River Eutrophication

December 2023

Redwood River Eutrophication Total Maximum Daily Load Report

Excessive phosphorus in Redwood River Reach 07020006-501, which is located in the greater Minnesota River Basin

MINNESOTA POLLUTION
CONTROL AGENCY

CLEAN
WATER
LAND &
LEGACY
AMENDMENT

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Location: Outlet of Lake Redwood in Redwood Falls, Minnesota

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Acronyms

1W1P	One Watershed One Plan
AU	animal unit
BMP	best management practice
BOD	biochemical oxygen demand
BWSR	Board of Water and Soil Resources
CAFO	Concentrated Animal Feeding Operation
chl-*a*	chlorophyll-*a*
CREP	Conservation Reserve Enhancement Program
DEM	digital elevation model
DO	dissolved oxygen
DNR	Minnesota Department of Natural Resources
EPA	U.S. Environmental Protection Agency
EQuIS	Environmental Quality Information System
FTPGW	fail to protect groundwater
GW	groundwater
HSPF	Hydrologic Simulation Program-Fortran
IBI	Index of Biotic Impairment
ITPHS	imminent threat to public health and safety
IWM	Intensive Watershed Monitoring
LA	load allocation
Lb	pound
lb/day	pounds per day
lb/yr	pounds per year
LC	loading capacity
LGU	Local Government Unit
LiDAR	Light Detection and Ranging
m	meter
MAWQCP	Minnesota Agricultural Water Quality Certification Program
mg/L	milligrams per liter
mL	milliliter

MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NLCD	National Land Cover Database
NPDES	National Pollutant Discharge Elimination System
NPS	nonpoint sources
NRS	Nutrient Reduction Strategy
PFA	Public Facilities Authority
RC	reserve capacity
RCRCA	Redwood-Cottonwood River Control area
RES	river eutrophication standard
SID	Stressor Identification
SRO	surface runoff
SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation Districts
SWPPP	Stormwater Pollution Prevention Plan
TMDL	total maximum daily load
TP	total phosphorus
µg/L	microgram per liter
WASCOBs	waterways and water and sediment control basins
WLA	wasteload allocation
WRAPS	Watershed Restoration and Protection Strategy
WQBEL	Water Quality Based Effluent Limits
WWTP	Wastewater Treatment Plant

Executive Summary

This Total Maximum Daily Load (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. In May 2023, the Redwood River Watershed TMDL Report (MPCA 2023a) was approved, which covers nine total suspended solids (TSS) impaired reaches, two bacteria (*E. coli*) impaired reaches, one chloride impaired reach, and six nutrient impaired lakes throughout the Redwood River Watershed. The Redwood River Fecal Coliform TMDL Report (RCRCA 2013) was approved in January 2014, and covers nine bacteria (fecal coliform) impaired reaches throughout the watershed. 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 2007). 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 study addresses one river eutrophication standard (RES) impaired reach of the Redwood River (07020006-501) that is listed on the 2022 State of Minnesota's 303(d) list of impaired waters. River eutrophication impairments are treated as phosphorus impairments. Thus, this TMDL establishes the maximum amount of a pollutant (i.e., phosphorus) that Redwood River Reach 501 can receive on a daily basis and still meet the RES water quality standard. The TMDL report is divided into wasteload allocations (WLAs) for point or permitted sources, load allocations (LAs) for nonpoint sources (NPSs) and natural background, a margin of safety (MOS), and a reserve capacity (RC).

This TMDL report used a variety of methods to evaluate current loading contributions from various pollutant sources as well as the allowable pollutant loading capacity (LC) of the impaired reach. These methods include monitored flow and water quality data, the Hydrologic Simulation Program – FORTRAN (HSPF) model, and the flow duration curve approach. This TMDL report was developed in conjunction with a basin-wide TMDL report described above (MPCA 2023a), which addresses multiple impairments throughout the Redwood River Watershed.

A general strategy and cost estimate for implementation to address the impairments are included. Both point sources and NPSs will be the focus of implementation efforts. NPS contributions are not regulated and will need to proceed on a voluntary basis. Permitted point sources will be addressed through the Minnesota Pollution Control Agency's (MPCA) National Pollutant Discharge Elimination System (NPDES)/State Disposal System (SDS) Permit programs.

1. Project Overview

1.1 Purpose

This TMDL addresses one RES impaired reach of the Redwood River (07020006-501) in the greater Redwood River Watershed. Redwood River Reach 501 is about four miles long and is the most downstream reach of the Redwood River before it discharges to the Minnesota River. The drainage area of the impaired reach presented in this TMDL covers portions of six counties in southwest Minnesota: Lincoln, Yellow Medicine, Redwood, Lyon, Pipestone, and Murray. The goal of this TMDL is to quantify the pollutant reductions needed to meet state water quality standards for phosphorus for Redwood River Reach 501 (Table 1 and Figure 1). This TMDL is established in accordance with Section 303(d) of the CWA and provides WLAs and LAs for the watershed areas as appropriate.

There have been TMDLs completed and approved by the EPA Region 5 in the Redwood River Watershed prior to this TMDL. In 2023, the *Redwood River Watershed TMDL Report* (MPCA 2023a) was completed and approved, which covers nine TSS impaired reaches, two bacteria (*Escherichia coli* [*E. coli*]) impaired reaches, one chloride impaired reach, and six nutrient impaired lakes throughout the Redwood River Watershed (see Appendix D for impairment details). 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.

In 2014, EPA Region 5 approved the *Redwood River Fecal Coliform TMDL Report* (RCRCA 2013), which covers nine bacteria reaches throughout the watershed (Appendix D). Prior to the watershed-wide TMDL study and the fecal coliform TMDLs, the MPCA completed the *Minnesota Statewide Mercury TMDL* (MPCA 2007) to address multiple impairments for mercury in fish tissue throughout the state. The six affected Redwood River Watershed reaches included in the mercury TMDL are listed in Appendix D.

There are also several approved TMDL reports for water bodies downstream of the Redwood River that include watershed area in the Redwood River Watershed:

- *Lower Minnesota River Dissolved Oxygen TMDL Report* (MPCA 2004)
- *South Metro Mississippi River TSS TMDL* (MPCA 2015)
- *Lake Pepin and Mississippi River Eutrophication TMDL Report* (MPCA 2021a)

Intensive watershed monitoring (IWM) was conducted in the Redwood River Watershed in 2017 and 2018 to determine the overall health of water resources, identify impaired waters, and identify waters in need of protection. Data from this IWM was combined with other available data collected within the last 10 years and used to assess water body health. In general, IWM results showed that most of the monitored lakes and streams in the Redwood River Watershed are degraded. Detailed results can be found in the Redwood River Watershed Monitoring and Assessment Report (MPCA 2020a).

The (IWM) efforts for the Redwood River Watershed identified 15 stream reaches that currently do not meet fish Index of Biotic Impairment (IBI) standards and 18 stream reaches that do not meet aquatic macroinvertebrate IBI standards. A Stressor Identification (SID) Report was developed for these reaches to determine the primary stressors to the biological communities (MPCA 2021b). Results from the SID report was incorporated into the Redwood River Watershed TMDL Report (MPCA 2023a) and the

Redwood River Watershed Restoration and Protection Strategies (WRAPS) Report (MPCA 2023b). The Redwood River Watershed RES TMDL addresses only the stream eutrophication impairment found in the Redwood River's most downstream reach (-501).

1.2 Identification of Waterbodies

This TMDL report addresses one river eutrophication impairment first listed on the State of Minnesota's 2016 303(d) list of impaired waterbodies (Table 1). Figure 1 shows the location of the impaired reach in the context of the greater Redwood River Watershed.

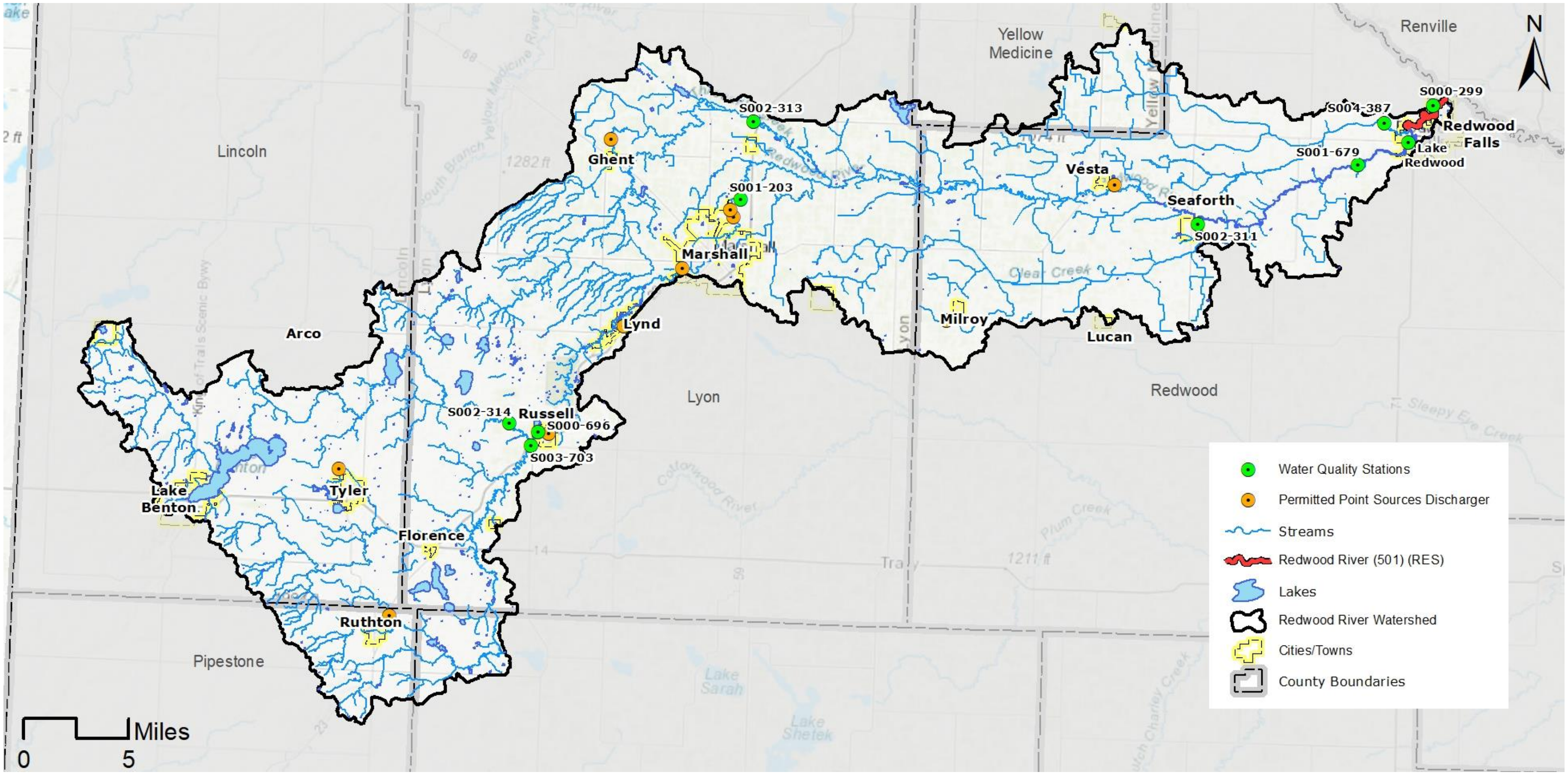
Table 1. Impaired river reach addressed in this TMDL report.

Affected use: Pollutant/ Stressor	Reach ID	Reach name	Reach description	Designated use Class	Listing year	Target start/ Completion
Aquatic Life: River Eutrophication	07020006-501	Redwood River	Ramsey Creek to Minnesota River	2Bg, 3	2016	2018/2021

1.3 Priority Ranking

The MPCA schedule for TMDL completions, as indicated on Minnesota's Section 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned TMDL priorities with the watershed approach. The schedule for TMDL completion corresponds to the WRAPS report completion following the 10-year IWM cycle. The MPCA developed a state plan, *Prioritization Plan for Minnesota 303(d) Listings to Total Maximum Daily Loads* (MPCA 2015), to meet the needs of EPA's national measure (WQ-27) under *EPA's Long-Term Vision for Assessment, Restoration and Protection under the CWA Section 303(d) Program* (EPA 2013). As part of these efforts, the MPCA identified water quality impaired segments that were to be addressed by TMDLs.

Figure 1. Overview of Redwood River impaired Reach 501 (in red) covered in this TMDL.



2. Applicable Water Quality Standards

The federal Clean Water Act requires states to designate beneficial uses for all waters and develop water quality standards to protect each use. Water quality standards consist of several parts:

- Beneficial uses—Identify how people, aquatic communities, and wildlife use our waters
- Numeric criteria—Amounts of specific pollutants allowed in a body of water that still protect it for the beneficial uses
- Narrative criteria—Statements of unacceptable conditions in and on the water
- Antidegradation protections—Extra protection for high-quality or unique waters and existing uses

Together, the beneficial uses, numeric and narrative criteria, and antidegradation protections provide the framework for achieving Clean Water Act goals. Minnesota's water quality standards are in Minn. R. chs. 7050 and 7052.

2.1 Beneficial uses

The beneficial uses for waters in Minnesota are grouped into one or more classes as defined in Minn. R. 7050.0140. The classes and associated beneficial uses are:

- Class 1 – domestic consumption
- Class 2 – aquatic life and recreation
- Class 3 – industrial consumption
- Class 4 – agriculture and wildlife
- Class 5 – aesthetic enjoyment and navigation
- Class 6 – other uses and protection of border waters
- Class 7 – limited resource value waters

The Class 2 aquatic life beneficial use includes a tiered aquatic life uses framework for rivers and streams. The framework contains three tiers—exceptional, general, and modified uses.

All surface waters are protected for multiple beneficial uses, and numeric and narrative water quality criteria are adopted into rule to protect each beneficial use. TMDLs are developed to protect the most sensitive use of a water body.

2.2 Narrative and numeric criteria and state standards

Narrative and numeric water quality criteria for all uses are listed for four common categories of surface waters in Minn. R. 7050.0220. The four categories are:

- Cold water aquatic life and habitat, also protected for drinking water: Classes 1B; 2A, 2Ae, or 2Ag; 3; 4A and 4B; and 5
- Cool and warm water aquatic life and habitat, also protected for drinking water: Classes 1B or 1C; 2Bd, 2Bde, 2Bdg, or 2Bdm; 3; 4A and 4B; and 5

- Cool and warm water aquatic life and habitat and wetlands: Classes 2B, 2Be, 2Bg, 2Bm, or 2D; 3; 4A and 4B; and 5
- Limited resource value waters: Classes 3; 4A and 4B; 5; and 7

The narrative and numeric water quality criteria for the individual use classes are listed in Minn. R. 7050.0221 through 7050.0227. The procedures for evaluating the narrative criteria are presented in Minn. R. 7050.0150.

The MPCA assesses individual water bodies for impairment for Class 2 uses—aquatic life and recreation. Class 2A waters are protected for the propagation and maintenance of a healthy community of cold water aquatic life and their habitats. Class 2B waters are protected for the propagation and maintenance of a healthy community of cool or warm water aquatic life and their habitats. Protection of aquatic life entails the maintenance of a healthy aquatic community as measured by fish and macroinvertebrate IBIs. Fish and invertebrate IBI scores are evaluated against criteria established for individual monitoring sites by water body type and use subclass (exceptional, general, and modified).

Both Class 2A and 2B waters are also protected for aquatic recreation activities including bathing and swimming, and the consumption of fish and other aquatic organisms. In streams, aquatic recreation is assessed by measuring the concentration of *(E. coli)* in the water, which is used as an indicator species of potential waterborne pathogens. Aquatic recreation in streams is also assessed by measuring phosphorus levels and its associated eutrophication response variables that can degrade recreational use potential.

2.3 Antidegradation policies and procedures

The purpose of the antidegradation provisions in Minn. R. ch. 7050.0250 through 7050.0335 is to achieve and maintain the highest possible quality in surface waters of the state. To accomplish this purpose:

- Existing uses and the level of water quality necessary to protect existing uses are maintained and protected.
- Degradation of high water quality is minimized and allowed only to the extent necessary to accommodate important economic or social development.
- Water quality necessary to preserve the exceptional characteristics of outstanding resource value waters is maintained and protected.
- Proposed activities with the potential for water quality impairments associated with thermal discharges are consistent with Section 316 of the Clean Water Act, United States Code, Title 33, Section 1326.

2.4 Redwood River Watershed RES water quality standards

The Redwood River RES impaired reach is classified as Class 2B and 3 water (Table 1). This TMDL addresses the class 2B standard, which is the most sensitive use of the impaired reach. As described above, 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.

The RES water quality standard consists of two parts, requiring an exceedance of the causative variable and a response variable which indicates the presence of eutrophication (Table 2). The causative variable is total phosphorus (TP). The response variables include chlorophyll-*a* (chl-*a*), dissolved oxygen (DO) flux, 5-day biochemical oxygen demand (BOD), or pH. Water quality standards for the response variables must be met, in addition to meeting phosphorus limits, for the water body to be considered meeting standards. The MPCA evaluated extensive datasets from across the state to establish clear relationships between the causal factor TP and the response variables. It is expected that by meeting the TP target, the response variables (Table 2) will also be met. The RESs apply to summer month mean values, for June to September. The Redwood River Watershed is located in the Southern River Nutrient Region and has a TP standard of 150 micrograms per liter (µg/L) or 0.15 milligrams per liter (mg/L).

Table 2. Surface water quality standards for Redwood River RES impaired reach 501 addressed in this TMDL report.

Standard	Parameter	Water Quality Standard[4]	Units	Criteria	Period of Time Standard Applies
River Eutrophication – Southern Rivers Nutrient Region	Total Phosphorus (causative[1])	Not to exceed 150	µg/L	Summer Mean	June - September
	Chlorophyll-*a* (response[2])	Not to exceed 35	µg/L	Summer Mean	June - September
	Diel dissolved oxygen flux (response[2])	Not to exceed 4.5	mg/L	Summer Mean	June - September
	5-day Biochemical Oxygen Demand (response[2])	Not to exceed 3.0	mg/L	Summer Mean	June - September
	pH (response[2])	Not to be less than 6.5 or greater than 9.0	su[3]	Summer Mean	June - September

[1] Primary, causative indicator of impairment; must be exceeded to be assessed as impaired.

[2] Secondary, response indicator of impairment; one of the four response parameters must be exceeded to be assessed as impaired.

[3] pH is standard units.

[4] Minn R. 7050.0222 incorrectly lists water quality standards for chl-*a*, DO flux and BOD for 2B Southern Streams. These errors will be addressed in future rule making efforts. The Standards approved by EPA are presented in Table 2.

3. Watershed and Waterbody Characterization

The Redwood River Watershed is a major HUC-8 watershed in the Minnesota River Basin, covering the south-central portion of the state. The Redwood River 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. There is no part of the Redwood River Watershed is located within the boundary of a federally recognized Tribal reservation, and the TMDL does not allocate pollutant loads to any federally recognized Tribal Nation in this watershed.

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. The streams and tributaries that make up these major subwatersheds flow to Redwood River Reach 501.

3.1 Streams

Redwood River Reach 501 covers approximately four stream miles and drains 447,531 acres of land across the watershed (Table 3).

Table 3. Stream impairments in the Redwood River Watershed.

Reach Name	Impaired Reach Id[1]	Impairment(s)	Reach Length [miles]	Watershed Area [acres]
Redwood River: Ramsey Creek to Minnesota River	501	RES	4.1	447,531

[1] Only the last three digits of the impaired reach are shown in this table for the Redwood River (07020006) impairments.

3.2 Subwatersheds

The drainage areas of the impaired reach were developed using multiple data sources, starting with watershed delineations from the MPCA's Hydrological Simulation Program – FORTRAN (HSPF) model application for the Redwood River Watershed (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. 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).

3.3 Land Use

Uninterrupted prairie originally covered a majority 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.

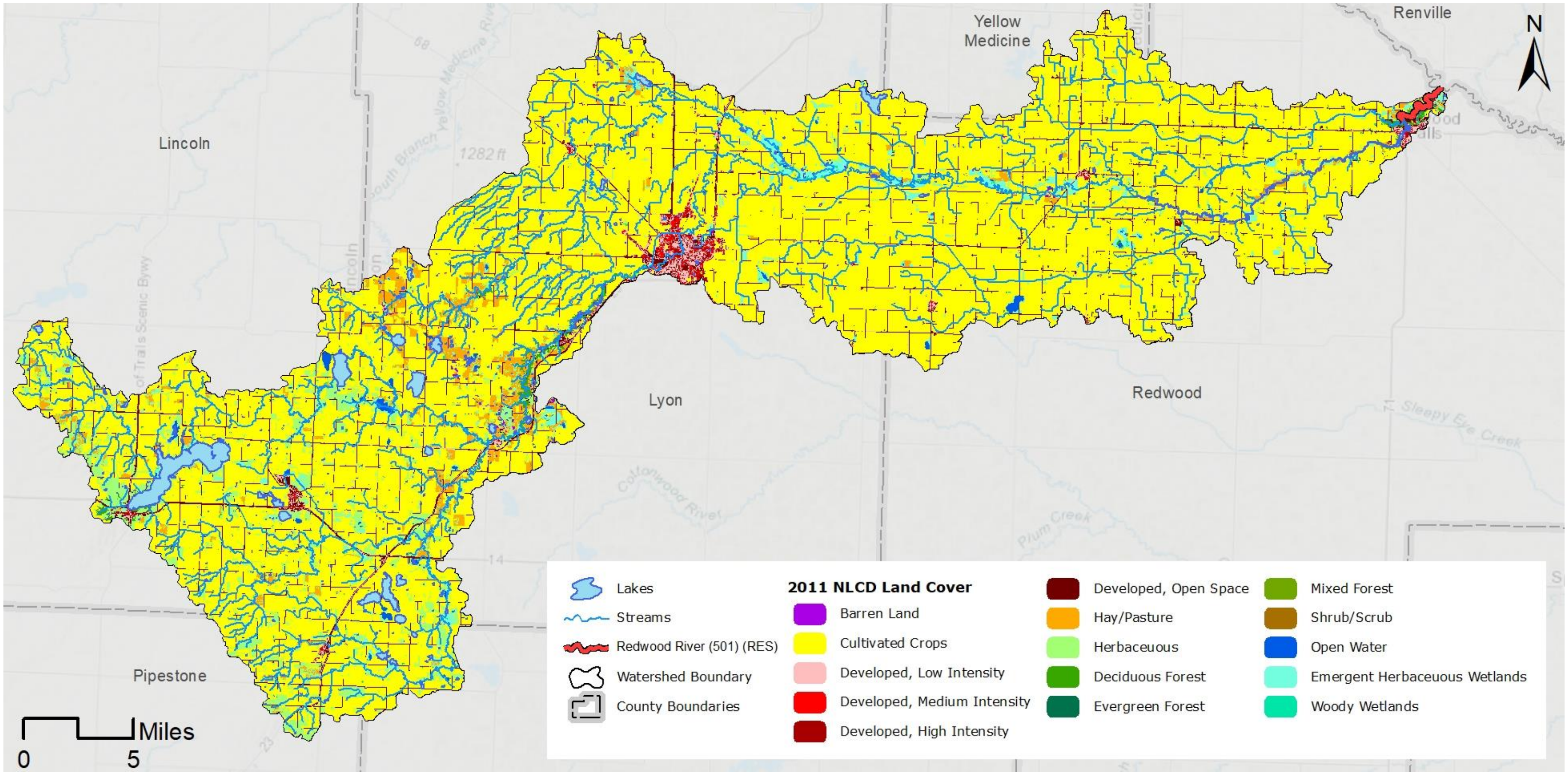
Land use within the Redwood River Watershed was analyzed using USGS's 2011 National Land Cover Database (NLCD). While this is an older database, it is still valid as land use within the watershed has changed minimally over the last 10+ years and is dominated by agriculture (mostly row crops) followed by rangeland, developed land, wetlands, open water and forest/shrub land (Table 4 and Figure 2). 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, however 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 City 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 4. Summary of land use and watershed area for the impaired reach.

Impaired Waterbody Name	Reach or Lake Id	Watershed Area [Acres]	Percent of Watershed [%]						
			Cropland	Rangeland	Developed	Forest/Shrub land	Open Water	Wetlands	Barren/Mining
Redwood River	07020006-501	447,532	78	9	6	1	2	3	< 1

Figure 2. Land cover in the Redwood River Watershed (Source: 2011 NLCD).



3.4 Current/Historical Water Quality

Existing water quality conditions are described using data downloaded from the MPCA's Environmental Quality Information System (EQuIS) database. EQuIS stores data collected by the MPCA, partner agencies, grantees, and citizen volunteers. All water quality sampling data utilized for assessments, modeling, and data analysis, for this report and reference reports, are stored in this database and are accessible through the MPCA's Environmental Data Access website. Various agencies and local partners, such as the MPCA, Soil and Water Conservation Districts (SWCD), local watershed districts, and volunteer monitoring programs collected data to develop this TMDL report. Phosphorus and the available response variables (chl-*a*, pH, and BOD) data are summarized in Table 5 for the impaired reach addressed in this TMDL report. The RES impairment is based on the Southern Rivers Nutrient Region TP standard of 150 µg/L. Chl-*a* has a numeric standard of 40 µg/L for the Southern Rivers Nutrient Region, BOD has a numeric standard of 3.5 mg/L, and pH must be greater than 6.5 but less than 9, all for Class 2B waters in the Southern Rivers Nutrient Region. No data is available within the impaired reach to evaluate diel DO flux.

Available data from the most recent 10-year assessment period were used for development of this TMDL report. However, there are only three years of RES data available (2009, 2017, and 2018) over this period, and therefore data dating back to 2000 was also included in Table 5 for reference. Precipitation in 2009 was approximately 7.5 inches below the long-term average, while 2017 and 2018 were approximately 9.5 inches and 7.5 inches above the long-term average, respectively. RES monitoring from 2000 through 2008 consisted of data collected in 2001 (~0.5 inches below normal), 2004 (~5 inches above normal), 2005 (~7 inches above normal), and 2006 (~1.5 inches below normal). Thus, RES data has been collected in four very wet years (i.e., 5+ inches above normal; 2004, 2005, 2017, and 2018), one very dry year (i.e., 5+ inches below normal; 2009), and two normal years (i.e., within 2 inches of normal; 2001 and 2006) since 2000. As shown in Figure 3, there are no clear patterns in the RES data between wet, dry, and normal precipitation years.

Table 5. Current condition RES-related water quality data for Redwood River Reach 501.

EQuIS Station(s)	Parameter	Period of Record	Summer Average (June-Sep)	Samples (Count)	Number of Exceedances
S000-299	Phosphorus (µg/L)	2009 - 2018	303	19	17
		2000 - 2018	315	38	36
	Chlorophyll-*a* (µg/L)	2009 - 2018	20	19	3
		2000 - 2018	46	38	11
	pH	2009 - 2018	8.5	21	0
		2000 - 2018	8.4	57	0
	Biochemical Oxygen Demand (mg/L)	2009 - 2018	3.7	4	3
		2000 - 2018	3.3	20	11

RES-related data upstream of the impaired reach were also obtained from EQuIS and analyzed to evaluate phosphorus and eutrophication variability throughout the main-stem of the Redwood River and its tributaries. Figure 1 shows the locations of the water quality monitoring stations upstream of the RES impaired reach that were included in this analysis. Figure 4 to Figure 7 are box plots showing the range of TP and chl-*a* concentrations from various monitoring locations throughout the watershed. Similar box plots for pH and BOD are presented in Appendix A.

Figure 3. Redwood River Reach 501 summer averages TP (top), chl-*a* (middle), and BOD (bottom) from 2000 - 2018. Summer averages are color-coded by wet years (blue), normal precipitation years (green), and dry years (orange). The solid red lines represent the Southern River Nutrient Region RES standards for TP (150 µg/L), chl-*a* (35 µg/L), and BOD (3 mg/L) (Table 2).

