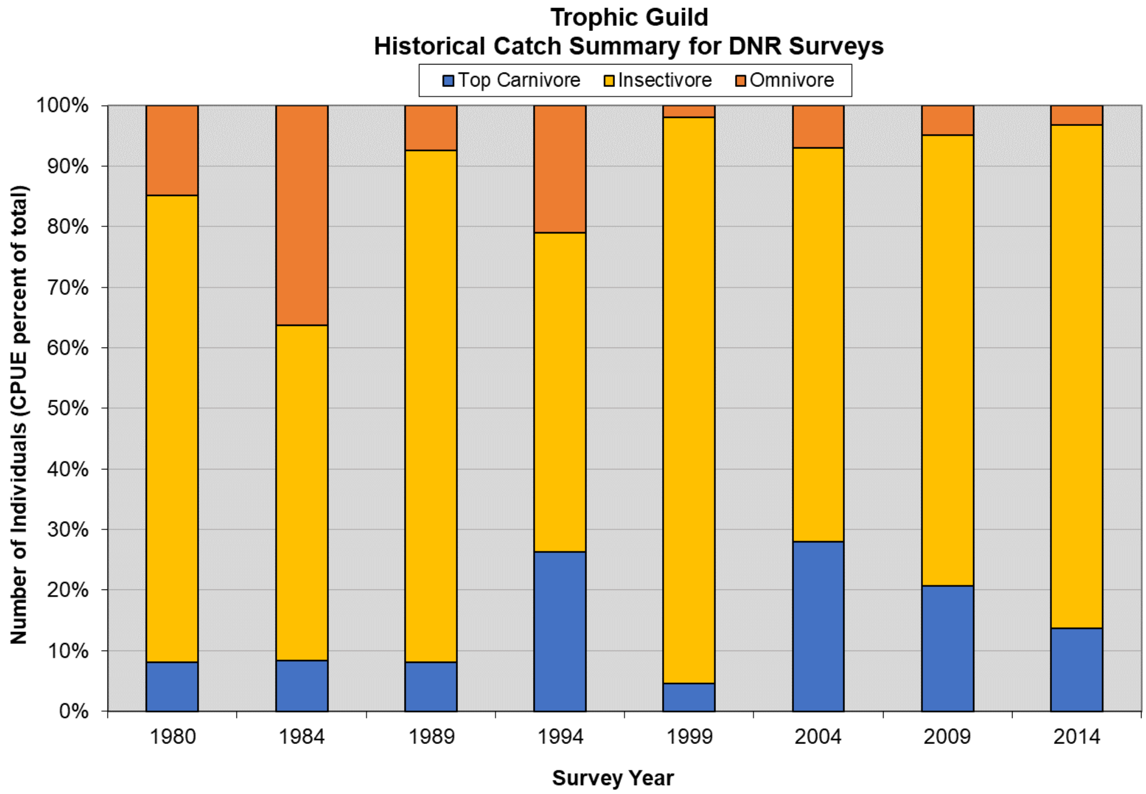


Figure C-4. Big Pine Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).

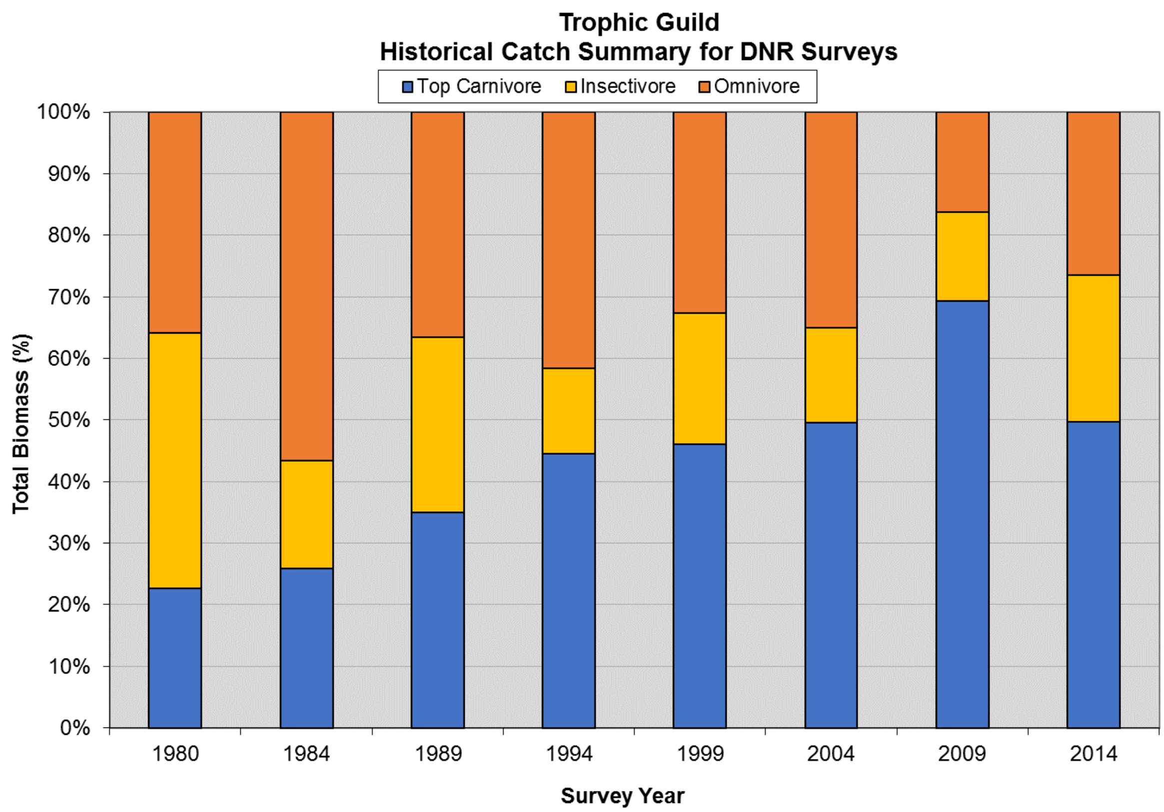


Figure C-5. Big Pine Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-1. Big Pine Lake Current Condition Lake Response Model.

	Average Loading Summary for Big Pine						
	Water Budgets				**Phosphorus Loading**		
	Inflow from Drainage Areas						
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Big Pine	3,959	10.5	3,457	70	1.0	654
2	0			0	0		0
3	0			0	0		0
4	0			0	0		0
5	0			0	0		0
6	0			0	0		0
	Summation	*3,959*	*10*	*3,456.50*			*653.6*
	Point Source Dischargers						
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	0			0	0		0
2	0			0	0.0		0
3	0			0	0.0		0
4	0			0	0.0		0
5	0			0	0.0		0
	Summation			*0*			*0.0*
	Curly-leaf Pondweed						
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
	Failing Septic Systems						
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		119
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*119.0*
	Inflow from Upstream Lakes						
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Pine			15,175	38.4	1.0	1,584
2	0			0		0.0	0
3	0			0		0.0	0
4	0			0		0.0	0
5	0			0		0.0	0
	Summation			*15,174.8*	*38.4*		*1,583.7*
	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]
	399	35.2	35.2	0.00	0.26	1.0	103.2
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
	Groundwater						
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	399	0.0		0.00	0	1.0	0
	Model Residual Load						
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
	Internal						
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.61	0		Oxic		1.0	0
	1.61	32.0		Anoxic	5.1	1.0	586
	Summation						*585.7*
			Net Discharge [ac-ft/yr] =	**18,631**		**Net Load [lb/yr] =**	**3,045**

Average Lake Response Modeling for Big Pine				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.59	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,381	[kg/yr]
		Q (lake outflow) =	23.0	[10^6 m^3/yr]
		V (modeled lake volume) =	6.6	[10^6 m^3]
		T = V/Q =	0.29	[yr]
		P_i = W/Q =	60	[µg/l]
Model Predicted In-Lake [TP]			**32.4**	**[ug/l]**
Observed In-Lake [TP]			**32.4**	**[ug/l]**

Table C-2. Big Pine Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for			*Big Pine*			
	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Big Pine	3,959	10.5	3,457	70	1.0	654
2	0			0	0		0
3	0			0	0		0
4	0			0	0		0
5	0			0	0		0
6	0			0	0		0
	Summation	*3,959*	*10*	*3,456.50*			*653.6*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	0			0	0		0
2	0			0	0.0		0
3	0			0	0.0		0
4	0			0	0.0		0
5	0			0	0.0		0
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		94
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*93.9*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Pine			15,175	30.0	0.8	1,238
2	0			0		0.0	0
3	0			0		0.0	0
4	0			0		0.0	0
5	0			0		0.0	0
	Summation			*15,174.8*	*30.0*		*1,238.5*
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]
	399	35.2	35.2	0.00	0.26	1.0	103.2
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	399	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.61	0		Oxic		1.0	0
	1.61	32.0		Anoxic	5.1	1.0	586
	Summation						*585.7*
			Net Discharge [ac-ft/yr] =	**18,631**		**Net Load [lb/yr] =**	**2,675**

TMDL Lake Response Modeling for	***Big Pine***			
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$$	C_P =	1.59	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	1,213	[kg/yr]
		Q (lake outflow) =	23.0	[10^6 m^3/yr]
		V (modeled lake volume) =	6.6	[10^6 m^3]
		T = V/Q =	0.29	[yr]
		P_i = W/Q =	53	[µg/l]
Model Predicted In-Lake [TP]			**29.2**	**[ug/l]**
Observed In-Lake [TP]			**32.4**	**[ug/l]**

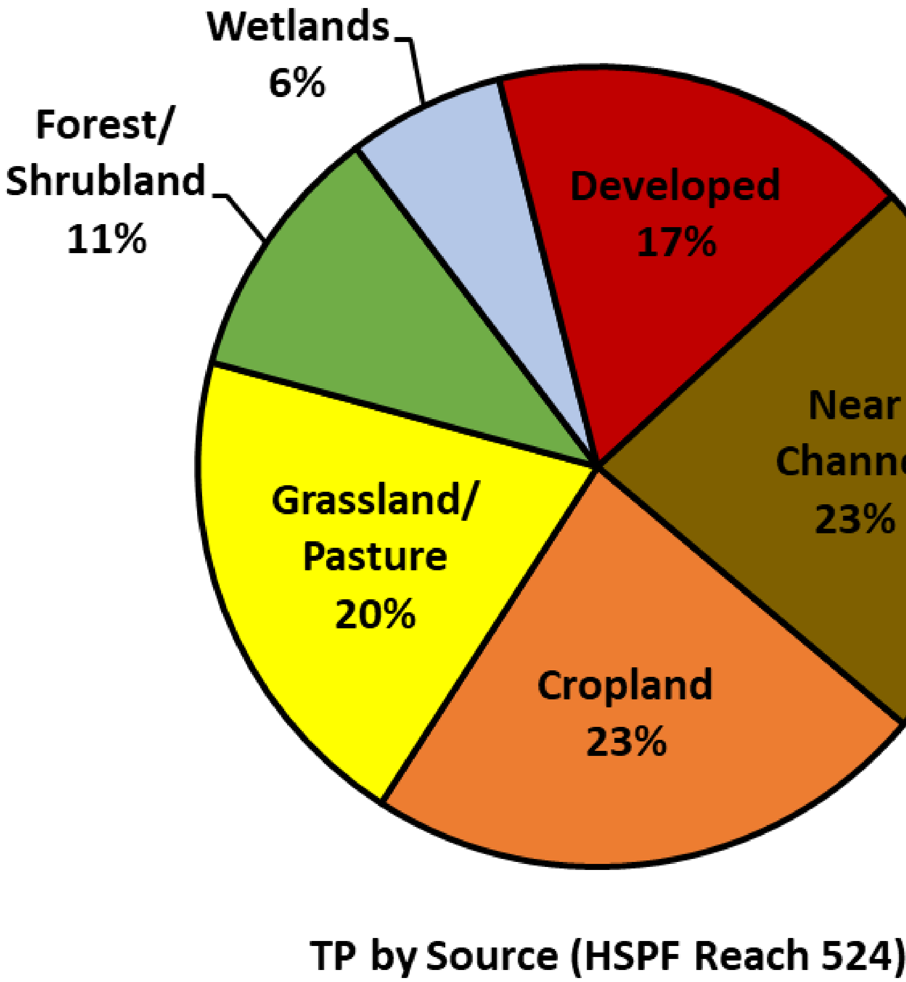


Figure C-6. Big Pine Lake HSPF-predicted watershed loading by source.

Supporting Items for Elbow Lake (58-0126-00)

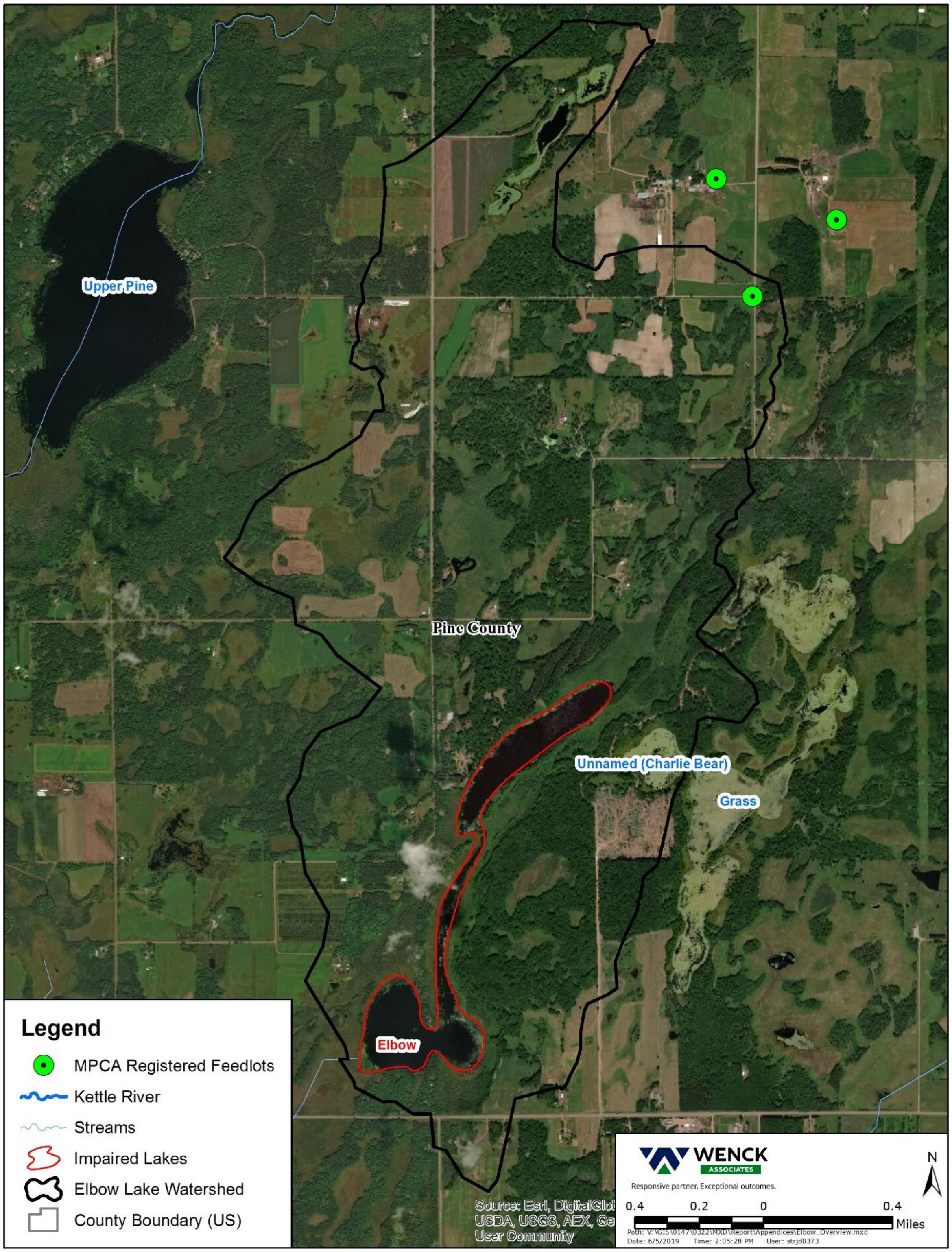


Figure C-7. Elbow Lake Overview.

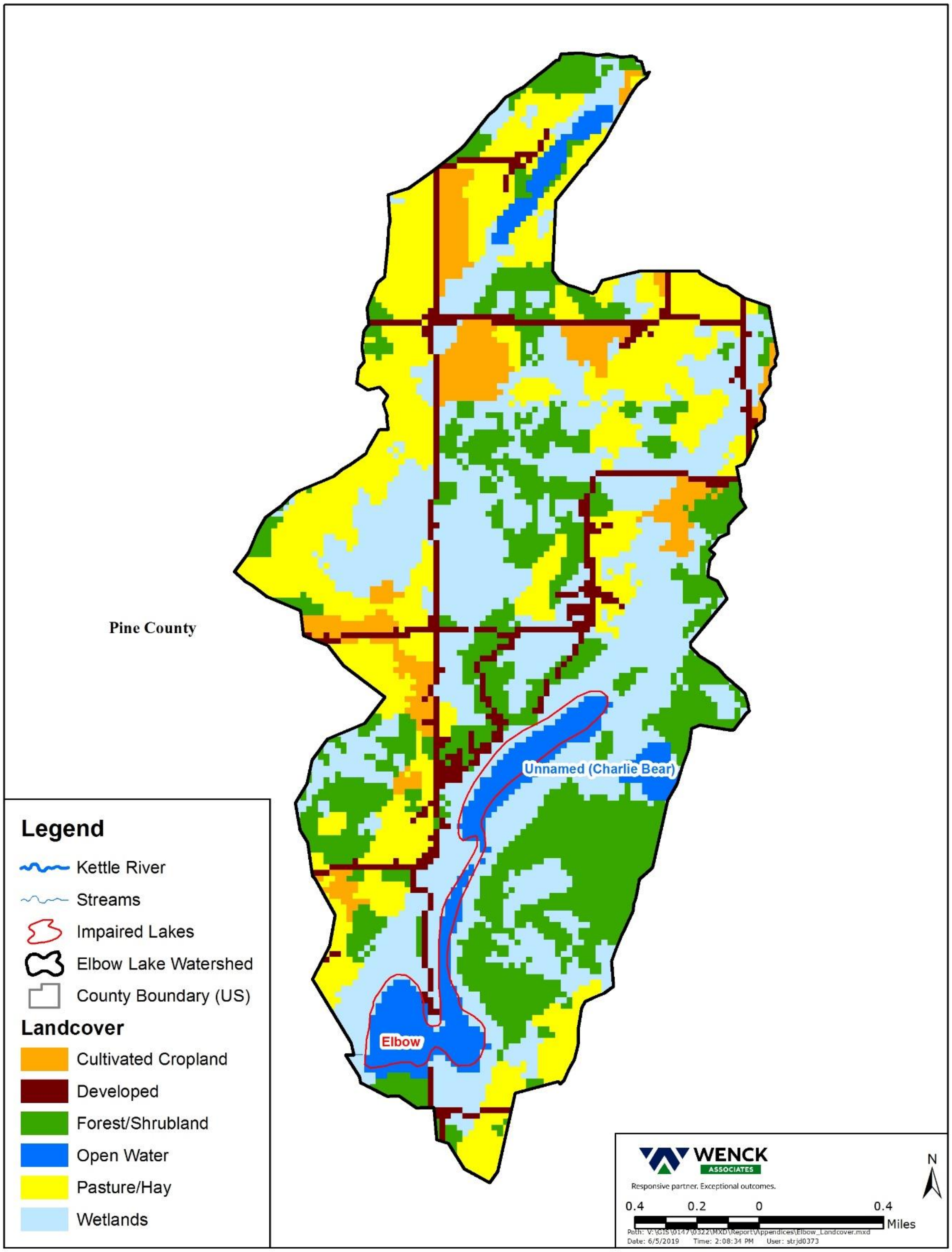


Figure C-8. Elbow Lake Landcover.

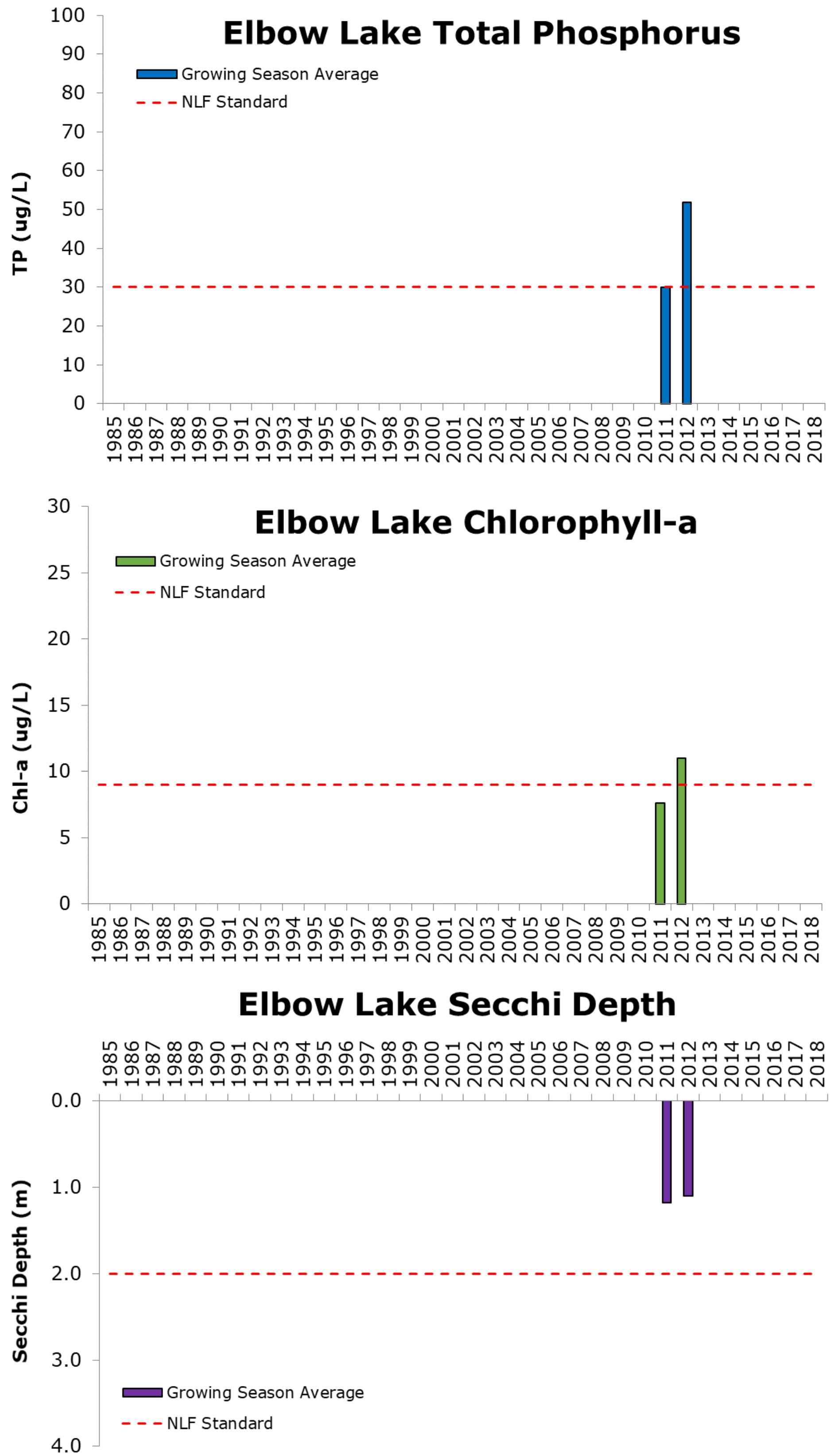
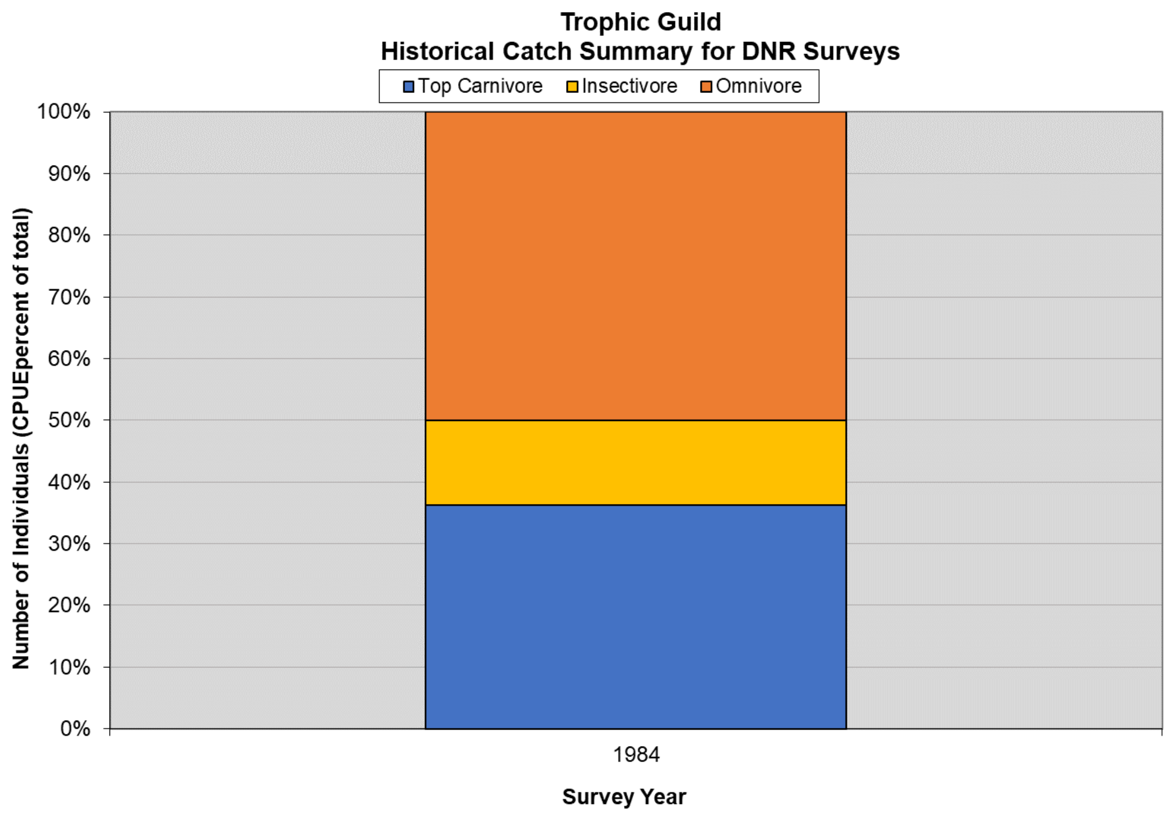


Figure C-9. Elbow Lake Historic Water Quality.



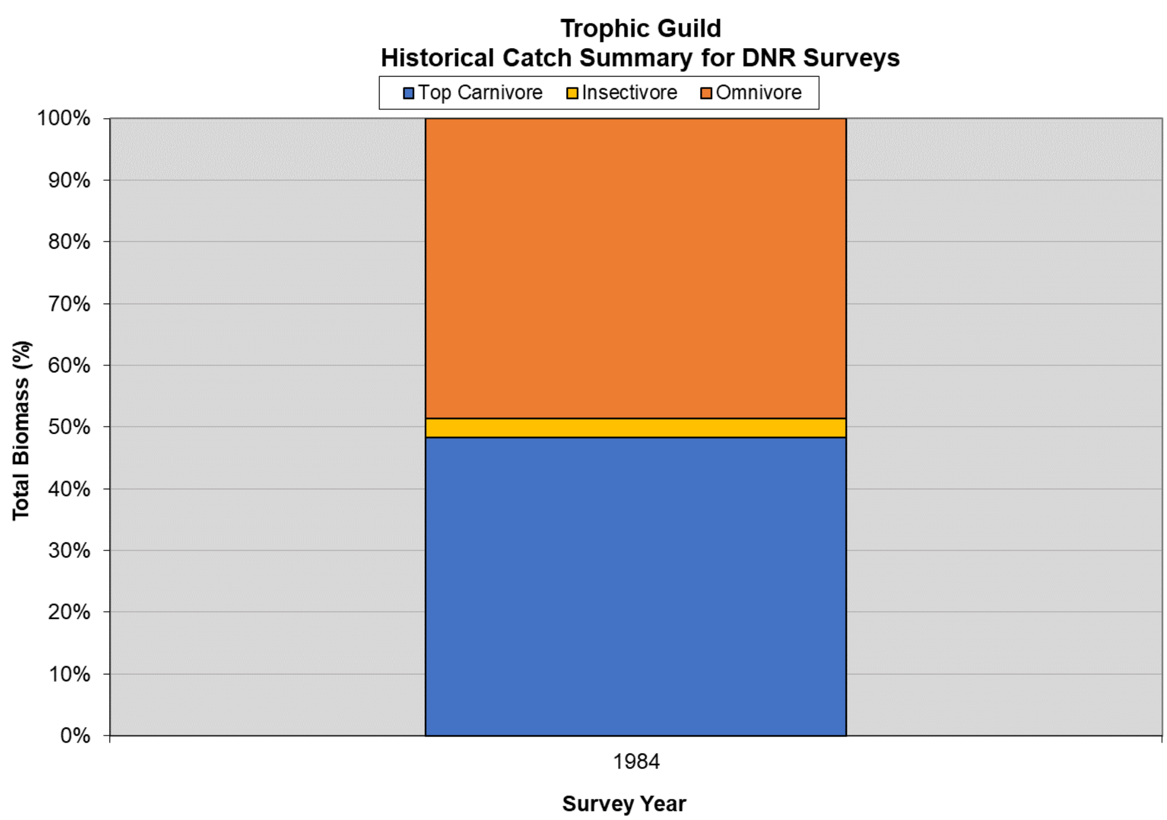


Figure C-10. Elbow Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-3. Elbow Lake Current Condition Lake Response Model.

	Average Loading Summary for Elbow						
		Water Budgets			**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Elbow	2,206	12.1	2,231	60	1.0	367
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,206*	*12*	*2,230.57*			*367.1*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	0	0		0%		36
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*0*	*0*	*0.0*	#DIV/0!		*36.2*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	104	28.9	28.9	0.00	0.26	1.0	26.9
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	104	0.0		0.00	0	1.0	0
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.42	0		Oxic		1.0	0
	0.42	37.0		Anoxic	0.4	1.0	14
	Summation						*13.6*
		Net Discharge [ac-ft/yr] =		**2,231**	**Net Load [lb/yr] =**		**444**

Average Lake Response Modeling for Elbow				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	201	[kg/yr]
		Q (lake outflow) =	2.8	[10^6 m^3/yr]
		V (modeled lake volume) =	1.4	[10^6 m^3]
		T = V/Q =	0.49	[yr]
		P_i = W/Q =	73	[µg/l]
Model Predicted In-Lake [TP]			**40.9**	**[ug/l]**
Observed In-Lake [TP]			**40.9**	**[ug/l]**

Table C-4. Elbow Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for	*Elbow*					
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Elbow	2,206	12.1	2,231	38	0.6	234
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,206*	*12*	*2,230.57*			*233.5*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	0	0		0%		28
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*0*	*0*	*0.0*	#DIV/0!		*28.3*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	104	28.9	28.9	0.00	0.26	1.0	26.9
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	104	0.0		0.00	0	1.0	0
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.42	0		Oxic		1.0	0
	0.42	37.0		Anoxic	0.4	1.0	14
	Summation						*13.6*
		Net Discharge [ac-ft/yr] =		**2,231**	**Net Load [lb/yr] =**		**302**

	TMDL Lake Response Modeling for	*Elbow*		
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	137	[kg/yr]
		Q (lake outflow) =	2.8	[10^6 m^3/yr]
		V (modeled lake volume) =	1.4	[10^6 m^3]
		T = V/Q =	0.49	[yr]
		P_i = W/Q =	50	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**40.9**	**[ug/l]**

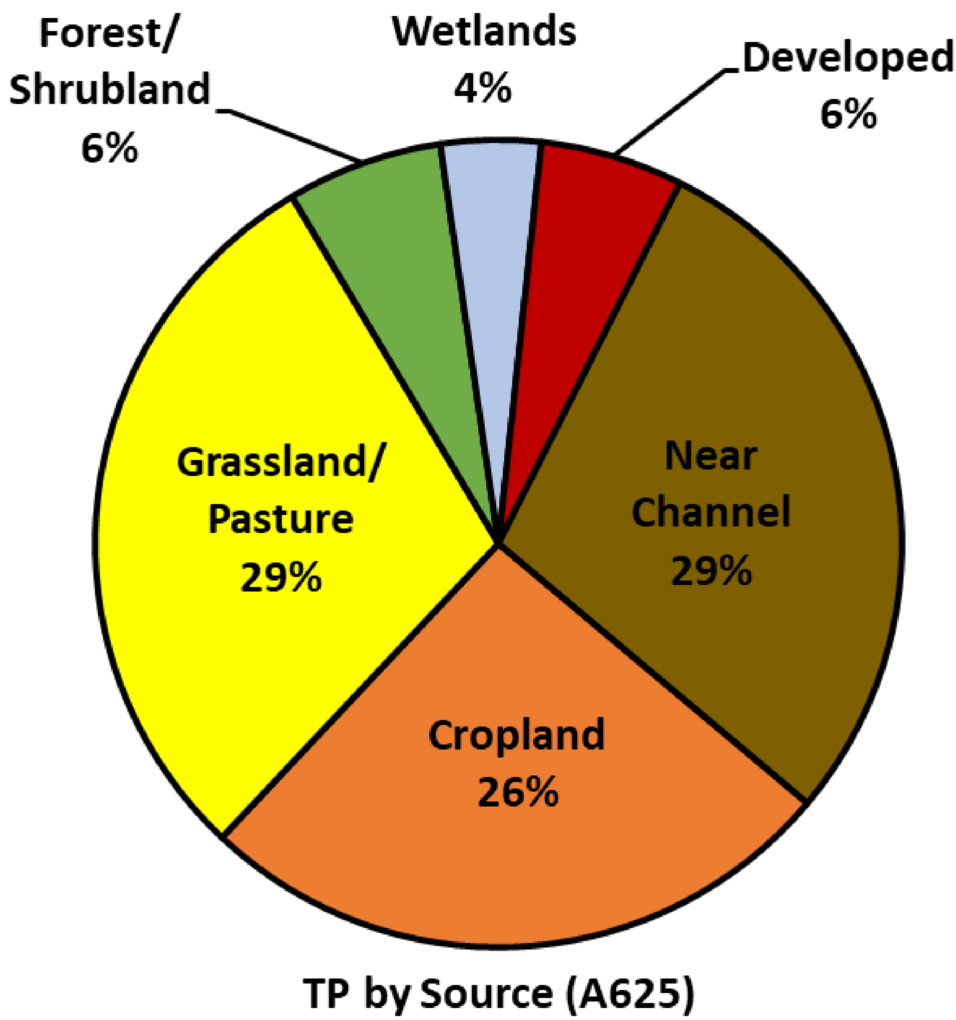


Figure C-11. Elbow Lake HSPF-predicted watershed loading by source.

Supporting Items for Eleven Lake (33-0001-00)

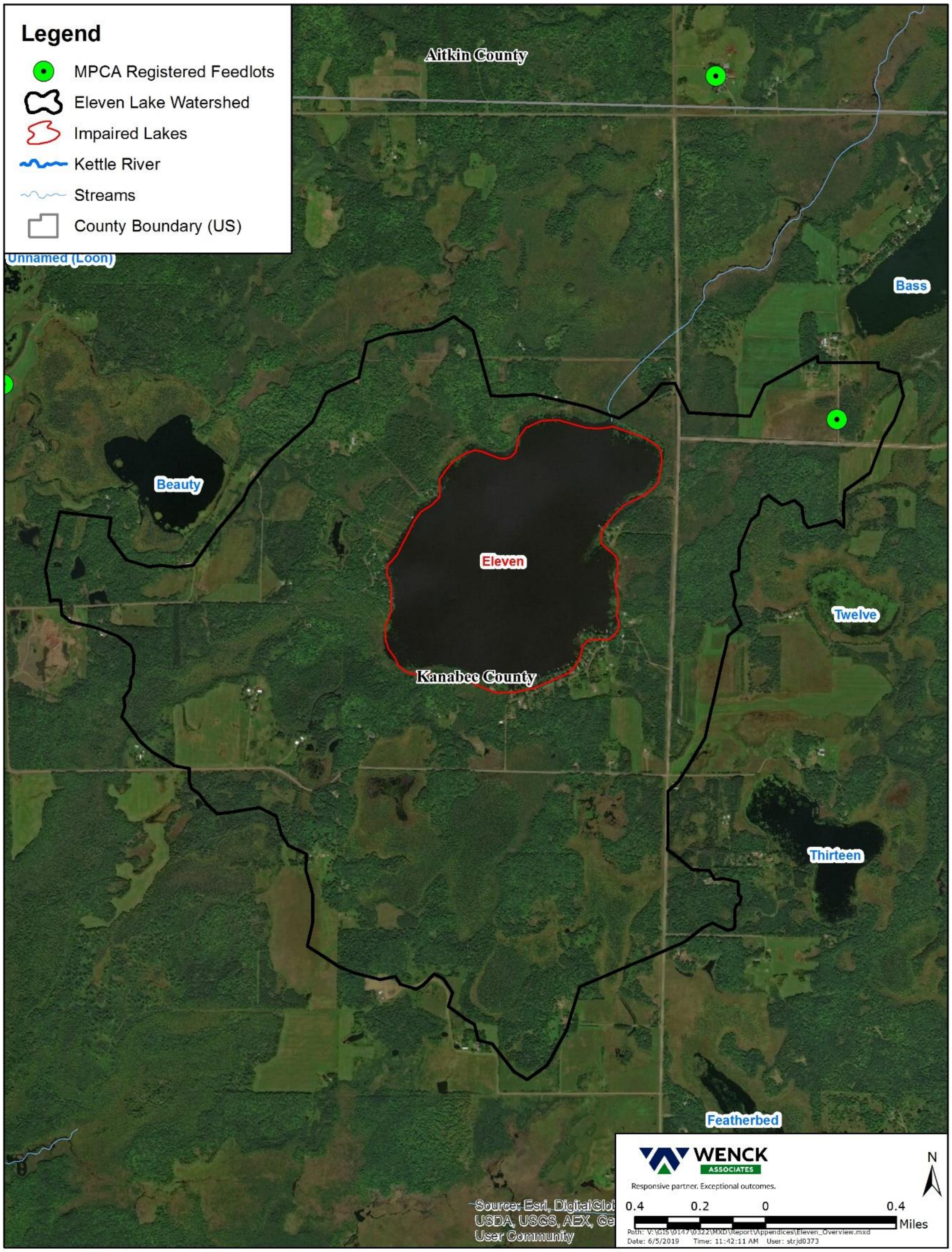


Figure C-12. Eleven Lake Overview.

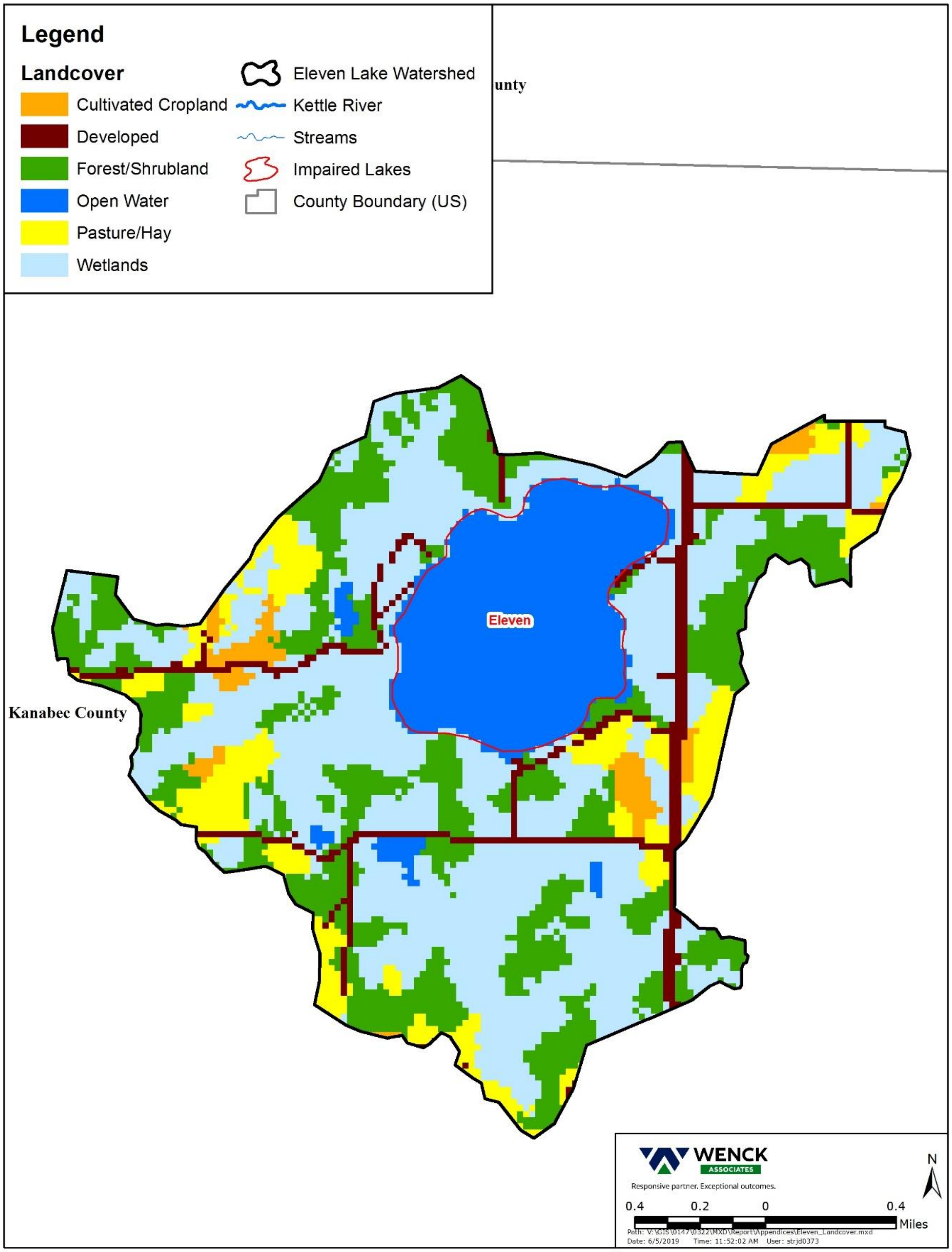


Figure C-13. Eleven Lake Landcover.

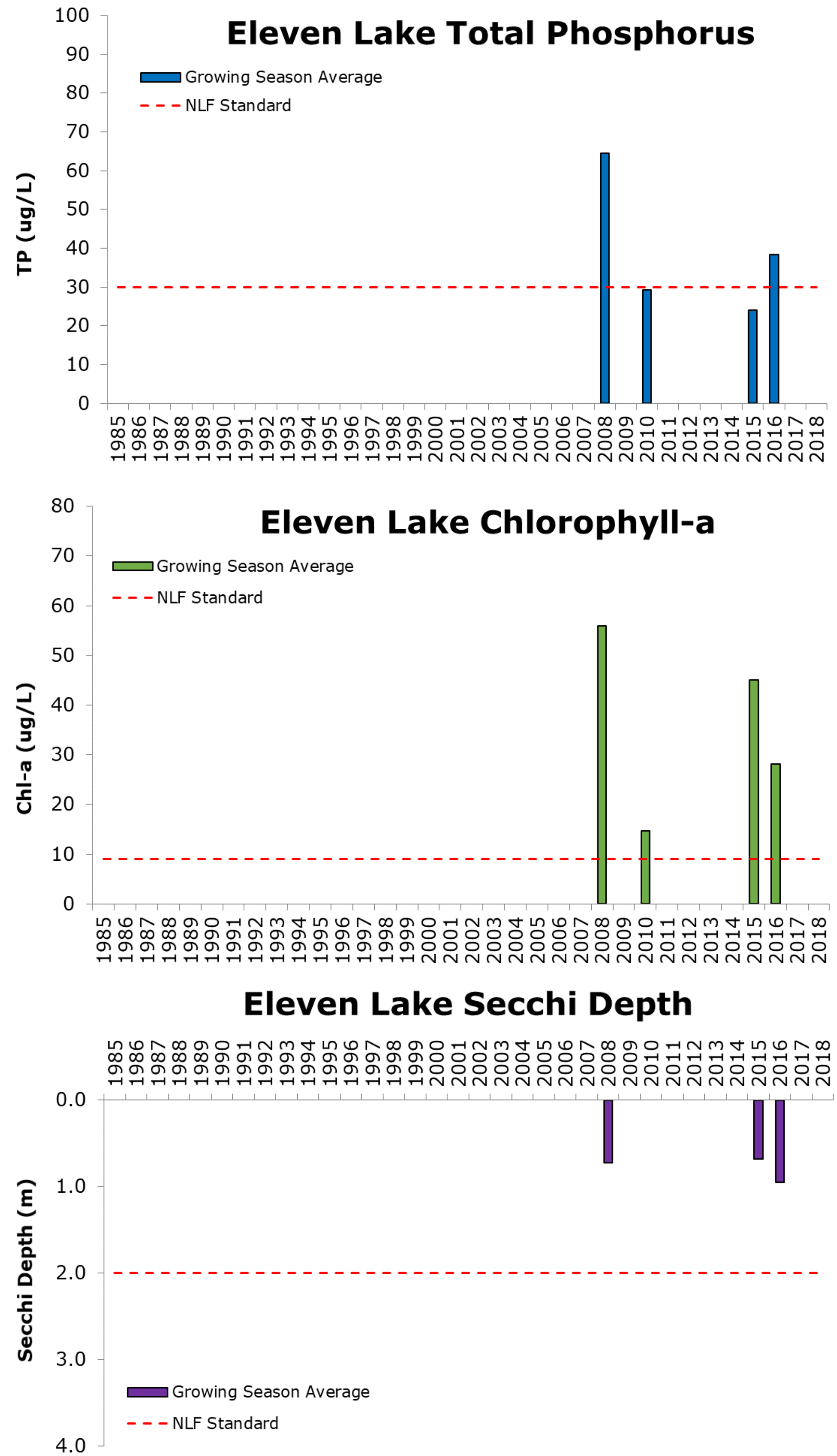
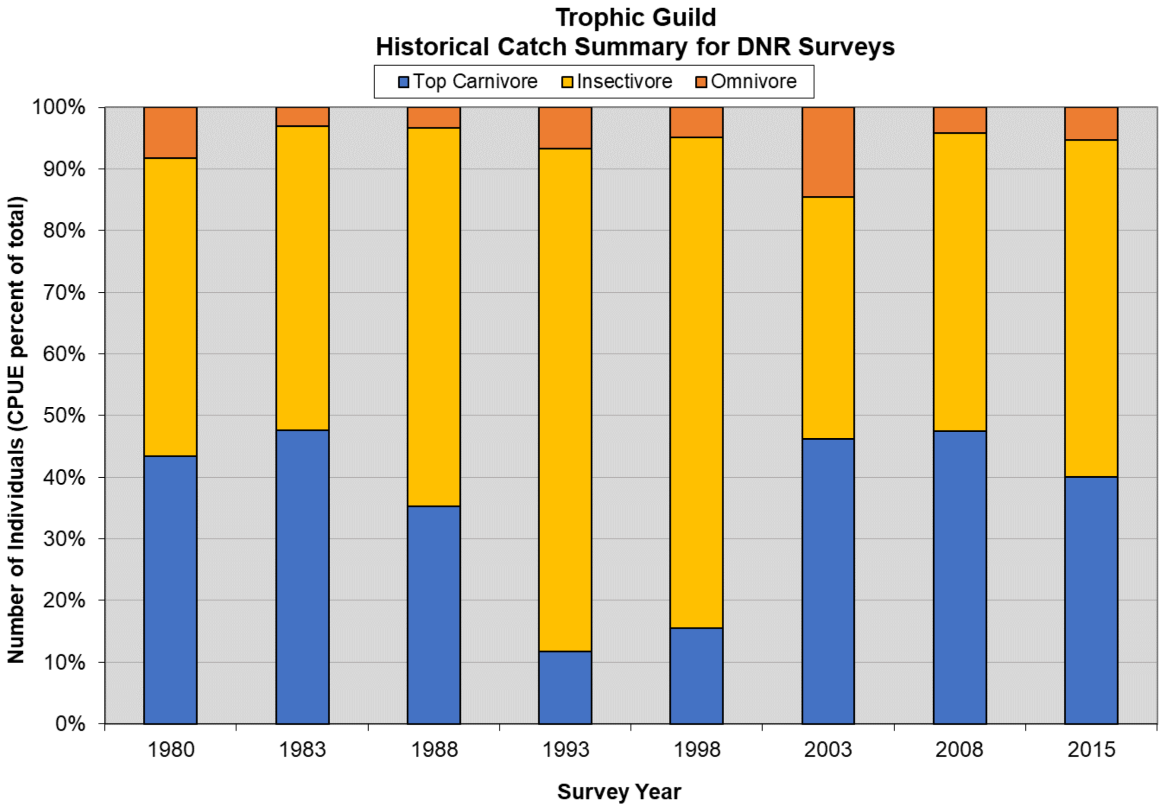


Figure C-14. Eleven Lake Historic Water Quality.



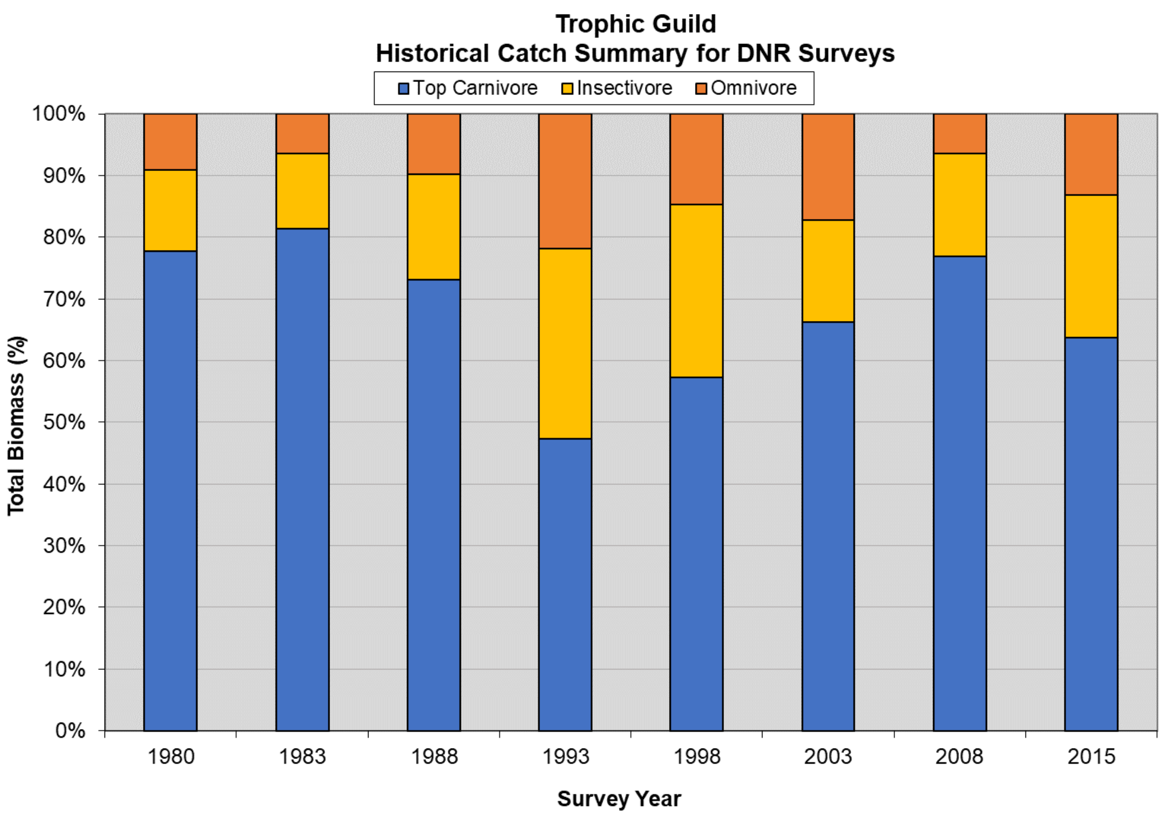


Figure C-15. Eleven Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-5. Eleven Lake Current Condition Lake Response Model.

	Average Loading Summary for	*Eleven*					
		Water Budgets			**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Eleven	1,967	10.2	1,670	60	1.0	273
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*1,967*	*10*	*1,670.15*			*273.2*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		49
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*49.1*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	302	35.8	35.8	0.00	0.26	1.0	78.1
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	302	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.22	0		Oxic		1.0	0
	1.22	37.2		Anoxic	0.4	1.0	44
	Summation						*44.1*
			Net Discharge [ac-ft/yr] =	**1,670**	**Net Load [lb/yr] =**		**445**

Average Lake Response Modeling for	*Eleven*			
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	202	[kg/yr]
		Q (lake outflow) =	2.1	[10^6 m^3/yr]
		V (modeled lake volume) =	2.6	[10^6 m^3]
		T = V/Q =	1.28	[yr]
		P_i = W/Q =	98	[µg/l]
Model Predicted In-Lake [TP]			**39.0**	**[ug/l]**
Observed In-Lake [TP]			**39.0**	**[ug/l]**

Table C-6. Eleven Lake TMDL Condition Lake Response Model.

TMDL Loading Summary for Eleven

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Eleven	1,967	10.2	1,670	35	0.6	157
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*1,967*	*10*	*1,670.15*			*156.8*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		32
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*31.8*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	302	35.8	35.8	0.00	0.26	1.0	78.1
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	302	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.22	0		Oxic		1.0	0
	1.22	37.2		Anoxic	0.4	1.0	44
	Summation						*44.1*
		Net Discharge [ac-ft/yr] =		**1,670**	**Net Load [lb/yr] =**		**311**

TMDL Lake Response Modeling for Eleven

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$	C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	141	[kg/yr]
		Q (lake outflow) =	2.1	[10^6 m^3/yr]
		V (modeled lake volume) =	2.6	[10^6 m^3]
		T = V/Q =	1.28	[yr]
		P_i = W/Q =	68	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**39.0**	**[ug/l]**

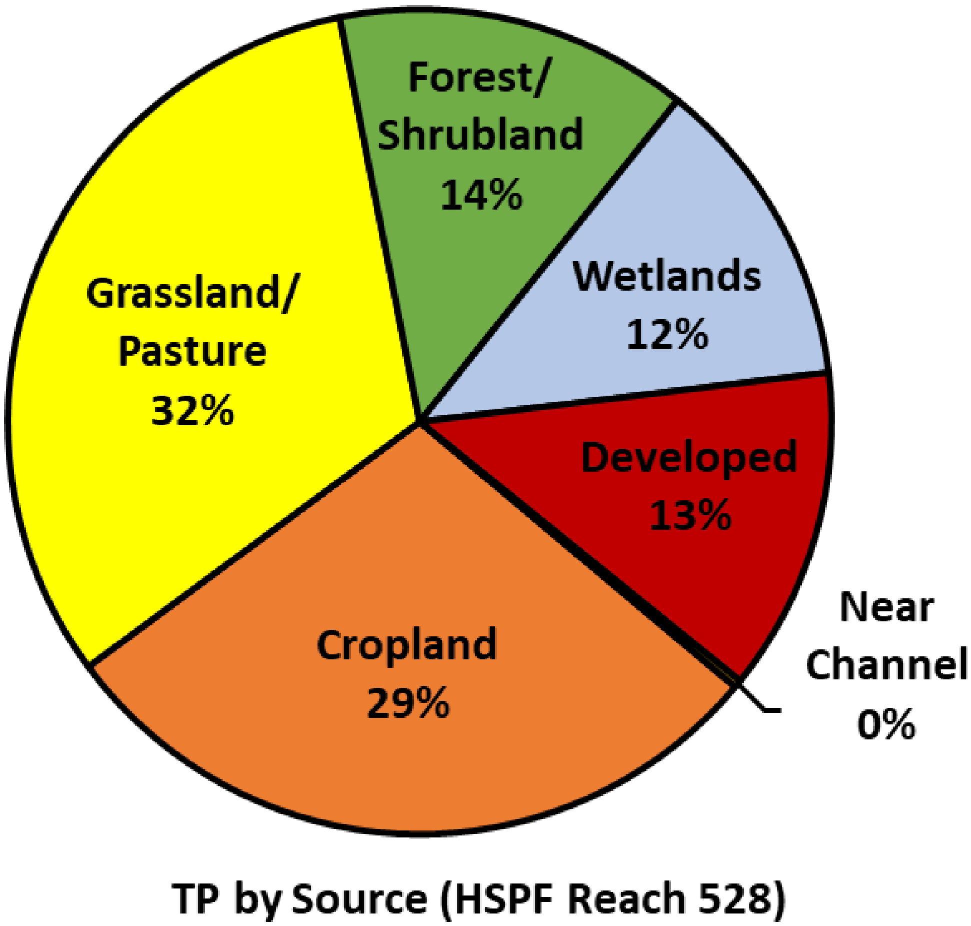


Figure C-16. Eleven Lake HSPF-predicted watershed loading by source.

Supporting Items for Fox Lake (58-0102-00)

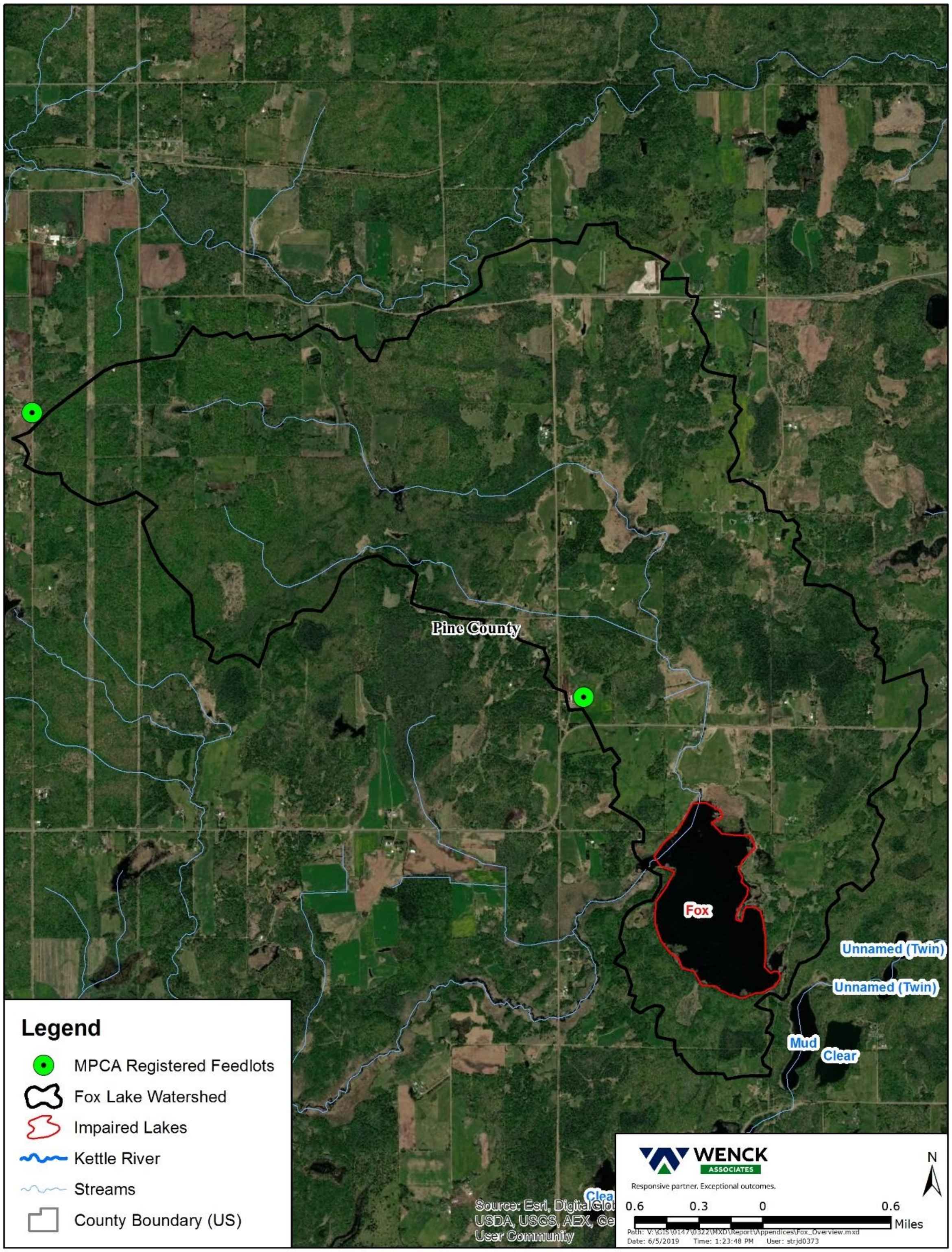


Figure C-17. Fox Lake Overview.

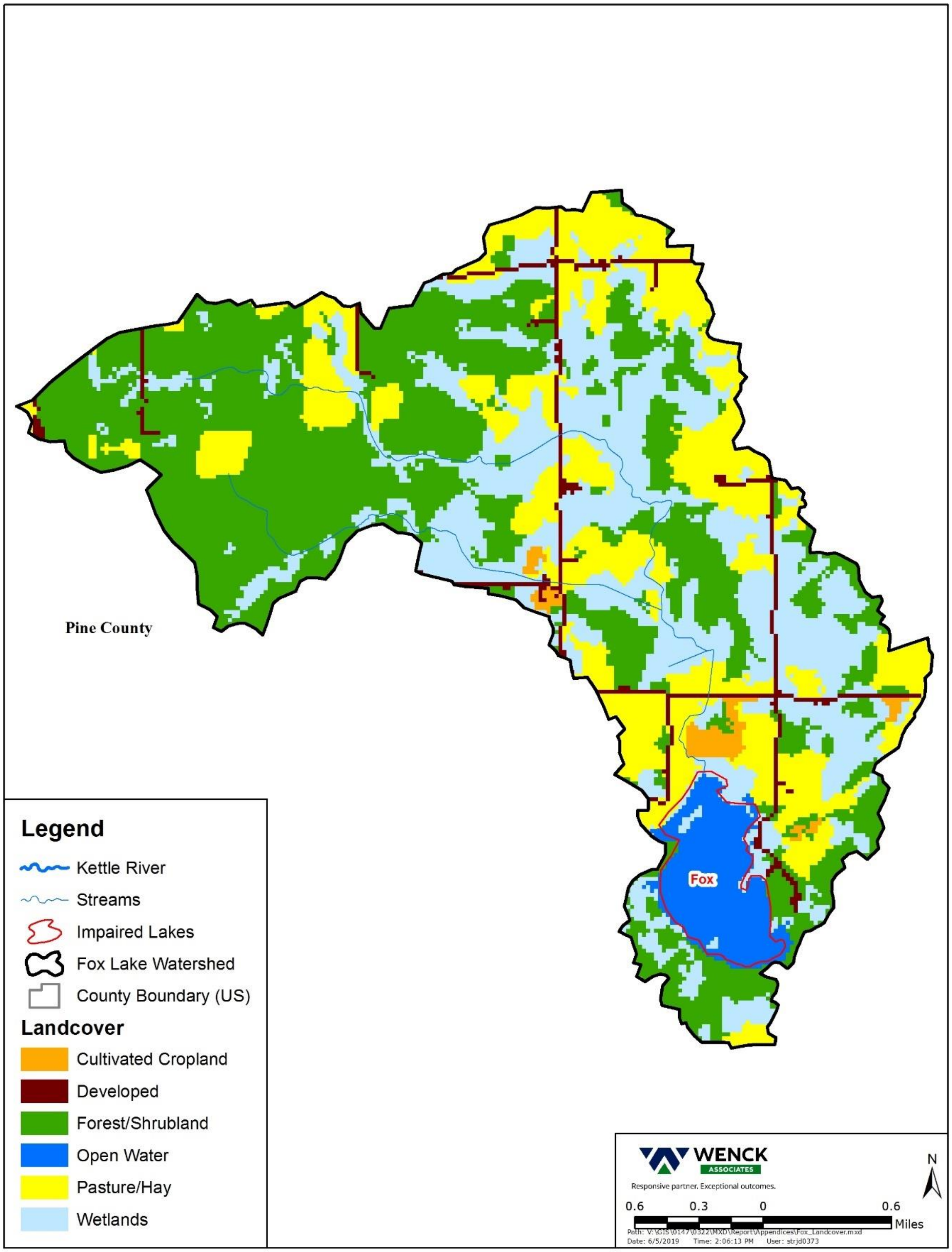


Figure C-18. Fox Lake Landcover.

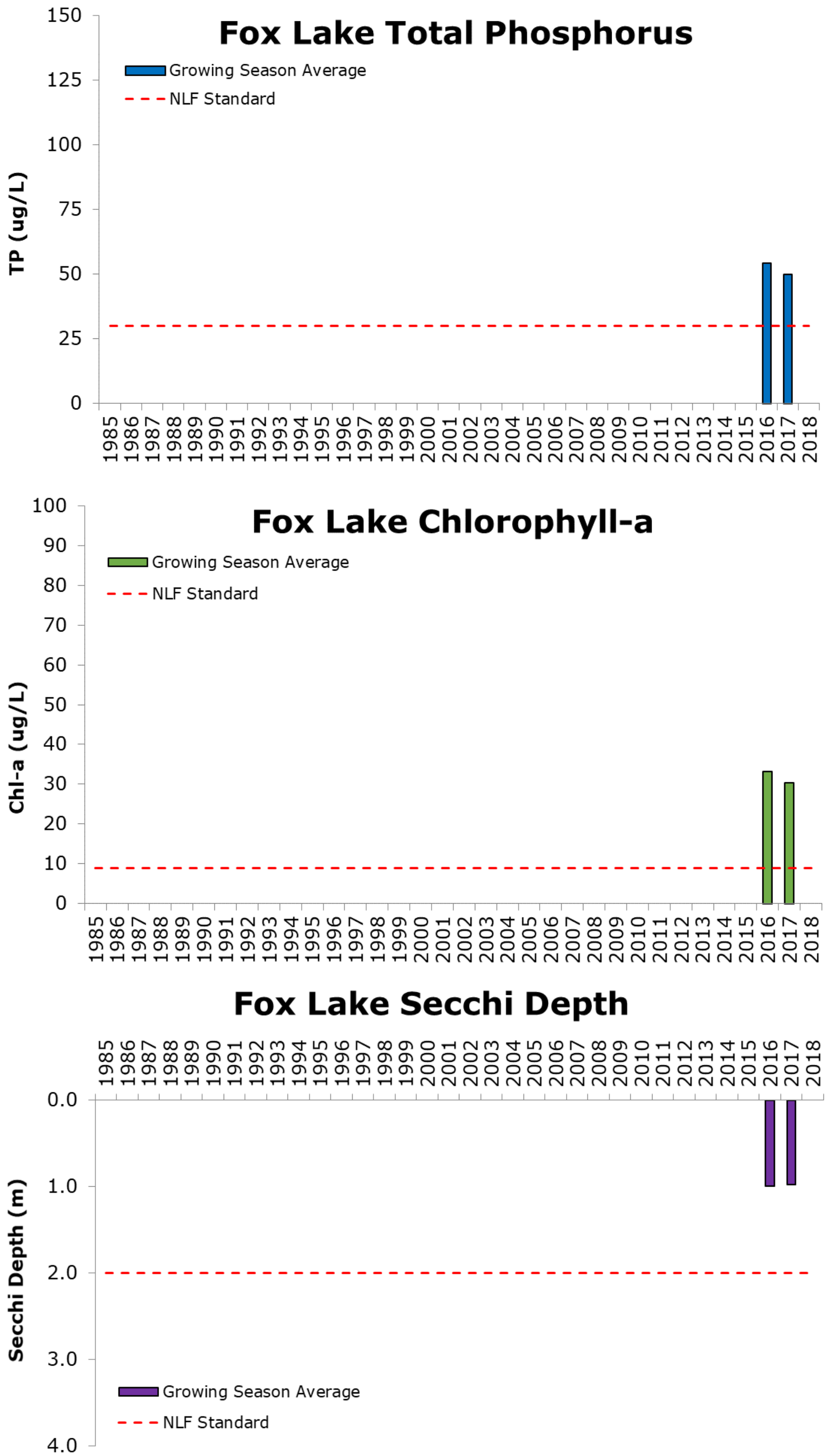
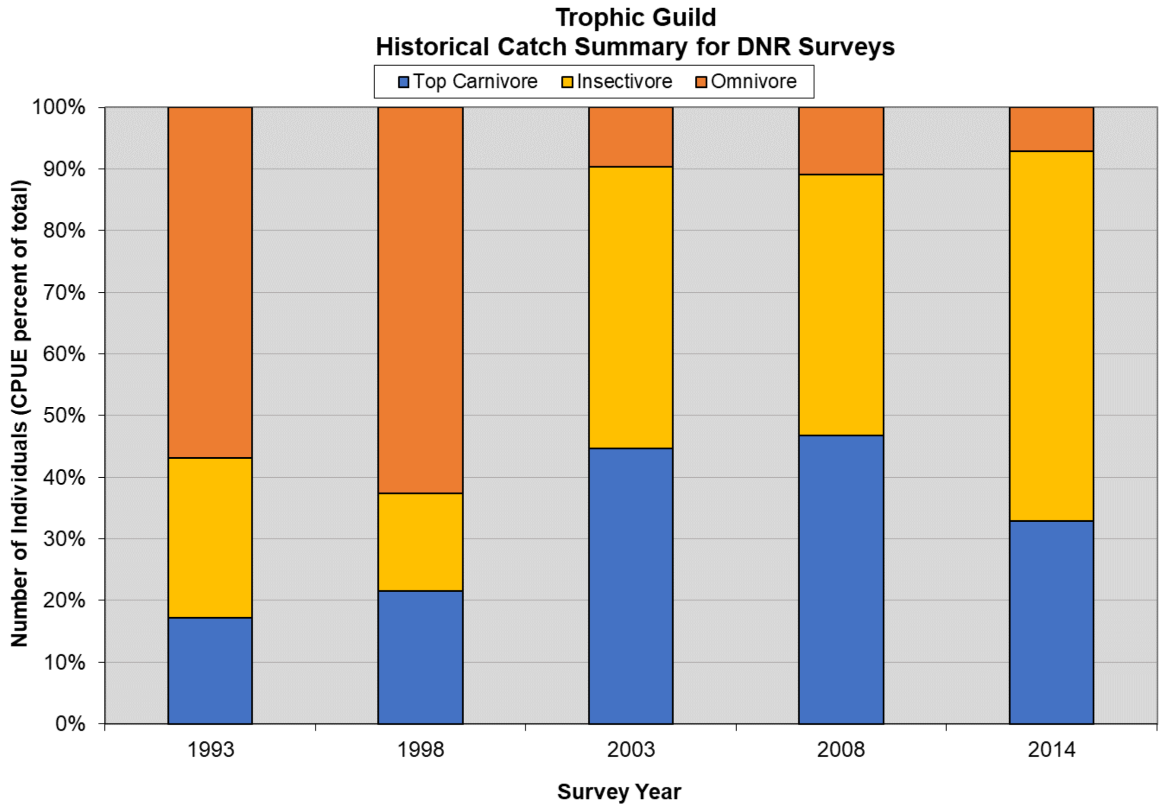


Figure C-19. Fox Lake Historic Water Quality.



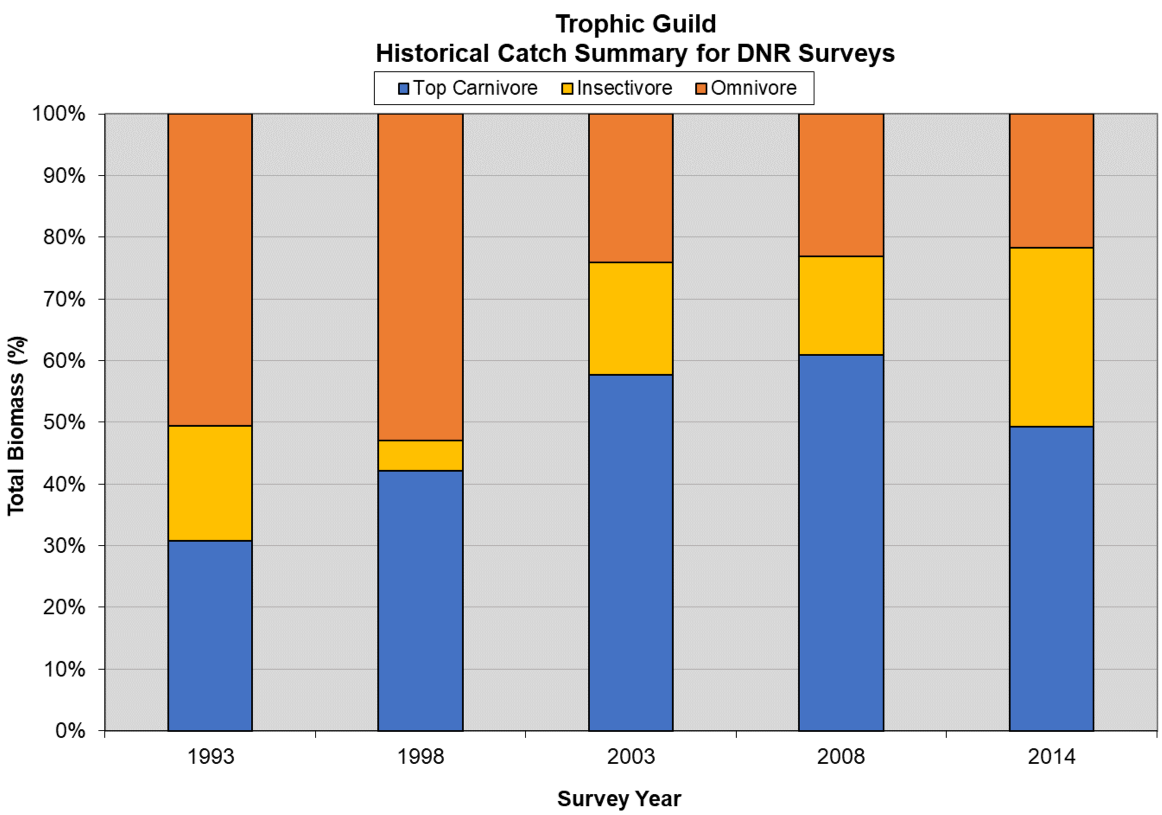


Figure C-20. Fox Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-7. Fox Lake Current Condition Lake Response Model.

