Watershed

February 2023

Draft Redwood River Watershed Total Maximum Daily Load Report

Watershed-wide TMDLs covering TSS, *E. coli*, chloride, and lake nutrient impairments in the Redwood River Watershed located in the greater Minnesota River Basin

MINNESOTA POLLUTION CONTROL AGENCY

CLEAN WATER LAND & LEGACY AMENDMENT

Authors and Contributors

Jeff Strom, Stantec (prior to November 2021) and MPCA (November 2021 to present)
Rena Weis, Stantec
Hagen Kaczmarek, Stantec
Tom Berry, Stantec
Aaron Claus, Stantec
Kerry Netzke, RCRCA
Shawn Wohnoutka, RCRCA
Mike Weckwerth, MPCA
Mark Hanson, MPCA
Scott MacLean, MPCA
Heather Johnson, MPCA

Contributors/acknowledgements

Marco Graziani, MPCA
Dennis Wasley, MPCA

Editing

Jinny Fricke, MPCA (Public Notice_2.1.23)

Cover Picture Credit

Shawn Wohnoutka, RCRCA
Location: Redwood River near Redwood Falls, Minnesota

Document number: wq-iw7-59b

Contents

List of Tables

List of Figures

Acronyms

1W1P	One Watershed, One Plan
AF	Anoxic factor
AFO	animal feeding operation
AU	animal unit
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
CWF	Clean Water Fund
CWP	Clean Water Partnership
DEM	Digital elevation model
DMR	discharge monitoring reports
DNR	Minnesota Department of Natural Resources
DO	Dissolved oxygen
E. coli	Escherichia coli
EPA	U.S. Environmental Protection Agency
FTPGW	fail to protect groundwater
GIS	Geographic Information System
HSPF	Hydrologic Simulation Program-Fortran
HUC	Hydrologic Unit Code
IBI	Index of Biotic Integrity
ITPHS	imminent threat to public health and safety
IWM	Intensive watershed monitoring
km^2	square kilometer
LA	load allocation
Lb	pound
lb/day	pounds per day

lb/yr	pounds per year
LDC	load duration curve
LGU	Local Government Unit
LiDAR	Light Detection and Ranging
LWG	Local Work Group
m	meter
MAWQCP	Minnesota Agricultural Water Quality Certification Program
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
mg/L	milligrams per liter
mg/m2-day	milligram per square meter per day
MMU	Marshall Municipal Utilities
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer System
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NRS	Nutrient Reduction Strategy
NTU	nephelometric turbidity units
PFA	Public Facilities Authority
PSIG	Point source implementation grant
RCRCA	Redwood Cottonwood River Control Area
RR	release rate
S-tube	Secchi tube
SAV	submerged aquatic vegetation
SDS	State Disposal System
SID	stressor identification
SIETF	SSTS Implementation and Enforcement Task Force
SONAR	Statement of Need and Reasonableness
SRF	state revolving fund

SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation District
SWPPP	Stormwater Pollution Prevention Plan
TALU	tiered aquatic life uses
TMDL	total maximum daily load
TP	total phosphorus
TSS	total suspended solids
μg/L	microgram per liter
USGS	United States Geological Survey
WASCOB	Water and sediment control basin
WCBP	Western Cornbelt Plain
WLA	wasteload allocation
WQBEL	Water quality based effluent limit
WRAPS	Watershed Restoration and Protection Strategy
WTP	Water Treatment Plant
WWTP	Wastewater Treatment Plant

Executive Summary

Redwood River Watershed Monitoring and Assessment Approach

Intensive watershed monitoring (IWM) and stressor identification (SID) were completed between 2017 and 2020 for the Redwood River Watershed, which is in the Minnesota River Basin (MPCA 2020a). Thirty-five river/stream reaches were assessed for their ability to support aquatic life and/or aquatic recreation. Of the assessed river/stream reaches, only seven were fully supporting of aquatic life and none fully supported aquatic recreation. Of the 18 lakes assessed in the Redwood River Watershed, 6 were determined to be impaired by nutrients (total phosphorus (TP)). Based on previous and current monitoring assessment data, there are 9 turbidity/total suspended solids (TSS) impaired river/stream reaches, 13 bacteria impaired river/stream reaches, 18 macroinvertebrate Index of Biotic Integrity (IBI) impaired river/stream reaches, 16 fish IBI impaired river/stream reaches, 1 chloride impaired river/stream reach, and 1 river eutrophication impaired river/stream reach within the Redwood River Watershed. For the remainder of this Total Maximum Daily Load (TMDL) report, the river/stream reach(es) will be referred to as just “reach(es)”.

Overview of this TMDL

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. This TMDL report is a continuation of previously completed TMDLs in the Redwood River Watershed that have been approved by the U.S. Environmental Protection Agency (EPA) Region 5. The Redwood River Fecal Coliform TMDL Report (RCRCA 2013) addressed nine impaired stream reaches and was approved in January 2014. Prior to the fecal coliform TMDL, the state of Minnesota submitted a state-wide TMDL to address mercury in fish which covered six reaches in the Redwood River Watershed and was approved in March 2007 (MPCA 2007a). In 2020, EPA Region 5 approved the Minnesota River and Greater Blue Earth River Basin TSS TMDL Study (MPCA 2020b) which included a TSS TMDL for Redwood River reach 501.

This TMDL report addresses nine turbidity/TSS impaired reaches, two bacteria impaired reaches, one chloride impaired reach, and six nutrient impaired lakes in the Redwood River Watershed. One river eutrophication impaired reach will have a TMDL developed independently from this TMDL report. The 18 macroinvertebrate IBI impaired reaches, and 15 fish IBI impaired reaches in the Redwood River Watershed are not addressed in this TMDL and will be deferred at this time 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 Redwood River Watershed Restoration and Protection Strategies (WRAPS) Report and local water planning efforts. Addressing multiple impairments in this TMDL report 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.

Turbidity/Total Suspended Solids Impairments

In 2014, Minnesota adopted new water quality standards for TSS that replaced the turbidity standard. The turbidity and TSS TMDLs in this report were developed using the TSS standard.

Hydrologic Simulation Program – Fortran (HSPF) simulated flow and TSS output were used to establish load duration curves (LDCs) for the nine TSS impairments covered in this TMDL. The curve displays the Class 2B TSS standard of 65 mg/L. TMDLs, which include wasteload allocations (WLAs), load allocations (LAs), and margin of safety (MOS) were established for five flow zones along the flow duration curve: very high, high, mid, low, and very low flow conditions. Sediment sources were assessed for the TSS impaired reaches which indicates loading is primarily driven by near-channel sources (i.e., bed, bank, ravine erosion) and upland erosion. Implementation activities should focus on upland best management practices (BMPs) to reduce soil erosion in highly erodible cropland areas and restoring and increasing water storage opportunities throughout the watershed to decrease peak discharge rates.

Bacteria (E. coli and Fecal Coliform) Impairments

HSPF simulated flow and monitored bacteria data for the two bacteria impaired reaches were used to establish LDCs. The curves were set to meet the *Escherichia coli* (*E. coli*) standard of no more than 126 organisms per 100 mL. TMDLs that include WLAs, LAs, and MOS for the bacteria impaired reaches were established for the five flow zones described in the previous paragraph. A bacteria source assessment exercise indicates livestock is by far the largest producer of bacteria in the bacteria impaired reach watersheds. However, monitoring data suggests exceedances during low-flow conditions, suggesting failing subsurface sewage treatment systems (SSTS) and/or livestock animals in the stream corridors are important sources during certain hydrologic conditions. Implementation activities will need to focus on feedlot and pasture manure management BMPs, livestock exclusion from waterways, and SSTS upgrades.

Chloride Impairment

HSPF simulated flow and monitored data for the chloride impaired reach were used to establish LDCs. The curve was set to meet the chloride standard of no more than 230 mg/L. TMDLs that include WLAs, LAs, and MOS for the chloride impaired reach was established for the five flow zones described above. The chloride monitoring data suggests elevated chloride levels in the impaired reach are driven by two wastewater dischargers, Archer Daniels Midland (ADM) and City of Marshall are currently covered by National Pollutant Discharge Elimination System (NPDES) permits. Implementation activities for these dischargers will need to focus on keeping chloride (salt) from entering the wastewater in the first place. To do this, the City of Marshall began introducing a lime softening process that added soda ash to reduce water hardness. The long-term goal is to reduce water hardness entering the city's wastewater plant by 88%. As of the fall of 2019, the City of Marshall has reduced incoming water hardness by 30%.

Lake Nutrient Impairments

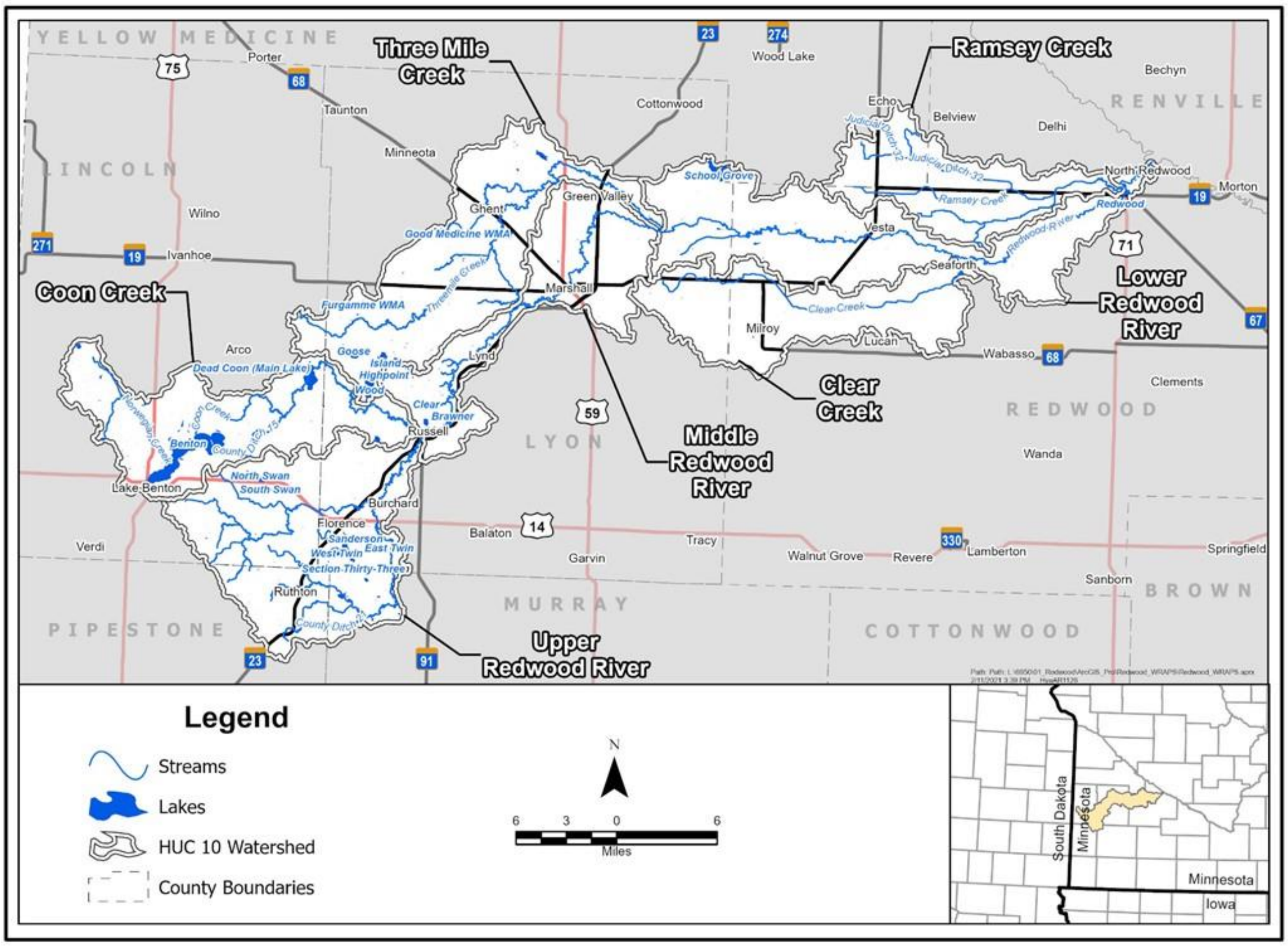
Nutrient budgets and lake response models were developed for the six nutrient impaired lakes in the Redwood River Watershed covered in this TMDL report. The HSPF model was used along with in-lake monitoring data to develop nutrient budgets for each lake and set up the lake response models and TMDL equations. Pollutant source assessment for these lakes indicates all the lakes require phosphorus reductions from both internal and external (watershed) sources. For some of the lakes, internal load is a significant source of phosphorus and in-lake efforts will be important to achieve water quality standards. Watershed implementation activities will need to focus on upland BMPs to prevent phosphorus delivery to the lake. Internal load reductions will need to come from in-lake management activities such as rough fish management, alum treatment and/or aquatic plant management.

1. Project Overview

1.1 Purpose

This TMDL report addresses nine turbidity/TSS impairments, two bacteria (*E. coli*) impairments, and one chloride impairment on several main stem and tributary reaches in the Redwood River Watershed. This TMDL also addresses nutrient (phosphorus) impairments for six lakes in the watershed. The drainage areas of the impaired reaches and lakes presented in this TMDL report cover portions of six counties in southwest Minnesota: Lincoln, Yellow Medicine, Redwood, Lyon, Pipestone, and Murray (Figure 1). Marshall is the largest city in the watershed (pop. 13,628), followed by Redwood Falls (pop. 5,102). Other towns in the watershed include Ruthton, Tyler, Florence, Lake Benton, Russell, Lynd, Ghent, Milroy, Seaforth, and Vesta.

Figure 1. Redwood River Watershed overview.



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

Table 1. List of stream and lake impairments addressed in the Redwood River Watershed TMDL.

Affected use: Pollutant/ Stressor	Reach/Lake ID	Reach/Lake name	Reach/Lake description	Designated use class	Listing year	Target start/ Completion
Aquatic Life: Turbidity/TSS	07020006-502	Redwood River	T111 R42W S33, west line to Three Mile Creek	2B, 3C	2002	2019/2022
	07020006-503	Redwood River	Three Mile Creek to Clear Creek	2B, 3C	2010	
	07020006-509	Redwood River	Clear Creek to Redwood Lake	2B, 3C	2002	
	07020006-510	Redwood River	Coon Creek to T110 R42W S20, north line	2B, 3C	2020	
	07020006-564, 565 & 566 [1]	Three Mile Creek	Headwaters to T113 R41W S33, east line (564); T113 R41W S34, west line to T112 R41W S12, east line (565)	2B, 3C	2004	
	07020006-567 & 568	Clear Creek	-95.323 44.466 to Redwood River	2B, 3C	2020	
Aquatic Recreation: Bacteria (Fecal Coliform, *E. coli*)	07020006-510	Redwood River	Coon Creek to T110 R42W S20, north line	2B, 3C	2008	2019/2022
	07020006-521	Ramsey Creek	T113 R36W S35, west line to Redwood River	1B, 2A, 3B	2020	
Aquatic Consumption, Life, and Recreation: Chloride	07020006-502	Redwood River	T111 R42W S33, west line to Three Mile Creek	2B, 3C	2008	2019/2022
Aquatic Recreation: Lake Nutrients	41-0043-00	Benton	T110 N. R45 W.	2B, 3C	2006	2019/2022
	41-0021-01	Dead Coon (Main Lake)	T110 N. R44 W.	2B, 3C	2010	
	42-0093-00	Goose	Sec. 32, T111 N., R43 W.	2B, 3C	2010	
	42-0002-00	School Grove	Sec. 36, T 113 N., R36 W.	2B, 3C	2010	
	42-0055-00	Clear	T 110 N. R 42 W.	2B, 3C	2020	
	42-0096-00	Island	Sec. 34, T111 N., R43 W.	2B, 3C	2020	

[1] Three Mile Creek Reach 504 was split into three separate reaches, 564, 565, and 566, for the 2020 303(d) impaired waters list assessment process

Figure 2. Overview of Redwood River Watershed impairments covered in this TMDL.

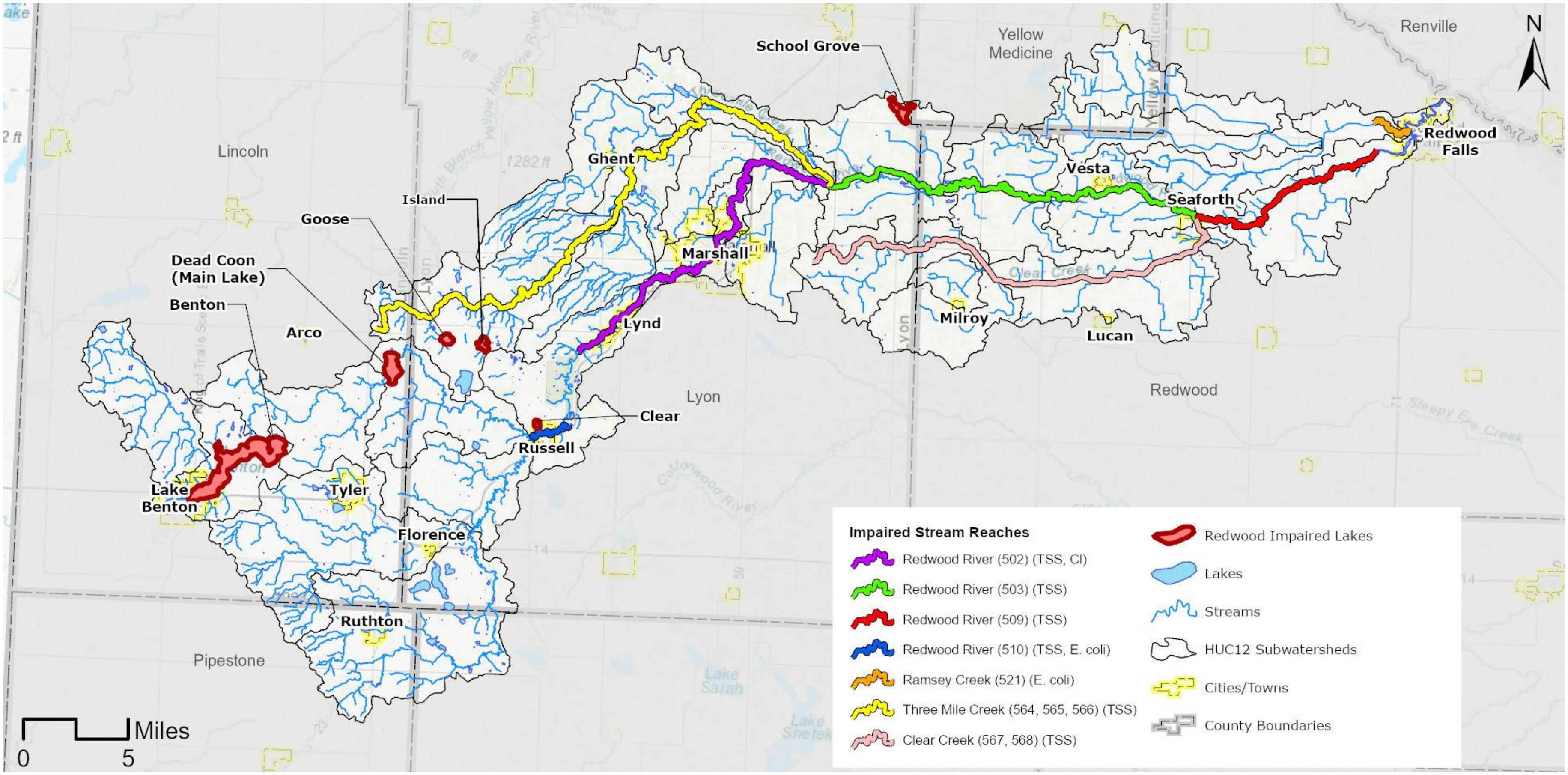


Table 2 provides a summary of the impaired stream reaches in the Redwood River Watershed with existing EPA approved TMDL studies that were completed prior to this TMDL report.

Table 2. Summary of completed TMDLs within the Redwood River Watershed.

Stream or Lake Name	Reach AUID (Last 3 Digits/lake ID)	Pollutant(s)	TMDL Report(s)
Redwood River (Ramsey Creek to Minnesota River)	501	Aquatic Recreation: Fecal coliform Aquatic Life: TSS Aquatic consumption: Mercury in fish	Redwood River Fecal Coliform TMDL Report (RCRCA 2013) Minnesota River and Greater Blue Earth River Basin TSS TMDL Study (MPCA 2020b) Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)
Redwood River (Clear Creek to Redwood Lake)	509	Aquatic Recreation: Fecal coliform Aquatic consumption: Mercury in fish	Redwood River Fecal Coliform TMDL Report (RCRCA 2013) Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)
Clear Creek (Headwaters to Redwood River)	506	Aquatic Recreation: Fecal coliform	Redwood River Fecal Coliform TMDL Report (RCRCA 2013)
Redwood River (T111 R42W S33 west line to Three Mile Creek)	502A	Aquatic Recreation: Fecal coliform	Redwood River Fecal Coliform TMDL Report (RCRCA 2013)
Redwood River (T111 R42W S33 west line to Three Mile Creek (excluding and above the City of Marshall))	502B	Aquatic Recreation: Fecal coliform	Redwood River Fecal Coliform TMDL Report (RCRCA 2013)
Three Mile Creek (Headwaters to Redwood River)	504	Aquatic Recreation: Fecal coliform	Redwood River Fecal Coliform TMDL Report (RCRCA 2013)
Redwood River (Headwaters to Coon Creek)	505	Aquatic Recreation: Fecal coliform Aquatic consumption: Mercury in fish	Redwood River Fecal Coliform TMDL Report (RCRCA 2013) Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)
Tyler Creek (Headwaters to Redwood River, a limited resource value water)	512	Aquatic Recreation: Fecal coliform	Redwood River Fecal Coliform TMDL Report (RCRCA 2013)
Coon Creek (Lake Benton to Redwood River)	511	Aquatic Recreation: Fecal coliform	Redwood River Fecal Coliform TMDL Report (RCRCA 2013)
Redwood River (Coon Creek to T110 R42W S20, north line)	510	Aquatic consumption: Mercury in fish	Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)

Stream or Lake Name	Reach AUID (Last 3 Digits/lake ID)	Pollutant(s)	TMDL Report(s)
Redwood River (T110 R42W S17, south line to T111 R42W S32, east line)	513	Aquatic consumption: Mercury in fish	Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)
Redwood River (Three Mile Creek to Clear Creek)	503	Aquatic consumption: Mercury in fish	Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)
Dead Coon (Main Lake)	41-0021-01	Aquatic consumption: Mercury in fish	Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)
Benton	41-0043-00	Aquatic consumption: Mercury in fish	Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a)
Redwood	64-0058-00	Aquatic consumption: Mercury in fish	Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a – 2008 revision)
School Grove	42-0002-00	Aquatic consumption: Mercury in fish	Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a – 2022 revision)

This TMDL does not address the river eutrophication impairment for Redwood River Reach 501 (07020006-501). A separate TMDL report will be prepared to address the river eutrophication impairment on the Redwood River.

The IWM efforts for the Redwood River Watershed identified 15 stream reaches that currently do not meet fish IBI standards and 18 stream reaches that do not meet aquatic macroinvertebrate IBI standards. A SID Report was developed for these reaches to determine the primary stressors to the biological communities (MPCA 2021a). Nonpollutant stressors (e.g., habitat, connectivity) 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 IBI impairments will not be covered in this TMDL and instead will be addressed through the implementation of the Redwood River WRAPS Report and local water planning efforts.

1.2 Identification of Water Bodies

The TSS impaired reaches were placed on the Clean Water Act Section 303(d) impaired waters list in 2002, 2004, 2010, and 2020. The bacteria impaired reaches were placed on the 303(d) list in 2008 and 2020. The nutrient impaired lakes were placed on the 303(d) list in 2006, 2010, and 2020. All the impaired reaches addressed in this TMDL are Class 2B or 2C waters (warm water).

Table 1 and the Redwood River Watershed Monitoring and Assessment Report (which includes notes regarding aquatic life impairments for which TMDLs are not computed) summarize Redwood River Watershed impairments and those addressed in this TMDL report. There are three reaches of Three Mile Creek, reaches 564, 565 and 566, that are covered under this TMDL report. These reaches were previously one contiguous reach, Three Mile Creek reach 504, for the 2004 303(d) impaired waters list assessment process. For the 2020 303(d) impaired waters list assessment process, reach 504 was split into three separate reaches (564, 565 and 566) due to new tiered aquatic life (TALU) standards for channelized streams. This impairment will be carried forward and one TMDL is presented in this report that covers all three reaches.

1.3 Priority Ranking

The Minnesota Pollution Control Agency (MPCA) schedule for TMDL completions, as indicated on the 2022 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 schedule for TMDL completion corresponds to the WRAPS report completion on a 10-year cycle. The MPCA developed a state plan (Minnesota's TMDL Priority Framework Report) to meet the needs of EPA's national measure (WQ-27) under EPA's Long-Term Vision for Assessment, Restoration and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. The Redwood River Watershed 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 2B, 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 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. Class 2B waters are also protected for aquatic recreation activities including bathing.

2.2 Turbidity/TSS

A historical perspective is important to understand the development of TSS TMDLs in this report. The class 2B turbidity standard (Minn. R. ch. 7050.0222) that was in place at the time of the impairment assessment for many reaches in the project area was 25 nephelometric turbidity units (NTUs). Impairment listings occurred when greater than 10% of data points collected within the previous 10-year period exceeded the 25 NTU standard (or equivalent values for TSS or the transparency tube). If sufficient turbidity data did not exist, transparency tube data were used to evaluate waters for turbidity impairments for the 2006 through 2014 303(d) lists of impaired waters. A transparency tube measurement less than 20 centimeters (cm) indicated a violation of the 25 NTU turbidity standard. A stream was considered impaired if more than 10% of the transparency tube measurements were less than 20 cm.

Due to weaknesses in the turbidity standards, the MPCA developed numeric TSS criteria to replace them. These TSS criteria are regional in scope and based on a combination of biotic sensitivity to the TSS concentrations and reference streams/least impacts streams as data allow. The results of the TSS criteria development were published by the MPCA in 2011. The new TSS standards were approved by EPA in January 2015. For the purpose of this TMDL report, the newly adopted 65 mg/L standard for class 2B waters is used to address the turbidity impairment listings.

The nine reaches of the Redwood River Watershed listed as impaired by turbidity/TSS are class 2B warm water streams. The class 2B TSS standard for streams and rivers in the Southern River Nutrient Region is 65 mg/L. This standard may not be exceeded more than 10% of the time from April through September over a multiyear data window (MPCA 2011).

Transparency values, as measured by Secchi tubes (S-tube), reliably predict TSS and can serve as surrogates. While TSS measurements themselves are generally preferred, datasets for S-tube are often more robust, and their relative strength will be considered in assessments.

Because S-tube measurements are not perfect surrogates, however, their use involves a MOS. Therefore, the S-tube surrogate thresholds for determining if a stream exceeds the TSS standard are different than for determining if a stream meets the standard.

A stream is considered to exceed the standard for TSS/S-tube if 1) the standard is exceeded more than 10% of the days of the assessment season (April through September) as determined from a data set that gives an unbiased representation of conditions over the assessment season, and 2) there are at least three such measurements exceeding the standard.

A stream is considered to meet the standard for TSS/S-tube if the standard is met at least 90% of the days of the assessment season. A designation of meeting the standard for TSS/S-tube generally requires at least 20 suitable measurements from a data set that gives an unbiased representation of conditions over at least two different years. However, if it is determined that the data set adequately targets periods and conditions when exceedances are most likely to occur, a smaller number of measurements may suffice.

S-tube measurements that fall between the two relevant surrogate values are considered indeterminate in exceeding or meeting the TSS standard. For Class 2B waters in the Southern River Nutrient Region, 10 cm and 15 cm represent the lower and upper surrogate values, respectively. If a stream satisfies neither the criterion for exceeding the standard nor the criterion for meeting the standard, the stream is considered to have insufficient information regarding TSS levels.

2.3 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 2007b). The revised standards now state:

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

The 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 SONAR (Statement of Need and Reasonableness) 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 milliliters (cfu/100 mL), not organisms per 100 mL. This TMDL report will present *E. coli* data in cfu/100 mL since all 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. Geometric mean is used in place of arithmetic mean to measure the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. Geometric means are calculated using the following equation:

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

The MPCA's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List (MPCA 2022) provides details regarding how waters are assessed for conformance to the *E. coli* standard.

2.4 Chloride

The chronic standard for chloride to protect for class 2B uses is 230 mg/L. The chronic standard is defined in Minn. R. 7050.0218, subp. 3.Q., as "the highest water concentration or fish tissue concentration of a toxicant or effluent to which aquatic life, humans, or wildlife can be exposed indefinitely without causing chronic toxicity." The 230 mg/L value is based on a four-day exposure of aquatic organisms to chloride and are written as four-day average concentrations. Two or more exceedances of the chronic standard in three years is considered an impairment. Because standards are expressed as four-day averages, care must be taken to ensure that the water quality measurements used in assessments provide an adequate representation of pollutant concentrations over the relevant time period. When concentrations are judged to be relatively stable over the four-day period in question, single samples can be sufficient. When concentrations are more variable, multiple samples or time-weighted composite samples are generally necessary to calculate a sufficiently accurate average concentration. If more than one sample was taken within a four-day period for flowing waters the values are averaged (usually an arithmetic mean is appropriate) and the four-day average is counted as one value in the assessment. This includes multiple samples in four days at one station or multiple stations along an assessment unit.

The maximum standard to protect for class 2B uses is 860 mg/L. The maximum standard is defined in Minn. R. 7050.0218, subp. 3.JJ., as "the highest concentration of a toxicant in water to which organisms can be exposed for a brief time with zero to slight mortality." The 860 mg/L value is based on a 24-hour exposure of aquatic organisms to chloride. Exceedances of the chronic and maximum standards are evaluated over consecutive three-year periods. One exceedance of the maximum standard is considered an impairment.

2.5 Lake Nutrients

Under Minn. R. 7050.0150 and 7050.0222, subp. 4, the lakes addressed in this TMDL report are shallow lakes located within the Western Cornbelt Plain (WCBP) Ecoregion. Shallow lakes are defined as lakes with a maximum depth of 15 feet or less, or with 80% or more of the lake area shallow enough to support emergent and submerged rooted aquatic plants (littoral zone). Minnesota water quality standards for TP, chlorophyll-a (Chl-*a*) and Secchi disk transparency are listed in Table 3.

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 2B lakes, shallow lakes, and reservoirs in the Western Corn Belt Plains ecoregion.

Parameter	Water Quality Standard	
	WCBP Ecoregion Standards (2B shallow lakes[1])	WCBP Ecoregion Standards (2B lakes)
Total Phosphorus [μg/L][2]	90	65
Chlorophyll-a [μg/L]	30	22
Secchi Disk Transparency [meters]	0.7	0.9

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

[2]Microgram per liter or part per billion.

3. Watershed and Water Body Characterization

The Redwood River Watershed is a major Hydrologic Unit Code (HUC)-8 watershed in the Minnesota River Basin, covering the central portion of the state. The Redwood River Watershed is approximately 699 square miles or 447,531 acres, split between six counties with the majority of watershed in Lyon (43%), Redwood (28%), and Lincoln (19%) Counties (Figure 1). There is no tribal land in the Redwood River Watershed and this TMDL does not allocate pollutant load to any federally recognized Indian tribe.

The subwatersheds (HUC-12s) of the Redwood River are shown in Figure 2. There are seven major HUC-10 subwatersheds in the Redwood River Watershed: Headwaters to Redwood River, Coon Creek, city of Marshall-Redwood River, Three Mile Creek, Clear Creek, Ramsey Creek, and Redwood River (Figure 1). The streams and tributaries that make up these major subwatersheds flow to the Redwood River upstream of the confluence with the Minnesota River.

3.1 Lakes

Collectively, lakes and open water areas in the Redwood River Watershed account for approximately 2% (6,365 acres) of the watershed. There are six assessed lakes impaired by nutrients in the watershed (Figure 2). Lake morphometry and watershed information for each impaired lake covered in this TMDL report are presented in Table 4. All six lakes are considered shallow with average depths ranging from 3.9 to 6.8 feet. Residence time is short to moderate and watershed to surface area ratios vary widely from 4:1 to 85:1.

Table 4. Lake morphometry and watershed area in the Redwood River Watershed.

Parameter	Benton	Dead Coon	Goose	School Grove	Clear	Island
County	Lincoln	Lincoln	Lyon	Lyon	Lyon	Lyon
Lake ID	41004300	41002101	42009300	42000200	42005500	42009600
Lake Type	Shallow	Shallow	Shallow	Shallow	Shallow	Shallow
Lake Surface Area [acres]	2,649	547	150	349	66	133
Ave. Depth [ft]	6.4	4.2	6.7	6.8	6.6	3.9
Max Depth [ft]	9	9	9	11	11	8
Residence Time [yrs]	2.6	0.2	0.7	2.3	2.3	0.8
Littoral Area [%]	100	100	100	100	100	100
Watershed Area[1] [acres]	25,332	46,464	1,788	1,390	391	1,089
Watershed Area: Surface Area	10:1	85:1	12:1	4:1	6:1	8:1

[1] Does not include lake surface area

3.2 Streams

The seven impaired reaches in the Redwood River Watershed addressed in this TMDL report cover approximately 182 stream miles and drain approximately 440,000 acres of land across the watershed (Figure 2, Table 5). Additional information for each impaired stream reach can be found in Appendix A.

Nine other bacteria-impaired reaches in the Redwood River Watershed were addressed in the Redwood River Fecal Coliform TMDL Report (RCRCA 2013) as discussed in Section 1.1.

Table 5. Redwood River Watershed stream impairments.

Reach Name	Impaired Reach Id[1]	Impairment(s)	Reach Length [miles]	Watershed Area [acres]	Upstream Impaired Assessment Units
Redwood River: T111 R42W S33, west line to Three Mile Cr	502	TSS, Chloride	28.1	197,821	510 (*E. coli*)
Redwood River: Three Mile Cr to Clear Cr	503	TSS	29.5	329,541	510 (*E. coli*), 502 (TSS), 504 (TSS)
Redwood River: Clear Cr to Redwood Lk	509	TSS	14.0	399,298	510 (*E. coli*), 502 (TSS), 504 (TSS), 503 (TSS)
Redwood River: Coon Cr to T110 R42W S20, north line	510	TSS, *E. coli*	3.3	148,455	None
Ramsey Creek: T113 R36W S35, west line to Redwood River	521	*E. coli*	3.7	42,629	None
Three Mile Creek: Headwaters to T113 R41W S33, east line (564); T113 R41W S34, west line to T112 R41W S12, east line (565)	564, 565 & 566[2]	TSS	48.6	75,085	None
Clear Creek: -95.323 44.466 to Redwood River	567 & 568	TSS	2.5	53,232	None

[1] Only the last three digits of the impaired reach are shown in this table for the Redwood River (07020006) impairments
[2] Three Mile Creek Reach 504 was split into three separate reaches, 564, 565 and 566, for the 2020 303(d) impaired waters list assessment process

3.3 Subwatersheds

The drainage areas of the impaired water bodies (Figure 2) were developed using multiple data sources, starting with watershed delineations from the MPCA's HSPF model application for the Redwood River Watershed (Tetra Tech 2019). 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 (DEM). Where additional watershed breaks were needed to define the impairment watersheds, DNR Level 8 and Level 9 watershed boundaries and delineation were used based on contours derived from Light Detection and Ranging (LiDAR). Maps showing specific watershed boundaries for each impaired lake and reach are included in Appendix C.

3.4 Land Use

Uninterrupted prairie originally covered most of the Redwood River Watershed. Like most areas across the Midwest, land throughout the watershed has been converted from a range of tallgrass prairie and a small amount of wet prairies to a mixture of intensive agricultural uses. This conversion has resulted in various changes throughout the watersheds, such as increases in overland flow, decreases in groundwater infiltration/subsurface recharge, and increases in the nonpoint source transport of sediment, nutrients, agricultural and residential chemicals, and feedlot runoff.

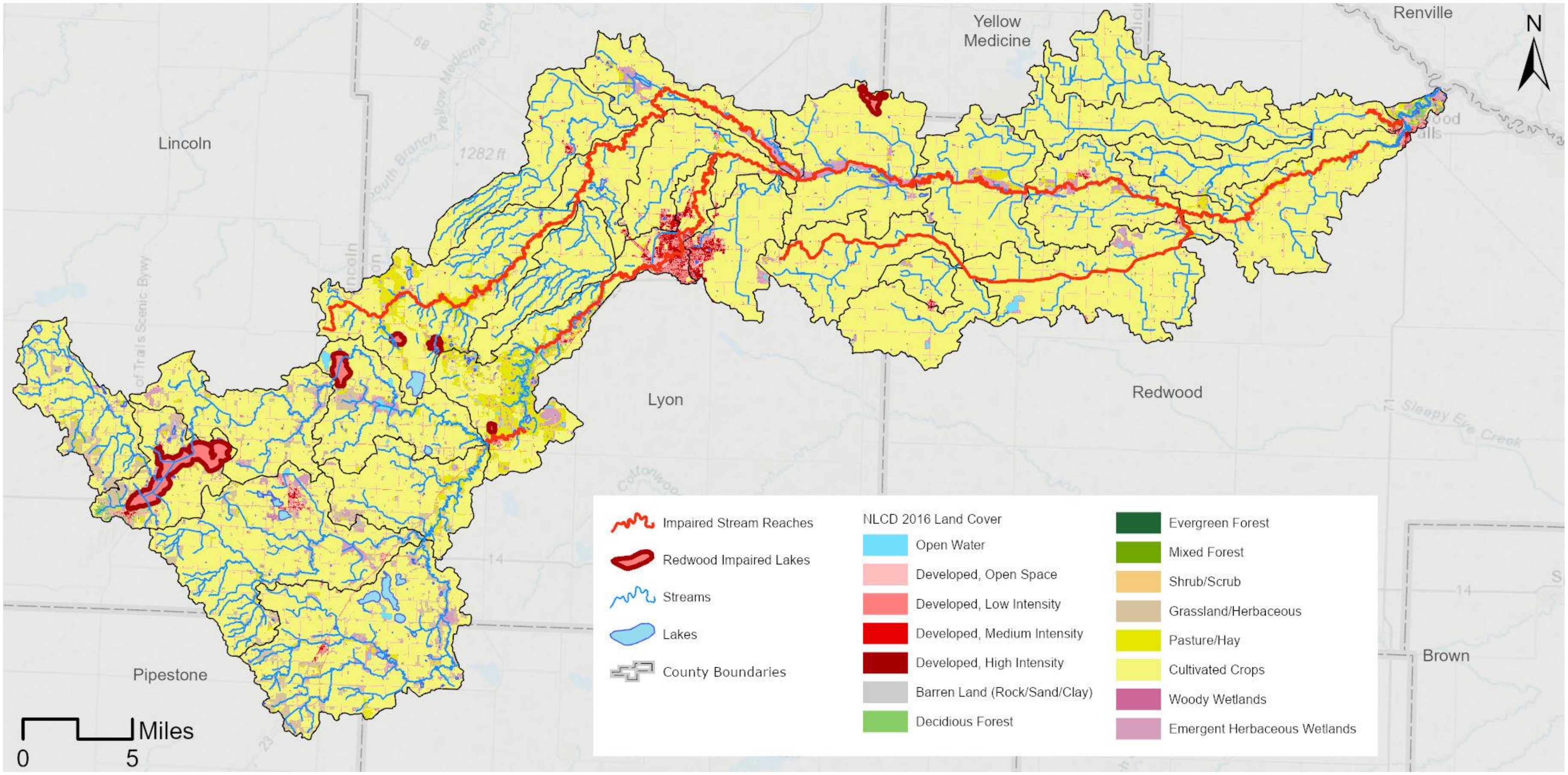
Land use within the Redwood River Watershed was analyzed using United States Geological Survey's (USGS's) 2016 National Land Cover Database (NLCD). Current land use within the watershed is dominated by agriculture (mostly row crops,) followed by rangeland, developed land, wetlands, open water, and forest/shrub land (Table 6 and Figure 3). Row crops throughout the watersheds are predominately planted in corn, forage for livestock, and soybeans (MDA 2009 and 2010a). Rangeland typically follows stream corridors, which is a large reason for less channelization of the streams than in other regions of Minnesota.

The city of Marshall (MS400241) is the largest urban center in the Redwood River Watershed and most of the city's boundary is within the watershed (a small portion is in the Cottonwood River Watershed). The city of Redwood Falls (MS400236) is also located within the Redwood River Watershed and is located at the confluence with the Minnesota River. Both the cities of Marshall and Redwood Falls are subject to the MPCA's Municipal Separate Storm Sewer System (MS4) Permit program (see Section 4.2.2).

Table 6. Summary of land use (2016) and watershed area for each impaired reach and lake in the Redwood River Watershed.

			Percent of Watershed [%]						
Impaired Water body Name	Reach or Lake Id	Watershed Area [Acres]	Cropland	Rangeland	Developed	Forest/Shrub land	Open Water	Wetlands	Barren/Mining
Redwood River	07020006-502	197,834	69	16	8	1	3	3	< 1
Redwood River	07020006-503	329,540	75	12	7	< 1	3	3	< 1
Redwood River	07020006-509	399,297	77	10	7	< 1	2	3	< 1
Redwood River	07020006-510	148,455	69	18	6	< 1	4	2	< 1
Ramsey Creek	07020006-521	42,629	92	1	5	1	<1	1	<1
Three Mile Creek	07020006-564, 565 & 566	75,072	81	9	5	< 1	1	3	< 1
Clear Creek	07020006-567 & 568	53,232	91	< 1	5	< 1	1	2	< 1
Benton Lake	41-0043-00	28,005	56	23	6	1	11	3	< 1
Dead Coon Lake	41-0021-01	47,050	64	19	5	1	8	2	< 1
Goose Lake	42-0093-00	1,938	68	9	4	< 1	17	< 1	< 1
School Grove Lake	42-0002-00	1,740	71	< 1	4	< 1	21	3	< 1
Clear Lake	42-0055-00	391	18	44	10	< 1	21	< 1	5
Island Lake	42-0096-00	1,089	54	22	3	<1	16	5	<1
Entire Watershed	07020006	447,532	78	9	6	1	2	3	< 1

Figure 3. Land cover in the Redwood River Watershed (Source: 2016 NLCD).



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, MDA, Redwood Cottonwood River Control Area (RCRCA), Soil and Water Conservation Districts (SWCDs), and volunteer monitoring programs. Although data prior to 2000 exists in each of the major watersheds, the more recent data represent current conditions.

Daily average flows were simulated using the MPCA's HSPF model for the Redwood River Watershed. Simulated flows are available for each impaired lake and reach for model years 1996 through 2017. Redwood River HSPF model documentation (Tetra Tech 2019) describes the framework of the model, the data used to develop the model, and calibration/validation results.

3.5.1 TSS

TSS data were summarized by site for each TSS impaired reach in the Redwood River Watershed using data from 2000 to 2018 (Table 7). The TSS impairments presented in this TMDL report are based upon the current TSS standard for the Southern River Nutrient Region of 65 mg/L. There is currently no TSS data available for reach 503, however S-tube (transparency) data is available for this reach and was used by the MPCA to assess the TSS impairment for this reach. The S-tube data for reach 503 is presented in Table 8. As discussed in Section 2.2, 10 cm represents the lower surrogate threshold for S-tube measurements while 15 cm represents the upper surrogate threshold. Thus, any S-tube measurement less than 10 cm is considered a violation of the TSS criterion for assessment purposes. Figure 7 through Figure 12 in Section 4.2.6 show the variability of TSS by flow condition over a 10-year period (2008 through 2017) for each TSS impaired reach.

Table 7. Summary of TSS data for the TSS impaired reaches (April – October) in the Redwood River Watershed.

Parameter	Redwood River	Redwood River	Redwood River	Three Mile Creek	Clear Creek
Reach Id	0702006-502	0702006-509	07020006-510	0702006-564, 565 & 566	07020006-568
Years of Data	8	18	17	15	5
Sample Count	121	207	215	97	82
90^{th} Percentile [mg/L]	260	210	152	89	74
Mean [mg/L]	114	103	66	49	42
Maximum [mg/L]	1,140	532	1,130	248	400
Number of Exceedances	57	117	47	23	11
Frequency of Exceedances	47%	57%	22%	24%	13%

Table 8. Summary of Secchi tube data for impaired reach 503 (April – October) in the Redwood River Watershed.

Parameter	Redwood River: Three Mile Creek to Clear Creek
Reach Id	0702006-503
Years of Data	1
Sample Count	21

Parameter	Redwood River: Three Mile Creek to Clear Creek
90th Percentile [cm]	10
Mean [cm]	18
Low [cm]	9
Number of Exceedances	2
Frequency of Exceedances	10%

3.5.2 Bacteria

Table 9 shows April through October monthly *E. coli* geometric means (2000 through 2018) for the bacteria impaired reaches addressed in this TMDL report. Older records for bacteria samples in these reaches were analyzed for fecal coliform prior to switching to *E. coli* in 2006. All fecal coliform data collected prior to 2006 were converted to *E. coli* equivalents using the equation described in Section 2.3. Table 9 shows the individual chronic sample exceedances, acute exceedances, and monthly geometric means for each impaired reach. Results indicate monthly geometric means exceeded the chronic standard in five of the seven months monitored during the index period for Redwood River Reach 510, and two of the three months monitored for Ramsey Creek Reach 521. Additionally, individual samples exceeded the chronic standard approximately 61% and 87% of the time from April through October for Reaches 510 and 521, respectively.

Table 9. Summary of *E. coli* data for Redwood River impaired reaches 510 and 521 in the Redwood River Watershed.

Monitored Month(s)	Parameter	Redwood River Reach 510	Ramsey Creek Reach 521
Apr-Oct	Years of data	6	2
Apr-Oct	Sample count	64	15
Apr-Oct	Maximum (MPN/100 mL)	2,420	529
Apr-Oct	Number of individual sample exceedances	39	13
Apr-Oct	Percent of individual sample exceedances	61%	87%
Apr-Oct	Geometric mean (MPN/100 mL)	**174***	**194***
Apr	Sample count	8	0
	Geometric mean (MPN/100 mL)	22	N/A
May	Sample count	11	0
	Geometric mean (MPN/100 mL)	100	N/A
Jun	Sample count	11	5
	Geometric mean (MPN/100 mL)	**356***	**318***
Jul	Sample count	10	5
	Geometric mean (MPN/100 mL)	**223***	100
Aug	Sample count	9	5
	Geometric mean (MPN/100 mL)	**208***	**229***
Sep	Sample count	10	0
	Geometric mean (MPN/100 mL)	**239***	N/A
Oct	Sample count	5	0
	Geometric mean (MPN/100 mL)	**764***	N/A

Table Notes:
- Red highlighted values with asterisks indicate monthly geometric mean concentration exceeds the 126 organisms per 100 milliliter chronic standard
-All geometric mean values presented in MPN/100 mL

3.5.3 Chloride

This section presents the historic monitoring data assessment for the Redwood River chloride impaired reach (502). This reach begins near the city of Lynd, flows approximately 28 miles northeast through the city of Marshall, and ends where Three Mile Creek flows into the Redwood River. There are seven point source dischargers that discharge either upstream of this reach (Tyler Wastewater Treatment Plant [WWTP], Ruthton WWTP, Russell WWTP) or directly to the reach (Lynd WWTP, Magellan Pipeline Co LP, ADM Corn Processing – Marshall and Marshall WWTP). Two of these point sources, ADM Corn Processing - Marshall and Marshall WWTP, have been known to have elevated levels of chloride in their effluent water. Thus, two long-term monitoring stations were established in this reach to evaluate in-stream chloride concentrations. The first station (S002-185) is located less than 0.5 miles upstream of ADM Corn Processing – Marshall and the second station (S001-203) is located approximately one mile downstream of Marshall WWTP. See the map in Appendix A for reach and monitoring locations.

Since 1997, ADM Corn Processing – Marshall has collected over 5,000 individual chloride samples at station S002-185 upstream of their facility as part of their permit. Table 10 and Table 11contain summaries of the chloride data for station S002-185, presented as four-day average concentrations. Results indicate four-day average concentrations are generally low at this station (mean of 24 mg/L) and there have been only three exceedances (<1%) of the 230 mg/L chronic standard over this time period. All three exceedances occurred during the winters of 2003 (February) and 2013 (January) (Table 10). There have been no observed exceedances of the maximum standard (860 mg/L) to date.

Over 7,000 individual chloride samples have been collected since 1997 at station S001-203 downstream of ADM Corn Processing – Marshall and Marshall WWTP. Four-day average chloride concentrations at this station are, on average, approximately five times higher (mean of 127 mg/L) than station S002-185 upstream of ADM Corn Processing – Marshall and Marshall WWTP. Approximately 8% of the four-day average concentrations (633 measurements) have exceeded the chronic standard; however, there were no observed exceedances of the chronic standard over the three-year monitoring period between 2016 and 2018. Chloride concentrations at this station are generally lower during high-flow conditions and higher during low-flow conditions. April and May, which are typically characterized as high-flow periods (i.e., snowmelt and spring rainfall), were the only months with no observed exceedances of the four-day chronic standard. There have been no observed exceedances of the maximum standard at this station since monitoring began in 1997.

Table 10. Annual summary of four-day average chloride data for reach 502 from 1997 – 2018 in the Redwood River Watershed.
Note: Includes measurements taken upstream of ADM Corn Processing - Marshall and Marshall WWTP (S002-185) and downstream of these facilities (S001-203).

	4-day Average Count		Mean of 4-day Average Results [mg/L]		4-day Average Maximum [mg/L]		Number of Exceedances of Chronic Standard		Percent Exceedance of Chronic Standard.	
Year	S002-185	S001-203	S002-185	S001-203	S002-185	S001-203	S002-185	S001-203	S002-185	S001-203
1997	102	190	17	133	65	**296***	--	9	0%	5%
1998	152	315	20	157	53	**338***	--	25	0%	8%
1999	275	365	21	121	48	**249***	--	13	0%	4%
2000	272	366	28	180	165	**317***	--	66	0%	18%
2001	276	365	26	133	57	**308***	--	30	0%	8%
2002	232	304	21	103	61	222	--	--	0%	0%
2003	260	365	25	179	**402***	**352***	2	86	<1%	24%
2004	285	366	26	158	72	**279***	--	43	0%	12%
2005	262	365	26	135	58	**389***	--	47	0%	13%
2006	303	365	24	124	70	**254***	--	20	0%	5%
2007	264	365	24	135	46	**392***	--	61	0%	17%
2008	263	366	26	135	89	**280***	--	21	0%	6%
2009	278	365	30	142	112	**318***	--	34	0%	9%
2010	275	365	22	63	48	205	--	--	0%	0%
2011	278	365	19	89	50	**242***	--	2	0%	<1%
2012	269	366	20	169	47	**316***	--	45	0%	12%
2013	238	365	26	167	**357***	**313***	1	85	<1%	23%
2014	248	306	22	128	151	**288***	--	27	0%	9%
2015	288	365	32	127	180	**260***	--	19	0%	5%
2016	314	366	28	78	96	185	--	--	0%	0%
2017	314	365	23	55	50	105	--	--	0%	0%
2018	147	212	18	64	51	197	--	--	0%	0%
All Years	5,595	7,537	24	127	402	392	3	633	<1%	8%

Red with asterisk = exceeds chronic standard

Table 11. Monthly summary of 4-day average chloride data for reach 502 over the most recent 10-year period (2008-2017) in the Redwood River Watershed.
Notes: This table includes measurements taken upstream (S002-185) of ADM Corn Processing - Marshall and Marshall WWTP and downstream (S001-203) of these facilities.

Month	4-day Average Count		Mean of 4-day Average Results [mg/L]		4-day Average Maximum [mg/L		Number of Exceedances of Chronic Std.		Percent Exceedance of Chronic Std.	
	S002-185	S001-203	S002-185	S001-203	S002-185	S001-203	S002-185	S001-203	S002-185	S001-203
Jan	12	279	50	161	357*	313*	1	53	8%	19%
Feb	37	255	28	165	112	312*	0	46	0%	18%
Mar	225	310	24	106	169	288*	0	20	0%	6%
Apr	294	300	23	73	40	199	0	0	0%	0%
May	306	310	24	57	47	203	0	0	0%	0%
Jun	298	300	23	55	55	233*	0	2	0%	1%
Jul	309	310	22	74	48	245*	0	7	0%	2%
Aug	309	310	23	127	81	254*	0	24	0%	8%
Sep	297	300	31	150	180	318*	0	63	0%	21%
Oct	307	310	22	138	51	260*	0	34	0%	11%
Nov	261	300	27	137	71	260*	0	37	0%	12%
Dec	110	310	36	148	96	316*	0	40	0%	13%
All Months	2,765	3,594	25	115	357*	318*	1	326	<1%	9%

Red with asterisk = exceeds chronic standard

3.5.4 Lake Phosphorus and Response Variables

In-lake water quality data collected from 2000 through 2018 was reviewed for use in this TMDL report. Table 12 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 12. Summer growing season averages for each water quality parameter for lakes in the Redwood River Watershed.

		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]**
WCBP Ecoregion Shallow Lake Standards		**90**	**30**	**0.7**
Benton	2002, 2017	129 (n=8)	37 (n=8)	0.9 (n=8)
Dead Coon	2002, 2007, 2017	170 (n=16)	30 (n=16)	0.6 (n=68)
Goose	2002, 2007, 2017	133 (n=11)	31 (n=11)	0.5 (n=10)
Clear (Lyon Co.)	2017, 2018	125 (n=8)	65 (n=8)	0.5 (n=8)
School Grove	2002, 2007, 2017	99 (n=12)	35 (n=12)	0.6 (n=11)
Island	2017, 2018	119 (n=8)	129 (n=8)	0.5 (n=8)

3.6 Pollutant Source Summary

<u>Overland Runoff/Erosion (Rural Areas)</u>

Nonpoint pollutant loads in rural areas can come from nonpermitted sources such as sediment erosion from upland fields, tile drainage, gully erosion, and livestock pastures in riparian zones (Schottler et al. 2013). Runoff from these sources can carry sediment, bacteria, phosphorus, and other nutrients to surface waters. For this TMDL study, upland nonpoint sources of sediment and phosphorus were evaluated using the Redwood HSPF Model (Tetra Tech 2019). 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 1996 through 2017. Model documentation contains additional details about model development and calibration (Tetra Tech 2019). 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 Redwood River HUC-8 Watershed, model results indicate approximately 23% of the TSS load and 55% of the phosphorus load was from agricultural overland runoff (i.e., cultivated crops and hay/pasture lands identified in the 2016 NLCD land use layer, in addition to loading from feedlots) and other rural upland sources. Relative contributions by source vary widely between individual reaches. Sections 3.6.1 and 3.6.4 below contain more detailed discussion of the upland watershed source contributions for each impaired lake and stream reach.

Animal Feeding Operations

Livestock animals are potential sources of bacteria, phosphorus, and other nutrients to streams in the Redwood River Watershed, particularly when direct access is not restricted and/or where feeding structures are located adjacent to riparian areas.

Minn. R. ch. 7020 governs the permitting, standards for discharge, design, construction, operation, and closure of animal feeding operations (AFOs) throughout Minnesota. By definition, an AFO is a site where animals are confined for 45 days or more in a 12-month period and vegetative cover is not maintained.

Concentrated Animal Feeding Operation (CAFO) is an EPA definition that implies not only a certain number of animals but also specific animal types. CAFO size is based on number of animals (head count) and can include large, medium, and small CAFOs. For example, 2,500 head of swine weighing 55 lbs or more is considered a large CAFO and 1,000 head of cattle other than mature dairy or veal calves are a large CAFO; but a site with 2,499 head of swine weighing 55 lbs or more or 999 head of cattle other than mature dairy would be considered a medium CAFO. The MPCA uses the federal definition of a CAFO in its permit requirements of animal feedlots along with the definition of animal unit (AU). In Minnesota, an NPDES permit is required for facilities that exceed any of the federal large CAFO threshold numbers and discharges to waters of the United States. State disposal system (SDS) permits are required for any facility that has a capacity of 1,000 AU or more. Facilities required to obtain SDS permit coverage may choose to obtain NPDES coverage in lieu of the SDS permit. Large CAFOs with less than 1,000 AU capacity and do not discharge to waters of the United States are not required to obtain NPDES Permit coverage.

CAFO production areas need to be designed, constructed, operated, and maintained to contain all manure, manure-contaminated runoff, or process wastewater, and direct precipitation. CAFOs and 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 5.2” 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 an NPDES permit, even if discharges have not occurred in the past at the facility. A current manure management plan, which 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.

Feedlots under 1,000 AUs and those that are not federally defined large CAFOs do not operate with permits; however, the requirements under Minn. R. ch. 7020 still applies. In Minnesota, feedlots with greater than 50 AUs, or greater than 10 AUs in shoreland areas, are required to register with the state. Facilities with fewer AUs are not required to register with the state. Livestock are also part of hobby farms, which are small-scale farms that are not large enough to require registration but may have small-scale feeding operations and associated manure application or stockpiles.

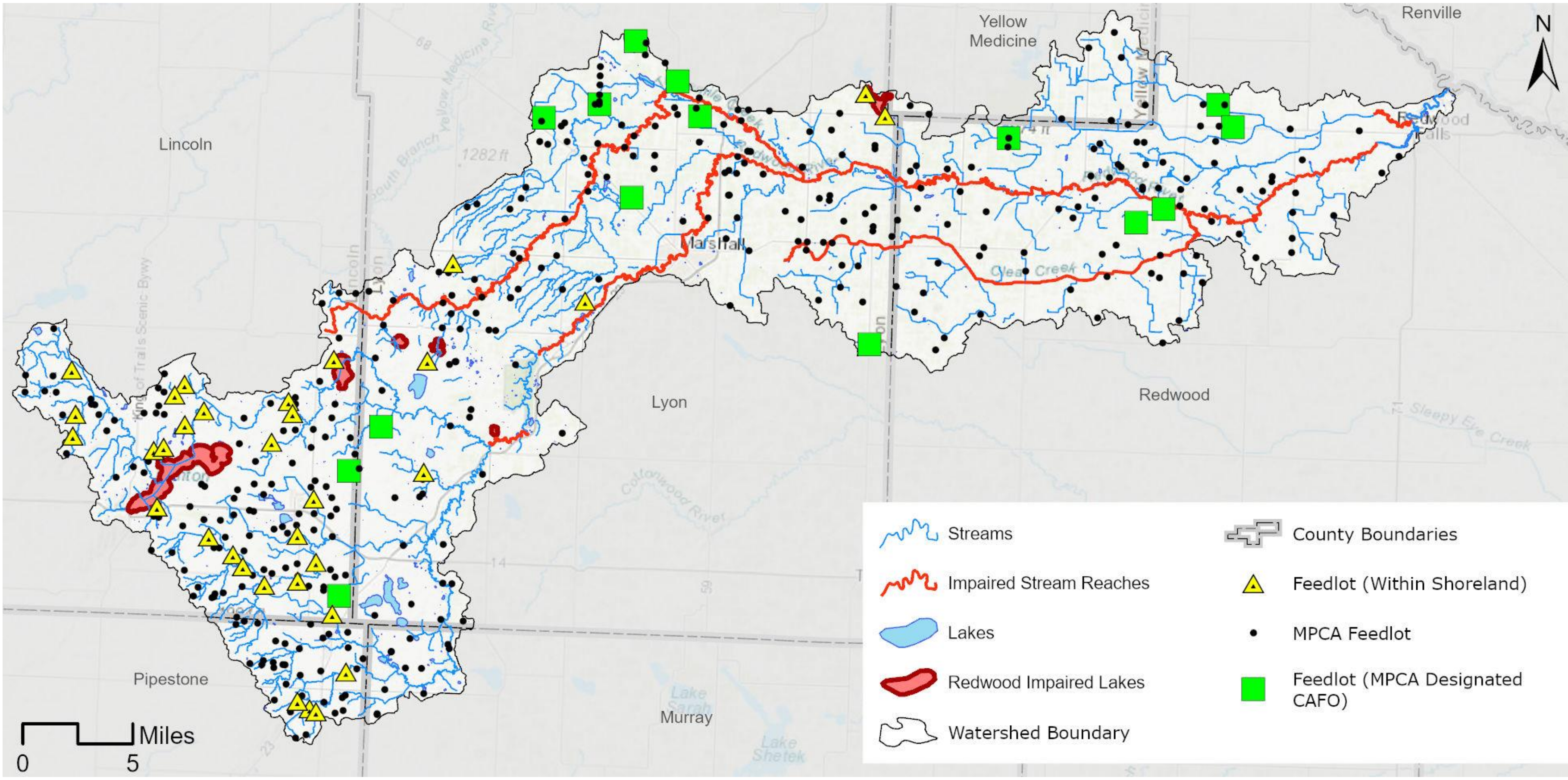
In the Redwood River Watershed, Redwood County is the only county that is not delegated to administer feedlot-related activities such as permitting, inspections, and compliance/enforcement. Lincoln, Pipestone, Lyon, Yellow Medicine, and Murray counties are delegated counties, and therefore administer a county feedlot program based on the requirements of the Minn. R. 7020, Feedlot Rules. These counties have the responsibility for implementing state feedlot regulations for facilities with fewer than 1,000 AUs and do not meet the federal definition of a large CAFO that are not subject to state or federal operating permit requirements. Responsibilities include registration, permitting, education and assistance, and complaint follow-up.

The MPCA maintains a feedlot registration database that contains feedlot locations and numbers and types of animals in CAFOs and registered feedlots. The database includes the maximum number of animals that each registered feedlot can hold; therefore, the actual number of livestock in registered facilities is likely lower. The MPCA registered feedlot database indicates there are approximately 352 active feedlot facilities with over 86,000 livestock AUs throughout the Redwood River Watershed as of 2018 (Figure 4). Table 13 summarizes facility type and livestock numbers for each impaired reach, lake, and the entire watershed. In the Redwood River Watershed, there are 28 feedlots located within 1,000 feet of a lake or 300 feet of a stream or river, an area generally defined as shoreland. See Appendix E: CAFO List and Watershed Summary for a full list of CAFOs in the watershed.

Table 13. MPCA active registered feedlots and feedlot type for each impaired lake and *E. coli* impaired reach in the Redwood River Watershed (data from 2018).

Impaired Reach/Lake	Impairment Type	Total Operations		CAFOs		Open Lots		Shoreland		Open Lots in Shoreland	
		Count	AUs	Operations	AUs	Operations	AUs	Operations	AUs	Operations	AUs
Redwood River Reach 510	*E. coli*	158	22,215	1	7,100	142	18,417	23	2,420	22	1,880
Reach 521	*E. coli*	21	9,188	2	2,340	13	2,994	--	--	--	--
Benton Lake	Nutrients	25	3,234	--	--	23	3,209	5	631	5	631
Dead Coon Lake	Nutrients	47	5,914	--	--	43	5,859	12	931	12	931
Goose Lake	Nutrients	0	0	--	--	--	--	--	--	--	--
School Grove Lake	Nutrients	2	200	--	--	2	200	2	200	2	200
Clear Lake	Nutrients	0	0	--	--	--	--	--	--	--	--
Redwood River Watershed	**All**	**352**	**86,514**	**8**	**10,750**	**282**	**54,954**	**28**	**3,556**	**27**	**3,016**

Figure 4. MPCA registered feedlots in the Redwood River Watershed (data from 2018).



Manure

Manure is a by-product of animal production and large numbers of animals create large quantities of manure. This manure is usually stockpiled and then spread over agricultural fields to help fertilize the soil. When stored and applied properly, this beneficial re-use of manure provides a natural source for crop nutrition. Manure, however, can pose water quality concerns when it is not applied properly or there are leaks or spills from nearby fields, storage pits, lagoons, tanks, etc. Animal waste contains high amounts of fecal bacteria, phosphorus, and nitrogen, and therefore when delivered to surface and groundwater can cause high bacteria levels, eutrophication, and oxygen demand (i.e., low oxygen levels) that negatively impacts human health, aquatic organisms, and aquatic recreation.

The Minnesota Feedlot rules include regulations regarding the requirements for MMPs and land application of manure. The MPCA has developed templates, guides and standards for the development and implementation of MMPs, manure nutrient management and application rates. MMPs are required when producers apply for a feedlot permit, or when a facility has 300 or more AUs and does not use a licensed commercial applicator. MMPs are designed to help ensure that application rates do not exceed crop nutrient needs, and that setbacks from waters and drain tile intakes are observed.

Based on the MPCA feedlot staff analysis of feedlot demographics, knowledge, and actual observations, 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. For feedlots with NPDES permits, surface applied solid manure is prohibited during the month of March. Winter application of manure (December through February) for permitted sites requires fields are approved in their MMP and the feedlot owner/operator must follow a standard list of setbacks and BMPs.

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 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 report does not explicitly estimate or model the contribution of manure to surface waters in the Redwood River Watershed; however, nutrient loads modeled by HSPF were calibrated using monitored, in-stream water quality data at several points throughout the watershed and manure contributions to nutrient loads are therefore implicit.

The active feedlot spatial dataset was extracted from the Minnesota Geospatial Commons. Feedlot data was intersected with impaired reach watersheds and queried to only include active feedlot registration. Table 14 provides a breakdown of AUs within each impaired lake and reach watershed by animal type: beef cattle, dairy cattle, swine, sheep, horses, and poultry. The “other” category encompasses AUs that do not fit into the category (i.e., llamas or alpaca). The MPCA feedlot dataset includes several subdivisions of beef cattle by age and weight; dairy cattle are similarly divided. The beef cattle animal count includes the following: steer, heifer, cow/calf pairs, and calves. Dairy cattle were summed from the following categories: cattle less than 1,000 lbs, heifers, calves, and cattle greater than 1,000 lbs. Poultry includes turkeys, chickens, and fowl produced for consumption.

Table 14. Registered livestock animal types within each *E. coli* impaired reach and impaired lake drainage area in the Redwood River Watershed (data from 2018).

Impaired Reach/Lake	Impairment Type	Active Facilities	Total AUs	Animal Units (AUs)						
				Beef Cattle	Dairy Cattle	Swine	Sheep	Horse	Poultry	Other
Reach 510	*E. coli*	158	22,215	14,441	2,963	3,4232	1,233	139	2	14
Reach 521	*E. coli*	21	9,188	2,355	4	6,400	1	18	410	0
Benton	Nutrients	25	3,234	2,052	585	40	539	17	1	0
Dead Coon	Nutrients	47	5,914	4,359	807	70	623	53	1	0
Goose	Nutrients	0	0	0	0	0	0	0	0	0
School Grove	Nutrients	1	200	200	0	0	0	0	0	0
Clear	Nutrients	0	0	0	0	0	0	0	0	0
Redwood River Watershed	**All**	**352**	**86,514**	**42,394**	**3,912**	**35,621**	**1,436**	**193**	**2,940**	**17**

Urban Stormwater

Cities and developed areas can be a source of sediment, bacteria, chloride, and nutrients to surface waters through the impact of urban systems on stormwater runoff. Stormwater runoff, which delivers and transports pollutants to surface waters, is generated in the watershed 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 Redwood River Watershed is predominantly cultivated crops, there are two medium-sized cities located in the watershed. The city of Marshall (MS400241; population 13,628) and Redwood Falls (MS400236; population 5,102) are in the central and eastern portion of the watershed, respectively (Figure 2). These cities are the only communities in the watershed that are subject to the MPCA's MS4 Permit program. MS4s are defined by the EPA as stormwater conveyance systems owned or operated by an entity such as a state, city, township, county, district, or other public body having jurisdiction over disposal of stormwater or other wastes. The municipal stormwater permit holds permittees responsible for stormwater discharging from the conveyance system they own and/or operate. The conveyance system includes ditches, roads, storm sewers, stormwater ponds, etc. Under the NPDES stormwater program, permitted MS4 entities are required to obtain a permit, then develop and implement an MS4 Stormwater Pollution Prevention Program (SWPPP), which outlines a plan to reduce pollutant discharges, protect water quality, and satisfy water quality requirements in the Clean Water Act. An annual report is submitted to the MPCA each year by the permittee documenting progress on implementation of the SWPPP.

In addition to Marshall and Redwood Falls, there are 12 smaller municipalities throughout the Redwood River Watershed that are not subject to MS4 permits (Table 15). Sediment and phosphorus loading from urban areas (both MS4 and non-MS4 communities) was estimated using the Redwood River Watershed HSPF model. The HSPF model estimates that urban areas account for approximately 3% of the TSS and

TP loading across the entire Redwood River Watershed. Sections 3.6.1 and 3.6.4 present urban TSS and TP source contributions for the individual reach and lake impairments covered in this TMDL.

Table 15. Municipalities in the Redwood River Watershed.

City	County	Downstream Impairment(s)	Area [acres]	Population*	Sewered (Sanitary)	MS4
Echo	Yellow Medicine	*E. coli*	7	243	Ponds	No
Florence	Lyon	TSS, *E. coli*	138	28	Unsewered**	No
Ghent	Lyon	TSS	222	376	Ponds	No
Lake Benton	Lincoln	Nutrients, TSS, *E. coli*, Chloride	2,272	687	Ponds	No
Lucan	Redwood	TSS	58	214	Ponds	No
Lynd	Lyon	TSS, Chloride	775	346	Ponds	No
Marshall	Lyon	TSS, Chloride	5,875	13,628	Mechanical	Yes
Milroy	Redwood	TSS	164	259	Ponds	No
Redwood Falls	Redwood	TSS, *E. coli*	1,698	5,102	Aerated Ponds	Yes
Russell	Lyon	TSS, *E. coli*, Chloride	628	348	Ponds	No
Ruthton	Pipestone	TSS, *E. coli*, Chloride	375	226	Ponds	No
Seaforth	Redwood	TSS	644	82	Ponds	No
Tyler	Lincoln	TSS, *E. coli*, Chloride	1,004	1,138	Ponds	No
Vesta	Redwood	TSS	215	276	Ponds	No
Green Valley	Lyon	TSS, *E. coli*	80	160	Unsewered	No

*2020 Census Population
**SSTS upgrades performed in 2008 to resolve unsewered issues

<u>Near-Channel Sources</u>

Near-channel sources of sediment and nutrients are those near 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. 2013).

The straightening and ditching of natural rivers increases the slope of the original watercourse and moves water off the land at a higher velocity in a shorter amount of time. 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 riverbanks (Schottler et al. 2013; Lenhart et al. 2013).

For the purposes of this TMDL study, near-channel TSS and TP loading from ravines, bluffs, and streambanks were estimated using the Redwood River Watershed HSPF model. The HSPF sediment simulation is based on multiple research efforts from various watersheds in the Minnesota River Basin. The partitioning of watershed and near-channel sources is based primarily on analysis of sediment cores (Schottler et al. 2010) and sediment mass balance studies for the Le Sueur River and Greater Blue Earth

River Watersheds (Gran et al. 2011; Bevis 2015). The model parameters developed for these watersheds were applied to the rest of the Minnesota River Basin, including the Lower Minnesota River Watershed. Model documentation (Tetra Tech 2016 and 2019) contains additional details about the model development and calibration. HSPF model output suggests approximately 72% of the TSS load and 2% of the TP load at the outlet of the Redwood River Watershed comes from near-channel sources. Sections 3.6.1 and 3.6.4 below contain more detailed discussion of the modeled near-channel source contributions for each impaired stream reach.

Additionally, the Redwood River Watershed Characterization Report (DNR 2020) provides an in-depth discussion of the processes, sources, and potential strategies to address near-channel sources in the Redwood River Watershed. This report includes the following components: characterization of the watershed, analysis of historical and existing hydrological data, assessment of geomorphic conditions, and stream connectivity throughout the watershed.