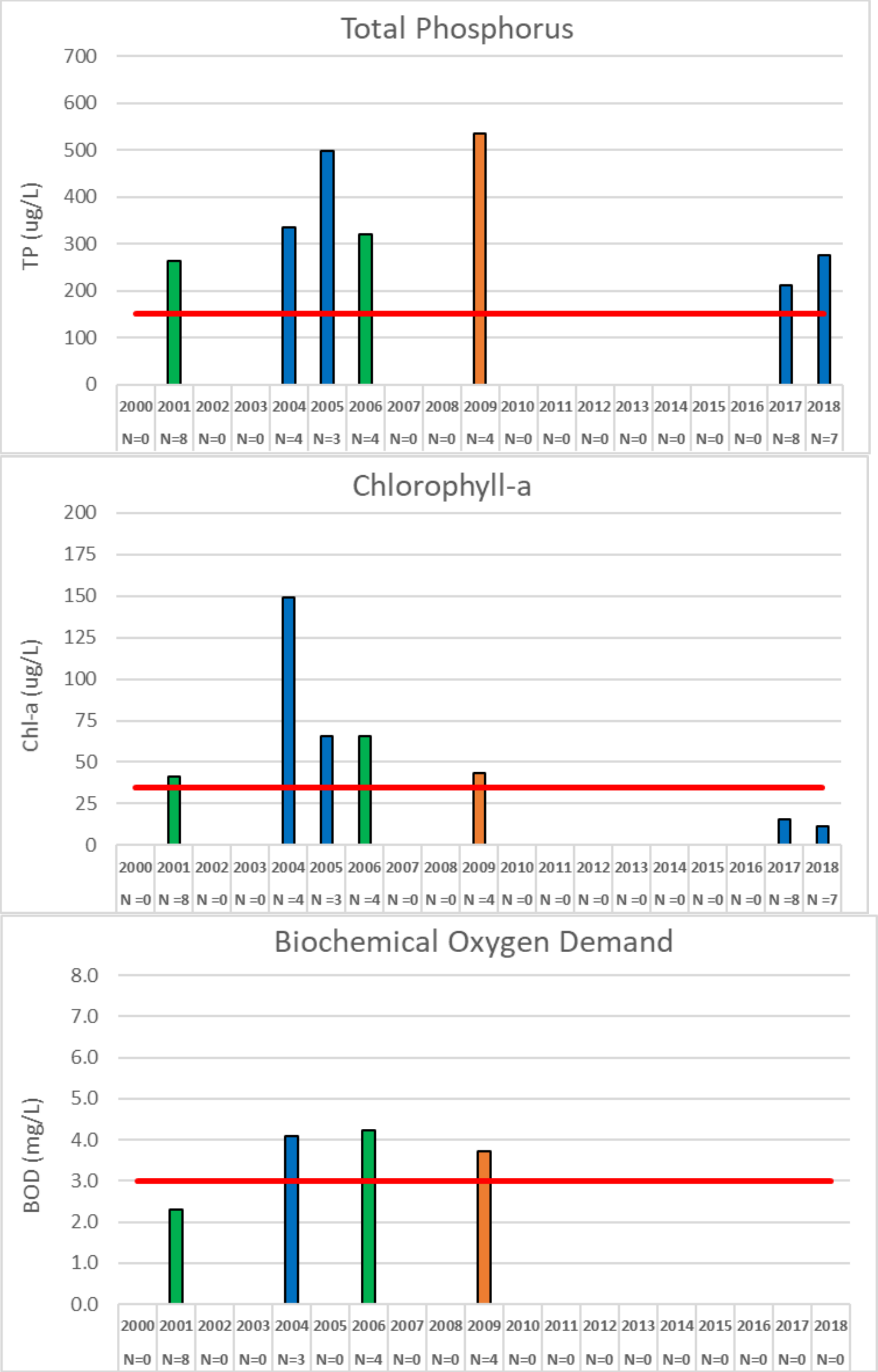


Figure 4. Summer (June-September) TP concentrations for Redwood River main-stem monitoring stations (2000-2018). The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. The error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median TP concentration. The solid red line represents the Southern River Nutrient Region RES TP standard (150 µg/L).

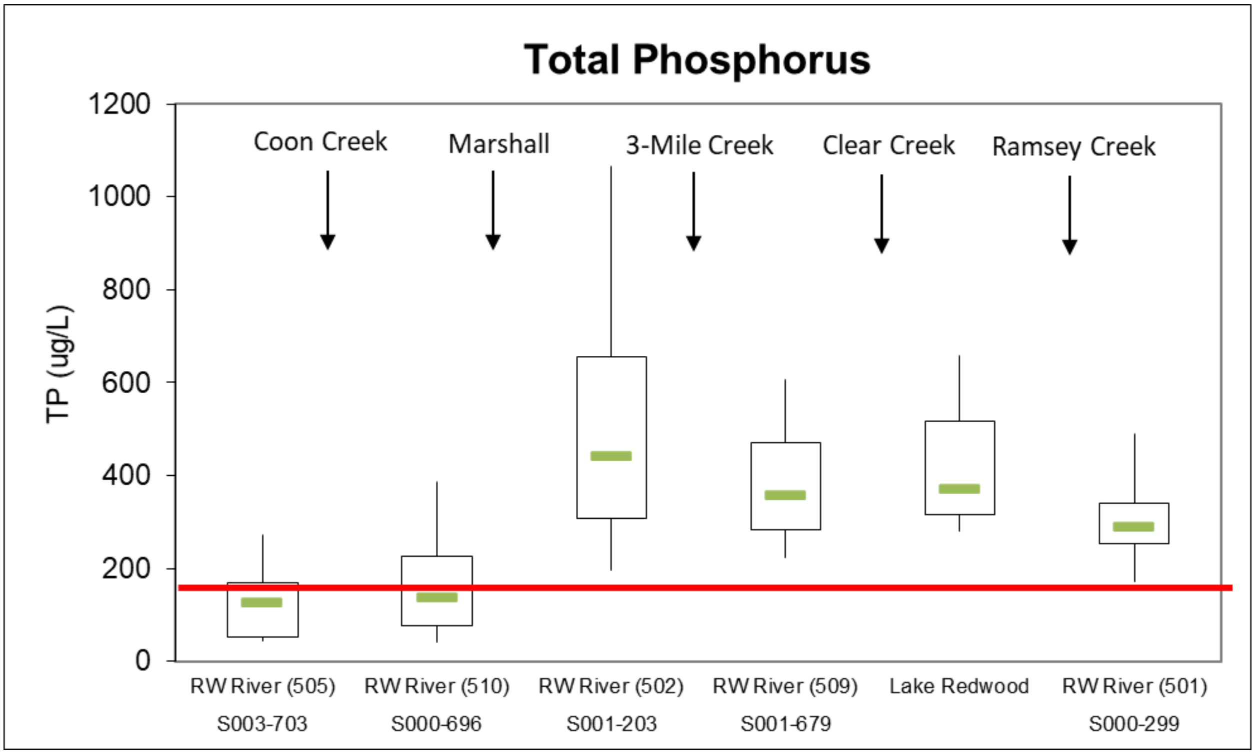


Figure 5. Summer (June-September) TP concentrations for Redwood River tributary monitoring stations (2000-2018).

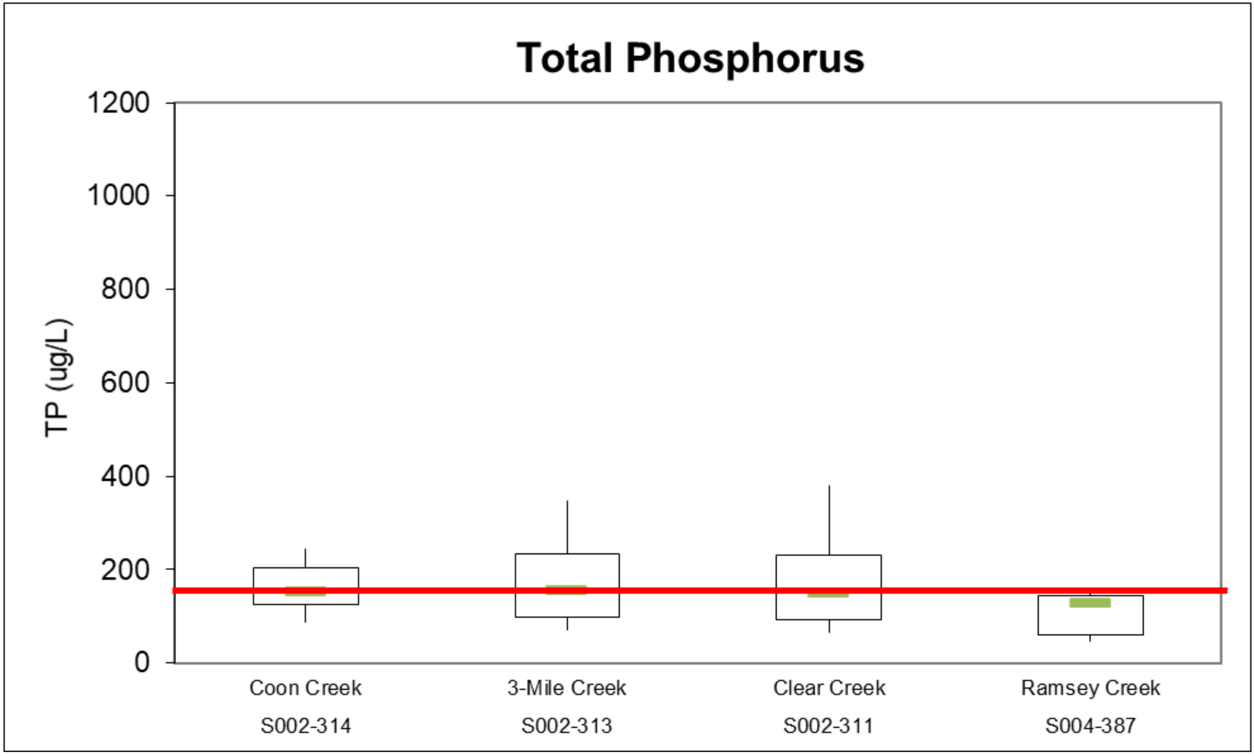


Figure 6. Summer (June-September) chl-*a* concentrations for Redwood River main-stem monitoring stations (2000-2018). The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. The error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median chl-*a* concentration. The solid red line represents the Southern Rivers Nutrient Region RES chl-*a* standard (35 µg/L).

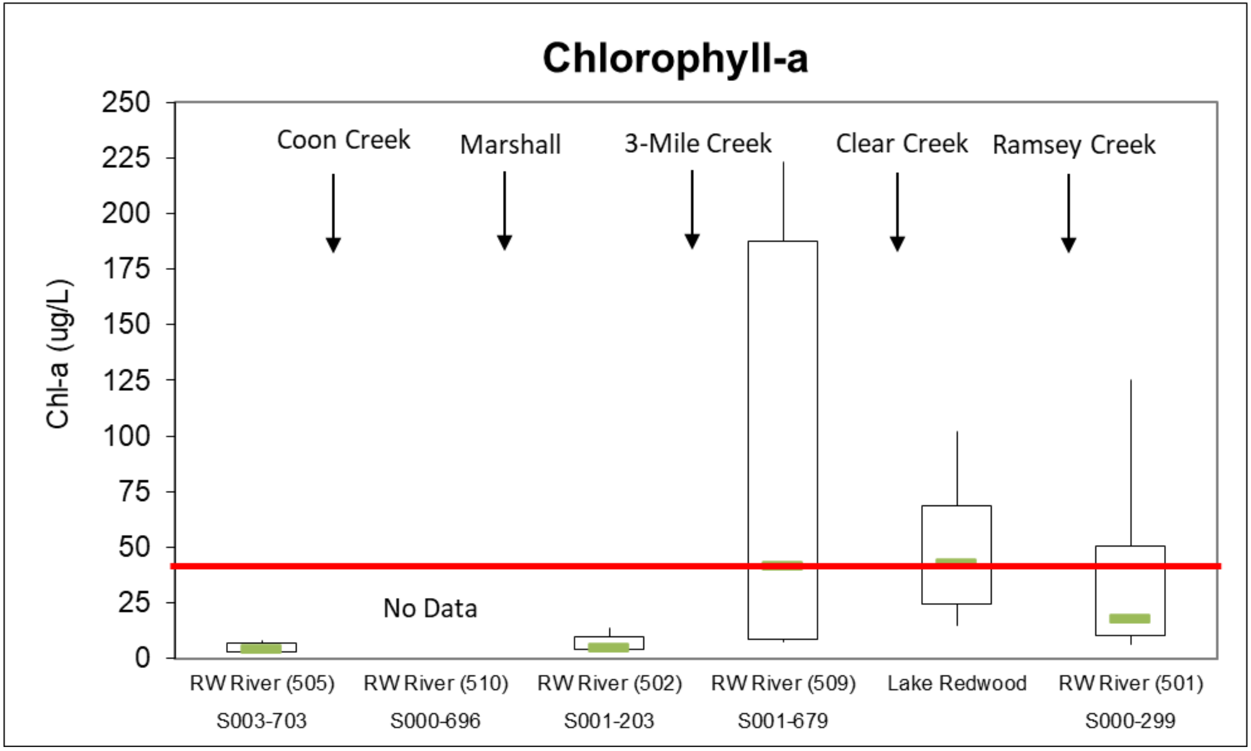
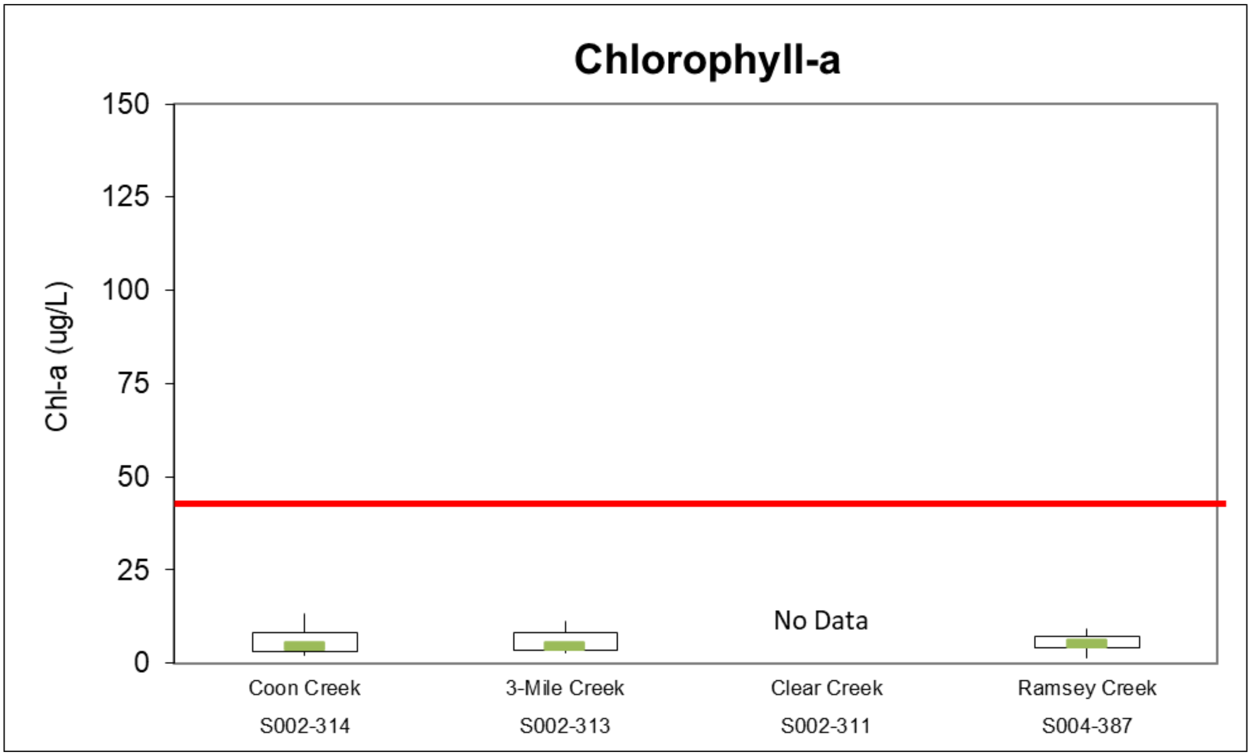


Figure 7. **Summer (June-September) chl-*a* concentrations for Redwood River tributary monitoring stations (2000-2018).**



3.5 Lake Redwood

Lake Redwood (64-0058-00) was created in 1902 when A.C. Burmeister dammed the Redwood River to power his grist mill in the city of Redwood Falls beginning around 1910. The 67-acre lake on the western edge of the city (Figure 8) provides water for the city's hydroelectric power plant and recreational opportunities to area residents. After a century of sedimentation, the once 20-foot-deep reservoir has decreased to less than 3 feet. Lake Redwood was assessed as impaired in 2006 for aquatic recreation use based on assessment of the available water quality for the lake. In 2016, an MPCA review team determined that Lake Redwood's short water residence time (less than 1 day) does not meet the MPCA's 14-day residence time for a lake/reservoir according to Minn. R. ch. 7050.0150, subp. 4, BB and; therefore, it was removed from the 2016 impaired waters list.

Average summer growing season water quality monitoring data available for Lake Redwood (TP, chl-*a* and Secchi depth) are presented in Appendix A. Although the monitoring data is rather limited, these data suggest Lake Redwood experiences high TP and chl-*a* concentrations relative to the EPA-approved river/stream RES standards. Lake Redwood chl-*a* levels are highly variable depending on river flow; however, concentrations are significantly higher than upstream main-stem river monitoring stations, indicating that the lake supports algae growth and functions more like a lake during certain parts of the year. Chl-*a* concentrations in Lake Redwood are highest during mid-summer (July and August) low-flow conditions (Appendix A). See Section 8.3.5, of this TMDL, for more details regarding the dredging of Lake Redwood.

Figure 8. Lake Redwood in Redwood Falls, Minnesota, upstream of the Redwood River RES impaired reach.

3.6 Pollutant Source Summary

Human-made influences typically include state- and federal- permitted discharges from wastewater, industrial and commercial entities, urban development, impervious surfaces (roads, roofs, and driveways), stormwater from artificial drainages on urban and agricultural lands, row cropping, pastured lands, individual sanitary-treatment systems, feedlots, and channelized streams/ditches. The internal loading of phosphorus in upstream lakes is an additional nonpoint source that can be both anthropogenic and natural in origin and is primarily caused by phosphorus releasing from lake sediments or aquatic plants. Natural background phosphorus sources include surface runoff (SRO) and atmospheric deposition of windblown particulate matter from the natural landscape, stream-channel erosion, and groundwater discharge. The following section provides brief descriptions of the primary TP sources in the Redwood River Watershed.

Overland Runoff/Erosion (Rural Areas)

Nonpoint pollutant loading of phosphorus in rural areas can come from nonpermitted sources such as sediment erosion from upland fields, tile drainage (Schottler 2013), gully erosion, and poorly managed livestock pastures in riparian zones. Runoff from these sources can carry sediment, phosphorus, and other pollutants to surface waters.

The Redwood River Watershed NPSs of phosphorus were evaluated using the Redwood HSPF Model (Tetra Tech 2019). Overall, across the entire Redwood River Reach 501 drainage area, approximately 53% of the phosphorus load is from agriculture (i.e., cultivated crops and hay/pasture lands identified in the 2011 NLCD land use layer, in addition to loading from feedlots) and other rural upland sources.

Nonpoint source pollution is accumulated by rainfall or snowmelt moving over and through the ground. As the runoff moves, it picks up and carries natural and human-made pollutants, finally depositing them into lakes and streams. Common nonpoint pollutant sources in the Redwood River Watershed are summarized below.

- **Watershed runoff**: Erosion from agricultural fields can deliver sediment to waterbodies that contain nutrients when soil is disturbed or exposed to wind and rain. Runoff from roads, parking lots and other impervious surfaces can also carry pollutants to lakes and streams. The HSPF model was used to estimate watershed runoff volumes and pollutant loads for all subwatersheds in the Redwood River Watershed. The HSPF model is based on land cover and soil type and was calibrated using meteorological data from 1996 through 2017.
- **Altered hydrology**: 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. Further, draining and tiling wetland areas can decrease water storage on the landscape, which can lead to lower evapotranspiration and increased river flow (Schottler et al. 2014). These hydrologic changes in the landscape, combined with the altered precipitation patterns driven by climate change, can lead to increased TSS and sediment-bound phosphorus loading to surface waters from eroded sediments. For more detailed information on how altered hydrology impacts TSS and phosphorus loading to water bodies, see the Redwood River Watershed Characterization Report (DNR 2020).

- **Fertilizer and manure**: Fertilizer and manure contain high concentrations of phosphorus, nitrogen, and bacteria that can run off into lakes and streams when not properly managed.
- **Failing septic systems**: Septic systems that are not maintained or are failing near a lake or stream can contribute excess phosphorus, nitrogen, and bacteria.

Animal Feeding Operations

Livestock 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 feedlots throughout Minnesota. By definition, a feedlot 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 a federal 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 state definition of an animal unit (AU). In Minnesota, all CAFOs and non-CAFOs that have 1,000 or more AUs must operate under an NPDES or state disposal system (SDS) permit. CAFOs with fewer than 1,000 AUs and that are not required by federal law to maintain NPDES permit coverage may choose to operate without an NPDES permit.

CAFO and feedlots with 1,000 or more AUs need to be designed to contain all manure, manure contaminated runoff, process wastewater, and the precipitation from a 25-year, 24-hour storm event. Having and complying with an NPDES or SDS permit authorizes discharges to waters of the United States and waters of the state (with NPDES permits) or waters of the state (with SDS permits) due to a 25-year, 24-hour precipitation event (approximately 5.2” in 24 hours) when the discharge does not cause or contribute to nonattainment of applicable state water quality standards. Large CAFOs with fewer than 1,000 AUs that have chosen to forego NPDES permit coverage are not authorized to discharge and must contain all runoff, regardless of the precipitation event. Large CAFOs permitted with an SDS permit are authorized to discharge to waters of the state, although they are not authorized to discharge to waters of the U.S. Therefore, many large CAFOs in Minnesota have chosen to obtain an NPDES permit, even if discharges have not occurred at the facility. A current manure management plan that complies with Minn. R. 7020.2225 and the respective permit is required for all permitted CAFOs and feedlots 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/SDS 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 as CAFOs do not operate with permits; however, the requirements under Minn. R. ch. 7020 still apply. In Minnesota, feedlots with greater than 50 AUs, or greater than 10 AUs in shoreland areas, are required to register with the county feedlot officer if the county is delegated, or with the MPCA if the county is nondelegated. Facilities with fewer AUs are not required to register. Shoreland is defined by Minn. R. 7020.0300 as land within 1,000 feet from the normal high water mark of a lake, pond, or flowage, and land within 300 feet of a river or stream. 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 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. Feedlot registration enables the County and the MPCA to communicate directly with feedlot owners regarding all aspects of feedlot management including technical requirements, permitting, inspections and corrective action. 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 within the last five years that the feedlot has held; therefore, the actual number of livestock in registered facilities is likely lower. Livestock in nonregistered, smaller operations (e.g., hobby farms) may contribute pollutant loads to surface waters through watershed runoff from fields and direct deposition in surface waters. The feedlot spatial dataset used in this TMDL was provided by MPCA staff in January of 2018. Feedlot data was intersected with the impaired reach watershed and queried to only include active feedlot registrations. The MPCA registered feedlot database indicates there are approximately 349 feedlot facilities with over 100,000 livestock AUs throughout the Redwood River Reach 501 drainage area (Figure 9). Table 6 summarizes facility type and livestock numbers for each impaired reach, lake, and the entire watershed. In the impaired reach drainage area, there are 33 feedlots located within 1,000 feet of a lake or 300 feet of a stream or river, an area generally defined as shoreland. Of these 33 feedlots, 32 have open lots and could present a potential pollution hazard if the runoff from the open lots is not treated prior to reaching surface water. See Appendix E for a list and summary of all CAFOs in the watershed.

Table 7 provides a breakdown of AUs within the RES impaired reach 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 pounds, heifers, calves, and cattle greater than 1,000 pounds. Poultry includes turkeys, chickens, and fowl produced for consumption.

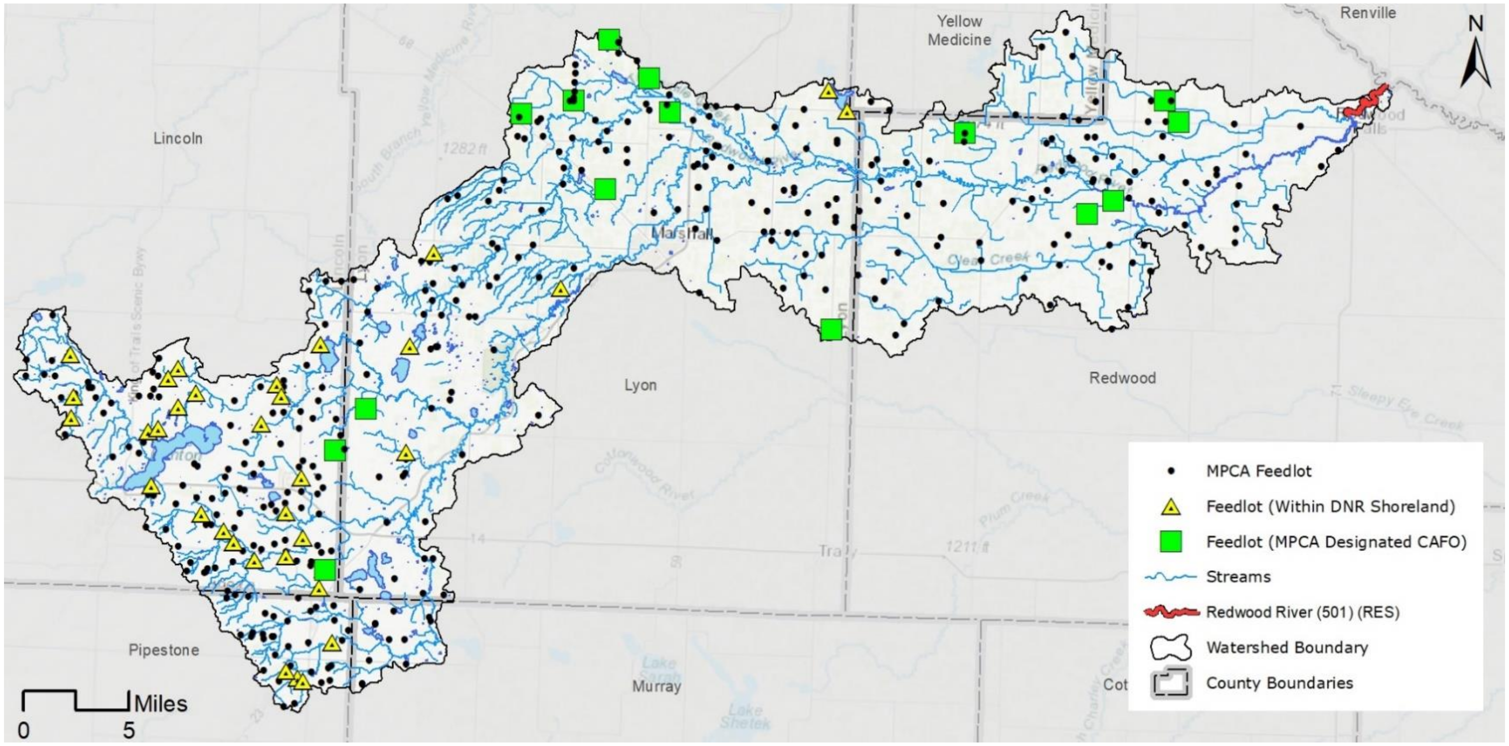
Table 6. MPCA active registered feedlots and feedlot type for Redwood River Reach 501.

Impaired Reach	Impairment Type	Total Facilities		CAFOs		Open Lots		Shoreland		Open Lots in Shoreland	
		Count	AUs	Facilities	AUs	Facilities	AUs	Facilities	AUs	Facilities	AUs
Redwood River Reach 501	RES	352	86,514	15	10,750	282	54,954	28	3,556	27	3,016

Table 7. Registered livestock animal types within the Redwood River Reach 501 drainage area.

Impaired Reach	Impairment Type	Active Facilities	Total AUs	Animal Units (AUs)						
				Beef Cattle	Dairy Cattle	Swine	Sheep	Horse	Poultry	Other
Redwood River Reach 501	RES	352	86,514	42,394	3,912	35,621	1,436	193	2,940	17

Figure 9. MPCA registered feedlots in the Redwood River Watershed.