	Average Loading Summary for Fox						
		Water Budgets			**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Fox	4,365	16.1	5,868	50	1.0	802
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*4,365*	*16*	*5,868.29*			*802.0*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		20
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*19.9*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	227	37.9	37.9	0.00	0.26	1.0	58.7
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	227	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.92	0		Oxic		1.0	0
	0.92	43.3		Anoxic	5.6	1.0	489
	Summation						*489.5*
			Net Discharge [ac-ft/yr] =	**5,868**		**Net Load [lb/yr] =**	**1,370**

Average Lake Response Modeling for Fox				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	622	[kg/yr]
		Q (lake outflow) =	7.2	[10^6 m^3/yr]
		V (modeled lake volume) =	2.2	[10^6 m^3]
		T = V/Q =	0.30	[yr]
		P_i = W/Q =	86	[µg/l]
Model Predicted In-Lake [TP]			**52.1**	**[ug/l]**
Observed In-Lake [TP]			**52.1**	**[ug/l]**

Table C-8. Fox Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for Fox						
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Fox	4,365	16.1	5,868	39	0.8	619
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*4,365*	*16*	*5,868.29*			*618.8*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		14
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*14.4*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	227	37.9	37.9	0.00	0.26	1.0	58.7
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	227	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.92	0		Oxic		1.0	0
	0.92	43.3		Anoxic	5.6	1.0	16
	Summation						*15.7*
			Net Discharge [ac-ft/yr] =	**5,868**	**Net Load [lb/yr] =**		**708**

TMDL Lake Response Modeling for Fox				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	321	[kg/yr]
		Q (lake outflow) =	7.2	[10^6 m^3/yr]
		V (modeled lake volume) =	2.2	[10^6 m^3]
		T = V/Q =	0.30	[yr]
		P_i = W/Q =	44	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**52.1**	**[ug/l]**

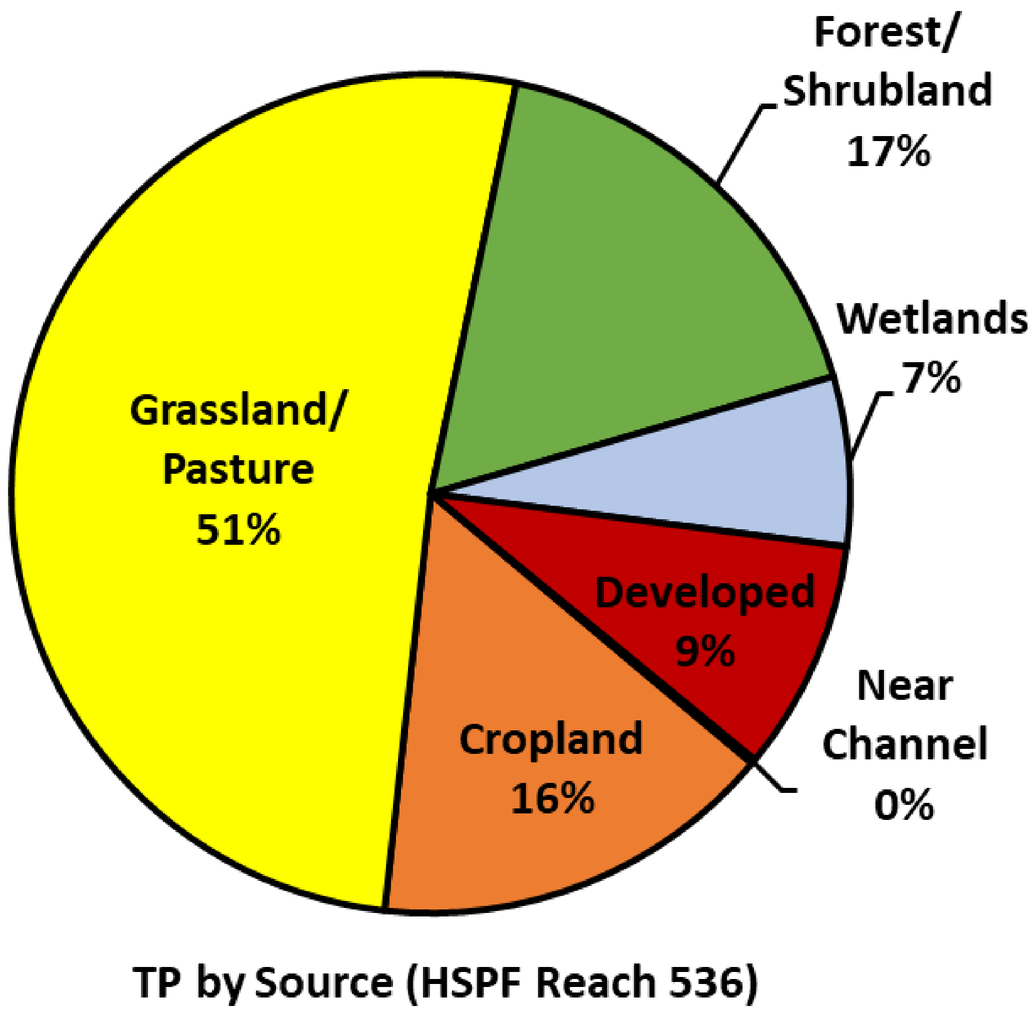


Figure C-21. Fox Lake HSPF-predicted watershed loading by source.

Supporting Items for Grace Lake (58-0029-00)

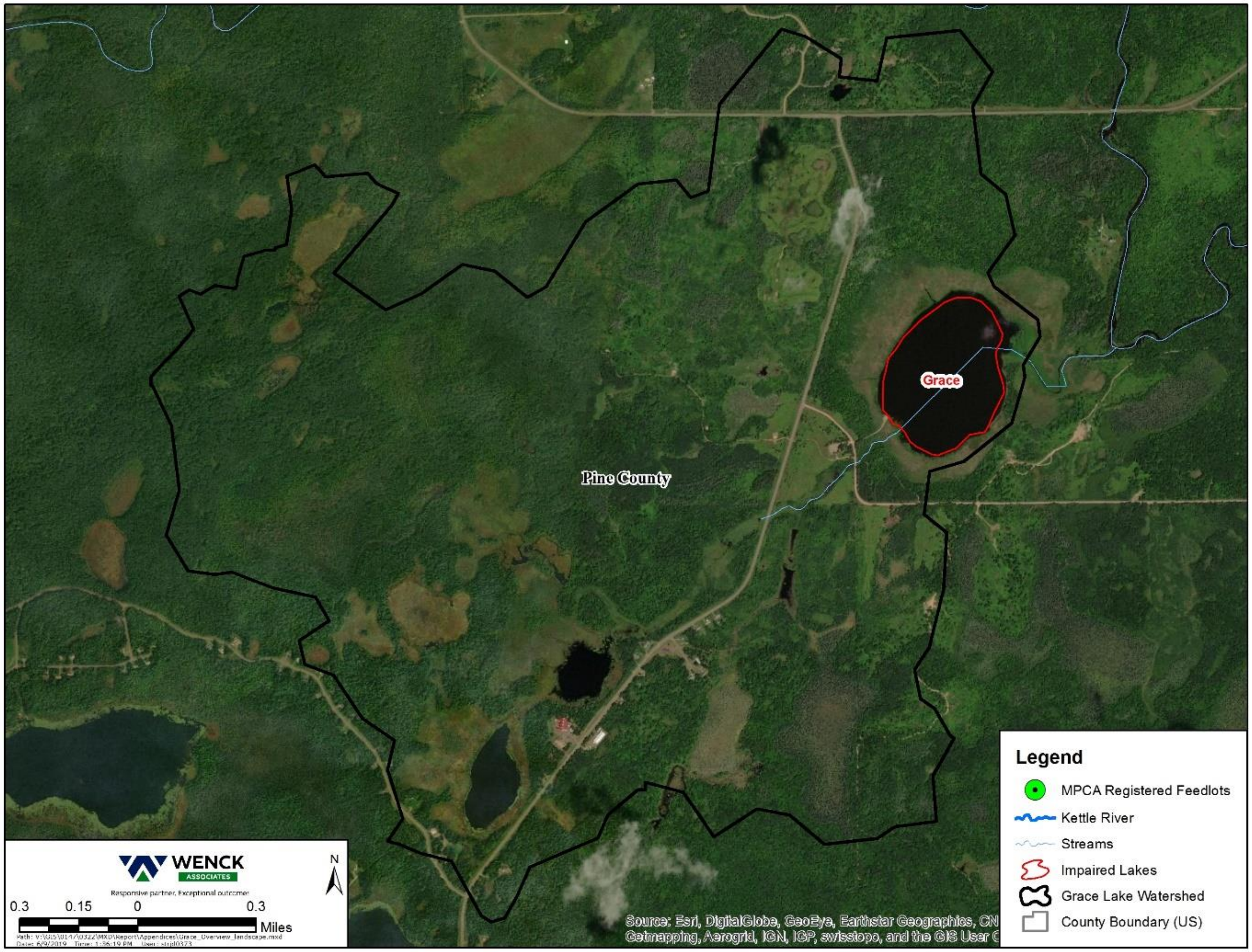


Figure C-22. Grace Lake Overview.

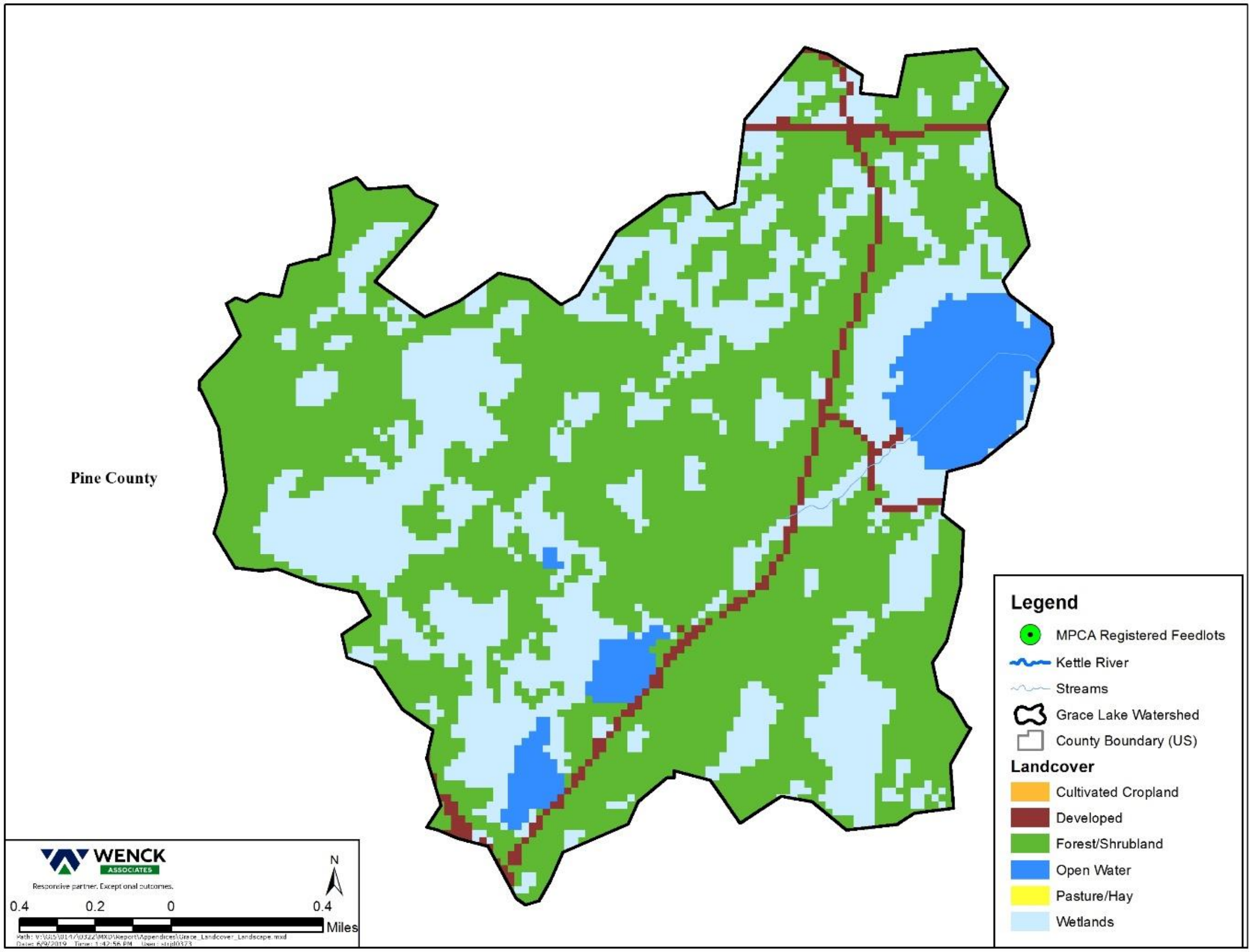
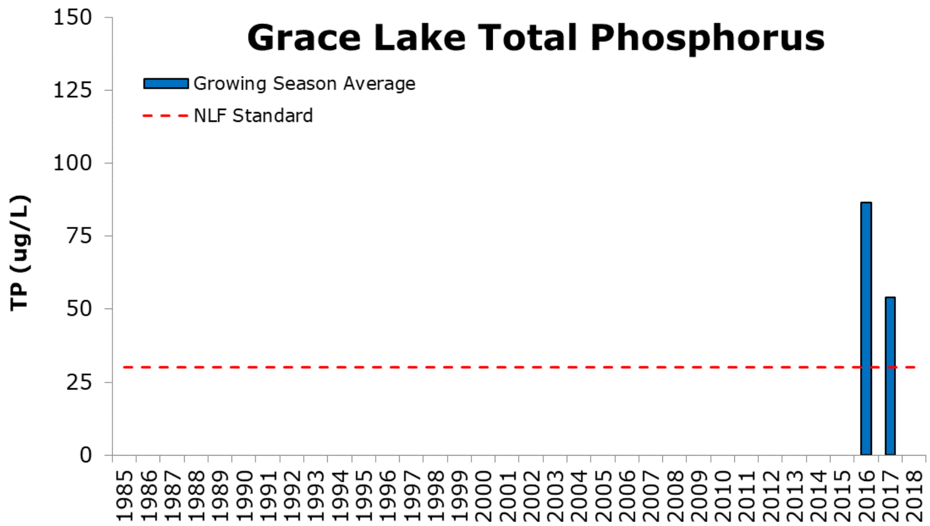
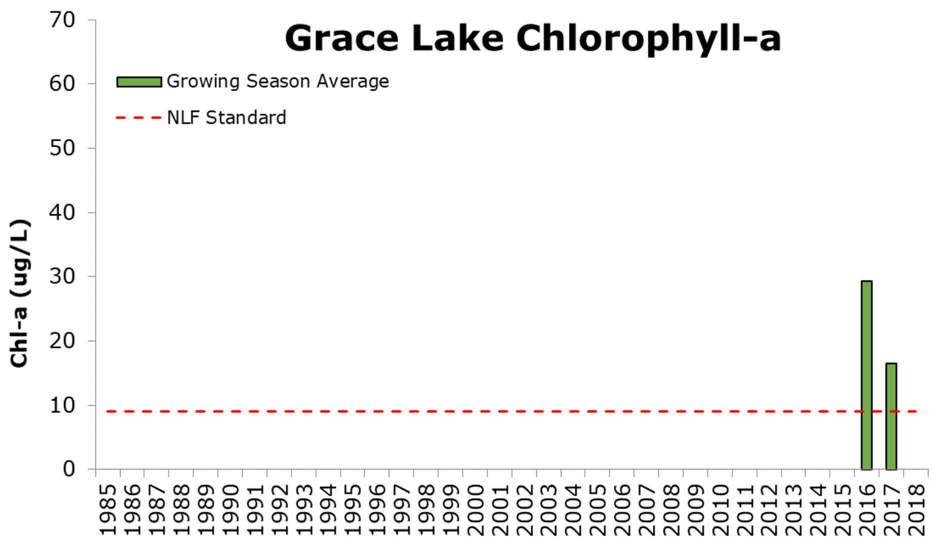


Figure C-23. Grace Lake Landcover.





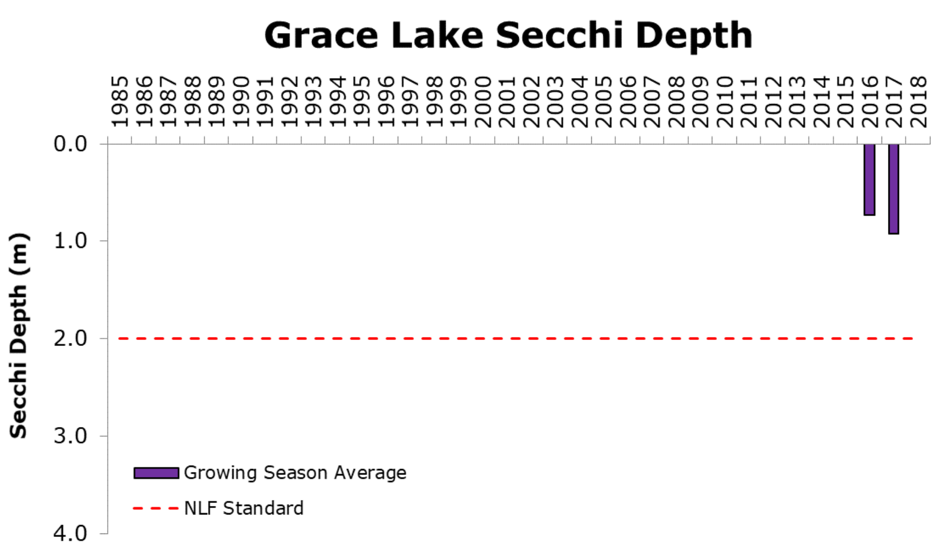
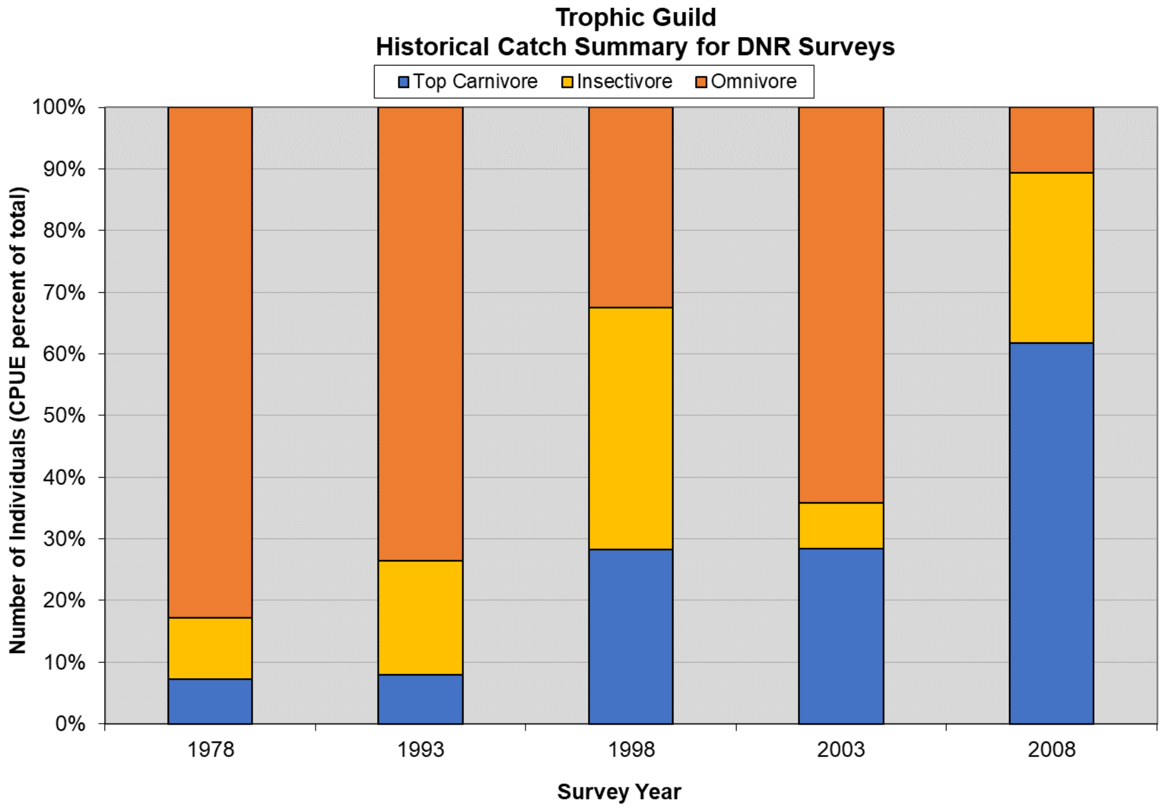


Figure C-24. Grace Lake Historic Water Quality.



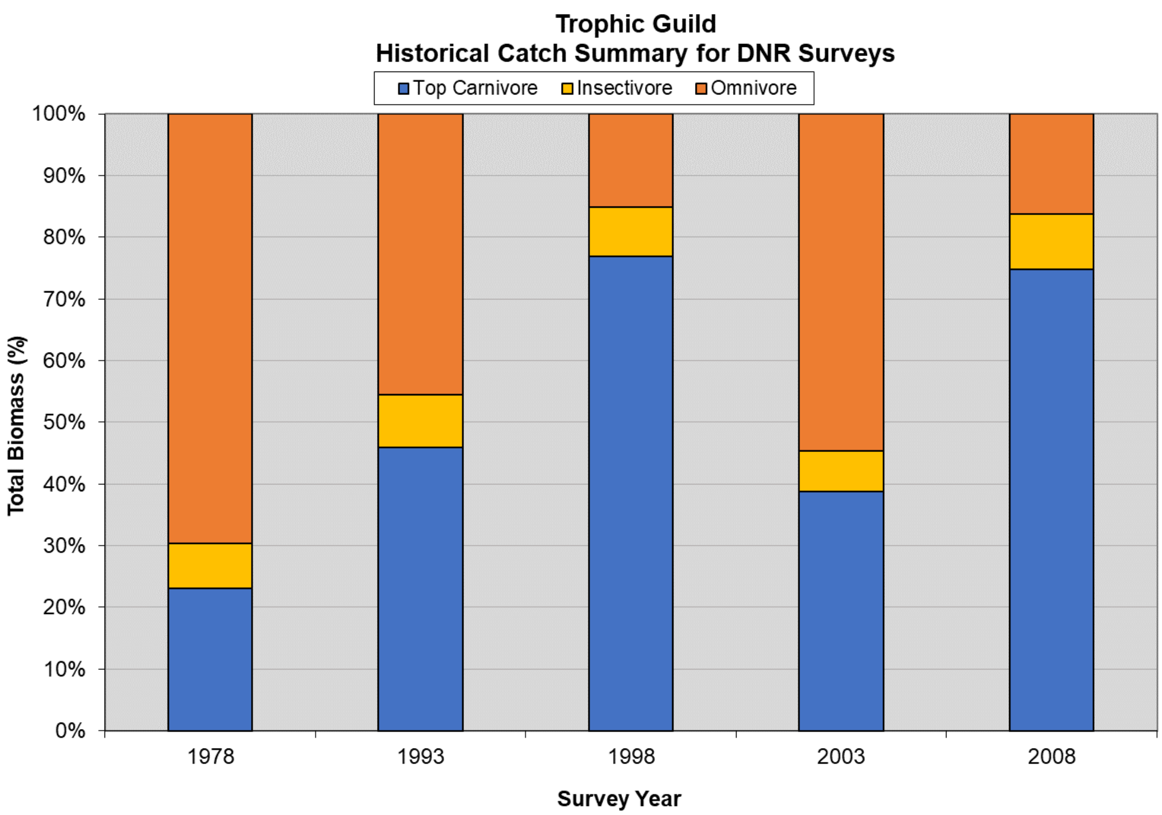


Figure C-25. Grace Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-9. Grace Lake Current Condition Lake Response Model.

Average Loading Summary for	***Grace***						
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Grace	1,956	16.8	2,743	37	1.0	272
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*1,956*	*17*	*2,742.59*			*272.3*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		17
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*16.8*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	62	37.9	37.9	0.00	0.26	1.0	16.0
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	62	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.25	0		Oxic		1.0	0
	0.25	49.6		Anoxic		1.0	437
	Summation						*437.0*
		Net Discharge [ac-ft/yr] =		**2,743**	**Net Load [lb/yr] =**		**742**

Average Lake Response Modeling for		***Grace***			
Modeled Parameter	**Equation**		**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION					
$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$		as f(W,Q,V) from Canfield & Bachmann (1981)			
			C_P =	1.00	[--]
			C_{CB} =	0.162	[--]
			b =	0.458	[--]
			W (total P load = inflow + atm.) =	337	[kg/yr]
			Q (lake outflow) =	3.4	[10^6 m^3/yr]
			V (modeled lake volume) =	0.4	[10^6 m^3]
			T = V/Q =	0.12	[yr]
			P_i = W/Q =	99	[µg/l]
Model Predicted In-Lake [TP]				**70.3**	**[ug/l]**
Observed In-Lake [TP]				**70.3**	**[ug/l]**

Table C-10. Grace Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for	*Grace*					
		Water Budgets			**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Grace	1,956	16.8	2,743	31	0.8	228
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*1,956*	*17*	*2,742.59*			*228.2*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		12
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*12.0*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	62	37.9	37.9	0.00	0.26	1.0	16.0
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	62	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.25	0		Oxic		1.0	0
	0.25	49.6		Anoxic	15.9	1.0	27
	Summation						*27.4*
		Net Discharge [ac-ft/yr] =		**2,743**	**Net Load [lb/yr] =**		**284**

TMDL Lake Response Modeling for		*Grace*		
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	129	[kg/yr]
		Q (lake outflow) =	3.4	[10^6 m^3/yr]
		V (modeled lake volume) =	0.4	[10^6 m^3]
		T = V/Q =	0.12	[yr]
		P_i = W/Q =	38	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**70.3**	**[ug/l]**

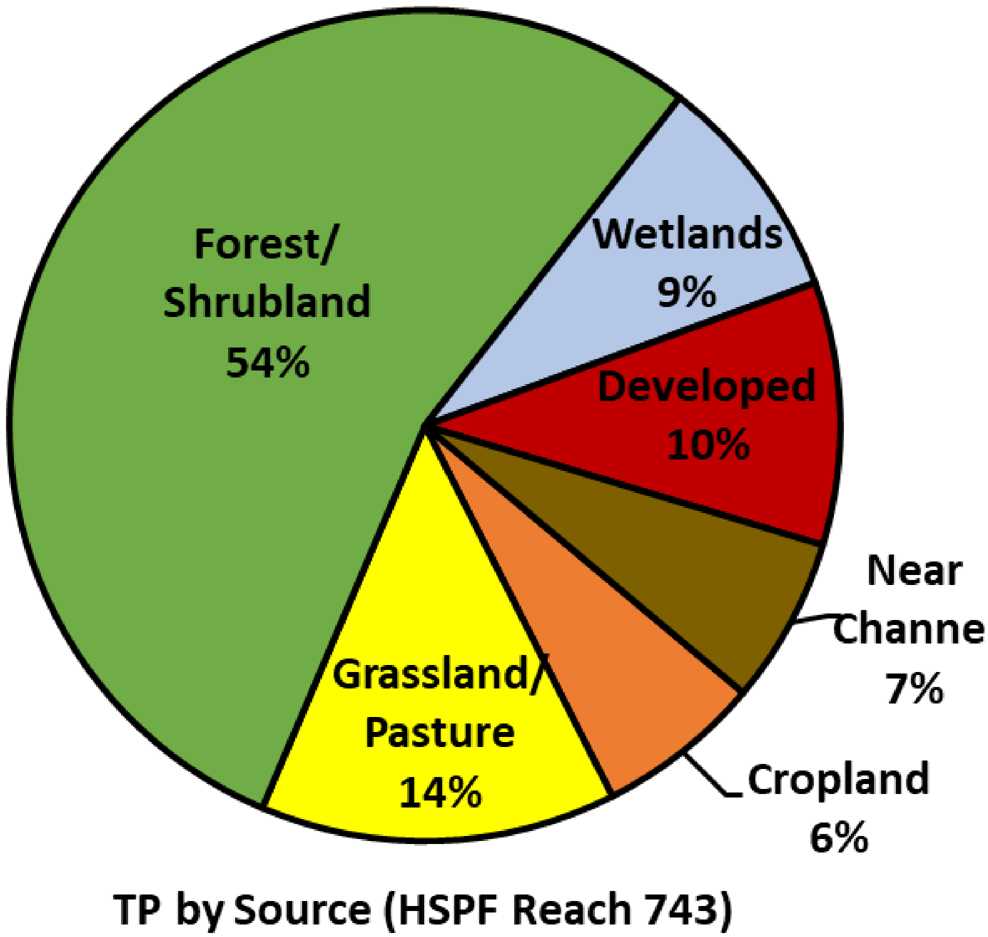


Figure C-26. Grace Lake HSPF-predicted watershed loading by source.

Supporting Items for Grindstone Lake (58-0123-00)

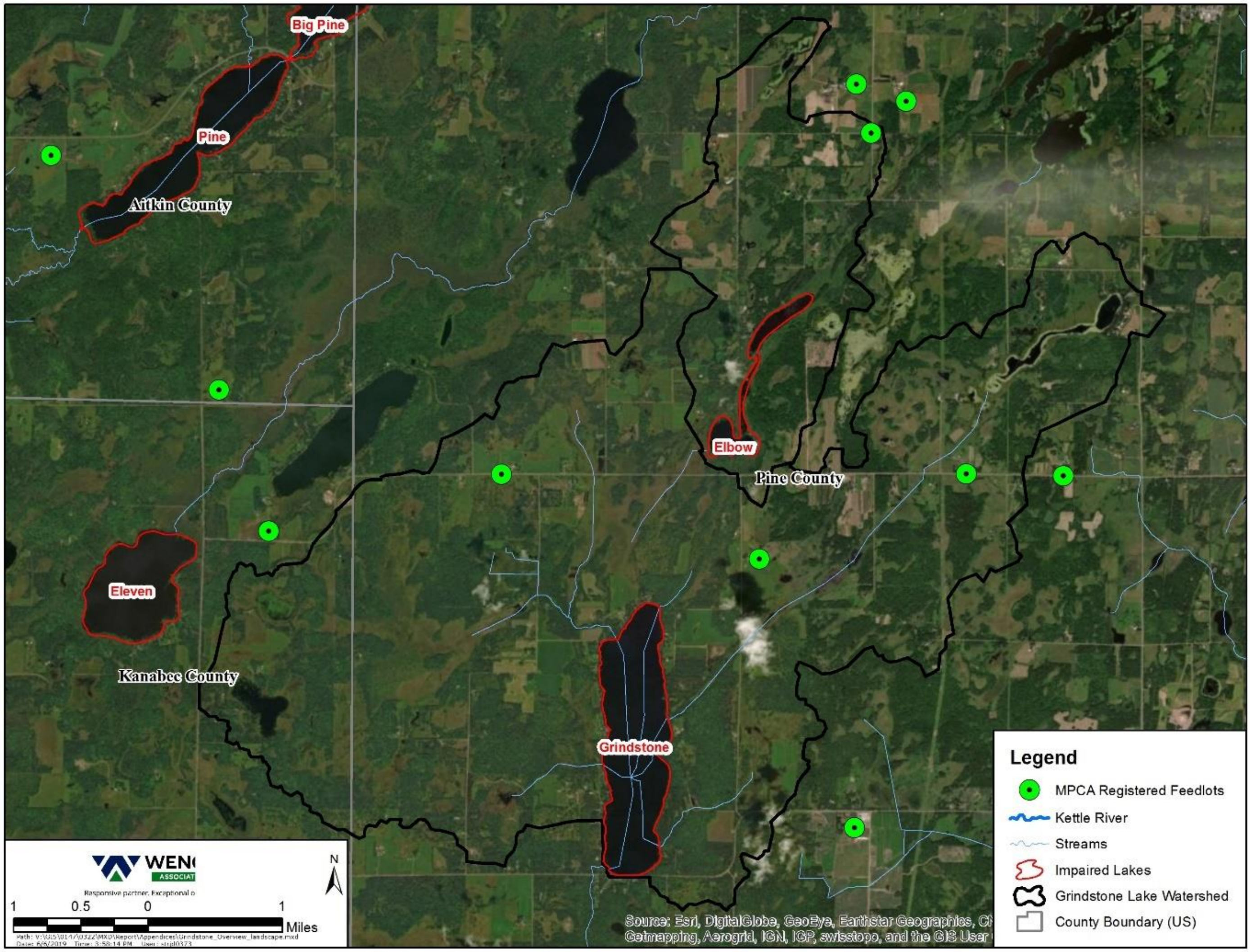


Figure C-27. Grindstone Lake Overview.

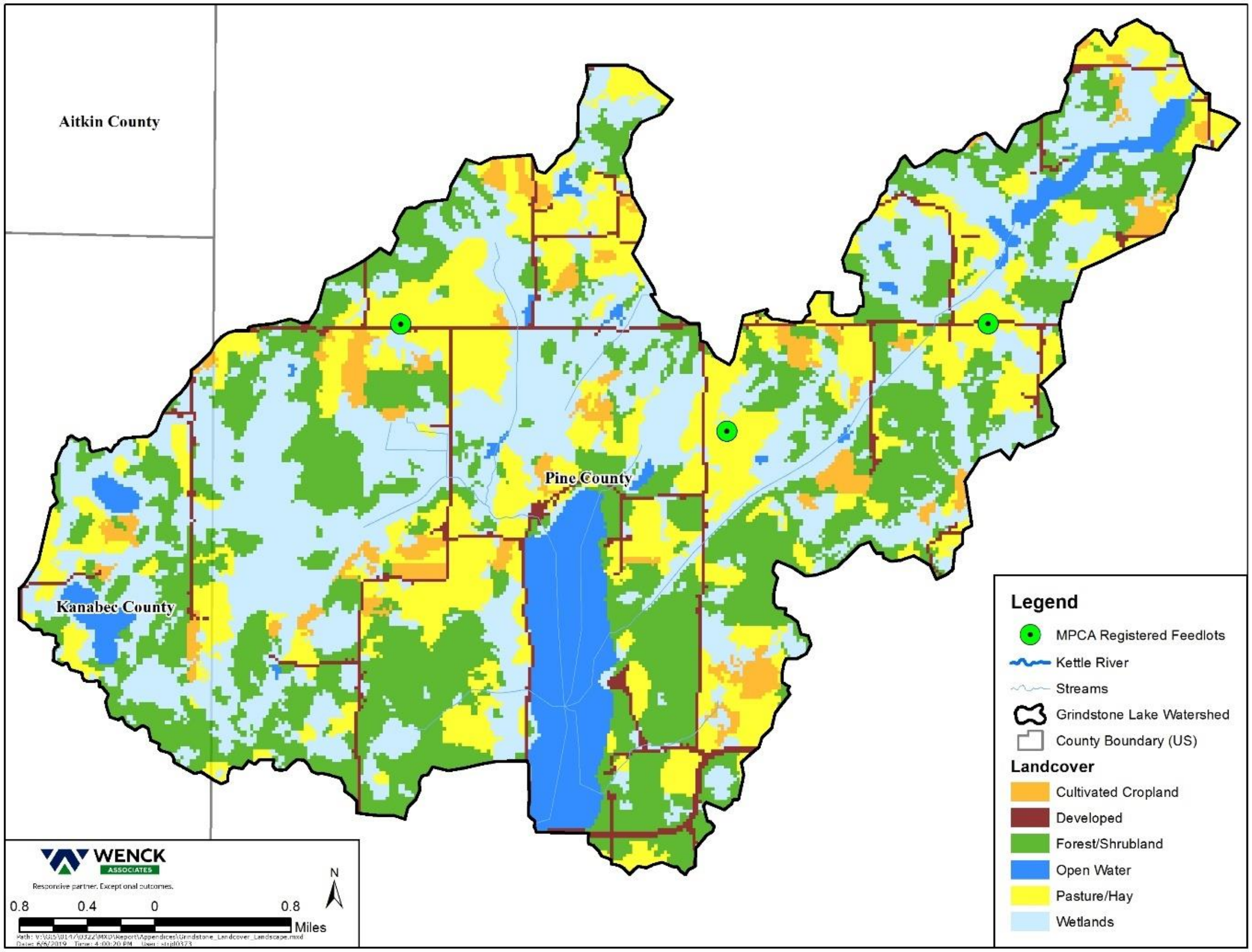
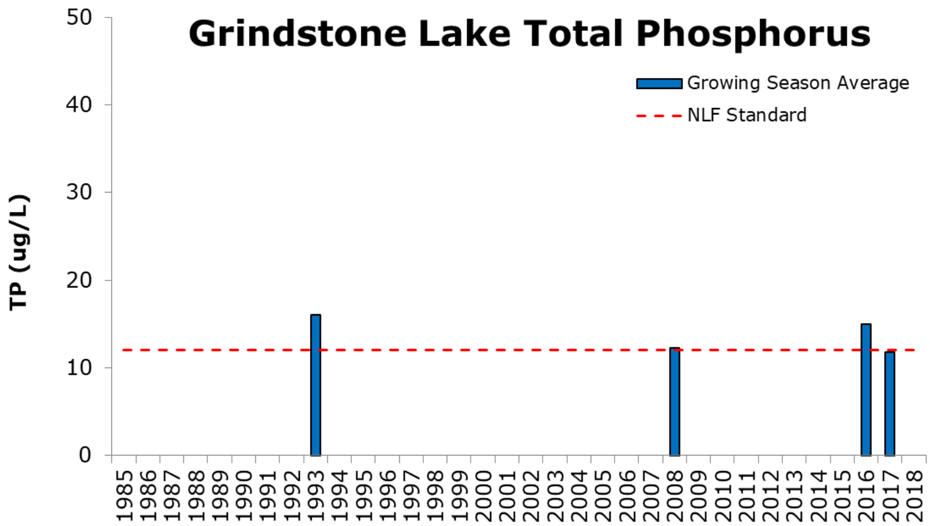
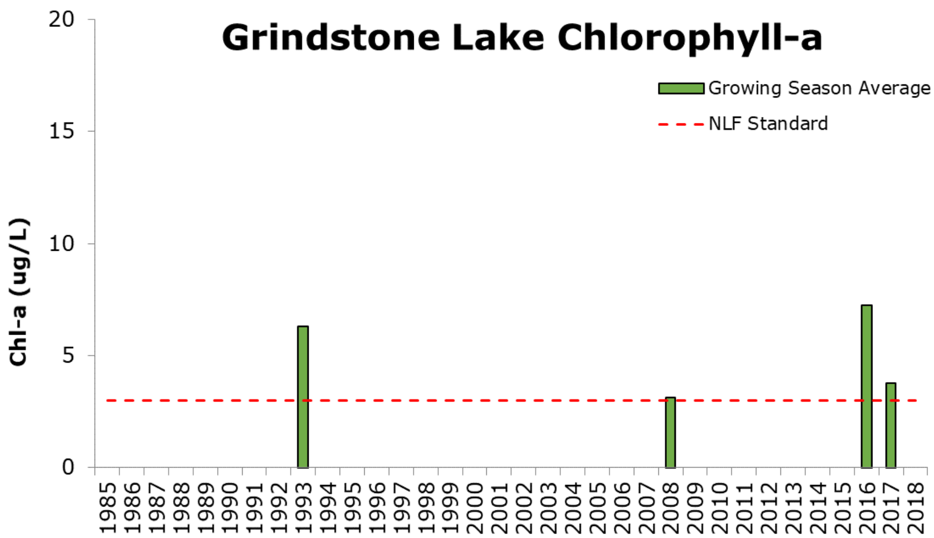


Figure C-28. Grindstone Lake Landcover.





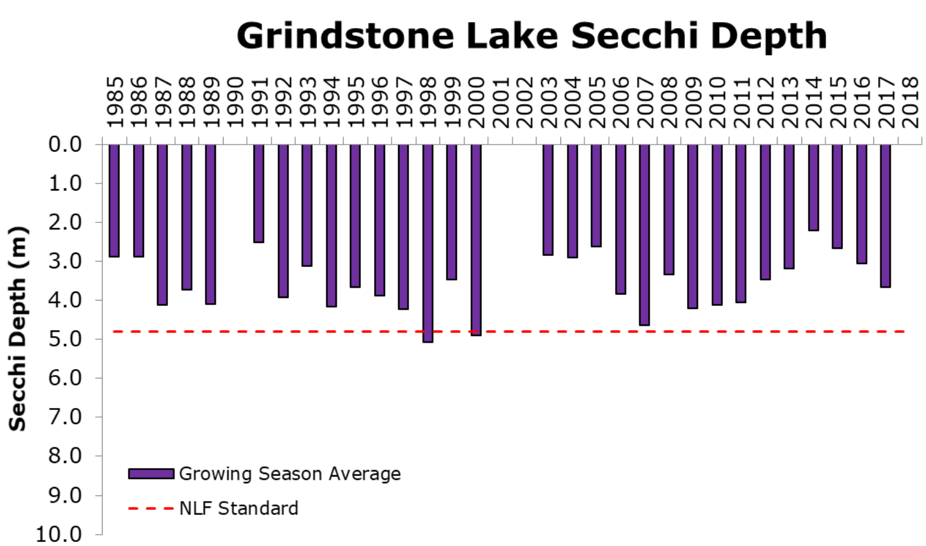
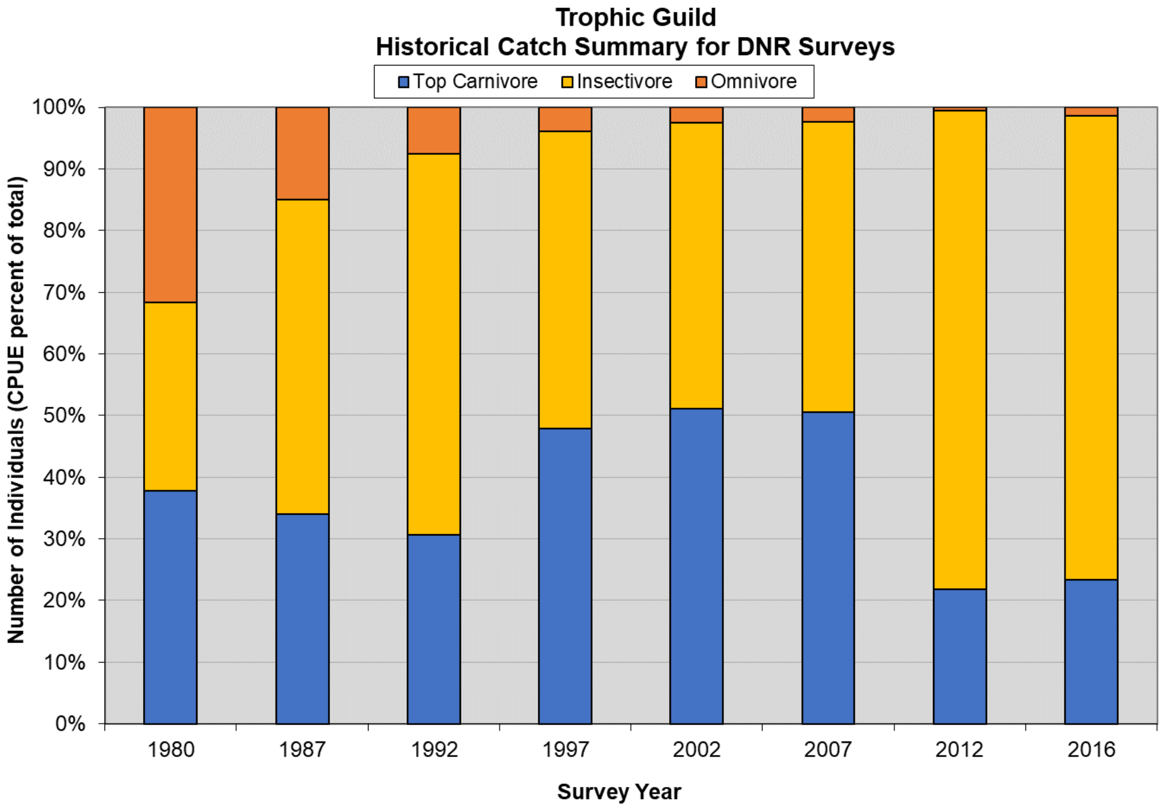


Figure C-29. Grindstone Lake Historic Water Quality.



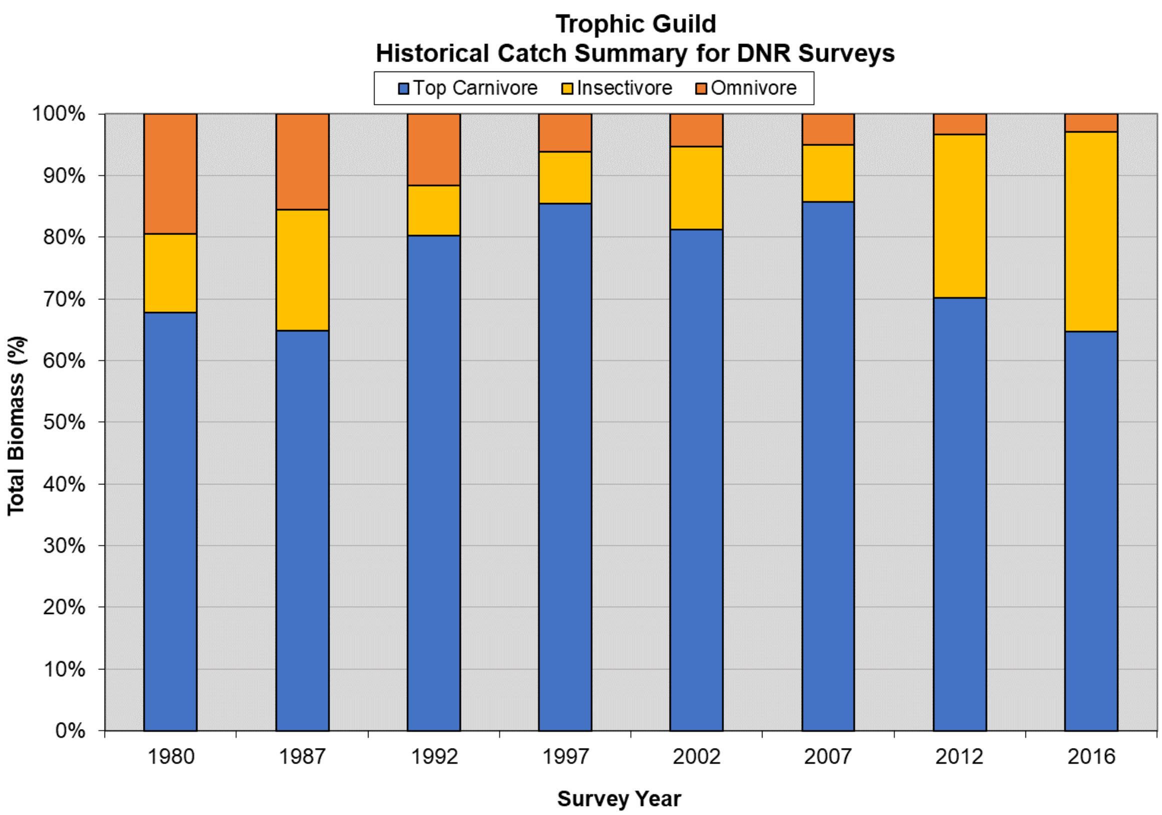


Figure C-30. Grindstone Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-11. Grindstone Lake Current Condition Lake Response Model.

Average Loading Summary for	***Grindstone***						
Water Budgets				**Phosphorus Loading**			
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Grindstone	13,098	12.2	13,357	47	1.0	1,697
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*13,098*	*12*	*13,356.95*			*1,697.1*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		180
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*179.8*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Elbow			2,250	40.9	1.0	250
2	0			0	-	1.0	0
3	0			0	-	1.0	0
4	0			0	-	1.0	0
5	0			0	-	1.0	0
	Summation			*2,249.6*	*40.9*		*250.2*
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]
	528	36.3	36.3	0.00	0.26	1.0	136.6
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	528	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	2.14	122		Oxic	0.1	1.0	57
	2.14	0.0		Anoxic		1.0	0
	Summation						*57.5*
		Net Discharge [ac-ft/yr] =		**15,607**	**Net Load [lb/yr] =**		**2,321**

Average Lake Response Modeling for	***Grindstone***		
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 =	1.95 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	1,053 [kg/yr]
		Q (lake outflow) =	19.3 [10^6 m^3/yr]
		V (modeled lake volume) =	46.4 [10^6 m^3]
		T = V/Q =	2.41 [yr]
		P_i = W/Q =	55 [µg/l]
Model Predicted In-Lake [TP]			**13.0 [ug/l]**
Observed In-Lake [TP]			**13.0 [ug/l]**

Table C-12. Grindstone Lake TMDL Condition Lake Response Model.

TMDL Loading Summary for Grindstone

Water Budgets | Phosphorus Loading

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Grindstone	13,098	12.2	13,357	42	0.9	1,521
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*13,098*	*12*	*13,356.95*			*1,521.0*

Point Source Dischargers

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

Curly-leaf Pondweed

	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		143
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*143.2*

Inflow from Upstream Lakes

	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1	Elbow			2,250	30.0	0.7	184
2	0			0	-	1.0	0
3	0			0	-	1.0	0
4	0			0	-	1.0	0
5	0			0	-	1.0	0
	Summation			*2,249.6*	*30.0*		*183.6*

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]
	528	36.3	36.3	0.00	0.26	1.0	136.6
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					

Groundwater

	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	528	0.0		0.00	0	1.0	0

Model Residual Load

	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*

Internal

	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	2.14	122		Oxic	0.1	1.0	57
	2.14	0.0		Anoxic		1.0	0
	Summation						*57.5*
		Net Discharge [ac-ft/yr] =		**15,607**	Net Load [lb/yr] =		**2,042**

TMDL Lake Response Modeling for Grindstone

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.95	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	926	[kg/yr]
		Q (lake outflow) =	19.3	[10^6 m^3/yr]
		V (modeled lake volume) =	46.4	[10^6 m^3]
		T = V/Q =	2.41	[yr]
		P_i = W/Q =	48	[µg/l]
Model Predicted In-Lake [TP]			**12.0**	**[ug/l]**
Observed In-Lake [TP]			**13.0**	**[ug/l]**

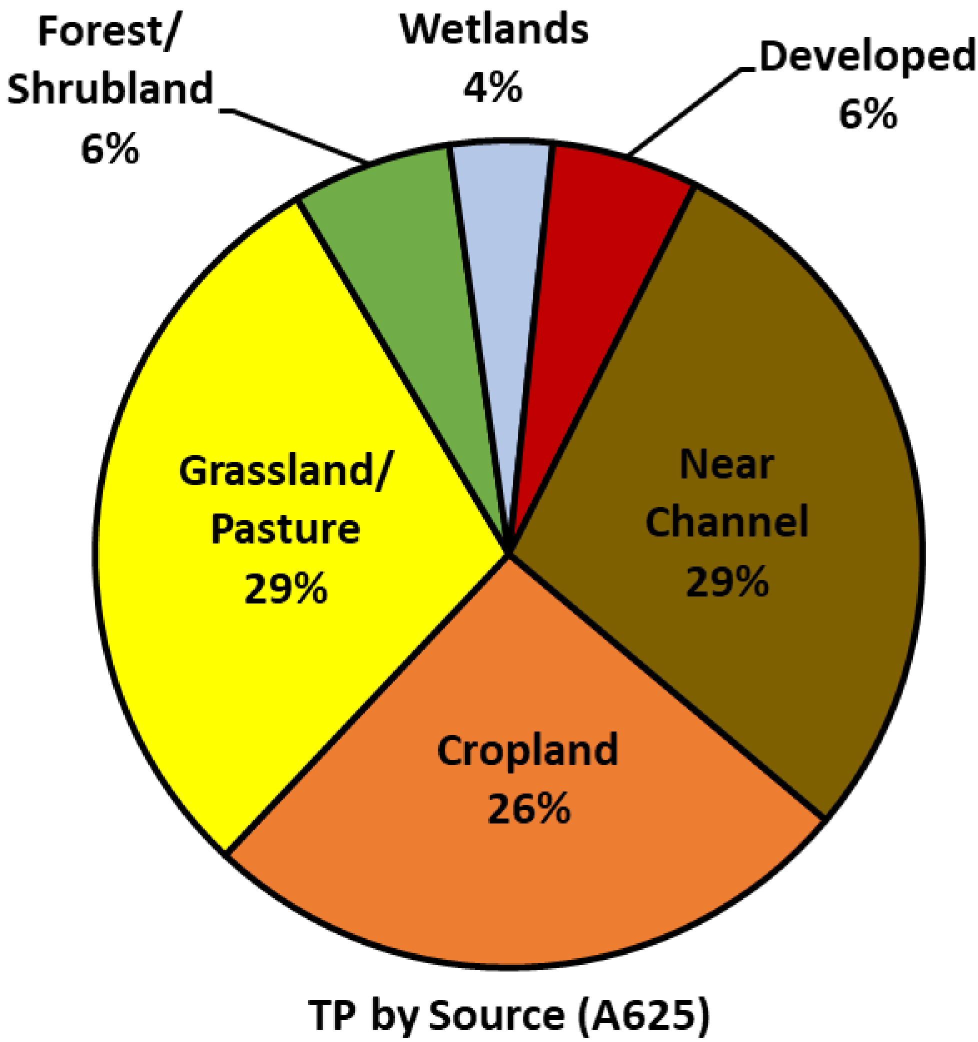


Figure C-31. Grindstone Lake HSPF-predicted watershed loading by source.

Supporting Items for McCormick Lake (58-0058-00)

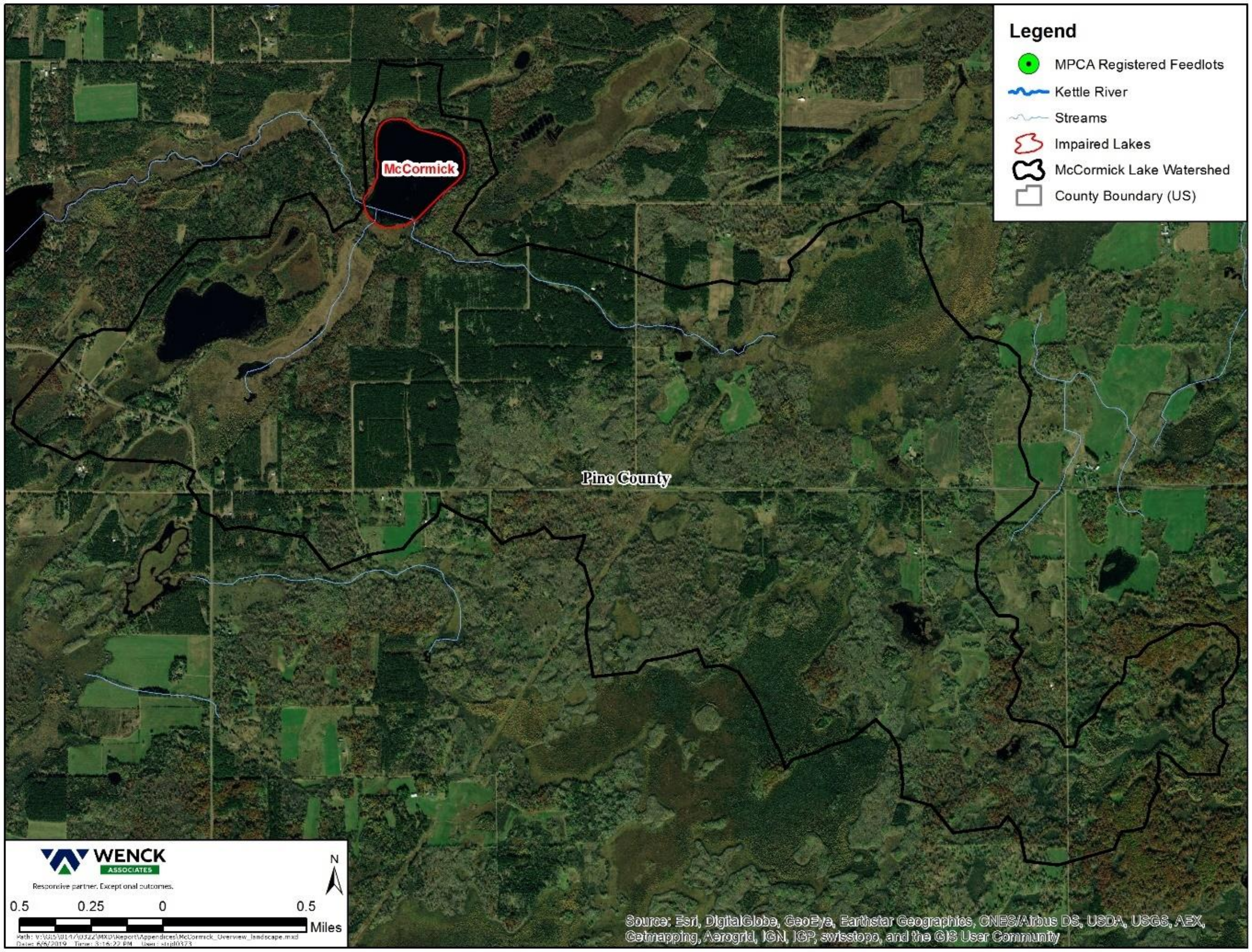


Figure C-32. McCormick Lake Overview.

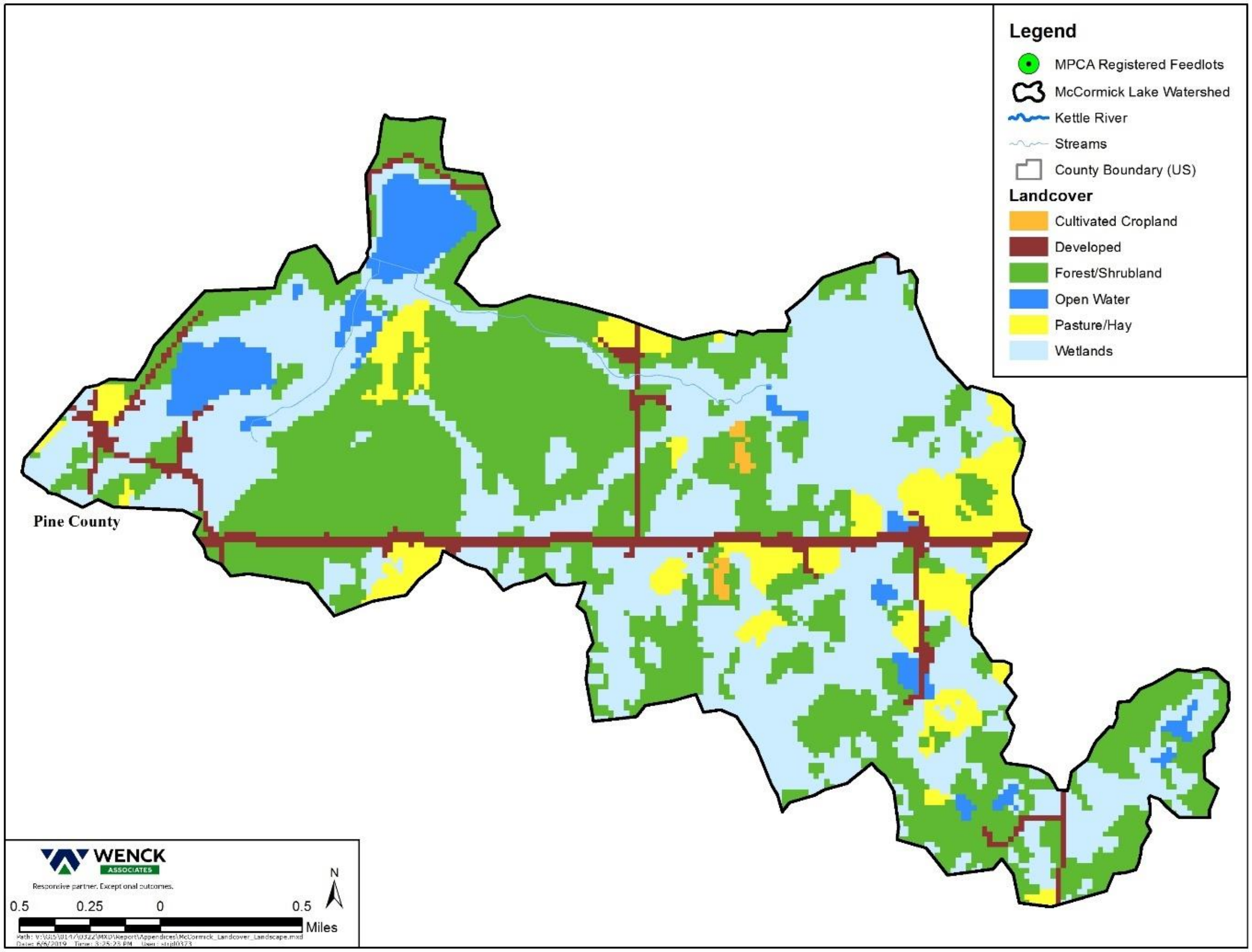
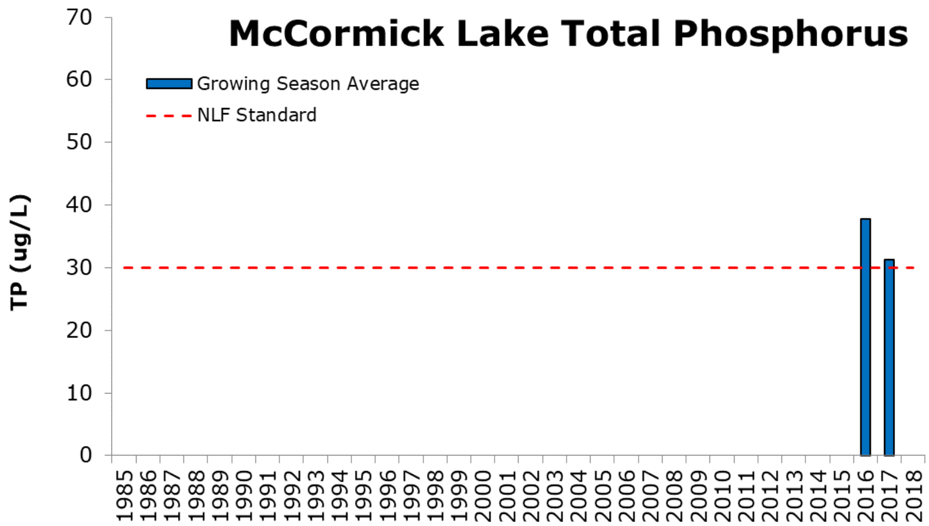
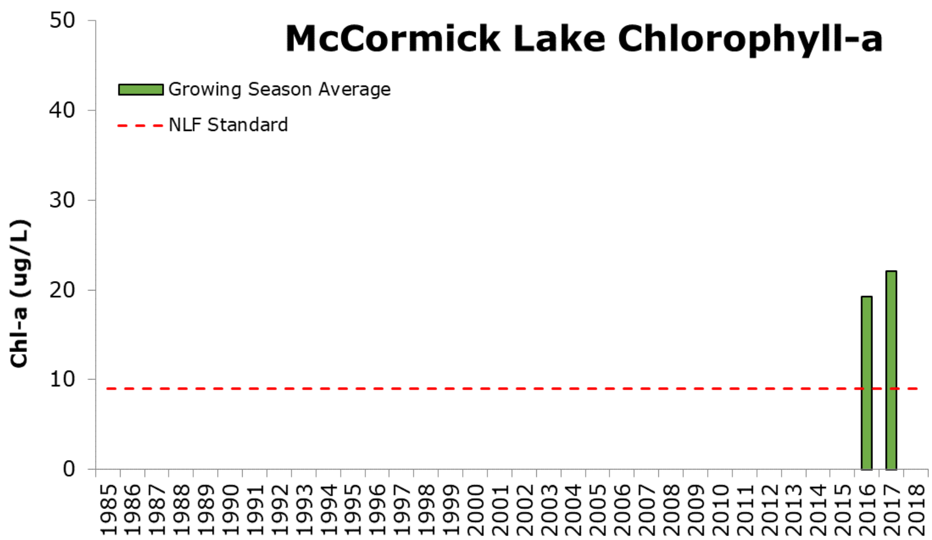


Figure C-33. McCormick Lake Landcover.





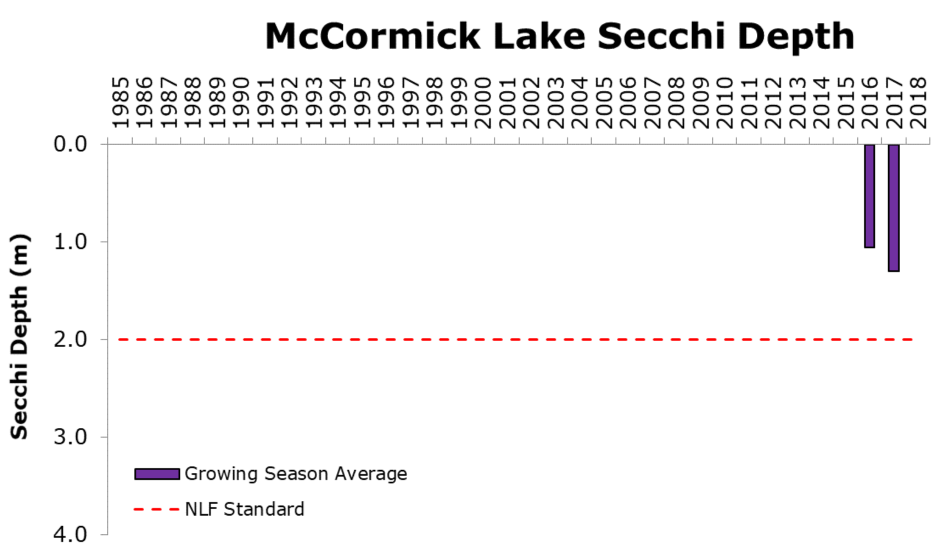
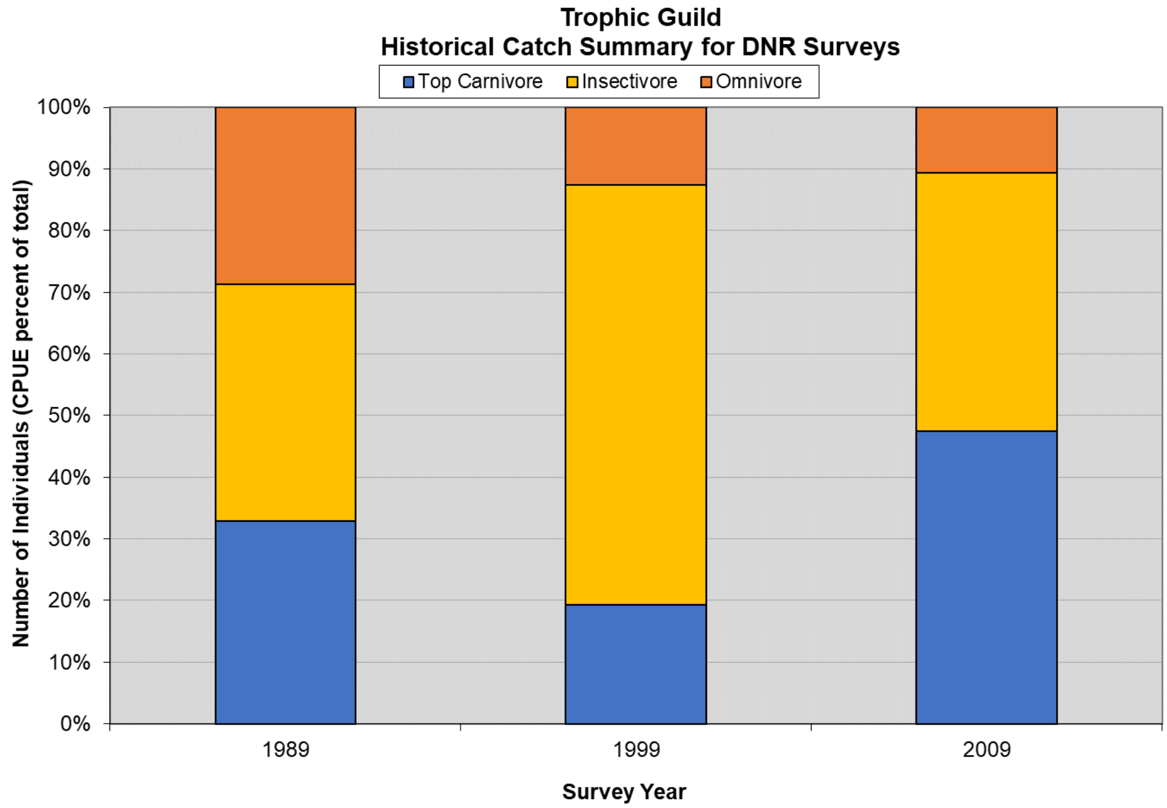


Figure C-34. McCormick Lake Historic Water Quality.



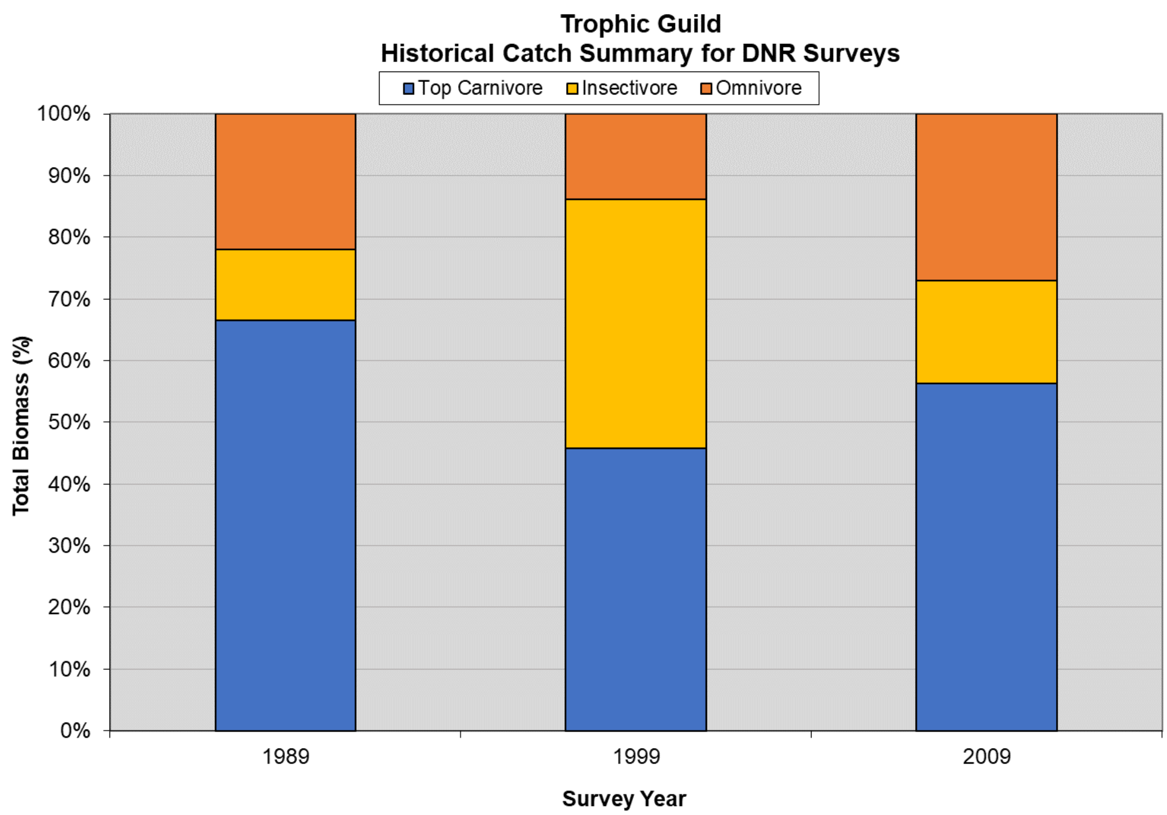


Figure C-35. McCormick Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-13. McCormick Lake Current Condition Lake Response Model.

Average Loading Summary for McCormick							
Water Budgets				**Phosphorus Loading**			
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	McCormick	2,752	16.6	3,799	61	1.0	634
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,752*	*17*	*3,798.74*			*634.1*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		18
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*17.5*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	62	37.9	37.9	0.00	0.26	1.0	16.0
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	62	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.25	0		Oxic		1.0	0
	0.25	36.5		Anoxic	0.5	1.0	10
	Summation						*10.1*
		Net Discharge [ac-ft/yr] =		**3,799**	**Net Load [lb/yr] =**		**678**

Average Lake Response Modeling for McCormick					
Modeled Parameter	**Equation**		**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION					
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)			
			C_P =	2.82	[--]
			C_{CB} =	0.162	[--]
			b =	0.458	[--]
			W (total P load = inflow + atm.) =	307	[kg/yr]
			Q (lake outflow) =	4.7	[10^6 m^3/yr]
			V (modeled lake volume) =	0.5	[10^6 m^3]
			T = V/Q =	0.10	[yr]
			P_i = W/Q =	66	[µg/l]
Model Predicted In-Lake [TP]				**34.5**	**[ug/l]**
Observed In-Lake [TP]				**34.5**	**[ug/l]**

Table C-14. McCormick Lake TMDL Condition Lake Response Model.