Internal Phosphorus 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 (RR) 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.

Common carp and other rough fish uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments, releasing phosphorus into the water column and decreasing water clarity. Additionally, wind energy and motorboat 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 re-suspension, and phosphorus release from sediment. 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.

Septic Systems and Unsewered Communities

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 (FTPGW) and those that are an imminent threat to public health and safety (ITPHS). Generally, FTPGW systems are those that do not provide adequate treatment and may contaminate groundwater. For example, a system deemed failing to protect groundwater 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 periodically saturated soil level 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 SSTSs in the Redwood River Watershed 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 (Section 3.6.4) utilizes recent estimated rates reported by the county to the MPCA (Table 16; MPCA personal communication 2018). It should be noted that these rates were county-wide estimates and were developed using a wide range of methods and resources and are intended for planning purposes only.

Table 16. Estimated SSTS compliance rates by county (MPCA personal communication 2018).

County	FTPGW SSTS	ITPHS SSTS
Lincoln	40%	16%
Lyon	24%	5%
Murray	15%	10%
Pipestone	9%	46%
Redwood	30%	5%
Yellow Medicine	15%	15%

Note: Estimated compliance rates reported by MPCA. Intended for planning purposes only.

Municipal and Industrial Wastewater

Domestic, commercial, and industrial waste waters are collected and treated to meet water quality standards by municipalities before being discharged to water bodies 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.

There are 10 active permitted wastewater facilities that discharge to the impaired reaches covered in this TMDL report (Figure 2 and Table 17).

Table 17. Wastewater treatment facilities in the Redwood River Watershed.

Facility Name	NPDES ID#	Facility Type	Impaired Reach(es)
ADM Corn Processing - Marshall	MN0057037	Industrial Wastewater	502, 503, 509
Ghent WWTP	MNG585121	WWTP	503, 509, 564/565/566
Lynd WWTP	MNG585030	WWTP	502, 503, 509
Marshall WWTP	MN0022179	WWTP	502, 503, 509
Russell WWTP	MNG585062	WWTP	502, 503, 509
Milroy WWTP	MNG585124	WWTP	509
Vesta WWTP	MNG585043	WWTP	503, 509
Magellan Pipeline Co LP - Marshall	MN0059838	Industrial Wastewater	502, 503, 509
Ruthton WWTP	MNG585105	WWTP	502, 503, 509
Tyler WWTP	MNG585116	WWTP	502, 503, 509

Construction and Industrial Stormwater

Construction stormwater is regulated through an NPDES permit. Untreated stormwater that runs off construction sites often carries sediment to surface water bodies. 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. On average, there is one permitted industrial stormwater site in every 23 square miles of the Redwood River Watershed.

On average, based on watershed-wide data, less than 0.4% of the watershed area is permitted under the construction and industrial stormwater permit in any given year. Thus, construction and industrial stormwater was not considered a significant source of sediment, phosphorus, chloride, or bacteria throughout the Redwood River Watershed.

Natural Bacterial Reproduction

It has been suggested that *E. coli* bacteria has the capability to reproduce naturally in water and sediment and therefore should be considered 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 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.

Natural reproduction of *E. coli* is included in the LA; however, it is not broken out as a separate allocation.

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 and Gannon 1991) documented survival and growth of fecal coliform in storm sewer sediment.
- Two studies in Maryland (Park et al. 2016; Pachepsky et al. 2017) 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 TSS Source Summary

As discussed in the previous section, sediment loading to streams can come from both external and internal sources. External sources of TSS include sediment loading from permitted sources such as construction and industrial stormwater, runoff from urban areas, and wastewater effluent; as well as nonpermitted sources such as overland runoff/erosion from cropland, hay/pasture, forest, and rangeland. Potential internal sources of sediment include bank erosion and in-channel algal production. This TMDL study used the Redwood River HSPF model to evaluate sediment loading from various sources to each of the nine TSS impaired reaches. Figure 5 and Table 18 present HSPF predicted annual TSS loads to each impaired reach by major source category.

Chl-*a* data for each impaired reach was also reviewed to determine whether algae growth is a potential source of TSS and poor water clarity. Only three of the impaired reaches have Chl-*a* data (Table 18). Chl-*a* concentrations in these reaches occasionally exceed the state's eutrophication criteria of 35 µg/L for streams in the South River Nutrient Region, suggesting algae may be a source of TSS. Most of these exceedances occurred during late summer (August and September) low flow conditions. More data will need to be collected to fully assess algal turbidity in the TSS impaired reaches.

Figure 5. TSS contributions by source for each impaired reach estimated using the Redwood River Watershed HSPF model.

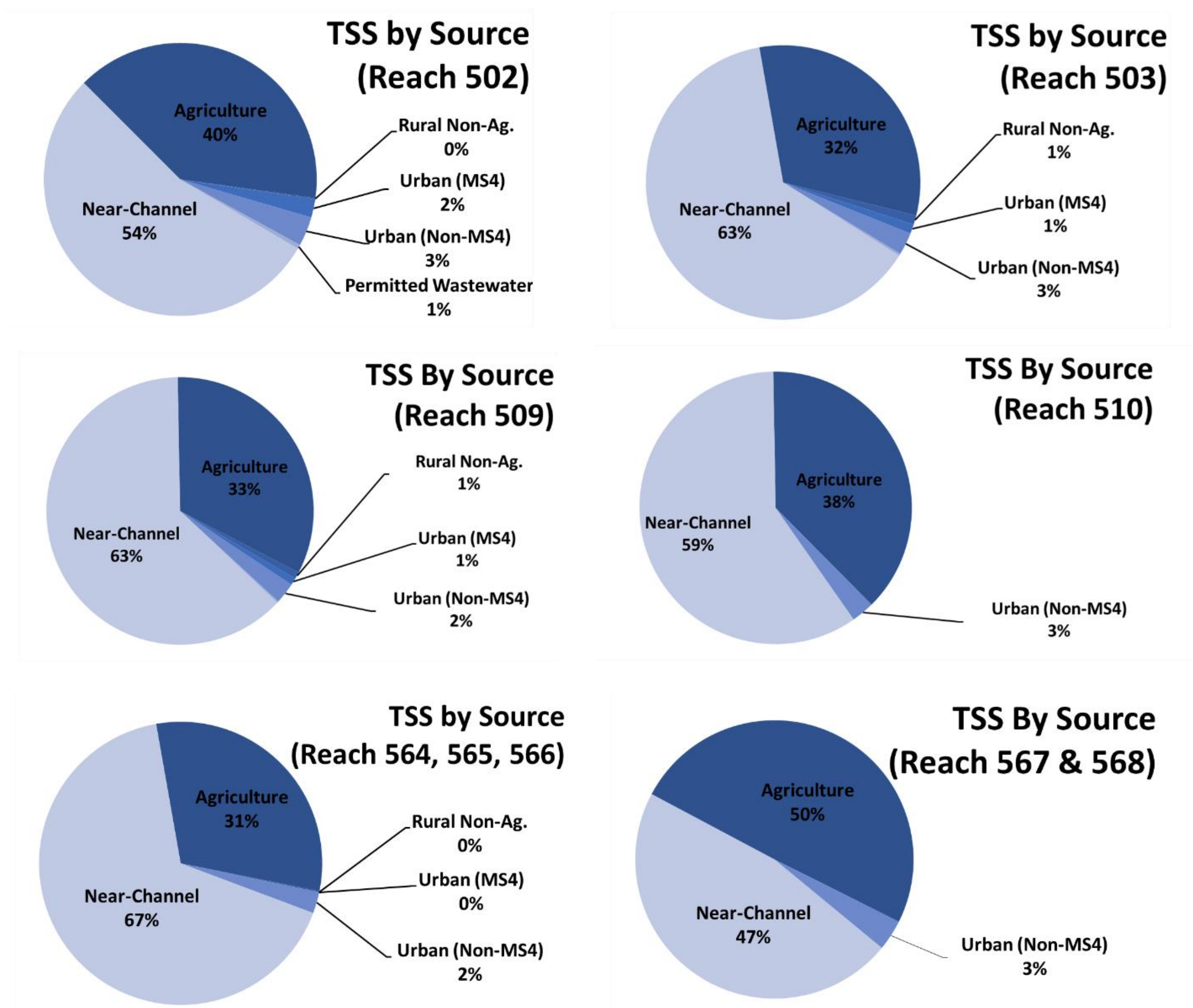


Table 18. TSS source assessment by land use category for the Redwood River Watershed.
Note: Numbers in this table are based on HSPF average annual TSS loads for model years 1996-2017.

Impaired Reach Description	Reach Id	Units	HSPF Model Estimates							Chl-*a* Data
			Agriculture[1]	Rural Non-Ag.[2]	Urban (MS4)	Urban (Non-MS4)	Permitted Wastewater	Near-Channel[3]	Total	
Redwood River: Clear Creek to Redwood Lake	509	tons/yr	11,078	284	285	858	68	21,116	33,689	Of the 12 samples collected, ~50% exceed 35 µg/L (all during mid and low flows)
		percent	33%	<1%	<1%	3%	<1%	63%		
Redwood River: T111 R42W S33, west line to Three Mile Creek	502	tons/yr	5,232	20	285	459	66	7,124	13,186	Of the eight samples collected, none exceed 35 µg/L
		percent	40%	<1%	2%	4%	<1%	54%		
Redwood River: Three Mile Creek to Clear Creek	503	tons/yr	8,150	278	285	680	67	16,288	25,748	No Chl-*a* data has been collected for this reach
		percent	32%	1%	1%	3%	<1%	63%		
Redwood River: Coon Creek to T110 R42W S20, north line	510	tons/yr	1,395	2	0	99	0	2,191	3,687	No Chl-*a* data has been collected for this reach
		percent	38%	<1%	<1%	3%	<1%	59%		
Three Mile Creek: Headwaters to T113 R41W S33, east line (564); T113 R41W S34, west line to T112 R41W S12, east line (565)	564, 565 & 566	tons/yr	1,428	6	22	90	0	3,072	4,618	Of the eight samples collected, none exceed 35 µg/L
		percent	31%	<1%	< 1%	2%	<1%	67%		
Clear Creek: -95.323 44.466 to Redwood River	567 & 568	tons/yr	2,031	3	0	145	1	1,917	4,097	No Chl-*a* data has been collected for this reach
		percent	50%	<1%	<1%	3%	<1%	47%		

[1] Includes cultivated cropland, grassland, hay/pasture, and feedlots
[2] Includes forest and shrub land, groundwater, wetlands, and open water
[3] Includes bluff and bed/bank erosion

3.6.2 Stream *E. coli* Source Summary

The primary *E. coli* sources considered for this TMDL include livestock manure, stormwater runoff from urban areas, wildlife, WWTP, 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. A simple 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 watersheds. This exercise was done using various Geographic Information System (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 A presents results of the desktop bacteria production exercise for each impaired reach watershed. Table 19below 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 was 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 for both reach 510 and reach 521 (99.51% and 99.69%, respectively). Bacteria production for ITPHS SSTS across the impaired reach watersheds was significantly low (0.09% or less) compared to livestock production. The production exercise estimates that there were approximately 99 ITPHS SSTS systems in the Redwood River Reach 510 subwatershed and approximately 13 in the Ramsey Creek Reach 521 subwatershed. Although these numbers were 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 B) from the three point source dischargers (Tyler WWTP, Ruthton WWTP, Russell WWTP) located within the impaired reach watersheds suggest *E. coli* effluent concentrations typically well below the *E. coli* standard. Thus, these point sources were not considered a source of concern. Since urban/developed land accounts for less than 6% (Table 5) of the land use within the impaired reach watersheds, urban sources (i.e., domestic pets) represent a very small portion (0.17% or less) of the total bacteria produced in the 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 2011b) studies. These estimates do not identify or directly account for areas in which wildlife inputs may be elevated. These could include but were not limited to open water areas with high waterfowl densities and lawns or golf courses near streams where geese or other waterfowl congregate.

Table 19. *E. coli* source summary for each impaired reach covered in this Redwood River Watershed TMDL. Based on data collected between 2009 – 2017.

Impaired Reach	Cropland/Manure	Livestock/Pastures near Streams	Wildlife	Urban	WWTPs	SSTS	Upstream Lake(s) & Reach(es)	In-stream (sediment)	Notes
Redwood River Reach 510	●	○	-	-	-	○	●	?	• Exceedances occur during very high (30%), high (62%), mid (82%) and low (65%) flow conditions. No samples collected during very low flow conditions. • Several impaired reaches (505, 511, and 512) that were covered under previous TMDL efforts (RCRCA, 2013) contribute to this reach.
Clear Creek Reach 521	●	X	-	-	X	○	X	?	• Exceedances occur during very high (100%), high (100%) and mid (100%) flow conditions. No samples collected during low and very low flow conditions. • None of the MPCA registered livestock in the watershed are in close proximity to streams/waterways.

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

3.6.3 Stream Chloride Source Summary

In Minnesota watersheds, the primary sources of chloride to surface waters include urban runoff (i.e., winter maintenance activities), agricultural runoff, septic systems, and wastewater effluent. The Redwood River chloride impaired reach (502) flows through the city of Marshall and land use in the 197,000-acre watershed draining to the impaired reach is dominated by cropland (69%), rangeland (16%), and residential/developed (8%). There are several permitted point source dischargers that either discharge directly to the chloride impaired reach (Lynd WWTP, Magellan Pipeline Co LP, ADM Corn Processing – Marshall, and Marshall WWTP) or are located upstream of the impaired reach (Tyler WWTP, Ruthton WWTP, and Russell WWTP). Discharge monitoring reports (DMRs) for all these facilities were downloaded and processed for this study; however, only two of the facilities, ADM Corn Processing – Marshall and Marshall WWTP, regularly monitor chloride concentrations in their effluent waters. A summary of the chloride effluent data for these facilities is presented in Appendix B. These data show that both facilities routinely exceed the 230 mg/L chronic standard. The mean effluent chloride concentration (2000 through 2018) for ADM Corn Processing (1,431 mg/L) was over six times higher than the chronic standard and Marshall WWTP's mean concentration (584 mg/L) was just under two times the chronic standard. As discussed in Section 3.5.3, monitoring efforts upstream and downstream of ADM Corn Processing – Marshall and Marshall WWTP reveal that the chloride impairment for reach 502 begins downstream of these dischargers (Table 9 and Table 10), therefore; upstream sources (i.e., other point source dischargers, stormwater from the city of Marshall, agricultural runoff etc.) were not contributing significantly, to the chloride impairment in this reach.

3.6.4 Lake Phosphorus Source Summary

Lake response models were set up for each of the six impaired lakes in the Redwood River Watershed to evaluate phosphorus sources and estimate annual phosphorus budgets. The lake response model selected for this exercise was the Canfield-Bachmann Lake equation (Canfield and Bachmann 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 appropriately to achieve an approximate match to monitored data.

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

Atmospheric Loads

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

SSTS Loads

Phosphorus loading from SSTSs to each impaired lake was estimated using methods similar to the Lower Minnesota River Watershed TMDL (MPCA 2020c). First, the total number of people in each lake drainage area was estimated 1) for unsewered shoreland areas (i.e., near the lake); and 2) for unsewered areas outside of the shoreland (i.e., farther from lakes). To estimate the number of people living within shoreland, aerial photos were used to estimate the number of homes/cabins. This number was then multiplied by the number of people per household (assumed to be 2.55 on average for the Minnesota River Basin; Barr Engineering 2004) and an adjustment factor to account for the assumption that approximately half of homes/cabins within shoreland were used only four months each year (adjustment factor was 2/3). To estimate the number of people living outside of the lake's shoreland, 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 from SSTSs was assumed to be 1.978 lbs of TP per person per year (Barr Engineering 2004) and was used in conjunction with the estimates above to obtain TP loading from SSTSs each year.

To determine TP loading to each impaired lake, total loading was calculated to SSTSs labeled compliant, failing, and ITPHS. Because the compliance status of each SSTS in each lakeshed was not known at this time, 2018 estimated compliance rates were used for this calculation (Table 15; MPCA personal communication 2018). Phosphorus removal rates for SSTSs in each of these compliance groups were then applied: for SSTSs adjacent to lakes, 80% removal rates were assumed for compliant systems, while 57% removal rates were assumed for both failing and ITPHS SSTSs (Barr Engineering 2004). For SSTSs father from lakes, 90%, 70%, and 57% removal rates were assumed for compliant, failing, and ITPHS SSTSs, respectively (Barr Engineering 2004). The phosphorus removal and soil phosphorus attenuation percentages assumed for conforming and nonconforming SSTSs in this analysis were within the range of literature values (Viraraghavan and Warnock 1975; Reckhow and Simpson 1980; Kellogg et al. 1995; EPA 2002b; ENSR 2003) as reported by Barr Engineering, 2004. Finally, the sum was taken of phosphorus loading from all compliance groups and from households both adjacent and farther from lakes to obtain TP loading to each impaired lake from SSTSs.

Watershed Loads

Watershed flow and phosphorus loads to each impaired lake were estimated using the Redwood River Watershed HSPF model (Appendix D). HSPF-predicted average annual runoff depths and TP concentrations to each impaired lake in the Redwood River Watershed ranged from 5 to 12 inches/year and 227-352 µg/L, respectively. HSPF utilizes several individual sub-routines/models and assumptions to model hydrology and pollutant loading fate and transport and therefore the watershed load to each lake can be further analyzed and broken down by sub-categories such as feedlots, manure, groundwater, bluff erosion, bed/bank erosion, and individual land uses (i.e., developed, forest, cropland, grassland, etc.). Figure 5 shows the HSPF-predicted average annual watershed TP inputs to each impaired lake.

Upstream Impaired Lake Loads

Dead Coon Lake is the only lake in the Redwood River Watershed that contains an upstream impaired lake (Lake Benton) in its drainage area. Outflow volumes from Lake Benton were estimated using the HSPF model and routed directly into Dead Coon Lake within the lake response model. Average TP loads from Lake Benton to Dead Coon Lake were then calculated by multiplying the HSPF predicted flow volume by the average summer growing season monitored TP concentrations for Lake Benton.

Internal Loads

Internal loading for the Redwood River Watershed impaired lakes was estimated through a model residual approach whereby the other four 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 study assumes that the additional loads are likely attributed to internal phosphorus loading from sediment, rough fish (i.e., common carp), vegetation (i.e., CLP) and/or wind/boat resuspension. It is also possible that a portion of the additional load needed to calibrate the models is the result of one (or more) of the other four sources being under-represented, or one or more loading source(s) that is not currently accounted for in the TP source assessment.

Although it is difficult and/or cost prohibitive to directly measure phosphorus inputs from sediment, fish, vegetation, and wind/boating, there are ways to evaluate whether these sources have significant potential to contribute to internal load. For example, internal loading from sediments can be estimated by combining sediment phosphorus RR estimates with an anoxic factor (AF) calculation (Nürnberg 2004). Sediment phosphorus RRs were assessed as part of this TMDL study for Benton and School Grove Lakes by collecting intact sediment cores and incubating them in the laboratory under anoxic conditions. Results of this analysis (Table 20 and Appendix B) indicate that both Lake Benton (RR = 9.1 mg/m^2/day) and School Grove Lake (RR = 5.9 mg/m^2/day) have high potential for sediment phosphorus release under anoxic conditions. The AF estimates the period of anoxia over the lake sediments and is calculated using temperature-DO profiles. AFs are often difficult to measure in shallow lakes since they can have intermittent anoxic periods that aren't measured with routine monitoring. Nonetheless, AFs were estimated for Lake Benton and School Grove Lake using available temperature-DO profile data and then multiplied by the laboratory measured phosphorus RR and total area of each lake to estimate gross internal loads for each lake. Results indicate that sediment release of phosphorus may be accounting for approximately 14% of the internal load in Lake Benton and approximately 23% of the internal load in School Grove Lake. Additional data on watershed inputs to both lakes would be valuable to validate the lake response models and the impact of internal loading in these lakes.

In-lake water quality, particularly in shallow lakes, is closely linked to the health and structure of the lake's biological communities. Water quality degradation can occur when certain aquatic invasive species (i.e., common carp) are present in high densities or certain native species (i.e., black bullhead, fathead minnow) become over-abundant thus creating an imbalanced fishery. Common carp uproot vegetation and re-suspend sediment which, when there are high densities of carp in a lake, can lead to increased water turbidity, 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). In 2018, Wenck Associates, Inc. conducted common carp population assessments for School Grove Lake using standard electroshocking methods (Bajer and Sorensen 2012). Results of this assessment indicate School Grove Lake has a common carp density (295 lbs/acre) over three times the critical threshold, suggesting that common carp (and possibly other fish) were contributing to poor water quality and habitat degradation. Appendix C contains a detailed discussion of the common carp assessment for School Grove Lake.

School Grove Lake was the only impaired lake in the Redwood River Watershed assessed for common carp densities; however, at least one DNR trap and gill net survey has been performed in all six of the impaired lakes covered in this TMDL report. Common carp along with certain native fishes (i.e., largemouth bass) avoid standard trap and gill nets used by the DNR, therefore, other techniques such as the electroshocking method described above are needed to accurately estimate population numbers and densities that can be used to inform management strategies. That said, the DNR trap and gill net surveys provide a good indicator of the presence/absence of common carp, black bullhead and other species that may impact water quality. Review of historic DNR trap and gill net surveys noted the presence of black bullhead in all five impaired lakes and common carp in four of the five lakes (Table 19 and Appendix B). In many of the lakes, black bullhead and/or common carp comprised a large percentage of the fish sampled in the trap and gill nets and therefore it is likely that these species are impacting water quality in these systems.

The final phosphorus source assessment results for each impaired lake are shown in Figure 5 (phosphorus lbs per year). Table 20 provides a summary of the source categories that are of most concern for each impaired lake, based on the quantitative lake response model results as well as the sediment core results for Lake Benton and School Grove Lake, the common carp survey for School Grove Lake, the DNR fish surveys and anecdotal information.

Figure 6. Redwood River Watershed impaired lakes average annual TP contributions by source based on HSPF and lake response modeling results.

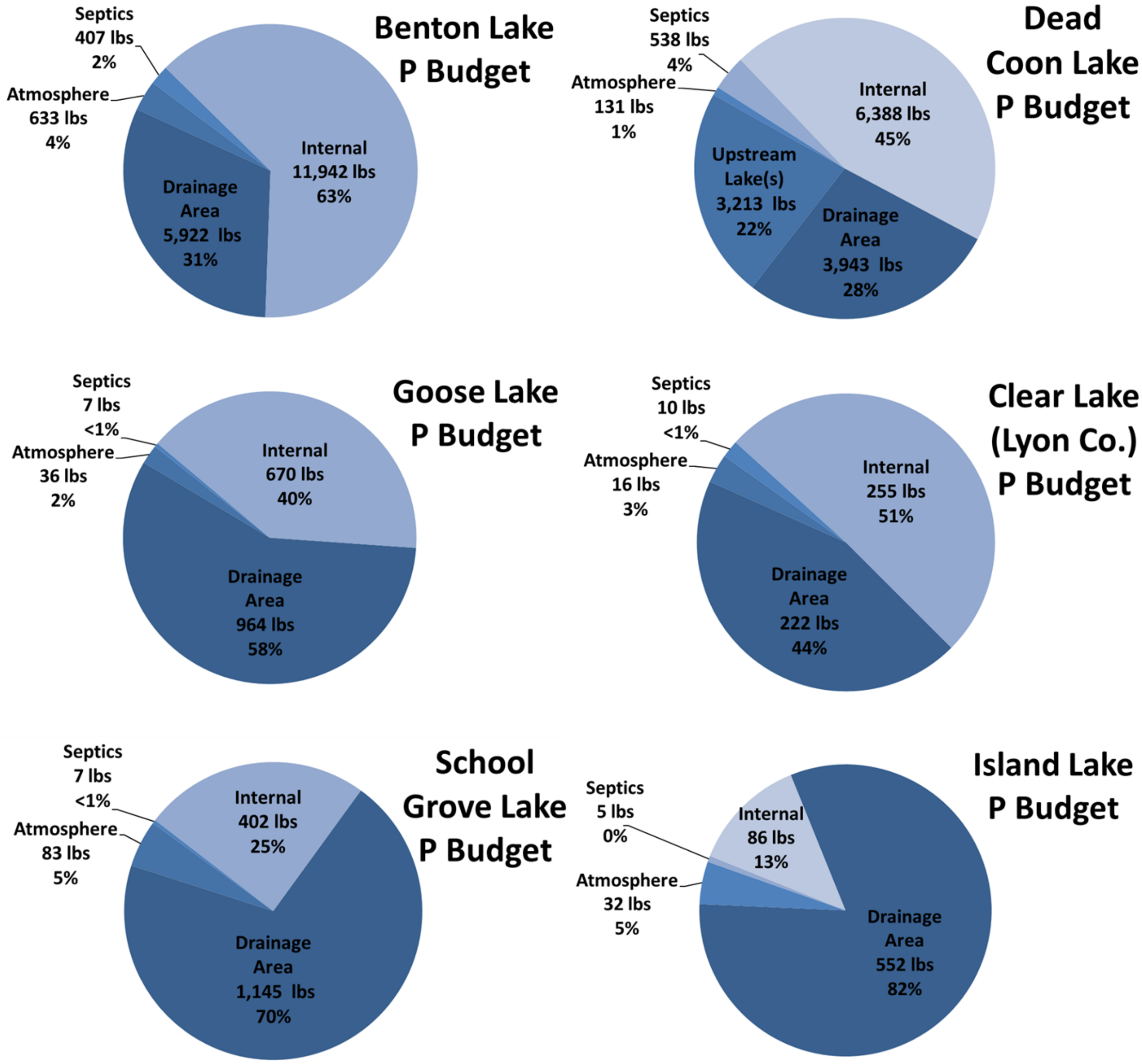


Table 20. TP source summary for Redwood River Watershed impaired lakes covered in this TMDL.

Lake Name	Watershed Sources					Internal Sources				Upstream Impaired Lake(s)	Notes
	Agriculture	Urban	SSTS	WWTPs	Upstream Lakes	Sediment Release	Aquatic Vegetation (i.e., (curly-leaf pondweed)	Rough Fish (i.e., common carp)	Other		
Benton	●	○	○	x	x	●	Δ	Δ	Wind Boating	NA	• DNR fish surveys observed a large presence of both black bullhead and common carp in 2017. • The lab measured sediment release rate (9.1 $mg/m^2/day$) was high compared to other lakes. • The HSPF predicted average annual watershed TP concentration (206 µg/L) exceeded the 150 µg/L eutrophication standard.
Dead Coon	●	x	○	x	●	Δ	Δ	Δ		Benton	• DNR fish surveys observed a large presence of common carp and a moderate presence of black bullhead in 2017. • The internal loading rate based on the model residual approach (40.6 $mg/m^2/day$) was extremely high. • The HSPF predicted average annual watershed TP concentration (167 µg/L; does not include Lake Benton contribution) exceeded the 150 µg/L eutrophication standard.
Goose	●	x	○	x	x	Δ	Δ	Δ		NA	• DNR fish surveys observed a large presence of both black bullhead and common carp in 2015. • The internal loading rate based on the model residual approach (16.3 $mg/m^2/day$) was high. • The HSPF predicted average annual watershed TP concentration (227 µg/L) exceeded the 150 µg/L eutrophication standard.
Clear (Lyon Co.)	●	x	○	x	x	Δ	Δ	Δ		NA	• DNR fish surveys observed a large presence of black bullhead in 2016. No common carp have been observed. • The internal loading rate based on the model residual approach (14.1 $mg/m^2/day$) was high. • The HSPF predicted average annual watershed TP concentration (234 µg/L) exceeded the 150 µg/L eutrophication standard.
School Grove	●	x	○	x	x	●	Δ	●		NA	• DNR fish surveys observed a large presence of both black bullhead and common carp in 2017.

Lake Name	Watershed Sources					Internal Sources				Upstream Impaired Lake(s)	Notes
	Agriculture	Urban	SSTS	WWTPs	Upstream Lakes	Sediment Release	Aquatic Vegetation (i.e., (curly-leaf pondweed)	Rough Fish (i.e., common carp)	Other		
											• The common carp population assessment conducted in 2018 suggests biomass density (~295 lbs/acres) more than three times the critical threshold (89 lbs/acre). • The lab measured sediment release rate (5.9 $mg/m^2/day$) was moderate compared to other lakes. • The HSPF predicted average annual watershed TP concentration (352 µg/L) exceeds the 150 µg/L eutrophication standard.
Island	●	x	○	x	x	Δ	Δ	○		NA	• DNR fish surveys observed a large presence of black bullhead in 2017. No common carp were captured during the 2017 DNR fish survey. • The Internal loading rate based on the model residual approach (1.2 $mg/m^2/day$) was low. • The HSPF predicted average annual watershed TP concentration (309 µg/L) exceeds the 150 µg/L eutrophication standard.

● Primary source
○ Secondary source
x Not considered a primary or secondary source at this time
Δ Potential source however not enough data/info available currently to evaluate

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 described as 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 water body 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 (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(1)), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures. For this TMDL report, 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 Redwood River Watershed HSPF model was used to estimate watershed runoff and pollutant loading to the impaired lakes and reaches included in this TMDL report. 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.

HSPF models for the Redwood River Watershed were originally developed in 2012 and then updated in 2016 and 2019 to support this TMDL and other planning and management efforts in the watershed (Tetra Tech 2016 and 2019). The HSPF models predict 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 three major watershed HSPF models (Tetra Tech 2016 and 2019).

4.1.2 Load Duration Curve Approach

Pollutant loading capacity for the TSS, *E. coli*, and chloride impaired stream reaches were developed using LDCs. Load duration curves 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 2008 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 report, only five points on the entire loading capacity 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, the entire curve represents the TMDL and is what is ultimately approved by the EPA. For the purposes of this TMDL report, the baseline year for implementation will be 2012, 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 study. 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 water body in the absence of measurable impacts from 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. For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment and therefore natural background is accounted for and addressed through the MPCA’s water body assessment process. Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this TMDL report. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, wastewater treatment facilities, failing SSTSs, and other anthropogenic sources.

Based on the MPCA’s water body assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of any of the impairments and/or affect the water bodies’ ability to meet state water quality standards. For all impairments addressed in this TMDL study, 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. Minnesota law does not compel the MPCA to develop a separate LA for natural background sources. For more information, see Crystal Lake TMDL Court of Appeals Decision; Filed February 4, 2019.

4.2 TSS - Streams

4.2.1 Loading Capacity Methodology

LDCs were used to represent the loading capacity (LC) for each TSS impaired reach. The flow component of the LC curve is based on the HSPF simulated daily average flows (2008 through 2017), and the concentration component is the TSS concentration criteria of 65 mg/L. TSS LDCs for each impaired reach are shown in Section 4.2.6. On these figures the red curve represents the allowable TSS LC of the reach for each daily flow. The median (or midpoint) load of each flow zone is 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 water quality sampling event (black circles in Figure 7 through 12). Each value that is above the curve represents an exceedance of the water quality standard, while those below the line are below the water quality standard.

The existing concentration for each impaired reach was calculated as the 90th percentile of observed TSS concentrations for all flow zones for the months that the standard applies (April through September). The 90th percentile was used because the TSS standard states that the numeric criterion (65 mg/L) may be exceeded for no more than 10% of the time. The overall estimated concentration-based percent reduction needed to meet each TMDL was calculated as the existing concentration minus the TSS standard (65 mg/L) divided by the existing concentration. Also plotted in each LDC figure is the 90th percentile monitored TSS load for each individual flow zone (solid green circles). Plotting these individual loads helps determine what flow zones and practices should be targeted to achieve the overall reduction goal for each impaired reach.

4.2.2 Wasteload Allocation Methodology

The WLAs for TSS were divided into three categories: NPDES permitted wastewater dischargers, NPDES MS4 stormwater, and NPDES permitted construction and industrial stormwater. The following sections describe how each WLA category was determined. 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 TSS TMDL tables in Section 4.2.6.

NPDES Permitted Wastewater Dischargers

There are 10 active regulated NPDES wastewater dischargers in the Redwood River TSS impaired reach subwatersheds that have been assigned TSS effluent limits. Facility maximum daily effluent TSS loads were established and provided by the MPCA and are a function of the facility design flows and permitted TSS concentration limits (Table 21). WLAs for each facility were calculated by multiplying the TSS effluent concentration limit, permitted facility design flow, and a unit conversion factor. All dischargers have TSS effluent concentration limits less than the TSS standard of 65 mg/L. Therefore, facilities that discharge consistent with their WLAs are not a cause for in-stream exceedances of the TSS standard within their receiving water bodies. WLAs for continuously discharging municipal WWTPs were calculated based on the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Controlled municipal pond discharge WWTP WLAs were calculated based on the maximum daily volume that may be discharged in a 24-hour period.

Table 21. TSS allocations for NPDES permitted wastewater dischargers in the Redwood River Watershed.

Impaired Reach	Facility Name and System Type	NPDES ID#	Flow Used for WLA* (MGD)	Permitted Concentration (mg/L)	Permitted Load (lbs/day)
502, 503, 509	ADM Corn Processing – Marshall/ Mechanical	MN0057037	2.64	30	661
503, 509, 564/565/566	Ghent WWTP/ Pond	MNG585121	0.26	45	97
502, 503, 509	Lynd WWTP/ Pond	MNG585030	0.34	45	128
502, 503, 509	Marshall WWTP/ Mechanical	MN0022179	4.50	30	1,126
502, 503, 509, 510	Russell WWTP/ Pond	MNG585062	0.59	45	220
509, 568	Milroy WWTP/ Pond	MNG585124	0.25	45	93
503, 509	Vesta WWTP/ Pond	MNG585043	0.26	45	97
502, 503, 509	Magellan Pipeline Co LP – Marshall/ Mechanical	MN0059838	0.72	30	180
502, 503, 509, 510	Ruthton WWTP/ Pond	MNG585105	0.38	45	142
502, 503, 509, 510	Tyler WWTP/ Pond	MNG585116	1.09	45	409

*Average wet weather design flow or maximum daily pond flow in million gallons per day (MGD).

NPDES Permitted MS4 Stormwater

The city of Marshall, which contributes to reaches 502, 503, and 509, is the only MS4 within the Redwood River TSS impaired reach subwatersheds covered by this TMDL. Figure 1 shows the city of Marshall's municipal boundary and its location in the Redwood River Watershed. The city covers 5,875 acres in the Redwood River Watershed which is approximately 3.0%, 1.8%, and 1.5% of the drainage area for reach 502, 503, and 509, respectively. TSS allocations for the City of Marshall were calculated by multiplying each reach's MS4 percent watershed coverage by the total watershed loading capacity (determined by LDCs). City of Marshall MS4 WLA areal loading rates (in lbs/acre/year) were estimated using the flow-zone correction approach presented in Section 4.2.6. and are included as footnotes in the TMDL tables.

NPDES Permitted Construction and Industrial Stormwater

Construction stormwater is regulated by NPDES Permits for any construction activity disturbing a) one acre or more of soil, b) less than one acre of soil if that activity is part of a "larger common plan of development or sale" that is greater than one acre, or c) less than one acre of soil, but the MPCA determines that the activity poses a risk to water resources. The WLA for stormwater discharges from sites where there are construction activities reflects the number of construction sites expected to be active in the impaired reach watershed at any one time. Industrial stormwater is regulated by NPDES Permits if the industrial activity has the potential for significant materials and activities to be exposed to stormwater discharges.

A categorical WLA was assigned to all construction activity in the watershed. Current acres under Construction and Industrial Stormwater Permits in each major watershed were available through the MPCA's Permit database. The amount of land under Construction and Industrial Stormwater Permits in the Redwood River Watershed was divided by the total area of the watershed to determine the percent of permitted land. Results of this analysis show that approximately 0.3% of land in the Redwood River Watershed is currently under a Construction and Industrial Stormwater Permit. To determine the WLAs for these activities, total loading capacity in each flow zone was multiplied by the appropriate construction and industrial coverage percentage.

4.2.3 Load Allocation Methodology

As stated in the TMDL equation, the LA is comprised of the nonpoint source load that is allocated to an impaired reach after the WLAs (point sources, construction and industrial stormwater) and MOS were determined and subtracted from the total LC for each reach and flow zone. This residual remaining LC is meant to represent all nonregulated (nonpoint) sources of TSS upstream of the impaired reach (summarized in Section 3.6). The LA, also referred to as the watershed LA, includes nonpoint pollution sources that are not subject to NPDES Permit requirements such as wind-blown materials, soil erosion from stream channel and upland areas, and natural background. The LA also includes runoff from agricultural lands and non-NPDES stormwater runoff.

Given the complexity of sediment dynamics and a lack of sufficient historical data in the Redwood River Watershed, attempting to allocate a specific natural background load to any river or stream reach would result in a margin of error that may be more than the estimated allocation. As such, the LA implicitly includes natural background without designating its own allocation. Schottler et al (2010) and other resources included in Section 3.6 discuss this matter further.

4.2.4 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 5% of the loading capacity. Five percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty. The LDC calculations are based on TSS 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 Redwood River HSPF model was calibrated and validated using 21 years (1996 through 2017) of flow data from five gaging stations throughout the watershed (Tetra Tech 2019). Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. See Appendix D of this TMDL report for the HSPF model calibration and validation results. The TSS stream LDCs were developed using HSPF modeled daily flow data from April through September. The TSS TMDLs applied a MOS to each flow zone along the duration curves by subtracting 5% of the flow zones' loading capacity.

4.2.5 Seasonal Variation and Critical Conditions

Both seasonal variation and critical conditions are accounted for in this TMDL report through the application of LDCs. LDCs evaluate water quality conditions across all flow zones including high flow, runoff conditions where sediment transport tends to be greatest. Seasonality is accounted for by addressing all flow conditions in each reach. Based on the LDCs presented in Figure 7 through Figure 12, critical conditions for the TSS impairments are the very high and high flow conditions as these are the conditions when a majority of the individual TSS standard exceedances occur.

4.2.6 TSS TMDL Summary

The TMDL allocation tables (Table 22 through Table 27) present the total LC (Total Load (TMDL) in tables), the MOS, the WLAs (Wasteload in tables) and the remaining watershed LAs (Load in tables) for the TSS impaired reaches. Allocations for this TMDL study were established using the 65 mg/L TSS standard. TMDL allocations for all reaches include the entire subwatershed draining to each impaired reach (See Figure 2 and Appendix A). For example, allocations for Redwood River reach 503 include the subwatersheds draining to Three Mile Creek reaches 564/565 and Redwood River reach 502, as well as the subwatersheds draining to all nonimpaired reaches upstream of these impairments.

The following rounding conventions were used in the TMDL tables:

- Values ≥1.0 reported in 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.

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.

The bottom line of the table shows the estimated load reduction for all flow zones and is calculated based on the difference between the 90th percentile monitored TSS concentration (all available data April through September 2008 through 2017) and the 65 mg/L TSS standard. Since the TSS monitoring data is biased to higher flows (i.e., 65% to 76% of TSS samples collected during very high and high flow conditions), a flow zone correction was applied when calculating the 90th percentile TSS concentration. This was done by multiplying each flow zone's 90th percentile monitored TSS concentration by the flow zone's frequency of occurrence. The following equation was used for this calculation:

$$90^{th} \text{ Percent. TSS Conc.} = (0.1 * TSS_{very\ high}) + (0.3 * TSS_{high}) + (0.2 * TSS_{mid}) + (0.3 * TSS_{low}) + (0.1 * TSS_{very\ low})$$

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 each table. Thus, the estimated load reduction for each flow zone applies to all sources. See Section 8 of this TMDL report and the WRAPS report for further information on which sources and geographical locations within the impaired reach subwatersheds should be targeted for sediment reduction BMPs and restoration strategies. LDCs for the TSS impaired reaches (Figure 7 through Figure 12) generally show TSS load exceedances during high and very high flows. TSS loading during high and very high flows is likely related to near-channel (bank erosion) and agricultural sources (overland erosion from cropland, hay/pasture, forest, and rangeland). Restoration and protection efforts should focus on these sources.

Figure 7. Redwood River Reach 502 TSS load duration curve and monitored loads and exceedances.

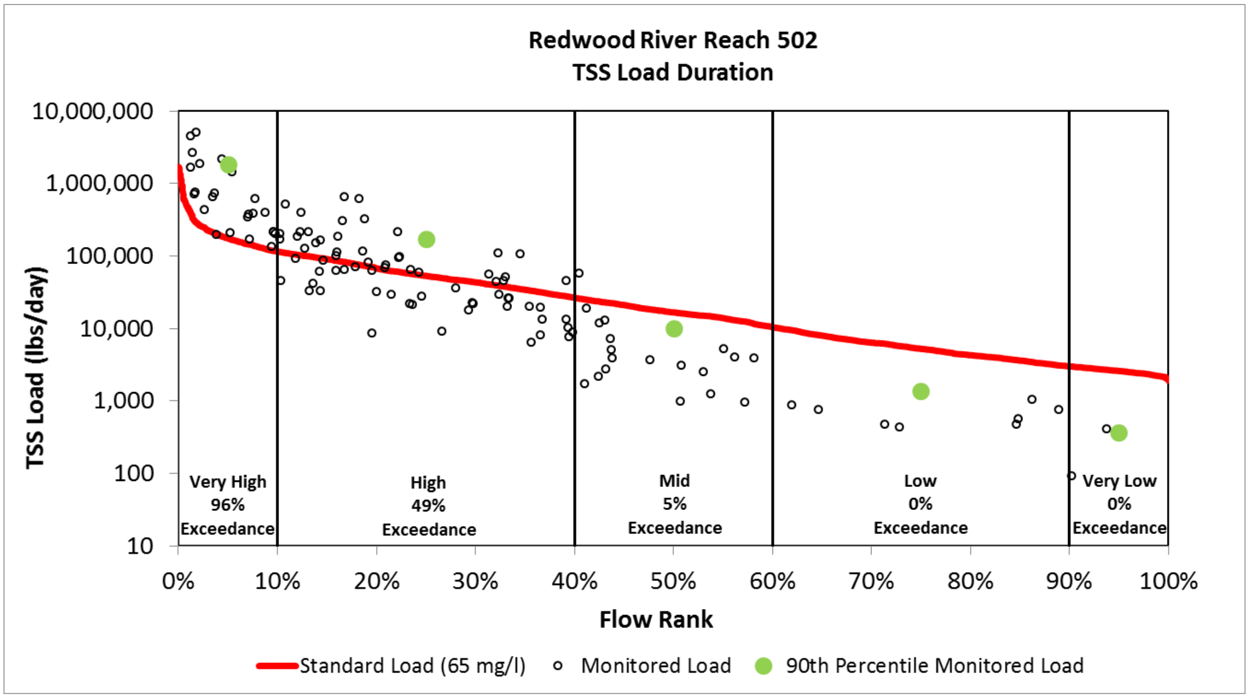


Table 22. TSS TMDL summary for Redwood River Reach 502.

Total Suspended Solids		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		TSS load (lbs/day)				
Wasteload	ADM Corn Processing – Marshall (MN0057037)	661	661	661	661	***
	Lynd WWTP (MNG585030)	128	128	128	128	***
	Marshall WWTP (MN0022179)	1,126	1,126	1,126	1,126	***
	Russell WWTP (MNG585062)	220	220	220	220	***
	Magellan Pipeline Co LP – Marshall (MN0059838)	180	180	180	180	***
	Ruthton WWTP (MNG585105)	142	142	142	142	***
	Tyler WWTP (MNG585116)	409	409	409	409	***
	City of Marshall MS4 (MS400241)**	5,173	1,579	495	155	***
	Construction/Industrial SW	538	164	52	16	***
	Total WLA	**8,577**	**4,609**	**3,413**	**3,037**	***
Load	**Total LA**	**156,895**	**45,909**	**12,434**	**1,933**	***
MOS		**8,709**	**2,659**	**834**	**262**	**130**
Total load		**174,181**	**53,177**	**16,681**	**5,232**	**2,591**
Existing 90th percentile concentration (mg/L)******		**145**				
Overall estimated percent reduction******		**55%**				

* Model simulated flow for HSPF reach 290 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The daily WLAs for the City of Marshall MS4 equate to an areal TSS loading rate of approximately 71 lbs/acre/year.
*** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
**** Water quality monitoring station(s) used to estimate reductions: S001-199, S001-203, S003-702, S009-023.

Figure 8. Redwood River Reach 503 TSS load duration curve and HSPF simulated TSS loads and exceedances.

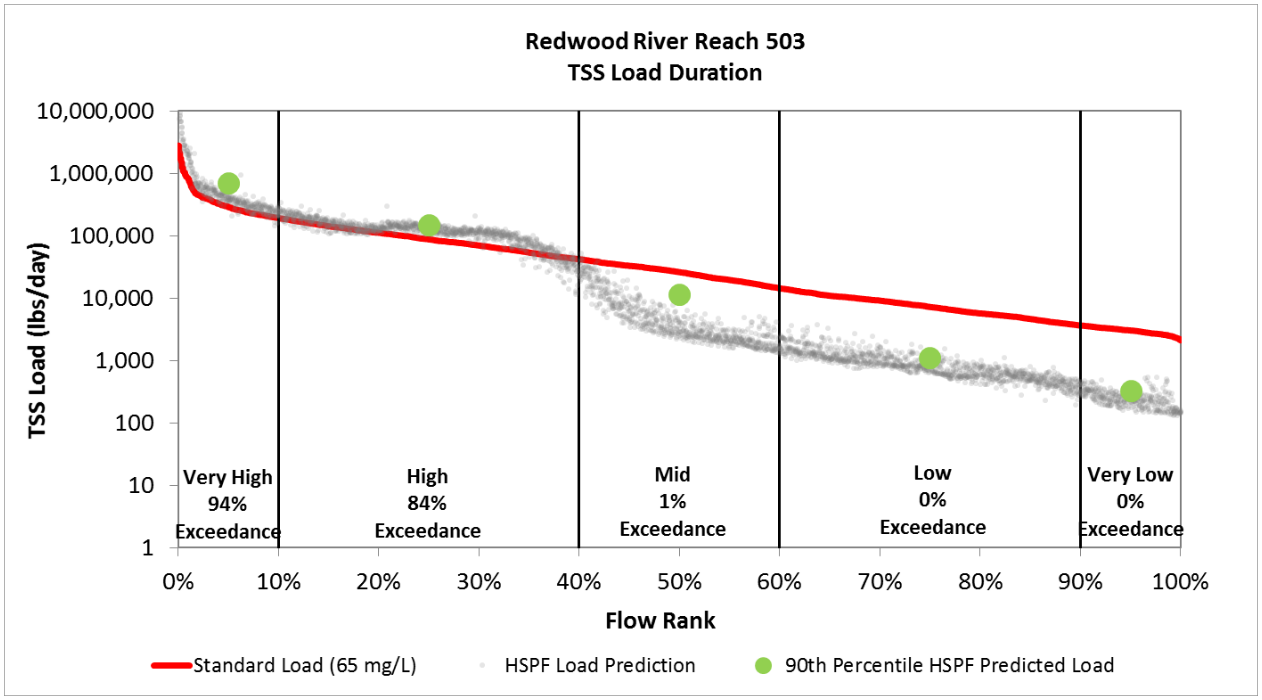


Table 23. TSS TMDL summary for Redwood River Reach 503.

Total Suspended Solids		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		TSS load (lbs/day)				
Wasteload	ADM Corn Processing – Marshall (MN0057037)	661	661	661	661	***
	Ghent WWTP (MNG585121)	97	97	97	97	***
	Lynd WWTP (MNG585030)	128	128	128	128	***
	Marshall WWTP (MN0022179)	1,126	1,126	1,126	1,126	***
	Russell WWTP (MNG585062)	220	220	220	220	***
	Vesta WWTP (MNG585043)	97	97	97	97	***
	Magellan Pipeline Co LP – Marshall (MN0059838)	180	180	180	180	***
	Ruthton WWTP (MNG585105)	142	142	142	142	***
	Tyler WWTP (MNG585116)	409	409	409	409	***
	City of Marshall MS4 (MS400241)**	5,173	1,579	495	155	***
	Construction/Industrial SW	892	270	81	22	***
	Total WLA	**9,125**	**4,909**	**3,636**	**3,237**	***
Load	**Total LA**	**265,001**	**78,147**	**21,199**	**3,632**	***
	MOS	**14,428**	**4,371**	**1,307**	**362**	**152**
	Total load	**288,554**	**87,427**	**26,142**	**7,231**	**3,038**
Existing 90th percentile concentration (mg/L)******		****				
Overall estimated percent reduction******		**56%**				

* Model simulated flow for HSPF reach 430 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The daily WLAs for the City of Marshall MS4 equate to an areal TSS loading rate of approximately 71 lbs/acre/year.
*** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.

**** The impairment listing for this reach is based on Secchi Tube data (see Table 7) as no TSS data have been collected for this reach. Therefore, the midpoint TSS reduction of the upstream adjacent reach (Reach 502; 55%) and downstream adjacent reach (509; 57%) is recommended as the TSS load reduction goal for this reach.

Figure 9. Redwood River Reach 509 TSS load duration curve and monitored loads and exceedances.

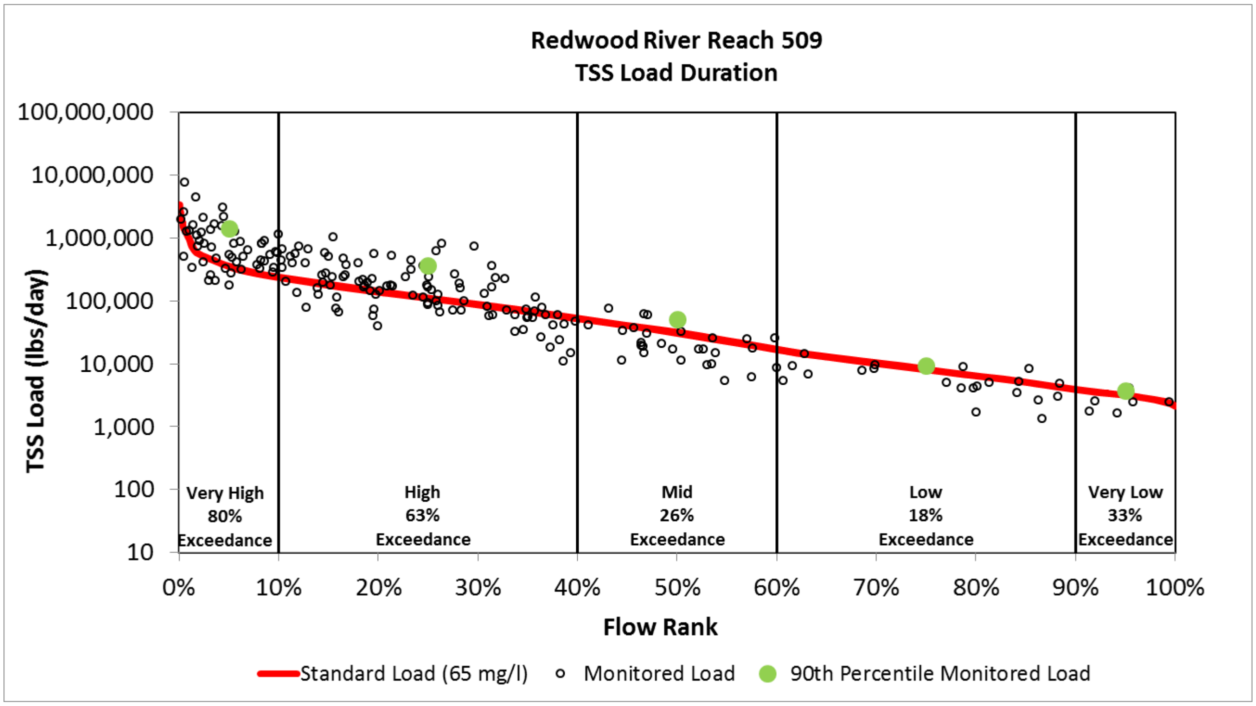


Table 24. TSS TMDL summary for Redwood River Reach 509.

Total Suspended Solids		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		TSS load (lbs/day)				
Wasteload	ADM Corn Processing – Marshall (MN0057037)	661	661	661	661	***
	Ghent WWTP (MNG585121)	97	97	97	97	***
	Lynd WWTP (MNG585030)	128	128	128	128	***
	Marshall WWTP (MN0022179)	1,126	1,126	1,126	1,126	***
	Russell WWTP (MNG585062)	220	220	220	220	***
	Milroy WWTP (MNG585124)	93	93	93	93	***
	Vesta WWTP (MNG585043)	97	97	97	97	***
	Magellan Pipeline Co LP – Marshall (MN0059838)	180	180	180	180	***
	Ruthton WWTP (MNG585105)	142	142	142	142	***
	Tyler WWTP (MNG585116)	409	409	409	409	***
	City of Marshall MS4 (MS400241)**	5,173	1,579	495	155	***
	Construction/Industrial SW	1,081	340	99	25	***
	Total WLA	**9,407**	**5,072**	**3,747**	**3,333**	***
Load	**Total LA**	**322,834**	**99,609**	**26,670**	**4,402**	***
MOS		**17,486**	**5,510**	**1,601**	**407**	**157**
Total load		**349,727**	**110,191**	**32,018**	**8,142**	**3,149**
Existing 90th percentile concentration (mg/L)******		**150**				
Overall estimated percent reduction******		**57%**				

* Model simulated flow for HSPF reach 470 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The daily WLAs for the City of Marshall MS4 equate to an areal TSS loading rate of approximately 71 lbs/acre/year.
*** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
**** Water quality monitoring station(s) used to estimate reductions: S001-679.

Figure 10. Redwood River Reach 510 TSS load duration curve and monitored loads and exceedances.

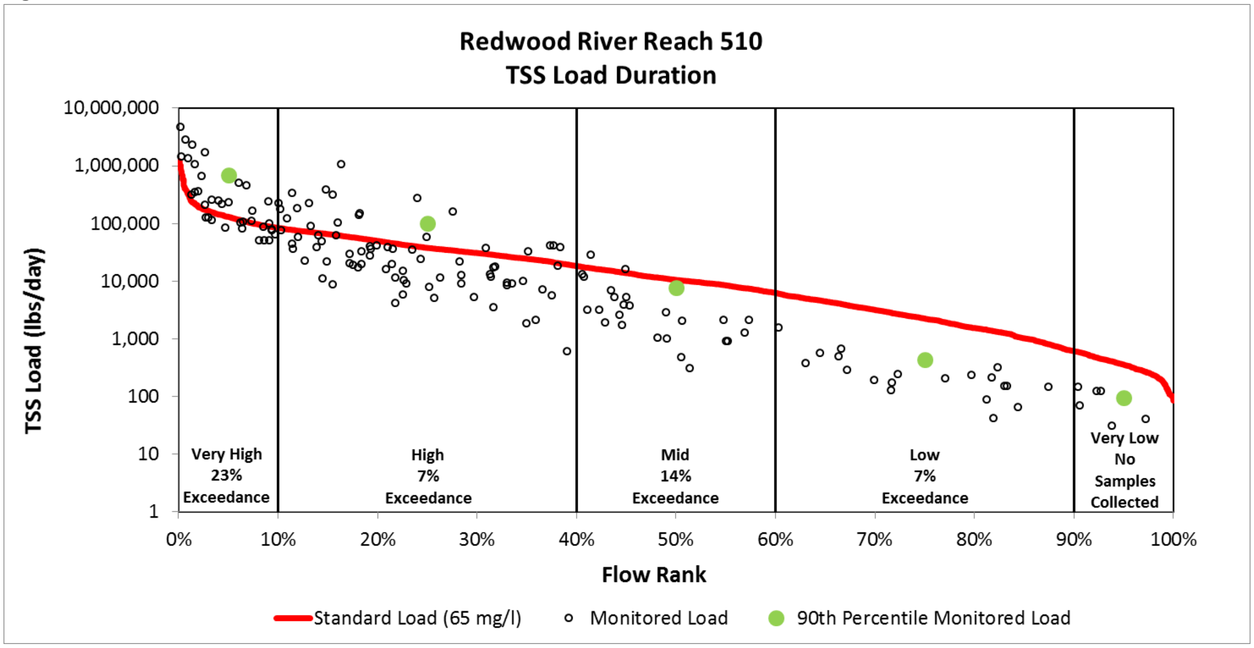


Table 25. TSS TMDL summary for Redwood River Reach 510.

Total Suspended Solids		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		TSS load (lbs/day)				
Wasteload	Ruthton WWTP (MNG585105)	142	142	142	142	**
	Tyler WWTP (MNG585116)	409	409	409	409	**
	Construction/Industrial SW	23	7	2	0.4	**
	Total WLA	**574**	**558**	**553**	**551**	**
Load	**Total LA**	**33,440**	**10,396**	**2,078**	**69**	**
MOS		**1,790**	**577**	**138**	**33**	**8**
Total load		**35,804**	**11,531**	**2,769**	**653**	**169**
Existing 90th percentile concentration (mg/L)* **		**103**				
Overall estimated percent reduction* **		**37%**				

* Model simulated flow for HSPF reach 495 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
*** Water quality monitoring station(s) used to estimate reductions: S000-696.

Figure 11. Three Mile Creek Reaches 564/565/566 TSS load duration curve and monitored loads and exceedances.

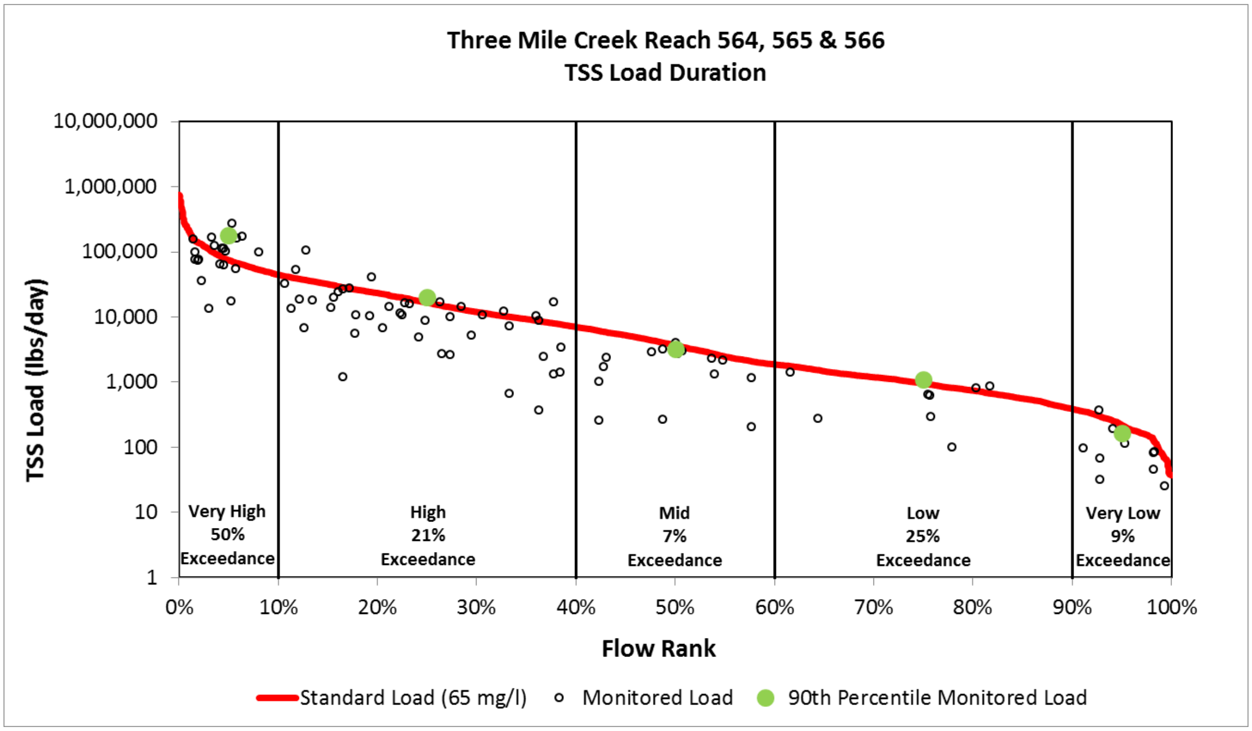


Table 26. TSS TMDL summary for Three Mile Creek Reaches 564/565/566.

Total Suspended Solids		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		TSS load (lbs/day)				
Wasteload	Ghent WWTP (MNG585121)	97	97	97	97	97
	Construction/Industrial SW	230	51	11	3	0.7
	Total WLA	**327**	**148**	**108**	**100**	**98**
Load	**Total LA**	**70,404**	**15,591**	**3,380**	**805**	**108**
MOS		**3,723**	**828**	**184**	**48**	**11**
Total load		**74,454**	**16,567**	**3,672**	**953**	**217**
Existing 90th percentile concentration (mg/L)**		**83**				
Overall estimated percent reduction**		**22%**				

* Model simulated flow for HSPF reach 315 (2008-2017) was used to develop the flow zones and LCs for this reach.

** Water quality monitoring station(s) used to estimate reductions: S002-313.

Figure 12. Clear Creek Reach 567 and 568 TSS load duration curve and monitored loads and exceedances.

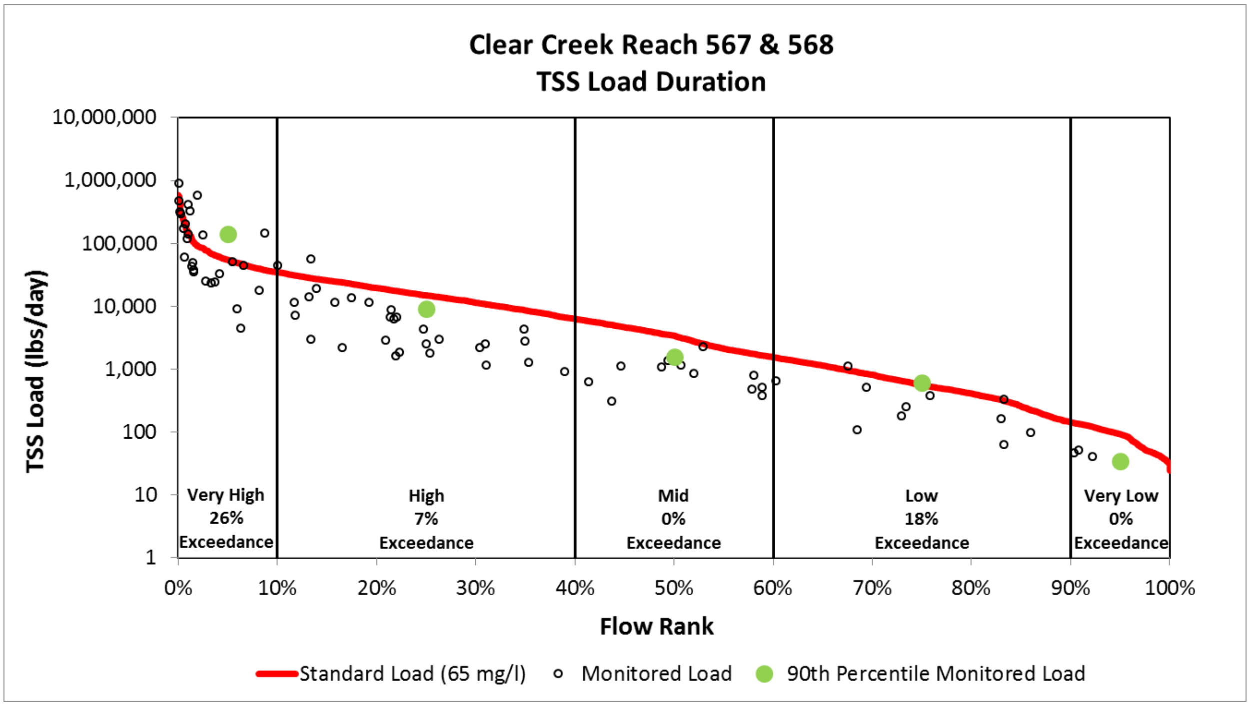


Table 27. TSS TMDL summary for Clear Creek Reach 567 and 568.

Total Suspended Solids		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		TSS load (lbs/day)				
Wasteload	Milroy WWTP (MNG585124)	93	93	93	93	**
	Construction/Industrial SW	35	10	2	0.4	**
	Total WLA	**128**	**102**	**95**	**93**	**
Load	**Total LA**	**51,753**	**14,023**	**3,138**	**444**	**
MOS		**2,731**	**743**	**170**	**28**	**5**
Total load		**54,611**	**14,868**	**3,403**	**565**	**92**
Existing 90th percentile concentration (mg/L)* **		****				
Overall estimated percent reduction* **		**5%**				

* Model simulated flow for HSPF reach 443 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
*** Water quality monitoring station(s) used to estimate reductions: S002-311
**** The 90th percentile flow-zone corrected monitored TSS concentration is at or below 65 mg/L and therefore a 5% load reduction is recommended to ensure the TSS standard is met. Continued monitoring in this reach will help inform if reductions beyond 5% are needed.

4.3 *E. coli* - Streams

4.3.1 Loading Capacity Methodology

LDCs were used to represent the LC for the *E. coli* impaired reaches (see Figure 2 and Appendix A) covered in this TMDL report. The flow component of the LC curve is based on the HSPF simulated average daily flows from April through October (2008 through 2017), and the concentration component is the *E. coli* concentration standard of 126 cfu/100 mL. *E. coli* LDCs for reaches 510 and 521 are shown in Section 4.3.6. On these figures the red curve represents the allowable *E. coli* LC of the reach for each daily flow. The median (or midpoint) loads of each flow zone were 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 Figure 13 and Figure 14). 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 water quality 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. 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* concentrations for reaches 510 and 521 were calculated as the geometric means 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 helps determine what flow zones and practices should be targeted to achieve the overall reduction goal for each impaired reach.

4.3.2 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 so it is not necessary to put them in the *E. coli* TMDL table.

<u>NPDES Permitted Wastewater Dischargers</u>

Two active NPDES permitted surface wastewater dischargers are in the reach 510 drainage area (Table 28). There are no NPDES dischargers in the reach 521 drainage area. WLAs for each wastewater discharger were calculated by multiplying the facility's wet weather design flow by the *E. coli* chronic standard (126 cfu/100 mL). DMRs were downloaded to assess the typical monthly discharge values and bacteria concentrations at which each facility discharges. 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 each wastewater treatment facility (200 organisms/100 mL) is intended to demonstrate 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 DMRs are presented in Appendix B.

Table 28. *E. coli* allocations for NPDES permitted dischargers in the Redwood River reach 510 watershed.

Impaired Reach	Facility Name and System Type	NPDES ID#	Flow Used for WLA* (MGD)	Chronic Standard (org./100 mL)	Permitted Load (billions of org./day)
510	Ruthton WWTP/ Pond	MNG585105	0.38	126	1.8
510	Tyler WWTP/ Pond	MNG585116	1.09	126	5.2

*Maximum daily pond flow in MGD.

NPDES Permitted MS4 Stormwater

The city of Redwood Falls, which contributes to Ramsey Creek reach 521, is the only MS4 within the *E. coli* impaired reach watersheds covered by this TMDL. Figure 1 shows the city of Redwood Fall's municipal boundary and its location in relation to the Ramsey Creek impaired reach. The city accounts for approximately 0.4% of the land area in the reach 521 watershed. *E. coli* allocations for the City of Redwood Falls were calculated by multiplying the MS4 percent watershed coverage (0.4%) by the total watershed loading capacity (determined by LDCs).

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 drainage areas and therefore no industrial stormwater WLAs were assigned.

4.3.3 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 reach 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 of *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 manure 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. Sadowsky 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.

4.3.4 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 5% of the loading capacity for the Redwood River Watershed *E. coli* impaired reaches. Five 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 Redwood River Watershed HSPF model was calibrated and validated using 21 years (1996 through 2017) of flow data from five gaging stations (Tetra Tech 2019). Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. See Appendix D of this TMDL report for the HSPF model calibration and validation results. The *E. coli* LDCs were developed using HSPF modeled daily flow data from April through October (2008 through 2017). The *E. coli* TMDL applied a MOS to each flow zone along the duration curves by subtracting 5% of the flow zones' loading capacity.

4.3.5 Seasonal Variation

E. coli monitoring data for the bacteria impaired reaches indicate both reaches had multiple exceedances of the monthly chronic standard (Table 9). Exceedances of the acute standard also occur in reach 510 during this time period. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during warmer summer months when stream flow is low and water temperatures are high. High *E. coli* concentrations in 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.

4.3.6 *E. coli* TMDL Summary

The TMDL summary table (Table 29and Table 30) for reaches 510 and 521 present the existing load, the total LC (Total Load (TMDL) in tables, MOS, WLA (Wasteload in tables), and LA (Load in tables). Figure 13 and Figure 14 illustrate the LDCs for reaches 510 and 521. 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 table shows the estimated concentration-based percent load reductions 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 table. Thus, the estimated load reduction for each flow zone applies to the water body as a whole. *E. coli* LDCs (Figures 13 and 14) for reaches in the Redwood River Watershed generally show *E. coli* load exceedances during all flow conditions for which there is data. This suggests a variety of sources contribute to the impairments. For example, during high flow conditions, watershed runoff is likely the primary source of *E. coli* to the river reaches. During low flow conditions, other sources such as noncompliant SSTS and livestock in streams increase in relative importance. See Section 8 of this TMDL report and the Redwood River WRAPS (MPCA 2023) report for further information on which sources and geographical locations within the impaired reach subwatershed should be targeted for bacteria BMPs and restoration strategies.

Figure 13. Redwood River Reach 510 *E. coli* load duration curve and monitored loads and exceedances.

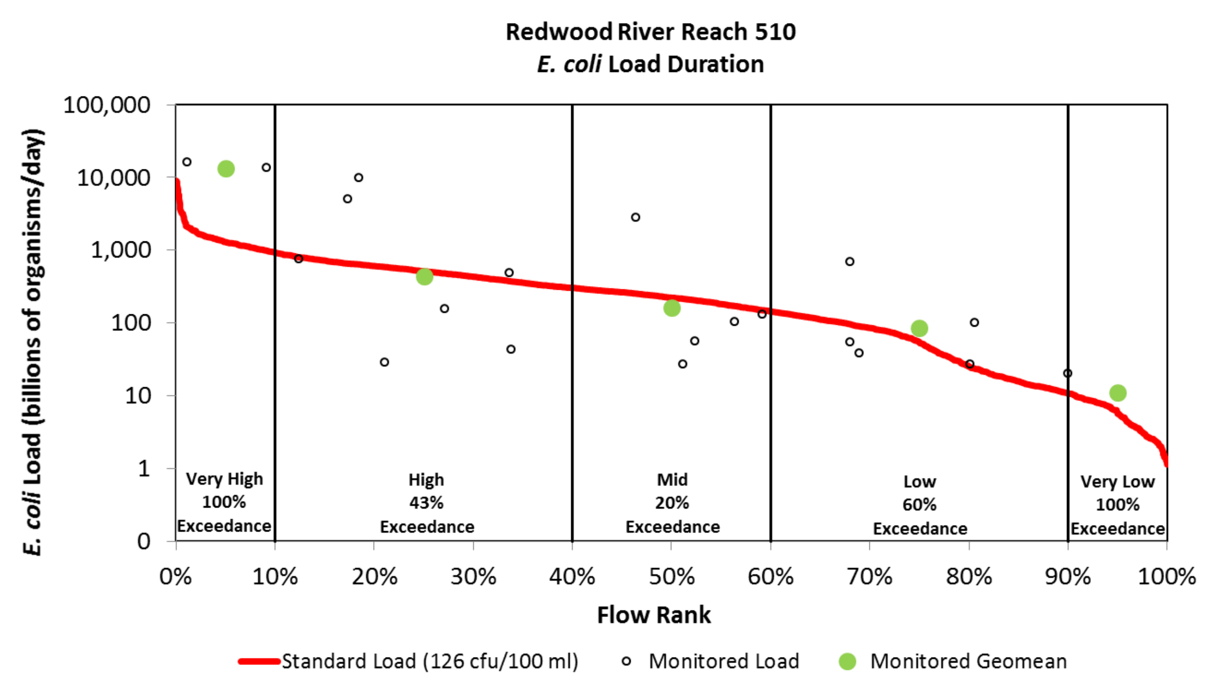


Table 29. *E. coli* TMDL summary for Redwood River Reach 510.