Manure

Manure is a by-product of animal production and large numbers of animals create large quantities of manure. This manure is usually stored 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 and builds soil health. Manure, however, can pose water quality concerns when it is not applied properly or leaks or spills from nearby fields, storage pits, lagoons, tanks, etc. Animal waste contains high amounts of phosphorus, nitrogen, and fecal bacteria, and therefore when delivered to surface and groundwater can cause high bacteria levels, eutrophication, and oxygen demand (i.e., low oxygen levels) that can negatively impact human health, aquatic organisms, and aquatic recreation.

The Minnesota Feedlot rules include regulations regarding the requirements for manure management plans and land application of manure. The MPCA has developed templates, guides, and standards for the development and implementation of manure management plans, manure nutrient management and application rates. Manure management plans 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. Manure management plans 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 (MPCA 2022). Winter application of solid manure (December through February) for permitted sites requires fields to be approved in their MMP, prior to manure application, and the feedlot owner/operator must follow a standard list of setbacks and best management practice (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 typically 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 does not explicitly estimate or model the contribution of manure to surface waters in the Redwood River Watershed; however, nutrient loads modeled by HSPF are calibrated using monitored, in-stream water quality data at several points throughout the watershed and manure contributions to nutrient loads are therefore implicit. The MDA website contains the Minnesota Runoff Risk Advisory Forecast (RRAF) system, a tool designed to help farmers and commercial applicators determine the best time to apply manure. Precipitation, snow melt or other conditions can cause recently applied manure to move off target. The movement can decrease productivity and increase the risk of impairing local bodies of water.

Urban Stormwater

Cities and developed areas can be a source of phosphorus 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 phosphorus in stormwater are many, including decaying vegetation (leaves, grass clippings, lawns, 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 cities of Marshall (MS400241; population 13,628) and Redwood Falls (MS400236; population 5,102) are located in the central and eastern portion of the watershed, respectively. 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 (CWA). 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 8). 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 TP loading across the Redwood River Watershed.

Table 8. Municipalities in the Redwood River Watershed.

City/Town	County	Area in Watershed [acres]	Population[1]	MS4
Echo[2]	Yellow Medicine	7	243	No
Florence	Lyon	138	28	No
Ghent	Lyon	222	376	No
Lake Benton	Lincoln	2,272	687	No
Lucan[2]	Redwood	58	214	No
Lynd	Lyon	775	436	No
Marshall	Lyon	5,875	13,628	Yes
Milroy	Redwood	164	259	No
Redwood Falls	Redwood	1,698	5,102	Yes
Russell	Lyon	628	348	No
Ruthton	Pipestone	375	226	No
Seaforth	Redwood	644	82	No
Tyler	Lincoln	1,004	1,138	No
Vesta	Redwood	215	276	No
Green Valley (Fairview Township)	Lyon	80	160	No

[1] 2020 Census Population

[2] A majority of the Echo and Lucan municipal boundaries are outside the Redwood River Watershed

Near-Channel Sources

Near-channel sources of sediment and phosphorus 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 increase 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 river banks (Schottler et al. 2013, Lenhart et al. 2013).

For the purposes of this TMDL study, near-channel TP loading from ravines, bluffs, and streambanks was 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 Redwood River Watershed. Model documentation (Tetra Tech 2016 and 2019) contains additional details about the model development and calibration. The HSPF model estimates that approximately 61% of the TSS load at the outlet of Redwood River Reach 501 comes from near-channel sources. However, since there is very little organic material and phosphorus attached to the sediment in eroding stream and river banks, the model estimates that less than 1% of the Reach 501 phosphorus load is from near channel-sources. Section 3.5.1 below contains more detailed discussion of the modeled near-channel source contributions.

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.

Septic systems

Failing Subsurface Sewage Treatment Systems (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 IAW 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 (Table 9). It should be noted that these rates are county-wide estimates and were developed using a wide range of methods and resources and are intended for planning purposes only. Phosphorus loading from SSTSs to the impaired reach were estimated in HSPF using the compliance data provided by each county in the watershed. The number of residences that were served by SSTSs were summed from the provided permit data per township; the total number of SSTS was determined based on the percent of each subwatershed. Loading rates that incorporated SSTS failure rates were developed for phosphorus and other pollutants on a per capita basis and applied to each modeled reach within the HSPF model.

Table 9. Estimated SSTS compliance rates by county (MPCA data 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 county and supplied to MPCA. Intended for planning purposes only.

Municipal and Industrial Wastewater

The Federal CWA prohibits point source discharges to waters of the United States, unless the discharge has a NPDES permit. NPDES permits specify conditions and limitations for such discharges. There are 10 active NPDES permitted wastewater facilities in the Redwood River Reach 501 drainage area (Figure 1 and Table 10), including one petroleum treatment facility, seven municipal treatment plants with treatment ponds that discharge seasonally, one major municipal discharger (Marshall) and one major industrial discharger (ADM – Marshall) that discharge continuously (i.e., mechanical facilities). Starting in 2000, the MPCA's Citizens' Board adopted a strategy for addressing phosphorus in NPDES permits, which established a process for the development of 1 mg/L phosphorus limits for new and expanding wastewater treatment plant (WWTPs) that had potential to discharge phosphorus in excess of 1,800 lbs/year. It also established requirements for other WWTPs to develop and implement phosphorus management plans. The MPCA's Phosphorus Strategy was formally adopted as Minn. R. 7053.0255, in 2008.

The data trend in Figure 10 shows summer (June through September) NPDES TP loads have decreased by approximately 34% in the Redwood River Watershed since 2015. A majority of the NPDES TP reduction can be attributed to improved phosphorus removal by the Marshall WWTP to meet an annual TP effluent limit, which has been in effect since April 2017. As a result, Marshall's June through September effluent TP concentrations have been reduced from 3.9 mg/L (2009 through 2015) to 0.97 mg/L (2016 through 2020).

Table 10. Wastewater treatment facilities that contribute to the Redwood River impaired reach.

Facility/City[1]	NPDES ID#	Facility Type	WLA Flow[2] (MGD)
ADM Corn Processing – Marshall	MN0057037	Mechanical	2.64
Ghent WWTP	MNG585121	Pond	0.26
Lynd WWTP	MNG585030	Pond	0.34
Magellan Pipeline Co LP – Marshall	MN0059838	PT[3]	0.72
Marshall WWTP	MN0022179	Mechanical	3.15[4]
Milroy WWTP	MNG585124	Pond	0.25
Russell WWTP	MNG585062	Pond	0.59
Ruthton WWTP	MNG585105	Pond	0.38
Tyler WWTP	MNG585116	Pond	1.09
Vesta WWTP	MNG585043	Pond	0.26

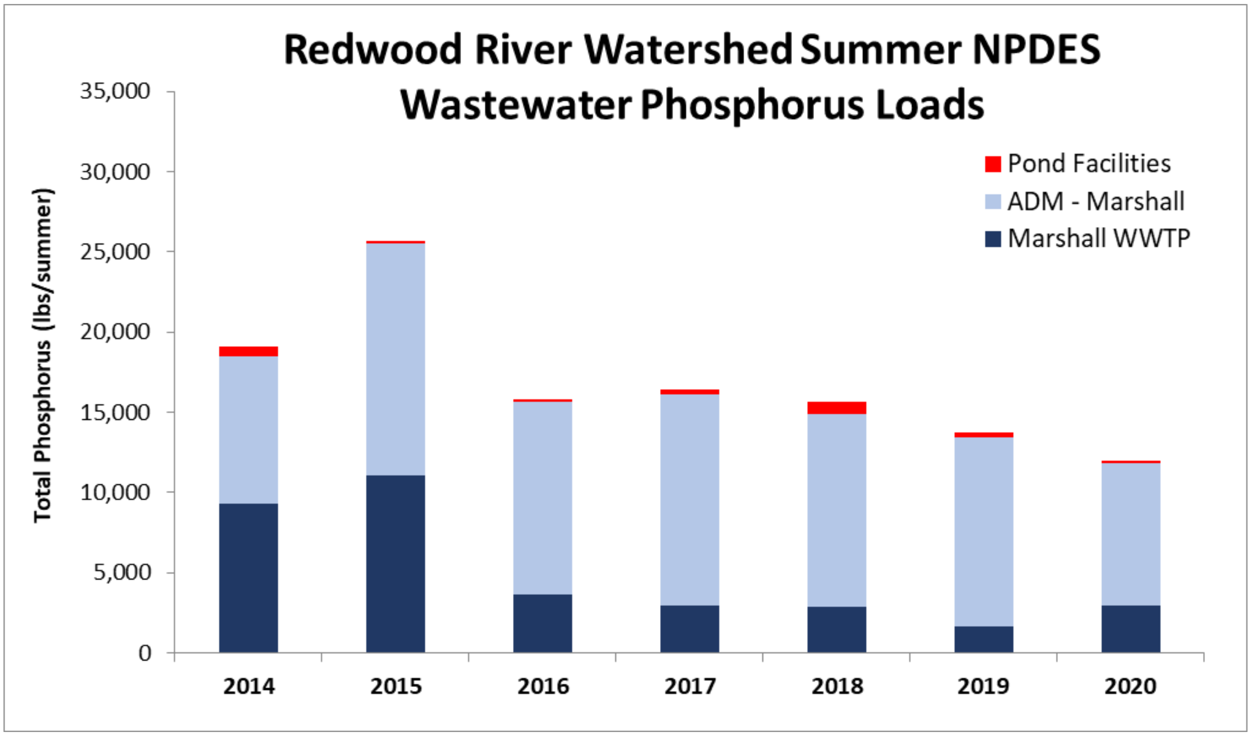
[1] The Echo, Lucan, Lake Benton, and Redwood Falls facilities discharge outside of the Redwood River Watershed.

[2] For WWTPs with wastewater ponds (Ghent, Lynd, Milroy, Russell, Ruthton, Tyler, and Vesta) the effluent design flow represents the maximum permitted daily discharge volumes from secondary ponds.

[3] Petroleum treatment (PT) with an oil/water separator, VOC treatment system and a 5 micron filter.

[4] 70% of average wet weather design flow (4.5 MGD) was used to develop WLA.

Figure 10. Summer NPDES wastewater phosphorus loads in the Redwood River Reach 501 Watershed from 2014-2020 based on facility Discharge Monitoring Report (DMR) data downloaded from the MPCA's Wastewater Data Browser (https://www.pca.state.mn.us/data/wastewater-data-browser).



Construction and Industrial Stormwater

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

Industrial stormwater is regulated through an NPDES permit when stormwater discharges have the potential to come into contact with materials and activities associated with the industrial activity. There are currently 30 industrial stormwater permits in the Redwood River Watershed, which cover approximately 500 acres (~0.1% of watershed). On average, based on watershed-wide data, construction stormwater permits in the Redwood River Watershed account for about 0.2% of watershed phosphorus load in any given year. Thus, construction and industrial stormwater is not considered a significant source of phosphorus throughout the Redwood River Reach 501 drainage area.

3.6.1 Phosphorus Source Summary

As discussed in the previous section, phosphorus loading to streams can come from both external and internal sources. External sources include phosphorus 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 phosphorus include bank erosion and sediment release of phosphorus (in-channel and in lakes). This TMDL used the Redwood River HSPF model to evaluate phosphorus loading from various sources throughout the Redwood River Watershed. Figure 11 displays HSPF-predicted areal phosphorus subwatershed loading rates (lbs/acre/year) from upland areas (i.e., NPSs) to local stream channels and waterways throughout the larger Redwood River Watershed. The HSPF model predicts the highest nonpoint phosphorus loading rates occur along the high-sloped areas of the Coteau (i.e., western portion of the watershed) and the eastern subwatersheds (e.g., Ramsey Creek) near the impaired reach. It is important to note that Figure 11 does not include loading from point sources, in-channel sources, and phosphorus fate and transport (e.g., settling and plant uptake) in the river and stream network upstream of the impaired reach. Therefore, from a management perspective, targeting upland BMPs in the high-loading subwatersheds closest to Redwood River Reach 501 will likely have the greatest impact in reducing phosphorus concentrations in the impaired reach. Table 11 and Figure 12 present HSPF predicted summer phosphorus loads by major source category to Redwood River Reach 501. Unlike the map below, the values in Table 11 and Figure 12 include all phosphorus sources as well as fate and transport through the river and stream network upstream of the impaired reach.

In addition to the HSPF model, this TMDL also used monitored data upstream of the impaired reach to evaluate what tributaries and locations within the Redwood River Watershed have the highest phosphorus concentrations and loading potential. Figure 4 through Figure 7 in Section 3.4 and Appendix A show how TP concentrations, as well as the other RES response variables, change from upstream to downstream throughout the Redwood River Watershed. The monitored data and the HSPF model both indicate that phosphorus levels generally increase from upstream to downstream across the watershed. The biggest increase in TP concentrations and areal loading rates occurs downstream of Marshall, mainly due to inputs from permitted wastewater facilities and large tributaries (e.g., Three Mile Creek and Clear Creek). Algae growth within the Redwood River (as measured by chl-*a*) also increases downstream of the city of Marshall as the river begins to slow near Lake Redwood (Figure 6 and Figure 11).

Figure 11. HSPF-predicted nonpoint TP loading rates from upland areas to local stream channels and waterways in the Redwood River Watershed (model averaging period: June through September 2009 through 2017).

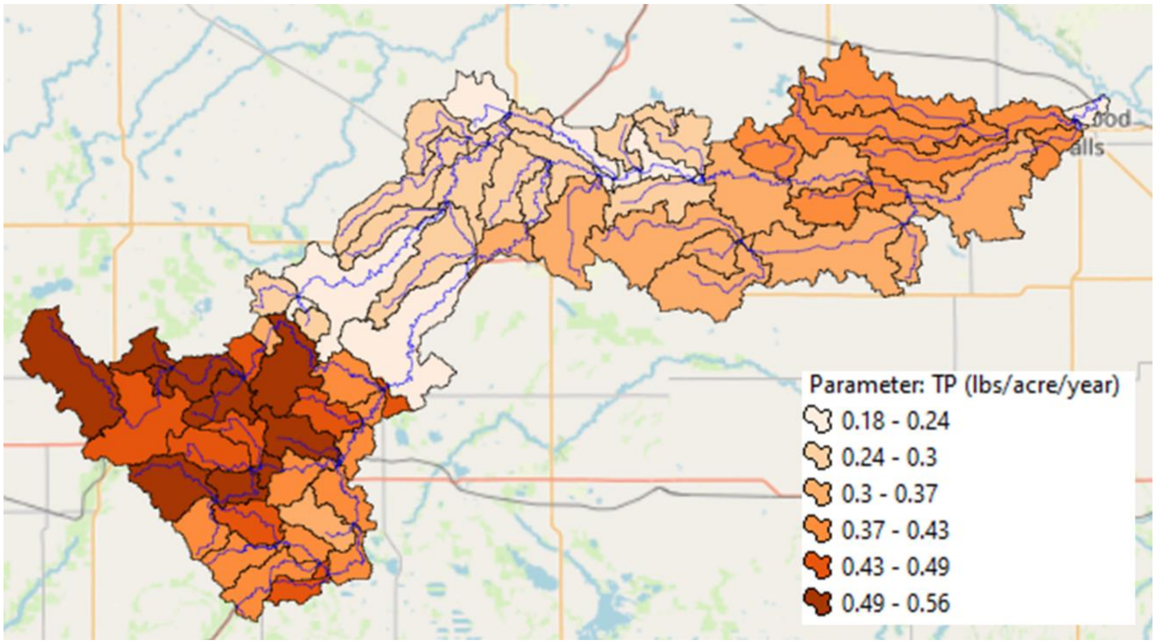


Figure 12. Phosphorus contributions by source (includes phosphorus fate and transport) at the outlet of Redwood River Reach 501 during the summer growing season (June through September) using the Redwood River HSPF model.

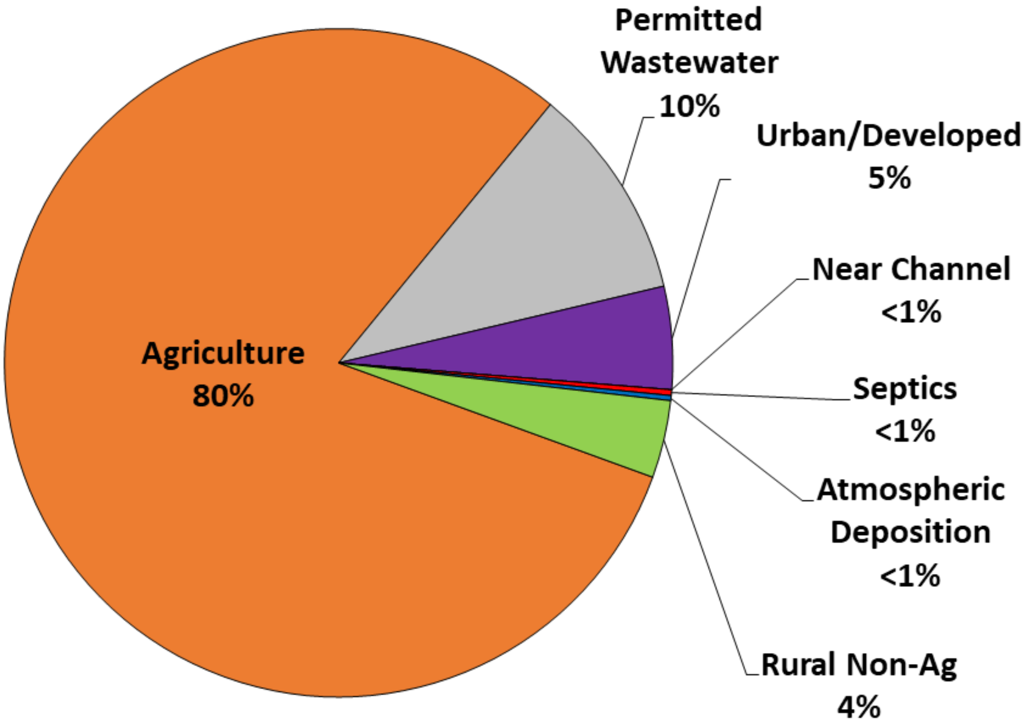


Table 11. HSPF-estimated phosphorus contributions by source at the outlet of Redwood River Reach 501.
Note: Numbers in this table are based on HSPF average summer growing season (June through September) phosphorus loads (accounting for upstream fate and transport) at the outlet of Reach 501 for model years 2009 through 2017.

Impaired Reach Description	Reach ID	Units	HSPF Model Estimates							
			Agriculture[1]	Rural Non-Ag.[2]	Urban/Developed	Septics	Permitted Wastewater	Near-Channel[3]	Atmospheric Deposition	Total
Redwood River: Ramsey Creek to Minnesota River	501	lbs/season	84,478	3,943	5,227	292	10,909	1	258	105,108
		percent	80%	4%	5%	<1%	10%	<1%	<1%	100%

[1] Includes cultivated cropland, grassland, hay/pasture, and feedlots

[2] Includes forest and shrub land, grassland, groundwater, wetlands, and open water

[3] Includes bluff and bed/bank erosion

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:

$$\mathrm{TMDL} = \mathrm{LC} = \Sigma \mathrm{WLA} + \Sigma\ \mathrm{LA} + \mathrm{MOS} + \mathrm{RC}$$

Where:

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

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

LA = load allocation, or the portion of the TMDL allocated to existing or future NPSs 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 LC (EPA 1999);

RC = reserve capacity, an allocation of future growth.

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, 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.

4.2 Natural Background Consideration

“Natural background” is defined in both Minnesota rule and statute: Minn. R. 7050.0150, subp. 4 “Natural causes” means the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in the absence of measurable impacts from human activity or influence.” The CWLA (Minn. Stat. § 114D.10, subd. 10) defines natural background as “characteristics of the waterbody resulting from the multiplicity of factors in nature, including climate and ecosystem dynamics that affect the physical, chemical, or biological conditions in a waterbody, but does not include measurable and distinguishable pollution that is attributable to human activity or influence.”

In general, 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 waterbody assessment process. Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this report. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, WWTPs, failing SSTSs, and other anthropogenic sources.

Based on the MPCA’s waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of the impairment and/or affect the waterbody’s ability to meet state water quality standards. For the impairment addressed in this TMDL report, natural background sources are implicitly included in the LA portion of the TMDL allocation table and TMDL reductions should focus on the major anthropogenic sources identified in the source assessment.

4.3 Model Approach

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

HSPF models for the Redwood River Watershed were originally developed in 2002 for the Lower Minnesota River Dissolved Oxygen TMDL project. These models were subsequently updated in 2009 for the Minnesota River Turbidity TMDL project and then further updated in 2016, 2019, and 2023 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 NPSs in a watershed, and the source contributions when paired flow and concentration data are limited. Supporting documentation is available that discusses modeling methodologies, data used, and calibration results for the three major watershed HSPF models (Tetra Tech 2016 and 2019).

4.4 Loading Capacity Methodology

The river eutrophication water quality standard of 150 µg/L is for the summer average concentration in a reach. In order to align with this standard, the LC for this TMDL is based on the seasonal (June through September) average phosphorus load. The LC was calculated as the average seasonal flow, estimated using the Redwood River HSPF model, multiplied by the South River Nutrient Region TP standard of 150 µg/L. The summer average flow was estimated by taking the midpoint flows of five equally spaced flow zones: 0% to 20%, 20% to 40%, 40% to 60%, 60% to 80%, and 80% to 100% exceeds flows. In other words, the average seasonal flow for the impaired reach is the average of the 10%, 30%, 50%, 70%, and 90% exceeds flows. This type of averaging was used over a simple average of all flows in order to limit the bias of very high flows on phosphorus loading, recognizing that the effects of phosphorus (i.e., algal growth) are most problematic at lower flows. Note that these five flow zones are divided up differently than those typically used in TSS and *E. coli* TMDLs (5%, 25%, 50%, 75%, and 95%). The phosphorus approach is based on using an average of the five flow zones and having five "equally-sized" zones avoid weighting some zones more than others when calculating the average flow condition. Table 12 below provides the average flows for each exceedance interval (June through September only) and the resulting summer weighted average flow used to develop the Redwood River Reach 501 RES TMDL.

Table 12. Summer weighted average flow for Redwood River Reach 501 (2009-2018).

Flow	
Exceedance	**Flow (cfs)**
10%	1,230
30%	362
50%	167
70%	75
90%	21
Weighted Average	371

The existing TP concentration of the impaired reach was calculated by taking the average of the summer growing season (June through September) average TP concentrations for years with available data (see Table 5). The overall estimated concentration-based percent reduction needed to meet the TMDL was calculated as the existing TP concentration minus the TP standard (150 µg/L) divided by the existing concentration (Table 13).

Table 13. Summer average phosphorus conditions for Redwood River Reach 501 (2009-2018).

Phosphorus	
Average Monitored TP concentration (µg/L)	303
Water Quality Standard (µg/L)	150
Existing Load (lbs/day)	606
Load Capacity (lbs/day)	300
Load Reduction (lbs/day)	306
Percent Reduction (%)	50%

4.5 Wasteload Allocation Methodology

The WLAs for phosphorus 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. WLAs are not assigned to CAFOs, including CAFOs with NPDES or SDS permits, and CAFOs not requiring permits; this is equivalent to a WLA of zero. Although the NPDES and SDS permits allow discharge of manure and manure contaminated runoff due to a precipitation event greater than or equal to a 25-year, 24-hour precipitation event, the permits prohibit discharges that cause or contribute to nonattainment of water quality standards.

All other non-CAFO feedlots and the land application of all manure are accounted for in the LA for nonpermitted sources.

NPDES Permitted Wastewater Dischargers

There are 10 active regulated NPDES wastewater dischargers in the Redwood River RES impaired reach drainage area (Table 14). Two of the facilities that drain directly to the Redwood River, the Marshall WWTP and ADM Corn Processing – Marshall, are mechanical plants that discharge daily. The Marshall WWTP is permitted with an average dry-weather design flow of 3.31 MGD and an average wet-weather design flow of 4.50 MGD. ADM Corn Processing – Marshall is permitted with a maximum permitted daily flow of 2.64 MGD. However, average discharge rates from both of these facilities over the TMDL time period are generally well under their design flows (1.55 MGD for Marshall WWTP and 1.63 MGD for ADM Corn Processing – Marshall).

The MPCA's "Phosphorus Effluent Limit Review: Redwood River Basin, Version 1.2" memorandum (memo; MPCA 2021d) evaluated various scenarios using HSPF to determine TP reductions needed for attainment of the 150 µg/L RES standard in Redwood River Reach 501 and several RES impaired reaches of the Minnesota River downstream of its confluence with the Redwood River. For these scenarios, it was demonstrated that average summer TP concentrations within the Redwood and Minnesota River RES impaired reaches would meet the RES standards as long as two conditions were met: 1) a broad suite of nonpoint source BMPs are implemented that targeted TSS and TP reductions; and 2) permitted wastewater treatment facility effluent limits are established at levels identified in the memo. These scenarios also showed that the wastewater treatment facility TP effluent limits needed for the Minnesota River to meet the 150 µg/L standard are more restrictive than those required for the Redwood River and therefore ensure that Redwood River Reach 501 will also meet applicable RES standards. Further, the permitted wastewater TP limits identified for the Minnesota River are more restrictive than those established in the Lake Pepin and Mississippi River TMDL Report (MPCA 2021a), and therefore ensure compliance with that TMDL's WLAs. Thus, the Minnesota River TP limits presented in the Redwood River memo were used to develop the permitted wastewater WLAs for Redwood River Reach 501 (Table 14). Marshall WWTP and ADM Corn Processing – Marshall will receive new, more stringent water quality based effluent limits (WQBEL) that are consistent with the WLAs in this TMDL.

Seven of the facilities are controlled discharge stabilization pond facilities that are authorized to discharge at a maximum flow rate of six inches per day from their secondary ponds (Table 14). These facilities are not authorized to discharge in the summer from June 15 to September 15, which leaves 30 days during the 122-day growing season in which they can discharge (24.6% of growing-season days). To set the WLA for each pond facility, it was assumed that they are allowed to discharge at their current design flow rate for 24.6% of the growing season at a TP concentration treatment level of 2.0 mg/L, which is consistent with the approach used in the Lake Pepin and Mississippi River TMDL Report (MPCA 2021a). Therefore, annual permit limits consistent with the Lake Pepin WLAs will be sufficient to ensure compliance and consistency with the daily RES WLAs for stabilization pond WWTPs in the Redwood River Watershed.

There is one petroleum treatment facility, Magellan Pipeline Co LP – Marshall, that intermittently discharges to the Redwood River. This facility is considered a “Small Industrial, Low Concentration” (i.e., <817 kg/year and concentration <1.0 mg/L) discharger and was assigned a TP WLA of 23 kg/year (0.14 lbs/day) in the Lake Pepin TMDL Report (MPCA 2021a). This WLA was calculated based on the facility’s average wet weather design flow (0.72 MGD), effluent concentration estimate (0.02 mg/L), and a 15% load uncertainty factor.

Table 14. NPDES wastewater TP WLAs for Redwood River Reach 501 derived from MPCA 2021d.

Facility Name	NPDES ID#	Flow Type	Design Flow[1] (MGD)	TP WLA Concentration (mg/L)	TP WLA (lbs/day)
Marshall WWTP	MN0022179	Continuous	4.5[2]	0.53	13.92
ADM Corn Processing - Marshall	MN0057037	Continuous	2.64	0.53	11.67
Tyler WWTP	MNG585116	Controlled	1.09	2.0	4.47
Russell WWTP	MNG585062	Controlled	0.59	2.0	2.40
Ruthton WWTP	MNG585105	Controlled	0.38	2.0	1.55
Lynd WWTP	MNG585030	Controlled	0.34	2.0	1.40
Ghent WWTP	MNG585121	Controlled	0.26	2.0	1.06
Vesta WWTP	MNG585043	Controlled	0.26	2.0	1.06
Milroy WWTP	MNG585124	Controlled	0.25	2.0	1.01
Magellan Pipeline Co LP - Marshall	MN0059838	Intermittent	0.72	0.02	0.14[3]

[1] For WWTPs with wastewater ponds (Ghent, Lynd, Milroy, Russell, Ruthton, Tyler, and Vesta) the effluent design flow represents the maximum permitted daily discharge volumes from secondary ponds. It is assumed that discharge from these facilities occurs (at most) for only 30 days during the 122-day summer growing season (24.6% of the summer). Since stabilization pond WWTP discharges have minimal eutrophication impacts during the summer season, their TP WLAs will be implemented as Kilogram/year, Calendar Year-to-Date effluent limits.

[2] WLA flow for Marshall WWTP (3.15 MGD) is calculated based on 70% of the facility's average wet weather design flow (4.5 MGD).