TMDL Loading Summary for McCormick							
Water Budgets				**Phosphorus Loading**			
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	McCormick	2,752	16.6	3,799	51	0.8	529
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,752*	*17*	*3,798.74*			*529.0*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		12
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*12.5*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	62	37.9	37.9	0.00	0.26	1.0	16.0
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	62	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.25	0		Oxic		1.0	0
	0.25	36.5		Anoxic	0.5	1.0	10
	Summation						*10.1*
			Net Discharge [ac-ft/yr] =	**3,799**		**Net Load [lb/yr] =**	**568**

TMDL Lake Response Modeling for McCormick				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	2.82	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	257	[kg/yr]
		Q (lake outflow) =	4.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.5	[10^6 m^3]
		T = V/Q =	0.10	[yr]
		P_i = W/Q =	55	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**34.5**	**[ug/l]**

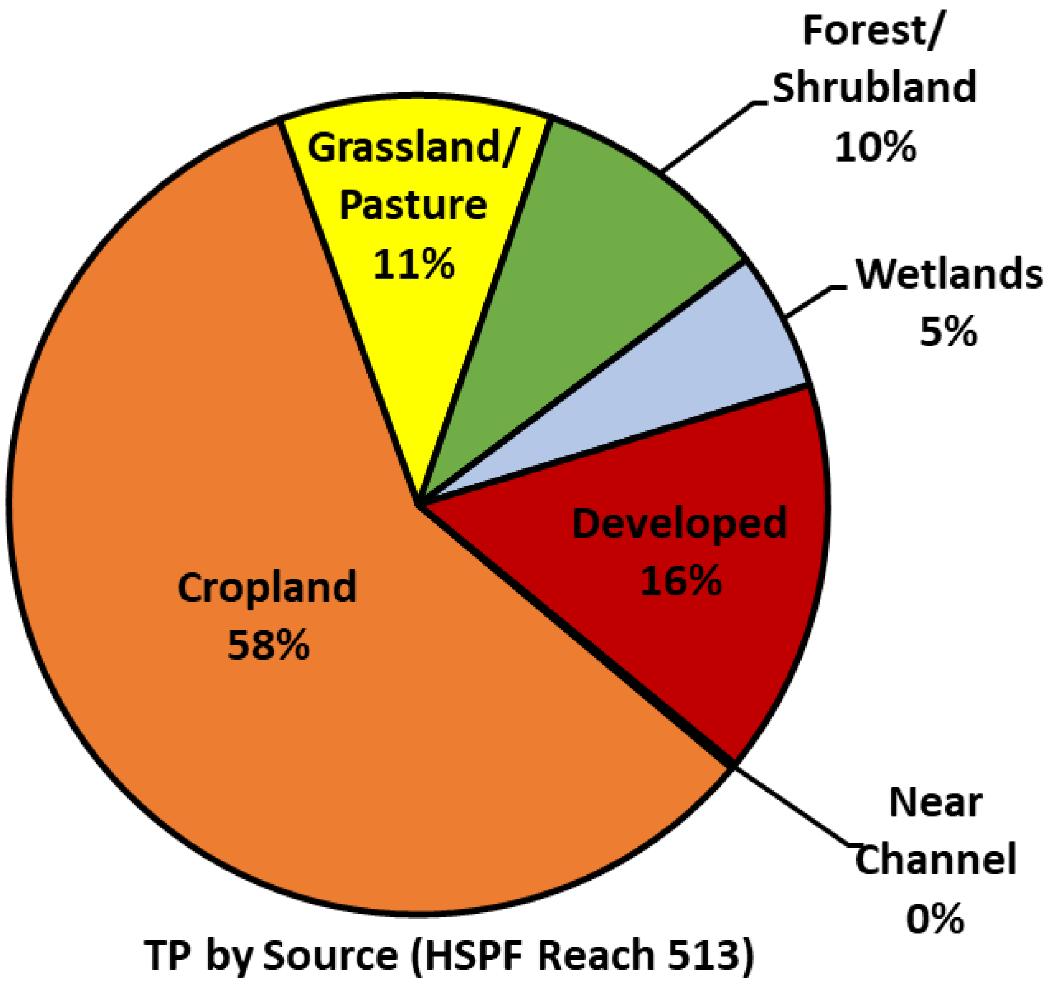


Figure C-36. McCormick Lake HSPF-predicted watershed loading by source.

Supporting Items for Merwin Lake (09-0058-00)

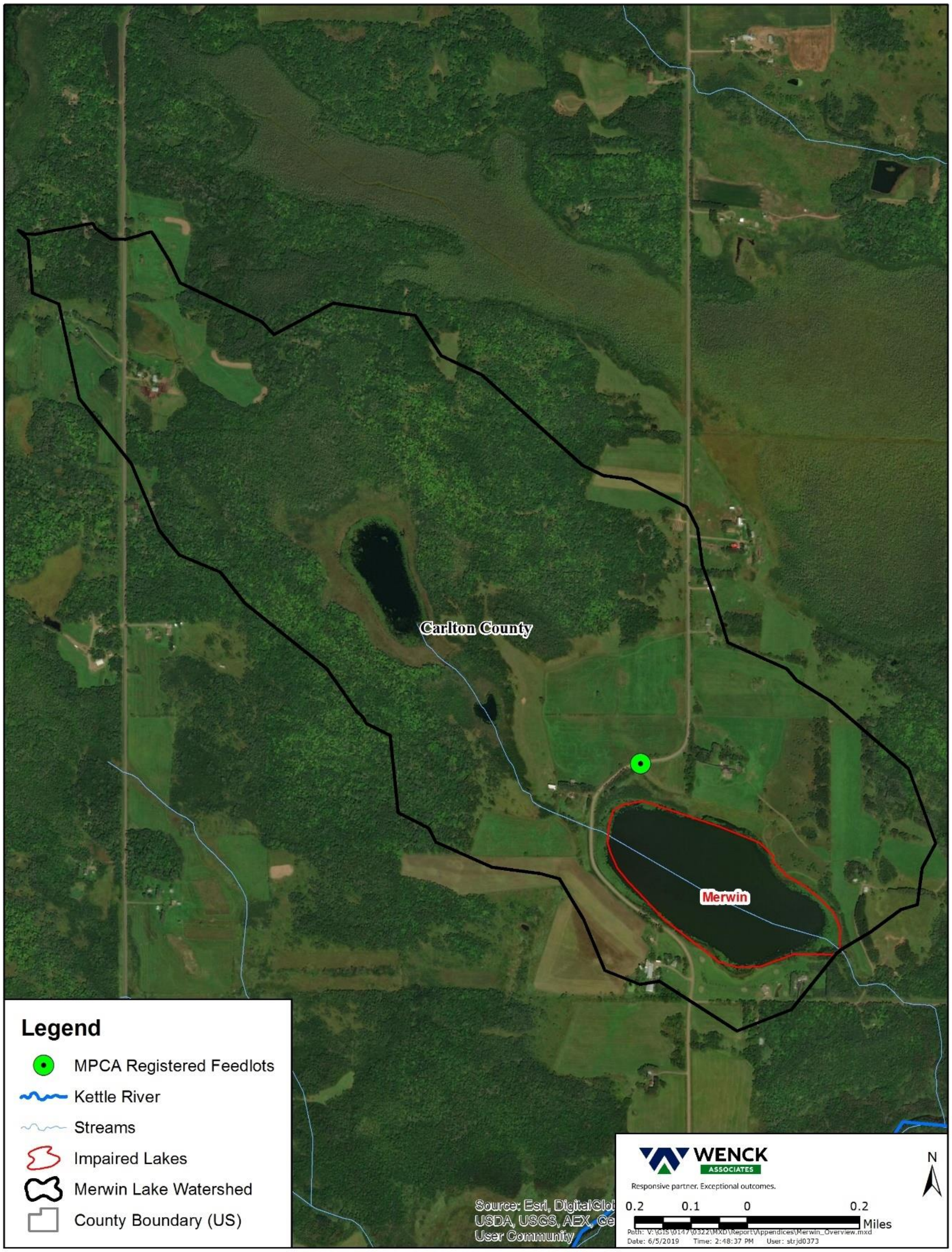


Figure C-37. Merwin Lake Overview.

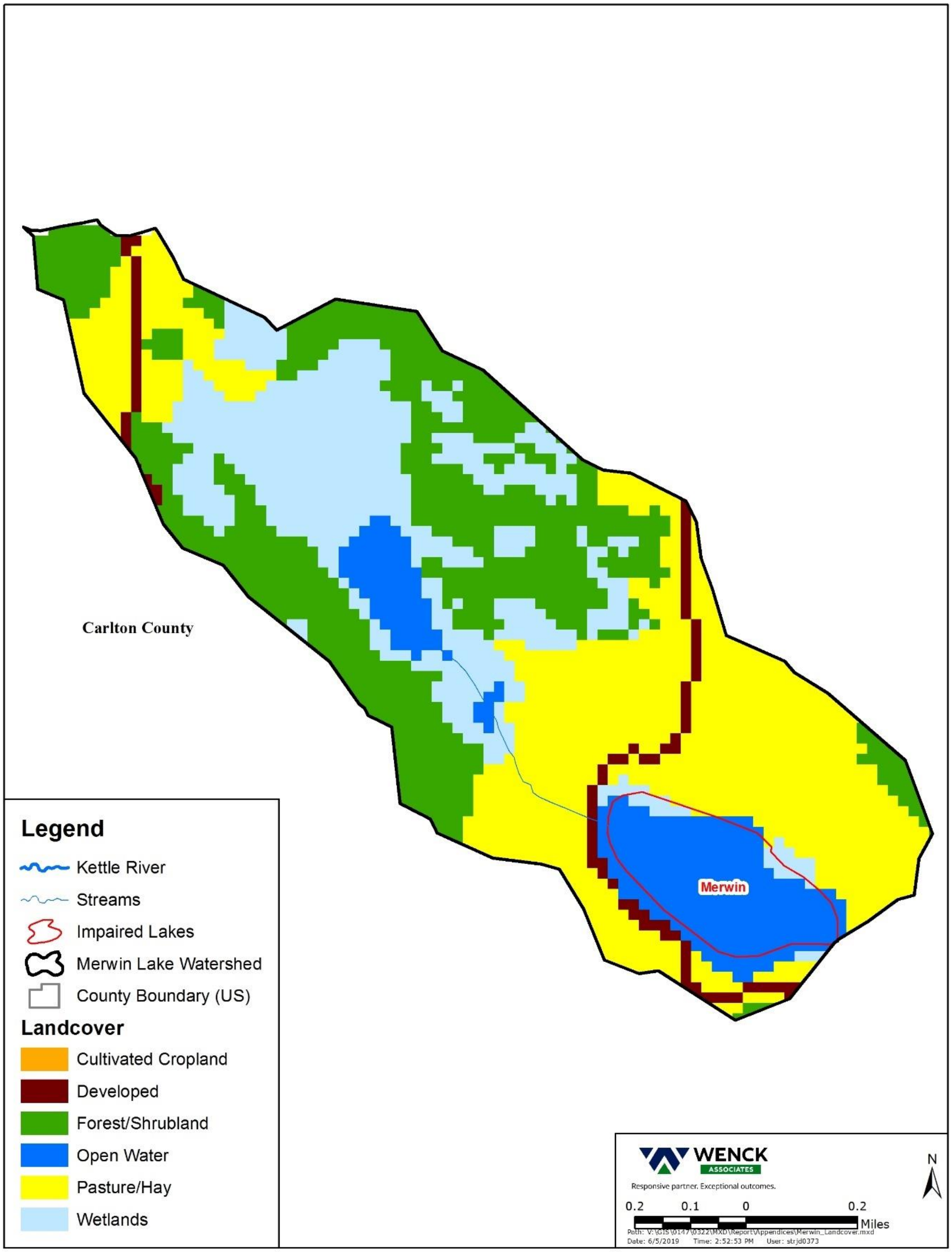


Figure C-38. Merwin Lake Landcover.

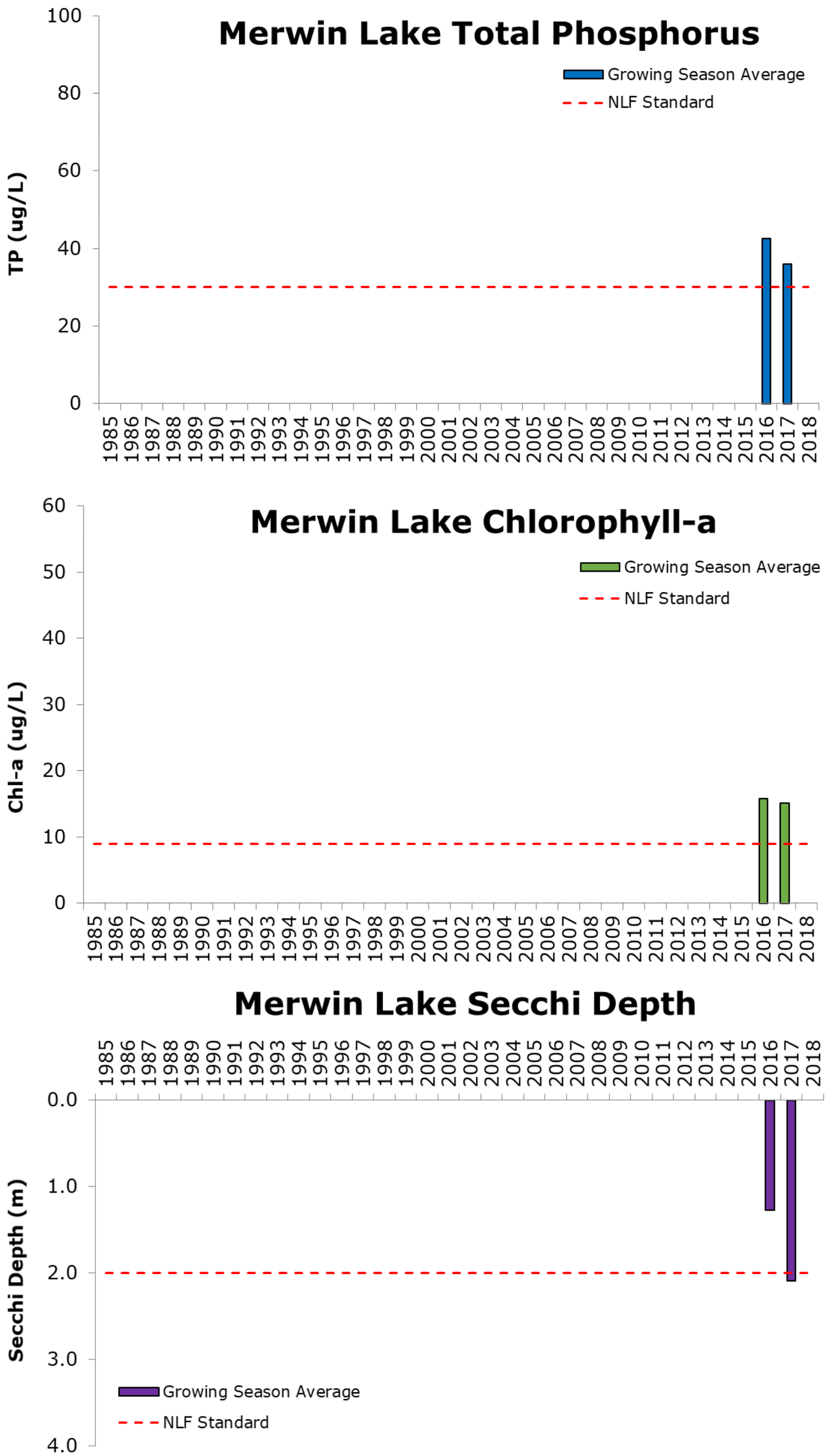


Figure C-39. Merwin Lake Historic Water Quality.

Table C-15. Merwin Lake Current Condition Lake Response Model.

	Average Loading Summary for Merwin						
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Merwin	628	16.7	874	46	1.0	110
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*628*	*17*	*873.92*			*110.4*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		9
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*9.2*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	53	37.9	37.9	0.00	0.26	1.0	13.7
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	53	0.0		0.00	0	1.0	0
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.21	0		Oxic		1.0	0
	0.21	40.5		Anoxic	1.8	1.0	34
	Summation						*33.8*
		Net Discharge [ac-ft/yr] =		**874**	**Net Load [lb/yr] =**		**167**

Average Lake Response Modeling for Merwin				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	76	[kg/yr]
		Q (lake outflow) =	1.1	[10^6 m^3/yr]
		V (modeled lake volume) =	0.6	[10^6 m^3]
		T = V/Q =	0.51	[yr]
		P_i = W/Q =	70	[µg/l]
Model Predicted In-Lake [TP]			**39.3**	**[ug/l]**
Observed In-Lake [TP]			**39.3**	**[ug/l]**

Table C-16. Merwin Lake TMDL Condition Lake Response Model.

TMDL Loading Summary for Merwin

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Merwin	628	16.7	874	33	0.7	79
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*628*	*17*	*873.92*			*79.0*

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

Curly-leaf Pondweed							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*

Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		8
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*7.7*

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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	53	37.9	37.9	0.00	0.26	1.0	13.7
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			

Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	53	0.0		0.00	0	1.0	0

Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*

Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.21	0		Oxic		1.0	0
	0.21	40.5		Anoxic	1.8	1.0	19
	Summation						*19.2*
			Net Discharge [ac-ft/yr] =	**874**		Net Load [lb/yr] =	**120**

TMDL Lake Response Modeling for Merwin

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	54	[kg/yr]
		Q (lake outflow) =	1.1	[10^6 m^3/yr]
		V (modeled lake volume) =	0.6	[10^6 m^3]
		T = V/Q =	0.51	[yr]
		P_i = W/Q =	50	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**39.3**	**[ug/l]**

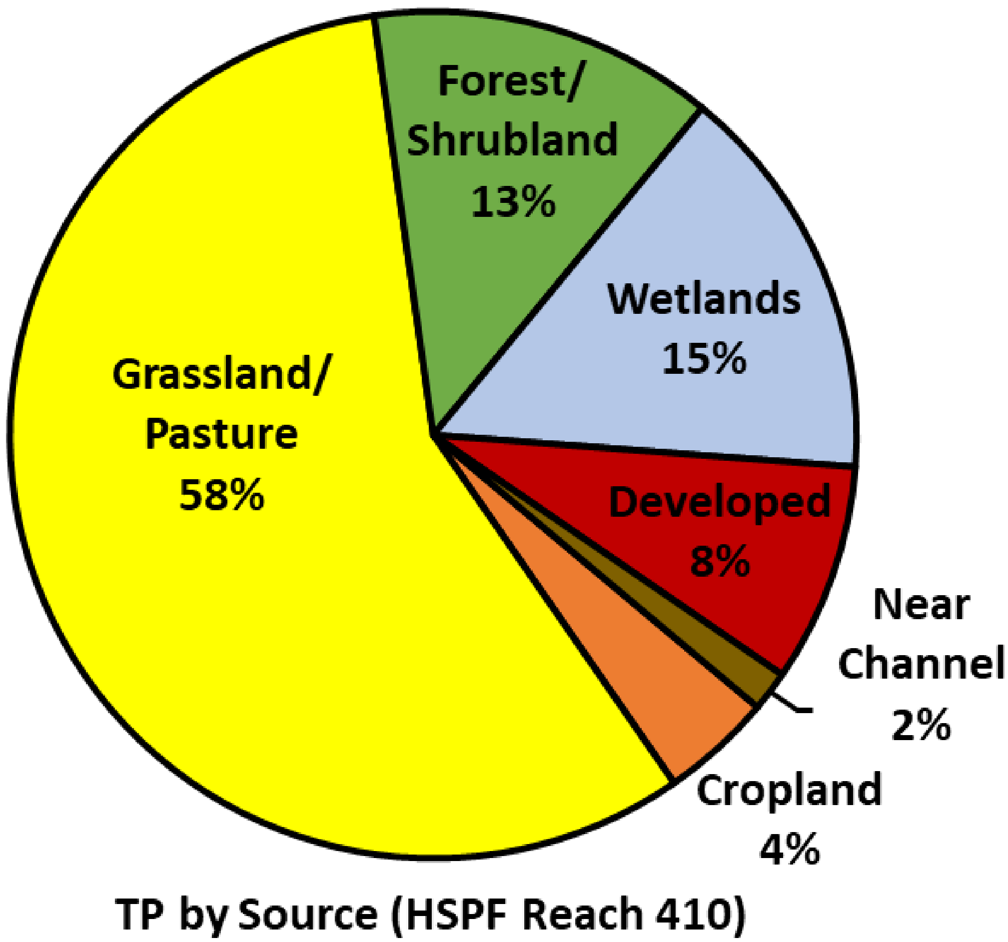


Figure C-40. Merwin Lake HSPF-predicted watershed loading by source.

Supporting Items for Oak Lake (58-0048-00)

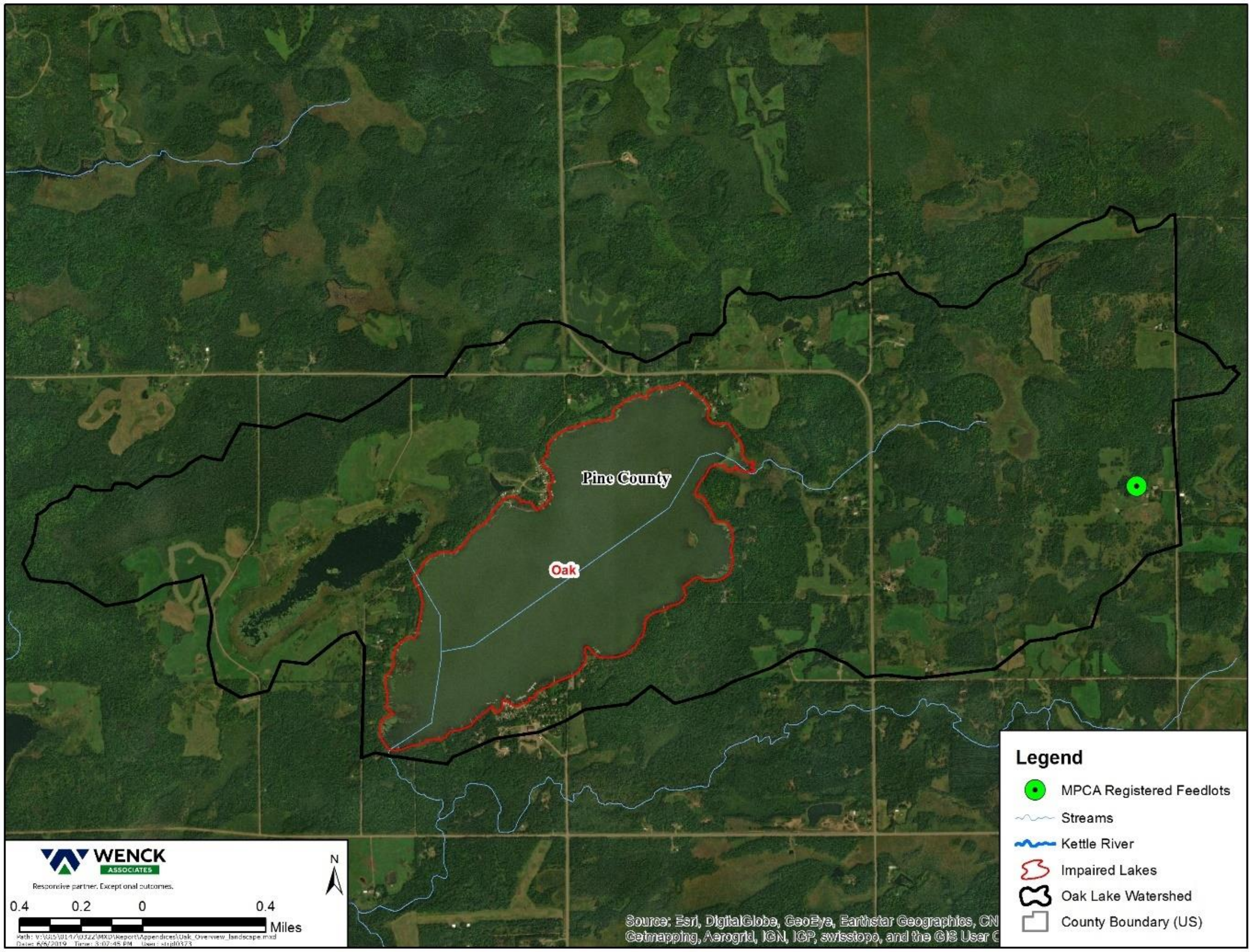


Figure C-41. Oak Lake Overview.

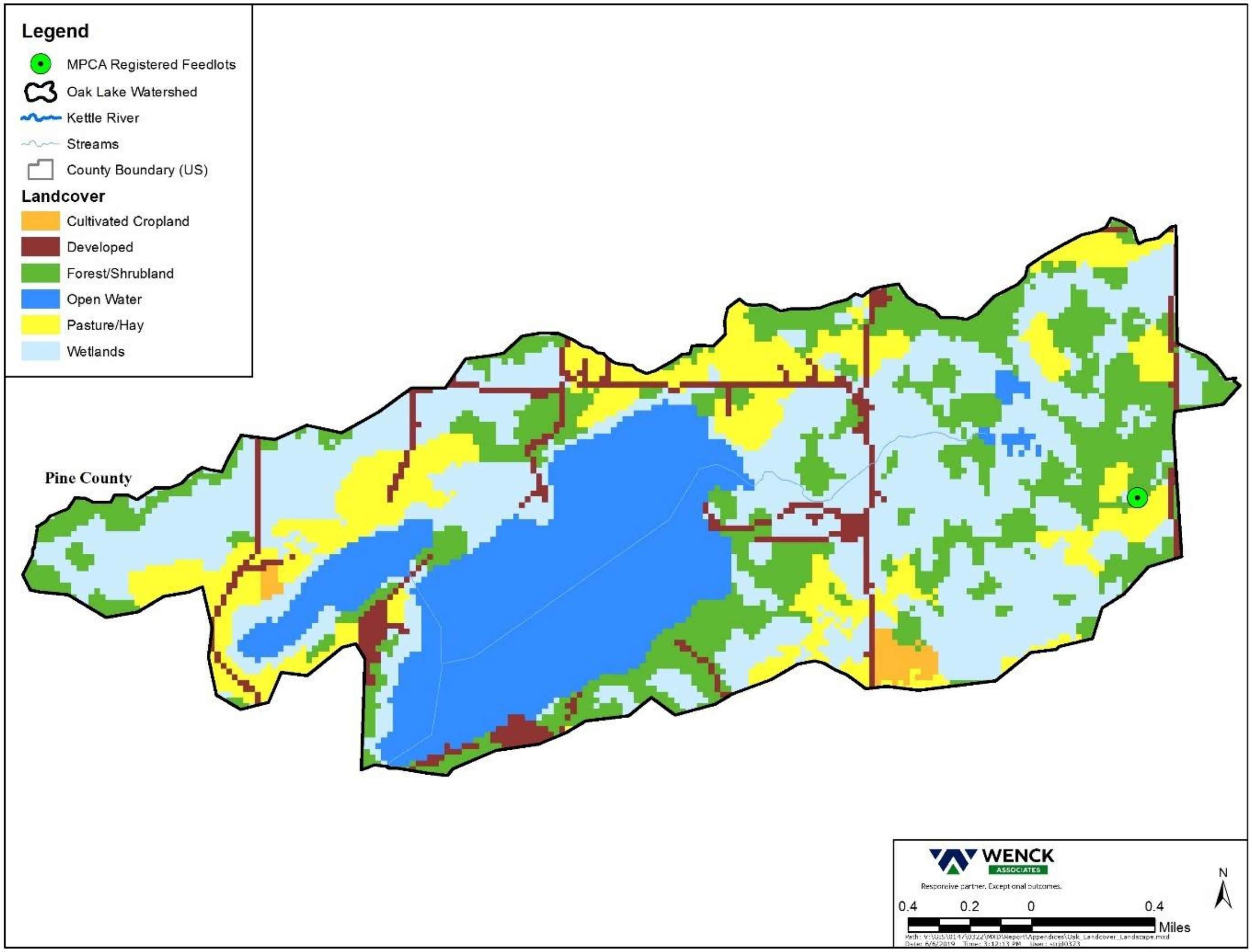


Figure C-42. Oak Lake Landcover.

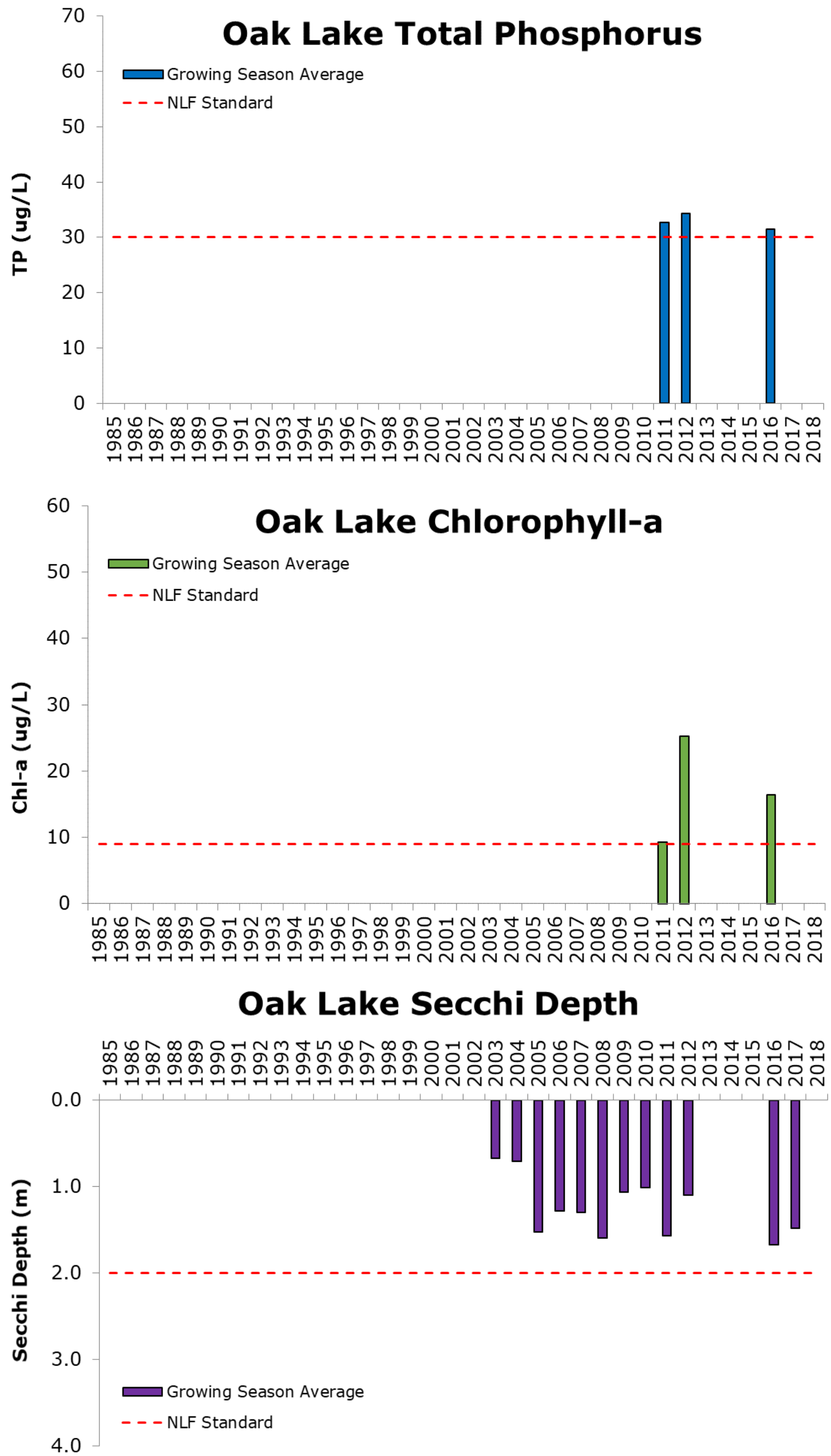
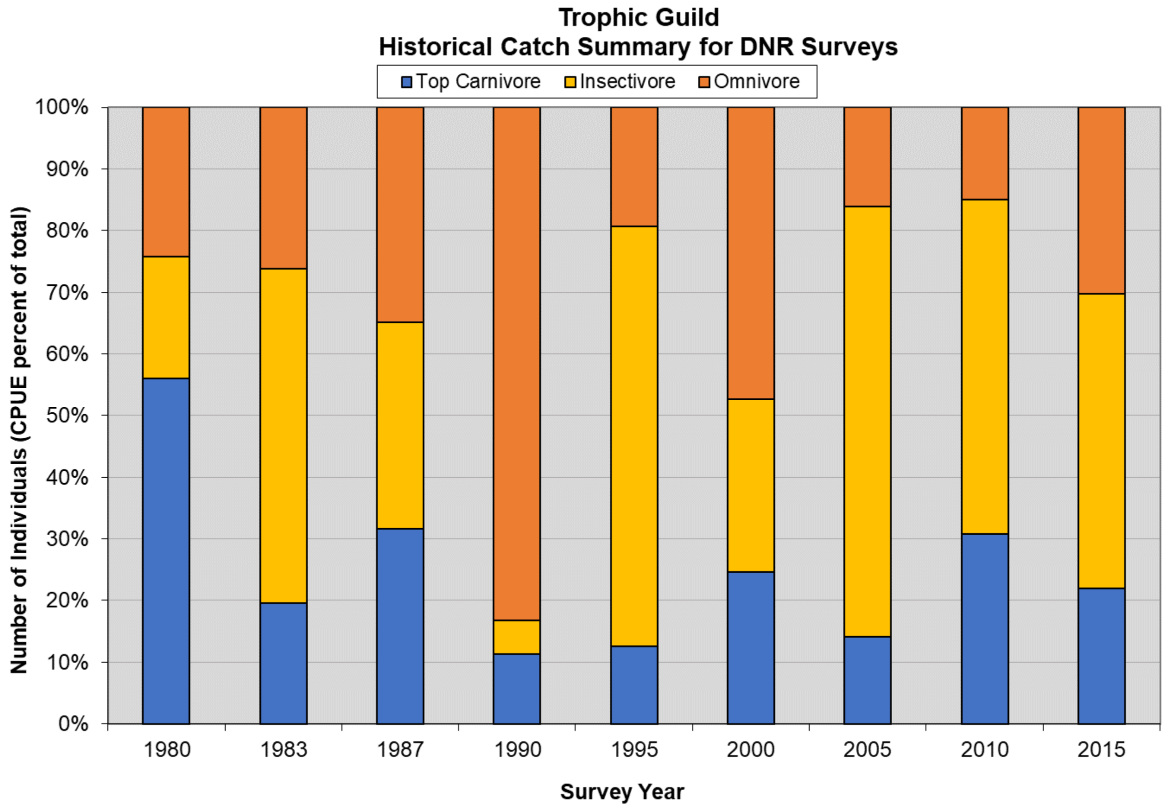


Figure C-43. Oak Lake Historic Water Quality.



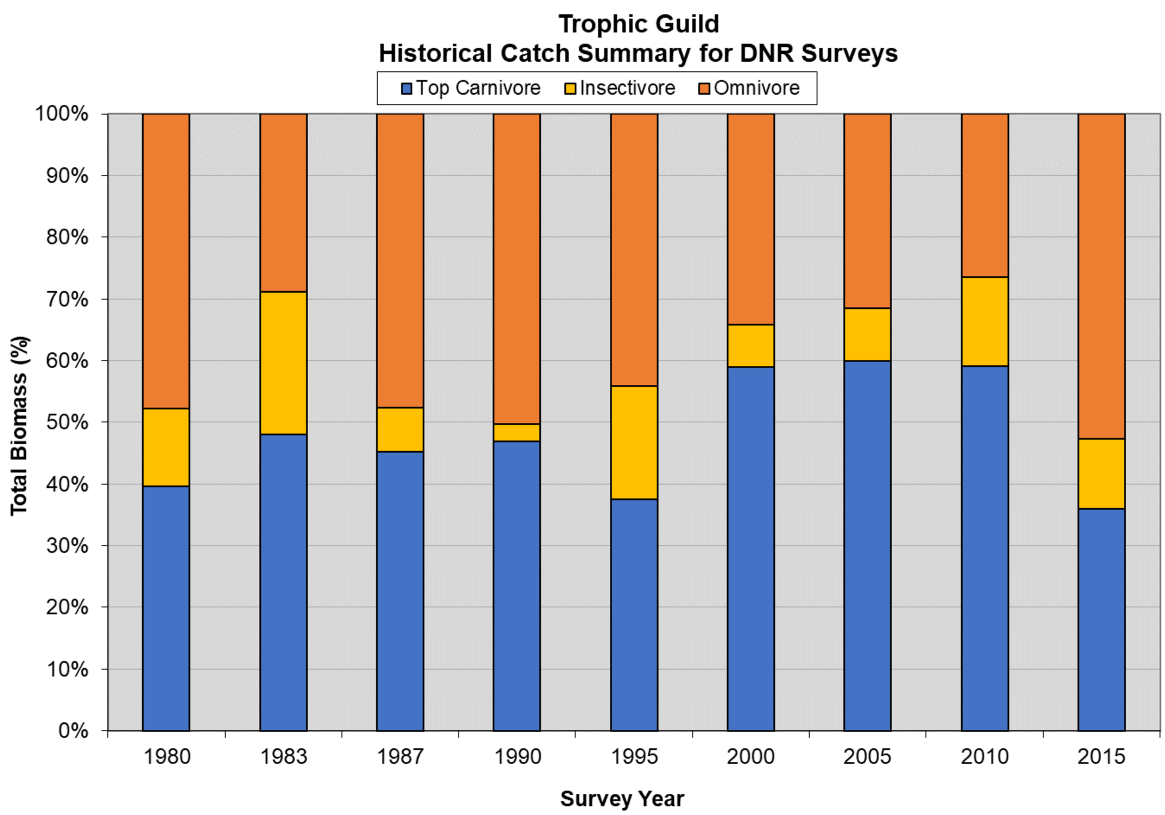


Figure C-44. Oak Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-17. Oak Lake Current Condition Lake Response Model.

Average Loading Summary for	***Oak***						
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Oak	2,459	18.0	3,685	44	1.0	445
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,459*	*18*	*3,685.03*			*444.8*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		37
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*36.8*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	456	32.2	32.2	0.00	0.26	1.0	118.0
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	456	0.0		0.00	0	1.0	0
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.85	0		Oxic		1.0	0
	1.85	33.8		Anoxic	0.6	1.0	84
	Summation						*83.6*
			Net Discharge [ac-ft/yr] =	**3,685**		**Net Load [lb/yr] =**	**683**

Average Lake Response Modeling for		***Oak***		
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	310	[kg/yr]
		Q (lake outflow) =	4.5	[10^6 m^3/yr]
		V (modeled lake volume) =	4.2	[10^6 m^3]
		T = V/Q =	0.93	[yr]
		P_i = W/Q =	68	[µg/l]
Model Predicted In-Lake [TP]			**32.8**	**[ug/l]**
Observed In-Lake [TP]			**32.8**	**[ug/l]**

Table C-18. Oak Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for	*Oak*					
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Oak	2,459	18.0	3,685	38	0.8	377
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,459*	*18*	*3,685.03*			*377.3*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		29
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*29.2*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	456	32.2	32.2	0.00	0.26	1.0	118.0
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	456	0.0		0.00	0	1.0	0
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.85	0		Oxic		1.0	0
	1.85	33.8		Anoxic	0.6	1.0	84
	Summation						*83.6*
		Net Discharge [ac-ft/yr] =		**3,685**	**Net Load [lb/yr] =**		**608**

TMDL Lake Response Modeling for	*Oak*			
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	276	[kg/yr]
		Q (lake outflow) =	4.5	[10^6 m^3/yr]
		V (modeled lake volume) =	4.2	[10^6 m^3]
		T = V/Q =	0.93	[yr]
		P_i = W/Q =	61	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**32.8**	**[ug/l]**

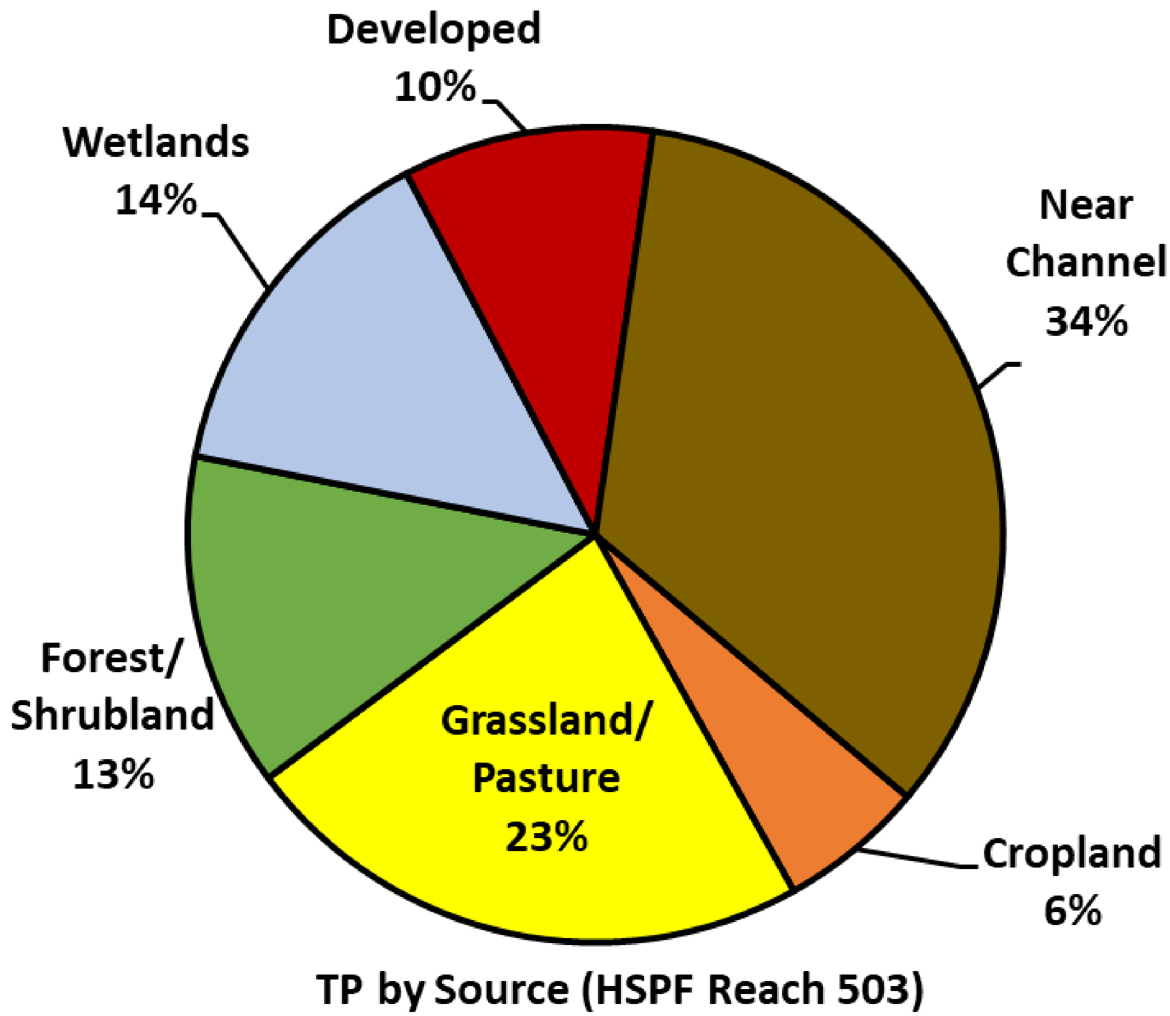


Figure C-45. Oak Lake HSPF-predicted watershed loading by source.

Supporting Items for Pine Lake (01-0001-00)

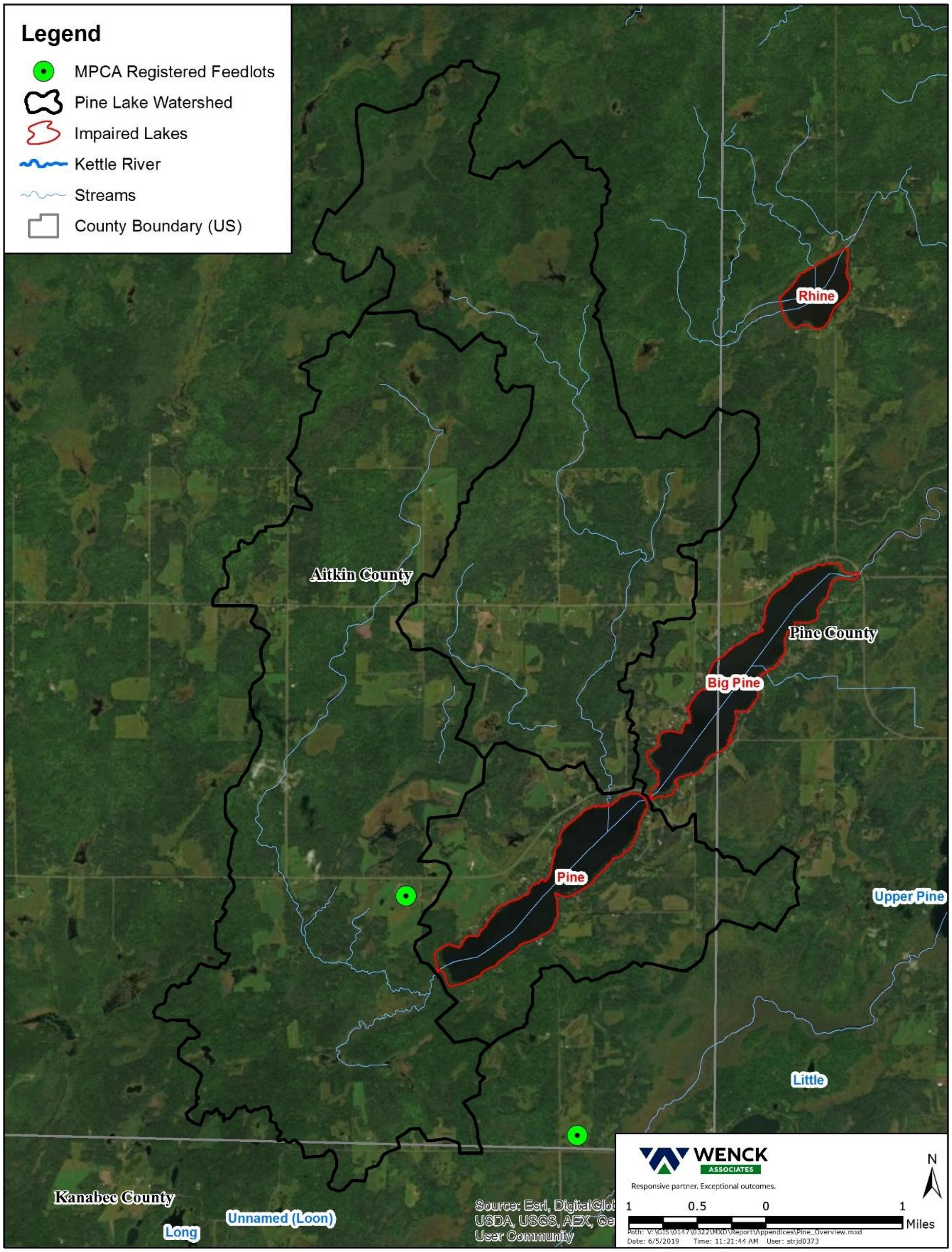


Figure C-46. Pine Lake Overview.

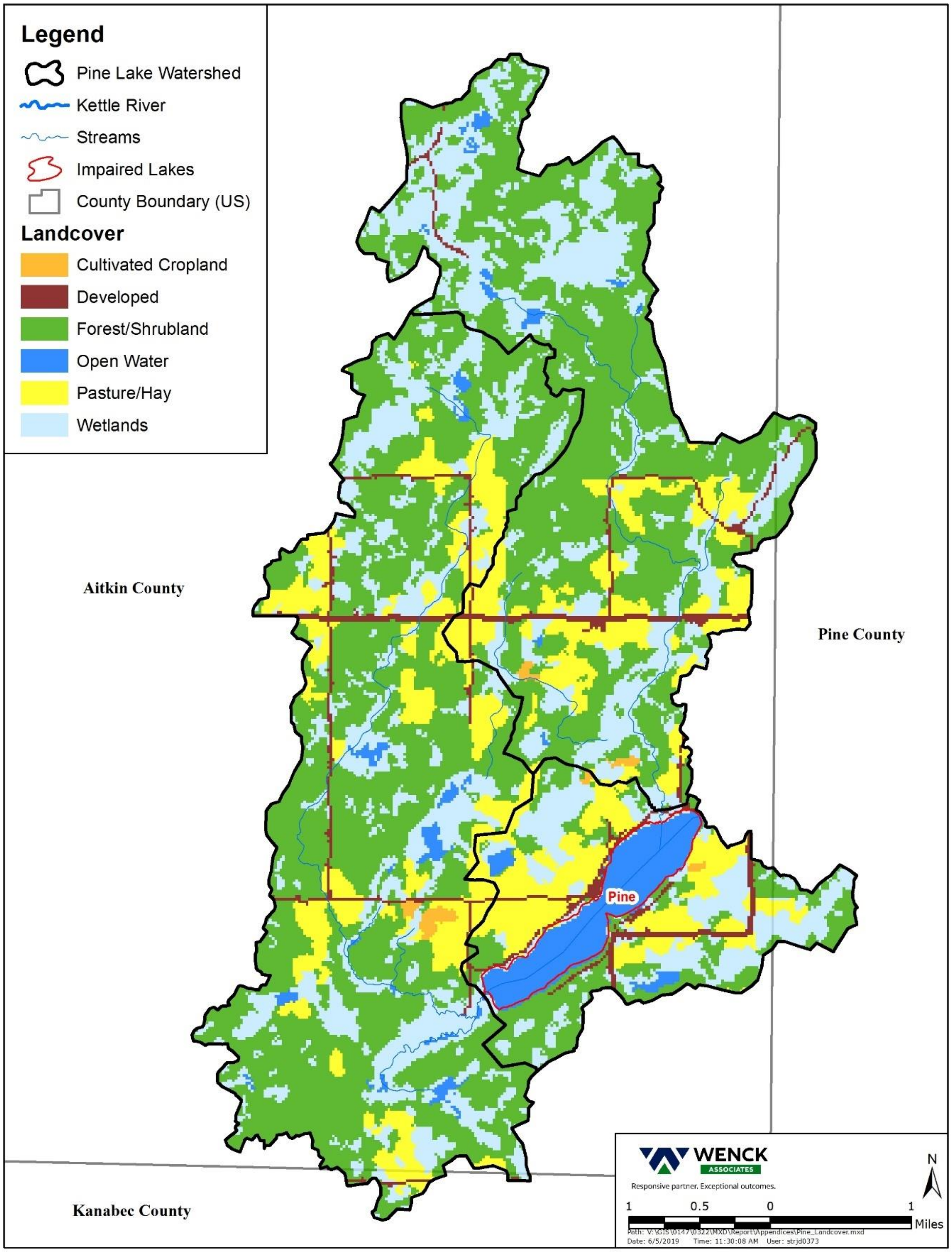


Figure C-47. Pine Lake Landcover.

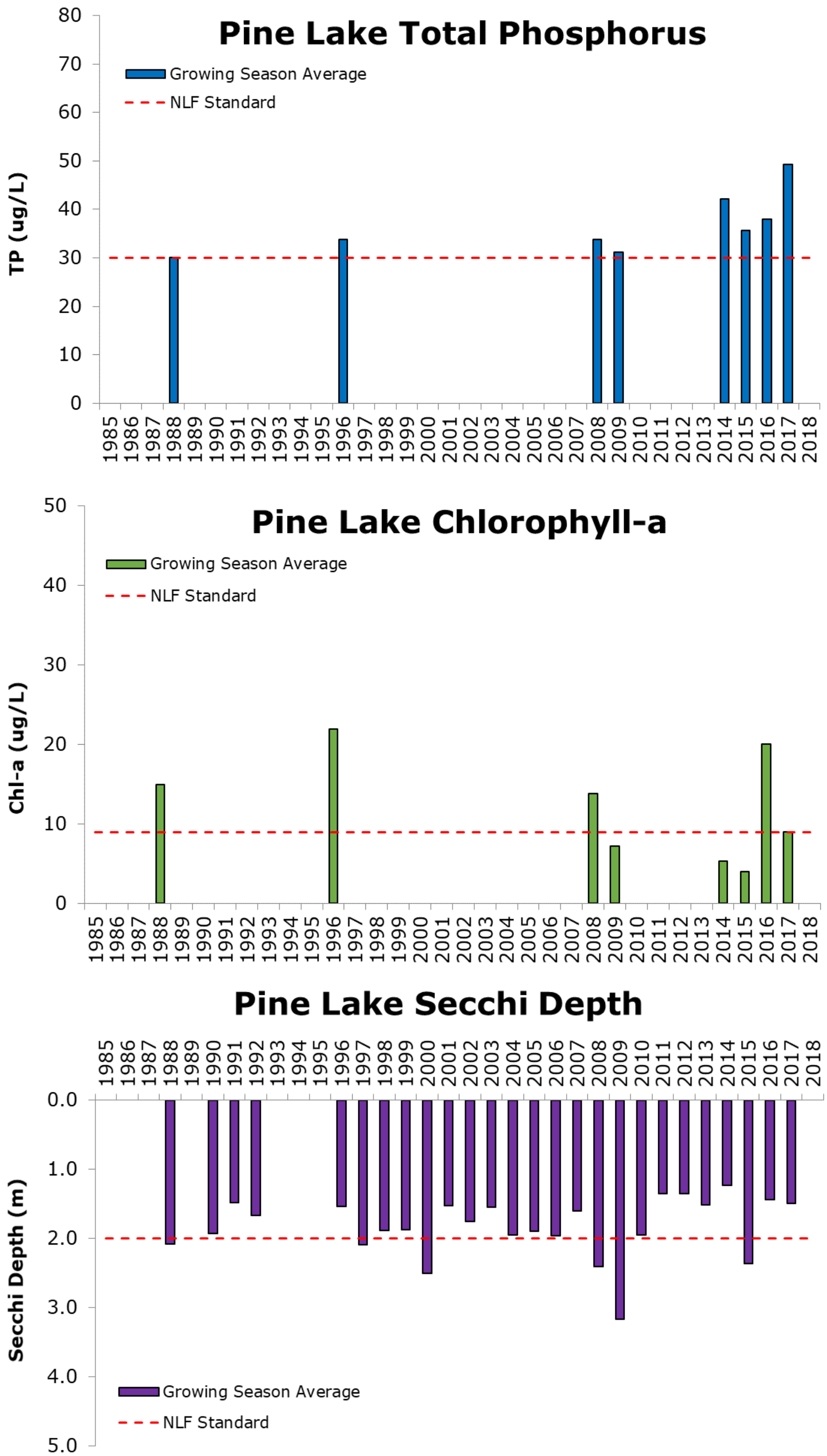
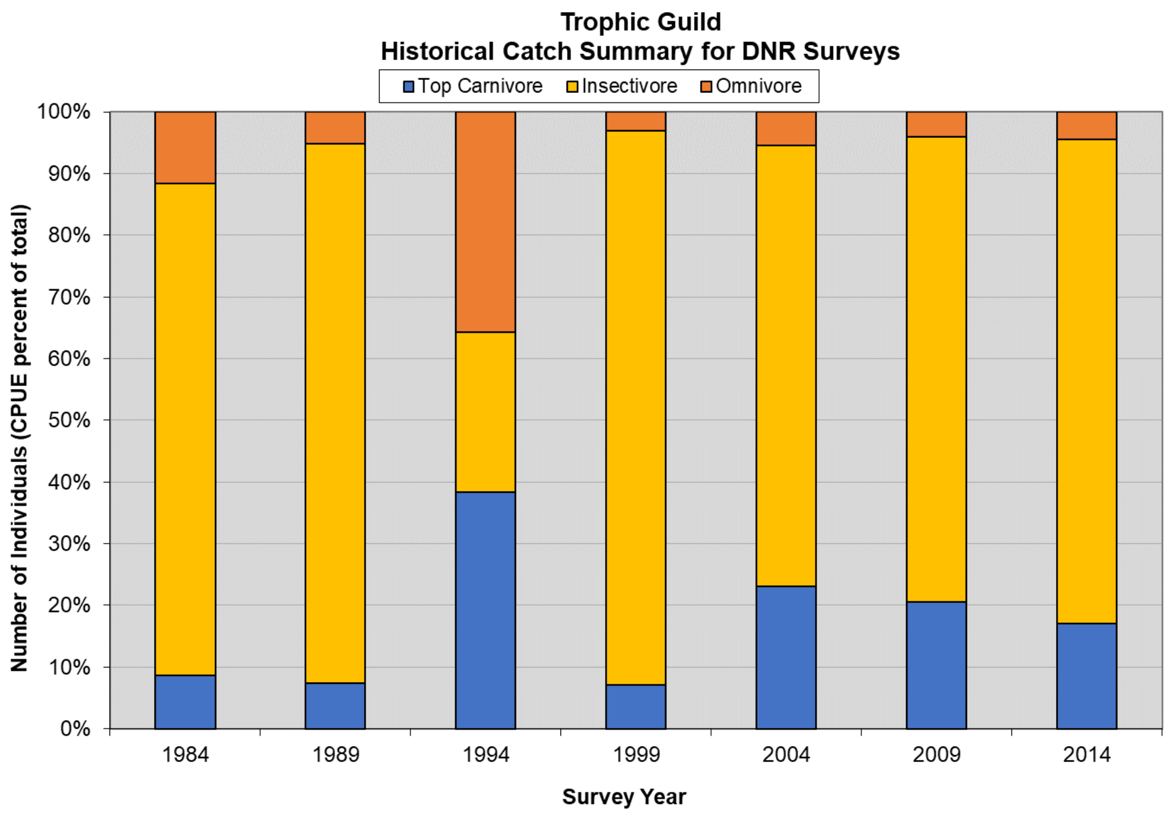


Figure C-48. Pine Lake Historic Water Quality.



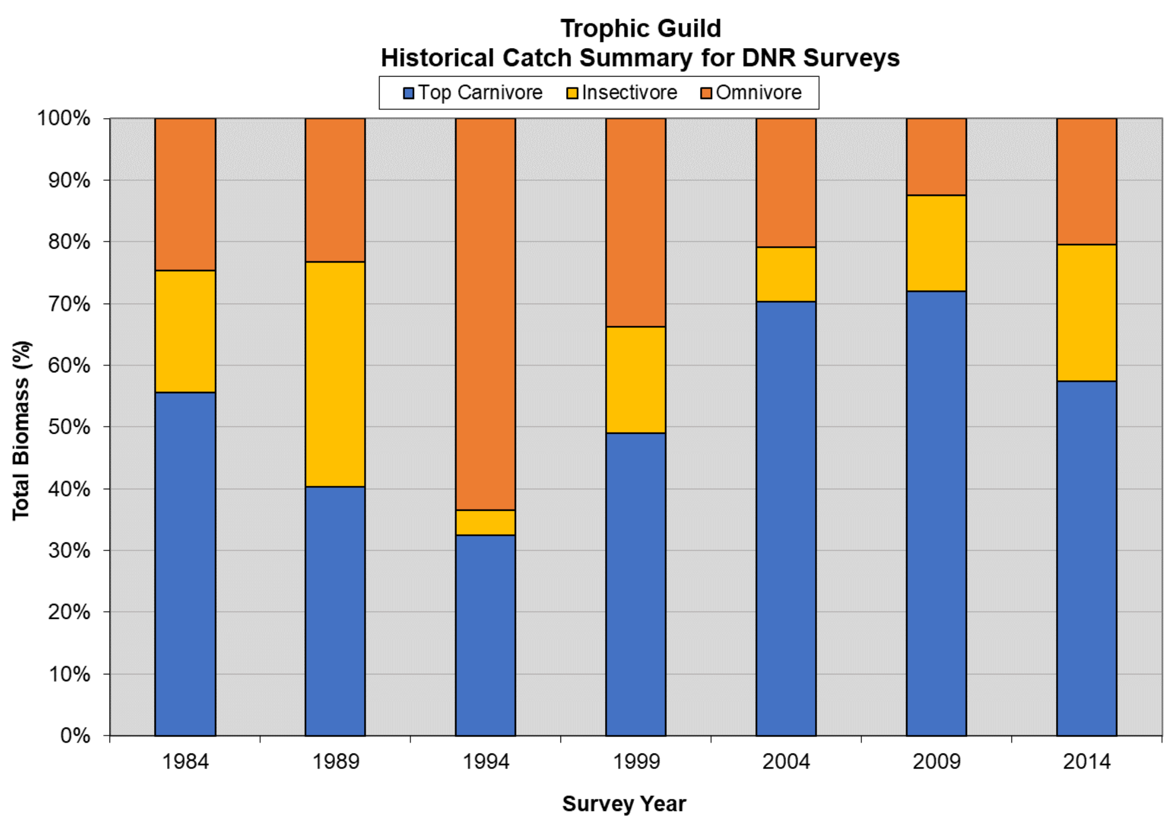


Figure C-49. Pine Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-19. Pine Lake Current Condition Lake Response Model.

Average Loading Summary for Pine

	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct	2,137	9.7	1,718	66	1.0	310
2	Trib 1	4,713	15.4	6,058	61	1.0	1,000
3	Trib 2	6,006	15.4	7,697	54	1.0	1,135
4	0			0	0		0
5	0			0	0		0
6	0			0	0		0
	Summation	*12,856*	*14.4*	*15,473.48*			*2,445.4*
Point Source Dischargers							
				Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		175
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*174.9*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	378	35.2	35.2	0.00	0.26	1.0	97.8
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area	Groundwater Flux		Net Inflow	Phosphorus Concentration	Calibration Factor	Load
	[acre]	[m/yr]		[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
	378	0.0		0.00	0	1.0	0
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.53	0		Oxic		1.0	0
	1.53	57.8		Anoxic	21.6	1.0	2,097
	Summation						*2,097.1*
			Net Discharge [ac-ft/yr] =	**15,473**		**Net Load [lb/yr] =**	**4,815**

Average Lake Response Modeling for Pine

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	2.30	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,184	[kg/yr]
		Q (lake outflow) =	19.1	[10^6 m^3/yr]
		V (modeled lake volume) =	7.6	[10^6 m^3]
		T = V/Q =	0.40	[yr]
		P_i = W/Q =	114	[µg/l]
Model Predicted In-Lake [TP]			**38.4**	**[ug/l]**
Observed In-Lake [TP]			**38.4**	**[ug/l]**

Table C-20. Pine Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for			***Pine***			
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct	2,137	9.7	1,718	50	0.8	234
2	Trib 1	4,713	15.4	6,058	50	0.8	822
3	Trib 2	6,006	15.4	7,697	50	0.9	1,047
4	0			0	0		0
5	0			0	0		0
6	0			0	0		0
	Summation	*12,856*	*40*	*15,473.48*			*2,102.5*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		143
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*143.4*
Inflow from Upstream Lakes							
	Name			Discharge [ac-ft/yr]	Estimated P Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
1					-	1.0	
2					-	1.0	
3					-	1.0	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	378	35.2	35.2	0.00	0.26	1.0	97.8
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	378	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.53	0		Oxic		1.0	0
	1.53	57.8		Anoxic	21.6	1.0	1,045
	Summation						*1,045.0*
		Net Discharge [ac-ft/yr] =		**15,473**	**Net Load [lb/yr] =**		**3,389**

TMDL Lake Response Modeling for Pine			
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 =	2.30 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	1,537 [kg/yr]
		Q (lake outflow) =	19.1 [10^6 m^3/yr]
		V (modeled lake volume) =	7.6 [10^6 m^3]
		T = V/Q =	0.40 [yr]
		P_i = W/Q =	81 [µg/l]
Model Predicted In-Lake [TP]			**30.0 [ug/l]**
Observed In-Lake [TP]			**38.4 [ug/l]**

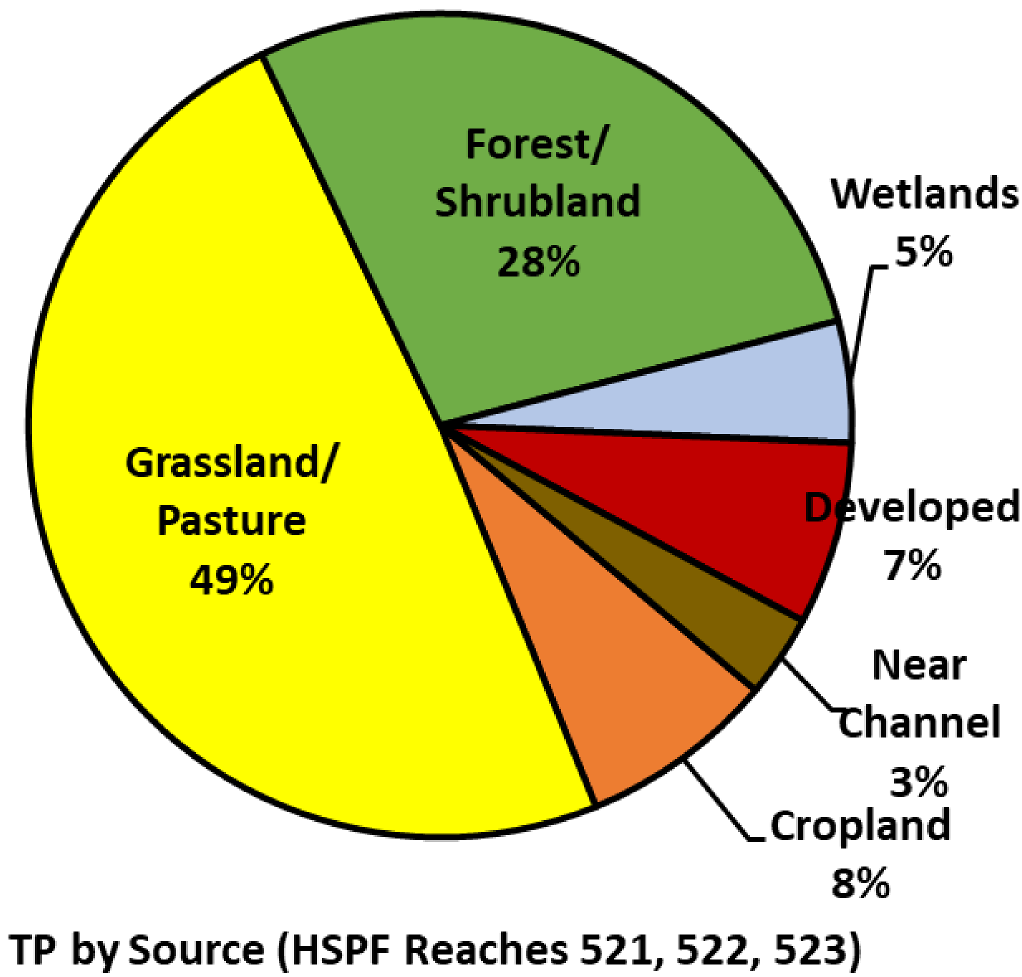


Figure C-50. Pine Lake HSPF-predicted watershed loading by source.

Supporting Items for Rhine Lake (58-0136-00)

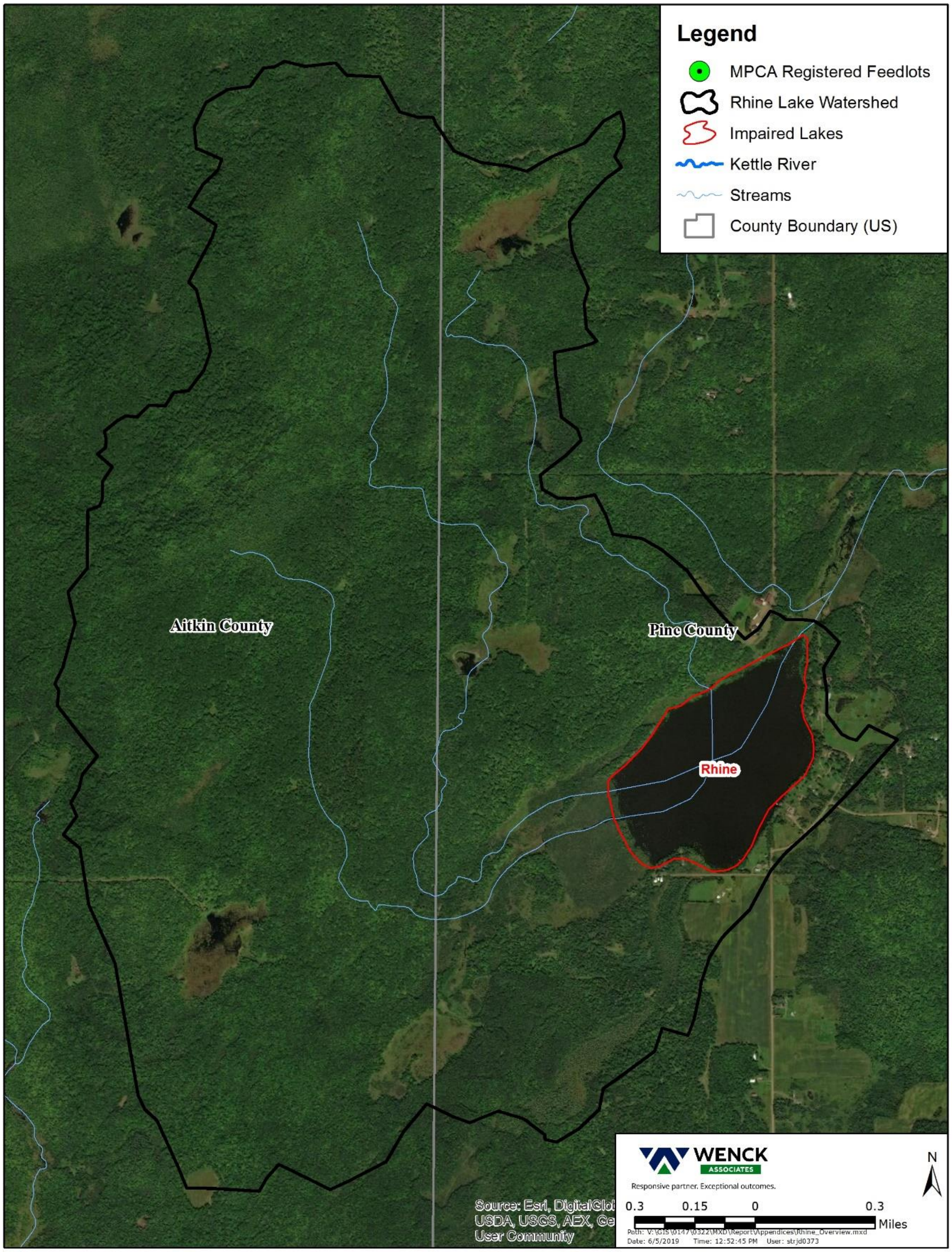


Figure C-51. Rhine Lake Overview.

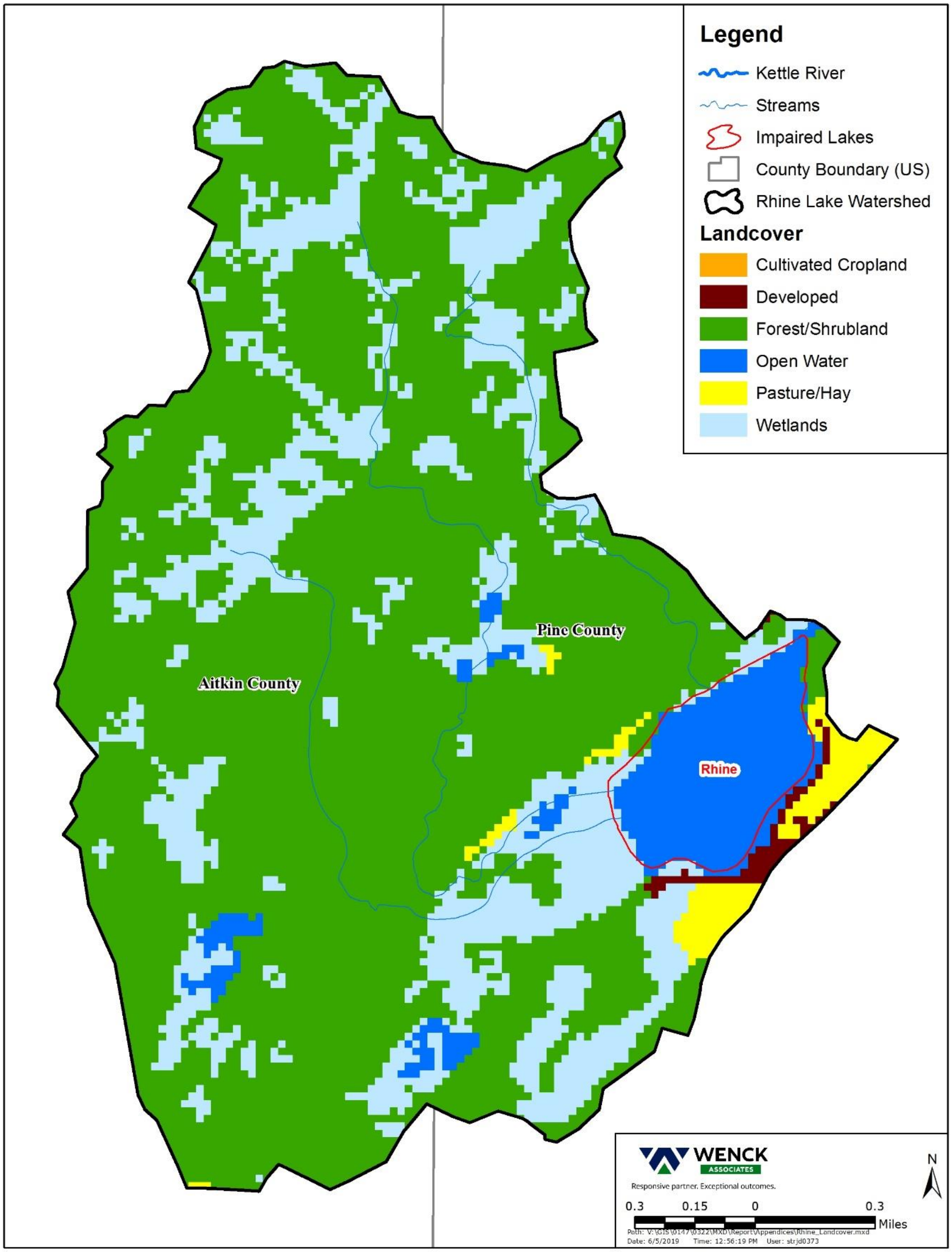


Figure C-52. Rhine Lake Landcover.