E. coli		Flow zones*				
		Very high	**High**	**Mid-range**	**Low**	**Very low**
Sources		***E. coli* load (billions of orgs/day)**				
Wasteload	Ruthton WWTP (MNG585105)	2	2	2	2	2
	Tyler WWTP (MNG585116)	5	5	5	5	5
	Total WLA	**7**	**7**	**7**	**7**	**7**
Load	**Total LA**	**1,899**	**753**	**321**	**71**	1
MOS		**100**	**40**	**17**	**4**	**0.4**
Total load		**2,006**	**800**	**345**	**82**	**8**
Existing Concentration, Apr-Oct (org/100 mL)**		**174**				
Maximum Monthly Geometric Mean (org/100mL)**		**764**				
Overall Estimated Percent Reduction**		**73%**				

* Model simulated flow for HSPF reach 190 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** Water quality monitoring station(s) used to estimate reductions: S000-696.

Figure 14. Ramsey Creek Reach 521 *E. coli* load duration curve and monitored loads and exceedances.

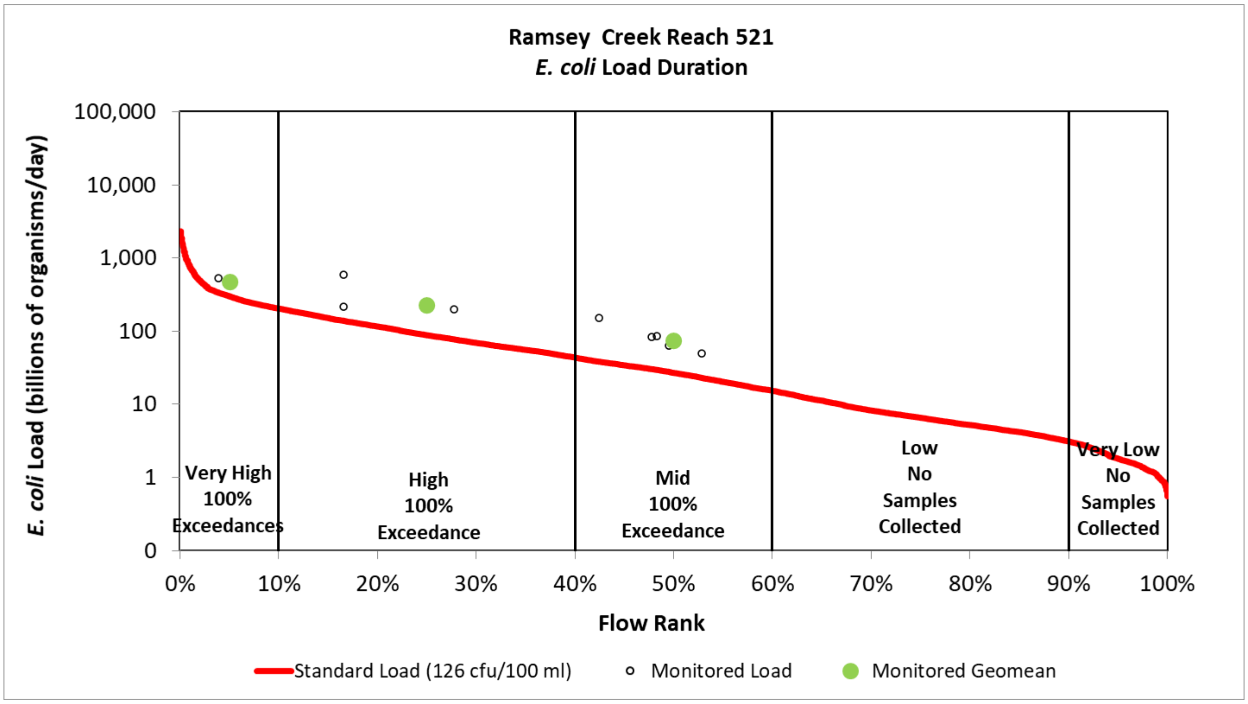


Table 30. *E. coli* TMDL summary for Ramsey Creek Reach 521.

E. coli		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		*E. coli* load (billions of orgs/day)				
Wasteload	City of Redwood Falls MS4 (MS400236)	1	0.4	0.1	0.02	0.006
	Total WLA	**1**	**0.4**	**0.1**	**0.02**	**0.006**
Load	**Total LA**	**298**	**96**	**23**	**5**	**1**
MOS		**16**	**5**	**1**	**0.3**	**0.07**
Total load		**315**	**101**	**24**	**5**	**1**
Existing Concentration, Apr-Oct (org/100 mL)**		**194**				
Maximum Monthly Geometric Mean (org/100mL)**		**318**				
Overall Estimated Percent Reduction**		**55%**				

* Model simulated flow for HSPF reach 495 from April-Oct (2008-2017) was used to develop the flow zones and LCs for this reach.
** Water quality monitoring station(s) used to estimate reductions: S004-387.

4.4 Chloride - Streams

4.4.1 Loading Capacity Methodology

LDCs were used to represent the LC for the Redwood River chloride impaired reach (502). The flow component of the LC curve is based on the HSPF simulated daily average flows for the most recent 10-year period (2008 through 2017). Historic chloride monitoring data for reach 502 indicate that at least one exceedance of the 230 mg/L chronic standard has occurred in every month except April and May over the past 10 years (Table 11) and therefore simulated flows for all months were included in the LDCs for this reach. The concentration component used to develop the LDCs is the chronic chloride concentration criteria of 230 mg/L. The LDC for Redwood River reach 502 is shown in Section 4.4.6. In this figure the red curve represents the reach's allowable chloride loading capacity for each daily flow. The median (or midpoint) load of each flow zone is used to represent the total load capacity in the TMDL table (Table 32). The reach's loading capacity can be compared to current conditions by plotting the observed loads, which are based on the monitored four-day average concentrations (black circles in Figure 15). Each value that is above the curve represents an exceedance of the chronic standard, while those below the line are below the chronic standard.

The existing chloride concentration for Redwood River reach 502 was calculated as the maximum monitored four-day average chloride concentration for all flow zones over the past 10 years. The maximum monitored four-day average concentration was used because the chloride standard states that no more than two four-day average concentrations may exceed the 230 mg/L chronic standard over a three-year period. The overall estimated concentration-based percent reduction needed to meet the TMDL was calculated as the maximum monitored four-day average concentration minus the chloride standard (230 mg/L) divided by the maximum monitored four-day average concentration. Also plotted in each LDC figure is the maximum monitored four-day average chloride load for each individual flow zone (solid green circles). Plotting these individual loads help determine what flow zones should be targeted to achieve the overall reduction goal for the impaired reach.

4.4.2 Wasteload Allocation Methodology

The WLAs for chloride were divided into three categories: NPDES permitted wastewater dischargers, NPDES MS4 stormwater, and NPDES permitted construction and industrial stormwater. The following sections describe how each WLA was assigned.

NPDES Permitted Wastewater Dischargers

There are seven active, regulated NPDES wastewater dischargers in the Redwood River chloride impaired reach subwatershed. Facility maximum daily effluent chloride loads are a function of the facility design flows and the 230 mg/L chronic standard for chloride (Table 31). WLAs for each facility were calculated by multiplying the chloride concentration standard, permitted facility design flow, and a unit conversion factor. WLAs for continuously discharging municipal WWTP were calculated based on the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Industrial wastewater and controlled discharge municipal pond discharge WWTP WLAs were calculated based on the maximum daily volume that may be discharged in a 24-hour period.

DMRs were downloaded and reviewed for each wastewater discharger in the impaired reach subwatershed. Currently, there are no chloride effluent monitoring data available for Magellan Pipeline Co LP – Marshall, Lynd, Russell, Ruthton, and Tyler WWTPs. As discussed in Section 3.6.3, effluent chloride concentrations for ADM Corn Processing – Marshall and Marshall WWTP routinely exceeded the chronic standard. Marshall will be assigned an effluent limit by MPCA based on the water quality standard which will be consistent with this TMDL. ADM Corn Processing – Marshall's permit currently contains a chloride effluent limit which will be evaluated by the MPCA for consistency with this TMDL's WLA. In-stream monitoring data collected shortly upstream of ADM Corn Processing – Marshall and Marshall WWTP (Table 10 and Table 11) indicated that reach 502 was not impaired upstream of these facilities. Based on these data, Magellan Pipeline Co LP – Marshall, Lynd, Russell, Ruthton, and Tyler WWTPs are not believed to be contributing to the chloride impairment in reach 502.

Table 31. Chloride allocations for NPDES permitted wastewater dischargers in the Redwood River reach 502 watershed.

Impaired Reach	Facility Name and System Type	NPDES ID#	Flow Used for WLA* (MGD)	Concentration Assumption (mg/L)	WLA (lbs/day)
502	ADM Corn Processing – Marshall/ Mechanical	MN0057037	2.64	230	5,064
502	Lynd WWTP/ Pond	MNG585030	0.34	230	655
502	Marshall WWTP/ Mechanical	MN0022179	4.50	230	8,632
502	Russell WWTP/ Pond	MNG585062	0.59	230	1,124
502	Magellan Pipeline Co LP – Marshall/ Mechanical	MN0059838	0.72	230	1,381
502	Ruthton WWTP/ Pond	MNG585105	0.38	230	724
502	Tyler WWTP/ Pond	MNG585116	1.09	230	2,091

*Average wet weather design flow or maximum daily pond flow in MGD.

NPDES Permitted MS4 Stormwater

The City of Marshall is the only MS4 within the Redwood River reach 502 subwatershed. Figure 1 in Section 1.2 shows the city of Marshall's municipal boundary and its location in the Redwood River Watershed. The city accounts for approximately 3.0% (5,875 acres) of the reach 502 drainage area. Marshall's MS4 chloride WLAs were calculated by multiplying the city's percent watershed coverage (~3.0%) by the total watershed loading capacity (determined by LDCs). As discussed in Section 3.6.4, the Redwood River reach 502 impairment begins downstream of the ADM Corn Processing – Marshall and Marshall WWTP effluent points. In-stream chloride monitoring data collected shortly upstream of these effluent points and downstream of the city of Marshall's MS4 boundary (monitoring station S002-185) indicate that chloride concentrations were generally low (mean = 25 mg/L) and only one exceedance (January 2013) has been observed over the past 10 years. Because of that, the city of Marshall is not believed to be a significant contributor to the chloride impairment in this reach.

NPDES Permitted Construction and Industrial Stormwater

WLAs for regulated construction stormwater (permit #MNR100001) were not developed since chloride 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 chloride benchmarks associated with any of the Industrial Stormwater Permits (permit #MNR050000) in the Redwood River Reach 502 Watershed and therefore no industrial stormwater chloride WLAs were assigned.

4.4.3 Load Allocation Methodology

The LA is comprised of the nonpoint source load that is allocated to an impaired reach after the WLAs and MOS were determined and subtracted from the total loading capacity for each flow zone. This residual remaining loading capacity is meant to represent all nonregulated (nonpoint sources) of chloride upstream of the impaired reach (summarized in Section 3.6). The LA, also referred to as the watershed LA, includes nonpoint chloride sources that are not subject to NPDES Permit requirements such as inputs from groundwater, septic systems, agricultural runoff, non-MS4 stormwater runoff and natural background.

Given the lack of sufficient historical data in the Redwood River Watershed, attempting to allocate a specific natural background load to the impaired reach would result in a margin of error that may be more than the estimated allocation. Due to this lack of data, the LA for chloride in the Redwood River Watershed includes natural background.

4.4.4 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 5% of the LC for the Redwood River chloride impaired reach. Five percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty. The LDC calculations are based on chloride 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 Redwood River Watershed HSPF model was calibrated and validated using 21 years (1996 through 2017) of flow data from five gaging stations (Tetra Tech 2019). Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. See Appendix D of this TMDL report for the HSPF model calibration and validation results. The chloride LDCs were developed using year-round HSPF modeled daily flow data from 2008 through 2017. The chloride TMDL applied a MOS to each flow zone along the duration curves by subtracting 5% of the flow zones' loading capacity.

4.4.5 Seasonal Variation

Both seasonal variation and critical conditions are accounted for in this TMDL study through the application of LDCs. LDCs evaluate water quality conditions across all flow zones including low-flow conditions where chloride exceedance is most common (Figure 15) in the Redwood River chloride impaired reach. Seasonality is accounted for by addressing all months and flow conditions within the impaired reach.

4.4.6 Chloride TMDL Summary

The TMDL summary table (Table 32) for Redwood River reach 502 presents the existing load, the total LC (Total Load in tables), MOS, WLA (Wasteload in tables), and LA (Load in tables). Chloride allocations for this TMDL were established using the 230 mg/L chronic standard. All LAs are reported in pounds per day and were rounded to the nearest whole number. The bottom line of the table shows the estimated concentration-based percent load reduction to meet the TMDL for all flow zones. This reduction was calculated by comparing the observed maximum 4-day average chloride concentration over the past 10 years to the 230 mg/L chronic 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 table. However, the chloride LDC (Figure 15) and chloride data summary (Table 11) show that most of the individual chloride standard exceedances occur year-round (except for April and May), downstream of the ADM Corn Processing – Marshall and Marshall WWTP outfalls, and during low and very low flow conditions. This, along with the effluent discharge monitoring data available for ADM Corn Processing – Marshall and Marshall WWTP and the lack of chloride standard exceedances observed upstream of their outfall locations, suggest these facilities contribute to the elevated chloride concentrations observed in the impaired reach during low-flow conditions. See Section 6.1.4 and 8.2.3 of this TMDL and the WRAPS report for further information on chloride reduction strategies for these facilities.

Figure 15. Redwood River Reach 502 chloride load duration curve and monitored loads and exceedances.

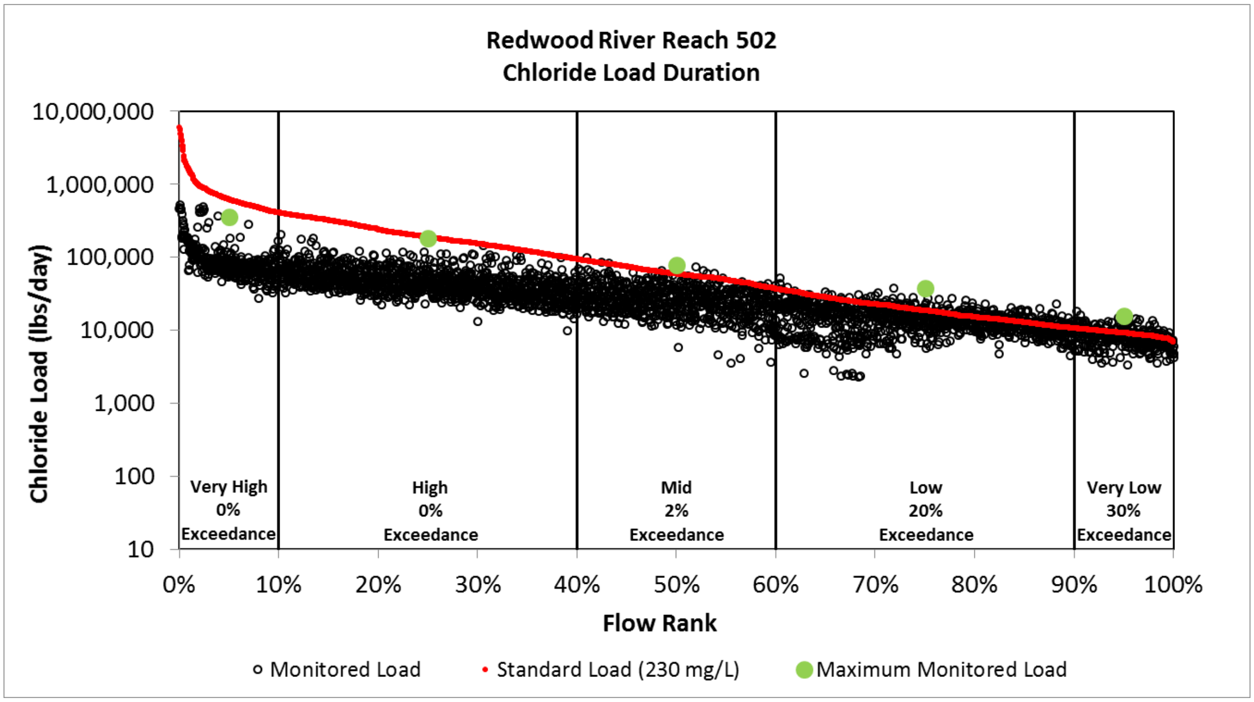


Table 32. Chloride TMDL summary for Redwood River Reach 502.

Chloride		Flow zones*				
		Very high	High	Mid-range	Low	Very low
Sources		Chloride load (lbs/day)				
Wasteload	ADM Corn Processing – Marshall (MN0057037)	5,064	5,064	5,064	**	**
	Lynd WWTP (MNG585030)	655	655	655	**	**
	Marshall WWTP (MN0022179)	8,632	8,632	8,632	**	**
	Russell WWTP (MNG585062)	1,124	1,124	1,124	**	**
	Magellan Pipeline Co LP – Marshall (MN0059838)	1,381	1,381	1,381	**	**
	Ruthton WWTP (MNG585105)	724	724	724	**	**
	Tyler WWTP (MNG585116)	2,091	2,091	2,091	**	**
	City of Marshall MS4 (MS400241)	18,304	5,588	1,753	**	**
	Total WLA	37,975	25,259	21,424	**	**
Load	**Total LA**	547,541	153,497	34,649	**	**
MOS		30,817	9,408	2,951	926	458
Total load		616,333	188,164	59,024	18,514	9,169
Existing maximum concentration (mg/L)***		**463**				
Overall estimated percent reduction***		**50%**				

* Model simulated flow for HSPF reach 290 from 2008-2017 (all months) was used to develop the flow zones and loading capacities for this reach.

** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (230 mg/L) x (conversion factors). The LA is the remainder after the WLA is applied.

*** Water quality monitoring station used to estimate reductions: S001-203.

4.5 Phosphorus - Lakes

4.5.1 Loading Capacity Methodology

Total Phosphorus LCs for each impaired lake in the Redwood River Watershed (see Figure 2 and Appendix A) were developed using the Canfield-Bachmann Lake Response Model. Phosphorus loading from the atmosphere, SSTSs, watershed, upstream impaired lakes, and internal load were the primary sources evaluated and incorporated into the Canfield-Bachmann Lake Response Models. Section 3.6.4 of this TMDL provides a detailed discussion of the phosphorus source assessment and lake response model methodology. Once each of the lake response models were calibrated, the resulting relationship between phosphorus load and in-lake water quality were 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 their ecoregion TP standard. This process is discussed in more detail in Section 4.5.6.

4.5.2 Wasteload Allocation Methodology

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

NPDES Permitted Wastewater Dischargers

There are currently no permitted wastewater dischargers located in the impaired lake watersheds covered in this TMDL report.

NPDES Permitted MS4 Stormwater

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

NPDES Permitted Construction and Industrial Stormwater

Construction and industrial stormwater WLAs were established based on estimated percentage of land in the Redwood River Watershed 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 (~0.3% of the watershed).

4.5.3 Load Allocation Methodology

The LA, also referred to as the watershed LA, includes all nonpermitted and nonpoint sources, including natural background, atmospheric deposition, SSTS, discharge from upstream lakes, watershed loading from nonregulated areas, and internal loading.

The LA is the portion of the total loading capacity assigned to nonpoint and natural background sources of nutrient loading. These sources include atmospheric loading and nearly all the loading from watershed runoff. 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. 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 soil erosion or nutrient leaching from cropland, 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.

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 study 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 very small part of the LA for lakes in the Redwood 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 very difficult to derive and would have a large potential for error without expensive, special studies such as paleolimnological analysis of sediment cores. Given the highly altered landscape in which the Redwood River Watershed impaired lakes are located, it is unlikely natural background is a major component of phosphorus loading.

4.5.4 Margin of Safety

An explicit MOS was used for each of the impaired lake TMDLs in this TMDL report. 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 Redwood River Basin HSPF model was calibrated and validated using 21 years (1996 through 2017) of flow data from five gaging stations. Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. See Appendix D of this TMDL report for the HSPF model calibration and validation results.

4.5.5 Seasonal Variation

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

4.5.6 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 sources, upstream lakes, SSTS, watershed, and internal loading. A uniform methodology was established to assign load reductions to the various sources to meet TMDL goals. 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.
- 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.
- Phosphorus loading from ITPHS SSTSs and SSTSs that FTPGW were reduced to levels expected from properly functioning SSTSs. See Section 3.6.4 for more discussion on the methods used to estimate SSTS contributions and Reasonable Assurance SSTS Section 6.1.5.
- Watershed loading will ideally be reduced until the lake response model indicates the lake is meeting lake water quality standards. Watershed loading was incrementally reduced until watershed TP concentrations met the river/stream eutrophication standard for the Southern River Nutrient Region (150 µg/L). If the lake model did not meet water quality standards after watershed phosphorus concentrations were set to the river/stream eutrophication standard, the remaining phosphorus reduction was taken from internal loading.
- For many of the lakes in the Redwood River Watershed, internal load is a significant source of phosphorus and in-lake efforts may be needed to achieve water quality standards. The general approach to internal load reductions is based on review of the potential internal loading sources (see discussion in Sections 3.6.4 and 8.3.5), the monitored/modeled sediment release rates (RRs), and lake morphometry. This is accomplished by comparing the existing monitored/modeled RRs to literature values of "healthy lakes" (~1 $mg/m^2/day$) (Nürnberg 1997; Wenck 2011). If the estimated RR is high, then the rate is reduced systematically until either a minimum of 1 $mg/m^2/day$ is reached or the lake meets TMDL requirements.

4.5.7 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 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.
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision; this is done primarily to make the arithmetic accurate.

Table 33 through Table 38 present the allocations for the impaired lakes in the Redwood River Watershed and Figure 16 through Figure 21 show the estimated phosphorus sources for each of the lakes. Internal phosphorus load and watershed phosphorus load are the dominant sources for the lakes in this TMDL report. A focus on reducing internal phosphorus loads will be required to return these lakes to a nonimpaired state, however, long-term improvement to the lakes' trophic status will also require reductions from external load sources. See the Minnesota State and Regional Government Review of Internal Phosphorus Load Control (MPCA 2020d) for more information on internal phosphorus load control planning and practices.

Table 33. Lake Benton (41-0043-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/year	lbs/day	lbs/year	lbs/day	lbs/year**	%
Wasteload	Construction/Industrial SW	18	0.05	18	0.05	0	0%
	Total WLA	**18**	**0.05**	**18**	**0.05**	**0**	**0%**
Load	Watershed runoff	5,903	16.16	3,941	10.79	1,962	33%
	SSTS	407	1.11	184	0.50	223	55%
	Atmospheric deposition	633	1.73	633	1.73	0	0%
	Internal load	11,942	32.70	4,915	13.46	7,027	59%
	Total LA	**18,885**	**51.70**	**9,673**	**26.48**	**9,212**	**49%**
MOS				**1,077**	**2.95**		
Total load		**18,903**	**51.75**	**10,768**	**29.48**	**9,212**	**43%**

* Model calibration year(s): 2002 & 2017
** Net reduction from current load to TMDL is 8,135 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 8,135 + 1,077 = 9,212 lbs/yr.

Figure 16. Lake Benton phosphorus source reductions to meet TMDL.

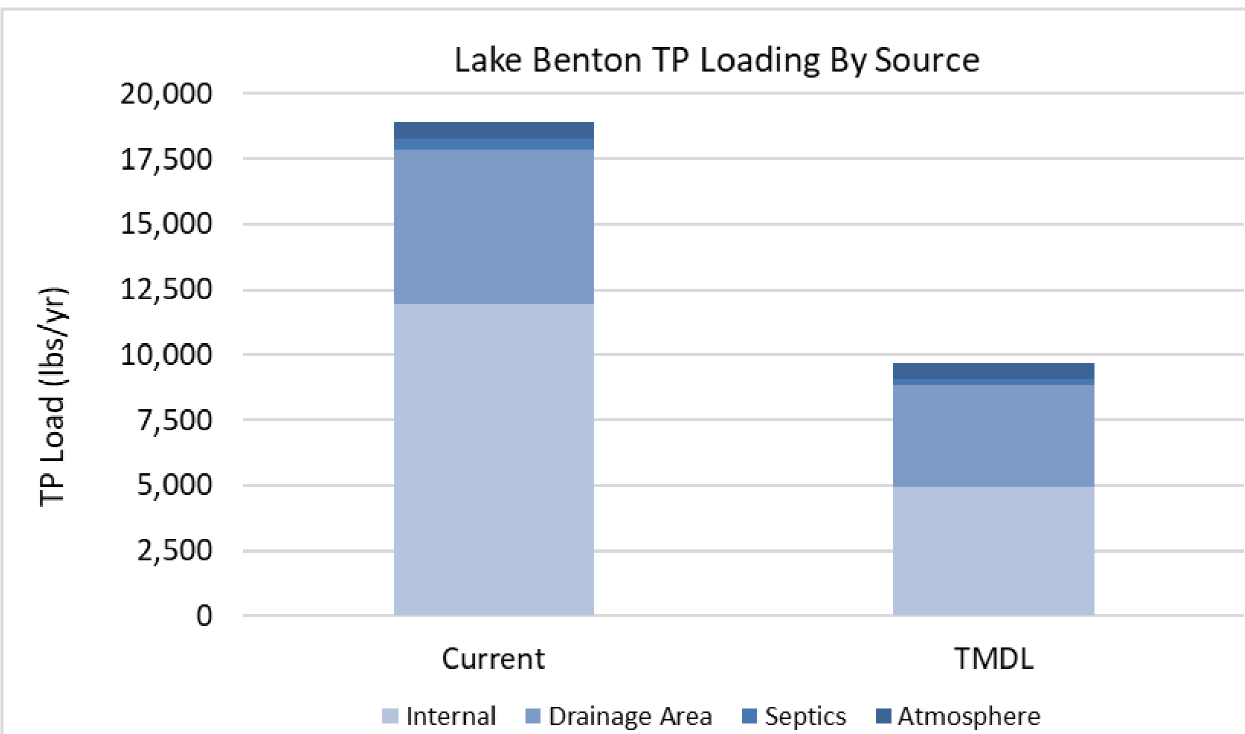


Table 34. Dead Coon Lake (Main Lake) (41-0021-01) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/year	lbs/day	lbs/year	lbs/day	lbs/year**	%
Wasteload	Construction/Industrial SW	12	0.03	12	0.03	0	0%
	Total WLA	**12**	**0.03**	**12**	**0.03**	**0**	**0%**
Load	Watershed runoff	3,930	10.76	3,166	8.67	764	19%
	SSTS	538	1.47	206	0.56	332	62%
	Upstream lakes (Benton)	3,213	8.80	2,083	5.70	1,130	35%
	Atmospheric deposition	131	0.36	131	0.36	0	0%
	Internal load	6,388	17.49	328	0.90	6,060	95%
	Total LA	**14,200**	**38.88**	**5,914**	**16.19**	**8,286**	**58%**
MOS				**658**	**1.80**		
Total load		**14,212**	**38.91**	**6,584**	**18.02**	**8,286**	**54%**

* Model calibration year(s): 2002, 2007 and 2017.
** Net reduction from current load to TMDL is 7,628 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 7,628 + 658 = 8,286 lbs/yr.

Figure 17. Dead Coon Lake (Main Lake) phosphorus source reductions to meet TMDL.

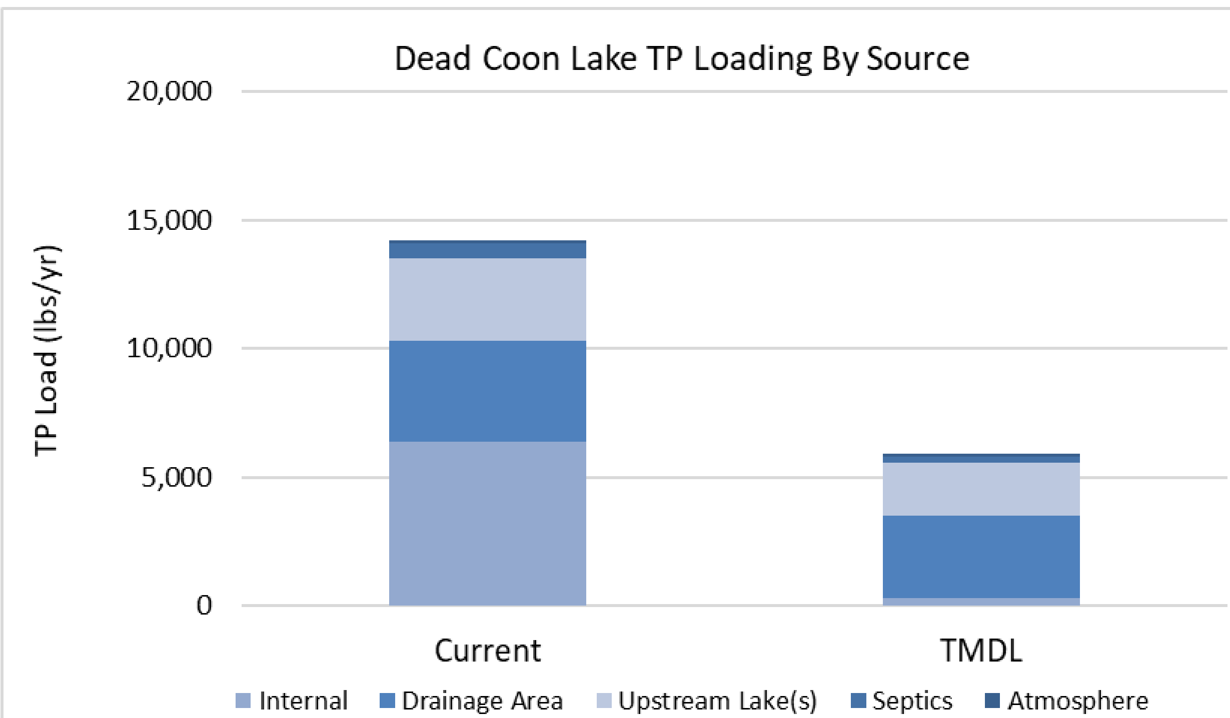


Table 35. Goose Lake (42-0093-00) phosphorus TMDL.

Phosphorus		Existing TP load*		Allowable TP load		Estimated load reduction	
Sources		lbs/year	lbs/day	lbs/year	lbs/day	lbs/year**	%
Wasteload	Construction/Industrial SW	3	0.01	3	0.01	0	0%
	Total WLA	**3**	**0.01**	**3**	**0.01**	**0**	**0%**
Load	Watershed runoff	961	2.63	576	1.58	385	40%
	SSTS	7	0.02	4	0.01	3	39%
	Atmospheric deposition	36	0.10	36	0.10	0	0%
	Internal load	670	1.83	251	0.69	419	63%
	Total LA	**1,674**	**4.58**	**867**	**2.38**	**807**	**48%**
MOS				**97**	**0.26**		
Total load		**1,677**	**4.59**	**967**	**2.65**	**807**	**42%**

* Model calibration year(s): 2002, 2007 and 2017.

** Net reduction from current load to TMDL is 710 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 710 + 97 = 807 lbs/yr.

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

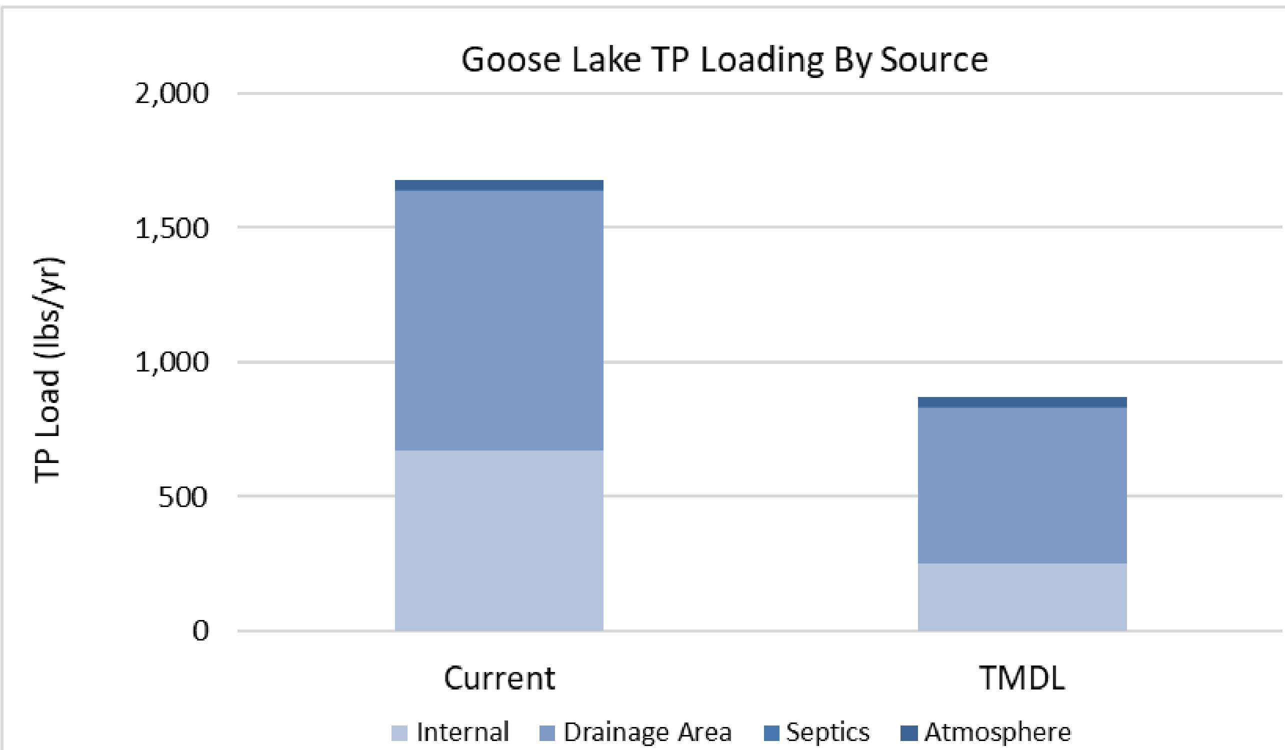


Table 36. Clear Lake - Lyon County (42-0055-00) phosphorus TMDL.

Phosphorus		Existing TP load*		Allowable TP load		Estimated load reduction	
Sources		lbs/year	lbs/day	lbs/year	lbs/day	lbs/year**	%
Wasteload	Construction/Industrial SW	0.7	0.002	0.7	0.002	0.0	0%
	Total WLA	**0.7**	**0.002**	**0.7**	**0.002**	**0.0**	**0%**
Load	Watershed runoff	221.3	0.606	127.4	0.349	93.9	42%
	SSTS	9.5	0.026	6.8	0.019	2.7	28%
	Atmospheric deposition	15.7	0.043	15.7	0.043	0.0	0%
	Internal load	255.0	0.698	124.3	0.340	130.7	51%
	Total LA	**501.5**	**1.373**	**274.2**	**0.751**	**227.3**	**45%**
MOS				**30.5**	**0.084**		
Total load		**502.2**	**1.375**	**305.4**	**0.837**	**227.3**	**39%**

* Model calibration year(s): 2017 and 2018

** Net reduction from current load to TMDL is 196.8 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 196.8+ 30.5 = 227.3 lbs/yr.

Figure 19. Clear Lake - Lyon County phosphorus source reductions to meet TMDL.

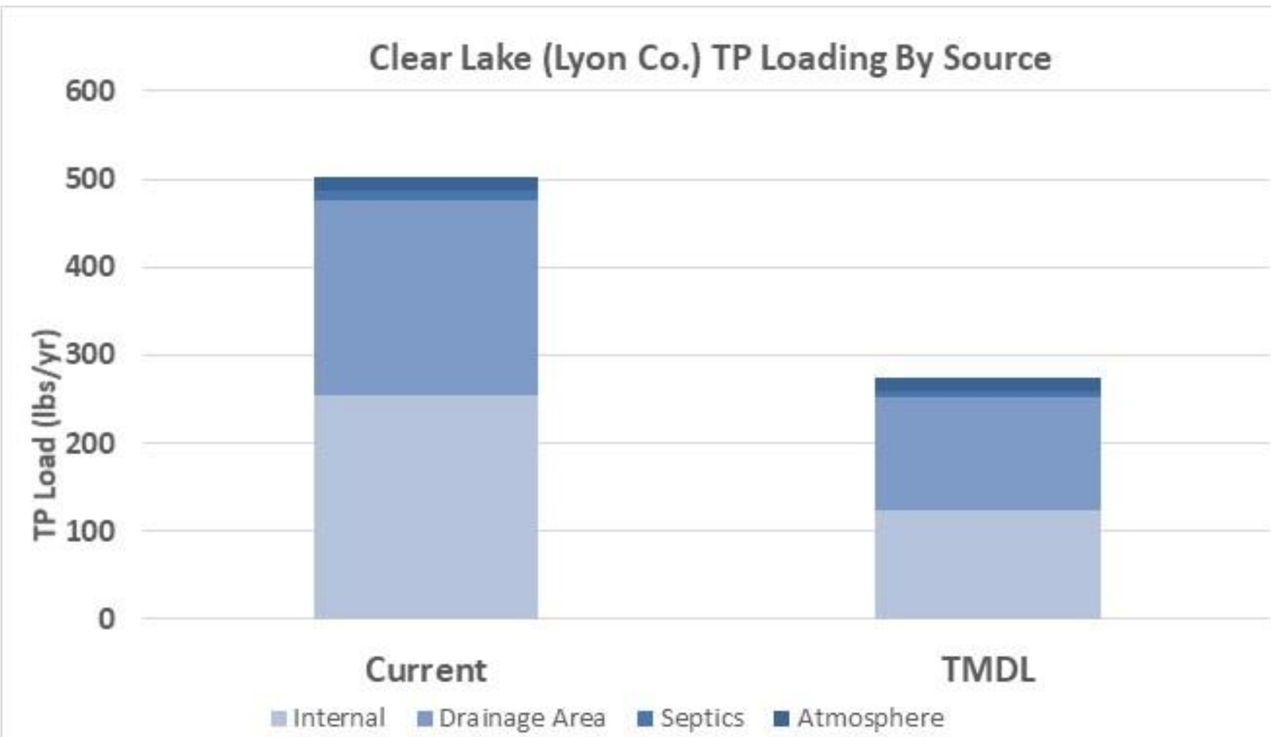


Table 37. School Grove Lake (42-0002-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/year	lbs/day	lbs/year	lbs/day	lbs/year**	%
Wasteload	Construction/Industrial SW	4	0.01	4	0.01	0	0%
	Total WLA	**4**	**0.01**	**4**	**0.01**	**0**	**0%**
Load	Watershed runoff	1,142	3.13	803	2.20	339	30%
	SSTS	7	0.02	5	0.01	2	28%
	Atmospheric deposition	83	0.23	83	0.23	0	0%
	Internal load	402	1.10	366	1.00	36	9%
	Total LA	**1,634**	**4.48**	**1,257**	**3.44**	**377**	**23%**
MOS				**140**	**0.38**		
Total load		**1,638**	**4.49**	**1,401**	**3.83**	**377**	**14%**

* Model calibration year(s): 2002, 2007 and 2017.
** Net reduction from current load to TMDL is 237 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 237 + 140 = 377 lbs/yr.

Figure 20. School Grove Lake phosphorus source reductions to meet TMDL.

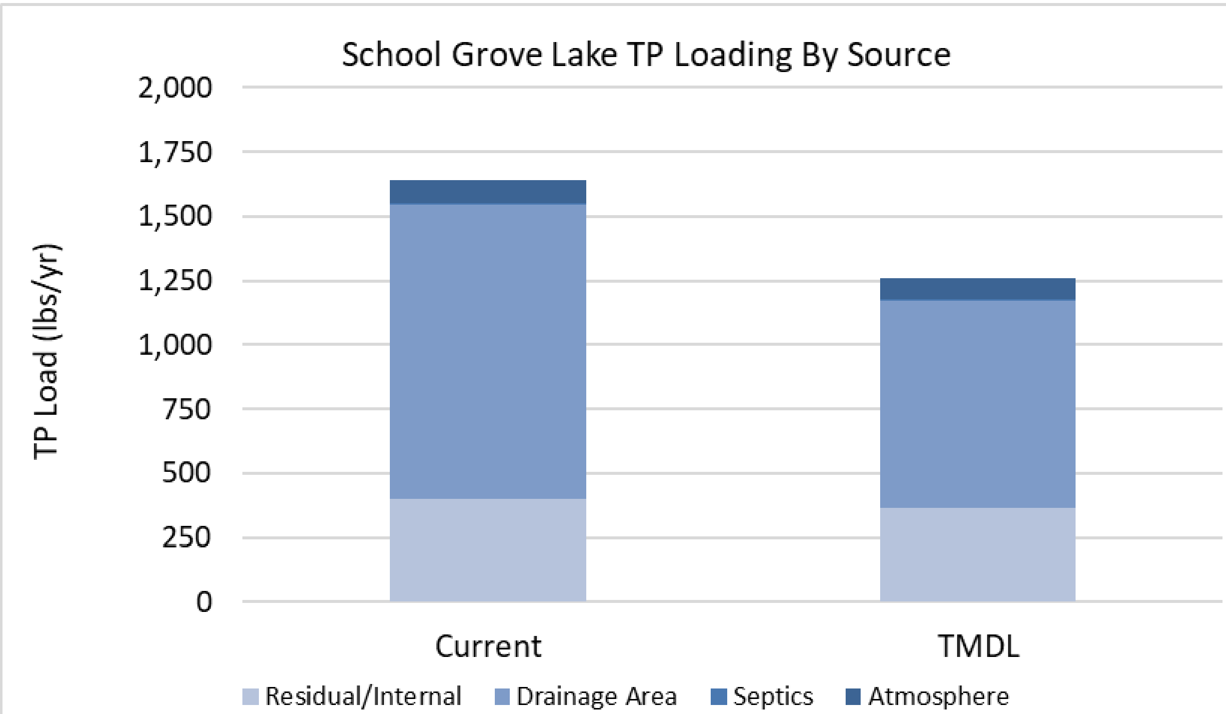
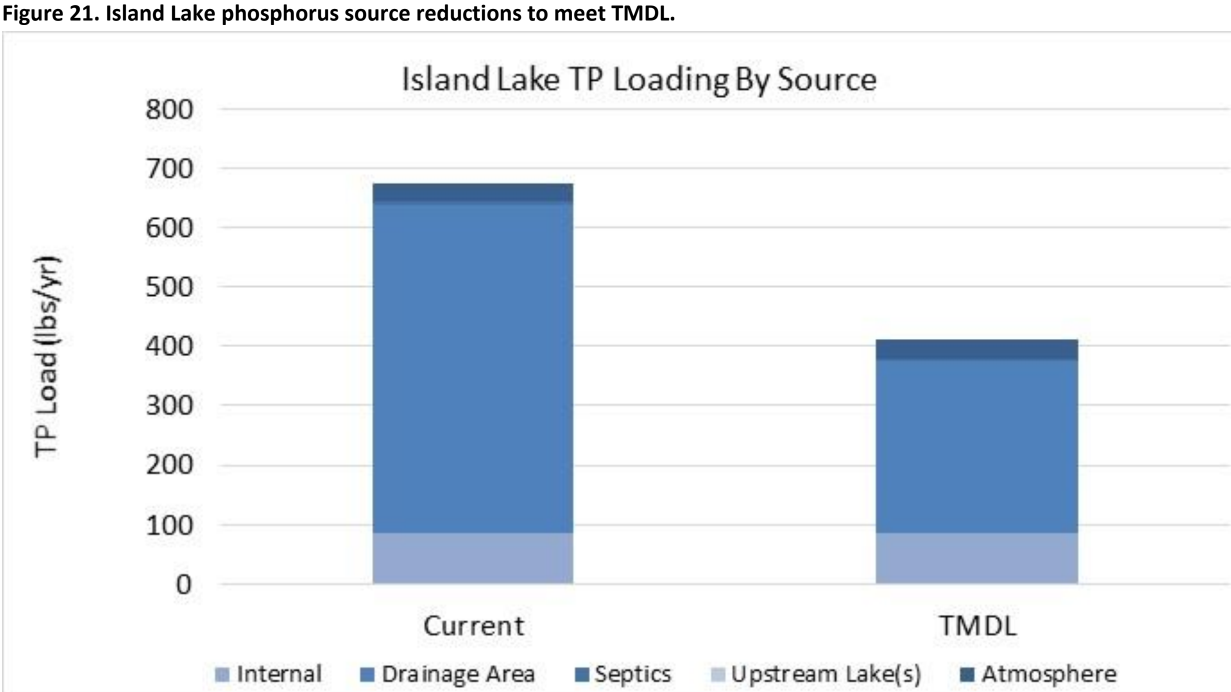


Table 38. Island Lake (42-0002-00) phosphorus TMDL.

Phosphorus Sources		Existing TP load*		Allowable TP load		Estimated load reduction	
		lbs/year	lbs/day	lbs/year	lbs/day	lbs/year**	%
Wasteload	Construction/Industrial SW	2	0.005	2	0.005	0	0%
	Total WLA	**2**	**0.005**	**2**	**0.005**	**0**	**0%**
Load	Watershed runoff	550	1.507	287	0.785	263	48%
	SSTS	5	0.012	3	0.009	2	28%
	Atmospheric deposition	32	0.087	32	0.087	0	0%
	Internal load	86	0.237	86	0.237	0	0%
	Total LA	**673**	**1.843**	**408**	**1.118**	**265**	**39%**
MOS				**45**	**0.123**		
Total load		**675**	**1.848**	**455**	**1.246**	**265**	**33%**

* Model calibration year(s): 2017 and 2018.
** Net reduction from current load to TMDL is 220 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 220 + 45 = 265 lbs/yr.

Figure 21. Island 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 all six counties in the Redwood River Watershed are projected to decrease, with Lyon County by 3% to as much as 18% in Redwood County. The overall projection for all six counties is a net decrease of 9%.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

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

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

Load transfers will be based on methods consistent with those used in setting the allocations in this TMDL study. 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 (TSS and *E. coli* TMDLs only)

The MPCA, in coordination with the EPA, has developed a streamlined process for setting or revising WLAs for new or expanding wastewater discharges to water bodies 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 all WLAs will be handled by the MPCA, with input and involvement by the EPA, once a permit request or reissuance is submitted. The overall process will use the permitting public notice process to allow for the public and EPA to comment on the permit changes based on the proposed WLA modification(s). Once any comments or concerns are addressed, and the MPCA determines that the new or expanded wastewater discharge is consistent with the applicable water quality standards, the permit will be issued and any updates to the TMDL WLA(s) will be made.

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

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 2002a), "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". In the Redwood River Watershed considerable reductions in nonpoint sources are required.

To provide reasonable assurance, 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

Regulated construction stormwater was given a categorical WLA is this study. Construction activities disturbing one acre or more are required to obtain NPDES permit coverage through the MPCA. Compliance with TMDL requirements is assumed when a construction site owner/operator meets the conditions of the Construction General Permit and properly selects, installs, and maintains all BMPs required under the permit, including any applicable additional BMPs required in Section 23 of the Construction General Permit for discharges to impaired waters, or compliance with local construction stormwater requirements if they are more restrictive than those in the State General Permit.

6.1.2 Industrial Stormwater

Industrial stormwater was given a categorical WLA in this study. Industrial activities require permit coverage under the state's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or NPDES/SDS Nonmetallic Mining/Associated Activities General Permit (MNG490000). If a facility owner/operator obtains stormwater coverage under the appropriate NPDES/SDS permit and properly selects, installs, and maintains BMPs sufficient to meet the benchmark values in the permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL report.

6.1.3 MS4 Permits

The MPCA is responsible for applying federal and state regulations to protect and enhance water quality in Minnesota. The MPCA oversees stormwater management accounting activities for all MS4 entities listed in this TMDL report. The MS4 General Permit requires regulated municipalities to implement BMPs that reduce pollutants in stormwater to the maximum extent practicable. A critical component of permit compliance is the requirement for the owners or operators of a permitted MS4 conveyance to develop a SWPPP. The SWPPP addresses all permit requirements, including the following six measures:

- Public education and outreach
- Public participation
- Illicit discharge detection and elimination program
- Construction site runoff controls
- Post-construction runoff controls
- Pollution prevention and municipal good housekeeping measures

A SWPPP is a management plan that describes the MS4 permittee's activities for managing stormwater within their regulated area. In the event of a completed TMDL study, MS4 permittees must document the WLA in their future NPDES/SDS permit application and provide an outline of the BMPs to be implemented that address needed reductions. The MPCA requires MS4 owners or operators to submit their application and corresponding SWPPP document to the MPCA for review. Once the application and SWPPP are deemed adequate by the MPCA, all application materials are placed on 30-day public notice, allowing the public an opportunity to review and comment on the prospective program. Once NPDES/SDS permit coverage is granted, permittees must implement the activities described within their SWPPP and submit an annual report to the MPCA documenting the implementation activities completed within the previous year, along with an estimate of the cumulative pollutant reduction achieved by those activities.

This TMDL report assigns TSS and chloride WLAs to the City of Marshall and an *E. coli* WLA to the City of Redwood Falls, both permitted MS4s in the study area. Depending on the pollutant, the MS4 General Permit either requires permittees to meet specific requirements, or to develop compliance schedules for EPA approved TMDL WLAs not already being met at the time of permit application. Assuming future MS4 General Permits requirements remain the same for chloride impairments, the chloride WLA will require Marshall to document the amount of deicer applied to permittee owned/operated surfaces, conduct an annual assessment of their winter maintenance practices, and use the assessment to establish goals for improving those practices.

A compliance schedule includes BMPs that will be implemented over the permit term, a timeline for their implementation, and a long-term strategy for continuing progress toward assigned WLAs. For WLAs being met at the time of permit application, the same level of treatment must be maintained in the future. Regardless of WLA attainment, all permitted MS4s are still required to reduce pollutant loadings to the maximum extent practicable.

The MPCA's stormwater program and its NPDES permit program are regulatory activities providing reasonable assurance that implementation activities are initiated, maintained, and consistent with WLAs assigned in this study.

6.1.4 Wastewater NPDES and SDS Permits

The MPCA issues permits for WWTPs or industrial facilities that discharge into waters of the state. The permits include monitoring requirements and effluent limits to ensure that wastewater is adequately treated prior to discharge. Where wastewater effluents are found to have the potential to cause or contribute to exceedances of water quality standards, permits include water quality based effluent limits (WQBELs) for specific pollutants. Examples of pollutants that may be subject to WQBELs include phosphorus, total suspended solids, and various toxic substances including chloride.

NPDES and SDS 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 report. Compliance with the WLAs, as developed and presented in this TMDL report, is assumed to ensure meeting the water quality standards for all the bacteria, TSS, and chloride 303(d) listings.

Bacteria and TSS

WWTPs discharging into impaired reaches did not require any changes to their discharge permit limits due to the WLAs calculated in this TMDL report.

Chloride

During the permit issuance or reissuance process, wastewater discharges will be evaluated for the potential to cause or contribute to violations of chloride water quality standards. As stated above, WQBELs will be developed for facilities whose discharges are found to have a reasonable potential to cause or contribute to chloride above the water quality standards. The WQBELs will be calculated based on low flow conditions, may vary slightly from the TMDL WLAs, and will include concentration based effluent limitations. As discussed in Section 4.4.6, the chloride monitoring data collected upstream and downstream of ADM Corn Processing – Marshall and Marshall WWTP show that these facilities contribute to the elevated chloride concentrations observed in the chloride impaired reach during low-flow conditions.

For municipal wastewater facilities, technologies capable of removing chloride from wastewater at the wastewater facility may be cost prohibitive. Some cities may be able to achieve compliance with the final chloride effluent limit by installing centralized softening and taking action to remove chloride sources, which may include encouraging or requiring removal of in-home ion-exchange water softeners or the replacement of in-home ion-exchange softeners with high efficiency softeners.

For cities who identify a viable path to compliance (whether via wastewater treatment upgrades, central softening, or removal of chloride sources), compliance schedules will be included in their NPDES/SDS permits giving them time to take the necessary actions to comply with the final limit. For cities where compliance would result in substantial and widespread economic and social impact, a city may qualify for a variance (40 CFR 131.14 and 131.10(g)(6) & Minn. R. 7050.0190). Variances are also available to industrial dischargers if the compliance pathways are cost prohibitive. Variances would provide time for the respective city to work on identifying sources of chloride, make source reductions (including nonpoint reductions), and evaluate treatment options while still being required to comply with an alternate effluent limit (a limit set to ensure that chloride levels do not increase). Variances are re-evaluated every five years to ensure that complying with the limit would still result in substantial and widespread economic and social impact and that the alternate effluent limit is representative of the highest quality effluent that is attainable by the permittee. The permittee is required to comply with the final limit for total chloride at the end of the variance term.

6.1.5 SSTS Program

SSTS, commonly known as septic systems, are regulated by Minn. Stat. §§ 115.55 and 115.56. Counties and other local government unit (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 LGUs 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 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 which 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. To increase the number of compliance inspections, the MPCA has developed and administers funds to LGUs for various ordinances, and specific actions. Additional funding dollars are awarded to counties that have provisions in their ordinance above the minimum program requirements. The MPCA has worked with counties through the SSTS Implementation and Enforcement Task Force (SIETF) to identify the most beneficial ways to use these funds to accelerate SSTS compliance statewide.

- Compliance inspection for property transfer
- Compliance inspection for any (all) permit-countywide
- Plan to improve compliance, such as records catalog or inventory (past, ongoing, or future)
- Plan to address unsewered areas

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 noncompliance, which starts a 10-month deadline to fix the system and bring it into compliance. From 2006 through 2017, 742 straight pipes have been tracked by the MPCA. Seven hundred one of those were abandoned, fixed, or were found not to be a straight pipe system as defined in Minn. Stat. 115.55, subd. 1. There have been 17 Administrative Penalty Orders issued and docketed in court.

Since 1996, the MPCA Southwest wastewater staff have helped 33 small communities with their work to build wastewater soil treatment systems throughout the region. The unsewered communities within the Redwood River Watershed are all addressing their wastewater treatment through SSTS upgrades regulated by county ordinances and funded by various sources, such as the Clean Water Fund (CWF) and Clean Water Partnership (CWP) State Revolving Fund (SRF) Loan Program.

6.1.6 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 LGU. 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. In the Redwood River Watershed, the counties of Lincoln, Pipestone, Murray, Lyon, and Yellow Medicine are delegated as the feedlot regulatory authority. The only nondelegated county in the Redwood River Watershed is Redwood County. The Counties and 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.

6.1.7 Buffers and Shoreland

Minnesota's buffer law requires perennial vegetative buffers along public ditches, lakes, rivers, and streams. Buffers along lakes, rivers, and streams are to be 50 feet in width, and buffers along public ditches are to be 16.5 feet wide or more. These buffers help filter out phosphorus, nitrogen, and sediment. 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. The law provides some flexibility for landowners to install alternative practices if they provide equal or better water quality benefits. An example of an alternative practice could be a narrower buffer if the land slopes away from the water body. This is not uncommon with some ditches, rivers, and streams. Alternative practices must be approved by the local governmental unit that implements the buffer law.

In general, most of the private lands in the Redwood River Watershed contain well vegetated buffers along ditches, lakes, and streams. Reported rates of compliance for every county in the Redwood River Watershed is between 80% and 100% (BWSR website).

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)

6.2 Nonregulatory

6.2.1 Pollutant Load Reduction

Reliable means of reducing nonpoint source pollutant loads are fully addressed in the WRAPS report (MPCA 2022), a document that is written to be a companion to this TMDL report. For the impaired waters to meet water quality standards, most pollutant reductions in the Redwood River Watershed 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 2015a) and related tools. As such, they were vetted by a statewide engagement process prior to being applied in the Redwood River Watershed.

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 Minnesota River 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 urban communities will need to voluntarily adopt the practices at the necessary scale and rates to achieve the 10-year targets presented in Implementation Table 17 through Table 24 of the WRAPS report and the Minnesota Stormwater Manual. The WRAPS also present the pollutant/stressor reduction goals and targets and the estimated years to meet the goal developed by the WRAPS Local Work Group (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.

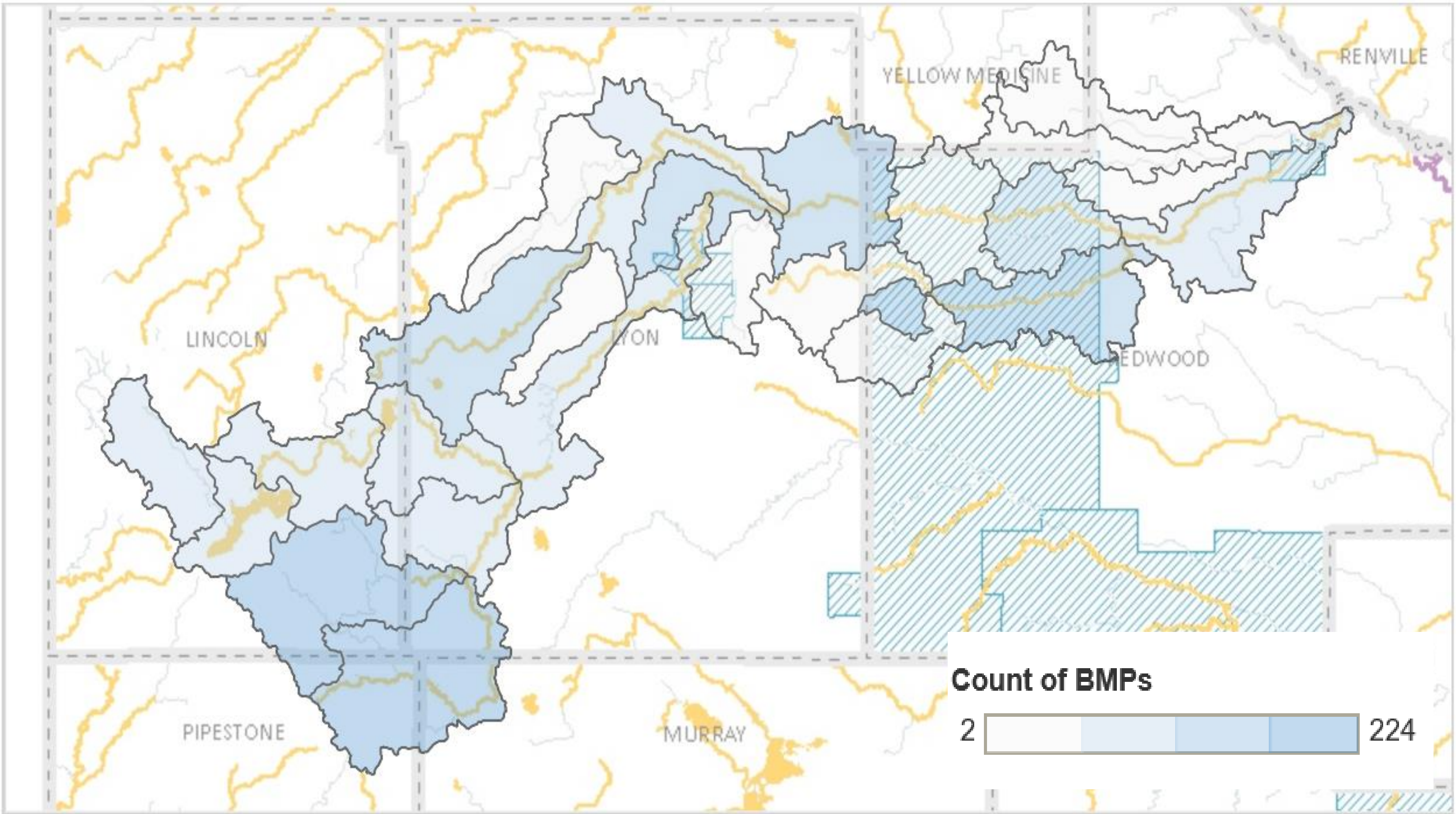
Several nonpermitted reduction programs exist to support implementation of nonpoint source reduction BMPs in the Redwood River Watershed. These programs identify BMPs, provide means of focusing BMPs, and support their implementation via state initiatives, ordinances, and/or dedicated funding.

From 2004 to 2021, over 2,000 BMPs were installed in the Redwood River Watershed by local partners (MPCA 2020a), tied to government assistance programs. More practices have also been implemented without government assistance, but are not able to be tracked and accounted for Table 39 summarizes the major types of BMPs that have been implemented throughout the watershed, while Figure 22 depicts the number of BMPs per subwatershed in the Redwood River Watershed. Additional information about the BMPs may be found on the MPCA's Healthier Watershed website.

Table 39. Most common reported BMPs in the Redwood River Watershed by BMP type (2004-2021).

BMP Type	Total BMPs
Tile Inlet Improvements	241
Tillage/residue Management	216
Nutrient Management (Cropland)	229
Septic System Improvements	53
Designed Erosion Control	146
Converting Land to Perennials	85
Buffers and Filters	60
Living Cover to Crops in Fall/Spring	108
Stream Banks, Bluffs, and Ravines	34
Pasture Management	44
Tile Drainage Treatment/Storage	2
Habitat and Stream Connectivity	2
Crop Rotation	6

Figure 22. Number of BMPs installed in the Redwood River Watershed by subwatershed (2004-2021).



One example of a government program available is The Minnesota Agricultural Water Quality Certification Program (MAWQCP). The MAWQCP is a voluntary opportunity for farmers and agricultural landowners to take the lead in implementing conservation practices that protect our water. Those who implement and maintain approved farm management practices are certified and in turn obtain regulatory certainty for a period of 10 years. Oversight of the program is provided by the Minnesota Department of Agriculture (MDA).

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 technical assistance:** producers seeking certification can obtain specially designated technical and financial assistance to implement practices that promote water quality.

As of January 31, 2023, the Redwood River Watershed has 17,112 acres enrolled in the MAWQCP.

Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites notes that sites across Minnesota, including the Redwood River, show long-term reductions in TSS, ammonia, and biochemical oxygen demand (MPCA 2014). 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 2015a). 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 Redwood 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.

Redwood-Cottonwood Rivers Control Area

The RCRCA was formed in 1983 as a joint powers organization (JPO) comprised of eight counties and eight SWCDs. The JPO was created to prevent the development of a watershed district, as the individual counties desired more local input and control into the watershed's activities. RCRCA has been very successful at securing grant funding to analyze and assess both the Redwood River and Cottonwood River watersheds and secure implementation funding for the construction of BMPs. One of the organization's goals was to see the dredging of Lake Redwood to restore it to its original depth and vitality as a lake. RCRCA, in cooperation with partner groups and landowners, works to improve water quality, reduce erosion, and enhance recreational opportunities by providing education, outreach, monitoring, and technical assistance within the watershed boundaries. Dredging was completed in 2022, removing approximately 650,000 cubic yards of sediment.

Area II Minnesota River Basin Projects

Area II Minnesota River Basin Projects (Area II), a nine-county joint powers organization was formed in 1978 in response to ongoing state and federal floodwater control planning efforts. The Public Law 87-639 Study, a joint effort by the Soil Conservation Service (now known as the Natural Resources Conservation Service) and the U.S. Army Corps of Engineers, identified over 200 possible floodwater retention sites within the nine-county area. Of these sites, only two were found to be cost-beneficial for federal government involvement. The report encouraged local governments to utilize the study information as LGUs could complete the recommendations more cost-effectively. Area II continues to incorporate floodwater retention projects upon the landscape offering engineering, project management, and up to 75% cost-share for the construction of retention structures. The Redwood River is one of the five major watersheds overseen by Area II which also includes the Yellow Bank, Lac qui Parle, Yellow Medicine, and Cottonwood River watersheds.

Accomplishments and Future Plans

The MPCA partnered with eight local governmental units in the Redwood River Watershed (Lincoln County and SWCD, Lyon County and SWCD, Murray County and SWCD, and Redwood County and SWCD) to directly advance civic engagement throughout the watersheds for much of the duration of this project. Through the partnership, the MPCA provided grant funds for the local partners to engage directly with watershed residents and landowners on a variety of water quality topics. These projects were successful in helping local watershed partners connect with watershed residents to build relationships that will be integral in implementing the strategies described in this report. The work begun under these projects will continue as implementation continues throughout the watershed.

6.2.2 Prioritization

The WRAPS report details several tools that provide means for identifying priority pollutant sources and implementation work in the watershed. Further, LGUs in the Redwood River Watershed often employ their own local analyses for determining priorities.

The State of Minnesota has provided tools to further the buffer initiative; they are being used in the implementation planning process to examine riparian land use in the Redwood River Watershed and ensure buffer compliance. The Buffer Initiative was signed into law by Governor Dayton in June 2015 (amended by the Legislature and signed into law by Governor Dayton on April 25, 2016). It provides clarification regarding which waters need buffers, a timeline for implementing them, and tools for LGUs to use in tracking and reporting buffer compliance.

LiDAR data and hydro-conditioned DEMs are available for the entire Redwood River Watershed. These data are being increasingly used by LGUs to examine landscapes, understand watershed hydrology, and prioritize BMP targeting.

6.2.3 Funding

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

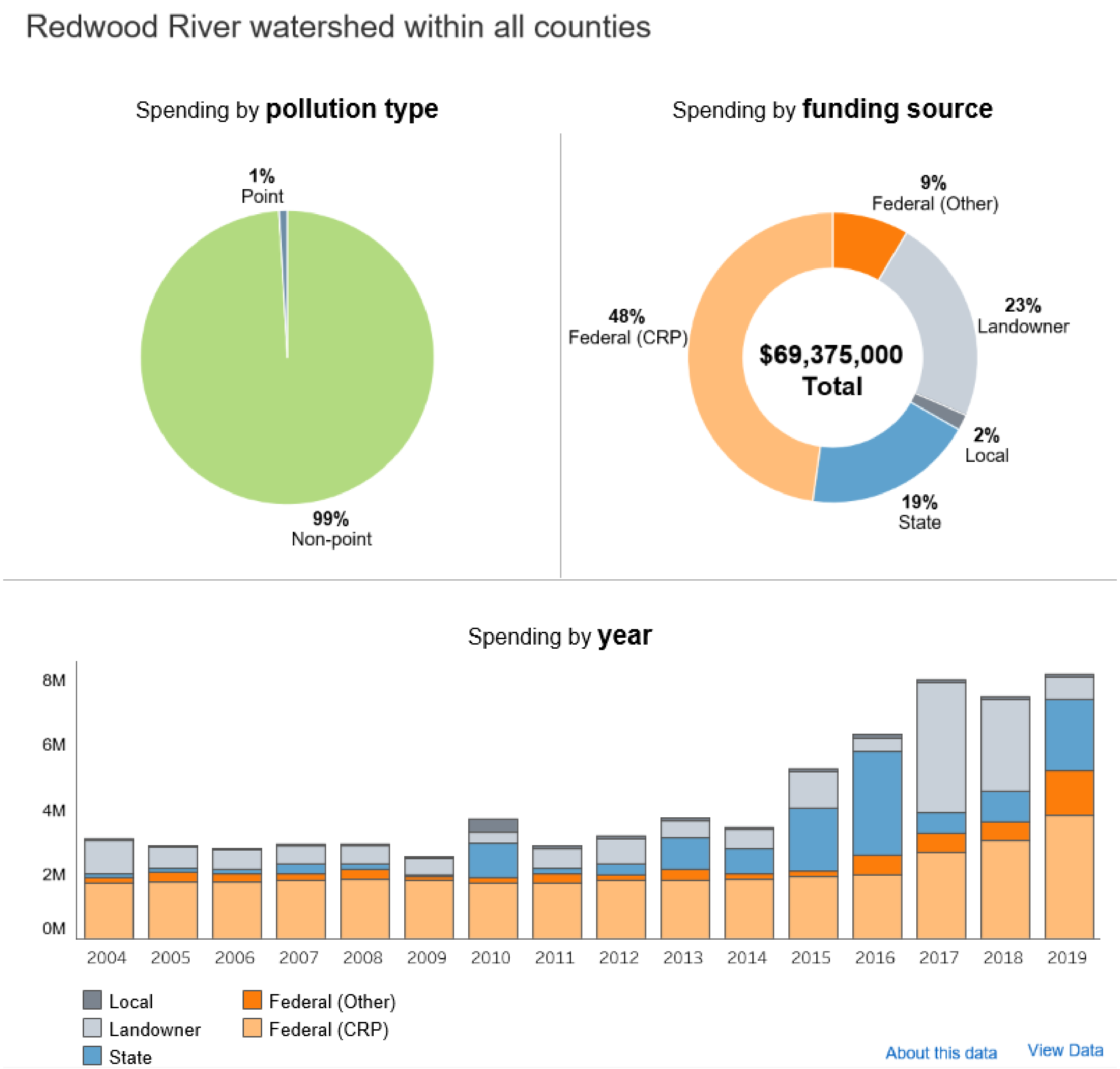
One-third of the funds generated by the sales tax authorized by the amendment is dedicated to the Clean Water Fund, a secure funding mechanism with the explicit purpose of supporting water quality improvement projects.

Additionally, there are other funding sources for nonpoint pollutant reduction work; they include but are not limited to the Clean Water Act Section 319 grant program, the Clean Water Partnership, Agricultural BMP loan programs, and several NRCS incentive programs funded through the federal Farm Bill. 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 CWP and federal Section 319 grants have been utilized to implement nonpoint source BMPs in the watershed.

Minnesota's third CREP signup is ongoing at the time of this report being developed, with a goal of providing financial assistance to landowners to secure sensitive acres into easement. Riparian areas and marginal agricultural land are a focus of the program. This aligns precisely with statewide and Redwood River Watershed strategies focused on converting marginal lands to perennials to reduce pollutant loading to surface and groundwater.

Since 2004, over $69 million have been spent addressing water quality issues in the Redwood River Watershed (Figure 23). Additional information about funding may be found on the MPCA's Healthier Watersheds website.

Figure 23. Spending addressing water quality issues in the Redwood River Watershed.



6.2.4 Planning and Implementation

WRAPS, TMDLs, and all the supporting documents provide a foundation for planning and implementation. Subsequent planning, including development in the near future of a One Watershed, One Plan (1W1P) comprehensive watershed management plan for the Redwood River Watershed, will draw on the goals, technical information, and tools to describe in detail strategies for implementation. The purpose of the 1W1P program is to develop comprehensive watershed management plans that align local water planning purposes and procedures on watershed boundaries to create a systematic, watershed-wide, science-based approach to watershed management. 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 flooding, erosion, 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 Redwood River Watershed are diverse and constitute a sufficient means for tracking progress and supporting adaptive management. See Section 7 for more information on monitoring efforts and programs in the Redwood River Watershed.

6.2.6 Reasonable Assurance Summary

In summary, significant time and resources have been devoted to identifying the best BMPs and locations for their implementation, and supporting their implementation via state initiatives and dedicated funding in southwest Minnesota and in the Redwood River Watershed.