[3] WLA for Magellan Pipeline Co LP is calculated as maximum permitted flow (0.72 mgd) and an effluent concentration assumption of 0.02 mg/L plus a 15% load uncertainty factor.

NPDES Permitted MS4 Stormwater

The cities of Marshall and Redwood Falls are the only permitted MS4s within the Redwood River Reach 501 drainage area. Figure 1 shows the municipal boundaries for Marshall and Redwood Falls and their locations in the Redwood River Watershed. Marshall and Redwood Falls account for approximately 1.3% (5,875 acres) and 0.4% (1,698 acres) of the land area for reach 501, respectively. Phosphorus allocations for these cities were calculated by multiplying the MS4 percent watershed coverage (percentages stated above) by the total watershed LC. The total watershed LC applies to all nonpoint source watershed sources (e.g., urban stormwater, lakes, wetlands, agriculture, etc.) and is the remaining load after the permitted wastewater facility, MOS, and RC loads were established and subtracted from the LC.

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 Permit in each major watershed were available through the MPCA's Permit database. The amount of land under Construction and Industrial Stormwater Permit 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 construction and industrial stormwater permit. To determine the WLA for these activities, the total watershed LC was multiplied by the construction and industrial coverage percentage.

4.6 Margin of Safety

The purpose of the MOS is to account for uncertainty with the allocations resulting in attaining water quality standards. Uncertainty can be associated with data collection, lab analysis, data analysis, modeling error, and implementation activities. An explicit 10% MOS was applied to the watershed WLAs and LAs in this TMDL report. The explicit 10% MOS accounts for:

- Uncertainty in the observed daily flow record;
- Uncertainty in the simulated flow data from the HSPF model;
- Uncertainty in the observed water quality data;

The majority of the MOS is apportioned to uncertainty related to the HSPF model than with the other causes for uncertainty. The HSPF model for the Redwood River HUC-12 watershed was originally developed in 2014 and then updated in 2016 to better refine the model's sediment calibration (Appendix C). In 2019, the model was extended and then recalibrated in 2023 to more accurately represent the system and recent monitoring data. Below is a summary of the hydrologic validation statistics for the HSPF model at the Redwood River near Redwood Falls, Minnesota (USGS station ID 05316500), which are presented in Table 7 of Appendix C (Tetra Tech 2019):

- 1.75% error in total flow volume;
- 9.63% error in bottom 50% low flows;
- -0.89% error in the top 10% high flows;
- A Nash-Sutcliffe coefficient of model fit efficiency (NSE) of 0.789 for daily flows;
- And, an NSE of 0.860 for monthly flows

Overall, the HSPF model was determined to be "Good." The load capacities were developed using the HSPF modeled daily flow and phosphorus concentrations data from June to September. There is no reason to believe a 10% MOS is inappropriate as it is consistent with HSPF modeling errors and the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. More information on the calibration of the HSPF model can be found in Tetra Tech (2016 and 2019).

4.7 Reserve Capacity

The RC represents a set-aside load for potential future loading sources. In this TMDL report, the RC is reserved for projects that address failing or nonconforming septic systems and "unsewered" communities, and will be made available only to new WWTPs or existing WWTPs that provide service to existing populations with failing or nonconforming systems. The potential need for RC for these situations has been estimated based on the assumption that 10% of the unsewered population within the project watershed may discharge to WWTPs in the future. The potential TP load from future WWTPs serving these populations has been calculated based on an assumption of 0.8 kg/capita/year of TP load to the WWTP and a reduction efficiency of 80% at the WWTP, resulting in a load to the receiving water of 0.16 kg/capita/year (MPCA 2012b).

The Redwood River Watershed is likely to have “unsewered” communities become “sewered” in the future, and therefore a RC was allocated for the Redwood River RES impaired reach addressed in this TMDL report. A summary of the RC calculations for future “sewered” communities is presented in Table 15.

Table 15. Reserve capacity for future “sewered” communities in the Redwood River Watershed.

Estimated population not currently connected to NPDES permitted WWTP	Estimated required future population	Estimated untreated TP load (lbs/year)	Reserve Capacity (80% removal) (lbs/year)	Reserve Capacity (80% removal) (lbs/day)
4,882	488	861	172	0.47

4.8 Baseline Year

For the purposes of this TMDL, the baseline year for implementation will be the mid-range year of the data years used to develop the TMDL. The TMDL was developed using summer weighted average flow data from 2009 through 2018, and therefore the baseline year is 2013. 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.

4.9 Load Allocation Methodology

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), MOS, and RC were determined and subtracted from the total LC. This residual remaining LC is meant to represent all nonregulated (nonpoint) sources of phosphorus upstream of the impaired reach. 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-MS4 stormwater runoff.

Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this study (Section 3.6). For all impairments addressed in this TMDL report, natural background sources are implicitly included in the LA portion of the TMDL tables, and reductions should focus on the major human attributed sources identified in the source assessment.

4.10 Seasonal Variation

Critical conditions for the RES impaired reach are during the summer months, which is when phosphorus and chl-*a* concentrations peak. Stream assessments for eutrophication focus on summer average TP concentration, chl-*a* concentration, BOD, and DO flux. The TMDL models are focused on the growing season (June 1 through September 30) as the critical condition, which inherently accounts for the seasonal variation. The frequency and severity of nuisance algal growth in Minnesota streams is typically highest during the growing season. The load reductions are designed so that the stream will meet the water quality standards over the course of the growing season as a long-term average. The nutrient standards set by the MPCA, which are a growing season concentration average rather than an individual sample (i.e., daily) concentration value, were set with this concept in mind. Additionally, by setting the

TMDL to meet targets established for the applicable summer period, the TMDL will inherently be protective of water quality during all other seasons.

4.11 TMDL Summary

The TMDL allocation table (Table 16) presents the total LC (Total Load (TMDL) in table), the MOS, the WLAs (wasteload in table), RC, and the remaining watershed LAs (total LA in table) for the RES impaired reach. Allocations for this TMDL were established using the 150 µg/L phosphorus standard. TMDL allocations for the impaired reach include the entire watershed draining to the impaired reach.

The following rounding conventions were used in the TMDL table:

- Values ≥ 10 reported in lbs/yr have been rounded to the nearest tenth of a pound
- Values < 10 and reported in lbs/yr have been rounded to the nearest hundredth of a pound
- While some of the numbers in the table show multiple digits, they are not intended to imply great precision

The bottom line of the table shows the estimated load reduction which was calculated based on the difference between the average summer monitored TP load and the TP load standard. Load reductions to achieve this TMDL will need to come from a variety of sources including permitted wastewater facilities, urban stormwater, and agriculture. See Section 8 of this TMDL and the WRAPS report for further information on which sources and geographical locations within the impaired reach watershed should be targeted for phosphorus BMPs and restoration strategies.

Table 16. River Eutrophication TMDL allocations for Redwood River Reach 501.

- Listing year: 2016
- Baseline year: 2013
- Numeric standard used to calculate TMDL: 150 µg/L TP
- TMDL and allocations apply Jun–Sep

TMDL Parameter		Summer Average Flow Condition[1] (lbs/day)
Wasteload	Marshall WWTP (MN0022179)	13.9
	ADM Corn Processing – Marshall (MN0057037)	11.7
	Tyler WWTP (MNG585116)[2]	4.47
	Russell WWTP (MNG585062)[2]	2.40
	Ruthton WWTP (MNG585105)[2]	1.55
	Lynd WWTP (MNG585030)[2]	1.40
	Ghent WWTP (MNG585121)[2]	1.06
	Vesta WWTP (MNG585043)[2]	1.06
	Milroy WWTP (MNG585124)[2]	1.01
	Magellan Pipeline Co LP – Marshall (MN0059838)	0.14
	City of Marshall MS4 (MS400241)[3]	3.03
	City of Redwood Falls MS4 (MS400236)[3]	0.88
	Construction/Industrial SW[3]	0.71
	Total WLA	**43.3**
Load	**Total LA [3]**	**226.4**
	Margin of Safety	**30.0**
	Reserve Capacity	**0.47**
	Loading Capacity (TMDL)	**300.2**
	Existing Load [4]	**606.4**
	Estimated Load Reduction [4]	**50%**

[1] Model simulated flow from June - September for HSPF reach 501 (2009-2017) and monitored flow from Redwood River USGS station 05316500 (2018) were used to develop the LC for this reach

[2] TP WLAs will be implemented as Kilogram/year, Calendar Year-to-Date effluent limits.

[3] The daily wasteload allocations for MS4s, construction and industrial stormwater, and the total LA (i.e., nonpermitted watershed runoff) equate to areal phosphorus loading rates of approximately 0.189 lbs/acre/calendar year or 0.063 lbs/acre/summer period (122 days – June through September)

[4] Water quality monitoring station(s) used to estimate reductions: S000-299

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 by 3% (Lyon County) to as much as 18% (Redwood County). The overall projection for all six counties is negative 9%. The MPCA does not anticipate significant population growth within the Redwood River Watershed.

5.1 New or Expanding Permitted MS4 WLA Transfer Process

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

1. New development occurs within a regulated MS4. Newly developed areas that are not already included in the WLA must be transferred from the LA to the WLA to account for the growth.
2. One regulated MS4 acquires land from another regulated MS4. Examples include annexation or highway expansions. In these cases, the transfer is WLA to WLA.
3. One or more 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. 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

A small RC was set aside for this TMDL for future treatment of unsewered communities that may become sewered and discharge to a WWTP in the future. Because phosphorus loading must be reduced substantially to the impaired reach, there is little capacity for new sources that will result in more phosphorus being added during the months of June through September. For this reason, only a small RC is available to establish WLAs for the conversion of existing phosphorus loads. The RC will support projects that convert unsewered communities to sewered communities and will be made available only to new WWTPs or existing WWTPs that provide service to existing unsewered populations.

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 NPSs are required.

6.1 Regulatory

6.1.1 Construction Stormwater

Regulated construction stormwater was given a categorical WLA in 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 regulated MS4 conveyance to develop a Stormwater Pollution Prevention Plan (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. For information on all requirements for annual reporting, please see the *Minnesota Stormwater Manual* (Minnesota Stormwater Manual contributors 2019): *Guidance for completing the TMDL reporting form*.

This TMDL report assigns WLAs to permitted MS4s of the cities of Redwood Falls and Marshall in the study area. The MS4 General Permit requires permittees to develop compliance schedules for EPA approved TMDL WLAs not already being met at the time of permit application. 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

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 if their discharges cause or have reasonable potential to cause or contribute to exceedance of RES. Attaining the WLAs, as developed and presented in this TMDL report, is assumed to ensure meeting the water quality standards for the river eutrophication 303(d) listing. During the permit issuance or reissuance process, wastewater discharges will be evaluated for the potential to cause or contribute to violations of phosphorus water quality standards. WQBELs will be developed for facilities whose discharges are found to have a reasonable potential to cause or contribute to phosphorus above the water quality standards. The WQBELs will be calculated based on summer average conditions, may vary slightly from the TMDL WLAs and will include concentration based effluent limitations, as found in the Redwood River Phosphorus Effluent Limit Review memo (MPCA 2021d).

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 units (LGUs) that regulate SSTS must meet the requirements for local SSTS programs in Minn. R. ch. 7082. Counties and other LGUs must adopt and implement SSTS ordinances in compliance with Minn. R. chs. 7080, through Minn. R. ch. 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. In order 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 additional 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 way to use these funds to accelerate SSTS compliance statewide through:

- Compliance inspection for property transfer
- Compliance inspection for any (all) permit-countywide
- Plan to improve compliance, like 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. The remaining straight pipe systems received a notification of noncompliance and are currently within the 10-month deadline.

Since 1996, the MPCA southwest wastewater staff have helped small communities build wastewater soil treatment systems throughout the region. The small communities with wastewater concerns 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 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 local unit of government. Delegated counties are then able to enforce Minn. R. ch. 7020 (along with any other local rules and regulations) within their respective counties for facilities that are under the CAFO threshold. In the Redwood River Watershed, the counties of Lincoln, Pipestone, Murray, Lyon, and Yellow Medicine are delegated 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.

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.

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.

6.1.7 Buffers, Shoreland, and NPS Statutes

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 P, 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 waterbody. 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 95% 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 Redwood River WRAPS Report (MPCA 2023b), a document written as a companion to this TMDL. For the impaired waters to meet water quality standards, the majority of pollutant reductions in the Redwood River Watershed will need to come from NPSs. Agricultural drainage and SRO are major contributors of phosphorus, 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 phosphorus to surface water. The combinations of BMPs discussed throughout the WRAPS process were derived from Minnesota's Nutrient Reduction Strategy (NRS) (MPCA 2014) 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. The Redwood River Watershed was selected for funding through the One Watershed One Plan (1W1P) process un 2023 to develop a comprehensive local water plan to guide this work. These BMPs are supported by programs administered by the SWCDs and the Natural Resource Conservation Service (NRCS). Local resource managers are well-trained in promoting, placing, and installing these BMPs. Some counties within the basin have shown significant levels of adoption of these practices. State and local agencies will need to work with landowners to identify priority areas for BMPs and practices that will help reduce nutrient runoff, as well as streambank and overland erosion. Agencies, organizations, LGUs, and citizens alike need to recognize that resigning waters to an impaired condition is not acceptable. Throughout the course of the WRAPS and TMDL meetings, the WRAPS local work group (LWG) endorsed the BMPs selected in the WRAPS report. These BMPs reduce phosphorus and other pollutants from runoff as well as pollutants delivered through drainage tiles or groundwater flow.

To help achieve nonpoint source reductions, a large emphasis has been placed on public participation, where the citizens and communities that hold the power to improve water quality conditions are involved in discussions and decision-making. The watershed's citizens and communities will need to voluntarily adopt the practices at the necessary scale and rates to achieve the 10-year targets presented in the WRAPS report. The WRAPS also presents the allocations of the pollutant/stressor goals and targets to the primary sources and the estimated years to meet the goal as developed by the WRAPS 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 NPSs. One example of a government program available is The Minnesota Agricultural Water Quality Certification Program (MAWQCP). The MAWQCP is an MDA led 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 will be certified and in turn obtain regulatory certainty for a period of 10 years.

Through this program, certified producers receive:

- **Regulatory certainty:** certified producers are deemed to be in compliance with any new water quality rules or laws during the period of certification
- **Recognition:** certified producers may use their status to promote their business as protective of water quality
- **Priority for 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. BMPs implemented to-date through this program include:

- 22 alternative/closed tile intakes
- 15 sediment basins
- 26.6 acres of filter strips
- 365 acres of residue management
- 113 acres of nutrient management
- 2,400 acres of nitrogen BMPs
- 913 acres of phosphorus BMPs
- 147 acres of cover crops
- 577 acres of conservation cover

Further, another MDA led initiative - The Nutrient Management Initiative Program (NMI) – has engaged farmers and increased agricultural BMP adoption in the Redwood River and Cottonwood River Watersheds. The NMI Program has provided financial incentives for participants to conduct on-farm trials comparing yields related to nitrogen fertilizer rate management. A total of 31 nutrient trials took place in these two watersheds between 2006 and 2019.

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 certain pollutants (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 2014). 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 phosphorus loading to surface waters have the potential to reduce pollutant loads.

6.2.2 Prioritization

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

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 prioritize potential buffer installation. 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 compliance (http://www.bwsr.state.mn.us/buffers/).

Light Detection and Ranging (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 constitution to:

- protect drinking water sources;
- protect, enhance, and restore wetlands, prairies, forests, and fish, game, and wildlife habitat;
- preserve arts and cultural heritage;
- support parks and trails; and
- protect, enhance, and restore lakes, rivers, streams, and groundwater

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

Additionally, there are many other funding sources for nonpoint pollutant reduction work; they include but are not limited to CWA Section 319 grant programs, Board of Water and Soil Resources (BWSR) state Clean Water Fund implementation funding, and NRCS incentive programs. Programs and activities are also occurring at the local government level, where county staff, commissioners, and residents work together to address water quality issues. In the past, several state CWP and federal Section 319 grants have been utilized to implement nonpoint source BMPs.

There are a variety of funding sources to help cover some of the cost to implement practices that reduce pollutants from entering surface waters and groundwater. Below are web links to the programs and contacts for each entity. The contacts for each grant program can assist in the determination of eligibility for each program, as well as funding requirements and amounts available.

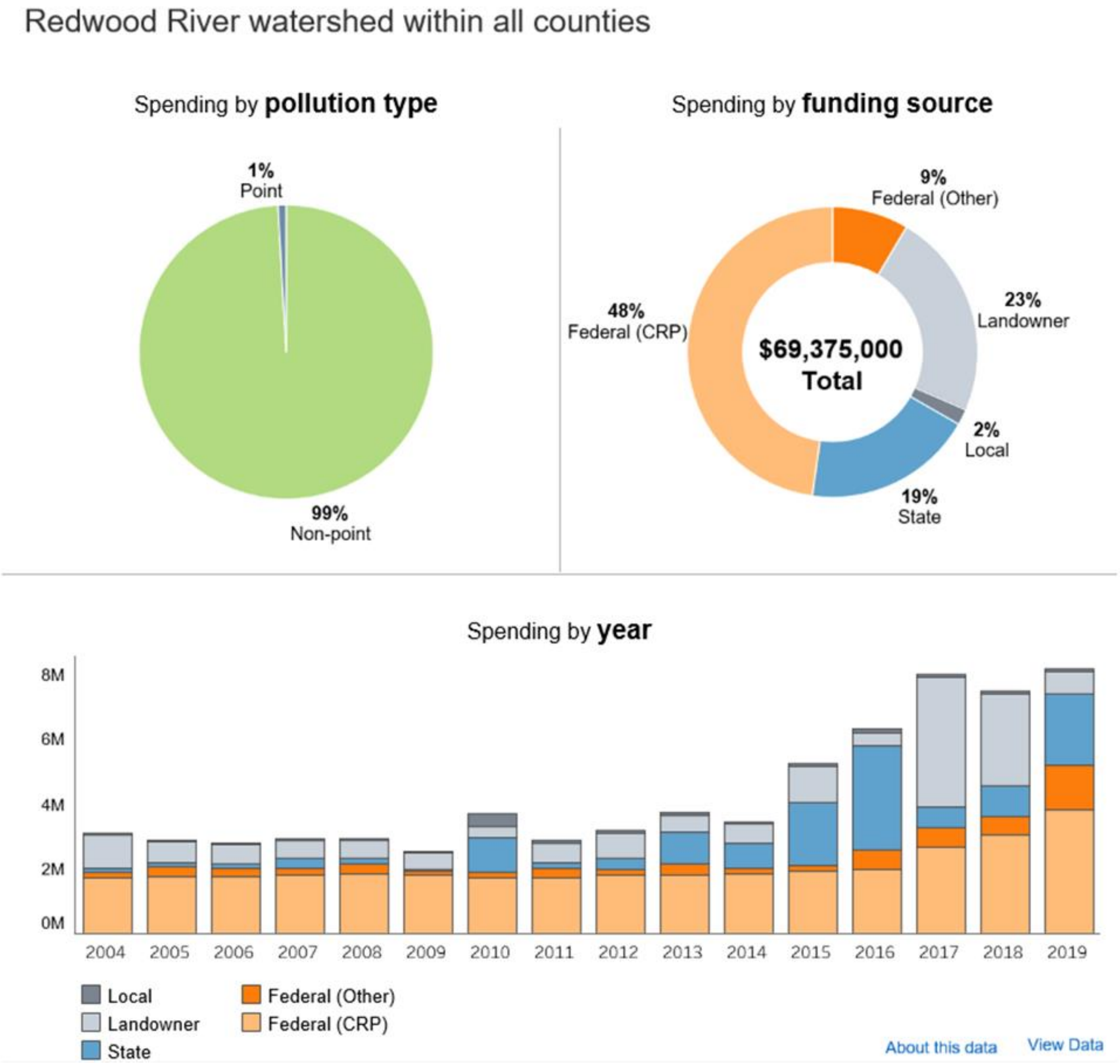
- Agriculture BMP Loan Program (MDA)
- Agricultural Water Quality Certification Program (MDA)
- Clean Water Fund Grants (BWSR)
- Clean Water Partnership Loans (MPCA)
- Environment and Natural Resources Trust Fund (Legislative-Citizen Commission on Minnesota Resources)
- Environmental Assistance Grants Program (MPCA)

- Phosphorus Reduction Grant Program (Minnesota Public Facilities Authority [PFA})
- Small Community Wastewater Treatment Construction Loans & Grants (PFA)
- Source Water Protection Grant Program (Minnesota Department of Health)
- Surface Water Assessment Grants (MPCA)
- Wastewater and Stormwater Financial Assistance Programs (MPCA)
- Conservation Partners Legacy Grant Program (DNR)
- Environmental Quality Incentives Program (Natural Resources Conservation Service)
- Conservation Reserve Program (USDA)
- Clean Water State Revolving Fund (EPA)

Minnesota was awarded $500 million to implement the Conservation Reserve Enhancement Program (CREP) that when fully implemented will convert approximately 60,000 acres of land to perennial cover (perpetual easements). 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 13). Additional information about funding may be found on the MPCA's Healthier Watersheds webpage and CREP webpage.

Figure 13. Spending addressing water quality issues in the Redwood River Watershed (2004-2019).



6.2.4 Planning and Implementation

The WRAPS, TMDLs, and all the supporting documents provide a foundation for planning and implementation. Subsequent planning, including imminent development of a 1W1P for the Redwood River Watershed, will draw on the goals, technical information, and tools to describe in detail strategies for implementation. For the purposes of reasonable assurance, the WRAPS document is sufficient in that it provides strategies for achieving pollutant reduction goals. However, many of the goals outlined in this TMDL are very similar to objectives outlined in the individual county water plans. Some general goals and themes in the individual county water plans are consistent such as:

- Protect, manage, and improve surface waters
- Target landscapes and sites for increased conservation practices and reduction in feedlot and septic pollutants

- Reduce 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

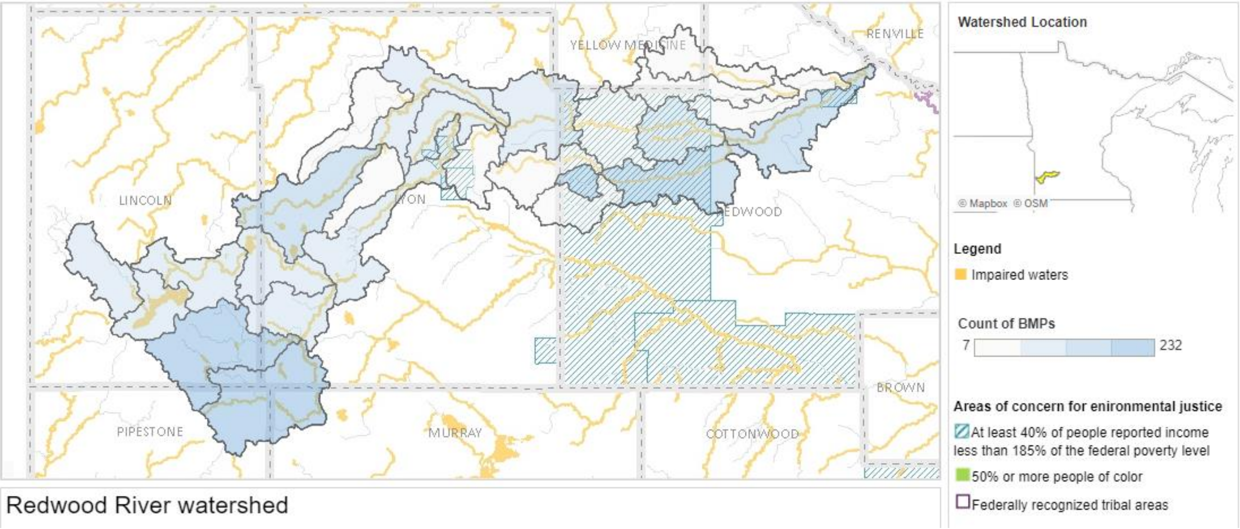
Water monitoring efforts within the Redwood River Watershed are diverse and constitute a sufficient means for tracking progress and supporting adaptive management. See Chapter 7 for more information on monitoring efforts and programs in the Redwood River Watershed.

To date, some agricultural and urban runoff in the Redwood River Watershed has been reduced through the implementation of conservation practices and stormwater BMPs. These efforts have been led by local resource professionals representing cities, counties, SWCDs, and Redwood-Cottonwood Rivers Control Area (RCRCA). The MPCA Healthier Watersheds webpage shows that over 1,000 BMPs were installed and reported through federal, state, and locally funded programs and grants in the Redwood River Watershed between 2004 and 2020. Table 17 summarizes the major types of BMPs that have been implemented throughout the watershed, while Figure 14 shows the total number of BMPs per subwatershed.

Table 17. Reported BMPs in the Redwood River Watershed by BMP type (2004-2020).

BMP Type	Total BMPs
Nutrient Management (Cropland)	252
Tillage/residue Management	194
Designed Erosion Control	188
Buffers and Filters	106
Converting Land to Perennials	62
Stream Banks, Bluffs, and Ravines	46
Living Cover to Crops in Fall/Spring	43
Septic System Improvements	43
Pasture Management	37
Tile Inlet Improvements	37
Drainage Ditch Modifications	21
Tile Drainage Treatment/Storage	11
Habitat and Stream Connectivity	9
Crop Rotation	4

Figure 14. Relative distribution of subwatershed BMPs in the Redwood River Watershed between 2004 – 2020.



6.2.6 Reasonable Assurance Summary

In summary, significant time and resources have been devoted to identifying the best BMPs and supporting their implementation via state initiatives and dedicated funding in 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. Local water planning using the 1W1P process was awarded funding in 2023, and will utilize WRAPS and TMDL information in the planning process. Minnesota is a leader in watershed planning, monitoring, and tracking progress toward water quality goals.

7. Monitoring Plan

Several types of monitoring are necessary to track progress toward achieving the load reductions required for this TMDL 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 2021c). Data needs are considered by each program and additional monitoring is implemented when deemed necessary and feasible. These monitoring programs are summarized as follows:

- Intensive Watershed Monitoring collects water quality and biological data for two years at established stream and lake monitoring stations across the Redwood River Watershed every 10 years. Starting in 2027, the MPCA, with assistance from LGUs, will re-visit and re-assess some of the Cycle 1 monitoring stations, as well as consider monitoring new sites with demonstrated state or local importance. It is expected that funding for monitoring and analysis will be available through the MPCA.
- Watershed Pollutant Load Monitoring Network data provides a continuous and long-term record of water quality conditions at the major watershed and subwatershed scale. This program collects pollutant samples and flow data to calculate continuous daily flow, sediment, and nutrient loads. There are three sites in the Redwood River Watershed with data that vary by site.
- Volunteer Water Monitoring Program data provide a continuous record of waterbody transparency and user perception 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 citizen monitors to track trends of water quality transparency for impaired waters within the basin.

8. Implementation Strategy Summary

The strategies described in this section are potential actions to reduce phosphorus loads in the Redwood River Watershed. These actions are further developed in a separate, more detailed WRAPS report (MPCA 2023b).

8.1 Minnesota Nutrient Reduction Strategy

The primary implementation strategies to achieve the phosphorus load reductions required by the RES TMDL in this report are described in Minnesota's NRS Report (MPCA 2014). The NRS is intended to guide the state in reducing excess nutrients in waters so that in-state and downstream water quality goals are ultimately met. Successful implementation of the NRS will require broad support, coordination, and collaboration among agencies, academia, local government, private industry, and citizens. The theme of the NRS is *A Path to Progress in Achieving Healthy Waters*, and highlights a multi-faceted approach to nutrient reduction that focuses on the following:

- **Progress goals for downstream waters**. The strategy includes clear, meaningful, and achievable nutrient loading reduction targets and interim milestones.
- **Progress on in-state nutrient criteria**. The strategy complements existing planning efforts to make progress toward meeting in-state nutrient criteria for impaired waters and provides protection to lakes and streams not yet assessed, or assessed as threatened or unimpaired by nutrients.
- **Prioritize and target watersheds**. The strategy helps to prioritize watersheds relative to nutrient loads and impacts, and target implementation activities to ensure efficient use of resources.
- **Build from existing efforts**. Many ongoing efforts are moving the state in the right direction. The strategy unifies and organizes information to align goals, identify the most promising strategies, and coordinate activities.
- **Local implementation**. The goal is for agencies and organizations to focus and adjust programs, policies, and monitoring efforts.