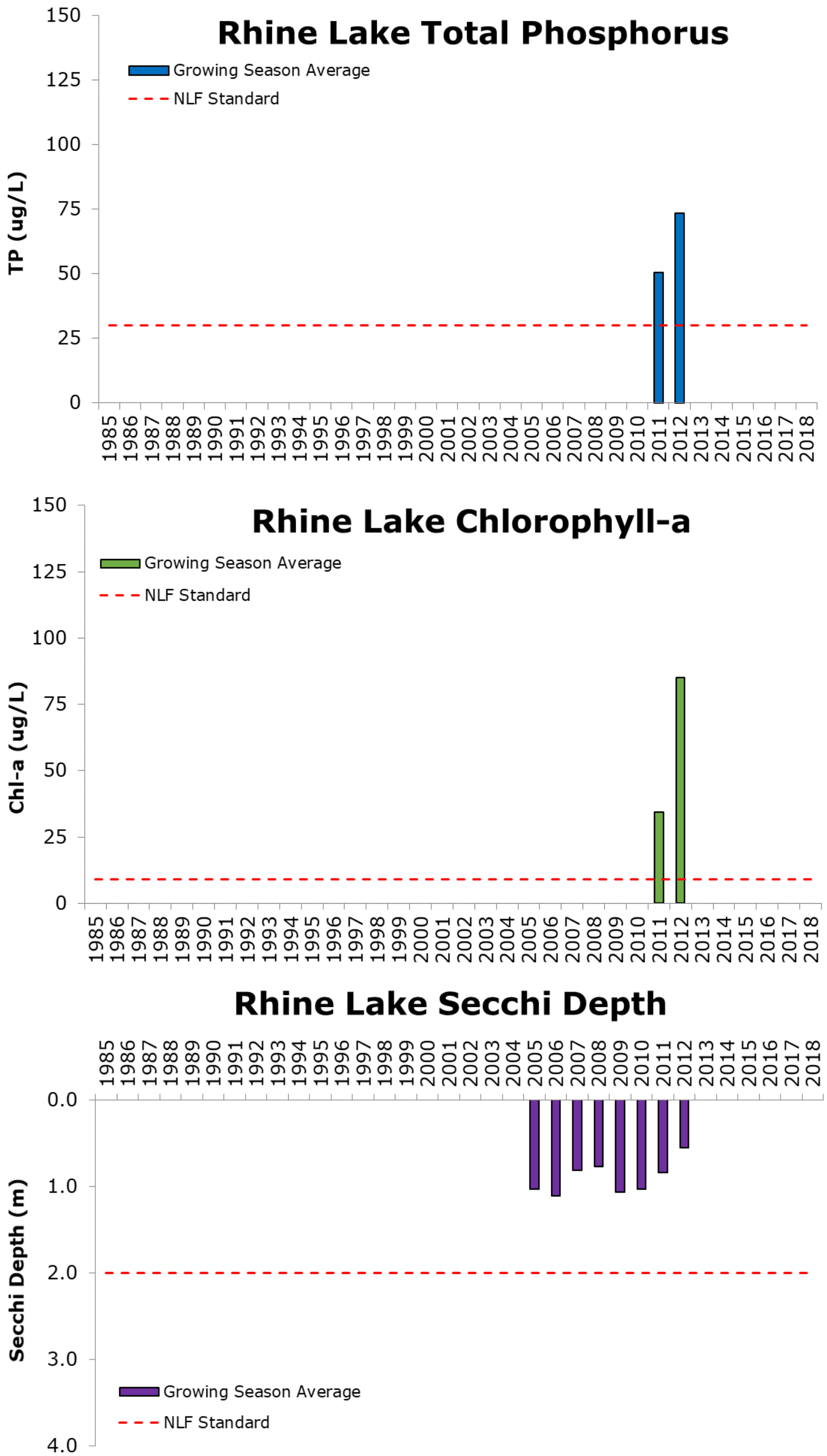
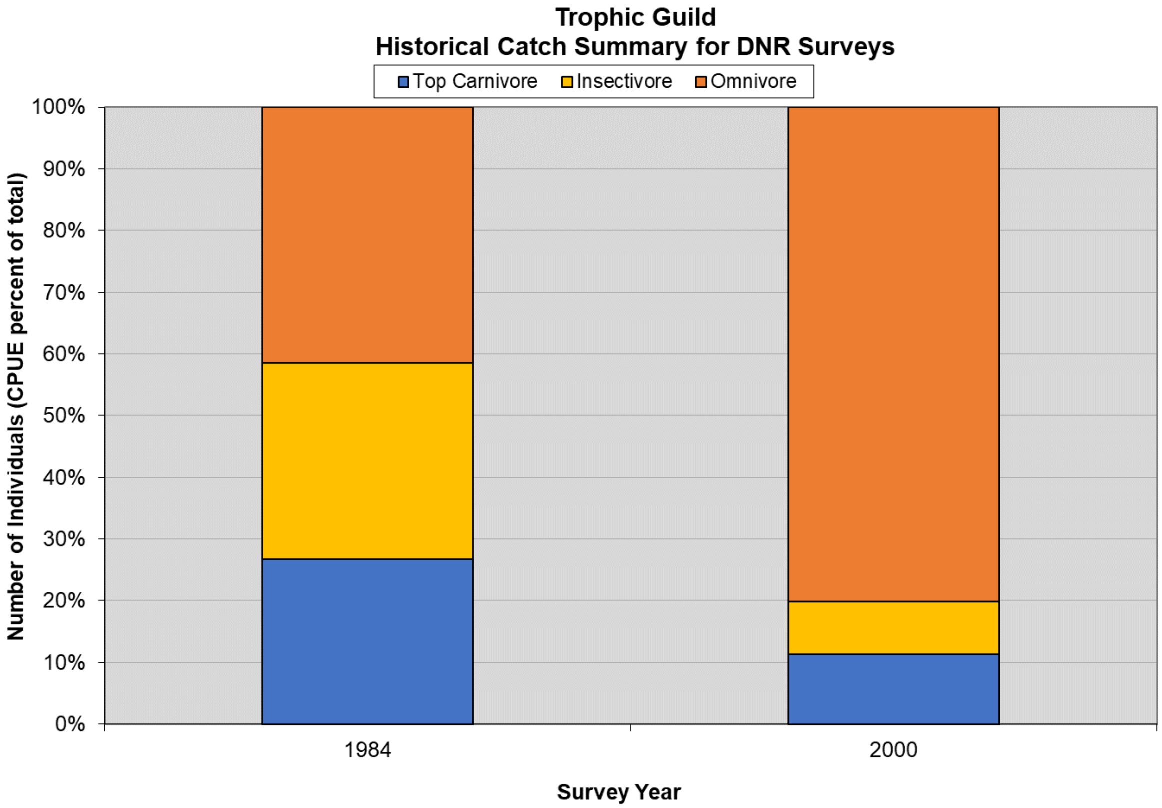


Figure C-53. Rhine Lake Historic Water Quality.



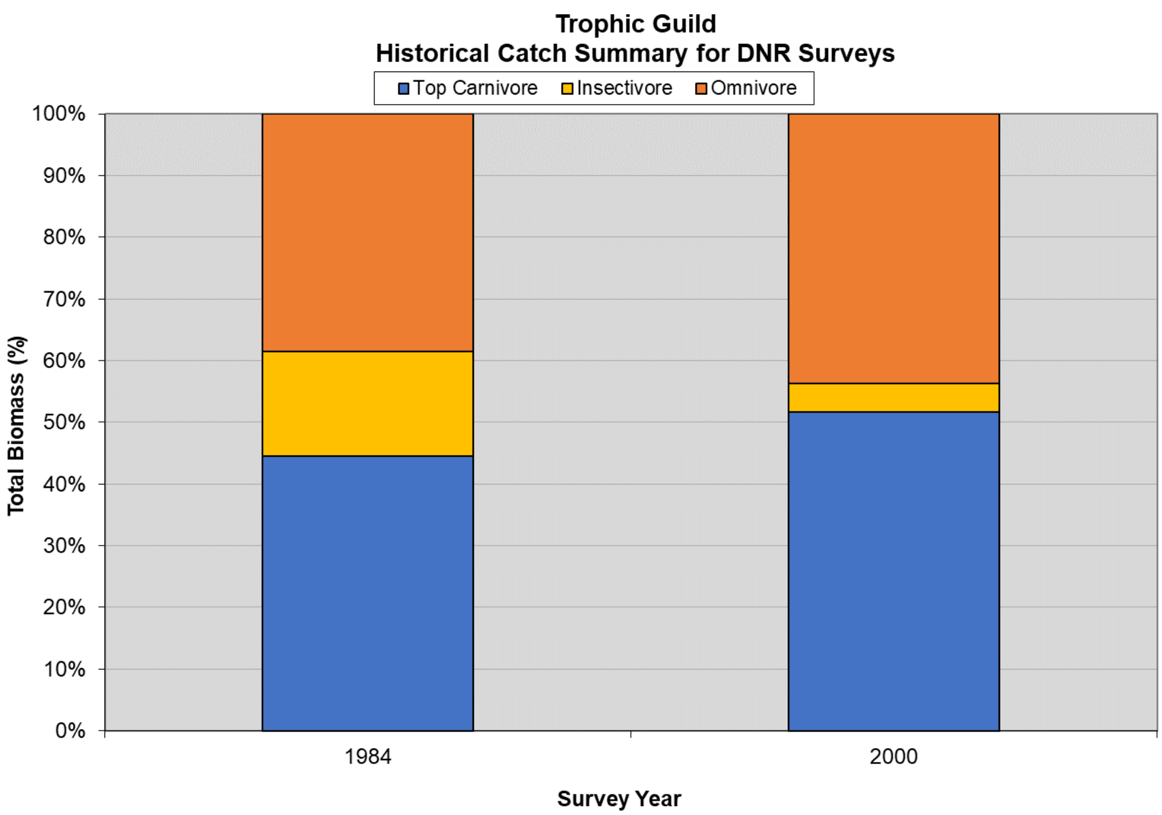


Figure C-54. Rhine Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-21. Rhine Lake Current Condition Lake Response Model.

	Average Loading Summary for Rhine						
		Water Budgets			Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Rhine	2,282	15.9	3,027	47	1.0	386
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,282*	*16*	*3,026.59*			*385.6*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		16
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*16.0*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	113	28.9	28.9	0.00	0.26	1.0	29.2
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	113	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.46	0		Oxic		1.0	0
	0.46	46.0		Anoxic	6.9	1.0	322
	Summation						*321.5*
		Net Discharge [ac-ft/yr] =		**3,027**	**Net Load [lb/yr] =**		**752**

Average Lake Response Modeling for Rhine			
Modeled Parameter	**Equation**	**Parameters**	**Value [Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$$P = \frac{P_i}{1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T}$$		as f(W,Q,V) from Canfield & Bachmann (1981)	
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	341 [kg/yr]
		Q (lake outflow) =	3.7 [10^6 m^3/yr]
		V (modeled lake volume) =	0.6 [10^6 m^3]
		T = V/Q =	0.16 [yr]
		P_i = W/Q =	91 [µg/l]
Model Predicted In-Lake [TP]			**62.0 [ug/l]**
Observed In-Lake [TP]			**62.0 [ug/l]**

Table C-22. Rhine Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for	*Rhine*					
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Rhine	2,282	15.9	3,027	29	0.6	239
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*2,282*	*16*	*3,026.59*			*238.5*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		13
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*12.8*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	113	28.9	28.9	0.00	0.26	1.0	29.2
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	113	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.46	0		Oxic		1.0	0
	0.46	46.0		Anoxic	6.9	1.0	46
	Summation						*46.3*
			Net Discharge [ac-ft/yr] =	**3,027**		**Net Load [lb/yr] =**	**327**

TMDL Lake Response Modeling for	*Rhine*			
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION		as f(W,Q,V) from Canfield & Bachmann (1981)		
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	148	[kg/yr]
		Q (lake outflow) =	3.7	[10^6 m^3/yr]
		V (modeled lake volume) =	0.6	[10^6 m^3]
		T = V/Q =	0.16	[yr]
		P_i = W/Q =	40	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**62.0**	**[ug/l]**

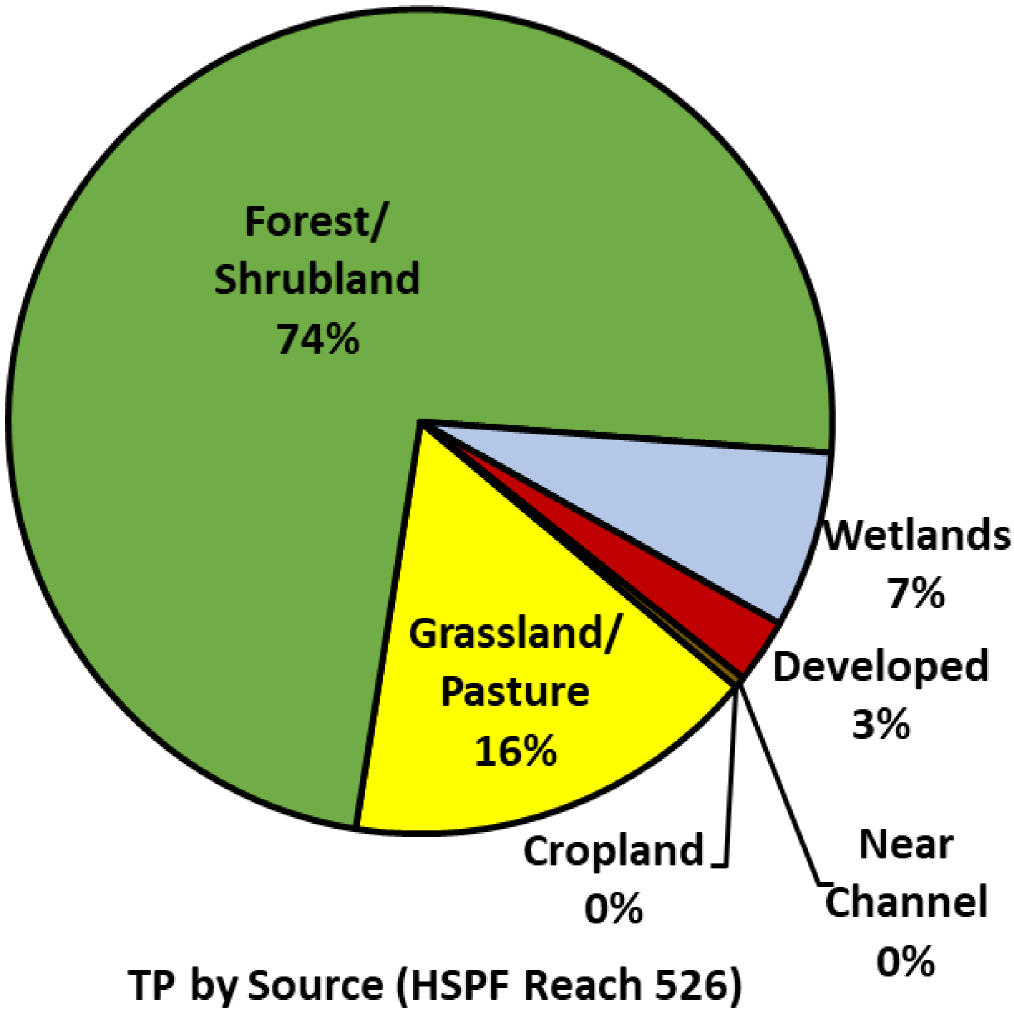


Figure C-55. Rhine Lake HSPF-predicted watershed loading by source.

Supporting Items for Twentynine Lake (09-0022-00)

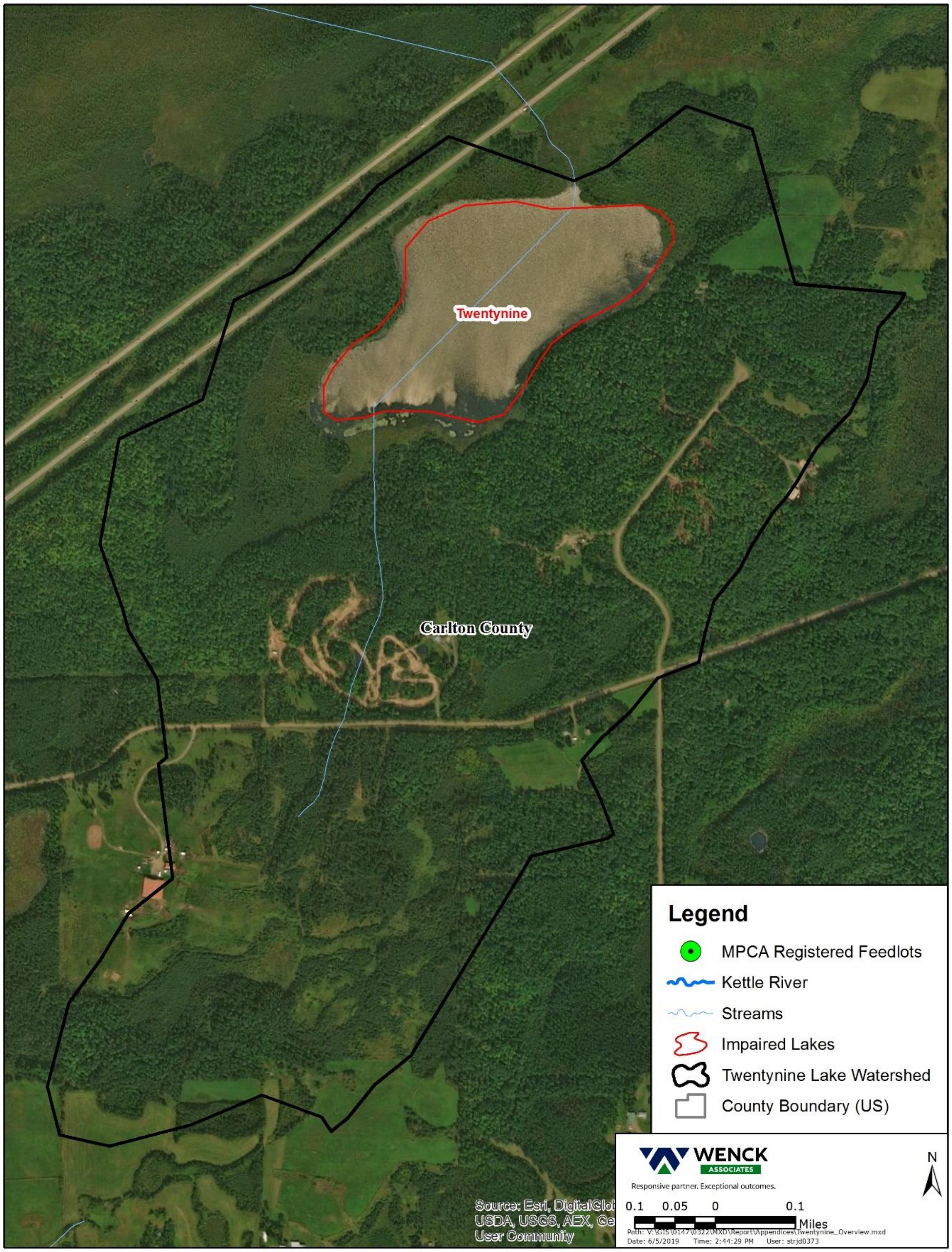


Figure C-56. Twentynine Lake Overview.

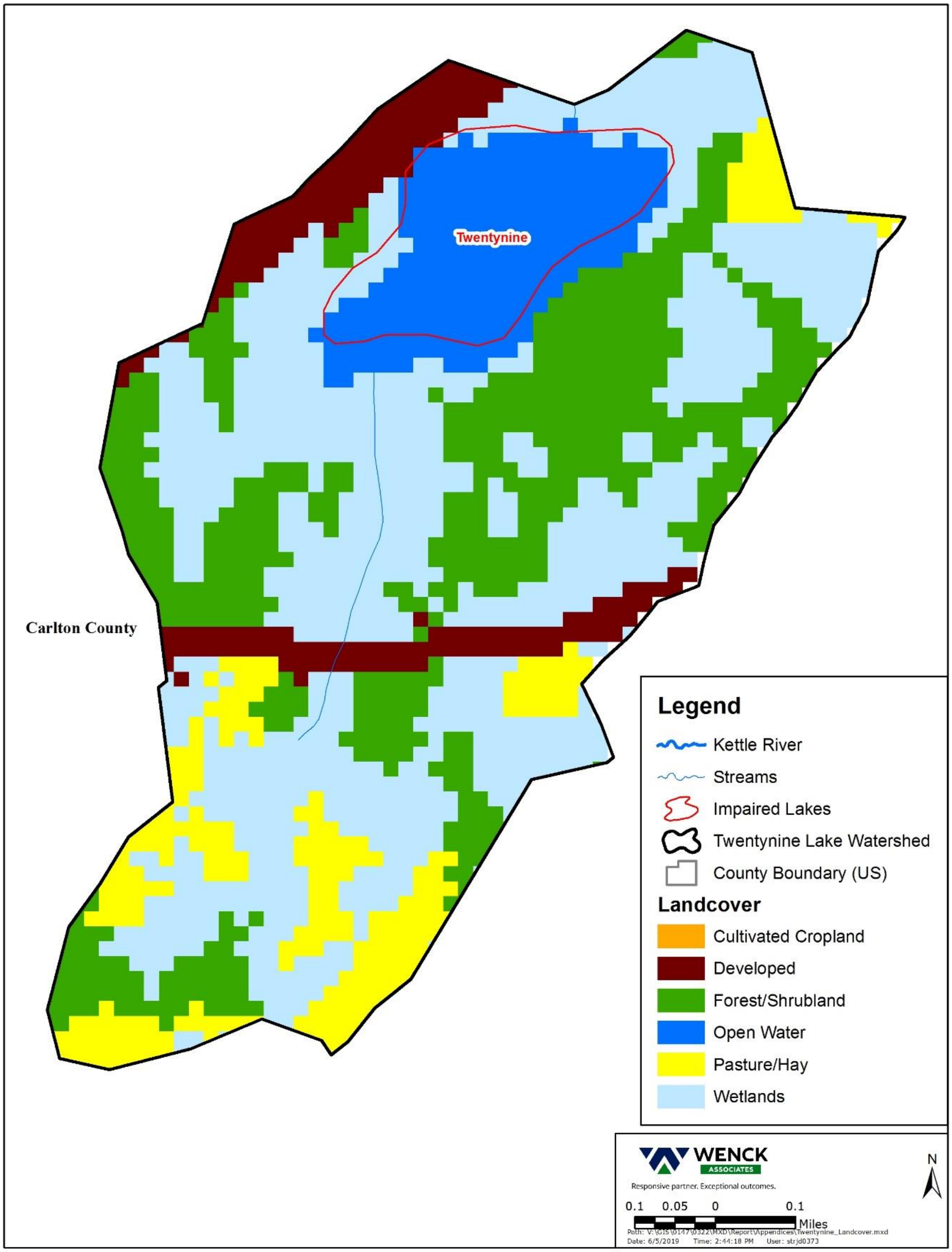
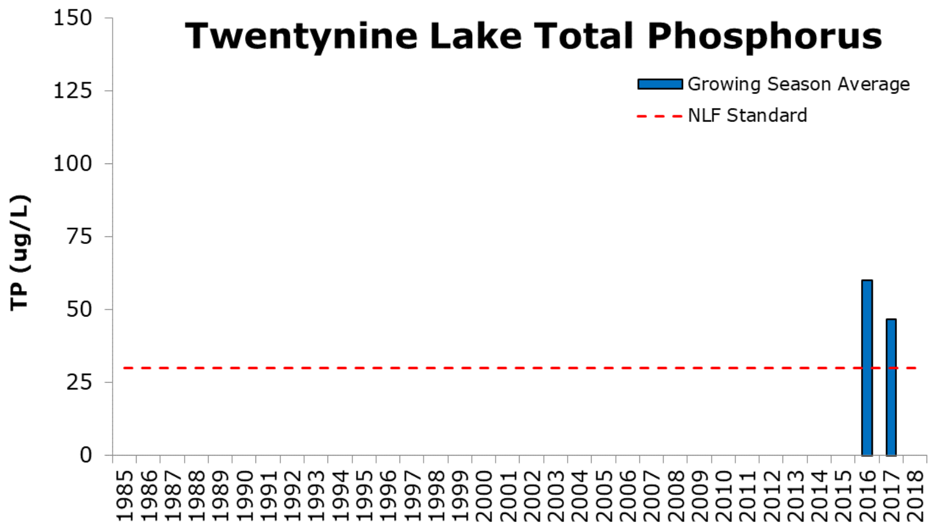
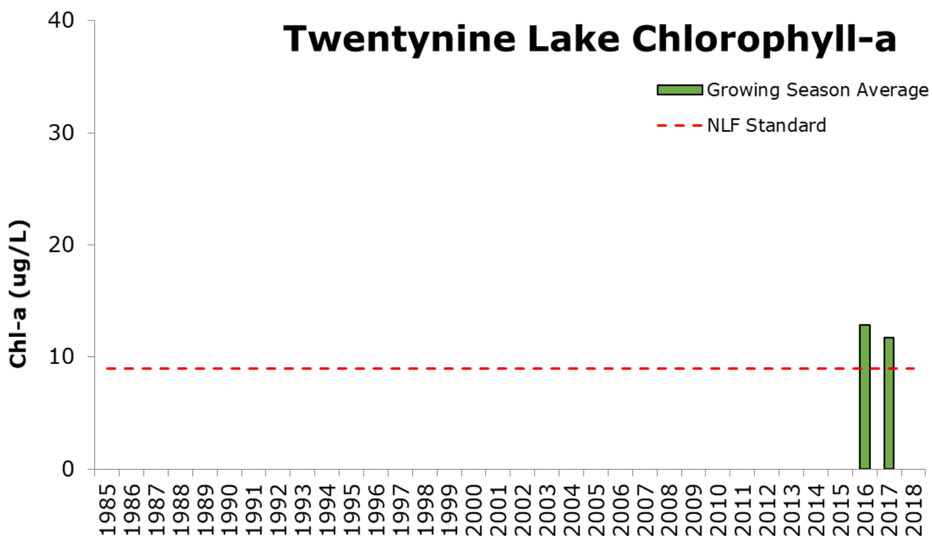


Figure C-57. Twentynine Lake Landcover.





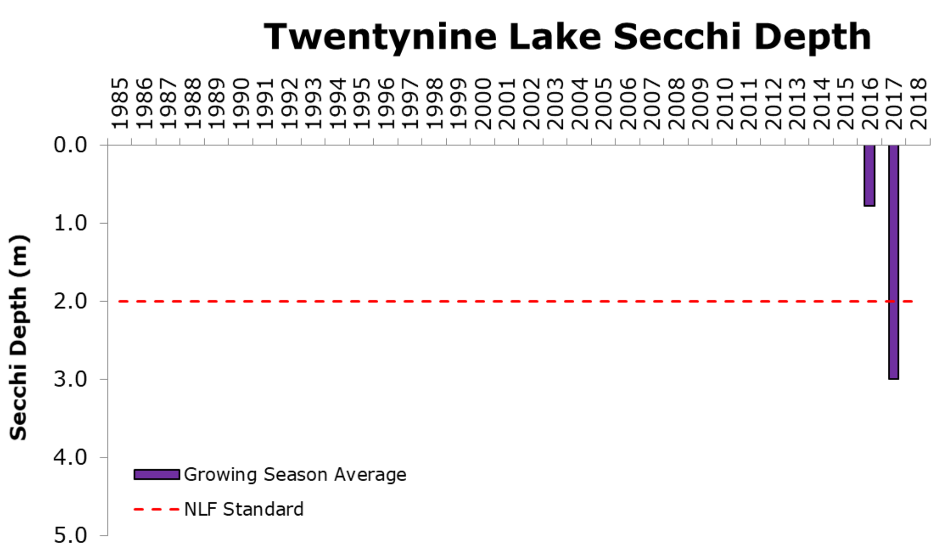
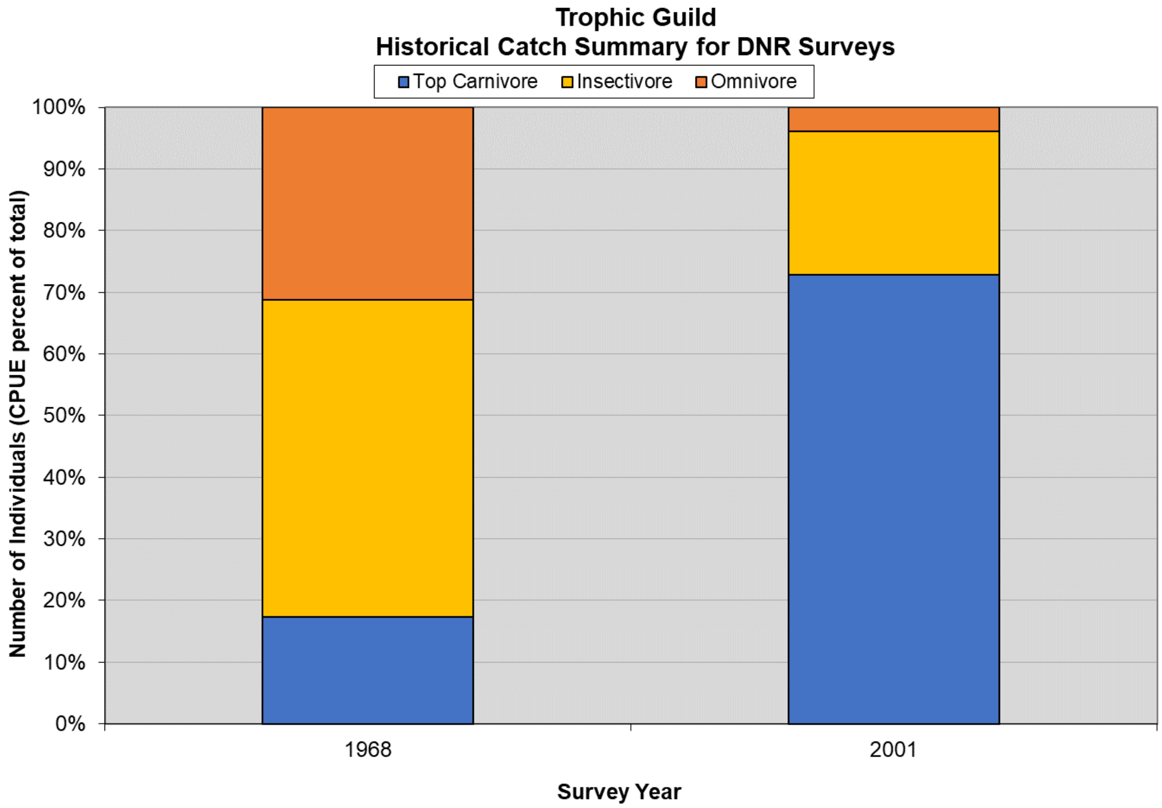


Figure C-58. Twentynine Historic Water Quality.



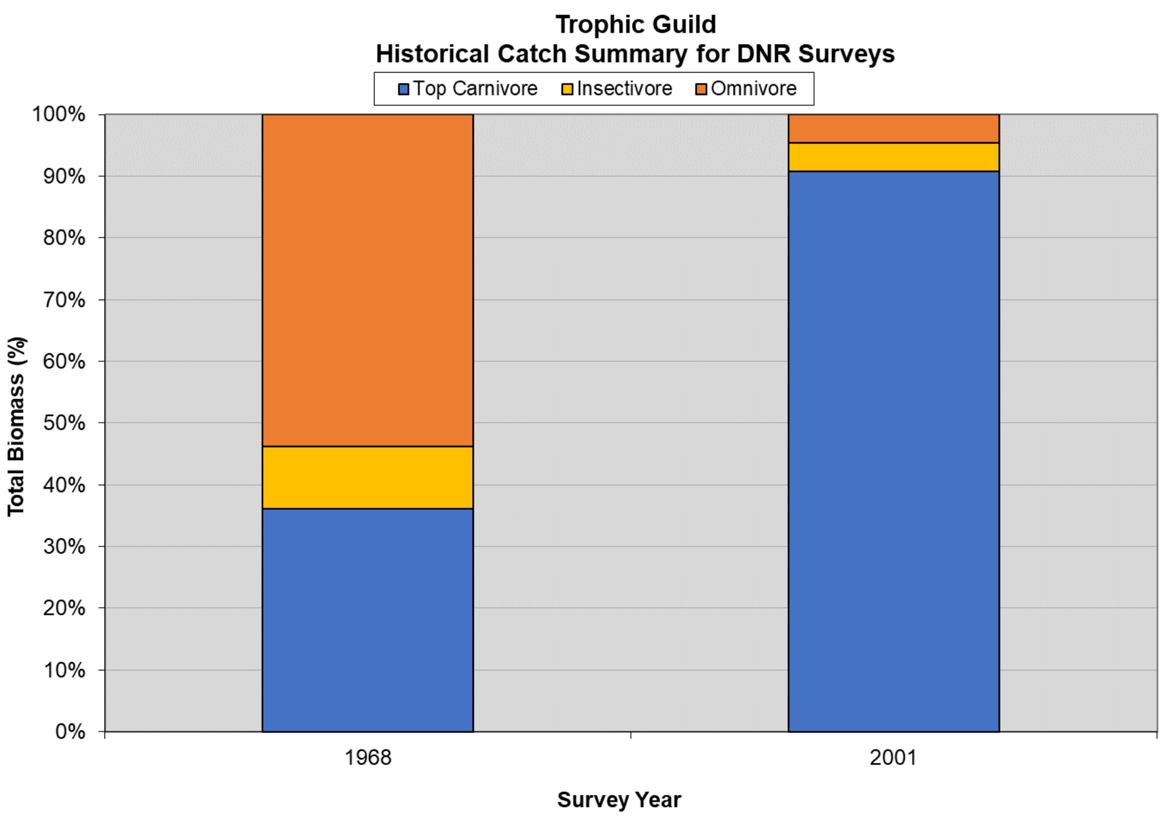


Figure C-59. Twentynine Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-23. Twentynine Lake Current Condition Lake Response Model.

Average Loading Summary for Twentynine

Water Budgets | **Phosphorus Loading**

Inflow from Drainage Areas

	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Twentynine	482	18.4	738	37	1.0	74
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*482*	*18*	*737.61*			*73.6*

Point Source Dischargers

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

Curly-leaf Pondweed

	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*

Failing Septic Systems

	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		5
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*5.3*

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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
52	37.9	37.9	0.00	0.26	1.0	13.5
			Dry-year total P deposition =	0.222		
			Average-year total P deposition =	0.239		
			Wet-year total P deposition =	0.259		
			(Barr Engineering 2004)			

Groundwater

Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
52	0.0		0.00	0	1.0	0

Model Residual Load

	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*

Internal

Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
0.21	0		Oxic		1.0	0
0.21	37.0		Anoxic	9.1	1.0	157
Summation						*156.9*
		Net Discharge [ac-ft/yr] =	738		Net Load [lb/yr] =	249

Average Lake Response Modeling for Twentynine

Modeled Parameter	Equation	Parameters	Value	[Units]
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
	$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	113	[kg/yr]
		Q (lake outflow) =	0.9	[10^6 m^3/yr]
		V (modeled lake volume) =	0.7	[10^6 m^3]
		T = V/Q =	0.82	[yr]
		P_i = W/Q =	124	[µg/l]
Model Predicted In-Lake [TP]			**53.4**	**[ug/l]**
Observed In-Lake [TP]			**53.4**	**[ug/l]**

Table C-24. Twentynine Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for Twentynine						
	Water Budgets				Phosphorus Loading		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Twentynine	482	18.4	738	37	1.0	74
2				0	0		0
3				0	0		0
4				0	0		0
5				0	0		0
6				0	0		0
	Summation	*482*	*18*	*737.61*			*73.6*
Point Source Dischargers							
	Name			Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1					#DIV/0!	1.0	
2					#DIV/0!	1.0	
3					#DIV/0!	1.0	
4					#DIV/0!	1.0	
5					#DIV/0!	1.0	
	Summation			*0*			*0.0*
Curly-leaf Pondweed							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Curly-leaf Pondweed Load					1.0	
	Summation						*0.0*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	#REF!	#REF!	#REF!		#REF!		4
2	0	0	0	0	0%		0
3	0	0	0	0	0%		0
4	0	0	0	0	0%		0
5	0	0	0	0	0%		0
	Summation	*#REF!*	*#REF!*	*0.0*	#REF!		*4.3*
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	
4					-	1.0	
5					-	1.0	
	Summation			*0.0*	-		*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]
	52	37.9	37.9	0.00	0.26	1.0	13.5
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Groundwater							
	Lake Area [acre]	Groundwater Flux [m/yr]		Net Inflow [ac-ft/yr]	Phosphorus Concentration [ug/L]	Calibration Factor [--]	Load [lb/yr]
	52	0.0		0.00	0	1.0	0
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	0
	Summation						*0.0*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.21	0		Oxic		1.0	0
	0.21	37.0		Anoxic	9.1	1.0	25
	Summation						*25.4*
		Net Discharge [ac-ft/yr] =		**738**	**Net Load [lb/yr] =**		**117**

TMDL Lake Response Modeling for Twentynine				
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$	as f(W,Q,V) from Canfield & Bachmann (1981)			
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	53	[kg/yr]
		Q (lake outflow) =	0.9	[10^6 m^3/yr]
		V (modeled lake volume) =	0.7	[10^6 m^3]
		T = V/Q =	0.82	[yr]
		P_i = W/Q =	58	[µg/l]
Model Predicted In-Lake [TP]			**30.0**	**[ug/l]**
Observed In-Lake [TP]			**53.4**	**[ug/l]**

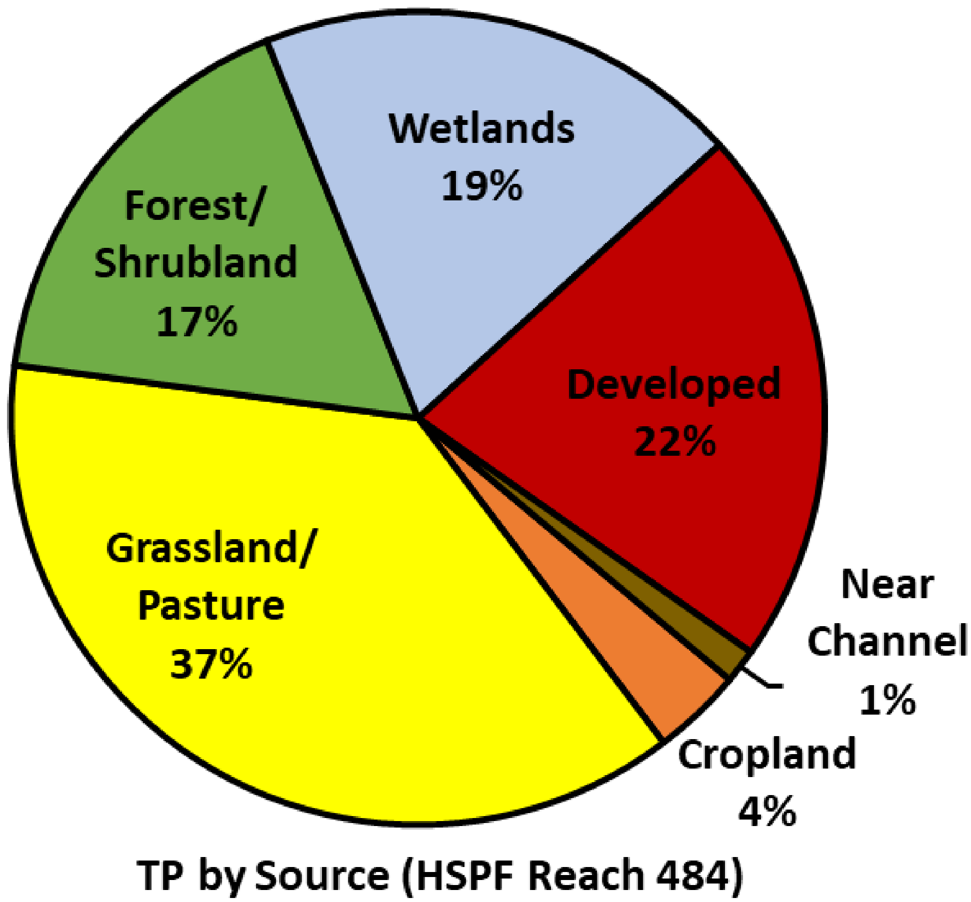


Figure C-60. Twentynine Lake HSPF-predicted watershed loading by source.

Appendix D – Hinckley WWTF DMR Data Summary

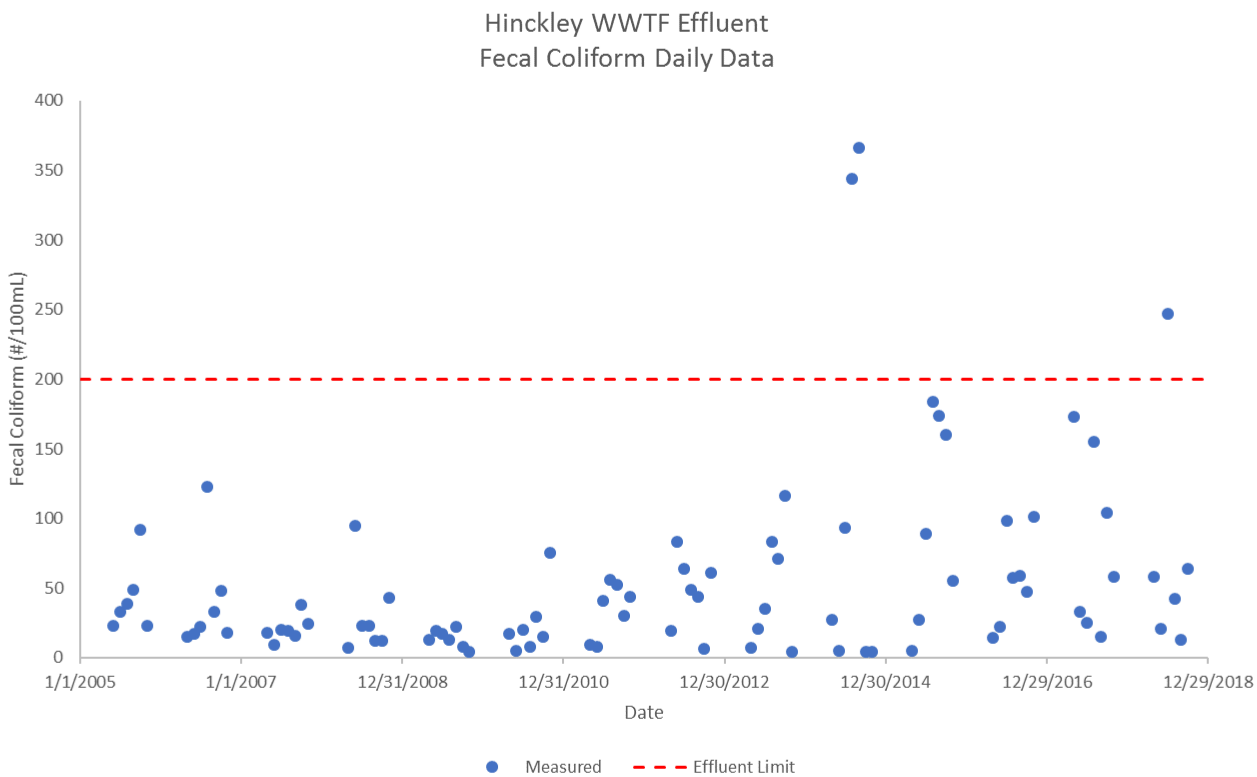


Figure D-1. Hinckley WWTF Effluent Fecal Coliform Daily Data (2005-2018).

Table D-1. Hinckley WWTF Effluent Fecal Coliform Monthly Geomeans (2005-2018).

Month	N	Month	Total Samples	Monthly Geomean	Maximum Individual Sample	Minimum Individual Sample	Individual Exceedances	Percent Individual Exceedances
1	N = 0	Jan	0	-	0	0	0	-
2	N = 0	Feb	0	-	0	0	0	-
3	N = 0	Mar	0	-	0	0	0	-
4	N = 13	Apr	13	30.4	173	5	0	0%
5	N = 14	May	14	19.2	95	5	0	0%
6	N = 14	Jun	14	41.9	247	17	1	7%
7	N = 14	Jul	14	52.4	344	8	1	7%
8	N = 14	Aug	14	39.6	366	12	1	7%
9	N = 14	Sep	14	31.6	160	4	0	0%
10	N = 13	Oct	13	25.3	101	4	0	0%
11	N = 0	Nov	0	-	0	0	0	-
12	N = 0	Dec	0	-	0	0	0	-

FINAL DRAFT

HSPF WATERSHED MODELING FOR THE UPPER ST. CROIX, KETTLE, AND SNAKE RIVER WATERSHEDS: CALIBRATION AND VALIDATION OF HYDROLOGY, SEDIMENT, AND WATER QUALITY CONSTITUENTS

Topical Report RSI-2606

prepared for

Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, Minnesota 55155

RESPEC

April 2016

HSPF WATERSHED MODELING FOR THE UPPER ST. CROIX, KETTLE, AND SNAKE RIVER WATERSHEDS: CALIBRATION AND VALIDATION OF HYDROLOGY, SEDIMENT, AND WATER QUALITY CONSTITUENTS TITLE

Topical Report RSI-2604

RESPEC Project Number: 02789.0001
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MPCA Contract/Shell No.: 20907/101894

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April 2016

FINAL DRAFT

EXECUTIVE SUMMARY

The U.S. Environmental Protection Agency (EPA) requires the Minnesota Pollution Control Agency (MPCA) to carry out the Total Maximum Daily Load (TMDL) Program in the state of Minnesota (MN). In an effort to expedite the completion of TMDL projects, the MPCA has sponsored the construction of watershed models to support the simultaneous development of TMDL studies for multiple listings within a cataloging unit or 8-digit Hydrologic Unit Code (HUC) watershed. As part of the model development process AQUA TERRA Consultants was contracted to develop watershed models for the Upper St. Croix River (HUC 07030001, only the Minnesota portion), the Kettle River (HUC 07030003), and the Snake River (HUC 07030004). The Kettle River flows into the Upper St. Croix River, which flows into the St. Croix River along with the Snake River.

This project was divided into two separate work orders. The first work order, performed by AQUA TERRA Consultants, focused on the hydrology calibration and validation, sediment calibration and validation, and nonpoint loading rate calibration and validation. The second work order was performed by RESPEC, following its acquisition of AQUA TERRA in September 2015, and includes the completion of the instream water quality calibration and validation. This report documents all completed tasks in both work orders, and by both companies, and serves as the final report of the project.

The three watersheds were developed as two separate watershed models: (1) for the Snake River Watershed, and (2) for the Upper St. Croix River (MN portion) and the Kettle River (STC-Kettle) Watersheds. Overall, the model performance for hydrology calibration and validation of the Snake River Watershed model was satisfactory based on meeting the majority of the model-performance criteria. The model performance for the hydrology calibration of the STC-Kettle Watershed model was also satisfactory, but the model results for the validation period did not meet many of the performance criteria because of issues with the observed meteorological data or flow data.

The sediment calibration and validation of the two models was satisfactory. The loading rates of the sediment were in the target loading rate range, and the visual assessment of the observed and simulated total suspended solids (TSS) concentrations illustrate that the simulated concentrations are generally in the observed-data range; however, the MPCA staff raised some concerns for the simulated TSS concentrations during storm events. RESPEC does not have sufficient observed data to fully assess the model performance during these storm events.

The nonpoint calibration and validation results were satisfactory and the loading rates from most of the land uses were within the target loading-rate range. The instream water quality calibration and validation followed suit with the nonpoint loading rates calibration. Instream water quality calibration included the calibration of water temperature, dissolved oxygen, nitrogen, phosphorus, and phytoplankton. Although the water quality data were not sufficient to conduct a detailed statistical analysis, observing ranges and trends at different parts of the watershed was sufficient. Additional graphs at all the locations were prepared to verify that the nutrient concentrations in all the stream are stable. The water quality calibration and validation were satisfactory. Because of the satisfactory model performance as demonstrated in this report, the HSPF watershed models for the Snake River, Kettle River, and Upper St. Croix River are deemed acceptable for use in TMDL and Watershed Restoration and Protection Strategy (WRAPS) development for these watersheds.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES (continued)

TABLE PAGE

LIST OF TABLES (continued)

TABLE PAGE

LIST OF FIGURES

LIST OF FIGURES (continued)

FIGURE PAGE

LIST OF FIGURES (continued)

FIGURE PAGE

1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Environmental Protection Agency (EPA) requires the Minnesota Pollution Control Agency (MPCA) to carry out the Total Maximum Daily Load (TMDL) Program in the state of Minnesota (MN). Minnesota has an abundance of lakes and rivers, many of which will require a TMDL study. In an effort to expedite the completion of TMDL projects, the MPCA sponsored the construction of watershed models. RESPEC was contracted to construct and apply the BASINS/HSPF model to the selected watersheds. These models have the potential to support the simultaneous development of TMDL studies for multiple listings within a cataloging unit or 8-digit Hydrologic Unit Code (HUC) watersheds within the state. This report documents the modeling of three 8-digit HUC watersheds: the Upper St. Croix River (HUC 07030001, only the Minnesota portion), the Kettle River (HUC 07030003), and the Snake River (HUC 07030004). The Kettle River flows into the Upper St. Croix River, which flows into St. Croix River along with the Snake River (Figure 1-1).

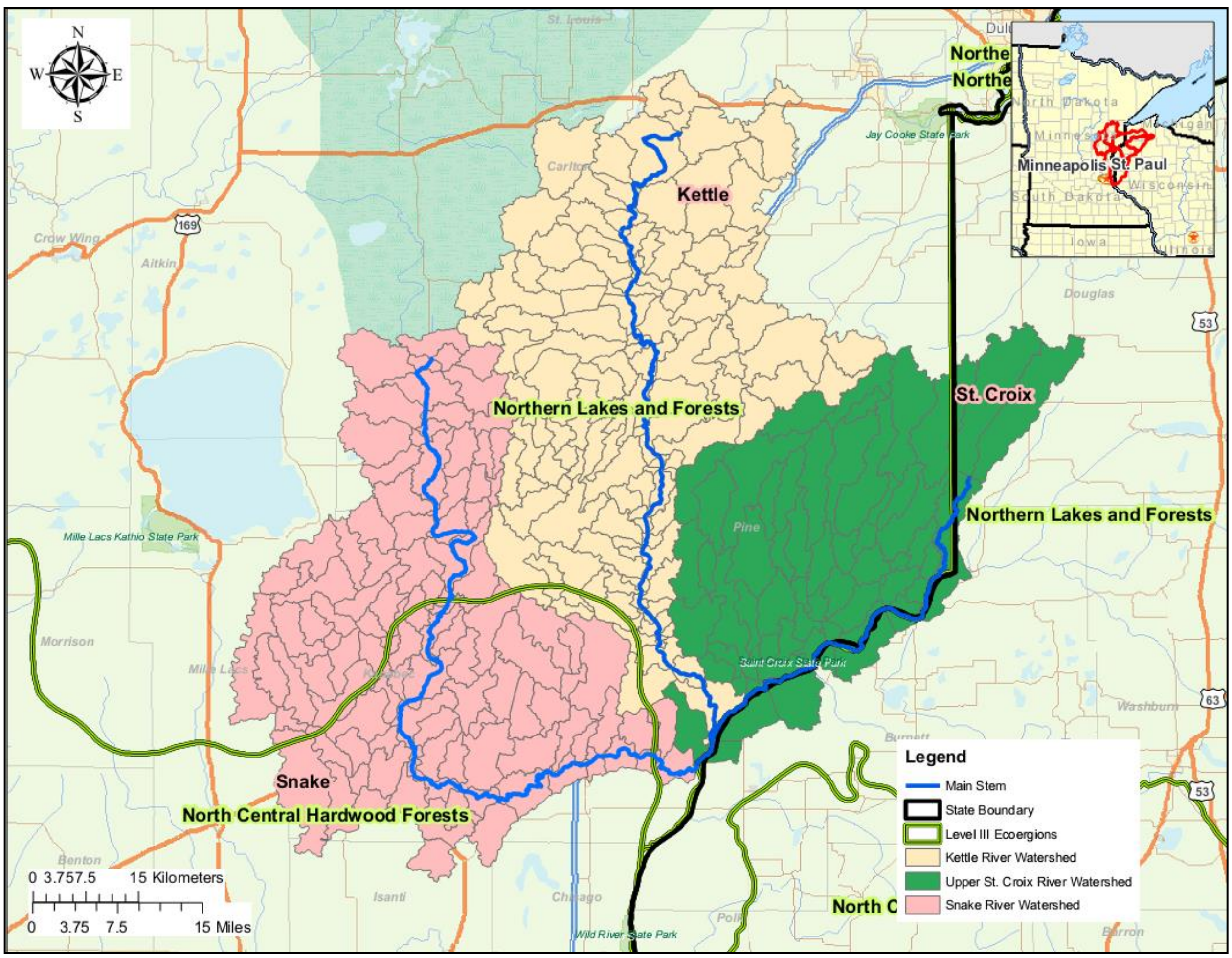


Figure 1-1. Location of the Snake River, Kettle River, and Upper St. Croix River Watersheds in Minnesota.

The objective of this work order is the successful calibration and validation of hydrologic and water quality models for the three watersheds using HSPF. These models can simulate the following constituents:

- Hydrology/flow
- Sediment/TSS
- Water temperature
- Dissolved oxygen (DO)
- Phytoplankton as Chlorophyll *a*
- Nitrite as Nitrogen (NO_2-N) and nitrate as nitrogen (NO_3-N)
- Ammonia as nitrogen (NH_4-N)
- Orthophosphate as phosphorus (PO_4-P)
- Biochemical oxygen demand (BOD)/organics, comprised of
  - Labile BOD
  - Refractory organic nitrogen (ON)
  - Refractory organic phosphorus (OP)
  - Refractory organic carbon (OC).

1.2 WATERSHED DESCRIPTIONS

The Upper St. Croix River and Kettle River Watersheds are mostly located in the Northern Lakes and Forest ecoregions of MN (Figure 1-1). The Upper St. Croix River Watershed covers more than 2,000 square miles (mi^2). However, only 711 mi^2 of the Upper St. Croix River Watershed is in MN. More than half of the Snake River Watershed is located in the Northern Central Hardwood Forests ecoregion, and the remainder is located in the Northern Lakes and Forests ecoregion. All the three watersheds are largely forested. Wetlands are the second biggest land use in the Upper St. Croix River and the Kettle River Watersheds, and third biggest in the Snake River Watershed. Basic facts about the three watersheds are summarized in Table 1-1.

Table 1-1. Snake River, Kettle River, and Upper St. Croix River Watersheds in Minnesota

Properties	Snake River	Kettle River	Upper St. Croix River (MN portion)
Area (sq mi)	1,006	1,051	711
Elevation range Above Mean Sea Level (ft)	800–1,420	816–1,437	800–1,373
Annual Precipitation (in)	28–32	29–31	29–33
Major Land use(s)	Forest, Grass/Pasture	Forest, Wetlands	Forest, Wetlands
Number of impaired Streams (2012)	14	17	9
Number of impaired Lakes (2012)	2	1	0

1.3 OBJECTIVE OF THIS REPORT

This report provides details on the final hydrologic and water quality calibration and validation of the Upper St. Croix River (MN portion), Kettle River, and Snake River Watersheds. The earlier portions of this project were completed in FY 2015 and included model building, data procurement, and initial calibration. The specific task objectives within this work order include the following:

1. Compile both the geographic and time-series data required to construct the model framework (FY2015)
2. Develop a representation of the watershed area and drainage network (FY2015)
3. Develop and implement a strategy for the representation of point sources within the HSPF model domain (FY2015)
4. Formulate a time series from observed flow and water quality monitoring for a watershed model calibration and validation (FY2015)
5. Perform the initial hydrologic calibration (FY2015)
6. Finalize the hydrologic calibration, conduct a hydrologic validation, and provide a water balance (FY2015)
7. Define sediment sources within the watershed and conduct sediment calibration and validation tests (FY2015)
8. Define the sources of nonpoint pollutants within the watershed, formulate the nonpoint model representations, and conduct a nonpoint calibration and validation (FY2015).
9. Conduct in-stream water quality calibration and validation (FY2016).

This report includes details on the tasks and Objectives 6, 7, 8 and 9.

2.0 HYDROLOGY CALIBRATION AND VALIDATION

2.1 MODEL SETUP AND DESCRIPTION

The Upper St. Croix River (MN portion) and the Kettle River Watersheds were set up as one watershed model (STC-Kettle), and the Snake River Watershed was set up as another watershed model. The details on model setup are described in an earlier memorandum [AQUA TERRA Consultants, 2015a]. Table 2-1 summarizes the number of subwatersheds and land areas in each HSPF model. The land-use distribution of each model is presented in Table 2-2. The drainage networks of the three watersheds are illustrated in Figure 2-1.

Table 2-1. The Number and Distribution of Subwatersheds in the HUC 8 Watersheds According to Different Levels of Delineation

HUC 8 Watersheds	Parameters	DNR Level 7 Watersheds	DNR Level 8 Watersheds
Snake River	Count	130	89
	Mean Area (ac)	8,786	7,231
	Minimum Area (ac)	1,200	597
	Maximum Area (ac)	25,830	24,477
Kettle River	Count	73	100
	Mean Area (ac)	9,218	6,729
	Minimum Area (ac)	2,894	234
	Maximum Area (ac)	25,084	25,084
Upper St. Croix River (MN portion)	Count	37	39
	Mean Area (ac)	12,192	11,375
	Minimum Area (ac)	2,977	1,565
	Maximum Area (ac)	33,201	33,201

Table 2-2. The Number and Distribution of Subwatersheds in the HUC 8 Watersheds After Final Delineation for Model Development

HUC 8 Watersheds	Parameters	Subwatershed Segmentation
Snake River	Count	109
	Mean Area (ac)	5,904
	Minimum Area (ac)	295
	Maximum Area (ac)	24,477
Kettle River	Count	123
	Mean Area (ac)	5,471
	Minimum Area (ac)	432
	Maximum Area (ac)	19,502
Upper St. Croix River (MN portion)	Count	57
	Mean Area (ac)	7,987
	Minimum Area (ac)	1246
	Maximum Area (ac)	26,764

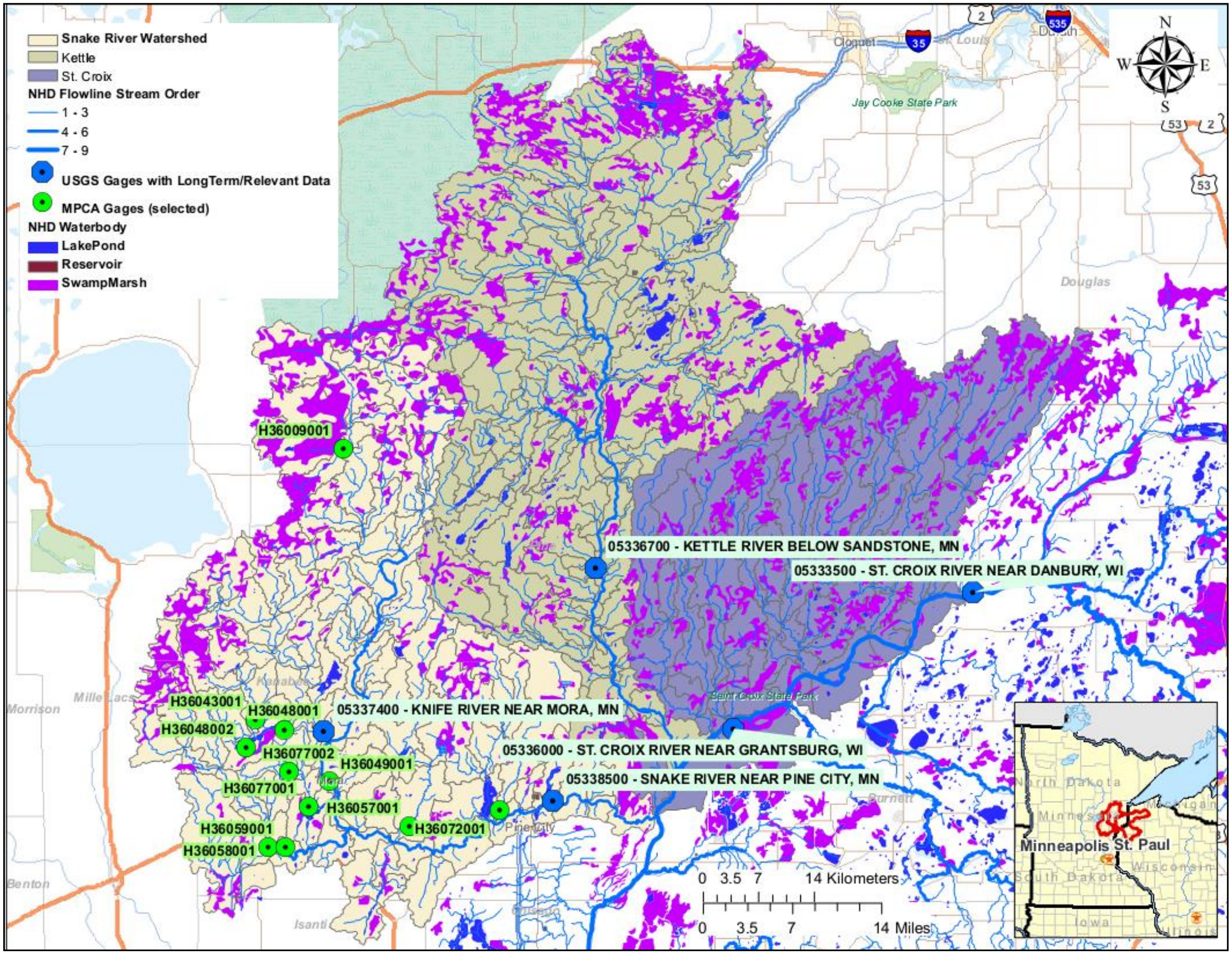


Figure 2-1. Drainage Network of the Upper St. Croix River (Minnesota Portion), Kettle River, and Snake River Watersheds.

Meteorological input data were obtained from the EPA's BASINS database, and local precipitation records were provided by the MPCA. The meteorological input data were assigned to the watersheds based on proximity to the station and quality of the data. The watershed maps in Figure 2-2 illustrate the meteorological stations that were used in the final watershed models. The detailed procedure of processing meteorological data and model segmentation has been described in literature [AQUA TERRA Consultants 2014a].

2.2 HYDROLOGY CALIBRATION

As described in the technical memorandum for deliverables 4 and 5 [AQUA TERRA Consultants, 2015a], the calibration period of the Snake River Watershed and STC-Kettle Watershed models was established as 2002 to 2009, and the validation period as 1995 to 2001. The land use did not change significantly from 2001 to 2006 in these watersheds (Table 2-3) and, therefore, the National Land Cover Database (NLCD) 2006 was used to describe the land use for both the calibration and validation periods. The calibration and validation process focused on the U.S. Geological Survey (USGS) Gages 05338500, 05337400 in the Snake River Watershed, and USGS Gage 05336700 in the Kettle River Watershed (Figure 2-2). On the St. Croix River mainstem, USGS Gage 05333500 near Danbury, Wisconsin, and USGS Gage 05336000 near Grantsburg, Wisconsin, were not used since much of the contributing drainage area for these gages was in Wisconsin and was not included in the watershed models.

2.2.1 Snake River Model

The primary USGS calibration and validation sites in the Snake River Watershed was the Snake River near Pine City (Figure 2-1). The Knife River gage near Mora was used only during the validation period because its period of record ends in 2002. Initial parameter values for the MPCA HSPF applications were derived from previous HSPF modeling efforts in the state [AQUA TERRA Consultants, 2014b]).

2.2.1.1 *Snow Depth*

The hydrology-calibration process started with snow calibration. Snow-depth data were available at several stations in and around the watershed (Figure 2-3). In some cases, the stations were several miles outside the watershed boundaries. This situation for snow-depth calibration is not uncommon. In spite of these issues, the snow-depth comparisons give important insight into assessing the magnitude of snow depth, snow-melt runoff, and timing of the snow-melt period. The snow depth of forest and pastureland-use categories in each meteorological segment were averaged and compared with the observed snow-depth data at the nearest stations. Observed and simulated snow depth were compared by plotting the time series (Figure 2-4a and Figure 2-5a) and the snow depth frequency-duration curves (Figure 2-4b and Figure 2-5b) for the winter period. Although, snow is simulated for all land uses, these two land uses are representative of the snow-range simulation for the other land uses; moreover, snow-depth measurement stations are assumed to be located in places without over-canopy cover that are similar to pasture. Forested areas are expected to have greater snow depth than pastures because of higher shade factors and, therefore, slower melt. The remaining snow-depth comparison figures are provided in the accompanying deliverable model file folders.

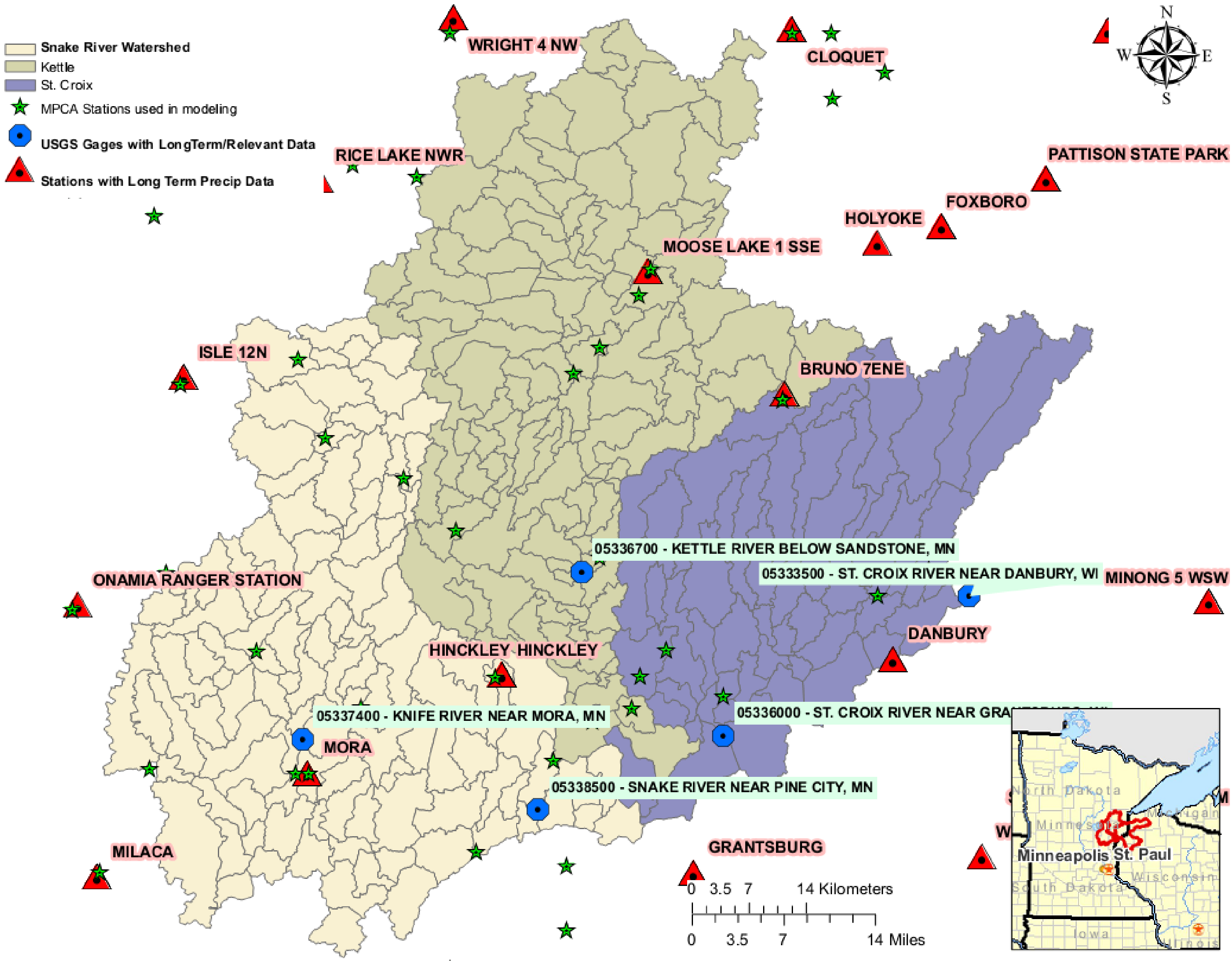


Figure 2-2. Locations of BASINS and Minnesota Pollution Control Agency Stations With Precipitation Data.

Table 2-3. Land-Use Distributions of the Three Modeled Watersheds According to the National Land Cover Database From 2001 to 2006 and the Percent Change

Land Use	NLCD2001			NLCD2006			Percent Change		
	St. Croix	Kettle	Snake	St. Croix	Kettle	Snake	St. Croix	Kettle	Snake
Open Water	6,252	18,232	11,328	6,159	17,976	11,271	–1.5	–1.4	–0.5
Forest-AB	42,281	30,780	8,656	42,142	30,476	8,652	–0.3	–1.0	0.0
Forest-CD	191,844	201,696	221,310	189,762	201,156	220,078	–1.1	–0.3	–0.6
Emergent, herbaceous wetlands	31,166	67,230	76,046	31,253	67,532	76,742	0.3	0.4	0.9
Woody Wetlands	112,198	190,501	95,491	112,077	190,435	95,686	–0.1	0.0	0.2
Grassland-AB	8,571	6,710	1,151	8,797	7,048	1,122	2.6	5.0	–2.5
Grassland-CD	19,381	29,640	24,497	21,608	30,184	24,711	11.5	1.8	0.9
Pasture-AB	3,225	10,967	6,362	3,217	10,943	6,368	–0.3	–0.2	0.1
Pasture-CD	22,142	75,721	118,353	22,124	75,601	118,235	–0.1	–0.2	–0.1
Cropland-AB	2,458	2,854	1,897	2,416	2,830	1,889	–1.7	–0.8	–0.4
Cropland-CD	2,743	6,496	27,180	2,718	6,511	27,245	–0.9	0.2	0.2
Cropland-Drained	2,635	5,023	24,918	2,630	5,010	24,856	–0.2	–0.3	–0.2
Developed, Open Space	10,019	24,130	22,048	10,008	24,118	22,063	–0.1	0.0	0.1
Developed, Low Intensity	111	2,012	3,179	130	2,051	3,290	16.6	1.9	3.5
Developed, Medium and High	34	829	1,020	55	943	1,224	62.8	13.8	20.0
Total	**455,060**	**672,821**	**643,436**	**455,096**	**672,814**	**643,432**			

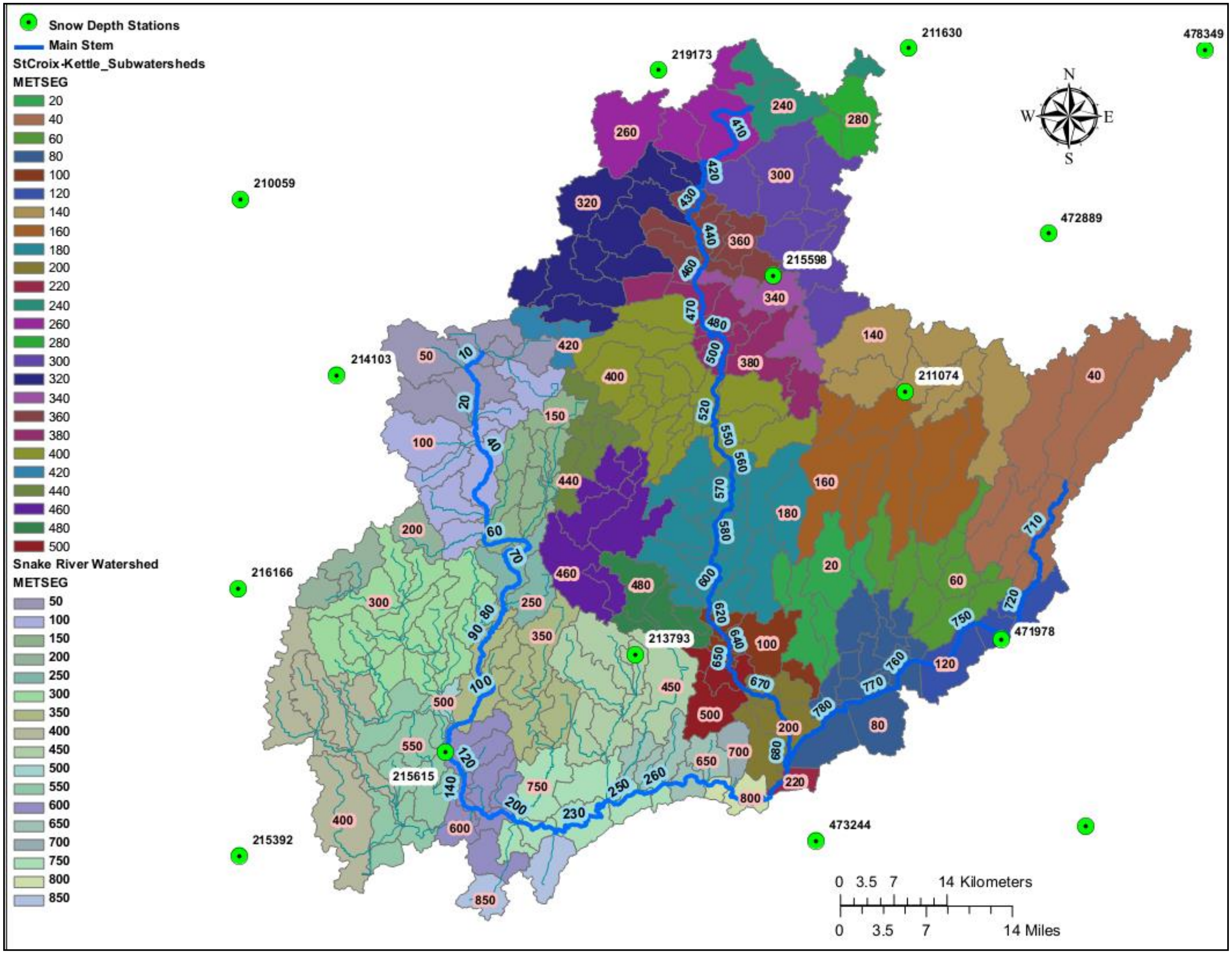
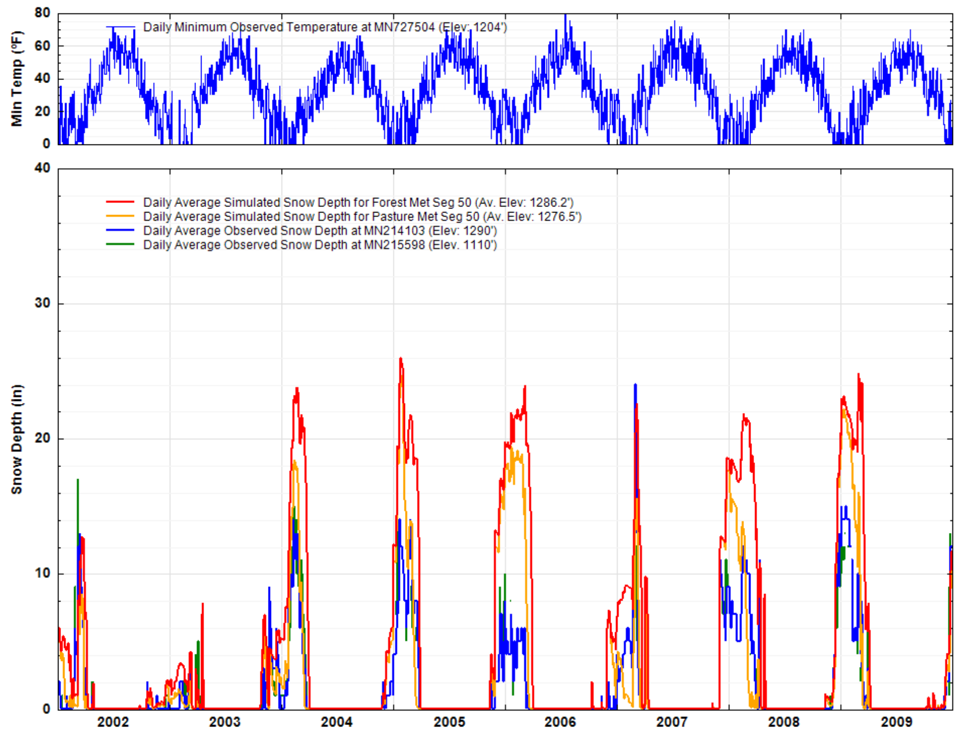


Figure 2-3. Location of Stations With Observed Snow-Depth Data for the Model Simulation Period.