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 & 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 toward water quality goals. These programs will continue to collect and analyze data in the Redwood River Watershed as part of Minnesota's Water Quality Monitoring Strategy (MPCA 2021b). 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 2 years at established stream and lake monitoring stations across the Redwood River Watershed every 10 years. From the initial IWM started in 2017, 42 stream WIDs and 18 lakes were assessed for aquatic life and aquatic recreation use support. Parameters sampled included fish and macro invertebrate communities, TSS, eutrophication indicators, and bacteria. Starting in 2027, the MPCA, with assistance from LGUs, will re-visit and re-assess some of the cycle 1 monitoring stations in the Redwood River Watershed, as well as consider monitoring new sites with demonstrated local or state importance. It is expected that some 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 three sites in the Redwood River Watershed with parameters that vary by site. Twenty to 25 samples are collected annually at each site.

- Volunteer Water Monitoring Program data provide a continuous record of water body transparency and user perception data throughout much of the basin. This program relies on a network of private volunteers who make monthly stream and lake measurements annually. There are currently two volunteer monitoring sites within the Redwood River Watershed. The MPCA will seek more volunteer monitors to track trends of water quality transparency for impaired waters within the basin.

- RCRCA has a long history of water quality monitoring in the Redwood River Watershed with a special focus on sediment and nutrient contributions from tributaries of the Redwood River. Water quality monitoring efforts have been based on a three-tier system. Primary, secondary, and tertiary monitoring stations have been developed to assess areas of the watershed delivering the greatest amount of sediment and nutrients to the Redwood River. There are currently three mainstem sites sampled 10 to 20 times per year for TSS, total solids, volatile solids (TSVS), total Kjeldahl nitrogen (TKN), nitrate nitrogen, ortho phosphorus, and TP. This information has been used to select priority management areas and measure progress toward watershed goals.

- MDA's pesticide monitoring program goal is to determine the presence and concentration of pesticides in Minnesota waters, and present long-term trend analysis based on information collected over the past 30 years. Trend analysis requires long-term investments in monitoring within the MDA's established networks. The MDA releases an annual water quality monitoring report that includes all pesticide water quality data and long-term trends available on MDA's website. The MDA will continue to conduct statewide pesticide monitoring in the future and will provide additional information related to the occurrence of pesticides in Minnesota waters.

  The MDA completed 14 pesticide water quality sample collection events from seven lakes within the Cottonwood and Redwood River watersheds from 2012 through 2019. The MDA completed 517 pesticide and/or nutrient water quality sample collection events from 10 river and stream locations within the Cottonwood and Redwood River watersheds from 1992 through 2019. Finally, the MDA completed 10 pesticide water quality sample collection events from 5 wetlands within the Cottonwood and Redwood River watersheds in 2014. No pesticide detections in the wetlands in either watershed were above the applicable water quality reference values.

8. Implementation Strategy Summary

8.1 Implementation Framework

The strategies described in this section are potential actions to reduce TSS, bacteria, chloride, and nutrient loads (TP) in the Redwood River Watershed. These actions are further described 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 Section 23 of the Construction General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL report. 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 report. All local stormwater management requirements must also be met.

8.2.3 MS4 Stormwater

The City of Marshall MS4 has been assigned several WLAs requiring reductions for TSS. New BMPs implemented by the City should target high flow conditions, as these are the critical conditions for the TSS impairments. The 2020 Comprehensive Stormwater Modeling project that the City completed as part of the 2020 MS4 General Permit reissuance will provide a basis to evaluate whether they are meeting the TSS WLAs in this report during the next MS4 General Permit reissuance.

The City of Marshall MS4 was assigned a WLA for chloride. The MS4 General Permit has instituted performance-based requirements for MS4s with chloride WLAs requiring reductions. If future permit requirements remain the same, MS4s are expected to document the amount of deicer applied to permittee owned/operated surfaces and conduct an annual assessment of the permittee's winter maintenance operations. Further information and up to date guidance can be found at: Guidance for meeting chloride TMDL MS4 permit requirements - Minnesota Stormwater Manual (state.mn.us).

The City of Marshall has been taking a proactive approach to stormwater management and salt application. The city continually makes investments in traditional stormwater BMPs and has started annual chloride training with Public Works staff. Beginning in 2020, all city staff who operate snow removal and sanding/salting equipment have participated in a Smart Salting course through the MPCA. The goal of MPCA's Smart Salting Training Program is to provide the latest technologies, best practices and tools, and available resources to assist cities and other organizations be effective and efficient in managing snow and ice while also creating safe surfaces, saving money, and protecting water resources. More information on the MPCA's Smart Salting trainings and certifications can be found on the agency's website (Smart Salt training). It is the city's intent to continue this training by maintaining Level 1 certification for all snow removal staff. Further, City Public Works leadership intends to conduct annual training internally to express the importance of minimizing salt and sand use on city streets.

The City of Redwood Falls MS4 has been assigned a WLA for bacteria. The MS4 General Permit has instituted performance-based requirements for MS4s with bacteria WLAs requiring reductions. If future permit requirements remain the same, MS4s are expected to inventory potential bacteria sources and prioritize bacteria reduction activities that address those identified sources. Further information and up to date guidance can be found at: Guidance for meeting bacteria TMDL MS4 permit requirements - Minnesota Stormwater Manual (state.mn.us).

Prior to implementation, permitted MS4s are encouraged to compare their sewersheds (e.g., catchments, pipesheds, etc.) with the drainage areas for each impaired water body to ensure appropriate BMP crediting. If a permitted MS4 sewershed is different from what is defined as the drainage area in this report, the sewershed should be considered part of the MS4 contribution to the impaired water if sufficient evidence of the appropriate sewershed area is provided to the MPCA. With Agency approval, any wasteload-reducing BMP implemented since the TMDL baseline year within the sewershed of an impaired water will be creditable towards an MS4's load reduction for purposes of annual reporting and demonstrating progress toward meeting the WLA(s).

For the purposes of this TMDL report, the baseline year for implementation will be the mid-range year of the data years used for the lake response modeling (Table 40) and development of the TSS, bacteria and chloride LDCs. Since the TSS, bacteria, and chloride LDCs were developed using the watershed HSPF models, the baseline year will coincide with the mid-range year of the HSPF model simulations. The rationale for developing a baseline year is that projects undertaken recently may take a few years to influence water quality. Any wasteload-reducing BMP implemented since the baseline year will be eligible to "count" toward an MS4's load reductions. If a BMP was implemented during or just prior to the baseline year, the MPCA is open to presentation of evidence by the MS4 Permit holder to demonstrate that it should be considered as a credit. The WRAPS report for the Redwood River Watershed was developed with input from the stakeholders to determine the appropriate BMPs and implementation strategies to meet the MS4 goals for all the TMDLs presented in this report.

Table 40. Implementation baseline years.

Impairment	Data Years Used for TMDL Development	Baseline Year
TSS Impairments (HSPF)	2008 through 2017	2012
E. coli Impairments (HSPF)	2008 through 2017	2012
Chloride Impairment (HSPF)	2008 through 2017	2012
Lake Benton	2002, 2017	2017
Dead Coon Lake	2002, 2007, 2017	2007
Goose Lake	2002, 2007, 2017	2007
Clear Lake	2017, 2018	2018
School Grove Lake	2002, 2007, 2017	2007
Island Lake	2017, 2018	2018

8.2.4 Wastewater

The MPCA issues permits for WWTPs 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 bacteria and TSS, WWTPs discharging into impaired reaches did not require any changes to their discharge permit limits due to the WLAs calculated in this TMDL report.

Due to the very hard nature of local and regional groundwater resources, City of Marshall water customers are required to significantly soften their water to reach a desired level of hardness. A water is typically considered 'very hard' at levels of seven to eight grains per gallon of hardness. Raw water has a hardness of approximately 56 grains per gallon as it enters the Marshall Water Treatment Plant (WTP). Prior to 2021, the water leaving the WTP had a hardness of approximately 35 grains per gallon; softened, but still significantly hard.

In 2017, Marshall Municipal Utilities (MMU) and the City of Marshall partnered on the goal of completing a WTP construction project that included enhanced water softening. The goal of the enhanced water softening project is to reduce the demand for ion exchange water softening from Marshall utility customers. The project will ultimately provide water that leaves the WTP at approximately six to nine grains per gallon of hardness. To achieve the goal of completing the project, MMU applied for a Point Source Implementation Grant (PSIG) grant from the State of Minnesota.

Once the WTP enhanced softening project is completed, the City of Marshall and MMU will distribute educational materials to its utility customers to inform customers of the softer water that is being delivered. The goal of distributing the educational materials is to ensure that our customers are adjusting their water softening equipment. City staff is optimistic that the reduced demand for ion exchange softening from utility customers will enable the city to meet its NPDES permit chloride limit of 261 mg/L. In 2020, the Marshall WWTP was discharging around 600 mg/L.

8.3 Nonpermitted Sources

Implementation of the Redwood River Watershed TMDL report will require BMPs that address the numerous 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 Redwood River Watershed, such as the Redwood River Fecal Coliform TMDL report (RCRCA 2013), and the Redwood River Watershed Stressor Identification Report (MPCA 2021a).

Agricultural sources such as livestock 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 high priority pollutant sources.

8.3.1 Agricultural Sources

Several different agricultural BMPs can be used to target priority sources and their associated pollutants. Table 41 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 41. 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	X	
Grassed waterways (412)	X	X		
Water and sediment control basins (638)	X	X		
Wetland restorations (657)	X	X	X	

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

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 settling basin or the feedlot itself. In Minnesota, there are five levels of runoff control, with Level 1 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 their 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.

Confined swine operations typically use liquid manure storage areas that are located under the confinement barn. Wash water used to clean the floors and remove manure buildup combines with the solid manure to form a liquid or slurry in the pit. The mixture is usually land applied in the spring and fall by injection/incorporation into the soil or transported offsite. Some facilities may have “open-air” liquid manure storage areas, which can pose a runoff risk if improperly managed.

Nonpermitted large dairies in the Redwood River Watershed mainly store and handle manure in liquid form to be land-applied later. 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. In addition, many small dairy operations have limited to no manure storage. Most poultry manure is handled as a dry solid in the state; liquid poultry manure handling and storage is rare. 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.

The MDA recommends that inorganic and organic (manure) fertilizer application follow the “4Rs” of nutrient management by optimizing application rate (Right rate), application timing (Right timing), source of nutrient (Right source), and placement of the application (Right placement). 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.

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 using 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, pre-treatment, 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

State-sponsored funding programs are 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 water bodies.

SSTS Upgrades/Replacement

When a straight pipe system or other ITPHS location is confirmed, the local SSTS LGU will send a Notice of Non-compliance 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 LGUs also require proof of a compliant SSTS for property transfers.

Many Counties offer low interest loan programs for SSTS upgrades or replacement. The Clean Water Partnership and Agricultural BMP loan programs also offer funding for SSTS projects.

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.

SSTS Maintenance

The most cost-effective BMP for managing loads from SSTSs 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 2002b). When not maintained properly, SSTSs 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 SSTSs. SSTSs are regulated under M.S. §§ 115.55 and 115.56. Counties must enforce ordinances in Minn. R. ch. 7080 to 7083.

Water Softeners

One approach to reducing chloride loading from residential water softeners is to prohibit the installation of timed water softeners for new construction and provide rebates and/or grants to homeowners that replace existing water softeners with high efficiency ion exchange softeners that use salt more efficiently.

Public Education

Education is another crucial component of reducing pollutant loading from SSTSs. 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

It is expected that implementation of the Sediment Reduction Strategy for the Minnesota River Basin (MPCA 2015b) will reduce sediment in the Redwood River Watershed. Both direct and indirect controls for reducing near-channel sediment can be used in the Redwood River Watershed.

Direct Sediment Controls

Direct controls for near channel sediment sources include practices such as limiting ravine erosion with a drop structure or energy dissipater or controlling streambank or bluff erosion through streambank stabilization and restoration. 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 by the LGUs.

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 many rivers, streams, and 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

Internal loading can be an important portion of the phosphorus budget for impaired lakes and legacy source-impacted wetlands. Implementation strategies for reducing internal load 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. Since internal phosphorus loading is typically the result of excessive historical watershed loading, a critical first step to reducing internal load is to reduce watershed sediment and phosphorus loads, which includes reducing runoff from shore lands, developed land, noncompliant SSTS, and other upland sources. 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 external phosphorus loads, 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. The Minnesota State and Regional Government Review of Internal Phosphorus Load Control paper provides more information on internal phosphorus load BMPs and considerations.

8.4 Education

Education is a crucial component of reducing pollutant sources in the Redwood River Watershed 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. 2007, § 114D.25). It is estimated that the costs to implement the activities outlined in the strategy document are over $120 million 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. Below is a general discussion of cost considerations for the four pollutants (TSS, bacteria, chloride, and phosphorus (lakes)) covered in this TMDL.

TSS

Utilizing estimates developed by an interagency work group (BWSR, USDA, MPCA, Minnesota Association of SWCDs, Minnesota Association of Watershed Districts, NRCS) who assessed restoration costs for several TMDLs, it was determined that implementing the Redwood River TSS TMDLs will cost approximately $82 million over 20 years. This was based on total area of the watershed (705 square miles) multiplied by the cost estimate of $117,000/square mile for a watershed-based treatment approach.

E. coli

The cost estimate for bacteria load reduction is based on unit costs for the two major sources of bacteria: livestock and ITPHS SSTSs. The unit cost for bringing AUs under manure management plans and feedlot lot runoff controls is $350/AU. This value is based on USDA EQIP payment history and includes buffers, livestock access control, manure management plans, waste storage structures, and clean water diversions. Repair or replacement of ITPHS systems was estimated at $20,000/system (Wenck, personal communication 2020). Multiplying those unit costs by an estimated 300 ITPHS systems and 86,514 AUs in the Redwood River Watershed provides a total cost of approximately $36 million. However, the MPCA staff calculates that approximately 75% of these AUs currently have controls or management plans in place, thus reducing this estimate to approximately $13 million.

Chloride

In 2019, the City of Marshall was awarded a PSIG grant in the amount of $7,000,000. The total capital cost of the softening enhancement portion of the project is $11,585,492. The WTP annual operating costs are expected to increase by roughly $1,000,000 per year; the actual figure will fluctuate due to chemical and energy costs. To cover the costs of the capital project and the yearly annual operating costs, the aggregate water rate has been increased by 36% across all customer classes. The rate increase was spread over two years, 2020 and 2021.

Additionally, the City of Marshall has recently purchased a second street sweeper for cleaning its 80 miles of locally controlled City streets. This $245,000 investment will enable the City to operate two street sweepers during critical periods to pick up more sand, salt, and organic debris when it matters the most. Using two sweepers will aid the street department staff in maximizing their resources and help them cover more ground quickly.

Lake Nutrients (phosphorus)

A detailed analysis of the cost to implement the nutrient TMDLs was not conducted. However, as a rough approximation one can use some general results from BMP cost studies across the U.S. For example, an EPA summary of several studies showed a median life cycle cost of approximately $2,200 per lb TP removed for watershed BMPs (Foraste et al. 2012). Another recent review (Macbeth et al. 2018) of lake restoration projects performed throughout the State of Minnesota suggests a median life cycle cost of approximately $500 per lb of TP removed for internal load BMPs such as aluminum sulfate. Multiplying these rates by the needed watershed (4,485 lbs per year) and internal (10,229 lbs per year) TP reductions needed for the five lake basins included in this TMDL provides a total cost of approximately $15 million. This cost estimate assumes a 20-year life cycle for watershed and internal load BMPs.

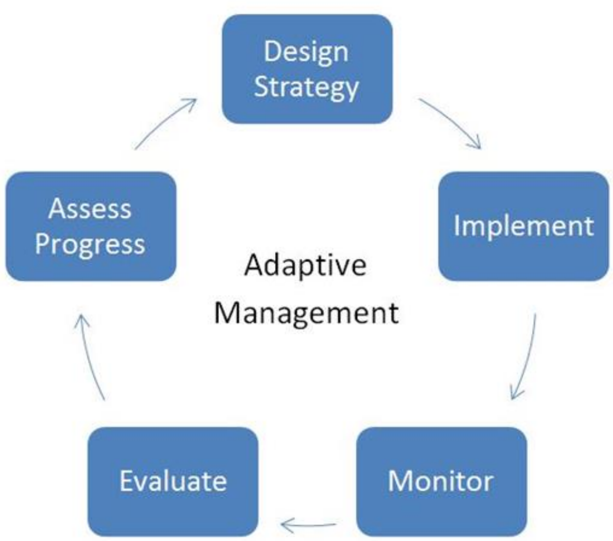
8.6 Adaptive Management

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. 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 TMDLs and lay the groundwork for de-listing 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 loading capacity. Any changes to water quality standards or loading capacity must be preceded by appropriate administrative processes, including public notice and an opportunity for public review and comment.

A list of implementation strategies in the WRAPS report prepared in conjunction with this TMDL report will focus on adaptive management (Figure 24). Though Implementation is shown in Figure 24 as a discrete box, implementation activities are ongoing and driven by local expertise. Continued monitoring and "course corrections" responding to monitoring results are the most appropriate strategy for achieving the water quality goals established in this TMDL report. Management activities will be changed or refined to efficiently meet the TMDLs and lay the groundwork for de-listing the impaired water bodies.

Figure 24. Adaptive management.



9. Public Participation

A stakeholder participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the public and a LWG that consisted of staff from county environmental services departments, SWCDs, RCRCA, MPCA, DNR, BWSR, MDA, Minnesota Department of Health (MDH) and other interested and affected agencies. The LWG, led by RCRCA and MPCA staff, convened multiple times to discuss and review TMDL results and provide input and feedback on the development of the Redwood River WRAPS. The entire public stakeholder process involved meetings and other forms of communication as described in Table 42.

Table 42. Summary of stakeholder meetings/events held during the development of the Redwood River Watershed TMDL/WRAPS.

Date	Description
4/19/2017	Local Work Group Meeting at Wabasso, MN
6/8/2017	Local Work Group Meeting at Marshall, MN
8/10/2017	Local Work Group Meeting at Marshall, MN
11/7/2017	Local Work Group Meeting at Marshall, MN
1/18/2018	Local Work Group Meeting at Marshall, MN
2/15/2018	Local Work Group Meeting at Marshall, MN
3/19/2018	Elected Officials Meeting at Lamberton, MN
4/19/2018	Local Work Group Meeting at Marshall, MN
6/28/2018	Local Work Group Meeting at Sleepy Eye, MN
7/24/2018	Public Informational Meeting at Lake Benton, MN
7/25/2018	Public Informational Meeting at Marshall, MN
7/26/2018	Public Informational Meeting at Redwood Falls, MN
8/16/2018	Local Work Group Meeting at Lamberton, MN
9/20/2008	Local Work Group Meeting at Redwood Falls, MN
11/15/2018	Local Work Group Meeting at Marshall, MN
1/17/2019	Local Work Group Meeting at Marshall, MN
3/21/2019	Local Work Group Meeting at Wabasso, MN
5/16/2019	Local Work Group Meeting at Marshall, MN
7/18/2019	Local Work Group Meeting at Redwood Falls, MN
9/19/2019	Local Work Group Meeting at Wabasso, MN
12/19/2019	Local Work Group Meeting at Redwood Falls, MN
2/25/2020	Local Work Group Meeting at Redwood Falls, MN
5/21/2020	Local Work Group Meeting via WebEx
6/18/2020	Local Work Group Meeting via WebEx
8/27/2020	Local Work Group Meeting via WebEx
9/17/2020	Local Work Group Meeting via WebEx
12/10/2020	Local Work Group Meeting via WebEx
1/21/2021	Local Work Group Meeting via WebEx

Public Notice

An opportunity for public comment on the draft TMDL was provided via a public notice in the State Register from February 21, 2023, 2023 March 23, 2023. There were xxxx comment letters received and responded to as a result of the public comment period.

10. Literature Cited

Adhikari, Hrishikesh, David L. Barnes, Silke Schiewer, and Daniel M. White. 2007. "Total Coliform Survival Characteristics in Frozen Soils." Journal of Environmental Engineering, Vol. 133, No. 12, pp: 1098–1105, December 2007.

Alderisio, K.A, and DeLuca, H. 1999. "Seasonal Enumeration of Fecal Coliform Bacteria from the Feces of Ring-Billed Gulls (Larus delawarensis) and Canada Geese (Branta canadensis)". Applied and Environmental Microbiology p. 5628-5630.

American Society of Agricultural Engineers (ASAE). 1998. "Standards Engineering Practices Data. Barr Engineering Company. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds". Prepared for the Minnesota Pollution Control Agency. https://www.pca.state.mn.us/water/detailed-assessments-phosphorus-sources-minnesota-watersheds

Bajer, P., G. Sullivan, P. Sorensen. 2009. "Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake". Hydrobiologia Vol. 632, pp: 235-245.

Bajer, P., P. Sorensen. 2012. "Using boat electrofishing to estimate the abundance of invasive common carp in small Midwestern lakes". North American Journal of Fisheries Management. Vol. 32, pp: 817-822.

Barr Engineering. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Prepared for Minnesota Pollution Control Agency, Saint Paul, MN. https://www.pca.state.mn.us/sites/default/files/pstudy-covertoc.pdf

Bevis, M. 2015. "Sediment budgets indicate Pleistocene base level fall drives erosion in Minnesota's greater Blue Earth River basin". M.S. Thesis. https://conservancy.umn.edu/bitstream/handle/11299/170661/Bevis_umn_0130M_15776.pdf?sequence=1

Canfield, D. E. Jr, and R. W. Bachmann. 1981. "Prediction of Total Phosphorus Concentrations, Chlorophyll-a, and Secchi Depths in natural and artificial lakes". Can. J. Fish. Aquat. Sci. 38: 414423

ENSR. 2003. Inputs of phosphorus to aquatic systems from machine dishwashing detergents: an analysis of measured and potential loading. Prepared for Minnesota Pollution Control Agency.

Foraste, A., Goo, R., Thrash, J., and L. Hair. June 2012. "Measuring the Cost-Effectiveness of LID and Conventional Stormwater Management Plans Using Life Cycle Costs and Performance Metrics". Presented at Ohio Stormwater Conference. Toledo, OH.

Gran, K.B., P. Belmont, S. Day, C. Jennings, J. Wesley Lauer, E. Viparelli, P. Wilcock, G Parker. 2011. "An Intetegrated Sediment Budget for the Le Sueur River Basin". Final Report. https://www.pca.state.mn.us/sites/default/files/wq-iw7-29o.pdf

Horsley and Witten, Inc. 1996. "Identification and evaluation of nutrient and bacterial loadings to Maquoit Bay, New Brunswick and Freeport, Maine Final Report".

Huser, B.J., S. Egemose, H. Harper, M. Hupfer, H. Jensen, K.M. Pilgrim, K. Reitzel, E. Rydin, and M. Futter. 2016. Longevity and effectiveness of aluminum addition to reduce sediment phosphorus release and restore lake water quality. Water Research 97 (June): 122–32. doi:10.1016/j.watres.2015.06.051.

Ishii, Satoshi, Tao Yan, Hung Vu, D.L. Hansen, R.E. Hicks, M.J. Sadowsky. 2010. "Factors Controlling Long-Term Survival and Growth of Naturalized Escherichia coli Populations in Temperate Field Soils". Microbes and Environment. Vol. 25 No. 1, pp. 8-14.

Kellogg, D. Q., L. Joubert, and A. Gold. 1995. MANAGE: a Method for Assessment, Nutrient-loading, and Geographic Evaluation of nonpoint pollution. Draft Nutrient Loading Component. University of Rhode Island, Kingston, RI.

Lenhart, C.F., M.L. Titov, J.S. Ulrich, J.L. Nieber, and B.J. Suppes. 2013. The Role of Hydrologic Alteration and Riparian Vegetation Dynamics in Channel Evolution along the Lower Minnesota River. Transactions of the ASABE 56 (2): 549–61.

Lenhart, C., B. Gordon, J. Peterson, W. Eshenaur, L. Gifford, B. Wilson, J. Stamper, L. Krider, and N. Utt. 2017. Agricultural BMP Handbook for Minnesota, 2nd Edition. St. Paul, MN: Minnesota Department of Agriculture. https://wrl.mnpals.net/islandora/object/WRLrepository%3A2955/datastream/PDF/view

Macbeth, E. J. Bischoff, W. James. 2018. Integrated Stormwater and Lake Management in the City of Eagan, Minnesota. LakeLine. Vol. 38 (3), pp: 20-25.

Marino, Robert P, and John J. Gannon. 1991. "Survival of Fecal Coliforms and Fecal Streptococci in Storm Drain Sediments." Water Research, Vol. 25 No. 9, pp. 1089–1098, 1991.

Metcalf and Eddy. 2003. "Wastewater Engineering: Treatment and Reuse". 4th Edition. McGraw-Hill, Inc., Boston.

Minnesota Court of Appeals. 2016. A15-1622 "MCEA vs MPCA & MCES". http://www.meserb.org/wp-content/uploads/2009/12/finalamicusmceavspca2016-signed.pdf

Minnesota Department of Administration. State Demographic Center. 2015. "2015-2035 County Population Projections, totals only". https://mn.gov/admin/demography/data-by-topic/population-data/

Minnesota Department of Agriculture (MDA). 2009. "2009 Water Quality Monitoring Report". Pesticide and Fertilizer Management Division, Minnesota Department of Agriculture, St. Paul, Minnesota. http://www.mda.state.mn.us/~/media/Files/chemicals/reports/2009waterqualitymonrpt.ashx s

Minnesota Department of Agriculture (MDA). 2010a. "2010 Water Quality Monitoring Report". Pesticide and Fertilizer Management Division, Minnesota Department of Agriculture, St. Paul, Minnesota. http://www.mda.state.mn.us/chemicals/pesticides/~/media/Files/chemicals/maace/2010wqmreport.ashx

Minnesota Department of Agriculture (MDA). 2010b. "Commercial Nitrogen and Manure Selection and Management Practices on Corn and Wheat in Minnesota" http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/~/media/Files/protecting/cwf/2010cornnitromgmt.pdf

Minnesota Department of Agriculture (MDA). 2012. "Commercial Nitrogen and Manure Fertilizer Section and Management Practices Associated with Minnesota's 2012 Corn Crop" https://www.mda.state.mn.us/sitecore/shell/Controls/Rich%20Text%20Editor/~/media/Files/protecting/cwf/2012nitrocorn.pdf

Minnesota Department of Natural Resources (DNR). 2011a. "Pre-Fawn Deer Density from Deer Population Model".

Minnesota Department of Natural Resources (DNR) and U.S. Fish and Wildlife Service. 2011b. "Waterfowl Breeding Population Survey for Minnesota". https://files.dnr.state.mn.us/recreation/hunting/waterfowl/waterfowl_survey2018.pdf

Minnesota Department of Natural Resources (DNR). 2020. "Redwood River Watershed Characterization Report". https://wrl.mnpals.net/islandora/object/WRLrepository%3A3670

Minnesota Pollution Control Agency (MPCA). 2002. "Regional Total Maximum Daily Load Evaluation of Fecal Coliform Bacteria Impairments in the Lower Mississippi River Basin in Minnesota". October 2002. http://www.pca.state.mn.us/index.php/view-document.html?gid=5992

Minnesota Pollution Control Agency (MPCA). 2005. "Minnesota Lake Water Quality Assessment Report: Developing Nutrient Criteria, 3rd Edition". https://www.pca.state.mn.us/sites/default/files/lwq-a-nutrientcriteria.pdf

Minnesota Pollution Control Agency (MPCA). 2007a. "Minnesota Statewide Mercury Total Maximum Daily Load". https://www.pca.state.mn.us/sites/default/files/wq-iw4-01b.pdf

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

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

Minnesota Pollution Control Agency (MPCA). 2012. "Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List". http://www.iwinst.org/wp-content/uploads/2012/04/2012_TMDL_Guidance_Manual.pdf

Minnesota Pollution Control Agency (MPCA). 2013. "2012 SSTS Annual Report". https://www.pca.state.mn.us/sites/default/files/wq-wwists1-51.pdf

Minnesota Pollution Control Agency (MPCA). 2014. "Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites". https://www.pca.state.mn.us/sites/default/files/wq-s1-71.pdf

Minnesota Pollution Control Agency (MPCA). 2015a. "Nutrient Reduction Strategy". http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/nutrient-reduction/nutrient-reduction-strategy.html

Minnesota Pollution Control Agency (MPCA). 2015b. "Sediment Reduction Strategy for the Minnesota River Basin and South Metro Mississippi River". https://www.pca.state.mn.us/sites/default/files/wq-iw4-02.pdf

Minnesota Pollution Control Agency (MPCA) and LimnoTech. 2016. “Twin Cities Metropolitan Area Chloride Total Maximum Daily Load Study”. St. Paul, MN. Document number wq-iw11-06e. https://www.pca.state.mn.us/sites/default/files/wq-iw11-06e.pdf

Minnesota Pollution Control Agency (MPCA). 2020a. “Redwood River Watershed Monitoring and Assessment Report”. https://www.pca.state.mn.us/sites/default/files/wq-ws3-07020006.pdf

Minnesota Pollution Control Agency (MPCA). 2020b. “Minnesota River and Greater Blue Earth River Basin Total Suspended Solids Total Maximum Daily Load Study”. https://www.pca.state.mn.us/sites/default/files/wq-iw7-47e.pdf

Minnesota Pollution Control Agency (MPCA). 2020c. “Lower Minnesota River Watershed TMDLs. Part 1 – Southern and Western Watersheds”.

Minnesota Pollution Control Agency (MPCA). 2020d. “Minnesota State and Regional Government Review of Internal Phosphorus Load Control”. https://www.pca.state.mn.us/sites/default/files/wq-s1-98.pdf

Minnesota Pollution Control Agency (MPCA). 2021a. “Redwood River Watershed Stressor Identification Report”. https://www.pca.state.mn.us/sites/default/files/wq-ws3-07020006a.pdf

Minnesota Pollution Control Agency (MPCA). 2021b. “Minnesota’s Water Quality Monitoring Strategy 2021-2031”. https://www.pca.state.mn.us/sites/default/files/p-gen1-10.pdf

Minnesota Pollution Control Agency (MPCA). 2022. “Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List”. https://www.pca.state.mn.us/sites/default/files/wq-iw1-04l.pdf

Nürnberg, G. 1997. Coping with water quality problems due to hypolimnetic anoxia in central Ontario lakes. Water Quality Research Journal of Canada. 32 (2) pp 391-405.

Nürnberg, G. 2004. Quantified hypoxia and anoxia in lakes and reservoirs. The Scientific World Journal. 4, pp 42-54.

Pachepsky, Y., M. Stocker, M.O. Saldana, D. Shelton. 2017. “Enrichment of stream water fecal indicator organisms during baseflow periods”. Environ Monit Assess (2017) 189:51

Park, Y., Y. Pachepsky, E.M. Hong, D. Shelton, C. Coppock. 2016. “Escherichia coli Release from Streambed to Water Column during Baseflow Periods: A Modeling Study”. Journal of Environmental Quality doi: 10.2134.

Redwood-Cottonwood Rivers Control Area (RCRCA). 2013. “Redwood River Fecal Coliform Total Maximum Daily Load Report.” https://www.pca.state.mn.us/sites/default/files/wq-iw7-21e.pdf

Reckhow, K.H and J. T. Simpson. 1980. A procedure using modeling and error analysis for the prediction of lake phosphorus concentration from land use information. Can. J. Fish. Aq. Sci. 37 (9:1439-1448.)

Sadowsky, M.J., A. Birr, P. Wang, C. Staley, S. Matteson, M. Hamilton, R. Chandrasekaran. 2015. “Geographic isolation of Escherichia coli genotypes in sediments and water of the Seven Mile Creek — A constructed riverine watershed”. http://www.sciencedirect.com/science/article/pii/S0048969715305179

Schottler, S.P., Engstrom, D.R., and D. Blumentritt. 2010. “Fingerprinting Sources of Sediment in Large Agricultural River Systems”. Final report prepared by the St. Croix Watershed Research Station. August 1.

Schottler, S.P, Jason Ulrich, Patrick Belmont, Richard Moore, J. Wesley Lauer, Daniel R. Engstrom, and James E. Almendinger. 2013. “Twentieth century agricultural drainage creates more erosive rivers”. Hydrological Processes, 28(4):1951-1961, Feb. 15, 2014. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_021703.pdf

Tetra Tech. 2016. “Minnesota River Basin HSPF Model Sediment Recalibration”. Technical Memorandum from J. Wyss and J. Butcher, Tetra Tech, to C. Regan and T. Larson, Minnesota Pollution Control Agency, St. Paul, MN, March 17, 2016.

Tetra Tech. 2019. “Cottonwood and Redwood Watersheds HSPF Model Extension”. Technical Memorandum from M. Schmidt, S. Job, and R. Birkemeier, Tetra Tech, to C. Regan, Minnesota Pollution Control Agency, St. Paul, MN, January 3, 2019.

United States Environmental Protection Agency (EPA). 1999. “Protocol for Developing Sediment TMDLs First Edition”. EPA 841-B-99-004 http://www.epa.gov/owow/tmdl/sediment/pdf/sediment.pdf

United States Environmental Protection Agency (EPA). 2002a. “Guidelines for Reviewing TMDLs under Existing Regulations issued in 1992”. https://www.epa.gov/sites/production/files/201510/documents/2002_06_04_tmdl_guidance_final52002.pdf

United States Environmental Protection Agency (EPA). 2002b. Onsite Wastewater Treatment Systems Manual. EPA/625/R-00/008. EPA Office of Water and Office of Research and Development. February 2002.

United States Environmental Protection Agency (EPA). 2003. National Management Measures to Control Nonpoint Source Pollution from Agriculture. EPA Office of Water, Washington, D.C. EPA 841-B-03-004. July 2003.

Viraraghavan, T. and R.G. Warnock. 1975. Treatment efficiency of a septic tile system. In Proc. National Home Sewage Disposal Symposium, ASAE, St. Joseph, MI. pp. 48-57.

Wenck. 2011. Ann Lake and Lake Emma Excess Nutrient TMDL. Prepared for Wright County Soil and Water Conservation District and Minnesota Pollution Control Agency. https://www.pca.state.mn.us/sites/default/files/wq-iw8-34e.pdf

Appendices

Appendix A - Stream Impairment Supporting Items

Supporting Items for Redwood River TSS and Chloride Impaired Reach (07020006-502)

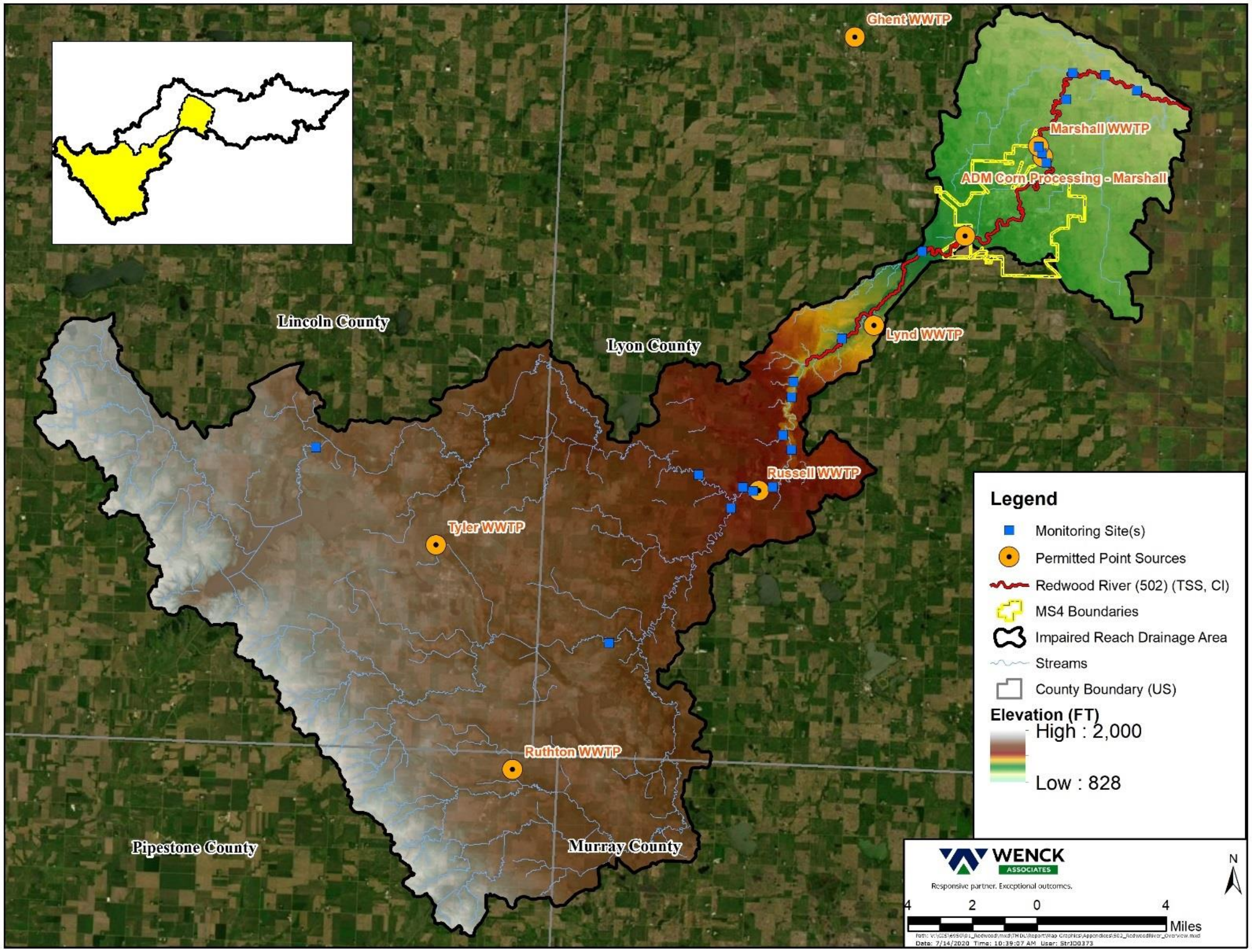


Figure A-1. Redwood River Reach 502 Overview.

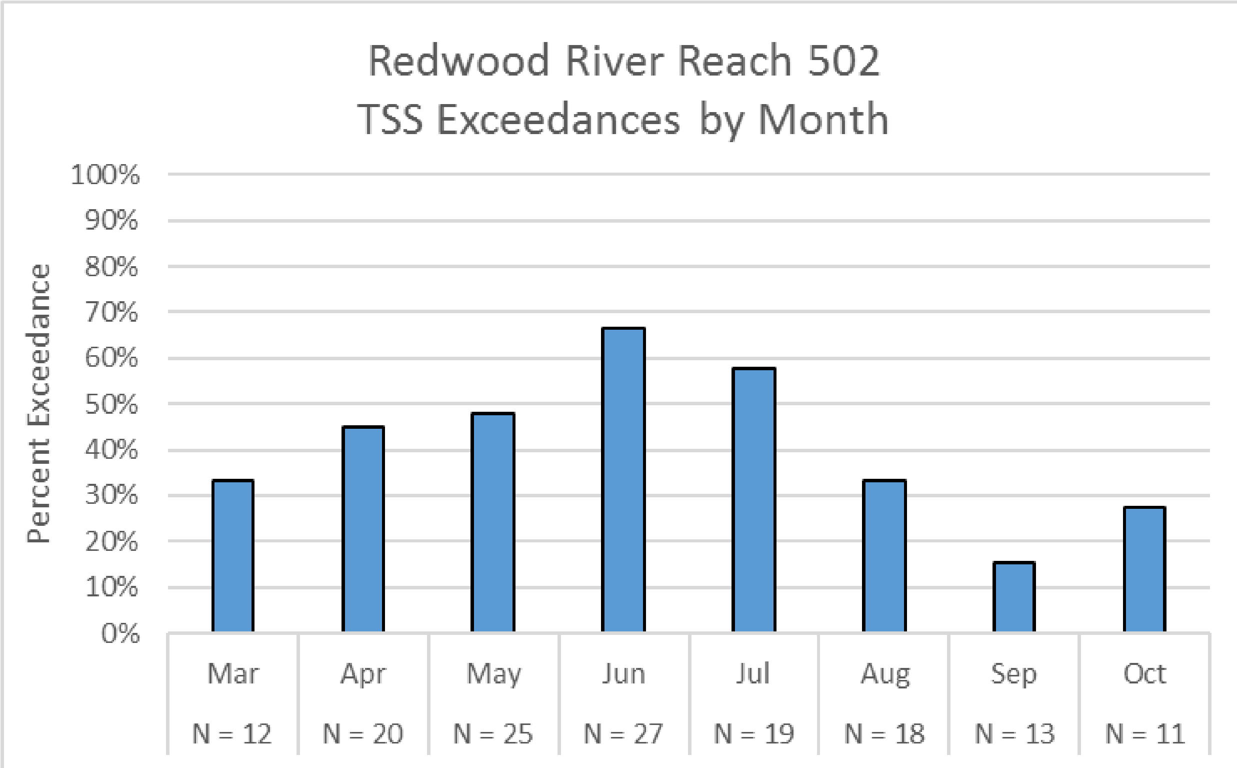


Figure A-2. Redwood River Reach 502 TSS Exceedances by Month.

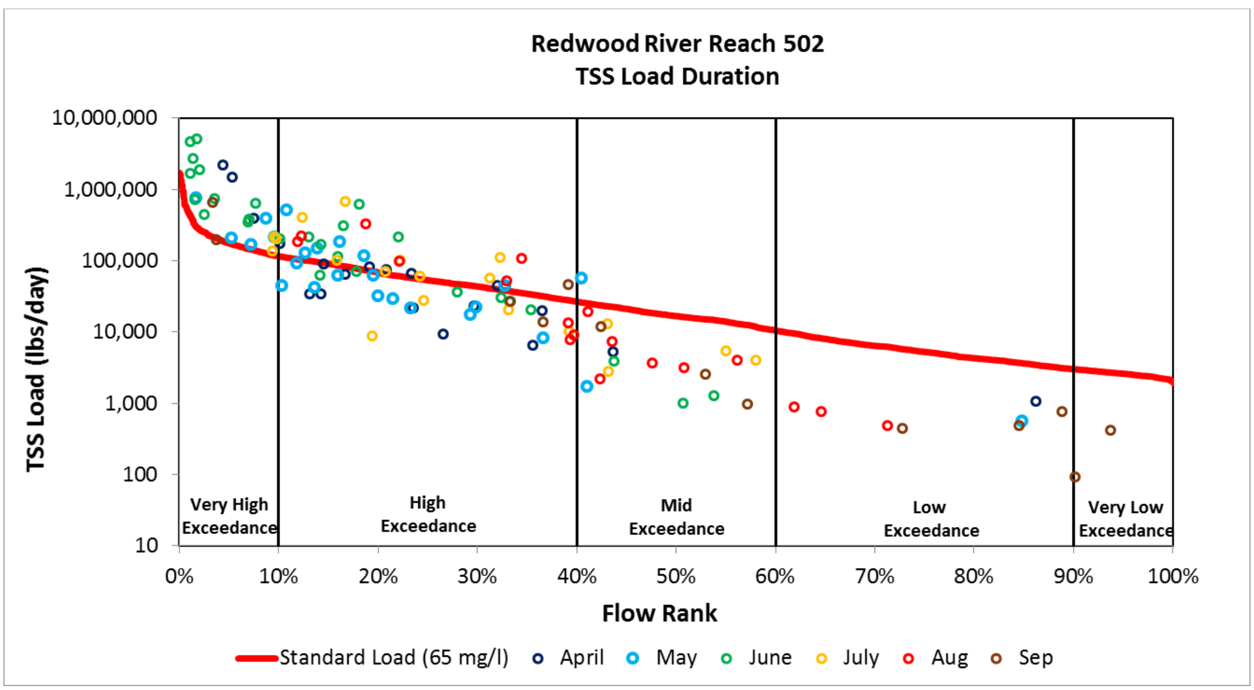


Figure A-3. Redwood River Reach 502 TSS Load Duration Curve (by month).

Supporting Items for Redwood River TSS Impaired Reach (07020006-503)

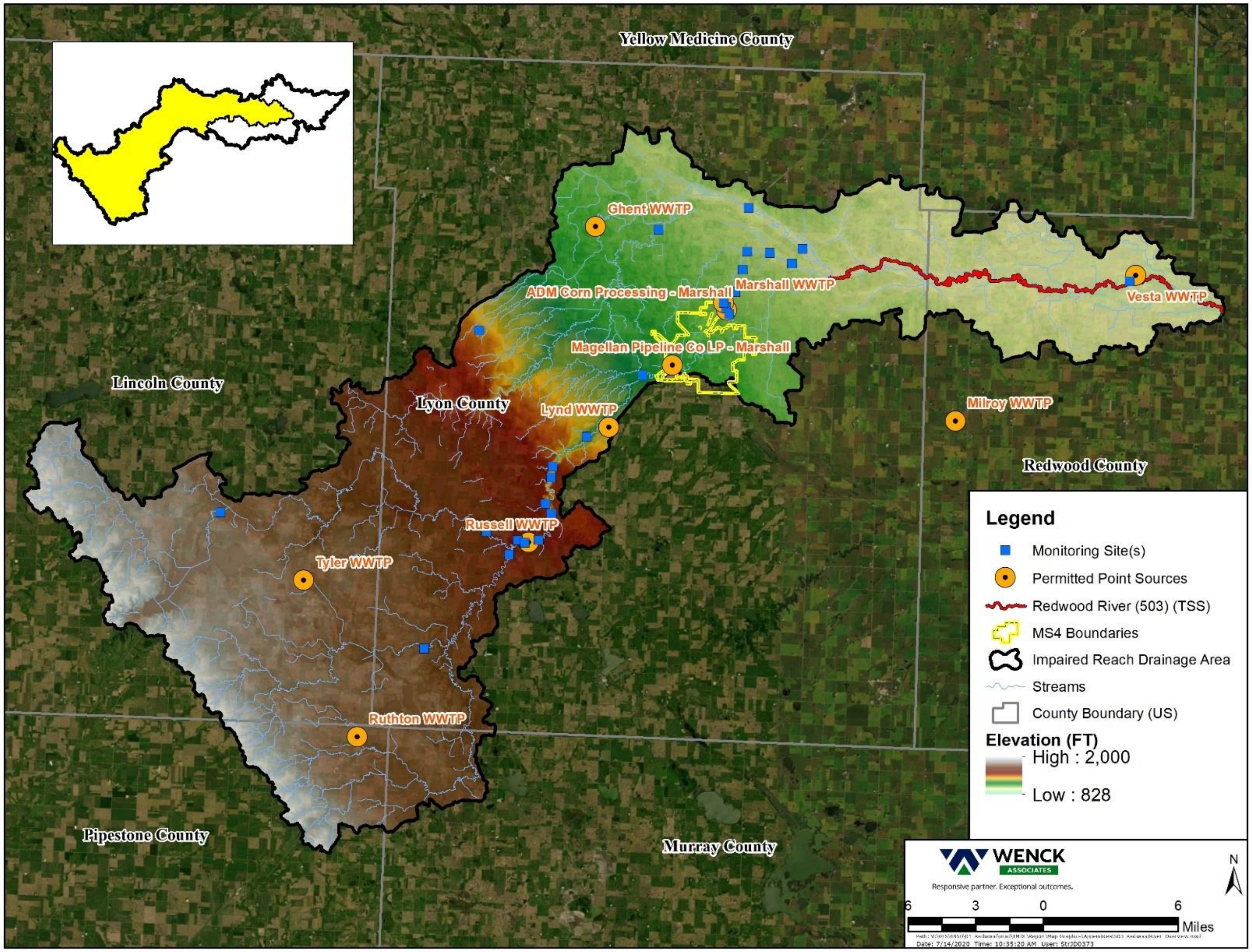


Figure A-4. Redwood River Reach 503 Overview.

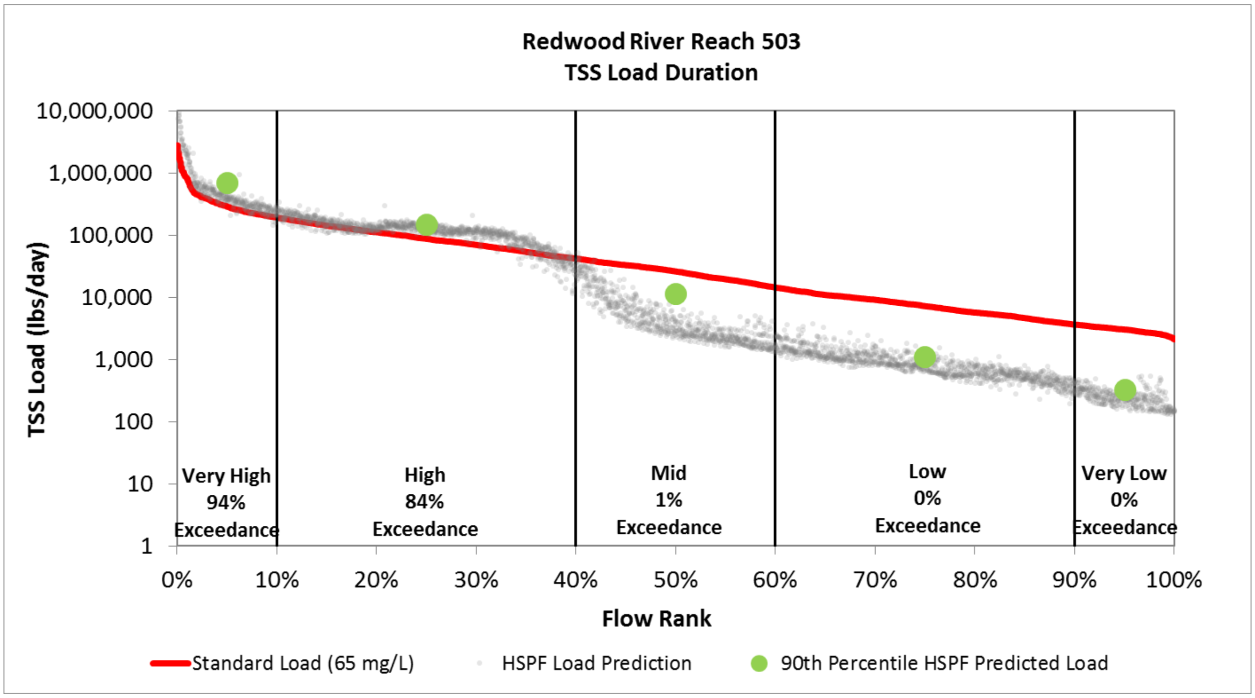


Figure A-5. Redwood River Reach 503 TSS Load Duration Curve (HSPF predicted loads).

Note: no TSS data has been collected for this reach

Supporting Items for Redwood River TSS Impaired Reach (07020006-509)

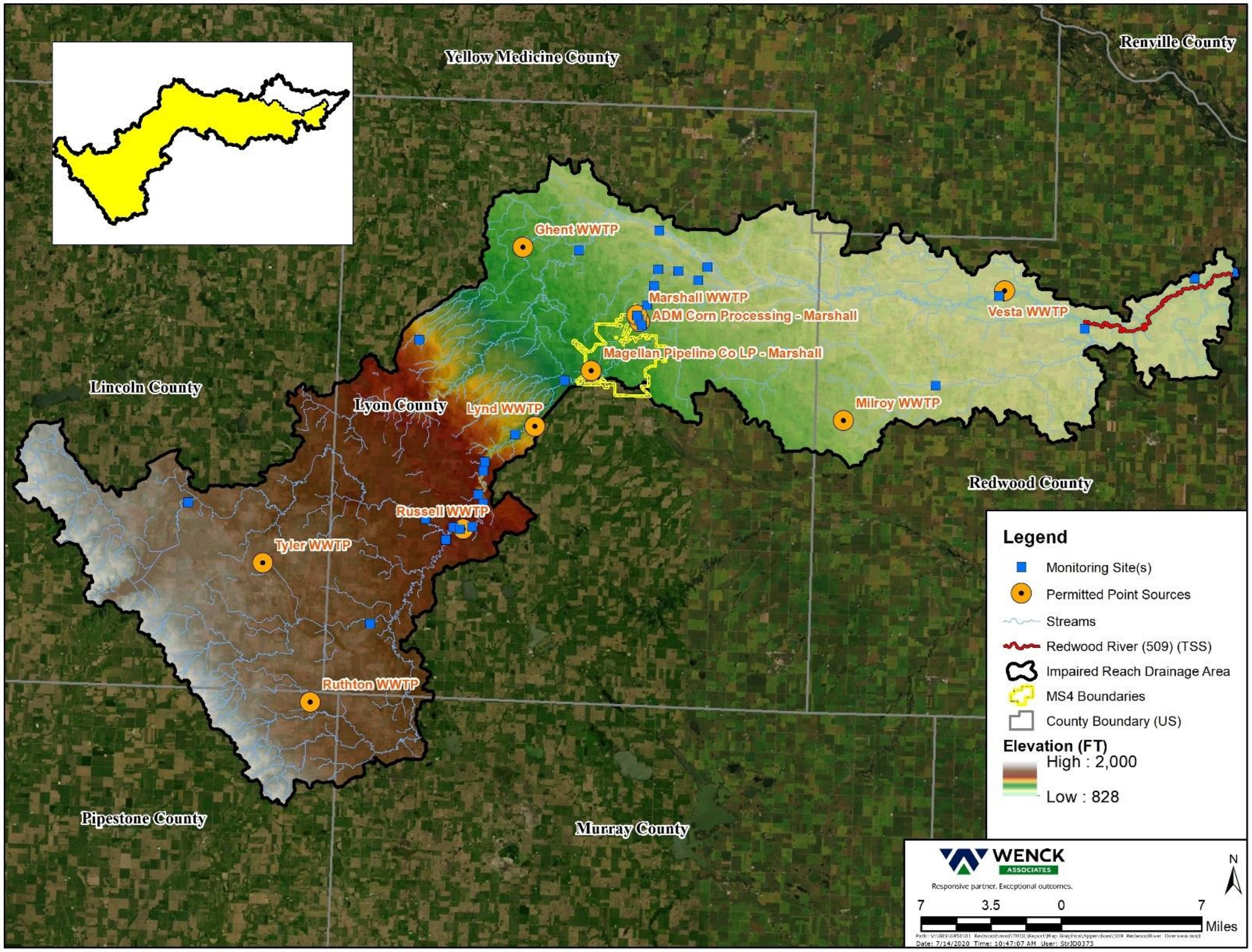


Figure A-6. Redwood River Reach 509 Overview.

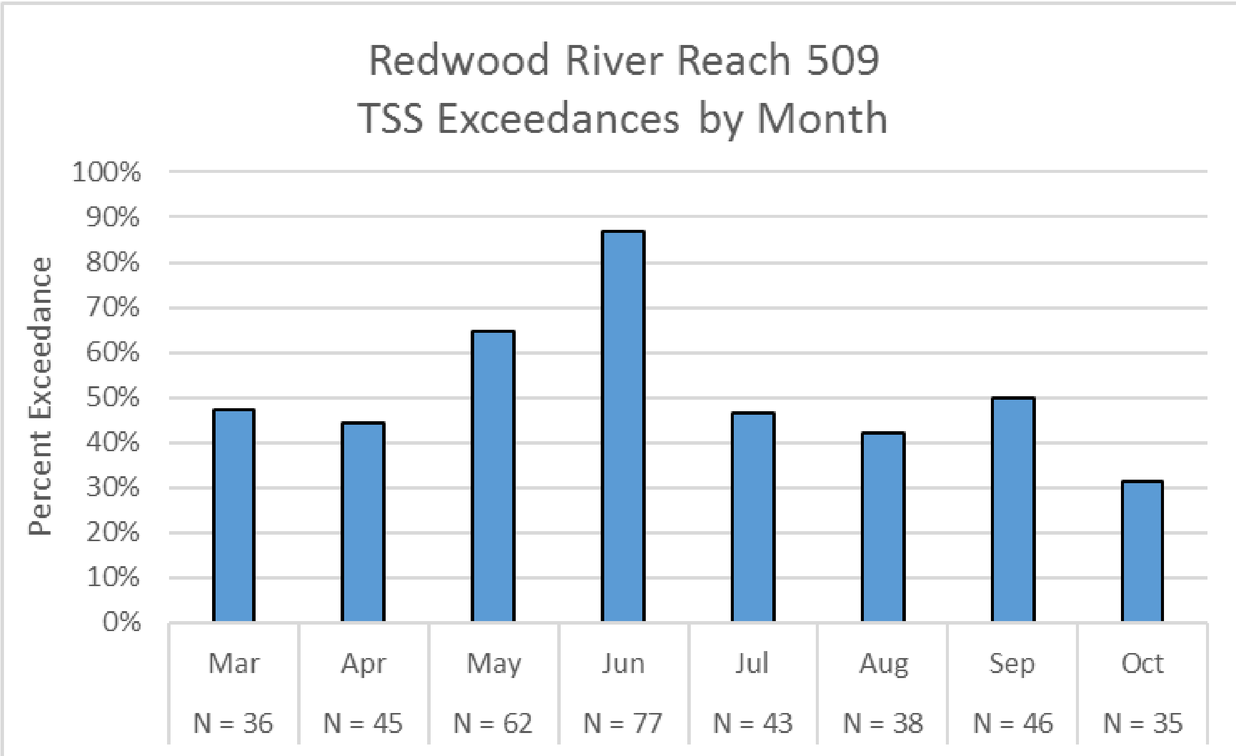


Figure A-7. Redwood River Reach 509 TSS Exceedances by Month.

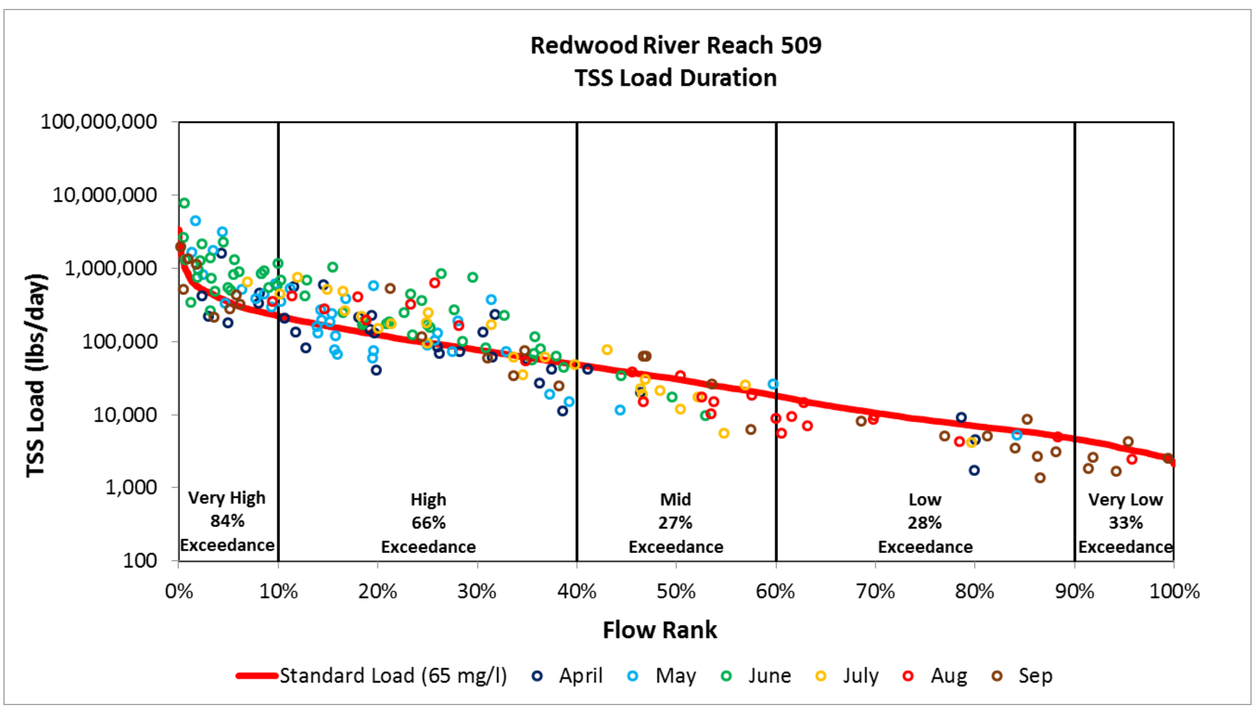


Figure A-8. Redwood River Reach 509 TSS Load Duration Curve (by month).

Supporting Items for Redwood River TSS and Bacteria Impaired Reach (07020006-510)

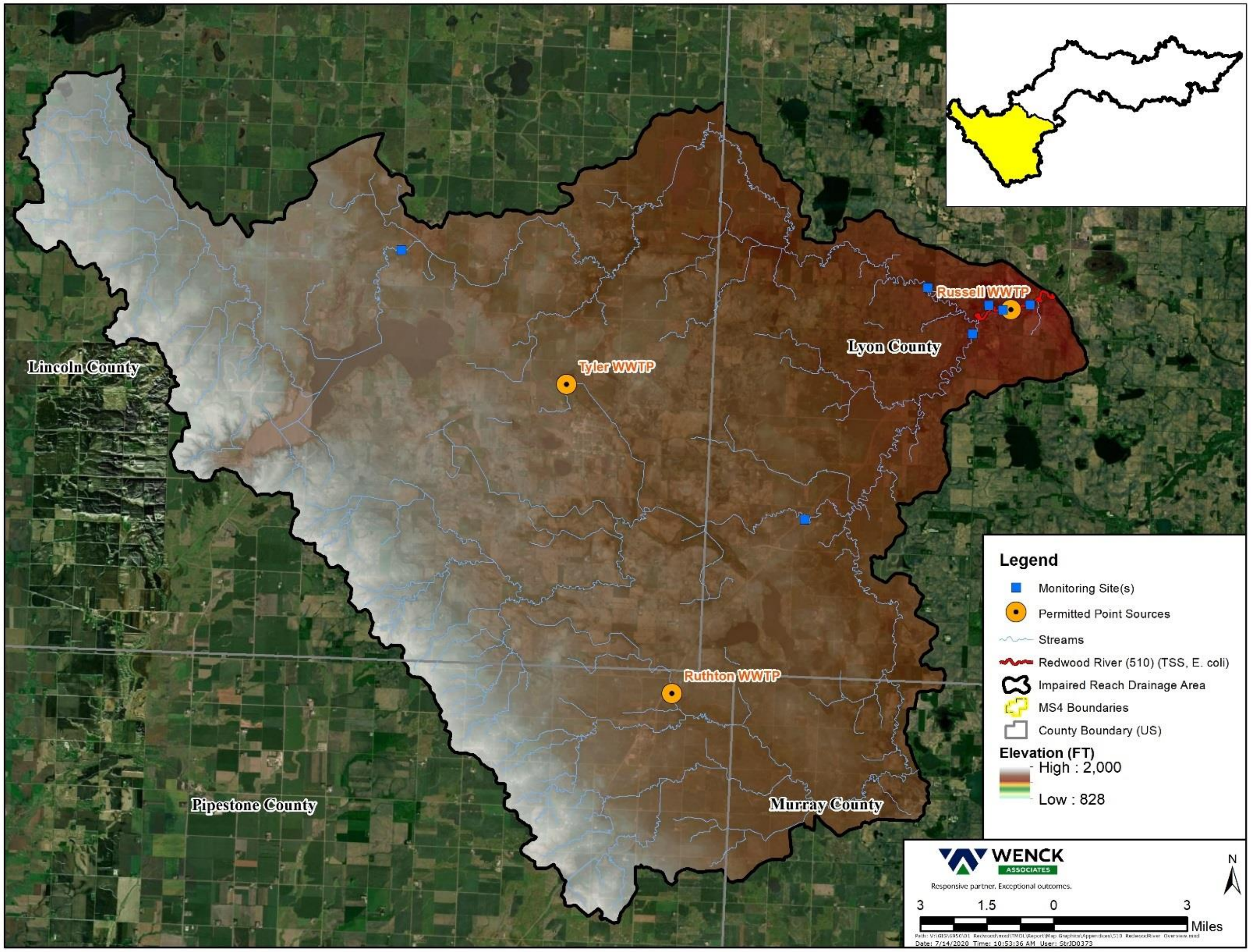


Figure A-9. Redwood River Reach 510 Overview.

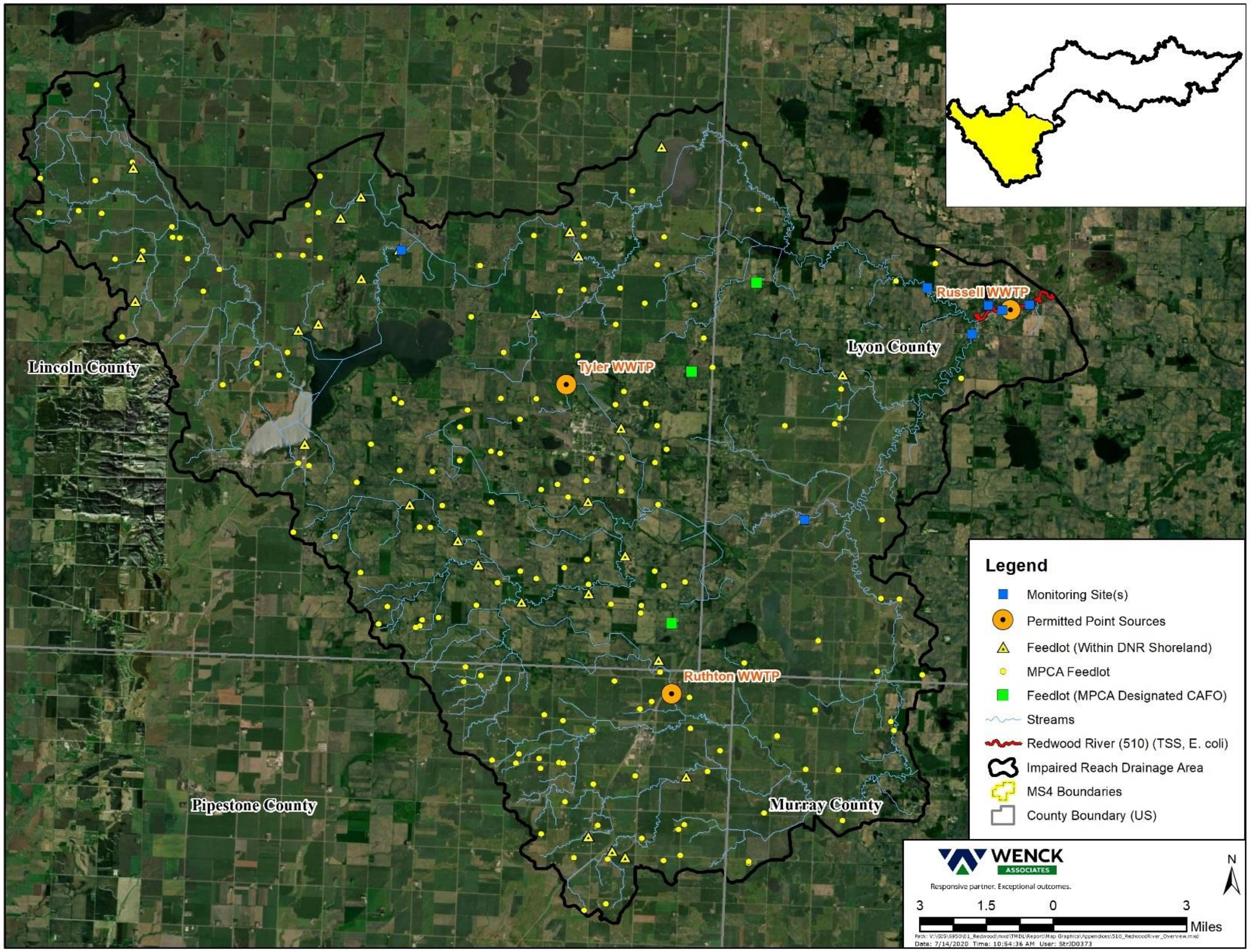


Figure A-10. Redwood River Reach 510 Feedlots.

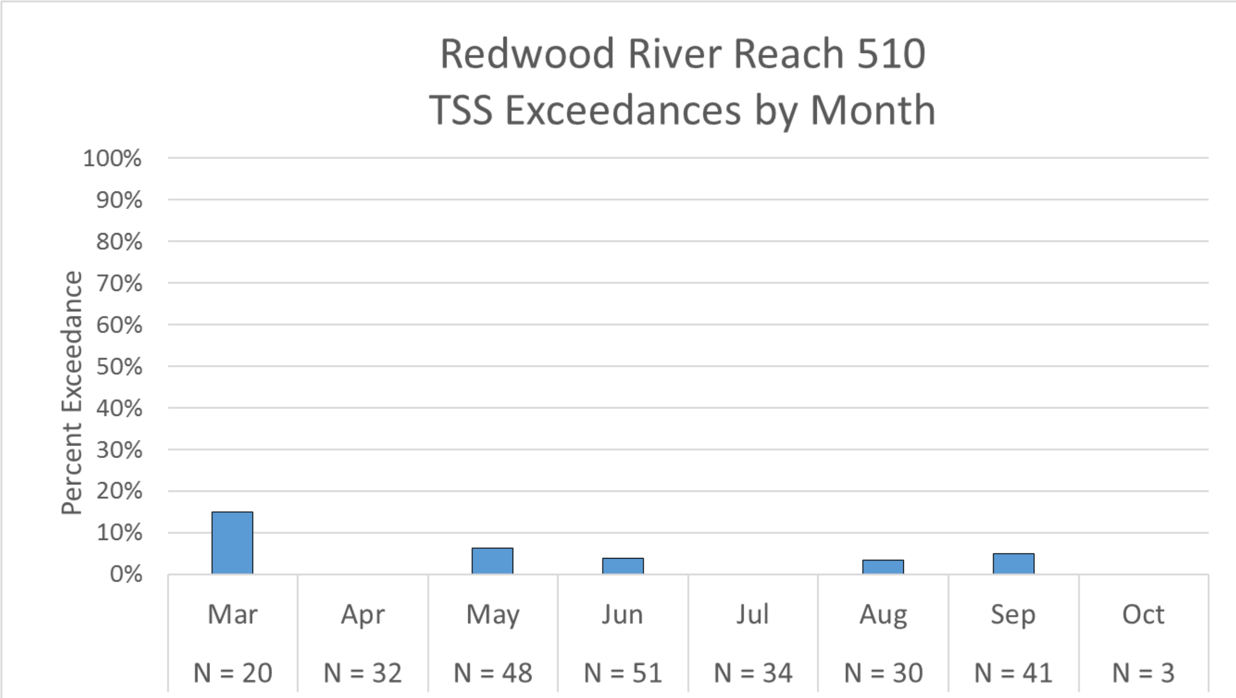


Figure A-11. Redwood River Reach 510 TSS Exceedances by Month.