The NRS includes a goal for reducing phosphorus in the Mississippi River, which includes the Minnesota River and its tributaries (e.g., Redwood River), by 45% from average 1980 through 1996 conditions by 2025. This goal applies where the Mississippi River leaves Minnesota boundaries. The NRS estimates that a 31% reduction of phosphorus in the Mississippi River at Red Wing, the upstream end of Lake Pepin, had been achieved by 2014 largely as a result of reductions in point sources.

While the RES TMDL presented in this report requires slightly different phosphorus reduction goals, similar strategies will be applied across the Redwood River Watershed. Priority sources of phosphorus targeted in the NRS for reduction include cropland runoff, wastewater point sources, and streambank erosion. Priority watersheds for phosphorus reduction were also identified in the NRS, one of which is the Redwood River Watershed. Watershed prioritization for phosphorus is based on a Spatially Referenced Regressions on Watersheds (SPARROW) model that combined nutrient loads leaving the HUC-8 watershed with a comparison to the (at the time pending) RES for that reach, and computed a yield reaching the state border. HUC-8 watersheds with a higher yield reaching the state border were assigned a higher priority ranking. This ranking process did not factor in the potential capacity for lakes to intercept phosphorus.

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. All local government 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. Minnesota's NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) and NPDES/SDS Nonmetallic Mining/Associated Activities General Permit (MNG490000) establish benchmark concentrations for pollutants in industrial stormwater discharges. 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. Industrial activity must also meet all local government stormwater requirements.

8.2.3 MS4 Stormwater

Phase II MS4 NPDES-permitted stormwater communities are required by permit (the General Permit Authorization to Discharge Stormwater Associated with small MS4s under the NPDES/SDS Permit [MNR040000]) to develop and implement a SWPPP. This Permit requires MS4s to develop regulatory mechanisms, including enforcement of construction sites under the MPCA's General Permit to Discharge Stormwater Associated with Construction Activity (MNR100001) and post-construction stormwater management. MS4s are also required to inventory and map the storm sewer system and implement a minimum of six control measures (MCMs – public education and outreach, public participation and involvement, illicit discharge detection and elimination, construction site runoff controls, post-construction stormwater runoff controls and pollution prevention, and good housekeeping measures). Measurable goals must be specified for each of the six MCMs, including public participation and involvement in reviewing the SWPPPs. Routine inspection and maintenance of the MS4 conveyance system is required. Additionally, the MS4 permit requires regulated communities to provide reasonable assurance that progress is being made toward achieving all TMDL WLAs approved by the EPA before the effective date of the MS4 General permit, which is issued at five-year intervals. MS4s must determine whether their applicable WLA(s) are being met, and if not, a compliance schedule is required. The compliance schedule includes interim milestones (expressed as BMPs such as pet waste programs and urban BMPs in MS4 areas) that are not one of the six MCMs and that will be implemented over the current five-year permit term. As MS4 management activities occur across 10-year capital budgetary cycles, a long-term implementation strategy and target date for full compliance to the WLAs must be included. The Minnesota Stormwater Manual includes specific BMPs to improve water quality for pollutants addressed in this TMDL. More information on MS4 regulations is included in Section 6.1.3 of this TMDL.

The cities of Marshall and Redwood Falls have MS4 wasteloads allocated in this TMDL. The WRAPS report for the Redwood River Watershed includes various BMPs and implementation strategies to meet the MS4 TMDL goals throughout the watershed. Some of these strategies include, but are not limited to:

- Infiltration basins
- Bioretention (rain gardens)
- Vegetated filter strips
- Stormwater ponds/wetlands
- Street sweeping
- Dedicated snow removal deposit locations
- Urban stormwater runoff controls
- Stormwater/rainwater harvest and reuse

8.2.4 Wastewater

Municipal and industrial WWTFs are regulated through NPDES permits. Ten permitted municipal and industrial wastewater dischargers have been assigned a WLA in this TMDL report. A summer WLA for each of these facilities was developed to protect Redwood River Reach 501. The approach and methodology for determining the summer WLA for each facility can be found in Section 4.6. The WLAs to protect Redwood River Reach 501, which have been determined to also protect Lake Pepin and the Mississippi River, will be implemented in permits as WQBELs in the facilities' NPDES permit if the discharges are found to have reasonable potential to cause or contribute to the Redwood River RES impairment in accordance with the procedures described in 40 CFR §122.44. These WQBELs will be evaluated on a monthly basis to ensure compliance.

Based on review of data available on the MPCA's Wastewater Data Browser, all pond facilities are currently meeting the TMDL requirements set forth in this TMDL (Table 14 and Table 16). The two continuous discharging facilities, ADM – Marshall and Marshall WWTP, currently exceed their TMDL allocations. Reductions of approximately 88% (~83 lbs/day) and 40% (~9 lbs/day) will be needed for ADM – Marshall and Marshall WWTP, respectively, to meet their TMDL goals.

8.3 Nonpermitted Sources

Implementation of the Redwood River Watershed RES TMDL will require BMPs that address phosphorus as well as other 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 (RCRCA 2013), Redwood River Watershed SID Report (MPCA 2021b), Redwood River Watershed TMDL Report (MPCA 2023a), and the Redwood River WRAPS Report (MPCA 2023b).

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 in upstream lakes 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 18 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 18. 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	

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

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

Filter Strips (636) and Riparian Buffers (390)

Feedlot/wastewater filter strips are defined as “a strip or area of vegetation that receive and reduce sediment, nutrients, and pathogens in discharge from a 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 its effectiveness.

Clean Water Diversions (362)

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

Access Control/Fencing (472 and 382)

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

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

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

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 at a later date. 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) (MDA 2010b). 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 through the use of a controlled drainage system reduces the volume of agricultural drainage flow to surface water and the nutrients and sediment it carries.

Alternative tile intakes (606)

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

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

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

Wetland Restoration (657)

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

8.3.2 Stormwater Runoff

Implementation strategies to address urban stormwater management are detailed in the Minnesota Stormwater Manual. Practices can be construction-related, post-construction, 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

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

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

SSTS Upgrades/Replacement

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

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

Many Counties and SWCDs offer low interest loan programs for SSTS upgrades or replacement. The Clean Water Partnership Loan Program administered by the MPCA offers low interest loans for LGUs to address SSTS. 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. The 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 Minn. Stat. §§ 115.55 and 115.56. Counties must enforce ordinances in Minn. R. ch. 7080 to 7083.

Public Education

Education is another crucial component of reducing pollutant loading from 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 and Phosphorus

It is expected that implementation of the Sediment Reduction Strategy (MPCA 2015) for the Minnesota River Basin will reduce sediment and phosphorus loads 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 and maintenance 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 Lake Redwood Reclamation and Enhancement Project

In 2019, the State Legislature appropriated $7.3 million in Capital Investment funds to the Lake Redwood Reclamation and Enhancement Project. This funding, when combined with a $900,000 commitment from the City of Redwood Falls, set a sediment removal goal of 650,000 cubic yards to bring the lake to its original depth. Dredging began in May of 2022 and was completed in the fall of the same year.

A local/state/federal investment of over $9 million of BMPs, water quality monitoring, and educational programming has occurred within the watershed since 1993 through a series of CWP Diagnostic Studies and Implementation grants. Watershed BMP improvements to Redwood River over the last half century have reduced sedimentation rates 1.5 feet/year to .13 feet/year (Houston Engineering 2007). With continued restoration and protection efforts, this rate will continue to decrease. It is anticipated that water volume (140 acre-ft to 541 acre-ft) and average summer residence time (0.7 days to 2.6 days) in Lake Redwood will increase by nearly a factor of four as a result of the Lake Redwood Reclamation and Enhancement Project. These increases should allow more time for sediment and particulate phosphorus to settle out and be removed as the Redwood River passes through Lake Redwood and moves downstream to Reach 501. It is expected that successful implementation of the watershed TP load reduction goals set forth in this TMDL, combined with implementation of the TSS load reduction goals defined in the Redwood River Watershed TMDL and WRAPS reports, will help protect the Lake Redwood Reclamation and Enhancement Project and the recreational quality of Lake Redwood (e.g., less frequent algae blooms).

8.3.6 Internal Loading in Lakes

Implementation strategies for internal loading in impaired lakes (i.e., Lake Benton, Dead Coon, Goose, Clear and School Grove) upstream of the RES impaired reach include water level drawdown, sediment phosphorus immobilization or chemical treatment (e.g., alum), management of aquatic vegetation, and biomanipulation (e.g., carp management).

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

The MPCA recommends feasibility studies for any lakes in which water level drawdown or chemical treatment is considered. For more information on internal phosphorus load reduction practices, see "Minnesota State and Regional Government Review of Internal Phosphorus Load Control".

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. RCRCA and the local LGUs that work within the boundaries of the Redwood River Watershed, have established connections with the public 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 NPS activities outlined in the strategy document are approximately $110 million dollars over the next 20 years. This TMDL will also require significant point source reductions for two wastewater facilities, so the total cost will be much higher. The NPS cost 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 cost estimates should also be considered in the context of the watershed-wide TMDL addressing sediment, *E. coli* and lake impairments, as many of the BMPs would help reduce multiple pollutants. The individual cost estimate exercises include: BMPs commonly implemented to address upland sediment-bound phosphorus sources, livestock BMPs, ITPHS system repairs/replacements, and addressing nutrient impairments in lakes upstream of the RES impaired reach. 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 the cost estimate assumptions used for this TMDL.

Sediment

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.

Livestock and SSTSs

The cost estimate for phosphorus is based on unit costs for the two major sources: livestock and ITPHS SSTSs. The unit cost for bringing AUs under manure management plans and feedlot 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. The MPCA staff calculates that approximately 75% of these AUs currently have controls or management plans in place, thus reducing this estimate to ~$13 million.

Upstream Impaired Lakes

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 pound TP removed for watershed BMPs (Foraste et al. 2012). Another recent review (Macbeth et al. 2015) of lake restoration projects performed throughout the State of Minnesota suggests a median life cycle cost of approximately $500 per pound of TP removed for internal load BMPs such as aluminum sulfate. Multiplying these rates by the needed watershed (4,485 pounds per year) and internal (10,229 pounds per year) TP reductions needed for the five impaired lakes (referenced in Section 8.3.6 above) in the Redwood River Watershed (MPCA 2023a) provides a total cost of approximately $15 million. This cost estimate assumes a 20-year life cycle for watershed and internal load BMPs.

Wastewater

Cost analyses for wastewater nutrient removal were provided in the Minnesota NRS (MPCA 2014). The reader is referred to the NRS for more details beyond the summary information included here. Costs for the vast majority (over 90%) of residents receiving municipal wastewater treatment range from $7 to $11 per pound of phosphorus removed to reach 1 mg/L concentration phosphorus in the effluent.

However, removal costs escalate sharply with declining effluent concentration targets. Costs range from $39 to $175 per pound for removal to a 0.8 mg/L concentration and $91 to $344 per pound for removal to a 0.1 mg/L concentration. These phosphorus removal cost estimates represent chemical phosphorus treatment by mechanical municipal WWTFs only. Stabilization pond and industrial WWTP phosphorus removal costs are not included in these estimates.

The Redwood River Reach 501 RES TMDL calls for a summer average phosphorus load reduction of approximately 306 lbs/day (see Table 16) from all sources. The seven WWTP pond facilities that received RES WLAs in Table 16 are currently meeting their WLA targets. However, the two mechanical facilities, ADM – Marshall and Marshall WWTP, are not meeting their WLA targets and will require significant reductions to meet these targets (~83 lbs/day for ADM; ~ 9 lbs/day for Marshall WWTP). It is difficult to project the potential project costs of upgrading these facilities until more planning and engineering feasibility work has been completed. However, using the NRS municipal wastewater treatment removal cost estimates outlined above, removal costs for the mechanical facilities included in this TMDL could range from $59 to $240 per pound of additional phosphorus removed.

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 and protection related activities is ongoing, can take many years, and water quality benefits associated with these activities can also take many years. As the pollutant source dynamics within the watershed are better understood, implementation strategies and activities will be adjusted and refined to efficiently meet the TMDL and lay the groundwork for 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 LC. Any changes to water quality standards or LC must be preceded by appropriate administrative processes, including public notice and an opportunity for public review and comment.

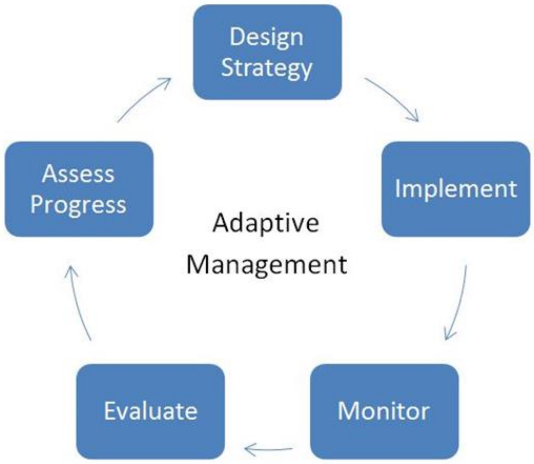


Figure 15. Adaptive management.

A list of implementation strategies in the Redwood River WRAPS Report prepared in conjunction with this TMDL focuses on adaptive management (Figure 15). Continued monitoring and “course corrections” responding to monitoring results are the most appropriate strategy for achieving the water quality goals established in this TMDL. Management activities will be changed or refined to efficiently meet the TMDLs and lay the groundwork for de-listing the impaired waterbody.

9. Public Participation

A stakeholder participation process was undertaken for this TMDL to obtain input from, review results with, and take comments from the general public and a LWG that consisted of staff from county environmental services departments, SWCDs, Redwood-Cottonwood River Control Area (RCRCA), MPCA, DNR, BWSR, MDA, Department of Health and other interested and affected agencies. The LWG, led by RCRCA and MPCA staff, convened multiple times from 2017 through 2021 to discuss and review TMDL results and provide input and feedback on the development of the Redwood River WRAPS and TMDLs. The entire public stakeholder process involved meetings and other forms of communication as described in Table 19. In addition to the stakeholder participation, the MPCA Municipal and Permitting Staff met with the City of Marshall and ADM to gather further input.

Table 19. Summary of stakeholder meetings/events held during the development of the Redwood 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
9/20/2018	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
3/18/2021	Local Work Group Meeting via WebEx
5/13/2021	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 October 16, 2023, through November 15, 2023. There were no comment letters received and responded to as a result of the public comment period.

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Appendices

Appendix A – Supporting Water Quality Analyses

Figure A-1. Summer (June-September) pH for Redwood River main-stem monitoring stations (2000-2018). The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. The error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median pH. The solid red lines represent the upper and lower Southern Rivers Nutrient Region pH range standards (6.5 and 9.0).

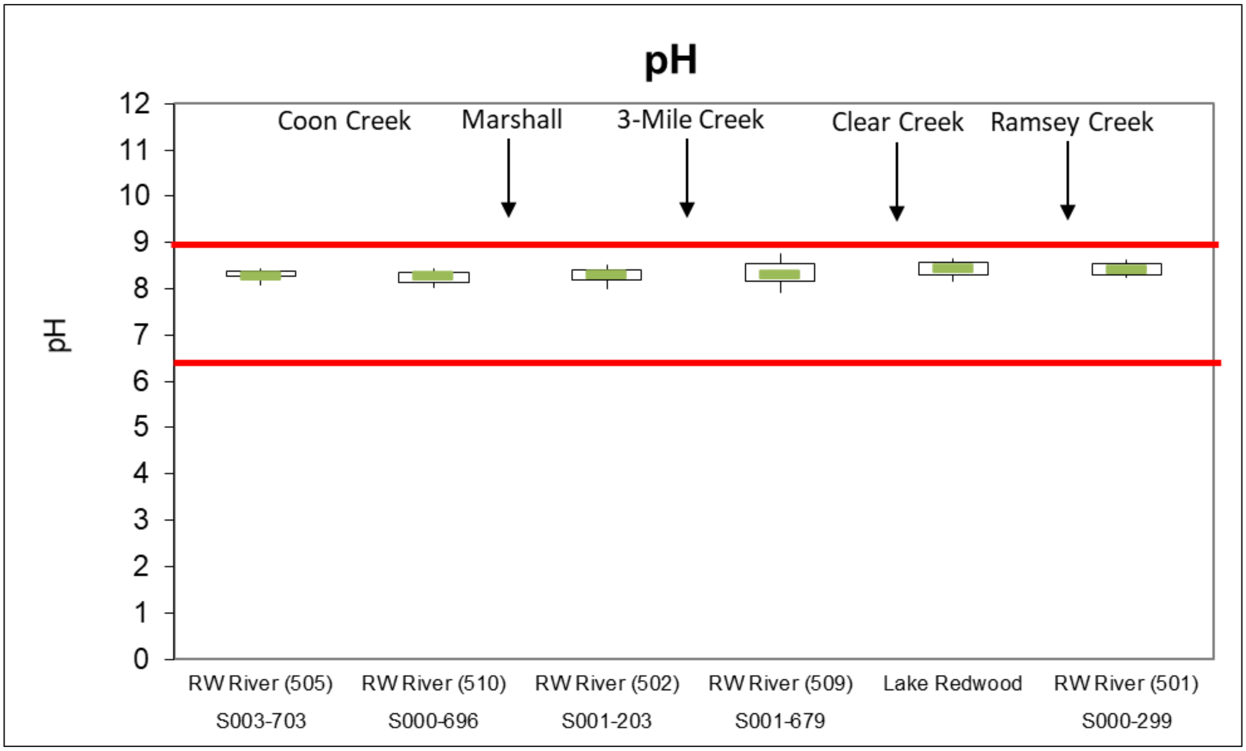


Figure A-2. Summer (June-September) pH for Redwood River tributary monitoring stations (2000-2018).

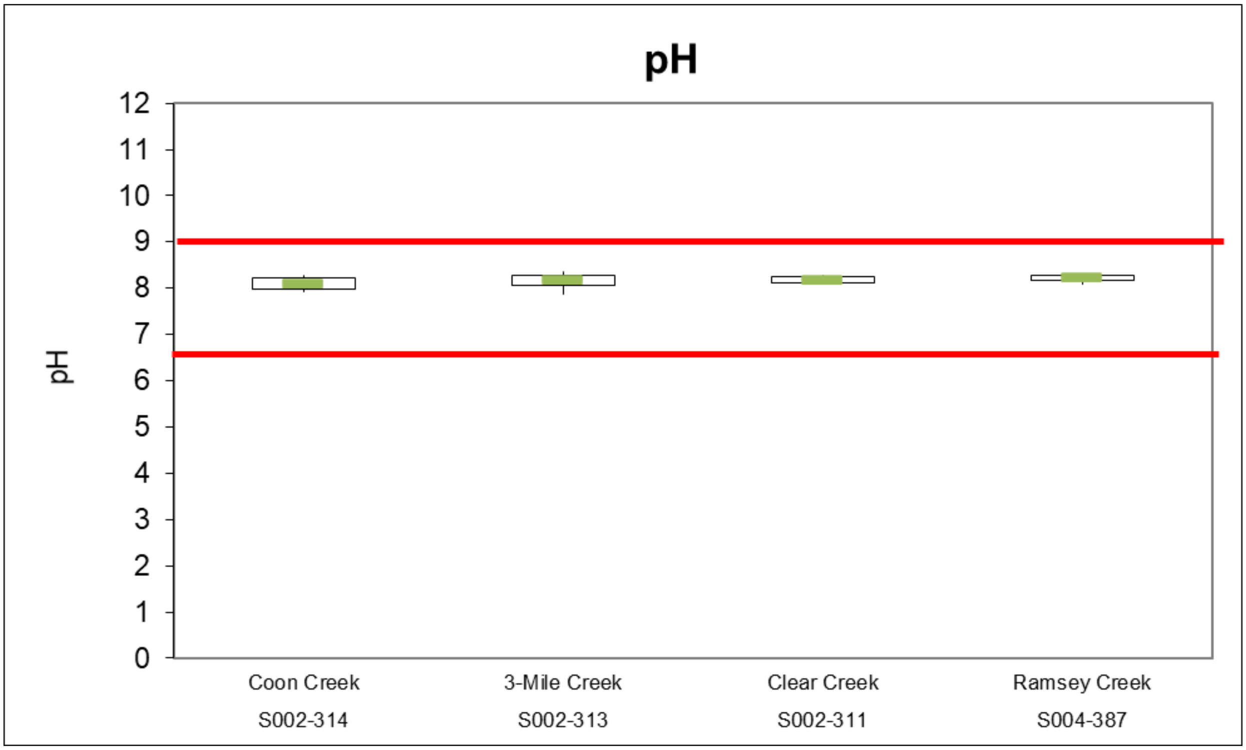


Figure A-3. Summer (June-September) 5-day BOD concentrations for Redwood River main-stem monitoring stations (2000-2018). The upper and lower edge of each box represents the 75th and 25th percentile of the data range for each site. The error bars above and below each box represent the 95th and 5th percentile of the dataset. The green dash is the median concentration. The solid red line represents the Southern Rivers Nutrient Region 5-day BOD standard (3.5 mg/L).

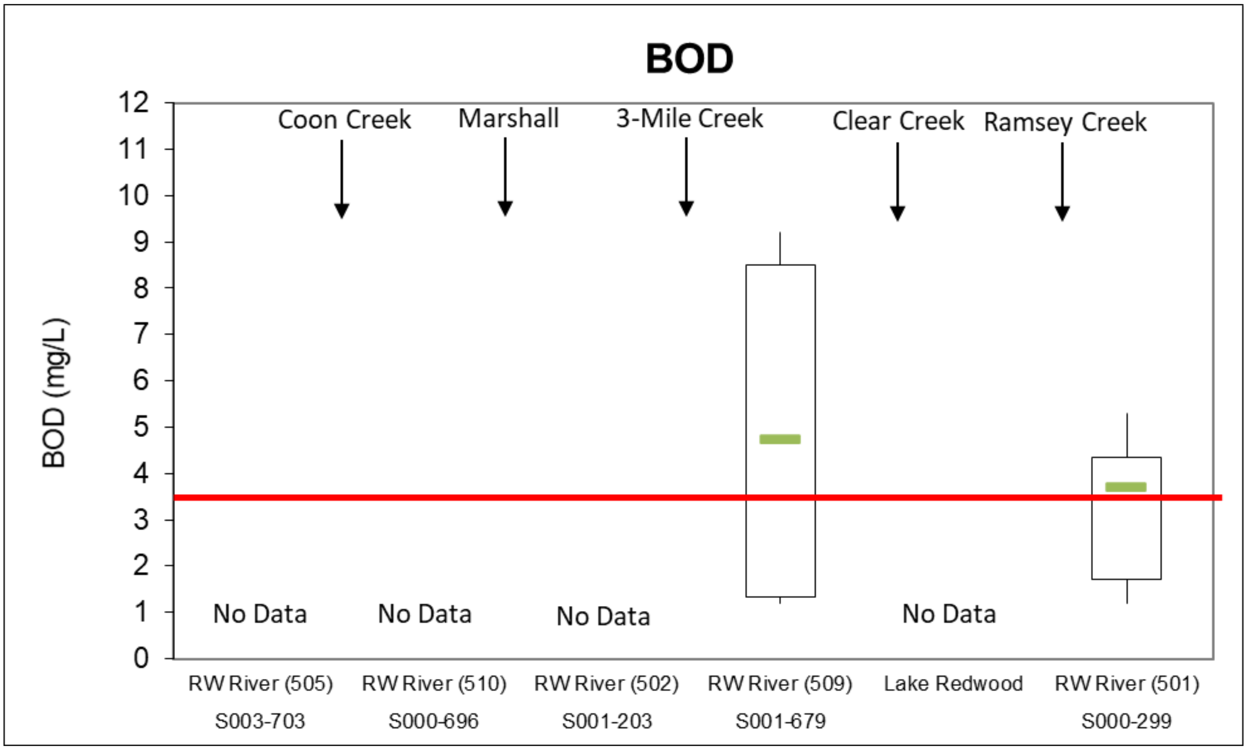


Figure A-4. Summer (June-September) 5-day BOD for Redwood River tributary monitoring stations (2000-2018).

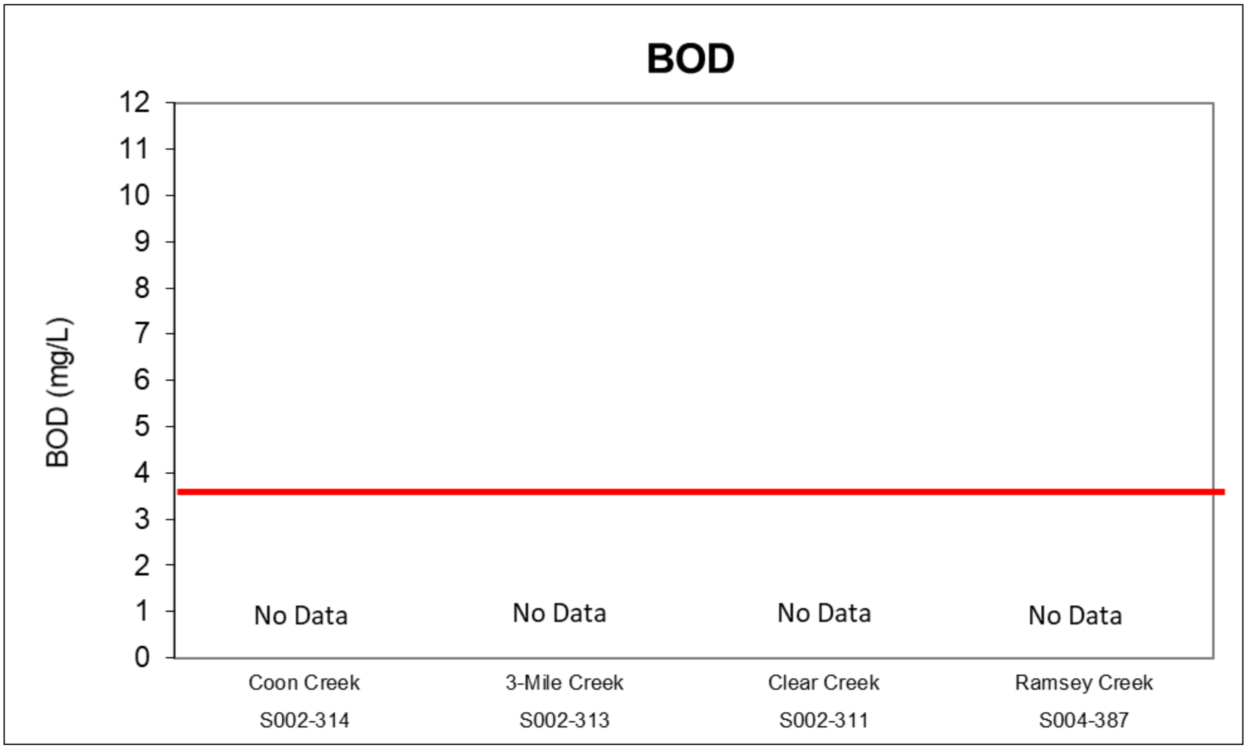


Figure A-5. Redwood River Reach 501 annual average (solid bars), minimum (lower error bar) and maximum (upper error bar) TP concentrations (2000-2018).