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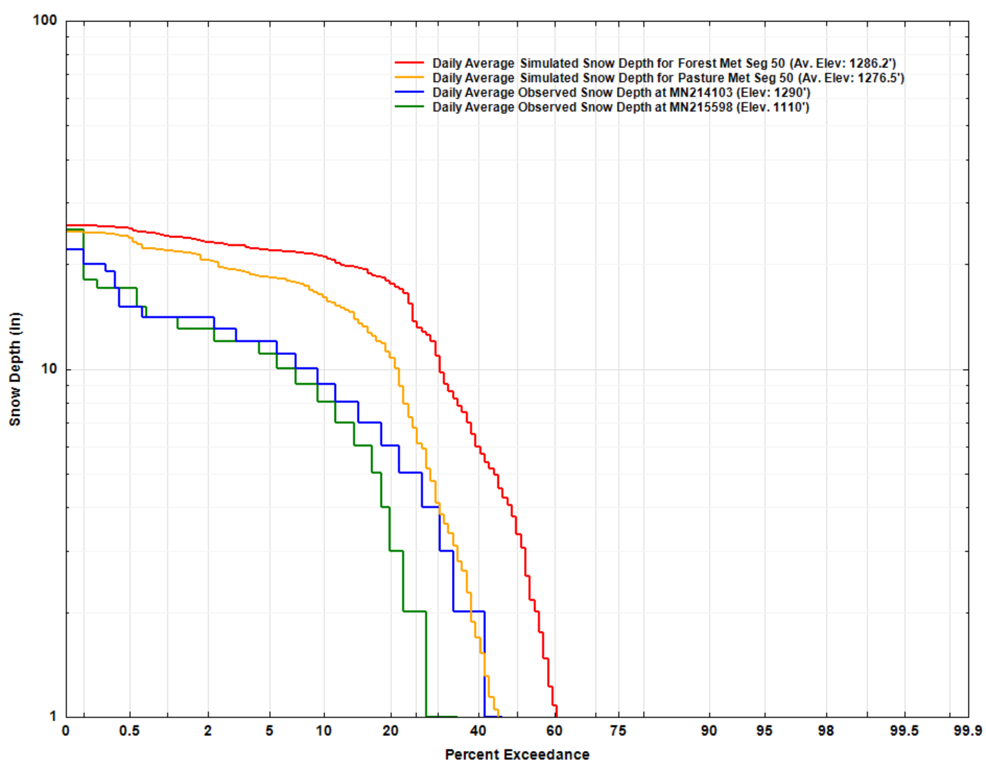

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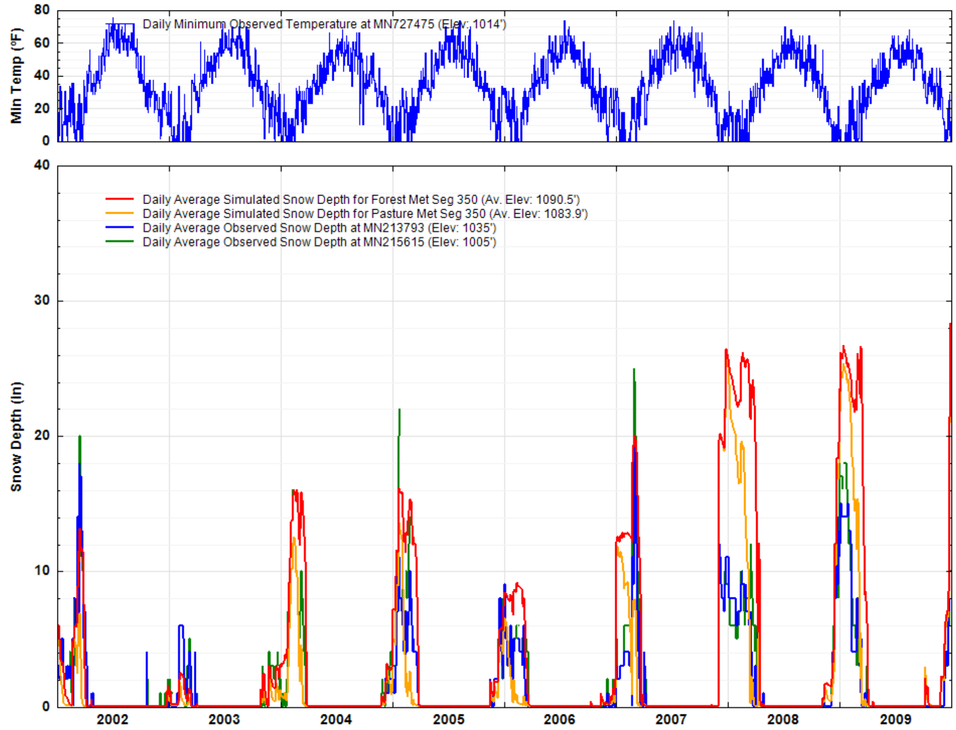
Figure 2-4. Simulated Snow Depth (a) and Snow Frequency (b) Compared With Observed Data for Met Segment 50 in the Snake River Watershed.



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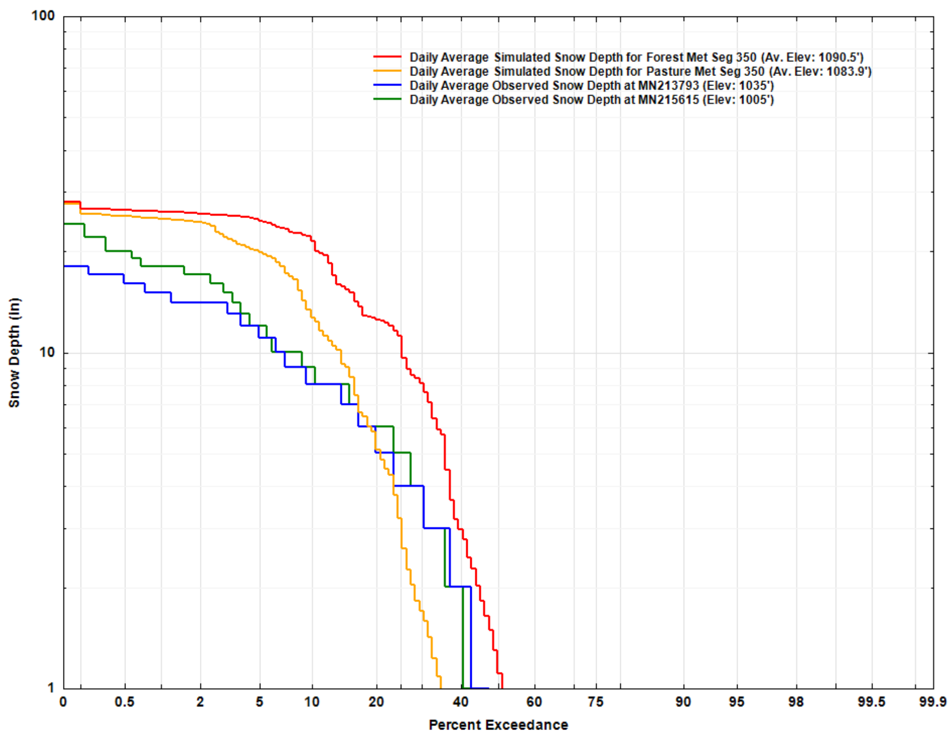


B

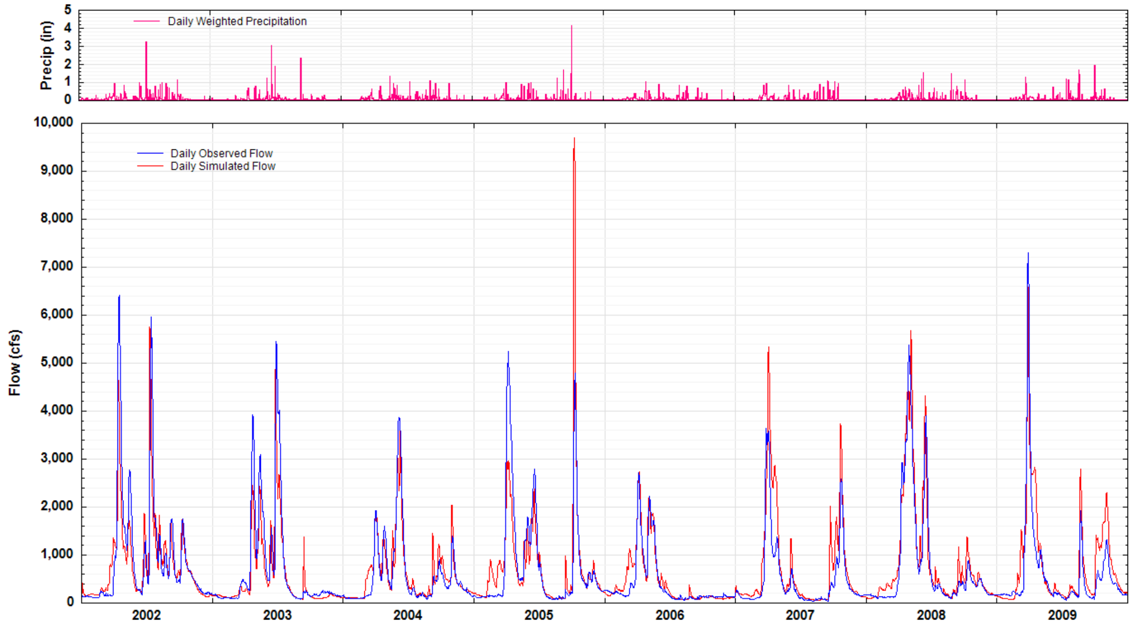
Figure 2-5. Simulated Snow Depth (a) and Snow-Depth Frequency (b) Compared With Observed Data for Met Segment 350 in on the Snake River Watershed.

In general, the comparison of observed and simulated snow depth suggests that the simulated snow depth is greater than the observed snow depth for multiple winter periods (Figure 2-4 and Figure 2-5). One reason for this perception is that the observed data are not available for every day of the winter period. Snow simulation was also adjusted after initial hydrologic calibration by increasing the snow catch factor (SNOWCF) to account for the inefficiency of snow catch by rain gages, and to provide the resulting increase in winter and spring runoff volumes. Part of the snow calibration also includes an evaluation of the resulting streamflow simulation of the spring melt period to assess consistency between the snow simulation and the melt-period flow simulation. For example, the snow simulation for winter 2007/08 and winter 2008/09 (Figure 2-4a and Figure 2-5a) appears to be oversimulated, but the spring 2008 and 2009 flow simulations are good to very good (Figure 2-6). This confirms that the higher snow depths are realistic and consistent with the subsequent melt volumes. Overall, the snow simulation was satisfactory in terms of the magnitude of snow depth and timing of snow melt. Similar snow-depth plots were prepared for the validation period, and the snow-depth simulations were also judged as equally acceptable for the validation period.

2.2.1.2 *Flow Simulation*

The hydrology calibration and validation results based on the daily flow hydrograph and flow frequency-duration curves are visually acceptable and looked satisfactory for the USGS gage at Snake River (Figure 2-6 and Figure 2-7). The error statistics (Table 2-4) for the calibration period are acceptable for most criteria; however, the error statistics for the validation period were not acceptable for some criteria, primarily the low flows. Note that this USGS gage was located downstream of a dam and, therefore, the flow characteristics are affected by the dam and its operation. The functional table (FTABLE) of the dammed reach was developed using the HEC-RAS model provided by the MPCA. Whether or not the HEC-RAS representation contains all of the operational controls for the dam is unknown, and no other operational controls were incorporated in the HSPF model. The major event to note is the October 2005 storm event, which was greatly oversimulated. The storm was a rare deluge event in east-central Minnesota where these watersheds are located and was recorded and described by the Minnesota Climatology Working Group [2005]. The nearby weather gages reported a total rainfall of 3 to 7 inches between October 4 and 5. Surprisingly, the response to this event at the outlet was lower than many other storm peaks during the calibration period. A flow-control device was possibly used to reduce the flow downstream or that the actual precipitation on the watershed was lower than the surrounding gages; however, we could not confirm this. The model-fit statistics suggest that the overall model performance was better during the validation period as compared to the calibration period (Table 2-5). Overall, the model performed good to very good for both the calibration and the validation period. The annual statistics (Table 2-6) suggest that the model overpredicted runoff during the latter part of the calibration period.

For the validation period, observed flow data were also available at the Knife River near Mora in the Snake River Watershed. Figure 2-8 and the expert statistics shown in Table 2-7 suggest that the model did not perform as well at the Knife River gage as at the Snake River gage for the validation period. Model statistics illustrated in Table 2-8 suggest that the model performance was fair to good for the validation period at the Knife River gage. The Knife River gage was downstream of Knife Lake. The outlet structure



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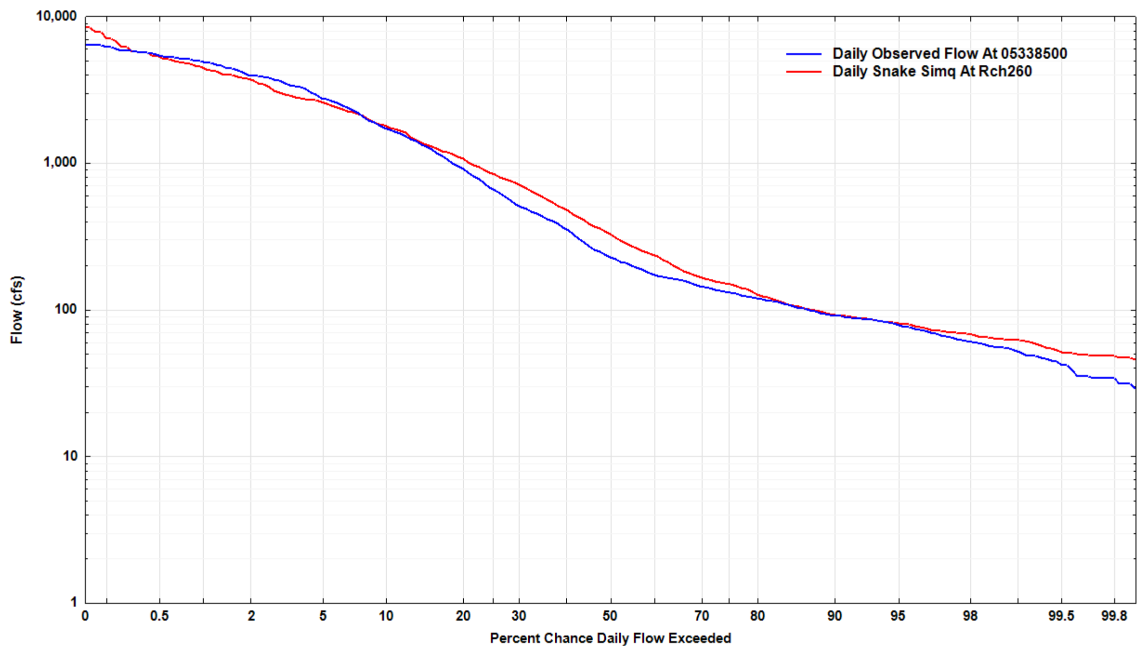

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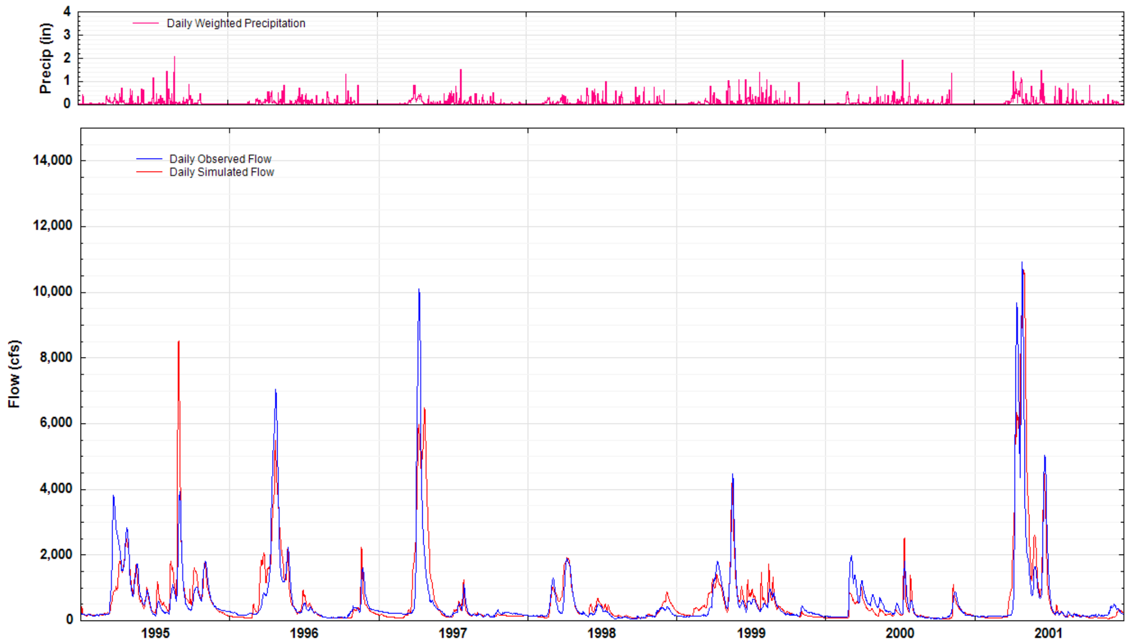
Figure 2-6. Observed and Simulated Flow (a) and Flow Frequency-Duration Curve (b) at U.S. Geological Survey Gage 05335800 in the Snake River Watershed for the Calibration Period.



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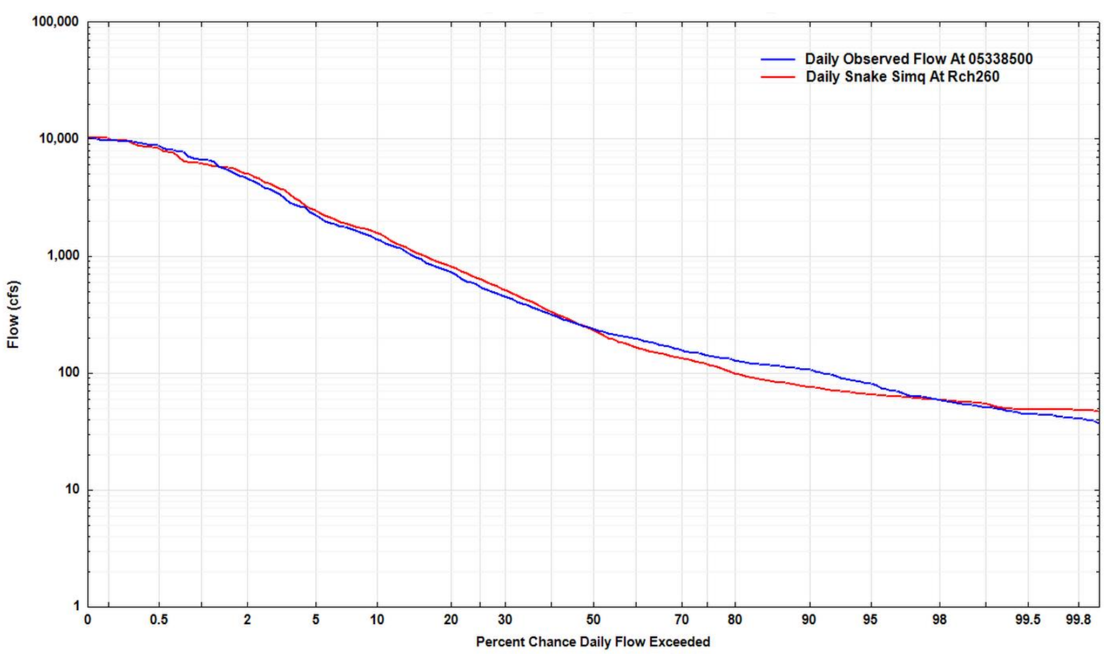

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Figure 2-7. Observed and Simulated Flow (a) and Flow Frequency-Duration Curve (b) at U.S. Geological Survey Gage 05335800 in the Snake River Watershed for the Validation Period.

at Knife Lake significantly affects the flow in the Knife River. Bathymetry data were available for Knife Lake, but no information was available for the Knife Lake outlet. It was assumed that the weir length at the Knife Lake outlet was 150 feet based on Google Earth™. Any additional information about this outlet can improve the validation results at this gage.

Table 2-4. Expert Statistics and Criteria for the Snake River Watershed at U.S. Geological Survey Gage 05335800 for the Calibration and Validation Periods

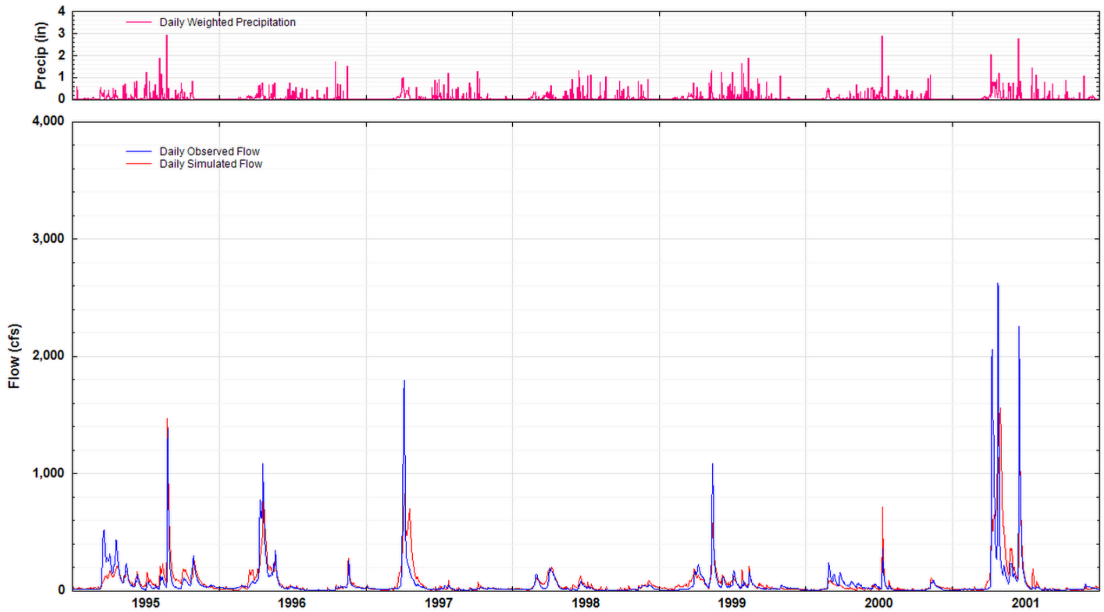
Statistics	Criteria	Calibration Period		Validation Period	
Error in total volume (%)	10	7.68	OK	4.72	OK
Error in 10% highest flows (%)	15	–5.27	OK	5.23	OK
Error in 25% highest flows (%)	10	–0.04	OK	7.10	OK
Error in 50% highest flows (%)	10	6.25	OK	7.47	OK
Error in 50% lowest flows (%)	10	20.09	Needs Work	–15.9	Needs Work
Error in 25% lowest flows (%)	15	5.49	OK	–21.3	Needs Work
Error in 10% lowest flows (%)	20	4.90	OK	–16.4	OK
Error in low-flow recession	0.03	0.01	OK	0.01	OK
Error in storm volumes (%)	15	–1.43	OK	4.63	OK
Seasonal volume error (%)	20	–10.82	OK	25.96	Needs Work
Error in average storm peak (%)	15	12.65	OK	24.2	Needs Work
Summer volume error (%)	20	–2.56	OK	20.7	Needs Work
Winter volume error (%)	15	8.26	OK	–5.24	OK
Summer storm volume error (%)	15	–7.54	OK	18.18	Needs Work
Winter storm volume error (%)	15	–18.62	Needs Work	–24.1	Needs Work

Table 2-5. Model Fit Statistics for the Snake River Watershed at U.S. Geological Survey Gage 05335800 for the Calibration and Validation Periods

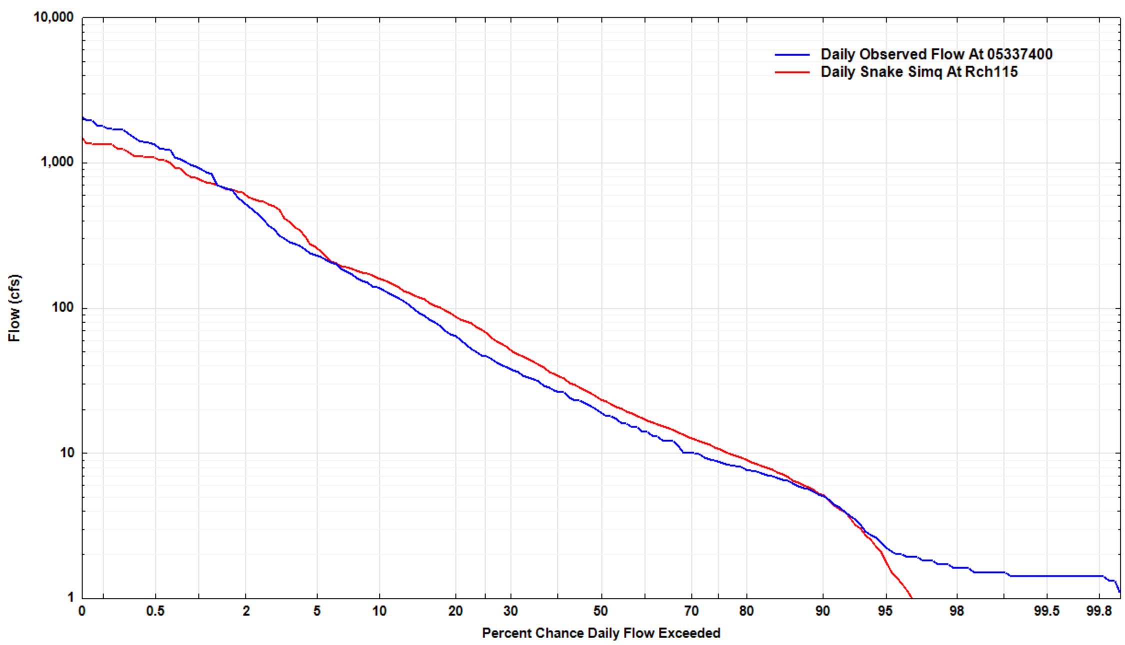
	Calibration	Validation
Monthly Flow Statistics		
Correlation Coefficient	0.91	0.94
Coefficient of Determination	0.82	0.89
Model Fit Efficiency	0.81	0.88
Daily Flow Statistics		
Correlation Coefficient	0.87	0.86
Coefficient of Determination	0.76	0.74
Model Fit Efficiency	0.74	0.71

Table 2-6. Annual Flows (Inches) and Associated Statistics at U.S. Geological Survey Gage 05335800 for the Calibration and Validation Periods

Year	Calibration Period					Validation Period					
	SUPY	Simulated	Observed	Residual	Error (%)	Year	SUPY	Simulated	Observed	Residual	Error (%)
2002	39.7	11.6	13.0	–1.4	–11.0	1995	35.7	12.0	11.8	0.3	2.1
2003	28.3	7.3	9.3	–2.0	–21.9	1996	27.9	9.4	9.7	–0.3	-3.0
2004	32.5	8.5	7.9	0.6	8.0	1997	29.1	9.3	8.3	1.0	12.4
2005	34.4	11.6	11.2	0.4	3.7	1998	28.8	5.2	4.3	0.9	21.4
2006	24.5	6.0	5.2	0.8	14.6	1999	32.1	7.7	7.0	0.7	9.8
2007	31.7	9.8	6.6	3.2	48.8	2000	25.8	3.9	5.3	–1.4	–27.0
2008	34.5	12.0	10.8	1.3	11.6	2001	37.5	15.2	13.6	1.7	12.2
2009	31.5	11.0	8.2	2.7	33.1						
Mean	**32.1**	**9.7**	**9.03**	**0.77**	**7.7%**	**Mean**	**31.0**	**9.0**	**8.6**	**0.4**	**4.7%**



A



B

Figure 2-8. Observed and Simulated Flow and Flow Frequency-Duration Curve at U.S. Geological Survey Gage 05337400 on the Knife River Near Mora for the Validation Period.

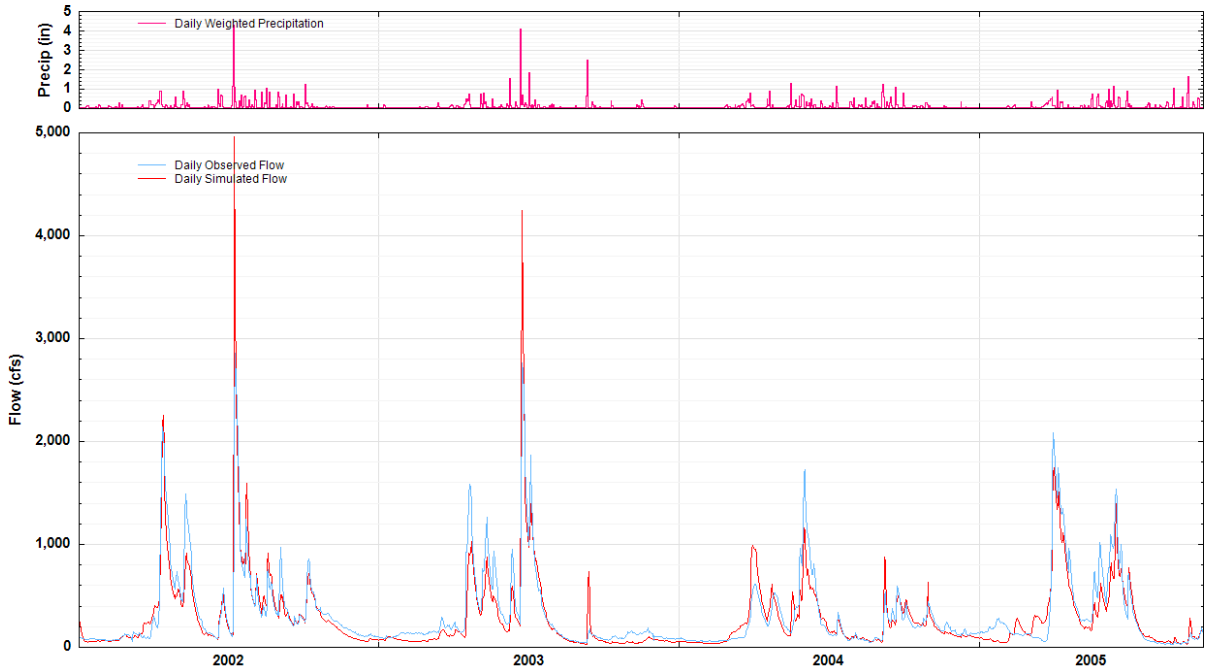
Table 2-7. Expert Statistics and Criteria for U.S. Geological Survey Gage 05337400 on the Knife River Near Mora for the Validation Period

Statistics	Criteria	Validation Period	
Error in total volume (%)	10	10.5	Needs Work
Error in 10% highest flows (%)	15	-0.28	OK
Error in 25% highest flows (%)	10	6.67	OK
Error in 50% highest flows (%)	10	9.90	OK
Error in 50% lowest flows (%)	10	18.42	Needs Work
Error in 25% lowest flows (%)	15	6.60	OK
Error in 10% lowest flows (%)	20	–18.65	OK
Error in low-flow recession	0.03	0.04	Needs Work
Error in storm volumes (%)	15	9.59	OK
Seasonal volume error (%)	20	19.09	OK
Error in average storm peak (%)	15	–21.73	Needs Work
Summer volume error (%)	20	24.54	Needs Work
Winter volume error (%)	15	5.45	OK
Summer storm volume error (%)	15	12.00	OK
Winter storm volume error (%)	15	20.44	Needs Work

Table 2-8. Model Fit Statistics at U.S. Geological Survey Gage 05337400 on the Knife River Near Mora for the Validation Period

	Validation Period
Monthly Flow Statistics	
Correlation Coefficient	0.94
Coefficient of Determination	0.88
Model Fit Efficiency	0.88
Daily Flow Statistics	
Correlation Coefficient	0.75
Coefficient of Determination	0.57
Model Fit Efficiency	0.56

Aside from the two USGS gages in the Snake River Watershed, observed flow data were also available at five MPCA gages. The data at these gages were not available for the whole calibration period and were missing during most winter periods. We compared the available data at these locations with the flow data at USGS Gage 05335800 in the Snake River and developed regression equations. These regression equations were used to fill the missing data. Simulated flow results at these locations were compared with the filled observed data to improve the model calibration (Figure 2-9 and Figure 2-10 provide



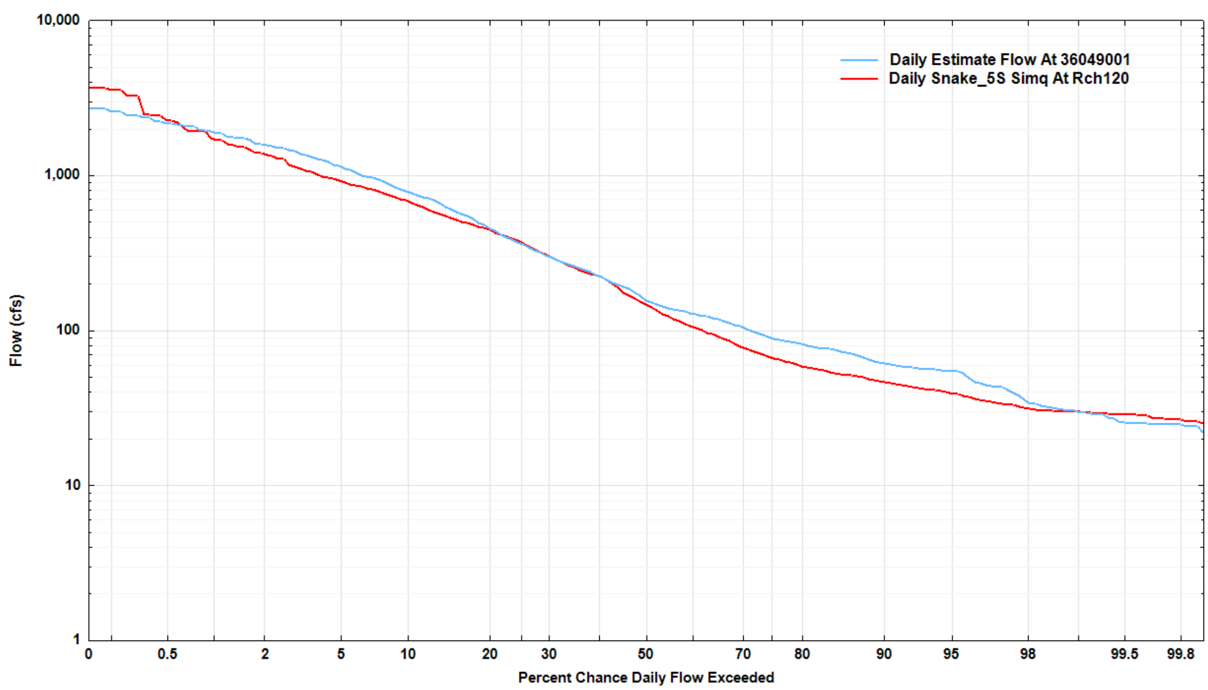


Figure 2-9. Observed and Simulated Flow Hydrograph and Frequency-Duration Curve at the Minnesota Pollution Control Agency Gage H36049001.

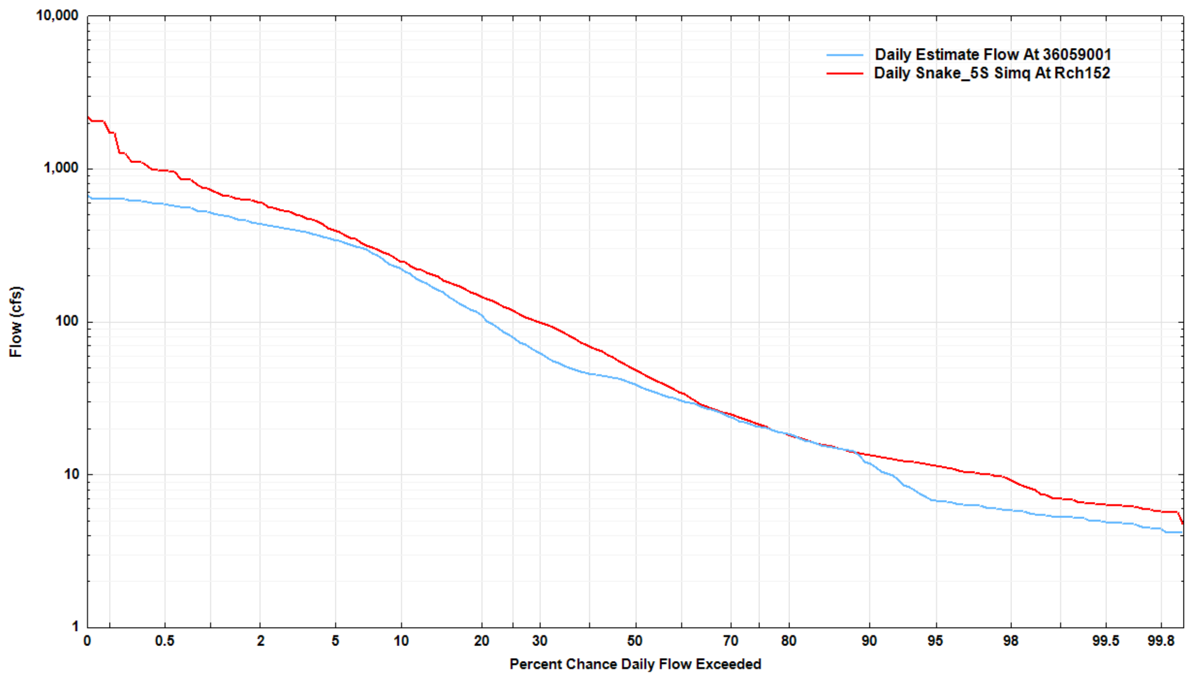


Figure 2-10. Observed and Simulated Flow Hydrograph and Frequency-Duration Curve at the Minnesota Pollution Control Agency Gage H36059001.

examples). The calibration results at MPCA Gage H36049001 (Snake River at Mora) were acceptable, but the calibration results at other stations were not satisfactory. Graphs and expert statistics at all of these locations are available in the accompanying deliverable folder. Additional resources would be required to investigate the observed flow data at these locations, process the missing data, and then calibrate the flow at these locations. Also note that the focus of calibration was the USGS gage in Snake River, since it has long-term, continuous data.

2.2.1.3 *Lake Levels*

Lake-level data were available at only a few lakes for the simulation period. The simulated and observed lake graphs (Figure 2-11) suggest an acceptable simulation of lake levels. Improvement in FTABLES and additional data at the lake outlet can improve the lake level calibration results.

2.2.1.4 *Water Balance*

As part of the calibration process of the Snake Watershed, simulated water balances of all land uses were calculated (Table 2-9). Although, there are no observed data to compare with the water balances, it is routinely checked to verify that the properties of different land uses are adequately represented. For example, the infiltration capacity of hydrologic soils group A and B is greater than C and D; therefore, less surface runoff is estimated for land uses with AB soils than the land uses with CD soils. The runoff from forestlands is generally lower than the runoff from all other land uses except wetlands. In general, the water balances are reasonable and satisfactory for all the land uses.

2.2.2 Upper St. Croix-Kettle River Model

2.2.2.1 *Snow Depth*

The STC-Kettle River model calibration started with the snow depth simulation (Figure 2-12 and Figure 2-13). Similar to the snow-depth simulation in the Snake River Watershed, the simulated snow depths for forest and pasture areas were compared with the observed data at the nearest snow-depth station. Snow depth was oversimulated occasionally; overall, the snow simulation was satisfactory in terms of depth and timing of snow melt. The snow simulation was adjusted to improve the hydrology simulation during the winter and spring. Additional snow simulation plots are provided in the accompanying deliverable folder. The snow-depth simulation for the validation period was also satisfactory.

2.2.2.2 *Flow Simulation*

The flow calibration in the STC-Kettle model focused on the USGS gage on the Kettle River near Sandstone (see Figure 2-1). The flow hydrograph and flow frequency-duration curves suggest that the model simulated the flow satisfactorily during the calibration period (Figure 2-14), but undersimulated during the validation period (Figure 2-15). Although, the model oversimulated flow during the calibration period by 6.7 percent, the flow was undersimulated during the validation period by 13.2 percent (Table 2-10). A comparison of annual flow volume (Table 2-11) shows that the observed flow volume during the validation period was 25 percent greater than the observed flow volume during the calibration period, even though the total precipitation volume is about 1 percent greater during the validation period.

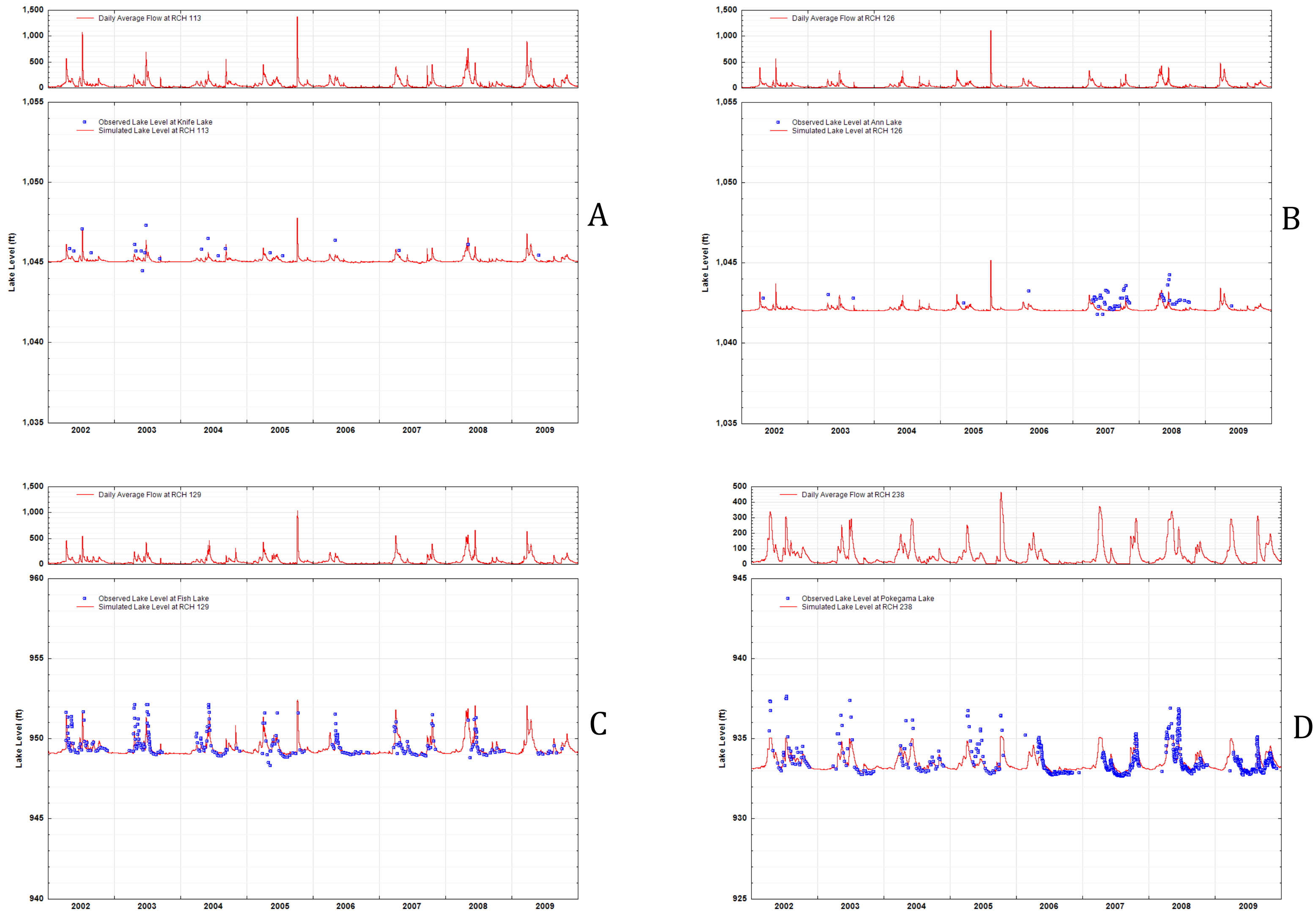


Figure 2-11. Simulated and Observed Lake Level Data at (a) Knife Lake, (b) Ann Lake, (c) Fish Lake, and (d) Pokegama Lake in the Snake River Watershed.

Table 2-9. Water Balance Summary of the Snake River Watershed (Units in Inches)

Land Use	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Watershed Total
Pervious Land Categories															
Area (acres)	8,626	220,171	76,743	95,699	1,123	24,713	6,385	118,188	1,898	27,174	24,869	21,617	2,958	794	630,958
Influx															
Rainfall	31.10	32.35	32.21	31.53	31.13	32.22	31.33	32.20	31.59	32.21	31.96	32.11	32.05	31.96	32.11
Runoff															
Surface	0.12	0.15	0.01	0.01	0.77	1.38	0.71	1.29	0.44	0.91	0.07	2.35	2.85	3.19	0.50
Interflow	1.06	1.41	0.39	0.40	2.09	2.30	2.19	2.28	1.52	2.05	3.08	1.70	1.80	1.89	1.44
Baseflow	7.31	7.94	7.85	7.76	7.73	7.87	7.92	7.84	7.97	7.49	7.17	7.60	6.84	6.27	7.80
Total	8.48	9.50	8.24	8.16	10.58	11.55	10.81	11.41	9.93	10.45	10.32	11.65	11.49	11.36	9.74
GW Inflow															
Deep	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Active	7.78	8.41	10.28	9.89	7.81	7.95	8.00	7.93	8.05	7.57	7.25	7.68	6.91	6.35	8.62
Evaporation															
Potential	33.22	33.34	33.32	32.37	33.89	33.98	33.58	34.28	34.57	34.42	34.39	34.15	34.34	34.35	33.52
Intercep St	6.22	6.29	5.87	6.00	5.72	5.70	5.76	5.76	5.76	5.69	5.76	5.48	5.57	5.62	5.98
Upper Zone	4.79	5.14	4.87	4.73	5.19	5.52	5.15	5.56	5.33	5.97	5.87	5.28	5.55	5.76	5.20
Lower Zone	10.63	10.46	10.35	10.05	9.12	8.94	9.08	8.97	10.09	9.65	9.57	9.24	9.00	8.80	9.91
Ground Water	0.00	0.00	2.33	2.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.59
Baseflow	0.37	0.37	0.14	0.14	0.14	0.14	0.13	0.14	0.13	0.13	0.13	0.13	0.13	0.13	0.22
Total	**22.00**	**22.25**	**23.55**	**22.96**	**20.17**	**20.30**	**20.12**	**20.42**	**21.31**	**21.44**	**21.33**	**20.12**	**20.25**	**20.31**	**21.91**
Impervious Land Categories															
Land Use												**Developed, Open Space**	**Developed Low Intensity**	**Developed Medium Intensity**	**Watershed Average**
Area (acres)												441	328	428	1,198
Influx															
Rainfall												32.03	31.96	31.91	31.97
Runoff															
Surface												27.51	27.35	27.25	27.37
Evaporation															
Potential												34.14	34.33	34.34	34.26
Actual												4.52	4.60	4.66	4.59

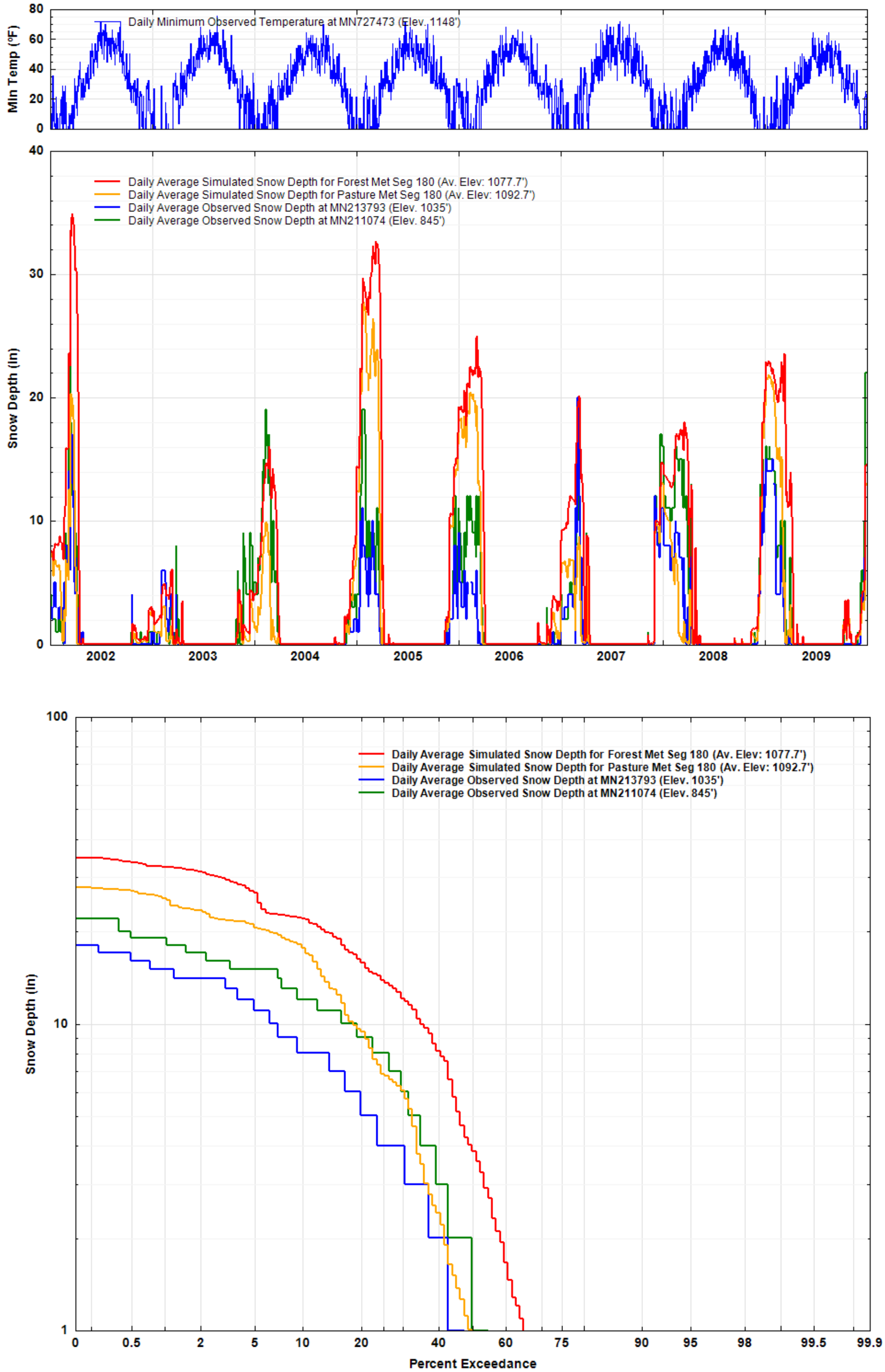


Figure 2-12. Simulated Snow Depth and Snow Frequency Compared With Observed Data for Met Segment 60 in the Kettle River Watershed.

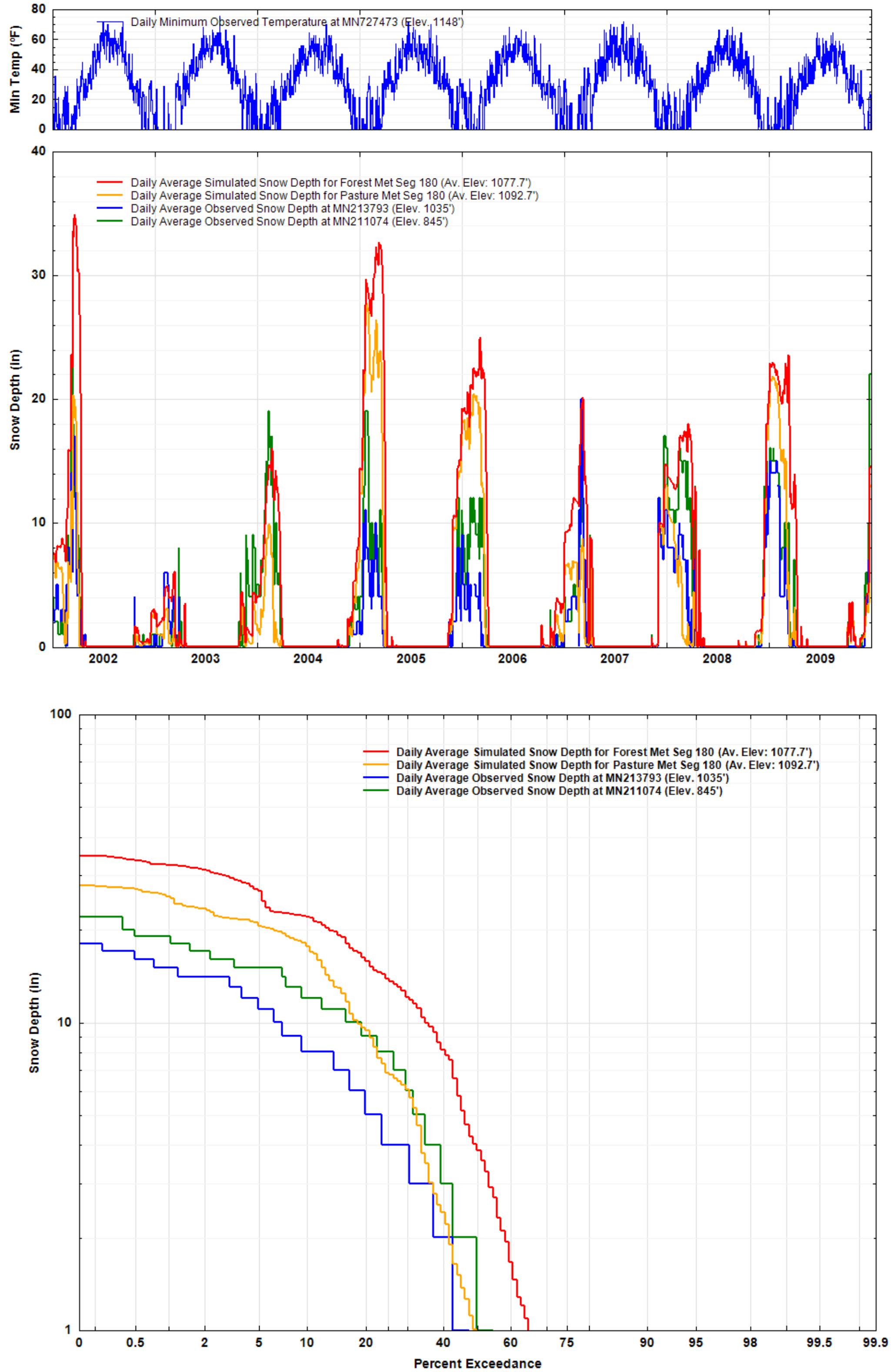


Figure 2-13. Simulated Snow Depth and Snow Frequency Compared With Observed Data for Met Segment 180 in the Kettle River Watershed.

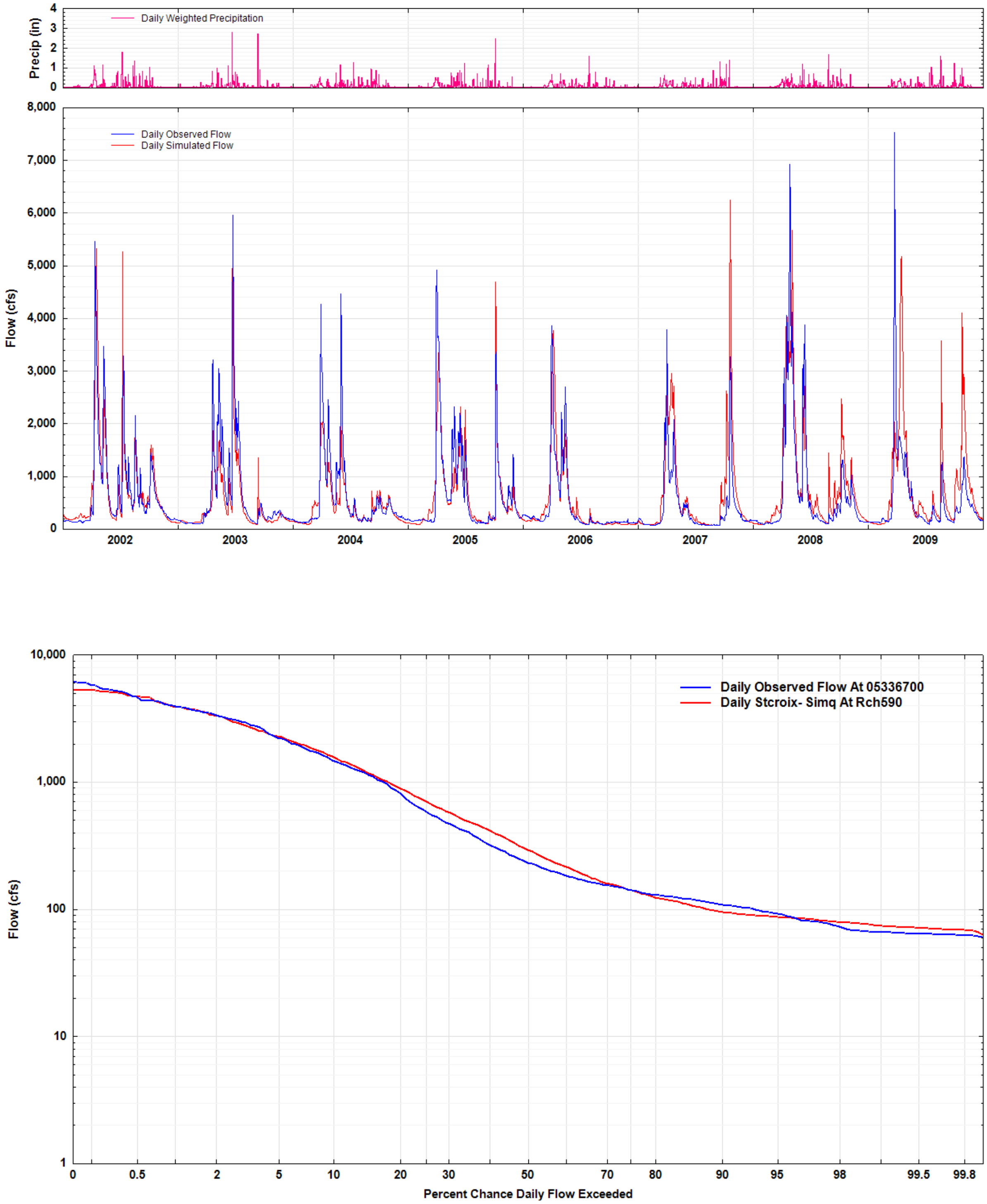
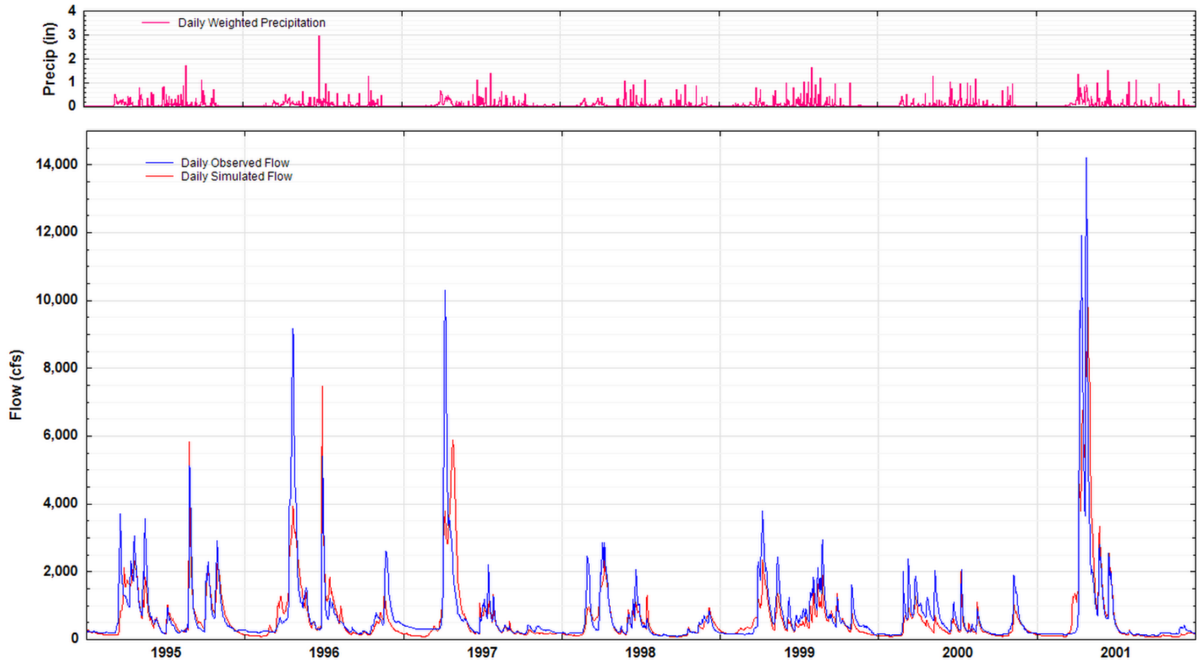


Figure 2-14. Observed and Simulated Flow and Flow Frequency Duration Curve at U.S. Geological Survey Gage 05336700 in the Kettle River Watershed for the Calibration Period.



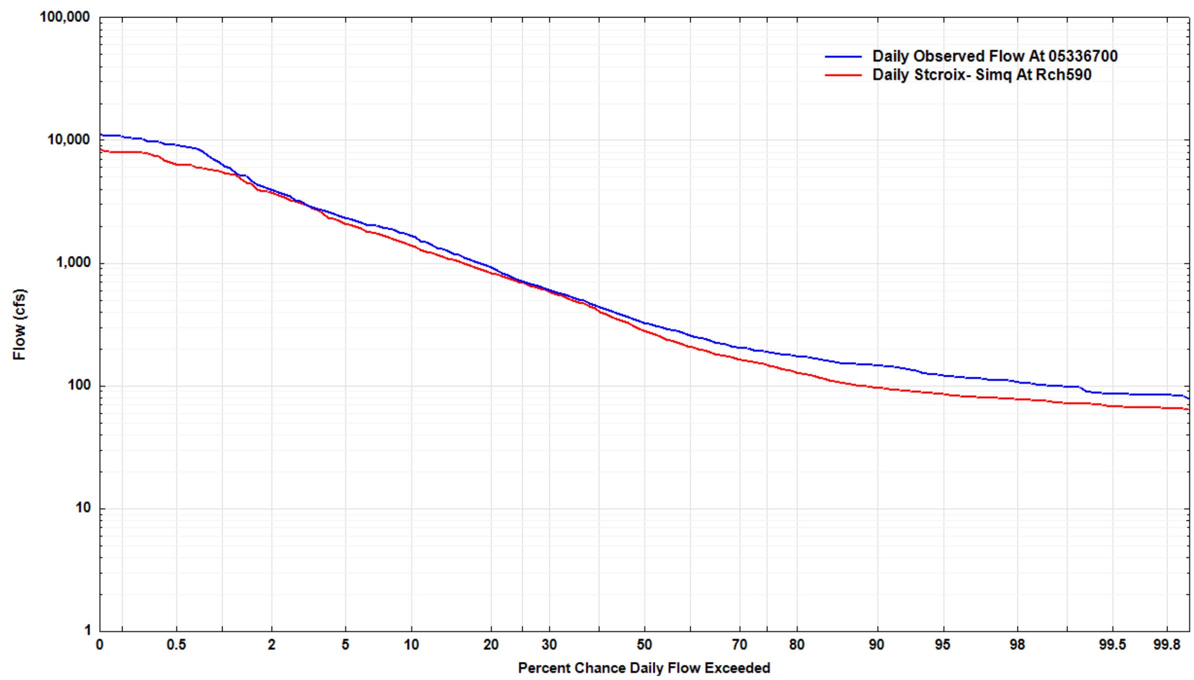


Figure 2-15. Observed and Simulated Flow and Flow Frequency Duration Curve at U.S. Geological Survey Gage 05336700 in the Kettle River Watershed for the Validation Period.

This change in the flow regime is confounding and could indicate measurement errors in precipitation and/or flow data. The water year summaries for this USGS gage are not available before 2002, and the USGS webpage for this watershed does not explain anything unusual that may have happened at this gage. The USGS was contacted to discuss this issue. Although the USGS acknowledged the difference in the flow regime during the calibration and validation period, it did not have any explanation [James Fallon, personal communication, June 22, 2015]. The STC-Kettle model cannot be validated because of these issues. The model-fit statistics for calibration and validation periods suggest that the watershed model is a good predictor for daily flows and very good for monthly flows (Table 2-12); however, these statistics do not take into account short-term differences for selected events or data issues, as noted above.

Table 2-10. Expert Statistics and Criteria for the Kettle River Watershed at the U.S. Geological Survey Gage 05336700 for the Calibration and Validation Periods

Statistics	Criteria	Calibration Period		Validation Period	
Error in total volume (%)	10	6.67	OK	–13.15	Needs Work
Error in 10% highest flows (%)	15	–0.29	OK	–14.17	OK
Error in 25% highest flows (%)	10	2.65	OK	–13.06	Needs Work
Error in 50% highest flows (%)	10	6.67	OK	–11.64	Needs Work
Error in 50% lowest flows (%)	10	6.64	OK	–22.51	Needs Work
Error in 25% lowest flows (%)	15	–5.60	OK	–28.92	Needs Work
Error in 10% lowest flows (%)	20	–4.08	OK	–30.78	Needs Work
Error in low-flow recession	0.03	0.003	OK	0.003	OK
Error in storm volumes (%)	15	4.37	OK	–11.88	OK
Seasonal volume error (%)	20	2.12	OK	12.15	OK
Error in average storm peak (%)	15	9.05	OK	–24.89	Needs Work
Summer volume error (%)	20	–2.31	OK	–6.74	OK
Winter volume error (%)	15	–4.43	OK	–18.88	Needs Work
Summer storm volume error (%)	15	0.15	OK	–8.98	OK
Winter storm volume error (%)	15	NaN	Needs Work	–48.83	Needs Work

2.2.2.3 *Lake Levels*

The watershed calibration included the calibration of lake levels (Figure 2-16). The lake-level data are available for three lakes during the simulation period. The lake-level simulation was acceptable for all of the lakes; however, Sand Lake may need additional adjustment. Sand Lake and Island Lake are in one subwatershed and were modeled as a single waterbody. The observed lake level at Sand Lake was compared with the simulated lake level for this combined waterbody; although, Island Lake appears to flow into Sand Lake only when it is full, there may be some additional groundwater interaction between the lakes. Additional information about the outlets at these lakes may be needed to improve the lake-level simulation.

Table 2-11. Annual Flows (Inches) and Associated Statistics at the U.S. Geological Survey Gage 05336700 in the Kettle River Watershed for the Calibration and Validation Periods

Year	Calibration Period					Validation Period					
	SUPY	Simulated	Observed	Residual	% Error	Year	SUPY	Simulated	Observed	Residual	% Error
2002	36.9	11.4	10.9	0.5	4.9	1995	33.7	11.5	12.6	–1.1	–8.6
2003	28.0	6.8	9.3	–2.5	–26.7	1996	30.9	11.5	13.5	–2.0	–15.0
2004	28.6	7.1	8.7	–1.6	–18.4	1997	29.8	10.2	10.8	–0.6	–5.7
2005	32.1	9.9	10.7	–0.7	–6.9	1998	28.1	6.7	7.4	–0.7	–9.7
2006	23.8	6.4	6.3	0.1	2.2	1999	32.5	8.4	11.3	–2.9	–26.0
2007	30.5	9.5	6.2	3.3	52.9	2000	27.1	5.3	8.0	–2.7	–33.9
2008	34.3	13.1	11.1	2.0	17.6	2001	34.2	14.1	14.2	–0.1	–1.0
2009	30.7	12.0	8.3	3.7	43.8						
Mean	30.6	9.5	8.9	0.6	6.7	Mean	30.9	9.7	11.1	–1.5	–13.2

Table 2-12. Model Fit Statistics for the Kettle River Watershed at the U.S. Geological Survey Gage 05336700 for the Calibration and Validation Periods

	Calibration	Validation
Monthly Flow Statistics		
Correlation Coefficient	0.89	0.95
Coefficient of Determination	0.79	0.91
Model Fit Efficiency	0.76	0.90
Daily Flow Statistics		
Correlation Coefficient	0.82	0.83
Coefficient of Determination	0.67	0.69
Model Fit Efficiency	0.64	0.68

2.2.2.4 *Water Balance*

Review of the simulated water balance of all the land-use categories in the STC-Kettle model (Table 2-13) suggests that the hydrology parameters adequately and reasonably reflect the differences in land uses.

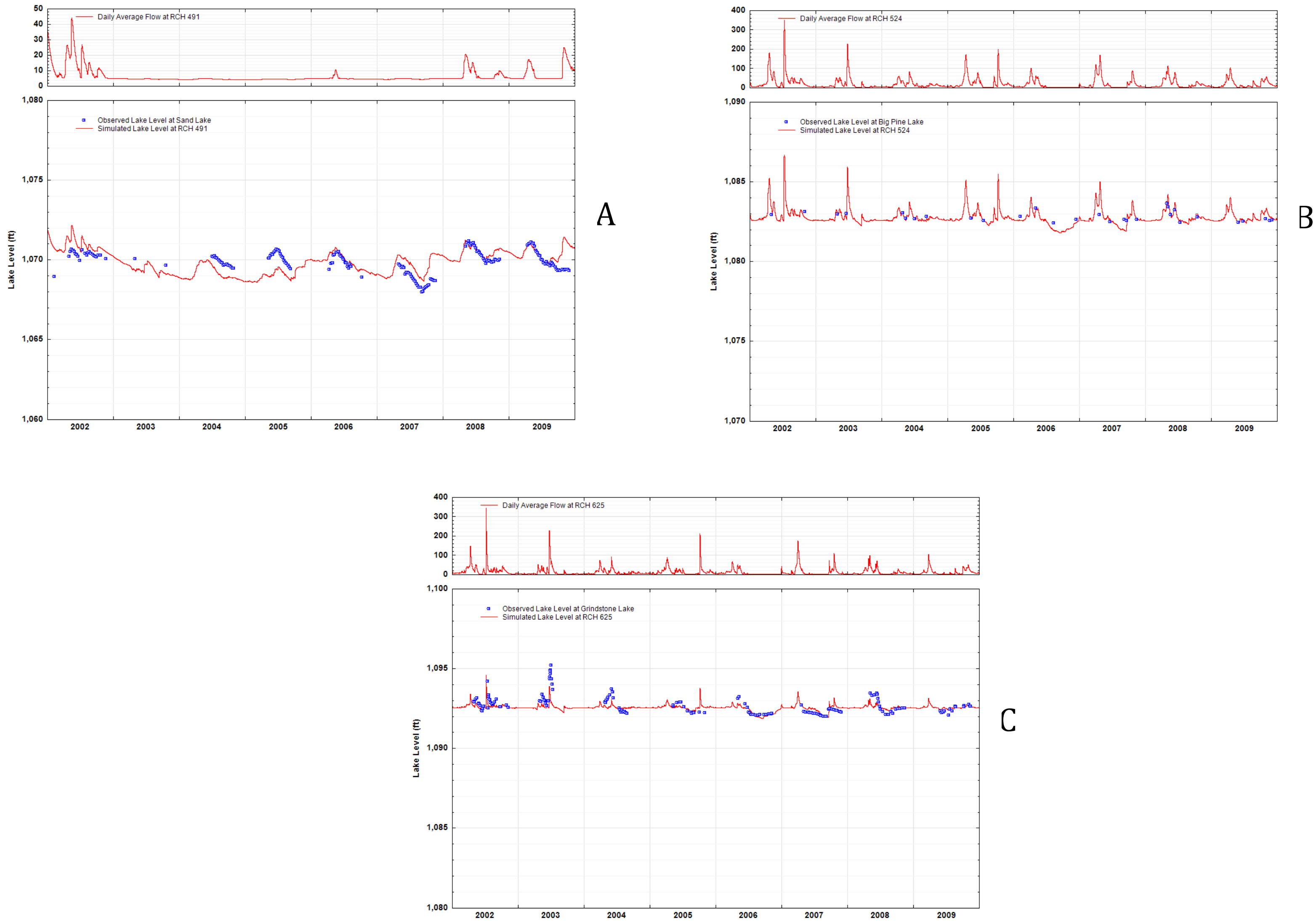


Figure 2-16. Simulated and Observed Lake Level Data at (a) Sand Lake, (b) Big Pine Lake, and (c) Grindstone Lake in the Kettle River Watershed.

Table 2-13. Water Balance Summary for the Kettle and the Upper St. Croix River Watersheds (Units in Inches)

Land Use	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetland	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed, Low Intensity	Developed, Medium Intensity	Watershed Total
Pervious Land Categories															
Area (acres)	72,305	383,632	95,718	299,119	15,823	50,796	14,160	97,555	5,267	9,235	7,628	33,323	1,966	652	1,087,178
Influx															
Rainfall	31.60	31.40	31.35	31.11	31.73	31.46	31.35	31.44	31.85	31.96	31.94	31.37	31.33	31.32	31.35
Runoff															
Surface	0.12	0.17	0.01	0.01	0.69	1.28	0.64	1.27	0.52	1.36	0.19	2.05	2.71	3.12	0.35
Interflow	1.45	1.63	0.49	0.47	2.86	2.85	2.72	2.83	2.62	2.93	4.42	2.21	2.41	2.53	1.45
Baseflow	8.27	8.24	8.42	8.52	8.56	7.95	8.45	7.82	8.96	7.76	7.71	7.96	6.93	6.35	8.27
Total	9.84	10.04	8.91	9.00	12.11	12.08	11.80	11.92	12.10	12.05	12.33	12.22	12.05	12.00	10.07
GW Inflow															
Deep	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Active	8.66	8.62	10.60	10.49	8.59	7.98	8.48	7.85	8.98	7.78	7.73	7.98	6.95	6.38	9.18
Evaporation															
Potential	29.99	29.07	29.48	28.91	30.45	29.56	30.51	30.23	30.26	30.88	30.01	30.05	30.29	30.38	29.35
Intercep St	6.03	6.14	5.68	5.86	5.43	5.60	5.46	5.56	5.38	5.48	5.44	5.26	5.35	5.37	5.88
Upper Zone	4.79	4.86	4.59	4.45	5.08	5.22	4.98	5.26	4.34	4.87	4.76	4.87	5.19	5.41	4.77
Lower Zone	10.07	9.54	9.54	9.40	8.69	8.17	8.68	8.30	9.66	9.22	9.07	8.67	8.39	8.20	9.30
Grnd Water	0.00	0.00	2.14	1.92	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.72
Baseflow	0.33	0.32	0.14	0.14	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.21
Total	**21.22**	**20.86**	**22.08**	**21.76**	**19.33**	**19.11**	**19.24**	**19.24**	**19.49**	**19.69**	**19.40**	**18.91**	**19.05**	**19.10**	**20.88**
Impervious Land Categories															
Area (acres)												680	218	351	1,249
Influx															
Rainfall												33.12	32.97	32.98	33.06
Runoff															
Surface												28.93	28.68	28.67	28.81
Evaporation															
Potential												29.9	30.1	30.2	30.0
Actual												4.19	4.29	4.31	4.24

3.0 SEDIMENT CALIBRATION AND VALIDATION

3.1 SEDIMENT TARGETS

Objective 7 of the HSPF watershed modeling for the Snake River, Kettle River, and Upper St. Croix River Watersheds project required defining the sources of sediment loads within the watersheds and conducting sediment calibration and validation. Defining the sources of the sediment loads within the watershed required the development of a sediment apportionment of various sources in the watershed (i.e., an assessment of how much [what percent] of the total sediment load at any point in the watershed is derived from upstream field and nonfield [i.e., instream] sources).