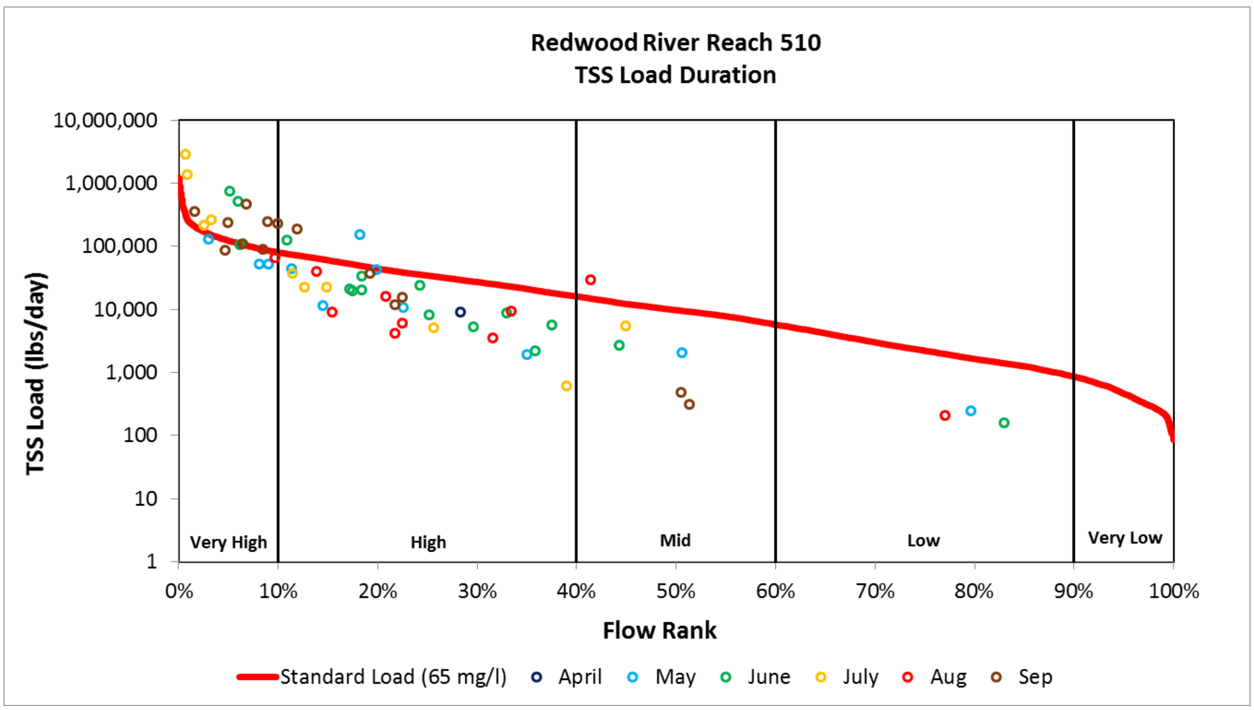


Figure A-12. Redwood River Reach 510 TSS Load Duration Curve (by month).

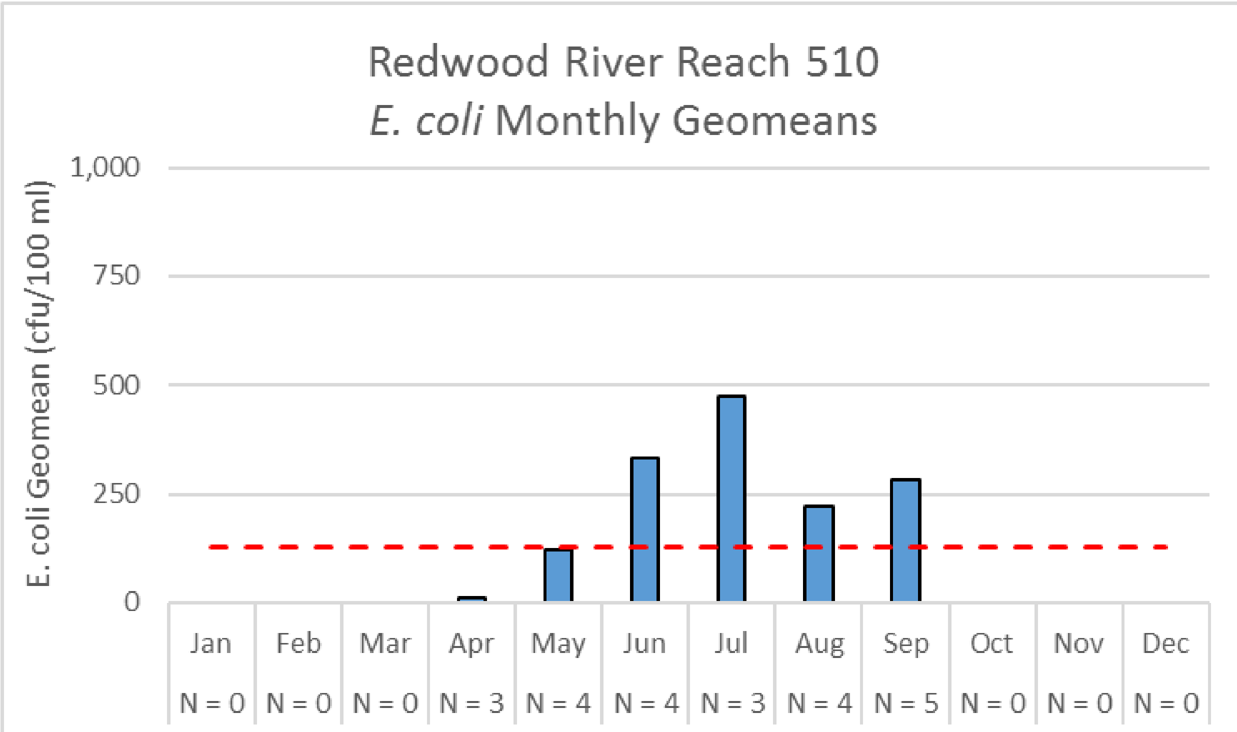


Figure A-13. Redwood River Reach 510 *E. coli* Monthly Geomeans.

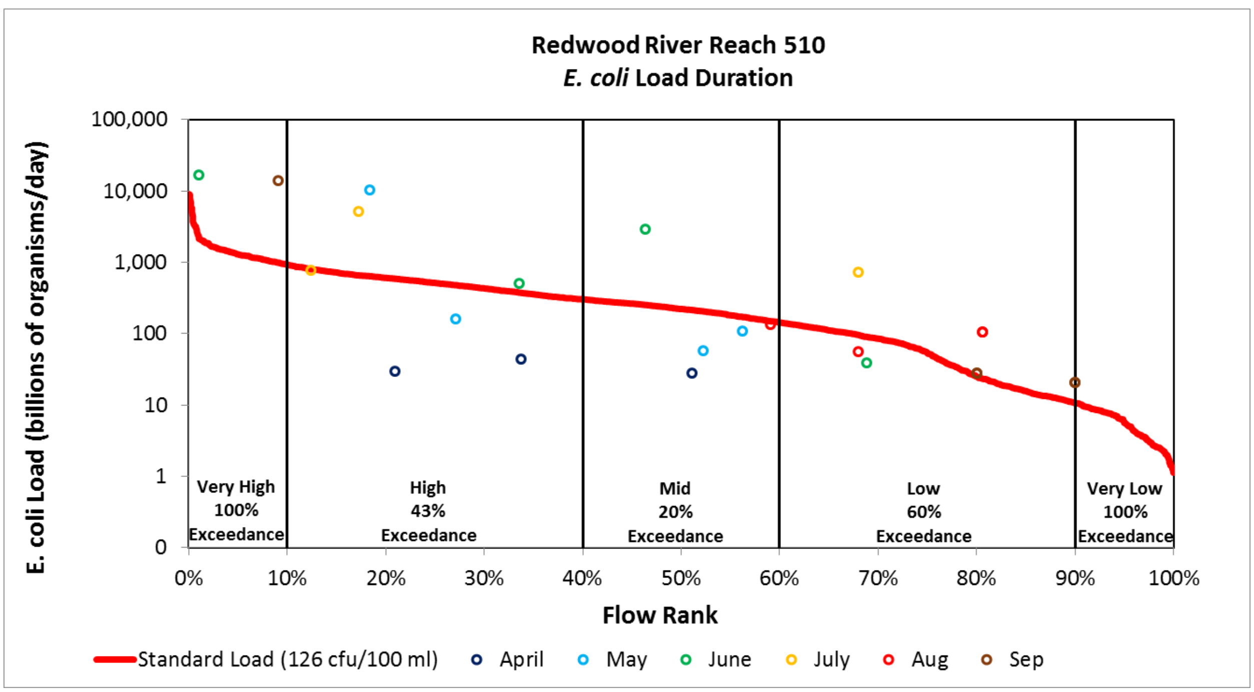


Figure A-14. Redwood River Reach 510 E. coli Load Duration Curve (by month).

Table A-1. Redwood River Reach 510 Bacteria Production Exercise.

Major Category	Source	Animal Units* or Individuals in Subwatershed	Bacteria Organisms Produced Per Unit Per Day	Total Bacteria Produced Per Day	Total Bacteria Produced Per Day by Major Category	Percent by Category
			[Billions of Org.] [8]	[Billions of Org.]	[Billions of Org.]	
Livestock (Surface Applied Manure) [1]	Horse*	138	58.2	8,032	641,813	99.51%
	Pig*	6,081	32.7	198,855		
	Cattle*	7,394	58.2	430,331		
	Chicken/Turkey*	2	20.5	34		
	Other Cattle*,[9]	139.5	32.7	4,562		
Wildlife	Deer [3]	1,160	0.5	580	1,508	0.23%
	Waterfowl [4]	2,320	0.4	928		
Human	Failing Septic Systems [5]	872	0.6	561	563	0.09%
	WWTP effluent [6]	3	0.6	2		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	1,142	0.9	1,068	1,068	0.17%

* 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 Ramsey Creek Bacteria Impaired Reach (07020006-521)

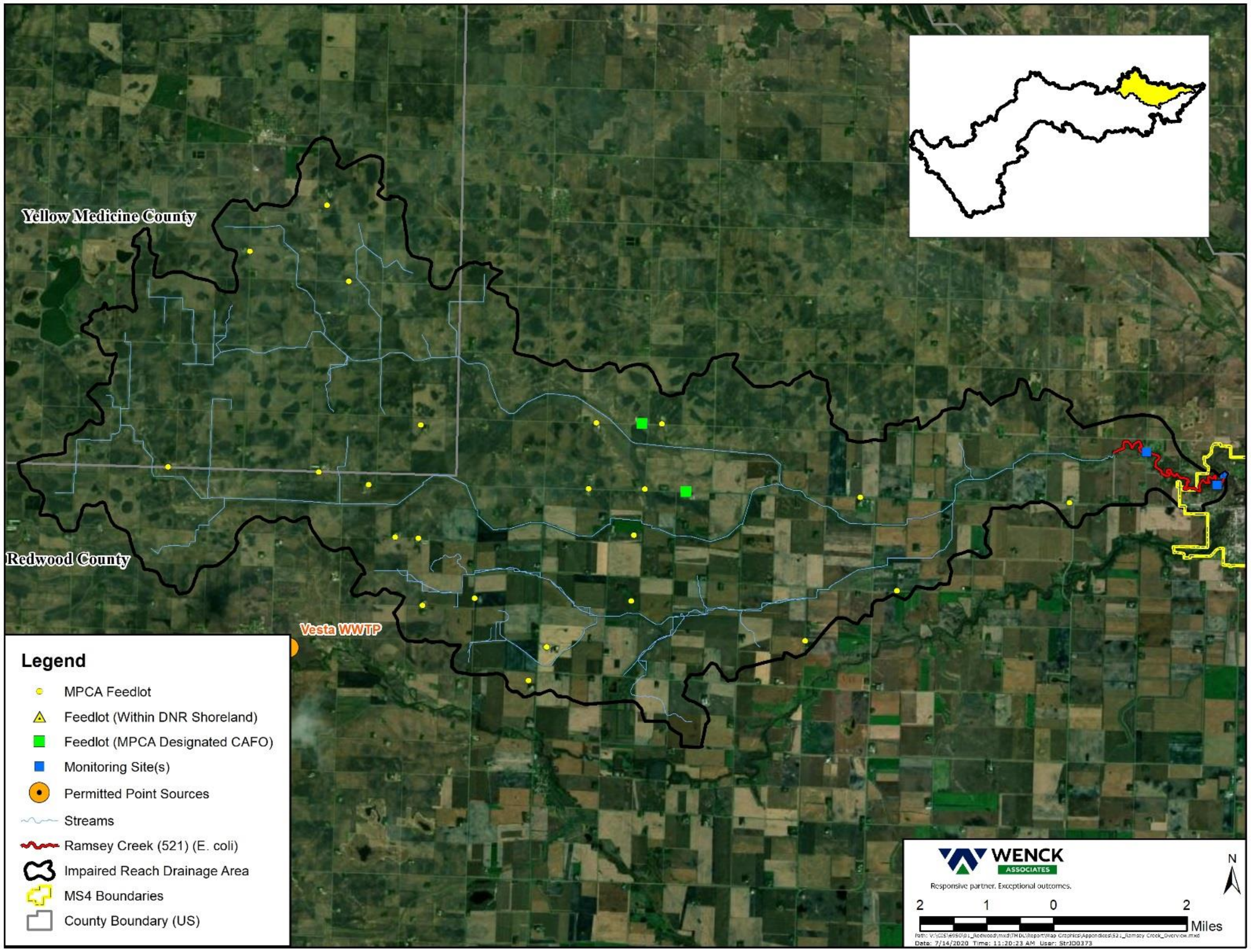


Figure A-15. Ramsey Creek Bacteria Impaired Reach 521 Overview.

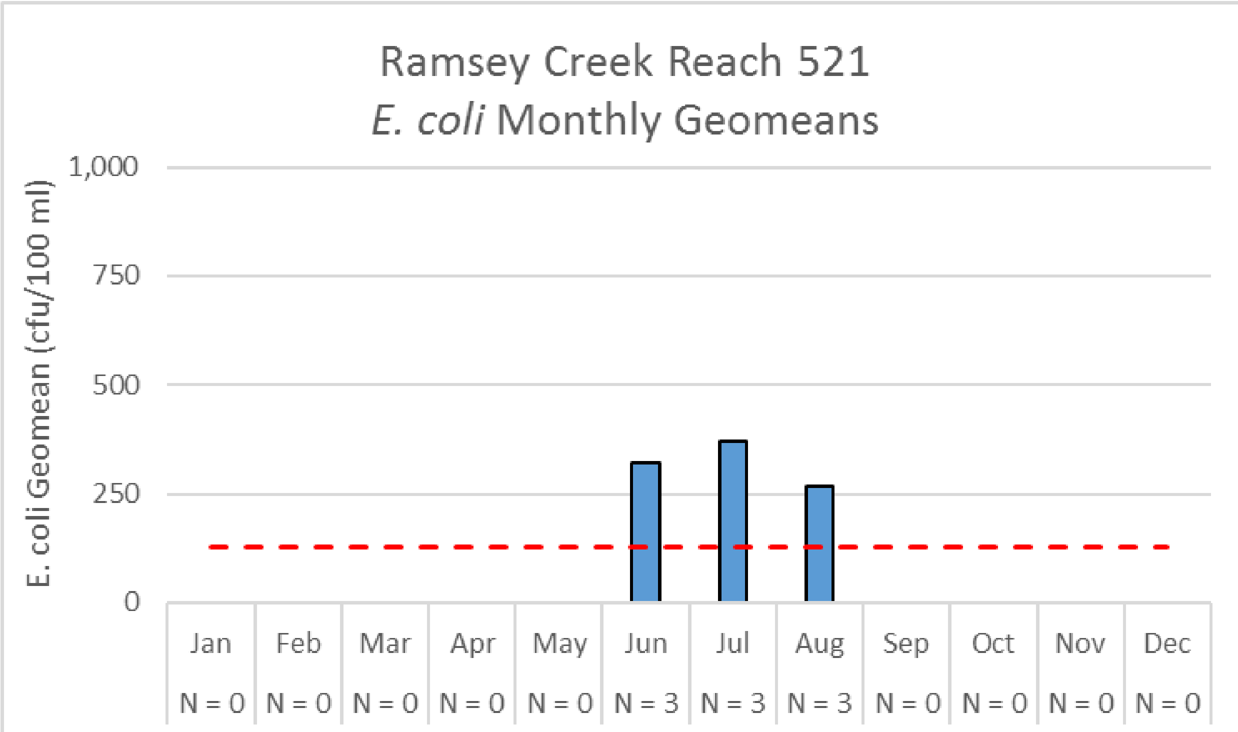


Figure A-16. Ramsey Creek Reach 521 *E. coli* Monthly Geomeans.

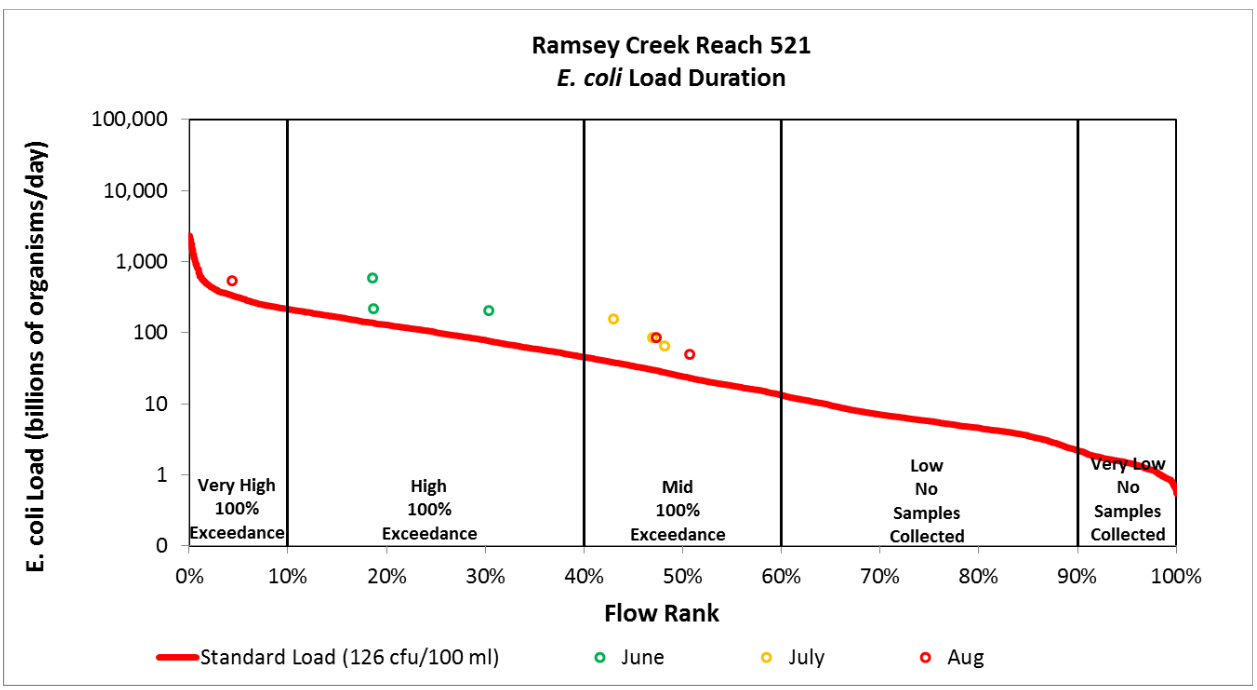


Figure A-17. Ramsey Creek Reach 521 E. coli Load Duration Curve (by month).

Table A-2. Ramsey Creek Reach 521 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*	18	58.2	1,048	356,021	99.69%
	Swine*	6,400	32.7	209,290		
	Bovine*	2,358	58.2	137,236		
	Poultry*	410	20.5	8,412		
	Other Livestock*,[9]	1	32.7	36		
Wildlife	Deer [3]	333	0.5	167	566	0.16%
	Waterfowl [4]	999	0.4	400		
Human	Failing Septic Systems [5]	13	5.7	76	76	0.02%
	WWTP effluent [6]	-	-	-		
Domestic Animals [2]	Improperly Managed Pet Waste [7]	799	0.6	449	449	0.13%

* 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 Three Mile Creek TSS Impaired Reach (07020006-564, 565, 566)

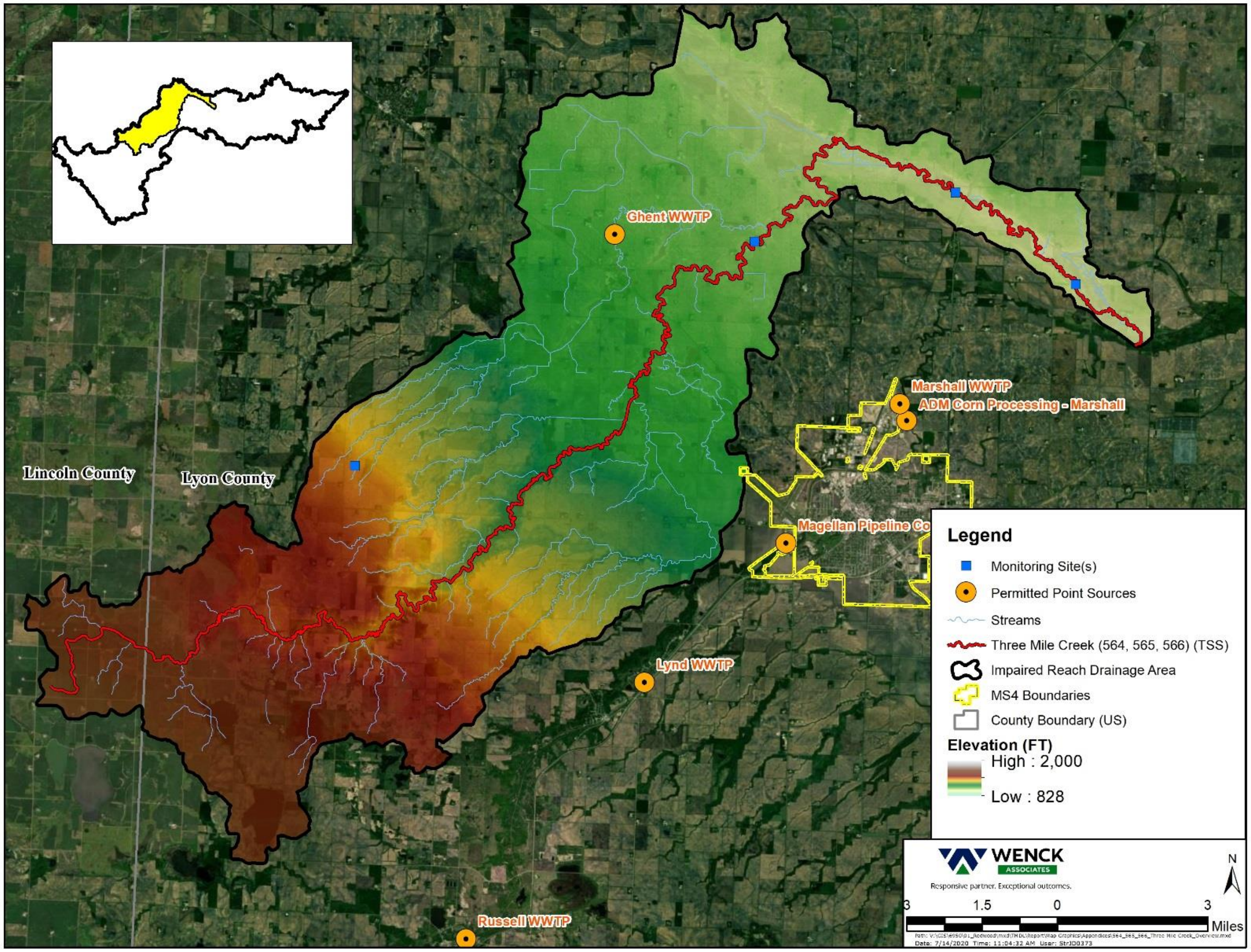


Figure A-18. Redwood River Reach 564, 565, and 566 Overview.

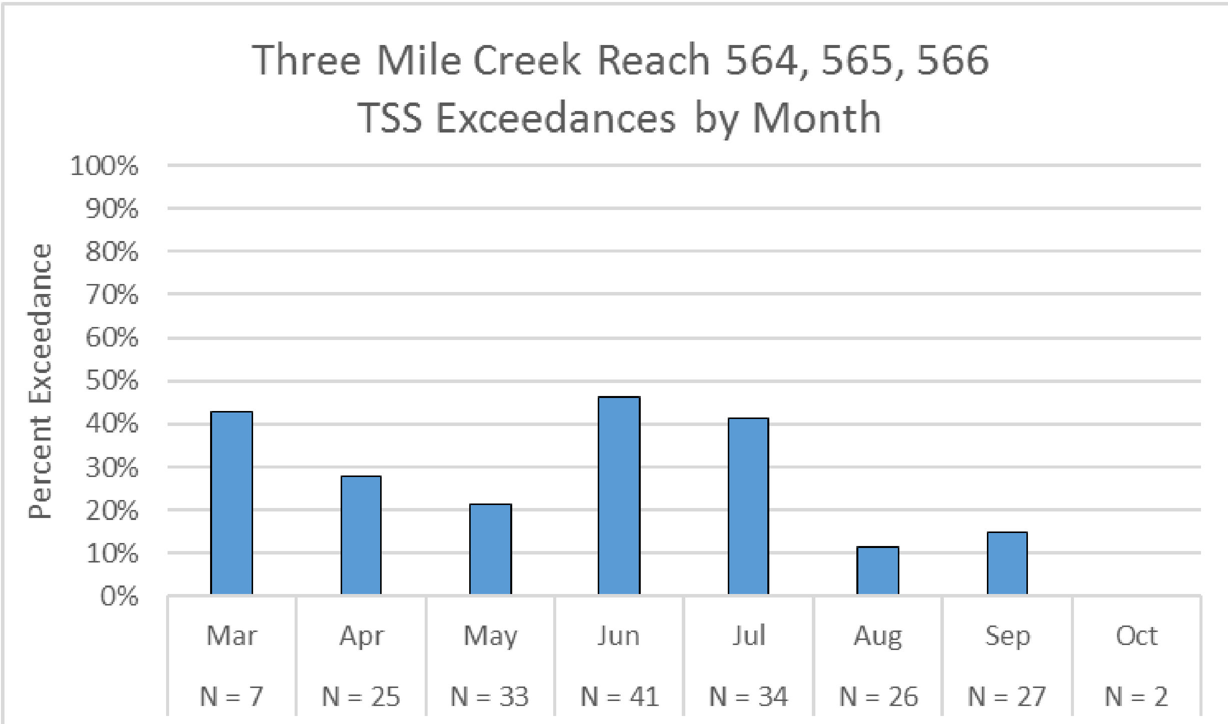


Figure A-19. Three Mile Creek Reach 564, 565, and 566 TSS Exceedances by Month.

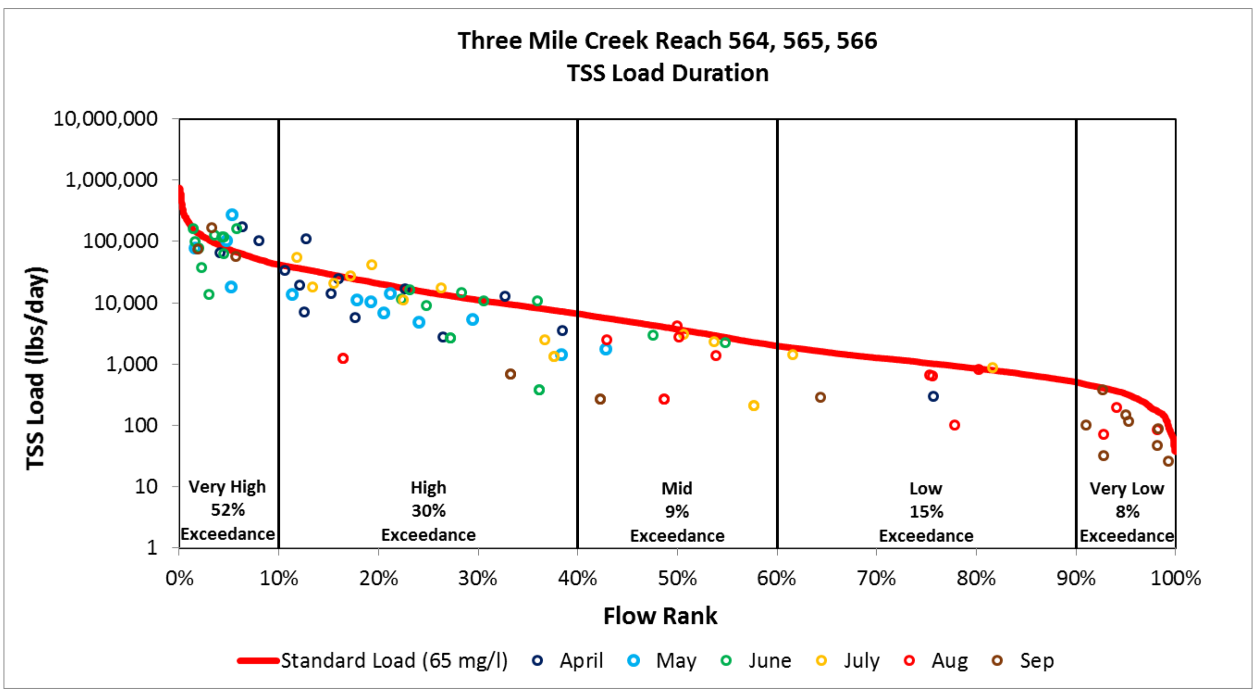


Figure A-20. Three Mile Creek Reach 564, 565, and 566 TSS Load Duration Curve (by month).

Supporting Items for Clear Creek TSS Impaired Reach (07020006-567, 568)

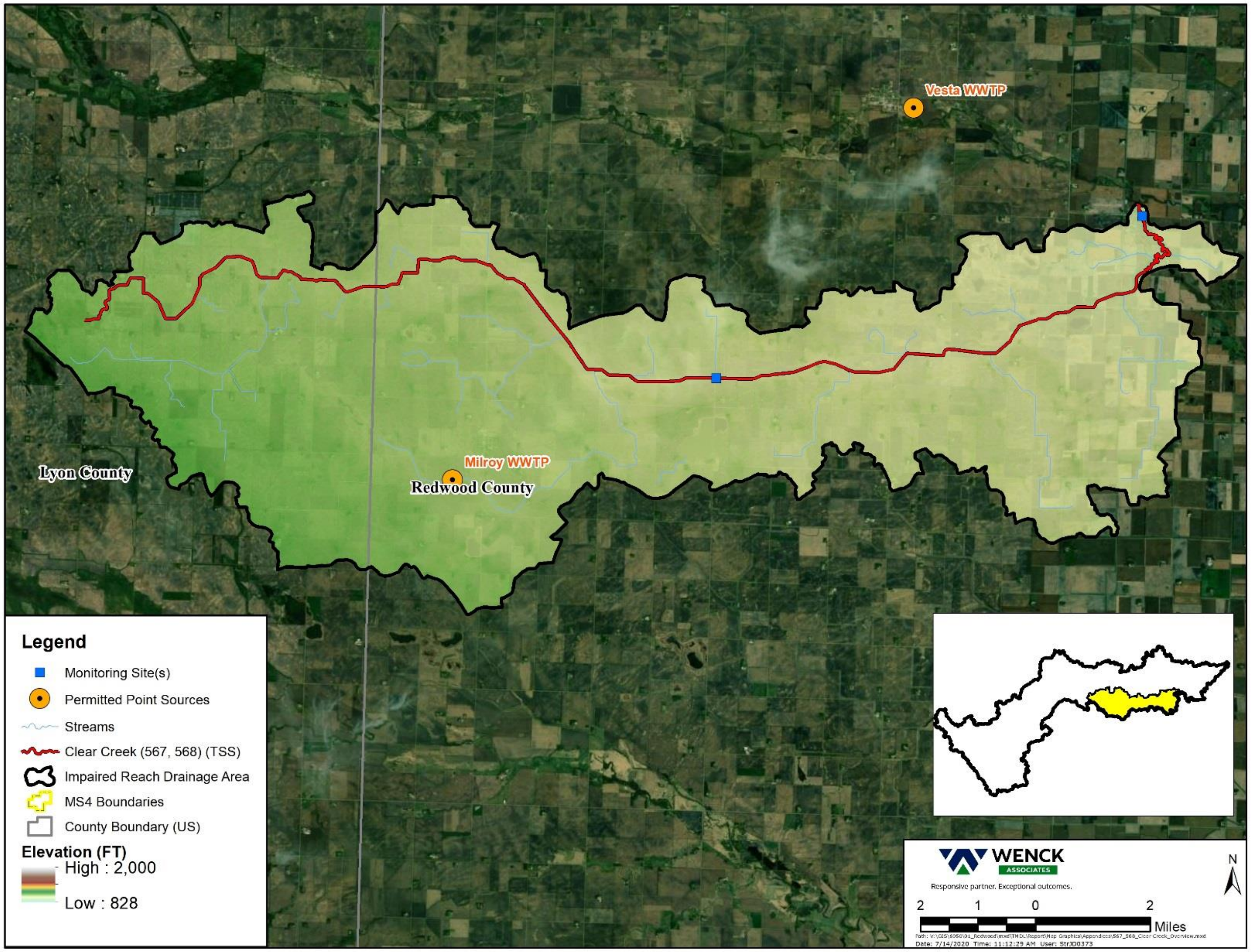


Figure A-21. Clear Creek Reach 567 and 568 Overview.

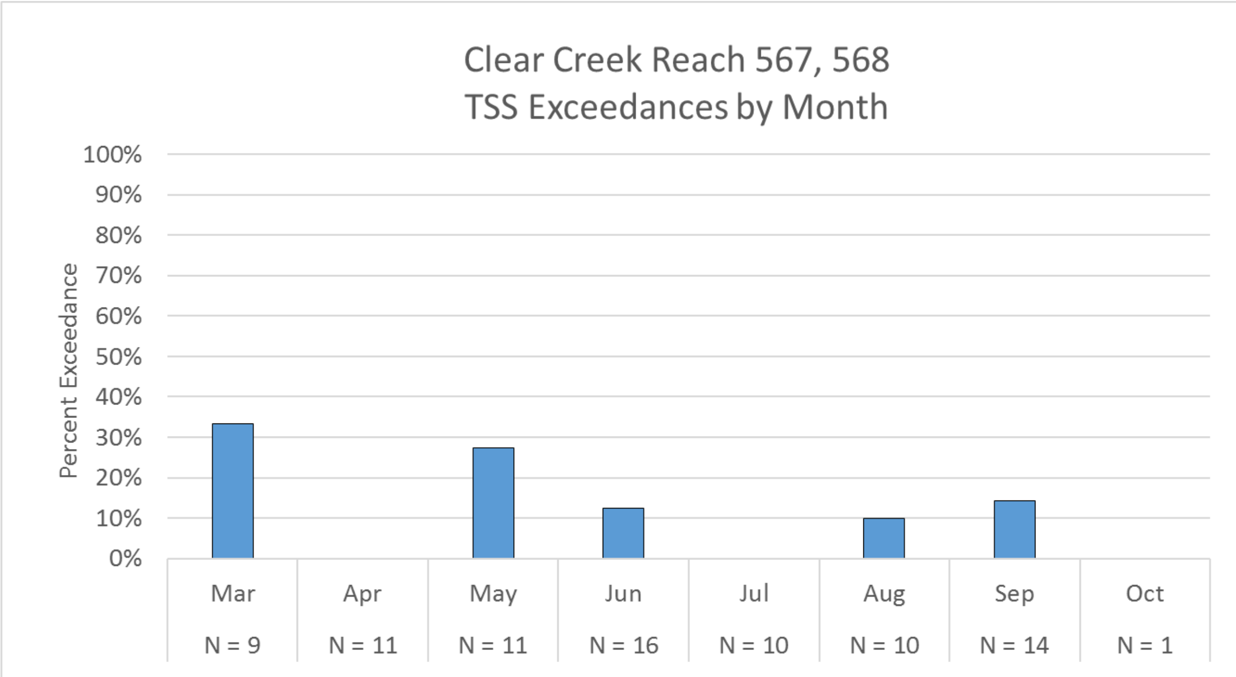


Figure A-22. Clear Creek Reach 567 and 568 TSS Exceedances by Month.

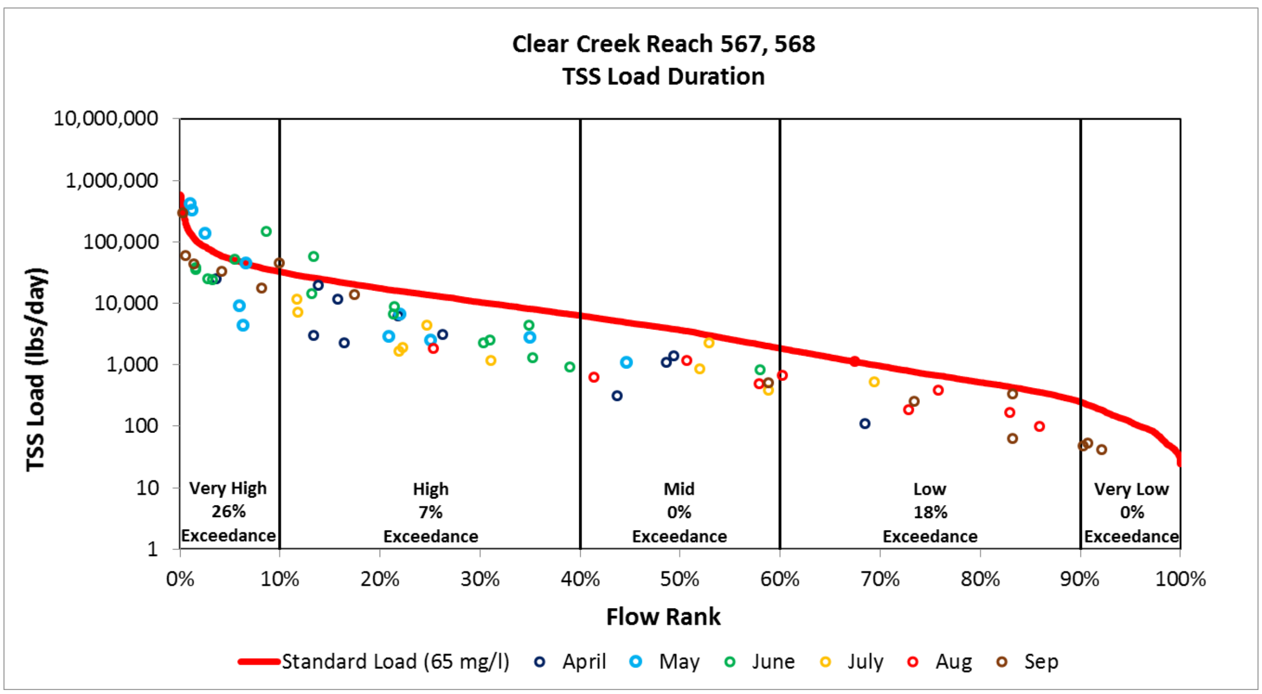


Figure A-23. Clear Creek Reach 567 and 568 TSS Load Duration Curve (by month).

Appendix B – WWTF DMR Data Summary

Table B-1. WWTF Effluent TSS Summary (2008-2017).

Facility	Number of Samples	TSS (ave; mg/L)	TSS (min; mg/L)	TSS (max; mg/L)	Samples exceeding 65mg/L	Facility Monthly Limit	Samples exceeding facility monthy limit
Ghent WWTP	18	14	3	60	0	45	1
Lynd WWTP	35	22	3	54	0	45	3
Milroy WWTP	30	39	12	81	3	45	9
Russell WWTP	27	25	3	63	0	45	3
Ruthton WWTP	50	16	2	42	0	45	0
Tyler WWTP	42	21	2	67	1	45	5
Vesta WWTP	30	15	2	53	0	45	1

Note: Samples refer to single monthly reported value

Table B-2. WWTF Effluent Fecal Coliform Summary (2000-2017).

Facility	count	min	max	Geomean (#/100ml)	samples >200/ml	% >200/ml
Russell WWTP	95	1	63	14	0	0%
Ruthton WWTP	161	1	361	11	1	1%
Tyler WWTP	102	2	588	21	4	4%

Appendix C - Lake Impairment Supporting Items

Supporting Items for Benton Lake (41004300)

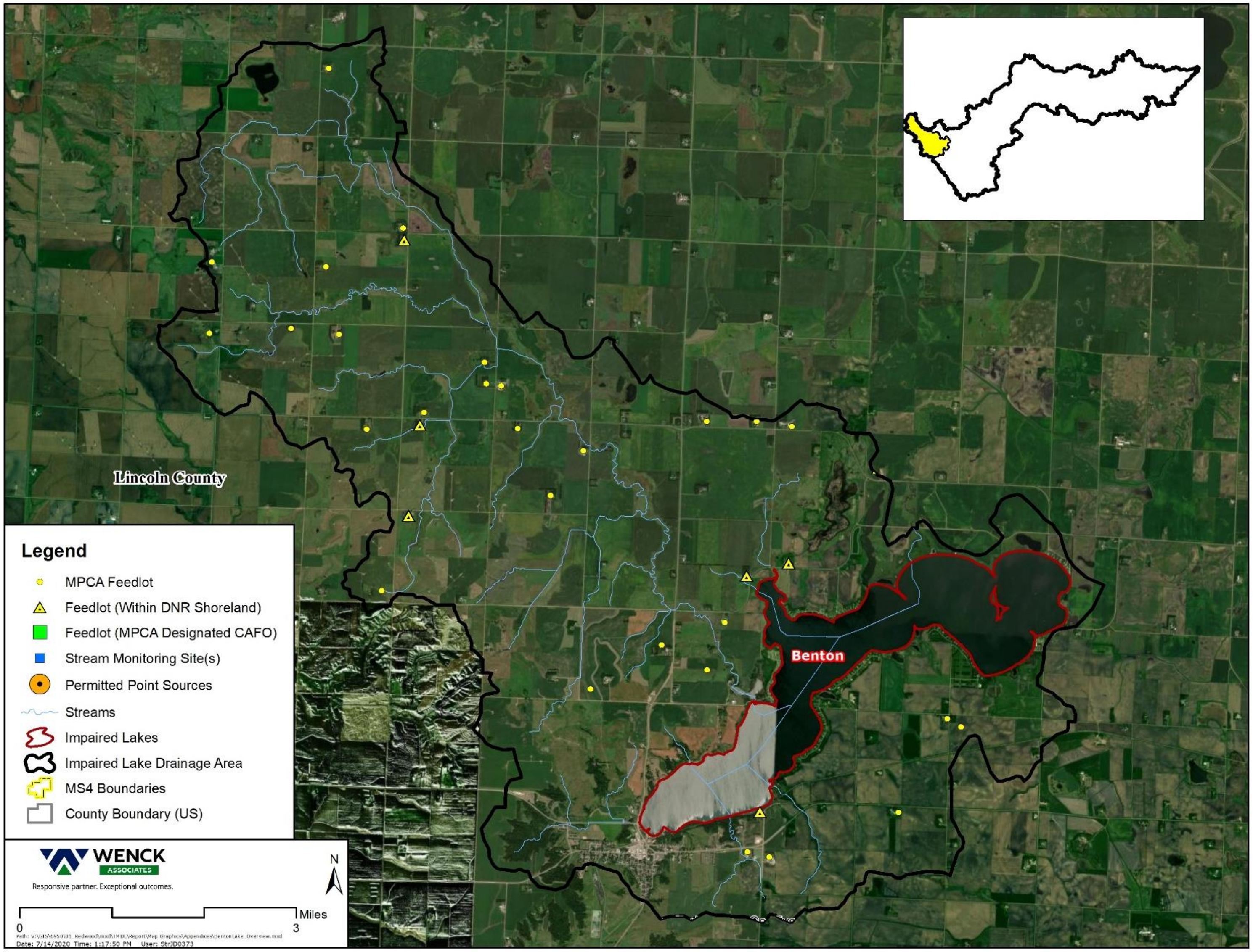


Figure C-1. Benton Overview.

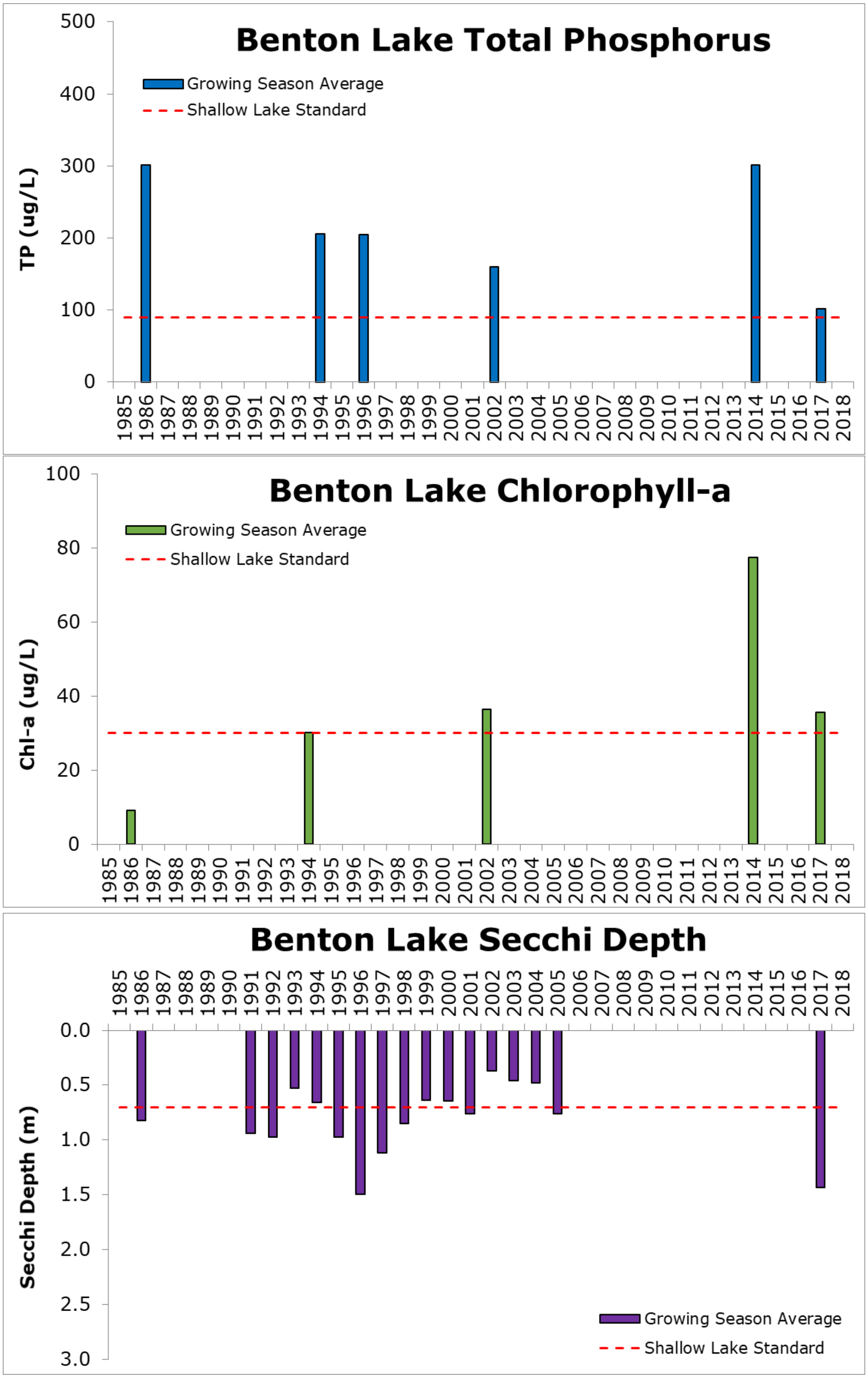


Figure C-2. Benton Lake Historic Water Quality.

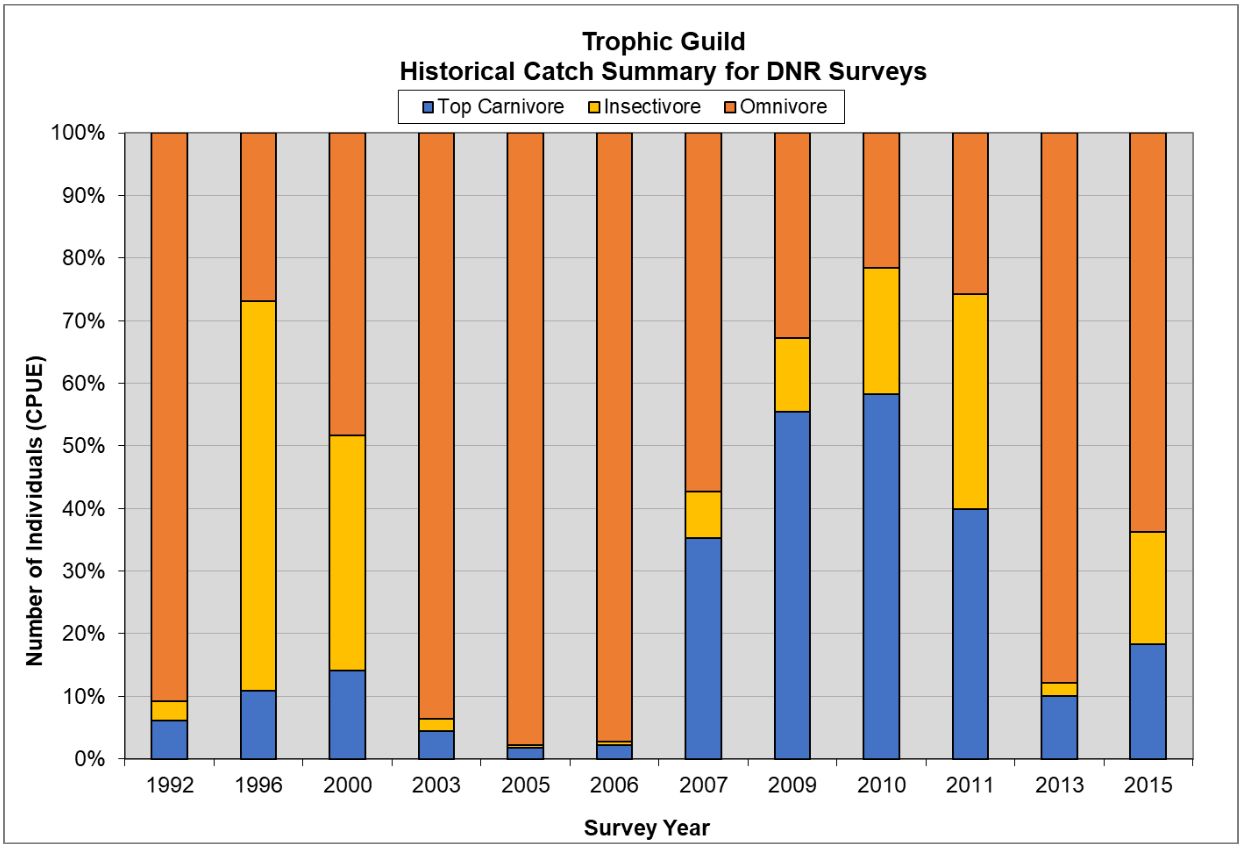


Figure C-3. Benton Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).

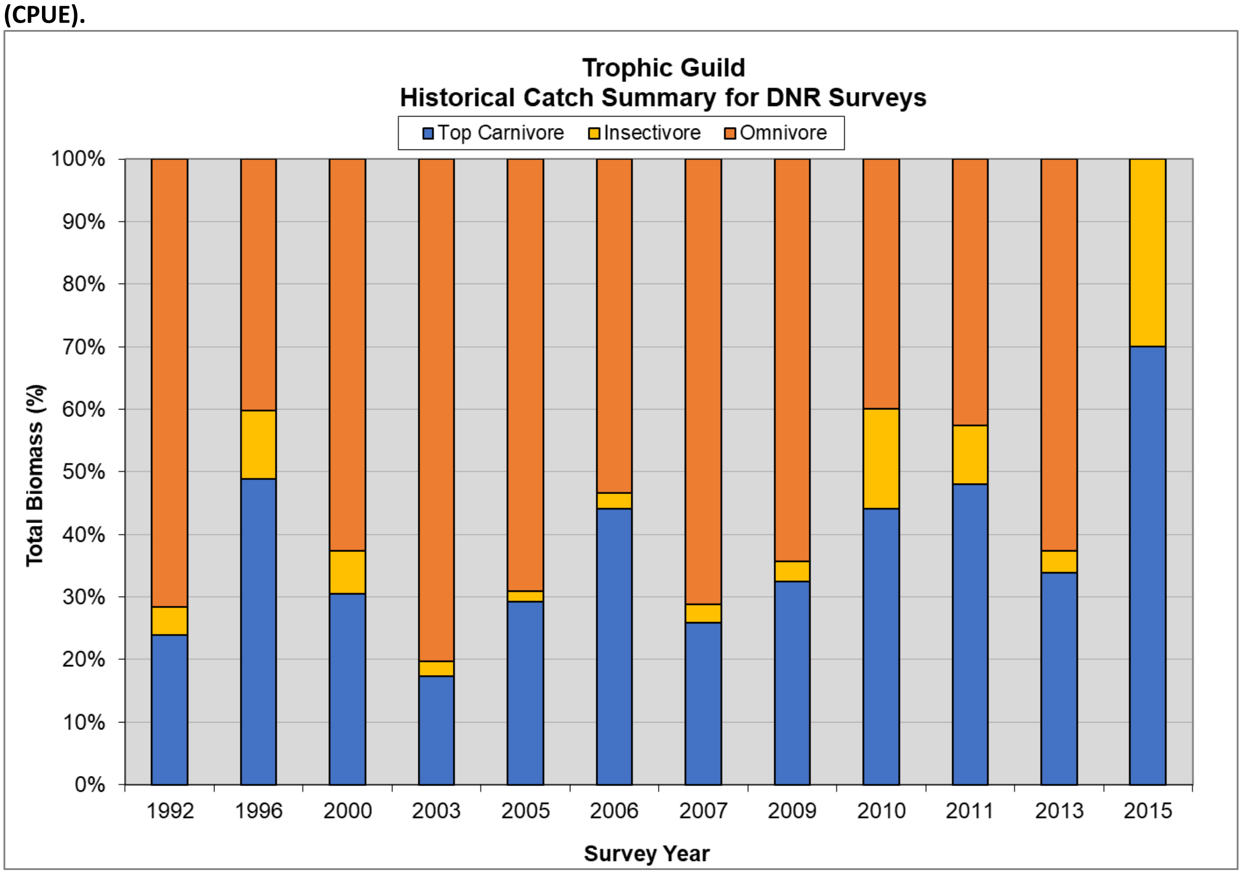


Figure C-4. Benton Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-1. Benton Lake Current Condition Lake Response Model.

	Average Loading Summary for	*Benton*					
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct Watershed (HSPF 162)	10,549	4.9	4,299	281	1.0	3,282
2	Norwegian Creek (HSPF 161)	14,783	5.1	6,276	155	1.0	2,640
3	0			0	0		0
4	0			0	0		0
5	0			0	0		0
6	0			0	0		0
	Summation	*25,332*	*10*	*10,574.99*			*5,921.7*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	0	322	153	0	48%		407
2	0	0	0	0	#DIV/0!		0
3	0	0	0	0	#DIV/0!		0
4	0	0	0	0	#DIV/0!		0
5	0	0	0	0	#DIV/0!		0
	Summation	*322*	*153*	*0.0*	48%		*407*
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]
	2649	27.2	27.2	0.00	0.24	1.0	633
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	10,270
	Summation						*10,270*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	10.72	0		Oxic		1.0	0
	10.72	7.8		Anoxic	9.1	1.0	1,672
	Summation						*1,672*
		Net Discharge [ac-ft/yr] =		**10,575**	**Net Load [lb/yr] =**		**18,904**

Average Lake Response Modeling for		***Benton***		
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.) =	8,575	[kg/yr]
		Q (lake outflow) =	13.0	[10^6 m^3/yr]
		V (modeled lake volume) =	20.9	[10^6 m^3]
		T = V/Q =	1.60	[yr]
		P_i = W/Q =	657	[µg/l]
Model Predicted In-Lake [TP]			**129.2**	**[ug/l]**
Observed In-Lake [TP]			**129.2**	**[ug/l]**

Table C-2. Benton Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for Benton						
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct Watershed (HSPF 162)	10,549	4.9	4,299	150	0.5	1,754
2	Norwegian Creek (HSPF 161)	14,783	5.1	6,276	150	1.0	2,561
3	0			0	0		0
4	0			0	0		0
5	0			0	0		0
6	0			0	0		0
	Summation	*25,332*	*10*	*10,574.99*			*4,315*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	0	322	0	9	0%		184
2							
3							
4							
5							
	Summation	*322*	*0*	*15.1*	0%		*184*
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]
	2649	27.2	27.2	0.00	0.24	1.0	633
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					0.4	3,963
	Summation						*3,963*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	10.72	0		Oxic		1.0	0
	10.72	7.8		Anoxic	9.1	1.0	1,672
	Summation						*1,672*
			Net Discharge [ac-ft/yr] =	**10,590**		**Net Load [lb/yr] =**	**10,769**

TMDL Lake Response Modeling for Benton			
Modeled Parameter	**Equation**	**Parameters**	**Value [Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION			
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$	as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00 [--]
		C_{CB} =	0.162 [--]
		b =	0.458 [--]
		W (total P load = inflow + atm.) =	4,885 [kg/yr]
		Q (lake outflow) =	13.1 [10^6 m^3/yr]
		V (modeled lake volume) =	20.9 [10^6 m^3]
		T = V/Q =	1.60 [yr]
		P_i = W/Q =	374 [µg/l]
Model Predicted In-Lake [TP]			**90.0 [ug/l]**
Observed In-Lake [TP]			**90.0 [ug/l]**

Supporting Items for Dead Coon Lake (41002101)

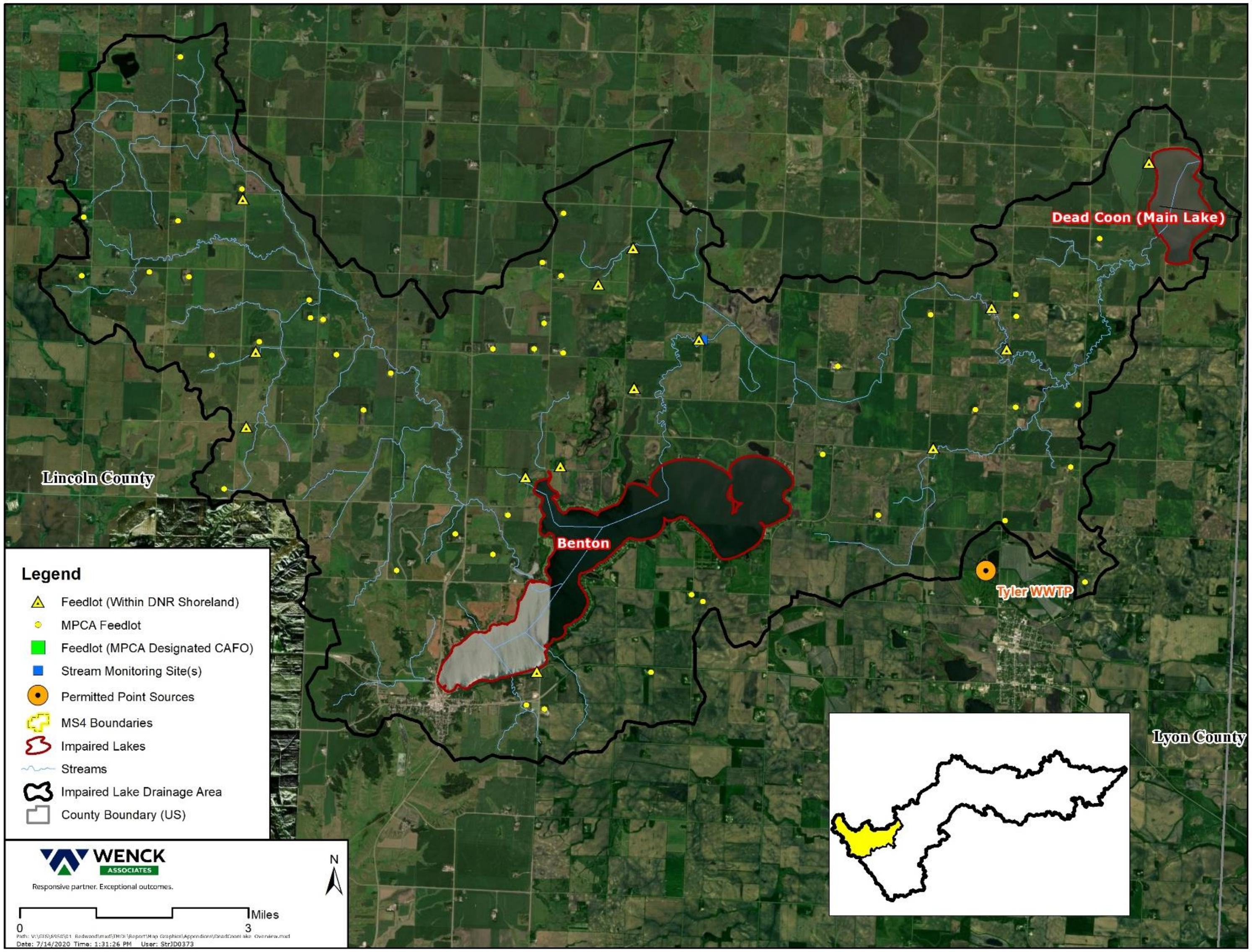


Figure C-5. Dead Coon Lake Overview.

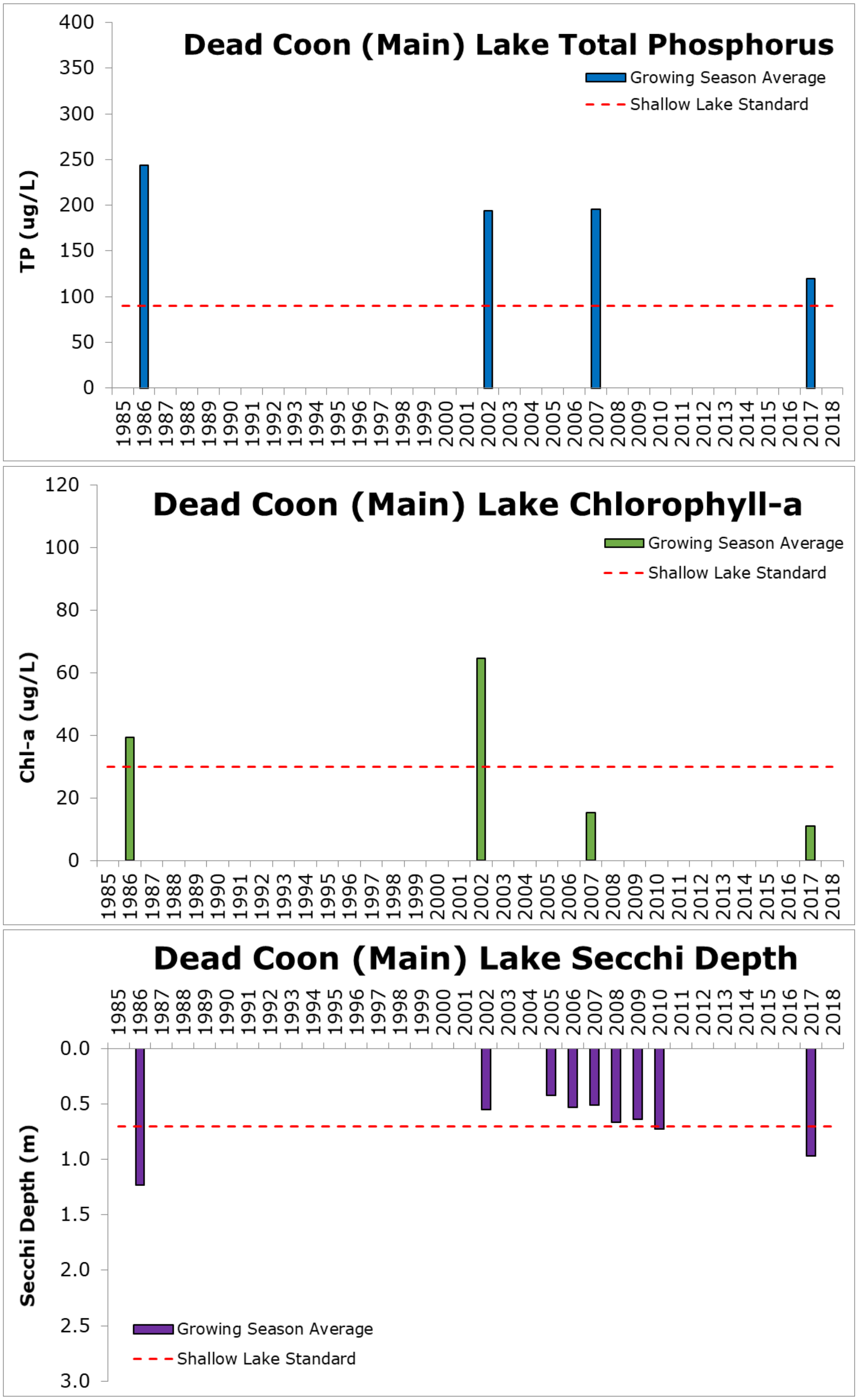


Figure C-6. Dead Coon Lake Historic Water Quality.

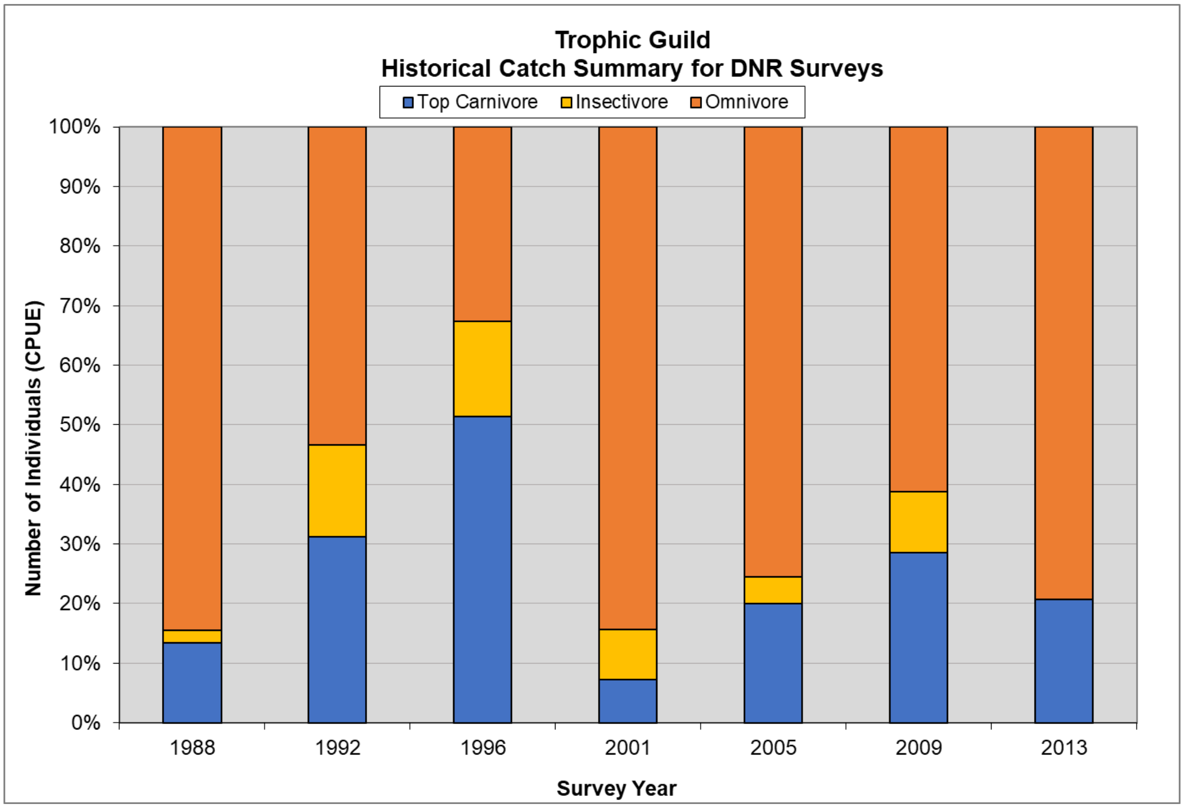


Figure C-7. Dead Coon Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).

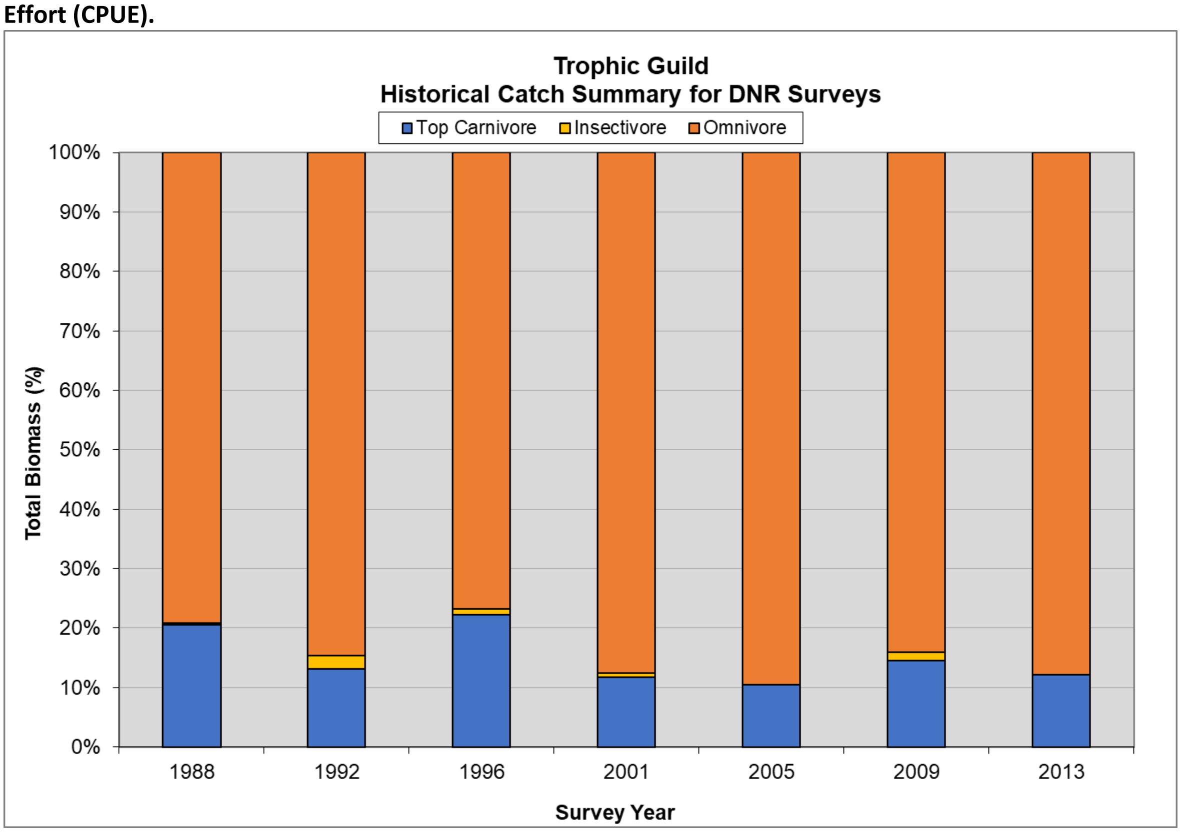


Figure C-8. Dead Coon Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-3. Dead Coon Lake Current Condition Lake Response Model.