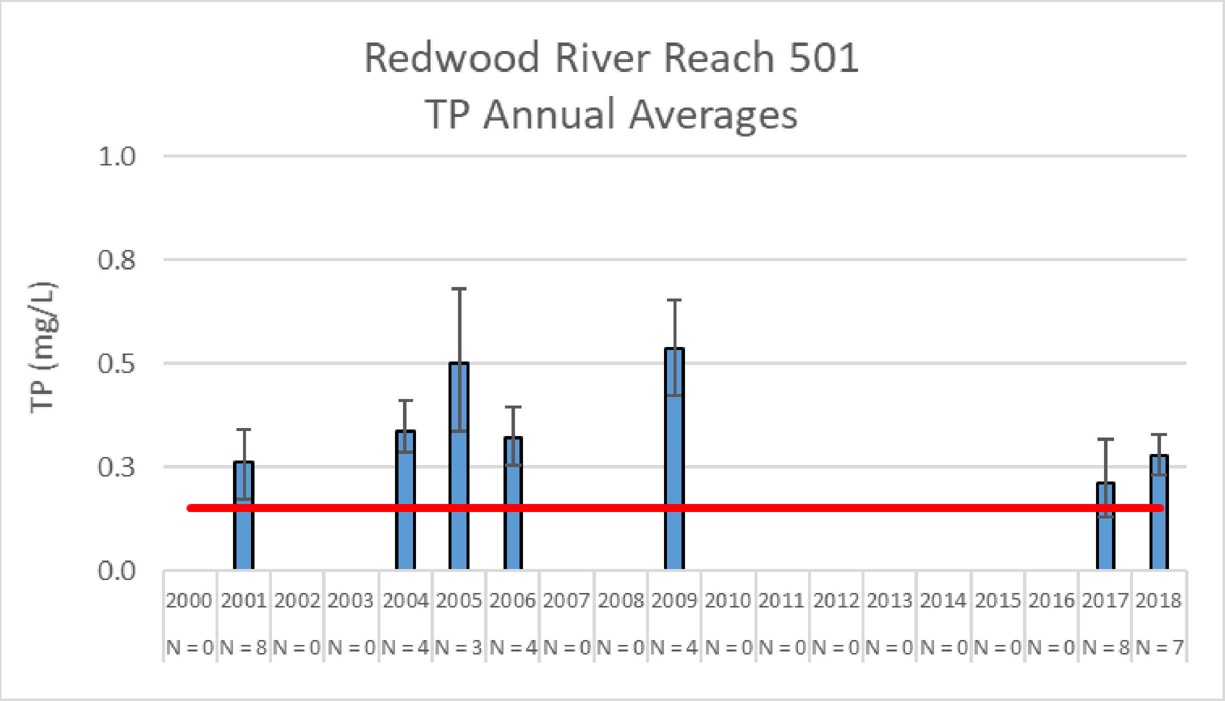


Figure A-6. Redwood River Reach 501 monthly average (solid bars), minimum (lower error bar) and maximum (upper error bar) TP concentrations (2000-2018).

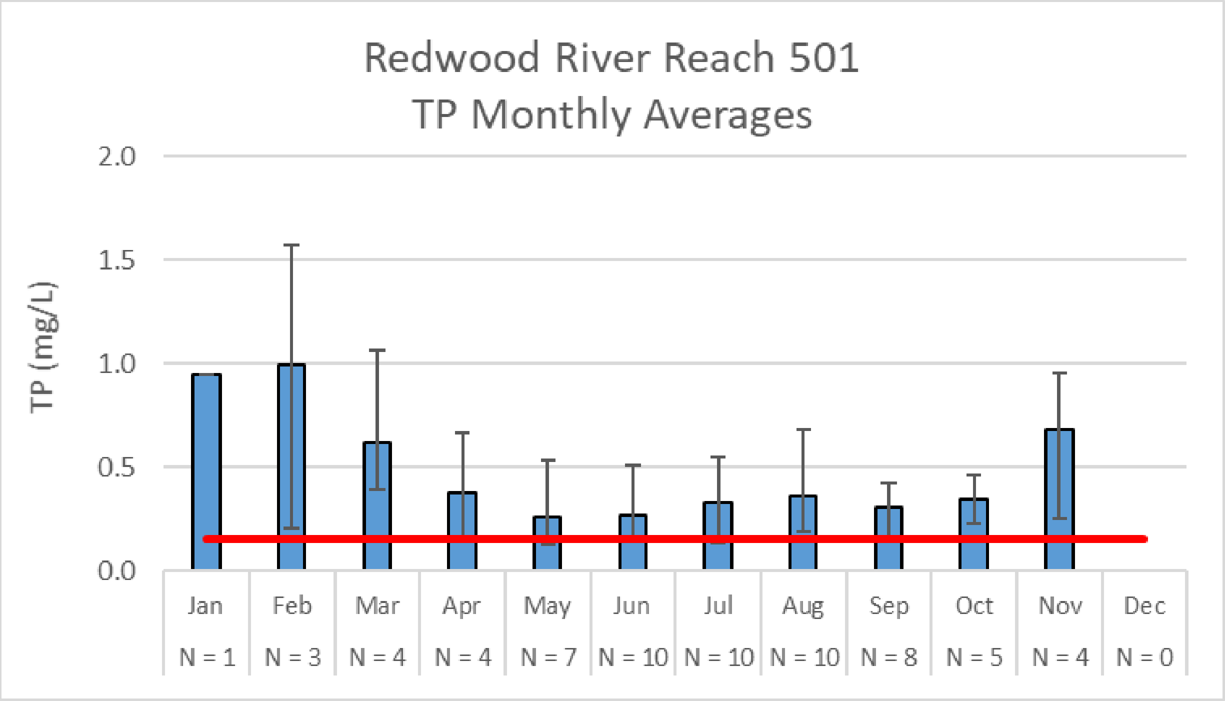


Figure A-7. Redwood River Reach 501 annual average (solid bars), minimum (lower error bar) and maximum (upper error bar) chlorophyll-*a* concentrations (2000-2018).

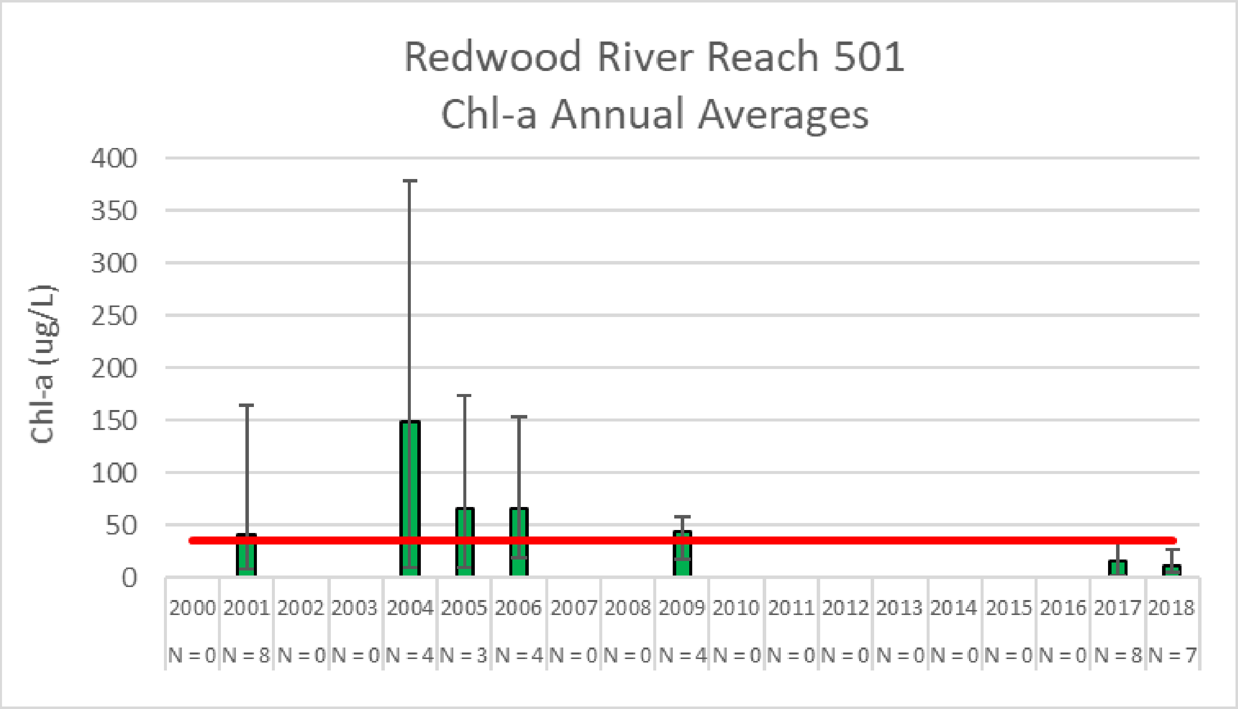


Figure A-8. Redwood River Reach 501 monthly average (solid bars), minimum (lower error bar) and maximum (upper error bar) chlorophyll-*a* concentrations (2000-2018).

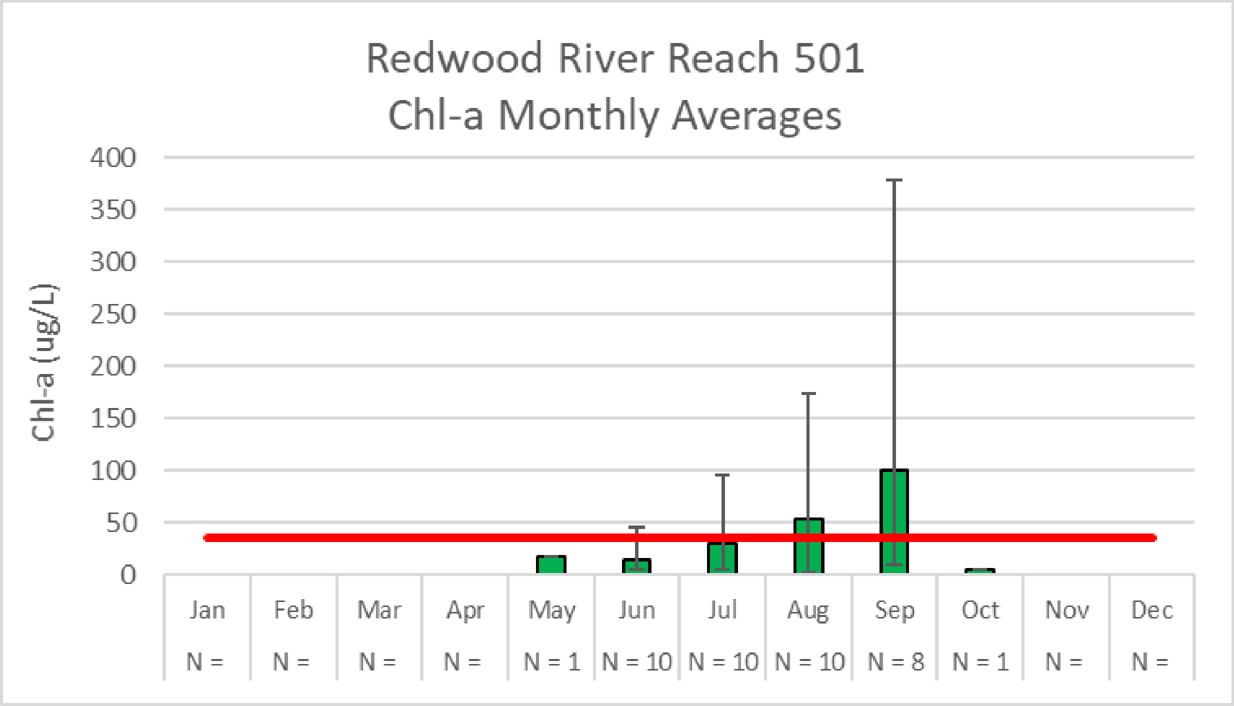


Figure A-9. Redwood River Reach 501 annual average (solid bars), minimum (lower error bar) and maximum (upper error bar) 5-day BOD concentrations (2000-2018).

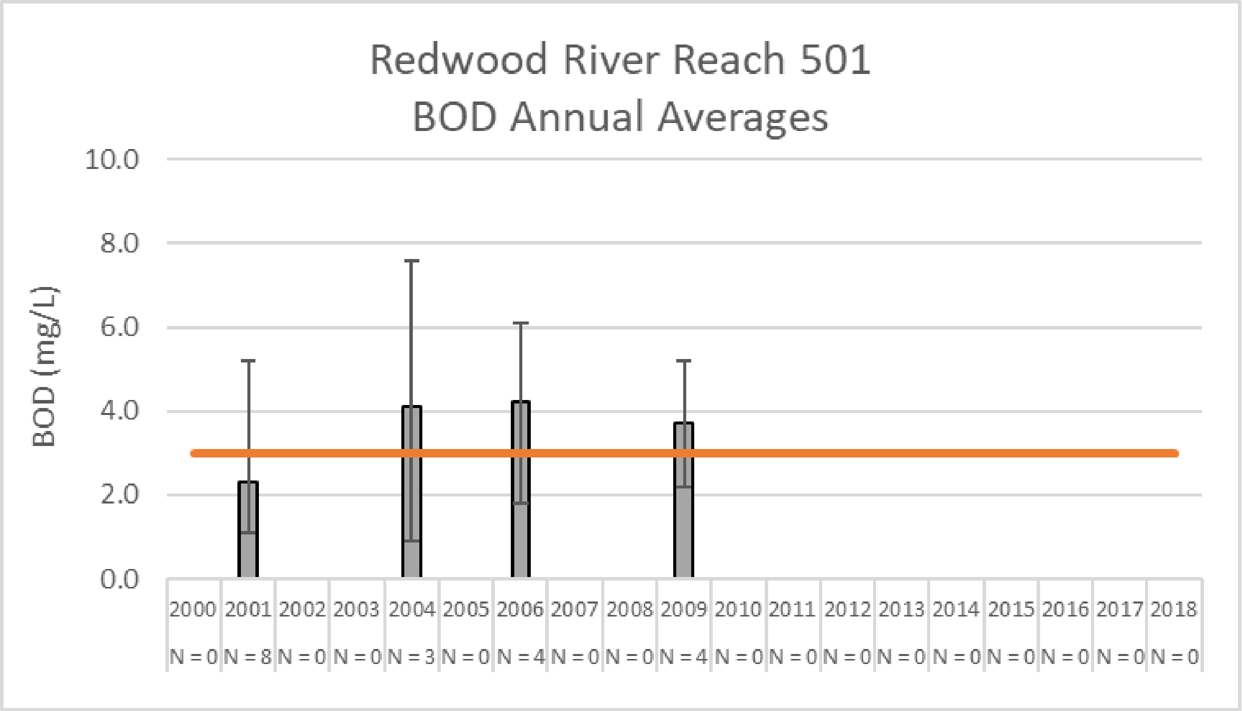


Figure A-10. Redwood River Reach 501 monthly average (solid bars), minimum (lower error bar) and maximum (upper error bar) 5-day BOD concentrations (2000-2018).

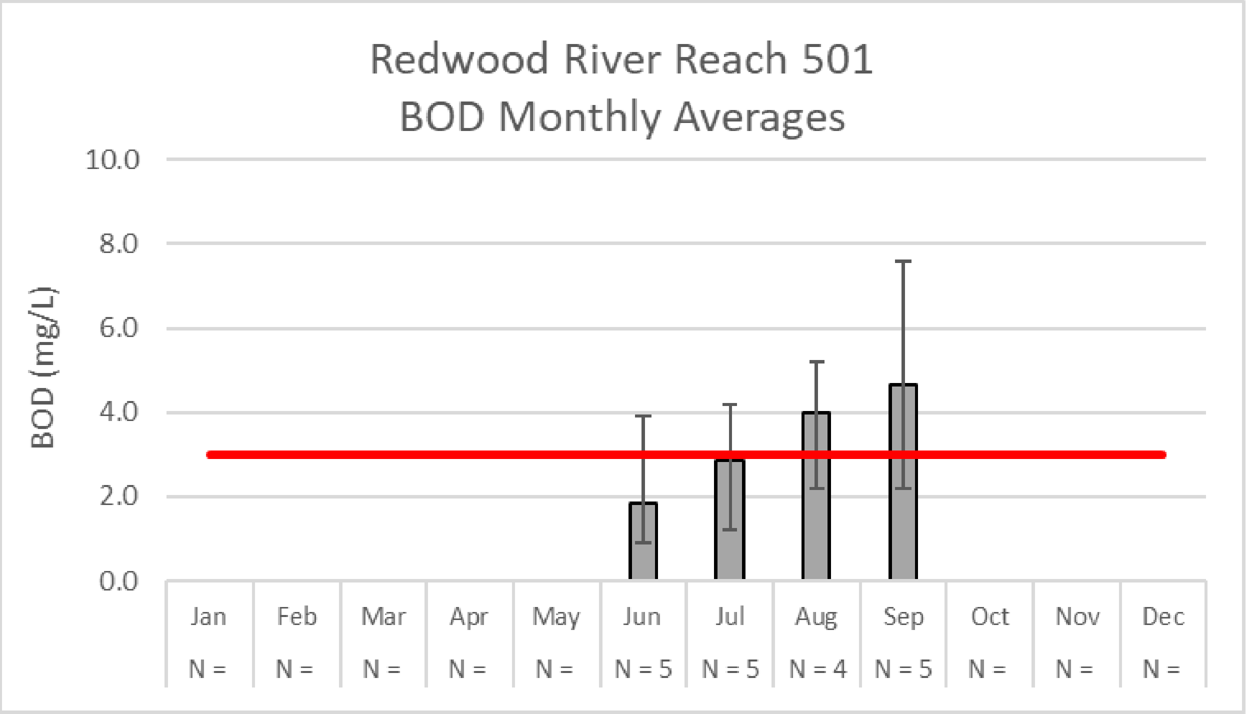


Figure A-11. Redwood River Reach 501 total phosphorus load duration curve and monitored loads (2000-2018) for station S000-299 (in reach 501) and Lake Redwood (upstream of reach 501).

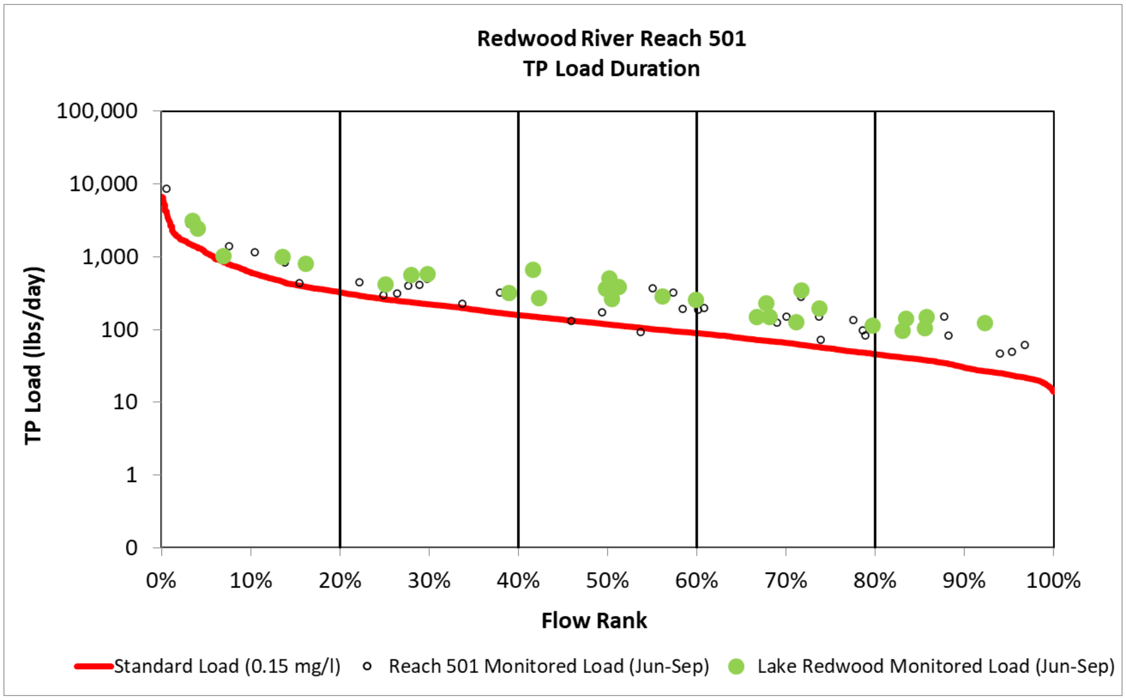


Figure A-12. Redwood River Reach 501 chlorophyll-*a* load duration curve and monitored loads (2000-2018) for station S000-299 (in reach 501) and Lake Redwood (upstream of reach 501)

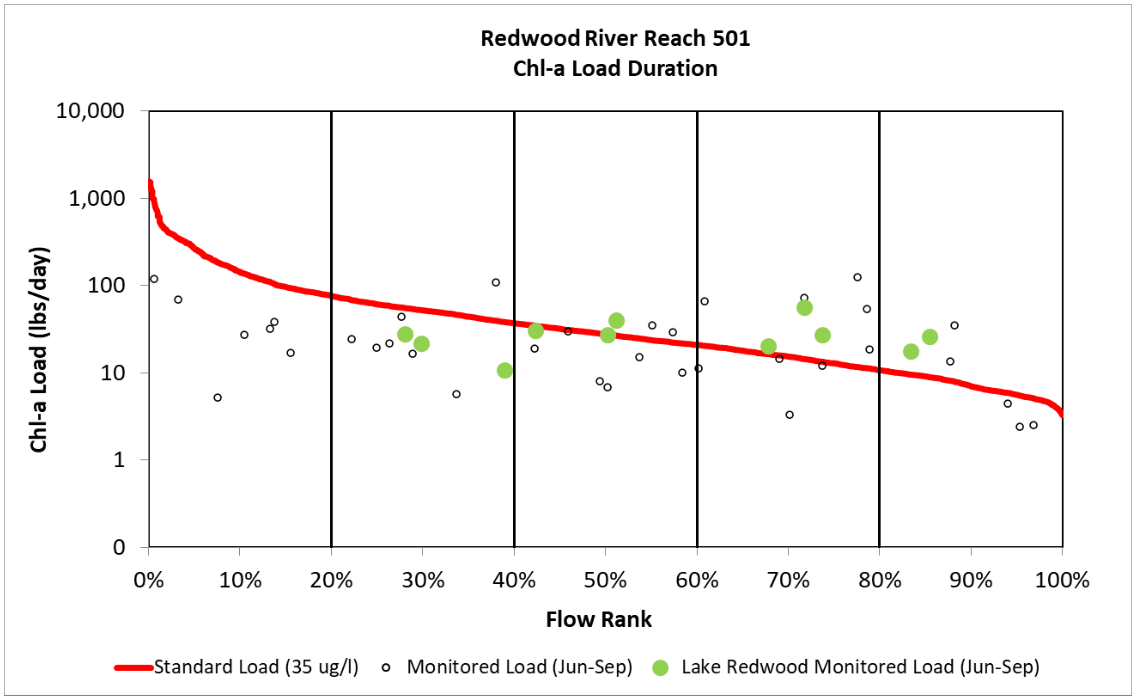


Figure A-13. Redwood River Reach 501 5-day BOD load duration curve and monitored loads (2000-2018) for station S000-299 (in reach 501).

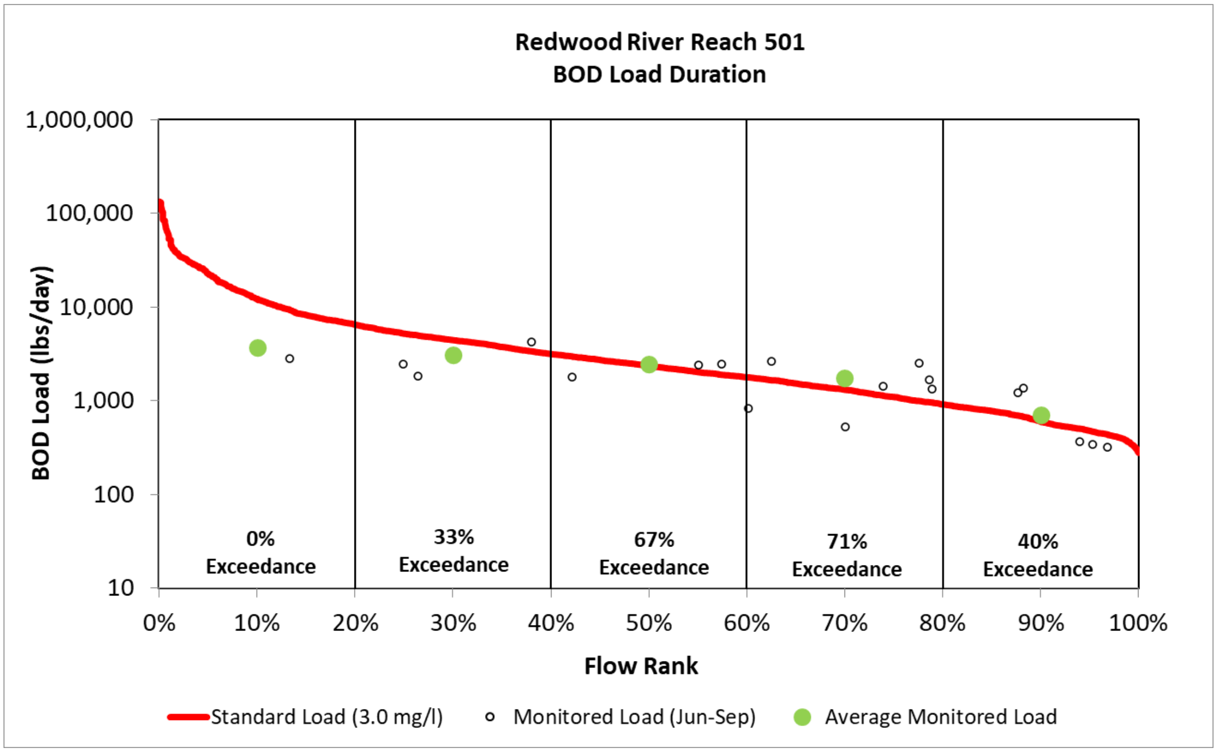
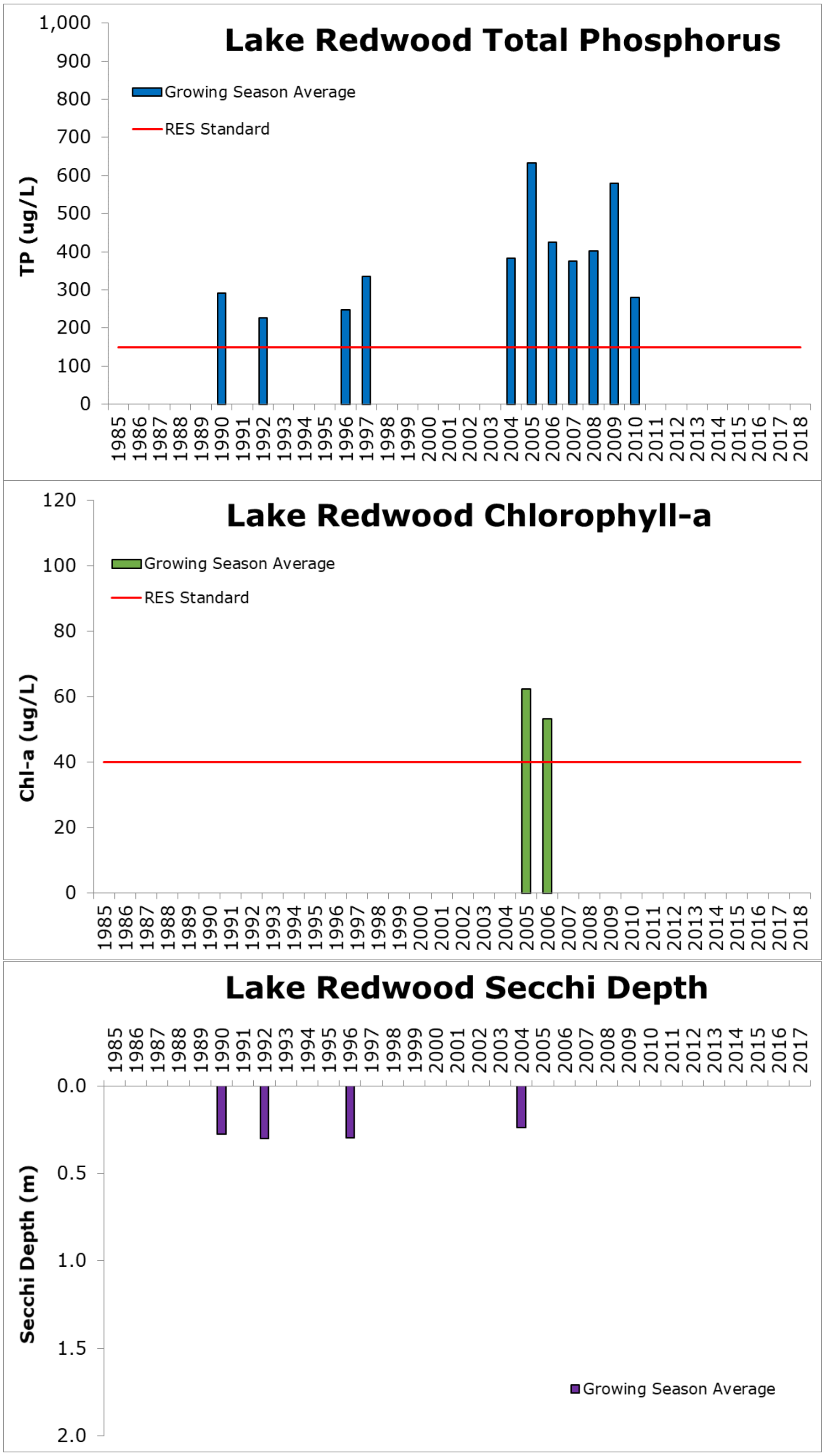


Figure A-14. Lake Redwood average summer TP, chlorophyll-*a*, and Secchi depth



Appendix B – WWTF DMR Data Summary

Table B-1. WWTF summer (June through September) monthly average effluent TP concentration summary (2009-2018).