A study of historical sediment fluxes conducted by Kelley and Nater [2000], suggests that the sediment contribution in the Minnesota River Basin increased by approximately 12-fold in the last 160 years, and the increase can mostly be attributed to the modern cultivation of row crops and animal husbandry. A recent effort by Schottler et al. [2010] to apportion the sediment contributions using sediment fingerprinting techniques suggests that non-field sources contribute the majority of the sediment load. They determined that the non-field sources contribute 60–85 percent of the sediment erosion entering the Minnesota River. Non-field loads were greatest in the large and steeply incised Blue Earth-LeSueur Watershed. Schottler et al. [2010] also concluded that the rate of sediment erosion from non-field sources has accelerated in the last 100 years and attributed this increase in sediment loading to an increase in the erosive nature of rivers, which in turn can be attributed to the change in land use over the last couple of centuries. The Minnesota River Turbidity TMDL study estimated that 35 percent of the sediment load originates from fields, 30 percent from gullies/ravines, and 35 percent from bank and bluff erosion [Tetra Tech, 2009].

In an effort to quantify the relationship of land-use change to the increase in erosive rivers, Schottler et al. [2013] conducted a study of all the watersheds in the Upper Mississippi River Basin (UMRB), which included the watersheds in this study. The study concluded that the UMBR watersheds went through major land-use changes in the twentieth century, such that forests and wetlands were converted to agriculture areas or forage, and small grain crops were converted to soybeans and corn, which resulted in an increase of water yield and runoff ratio by as much as 200 percent. The increased water yield increases the erosive nature of the rivers, and the associated sediment contribution by bank and bluff erosion (i.e., non-field sources) also increases.

Crow Wing Watersheds were also studied by Schottler et al. [2013], and the change in water yield and the runoff ratio was not statistically significant in these watersheds; therefore; the non-field sources in the Crow Wing River Watersheds are presumably responsible for less than 50 percent of the sediment loading. Based on this information, prior modeling efforts in Minnesota, and discussions with MPCA staff, field sources in the Crow Wing River Watersheds presumably account for 80 percent, and nonfield sources presumably account for about 20 percent of the total sediment load. This information was used to guide the sediment calibration in the Crow Wing River Watersheds [AQUA TERRA Consultants, 2014b)].

Farther south, in the Sauk River Watershed, 55 percent of sediment loading was attributed to stream bed, bank, and gully [Reisinger and Love, 2012], and in the South Fork River Watershed, 45 percent of the sediment loading was attributed to stream bed, bank, and gully sources. However, in the North Crow River Watershed, 55 percent of sediment loading was attributed to stream bed, bank, and gully sources. Thus, in this region of Minnesota, field sources are generally thought to contribute about 45 percent to 55 percent of the total sediment load at the watershed outlets.

The Kettle River, and Upper St. Croix River Watersheds are mostly located in the Northern Lakes and Forests ecoregion. More than half of the Snake River Watershed is located in the Northern Central Hardwood Forests ecoregion, and the remainder of the watershed is in the Northern Lakes and Forests ecoregion (see Figure 3-1). The Minnesota River Basin (farther south) is located in the Western Corn Belt Plains ecoregion, and the Crow Wing Watersheds are mostly in the North Central Hardwood Forests ecoregion. The North Central Hardwood Forests and Northern Lakes and Forests ecoregions are mostly forested and are less arable than the Western Corn Belt Plains ecoregion, where as much as 80 percent of the area is used for agriculture. The area under agriculture increases in the southern portion of the North Central Hardwood Forests ecoregion.

According to the Ecological Classification System of Minnesota, the Snake River, Kettle River, and Upper St. Croix River Watersheds are in the Mille Lacs Uplands Subsection (see Figure 3-2). The Mille Lacs Uplands Subsection is mostly undeveloped, and agriculture is concentrated in the western and southern portions of the subsection, which includes the Snake River Watershed. Forestry and recreation are the most important land uses in most of the other areas of this subsection. The drainage network of this subsection is undeveloped and has extensive wetland areas.

The rapid watershed assessment report of the Snake River and Kettle River suggests that the main resource concerns in the watersheds are excessive erosion, woodland management, surface water quality, streambank stabilization, groundwater quality and quantity, and wetland management. In the Snake River Watershed, impaired waters is an additional resource concern; however, the cropland soil-erosion issue is however most evident in southern portions of this watershed. The development pressure in this watershed is moderate.

The National Resource Inventory (NRI) erosion estimates for sheet and rill erosion by water on cropland and pastureland in the Snake River Watershed increased by approximately 6.5 percent between 1982 and 1997, whereas sheet and rill erosion decreased for the Kettle River Watershed by 23.5 percent for the same reporting period.

A literature review and our field visit suggest that the rivers in the Snake River and Kettle River Watersheds are not as erosive as the rivers in the Minnesota River Basin. The sediment apportionment of 80 percent from field sources and 20 percent from non-field sources used for the Long Prairie, Redeye, and Crow Wing River Watersheds are likely to be applicable for the Snake, Kettle, and Upper St. Croix River Watersheds.

In regard to the sediment loading from field sources, the calibrated sediment loading rates from previous studies in the Crow Wing and Minnesota River Watersheds were reviewed and tabulated (Table 3-1). The loading rates from previous studies serve as a general criteria for calibration and may not be used as strict

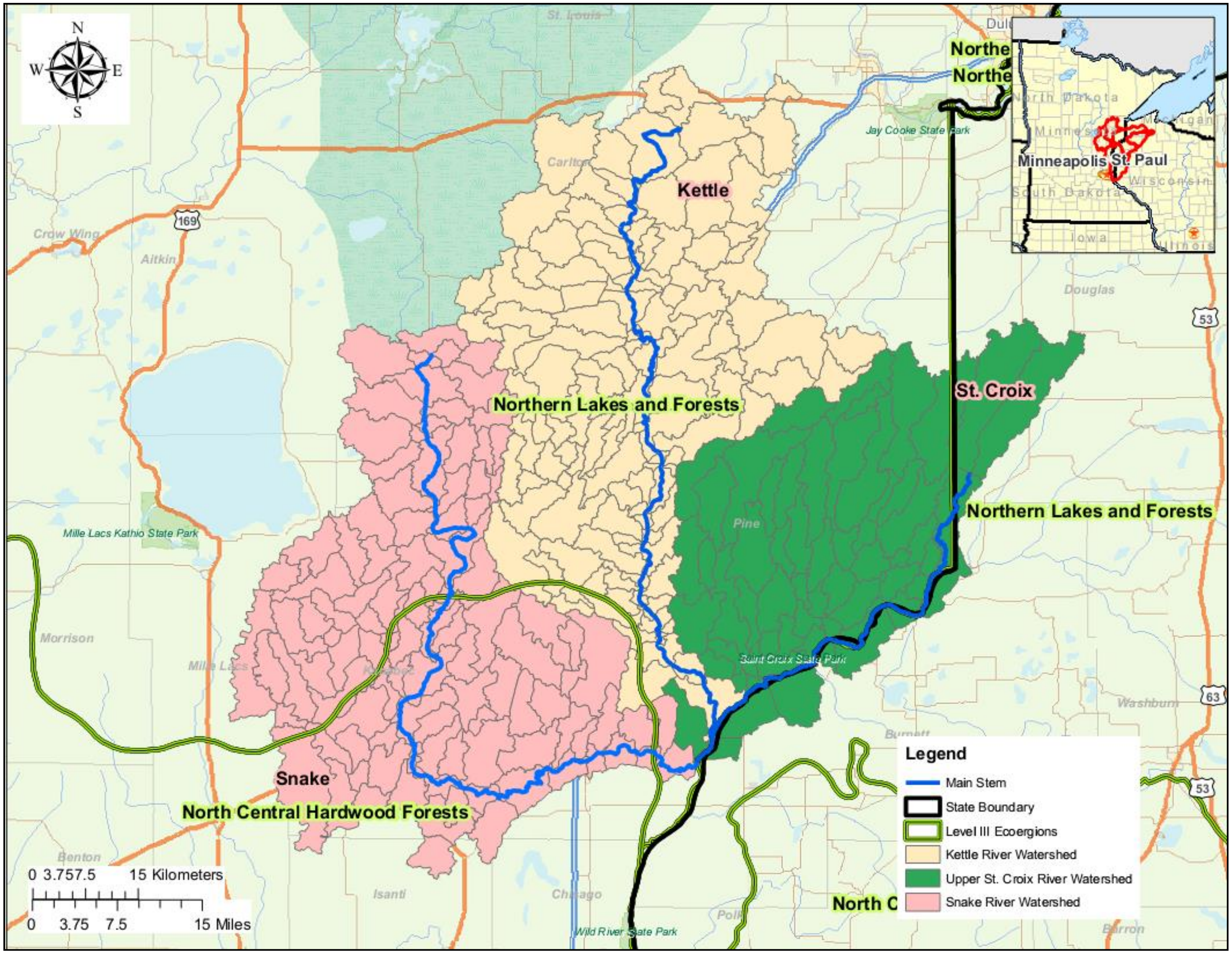


Figure 3-1. Location of the Snake, Kettle and Upper St. Croix River, and Long Prairie Watersheds and Level III Ecoregions.

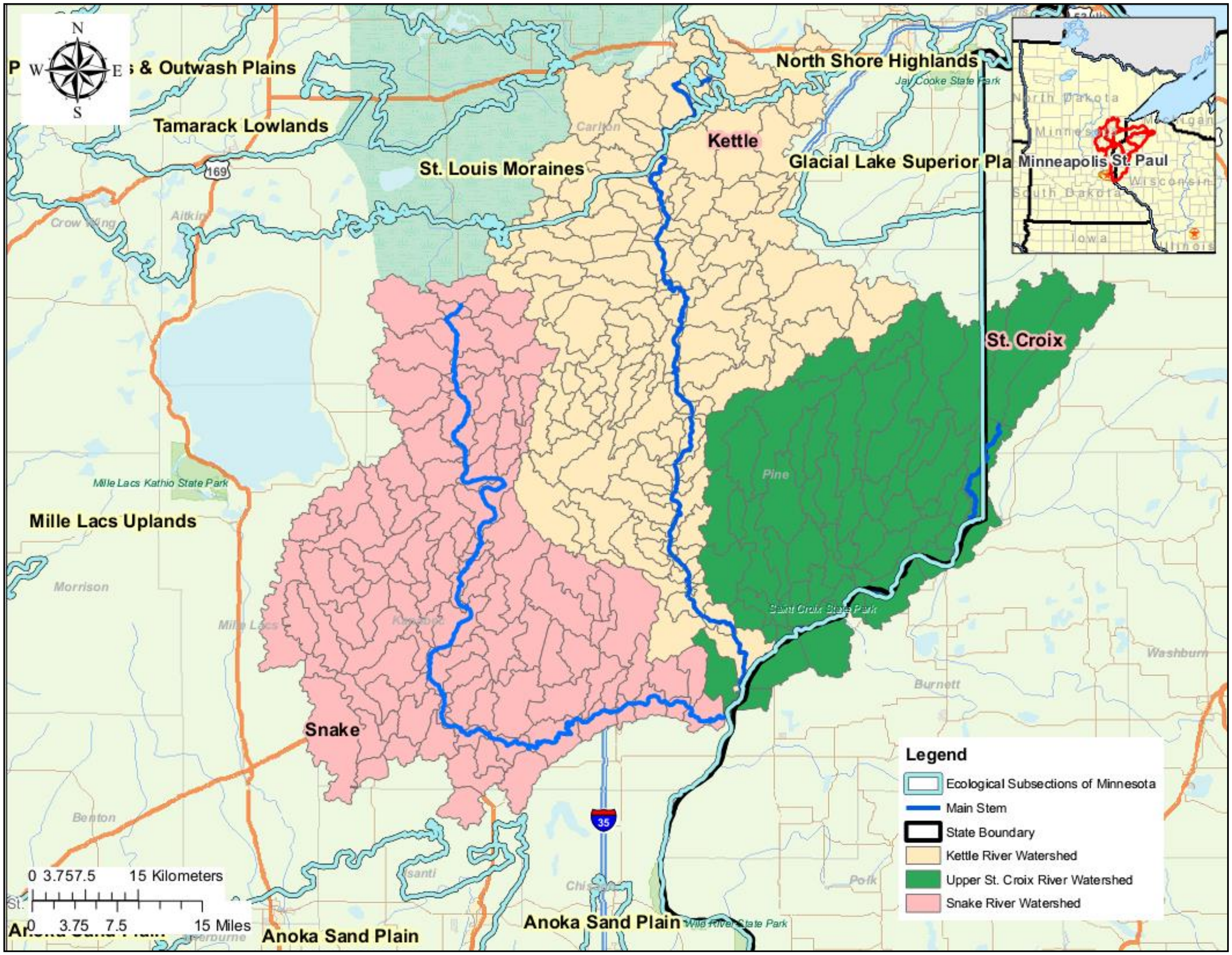


Figure 3-2. Location of the Snake, Kettle, and Upper St. Croix River Watersheds and Ecological Subsections of Minnesota.

Table 3-1. Calibrated Sediment Loading From Different Minnesota Watersheds in Tons per Acre per Year [AQUA TERRA Consultants, 2014b; EPA, 2005; Tetra Tech, 2009]

	Conservation Tillage	Conventional Tillage	Manured Cropland	Forest	High Till Cropland	Low Till Cropland	Grass/ Pasture	Urban	Impervious Areas
Crow Wing Watershed				0.012	0.042	0.019	0.007	0.013	0.148
Blue Earth River	0.330	0.396	0.166	0.076			0.137	0.235	
Chippewa	0.055	0.077	0.010	0.007			0.006	0.177	
Cottonwood	0.125	0.192	0.027	0.027			0.032	0.198	
Hawk	0.055	0.083	0.008	0.025			0.033	0.061	
Le Sueur	0.347	0.389	0.204	0.156			0.165	0.357	
Lower MN	0.067	0.146	0.052	0.032			0.034	0.201	
Middle MN	0.041	0.121	0.019	0.025			0.022	0.266	
Redwood	0.086	0.092	0.031	0.039			0.059	0.161	
Watonwan	0.066	0.126	0.009	0.032			0.034	0.215	
Yellow Medicine	0.093	0.101	0.027	0.040			0.068	0.094	
	Cropland/ Conservation	**Cropland/ Conventional**		**Forest**			**Grass/ Pasture**	**Urban**	**Impervious Areas**
Long Prairie	0.111			0.015			0.085	0.169	0.193
Redeye	0.105			0.006			0.060	0.158	0.190
Crow Wing	0.026			0.001			0.053	0.093	0.154
Recommended Target Range	0.10–0.50	0.20–2.0		0.01–0.10			0.02–0.50	0.05–0.25	0.05–0.30

limits. The loading rates are not only a function of land use but are also a function of soil type, slope, rainfall intensity and patterns, and data available for calibration. For example, grass/pasture areas are logically expected to have higher sediment loading rates than forested areas, but the EPA [2005] study suggests comparable values; this is likely because of a lack of sufficient spatially distributed data to allow accurate calibration of loading rates by land use. In these cases, the modeler must impose logical and expected differences in the modeled sediment loading rates by land use to provide a consistent, useful, and robust model.

Based on calibrated sediment loading rates reported in literature and professional judgment, recommended target ranges for sediment loading rates were prepared (see bottom rows in Table 3-1). The sediment loading rate is generally expected to increase from Forest → Pasture/Grassland → Urban → Cropland. During calibration, the sediment erosion model parameters are adjusted to produce the final rates within the target range, while producing TSS concentrations within the range of the observations at a downstream site. The calibration procedure involves adjustments to both the loading rates and the instream sediment transport parameters until overall agreement is reached.

3.2 SEDIMENT APPORTIONMENT CONCLUSION

A literature review of sediment apportionment in other Minnesota watersheds and their comparison with the Snake River, Kettle River, and Upper St. Croix River Watersheds suggest that the rivers in the Snake River, Kettle River, and Upper St. Croix River Watersheds may not be as erosive as the agricultural watersheds in southern MN, and may be similar to the rivers in the Crow Wing River Watershed. Assuming a sediment apportionment similar to the Crow Wing River Watersheds, 80 percent sediment from land surface and 20 percent sediment from river beds is appropriate for the project watersheds. The target sediment loading rates developed from multiple watershed studies in Minnesota (shown in Table 3-1) will be used as general guidance for calibrating sediment loads in the Snake River and STC-Kettle Watershed models.

3.3 SEDIMENT CALIBRATION

The sediment calibration and validation periods were the same as those for the hydrologic calibration (January 1, 2002, to December 31, 2009) and validation (January 1, 1995, to December 31, 2001). The sediment calibration process started with calculating the KRER (detachment coefficient dependent on soil properties) parameter for all of the PERLNDs. The KRER is similar to the *K* Factor in the Universal Soil Loss Equation, which is available in the soils data map provided by the Natural Resources Conservation Service (NRCS). As recommended in the Minnesota River Turbidity TMDL report [Tetra Tech, 2009], the JRER (detachment exponent dependent on soil properties) was set to 1.81. The remaining sediment parameters were adapted from the previous Crow Wing Watershed calibration report [AQUA TERRA Consultants, 2014b].

The sediment parameters KSER (coefficient for transport of detached sediment), AFFIX (the fraction by which detached sediment storage decreases each day as a result of soil compaction), and NVSI (the rate at which sediment enters detached storage from the atmosphere) were adjusted to match the overall sediment-loading rates from different land uses to the target loading rates compiled from studies of nearby areas. The sediment loading rates were tabulated and compared with the target loading rates for the model watersheds (Table 3-2 to Table 3-5). The loading rates from most of the land uses in different met segments are within the target range. The loading rates for developed land uses in some met segments are greater than the maximum range for pervious and impervious areas. Some of the higher loading rates from developed land uses caused by higher surface runoff from these land uses. Cropland-Drained shows lower loading rates than the target rates for many met segments. The surface sediment loading rates from Cropland-Drained is generally lower than other land uses because of lower surface runoff.

Once the sediment loading rates were calibrated, the instream transport of sediment, which is affected by stream hydraulics, was calibrated. The eroded sediment from land surface is assumed to be made of 55 percent silt, 40 percent clay, and 5 percent sand. This fractionation is the same as that used in the previous Crow Wing Study [AQUA TERRA Consultants, 2014b]. In HSPF, the transport of sand is commonly calculated as a power function of average velocity, whereas the transport of silt and clay depends upon the shear stress values calculated in the Hydraulic Behavior (HYDR) section of the Free-flowing Reach or Mixed Reservoir (RCHRES) module, and the input critical shear stress parameter values for deposition and scour. At every time step, the scour or deposition of sand is calculated based on transport capacity of flow, and the scour and deposition of silt and clay is calculated based on the relative magnitudes of the calculated shear stress compared to the input critical (threshold) shear stress parameters and erodibility rate.

The critical shear stresses of each reach are different for scour and deposition, as each reach has its own FTABLE that affects the hydraulics and therefore shear stress. Reasonable starting values for critical shear stress were generally chosen based on graphical analysis [Donigian and Love, 2007] of a few reaches. For the Snake River and STC-Kettle watershed models hourly shear stress values for each reach were output and different percentiles were calculated (95, 90, 10, and 5). For each reach, 10th and 5th percentiles of hourly shear stress values were used as critical shear stress values for deposition of silt and clay respectively, and 95th and 90th percentiles were used as critical shear stress values for scour of silt and clay, respectively.

The shear stress on a lake bed is calculated differently than the shear stress in streams; these values generally are very low and closer to zero. We do not expect any scouring to happen in the lake beds, so a critical shear stress value of 0.001pound per square foot (lb/ft^2) was assigned for all the lakes for silt and clay for deposition and scour.

Following the initial parameter assignment, the annual sediment scour and deposition as well as bed depth for each reach was output and analyzed. The bed depths are generally expected to stay stable for the period of simulation with no dramatic changes unless supported by a physical observation of aggrading or degrading stream reaches. The critical shear stresses for scour and deposition were adjusted until all of the reaches exhibited relatively stable behavior. Bed depth outputs of lakes increased slightly as expected because of deposition.

Based on the research described in Section 3.1, it was postulated that in the Snake River, Kettle River, and Upper St. Croix River Watersheds, about 80 percent of sediment erosion is contributed by land surfaces and 20 percent is contributed by streams. We calculated the total sediment erosion for each stream

Table 3-2. Sediment Loading Rates in Tons per Acre per Year From Pervious Land Uses and the Target Loading Rates for the Calibration Period for the Snake River Watershed

	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity
Target Rates/ Met Segments	0.05–0.15				0.20–1.00				0.10–1.50			0.15–0.50		
50	0.013	0.022	0.000	0.000	0.165	0.230	0.149	0.206	0.212	0.411	0.011	0.235	0.275	0.325
100	0.032	0.033	0.000	0.000	0.236	0.359	0.215	0.373	0.239	0.435	0.007	0.235	0.324	0.384
150	0.052	0.093	0.000	0.000	0.202	0.361	0.222	0.324	0.350	0.687	0.289	0.394	0.530	0.513
200	0.004	0.008	0.000	0.000	0.098	0.169	0.131	0.195	0.209	0.386	0.039	0.234	0.301	0.321
250	0.005	0.034	0.000	0.000	0.146	0.269	0.137	0.248	0.235	0.414	0.096	0.240	0.309	0.345
300	0.020	0.027	0.000	0.000	0.202	0.251	0.197	0.270	0.278	0.478	0.012	0.298	0.336	0.308
350	0.015	0.032	0.000	0.000	0.136	0.279	0.109	0.261	0.143	0.332	0.013	0.353	0.352	0.326
400	0.016	0.036	0.000	0.000	0.154	0.213	0.161	0.248	0.249	0.445	0.020	0.366	0.369	0.208
450	0.017	0.030	0.000	0.000	0.178	0.317	0.182	0.303	0.265	0.457	0.019	0.336	0.441	0.489
500	0.007	0.009	0.000	0.000	0.104	0.131	0.100	0.129	0.074	0.196	0.005	0.156	0.232	0.301
550	0.015	0.017	0.000	0.000	0.085	0.138	0.105	0.142	0.109	0.269	0.013	0.230	0.223	0.196
600	0.019	0.024	0.000	0.000	0.174	0.222	0.171	0.189	0.178	0.333	0.017	0.248	0.318	0.373
650	0.030	0.038	0.000	0.000	0.179	0.283	0.164	0.261	0.196	0.334	0.014	0.259	0.350	0.380
700	0.023	0.021	0.000	0.000	0.216	0.325	0.211	0.325	0.255	0.519	0.017	0.314	0.393	0.461
750	0.032	0.040	0.000	0.000	0.145	0.268	0.138	0.255	0.218	0.363	0.019	0.251	0.324	0.369
800	0.043	0.034	0.001	0.002	0.140	0.174	0.131	0.235	0.373	0.509	0.172	0.306	0.390	0.442
850	0.015	0.038	0.000	0.000	0.084	0.222	0.081	0.245	0.128	0.414	0.016	0.249	0.317	0.361
Mean	**0.021**	**0.032**	**0.000**	**0.000**	**0.156**	**0.248**	**0.153**	**0.248**	**0.218**	**0.411**	**0.046**	**0.277**	**0.340**	**0.359**
Maximum	**0.052**	**0.093**	**0.001**	**0.002**	**0.236**	**0.361**	**0.222**	**0.373**	**0.373**	**0.687**	**0.289**	**0.394**	**0.530**	**0.513**
Minimum	**0.004**	**0.008**	**0.000**	**0.000**	**0.084**	**0.131**	**0.081**	**0.129**	**0.074**	**0.196**	**0.005**	**0.156**	**0.223**	**0.196**

and calculated the percent contributed from land surfaces, point sources, and scour from the streams (Table 3-6). In these calculations, the watersheds draining to the lakes were ignored, as lakes are mostly sediment traps where no scour of bed sediment occurs. As evident from the results, the sediment contribution from the surface was more than 90 percent of the total sediment erosion. The sediment loading rates from most of the land uses is at the lower end of the target and, therefore, the only way to adjust the sediment apportionment from the streams is to increase the scour from the streams. The average slopes in the Snake River, Kettle River, and Upper St. Croix River Watersheds are lower than the neighboring Crow Wing River Watersheds, which are less developed than the neighboring watersheds. The rivers in these watersheds are, therefore, less erosive. Consultation with the MPCA staff also suggested that most of the streams in these watersheds are depositing and chances of excess scour from these streams is pretty low. As described later in the instream TSS calibration section, the simulated TSS concentration was mostly in the range of observed data or greater; therefore, any additional increase in scour from the streams was not considered.

Table 3-3. Sediment Loading Rates in Tons per Acre per Year From Impervious Land Uses and the Target Loading Rates for the Calibration Period for the Snake River Watershed

	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target Rates/ Met Segment	0.05–0.50		
50	0.149	0.264	0.345
100	0.154	0.289	0.375
150	0.157	0.295	0.400
200	0.149	0.276	0.366
250	0.159	0.300	0.380
300	0.155	0.286	0.375
350	0.161	0.303	0.407
400	0.158	0.302	0.415
450	0.152	0.284	0.384
500	0.151	0.275	0.364
550	0.148	0.271	0.369
600	0.149	0.281	0.383
650	0.161	0.293	0.386
700	0.146	0.286	0.400
750	0.148	0.279	0.376
800	0.152	0.282	0.372
850	0.152	0.282	0.382
Mean	**0.153**	**0.285**	**0.381**
Maximum	**0.161**	**0.303**	**0.415**
Minimum	**0.146**	**0.264**	**0.345**

Table 3-4. Sediment Loading Rates in Tons per Acre per Year From Pervious Land Uses and the Target Loading Rates for the Calibration Period for the Kettle and Upper St. Croix Watersheds

	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity
Target Rates/ Met Segments	0.05–0.15				0.20–1.00				0.10–1.50			0.15–0.50		
20	0.025	0.059	0.000	0.000	0.211	0.240	0.199	0.233	0.285	0.621	0.088	0.335	0.434	0.462
40	0.023	0.026	0.000	0.000	0.199	0.183	0.202	0.214	0.291	0.553	0.076	0.226	0.285	0.339
60	0.016	0.027	0.000	0.000	0.140	0.187	0.135	0.188	0.231	0.402	0.113	0.187	0.244	0.275
80	0.024	0.047	0.000	0.000	0.122	0.197	0.141	0.246	0.281	0.610	0.103	0.237	0.341	0.378
100	0.004	0.014	0.000	0.000	0.159	0.242	0.160	0.238	0.184	0.517	0.082	0.272	0.355	0.398
120	0.028	0.025	0.000	0.000	0.135	0.134	0.104	0.167	0.183	0.238	0.063	0.210	0.272	0.309
140	0.003	0.008	0.000	0.000	0.090	0.114	0.084	0.105	0.043	0.196	0.009	0.117	0.146	0.199
160	0.013	0.027	0.000	0.000	0.183	0.187	0.184	0.191	0.180	0.432	0.042	0.213	0.203	0.279
180	0.035	0.044	0.000	0.000	0.185	0.151	0.182	0.148	0.263	0.267	0.060	0.169	0.175	0.215
200	0.013	0.018	0.000	0.000	0.194	0.171	0.190	0.315	0.292	0.441	0.180	0.243	0.389	0.460
220	0.039	0.040	0.001	0.001	0.136	0.169	0.182	0.154	0.215	0.207	0.087	0.225		
240	0.001	0.008	0.000	0.000	0.064	0.121	0.064	0.118	0.083	0.179	0.012	0.120	0.187	0.162
260	0.021	0.029	0.000	0.000	0.088	0.178	0.081	0.185	0.146	0.288	0.010	0.181	0.242	0.230
280	0.009	0.021	0.000	0.000	0.119	0.218	0.116	0.179	0.110	0.263	0.045	0.149	0.217	0.257
300	0.003	0.010	0.000	0.000	0.094	0.149	0.084	0.096	0.086	0.173	0.010	0.130	0.187	0.217
320	0.004	0.006	0.000	0.000	0.066	0.171	0.097	0.160	0.080	0.312	0.012	0.141	0.174	0.256
340	0.024	0.015	0.000	0.000	0.145	0.095	0.140	0.078	0.346	0.145	0.051	0.172	0.233	0.222
360	0.001	0.001	0.000	0.000	0.050	0.086	0.040	0.082	0.041	0.148	0.005	0.083	0.141	0.179
380	0.012	0.017	0.000	0.000	0.176	0.091	0.174	0.083	0.120	0.100	0.019	0.228	0.311	0.362
400	0.031	0.026	0.000	0.000	0.190	0.160	0.172	0.139	0.103	0.314	0.018	0.225	0.328	0.402
420	0.014	0.029	0.000	0.000	0.112	0.154	0.154	0.145	0.273	0.494	0.097	0.204		
440	0.073	0.094	0.000	0.000	0.232	0.333	0.224	0.342	0.333	0.654	0.300	0.372	0.496	0.538
460	0.028	0.031	0.000	0.000	0.155	0.190	0.148	0.183	0.198	0.378	0.085	0.184	0.244	
480	0.024	0.044	0.000	0.000	0.192	0.245	0.191	0.252	0.297	0.751	0.133	0.289	0.382	0.434
500	0.020	0.038	0.000	0.000	0.197	0.180	0.190	0.242	0.332	0.674	0.080	0.273	0.348	0.313
Mean	0.020	0.028	0.000	0.000	0.145	0.174	0.146	0.179	0.200	0.374	0.071	0.207	0.274	0.306
Maximum	0.073	0.094	0.001	0.001	0.232	0.333	0.224	0.342	0.346	0.751	0.300	0.372	0.496	0.538
Minimum	0.001	0.001	0.000	0.000	0.050	0.086	0.040	0.078	0.041	0.100	0.005	0.083	0.141	0.162

Table 3-5. Sediment Loading Rates in Tons per Acre per Year From Impervious Land Uses and the Target Loading Rates for the Calibration Period for the Kettle River and Upper St. Croix Watersheds

	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target Rates/ Met Segment	0.05–0.50		
20	0.149	0.312	
40	0.150	0.302	0.410
60	0.159	0.279	0.348
80	0.168	0.325	0.438
100	0.158	0.314	0.423
120	0.157	0.277	0.350
140	0.149	0.303	0.410
160	0.146	0.299	0.417
180	0.145	0.283	0.378
200	0.166	0.308	0.418
220	0.153		
240	0.147	0.280	0.366
260	0.162	0.287	0.378
280	0.146	0.279	0.363
300	0.146	0.290	0.390
320	0.160	0.291	0.373
340	0.157	0.309	0.399
360	0.150	0.292	0.377
380	0.158	0.298	0.396
400	0.158	0.303	0.407
420	0.146		
440	0.152	0.300	0.414
460	0.163	0.309	
480	0.155	0.298	0.403
500	0.148	0.298	0.420
Mean	**0.154**	**0.297**	**0.394**
Maximum	**0.168**	**0.325**	**0.438**
Minimum	**0.145**	**0.277**	**0.348**

Table 3-6. Sediment Erosion From Land Surface and Streams in the Watersheds for the Calibration Period

Description	Snake River Model	STC-Kettle Model
Total sediment erosion in the watershed from the land surface (t/yr)	62,948	51,291
Total sediment erosion from land surfaces in watersheds with no lakes (t/yr)	57,763	48,764
Total point source contribution of sediments (t/yr)	16	31
Total point source contribution of sediments in watersheds with no lakes (t/yr)	16	31
Total deposition (+) / Scour (-) of sediment in all the lakes and streams (t/yr)	24,512	2,832
Total deposition (+) / Scour (-) in streams only (t/yr)	–1,462	–3,579
Fraction of sediment from land surfaces in watersheds with no lakes (%)	97.5	93.2
Fraction of sediment erosion from streams in watersheds with no lakes (%)	2.5	6.8

Following this step, the simulated TSS concentrations and observed TSS data were plotted for 25 locations in the Snake River Watershed and for 14 locations in the STC-Kettle Watershed model. Parameters affecting sediment loading from land surface and sediment transport were adjusted to obtain a good fit between observed and simulated data. The calibration process required returning to previous steps and readjusting parameters to match the outputs with the target sediment loading and sediment apportionment rates.

A selection of graphs is presented here for illustration (Figure 3-3 and Figure 3-4); the complete set of TSS graphs is provided in the accompanying model result files. The simulated TSS concentrations are generally in the range of observed TSS concentrations, except during the storm events. The observed TSS concentration measurements were not available during any of the storm events; therefore, assessing whether or not the model satisfactorily simulated the TSS concentration during the storm events is difficult. Note that the simulated and observed TSS concentrations are not expected to match exactly, as the observed data are collected at different depths and at different parts of the lake (generally near the outlet), whereas HSPF assumes the whole lake to be a well-mixed reservoir.

3.4 SEDIMENT VALIDATION

Sediment validation followed sediment calibration. As with hydrology, the sediment parameters from the calibrated model were used in the validation model. Sediment loading rate reports similar to the calibrated model were generated. The sediment loading rates of different land uses were generally in the target sediment loading rate range. The sediment loading rates for the validation period were marginally lower than the loading rates reported for the calibration period.

The sediment apportionment shows that nonpoint sources are responsible for about 90 percent of the total sediment erosion in the Snake Watershed model, and 88 percent of the total sediment erosion in the STC-Kettle model (Table 3-7). The sediment apportionment for the nonpoint sources for the validation period is also greater than the postulated sediment apportionment value of 80 percent.

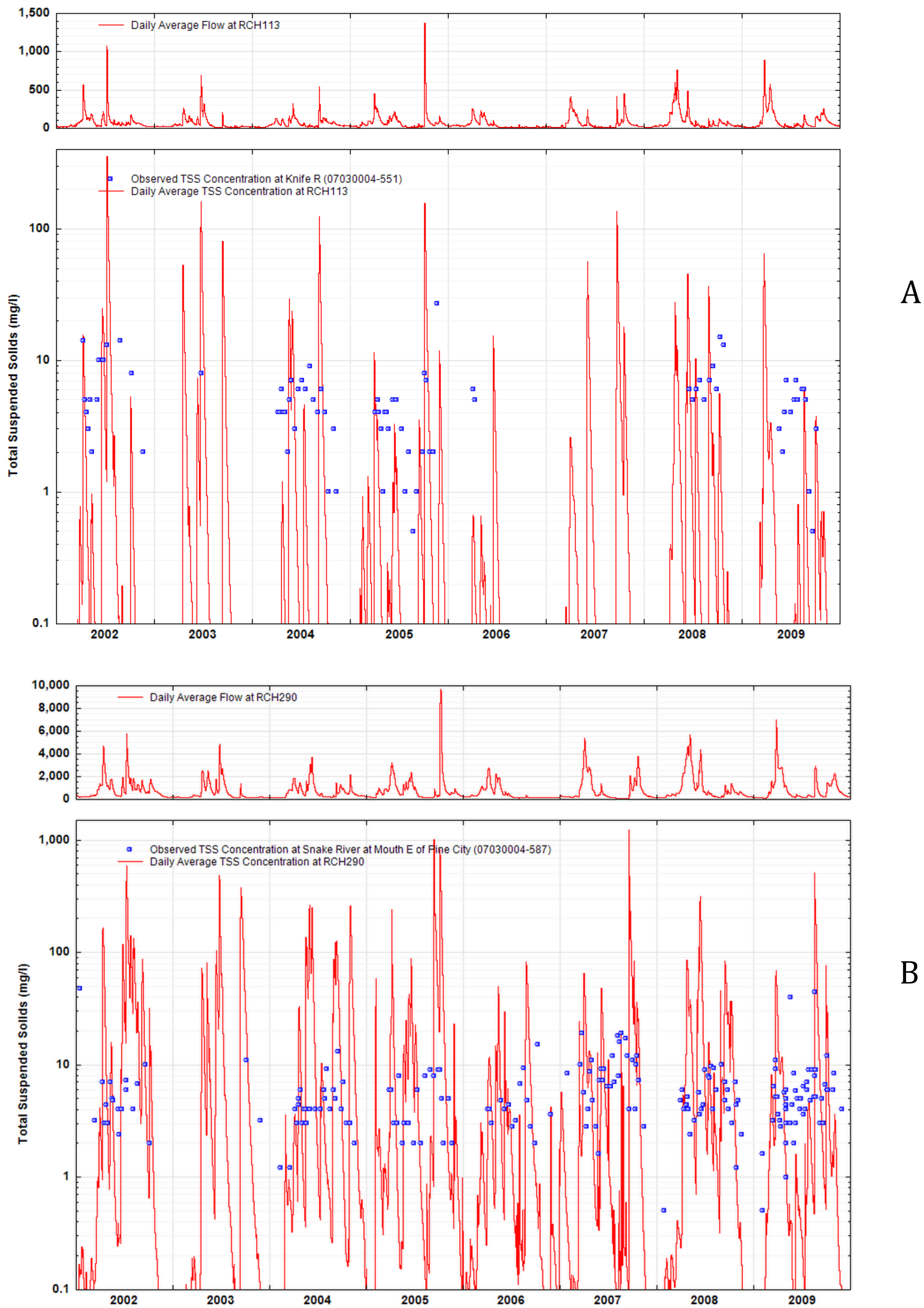


Figure 3-3. Observed and Simulated Total Suspended Solids Concentrations in the Snake River Watershed at (a) the Knife River Near the Knife Lake Outlet and (b) the Snake River Near the Snake River Watershed Outlet for the Calibration Period.

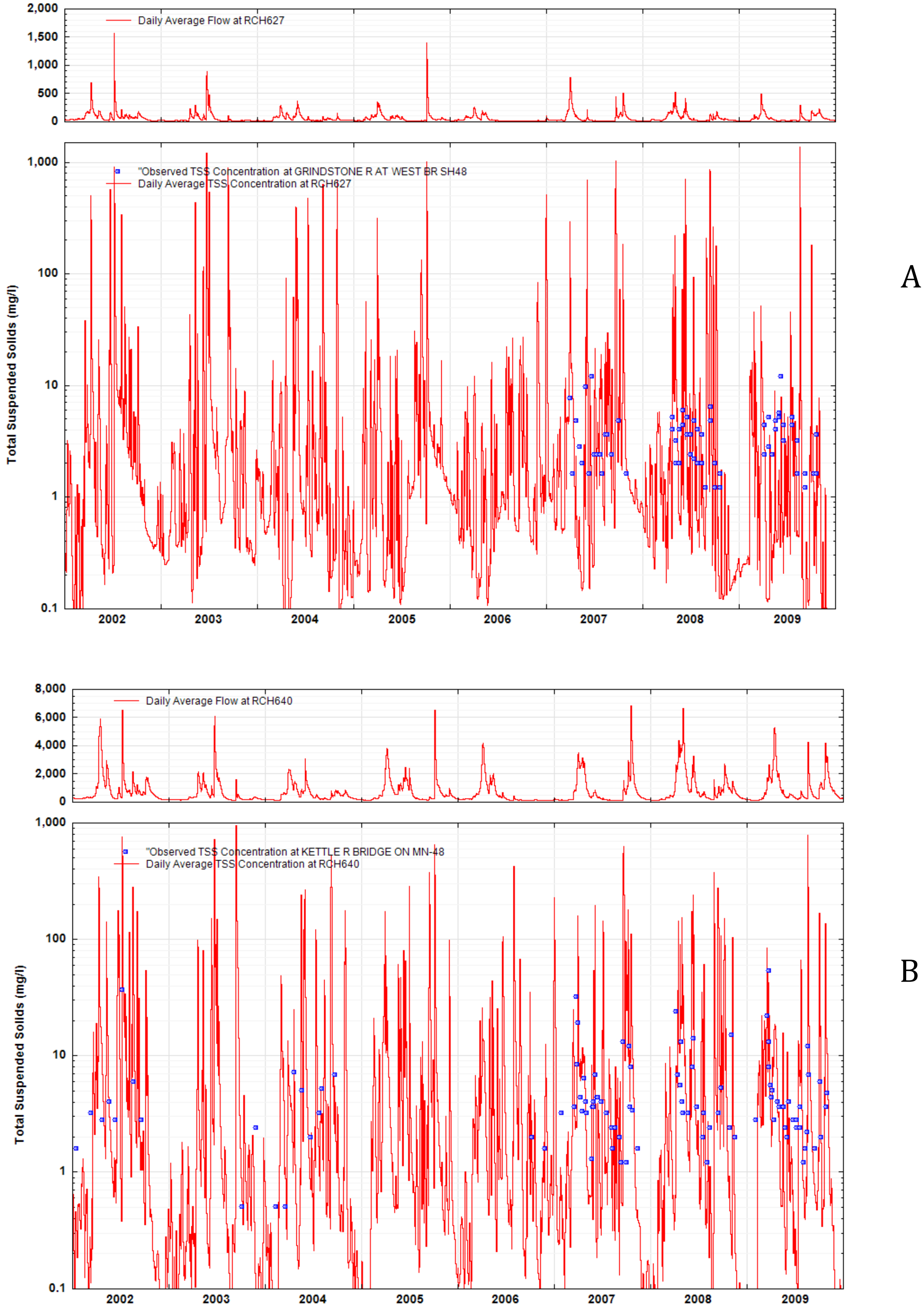


Figure 3-4. Observed and Simulated Total Suspended Solids Concentrations in the Kettle River Watershed at (a) the Grindstone River and (b) the Kettle River for the Calibration Period.

3.5 SEDIMENT VALIDATION

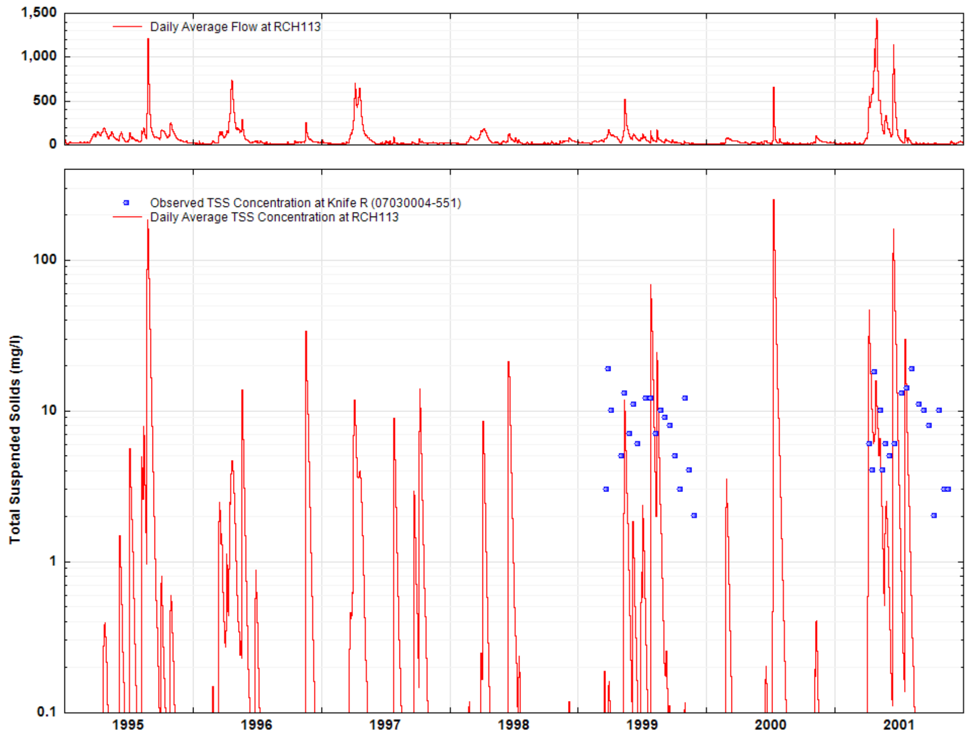
Sediment validation followed sediment calibration. As with hydrology, the sediment parameters from the calibrated model were used in the validation model. Sediment loading rate reports similar to the calibrated model were generated. The sediment loading rates of different land uses were generally in the target sediment loading rate range. The sediment loading rates for the validation period were marginally lower than the loading rates reported for the calibration period.

The sediment apportionment shows that nonpoint sources are responsible for about 90 percent of the total sediment erosion in the Snake Watershed model, and 88 percent of the total sediment erosion in the STC-Kettle model (Table 3-7). The sediment apportionment for the nonpoint sources for the validation period is also greater than the postulated sediment apportionment value of 80 percent.

Table 3-7. Sediment Erosion From Land Surface and Streams in the Watersheds for the Validation Period

	Snake River	Kettle and Upper St. Croix River
Total sediment erosion in the watershed from the land surface (t/yr)	38,421	43,406
Total sediment erosion from land surfaces in watersheds with no lakes (t/yr)	35,220	41,576
Total point source contribution of sediments (t/yr)	15	29
Total point source contribution of sediments in watersheds with no lakes (t/yr)	15	29
Total deposition (+) / scour (-) of sediment in all the lakes and streams (t/yr)	14,441	–333
Total Deposition (+) / Scour (-) in streams only (t/yr)	–4,022	–5,724
Fraction of sediment from land surfaces in watersheds with no lakes (%)	89.7	87.9
Fraction of sediment erosion from streams in watersheds with no lakes (%)	10.3	12.1

Simulated and observed TSS concentrations were plotted at several locations for the validation period (Figure 3-5). The simulated and observed TSS concentrations were in the same general range for the validation period (for e.g. Figure 3-5). Additional TSS graphs are provided in the accompanying deliverable folder. At this stage, the sediment simulation was considered acceptable and the calibration and validation processes of the remaining water quality constituents were performed.



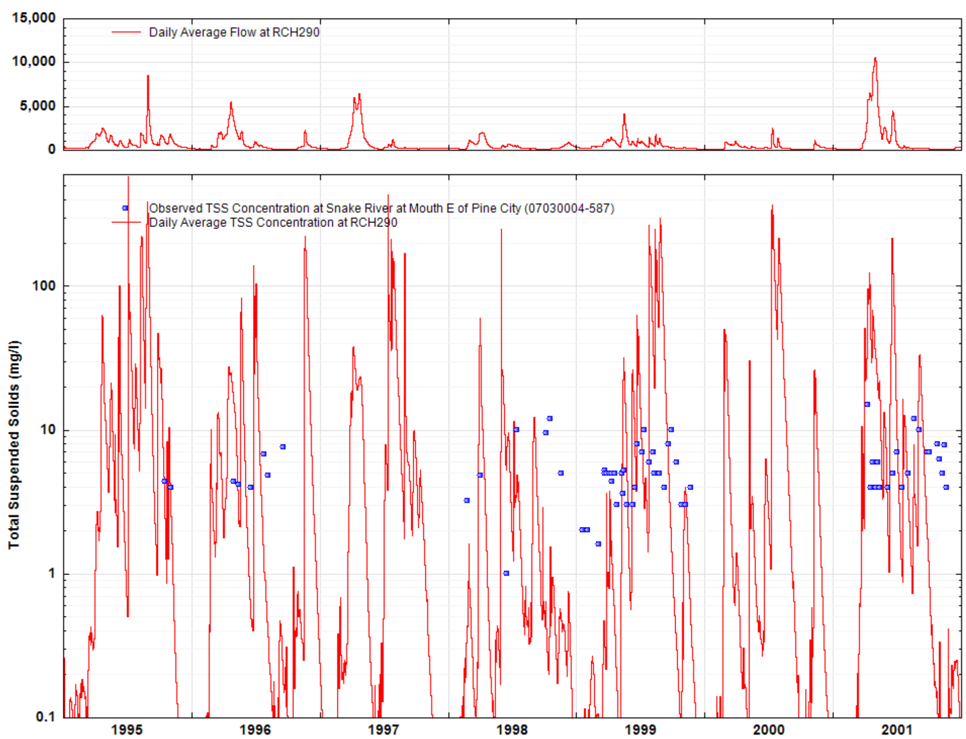


Figure 3-5. Observed and Simulated Total Suspended Solids Concentrations in Snake River Watershed at (a) the Knife River and (b) the Snake River Near the Outlet for the Validation Period.

4.0 NONPOINT LOADING RATE AND WATER QUALITY CALIBRATION AND VALIDATION

In the Upper St, Croix River (MN portion), Kettle River, and Snake River Watersheds, various forms of nitrogen (N) and phosphorus (P), their interactions and transformations, and other associated constituents (e.g., water temperature, DO, BOD, and Phytoplankton) were modeled. The sources of these nutrients include point sources, nonpoint sources, and atmospheric deposition. Nonpoint sources are calculated by considering accumulation, depletion/removal, and a first-order washoff rate of the available constituent removed by overland flow. Quantities of these constituents in the subsurface flow are simulated using monthly varying concentrations. The resulting nonpoint loadings, which are calculated separately for each land use in each met segment, are input to the reaches and lakes along with the point sources in order to simulate fate, transport, and delivery of the nutrients. Atmospheric deposition on all land surfaces provides a contribution to the nonpoint source load through the runoff/washoff process; deposition onto water surfaces represented in the model is also considered a direct input to the river systems.

Following the estimation of nutrient contributions from all land uses, the modeled hydrological and hydraulic processes are superimposed to provide transport mechanisms, and then water quality modeling is performed to allow adjustments in parameters and evaluation of sources as part of the calibration process. Nonpoint contributions from the watershed include the following constituents:

- Sediment
- Heat
- NO_3-N
- NH_4-N
- PO_4-P
- BOD/Organics, comprised of
  - Labile BOD
  - Refractory ON
  - Refractory OP
  - Refractory OC.

Sediment calibration and validation was discussed in the previous chapter. All of the remaining constituents are modeled within the stream module, along with algal components of phytoplankton and benthic algae. Water quality calibration is an iterative process; the model predictions are the integrated result of all the assumptions used in developing the model input and representing the model processes. Differences in model predictions and observations require the model user to reevaluate these assumptions, in terms of both the estimated model input and parameters and to consider the accuracy and uncertainty in the observations. Note that at present, water quality calibration is more an art than a science, especially for comprehensive simulations of nonpoint, point, and atmospheric sources and their impacts on water quality.

The time periods used for water quality calibration/validation were the same as those used for hydrologic calibration and validation. The following steps were performed for water quality calibration.

1. Estimate all model parameters, including land use specific accumulation and depletion/removal rates, washoff rates, and subsurface concentrations
2. Tabulate, analyze, and compare simulated nonpoint loadings with expected range of nonpoint loadings from each land use and adjust loading parameters as necessary
3. Calibrate instream water temperature
4. Compare simulated and observed instream concentrations at all the locations where data are available
5. Analyze the comparisons in steps 3 and 4 to determine appropriate instream and/or nonpoint parameter adjustments.

The primary instream water quality parameters adjusted were advection and settling rates for phytoplankton and refractory organics, settling rates for BOD, benthal release of BOD, NH_4-N, or PO_4-P with secondary changes to nitrification rates, and phytoplankton and benthic algae growth and respiration rates. Initial parameter values were obtained from the Crow Wing Watershed Study [AQUA TERRA Consultants, 2014b].

This section discusses each of the water quality constituents individually and presents the calibration and validation results.

4.1 WATER TEMPERATURE

Water temperature controls the instream reaction rates and also determines the saturation concentration of dissolved oxygen; therefore, temperature calibration is conducted before calibration of other water quality constituents. To model the instream water temperature, HSPF calculates the heat loadings to a stream reach from all sources and then performs a balance of the heat fluxes across the reach boundaries to arrive at the reach water temperature in each model time step. Heat sources/sinks to a reach include upstream or tributary reaches, nonpoint runoff, point sources, heat exchange with the atmosphere, and conduction from the streambed. Heat outputs from a reach include downstream advection, losses to the atmosphere, and conduction to the streambed.

Details on heat loading and water temperature simulation are available in the HSPF Manual [Bicknell et al., 2005]. To conduct temperature calibration, the soil temperature parameters are first adjusted as the heat content of the runoff is a function of the modeled soil temperatures in each soil layer. The monthly ASLT (Y intercept for surface layer temperature regression equation), BLST (slope for surface layer temperature regression equation), ULTP1 (intercept for upper layer temperature regression equation), ULTP2 (slope for upper layer temperature regression equation), and LGTP1 (monthly water temperature for lower zone and groundwater; interpolated for daily values between the first day of each month) were adjusted for each PERLND to improve the soil temperature simulation. After reasonable soil temperatures are attained, the instream parameters of monthly TGRND (bed/ground temperature), CFSAEX (fraction of RCHRES exposed to sun's radiation), KATRAD (longwave radiation coefficient), and KCOND (conduction-convection heat transport coefficient) were adjusted for each RCHRES in comparison with available stream-water temperature data.

Although water temperature data were available at a few locations in the watershed, the data were not dense enough to conduct a detailed statistical analysis. However, plotting the data at several locations provided a good indication of how well the model was performing in terms of water temperature simulation (Figure 4-1 and Figure 4-2). Recognize that the observed data represents a snapshot of time and a location, whereas simulated data are averaged for the whole day with the assumption that the entire water body (e.g., a lake or reach) is a well-mixed reservoir. The water temperature at Cross Lake was measured at multiple depths; therefore, multiple temperature values are displayed in Figure 4-1(a). This figure underscores the issue of difficulty in accurately mimicking the observed data.

Water temperature also exhibits significant diurnal variation (Figure 4-3), with as much as a 10 ºF variation in summers, whereas the observed data are mostly available for daytime, which makes mimicking observed data more difficult. However, the general trend and range of simulated water temperature matched very well with the observed data at all the 22 locations where data were available. Plots of observed data versus simulated values at the remaining locations for calibration and validation periods are available in the accompanying deliverable folder.

4.2 DISSOLVED OXYGEN

The DO concentration generally indicates the overall ecological wellbeing of streams and lakes. In relatively unpolluted waters, the sources and sinks of oxygen are in proper balance and the DO concentration remains close to saturation. However, when the water receives pollutants from different sources, this balance may be upset, populations of oxygen-consuming bacteria may increase, and the DO concentration may decrease. The DO concentration is affected by a combination of water temperature, reaeration, loading of oxygen-demanding wastes, sediment oxygen demand, production of algae, and respiration by algae. The calibration of DO, therefore, was an iterative process that included the calibration of other water quality parameters (e.g., phytoplankton, N, and P) in tandem. During calibration, parameters affecting the loading rates of BOD, N, and P (e.g., the accumulation rate, and monthly concentration of interflow and groundwater) were adjusted. Parameters affecting the release of nutrients from reach beds, nutrient transformation, growth and respiration of phytoplankton, and algae were also adjusted. The loading rates of BOD/organics from all the land uses are presented in Table 4-1 and Table 4-2. In general, the loading rates of BOD/organics were within the recommended target ranges.

The labile (or reactive) BOD in streams is 40 percent of the total BOD/Organics washed off the surface. The remaining 60 percent is refractory organics that include ON, OP, and OC. The observed data for BOD in streams was available only for three locations in the Snake River Watershed, and one location in the Kettle River Watershed. The density of the BOD data were also poor compared to other water quality constituents. Aside from adjusting the BOD loading rate, the BOD release rates from the RCHRES were also adjusted to improve the match between observed and simulated data. The comparison of observed and simulated data suggested satisfactory simulation of BOD (Figure 4-4).

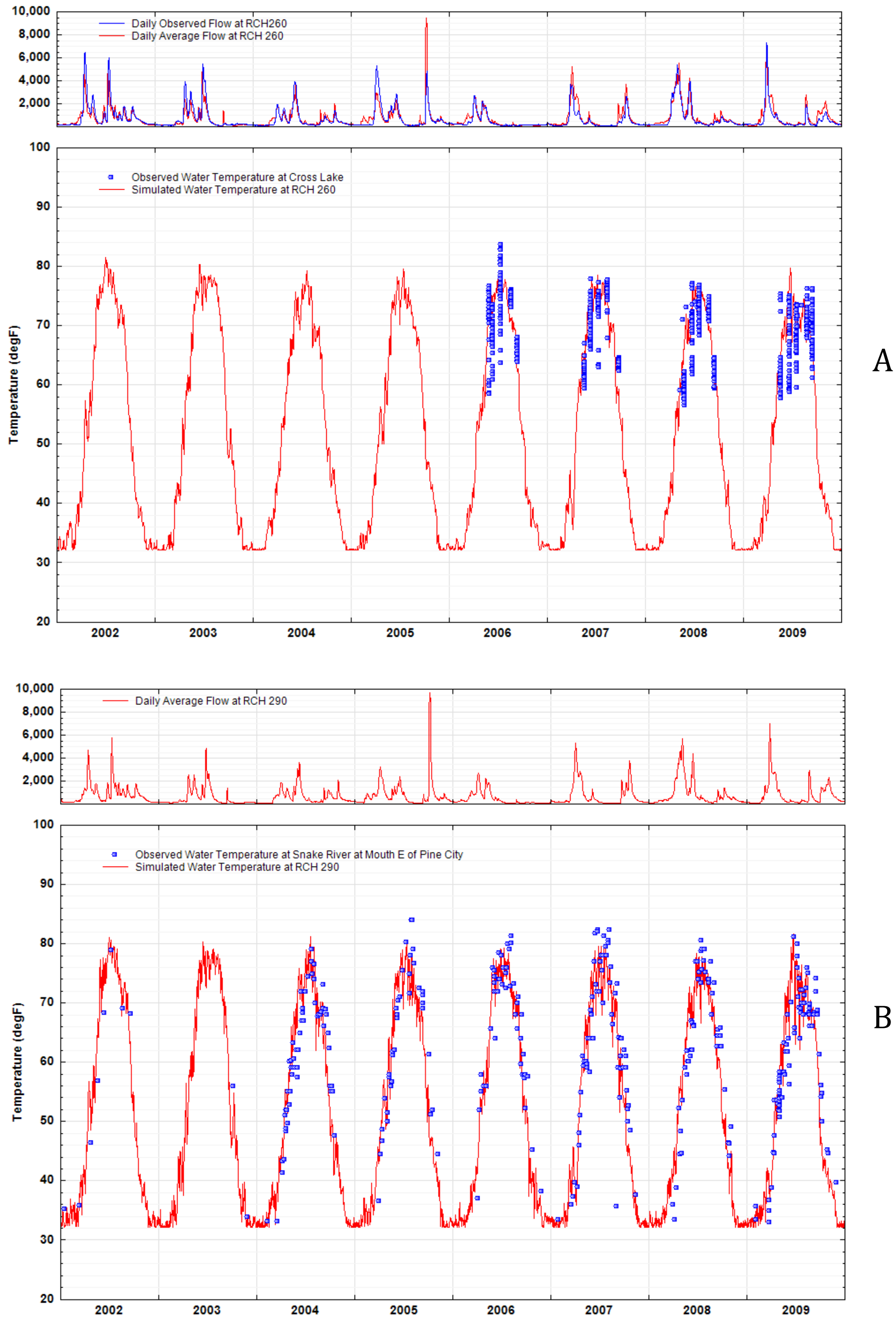


Figure 4-1. Observed and Daily Average Simulated Water Temperature at (a) Cross Lake on Snake River (RCH260) and (b) Snake River Watershed Outlet (RCH290).

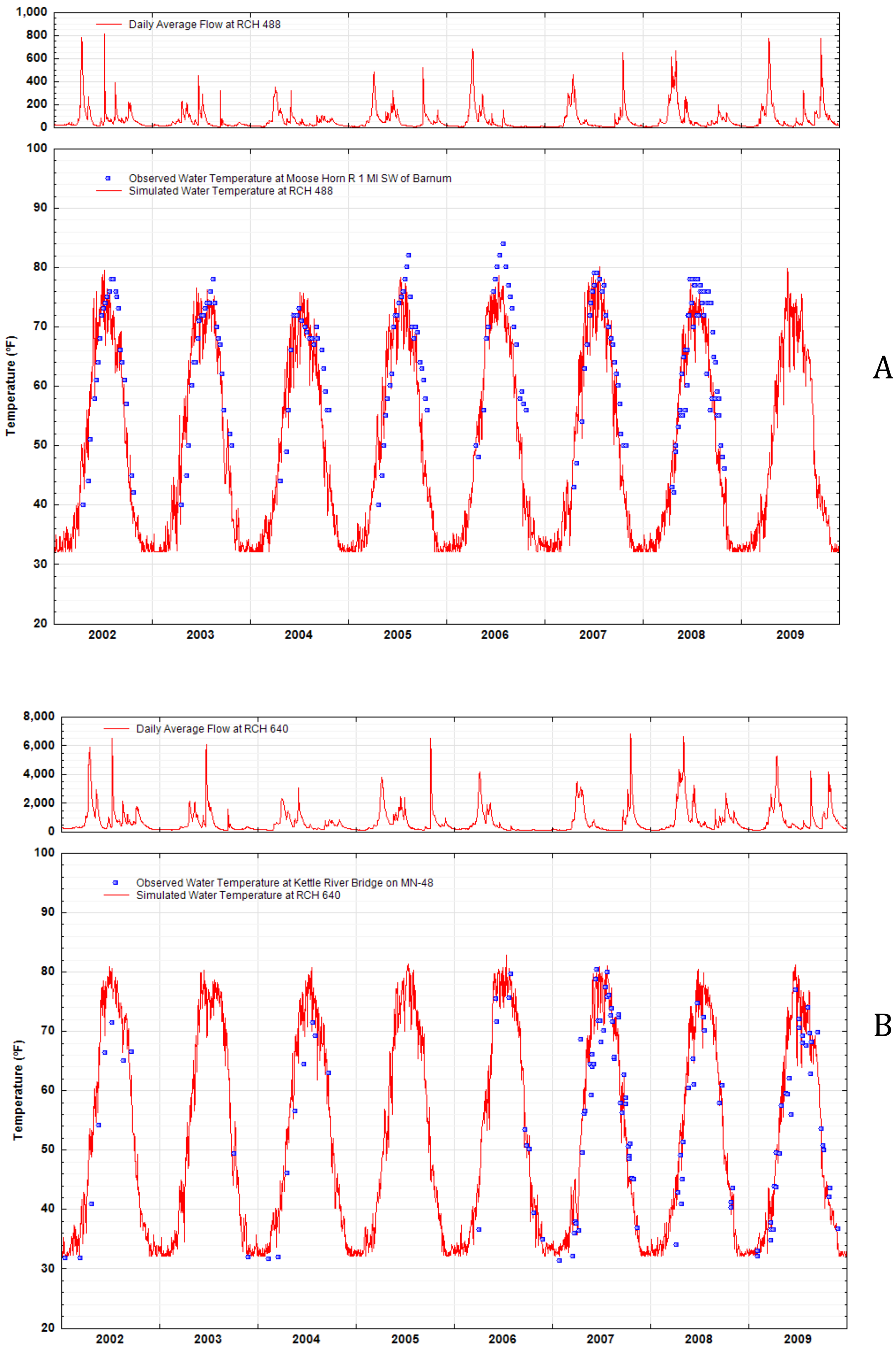


Figure 4-2. Observed and Daily Average Simulated Water Temperature at (a) Moose Horn River (RCH488) and (b) Kettle River Bridge on MN-48 (RCH640).

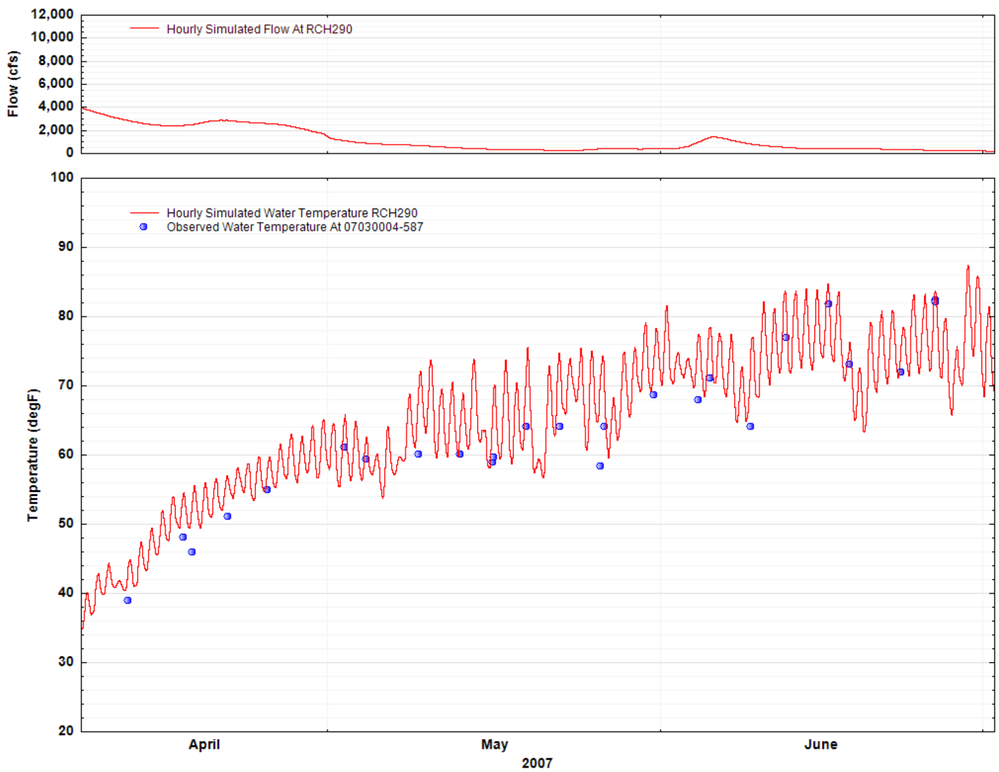


Figure 4-3. Observed and Hourly Simulated Water Temperature at Snake River Near Snake River Watershed Outlet (RCH290) for a Small Period.

The plots of observed and simulated DO, suggest that the model simulates DO in a reasonable and acceptable manner (Figure 4-5 and Figure 4-6). As evident in the DO plots for Cross Lake, DO was measured at multiple depths (anywhere from 0 feet to 6.5 feet (sometimes even 25 feet). Generally, DO decreased at deeper depths. HSPF, however, considers the reach as a complete mixed system, even for lakes, and cannot simulate DO at different depths. The model, however, generally simulates the range and overall trend of DO concentrations quite well. At some locations, the observed DO values have been reported to be greater than 15 milligrams per liter (mg/l) and sometimes lower than 1 mg/l (Figure 4-7). These outliers may occur at certain sections of the reaches depending on the local conditions and may be difficult to reproduce in a watershed-scale model.

4.3 NITROGEN

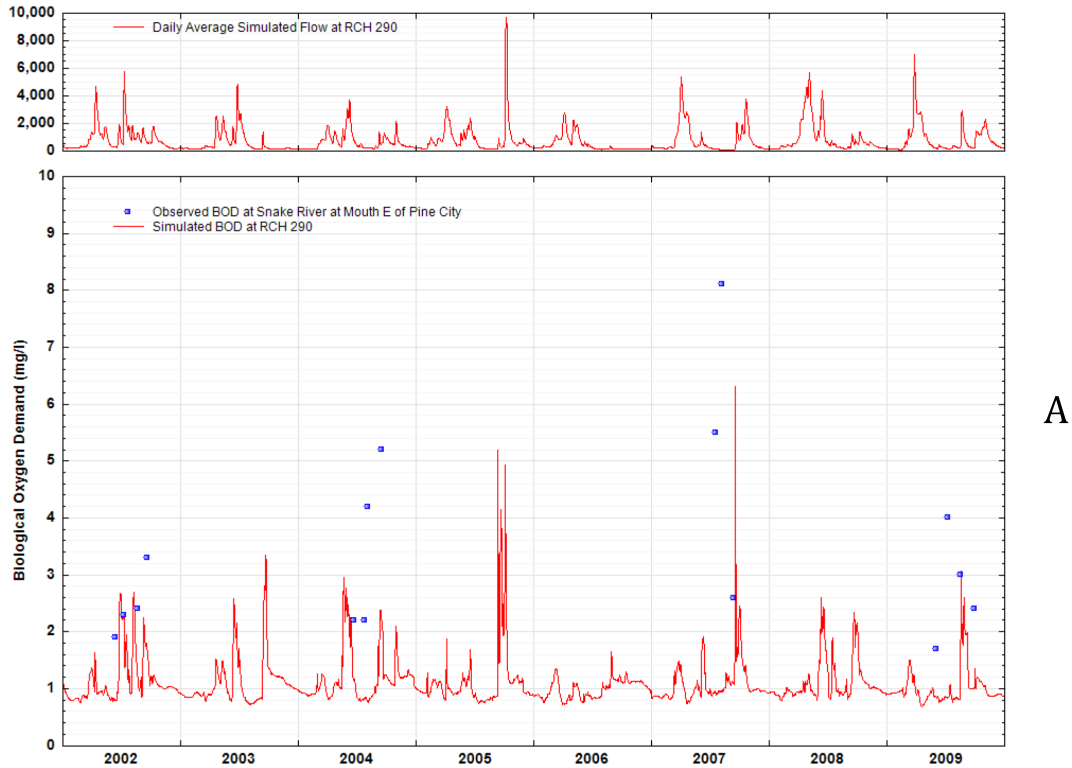
Nitrogen is simulated as NO_3-N and NH_4-N in terms of land surface and subsurface contributions to the stream reach. Organic N is calculated as a fraction (0.048) of the total BOD/Organics entering streams. NO_3-N, NH_4-N, and BOD are represented with buildup-washoff parameters on the land surface. The buildup and washoff of these constituents, as represented by the parameters Accumulation Rate (ACCUM) and Limiting Storage (SQOLIM) were adopted from the Minnesota River Turbidity TMDL report [Tetra Tech, 2002] for all the land uses, except agriculture, (as explained below) because there was no reason to believe that the loading of these nutrients in the Crow Wing River Watersheds would differ from other Minnesota River Watersheds.