	Average Loading Summary for Dead Coon						
	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	Coon Creek (HSPF171) and Direct (172)	18,483	5.6	8,674	167	1.0	3,943
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	*18,483*	*6*	*8,674.05*			*3,943*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Benton			9,146	129.2	1.0	3,213
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			*9,145.6*	*129.2*		*3,213*
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]
	547	27.5	27.5	0.00	0.24	1.0	131
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	2.21	0		Oxic		1.0	0
	2.21	5.0		Anoxic		1.0	6,388
	Summation						*6,388*
		Net Discharge [ac-ft/yr] =		**17,825**	**Net Load [lb/yr] =**		**14,213**

Average Lake Response Modeling for Dead Coon				
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.) =	6,447	[kg/yr]
		Q (lake outflow) =	22.0	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	0.13	[yr]
		P_i = W/Q =	293	[µg/l]
Model Predicted In-Lake [TP]			**170.0**	**[ug/l]**
Observed In-Lake [TP]			**170.0**	**[ug/l]**

Table C-4. Dead Coon Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for	***Dead Coon***					
	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	Coon Creek (HSPF171) and Direct (172)	18,483	5.6	8,674	143	0.9	3,370
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	*18,483*	*6*	*8,674.05*			*3,370*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	0	407.0588235	0	0	0%		206
2	0	0	0	0	#DIV/0!		0
3	0	0	0	0	#DIV/0!		0
4	0	0	0	0	#DIV/0!		0
5	0	0	0	0	#DIV/0!		0
	Summation	*407*	*0*	*0.0*	0%		*206*
Inflow from Upstream Lakes							
				Discharge	Estimated P Concentration	Calibration Factor	Load
	Name			[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Benton			9,146	90.0	0.7	2,239
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			*9,145.6*	*90.0*		*2,239*
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]
	547	27.5	27.5	0.00	0.24	1.0	131
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	2.21	0		Oxic		1.0	0
	2.21	32.2		Anoxic		1.0	639
	Summation						*639*
		Net Discharge [ac-ft/yr] =		**17,820**	**Net Load [lb/yr] =**		**6,584**

TMDL Lake Response Modeling for		***Dead Coon***		
Modeled Parameter	**Equation**	**Parameters**	**Value**	**[Units]**
TOTAL IN-LAKE PHOSPHORUS CONCENTRATION				
$$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$		as f(W,Q,V) from Canfield & Bachmann (1981)		
		C_P =	1.00	[--]
		C_{CB} =	0.162	[--]
		b =	0.458	[--]
		W (total P load = inflow + atm.) =	2,987	[kg/yr]
		Q (lake outflow) =	22.0	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	0.13	[yr]
		P_i = W/Q =	136	[µg/l]
Model Predicted In-Lake [TP]			**90.0**	**[ug/l]**
Observed In-Lake [TP]			**170.0**	**[ug/l]**

Supporting Items for Goose Lake (42009300)

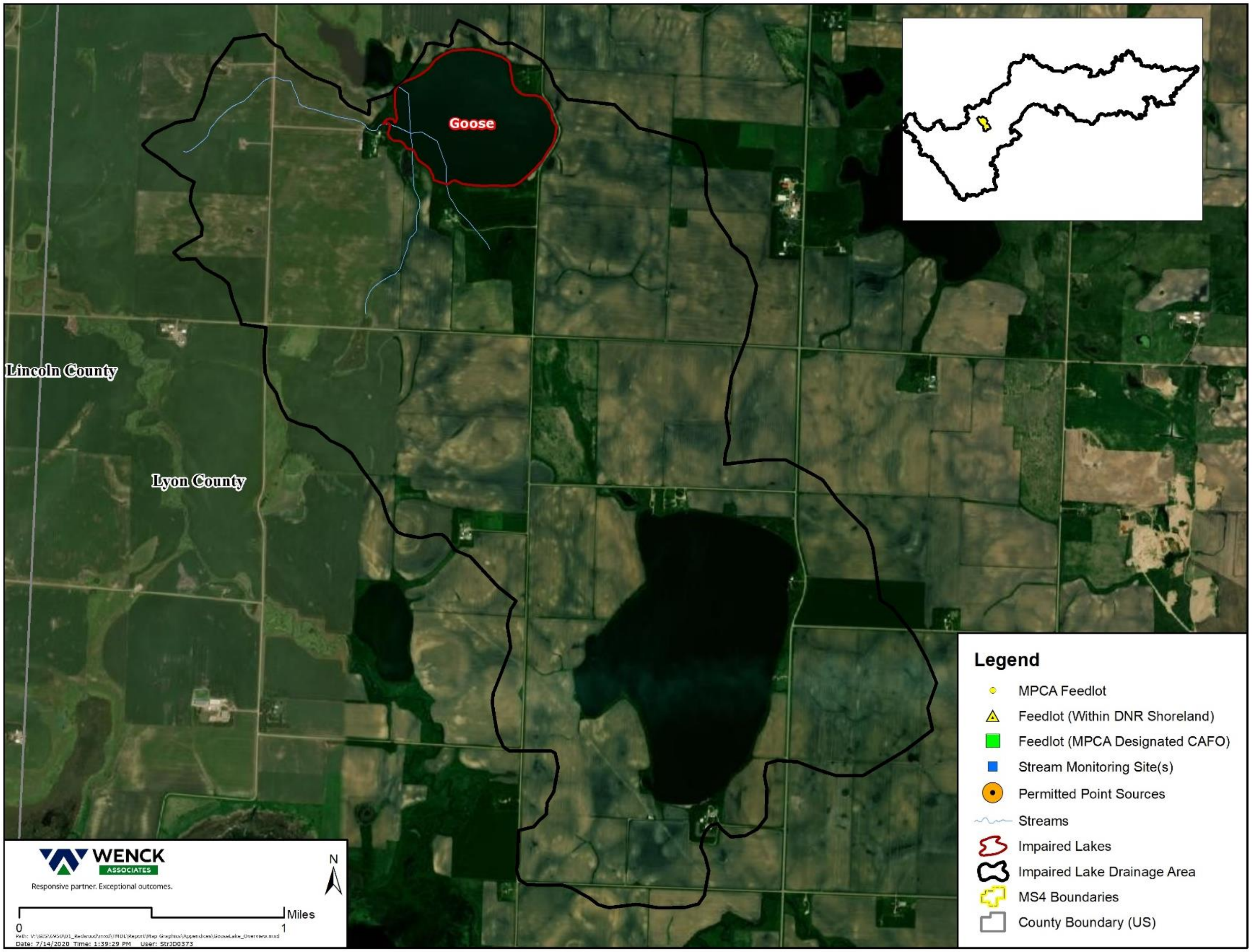


Figure C-9. Goose Lake Overview.

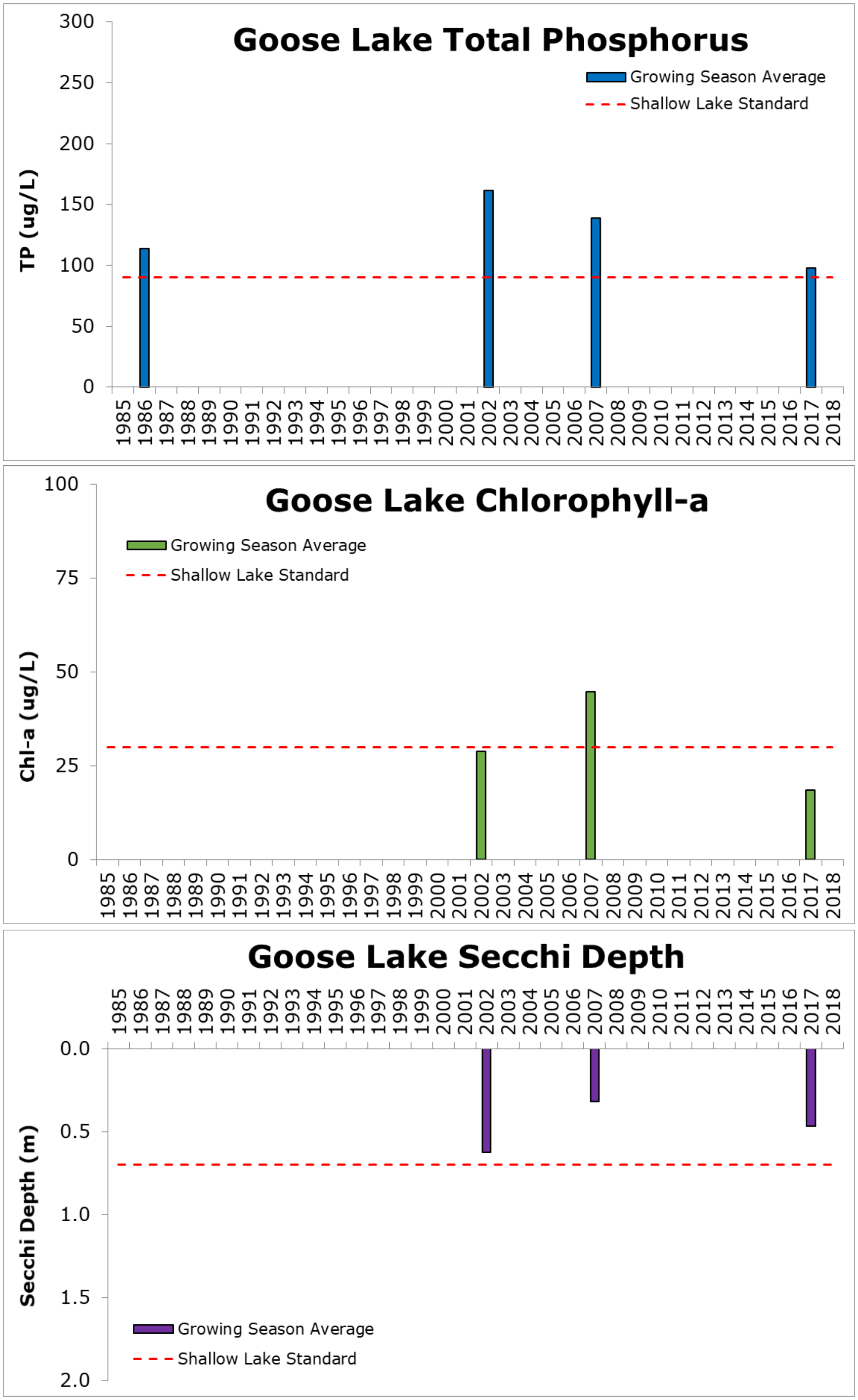


Figure C-10. Goose Lake Historic Water Quality.

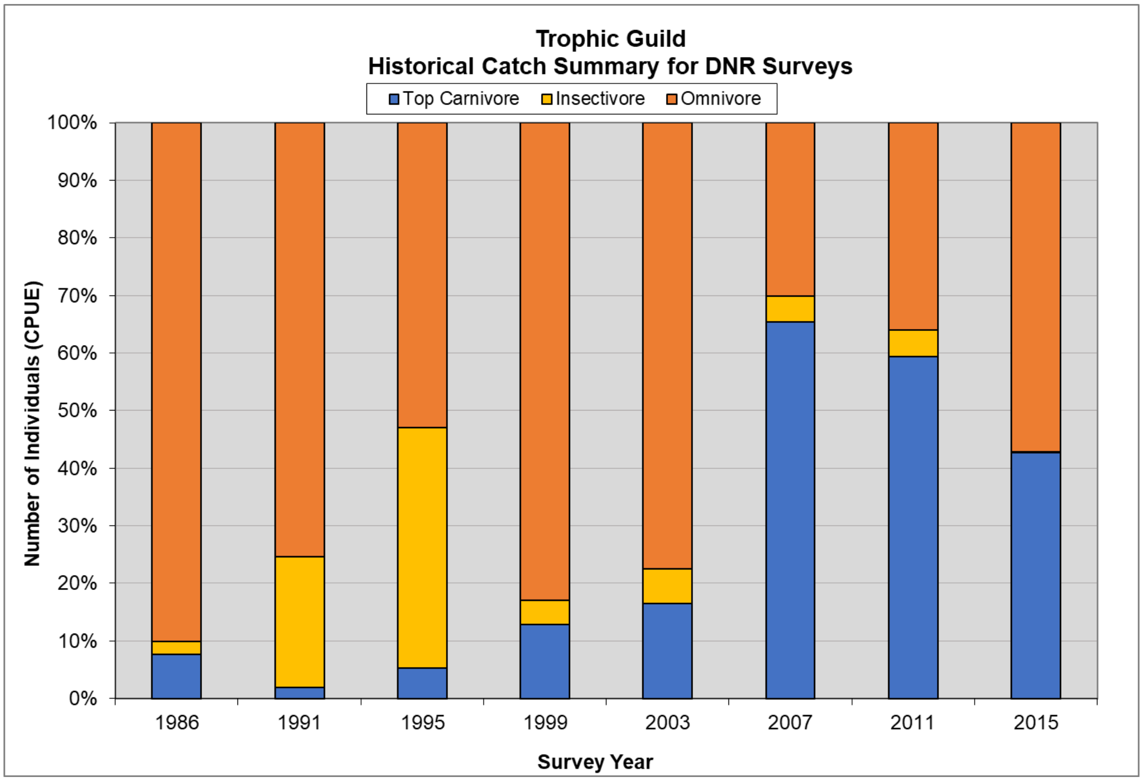


Figure C-11. Goose Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).

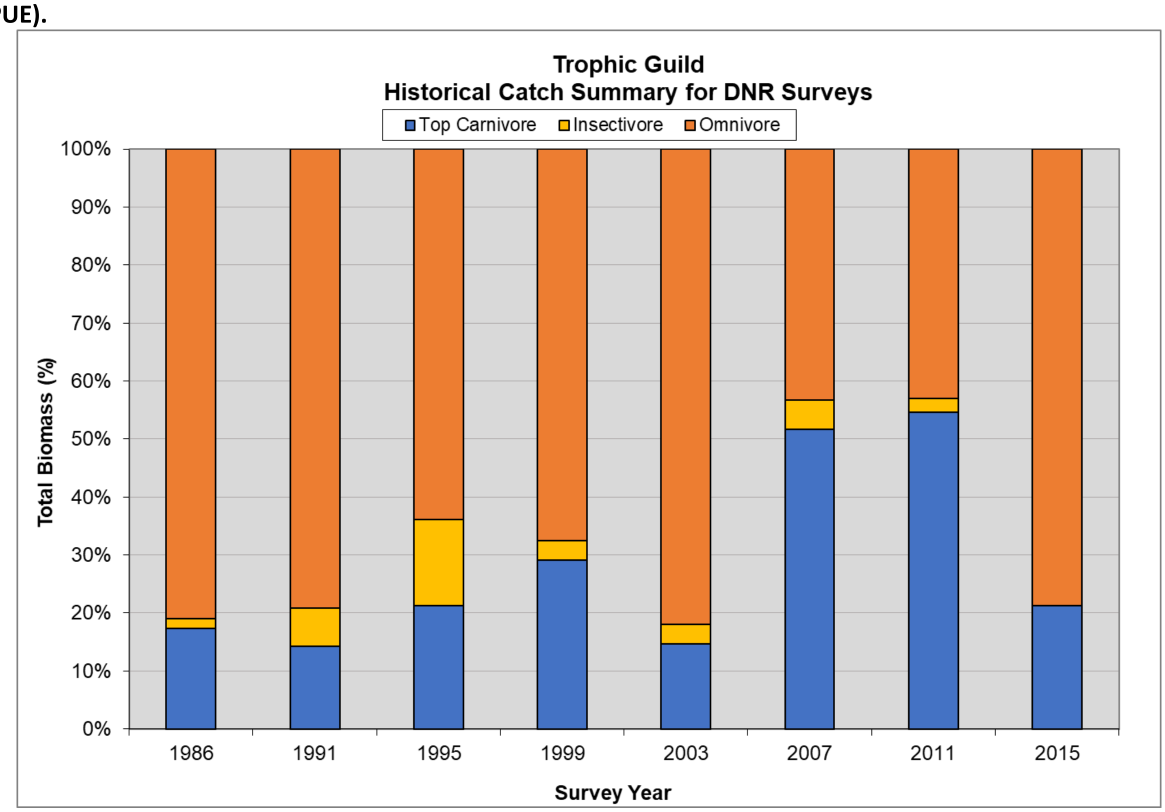


Figure C-12. Goose Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

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

Average Loading Summary for Goose

	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	Lake Direct (HSPF 292)	1,788	10.5	1,559	227	1.0	964
2							
3							
4							
5							
6							
	Summation	*1,788*	*10*	*1,559*			*964*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	0	8	2	0	31%		7
2							
3							
4							
5							
	Summation	*8*	*2*	*0.0*	31%		*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]
	150	27.5	27.5	0.00	0.24	1.0	36
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.61	0		Oxic		1.0	0
	0.61	5.0		Anoxic		1.0	670
	Summation						*670*
		Net Discharge [ac-ft/yr] =		**1,559**	**Net Load [lb/yr] =**		**1,677**

Average Lake Response Modeling for Goose

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.) =	761	[kg/yr]
		Q (lake outflow) =	1.9	[10^6 m^3/yr]
		V (modeled lake volume) =	1.2	[10^6 m^3]
		T = V/Q =	0.64	[yr]
		P_i = W/Q =	395	[µg/l]
Model Predicted In-Lake [TP]			**133.0**	**[ug/l]**
Observed In-Lake [TP]			**133.0**	**[ug/l]**

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

	TMDL Loading Summary for Goose						
	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	Lake Direct (HSPF 292)	1,788	10.5	1,559	150	0.7	636
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	*1,788*	*10*	*1,559*			*636*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	0	8	0	0	0%		4
2							
3							
4							
5							
	Summation	*0*	*0*	*0.0*	#DIV/0!		*4*
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*
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]
	150	27.5	27.5	0.00	0.24	1.0	36
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.61	0		Oxic		1.0	0
	0.61	5.0		Anoxic		1.0	291
	Summation						*291*
			Net Discharge [ac-ft/yr] =	**1,559**		**Net Load [lb/yr] =**	**967**

TMDL Lake Response Modeling for Goose				
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.) =	439	[kg/yr]
		Q (lake outflow) =	1.9	[10^6 m^3/yr]
		V (modeled lake volume) =	1.2	[10^6 m^3]
		T = V/Q =	0.64	[yr]
		P_i = W/Q =	228	[µg/l]
Model Predicted In-Lake [TP]			**90.0**	**[ug/l]**
Observed In-Lake [TP]			**133.0**	**[ug/l]**

Supporting Items for School Grove Lake (42000200)

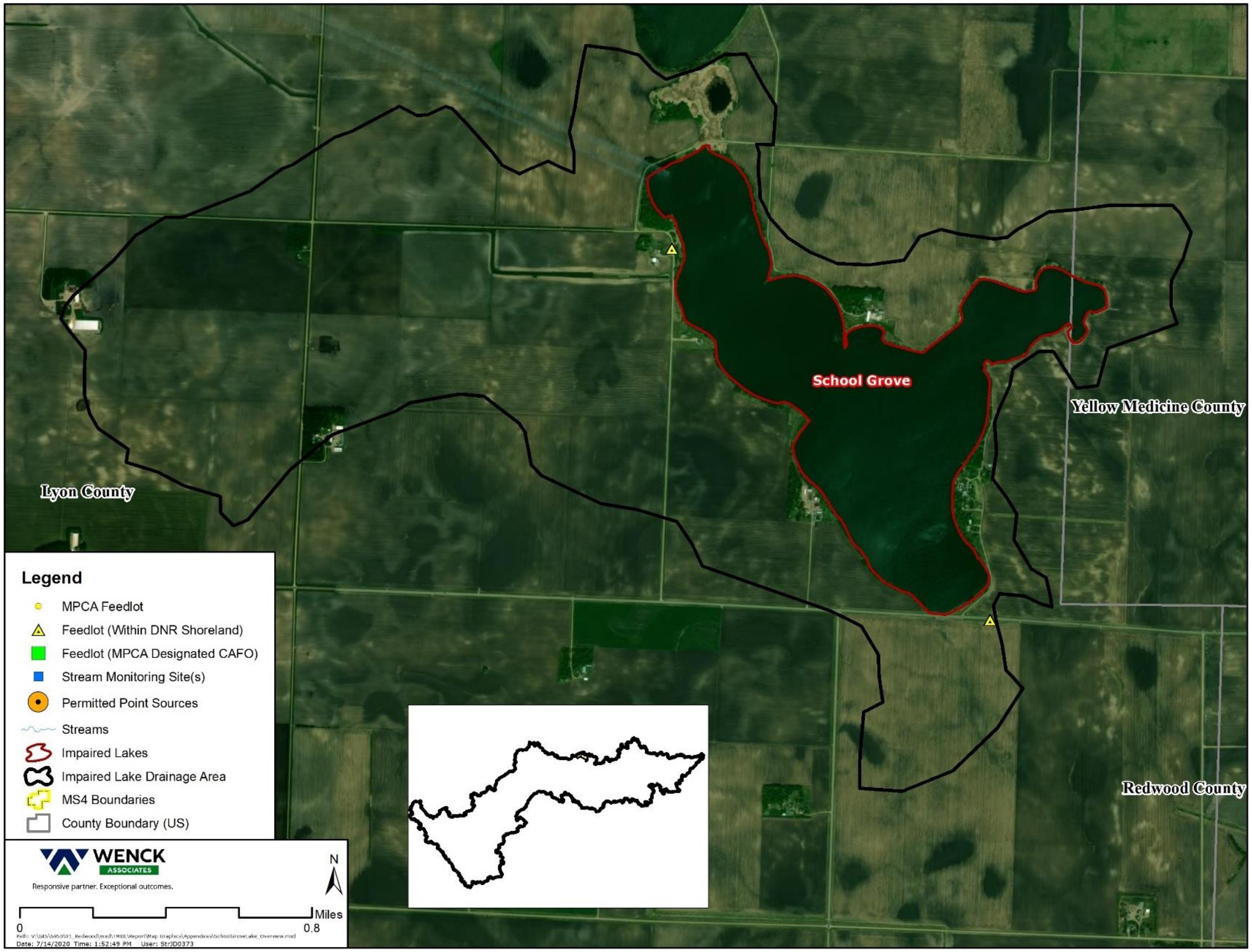


Figure C-13. School Grove Lake Overview.

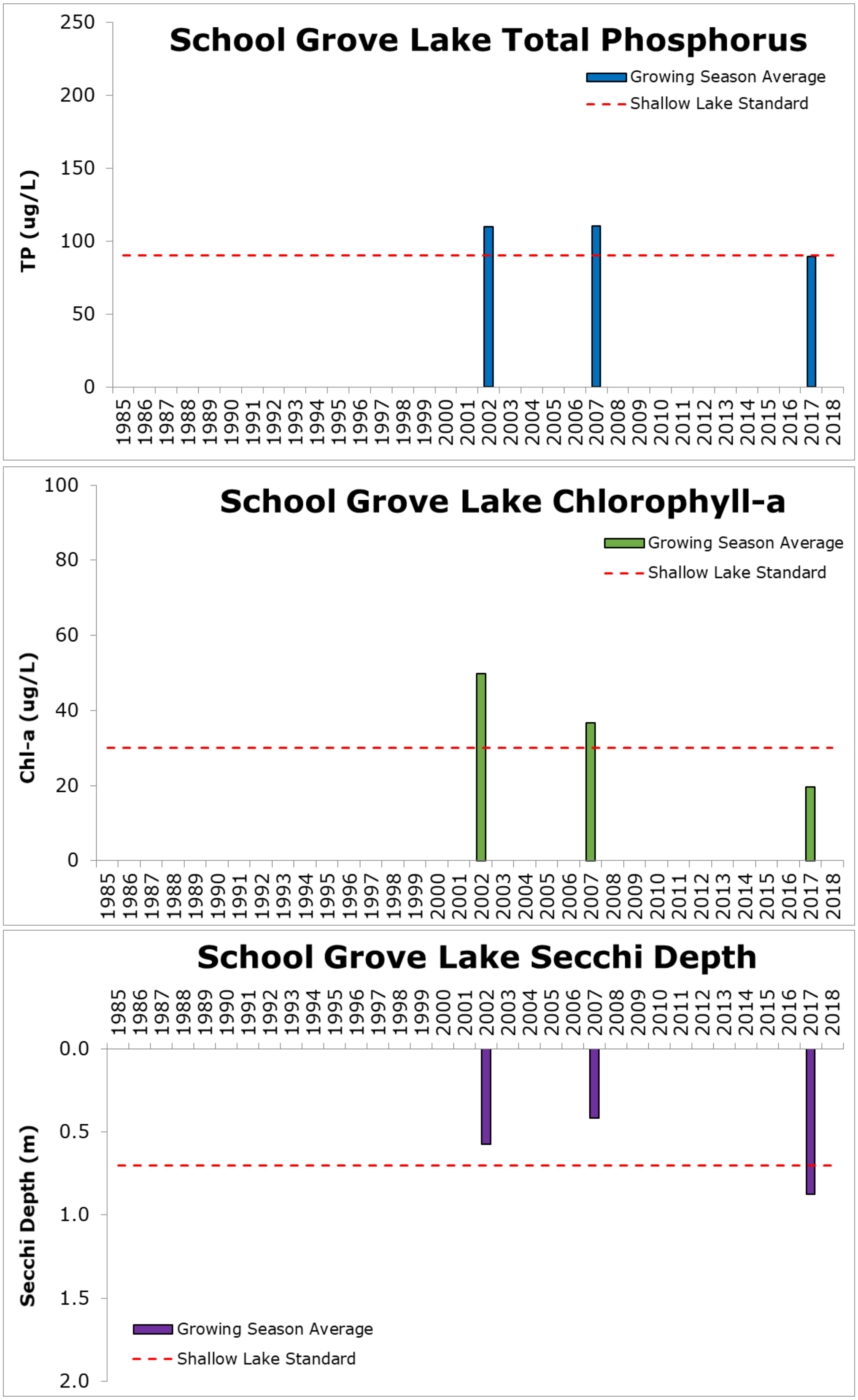


Figure C-14. School Grove Lake Historic Water Quality.

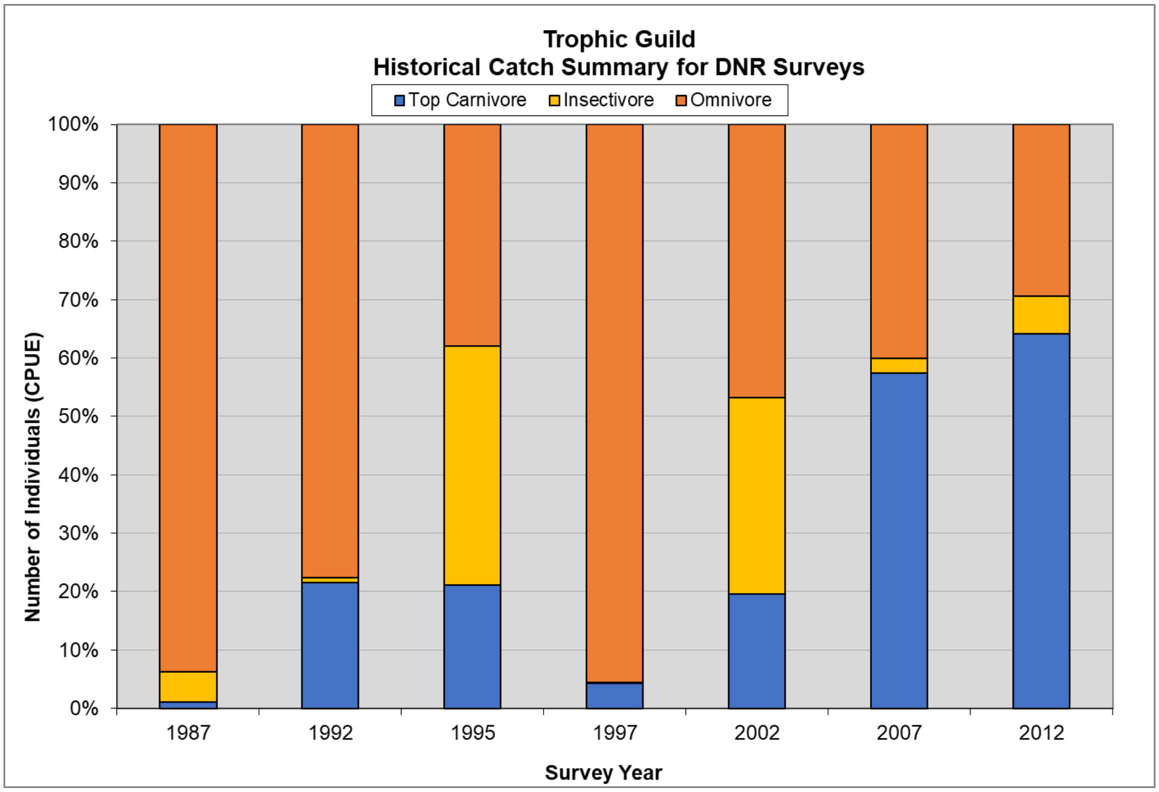


Figure C-15. School Grove Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).

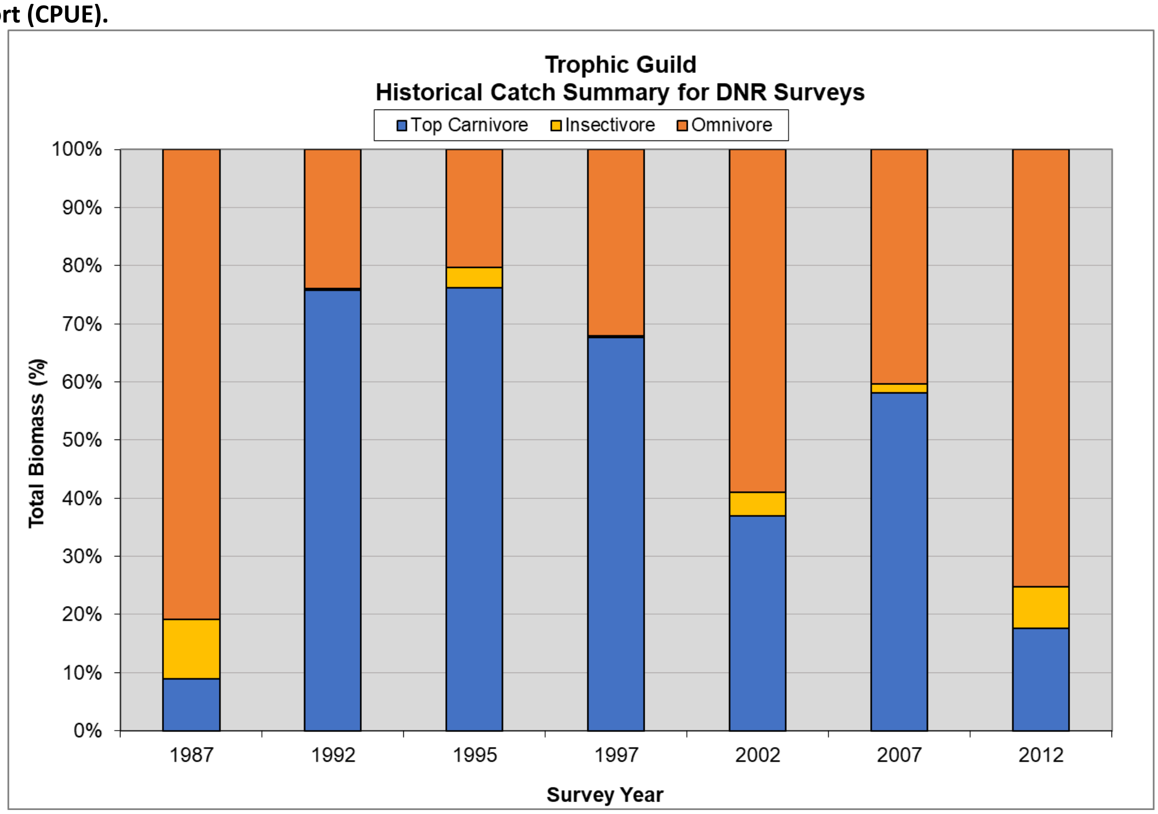


Figure C-16. School Grove Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

Table C-7. School Grove Lake Current Condition Lake Response Model.

	Average Loading Summary for	*School Grove*					
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
		Drainage Area	Runoff Depth	Discharge	Phosphorus Concentration	Loading Calibration Factor (CF)[1]	Load
	Name	[acre]	[in/yr]	[ac-ft/yr]	[ug/L]	[--]	[lb/yr]
1	Direct Watershed (HSPF 372)	1,390	10.3	1,198	352	1.0	1,145
2							
3							
4							
5							
6							
	Summation	*1,390*	*10*	*1,197.80*			*1,145*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1	0	7	2.03	0	29%		7
2							
3							
4							
5							
	Summation	*7*	*2*	*0.0*	29%		*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]
	349	27.5	27.5	0.00	0.24	1.0	83
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Model Residual Load							
						Loading Calibration Factor (CF)[1]	Load
	Name					[--]	[lb/yr]
1	Model Residual Load					1.0	310
	Summation						*310*
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	1.41	0		Oxic		1.0	0
	1.41	5.0		Anoxic	5.9	1.0	92
	Summation						*92*
			Net Discharge [ac-ft/yr] =	**1,198**		Net Load [lb/yr] =	**1,638**

Average Lake Response Modeling for		***School Grove***		
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.) =	743	[kg/yr]
		Q (lake outflow) =	1.5	[10^6 m^3/yr]
		V (modeled lake volume) =	2.9	[10^6 m^3]
		T = V/Q =	1.99	[yr]
		P_i = W/Q =	503	[µg/l]
Model Predicted In-Lake [TP]			**99.4**	**[ug/l]**
Observed In-Lake [TP]			**99.4**	**[ug/l]**

Table C-8. School Grove Lake TMDL Condition Lake Response Model.

	TMDL Loading Summary for School Grove						
	Water Budgets				**Phosphorus Loading**		
Inflow from Drainage Areas							
	Name	Drainage Area [acre]	Runoff Depth [in/yr]	Discharge [ac-ft/yr]	Phosphorus Concentration [ug/L]	Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Direct Watershed (HSPF 372)	1,390	10.3	1,198	279	0.8	910
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	*1,390*	*10*	*1,197.80*			*910*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1		7	0	0	0%		5
2							
3							
4							
5							
	Summation	7	*0*	*0.0*	0%		*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]
	349	27.5	27.5	0.00	0.24	1.0	83
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Model Residual Load							
	Name					Loading Calibration Factor (CF)[1] [--]	Load [lb/yr]
1	Model Residual Load					1.0	310
	Summation						*310*
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	1.41	0		Oxic		1.0	0
	1.41	5.0		Anoxic	5.9	1.0	92
	Summation						*92*
			Net Discharge [ac-ft/yr] =	**1,198**		**Net Load [lb/yr] =**	**1,401**

TMDL Lake Response Modeling for School Grove			
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.) =	635	[kg/yr]
	Q (lake outflow) =	1.5	[10^6 m^3/yr]
	V (modeled lake volume) =	2.9	[10^6 m^3]
	T = V/Q =	1.99	[yr]
	P_i = W/Q =	430	[µg/l]
Model Predicted In-Lake [TP]		**90.0**	**[ug/l]**
Observed In-Lake [TP]		**99.4**	**[ug/l]**

Supporting Items for Clear Lake (42005500)

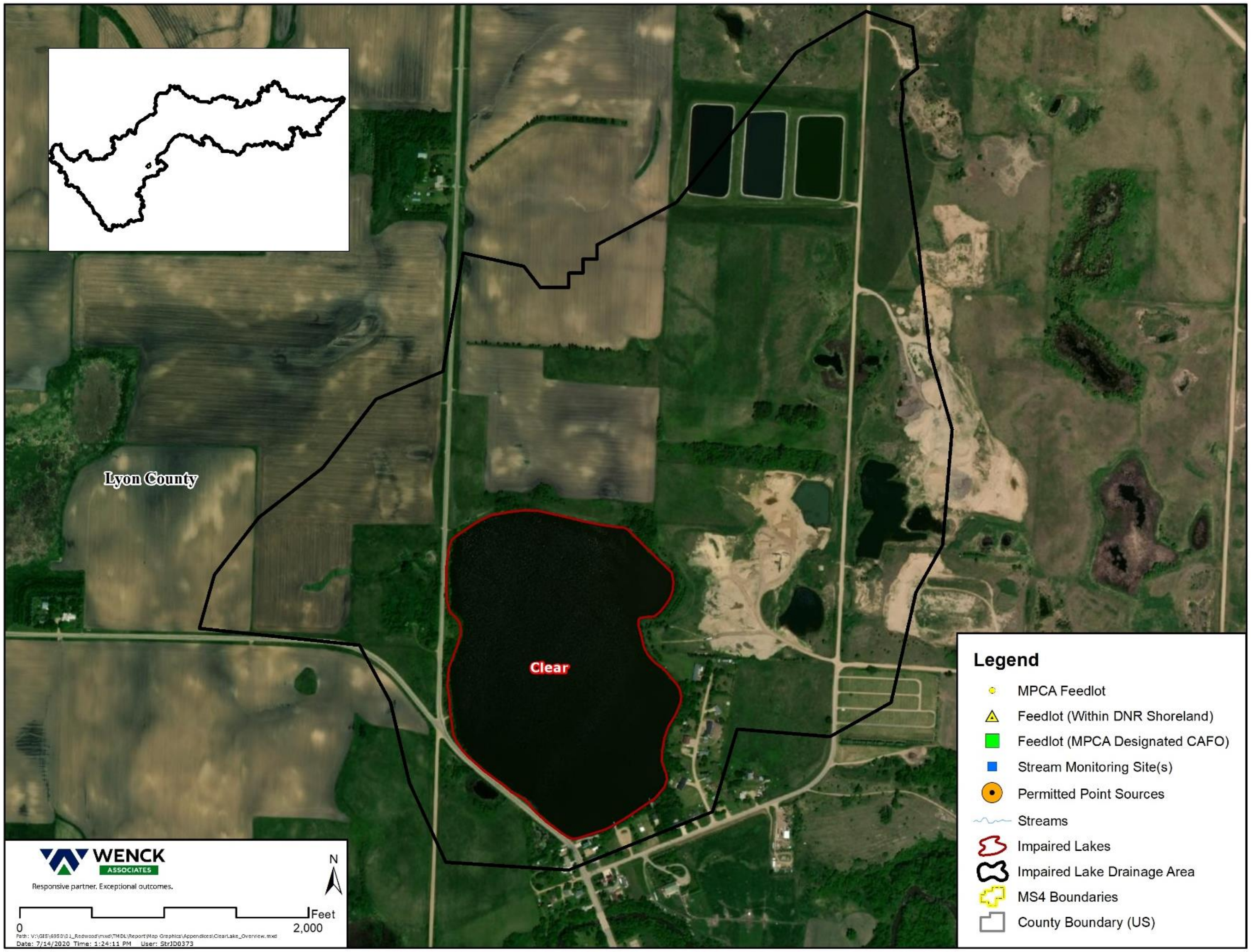


Figure C-17. Clear Lake Overview.

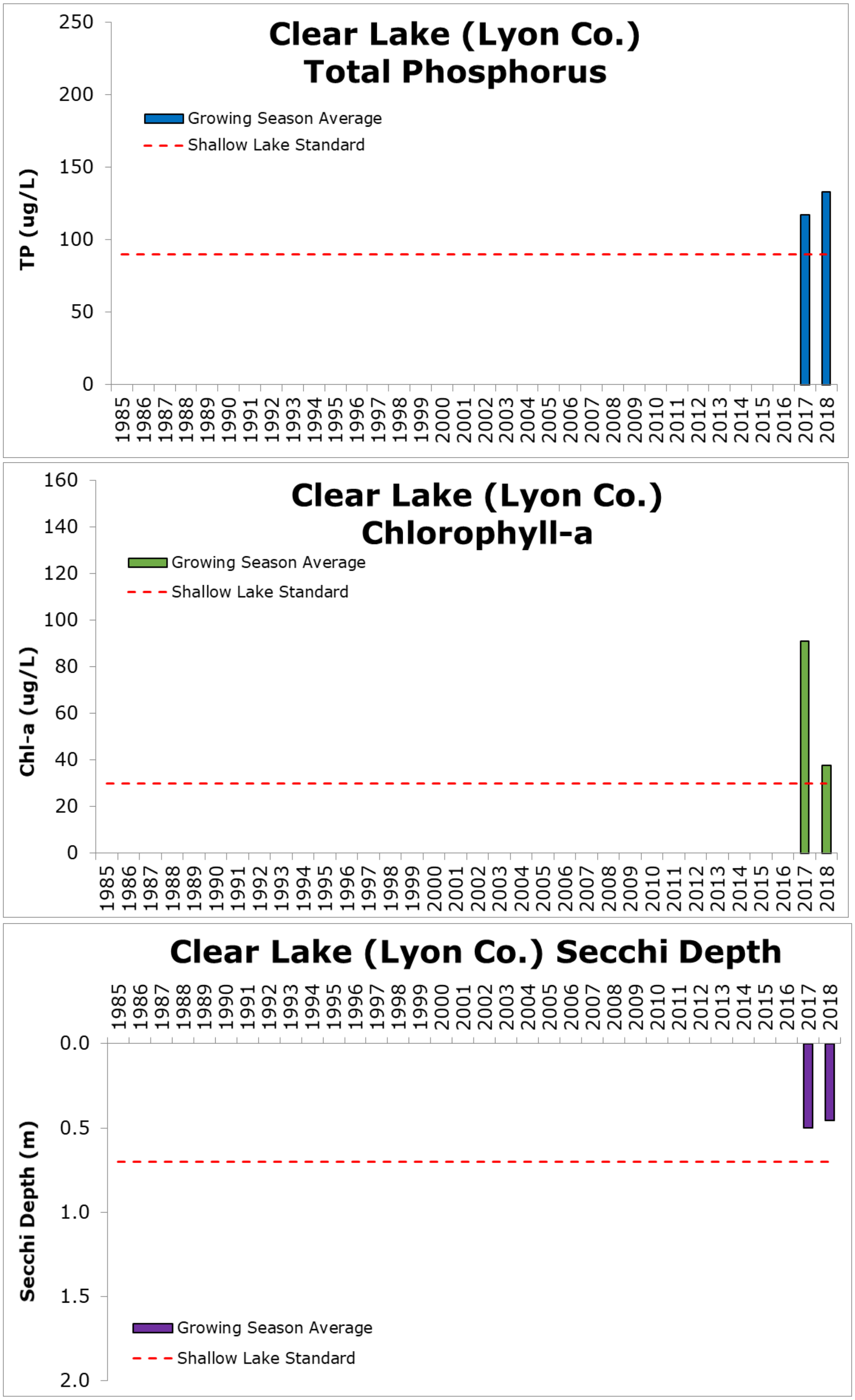


Figure C-18. Clear Lake Historic Water Quality.

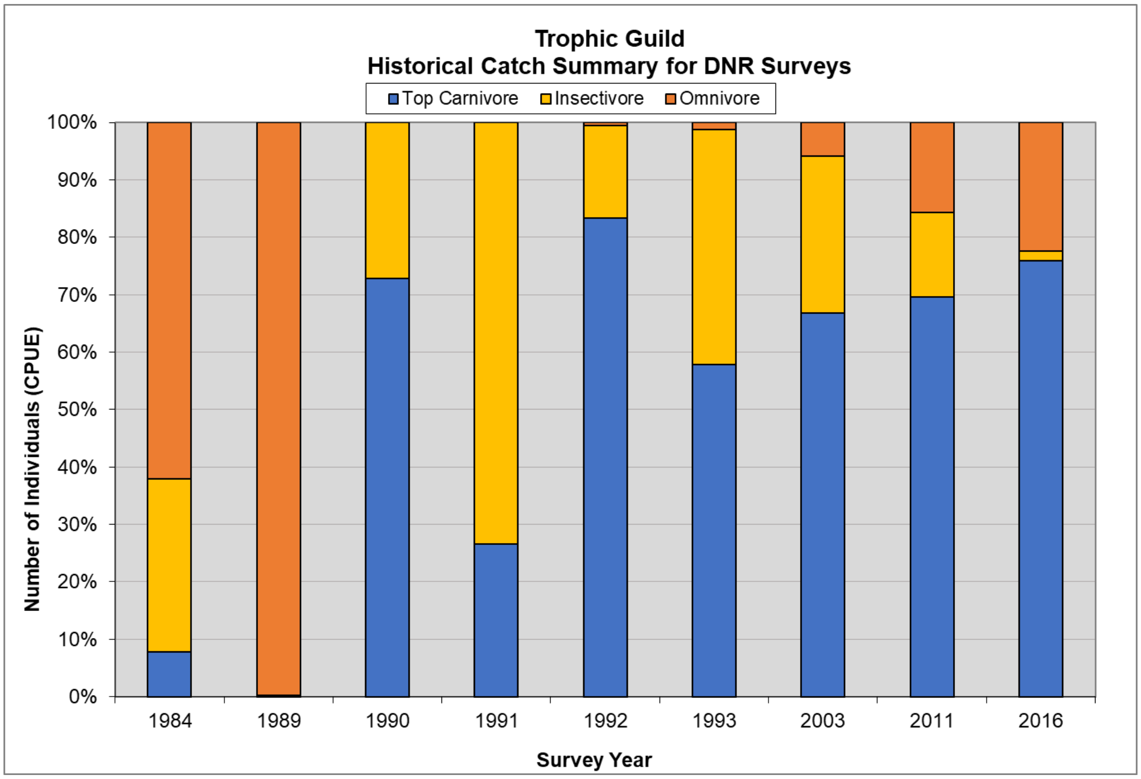


Figure C-19. Clear Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).

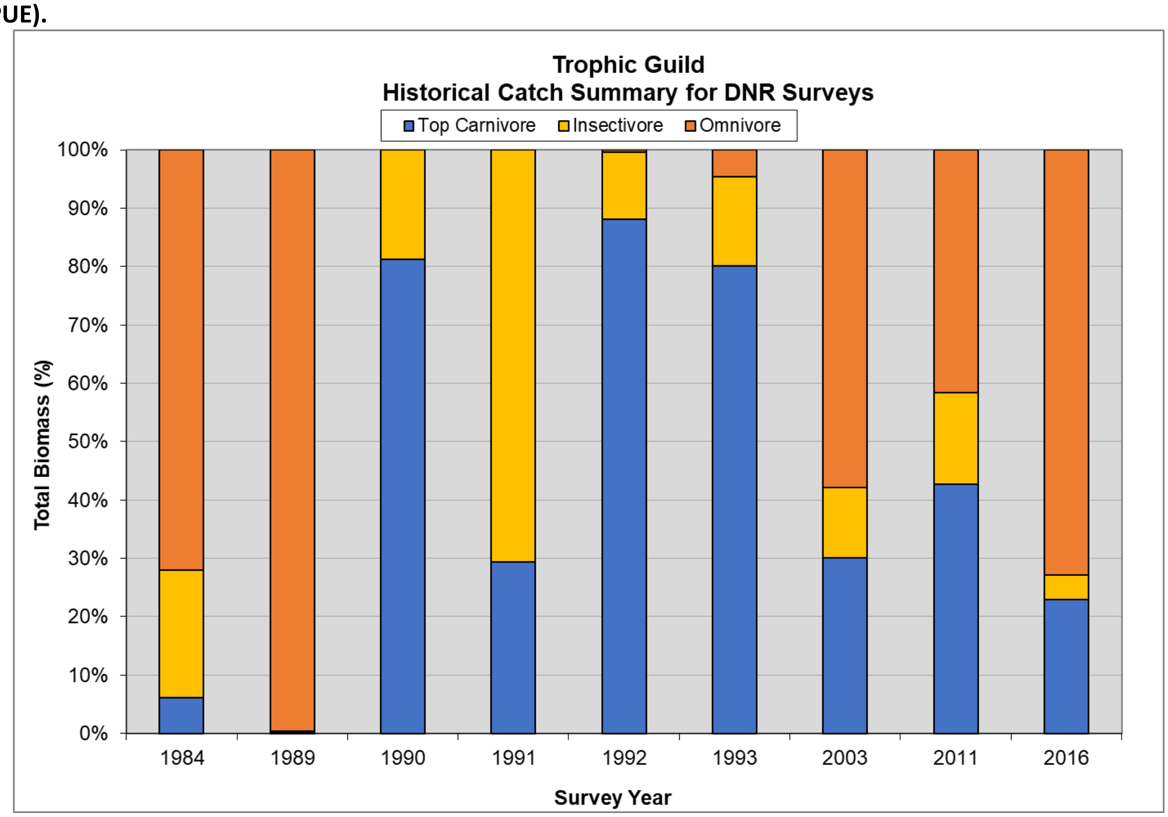


Figure C-20. Clear Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

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

	Average Loading Summary for				***Clear (Lyon Co.)***		
	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	All	324	12.9	349	234	1.0	222
2							
3							
4							
5							
6							
	Summation	*324*	*13*	*348.63*			*222*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1		10	3	0	29%		10
2							
3							
4							
5							
	Summation	*10*	*3*	*0.0*	29%		*10*
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]
	66	33.6	33.6	0.00	0.24	1.0	16
			Dry-year total P deposition =		0.222		
			Average-year total P deposition =		0.239		
			Wet-year total P deposition =		0.259		
			(Barr Engineering 2004)				
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.27	0		Oxic		1.0	0
	0.27	5.0		Anoxic		1.0	255
	Summation						*255*
			Net Discharge [ac-ft/yr] =	**349**		**Net Load [lb/yr] =**	**502**

Average Lake Response Modeling for			***Clear (Lyon Co.)***	
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.) =	228	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	0.5	[10^6 m^3]
		T = V/Q =	1.25	[yr]
		P_i = W/Q =	530	[µg/l]
Model Predicted In-Lake [TP]			**125.0**	**[ug/l]**
Observed In-Lake [TP]			**125.0**	**[ug/l]**

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

	TMDL Loading Summary for	***Clear (Lyon Co.)***					
	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	All	324	12.9	349	150	0.6	142
2							
3							
4							
5							
6							
	Summation	*324*	*13*	*348.63*			*142*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1		10	0	0	0%		7
2							
3							
4							
5							
	Summation	*10*	*0*	*0.0*	0%		*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]
	66	33.6	33.6	0.00	0.24	1.0	16
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.27	0		Oxic		1.0	0
	0.27	5.0		Anoxic		1.0	141
	Summation						*141*
			Net Discharge [ac-ft/yr] =	**349**		**Net Load [lb/yr] =**	**305**

TMDL Lake Response Modeling for		***Clear (Lyon Co.)***		
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.) =	139	[kg/yr]
		Q (lake outflow) =	0.4	[10^6 m^3/yr]
		V (modeled lake volume) =	0.5	[10^6 m^3]
		T = V/Q =	1.25	[yr]
		P_i = W/Q =	322	[µg/l]
Model Predicted In-Lake [TP]			**90.0**	**[ug/l]**
Observed In-Lake [TP]			**125.0**	**[ug/l]**

Supporting Items for Island Lake (42009600)

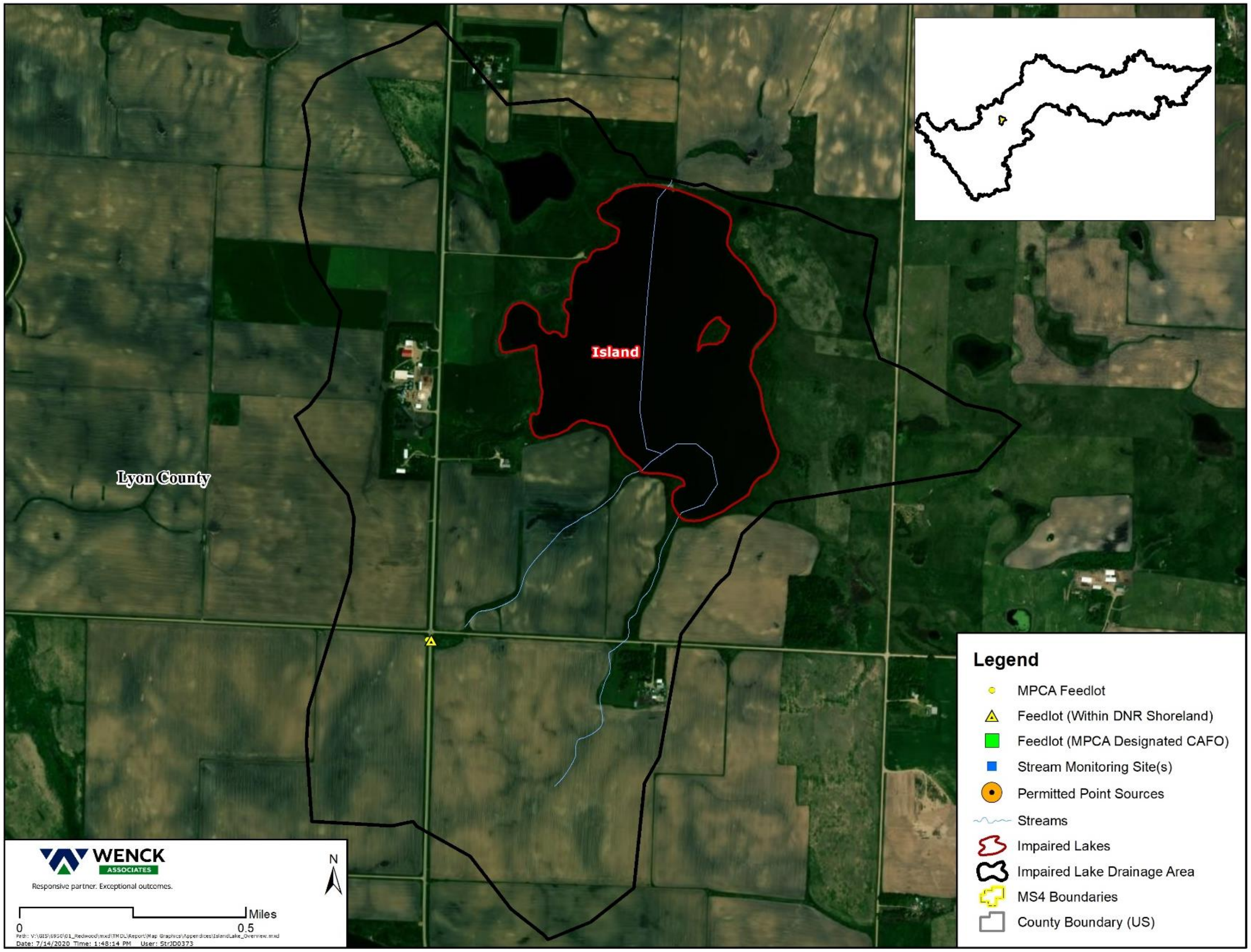
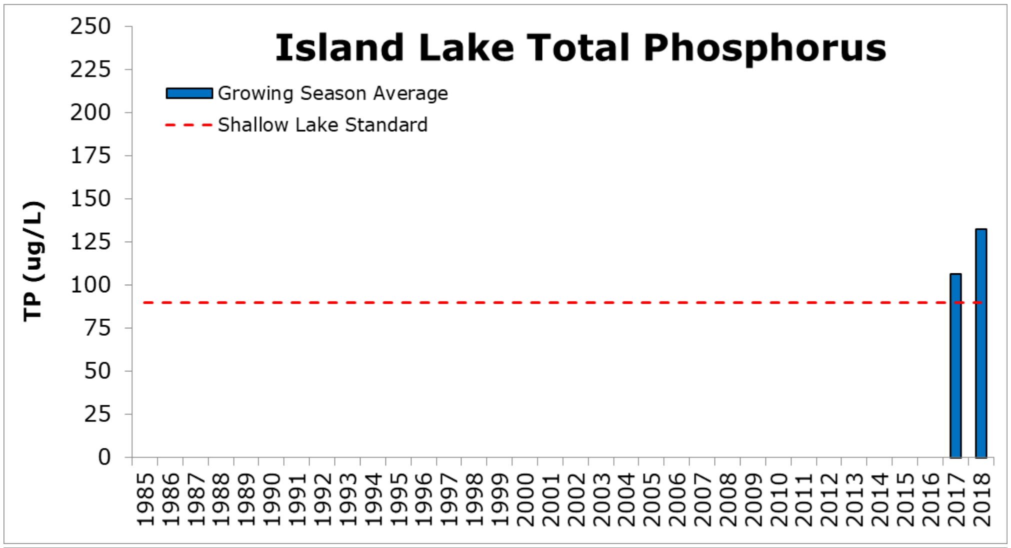
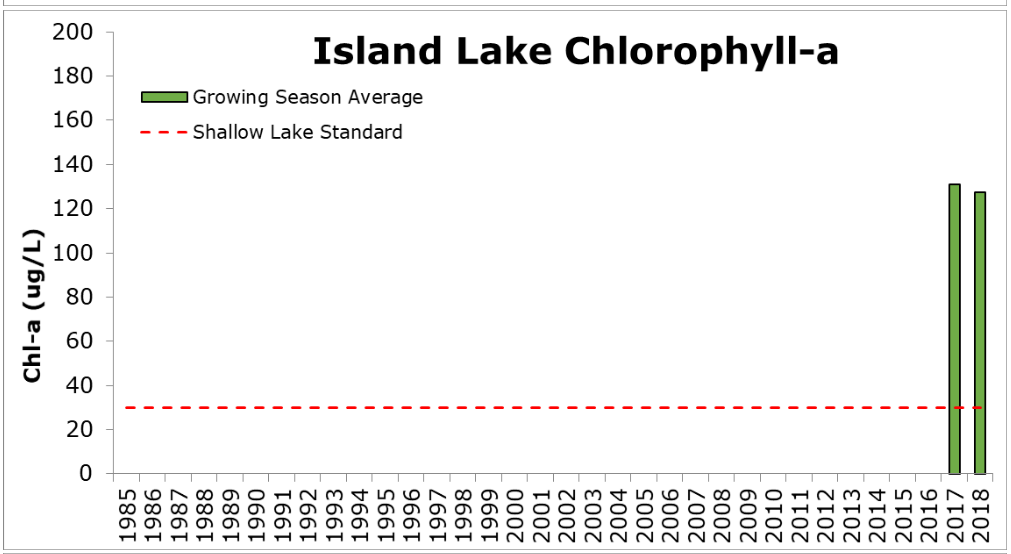


Figure C-21. Island Lake Overview.





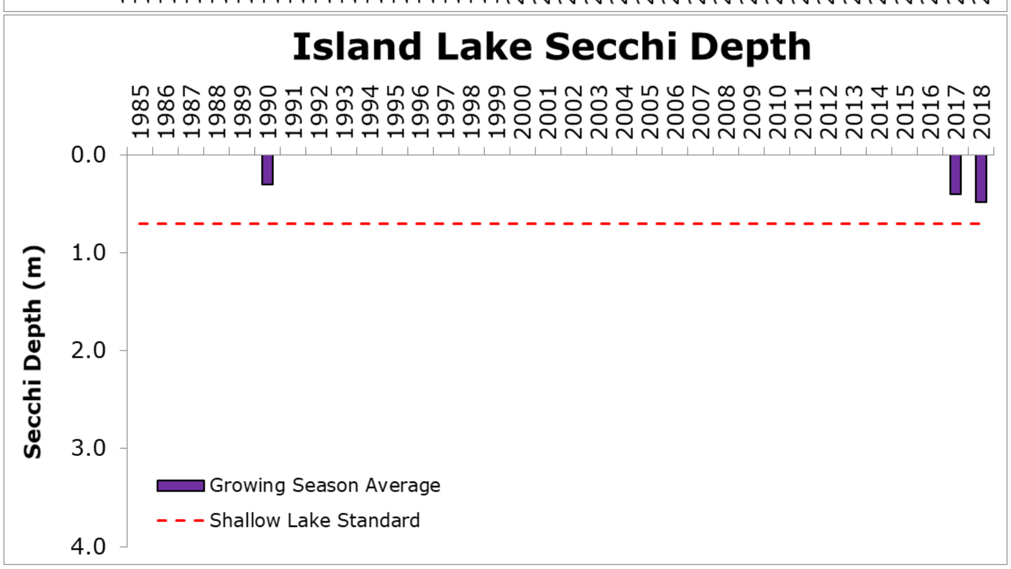


Figure C-22. Island Lake Historic Water Quality.

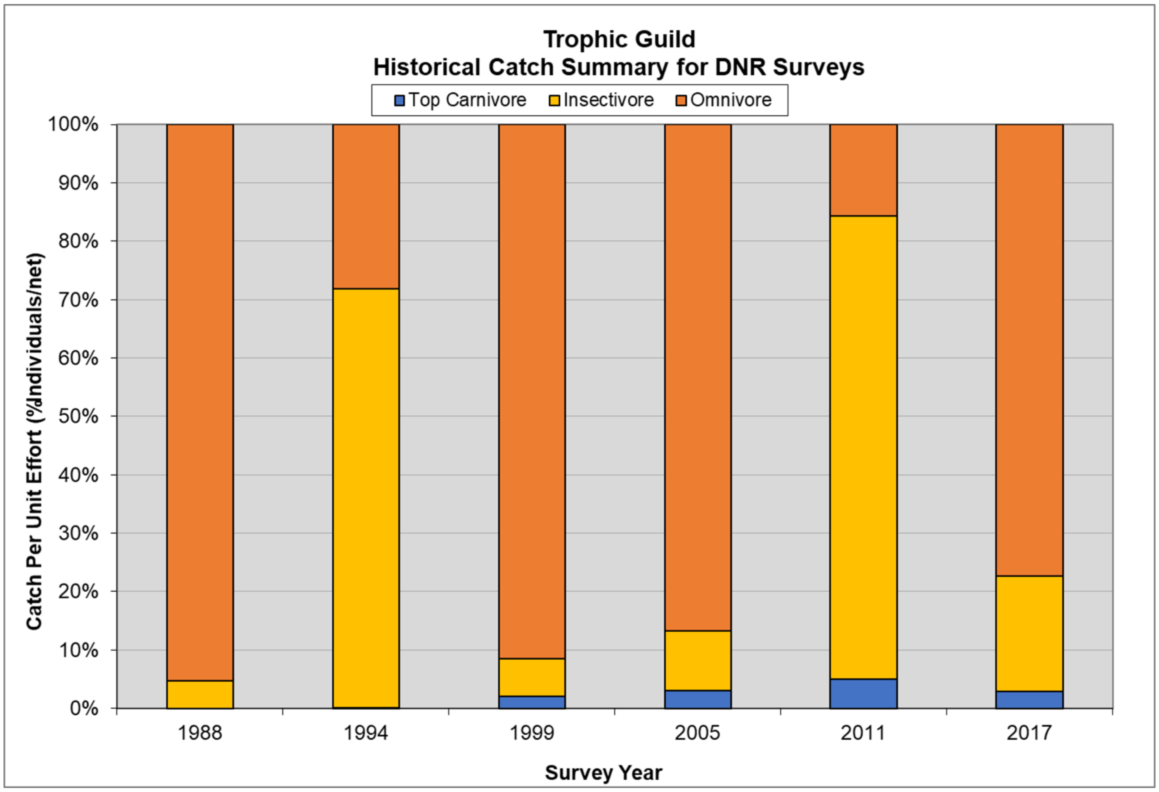


Figure C-23. Island Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).

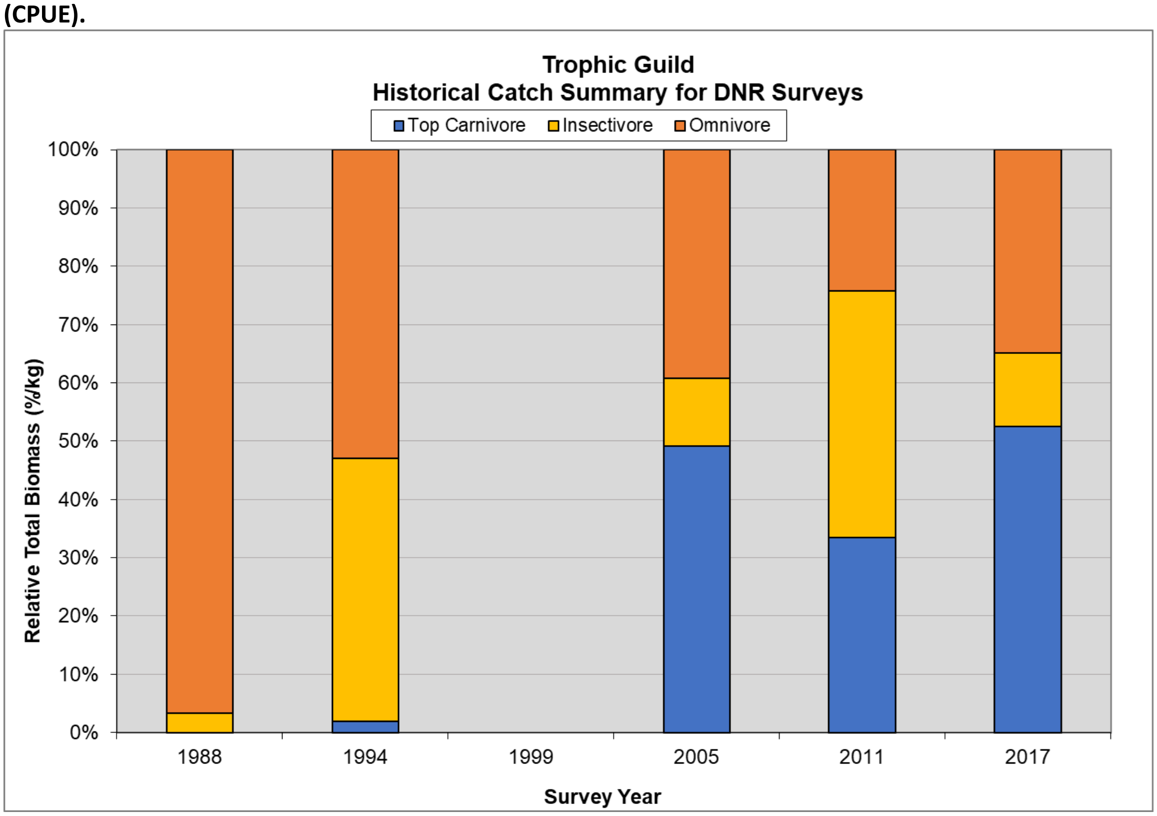


Figure C-24. Island Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.

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

Average Loading Summary for Island

	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	All	1,089	7.2	657	309	1.0	552
2							
3							
4							
5							
6							
	Summation	*1,089*	*7*	*657*			*552*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1		3	1	0	29%		5
2							
3							
4							
5							
	Summation	*3*	*1*	*0.0*	29%		*5*
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]
	133	33.6	33.6	0.00	0.24	1.0	32
				Dry-year total P deposition =	0.222		
				Average-year total P deposition =	0.239		
				Wet-year total P deposition =	0.259		
				(Barr Engineering 2004)			
Internal							
	Lake Area	Anoxic Factor			Release Rate	Calibration Factor	Load
	[km^2]	[days]			[mg/m^2-day]	[--]	[lb/yr]
	0.54	0		Oxic		1.0	0
	0.54	58.3		Anoxic	1.2	1.0	86
	Summation						*86*
			Net Discharge [ac-ft/yr] =	**657**		Net Load [lb/yr] =	**675**

Average Lake Response Modeling for Island

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.) =	306	[kg/yr]
		Q (lake outflow) =	0.8	[10^6 m^3/yr]
		V (modeled lake volume) =	0.6	[10^6 m^3]
		T = V/Q =	0.79	[yr]
		P_i = W/Q =	378	[µg/l]
Model Predicted In-Lake [TP]			**119.3**	**[ug/l]**
Observed In-Lake [TP]			**119.3**	**[ug/l]**

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

	TMDL Loading Summary for Island						
	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	All	1,089	7.2	657	183	0.6	327
2							
3							
4							
5							
6							
	Summation	*1,089*	*7*	*656.56*			*327*
Failing Septic Systems							
	Name	Total Systems	Failing Systems	Discharge [ac-ft/yr]	Failure [%]		Load [lb/yr]
1		3	0	0	0%		3
2							
3							
4							
5							
	Summation	3	*0*	*0.0*	0%		*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]
	133	33.6	33.6	0.00	0.24	1.0	32
		Dry-year total P deposition =			0.222		
		Average-year total P deposition =			0.239		
		Wet-year total P deposition =			0.259		
		(Barr Engineering 2004)					
Internal							
	Lake Area [km^2]	Anoxic Factor [days]			Release Rate [mg/m^2-day]	Calibration Factor [--]	Load [lb/yr]
	0.54	0		Oxic		1.0	0
	0.54	58.3		Anoxic	1.2	1.0	86
	Summation						*86*
			Net Discharge [ac-ft/yr] =	**657**		**Net Load [lb/yr] =**	**449**

TMDL Lake Response Modeling for Island				
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.) =	204	[kg/yr]
		Q (lake outflow) =	0.8	[10^6 m^3/yr]
		V (modeled lake volume) =	0.6	[10^6 m^3]
		T = V/Q =	0.79	[yr]
		P_i = W/Q =	251	[µg/l]
Model Predicted In-Lake [TP]			**90**	**[ug/l]**
Observed In-Lake [TP]			**119**	**[ug/l]**

To: Redwood Cottonwood Rivers Control Area

Minnesota Pollution Control Agency

From: Tom Langer, Wenck Associates, Inc.
Jeff Strom, Wenck Associates, Inc.

Date: February 4, 2019

Memo Subject: Redwood and Cottonwood River Watershed Lake Common Carp Assessments

Wenck Associates conducted common carp (*Cyprinus carpio)* population assessments on School Grove, Double and Sleepy Eye Lakes on June 27- 28, 2018. These were the first common carp population assessment conducted on these systems. The survey efforts were intended to better inform lake managers of the abundance and density of carp within the system and to inform of possible water quality degradation occurring from an overabundance of common carp. This technical memo summarizes the methods and results of the June 27- 28, 2018 assessment and provides management recommendations.

Methods

Biologists and scientists from Wenck Associates conducted common carp population assessments using standard research methods described in (Bajer and Sorensen 2012). Boat electrofishing was implemented to sample three shoreline transects per lake for approximately 20 minutes each under MnDNR permit approval.

All common carp were netted (some carp are inevitability missed), counted and measured for total length (weight was extrapolated from length using a regression model) prior to being released. This information, along with the amount of time spent electrofishing, were used in linear regression models developed by (Bajer and Sorensen 2012) to estimate the current population size and density within each lake.

Results

The total number of carp captured, average total length, and average weight varied across the three lakes. School Grove observed the greatest catch per unit effort (CPUE) and had the 2nd highest total length and weight of the three lakes surveyed. Sleepy Eye observed the lowest CPUE and the smallest and shortest carp, while Double had the 2nd highest CPUE but the largest and longest carp on average.

Using results of this assessment and the regression equation described above, the estimated common carp densities varied across the three lakes. School Grove Lake observed a biomass density of 331 kg/ha (295 lbs/acre). Extrapolating this density across the entire basin suggests that there are ~15,447 individual carp within the lake. Using this population estimate and the average weight of the fish capture suggests that there are currently ~102,631 pounds of carp in School Grove Lake. Double Lake observed a biomass density of 234 kg/ha (208 lbs/acre). Extrapolating this density across the entire basin suggests that there are ~3,109 individual carp and ~26,858 pounds of carp in Double Lake. Sleepy Eye Lake observed a biomass density of 19 kg/ha (17 lbs/acre). Extrapolating this density across the entire basin suggests that there are ~1,215 individual carp and ~4,105 pounds of carp in Sleepy Eye Lake.

Table 1: Summary of common carp assessments.

Lake	Carp Collected	Shock Time (hour)	Average Length (cm)	Average Weight (kg)	Biomass Mean (kg/ha)	Estimated Population Size
School Grove	24	1.06	59.6	3.02	331.0	15,447
Double	12	1	65.4	3.92	233.7	3,109
Sleepy Eye	2	1	55.3	1.53	19.1	1,215

Discussion

Common carp (*Cyprinus carpio)* are among the most widespread aquatic invasive species in North America. Common Carp can rapidly colonize a waterbody and significantly alter habitat, water quality conditions and nutrient dynamics within a lake. High densities of common carp can have specific impacts within a system, including reduced vegetation coverage, lower water fowl populations and increased water turbidity. Research suggests that these impacts begin to occur at densities of ~100 kg of carp biomass/hectare (89 lbs/acre) (Bajer *et al.* 2009). Populations observed at or above this density threshold would benefit from population reductions below 100 kg/ha as a strategy to improve water quality and restore a healthy functioning ecosystem.

Results of the common carp assessments indicate that School Grove and Double Lakes currently have carp biomass densities more than double the critical threshold (100kg/ ha). Sleepy Eye Lake was observed to be well below the critical threshold.