Facility	Number of Samples	TP (ave; mg/L)	TP (min; mg/L)	TP (max; mg/L)	Samples exceeding 1.0 mg/L	Samples exceeding 2.0 mg/L
ADM Corn Processing - Marshall	36	7.3	1.7	12.0	36	35
Ghent WWTP	6	1.9	0.4	3.2	5	2
Lynd WWTP	2	3.3	1.5	5.2	2	1
Marshall WWTP	35	4.1	0.9	9.3	31	20
Milroy WWTP	5	1.9	1.5	2.4	5	1
Russell WWTP	7	1.0	0.4	2.3	3	1
Ruthton WWTP	14	1.2	0.3	3.0	7	2
Tyler WWTP	9	1.4	0.8	2.7	5	2
Vesta WWTP	4	5.3	1.3	13.8	4	3

Note: Samples refer to single monthly average reported value

Appendix C – HSPF Model Documentation

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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

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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

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[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).

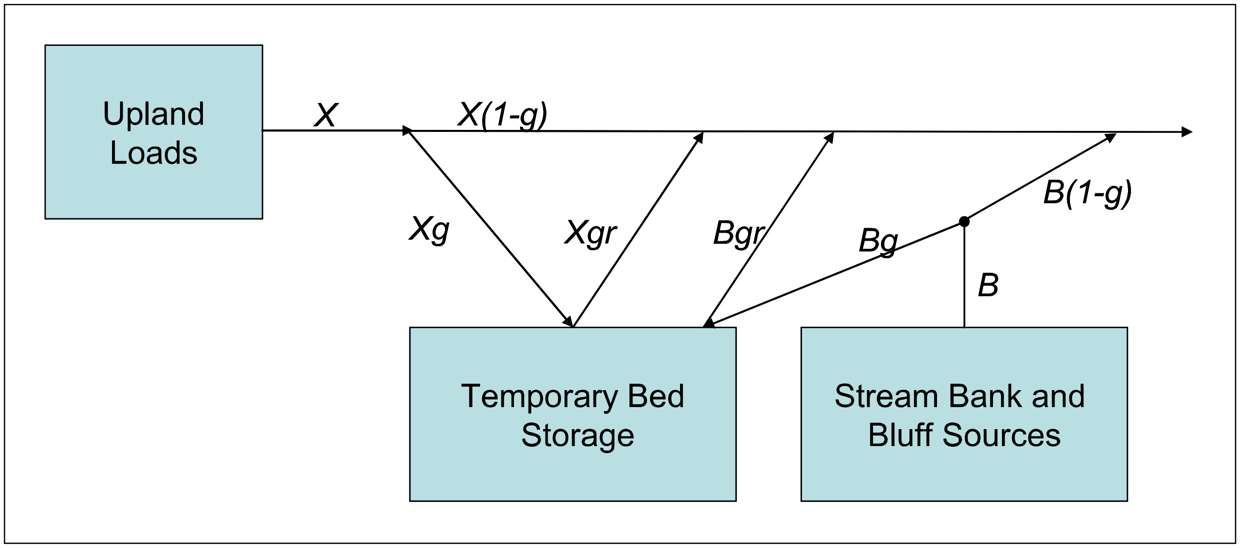


Figure 1. Conceptual Representation of Stream Sediment Processing

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:

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

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%

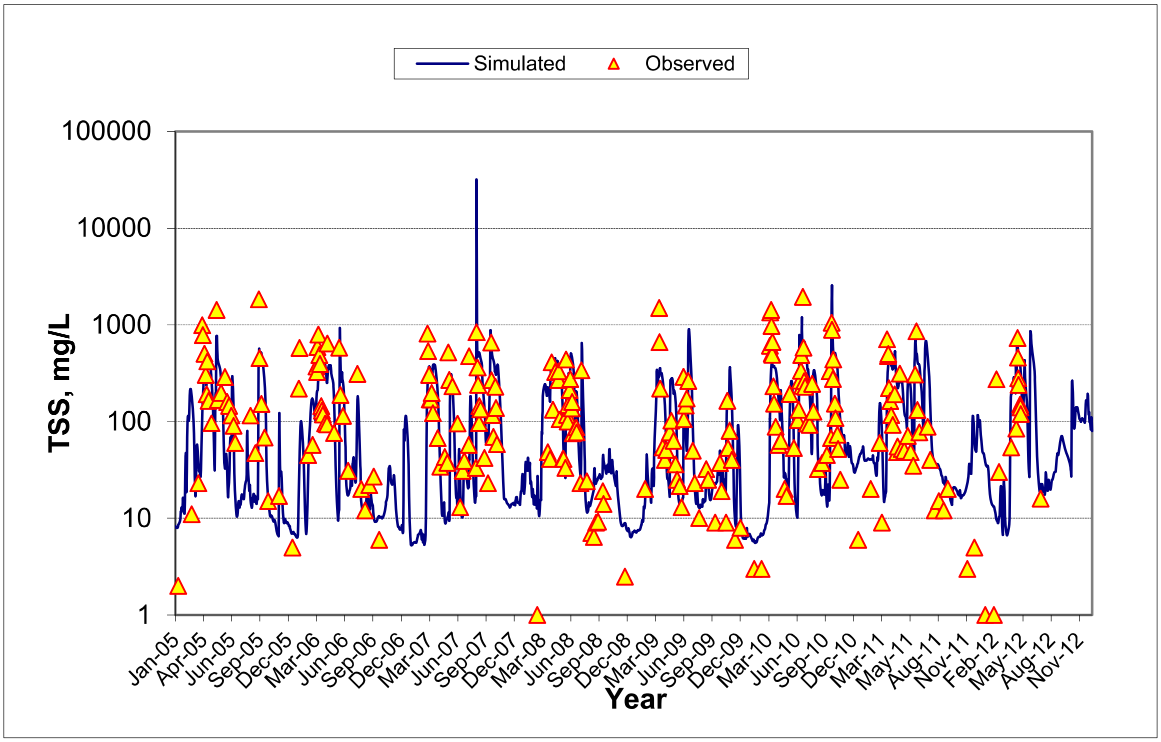


Figure 2. Timeseries Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

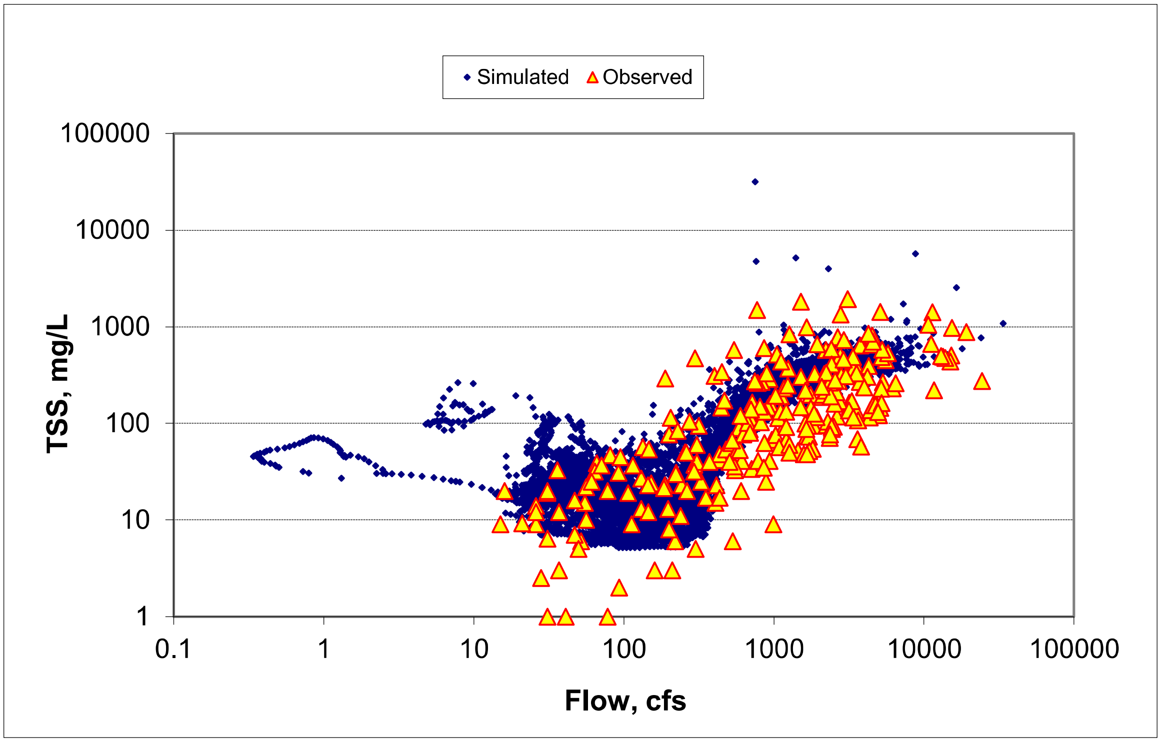


Figure 3. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

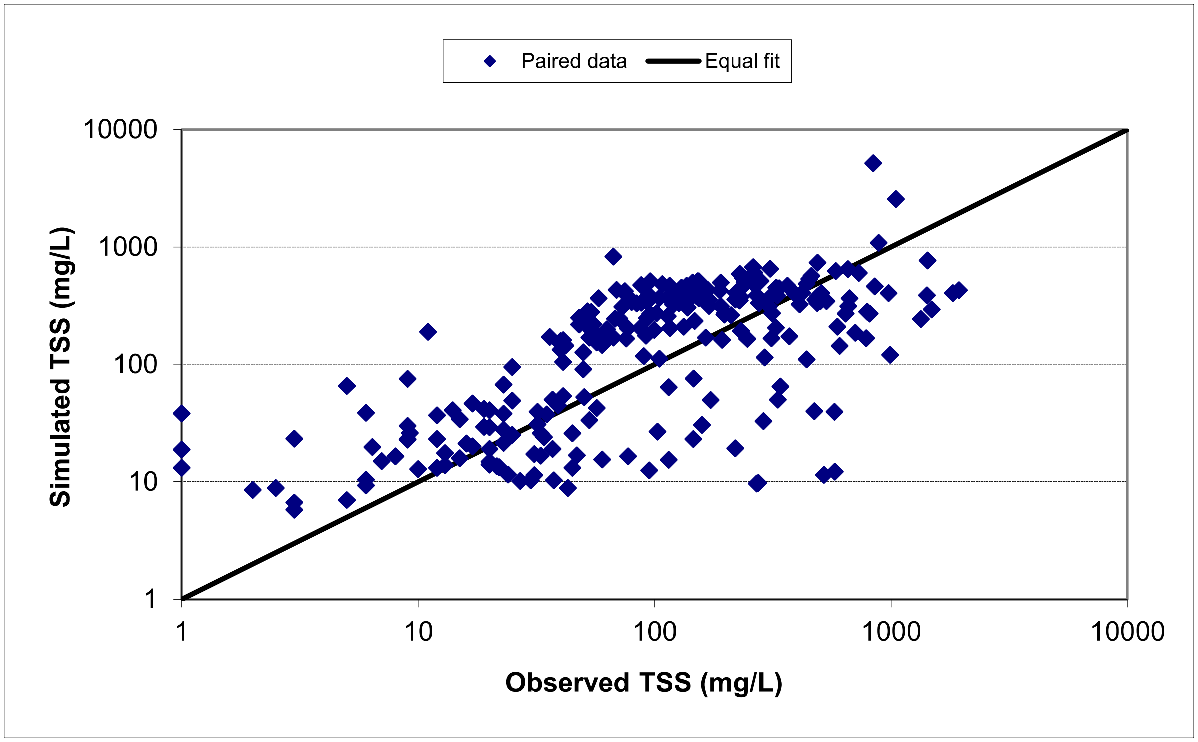


Figure 4. Simulated and Observed TSS Concentration Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

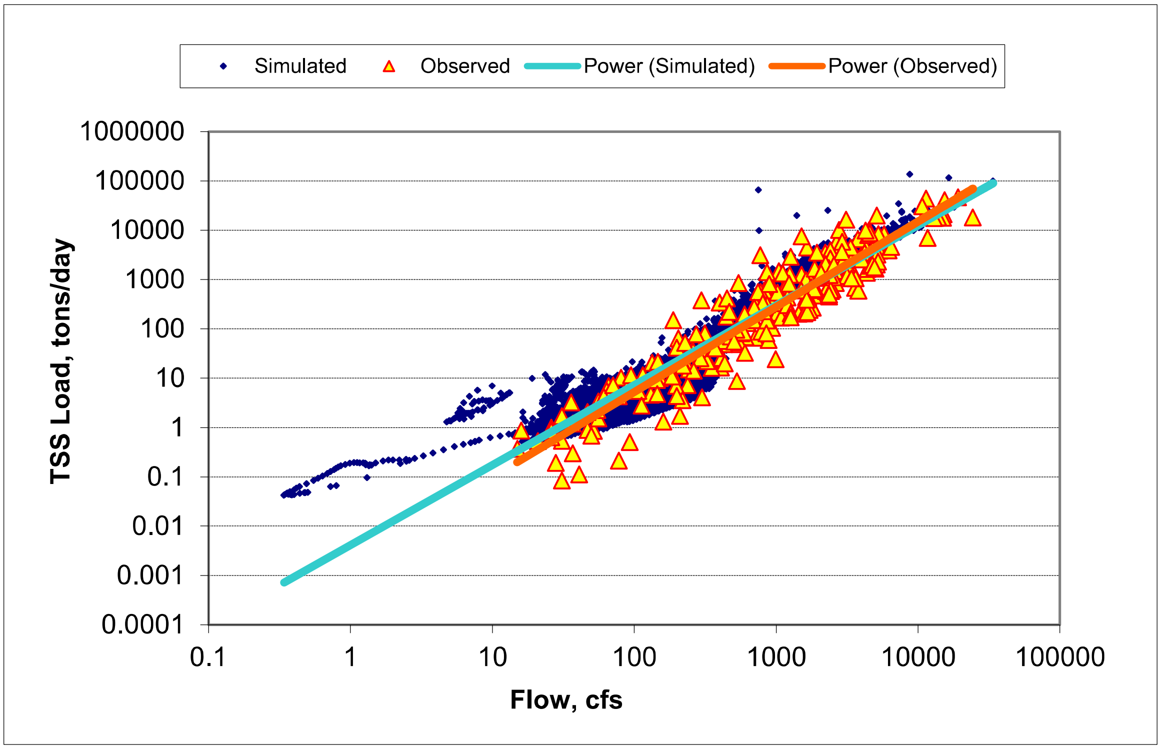


Figure 5. Load vs Flow Plot of Simulated and Observed TSS Load for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

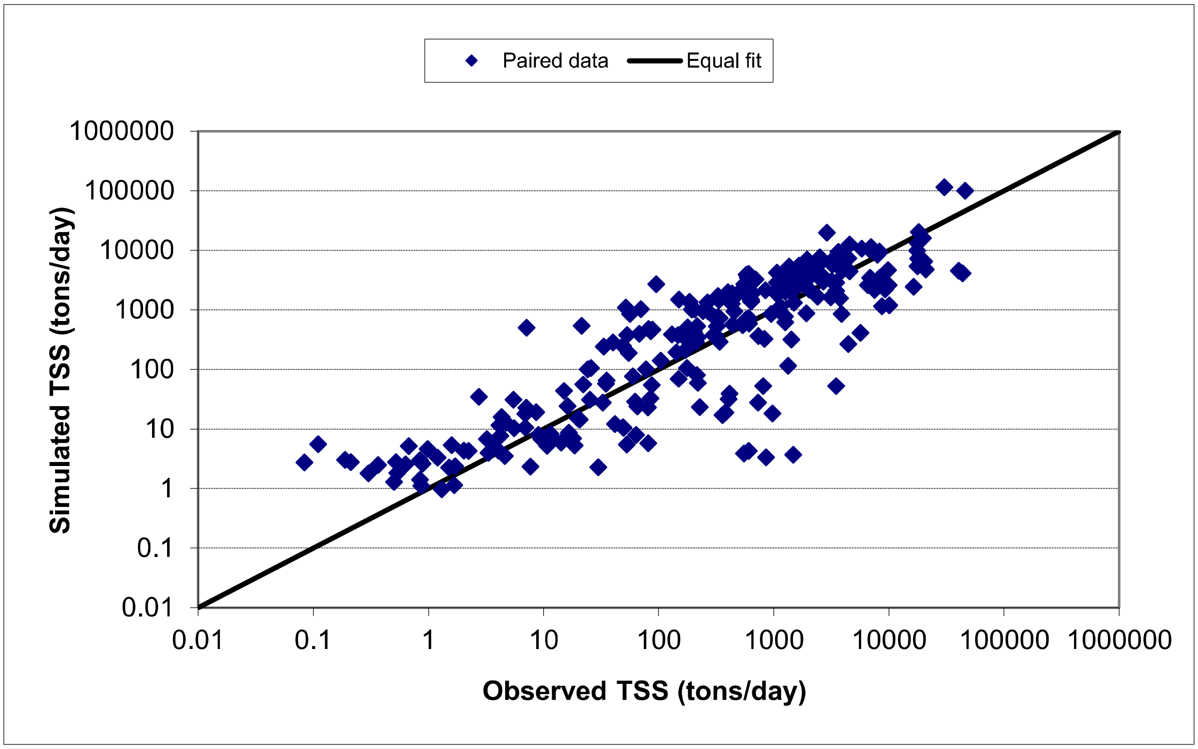


Figure 6. Simulated and Observed TSS Load Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012

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%

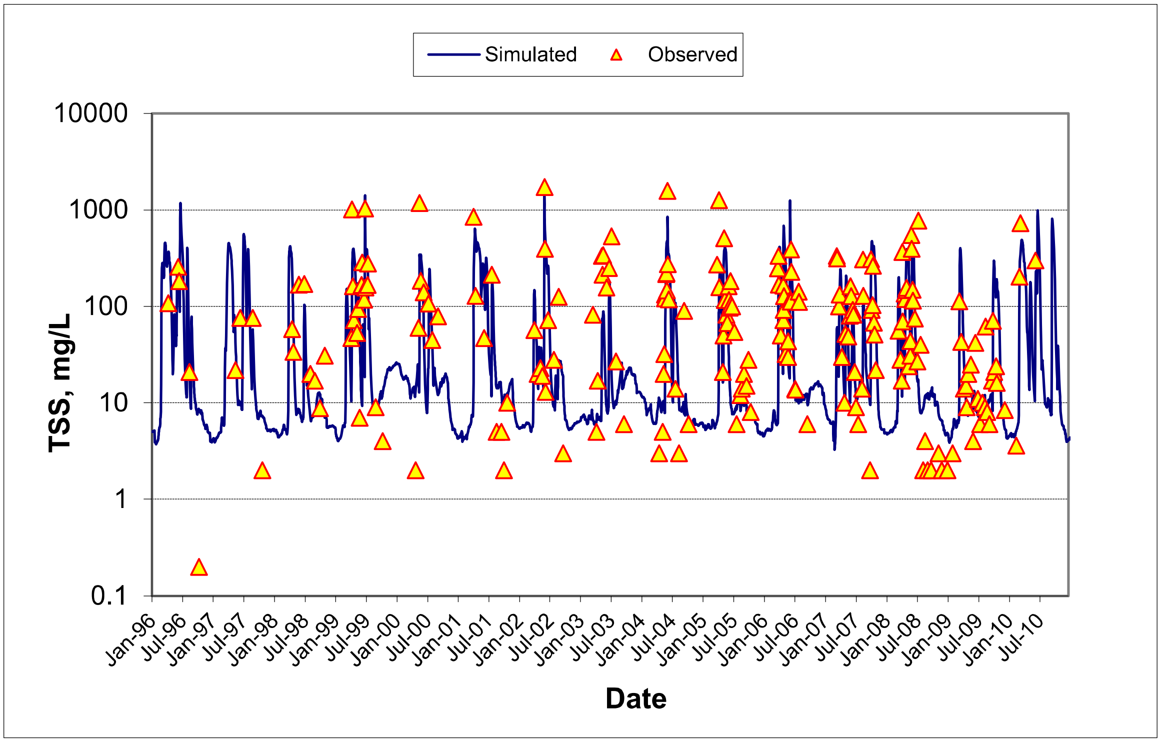


Figure 7. Timeseries Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010

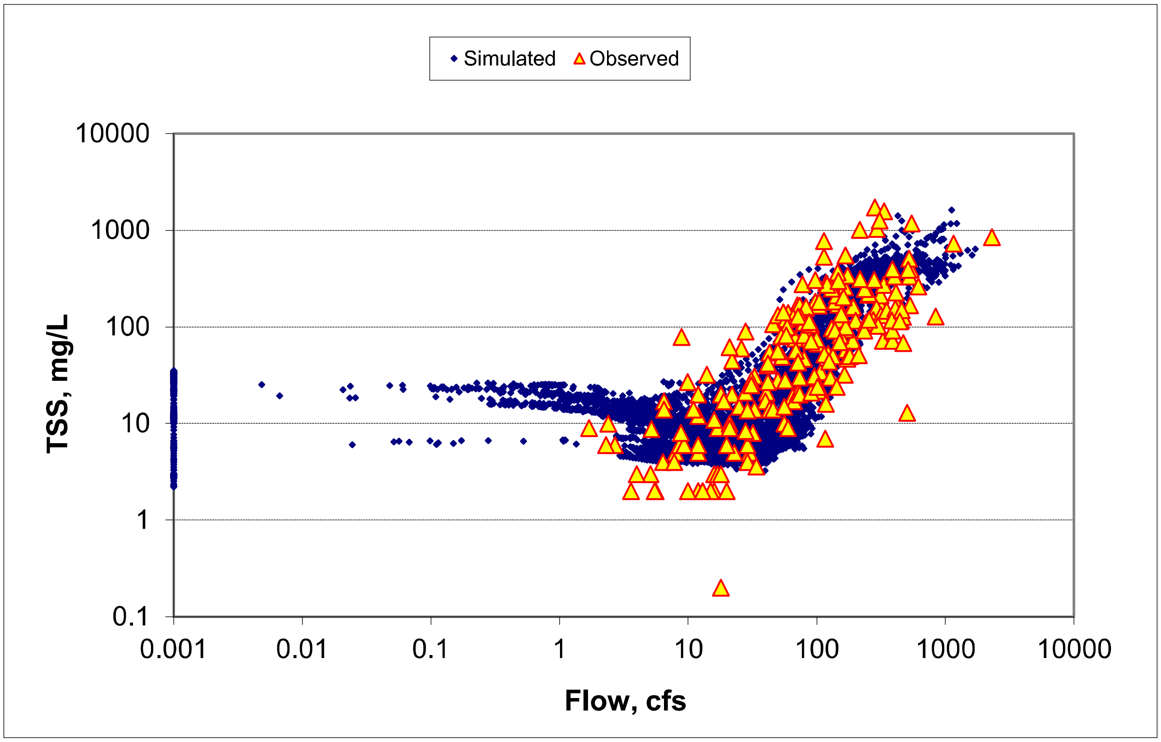


Figure 8. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010

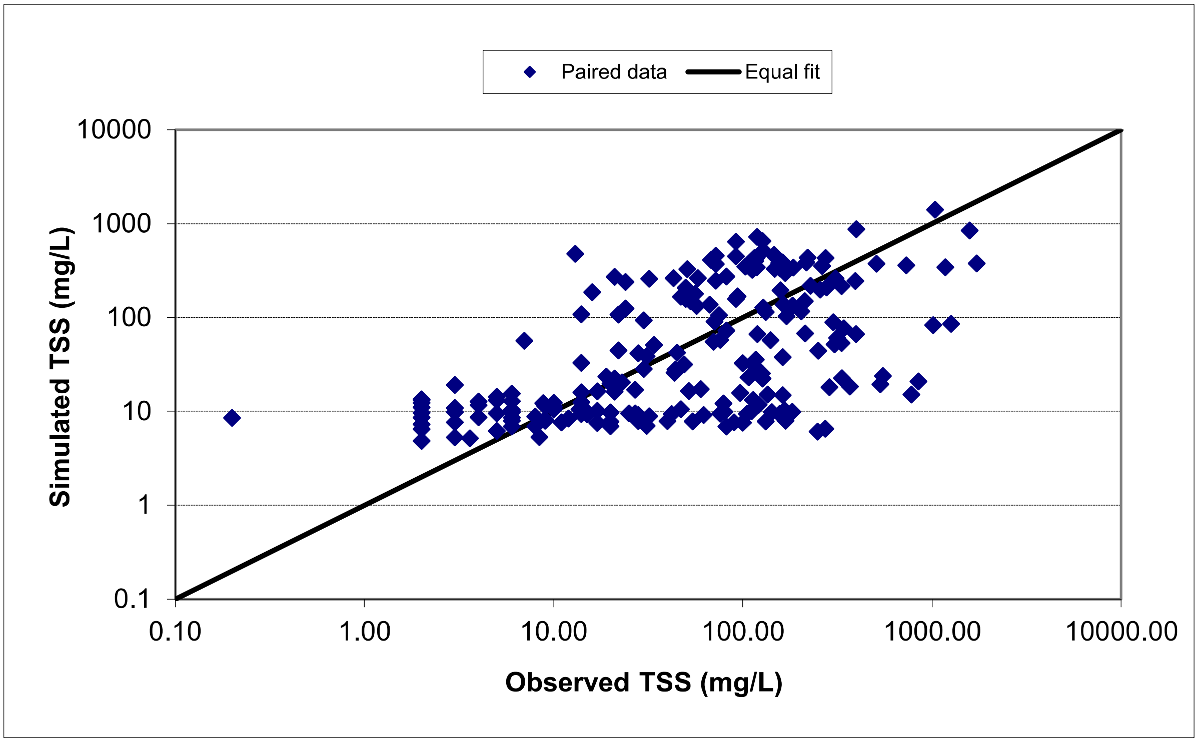


Figure 9. Simulated and Observed TSS Concentration Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010

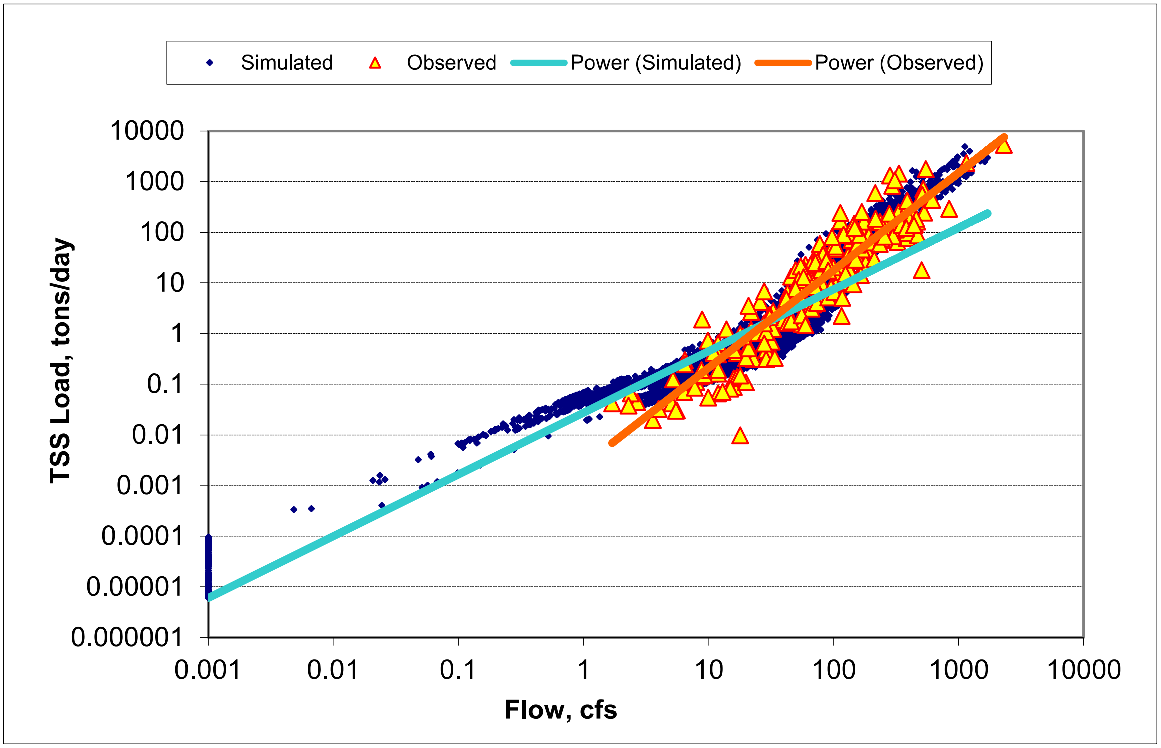


Figure 10. Load vs Flow Plot of Simulated and Observed TSS Load for Little Cottonwood River at Apple Road for 1996-2010