Table 4-1. Loadings of Biochemical Oxygen Demand-Organics From Different Land Uses in the Snake River Watershed for the Calibration Period

MET Segments	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	2–10				5–70				5–50			5–15			3–20		
50	3.7	4.0	3.1	3.1	14.2	15.1	13.9	14.8	53.4	53.3	45.8	17.8	20.1	27.0	14.0	15.5	16.9
100	4.2	4.3	3.1	3.1	16.3	18.8	15.9	19.1	54.9	54.5	46.6	17.9	21.3	10.8	14.1	15.7	17.1
150	5.6	6.6	4.0	4.0	17.7	20.8	18.0	20.1	66.7	69.0	61.0	24.6	29.7	14.9	14.5	16.2	17.7
200	3.6	3.7	3.1	3.1	13.5	14.6	14.2	15.3	56.4	55.7	48.7	18.8	22.3	11.4	14.6	16.2	17.8
250	3.7	4.5	3.2	3.2	14.2	16.7	14.1	16.2	56.9	56.2	49.7	18.7	22.1	11.4	14.7	16.3	17.9
300	4.3	4.7	3.6	3.6	16.2	16.9	16.1	17.3	58.2	58.6	49.8	20.7	22.9	10.3	14.8	16.5	18.0
350	4.0	4.4	3.1	3.1	14.1	17.1	13.5	16.6	55.7	55.4	49.2	20.5	22.4	10.8	14.2	15.8	17.3
400	4.9	5.5	4.1	4.3	17.9	18.1	17.5	18.9	67.2	66.8	58.4	24.7	27.2	11.7	14.6	16.3	17.9
450	4.4	4.7	3.4	3.5	15.8	18.5	15.9	18.2	61.0	60.7	52.4	21.4	25.3	12.7	14.2	15.8	17.3
500	3.7	3.8	3.1	3.1	13.1	13.2	13.1	13.3	51.0	49.1	45.8	16.5	19.4	10.1	14.4	16.0	17.5
550	3.9	4.0	3.0	3.1	12.7	13.4	13.1	13.5	52.6	52.7	47.8	17.8	19.5	9.9	14.3	15.9	17.4
600	4.0	4.2	3.1	3.2	14.9	15.6	14.8	14.9	54.0	53.1	47.1	18.8	21.7	11.3	14.4	16.0	17.5
650	4.1	4.4	2.9	2.9	14.0	16.1	13.7	15.6	51.4	50.4	44.6	17.9	21.2	10.6	14.3	15.9	17.4
700	4.6	4.6	3.5	3.6	16.7	18.6	16.6	18.8	60.6	61.1	51.8	21.3	25.0	12.1	14.7	16.4	17.9
750	4.4	4.7	3.3	3.3	14.3	16.7	14.1	16.4	55.3	54.0	48.0	18.7	21.9	11.1	14.6	16.3	17.8
800	4.1	3.9	2.8	2.8	12.4	12.7	12.2	14.3	51.2	49.6	44.5	18.3	21.1	10.6	14.2	15.8	17.2
850	3.9	4.5	3.1	3.2	12.5	15.4	12.5	15.9	51.2	52.8	45.8	18.5	21.5	10.8	14.6	16.3	17.8
Mean	**4.2**	**4.5**	**3.3**	**3.3**	**14.7**	**16.4**	**14.7**	**16.4**	**56.3**	**56.0**	**49.2**	**19.6**	**22.6**	**12.2**	**14.4**	**16.1**	**17.6**
Maximum	**5.6**	**6.6**	**4.1**	**4.3**	**17.9**	**20.8**	**18.0**	**20.1**	**67.2**	**69.0**	**61.0**	**24.7**	**29.7**	**27.0**	**14.8**	**16.5**	**18.0**
Minimum	**3.6**	**3.7**	**2.8**	**2.8**	**12.4**	**12.7**	**12.2**	**13.3**	**51.0**	**49.1**	**44.5**	**16.5**	**19.4**	**9.9**	**14.0**	**15.5**	**16.9**

Table 4-2. Loadings of Biochemical Oxygen Demand-Organics From Different Land Uses in the Upper St. Croix and Kettle Watershed for the Calibration Period

MET Segments	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	2–10				5–70				5–50			5–15			3–20		
20	6.0	6.9	5.1	5.1	20.5	20.1	20.3	20.0	75.2	74.1	66.1	26.2	30.4	32.7	13.9	15.6	
40	5.2	5.3	4.3	4.3	18.0	17.3	18.1	17.9	67.6	67.3	58.7	21.7	25.6	28.3	14.0	15.7	17.2
60	3.7	4.0	3.0	3.0	13.0	13.8	12.9	13.8	52.7	52.1	47.3	16.2	19.0	21.2	14.1	15.6	17.0
80	5.0	5.6	4.1	4.1	15.9	16.7	16.3	18.1	67.4	67.9	59.0	21.5	25.6	28.5	14.3	16.0	17.5
100	5.0	5.3	4.5	4.5	17.6	19.0	17.7	19.1	71.2	71.6	64.7	23.7	27.2	29.5	14.2	15.9	17.4
120	4.4	4.3	3.3	3.3	13.8	13.1	13.2	14.3	55.2	50.7	49.7	18.2	21.4	23.6	15.1	16.8	18.4
140	4.4	4.6	4.1	4.1	15.4	15.5	15.3	15.3	61.5	58.6	55.7	19.2	22.0	25.3	14.0	15.6	17.1
160	4.7	5.1	4.1	4.1	17.5	16.9	17.5	17.0	64.1	63.5	57.0	20.9	22.8	25.5	14.0	15.5	17.0
180	5.2	5.5	4.0	4.0	16.9	15.5	16.8	15.5	65.2	58.6	57.0	18.9	20.9	23.5	14.4	16.0	17.6
200	3.9	4.1	3.0	3.0	15.4	14.2	15.3	17.7	59.1	56.1	52.8	18.8	24.2	26.4	14.2	15.6	17.0
220	4.8	4.8	3.5	3.5	14.2	14.1	15.1	13.7	58.7	53.5	52.5	19.6	22.4	24.9	14.7		
240	3.9	4.1	3.6	3.6	13.3	14.1	13.3	14.1	58.8	55.1	53.1	17.8	21.2	22.5	14.3	15.9	17.5
260	3.9	4.1	3.0	3.1	12.0	13.9	11.9	14.1	53.3	52.9	47.7	16.7	19.4	21.7	14.1	15.7	17.1
280	4.1	4.5	3.6	3.7	14.8	16.9	14.7	16.0	59.2	57.6	53.6	18.4	21.9	24.6	14.3	15.9	17.4
300	3.9	4.1	3.5	3.6	14.0	15.0	13.8	13.6	58.7	54.9	53.1	17.5	20.5	23.0	13.9	15.4	16.9
320	2.9	3.1	2.5	2.5	10.7	12.8	11.3	12.5	47.9	49.5	43.0	14.6	17.0	19.1	13.8	15.4	16.8
340	4.4	4.2	3.4	3.4	14.6	12.8	14.5	12.4	60.6	49.9	50.4	17.6	20.7	21.8	14.4	16.1	17.6
360	3.4	3.5	3.1	3.2	11.5	12.4	11.4	12.3	52.0	50.3	48.0	15.3	18.4	20.9	14.2	15.8	17.3
380	3.7	3.9	3.0	3.1	14.9	12.2	14.9	12.0	53.7	46.8	48.3	18.0	21.5	24.0	14.2	15.8	17.2
400	4.9	4.9	3.9	3.9	17.1	15.6	16.8	15.2	61.6	59.7	55.9	20.4	24.5	27.7	14.0	15.7	17.2
420	3.7	4.2	3.1	3.1	13.2	13.6	14.1	13.3	56.6	57.1	49.5	17.6	20.1	22.3	13.7		
440	6.4	7.0	4.5	4.5	19.0	20.9	18.8	21.1	71.6	71.8	66.0	25.5	30.8	33.9	13.8	15.4	16.9
460	4.3	4.4	3.2	3.2	14.3	14.8	14.2	14.6	56.6	56.2	50.4	17.7	20.7	24.0	14.7	16.4	
480	4.5	5.0	3.5	3.5	16.0	16.7	16.0	16.9	62.9	68.1	55.8	20.7	24.5	27.4	14.4	16.0	17.6
500	4.6	5.0	3.6	3.7	16.5	15.4	16.3	17.1	64.6	67.1	55.7	21.2	24.2	25.2	14.8	16.5	18.0
Mean	**4.4**	**4.7**	**3.6**	**3.6**	**15.2**	**15.3**	**15.2**	**15.5**	**60.6**	**58.8**	**54.0**	**19.4**	**22.7**	**25.1**	**14.2**	**15.8**	**16.5**
Maximum	**6.4**	**7.0**	**5.1**	**5.1**	**20.5**	**20.9**	**20.3**	**21.1**	**75.2**	**74.1**	**66.1**	**26.2**	**30.8**	**33.9**	**15.1**	**16.8**	**18.4**
Minimum	**2.9**	**3.1**	**2.5**	**2.5**	**10.7**	**12.2**	**11.3**	**12.0**	**47.9**	**46.8**	**43.0**	**14.6**	**17.0**	**19.1**	**13.7**	**15.4**	**16.8**



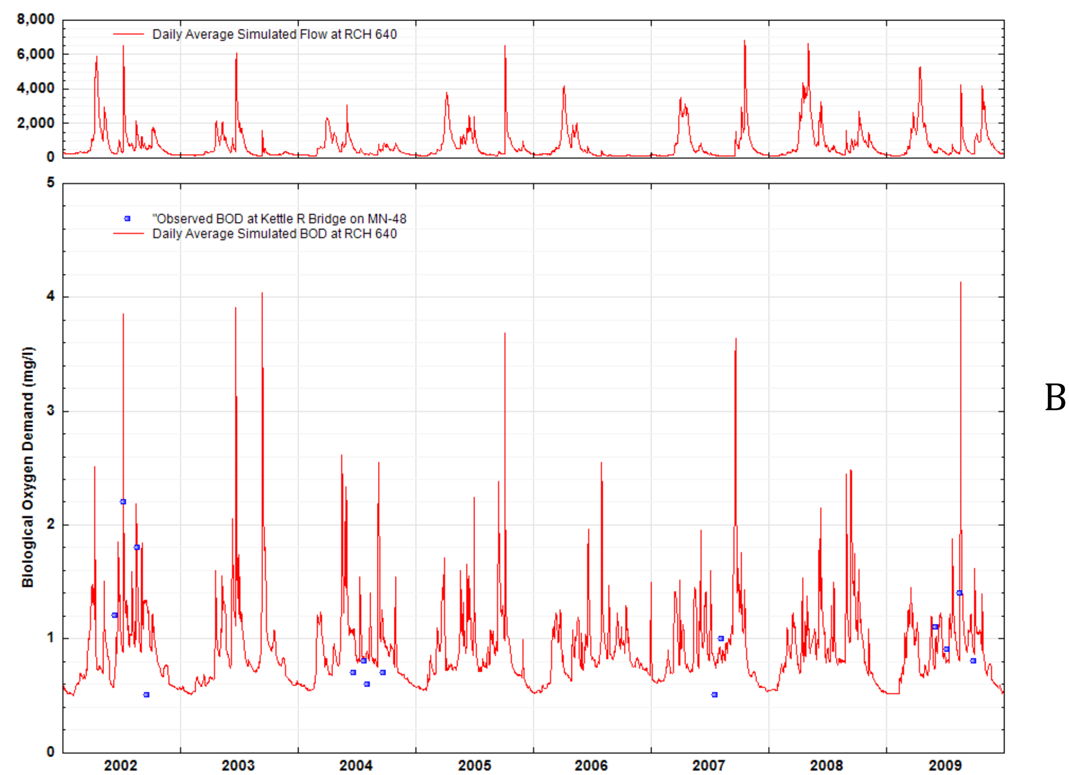
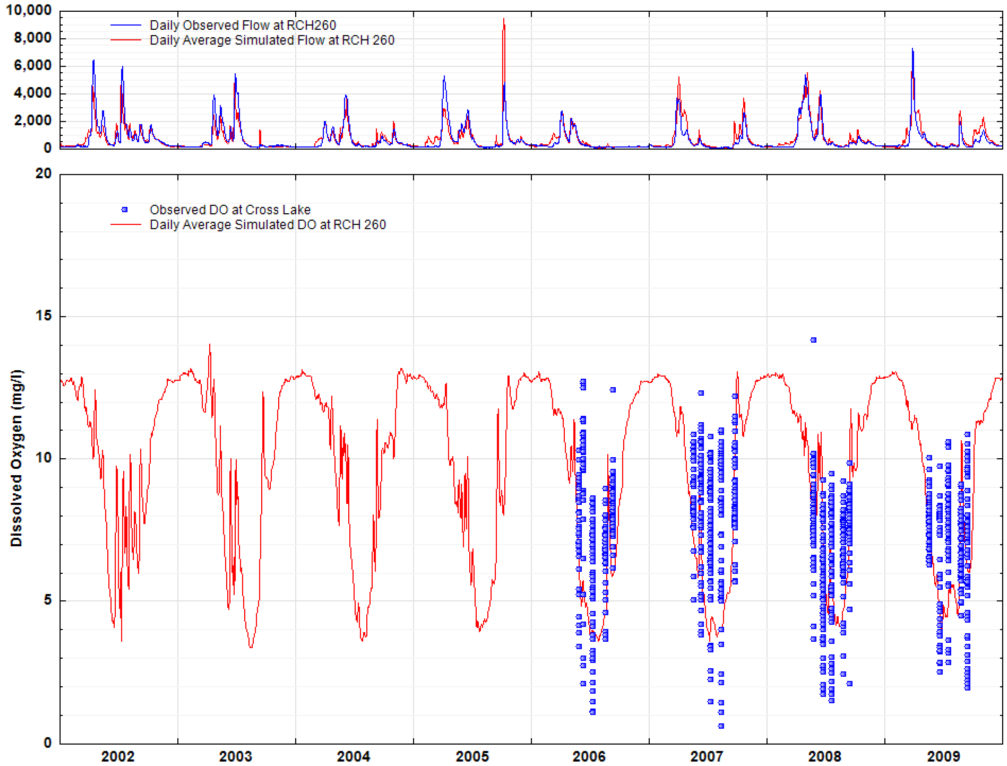


Figure 4-4. Observed and Daily Average Simulated Biological Oxygen Demand at (a) Snake River Watershed Outlet (RCH290) and (b) Kettle River Bridge on MN-48 (RCH 640).



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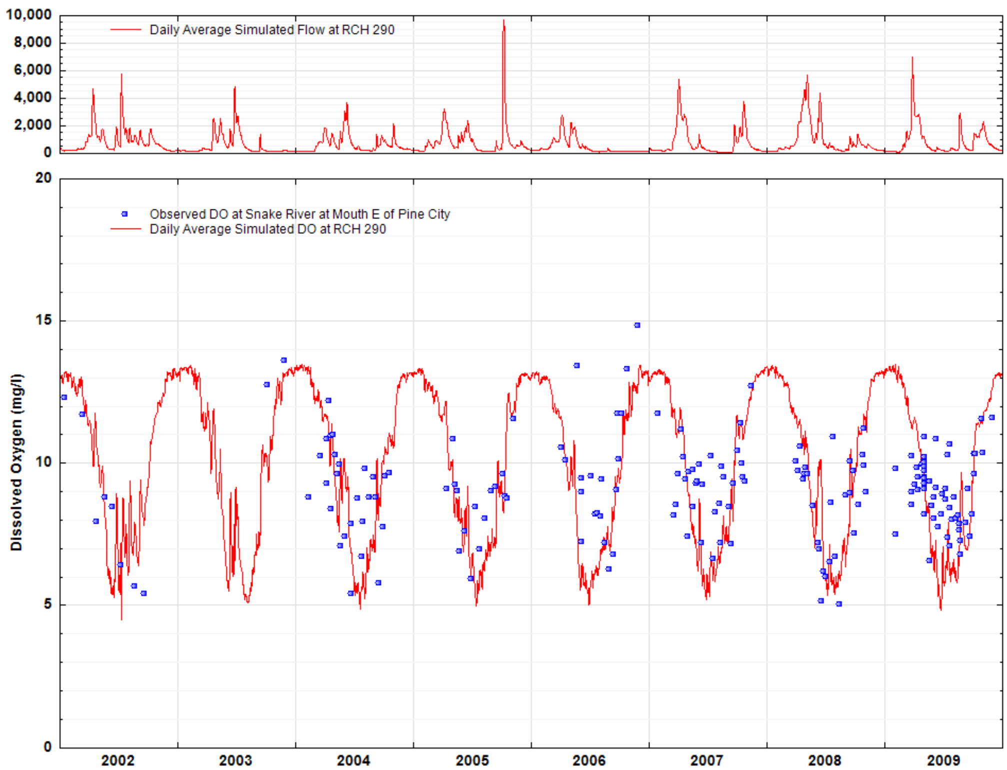

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Figure 4-5. Observed and Daily Average Simulated Water Temperature at (a) Cross Lake on Snake River (RCH260) and (b) Snake River Watershed Outlet (RCH290).

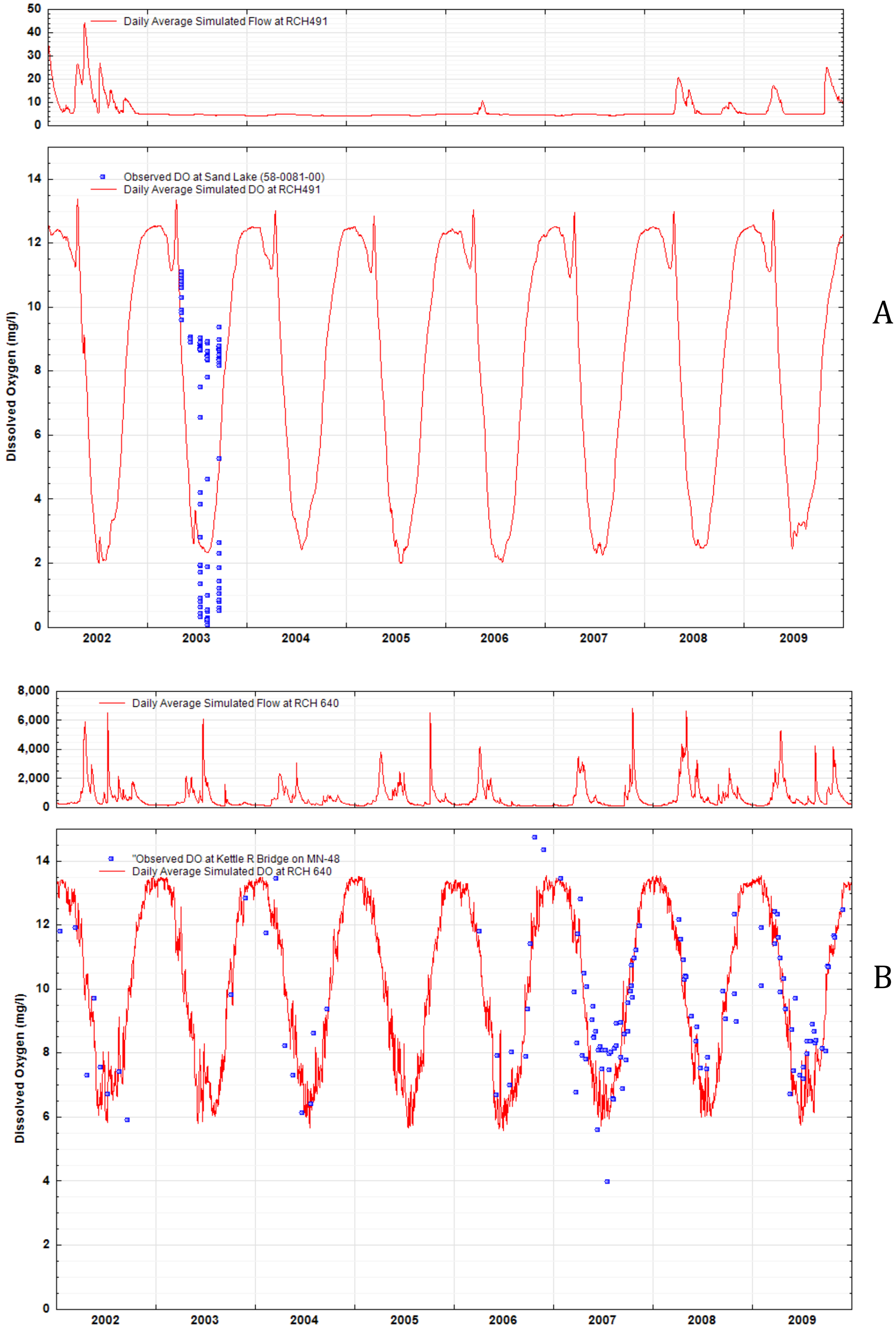


Figure 4-6. Observed and Daily Average Simulated Dissolved Oxygen at (a) Sand Lake (RCH491) and (b) Kettle River Bridge on MN-48 (RCH640).

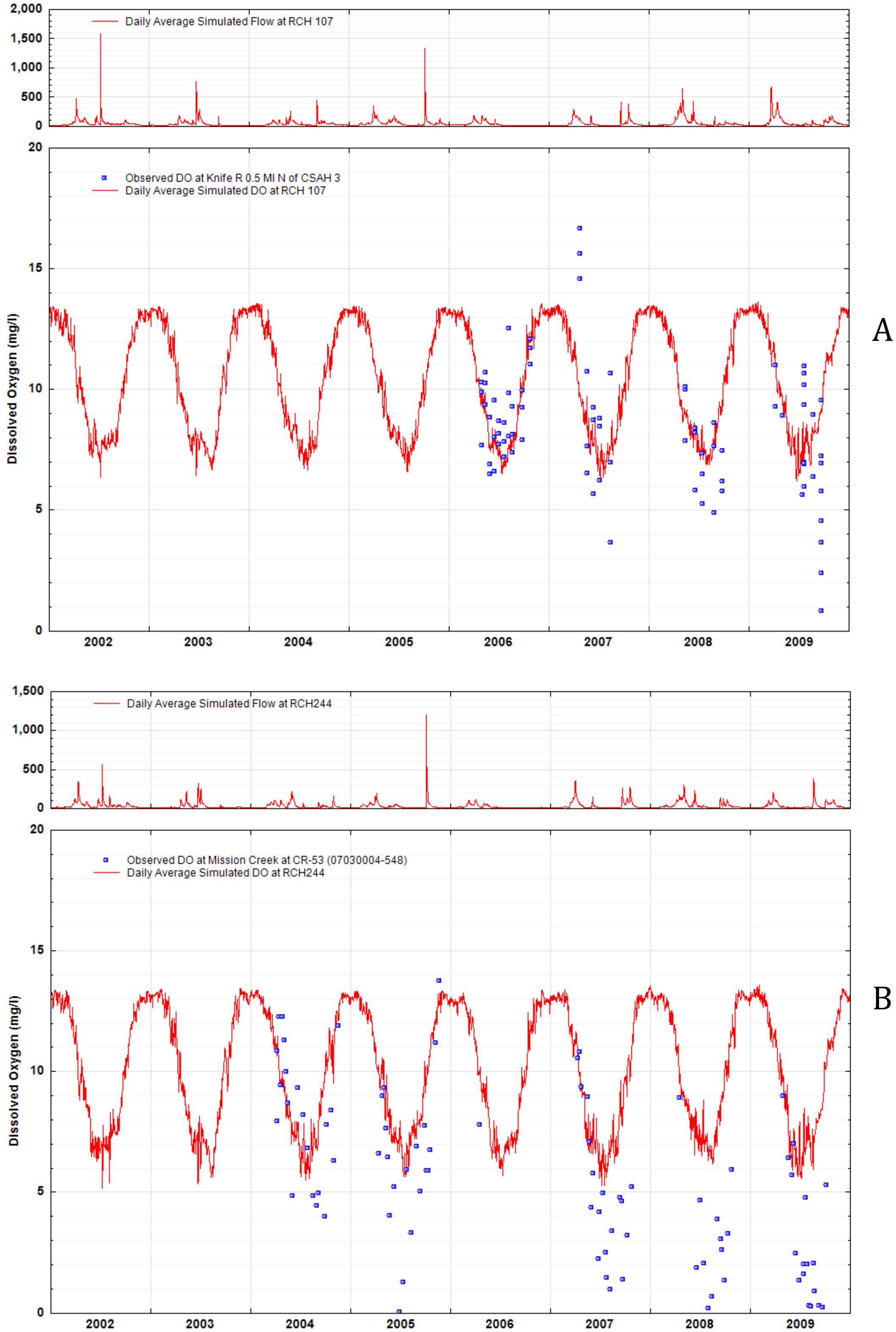


Figure 4-7. Observed and Daily Average Simulated Dissolved Oxygen at (a) Knife River (RCH107) and (b) Mission Creek at CR-53 (RCH244).

The ACCUM and SQOLIM parameters for agricultural areas were calculated in the Minnesota River TMDL based on the type of tillage (conventional and conservation) and manure application. In the Upper St. Croix River, Kettle River, and Snake River Watersheds, no evidence of conservation tillage was found [Chuck Regan, personal communication, August, 2015]; therefore, the entire agricultural area was considered under conventional tillage and under manure application if enough manure was available in the area.

Manure availability was estimated based on the number of animal units in each model segment of the three watersheds. A GIS file obtained from MPCA provided the locations of feedlots, type of animals, and number of animal units in each watershed (Figure 4-8). Approximately 86 of 282 feedlots had less than 50 animal units and composed approximately 5 percent of total animal units in the three project watersheds. These smaller feedlots were ignored in the manure-application estimation to cropland and pastureland areas to simplify the calculation. Adapting from previous studies, an average animal-manure-application area per animal unit was assumed at 1.29623 acres/animal unit Nick Gervino (2002). The number of acres on which animal manure was applied was calculated by multiplying the number of animal units in each model segment by the 1.29623 acres/animal unit factor. The resulting acreage was then compared with the total cropland area in each model segment. A weighted average of ACCUM and SQOLIM based on ACCUM and SQOLIM rates for conventional tillage and manured land as estimated by Tetra Tech [2002] was calculated (e.g., Table 4-3). If the total cropland area was less than the area on which manure could be applied to (11 out of 42 met segments), the ACCUM rate for manured land was used, and the ACCUM rate for Pasture areas was doubled assuming that the remaining manure will be applied to pasture areas. Similar calculations were performed for NH_4-N, and PO_4-P.

During water quality calibration, the concentration of NO_3-N, and NH_4-N in interflow and groundwater were reduced for all the land uses to match the observed data. The ACCUM and SQOLIM parameters were also adjusted to reflect the differences in level of urban-area development. Overall, loading of NO_3-N, and NH_4-N, and total N are presented in Table 4-4 to Table 4-9 for the Snake River Watershed, and STC-Kettle models. The total N loading from surface includes NO_3-N, NH_4-N, and refractory and labile portions of ON. The loading of ON from the surface to RCHRES is calculated as a portion of BOD/Organics. In the Snake River, and STC-Kettle models, refractory ON is 4.8 percent of the total BOD/Organics simulated on the surface, and labile ON is 0.2 percent of the total BOD/Organics simulated on the surface. Partitioning fractions of the BOD/Organics to labile and refractory ON were adopted from similar studies conducted in MN watersheds [AQUA TERRA Consultants, 2005].

The loading rate tables (Table 4-4 to Table 4-9) also show the proposed target loading rates for the mid-western United States [AQUA TERRA Consultants, 2015b]. Most of the loading rates are within the target range or at the lower end of the target range. Some loadings are not in the proposed ranges as the loadings had to be adjusted during the instream calibration to match the observed water quality data.

The effective load of total N in different parts of the watershed (Table 4-10 and Table 4-11) was calculated using HSPEXP+ [Mishra et al., 2015]. The load of total N at the outlet of Snake River is approximately 50 percent greater than the load of total N at the outlet of Upper St. Croix River that includes Kettle River, even though the total area modeled in STC-Kettle Watershed model is 76 percent greater than the area of

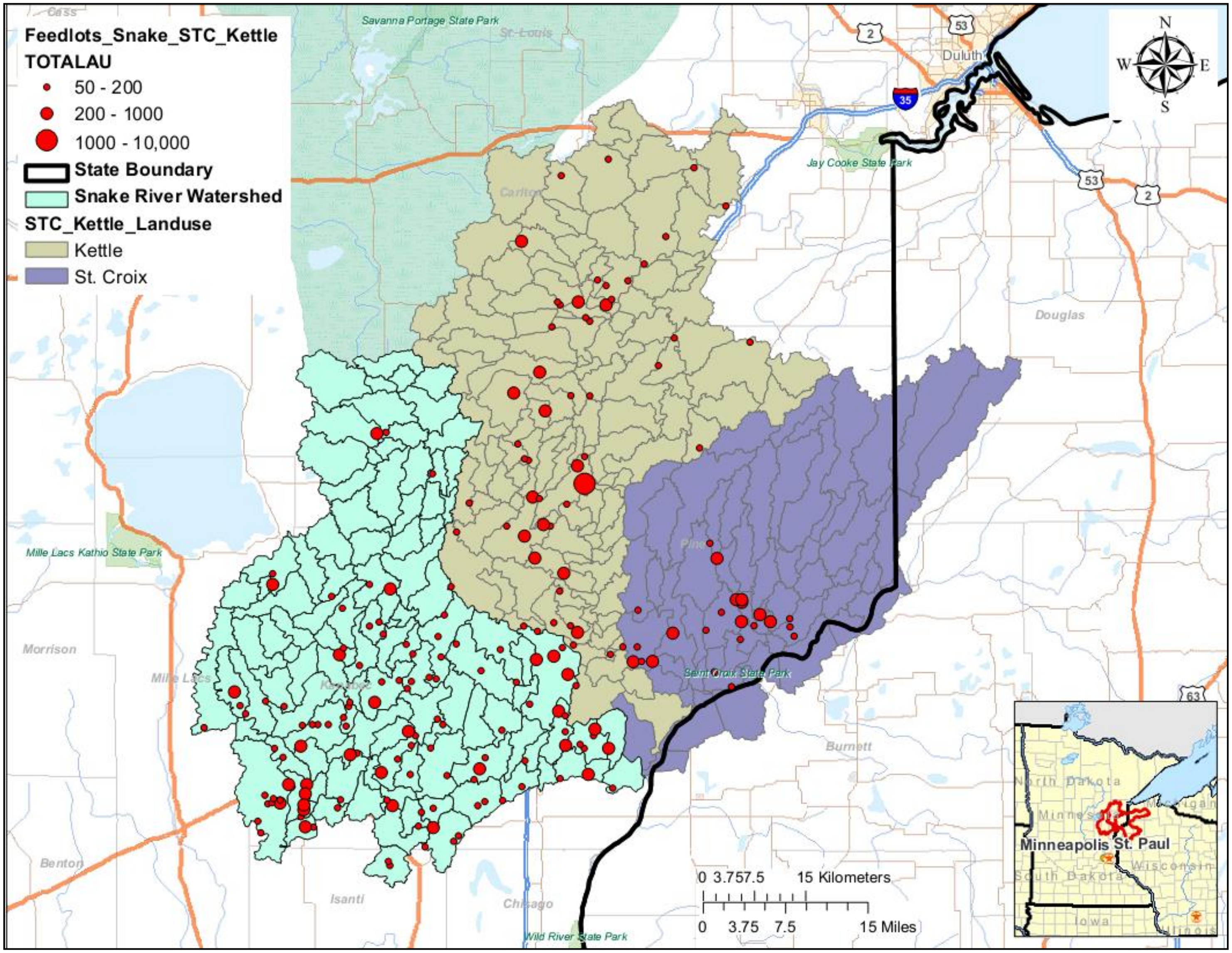


Figure 4-8. Locations of Feedlots With More Than 50 Animal Units in the Redeye, Long Prairie, and Crow Wing Watersheds.

River Watershed model. The primary reason of this difference is that 78 percent of Upper St. Croix-Kettle Rivers model is forest or wetland, as opposed to 63 percent for Snake Watershed model. Also, about 8.5 percent of Snake River is cropland as compared to about 2 percent for Upper St. Croix and Kettle River Watershed. Note that the load allocation depends also on the instream simulation because the actual loadings are calculated by applying the instream losses back to the respective sources. The load allocation table has been introduced for ease of discussion.

Table 4-3. Example Calculation for ACCUM rate of NO3-N at Met Segment 100 in the Snake River Watershed

Total Cropland (ac)	Area Where the Manure Can Be Applied (ac)	Ratio
184.5	138.0	0.75
NO_3-N ACCUM Rate for Conventional Cropland for January (lbs/ac)		0.297
NO_3-N ACCUM Rate for Manured Land in January (lbs/ac)		0.461
Weighted NO_3-N ACCUM Rate in January (lbs/ac)		0.461 × 0.75 + 0.297 × (1–0.75)
		0.420

Following the calibration of N loading rates and its constituents, calibration was shifted to instream simulation of water quality constituents. Observed data were available for instream NH_4+N, and NO_3-N at multiple locations in the three watersheds; however, the frequency of observed data was greater in the Snake River Watershed. Calibration of N and its constituents was conducted in tandem with other constituents as the interaction among these nutrients in the RCHRES required comparing and adjusting several instream parameters that included benthic release of N, P, and BOD; and phytoplankton growth, decay, and advection. The observed concentrations of NO_3-N in the Snake River, Kettle River, and St. Croix River Watersheds were generally lower than the observed values in the Crow Wing River Watersheds; therefore, the NO_3-N concentration of interflow and groundwater were reduced by as much as 50 to 80 percent. The NH_4-N concentration of interflow and groundwater was also reduced by 10–20 percent to match the observed data. Simulated concentrations of NH_4+N or total NH_4+N was in the general range of the observed data (Figure 4-9 and Figure 4-10). Some outliers of observed NH_4+N were evident.

Graphs of NO_3-N plus NO_2-N (Figure 4-11 and Figure 4-12), generally show good agreement between observed and simulated values. In general, nitrite-N is a short-lived compound, and it forms as an intermediate compound during the denitrification process when ammonia converts to nitrate. Often, the observed data are available for nitrate as N only. However, for Snake, Kettle, and Upper St. Croix River, the observed data were reported as the sum of nitrite and nitrate as N for multiple locations. Therefore the simulated concentrations of nitrate and nitrite as N were summed before comparing with the observed data. The analysis of nitrite and nitrate as N concentrations in the RCH290 (Snake River Watershed outlet), suggests that NO_2-N is less than 25 percent of NO_3-N plus NO_2-N, almost half of the time. However, nitrite concentration can be greater than nitrate during some periods, when excess algae growth consumes the nitrate-N.

Table 4-4. Loadings of Nitrate-Nitrogen From Different Land Uses in the Snake River Watershed for the Calibration Period

MET Segments	NO_3-N (lbs/ac)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	1–5				1–15				10–30			3–10			2–5		
50	0.2	0.2	0.1	0.1	1.0	1.1	1.1	1.3	4.5	7.2	3.5	2.1	3.1	3.8	3.5	3.8	4.2
100	0.2	0.2	0.1	0.1	1.0	1.2	1.0	1.2	4.9	7.5	3.3	2.4	3.4	4.0	3.6	3.9	4.4
150	0.3	0.3	0.2	0.2	1.2	1.4	1.4	1.6	4.9	7.4	4.9	2.8	4.0	4.6	3.9	4.1	4.6
200	0.2	0.2	0.1	0.1	1.0	1.1	1.0	1.1	3.9	5.8	3.5	2.2	3.3	3.9	3.7	4.0	4.5
250	0.2	0.2	0.1	0.1	1.0	1.1	1.0	1.1	3.5	4.6	3.5	2.1	3.1	3.8	3.8	4.0	4.5
300	0.2	0.2	0.2	0.2	1.1	1.2	1.3	1.4	5.1	7.2	3.9	2.4	3.4	4.1	3.8	4.1	4.5
350	0.2	0.2	0.1	0.1	1.0	1.1	0.9	1.1	3.4	5.4	3.4	2.7	3.4	3.9	3.7	3.9	4.4
400	0.2	0.2	0.2	0.2	1.2	1.3	1.2	1.3	5.4	7.8	4.5	3.0	3.9	4.4	4.0	4.2	4.7
450	0.2	0.2	0.1	0.1	1.1	1.3	1.1	1.3	4.7	6.6	3.9	2.5	3.6	4.3	3.7	4.0	4.4
500	0.2	0.2	0.1	0.1	0.9	1.1	0.9	1.0	3.5	5.5	3.2	2.2	3.4	4.1	3.7	3.9	4.4
550	0.2	0.2	0.1	0.1	0.9	1.0	0.9	1.0	3.5	5.2	3.2	2.4	3.2	3.6	3.7	3.9	4.4
600	0.2	0.2	0.1	0.1	1.0	1.1	1.0	1.1	3.9	5.6	3.6	2.4	3.5	4.1	3.7	4.0	4.5
650	0.2	0.2	0.1	0.1	0.9	1.0	0.9	1.0	3.5	5.0	3.2	2.0	3.0	3.6	3.7	3.9	4.4
700	0.2	0.2	0.2	0.2	1.2	1.3	1.2	1.2	4.8	7.0	4.0	2.5	3.6	4.5	3.9	4.1	4.6
750	0.2	0.2	0.1	0.1	1.0	1.1	1.0	1.1	3.5	5.2	3.3	2.2	3.3	4.0	3.7	4.0	4.5
800	0.2	0.2	0.1	0.1	0.8	0.9	0.8	0.9	3.1	5.0	3.3	2.0	3.1	3.6	3.7	3.9	4.4
850	0.2	0.2	0.1	0.1	0.9	1.1	0.9	1.1	3.4	5.9	3.4	2.2	3.3	3.9	3.8	4.0	4.5
Average	**0.2**	**0.2**	**0.1**	**0.1**	**1.0**	**1.1**	**1.0**	**1.2**	**4.1**	**6.1**	**3.6**	**2.4**	**3.4**	**4.0**	**3.7**	**4.0**	**4.5**
Maximum	**0.3**	**0.3**	**0.2**	**0.2**	1.2	**1.4**	**1.4**	**1.6**	**5.4**	**7.8**	**4.9**	**3.0**	**4.0**	**4.6**	**4.0**	**4.2**	**4.7**
Minimum	**0.2**	**0.2**	**0.1**	**0.1**	0.8	**0.9**	**0.8**	**0.9**	**3.1**	**4.6**	**3.2**	**2.0**	**3.0**	**3.6**	**3.5**	**3.8**	**4.2**

Table 4-5. Loadings of Ammonia-Nitrogen From Different Land Uses in the Snake River Watershed for the Calibration Period

MET Segments	NH₄ N (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	0.1–1.0				0.2–1.5				0.5–2.0			0.2–2.0			0.5–1.5		
50	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.5	0.7	0.4	0.9	1.0	1.2	2.5	2.6	2.7
100	0.1	0.1	0.1	0.1	0.3	0.5	0.3	0.4	0.5	0.7	0.3	1.1	1.2	1.3	2.7	2.8	2.9
150	0.2	0.2	0.2	0.1	0.4	0.5	0.4	0.5	0.6	0.8	0.5	1.3	1.4	1.4	2.9	3.0	3.1
200	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.6	0.4	1.0	1.1	1.2	2.7	2.8	2.9
250	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.4	0.4	0.9	1.0	1.1	2.7	2.8	2.9
300	0.1	0.1	0.2	0.1	0.4	0.4	0.4	0.4	0.6	0.8	0.4	1.1	1.2	1.3	2.8	2.8	2.9
350	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.6	0.4	1.2	1.2	1.2	2.7	2.8	2.9
400	0.1	0.2	0.2	0.1	0.4	0.4	0.4	0.5	0.5	0.7	0.5	1.4	1.4	1.3	3.0	3.1	3.2
450	0.1	0.1	0.1	0.1	0.4	0.5	0.4	0.5	0.5	0.6	0.4	1.1	1.3	1.3	2.7	2.8	2.9
500	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.3	0.5	0.3	1.0	1.2	1.3	2.7	2.8	2.9
550	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.4	0.5	0.4	1.1	1.1	1.0	2.7	2.7	2.8
600	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.5	0.4	1.0	1.2	1.3	2.7	2.8	2.9
650	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.6	0.4	0.9	1.0	1.1	2.6	2.7	2.8
700	0.1	0.1	0.2	0.1	0.4	0.5	0.4	0.5	0.6	0.7	0.4	1.2	1.3	1.4	2.9	3.0	3.1
750	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.5	0.4	1.0	1.1	1.2	2.6	2.7	2.8
800	0.2	0.2	0.1	0.1	0.3	0.3	0.3	0.3	0.4	0.5	0.4	0.9	1.1	1.1	2.7	2.7	2.8
850	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.5	0.4	1.0	1.1	1.2	2.7	2.8	2.9
Average	**0.1**	**0.1**	**0.1**	**0.1**	**0.3**	**0.4**	**0.3**	**0.4**	**0.4**	**0.6**	**0.4**	**1.1**	**1.2**	**1.2**	**2.7**	**2.8**	**2.9**
Maximum	**0.2**	**0.2**	**0.2**	**0.1**	**0.4**	**0.5**	**0.4**	**0.5**	**0.6**	**0.8**	**0.5**	**1.4**	**1.4**	**1.4**	**3.0**	**3.1**	**3.2**
Minimum	**0.1**	**0.1**	**0.1**	**0.1**	**0.3**	**0.3**	**0.3**	**0.3**	**0.3**	**0.4**	**0.3**	**0.9**	**1.0**	**1.0**	**2.5**	**2.6**	**2.7**

Table 4-6. Loadings of Total Nitrogen From Different Land Uses in the Snake River Watershed for the Calibration Period

MET Segments	TN (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	2–8				2–25				10–50			5–15			3–10		
50	0.5	0.6	0.4	0.4	2.3	2.6	2.4	2.7	8.7	11.6	7.0	4.3	5.5	6.5	7.0	7.4	8.1
100	0.6	0.6	0.4	0.4	2.5	2.9	2.4	2.9	9.1	11.9	6.9	4.7	6.1	7.0	7.3	7.7	8.4
150	0.9	1.0	0.6	0.6	2.8	3.3	3.1	3.5	10.1	13.0	9.7	5.8	7.5	8.2	7.8	8.2	8.9
200	0.5	0.5	0.4	0.4	2.2	2.5	2.3	2.5	8.2	10.2	7.2	4.5	5.9	6.7	7.5	7.9	8.6
250	0.5	0.6	0.4	0.4	2.3	2.6	2.3	2.6	7.8	8.9	7.4	4.3	5.7	6.6	7.5	8.0	8.7
300	0.6	0.7	0.5	0.5	2.6	2.8	2.8	3.1	9.7	12.1	7.8	4.9	6.2	7.0	7.6	8.0	8.7
350	0.6	0.6	0.4	0.4	2.2	2.6	2.2	2.6	7.7	9.8	7.2	5.3	6.2	6.7	7.4	7.8	8.5
400	0.7	0.8	0.6	0.6	2.8	3.0	2.8	3.1	10.6	13.1	9.0	6.0	7.1	7.6	8.0	8.4	9.1
450	0.6	0.7	0.5	0.5	2.6	3.0	2.6	3.0	9.5	11.5	7.9	5.1	6.6	7.5	7.4	7.9	8.5
500	0.5	0.5	0.4	0.4	2.1	2.3	2.1	2.3	7.4	9.4	6.8	4.3	5.9	7.0	7.4	7.8	8.5
550	0.6	0.6	0.4	0.4	2.0	2.3	2.1	2.3	7.5	9.4	6.9	4.8	5.6	6.1	7.3	7.7	8.4
600	0.6	0.6	0.4	0.4	2.4	2.6	2.4	2.5	8.0	9.8	7.2	4.7	6.2	7.1	7.4	7.9	8.6
650	0.6	0.6	0.4	0.4	2.2	2.5	2.2	2.4	7.5	9.1	6.6	4.1	5.5	6.2	7.3	7.7	8.4
700	0.7	0.7	0.5	0.5	2.7	3.0	2.7	3.0	9.6	12.0	8.0	5.2	6.6	7.8	7.8	8.2	8.9
750	0.6	0.7	0.5	0.5	2.2	2.6	2.2	2.6	7.7	9.4	7.0	4.5	5.9	6.8	7.4	7.8	8.5
800	0.6	0.6	0.4	0.5	2.0	2.2	2.0	2.3	7.0	8.9	6.8	4.2	5.6	6.4	7.3	7.7	8.4
850	0.6	0.6	0.4	0.4	2.1	2.5	2.1	2.5	7.3	10.0	6.9	4.5	5.9	6.8	7.5	7.9	8.6
Average	**0.6**	**0.7**	**0.5**	**0.5**	**2.4**	**2.7**	**2.4**	**2.7**	**8.4**	**10.6**	**7.4**	**4.8**	**6.1**	**6.9**	**7.5**	**7.9**	**8.6**
Maximum	**0.9**	**1.0**	**0.6**	**0.6**	**2.8**	**3.3**	**3.1**	**3.5**	**10.6**	**13.1**	**9.7**	**6.0**	**7.5**	**8.2**	**8.0**	**8.4**	**9.1**
Minimum	**0.5**	**0.5**	**0.4**	**0.4**	**2.0**	**2.2**	**2.0**	**2.3**	**7.0**	**8.9**	**6.6**	**4.1**	**5.5**	**6.1**	**7.0**	**7.4**	**8.1**

Table 4-7. Loadings of Nitrate-Nitrogen From Different Land Uses in the Upper St. Croix and Kettle River Watersheds for the Calibration Period

MET Segments	NO_3 N (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	1–5				1–15				10–30			3–10			2–5		
20	0.3	0.3	0.2	0.2	1.4	1.7	1.4	1.6	7.5	13.1	7.1	3.5	4.8	5.5	3.8	4.0	
40	0.2	0.2	0.2	0.2	1.2	1.3	1.2	1.3	5.6	8.4	5.3	2.7	3.9	4.8	3.7	3.9	4.4
60	0.2	0.2	0.1	0.1	0.9	1.0	0.9	1.0	4.0	6.1	3.9	2.0	3.1	3.6	3.5	3.7	4.2
80	0.2	0.3	0.2	0.2	1.2	1.4	1.2	1.4	6.1	11.4	6.0	2.8	4.1	4.8	3.8	4.0	4.5
100	0.2	0.3	0.2	0.2	1.3	1.4	1.3	1.4	6.0	10.6	5.9	2.9	4.4	5.2	3.8	4.0	4.5
120	0.2	0.2	0.1	0.1	1.0	1.1	1.0	1.1	4.0	6.1	4.1	2.0	3.0	3.7	3.8	4.0	4.5
140	0.2	0.2	0.2	0.2	1.1	1.2	1.1	1.3	4.5	8.0	4.8	2.6	4.0	4.7	3.6	3.9	4.3
160	0.2	0.2	0.2	0.2	1.2	1.4	1.2	1.3	5.5	8.7	5.1	2.7	3.9	4.8	3.7	3.9	4.3
180	0.2	0.3	0.2	0.2	1.1	1.2	1.1	1.2	6.3	9.4	5.4	2.5	3.6	4.3	3.6	3.9	4.4
200	0.2	0.2	0.1	0.1	1.1	1.2	1.1	1.2	5.0	7.3	5.2	2.4	3.4	4.0	3.7	3.9	4.4
220	0.2	0.3	0.2	0.2	1.0	1.2	1.1	1.2	3.7	4.8	4.1	1.9	3.0	3.7	3.8		
240	0.2	0.2	0.2	0.2	1.0	1.1	1.0	1.1	3.6	5.5	4.0	1.9	3.3	4.0	3.6	3.8	4.3
260	0.2	0.2	0.1	0.1	0.9	1.0	0.9	1.0	4.2	5.7	3.8	1.9	3.1	3.5	3.5	3.8	4.2
280	0.2	0.2	0.2	0.2	1.1	1.2	1.1	1.2	4.9	7.6	4.9	2.3	3.5	4.2	3.6	3.8	4.3
300	0.2	0.2	0.2	0.2	1.0	1.2	1.0	1.2	4.2	7.8	4.2	2.4	3.7	4.4	3.5	3.8	4.2
320	0.1	0.1	0.1	0.1	0.8	0.9	0.8	0.9	3.5	6.0	3.2	1.8	2.7	3.7	3.5	3.7	4.1
340	0.2	0.2	0.2	0.2	1.1	1.2	1.1	1.2	5.8	8.6	5.5	2.4	3.5	4.2	3.7	3.9	4.4
360	0.2	0.2	0.1	0.1	0.8	0.9	0.8	0.9	3.4	5.5	3.3	1.9	3.1	3.7	3.6	3.8	4.3
380	0.2	0.2	0.1	0.1	1.0	1.1	1.0	1.1	4.7	8.2	4.3	2.6	3.5	4.1	3.6	3.8	4.3
400	0.2	0.2	0.2	0.2	1.2	1.4	1.2	1.3	5.6	10.4	4.9	2.9	4.0	4.7	3.6	3.9	4.4
420	0.2	0.2	0.1	0.1	0.9	1.1	1.0	1.1	4.4	6.2	4.1	2.0	3.0	3.6	3.5		
440	0.3	0.3	0.2	0.2	1.3	1.4	1.3	1.4	5.4	10.0	5.9	2.8	4.0	4.8	3.7	3.9	4.4
460	0.2	0.2	0.1	0.1	1.0	1.0	1.0	1.0	3.9	5.7	4.0	2.0	3.1	3.0	3.8	4.0	
480	0.2	0.2	0.1	0.1	1.1	1.2	1.1	1.2	5.4	8.8	5.2	2.4	3.5	4.1	3.7	4.0	4.5
500	0.2	0.3	0.2	0.2	1.1	1.2	1.1	1.2	5.1	7.3	4.9	2.4	3.7	4.3	3.9	4.1	4.6
Mean	**0.2**	**0.2**	**0.2**	**0.2**	**1.1**	**1.2**	**1.1**	**1.2**	**4.9**	**7.9**	**4.8**	**2.4**	**3.6**	**4.2**	**3.7**	**3.9**	**4.4**
Maximum	**0.3**	**0.3**	**0.2**	**0.2**	**1.4**	**1.7**	**1.4**	**1.6**	**7.5**	**13.1**	**7.1**	**3.5**	**4.8**	**5.5**	**3.9**	**4.1**	**4.6**
Minimum	**0.1**	**0.1**	**0.1**	**0.1**	**0.8**	**0.9**	**0.8**	**0.9**	**3.4**	**4.8**	**3.2**	**1.8**	**2.7**	**3.0**	**3.5**	**3.7**	**4.1**

Table 4-8. Loadings of Ammonia-Nitrogen From Different Land Uses in the Upper St. Croix and Kettle River Watersheds for the Calibration Period

MET Segments	NH_4 N (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	0.1–1.0				0.2–1.5				0.5–2.0			0.2–2.0			0.5–1.5		
20	0.2	0.2	0.1	0.1	0.4	0.5	0.4	0.5	0.7	1.2	0.7	1.4	1.5	1.6	2.9	3.0	
40	0.1	0.2	0.1	0.1	0.4	0.4	0.4	0.4	0.5	0.6	0.5	1.1	1.2	1.3	2.8	2.8	2.9
60	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.4	0.6	0.4	0.9	1.0	1.0	2.4	2.4	2.5
80	0.2	0.2	0.1	0.1	0.4	0.5	0.4	0.5	0.8	1.3	0.7	1.2	1.4	1.4	2.8	2.8	2.9
100	0.1	0.2	0.1	0.1	0.4	0.5	0.4	0.5	0.6	1.0	0.6	1.3	1.5	1.6	2.9	2.9	3.0
120	0.2	0.2	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.5	0.5	0.9	1.0	1.1	2.6	2.7	2.8
140	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.4	0.7	0.5	1.0	1.1	1.2	2.7	2.7	2.8
160	0.1	0.1	0.1	0.1	0.4	0.4	0.4	0.4	0.5	0.7	0.5	1.1	1.2	1.4	2.7	2.8	2.9
180	0.2	0.2	0.1	0.1	0.3	0.4	0.3	0.4	0.7	1.0	0.6	1.0	1.1	1.2	2.6	2.7	2.8
200	0.1	0.1	0.1	0.1	0.4	0.4	0.3	0.4	0.5	0.6	0.5	1.1	1.2	1.3	2.8	2.8	2.9
220	0.2	0.2	0.1	0.1	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.9	1.0	1.1	2.8		
240	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.4	0.5	0.4	0.8	1.0	1.0	2.5	2.6	2.7
260	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.5	0.6	0.5	0.9	1.0	1.0	2.5	2.6	2.7
280	0.1	0.1	0.1	0.1	0.3	0.3	0.3	0.3	0.5	0.7	0.5	1.0	1.1	1.1	2.5	2.6	2.7
300	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.5	0.8	0.4	1.0	1.1	1.2	2.6	2.7	2.7
320	0.1	0.1	0.1	0.1	0.2	0.3	0.2	0.3	0.4	0.6	0.4	0.8	0.9	1.1	2.5	2.5	2.6
340	0.2	0.2	0.1	0.1	0.4	0.5	0.4	0.4	0.6	0.9	0.6	1.1	1.2	1.3	2.7	2.8	2.9
360	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.4	0.5	0.4	0.8	0.9	1.0	2.6	2.6	2.7
380	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.7	0.4	1.2	1.2	1.3	2.6	2.7	2.8
400	0.2	0.2	0.1	0.1	0.3	0.5	0.3	0.4	0.6	1.0	0.5	1.3	1.4	1.5	2.7	2.8	2.9
420	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.5	0.4	0.9	1.0	1.0	2.5		
440	0.2	0.3	0.1	0.1	0.4	0.5	0.4	0.5	0.6	1.0	0.6	1.2	1.3	1.4	2.8	2.9	3.0
460	0.1	0.1	0.1	0.1	0.3	0.4	0.3	0.4	0.4	0.6	0.4	0.9	1.0	0.8	2.7	2.8	
480	0.1	0.2	0.1	0.1	0.4	0.4	0.4	0.4	0.6	0.8	0.5	1.1	1.2	1.3	2.7	2.8	2.9
500	0.1	0.2	0.1	0.1	0.4	0.4	0.4	0.4	0.5	0.6	0.5	1.1	1.3	1.3	2.9	3.0	3.1
Average	**0.1**	**0.2**	**0.1**	**0.1**	**0.3**	**0.4**	**0.3**	**0.4**	**0.5**	**0.7**	**0.5**	**1.0**	**1.2**	**1.2**	**2.7**	**2.7**	**2.8**
Maximum	**0.2**	**0.3**	**0.1**	**0.1**	**0.4**	**0.5**	**0.4**	**0.5**	**0.8**	**1.3**	**0.7**	**1.4**	**1.5**	**1.6**	**2.9**	**3.0**	**3.1**
Minimum	**0.1**	**0.1**	**0.1**	**0.1**	**0.2**	**0.2**	**0.2**	**0.2**	**0.4**	**0.5**	**0.4**	**0.8**	**0.9**	**0.8**	**2.4**	**2.4**	**2.5**

Table 4-9. Loadings of Total Nitrogen From Different Land Uses in the Upper St. Croix and Kettle River Watersheds for the Calibration Period

MET Segments	TN (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	2–8				2–25				10–50			5–15			3–10		
20	0.9	1.0	0.7	0.7	3.3	3.6	3.2	3.6	13.4	19.4	12.3	6.7	8.4	9.4	7.6	8.1	
40	0.7	0.8	0.6	0.6	2.8	2.9	2.8	3.0	10.8	13.6	9.9	5.3	6.9	8.1	7.4	7.9	8.5
60	0.5	0.6	0.4	0.4	2.1	2.3	2.1	2.3	8.1	10.3	7.6	4.0	5.4	6.1	6.8	7.2	7.9
80	0.7	0.9	0.6	0.6	2.6	3.0	2.7	3.1	11.6	17.5	10.8	5.5	7.3	8.2	7.5	7.9	8.6
100	0.7	0.8	0.6	0.6	2.9	3.2	2.9	3.2	11.5	16.5	11.0	5.8	7.7	8.8	7.6	8.1	8.7
120	0.7	0.7	0.5	0.5	2.3	2.5	2.2	2.5	8.2	10.1	8.0	4.2	5.5	6.5	7.4	7.9	8.6
140	0.6	0.7	0.6	0.6	2.5	2.7	2.4	2.7	9.2	12.8	9.1	4.9	6.6	7.7	7.3	7.7	8.3
160	0.7	0.7	0.6	0.6	2.8	2.9	2.8	2.9	10.4	13.7	9.6	5.3	6.7	7.9	7.4	7.8	8.4
180	0.7	0.8	0.6	0.6	2.7	2.7	2.6	2.7	11.5	14.5	9.9	4.8	6.2	7.1	7.3	7.7	8.4
200	0.6	0.6	0.4	0.4	2.5	2.5	2.5	2.9	9.6	11.7	9.4	4.8	6.2	7.2	7.5	7.8	8.5
220	0.7	0.8	0.5	0.5	2.4	2.6	2.5	2.6	8.2	8.9	8.2	4.2	5.6	6.5	7.6		
240	0.6	0.6	0.5	0.5	2.2	2.4	2.2	2.4	8.0	9.8	8.1	3.9	5.7	6.6	7.1	7.5	8.2
260	0.6	0.6	0.4	0.5	2.0	2.3	2.0	2.3	8.3	9.9	7.6	3.9	5.5	6.0	7.0	7.4	8.1
280	0.6	0.6	0.5	0.5	2.4	2.7	2.4	2.6	9.4	12.3	9.1	4.5	6.1	7.0	7.1	7.5	8.2
300	0.6	0.6	0.5	0.5	2.3	2.6	2.3	2.5	8.7	12.3	8.4	4.6	6.2	7.2	7.1	7.5	8.2
320	0.4	0.4	0.3	0.4	1.7	2.0	1.8	2.0	7.2	10.1	6.5	3.5	4.7	6.1	6.9	7.3	7.9
340	0.7	0.7	0.5	0.5	2.5	2.5	2.5	2.5	10.7	12.9	9.6	4.8	6.2	7.0	7.4	7.8	8.5
360	0.5	0.5	0.4	0.4	1.9	2.0	1.8	2.0	7.4	9.5	7.0	3.8	5.3	6.2	7.1	7.5	8.2
380	0.5	0.6	0.4	0.4	2.4	2.4	2.4	2.4	8.8	12.1	8.0	5.0	6.2	7.0	7.2	7.6	8.3
400	0.7	0.7	0.5	0.6	2.7	2.9	2.6	2.8	10.5	15.6	9.3	5.6	7.1	8.1	7.3	7.8	8.4
420	0.5	0.6	0.4	0.4	2.1	2.4	2.3	2.3	8.7	10.6	7.9	4.0	5.3	6.1	6.9		
440	1.0	1.1	0.6	0.6	3.0	3.4	3.0	3.4	11.0	16.0	11.2	5.8	7.5	8.5	7.5	7.9	8.5
460	0.6	0.6	0.4	0.5	2.3	2.4	2.3	2.4	8.3	10.2	7.9	4.1	5.5	5.5	7.5	8.0	
480	0.6	0.7	0.5	0.5	2.6	2.8	2.6	2.8	10.3	14.3	9.6	5.0	6.4	7.3	7.5	7.9	8.6
500	0.7	0.8	0.5	0.5	2.7	2.8	2.6	2.9	10.1	12.5	9.3	5.0	6.7	7.4	7.8	8.3	9.0
Mean	**0.6**	**0.7**	**0.5**	**0.5**	**2.5**	**2.7**	**2.5**	**2.7**	**9.6**	**12.7**	**9.0**	**4.8**	**6.3**	**7.2**	**7.3**	**7.7**	**8.4**
Maximum	**1.0**	**1.1**	**0.7**	**0.7**	**3.3**	**3.6**	**3.2**	**3.6**	**13.4**	**19.4**	**12.3**	**6.7**	**8.4**	**9.4**	**7.8**	**8.3**	**9.0**
Minimum	**0.4**	**0.4**	**0.3**	**0.4**	**1.7**	**2.0**	**1.8**	**2.0**	**7.2**	**8.9**	**6.5**	**3.5**	**4.7**	**5.5**	**6.8**	**7.2**	**7.9**

Table 4-10. Load Allocation Report for Total Nitrogen in the Snake River and St. Croix-Kettle Watersheds

Source	Snake River Watershed				St. Croix and Kettle River Watershed			
	Snake River–Cross Lake		Snake River at Outlet		Kettle River		St. Croix River	
	Annual Load (lbs)	Percent of Total	Annual Load (lbs)	Percent of Total	Annual Load (lbs)	Percent of Total	Annual Load (lbs)	Percent of Total
P[(a)]:Forest - AB	5,083	0.3	5,946	0.4	12,100	1.9	39,490	3.6
P:Forest - CD	167,929	10.9	166,665	10.7	90,624	14.0	194,136	17.9
P:Emerg Herb Wetland	40,355	2.6	40,252	2.6	21,533	3.3	33,799	3.1
P:Woody Wetlands	49,064	3.2	49,169	3.2	58,296	9.0	104,959	9.7
P:Grassland - AB	2,474	0.2	3,069	0.2	10,730	1.7	31,761	2.9
P:Grassland - CD	78,303	5.1	77,720	5.0	50,205	7.8	94,461	8.7
P:Pasture - AB	16,779	1.1	18,293	1.2	17,624	2.7	24,933	2.3
P:Pasture - CD	379,069	24.6	381,148	24.5	140,505	21.8	192,962	17.8
P:Cropland - AB	15,839	1.0	19,292	1.2	20,662	3.2	43,875	4.0
P:Cropland - CD	350,236	22.8	358,695	23.0	63,128	9.8	98,484	9.1
P:Cropland-Drained	247,998	16.1	249,203	16.0	33,887	5.3	56,227	5.2
P:Dev, Open Space	126,684	8.2	127,232	8.2	74,508	11.5	114,951	10.6
P:Dev, Low Intensity	25,544	1.7	25,078	1.6	8,627	1.3	9,204	0.9
P:Dev, Medium Intensity	8,284	0.5	8,095	0.5	3,263	0.5	3,456	0.3
I:Dev, Open Space	3,966	0.3	3,996	0.3	2,338	0.4	3,516	0.3
I:Dev, Low Intensity	3,647	0.2	3,582	0.2	1,185	0.2	1,261	0.1
I:Dev, Medium Intensity	5,492	0.4	5,367	0.3	2,083	0.3	2,205	0.2
Point Sources	10,423	0.7	12,554	0.8	32,955	5.1	33,203	3.1
Direct Atmospheric Deposition on the Reach	1,417	0.1	1,471	0.1	1,268	0.2	1,760	0.2
Mass Balance Differences/ Additional Sources[(b)]	76	0.0	79	0.0	62	0.0	105	0.0
Diversion	0	0.0	0	0.0	0	0.0	0	0.0
Cumulative Instream Losses	–427,922	–27.8	–451,190	–29.0	–290,736	–45.0	–408,846	–37.7
Cumulative Instream Gains	0	0.0	0	0.0	0	0.0	0	0.0
Total[(c)]	**1,538,659**	**100.0**	**1,556,908**	**100.0**	**645,582**	**100.0**	**1,084,749**	**100.0**

(a) P stands for pervious and I stands for impervious land uses.
(b) The additional sources may include sources other than nonpoint sources, point sources, atmospheric deposition, and upstream contribution.
(c) The total does not include losses because they have already been applied to the respective sources.

Table 4-11. Nitrogen Loads (Pounds) and Percentages From Various Sources in Each Watershed for the Calibration Period

Source	STC-Kettle Model		Snake River	
	Annual Load	Percent of Total	Annual Load	Percent of Total
Pervious	1,042,698	96.1	1,529,858	98.3
Impervious	6,983	0.6	12,944	0.8
Point Sources	33,203	3.1	12,554	0.8
Total	**1,084,749**	**100.0**	**1,556,908**	**100.0**

Overall, the N simulation results were satisfactory. Plots comparing observed and simulated NH_4-N, and NO_2-N + NO_3-N graphs at additional locations are provided in the appendices.

4.4 PHOSPHORUS

HSPF simulates surface washoff of inorganic P using a potency-factor approach, where the inorganic P load is estimated as a fraction of sediment yield. OP (refractory and labile) is calculated as a fraction (0.0023) of total BOD-Organics entering into streams. The potency factors for all the land uses were adopted from the previous models [Tetra Tech, 2009 and AQUA TERRA Consultants, 2005]. To calculate the potency factor of inorganic P and organic matter for agricultural areas, a methodology similar to the calculation of ACCUM and SQOLIM for NO_3-N, and NH_4-N was used. The loading of different P components from land surfaces is presented in Table 4-12 to Table 4-15. In general, the loading rate from all the land uses for PO_4-P, and total P are within the target range.

The effective load of total P in different parts of the watershed (Table 4-16 and Table 4-17) was calculated using HSPEXP+ [Mishra et al., 2015]. The load of total P at the outlet of Snake River is about 67 percent greater than the load of total P at the outlet of the Upper St. Croix River that includes the Kettle River, even though the total area in STC-Kettle model is 76 percent greater than the area of Snake River Watershed. The primary reason of this difference is that 78 percent of the area modeled in STC-Kettle model is forest or wetland, as opposed to 63 percent for Snake. Also, about 8.5 percent of Snake River Watershed model is cropland as compared to approximately 2 percent of the area modeled in STC-Kettle model.

Following the calibration of loading rates of PO_4-P and total P, the focus of the calibration shifted to the instream simulation of PO_4-P and total P. As noted earlier, the instream calibration of P was conducted in tandem with other nutrients. The plots of observed and simulated PO_4-P and TP concentrations suggest a reasonable calibration of P (Figure 4-13 to Figure 4-15). The observed and simulated concentrations of PO_4-P and total P generally stayed lower than 0.5 and 1.0 mg/l, respectively. In the streams, concentrations generally peaked following rainfall events as that is the major source of P in these watersheds. However, in all the lakes and some slow-moving rivers, P concentrations decreased in the summer because of increased phytoplankton growth and increased in fall following the decay and die-off of phytoplankton.

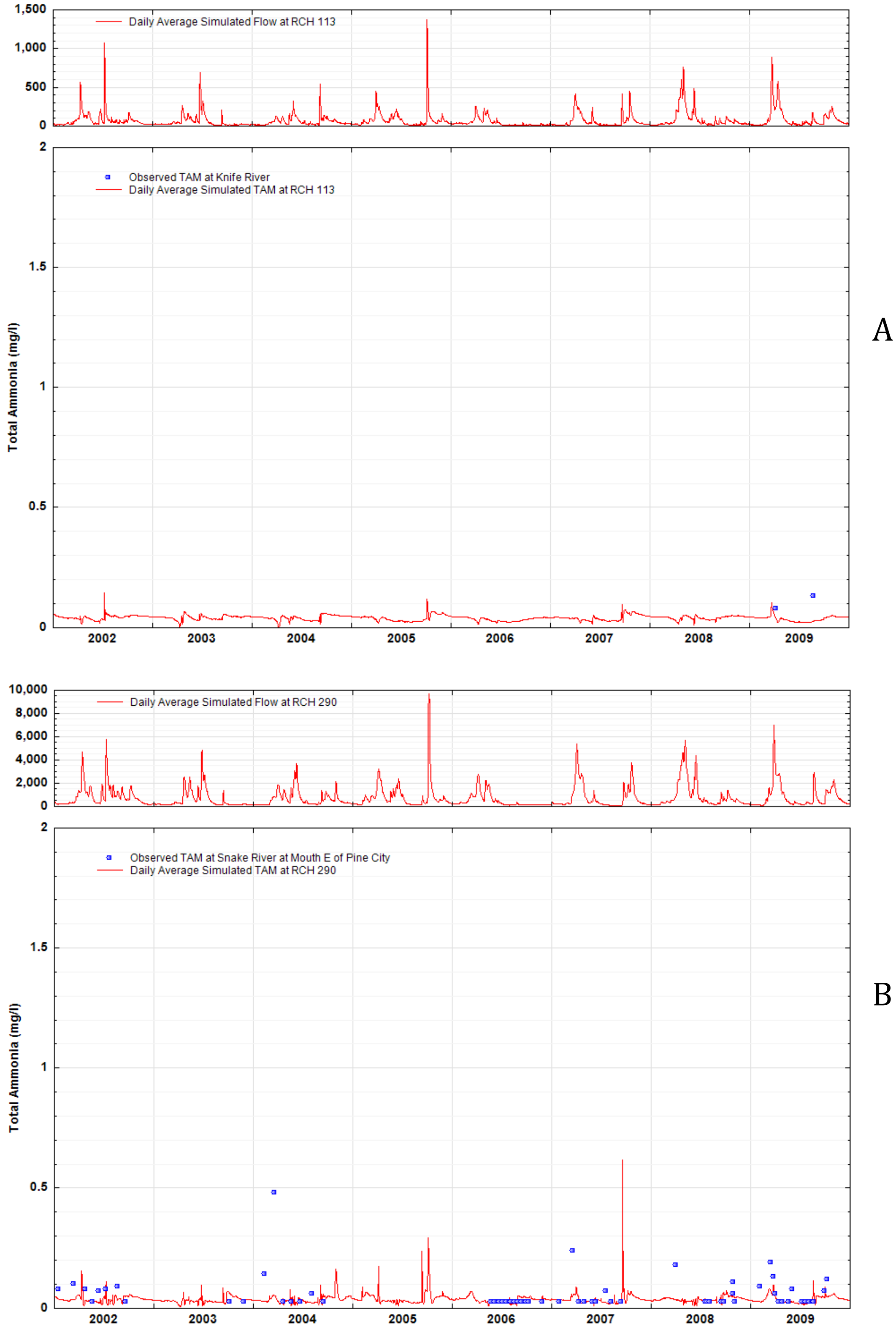


Figure 4-9. Observed and Daily Average Simulated Ammonia as Nitrogen at (a) Knife River (RCH113) and (b) Snake River Near the Watershed Outlet (RCH290).

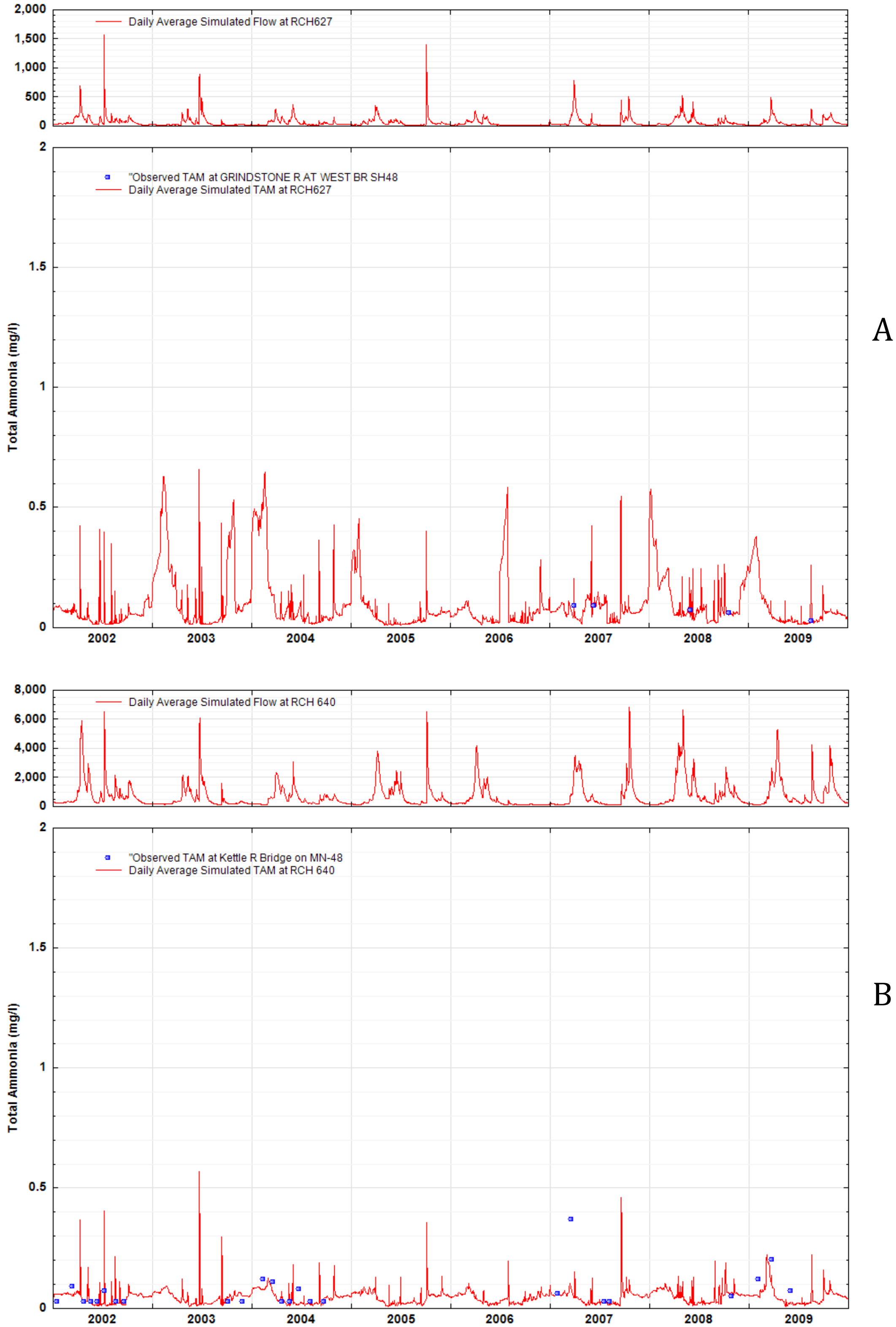
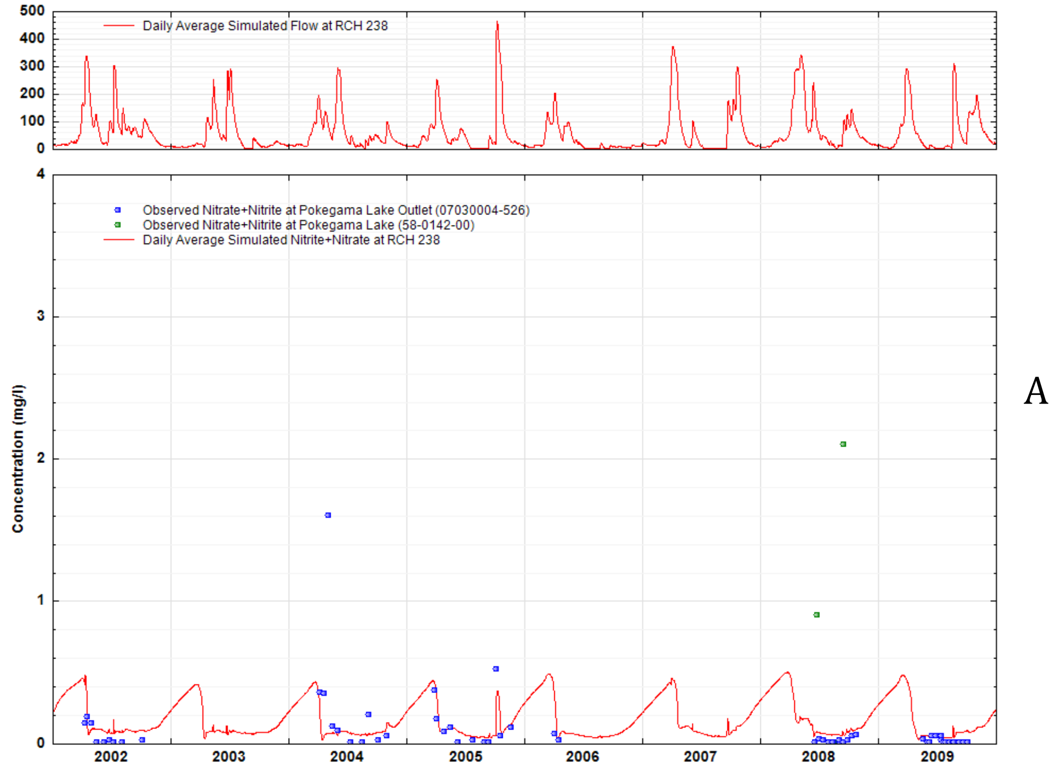


Figure 4-10. Observed and Daily Average Simulated Ammonia as Nitrogen at (a) Grindstone River (RCH627) and (b) Kettle River Bridge (RCH640).



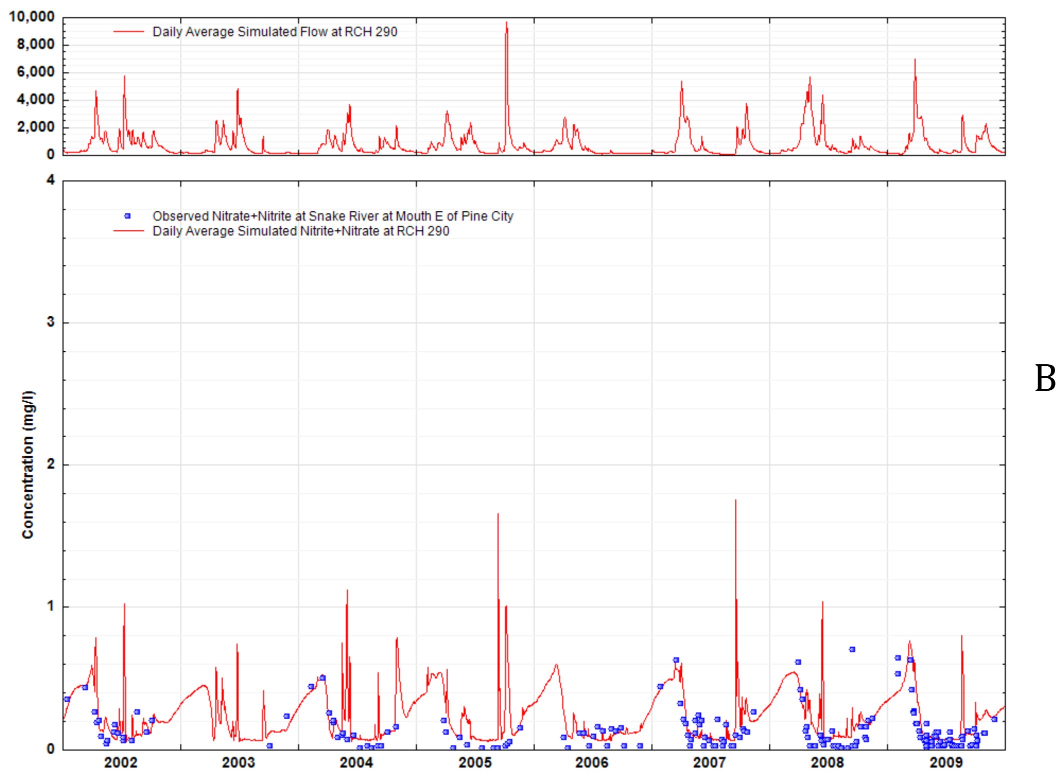


Figure 4-11. Observed and Daily Average Simulated Nitrate as Nitrogen at (a) Pokegama Lake (RCH238) and (b) Snake River Watershed Outlet (RCH290).