These results suggest common carp are a contributing factor to water quality impairments and habitat degradation within School Grove and Double Lakes, but not in Sleepy Eye Lake. To achieve density levels right at the 100 kg/ha threshold would require the removal of ~4,667 carp or ~10,780 kg in School Grove Lake and ~1,331 carp or ~1,779 kg in Double Lake. We recommend establishing removal goals below the critical threshold to 50 kg/ha to allow for potential growth of individuals that are not removed from the system.

References

Bajer, P.G, G. Sullivan, and P.W. Sorensen. 2009. Effects of a rapidly increasing population of common carp on vegetative cover and waterfowl in a recently restored Midwestern shallow lake. Hydrobiologia 632: 235-245.

Bajer, P.G. and P.W. Sorensen. 2012. Using Boat Electrofishing to Estimate the Abundance of Invasive Common Carp in Small Midwestern Lakes. North American Journal of Fisheries Management 32: 817-822.

Photos

Photo 1: Common carp.

Photo 2: Holding tanks filled with common carp during the assessment.

WENCK
Responsive partner.
Exceptional outcomes.

To: Redwood Cottonwood Rivers Control Area
Minnesota Pollution Control Agency

From: Anne Wilkinson, Wenck Associates, Inc.
Jeff Strom, Wenck Associates, Inc.

Date: February 5, 2019

Memo Subject: Redwood and Cottonwood River Watershed Lake Sediment Phosphorus Release Analysis

The Redwood Cottonwood Rivers Control Area (RCRCA) contracted with Wenck Associates, Inc. (Wenck) for the Redwood and Cottonwood River Watershed-wide total maximum daily load (TMDL) studies. As part of this contract, Wenck Associates collected sediment cores on four of the impaired lakes (Benton, Double School Grove and Sleepy Eye Lakes) included in the TMDL studies to better characterize potential drivers of internal load. This memo presents the results of the sediment phosphorus release analysis which includes the following components:

- Review of temperature and dissolved oxygen (DO) profile data
- Anoxic Factor (AF) calculations
- Sediment core collection and laboratory analysis
- Sediment phosphorus release estimates

Water Column Profile Results

Water column stability can have a significant impact on phosphorus loading and lake nutrient cycling. Lake stratification, mixing, and absence of DO can all affect whether a lake releases phosphorus from benthic sediments. Temperature and DO profiles have been recorded for each lake over the past 20 years, most recently in 2017. These profiles show lake stratification occasionally occurs during the summer growing season in all the lakes in this study. Low oxygen (DO< 5.0 mg/L) and anoxic (DO <2.0 mg/L) conditions have been observed in the hypolimnion in Benton and Sleepy Eye. Stratification establishes anywhere from 5-9 feet below the surface during the summer season. The profiles also showed that large storm events, high winds and changes in air temperatures can cause stratification to weaken and breakdown during the summer growing season which results in mixing and re-oxygenation throughout the water column. Table 1 summarizes observed stratification and DO conditions for the four lakes in which sediment cores were collected for the Redwood and Cottonwood TMDL studies (Benton, School Grove, Double and Sleepy Eye). Table 2 summarizes observed stratification and DO conditions for the six other impaired lakes in the Redwood and Cottonwood River watersheds which sediment cores were not collected.

Table 1. Stratification and DO profile summary for the sediment cored lakes.

Parameter	Unit	Benton	School Grove	Double	Sleepy Eye
Year(s)		4	4	2	5
Summer Growing Season Profiles	[Count]	13	10	9	18
Profiles Demonstrating Stratification	[Count]	2	4	2	4
Profiles Demonstrating DO < 5.0 mg/L	[Count]	2	-	-	3
Profiles Demonstrating DO < 2.0 mg/L	[Count]	1	-	-	13
Ave Depth of Stratification	[ft]	5.1	5.7	6.6	9.4
Ave Depth of DO <5.0 mg/L	[ft]	4.5	-	-	14.9
Ave Depth of DO <2.0 mg/L	[ft]	6.6	-	-	15.5

Table 2. Stratification and DO profile summary for other impaired lakes in the Redwood and Cottonwood River watersheds.

Parameter	Unit	Dead Coon	Goose	Clear (Lyon Co.)	Bean	Rock	Clear (Brown Co.)
Year(s)		4	3	1	2	4	2
Summer Growing Season Profiles	[Count]	13	11	0	10	14	4
Profiles Demonstrating Stratification	[Count]	2	1	-	5	2	1
Profiles Demonstrating DO < 5.0 mg/L	[Count]	2	3	-	1	1	3
Profiles Demonstrating DO < 2.0 mg/L	[Count]	-	-	-	3	-	2
Ave Depth of Stratification	[ft]	1.5	2.15	-	2.1	1.5	1.5
Ave Depth of DO <5.0 mg/L	[ft]	2.1	2.3	-	3.4	2.5	-
Ave Depth of DO <2.0 mg/L	[ft]	-	-	-	3.2	-	2.4

Anoxic Factor Estimates

Shallow lakes, like the lakes presented here, often demonstrate short periods of anoxia due to instability of stratification, which can last a few days or even a few hours, that are often missed by periodic field measurements. Thus, the following equation was used to estimate the anoxic factor for all shallow lakes in this TMDL study (Nürnberg 2005):

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

Where TP is the average summer phosphorus concentration of the lake, z is the mean depth (m) and A is the lake surface area (km2).

The shallow lakes equation provides an AF estimate based on an empirical relationship with AF being a function of lake bathymetry and TP concentration, however, when DO oxygen data is available, the AF can be estimated directly, by calculating the number of days in which there is observed anoxia above the sediments. The anoxic factor is expressed in days but is normalized by the area of the lake. The anoxic factor is then used along with a sediment release rate to estimate the total phosphorus load from the sediments.

Anoxic factors were estimated using both the shallow lakes equation and the DO profiles collected at the four lakes in which sediment cores were collected and the other impaired lakes in the Redwood and Cottonwood River watershed (Table 3).

Table 3. Anoxic Factor Estimates for the sediment cored lakes.

	Anoxic Factor Estimation		
Lake	Shallow Lake Eq (days)	DO Profiles (days)	Average (days)
Benton	58.9	19.7	39.3
School Grove	55	-	55
Double	62.2	-	62.2
Sleepy Eye	49.8	14.4	32.1

NOTE: section 2 of the table compares AF estimates for lakes without sediment core data
[1]average of two years (2007 and 2008)

Table 4. Anoxic Factor Estimates other impaired lakes in the Redwood and Cottonwood River watersheds.

	Anoxic Factor Estimation		
Lake	Shallow Lake Eq (days)	DO Profiles (days)	Average (days)
Dead Coon	64.42	56.7	60.6
Goose	61.4	128.2	94.8
Clear (Lyon Co.)	61.5	-	61.5
Bean	61.3	30.7	46
Rock	68.5	-	68.5
Clear (Brown County)	49.8	14.43	35.1

Sediment Core Results

Three intact sediment cores were collected at one location in Benton, School Grove and Double Lakes on June 27th and 28th, 2018. For Sleepy Eye Lake, three cores were collected at two locations (one dredged location and one un-dredged location) on June 28th to assess potential impacts of dredging on phosphorus release from the sediment. Sediment cores were collected using a gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length). In general, the sediment core locations coincide with the long-term water quality monitoring site for each lake. The sediment cores were transported to the University of Wisconsin - Stout Discovery Center Laboratory where they were analyzed for phosphorus release under anoxic conditions.

Anaerobic phosphorus release rates for Redwood/Cottonwood lakes are range from 3.8-9.2 $mg/m^2/day$ (Table 3). Sleepy Eye Lake had the lowest rates of of phosphorus release (3.8-4.8 $mg/m^2/day$) which are near the 25th percentile for release rates measured in lakes throughout Minnesota. Benton and Double show the highest release rates, 9.1 and 9.2 $mg/m^2/day$, respectively. These rates are considered high and near the 75th percentile for release rates measured in Minnesota lakes. Sleepy Eye and School Grove are both near the 50th percentile for release rates measured in Minnesota lakes.

Table 3. Anaerobic phosphorus release rates.

Lake	Anaerobic Release Rate ($mg/m^2/day$)	Other MN Lakes		
		25th Percentile	Median	75th Percentile
Lake Benton (Lincoln Co.; Redwood River)	9.1	2.7	5.1	9.3
School Grove Lake (Lyon Co.; Redwood River)	5.9			
Double Lake (Cottonwood Co.; Cottonwood River)	9.2			
Sleepy Eye Lake (Un-dredged; Brown Co.; Cottonwood River)	3.8			
Sleepy Eye Lake (Dredged; Brown Co.; Cottonwood River)	4.8			

References

Nürnberg, G. 2005. Quantification of Internal Phosphorus Loading in Polymictic Lakes. Verhanlungen Interationalen Vereinigung Limnologie (SIL). Vol. 29.

Appendix D – HSPF Model Documentation

1 Park Drive, Suite 200 • PO Box 14409
Research Triangle Park, NC 27709
Tel 919-485-8278 • Fax 919-485-8280

TETRA TECH

Memorandum

To:	Dr. Chuck Regan, Tim Larson (MPCA)	**Date:**	03/17/2016 (Revised)
From:	J. Wyss, H.I.T; J. Butcher, Ph.D., P.H.	**Subject:**	**Minnesota River Basin HSPF Model Sediment Recalibration**
Cc:	Jennifer Olson	**Includes:**	Electronic supplement

1 Introduction

The Minnesota River basin HSPF models have a long history. Models for six of the 8-digit Hydrologic Unit Code (HUC8) basins were originally developed by MPCA in the 1990s and subsequently expanded and calibrated to include the entire basin from Lac qui Parle to Jordan, MN by Tetra Tech in 2002. Those models were used to support the development of a nutrient/dissolved oxygen TMDL and associated wasteload allocations. Tetra Tech (2008) subsequently refined these models for sediment simulation. These models were discretized at approximately the HUC10 scale. Tetra Tech later developed finer-resolution (HUC12-scale) models of the Chippewa and Hawk-Yellow Medicine HUC8 sub-models. MPCA then contracted with RESPEC to develop HUC12-scale models of the entire basin downstream of Lac qui Parle, as well as to extend the models in time through 2012. That effort was completed in 2014.

In 2015, MPCA contracted with Tetra Tech to refine the hydrologic and sediment calibrations for the Basin. The initial review of the RESPEC models provided to MPCA by Tetra Tech suggested that hydrology was fit reasonably well; however, sediment source attribution did not match up well with the evidence available from radiometric data (e.g., Schottler et al., 2010). Subsequent analysis revealed other aspects of the hydrologic calibration that potentially affect sediment calibration. Accordingly, MPCA requested review and revisions to the hydrologic calibration as part of the sediment recalibration effort. Tetra Tech completed the hydrology recalibration in November, 2015 and then used those models to complete the sediment recalibration.

The hydrologic recalibration is summarized in *Minnesota River Basin HSPF Model Hydrology Recalibration*, submitted to MPCA on November 3, 2015. This memorandum, along with accompanying electronic files, specifically documents the sediment recalibration and validation of the Minnesota River Basin HSPF modeling system, including linked models for the following HUC8 watersheds:

- Hawk-Yellow Medicine (07020004)
- Chippewa (07020005)
- Redwood (07020006)

- Middle Minnesota (07020007)
- Cottonwood (07020008)
- Blue Earth (07020009)
- Watonwan (07020010)
- Le Sueur (07020011)
- Lower Minnesota (07020012).

2 Approach

2.1 Goals and Objectives for Recalibration

The goal of this effort is to update the sediment calibration of the Minnesota River HSPF models using all relevant available sources of information including evidence on source attribution. Model performance was adjusted at all calibration gages in the watershed to meet the following objectives:

- **Formulation of sediment source attribution targets**. The MPCA was responsible for generating the first set of sediment apportionment calibration targets for Minnesota River HSPF models. The greatest amount of data is available from the detailed sediment budget study of the Le Sueur River, where estimates have been developed for sediment load deriving from upland sheet and rill erosion, ravines, channel degradation, and bluff collapse. Sediment apportionment calibration targets in the Le Sueur are based on flow and sediment measurements above and below the nick zones of active headcuts in the Le Sueur mainstem, Big Cobb River, and Maple River. Radiometric information aided in the partitioning of the field derived and channel derived sediment contributions based primarily on analysis of cores from depositional "integrator sites" (Schottler et al., 2010 plus additional ongoing work to further refine the interpretation by Schottler, as presented to Chuck Regan of MPCA, with additional information from the Le Sueur and Greater Blue Earth sediment mass balance studies of Gran et al., 2011 and Bevis, 2015).. Information from the Le Sueur Sediment Budget and other on-going work in the Greater Blue Earth watershed (Greater Blue Earth Sediment Budget) and throughout the Minnesota Basin are used to partition sediment contributions among fields, ravines, bluff, and channel incision sources. The sediment apportionment target information is summarized below in Table 1, showing the range of attributed upland loads from all sources and the current best estimate for this source.
- **Implementation of the sediment apportionment calibration targets.** The 2014 Minnesota River Basin HSPF models parameters were modified so that the amount of sediment coming from the four source categories were consistent with the calibration targets formulated in the previous task. The models were adjusted as needed to maintain acceptable levels of calibration for sediment transport.
- **Tabulation of the simulated sediment source apportionment.** For each watershed, Excel™ workbooks were created that tabulate the simulated sediment source apportionment. Each workbook is currently set up to supply simulated sediment source apportionment at instream calibration and validation stations for each watershed. They have been created in such a way that the workbooks can easily be modified to provide simulated sediment source apportionment at any pour point in each model. Each workbook uses standard model output from the HBN file so the

structure of the 2014 Minnesota River Basin HSPF models did not need to be modified to generate these results.

- **Assess the per-acre sediment loading rates for all of the pervious and impervious land classes in each model.** The 2014 Minnesota River Basin HSPF models generated per-acre upland sediment loading rates that are inconsistent with current constraining information. The models were adjusted as needed to make the sediment loading rates consistent with current constraining information.
- **Maintain acceptable fit between observed and simulated loads and concentrations** as recommended by MPCA's modeling guidance (AQUA TERRA, 2012). The existing calibration for sediment in the 2014 models appears to provide a decent fit to observations of suspended sediment concentrations, but the source apportionment is not consistent with available evidence and statistical analysis of model fit was not presented in RESPEC (2014). The objective of this work is to develop models that conform to constraining information on sediment source apportionment and annual loads while maintaining a high quality fit to instream observations of suspended sediment concentrations. The multi-objective calibration helps ensure a robust model; however, assuring an appropriate fit to source attribution information does appear to make it more difficult to match instream observations.

Table 1. Sediment Apportionment Calibration Targets

HUC8	Upland Best Estimate	Upland Range	Ravine	Bluff	Stream
Chippewa	31%	30-31%	ND	ND	ND
Redwood	23%	21-25%	ND	ND	ND
Yellow Medicine	ND	ND	ND	ND	ND
Cottonwood	21%	21-41%	ND	ND	ND
Watonwan	27%	27-41%	7%	43%	21%
Le Sueur	27%	12-27%	9%	57%	8%
Blue Earth	26%	19-28%	5%	55%	18%
Middle	27%	16-27%	ND	ND	ND
Lower/Metro	23%	14-31%	ND	ND	ND

2.2 Sediment Performance Metrics

Sediment is one of the more difficult water quality constituents to represent accurately in watershed and stream models. Important aspects of sediment behavior within a watershed system include loading and erosion sources, delivery of these eroded sediment sources to streams, drains and other pathways, and subsequent instream transport, scour and deposition processes (USEPA, 2006).

Sediment calibration for watershed models involves numerous steps in estimating model parameters and determining appropriate adjustments needed to insure a reasonable simulation of the sediment sources on the watershed, delivery to the waterbody, and transport behavior within the channel system. Rarely is there sufficient observed local data at sufficient spatial detail to obtain a unique calibration for all parameters for all land uses and each stream and waterbody reach. Consequently, model users focus the calibration on sites with observed data and review simulations in all parts of the watershed to ensure that the model results are consistent with field observations, historical reports, and expected behavior from past experience (Donigian and Love, 2003, AQUA TERRA, 2012).

The level of performance and overall quality of sediment calibration is evaluated in a weight of evidence approach that includes both visual comparisons and quantitative statistical measures. For this effort, the models were already stated to be calibrated for sediment, but did not match evidence on source attribution. Therefore, the primary focus of the model re-calibration was on approximating the source attribution evidence. We also adopted a philosophy, consistent with the RESPEC model representation, of using a parsimonious parameter set in which the parameter KSER, which controls washoff of upland sediment, were generally held constant for a given land use within a HUC8 basin. Similarly, the instream critical shear stresses for scour and deposition were held to narrow and consistent ranges. This approach leads to a robust model that is not over-fit to uncertain data and the fine-scale factors that may skew observations at individual stations; however, it also can reduce the apparent quality of fit in comparing model predictions to observations at individual stations.

The standard approach to sediment calibration focuses on the comparison of model predictions and observed total suspended solids or suspended sediment concentration data. Given the inherent errors in input and observed data and the approximate nature of model formulations, absolute criteria for watershed model performance are not generally considered appropriate by most modeling professionals. Yet, most decision makers want definitive answers to the questions—"How accurate is the model?" and "Is the model good enough for this evaluation?" Consequently, the current state of the art for model evaluation is to express model results in terms of ranges that correspond to "very good", "good", "fair", or "poor" quality of simulation fit to observed behavior. These characterizations inform appropriate uses of the model: for example, where a model achieves a good to very good fit, decision-makers often have greater confidence in having the model assume a strong role in evaluating management options. Conversely, where a model achieves only a fair or poor fit, decision makers may assign a less prominent role for the model results in the overall weight-of-evidence evaluation of management options.

For HSPF and similar watershed models, a variety of performance targets for comparison to observed suspended sediment concentrations have been documented in the literature, including Donigian et al. (1984), Lumb et al. (1994), Donigian (2000), and Moriasi et al. (2007). Based on these references and past experience, HSPF performance targets for sediment are summarized in Table 2.

Table 2. Performance Targets for HSPF Suspended Sediment Simulation (Magnitude of Annual and Seasonal Relative Mean Error (*RE)*; daily and monthly NSE)

Model Component	Very Good	Good	Fair	Poor
Sediment	≤ 20%	20 - 30%	30 - 45%	> 45%

It is important to clarify that the tolerance ranges are intended to be applied to mean values, and that individual events or observations may show larger differences and still be acceptable (Donigian, 2000).

Where model fit to observations is rated less than "good" this can be due to deficiencies in the model simulation of sediment, deficiencies in the model simulation of hydrology, deficiencies in the flow gage and water quality monitoring records, or a combination of the three. Model calibration typically assumes that the observed records are "correct" and maximizes the fit of the model to those records. It is clear in some cases, however, that uncertainty in the monitoring record itself is a major contributor to poor predictability. This is most likely to be true for stations that have short periods of record, locations that are impacted by backwater effects, and sites with unstable channels at which rating curve adjustments (which are essential to the simulation of shear stress and sediment scour and deposition) have not been frequently revised. In addition, most of the observed data consist of grab samples that represent a specific point in space and time. These are compared to model predictions that represent a daily average over a whole model reach (typically several miles in length) that is assumed to be completely mixed. An instantaneous grab sample may not be representative of an average concentration over the course of a day, and small errors in the timing of storm flows will propagate into apparent error in the fit to suspended sediment concentration. Further, observations at a specific spatial location may be affected by local conditions, such as bridge scour, that deviate from the average over the whole reach. As a result, calibration is an inexact science that must proceed by a weight-of-evidence approach.

2.3 Calibration and Validation/Corroboration

Traditional model validation is intended to provide a test of the robustness of calibrated parameters through application to a second time period. In watershed models, this is, in practice, usually an iterative process in which evaluation of model application to a validation period leads to further adjustments in the calibration. A second, and perhaps more useful constraint on model specification and performance is a spatial calibration/corroboration approach in which the model is tested at multiple gages on the stream network to ensure that the model is not over parameterized to fit any one gage or collection of gages. In particular, obtaining model fit to numerous gages at multiple spatial scales from individual headwater streams to downstream stations that integrate across the entire Minnesota River basin helps to ensure that the model calibration is robust. This is especially appropriate for the present model recalibration effort in which the full set of available data has already been used to develop the initial model calibration.

The overall model application period is 1/1/1995 – 12/31/2012. Typical sediment sampling frequencies range from once a week to once a month, but often cover only a subset of years within the overall application period. All of the sediment samples at a gage were used as a full record for that gage and no split sample calibration/validation periods were adopted. Instead a spatial distribution of calibration and validation stations was selected in which initial efforts focused on the "calibration" stations, followed by additional testing and refinement using the corroboration stations. Generally, headwater and upstream gages are considered corroboration stations, which ensures that a corroboration station is not downstream of a calibration station and thus represents a semi-independent test of the model parameterization. Note, however, that model fit to observations is likely to decline for stations with smaller drainage areas because these stations are likely to have flashier responses that amplify the potential discrepancy between grab sample observations and model daily average predictions.

2.4 Components not Adjusted

The adjustments to the sediment calibration are conditional on accepting several aspects of the RESPEC model development (RESPEC, 2014). Most of these were discussed in the hydrology recalibration memo:

- Development and assignment of meteorological forcing time series, including the calculation of potential evapotranspiration, was not adjusted. The models are forced by rainfall gauge records, which have in many instances have been shown not to be representative of areal average precipitation totals during large convective summer storm events.
- Point source discharges are accepted as specified by RESPEC.
- The RESPEC models use a degree-day method for the simulation of snow melt in which melt is estimated solely as a function of air temperature. This provided a good fit to the overall water balance at most stations, but is less adept at simulating rapid changes in the snow balance and does not account for sublimation from the snow pack.

- Hydraulic functional tables (FTables) are not altered from the RESPEC models. Lake simulation is also as set up by RESPEC. Most of the stream reach FTables appear to be specified based on regional hydraulic geometry information and do not incorporate measured channel cross section data[1]. This can bias simulation of channel shear stresses, especially during large storm events.

Also significant to the sediment recalibration are the following:

- The RESPEC models represent sediment contributions from tile drains with surface inlets through the use of GENER statements. The methodology used to generate tile drain sediment loads in this application is unchanged; however, the area factors associated with the GENER statements were updated to properly represent the modifications made to separate agricultural lands by hydrologic soil group (HSG), as described in Section 4. Examination of the approach to simulating tile drain sediment in these models indicates a much more rapid response and quick recession of sediment loads compared to those represented through Special Actions in the Tetra Tech (2008) models.
- The setup of which land uses contribute mass scour (ravine erosion) from the uplands was unchanged. The RESPEC models assign ravine erosion to agricultural lands and to the special bluff and ravine land uses. With the exception of the bluff and ravine land uses (where scour rates were increased to generate considerably more sediment from the land), the setup for ravine erosion is unchanged from what RESPEC provided; however, the results will differ due to the revisions to model hydrology.
- The partitioning from upland total sediment yield to instream sand, silt, and clay fraction loads is not modified from what RESPEC provided.
- Initial stream bed composition of sand, silt, and clay is not modified from what RESPEC provided.
- The Chippewa model received from RESPEC and adapted from the earlier Tetra Tech model is set up with an additional general quality constituent simulating sediment load independent of sheet and rill or gully erosion. This was done because suspended solids concentrations at the upstream station on the Chippewa River at Cyrus have an atypical relationship to flow. That is, high concentrations of TSS often occur at relatively low flows, while the concentration tends to decrease for higher flows. This suggests the presence of an approximately constant load of solids that is independent of flow, such as could occur from extensive animal activity in the stream or sand mining operations. This approach was not modified for the sediment recalibration.

3 Calibration Gage Sites

A total of 63 in-stream water quality stations were used for the Minnesota River Basin HSPF model sediment recalibration. All selected in-stream stations have at least 100 TSS samples during the simulation period. Additionally, with the exception of Watonwan (Watonwan has only one station with more than 100 samples) at least three stations were included for each HUC8. As previously discussed the stations were split into calibration (31 stations) and corroboration (32 stations) based on spatial

[1] The RESPEC memoranda say that for reaches where Tetra Tech previously calculated FTables using results of HEC-RAS models, those FTables "will be scaled by reach length and applied to corresponding reaches in order to maximize the use of the best available data." For reaches that did not have HEC-RAS models, the documentation implies that cross-sectional measurements at USGS gage sites will be used, and, when field information on a gage is not available, "The USGS maximum width, depth, and area data will be used to calculate cross-sections assuming a trapezoidal channel and a bank slope of 1/3."

information. The in-stream water quality stations used for sediment calibration and corroboration are listed in Table 3.

Table 3. Sediment Calibration and Corroboration Stations

Site	HUC_8	HYDSTRA ID	STORET ID	Period of Record	Type
Chippewa R at 140th St, 7 mi N of Cyrus	7020005	276033	S002-190	5/1999 - 9/2012	Calibration
Chippewa R at CSAH-22, 1 mi E of Clontarf	7020005	276036	S002-193	5/1998 - 9/2012	Calibration
Shakopee Ck, at Unn Twnshp Rd, 1 mi W Mn-29, 8 mi*	7020005	276043	S002-201	5/1998 - 9/2012	Calibration
Chippewa R, at MN-40, 5.5 mi E of Milan	7020005	276045	S002-203	5/1998 - 12/2012	Calibration
Dry Weather Creek, at 85th Ave NW, 4 mi NE of Wat*	7020005	276046	S002-204	5/1998 - 9/2012	Corroboration
Shakopee Ck S Andrew Rd at Lk Andrew Otl 4.5 mi W*	7020005	276051	S002-209	6/1996 - 10/2007	Corroboration
Little Chippewa R at MN-28, 4 mi W of Starbuck	7020005	276146	S004-705	3/2007 - 9/2009	Corroboration
Chippewa R, EB, at 15th Ave Ne, 2.5 mi N of Benson	7020005	276156	S005-364	5/1998 - 9/2012	Corroboration
W Fk Beaver Ck at CSAH-4 6.5 mi S of Olivia	7020004	275971	S000-405	6/1999 - 9/2009	Corroboration
Beaver Ck at CSAH-2 2.5 mi NE of North Redwood	7020004	275976	S000-666	6/1999 - 9/2012	Calibration
Sacred Heart Ck at CSAH-15 Br, 5 mi NW of Delhi, *	7020004	275988	S001-341	4/1999 - 9/2012	Corroboration
Hawk Ck at Cr 52 Br, 6.5 mi SE of Granite Falls	7020004	276009	S002-012	6/1999 - 12/2012	Calibration
Palmer Ck at 15th Ave Se, 2 mi NW of Granite Falls	7020004	276010	S002-136	4/1999 - 9/2012	Corroboration
Hawk Ck, at Cr-116, 1.25 mi S of MN-40, 4.2 mi SW*	7020004	276014	S002-140	6/1999 - 9/2012	Corroboration
Hawk Ck, at MN-23, 2.2 mi SW of Maynard	7020004	276022	S002-148	6/1999 - 9/2012	Calibration
Chetomba Ck, at Unnamed Twp Rd, 5 mi SE of Maynard	7020004	276026	S002-152	6/1999 - 9/2012	Corroboration
Yellow Med R, 1 1/3 mi No CSAH-18, 5 1/4 mi NE Ha*	7020004	276068	S002-316	4/2001 - 10/2012	Calibration
So Br Yellow Medicine R On CSAH-26, 4 mi N Minneo*	7020004	276071	S002-320	4/2001 - 8/2012	Corroboration
Cd-119 at CSAH-15, 5.6 mi S of Sacred Heart, Minn*	7020004	276116	S003-866	4/2005 - 8/2012	Corroboration
Timms Ck at CSAH-15, 2.8 mi NNE of Delhi, Minneso*	7020004	276117	S003-867	4/2005 - 8/2012	Corroboration
MM R 500 Ft S CSAH-13 near USGS Gage House Dwnst *	7020004	276123	S004-649	3/2007 - 12/2012	Calibration
Minnesota R, Ethanol Facility Water Supply Intake*	7020004	276349	S007-748	2/2007 - 1/2008	Calibration
Redwood R at CSAH-15 In Russell	7020006	272519	S000-696	5/2001 - 9/2012	Calibration
Redwood R at CSAH-17, 3 miles SW of Redwood Falls	7020006	272872	S001-679	3/1996 - 9/2012	Calibration
Clear Ck Cr-56, 1/3 mi upst conflu Redwd R, NE Ed*	7020006	272541	S002-311	3/1996 - 9/2012	Corroboration
Three mile Ck at Cr-67, 1 mi No of Green Valley	7020006	273019	S002-313	3/1996 - 10/2011	Corroboration
Plum Creek at CSAH 10 Br, 4.75 mi NE of Walnut Gr*	7020008	273015	S001-913	4/1997 - 7/2012	Corroboration
Cottonwood R near MN-68 And Cottonwood St In New *	7020008	273017	S001-918	4/1997 - 10/2011	Calibration
Sleepy Eye Cr at CSAH 8 Br, 2.2 mi N of Leavenwor*	7020008	272478	S001-919	4/1997 - 9/2012	Corroboration
Cottonwood R at CSAH 8 Br, 0.4 mi N of Leavenwort*	7020008	272479	S001-920	4/1997 - 9/2012	Calibration
Cottonwood R at Us-14 Brg, 1 mi NE of Lamberton	7020008	272532	S002-247	5/2000 - 9/2012	Calibration
Watonwan R Br On CSAH-13, 1 mi W of Garden City	7020010	272526	S000-163	10/1996 - 3/2012	Calibration
Le Sueur R MN-66 1.5 mi NE of Rapidan	7020011	272867	S000-340	1/2005 - 7/2012	Calibration
Unn Trib To Big Cobb R, Sh22 0.5 mi N Beauford	7020011	273013	S001-210	1/2005 - 9/2012	Corroboration
Maple R at CSAH 35 5.2 mi S of Mankato, MN	7020011	272950	S002-427	4/2003 - 8/2012	Calibration
Cobb R at CSAH-16, 4.4 mi NE of Good Thunder, MN	7020011	272629	S003-446	3/2006 - 9/2011	Calibration
Le Sueur R at CSAH 28 in Saint Clair, MN	7020011	273029	S003-448	3/2007 - 6/2012	Corroboration
Little Cobb near CSAH-16, 6.3 mi W of Pemberton, *	7020011	272962	S003-574	1/2005 - 9/2012	Corroboration
Le Sueur R at CSAH-8, 5.1 mi SSE of Mankato, MN	7020011	272617	S003-860	3/2006 - 9/2011	Calibration
Maple R at CSAH-18, 2 miles North of Sterling Cen*	7020011	272627	S004-101	4/2006 - 9/2012	Corroboration
Blue Earth River 150 Ft dwst of Rapidan Dam	7020009	272948	S001-231	1/2005 - 3/2012	Calibration
Dutch Creek at 100th St, 0.5 miles W of Fairmont	7020009	272881	S003-000	4/2000 - 10/2008	Corroboration
Center Creek at 315th Avenue - 1 mi S of Huntley	7020009	272608	S003-024	2/2002 - 10/2008	Corroboration
Elm Creek at 290th Ave - 4.5 mi NE of Granada	7020009	272609	S003-025	2/2002 - 10/2008	Calibration
Minnesota River at Mankato, MN	7020007	273053	5325000	3/1996 - 8/2007	Calibration
Minnesota R Bridge On Us-71 And MN-19 at Morton	7020007	272517	S000-145	10/2000 - 10/2011	Calibration
Minnesota R at CSAH 42 at Judson	7020007	272509	S001-759	1/2005 - 2/2012	Calibration
Sevenmile Ck dwst of MN-99, 6 mi SW of St. Peter	7020007	272646	S002-934	4/1996 - 8/2011	Corroboration
Cty Dtch 46A dwst of CSAH-13, 6 mi SW of St. Peter	7020007	272880	S002-936	4/2000 - 9/2011	Corroboration
Sevenmile Ck in Sevenmile Ck Cty Pk, 5.5 mi SW of*	7020007	273028	S002-937	4/1996 - 9/2011	Calibration
Minnesota R at MN-99 in St. Peter, MN	7020007	273031	S004-130	1/2005 - 2/2012	Calibration
Little Cottonwood R at Apple Rd, 1.6 mi S of Courtland	7020007	273033	S004-609	4/1996 - 6/2010	Corroboration
High Island Cr., CSAH-6 By Henderson	7020012	272518	S000-676	6/1998 - 9/2012	Calibration

Site	HUC_8	HYDSTRA ID	STORET ID	Period of Record	Type
Rush River, Sh-93 By Henderson	7020012	272599	S000-822	6/1998 - 9/2012	Calibration
Bevens Cr.,CSAH-41 By East Union	7020012	272871	S000-825	2/1998 - 9/2011	Calibration
Silver Cr.,CSAH-41 By East Union	7020012	272600	S000-843	6/2000 - 8/2011	Corroboration
Buffalo Ck, at 270th St, 1.5 mi NW of Henderson	7020012	272468	S001-807	5/2000 - 9/2012	Corroboration
High Island Ck at CSAH 9, 1 mi NW of Arlington	7020012	272482	S001-891	5/2000 - 9/2012	Corroboration
Carver Ck at Us-212, 2.5 mi E of Cologne, MN	7020012	273022	S002-489	5/1997 - 9/2011	Corroboration
Carver Ck at Cr-140, 2.3 mi NE of Benton, MN	7020012	272489	S002-490	5/1997 - 9/2011	Corroboration
Bevens Ck at 321st Ave, 3 mi SE of Hamburg, MN	7020012	272503	S002-516	11/1999 - 9/2011	Corroboration
Bevens Ck at Rice Ave, 3.9 mi SE of Norwood Yng America	7020012	272470	S002-539	5/1997 - 9/2011	Corroboration
W Chaska Ck, 250' W of Cty Rd 10, behind VFW, in *	7020012	272472	S002-548	4/1998 - 9/2011	Calibration

* Name truncated in RESPEC database

4 Model Updates

4.1 Model Structural Reconfiguration

After consultation with MPCA, a number of changes were made in the structure of the 2014 models. These included subdivision of agricultural land to separate hydrologic soil group (HSG) classes and separation of cropland areas receiving manure applications – both of which may be useful for development of model scenarios. The reconfiguration of the models is described below.

- **Separation of cropland into two classes based on HSG.** Most of the agricultural land in the watershed incorporates tile drainage to improve spring water balance, with intensity of tile drainage generally being greatest in the lacustrine soils of the Le Sueur watershed and adjacent parts of the Blue Earth and Middle Minnesota 8-digit HUCs. The RESPEC (2014) models (exclusive of the Chippewa and Hawk-Yellow Medicine models developed by Tetra Tech) lumped all cropland into two conventional and conservation tillage groups regardless of soil type, which precludes identification of critical areas with marginal soil characteristics. This was rectified by reprocessing the land use information and generating four cropland classes representing Cropland – Conservation Till (HSG A,B), Cropland – Conservation Till (HSG C,D), Cropland – Conventional Till (HSG A,B), and Cropland – Conventional Till (HSG C,D), where the HSG class for cropland is the designation "with drainage" for dual classification soils (i.e., B/D soils are soils that have B characteristics when drained) under the assumption that tile drainage is ubiquitous where it is necessary to improve production performance in the corn belt. This change was implemented before the completion of the hydrology recalibration but not discussed in the November 2015 memo.
- **Representation of manured lands.** For all models except Chippewa and Hawk Yellow Medicine, land receiving manure application was not explicitly represented in the RESPEC (2014) models. The models were set up with a land use called "Cropland – Reserved" for this purpose, but this land use was assigned no area in the 2014 models. The Cropland – Reserved category was changed to "Manure Application (conventional A,B)" and area from Cropland – Conventional Till (HSG A,B) was changed to the Manure Application land use to reflect the estimated acreage that receives manure application. We assumed that manure would primarily be applied to land with better drainage, as the (A,B) grouping (with drainage) is also the dominant component of the overall cropland area, and also that regular manure application is not generally consistent with conservation tillage maintenance of residue cover. The decision by MPCA to incorporate this change in the model structure occurred after the hydrology recalibration and most of the sediment recalibration was complete. To have no net impact on the hydrology and

sediment recalibrations, the manured land was reassigned solely from Cropland – Conventional Till (HSG A,B) and the hydrologic and sediment parameters for manured land were set equal to those for Cropland – Conventional Till (HSG A,B). This was the approach that used in the 2008 TMDL model as well.

- **Separation of Lower Minnesota model into two models.** The increase in the number of model pervious upland land units (PERLNDs) due to the cropland and manured area modifications increased the number of operations in the Lower Minnesota model beyond the upper limit for the current version of the HSPF model. The 2014 Lower Minnesota model was split into two separate linked models: a revised Lower Minnesota model incorporating all sub-basins upstream of and including reach 310 and a new "Metro" Minnesota that incorporates the portion of the original Lower Minnesota model downstream of reach 310.
- **Representation of bluff land area.** The RESPEC (2014) models include the land area in bluffs (as shown on a spatial coverage of bluff area developed in 2011-2012 and provided by MPCA) for all the models except for Chippewa and Hawk Yellow Medicine. There is newer work in progress to better delineate bluffs from LiDAR elevation data; however, those coverages are not yet suitable for use as they identify many small features, such as ditch banks, as bluffs, which is not consistent with the characterization of bluff areas in the model. Similarly, ravine land use has been identified as a separate coverage in the Le Sueur watershed, but work is not complete in other basins (although ravine loading is simulated as a part of the general crop land simulation). Both the bluff and ravine coverages should be updated when this ongoing work is completed. For the present round of models, bluff land use area (as shown on the 2011-12 bluff coverage) was incorporated into the Chippewa and Hawk Yellow Medicine models.
- **Representation of bluff collapse.** The RESPEC (2014) models removed the earlier models' pseudo-random process of contribution from bluff collapse that was implemented via SPECIAL ACTIONS. The old approach, where the process of bluff collapse is simulated as an increase in the bed sediment that is available for transport in stream segments, was reincorporated in the updated models. Table 5-2 (*Bluff Erosion Contribution Rates to Available Stream Bed Sediment*) from Tetra Tech (2008) was used as a starting point along with information from the Le Sueur and Greater Blue Earth sediment mass balance studies (Gran et al., 2011; Bevis, 2015). The watershed-specific estimated total bluff loads were split by area-weighting the bluff contribution based on each individual sub-watershed bluff area for each of the watersheds and then that load was supplied as a constant replenishment to the bed via SPECIAL ACTIONS. This approach maintains the watershed-specific bluff contribution loads at the mouth of each model but proportionally modifies the amount of sediment load applied to a reach containing a bluff land use by the area of bluff contributing to the reach. In the Tetra Tech (2008) report, bluff loading was not represented in the Middle Minnesota and Lower Minnesota models and no specific information on bluff loading rates has been obtained. However, there is bluff land use area in those two models. To implement the SPECIAL ACTIONS in the Middle and Lower Minnesota models, the Le Sueur bluff contribution loads were used as a proxy at the recommendation of the MPCA project manager. First, the Le Sueur bluff loading rate was converted to a yield in tons/ac relative to the specified bluff acreage. Second, the converted Le Sueur rate was applied to the bluff area in the Middle, Lower, and Metro models to develop the bluff erosion contribution rates to available stream bed sediment.
- **Creation of PLTGEN outputs for models not having those outputs.** Most of the RESPEC (2014) models provided model output at instream monitoring locations by writing to PLTGEN's. PLTGEN output was added to the Chippewa, Hawk-Yellow Medicine, Middle Minnesota, Lower Minnesota, and Metro Minnesota models. This allowed for a consistent set of tools to compare simulated and observed instream concentrations and load summaries.

4.2 Upland Sediment Simulation

The RESPEC (2014) Minnesota River Basin HSPF models in most cases had upland sediment parameters similar to those calibrated in Tetra Tech (2008) and thus produce consistent loading rate estimates. This was not the case for the impervious land simulation, where the use of a high value of the washoff parameter (KEIM) resulting in extremely high loading rates from urban land, apparently accidentally set at ten times the previously calibrated value, resulted in urban impervious land generating about 1 ton per acre per year of solids and dominating total sediment load in some watersheds. Municipal Separate Storm Sewer System (MS4) monitoring results summarized by MPCA suggest that the sediment rate for urban developed land should, on average, be less than 0.1 ton/ac/yr.

The main parameters controlling upland sediment generation and transport to the stream are:

- KRER coefficient in the soil detachment equation for pervious land
- KSER coefficient in the detached sediment washoff equation for pervious land
- KEIM coefficient in the solids washoff equation for impervious land

The above parameters were the main PERLND and IMPLND parameters modified to bring consistency with the current constraining information and the simulated per acre sediment loading rates. There are other parameters that have a major influence specifically the exponential terms (JRER, JSER, and JEIM), although those were not modified from what RESPEC previously used because reasonable per acre sediment loading rates were obtained without modifying them. However, almost all sediment parameters were modified for Bluffs and Ravines. Since these land uses have small area and are large contributors of the overall sediment load in the stream, all of the parameters were set up so that the land areas have high loading rates.

Table 4 through Table 6 show the range of values used for each land use and each model for the three main parameters modified for the upland sediment simulation. KRER was calculated using the land use coverage and soils coverage and then area weighted to a value for each land use and weather station zone and was not further modified during calibration. KSER was the main parameter adjusted to control the sediment washoff and delivery. KEIM was the only parameter adjusted to control solids washoff and delivery. Table 7 provides the typical monthly erosion-related cover used for all models to provide some context to the calibrated values of KRER and KSER.

Table 4. KRER Values Used for Updated Models

Land Use	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban	0.241 - 0.287	0.233 - 0.27	0.233 - 0.266	0.237 - 0.278	0.239 - 0.289	0.228 - 0.268	0.229 - 0.271	0.207 - 0.281
Forest	0.24 - 0.281	0.234 - 0.273	0.211 - 0.253	0.209 - 0.287	0.24 - 0.292	0.165 - 0.269	0.2 - 0.274	0.177 - 0.261
Cropland - Conservation Till (HSG A,B)	0.243 - 0.277	0.233 - 0.27	0.232 - 0.265	0.225 - 0.272	0.217 - 0.284	0.23 - 0.251	0.217 - 0.256	0.04 - 0.305
Cropland - Conservation Till (HSG C,D)	0.314 - 0.363	0.312 - 0.362	0.127 - 0.331	0.106 - 0.286	0.15 - 0.336	0.192 - 0.339	0.219 - 0.357	0.02 - 0.313
Cropland - Conventional Till (HSG A,B)	0.243 - 0.277	0.233 - 0.27	0.232 - 0.265	0.225 - 0.272	0.217 - 0.284	0.23 - 0.251	0.217 - 0.256	0.04 - 0.305
Cropland - Conventional Till (HSG C,D)	0.314 - 0.363	0.312 - 0.362	0.127 - 0.331	0.106 - 0.286	0.15 - 0.336	0.192 - 0.339	0.219 - 0.357	0.02 - 0.313
Cropland - Manure Application (conv A,B)	0.243 - 0.277	0.233 - 0.27	0.232 - 0.265	0.225 - 0.272	0.217 - 0.284	0.23 - 0.251	0.217 - 0.256	0.04 - 0.305
Grassland	0.249 - 0.28	0.212 - 0.277	0.217 - 0.287	0.209 - 0.264	0.214 - 0.274	0.204 - 0265	0.21 - 0.275	0.171 - 0.276
Pasture	0.211 - 0.288	0.22 - 0.284	0.211 0.261	0.192 - 0.282	0.227 - 0.279	0.208 - 0.27	0.217 - 0.268	0.113 - 0.274
Wetland	0.254 - 0.313	0.227 - 0.278	0.155 - 0.244	0.042 - 0.249	0.104 - 0.276	0.066 - 0.311	0.072 - 0.264	0.049 - 0.236
Feedlot	0.25	0.25	0.25	0.23 - 0.27	0.246	0.245	0.244	0.244
Bluff	0.24	0.24	0.24	0.23 - 0.27	0.243	0.243	0.174	0.174
Ravine	0.28	0.28	0.28	0.23	0.278	0.278	0.278	0.278

Notes: KRER estimates are derived from soil survey data on the Universal Soil Loss Equation erodibility (K) factor. Values for Chippewa and Hawk Yellow Medicine not presented here due to different PERLND configurations. Refer to their UCI files for their parameterization

Table 5. KSER Values Used for Updated Models

Land Use	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban	0.08	0.08	0.07	0.08	0.08	0.08	0.08	0.08
Forest	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cropland - Conservation Till (HSG A,B)	0.2	0.3	0.08	0.2 & 0.05	0.25	0.3	0.15	0.15
Cropland - Conservation Till (HSG C,D)	0.15	0.3	0.08	0.2 & 0.05	0.1	0.3	0.15	0.15
Cropland - Conventional Till (HSG A,B)	0.25	0.4	0.11	0.3 & 0.1	0.3	0.4	0.2	0.2
Cropland - Conventional Till (HSG C,D)	0.2	0.4	0.11	0.3 & 0.1	0.15	0.4	0.2	0.2
Cropland - Manure Application (conv A,B)	0.25	0.4	0.09	0.3 & 0.1	0.3	0.4	0.2	0.2
Grassland	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Pasture	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Wetland	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Feedlot	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
Bluff	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
Ravine	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

Note: Values for Chippewa and Hawk Yellow Medicine not presented here due to different PERLND configurations. Refer to their UCI files for their parameterization

Table 6. KEIM Values Used for Updated Models

Land Use	Chippewa	HYM	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban Impervious	0.03	0.02	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015

Table 7. Typical Monthly Cover Values Used for Updated Models

Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Urban	0.85	0.85	0.85	0.88	0.88	0.88	0.88	0.88	0.88	0.86	0.85	0.85
Forest	0.85	0.85	0.85	0.9	0.95	0.95	0.95	0.95	0.95	0.95	0.85	0.85
Cropland - Conservation Till A,B	0.2	0.2	0.2	0.35	0.35	0.3	0.4	0.85	0.85	0.7	0.55	0.35
Cropland - Conservation Till C,D	0.2	0.2	0.2	0.35	0.35	0.3	0.4	0.85	0.85	0.7	0.55	0.35
Cropland - Conventional Till A,B	0.05	0.05	0.05	0.15	0.15	0.2	0.4	0.85	0.85	0.6	0.4	0.15
Cropland - Conventional Till C,D	0.05	0.05	0.05	0.15	0.15	0.2	0.4	0.85	0.85	0.6	0.4	0.15
Cropland - Manure Application (conv A,B)	0.05	0.05	0.05	0.15	0.15	0.2	0.4	0.85	0.85	0.6	0.4	0.15
Grassland	0.75	0.75	0.75	0.8	0.85	0.9	0.9	0.9	0.9	0.9	0.85	0.8
Pasture	0.75	0.75	0.75	0.8	0.85	0.9	0.9	0.9	0.9	0.9	0.85	0.8
Wetland	0.9	0.9	0.9	0.92	0.97	0.97	0.97	0.97	0.97	0.97	0.92	0.9
Feedlot	0.1	0.1	0.1	0.03	0.03	0.1	0.6	0.85	0.85	0.7	0.2	0.15
Bluff	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Ravine	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

4.3 INSTREAM SEDIMENT SIMULATION

As previously discussed the 2014 Minnesota River Basin HSPF models had sediment source apportionment results that were inconsistent with the current constraining information. For example, the 2014 models of the Blue Earth and Le Sueur watersheds attributed over 70 percent of the total sediment load to upland sources compared to less than 30 percent based on radiometric analysis (see Table 1 above). This fact, along with the updated hydrology calibration, required adjustment of the instream simulation of sediment.

There are two types and three classes of sediment simulated in HSPF non-cohesive (sand) and cohesive (silt and clay). The three sediment classes are simulated independently of one another in the stream. Load delivered from the land surface is simulated as total sediment and partitioned into sand, silt, and clay factions at the stream edge. As previously stated, the upland to instream partitioning of sediment was not modified from what was provided by RESPEC.

In HSPF, sand can be simulated by one of three approaches: 1) Toffaletti equation, 2) Colby method, or 3) power function of velocity. For the Minnesota River Basin HSPF the selected sand method is 3) power function of velocity. This was the method that RESPEC used and was unmodified for the recalibration.

The main parameters controlling the cohesive instream sediment simulation are listed below. These values are contained in the SILT-CLAY-PM block of the UCI and the data block is repeated twice. The first set in the UCI pertains to silt and the second set in the UCI pertains to clay.

- D effective diameter of the particles
- W particle fall velocity in still water
- RHO particle density
- TAUCD critical bed shear stress for deposition
- TAUCS critical bed shear stress for scour
- M erodibility coefficient of the sediment

D, W, and RHO were parameterized with values in range with those outlined in US EPA (2006) and following the approach laid out for MPCA One Water projects by AQUA TERRA (2012). Values for TAUCD, TAUCS, and M were calibrated by first outputting the hourly TAU (bed shear stress) for the simulation period. Second, the percentile ranges of TAU for each simulated reach were tabulated. Third, initial values TAUCD, TAUCS, were input by selecting a percentile used in previous model calibrations and finding each reaches TAU value corresponding to that percentile. Lastly, after the upland simulation was completed, TAUCD, TAUCS, and M were adjusted through an iterative process until an acceptable match was achieved between observed instream concentrations and loads and simulated concentrations and loads, and sediment source apportionment (percent and estimated load where available) were consistent with the current constraining information.

As noted above, the representation of sediment load associated with mass wasting of bluffs was reverted to the prior approach (Tetra Tech, 2008) where the process of bluff collapse is simulated as an increase in the bed sediment that is available for transport in stream segments. Table 8 shows the bluff erosion contribution rates to available stream bed sediment as a total rate above each models pour point or end point. The watershed-specific bluff contribution loads were split among identified bluff land uses based on the bluff area by sub-basin. That load was then supplied as a constant replenishment rate to the bed for the reaches containing upland bluff area via SPECIAL ACTIONS. The added sediment was then mobilized when higher flows occur (i.e., TAU values greater than TAUCS). The bluff reaches had higher values of the erodibility coefficient M specified to maintain proper stream bed balance.

Table 8. Total Sediment Loading to Stream Bed Storage from Bluff Mass Wasting Processes

Watershed	Bluff Contribution (tons/hr)
Blue Earth River	28
Chippewa River	0.1
Cottonwood River	2.1
Hawk Creek	0.97
Le Sueur River	11.2
Lower Minnesota River	0.05
Middle Minnesota River	0.13
Redwood River	1.6
Watonwan River	2.1
Yellow Medicine River	1.5

In the initial calibration the simulated TSS concentrations were generally lower than those observed at base flow conditions. To improve the baseflow simulation, a clay load associated with groundwater was supplied as a surrogate for a combination of fine material in actual groundwater discharges, and activity of fish, animals, and humans in the streams. The added clay load equated to 5 mg/L for all models except Hawk-Yellow Medicine, and Chippewa, which were assigned 1 mg/L.

Table 9 provides the range of values used in the SILT- and CLAY-PM blocks. Values for D, W, RHO, and M in this table are the actual values input into the UCI, while entries for TAUCD and TAUCS provide the percentile range of simulated TAU. Since each reach has its own model derived value for TAU providing the percentile range of TAU provides much more insight into the parameterization of TAUCD and TAUCS. For each basin, parameters other than the critical shear stresses were specified separately for stream, lake, and bluff-area reaches but otherwise held constant or varied only slightly (in the case of M) across the basin. The erodibility and critical shear stress parameters were varied within relatively constrained ranges to improve the calibration fit.

Table 9. SILT-CLAY-PM Block Values Used for Updated Models

Constituent	RCHRES Type	Parameter	Chippewa	HYM	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Silt	Stream	D	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
		W	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039
		RHO	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
		TAUCD*	1-50	4-7	1-18	4-6	1-10	4-10	1-13	1-18	1-13	1-16
		TAUCS*	80-85	80-81	75-76	75-76	66-78	65-92	65-80	73-91	74-78	68-80
		M	0.004	0.004	0.015	0.015-0.025	0.01	0.006-0.03	0.025	0.01	0.02	0.02
	Bluff	D	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
		W	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039
		RHO	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
		TAUCD*	6	5-6	6	5-6	5-6	4-11	5-6	5-6	5-6	5-6
		TAUCS*	80-81	81	76	75-76	66-78	65-92	65-75	85-86	75-76	75-76
		M	0.01	0.07	0.1	0.05-0.1	0.03-0.05	0.008-0.07	0.1	0.1	0.1	0.1
	Lake	D	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
		W	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039	0.0039
		RHO	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
		TAUCD*	97-99.9	97-98	97-99.9	97-99.9	98-99	97-99	95-99	97-99	97-99	97-99
		TAUCS*	99-99.9	99	99-99.9	97-99.9	99-99.9	99-99.9	96-99.9	99-99.9	99-99.9	99-99.9
		M	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005
Clay	Stream	D	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		W	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
		RHO	2	2	2	2	2	2	2	2	2	2
		TAUCD*	1-47	3-4	1-18	3-4	1-10	1-9	1-13	1-16	1-12	1-13
		TAUCS*	75-85	75-76	70-71	70-72	60-73	60-87	65-80	60-89	68-75	64-73
		M	0.004	0.004	0.015	0.015-0.025	0.01	0.006-0.03	0.025	0.01	0.02	0.02
	Bluff	D	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		W	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
		RHO	2	2	2	2	2	2	2	2	2	2
		TAUCD*	3-4	3-4	3-4	3-4	3-4	1-5	3-4	3-4	3-4	3-4
		TAUCS*	76	75-76	70	70-71	60-73	60-87	60-70	80-81	70-71	70-71
		M	0.01	0.07	0.1	0.05-0.1	0.03-0.05	0.008-0.07	0.1	0.1	0.1	0.1
	Lake	D	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
		W	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001	0.00001
		RHO	2	2	2	2	2	2	2	2	2	2
		TAUCD*	97-99.9	97-98	97-99.9	97-99.9	98-99	97-99	95-99	97-99	97-99	97-99
		TAUCS*	99-99.9	99	99-99.9	97-99.9	99-99.9	99-99.9	96-99.9	99-99.9	99-99.9	99-99.9
		M	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005

* Value in table provided as a percentile of the hourly simulated TAU range

4.4 Sediment Source Apportionment

Sediment source data is primarily based on interpretation of radiometric data (^{210}Pb and ^{137}Cs) that provides an estimate of the fraction of sediment that has recently been in contact with the atmosphere (Schottler et al., 2010). To a first approximation, the percentage of "new" sediment is interpreted as the fraction of stream sediment load that derives from upland surface erosion, as opposed to load from channel erosion, ravine erosion, or bluffs. That interpretation is not exact, however, as each source contains some mixture of older, buried soil and exposed surface sediment. Another problem for interpretation is that upland sediment load may be temporarily stored and then re-scoured from the stream bed, so model output of channel scour does not necessarily represent only "old" sediment. A unique set of upland loading rates, bed erosion rates, and downstream sediment transport measures is thus not readily interpretable from the model output and the ratio of old to new sediment is not directly extractable from the model because individual sediment particles are not tracked as they move in and out of bed storage.

This issue was explored in some detail in Tetra Tech (2008), from which the following text is summarized:

Consider a case in which there is an external (upland) sediment load of *X* and a bank and bluff erosion load of *B*. The processes can be conceptually represented by a simple box model (Figure 1).

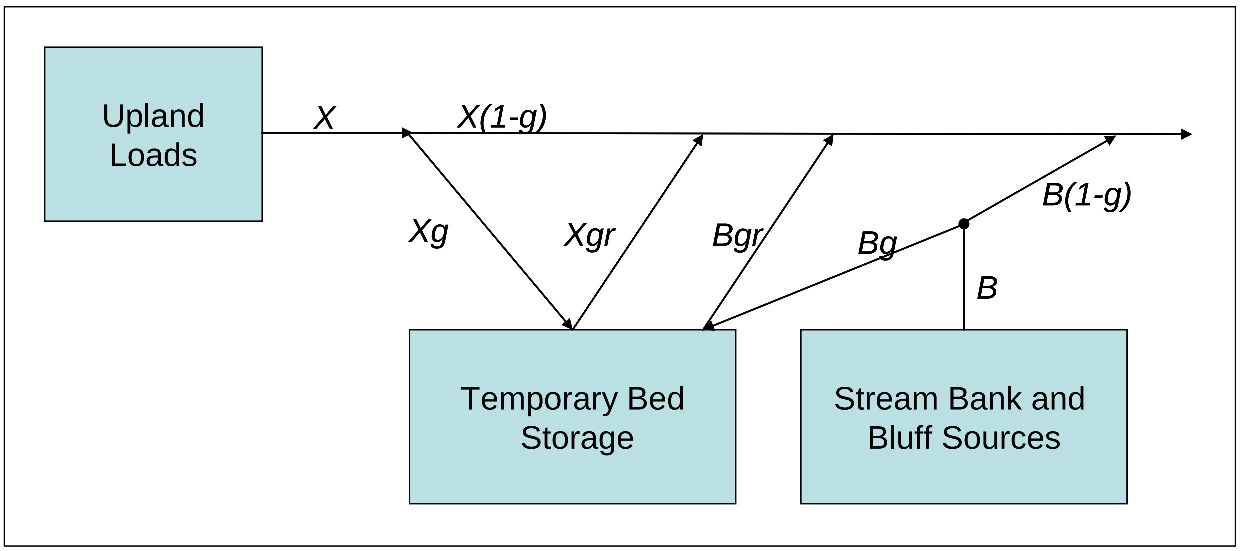


Figure 1. Conceptual Representation of Stream Sediment Processing

For an external sediment load *X*, a fraction *g* goes into temporary bed or floodplain storage. A fraction of this (*r*) is in turn resuspended and transported downstream as *Xgr*. Similarly, erosion of established stream banks and bluffs yields a total load *B*. This is assumed to be subject to the same physical processes as the upland load, *X*: A fraction *g* goes into temporary storage, of which a further fraction *r* is transported downstream. (The factor *r* may be thought of as a recycle rate. The total sediment load transported downstream, *Y*, is then:

$$Y = (X + B)(1 - g + gr).$$

The model output provides information on both gross bed scour (*GS*, resuspension flux only) and net bed scour (*NS*, balance of scour and deposition). Two additional equations can be written for *GS* and *NS* based on the simple box model:

$$GS = Xgr + B + Bgr$$
$$NS = X\left(gr - g\right) + B\left(1 + gr - g\right).$$

Given X, this appears to yield three equations in three unknowns. However, the system of equations is indeterminate, as the output, *Y,* is simply equal to the net scour (*NS*) + *X*. Therefore, there is not a unique solution unless additional constraints are imposed regarding the recycle rate, *r*.

Tetra Tech (2008) explored this issue further and concluded that the net effect of scour plus deposition was that the true upland-derived fraction at the outlet was likely to be about 95% of the simulated upland load divided by the downstream output load. Conducting the analysis is, however, difficult because the gross scour and net scour components need to be separated based on analysis of hourly simulation results and the results, in the end, remain uncertain because a value for *r* must be assumed.

To address these issues, a new approximate methodology was developed to generate simulated source apportionments in an efficient manner. For this purpose, Excel™ "Sediment Sources" workbooks were created with live equations that tabulate the simulated sediment source apportionment. The workbooks are provided for further investigation. The following discusses how to update the workbooks and the calculations that are being performed in the workbooks.

To use/update the workbook for any of the watershed models in the Minnesota River Basin HSPF the user must first generate yearly reach.HBN and wshd.HBN files for sediment. To do this the user must specify a flag of 5 for SED, SLD, and SED in the BINARY-INFO blocks for PERLND, IMPLND, and RCHRES respectively and then run the model. The needed HBN files can be found in the PLTGEN folder for the model that you are working with. Data for certain constituents contained in the reach.HBN and wshd.HBN are used to update the reachHBN and wshdHBN tabs in the EXCEL workbook. To access the data the user must open the reach.HBN and wshd.HBN files with the SARA Timeseries Utility. The reach.HBN file is populated with ISED-TOT (inflow of total sediment to each RCHRES by year), ROSED-TOT (outflow of total sediment from each RCHRES by year), and RSED-BED-TOT (average bed storage mass of sediment for each RCHRES by year). The wshd.HBN is populated with WSSD (washoff of detached sediment for each PERLND by year), SCRSD (scour of matrix soil for each PERLND by year), and SOSLD (washoff of solids for surface for each IMPLND per year). The user must select each constituent individually and also be sure to select the location attribute otherwise the workbook will not function properly. Copy/Paste the created list from SARA to the appropriate location in the attribution workbook and the pertinent information should be updated.

The All_Reach_Summary worksheet performs a series of tabulations that calculate the necessary information to determine the source apportionment. The workbook has comments associate with cells A4:A21 to provide the user with information about what is actually being calculated. The calculations use the information in the reachHBN and wshdHBN along with information in the SchemPLS_All, SchemPLS_RAV, SchemPLS_BLF, SchemPLS_OTH, SchemILS, and SchemRch tabs. All of the tabs listed in this paragraph contain live equations so please be very cautious about inserting, deleting, or modifying anything in all of the listed tabs.

The results of the All_Reach_Summary are then used to populate the Source_Attribution tab. For each workbook the Source_Attribution tab varies in the number of locations where source attributions are currently calculated, and the number of upstream reaches that are used to develop the source attribution. Basically, the source attribution is calculated by using the full 18 year simulation for all reaches upstream and including the reach pour point of interest. For each reach the sediment load of WSSD and SCOUR for Ravine, Bluff, and all other PERLND's are found in the All_Reach_Summary tab. Also found for each reach is the amount of sediment coming from IMPLND's as well as the deposition (positive value) or scour (negative value) from the instream simulation. Upland, Ravine, Bluff, and Stream mass are then approximated using the following calculations:

- Upland = Sum of WSSD Other, SCRSD Other, and SOSLD

- Ravine = Sum of WSSD Ravine and SCRSD Ravine
- Bluff = Sum of WSSD Bluff , SCRSD Bluff, and (-1* Deposition/Scour from Bluff Reaches)
- Stream = Sum of -1* Deposition/Scour from Non-Bluff Reaches (as scour is negative in the output).

Sediment source apportionments from upstream models are copy/pasted into the downstream model workbooks. For instance, for the Blue Earth at the mouth the workbook is theoretically only calculating the input from the Blue Earth model itself (the local drainage); however, when the Watonwan and Le Sueur source apportionment results are incorporated you can calculate the source apportionment at the mouth for the entire drainage basin. Additionally, the Chippewa model accounts for the Watson Sag Diversion to the Lac Qui Parle. The source apportionment calculations do not explicitly account for the sediment lost due to the diversion. Instead the apportionment is calculated on a percentage basis as though the diversion did not exist and then the calculated source fractions are applied to the Chippewa ROSED value at the mouth to calculate the source apportionment going into the Hawk Yellow Medicine model. That same source apportionment is applied to the Lac qui Parle input to the Hawk-Yellow Medicine model as simulation model results are not yet available for Lac qui Parle and its upstream watershed.

Based on comparison to a detailed (hourly) analysis of the Le Sueur River basin, this method, which includes only annual totals of scour and/or deposition, provides a close approximation to a more complex analysis using hourly data. However, as noted above, complete attribution of surface sediment sources would require correction for net storage/resuspension within the stream network, which would be expected to result in a small reduction in the estimated surface-derived fraction.

5 Results

5.1 Upland Unit Area Loads

As described above, some of the existing (2014) models provided unrealistic results for the amount of sediment being generated from upland sources, especially from developed land. Table 10 displays the simulated upland sediment loading rates by basin and land use for the revised model. HSPF simulates urban pervious and impervious lands separately, so a combination result for 25 percent impervious (and 75 percent developed pervious) land is shown for comparison with MS4 loading rates. These results were calculated by taking the wshd.HBN outputs of WSSD, SCRSD, and SOSLD (discussed in section 4.4) and 1) calculating the average annual sediment load for each PERLND/IMPLND (combination of weather station zone and land use) and 2) averaging the PERLND/IMPLND average annual sediment load across all weather station zones to find the average annual sediment load for each land use. Note, the loads are not area weighted but are simply a tabulation of unit area load as provided by the wshd.HBN output.

Excel™ workbooks for each watershed model were created and are provided as a supplement to this memorandum to allow for further investigation.

Le Sueur, Blue Earth, and Watonwan watersheds had much more constraining information for the apportionment of sediment mass and percent contribution due to the Le Sueur sediment budget and Greater Blue Earth sediment budget efforts (Gran et al., 2011; Bevis, 2015). That information along with results of Schottler et al. (2010) as further updated in presentations by the investigators to MPCA (personal communication from Chuck Regan, MPCA) was used to constrain the upland sediment source apportionment.

A goal for the upland sediment simulation was to supply largely homogeneous parameterization throughout the entire suite of Minnesota River Basin HSPF. Simulated upland unit area loading rates are in general roughly consistent between basins, but differ according to the local meteorological forcing, soil characteristics, and hydrologic simulation. Some deviations between basins are intentional: Specifically, for the Watonwan basin, the unit area loadings were reduced to obtain a better match between simulated and observed upland source mass as provided in the Greater Blue Earth sediment budget (Bevis, 2015). Additionally, for the Blue Earth the unit area loading was increased to get a better match between simulated upland source mass and observed upland source mass provided in the Greater Blue Earth sediment budget. It is also worth noting that the Hawk-Yellow Medicine model shows less distinction between HSG A,B and C,D soils for agriculture. This basin contains primarily B and B/D (B when drained) soils so the difference is not of great practical importance for total load simulation. The similarity between loading rates for different soil groups appears to be due to the hydrology set up of the model, which specifies only a small difference in infiltration rates between the different HSG classes.

Table 10. Revised Annual Average Unit Area Sediment Loads, 1995-2012 pound/acre/year

Land Use	Chippewa	HawkYM	Redwood	Cottonwood	Watonwan	Le Sueur	Blue Earth	Middle	Lower	Metro
Urban Pervious	31.3	129.6	72.1	86.1	89.6	195.7	147.2	46.1	38.4	70.5
Urban Impervious	325.7	285.3	292.9	304.9	338.1	364.4	361.0	318.5	318.9	349.9
Urban Combo (75% Pervious 25% Impervious)	104.9	168.5	127.3	140.8	151.7	238.9	200.7	114.2	108.5	140.4
Forest	0.6	7.5	6.0	6.8	14.2	13.6	16.5	4.4	3.7	7.0
Cropland - Conservation Till (HSG A,B)	61.3	47.5	36.8	55.6	31.0	85.3	77.4	107.0	45.3	81.4
Cropland - Conservation Till (HSG C,D)	126.4	52.5	247.1	375.8	198.1	350.0	266.1	244.3	283.4	347.7
Cropland - Conventional Till (HSG A,B)	63.5	71.2	51.0	79.2	48.2	138.9	104.4	150.8	67.4	115.5
Cropland - Conventional Till (HSG C,D)	160.3	77.4	312.6	497.7	260.5	512.1	359.0	301.1	355.2	426.9
Cropland - Manure Application (conv A,B)	148.3	77.1	51.0	79.1	48.2	138.4	104.4	150.3	67.4	114.5
Grassland	1.6	13.7	8.7	8.7	22.3	26.1	25.7	3.4	1.1	2.3
Pasture	28.2	NA	16.5	17.2	36.4	47.5	39.4	6.1	2.3	4.8
Wetland	0.6	0.0	0.5	0.3	2.9	1.5	1.2	0.6	0.5	0.9
Feedlot	NA	NA	233.5	294.8	367.5	570.8	563.7	167.7	129.7	239.4
Bluff	271	25	2,276	3,124	5,696	6,262	10,550	1,202	516	1,053
Ravine	NA	NA	7,827	16,369	95,117	31,237	393,722	8,996	1,097	2,198

Note: For Chippewa, results shown for Forest, Grass, and Pasture are for D soils. For Hawk-Yellow Medicine, results shown for Forest, Grass, and Pasture are for D soils on low slopes. Feedlot and Ravine land uses are not specified separately in the Chippewa and Hawk-Yellow Medicine models.

5.2 Instream Calibration and Validation

As previously discussed, separate calibration and validation tests were conducted based on a spatial and temporal distribution of stations (Table 3). These are summarized in electronic spreadsheets provided as a supplement to this memorandum. The statistical results below are reported according to the two groups of gages (calibration and validation) in the next two sub-sections. A representative station was selected for each group and graphical results are provided for those stations for example purposes. Comprehensive graphics for each gage are provided in the electronic files.

The summary statistics include concentration average error, concentration median error, load average error and load median error. All of the statistics are performed on paired comparisons of simulated daily average and observed instream instantaneous grab measurements. Also provided is the number of paired comparisons for each station.

5.2.1 Calibration Stations

Table 11 (in five parts) shows the statistical results for the calibration gages. The calibration strategy focused foremost on sediment source attribution and used harmonized parameter estimates instead of over-fitting individual gages, resulting in some relatively large errors, especially at some of the stations where there are limited data for accurate hydrologic calibration. The quality of fit for suspended sediment is generally in the good to very good range for concentration and load median errors. The quality of fit ranges from very good to poor for concentration and load average errors. Average errors are more susceptible to large deviations because they can be heavily influenced by extreme events and slight shifts in timing. Additionally, the stations that show large differences in the average error have a much more favorable comparison when looking at the graphical comparisons. It is advised to look at both the statistical comparison and graphical comparison when assessing the overall model fit to instream monitoring data.

Graphical examples of the calibration for Le Sueur River at MN-66 1.5 miles NE of Rapidan are provided in Figure 2 through Figure 6. Results for all other calibration gages are contained in the electronic files.

Table 11. Summary Statistics for Calibration Stations

Site	Chippewa R at 140th St, 7 mi N of Cyrus	Chippewa R at CSAH-22, 1 mi E Of Clontarf	Shakopee Ck, at Unn Twnshp Rd, 1 mi W MN-29	Chippewa R, at MN-40, 5.5 mi E of Milan	Beaver Ck at CSAH-2 2.5 mi NE of North Redwood	Hawk Ck at CR 52 Br, 6.5 mi SE off Granite Falls	Hawk Ck, at MN-23, 2.2 mi SW of Maynard
STORET Code	S002-190	S002-193	S002-201	S002-203	S000-666	S002-012	S002-148
Count	243	322	314	367	374	408	375
Conc Ave Error	68.7%	-129.9%	-33.9%	-141.7%	-428.6%	-76.6%	-3.89074
Conc Median Error	1.6%	-26.3%	-52.5%	-26.9%	20.0%	14.1%	-1.0%
Load Ave Error	340.3%	39.1%	-62.1%	-23.3%	3.8%	62.0%	44.6%
Load Median Error	5.9%	-14.4%	-33.9%	-10.2%	0.2%	0.5%	-0.4%

(Table 11. Continued)

Site	Yellow Med R, 1 1/3 mi N CSAH-18	MN R 500 Ft S CSAH-13 near USGS Gage	Minnesota R, Ethanol Facility WS Intake*	Redwood R at CSAH-15 in Russell	Redwood R at CSAH-17, 3 Miles SW of Redwood Falls	Cottonwood R near MN-68 In New Ulm	Cottonwood R at CSAH 8 Br, 0.4 mi N Leavenworth
STORET Code	S002-316	S004-649	S007-748	S000-696	S001-679	S001-918	S001-920
Count	-7.7%	-59.8%	61.1%	47.1%	-21.0%	-37.8%	-18.7%
Conc Ave Error	7.7%	22.7%	8.7%	3.1%	-6.9%	0.2%	-1.6%
Conc Median Error	136.5%	-2.3%	-27.5%	-35.3%	76.2%	-3.2%	62.8%
Load Ave Error	0.4%	5.2%	1.7%	0.1%	-1.5%	0.0%	-0.1%
Load Median Error	-7.7%	-59.8%	61.1%	47.1%	-21.0%	-37.8%	-18.7%

(Table 11. Continued)

Site	Cottonwood R at US-14 Brg, 1 mi NE Lamberton	Watonwan R Br on CSH-13, 1 mi W of Garden City	Le Sueur R Mn-66 1.5 mi NE of Rapidan	Maple R At CSAH 35 5.2 mi S of Mankato	Cobb R at CSAH-16, 4.4 mi NE of Good Thunder	Le Sueur R at CSAH-8, 5.1 mi SSE of Mankato	Blue Earth R 150 Ft dnst of Rapidan Dam
STORET Code	S002-247	S000-163	S000-340	S002-427	S003-446	S003-860	S001-231
Count	210	502	251	378	210	205	240
Conc Ave Error	17.5%	-423.8%	39.2%	14.6%	-162.7%	164.7%	-18.9%
Conc Median Error	5.7%	-13.5%	11.5%	-0.2%	51.0%	2.9%	4.9%
Load Ave Error	123.3%	15.6%	12.2%	19.0%	161.7%	-25.1%	-4.3%
Load Median Error	0.1%	-1.3%	0.6%	0.1%	15.3%	0.0%	0.7%

(Table 11. Continued)

Site	Elm Creek at 290th Ave - 4.5 mi NE of Granada	Minnesota River at Mankato	Minnesota R Bridge on US-71 and MN-19 at Morton	Minnesota R at CSAH 42 at Judson	Sevenmile Ck In Sevenmile Ck Cty Pk	Minnesota R at MN-99 in St. Peter	High Island Cr., CSAH-6, Henderson
STORET Code	213	45	165	199	261	239	297
Count	213	45	165	199	261	239	297
Conc Ave Error	-31.7%	77.6%	-43.1%	-58.8%	-710.8%	-39.3%	16.6%
Conc Median Error	-3.5%	9.6%	-1.5%	5.7%	2.5%	6.4%	1.3%
Load Ave Error	126.7%	34.7%	92.3%	66.8%	-43.5%	42.6%	-55.6%
Load Median Error	0.5%	0.6%	-0.5%	0.3%	0.0%	1.8%	-0.1%

(Table 11. Continued)

Site	Rush River, SH-93 by Henderson	Bevens Cr.,CSAH-41 by East Union	W Chaska Ck, 250' W of Cty Rd 10
STORET Code	S000-822	S000-825	S002-548
Count	266	135	129
Conc Ave Error	1.1%	27.1%	-4.4%
Conc Median Error	-7.2%	-14.0%	3.0%
Load Ave Error	-81.5%	-34.4%	-56.0%
Load Median Error	-2.3%	-3.5%	0.2%

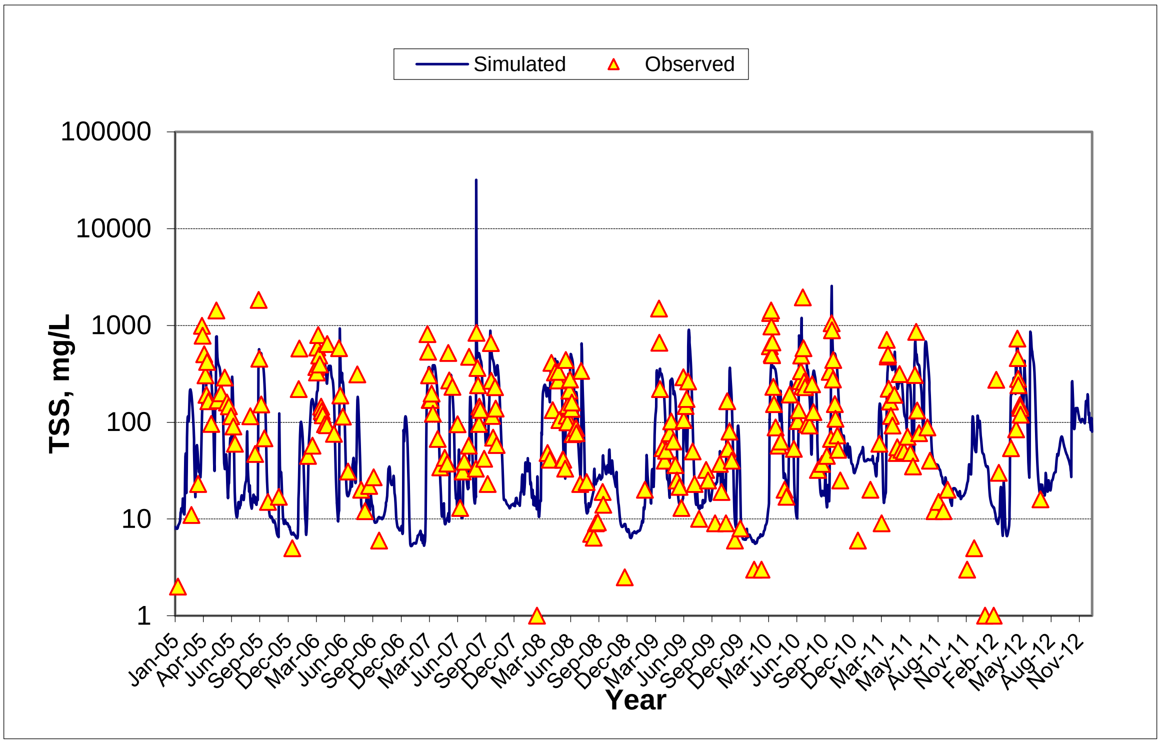


Figure 2. Timeseries Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

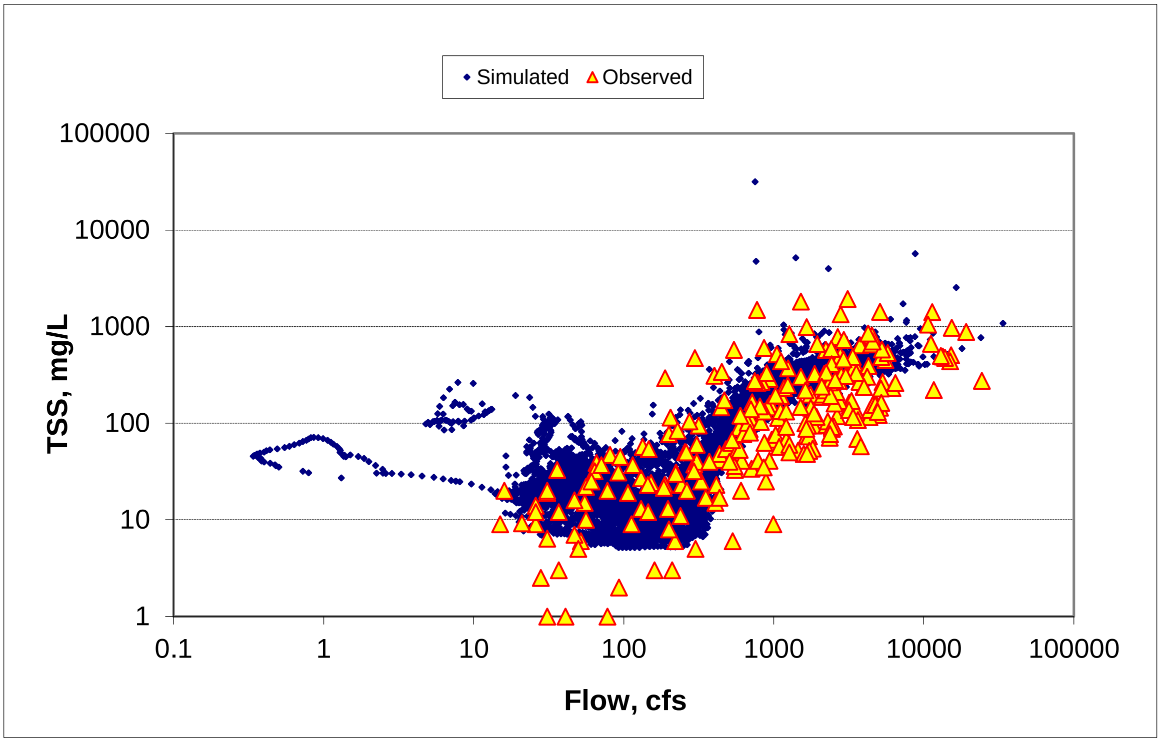


Figure 3. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

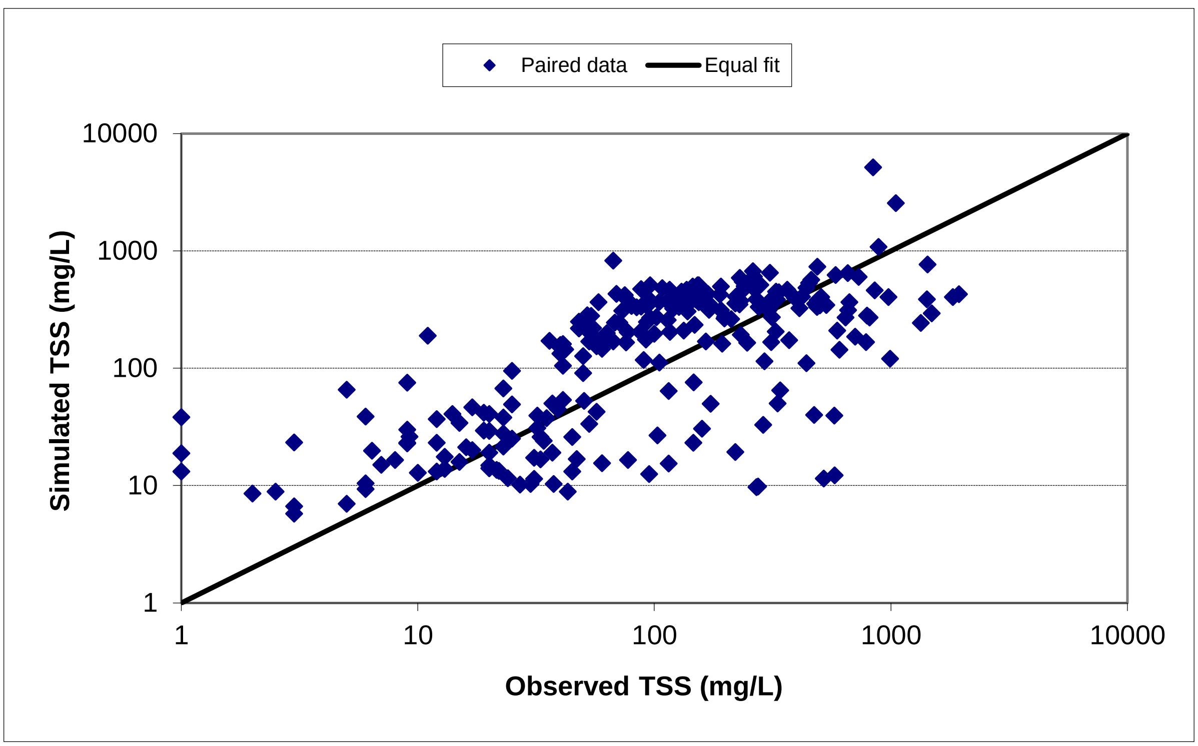


Figure 4. Simulated and Observed TSS Concentration Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

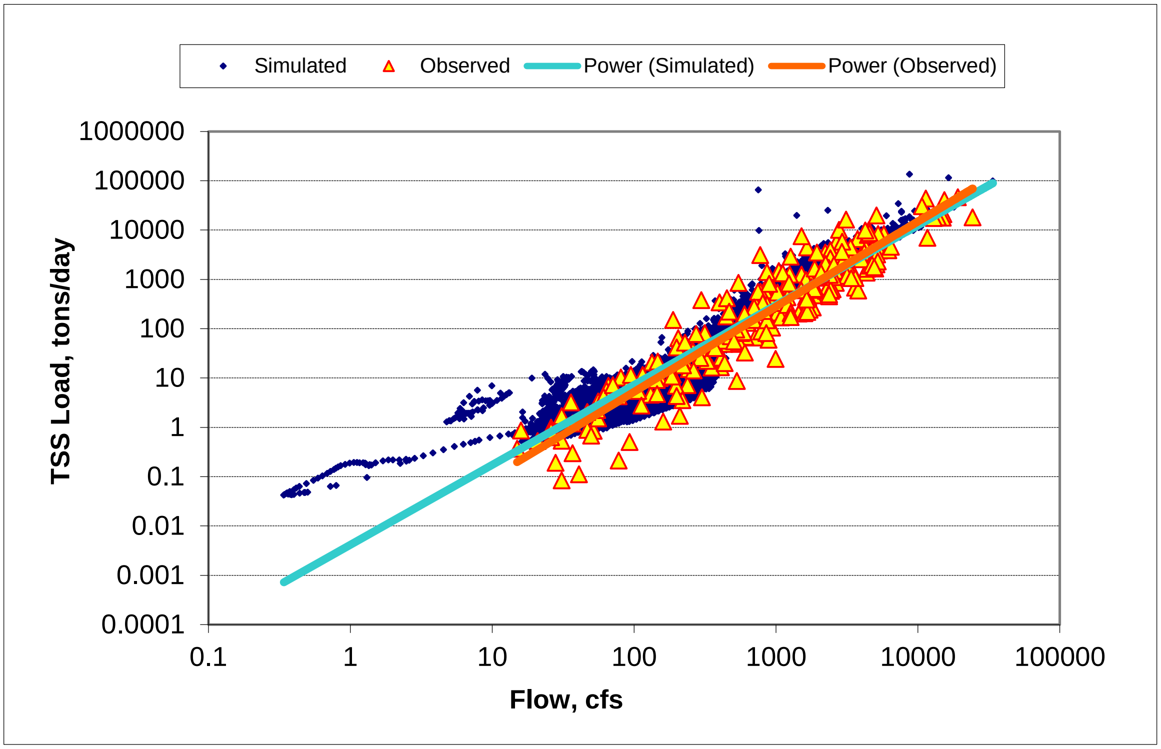


Figure 5. Load vs Flow Plot of Simulated and Observed TSS Load for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

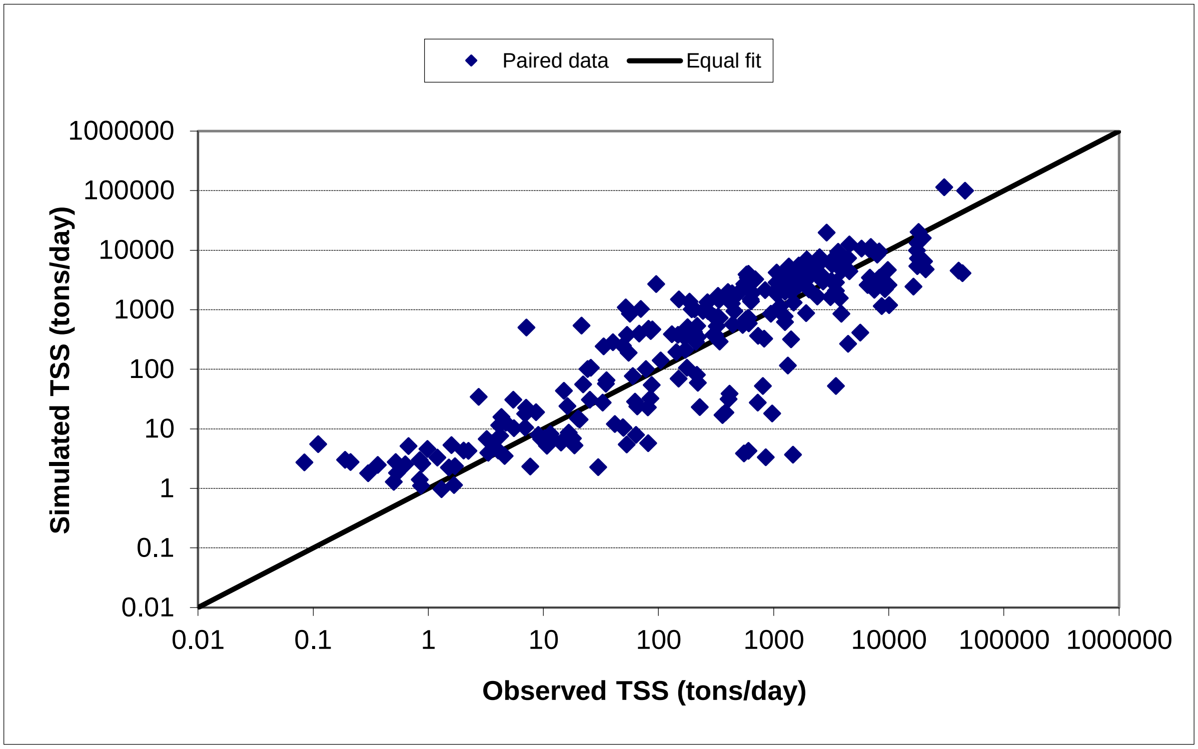


Figure 6. Simulated and Observed TSS Load Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

5.2.2 Validation Stations

The parameters developed during calibration were applied without modification to the validation stations. Table 12 (in five parts) shows the statistical results for the validation gages. Similar to the calibration stations the quality of fit is generally in the good to very good range for concentration and load median errors but from very good to poor for concentration and load average errors. There are a few validation stations that have poor fit for both averages and medians (e.g., Shakopee Creek S002-209 and High Island Creek S001-891). Model performance could likely be improved at individual stations; however, the parameters were not modified due to the desire to maintain spatial homogeneity across all models in the upland parameters and maintain reach homogeneity within each individual model.

Graphical examples of the calibration for Little Cottonwood River at Apple Road are provided in Figure 7 through Figure 11. While fit is reasonable at this station, the model appears to under-estimate suspended sediment concentrations observed at high flows Results for all other validation gages are contained in the electronic files.

Table 12. Summary Statistics for Validation Stations

Site	Dry Weather Creek, at 85th Ave NW, 4 mi NE of Watson	Shakopee Ck ,S Andrew Rd at Lk Andrew Otl	Little Chippewa R at Mn-28, 4 mi W of Starbuck	Chippewa R, EB, at 15th Ave NE, 2.5 mi N of Benson	W Fk Beaver Ck at CSAH-4 6.5 mi S of Olivia	Sacred Heart Ck at CSAH-15 Br, 5 mi NW of Delhi	Palmer Ck at 15th Ave SE, 2 mi NW of Granite Falls
STORET Code	S002-204	S002-209	S004-705	S005-364	S000-405	S001-341	S002-136
Count	322	116	64	307	234	131	126
Conc Ave Error	17.8%	715.2%	-96.4%	-4.0%	-189.5%	-321.7%	107.9%
Conc Median Error	-2.5%	258.1%	37.9%	1.0%	-14.9%	19.5%	6.9%
Load Ave Error	-63.0%	474.3%	-21.0%	25.2%	418.1%	-52.1%	-25.5%
Load Median Error	0.0%	182.3%	8.7%	0.3%	0.5%	0.4%	0.4%

(Table 12. Continued)

Site	Hawk Ck, at CR-116, 1.25 mi S of MN-40	Chetomba Ck, 5 mi SE of Maynard	S Br Yellow Medicine R on CSAH-26	CD-119 at CSAG-15, 5.6 mi S of Sacred Heart	Timms Ck at CSAG-15, 2.8 mi NNE of Delhi	Clear Ck Cr, 1/3 mi upst confl Redwd R	Three Mile Ck at CR-67, 1 mi N Green Valley
STORET Code	S002-140	S002-152	S002-320	S003-866	S003-867	S002-311	S002-313
Count	368	374	105	96	124	208	209
Conc Ave Error	-141.1%	35.7%	89.6%	33.2%	34.6%	-7.9%	-47.9%
Conc Median Error	-8.7%	17.0%	20.6%	8.2%	7.9%	-6.5%	-14.4%
Load Ave Error	60.7%	61.4%	36.8%	-69.3%	-62.6%	150.3%	-18.3%
Load Median Error	-2.1%	0.2%	0.8%	0.4%	0.1%	-0.1%	-0.4%

(Table 12. Continued)

Site	Plum Creek At CSAH 10 Br	Sleepy Eye Cr at CSAH 8 Br, 2.2 mi N of Leavenworth	Unn Trib To Big Cobb R, 0.5 mi N Beauford	Le Sueur R at CSAH 28 In Saint Clair	Little Cobb nr CSAH-16, 6.3 mi W of Pemberton	Maple R at CSAH-18, 2 mi N of Sterling Center	Dutch Creek at 100th St, 0.5 mi W of Fairmont
STORET Code	S001-913	S001-919	S001-210	S003-448	S003-574	S004-101	S003-000
Count	193	221	201	181	250	232	202
Conc Ave Error	-993.4%	-84.9%	-22.3%	-97.4%	-223.6%	-118.1%	-367.7%
Conc Median Error	-1.6%	1.5%	-1.2%	-5.2%	-19.4%	-11.6%	6.1%
Load Ave Error	-10.4%	20.4%	102.4%	84.1%	210.4%	280.2%	23.5%
Load Median Error	0.0%	0.1%	-0.1%	-0.3%	-0.8%	-0.5%	0.1%

(Table 12. Continued)

Site	Center Creek at 315th Avenue - 1 mi S of Huntley	Sevenmile Ck dwst of MN-99, 6 mi SW of St. Peter	CD 46A dwst of CSAH-13, 6 mi SW of St. Peter	Little Cottonwood R at Apple Rd, 1.6 mi S of Courtland*	Silver Cr.,CSAH-41 by East Union	Buffalo Ck, at 270th St, 1.5 mi NW of Henderson	High Island Ck at CSAH 9, 1 mi NW of Arlington
STORET Code	S003-024	S002-934	S002-936	S004-609	S000-843	S001-807	S001-891
Count	220	197	188	212	113	276	274
Conc Ave Error	-39.4%	118.0%	474.9%	35.5%	17.0%	24.6%	987.1%
Conc Median Error	-15.2%	27.7%	5.7%	-0.6%	2.3%	3.0%	131.7%
Load Ave Error	28.0%	288.3%	15.3%	-9.9%	-15.0%	-91.1%	551.2%
Load Median Error	-1.1%	3.8%	0.1%	0.0%	0.3%	0.0%	75.3%

(Table 12. Continued)

Site	Carver Ck at US-212, 2.5 mi E of Cologne	Carver Ck at Cr-140, 2.3 mi NE of Benton	Bevens Ck at 321st Ave, 3 mi SE of Hamburg	Bevens Ck at Rice Ave, 3.9 mi SE of Norwood Yng America
STORET Code	S002-489	S002-490	S002-516	S002-539
Count	165	164	116	153
Conc Ave Error	-40.1%	-98.3%	41.2%	-73.0%
Conc Median Error	-16.2%	153.4%	3.2%	-5.4%
Load Ave Error	-47.8%	499.4%	-42.9%	3.3%
Load Median Error	-4.7%	42.0%	0.5%	-0.6%

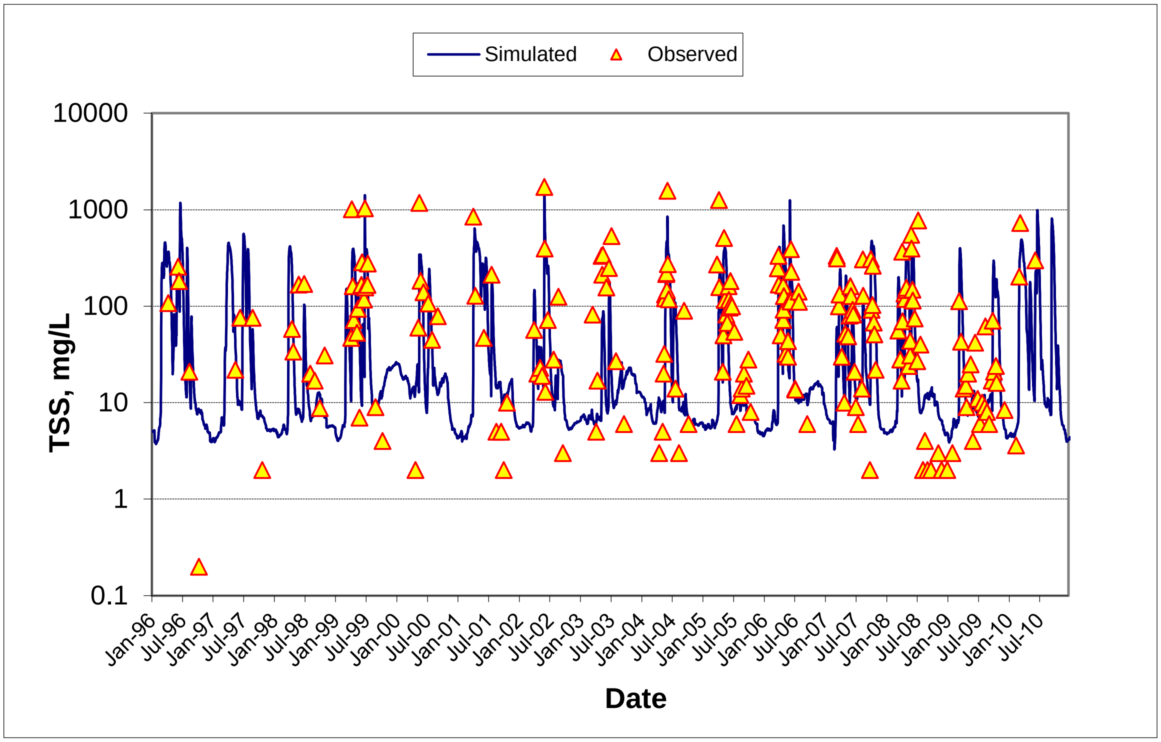


Figure 7. Timeseries Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010

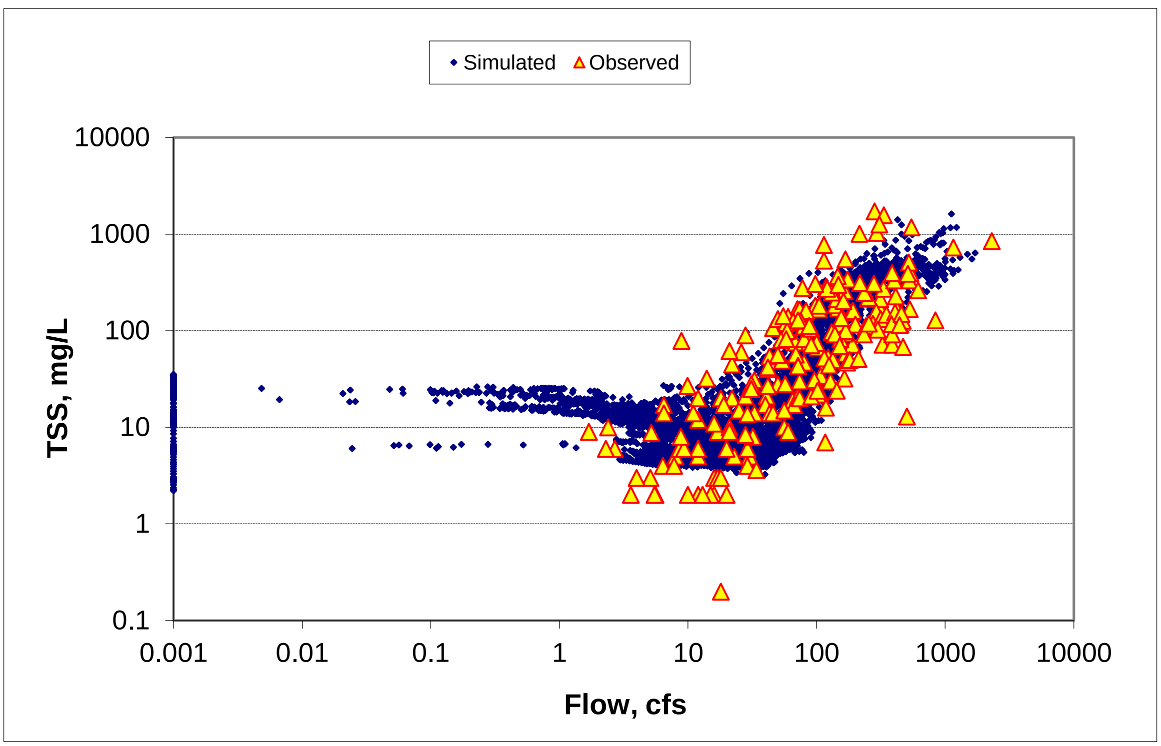


Figure 8. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010

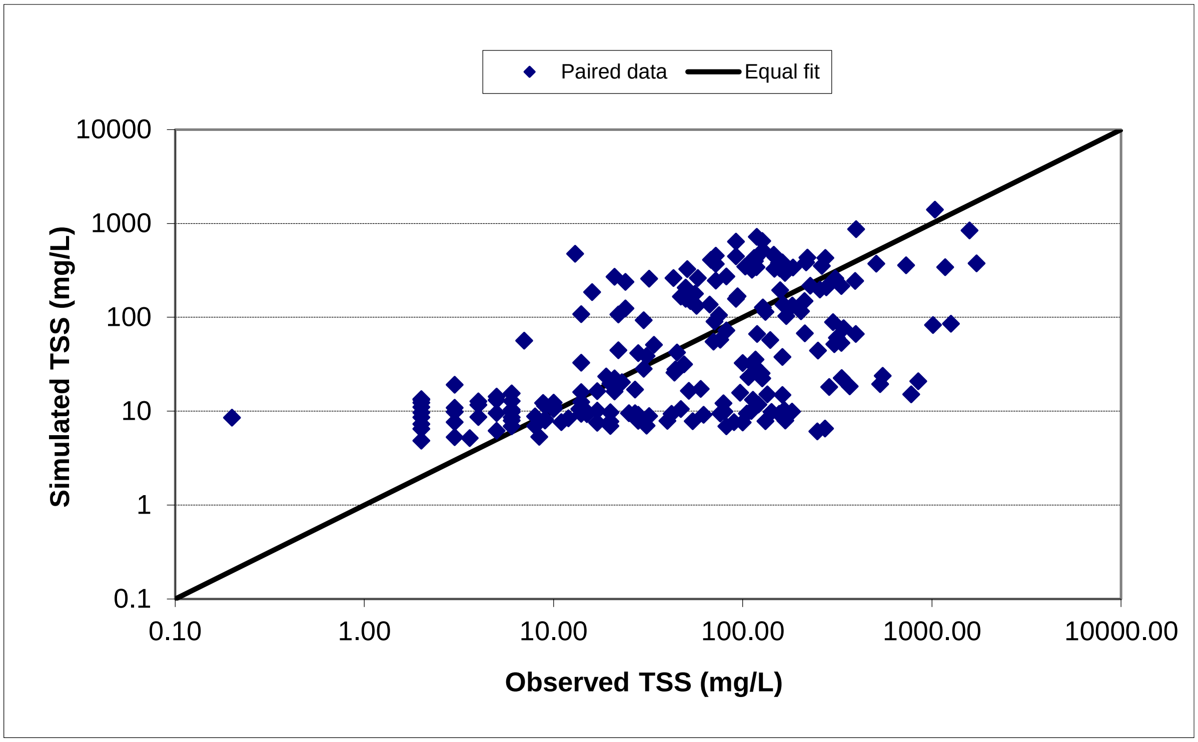


Figure 9. Simulated and Observed TSS Concentration Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010

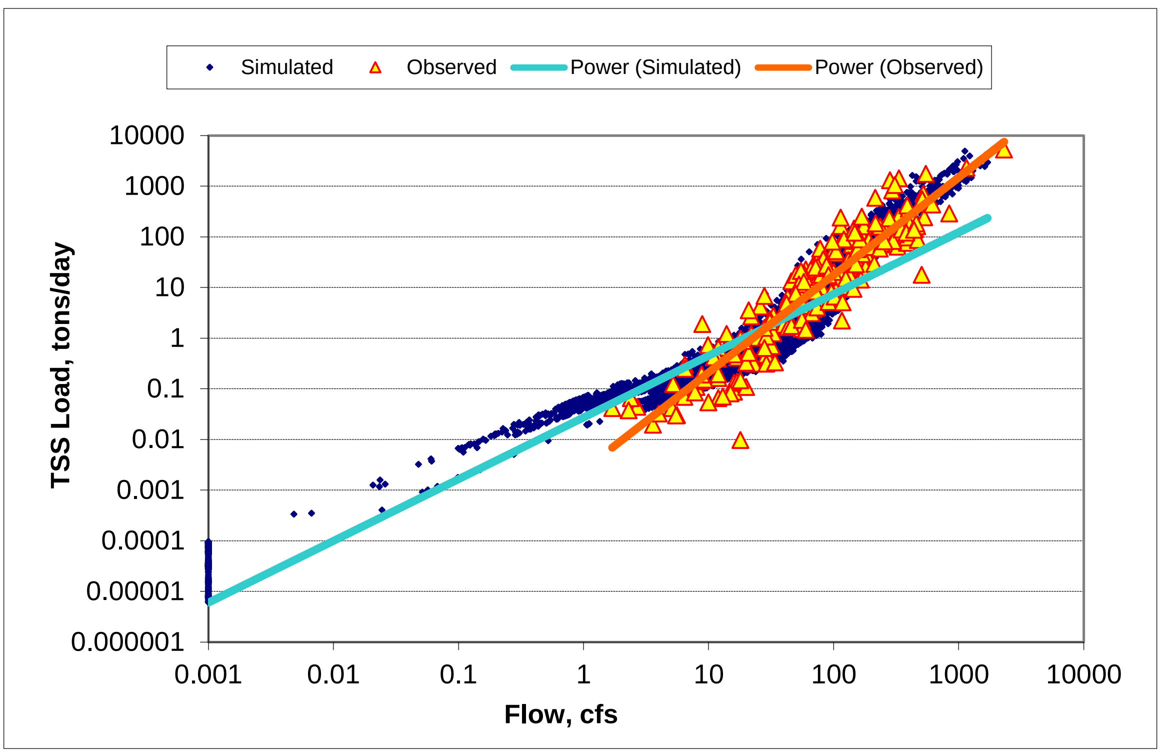


Figure 10. Load vs Flow Plot of Simulated and Observed TSS Load for Little Cottonwood River at Apple Road for 1996-2010

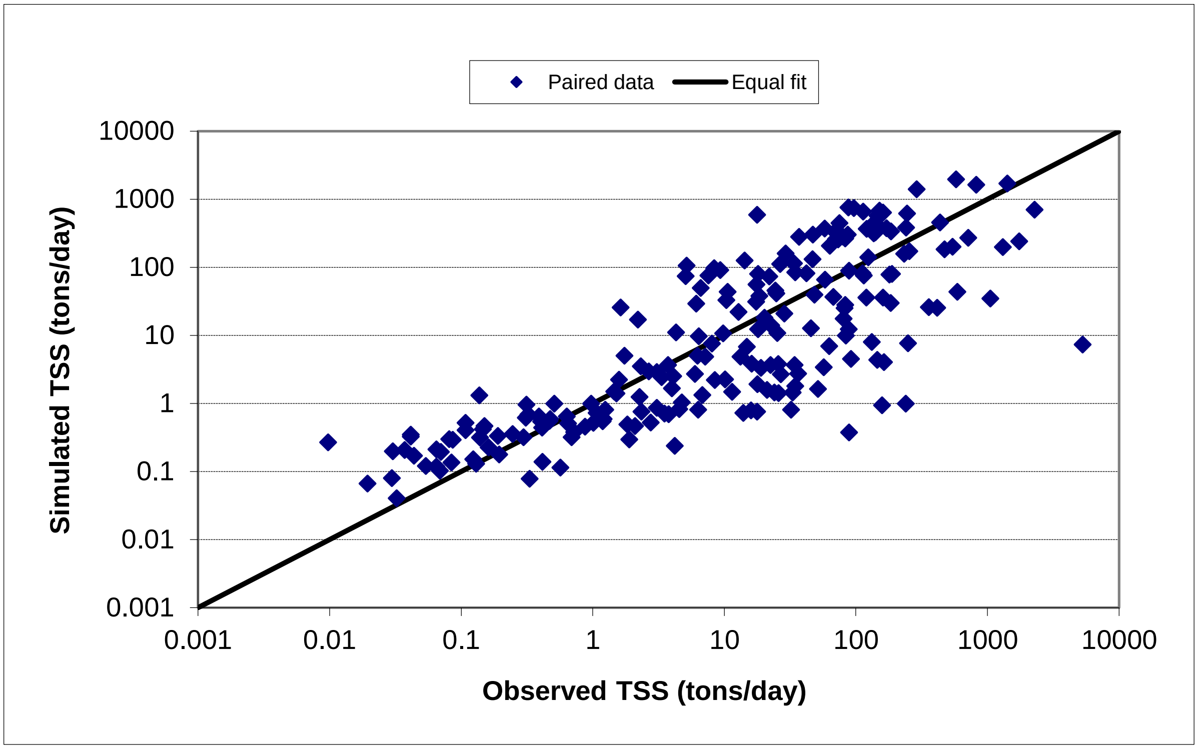


Figure 11. Simulated and Observed TSS Load Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010

5.3 Comparison to FLUX Loads

MPCA's Watershed Pollutant Load Monitoring Network (WPLMN) is designed to obtain spatial and temporal pollutant load information from Minnesota's rivers and streams and track water quality trends. As part of this program, MPCA releases estimates of annual pollutant loads for each 8-digit hydrologic unit code basin. These "observed" monthly loads are estimated using the USACE FLUX32 program (a Windows-based update of the FLUX program developed by Walker, 1996; available at https://www.pca.state.mn.us/water/watershed-pollutant-load-monitoring-network#flux32-8f1620f5), and are themselves subject to significant uncertainty.

MPCA estimates at the downstream gage station on each of the HUC-8 watersheds within the Minnesota River basin are currently available for calendar years 2007 – 2011. The model and FLUX estimates are compared in Figure 12. While the fit is generally close, there are some discrepancies at individual stations during 2011 and 2012 where FLUX estimates are higher than loads produced by the model.

Figure 12. Comparison of Model and FLUX TSS Load Estimates, Calendar Years 2007 - 2011

5.4 SEDIMENT SOURCE APPORTIONMENT

Provided below are results for simulated source apportionment at the mouth of each 8-digit (HUC). Results at the mouth include the influence of upstream model(s) if one or more exist. As previously stated each model had its own unique processing workbook created and those are provided in electronic format as a supplement to this memorandum. Each electronic workbook contains source apportionment at additional locations in each watershed. Also include are the incremental or local drainage area contributions for those locations that receive influence of upstream model(s). Specifically for Le Sueur, the between stations (between upper and lower stations) source apportionment has been calculated. This allows you to see the proportion and amount of sediment generated in the nick zone area for each drainage basin. Table 13 provides the average annual sediment load and source percentage at the mouth of each model.

Figure 13 (in two parts) shows the source percentage as pie charts which are similar to how source apportionment was shown in the Le Sueur and Greater Blue Earth sediment budgets. The Le Sueur and greater Blue Earth produce sediment source apportionment (mass and percentage) that are consistent with the full sediment budgets, while the other basins approximately replicate the upland source fraction attribution provided in Table 1 (see Figure 13). An exact match is not expected because the model results are for 1995 – 2012, while the radiometric source data are primarily depositional sediment cores collected in 2007 and 2008 that integrate over an uncertain time period.

Also provided in Table 14 and Figure 15 is an apportionment of the annual average sediment load at the mouth of the Metro model for each HUC8 watershed contributing to that point. Note, the Lac Qui Parle is not explicitly modeled as part of the Minnesota River Basin HSPF model suite but it is represented like a point source input to the Hawk Yellow Medicine model.

Table 13. Summary of Source Apportionment at the Mouth of each HUC8

HUC8	Metric	Upland	Ravine	Bluff	Stream	Total
Chippewa	Mass (ton/year)	4,309	66	2,107	5,518	12,000
	Source Percentage	36%	1%	18%	46%	100%
Redwood	Mass (ton/year)	11,438	937	17,180	12,572	42,127
	Source Percentage	27%	2%	41%	30%	100%
Hawk Yellow Medicine	Mass (ton/year)	71,513	2,564	64,997	67,262	206,336
	Source Percentage	35%	1%	32%	33%	100%
Cottonwood	Mass (ton/year)	31,846	1,492	75,227	50,067	158,633
	Source Percentage	20%	1%	47%	32%	100%
Watonwan	Mass (ton/year)	12,602	2,283	21,451	8,483	44,819
	Source Percentage	28%	5%	48%	19%	100%
Le Sueur	Mass (ton/year)	59,352	32,103	135,185	18,837	245,477
	Source Percentage	24%	13%	55%	8%	100%
Blue Earth	Mass (ton/year)	127,406	40,968	284,940	93,384	546,698
	Source Percentage	23%	7%	52%	17%	100%
Middle	Mass (ton/year)	289,417	48,976	482,842	297,839	1,119,074
	Source Percentage	26%	4%	43%	27%	100%
Lower/Metro	Mass (ton/year)	331,411	53,414	624,074	354,566	1,363,464
	Source Percentage	24%	4%	46%	26%	100%

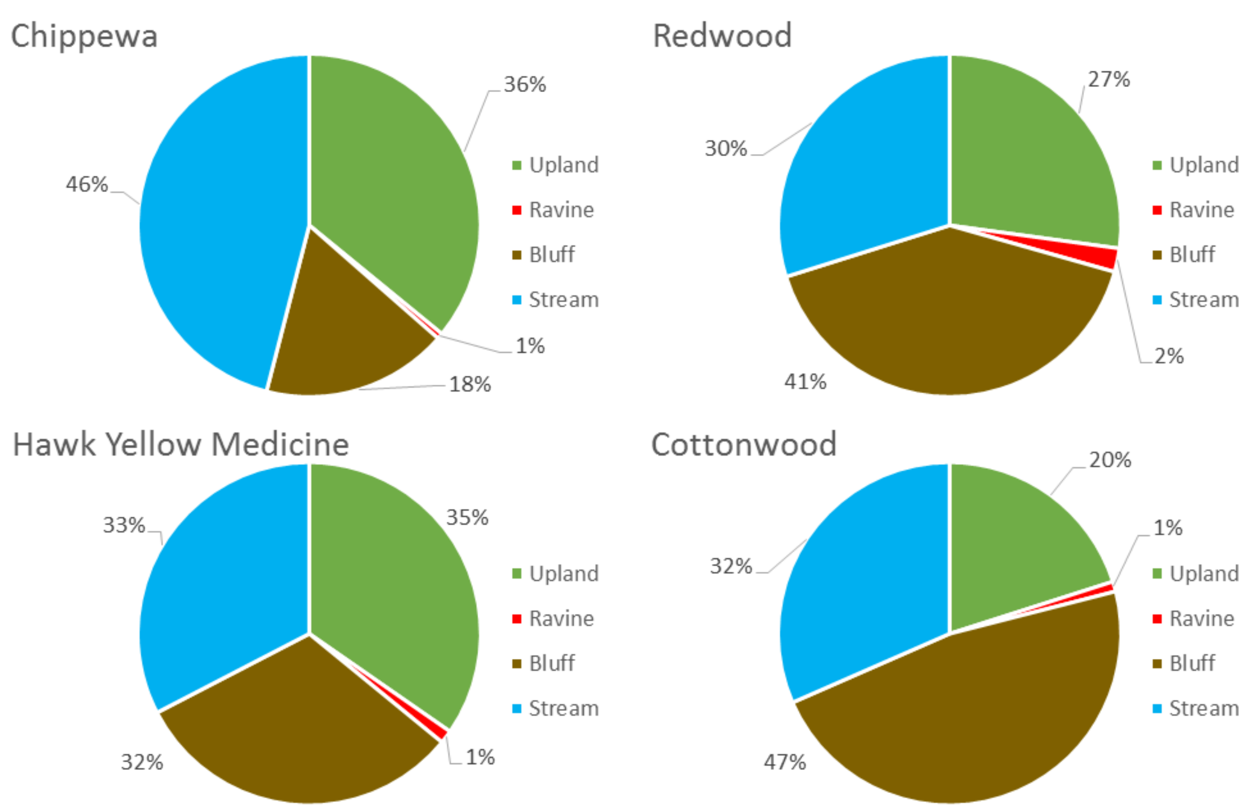
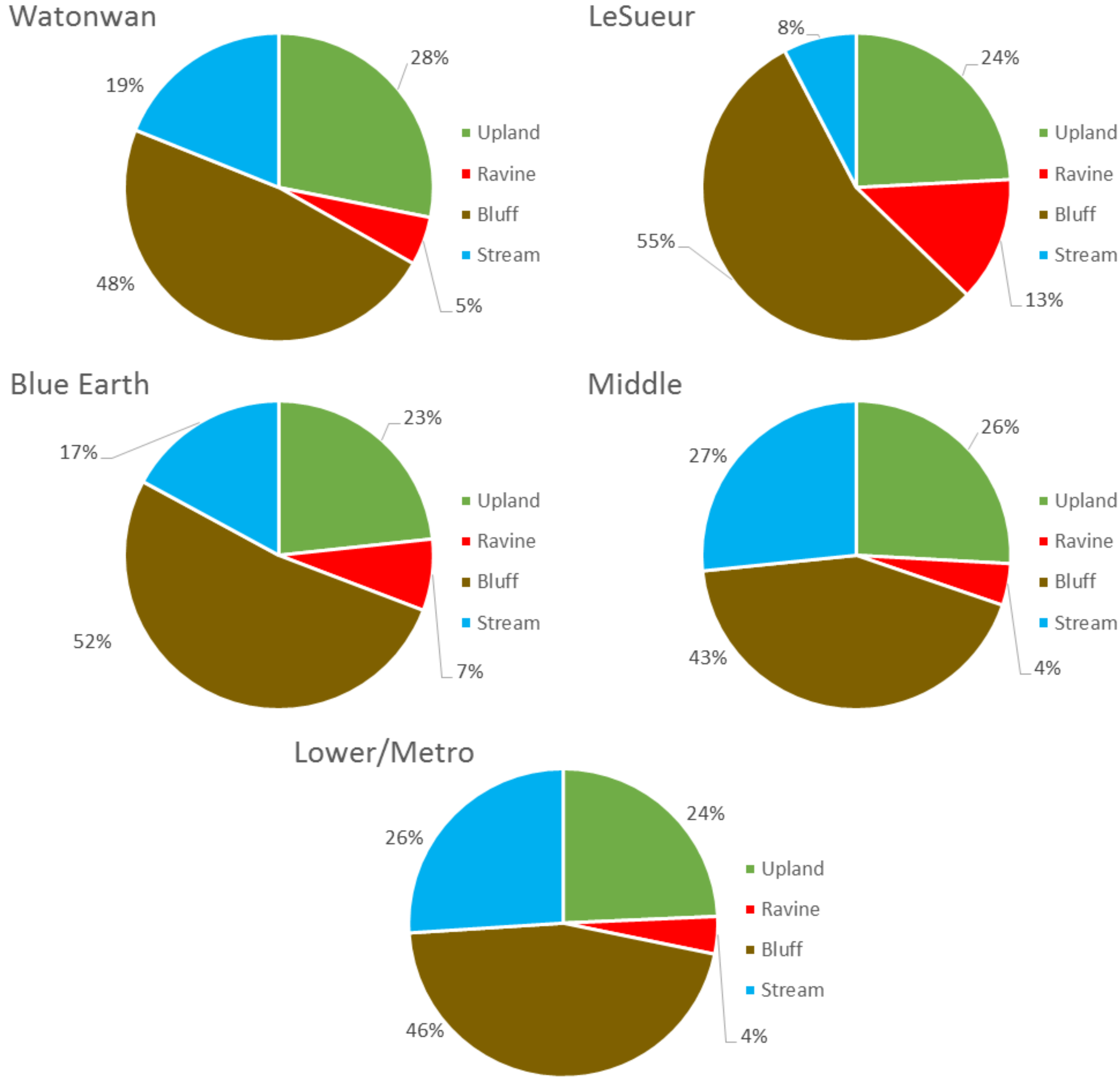


Figure 13. Instream Sediment Source Apportionment at HUC8 Outlets



(Figure 13 Continued, Instream Sediment Source Apportionment at HUC8 Outlets)

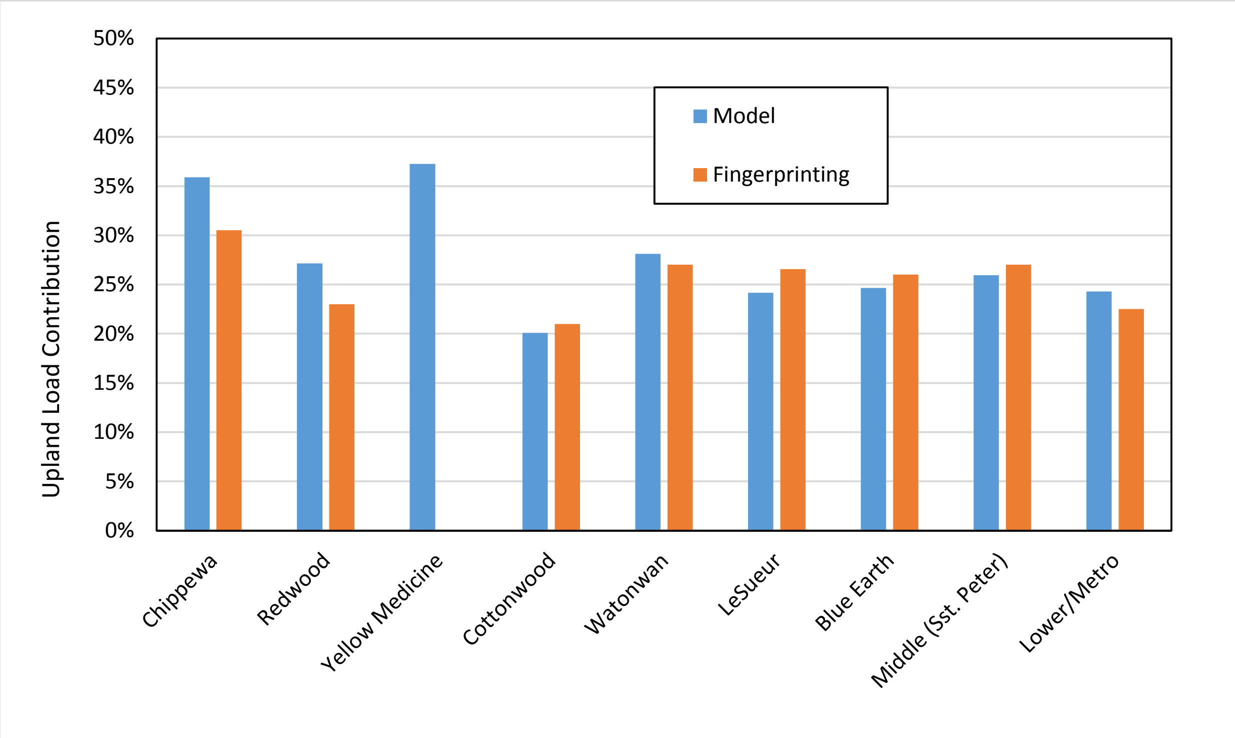


Figure 14. Comparison of Simulated Surface Washoff Loading to Surface Source Fraction from Sediment Fingerprinting Analysis

Note: Refer to Table 1 for sediment source attribution targets.

Table 14. HUC8 Contributions to Sediment Load at the Mouth of the Metro Model

Watershed	Sediment Ton/year	Percent of Total
Chippewa	12,000	0.9%
Redwood	42,127	3.1%
Hawk Yellow Medicine	104,604	7.7%
Lac Qui Parle	54,269	4.0%
Cottonwood	158,633	11.6%
Watonwan	44,819	3.3%
LeSueur	245,477	18.0%
Blue Earth	256,370	18.8%
Middle	200,776	14.7%
Lower	127,446	9.3%
Metro	116,948	8.6%
Total at Metro Mouth	1,363,464	100.0%

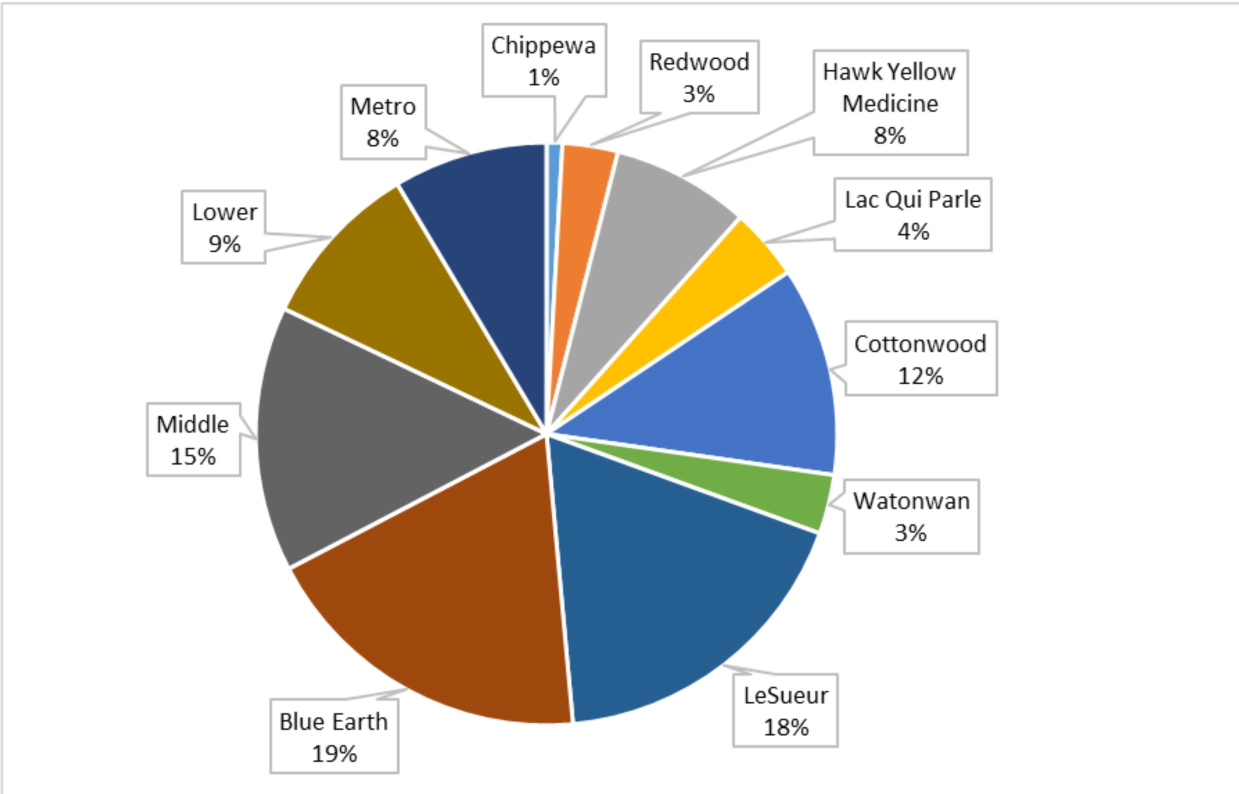


Figure 15. HUC8 Contributions to Sediment Load at the Mouth of the Metro Model

6 Summary and Potential Enhancements

The primary motivation for the sediment recalibration for the Minnesota River Basin was to better represent the source attribution information available from radiometric data and the detailed sediment source budgets for the Greater Blue Earth basin. Adjustments to the calibration to better simulate observed suspended sediment concentration data was also pursued, but under a constraint to use a relatively parsimonious parameter set that kept sediment parameters that are not based on observed soils and geological data at values that are generally constant across a basin for a given land use or waterbody type. Better fits to observed data could likely be obtained at many observation sites if more site-specific calibration with local parameter adjustments was pursued. While such an approach is likely to provide better model fit statistics it also raises the danger of over-calibration. Before taking such an approach it would be wise to consider several other factors that may be contributing to model uncertainty and potential enhancements that might improve overall model performance. Among other issues, the following items should be considered if the models are further developed:

1. **Meteorological Data**: The current model refinements make use of the meteorological time series developed by RESPEC (2014). These are based on point rainfall measurements and are often derived from volunteer daily total observations that have been disaggregated based on nearest available hourly station templates. We have seen through previous model applications that point gauges can be un-representative of the areal average precipitation depth over a model sub-basin, especially during summer convective storms, which often have local variability. The switch back to point gauge measurements appears to have resulted in a significant decline in hydrologic calibration performance in the model Chippewa basin, which has strong precipitation gradients but rather limited precipitation gauging. Further, temporal disaggregation to a template station that is some distance away can incorporate significant biases in the timing of major rainfall events, which in turn translates into apparent mismatches between model simulation and observed sediment concentrations. The newest generation of PRISM gridded precipitation products (which incorporate gage data, NEXRAD radar precipitation intensity information, and regressions against topographic characteristics) provide a potentially stronger approach to estimate the average precipitation characteristics on a reach. Downscaling to an hourly scale in the absence of nearby hourly template stations may be better achieved by using a fractal simulation approach to assign random intra-day intensities rather than assuming timing is synchronized with the template station. Potential evapotranspiration time series construction is also an issue as the energy inputs (e.g., solar radiation, dew point, wind) are often not available for rural areas and are translated from distant airport stations. The gridded NLDAS evapotranspiration estimates may provide a better means of estimation for areas far from first-order airport meteorological stations. Improvements in the representation of storm hydrology would lead directly to improvements in the simulation of sediment washoff and channel erosion during large storm events, which typically move the majority of sediment in a given year.
2. **Hydraulics**: The current models incorporate only limited information on channel hydraulics. RESPEC (2014) created much finer-scale models than the earlier Tetra Tech (2008) models. This required the development of new hydraulic functional tables (FTables), expressing the relationship between reach storage volume, outflow, surface area, and depth. These calculations in turn determine the shear stress exerted on the channel. As channel erosion has been identified as a major contributor to the total sediment load in the basin this component of the model is critical. The RESPEC memoranda say that for reaches where Tetra Tech previously calculated FTables using results of HEC-RAS models, those FTables "will be scaled by reach length and applied to corresponding reaches in order to maximize the use of the best available data." For reaches that did not have HEC-RAS models, the documentation implies that cross-sectional measurements at USGS gage sites will be used, and, when field information on a gage is not

available, "the USGS maximum width, depth, and area data will be used to calculate cross-sections assuming a trapezoidal channel and a bank slope of 1/3." Exact details of how FTables were developed for individual reaches are not provided. It is clear, however, that a scaling approach related to gage data can introduce problems because gage rating curves are often developed at constrictions, such as bridge crossings. Similarly, FTables derived from HEC models should be re-calculated based on new reach lengths (not scaled relative to coarser determinations) to incorporate the information available in the HEC models. Re-evaluation of HEC model output plus analysis of measured cross-sections would likely improve the hydraulic performance – and thus the channel sediment scour performance – of the models. Related to this topic, we noted that the 2014 models omit representation of Rapidan Dam on the Blue Earth River. While the pool behind Rapidan Dam is largely silted up, the dam does have an effect on hydraulics and sediment transport in the lower Blue Earth, which is a major source of sediment load to the lower Minnesota River. Therefore it should be important to incorporate the effects of this structure into the models.

3. **Ravine and Bluff Areas**: At the start of this work assignment it was anticipated that new information on the extent of ravine and bluff land use areas would be provided for each HUC8 watershed. Those coverages have not been finalized (and the current bluff coverage based on LiDAR appears to delineate features such as ditch banks as "bluffs," which is not particularly useful to basin-scale modeling). When these delineation efforts are completed the models should be updated to incorporate the information.
4. **Parameters for Manured Land**: It required a considerable amount of time to reach an agreement with MPCA on the appropriate approach to determine the land area that received manure applications. Manure applications have impacts on nutrient loading, but also change the soil structure in somewhat subtle ways that can change runoff and sediment loading impacts. Due to the delay in resolving the manured land area representation, the definition of manured area was not finalized until after the hydrologic recalibration had been completed. To avoid disturbing the hydrologic calibration, the manure application areas were specified (and area shifted from) as equal to existing conventional tillage on A/B soils. In fact, evidence (summarized in Tetra Tech, 2008) suggests that land receiving manure application should have somewhat greater upper zone storage capacity (UZSN), which in turn affects runoff sediment transport capacity. This refinement should be incorporated into any revised models.
5. **Tile Drain Sediment**: RESPEC (2014) adopted a modified approach to the simulation of sediment transport through surface tile inlets that was much simpler and more efficient than the SPECIAL ACTIONS approach implemented by Tetra Tech (2008). The revised approach gives a similar estimate of total sediment load transported by this pathway, but the pollutograph is very different, with the load transmitted to the stream much more quickly. At this point it is not clear which representation is correct, although the approach earlier use by Tetra Tech did result in a good match between observed and simulated sediment concentrations. This topic appears worthy of further investigation.

7 References

AQUA TERRA. 2012. Modeling Guidance for BASINS/HSPF Applications under the MPCA One Water Program. Prepared for Minnesota Pollution Control Agency by AQUA TERRA Consultants, Mountain View, CA.

Bevis, M. 2015. Sediment Budgets Indicate Pleistocene Base Level Fall Drives Erosion in Minnesota's Greater Blue Earth River Basin. A thesis submitted to the Faculty of the University of Minnesota in partial fulfillment of the requirements for the degree of Master of Science, Dr. Karen Gran, Advisor.

Donigian, A.S., J.C. Imhoff, B.R. Bicknell, and J.L. Kittle. 1984. Application Guide for the Hydrologic Simulation Program - FORTRAN. EPA 600/3-84-066. U.S. Environmental Protection Agency, Athens, GA.

Donigian, A.S. Jr. 2000. *HSPF Training Workshop Handbook and CD*. Lecture #19. Calibration and Verification Issues, Slides #L19-22. U.S. Environmental Protection Agency, Washington Information Center, January 10–14, 2000. Prepared for U.S. Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC.

Donigian, A.S. Jr., and J.T. Love. 2003. Sediment Calibration Procedures and Guidelines for Watershed Modeling. Presented at the Water Environment Federation Total Maximum Daily Load Conference, November 16–19, 2003, Chicago, IL.

Gran, K., P. Belmont, S. Day, C. Jennings, J.W. Lauer, E. Viparelli, P. Wilcock, and G. Parker. 2011. An Integrated Sediment Budget for the Le Sueur River Basin, Final Report. National Center for Earth Systems Dynamics.

Lumb, A.M., R.B. McCammon, and J.L. Kittle, Jr. 1994. Users Manual for an Expert System (HSPEXP) for Calibration of the Hydrological Simulation Program – FORTRAN. Water-Resources Investigation Report 94-4168. U.S. Geological Survey, Reston, VA.

Moriasi, D.N., J.G. Arnold, M.W. Van Liew, R.L. Bingner, R.D. Harmel, and T.L. Veith. 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Transactions of the ASABE*, 50(3): 885-900.

RESPEC. 2014. Hydrology and Water Quality Calibration and Validation of Minnesota River Watershed Modeling Applications. Memorandum to Dr. Charles Regan, Minnesota Pollution Control Agency.

Schottler, S., D. Engstrom, and D. Blumentritt. 2010. Fingerptinting Sources of Sediment in Large Agricultural River Systems. St. Croix Watershed Research Station, Marine, MN.

Tetra Tech. 2008. Minnesota River Basin Turbidity TMDL and Lake Pepin Excessive Nutrient TMDL, Model Calibration and Validation Report. Prepared for Minnesota Pollution Control Agency by Tetra Tech, Inc., Research Triangle Park, NC.

US EPA. 2006. BASINS Technical Note 8: Sediment Parameter and Calibration Guidance for HSPF. Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Walker, W.W. 1996. Simplified Procedures for Eutrophication Assessment and Prediction: User Manual. Instruction Report W-96-2. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Appendix E – CAFO List and Watershed Summary

Table E- 1. List of CAFOs by HUC-10 subwatershed in the Redwood River Watershed.

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
Upper Redwood River	081-50002	1400	
	081-87131	99	N
	081-87133	140	Y
	081-87135	170	N
	081-87139	54	N
	081-87143	54	N
	081-87168	450	N
	081-87185	180	Y
	081-87186	290	N
	081-87224	990.18	N
	081-87227	50	N
	081-87233	23	Y
	081-87257	60	N
	081-87259	807.5	N
	081-87261	54	N
	081-87262	108	N
	081-87263	57	N
	081-87297	99	N
	081-87303	56	N
	081-87304	50	N
	081-87305	21	Y
	081-87322	61.5	N
	081-87332	51.5	Y
	081-87363	196	N
	081-87364	60	N
	081-87383	225	N
	081-87399	52.5	N
	081-87414	50.2	N
	081-87415	52.5	Y
	081-87416	55.5	N
	081-87424	450	Y
	081-87432	255	N
	081-87433	58	N
	081-87446	17	Y

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	081-87471	265.8	N
	081-87472	90	N
	081-87478	170	N
	081-87528	53.5	Y
	081-87555	200	N
	081-87561	70	N
	081-87597	90	N
	081-93882	60	N
	081-95343	445.5	N
	081-95347	420	N
	081-95348	50	N
	081-95354	280	N
	081-95362	56	N
	081-95363	96	N
	081-95364	210	Y
	081-103220	95	N
	081-103227	56	N
	081-107840	50	N
	081-126161	50	
	083-50017	84	N
	083-50023	120	N
	083-61774	315	N
	083-62431	299	N
	083-62440	290	N
	083-62557	136	N
	083-62707	51.7	Y
	083-63419	85	N
	083-113094	397	N
	083-122506	270	N
	083-126538	720	
	101-68925	394	N
	101-77119	135	N
	101-77385	89	N
	101-82347	490	N
	101-108019	95	N
	101-108020	120	N

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	101-123945	87.5	N
	117-85305	999	N
	117-85516	132	N
	117-85517	55	N
	117-85519	54	N
	117-85530	297.5	N
	117-85542	52.8	Y
	117-85545	50	N
	117-85546	309.25	N
	117-85549	200.8	N
	117-85553	154	N
	117-85555	540	Y
	117-85563	50	N
	117-85564	72	N
	117-85632	24	Y
	117-85635	85.5	N
	117-95027	48	Y
Coon Creek	081-87121	22	Y
	081-87122	60	N
	081-87136	60	N
	081-87137	120	N
	081-87138	14	Y
	081-87156	102	Y
	081-87157	53	N
	081-87160	195.75	Y
	081-87161	30	Y
	081-87191	98	N
	081-87192	55	N
	081-87201	60	N
	081-87229	26	Y
	081-87246	60	Y
	081-87258	22	Y
	081-87296	1200	
	081-87301	70	N
	081-87302	53.5	N
	081-87313	290	N

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	081-87314	60	N
	081-87316	110.25	N
	081-87336	14.4	Y
	081-87337	950	N
	081-87345	12	Y
	081-87348	57	N
	081-87349	74	N
	081-87354	96	N
	081-87366	172	N
	081-87373	155	N
	081-87375	72	N
	081-87376	62	N
	081-87385	252.25	Y
	081-87417	450	N
	081-87435	99	Y
	081-87476	178	N
	081-87493	471	N
	081-87510	154	Y
	081-87522	12	Y
	081-87536	84	N
	081-87560	54.075	N
	081-93696	250	N
	081-93871	98	N
	081-95342	62.5	N
	081-95350	90	N
	081-103223	50	N
	081-108043	120	N
	081-108305	132	N
	081-110862	52	N
	081-114317	21.6	Y
	081-114856	55	N
	081-117923	60	N
	081-125947	990	N
	083-50005	900	N
	083-62921	116	N
	083-63768	82	N

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	083-99560	990	N
	083-121701	90	N
Middle Redwood River	083-50009	143	N
	083-60600	300	N
	083-60761	59.5	N
	083-61755	235	N
	083-61763	875	Y
	083-61773	72	N
	083-61777	400	N
	083-62113	82.5	N
	083-62342	175.58	N
	083-62343	475	N
	083-62434	630	N
	083-62455	126	N
	083-62712	495	N
	083-62859	763	N
	083-63553	1020	N
	083-64011	57.2	N
	083-65088	975	N
	083-98340	240	N
	083-100380	125	N
	083-115204	295	N
	083-121700	150	N
	083-127074	105	
	083-127075	70	N
Three Mile Creek	081-87159	50.3	N
	081-87243	525	N
	083-50008	1780	
	083-50016	1807	N
	083-50019	490	N
	083-50020	720	N
	083-50025	250	N
	083-60023	3270	N
	083-60846	298.5	N
	083-61733	195.5	N
	083-61751	990	N

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	083-61752	650	N
	083-61758	521	N
	083-62101	180	N
	083-62168	895	N
	083-62429	420	N
	083-62438	429	N
	083-62439	995	N
	083-62561	240	N
	083-62598	182	N
	083-62675	360	Y
	083-62693	252	N
	083-62705	61	N
	083-62713	240	N
	083-62753	990	N
	083-62786	270	N
	083-62820	30	Y
	083-62821	191.85	N
	083-62841	360	N
	083-62849	478	N
	083-62850	650	N
	083-62861	294	N
	083-63525	430	N
	083-63530	115	N
	083-63556	55	N
	083-65512	210	N
	083-65514	710	N
	083-65526	487.5	N
	083-65533	290	N
	083-65617	300	N
	083-66480	950	N
	083-81605	120	N
	083-89076	960	N
	083-89077	585	N
	083-100422	150	N
	083-104380	100	N
	083-106760	650	N

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	083-112578	1440	N
	083-119657	114.8	N
	083-121842	400	N
	083-122917	190	N
	083-124932	175	N
	083-125995	720	N
	083-126068	300	
	083-126539	720	N
Clear Creek	083-62200	760.52	N
	083-62721	120	N
	083-62844	495	N
	083-63771	637.5	N
	083-64975	750	N
	083-65530	450	N
	083-65820	944	N
	083-89078	1408	N
	083-101420	250	N
	083-119906	195	N
	083-121594	720	N
	083-121699	720	N
	083-125965	82.4	
	083-126369	295	
	083-126506	600	N
	127-50008	770	N
	127-50012	105	N
	127-50013	73.2	N
	127-50015	247.7	N
	127-50076	490	N
	127-61732	158.1	N
	127-61743	72.5	N
	127-62526	166.08	N
	127-62533	150	N
	127-62911	272.4	N
	127-63121	77.7	N
	127-105460	428.8	N
	127-115816	190	N

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
Ramsey Creek	127-50005	360	N
	127-50018	1440	N
	127-50028	88.13	N
	127-60849	159.5	N
	127-62885	680	N
	127-62889	89	N
	127-62942	360	N
	127-64985	50	N
	127-99760	900	N
	127-103040	499	N
	127-111442	600	N
	127-115531	954	N
	127-120148	250	N
	173-50070	844.8	N
	173-108031	360	N
	173-116157	720	N
	173-118389	1999	N
Lower Redwood River	083-50001	1840.15	N
	083-61735	250	N
	083-62185	852	N
	083-62715	215	N
	083-62853	150	Y
	083-62854	182	N
	083-62855	50	Y
	083-62860	299	N
	083-63764	412	N
	083-63807	280	N
	083-64976	223	N
	083-64981	62.5	N
	083-81586	440	N
	083-98780	420	N
	083-106860	900	N
	083-122484	1440	N
	083-125996	720	
	083-126537	720	N
	127-50004	800	N

HUC10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	127-50006	350	N
	127-50020	79.1	N
	127-50030	63	N
	127-50073	1440	N
	127-50077	784	N
	127-50081	143	N
	127-50087	1248	N
	127-60087	505	N
	127-60320	289.8	N
	127-60343	500	N
	127-60843	90	N
	127-62482	275	N
	127-62528	205	N
	127-62530	408	N
	127-62532	270	N
	127-62895	440	N
	127-62907	87	N
	127-62962	500	N
	127-64984	144.8	N
	127-64989	360	N
	127-65510	310	N
	127-80031	840.7	N
	127-110660	498	N
	127-112519	355	N
	127-115333	99	N
	127-124583	1440	N
	127-125524	1713.8	N
	127-125859	990	N
	173-50370	180	N
	20190001	290	N

Table E- 2. Redwood River Watershed CAFO Summary

General	
Total Feedlots	316
Total Permitted CAFO’s	23
Total Animal Units (AUs)	111,489

Primary Animal Type[1]	Cattle (49%)
	Swine (43%)
Sensitive Areas	
Open Lot Feedlots	235
Feedlots in Shoreland	35
Open Lot Feedlots in Shoreland	33

[1]Percentages are based on animal units.