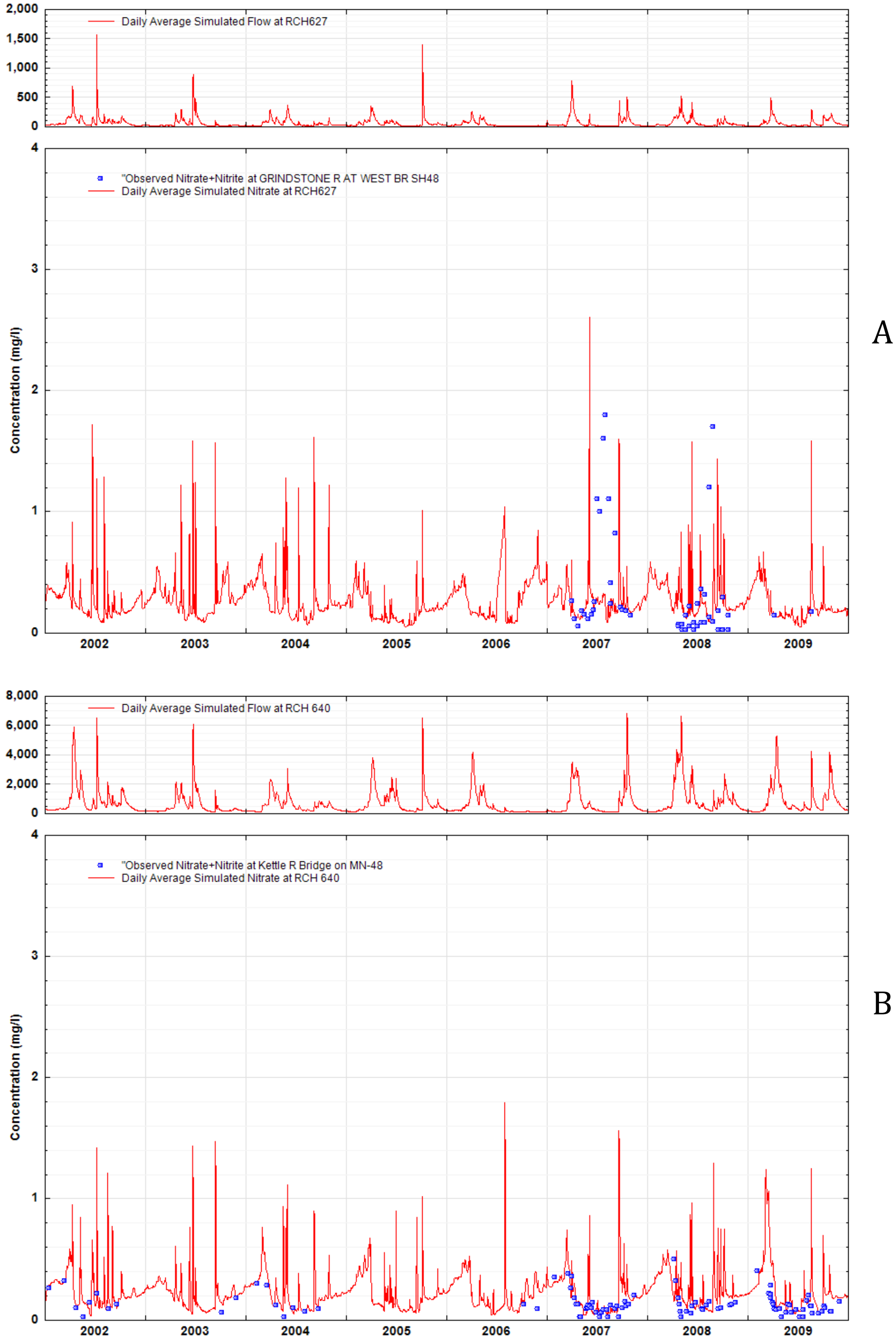


Figure 4-12. Observed and Daily Average Simulated Nitrate as Nitrogen at (a) Grindstone River (RCH627) and (b) Kettle River Bridge (RCH640).

Table 4-12. Loadings of Ortho-Phosphorus From Different Land Uses in the Snake River Watershed for the Calibration Period

MET Segments	ORTHO-P (lbs/ac-yr)															
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	0.2–0.10				0.2–2.0				0.3–2.0			0.1–1.0			0.2–0.7		
50	0.02	0.03	0.01	0.01	0.16	0.21	0.27	0.36	1.29	2.32	0.22	0.22	0.26	0.30	0.41	0.42	0.43
100	0.03	0.03	0.01	0.01	0.22	0.32	0.21	0.33	1.14	1.97	0.16	0.22	0.30	0.36	0.42	0.42	0.44
150	0.05	0.09	0.01	0.01	0.20	0.33	0.40	0.56	2.08	3.91	1.81	0.35	0.47	0.47	0.44	0.45	0.46
200	0.01	0.02	0.01	0.01	0.11	0.17	0.14	0.19	0.99	1.67	0.29	0.22	0.28	0.31	0.44	0.44	0.46
250	0.01	0.04	0.01	0.01	0.15	0.25	0.14	0.23	0.34	0.51	0.21	0.22	0.29	0.32	0.44	0.45	0.46
300	0.03	0.03	0.01	0.01	0.20	0.23	0.35	0.47	1.52	2.50	0.32	0.27	0.31	0.29	0.45	0.45	0.46
350	0.02	0.03	0.01	0.01	0.14	0.26	0.12	0.24	0.62	1.40	0.16	0.31	0.32	0.31	0.42	0.43	0.44
400	0.02	0.04	0.01	0.01	0.16	0.21	0.17	0.24	1.05	1.81	0.22	0.33	0.34	0.22	0.45	0.45	0.47
450	0.02	0.03	0.01	0.01	0.18	0.29	0.18	0.28	0.79	1.29	0.17	0.30	0.40	0.44	0.42	0.43	0.44
500	0.01	0.02	0.01	0.01	0.11	0.13	0.11	0.13	0.29	0.59	0.12	0.15	0.22	0.29	0.43	0.44	0.45
550	0.02	0.02	0.01	0.01	0.10	0.14	0.12	0.14	0.41	0.90	0.15	0.21	0.21	0.20	0.43	0.43	0.44
600	0.02	0.03	0.01	0.01	0.17	0.21	0.17	0.18	0.42	0.73	0.15	0.23	0.29	0.34	0.43	0.44	0.45
650	0.03	0.04	0.01	0.01	0.17	0.26	0.16	0.24	0.65	1.09	0.14	0.24	0.32	0.35	0.43	0.43	0.45
700	0.03	0.03	0.01	0.01	0.21	0.30	0.21	0.30	0.81	1.53	0.17	0.28	0.36	0.42	0.44	0.45	0.46
750	0.03	0.04	0.01	0.01	0.15	0.25	0.14	0.24	0.46	0.76	0.14	0.23	0.30	0.34	0.44	0.44	0.46
800	0.04	0.03	0.01	0.01	0.14	0.17	0.13	0.22	0.93	1.32	0.48	0.27	0.35	0.40	0.42	0.42	0.43
850	0.02	0.04	0.01	0.01	0.10	0.21	0.10	0.23	0.25	0.65	0.13	0.23	0.29	0.34	0.44	0.45	0.46
Mean	**0.02**	**0.03**	**0.01**	**0.01**	**0.16**	**0.23**	**0.18**	**0.27**	**0.83**	**1.47**	**0.30**	**0.25**	**0.31**	**0.33**	**0.43**	**0.44**	**0.45**
Maximum	**0.05**	**0.09**	**0.01**	**0.01**	**0.22**	**0.33**	**0.40**	**0.56**	**2.08**	**3.91**	**1.81**	**0.35**	**0.47**	**0.47**	**0.45**	**0.45**	**0.47**
Minimum	**0.01**	**0.02**	**0.01**	**0.01**	**0.10**	**0.13**	**0.10**	**0.13**	**0.25**	**0.51**	**0.12**	**0.15**	**0.21**	**0.20**	**0.41**	**0.42**	**0.43**

Table 4-13. Loadings of Total Phosphorous From Different Land Uses in the Snake River Watershed for the Calibration Period

MET Segments	Total Phosphorous (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	0.05–0.50				0.5–2.5				0.5–3.0			0.2–1.5			0.3–1.0		
50	0.04	0.05	0.02	0.02	0.24	0.29	0.34	0.44	1.57	2.60	0.46	0.31	0.36	0.42	0.49	0.50	0.52
100	0.06	0.06	0.02	0.02	0.31	0.42	0.29	0.43	1.43	2.25	0.41	0.31	0.41	0.48	0.49	0.51	0.53
150	0.08	0.12	0.03	0.03	0.29	0.44	0.49	0.67	2.43	4.27	2.13	0.48	0.63	0.64	0.52	0.53	0.56
200	0.03	0.03	0.02	0.02	0.18	0.24	0.21	0.27	1.28	1.97	0.55	0.32	0.40	0.44	0.51	0.53	0.55
250	0.03	0.06	0.02	0.02	0.22	0.34	0.22	0.32	0.64	0.80	0.47	0.32	0.40	0.45	0.52	0.54	0.56
300	0.05	0.06	0.03	0.03	0.28	0.32	0.43	0.56	1.83	2.81	0.58	0.38	0.43	0.41	0.52	0.54	0.56
350	0.04	0.06	0.02	0.02	0.21	0.35	0.19	0.33	0.91	1.69	0.41	0.42	0.44	0.43	0.50	0.51	0.53
400	0.05	0.07	0.03	0.03	0.26	0.30	0.26	0.34	1.40	2.16	0.52	0.46	0.48	0.35	0.52	0.54	0.56
450	0.05	0.06	0.02	0.02	0.26	0.39	0.26	0.37	1.11	1.61	0.45	0.41	0.53	0.59	0.50	0.51	0.53
500	0.03	0.04	0.02	0.02	0.18	0.20	0.18	0.20	0.56	0.85	0.36	0.24	0.32	0.40	0.51	0.52	0.54
550	0.04	0.04	0.02	0.02	0.17	0.21	0.18	0.21	0.69	1.17	0.40	0.30	0.31	0.31	0.50	0.51	0.53
600	0.04	0.05	0.02	0.02	0.25	0.29	0.25	0.26	0.71	1.01	0.39	0.32	0.41	0.47	0.51	0.52	0.54
650	0.05	0.06	0.02	0.02	0.25	0.34	0.23	0.32	0.91	1.35	0.37	0.33	0.43	0.47	0.50	0.52	0.54
700	0.05	0.05	0.03	0.03	0.30	0.39	0.29	0.40	1.13	1.85	0.44	0.40	0.49	0.56	0.52	0.53	0.55
750	0.06	0.07	0.02	0.02	0.22	0.33	0.22	0.32	0.75	1.04	0.39	0.33	0.41	0.47	0.51	0.53	0.55
800	0.06	0.05	0.02	0.02	0.20	0.23	0.20	0.29	1.19	1.58	0.71	0.37	0.46	0.52	0.49	0.50	0.52
850	0.04	0.06	0.02	0.02	0.16	0.29	0.16	0.31	0.52	0.93	0.37	0.32	0.41	0.46	0.52	0.53	0.55
Mean	**0.05**	**0.06**	**0.02**	**0.02**	**0.23**	**0.32**	**0.26**	**0.36**	**1.12**	**1.76**	**0.55**	**0.35**	**0.43**	**0.46**	**0.51**	**0.52**	**0.54**
Maximum	**0.08**	**0.12**	**0.03**	**0.03**	**0.31**	**0.44**	**0.49**	**0.67**	**2.43**	**4.27**	**2.13**	**0.48**	**0.63**	**0.64**	**0.52**	**0.54**	**0.56**
Minimum	**0.03**	**0.03**	**0.02**	**0.02**	**0.16**	**0.20**	**0.16**	**0.20**	**0.52**	**0.80**	**0.36**	**0.24**	**0.31**	**0.31**	**0.49**	**0.50**	**0.52**

Table 4-14. Loadings of Ortho-Phosphorous From Different Land Uses in the Upper St. Croix and Kettle River Watersheds for the Calibration Period

MET Segments	ORTHO-P (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	0.02–0.10				0.2–2.0				0.3–2.0			0.1–1.0			0.2–0.7		
20	0.03	0.06	0.01	0.01	0.22	0.24	0.21	0.23	1.12	2.30	0.48	0.34	0.41	0.44	0.43	0.44	
40	0.03	0.03	0.01	0.01	0.20	0.19	0.20	0.21	0.40	0.62	0.22	0.24	0.29	0.33	0.43	0.44	0.45
60	0.02	0.03	0.01	0.01	0.14	0.18	0.14	0.18	0.71	1.11	0.44	0.19	0.24	0.26	0.41	0.42	0.43
80	0.03	0.05	0.01	0.01	0.14	0.20	0.27	0.44	1.42	3.02	0.62	0.25	0.33	0.36	0.44	0.45	0.46
100	0.01	0.02	0.01	0.01	0.17	0.24	0.17	0.23	0.30	0.57	0.23	0.28	0.34	0.38	0.43	0.44	0.45
120	0.03	0.03	0.01	0.01	0.14	0.14	0.12	0.17	0.29	0.32	0.18	0.22	0.27	0.30	0.45	0.46	0.47
140	0.01	0.02	0.01	0.01	0.11	0.13	0.11	0.12	0.28	0.82	0.17	0.15	0.17	0.21	0.43	0.44	0.45
160	0.02	0.03	0.01	0.01	0.19	0.19	0.19	0.19	0.40	0.76	0.21	0.23	0.22	0.28	0.43	0.43	0.45
180	0.04	0.05	0.01	0.01	0.19	0.16	0.33	0.28	1.34	1.43	0.42	0.19	0.19	0.22	0.44	0.44	0.46
200	0.02	0.02	0.01	0.01	0.19	0.17	0.19	0.29	0.36	0.50	0.29	0.24	0.36	0.42	0.42	0.42	0.43
220	0.04	0.04	0.01	0.01	0.14	0.17	0.18	0.16	0.27	0.28	0.18	0.23	0.27	0.29	0.45		
240	0.01	0.02	0.01	0.01	0.09	0.13	0.09	0.13	0.20	0.27	0.14	0.15	0.20	0.18	0.44	0.44	0.45
260	0.02	0.03	0.01	0.01	0.10	0.17	0.16	0.33	0.89	1.62	0.16	0.19	0.24	0.23	0.42	0.43	0.44
280	0.02	0.03	0.01	0.01	0.13	0.21	0.22	0.33	0.70	1.48	0.36	0.17	0.23	0.26	0.43	0.44	0.45
300	0.01	0.02	0.01	0.01	0.11	0.15	0.17	0.19	0.59	0.97	0.23	0.15	0.20	0.22	0.42	0.43	0.44
320	0.01	0.01	0.00	0.00	0.08	0.17	0.19	0.29	0.49	1.61	0.16	0.15	0.18	0.24	0.41	0.42	0.43
340	0.03	0.02	0.01	0.01	0.15	0.11	0.26	0.16	2.03	0.84	0.41	0.19	0.23	0.22	0.43	0.44	0.45
360	0.01	0.01	0.01	0.01	0.07	0.10	0.06	0.10	0.27	0.68	0.13	0.11	0.16	0.19	0.43	0.44	0.45
380	0.02	0.02	0.01	0.01	0.18	0.10	0.17	0.10	0.38	0.33	0.17	0.23	0.30	0.34	0.42	0.43	0.44
400	0.03	0.03	0.01	0.01	0.19	0.17	0.18	0.15	0.64	1.69	0.23	0.23	0.32	0.38	0.42	0.43	0.45
420	0.02	0.03	0.01	0.01	0.12	0.16	0.16	0.15	0.38	0.59	0.22	0.21	0.24	0.26	0.41		
440	0.07	0.09	0.01	0.01	0.23	0.31	0.41	0.60	2.01	3.59	1.88	0.36	0.46	0.50	0.43	0.44	0.45
460	0.03	0.03	0.01	0.01	0.16	0.19	0.15	0.18	0.85	1.41	0.45	0.20	0.24	0.20	0.45	0.46	
480	0.03	0.05	0.01	0.01	0.19	0.23	0.19	0.24	1.27	3.06	0.69	0.28	0.36	0.40	0.43	0.44	0.45
500	0.03	0.04	0.01	0.01	0.20	0.18	0.19	0.23	0.49	0.88	0.22	0.27	0.33	0.30	0.45	0.46	0.47
Average	**0.02**	**0.03**	**0.01**	**0.01**	**0.15**	**0.17**	**0.19**	**0.23**	**0.72**	**1.23**	**0.36**	**0.22**	**0.27**	**0.30**	**0.44**	**0.45**	**0.45**
Maximum	**0.07**	**0.09**	**0.01**	**0.01**	**0.23**	**0.31**	**0.41**	**0.60**	**2.03**	**3.59**	**1.88**	**0.36**	**0.46**	**0.50**	**0.46**	**0.47**	**0.47**
Minimum	**0.01**	**0.01**	**0.00**	**0.00**	**0.07**	**0.10**	**0.06**	**0.10**	**0.20**	**0.27**	**0.13**	**0.11**	**0.16**	**0.18**	**0.42**	**0.43**	**0.43**

Table 4-15. Loadings of Total Phosphorous From Different Land Uses in the Upper St. Croix and Kettle River Watersheds for the Calibration Period

MET Segments	Total Phosphorous (lbs/ac-yr)																
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
Target	0.05–0.50				0.5–2.5				0.5–3.0			0.2–1.5			0.3–1.0		
20	0.06	0.10	0.04	0.04	0.32	0.34	0.31	0.34	1.51	2.69	0.83	0.47	0.57	0.61	0.51	0.52	
40	0.06	0.06	0.03	0.03	0.30	0.28	0.30	0.31	0.75	0.97	0.53	0.35	0.42	0.48	0.51	0.52	0.54
60	0.04	0.05	0.02	0.02	0.21	0.25	0.21	0.25	0.99	1.38	0.68	0.28	0.34	0.37	0.48	0.50	0.52
80	0.06	0.08	0.03	0.03	0.22	0.28	0.35	0.54	1.77	3.37	0.93	0.36	0.46	0.51	0.51	0.53	0.55
100	0.04	0.05	0.03	0.03	0.26	0.34	0.26	0.33	0.67	0.95	0.57	0.40	0.49	0.53	0.51	0.52	0.55
120	0.05	0.05	0.02	0.02	0.21	0.21	0.19	0.24	0.58	0.59	0.44	0.31	0.38	0.42	0.53	0.55	0.57
140	0.04	0.04	0.03	0.03	0.19	0.21	0.19	0.20	0.60	1.13	0.47	0.25	0.29	0.35	0.51	0.52	0.54
160	0.04	0.06	0.03	0.03	0.28	0.28	0.28	0.28	0.73	1.10	0.51	0.34	0.34	0.41	0.50	0.52	0.54
180	0.07	0.07	0.03	0.03	0.28	0.24	0.42	0.36	1.68	1.74	0.72	0.29	0.30	0.34	0.51	0.53	0.55
200	0.04	0.04	0.02	0.02	0.27	0.24	0.27	0.38	0.67	0.79	0.56	0.34	0.49	0.56	0.49	0.50	0.52
220	0.07	0.07	0.02	0.02	0.22	0.24	0.26	0.23	0.57	0.56	0.45	0.33	0.38	0.42	0.53		
240	0.03	0.04	0.03	0.03	0.15	0.21	0.15	0.20	0.51	0.56	0.41	0.24	0.31	0.30	0.51	0.52	0.55
260	0.04	0.05	0.02	0.02	0.16	0.25	0.22	0.41	1.17	1.89	0.41	0.28	0.34	0.34	0.49	0.51	0.53
280	0.04	0.05	0.03	0.03	0.21	0.30	0.30	0.41	1.01	1.78	0.64	0.27	0.34	0.39	0.51	0.52	0.54
300	0.03	0.04	0.03	0.03	0.18	0.23	0.24	0.26	0.90	1.26	0.51	0.24	0.31	0.34	0.49	0.51	0.53
320	0.02	0.03	0.02	0.02	0.14	0.23	0.24	0.36	0.74	1.87	0.38	0.23	0.27	0.34	0.48	0.50	0.52
340	0.05	0.04	0.02	0.02	0.23	0.17	0.34	0.22	2.34	1.10	0.67	0.28	0.34	0.34	0.51	0.52	0.54
360	0.03	0.03	0.02	0.02	0.13	0.16	0.12	0.16	0.54	0.95	0.38	0.19	0.25	0.30	0.50	0.52	0.54
380	0.04	0.04	0.02	0.02	0.25	0.17	0.25	0.16	0.66	0.57	0.42	0.32	0.41	0.46	0.50	0.51	0.53
400	0.06	0.06	0.03	0.03	0.28	0.25	0.27	0.23	0.96	2.00	0.52	0.34	0.45	0.52	0.50	0.51	0.54
420	0.04	0.05	0.02	0.02	0.19	0.23	0.23	0.22	0.68	0.89	0.48	0.30	0.34	0.38	0.49		
440	0.10	0.12	0.03	0.03	0.33	0.42	0.51	0.71	2.38	3.97	2.22	0.49	0.62	0.67	0.50	0.52	0.54
460	0.05	0.06	0.02	0.02	0.23	0.26	0.23	0.26	1.14	1.71	0.72	0.29	0.35	0.33	0.53	0.54	
480	0.05	0.07	0.02	0.02	0.27	0.32	0.27	0.33	1.60	3.42	0.98	0.39	0.49	0.55	0.51	0.53	0.55
500	0.05	0.07	0.03	0.03	0.28	0.26	0.28	0.32	0.82	1.23	0.51	0.38	0.46	0.43	0.53	0.54	0.56
Average	**0.05**	**0.06**	**0.03**	**0.03**	**0.23**	**0.25**	**0.27**	**0.31**	**1.04**	**1.54**	**0.64**	**0.32**	**0.39**	**0.43**	**0.50**	**0.52**	**0.54**
Maximum	**0.10**	**0.12**	**0.04**	**0.04**	**0.33**	**0.42**	**0.51**	**0.71**	**2.38**	**3.97**	**2.22**	**0.49**	**0.62**	**0.67**	**0.53**	**0.55**	**0.57**
Minimum	**0.02**	**0.03**	**0.02**	**0.02**	**0.13**	**0.16**	**0.12**	**0.16**	**0.51**	**0.56**	**0.38**	**0.19**	**0.25**	**0.30**	**0.48**	**0.50**	**0.52**

Table 4-16. Load Allocation Report for Total Phosphorous in the Snake River and St. Croix-Kettle Watersheds

Source	Snake River Watershed				St. Croix and Kettle River Watershed			
	Snake River–Cross Lake		Snake River at Outlet		Kettle River		St. Croix River	
	Annual Load (lbs)	Percent of Total	Annual Load (lbs)	Percent of Total	Annual Load (lbs)	Percent of Total	Annual Load (lbs)	Percent of Total
P[(a)]:Forest - AB	520	0.3	614	0.3	1,040	1.5	3,261	2.8
P:Forest - CD	19,842	10.4	19,998	10.1	8,688	12.1	19,265	16.4
P:Emerg Herb Wetland	2,608	1.4	2,638	1.3	1,384	1.9	2,154	1.8
P:Woody Wetlands	3,466	1.8	3,512	1.8	3,778	5.3	6,791	5.8
P:Grassland - AB	326	0.2	397	0.2	1,317	1.8	3,243	2.8
P:Grassland - CD	11,833	6.2	11,958	6.1	5,976	8.3	11,318	9.6
P:Pasture - AB	2,365	1.2	2,564	1.3	2,201	3.1	3,009	2.6
P:Pasture - CD	56,550	29.6	57,841	29.3	18,245	25.4	25,474	21.6
P:Cropland - AB	1,817	1.0	2,386	1.2	2,310	3.2	4,984	4.2
P:Cropland - CD	55,219	28.9	57,724	29.3	10,511	14.7	16,412	13.9
P:Cropland-Drained	15,552	8.1	15,996	8.1	2,630	3.7	4,419	3.8
P:Dev, Open Space	11,269	5.9	11,525	5.8	5,739	8.0	8,914	7.6
P:Dev, Low Intensity	1,969	1.0	1,973	1.0	553	0.8	595	0.5
P:Dev, Medium Intensity	601	0.3	600	0.3	201	0.3	215	0.2
I:Dev, Open Space	322	0.2	329	0.2	200	0.3	296	0.3
I:Dev, Low Intensity	271	0.1	271	0.1	89	0.1	96	0.1
I:Dev, Medium Intensity	377	0.2	376	0.2	147	0.2	156	0.1
Point Sources	5,570	2.9	5,920	3.0	6,185	8.6	6,470	5.5
Direct Atmospheric Deposition on the Reach	0	0.0	0	0.0	0	0.0	0	0.0
Mass Balance Differences/ Additional Sources[(b)]	10	0.0	10	0.0	7	0.0	11	0.0
Diversion	0	0.0	0	0.0	0	0.0	0	0.0
Cumulative Instream Losses	−30,075	−15.7	−30,762	−15.6	−13,421	−18.7	−16,068	−13.7
Cumulative Instream Gains	608	0.3	608	0.3	564	0.8	627	0.5
Total[(c)]	**191,096**	**100.0**	**197,243**	**100.0**	**71,766**	**100.0**	**117,707**	**100.0**

(a) P stands for pervious and I stands for impervious land uses.
(b) The additional sources may include sources other than nonpoint sources, point sources, atmospheric deposition, and upstream contribution.
(c) The total does not include losses because they have already been applied to the respective sources.

Table 4-17. Total Phosphorous Loads (Pounds) and Percentages From Various Sources in Each Watershed for the Calibration Period

Source	Upper St. Croix and Kettle Rivers		Snake River	
	Load	Percent	Load	Percent
Pervious	110,052	93.5	189,728	96.2
Impervious	606	0.5	977	0.5
Point Sources	6,470	5.5	5,920	3
Total	**117,707**	**100**	**197,243**	**100**

4.5 PHYTOPLANKTON

Phytoplankton is simulated in HSPF as a representation of algae that floats in the water of each RCHRES and is transported (advected) downstream with the flow. Biological activity of the aquatic ecosystem depends on the rate of primary production by these photosynthetic organisms, which in turn depends on the physical environment, including nutrient availability, temperature, and light. The process of photosynthesis consumes carbon-dioxide (CO_2) and releases oxygen (O_2), while the process of respiration consumes O_2 and releases CO_2. Phytoplankton consume the nutrients in water, and through assimilation, these nutrients are transformed into organic materials. These organic materials serve as a food source for higher trophic levels. The portion of organic matter not used for food decomposes, which further affects the nutrient and organic level in the water.

With excessive phytoplankton growth, much of the oxygen supply in the water may be depleted by decomposition of dead algae and by respiration. Phytoplankton, when excessive, can place a serious stress on the system. HSPF assumes that the entire phytoplankton population consists of a single species whose mean behavior is defined through a series of generalized mathematical formulations. The details on these formulations can be provided in the HSPF manual [Bicknell, et al., 2005].

Calibration of the concentration of phytoplankton is achieved through several parameters that control the conversion of one nutrient form to another and the release of these nutrients from the bed of the RCHRES. As with other water quality constituents, the calibration of phytoplankton is conducted in tandem with other nutrients as these nutrients interact with each other, and influence the phytoplankton simulation. The comparison of observed and simulated Chlorophyll *a* (Figure 4-16 and Figure 4-17) suggest an acceptable simulation of Chlorophyll *a*. Generally, the phytoplankton values of more than 10 micrograms per liter (µg/l) were observed in lakes and slow moving deep reaches only. The phytoplankton growth generally starts in middle to late spring and its decay starts in fall. The observed phytoplankton values are available for summer months only. Simulated data matches the pattern and the general trend of observed phytoplankton, however, the data cannot match the exact values as the phytoplankton concentration varies with the location and depth, but HSPF assumes the RCHRES to be a completely mixed reservoir.

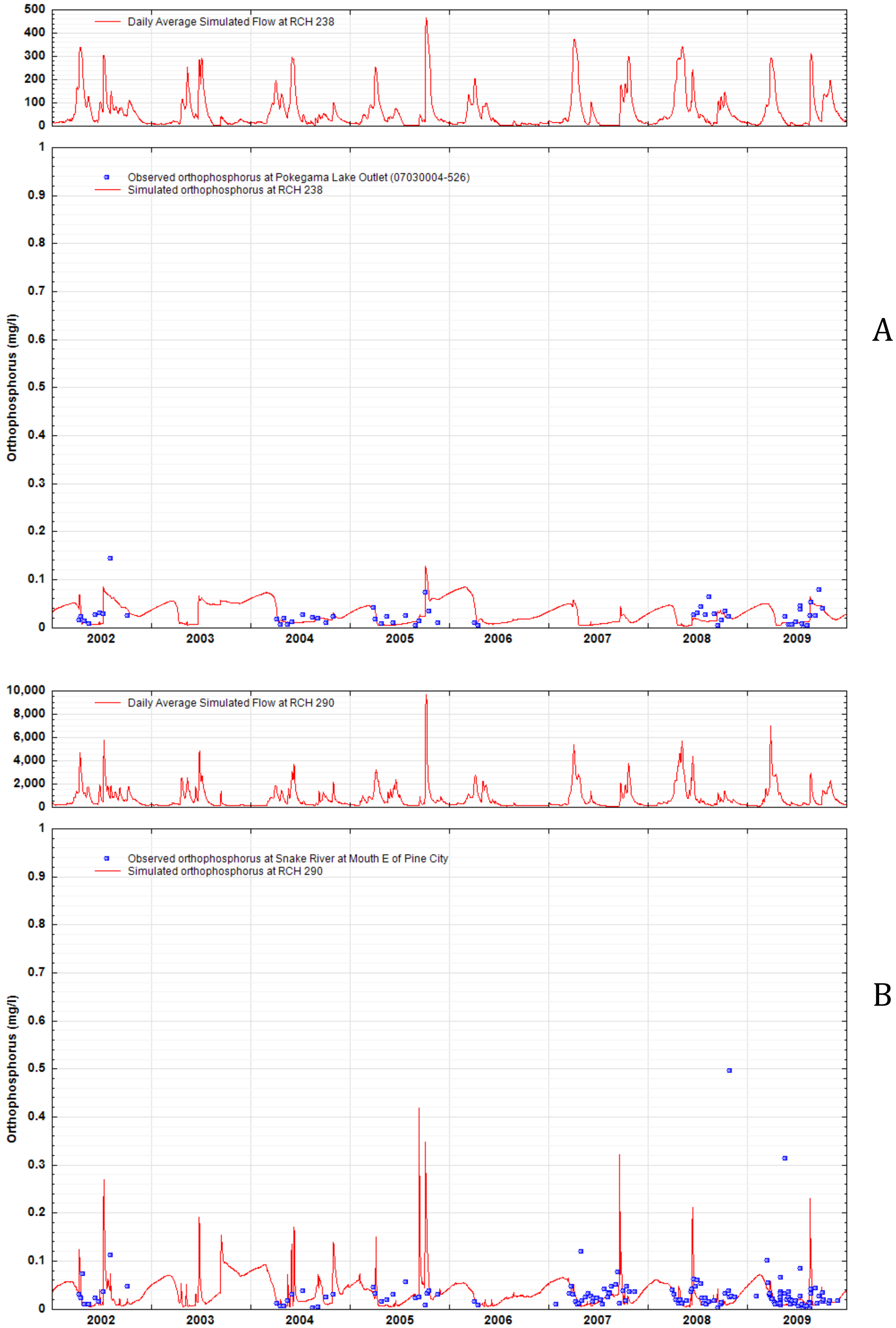


Figure 4-13. Observed and Daily Average Simulated Ortho-Phosphorus as Phosphorus at (a) Pokegama Lake (RCH238) and (b) Snake River Near the Watershed Outlet (RCH290).

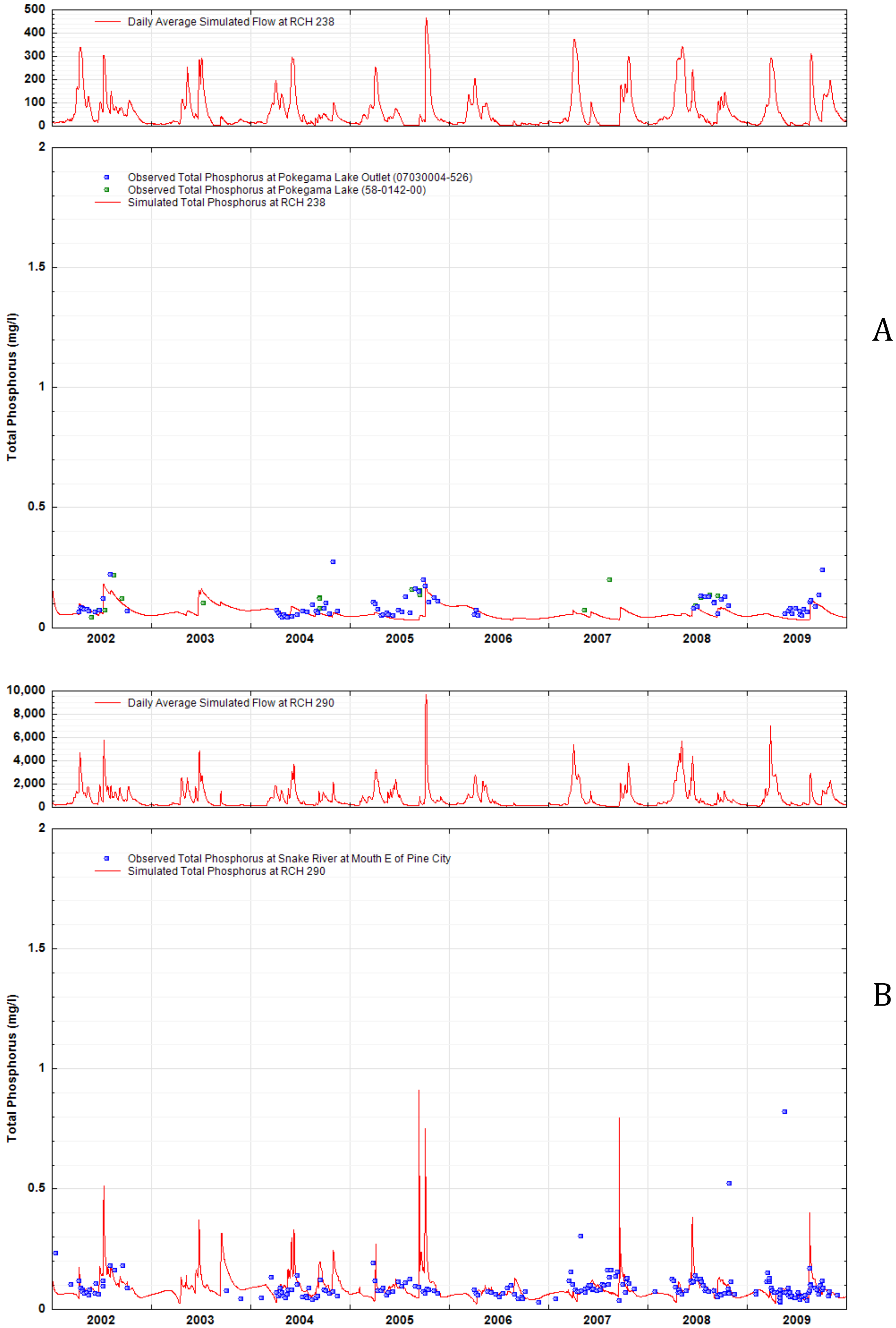


Figure 4-14. Observed and Daily Average Simulated Total Phosphorus as Nitrogen at (a) Pokegama Lake (RCH238) and (b) Snake River Near the Watershed Outlet (RCH290).

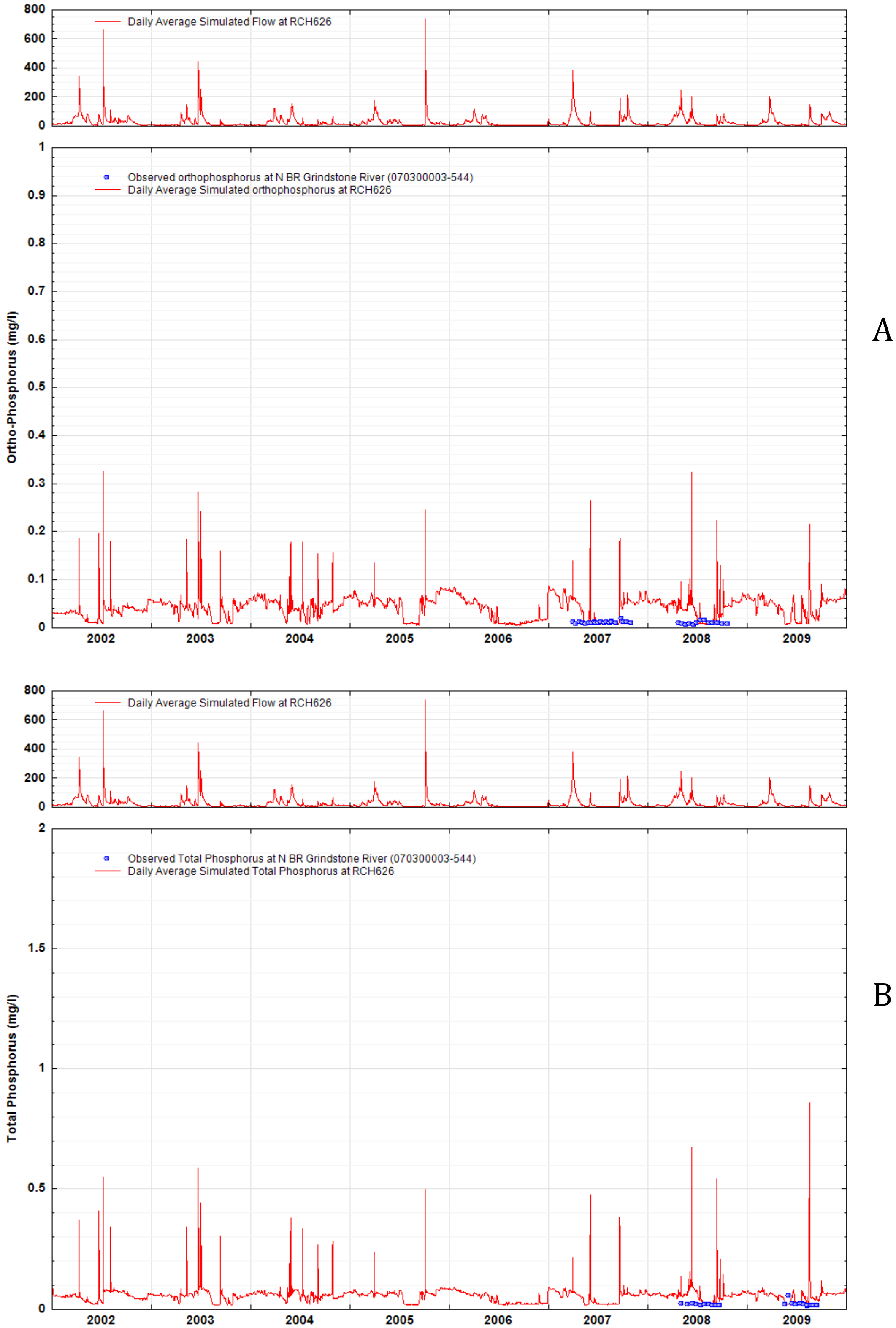
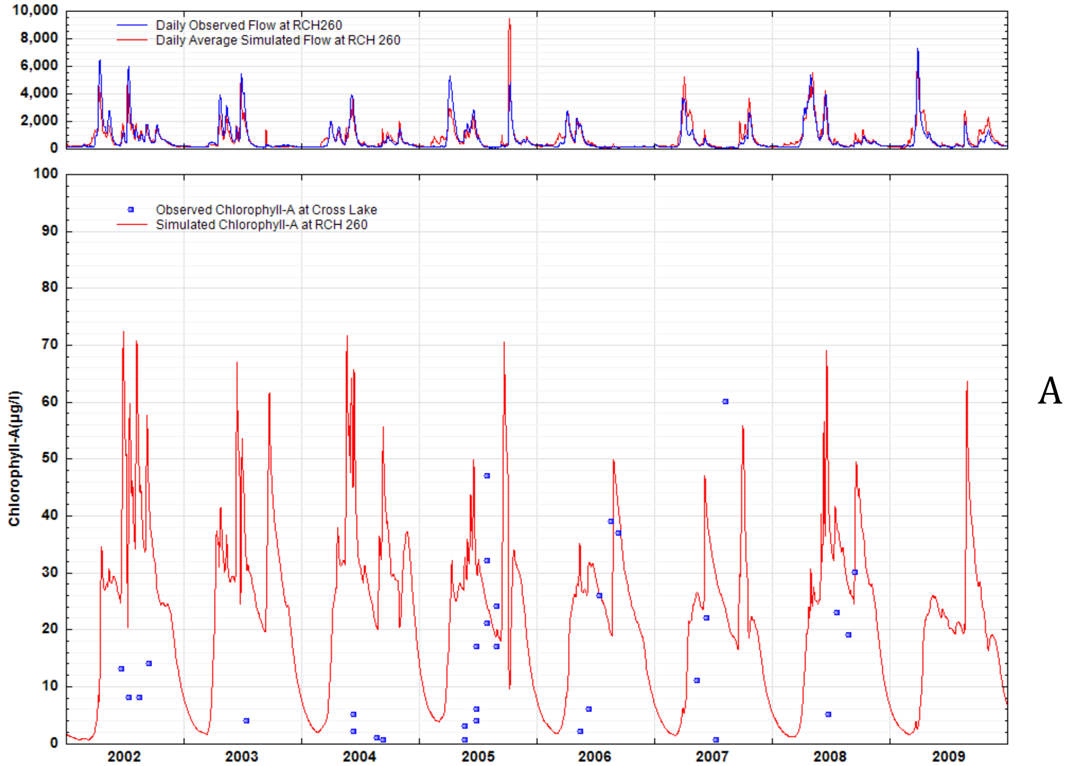


Figure 4-15. Observed and Daily Average Simulated (a) Ortho-Phosphorus as Phosphorus and (b) Total Phosphorus at N BR Grindstone River (RCH62) in the Kettle River Watershed.



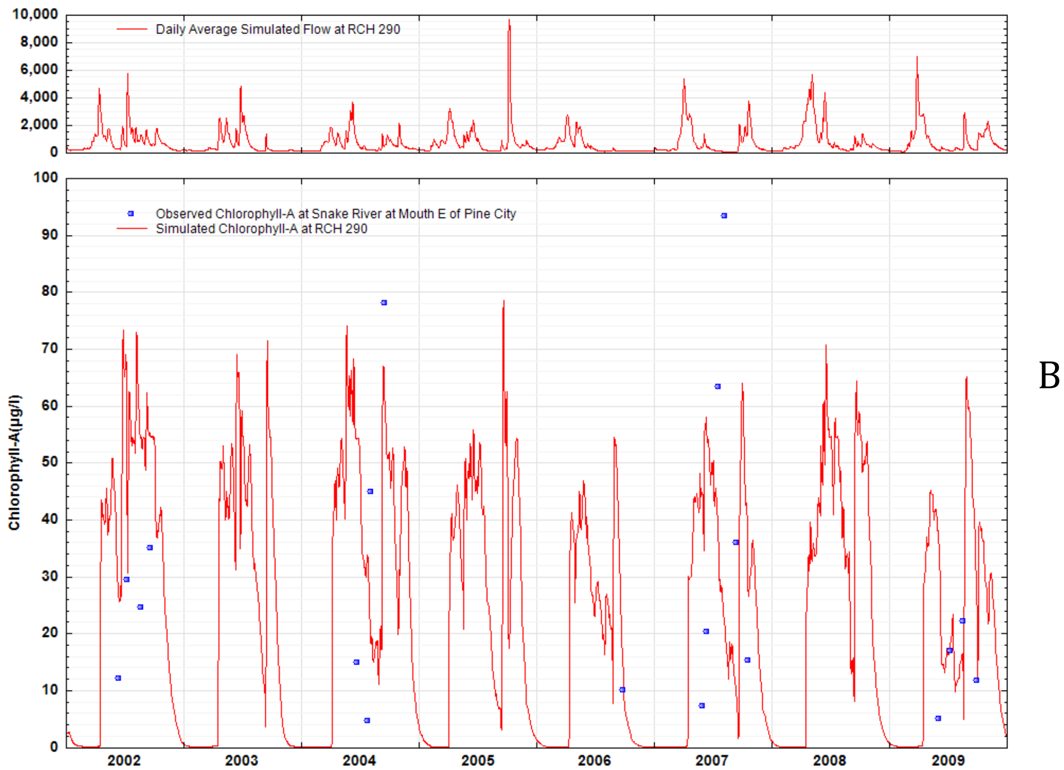


Figure 4-16. Observed and Daily Average Simulated Phytoplankton as Chlorophyll *a* at (a) Cross Lake Outlet (RCH260) and (b) Snake River Near the Watershed Outlet (RCH290).

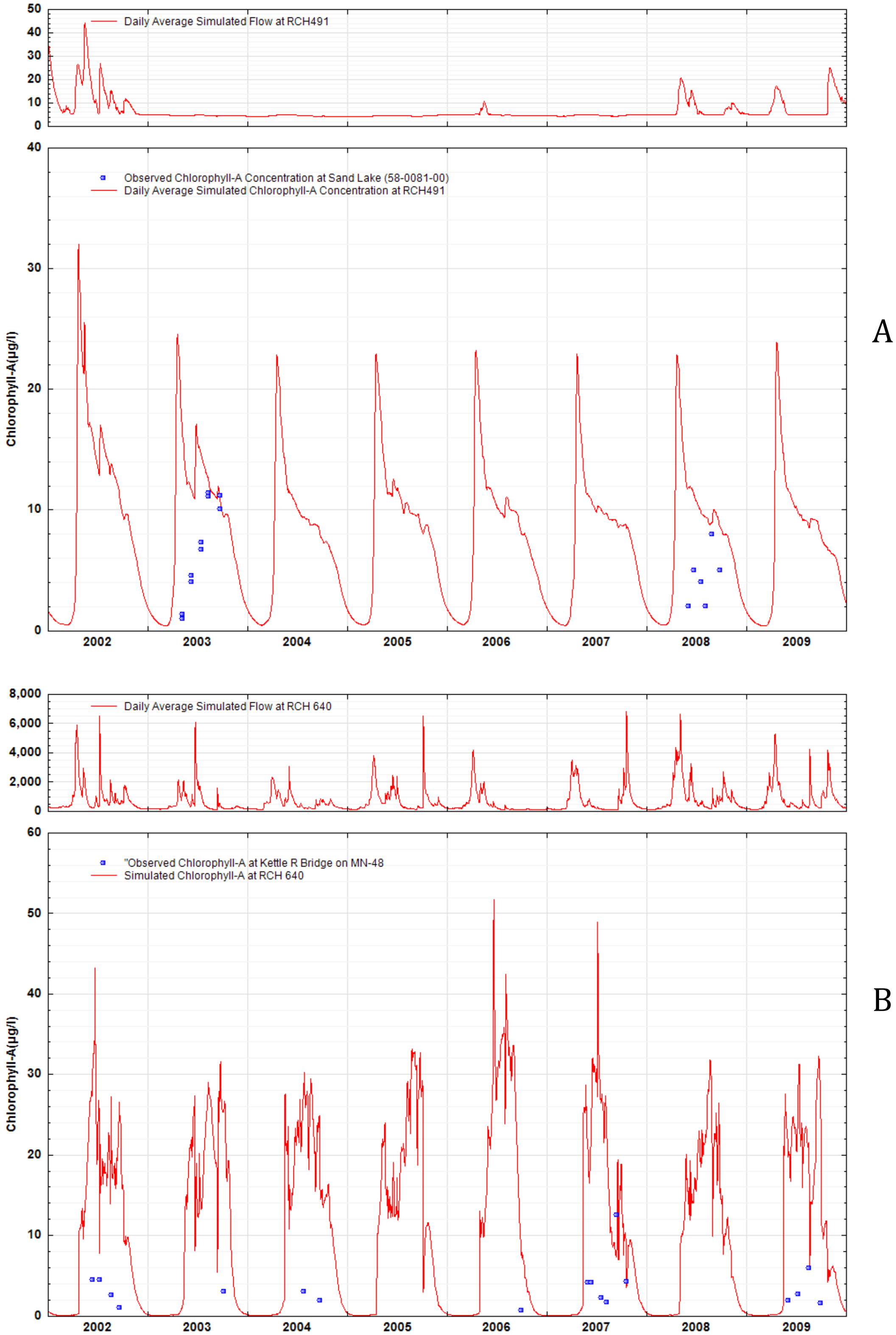


Figure 4-17. Observed and Daily Average Simulated Phytoplankton as Chlorophyll *a* at (a) Sand Lake Outlet (RCH491) and (b) Kettle River Bridge on MN-48 Outlet (RCH640).

As an additional test to evaluate the reasonableness of phytoplankton and benthic algae simulation, a graph of phytoplankton as Chlorophyll *a*, benthic algae, dissolved NO_3-N, dissolved NH_4-N, and dissolved PO_4-P was plotted at every reach (Figure 4-18 and Figure 4-19). This graph helped in evaluating whether or not the concentration of all the constituents are at near-reasonable levels for the entire simulation period and do not demonstrate an increasing or decreasing pattern throughout the period of simulation. As illustrated in the Figure 4-18, the benthic algae concentration is generally negligible in lakes (RCH260), but higher in streams (RCH290). The lakes are generally deeper and lack enough light to grow benthic algae. The concentration of nutrients cycles through different seasons, with decreases in summers as phytoplankton growth consumes the nutrients. None of the nutrients in all the 108 reaches in the Snake Watershed model, and 180 reaches in the STC-Kettle model illustrated any unreasonable increase or decrease for the period of simulation. The results suggest a reasonable water quality simulation during the calibration time period of 2002 to 2009.

4.6 WATER QUALITY VALIDATION

Following a satisfactory water quality calibration, the water quality validation process began. The time period for the water quality validation was same as the hydrology validation time period (1995–2001). For the water quality validation period, the loading rates of all the nutrients were generated similar to the calibration period (Table 4-18 to Table 4-21) and water quality graphs were generated at all the locations where observed data were available. Water quality calibration was revisited when the water quality graphs during the validation period did not show reasonable simulation of water quality constituents. The loading rates of nutrients are generally in the target ranges, which is similar to the calibration period.

The observed instream water quality data during the validation period was not available for as many locations as during the calibration period. The frequency of observed data was also less during the validation period. Figure 4-20 depicts the comparison of observed and simulated Chlorophyll *a* at two locations in the Snake River Watershed. Additional graphs showing the comparison of observed and simulated instream water quality data are available in the accompanying deliverable folder. In general, the simulated data replicates the trend and range of observed data reasonably well.

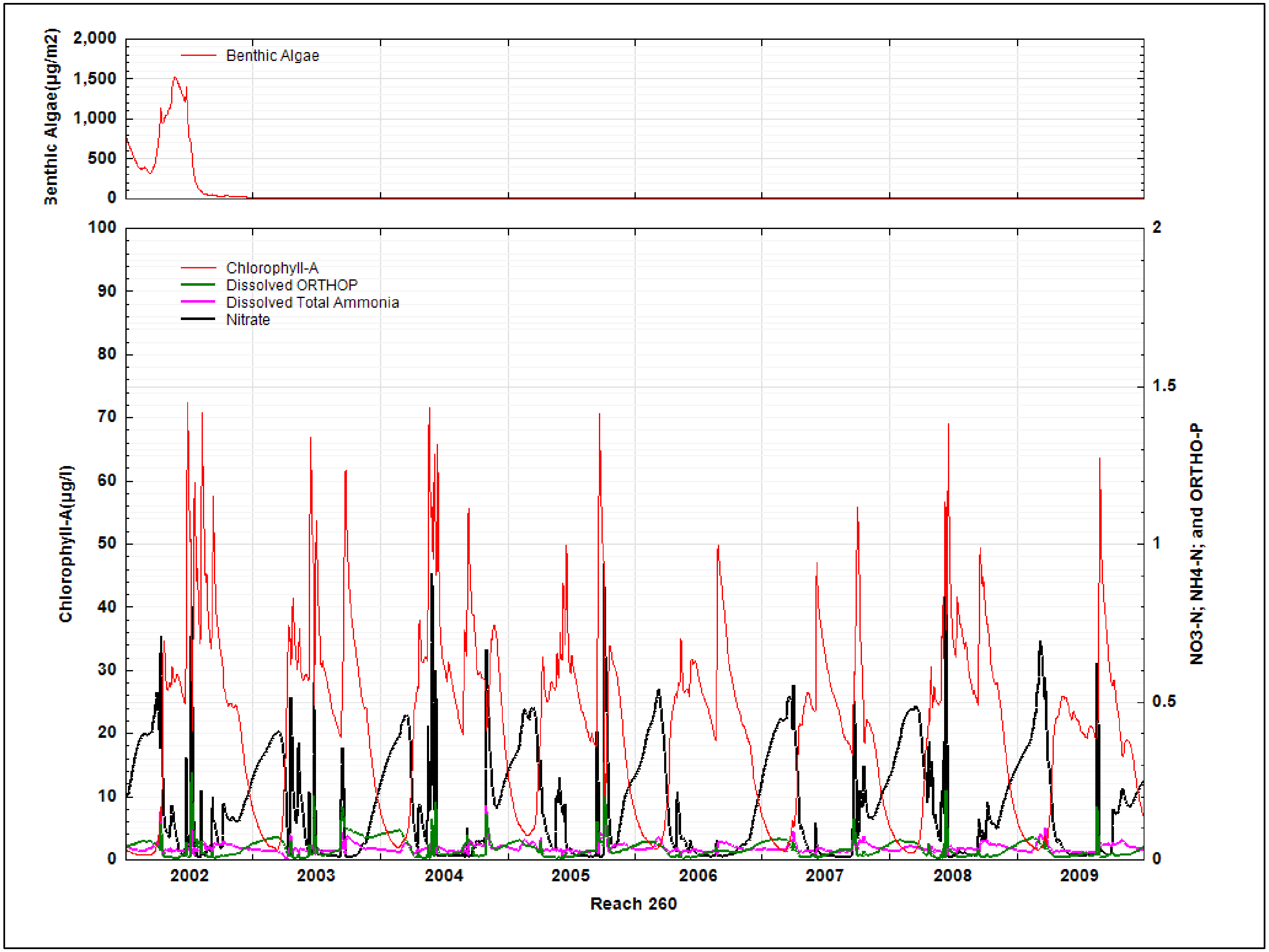


Figure 4-18. Daily Average Simulated Phytoplankton as Chlorophyll *a*, Benthic Algae, Dissolved Nitrate-N, Ammonia-N, and Ortho-Phosphorus-P at Cross Lake Outlet (RCH260).

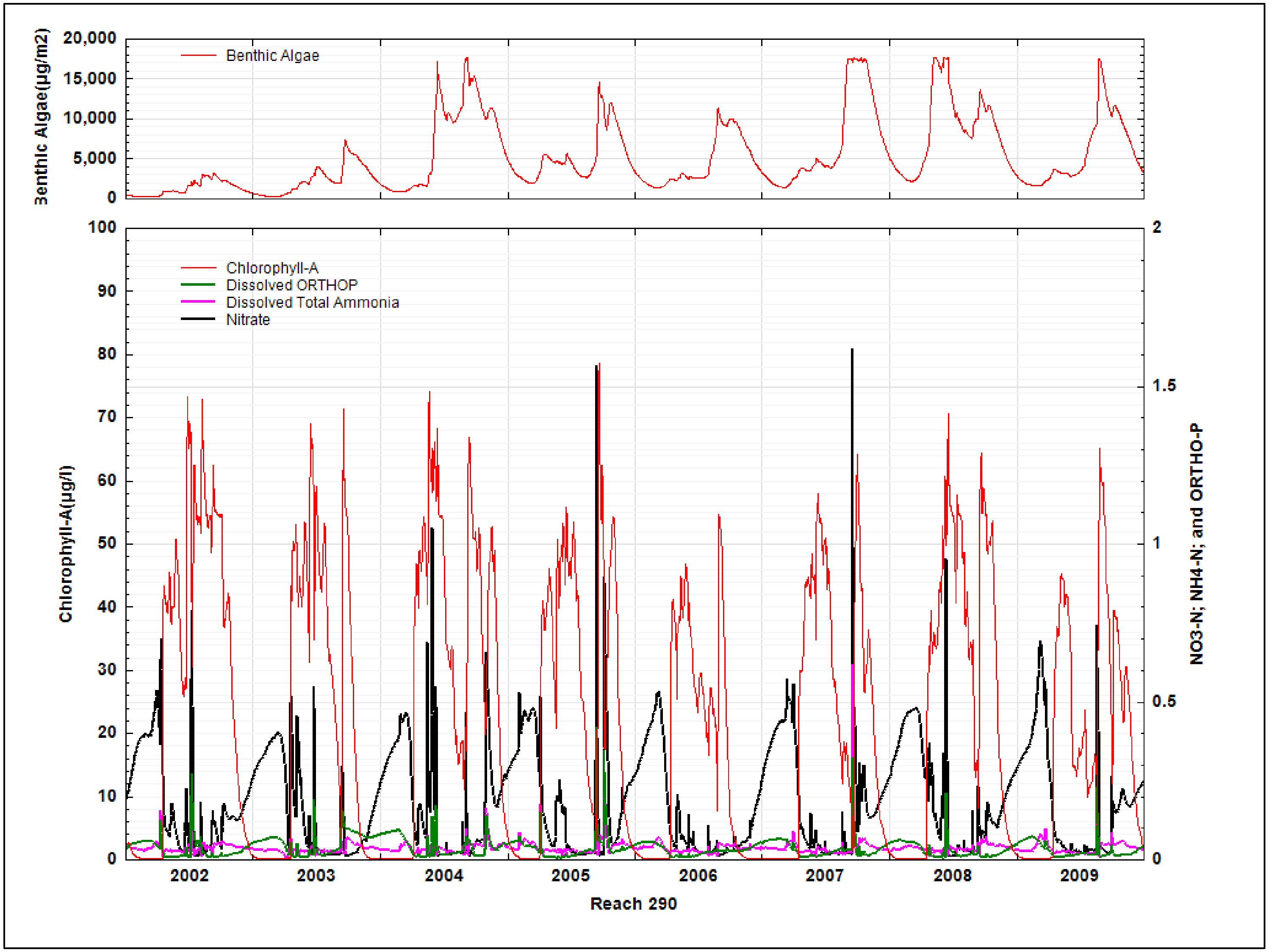


Figure 4-19. Daily Average Simulated Phytoplankton as Chlorophyll *a*, Benthic Algae, Dissolved Nitrate-N, Ammonia-N, and Ortho-Phosphorus-P at Snake River Outlet (RCH290).

Table 4-18. Loadings of Nitrogen and Its Components From Different Land Uses in the Snake River Watershed for the Validation Period

	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
	NO_3-N (lbs/ac-yr)																
Average	0.15	0.16	0.12	0.12	0.96	1.07	0.98	1.10	3.79	5.60	3.51	2.21	3.26	3.87	3.78	4.01	4.47
Maximum	0.20	0.23	0.15	0.15	1.20	1.33	1.39	1.53	5.55	7.71	4.78	2.58	3.83	4.61	4.02	4.26	4.74
Minimum	0.12	0.12	0.09	0.09	0.79	0.85	0.78	0.85	2.89	3.94	2.66	1.78	2.48	2.91	3.62	3.84	4.30
Target	**1–5**				**1–15**				**10–30**			**3–10**			**2–5**		
	NH_4-N (lbs/ac-yr)																
Average	0.10	0.11	0.12	0.08	0.25	0.30	0.25	0.30	0.36	0.51	0.32	0.86	0.94	1.01	2.46	2.53	2.62
Maximum	0.14	0.14	0.15	0.10	0.33	0.40	0.34	0.38	0.53	0.76	0.43	0.98	1.07	1.19	2.73	2.80	2.90
Minimum	0.08	0.08	0.09	0.06	0.20	0.24	0.20	0.24	0.27	0.36	0.26	0.70	0.73	0.73	2.29	2.36	2.45
Target	**0.1–1.0**				**0.2–1.5**				**0.5–2.0**			**0.2–2.0**			**0.5–1.5**		
	TN (lbs/ac-yr)																
Average	0.5	0.5	0.4	0.4	2.1	2.4	2.2	2.4	7.7	9.5	6.9	4.3	5.6	6.4	9.1	9.1	9.1
Maximum	0.7	0.8	0.5	0.5	2.7	3.0	2.9	3.2	10.3	12.5	8.9	5.1	6.7	7.5	9.7	9.7	9.7
Minimum	0.4	0.4	0.3	0.3	1.8	1.9	1.7	1.9	6.2	7.2	5.6	3.5	4.4	4.9	8.6	8.6	8.6
Target	**2–8**				**2–25**				**10–50**			**5–15**			**3–10**		

Table 4-19. Loadings of Nitrogen and Its Components From Different Land Uses in the St. Croix and Kettle River Watersheds for the Validation Period

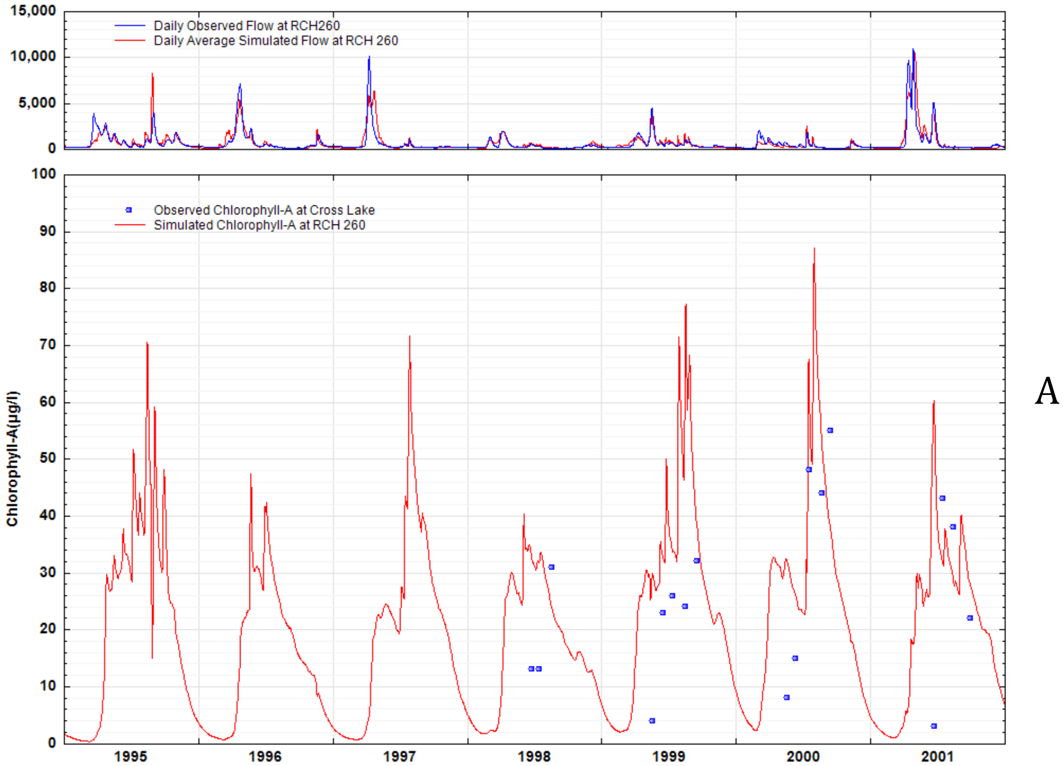
	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed Open Space	Developed Low Intensity	Developed Medium Intensity
	NO_3-N (lbs/ac-yr)																
Average	0.20	0.22	0.15	0.15	1.11	1.24	1.15	1.31	5.12	7.81	4.92	2.48	3.70	4.39	3.84	4.07	4.52
Maximum	0.27	0.30	0.20	0.20	1.38	1.54	1.54	1.79	7.26	11.13	6.76	3.19	4.65	5.44	4.05	4.28	4.75
Minimum	0.13	0.14	0.10	0.10	0.77	0.88	0.86	1.01	3.63	5.58	3.36	1.83	2.72	3.10	3.59	3.81	4.26
Target	**1–5**				**1–15**				**10–30**			**3–10**			**2–5**		
	NH_4-N (lbs/ac-yr)																
Average	0.13	0.14	0.10	0.10	0.30	0.36	0.30	0.36	0.48	0.69	0.46	0.97	1.08	1.15	2.57	2.64	2.73
Maximum	0.20	0.22	0.13	0.13	0.42	0.49	0.42	0.50	0.70	1.05	0.67	1.26	1.39	1.46	2.84	2.90	3.00
Minimum	0.09	0.10	0.07	0.07	0.20	0.25	0.21	0.25	0.34	0.44	0.32	0.71	0.80	0.64	2.30	2.38	2.46
Target	**0.1–1.0**				**0.2–1.5**				**0.5–2.0**			**0.2–2.0**			**0.5–1.5**		
	TN (lbs/ac-yr)																
Average	0.64	0.69	0.50	0.50	2.47	2.67	2.52	2.75	9.83	12.49	9.10	4.80	6.34	7.26	7.38	7.78	8.42
Maximum	0.86	0.91	0.65	0.66	3.06	3.50	3.21	3.67	12.58	16.66	12.00	6.13	7.98	9.05	7.87	8.27	8.95
Minimum	**0.43**	**0.47**	**0.33**	**0.33**	**1.70**	**1.97**	**1.82**	**2.13**	**7.16**	**9.38**	**6.50**	**3.53**	**4.68**	**5.33**	**6.85**	**7.25**	7.88
Target	**2–8**				**2–25**				**10–50**			**5–15**			**3–10**		

Table 4-20. Loadings of Ortho-Phosphorus and Total Phosphorus From Different Land Uses in the Snake River Watershed for the Validation Period

	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity
	Ortho-P (lbs/ac-yr)																
Average	0.02	0.02	0.01	0.01	0.11	0.16	0.13	0.19	0.50	0.93	0.15	0.17	0.21	0.24	0.41	0.42	0.43
Maximum	0.03	0.05	0.01	0.01	0.18	0.24	0.32	0.39	1.44	2.02	0.31	0.23	0.29	0.35	0.44	0.45	0.46
Minimum	0.01	0.01	0.00	0.00	0.08	0.08	0.08	0.08	0.16	0.25	0.11	0.10	0.14	0.14	0.39	0.40	0.41
Target	**0.02–0.10**				**0.2–2.0**				**0.3–2.0**			**0.1–1.0**			**0.2–0.7**		
	Total P (lbs/ac-yr)																
Average	0.03	0.04	0.02	0.02	0.18	0.24	0.20	0.26	0.77	1.18	0.39	0.25	0.31	0.35	0.56	0.56	0.56
Maximum	0.06	0.08	0.03	0.03	0.26	0.34	0.41	0.49	1.75	2.34	0.57	0.35	0.42	0.47	0.57	0.57	0.57
Minimum	0.02	0.02	0.02	0.02	0.14	0.15	0.14	0.14	0.41	0.50	0.31	0.17	0.23	0.23	0.53	0.53	0.53
Target	**0.05–0.50**				**0.5–2.5**				**0.5–3.0**			**0.2–1.5**			**0.3–1.0**		

Table 4-21. Loadings of Ortho-Phosphorus and Total Phosphorus From Different Land Uses in the Upper St. Croix and Kettle River Watersheds for the Validation Period

	Pervious Land Uses														Impervious Land Uses		
	Forest AB	Forest CD	Emergent Herb Wetland	Woody Wetlands	Grassland AB	Grassland CD	Pasture AB	Pasture CD	Cropland AB	Cropland CD	Cropland Drained	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity	Developed, Open Space	Developed Low Intensity	Developed Medium Intensity
	Ortho-P (lbs/ac-yr)																
Average	0.03	0.03	0.01	0.01	0.14	0.16	0.17	0.21	0.69	1.10	0.33	0.19	0.24	0.26	0.43	0.44	0.44
Maximum	0.05	0.06	0.01	0.01	0.21	0.28	0.36	0.46	2.17	3.44	1.33	0.28	0.36	0.38	0.46	0.47	0.47
Minimum	0.01	0.02	0.00	0.00	0.07	0.08	0.09	0.09	0.16	0.31	0.15	0.13	0.16	0.13	0.41	0.42	0.42
Target	**0.02—0.10**				**0.2—2.0**				**0.3—2.0**			**0.1—1.0**			**0.2—0.7**		
	Total P (lbs/ac-yr)																
Average	0.05	0.06	0.03	0.03	0.22	0.24	0.25	0.29	1.01	1.41	0.61	0.29	0.35	0.39	0.50	0.51	0.53
Maximum	0.08	0.10	0.03	0.04	0.30	0.40	0.44	0.57	2.52	3.78	1.64	0.40	0.49	0.52	0.52	0.54	0.56
Minimum	0.03	0.04	0.02	0.02	0.12	0.14	0.15	0.15	0.46	0.56	0.43	0.20	0.25	0.25	0.47	0.48	0.50
Target	**0.05—0.50**				**0.5—2.5**				**0.5—3.0**			**0.2—1.5**			**0.3—1.0**		



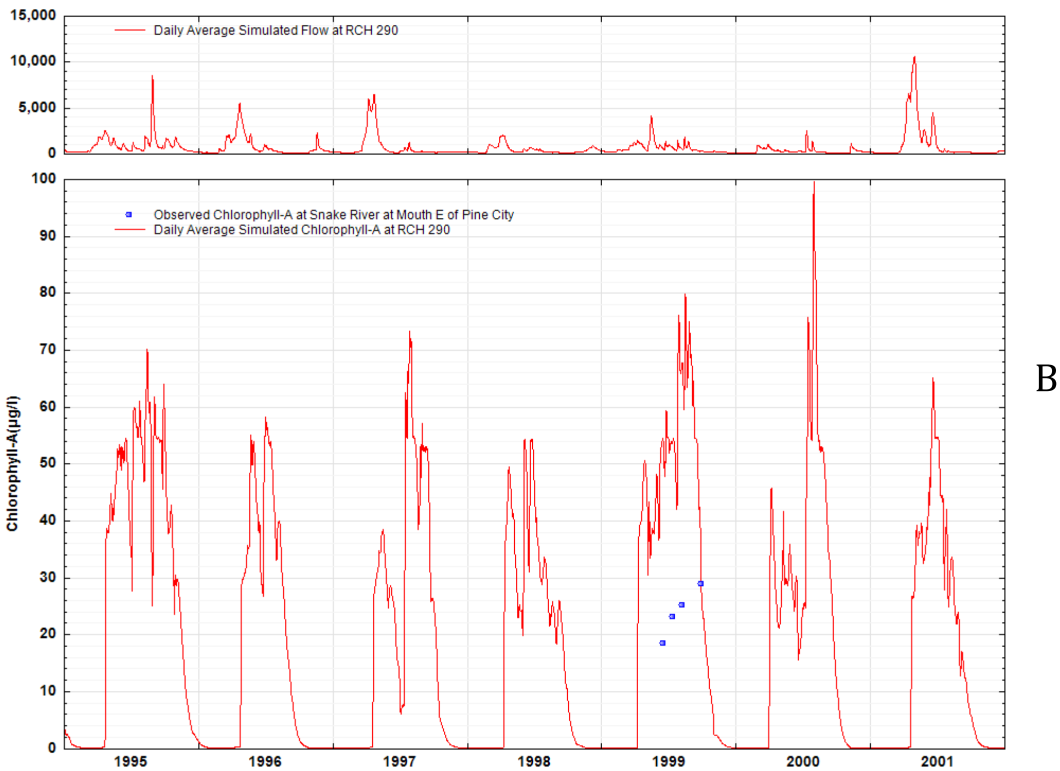


Figure 4-20. Observed and Daily Average Simulated Phytoplankton as Chlorophyll-A at (a) Cross Lake Outlet (RCH260) and (b) Snake River Near the Watershed Outlet (RCH290).

5.0 SUMMARY AND CONCLUSIONS

RESPEC and AQUA TERRA Consultants (acquired by RESPEC in September 2015) were contracted to construct and apply the BASINS/HSPF model to the Upper St. Croix River (MN portion), Kettle River, and Snake River Watersheds. Two separate models were constructed: (1) to simulate the Snake River Watershed and (2) to simulate the Upper St. Croix River and Kettle River (STC-Kettle) Watersheds. These models can simulate hydrology and several water quality constituents, including temperature, N, P, organics, and DO. The calibration and validation time period of these models were set up to be 2002 to 2009, and 1995 to 2001, respectively. The hydrology calibration and validation of the Snake River Watershed model was satisfactory and is acceptable for water quality calibration and validation. The hydrology calibration of STC-Kettle Watershed model was deemed satisfactory, but its validation was not acceptable. Note that the volume of runoff during validation was 25 percent greater than during the calibration time period with no significant change in rainfall amount. Additional research into the issue yielded no specific reason for this discrepancy. The STC-Kettle model was also deemed satisfactory for water quality calibration.

The sediment-calibration process started with sediment apportionment and the establishment of sediment loading rates for different land-use categories. The calibration and validation of sediment loading rates from different land uses was reasonable and acceptable. In general, the sediment loading rates from most land uses were at the lower end of the target range. The sediment apportionment suggested more than 90 percent of sediment loading from field sources with the remaining from instream sources, as compared to a postulated sediment apportionment of 80 percent from field sources and 20 percent from instream sources. Discussion with the MPCA staff suggested that the 90 percent of sediment loadings from field and 10 percent from instream sources is a more appropriate apportionment for this watershed as most of the streams are non-erosive in this region.

The graphical comparison of TSS concentrations suggested that the simulated TSS concentrations are within the range of the observed data for the calibration and validation periods. However, the TSS concentrations were not available for most storm periods; therefore, establishing how well the model performed during the storm events is difficult. The discussion with the MPCA staff suggested that the TSS concentrations did not rise to a magnitude to a 1,000 mg/l during the storm events, so concentrations in this range may be overestimated by the model.

Nonpoint calibration was conducted by comparing the nonpoint loading rates with the target loading rates for MN compiled by AQUA TERRA Consultants [2015b]. Almost all the nonpoint loading rates were within the target loading rate ranges for the calibration and validation time periods. Loading rates for sediment and some nutrients were generally lower than the target ranges, as well. The instream water quality calibration suggested lower loading rates of nutrients; therefore, the concentration of these nutrients was reduced in interflow and groundwater.

The instream water quality calibration and validation followed suit with the nonpoint loading rates calibration. Instream water quality calibration included the calibration of sediment, water temperature, dissolved oxygen, nitrogen, phosphorus, and phytoplankton as chlorophyll a. Water quality data were available for multiple locations in the watershed. Although the water quality data were not sufficient to conduct a detailed statistical analysis, observing ranges and trends at different parts of the watershed was sufficient. Graphs comparing observed and simulated water quality data were prepared at all the locations where observed data were available. Additional graphs at all the locations were prepared to verify that the nutrient concentrations in all the stream are stable. The water quality calibration and validation were satisfactory.

The final hydrology and water quality model for the Upper St. Croix River, Kettle River, and Snake River Watersheds can be used for TMDL and WRAPS development. As more water quality data becomes available, it is recommended that the model be extended and refined to allow further calibration and thereby increase the confidence in the water quality simulation.

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