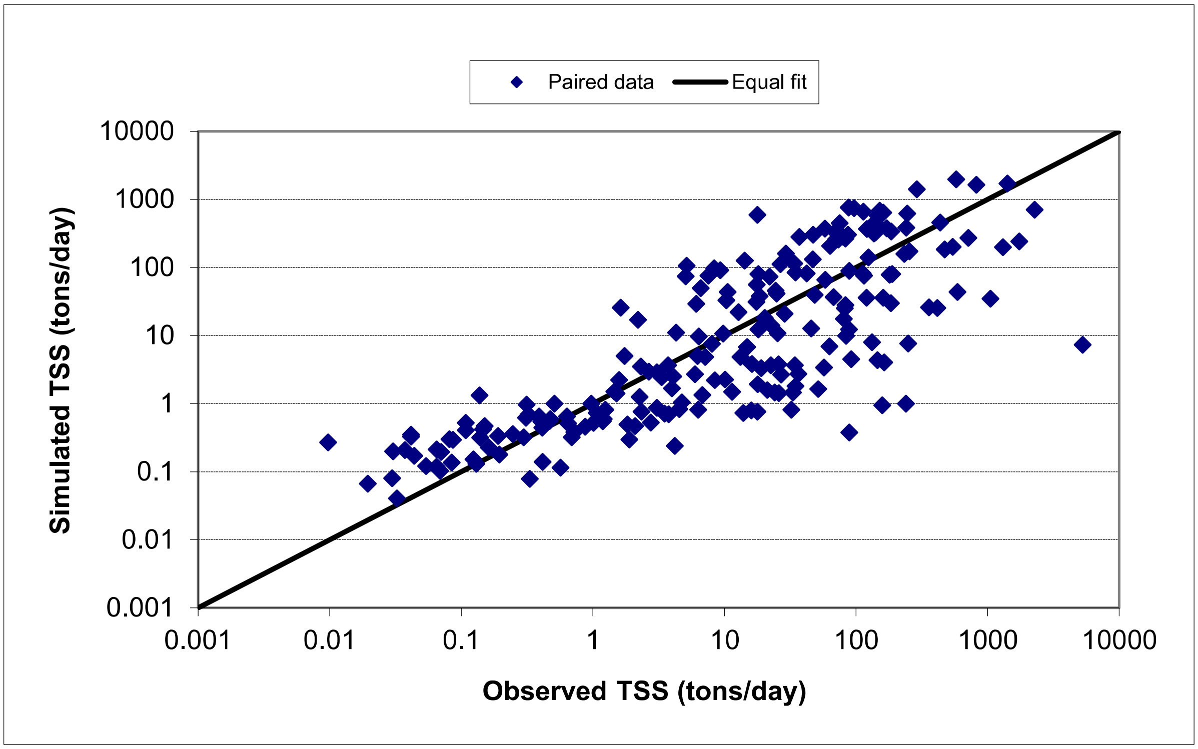


Figure 11. Simulated and Observed TSS Load Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010

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%

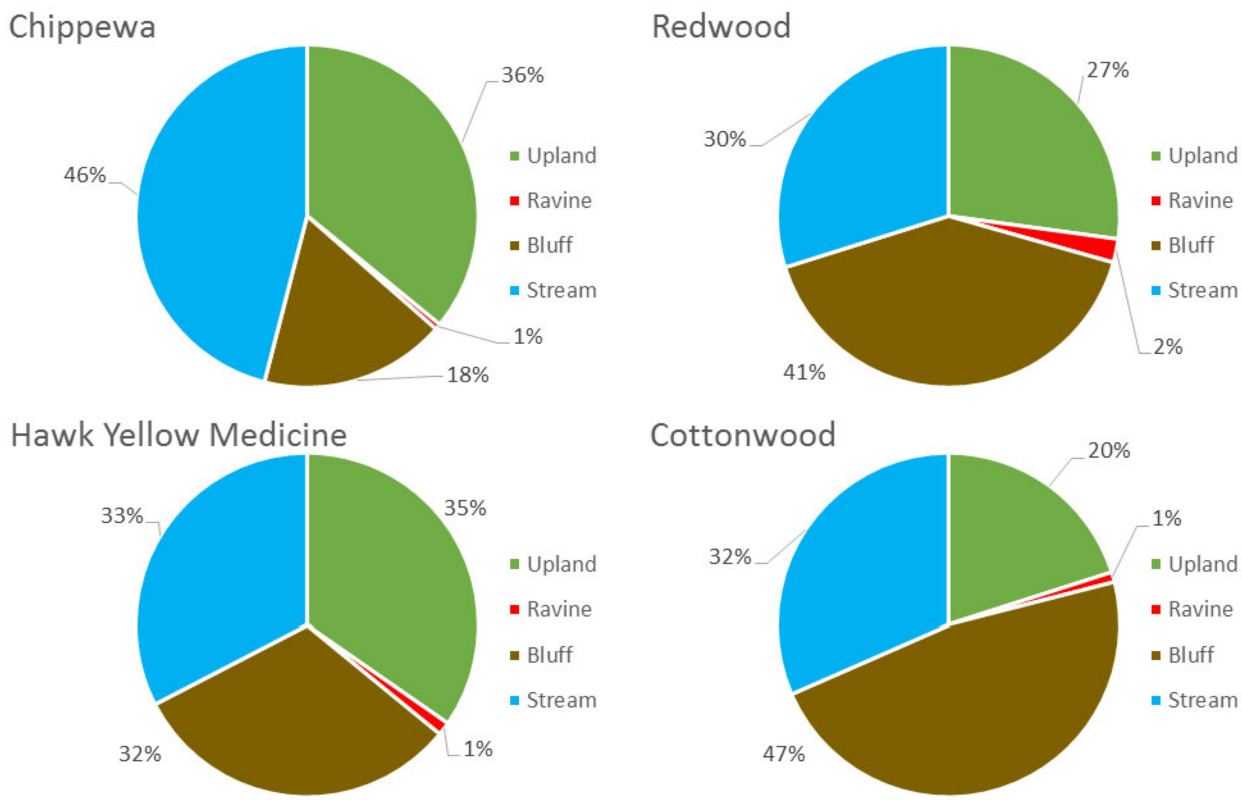
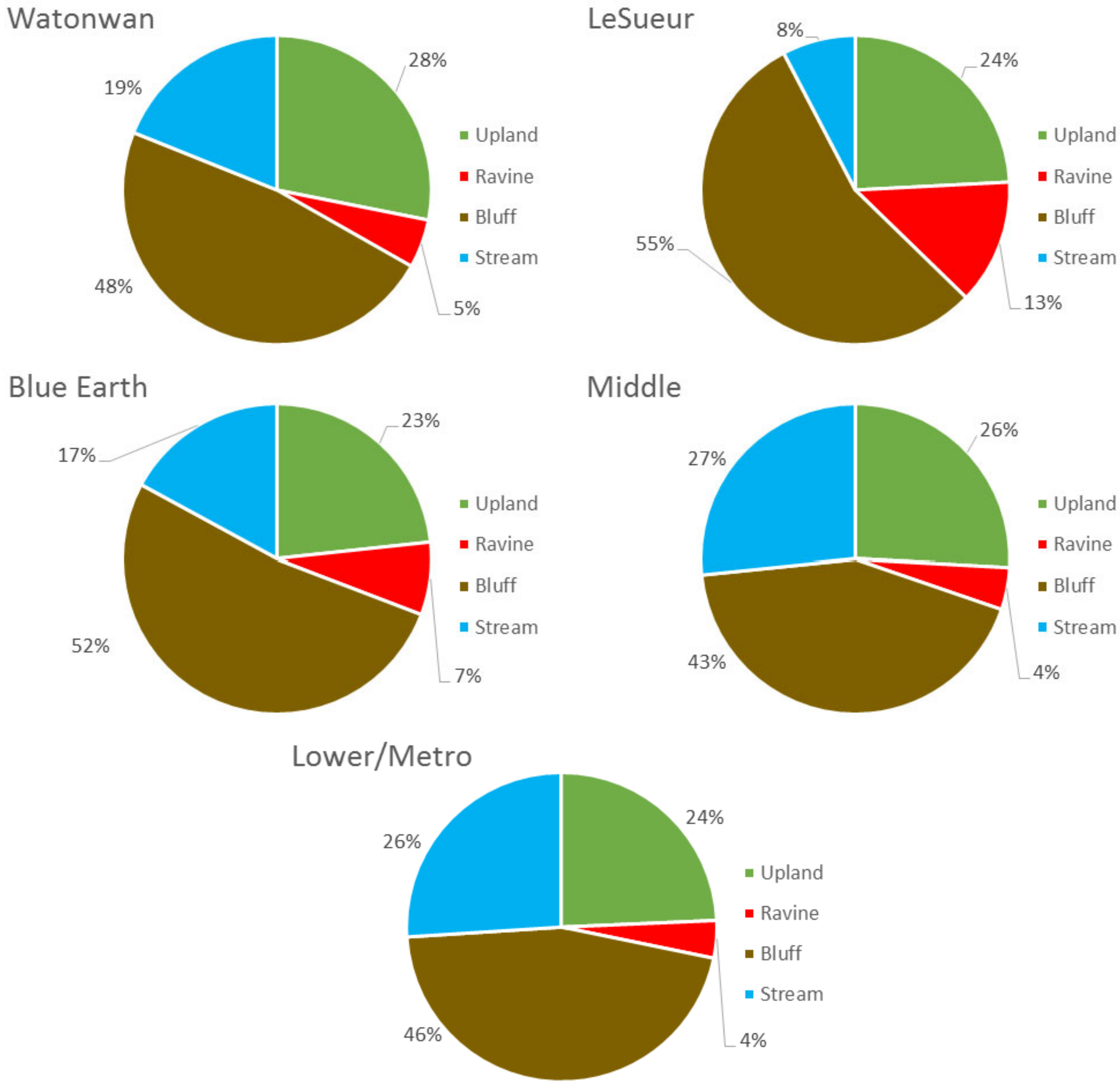


Figure 13. Instream Sediment Source Apportionment at HUC8 Outlets



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

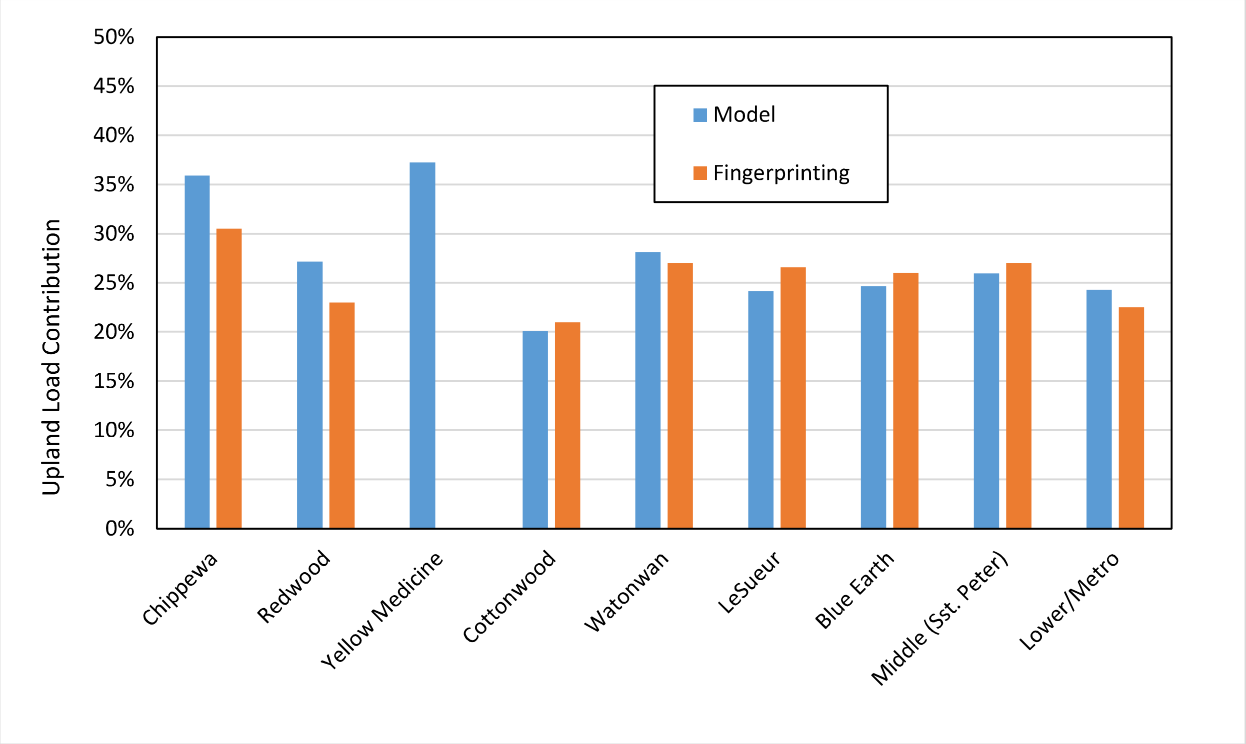


Figure 14. Comparison of Simulated Surface Washoff Loading to Surface Source Fraction from Sediment Fingerprinting Analysis

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%

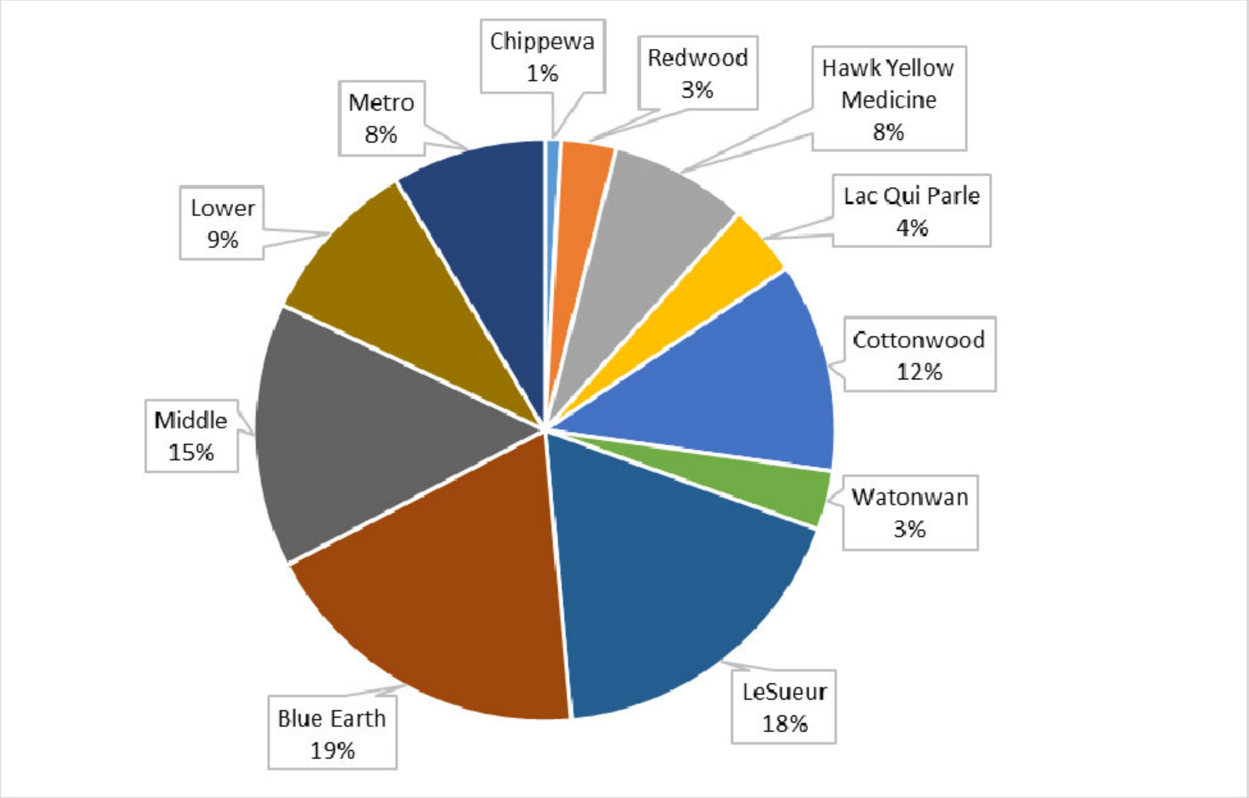


Figure 15. HUC8 Contributions to Sediment Load at the Mouth of the Metro Model

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.

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MEMORANDUM

To:	Chuck Regan (MPCA)
Cc:	Jon Butcher, Jennifer Olson (Tetra Tech)
From:	Michelle Schmidt, Scott Job, and Ryan Birkemeier (Tetra Tech)
Date:	January 3, 2019
Subject:	Cottonwood and Redwood Watersheds HSPF Model Extension

1.0 INTRODUCTION

Two Hydrologic Simulation Program – FORTRAN (HSPF) models of the Cottonwood and Redwood watersheds in the Minnesota River Basin were refined and calibrated for hydrology and water quality by RESPEC (2012; 2014a; 2014b) and recalibrated by Tetra Tech (2015; 2016). HUC8 scale HSPF models have also been developed and calibrated for the other watersheds in the Minnesota River Basin. The Minnesota Pollution Control Agency (MPCA) is facilitating the effort to keep the Minnesota River Basin models up-to-date for various planning and management efforts, such as stressor identification, water quality implementation planning, and wastewater permit development. In addition, it is advantageous to keep the simulation periods of the HSPF models current to utilize recently collected monitoring data. Therefore, several of the Minnesota River Basin HSPF models (Minnesota River Headwaters, Lac qui Parle, Cottonwood, Redwood, Pomme de Terre, Le Sueur, Watonwan, and Blue Earth) are being extended through 2017. This memorandum documents updates to the HSPF models for the Cottonwood and Redwood watersheds.

Figure 1. Minnesota River Basin HSPF Model Domains

1.0 MODEL EXTENSION

The approaches used to extend the input times series for the Cottonwood and Redwood HSPF models through 2017 are discussed in the following subsections. As discussed in Section 1.1, the meteorological input series from the original models were derived from ground weather station data; these were replaced with hourly inputs for the full simulation period derived from gridded weather data sources. The point source discharge and pollutant load time series (Section 1.2) and wet and dry atmospheric deposition time series (Section 1.3) were also extended through 2017. Lastly, the hydrology calibration was reviewed following these updates for the period of 1995 – 2012. A few coarse updates were made to the parameterization following the review, and recommendations for future fine-tuning were identified.

1.1 METEOROLOGY

Weather forcing series for the original versions of the HSPF models were derived from ground weather station data. Gridded weather products, however, better represent climatic variations across a diverse landscape compared to point-in-space station weather data. Moreover, the gridded weather data products directly provide hourly air temperature, wind, and solar radiation data as well as parameters for computing cloud cover, dew point temperature, and potential evapotranspiration, which are inputs to HSPF.

PRISM (Parameter-elevation Relationships on Independent Slopes Model) provides annual, monthly, and daily gridded precipitation data for the conterminous United States (Daly et al., 2008, 2015; daily output was added to PRISM in 2015). PRISM calculates a climate-elevation regression function for each grid cell and the regression is used to distribute station-based precipitation data to the grid cell. Approximately 13,000 precipitation stations are used in the analysis. For each grid cell, precipitation stations are assigned weights based on location, elevation, coastal proximity, topographic facet orientation, vertical atmospheric layer, topographic position, and orographic effectiveness of the terrain; the stations are then entered into the regression function to establish the gridded precipitation product.

Another gridded product is the North American Land Data Assimilation System (NLDAS-2) meteorological time-series (Mitchell et al., 2004). NLDAS-2 (http://ldas.gsfc.nasa.gov/nldas/NLDAS2forcing.php) provides continuous hourly data from 1979 to present on a 1/8-degree grid that has been processed to fill gaps. The precipitation data in NLDAS-2 are based on interpolation of daily gauge precipitation including orographic adjustments based on PRISM and temporally disaggregated using Doppler radar and satellite data. NLDAS-2 also provides solar radiation, wind at 10 m (which can be scaled to wind at 2 m), and absolute humidity plus air pressure, from which dew point can be calculated. Cloud cover (which is only needed to estimate long wave radiation exchange with the atmosphere) is not included in the NLDAS output, but can be back-calculated from the ratio of estimated incident solar radiation to cloud free solar radiation during daylight hours using the regression relationship developed by Davis (1996).

Meteorological data from both PRISM and NLDAS were used to develop hourly weather forcing series for the full simulation period for both models. The basic overview of each meteorological input, data source, and processing notes are provided in Table 1 and discussed in more detail in the following sections. Python scripts developed by Tetra Tech were used to download, extract, and process PRISM and NLDAS data for the grids intersecting the watershed. Data from the grids were processed and aggregated by weather zone.

Table 1. Summary of HSPF Meteorological Input Time Series

HSPF Model Input	Description (units)	Parameter Source	Base Data Series Number (DSN)	Processing Notes
PREC	Precipitation (in)	PPT (PRISM), APCP (NLDAS)	100	Daily PRISM precipitation data are disaggregated using the random cascade method
ATEM	Air Temperature (°F)	TMP (NLDAS)	200	Hourly air temperature, used directly
SOLR	Solar Radiation (Ly)	DSWRF (NLDAS)	500	Hourly short wave radiation, used directly
CLOU	Cloud Cover (tenths; 0-10)	DSWRF (NLDAS)	400	Inferred from hourly short wave radiation at 2 meters, and estimated cloudless-sky short wave radiation
DEWP	Dew Point Temperature (°F)	SPFH, PRES, TMP (NLDAS)	300	Function of hourly specific humidity, air pressure, and air temperature
WIND	Wind Travel (mi)	UGRD, VRGD (NLDAS)	600	Net wind travel from component vectors
PEVT	Potential Evapotranspiration (in)	DSWRF, TMP, WIND, SPFH, PRES (NLDAS)	700	Computed from solar radiation, air temperature, wind travel, and dew point temperature

1.1.1 Precipitation

PRISM has been shown to better represent precipitation than WorldClim and Daymet, which are other publicly available gridded meteorological products (Daly et al., 2008). Because of this PRISM was used to generate precipitation (PREC) series for the HSPF model. Daily precipitation series for grid cells aligning with the drainage area were retrieved from the PRISM database using Python scripts.

The HSPF model requires hourly precipitation, but direct observations of hourly precipitation are not available through PRISM. We used a statistical approach to develop estimates of hourly precipitation. Specifically, daily precipitation records for each of the model weather zones were disaggregated to an hourly time step using the random multiplicative cascade model, based on fractal theory. A Python code to implement the random multiplicative cascade method is available as AMBHAS rain_disagg.py at (https://github.com/neel9102/ambhas/blob/master/ambhas/rain_disagg.py). This method distributes mass of the initial time interval successively over regular subdivisions as a fractal process (usually subdivided by factors or two). The initial time scale rainfall depth is multiplied by a cascade generator at each subdivision (multiplied by more cascade generators as further subdivisions occur). The distribution of the scaling generator(s) determine the scaling properties of the rainfall. Therefore, the main goal in the random cascade is to determine the distribution of the cascade generator. As explained in Kumar et al. (2009), this method first aggregates the provided time series by a factor of two, up to five times, to generate the moments, varying from zero to five. For example, the provided daily rainfall time series is aggregated in series to a two, four, eight, sixteen, and thirty two-day time step. Sample moments are defined as:

$$M_n(q) = \sum_{i=1}^{b^n} \mu_n^q(\Delta_n^i)$$

Here q is the moment order, the ith interval after n level of subdivision is shown as Δ_n^i (i=1,…,b_n intervals at level n).

The slope of the scaling relationship is called the Mandelbrot-Kahane-Peyriere (MKP) function (Mandelbrot, 1974; Kahane and Peyriere, 1976), calculated as:

$$X_b(q) = 1 - q + \log_b E(W^q)$$

The MKP contains information about the cascade generator (W) and, therefore, contains information about the scaling properties of the rainfall.

The slope of the sample moment is defined as:

$$\tau(q) = \lim_{\lambda_n \to 0} \frac{\log M_n(q)}{-\log \lambda_n}$$

Here λ_n is the dimensionless spatial scale defined as $\lambda_n = b^{-n}$.

$\tau(q)$ is used to approximate $X_b(q)$, and thus the distribution of a cascade generator can determined by fitting tau as a function of sample moments, and then using the probability density function of that distribution. The cascade generator is then able to get an hourly timestep rainfall from a daily timestep rainfall.

The mass in “subcube” Δ_n^i (or ith interval in the nth subdivision) is defined as:

$$\mu_n(\Delta_n^i) = R_0 \lambda_n \prod_{i=1}^{n} W_j(i)$$

Where R_0 is the initial rainfall depth at level n=0.

The fractal approach produces realistic sub-daily precipitation patterns, but does not guarantee that estimated peak rainfall is matched in time with actual rainfall. This can create discrepancies between observed and simulated rainfall-runoff processes; however, a similar problem is also present when disaggregating daily total rainfall based on patterns observed outside the watershed.

1.1.2 Air Temperature

NLDAS directly provides estimation of hourly air temperature (TMP) at 2 meters above the surface. NLDAS reports temperatures in Kelvin and data retrieved for the HSPF model were converted to degrees Fahrenheit. The hourly temperature series are used to define daily minimum (TMIN) and maximum (TMAX) temperatures to support subsequent calculations.

1.1.3 Solar Radiation

NLDAS directly provides estimation of hourly shortwave solar radiation (DSWRF) at 2 meters above the surface (W/m^2) corrected for atmospheric conditions. The solar radiation data were converted to HSPF compatible units (Langleys).

1.1.4 Wind

NLDAS provides estimation of directional hourly wind speeds (m/s) at 10 meters above land surface as northing and easting vector components (UGRD and VGRD), which are used to compute total wind travel distance for the hour ($\sqrt{UGRD^2 + VGRD^2}$). The 10-meter wind travel is scaled to 2 meters above the ground using a wind speed power law:

$$W_{2-meters} = \left(\frac{z}{z_a}\right)^r \times W_{10-meters}, 0 \le z \le z_a$$

where, $W_{10-meters}$ is the wind travel at 10 meters above the ground in m/s, $\frac{z}{z_a}$ is an elevation ratio (0.2), r is a surface roughness exponent (0.143 for agricultural land with some houses, shrubs, and plants) and $W_{2-meters}$ is wind travel at 2 meters above the ground in m. Wind travel is then converted to miles for HSPF.

1.1.5 Cloud Cover

Cloud cover is not reported by NLDAS; however, it can be back-calculated during daylight hours from the relationship of Davis (1996) describing the ratio of ambient solar radiation at the surface (E_{surf}) to radiation from a cloudless sky ($E_{cloudless}$):

$$\frac{E_{surf}}{E_{cloudless}} = 1 - 0.6740\, C^{2.854}$$

where, *C* is the fractional cloud cover and E_{surf} is obtained from NLDAS. $E_{cloudless}$ is a function of latitude and time of year and is calculated using an approach from Baig et al. (1991). HSPF requires cloud cover inputs to be specified as tenths, ranging from 0 to 10.

Baig et al. (1991) use a Gaussian distribution centered at solar noon, or local time t = 12:00 to estimate the fraction of daily solar radiation at different times of day as r_t. Their model is similar to that of Jain (1984), but with an additional correction factor.

$$r_t = \frac{1}{2\sigma\sqrt{2\pi}}\left\{\exp\left(-\frac{(t-12)^2}{2\sigma^2}\right) + \cos\left(180°\frac{(t-12)}{(S_0-1)}\right)\right\}$$

S_0 is the length of day in hours which is obtained from two standard NOAA equations, which are similarly implemented in the QUAL2Kw model code:

$$\delta = 23.45 * \sin\left(\frac{360°(n+284)}{365}\right)$$

$$S_0 = \frac{2}{15}\arccos(-\tan(\varphi)\tan(\delta))$$

Here, δ is the declination angle, n is day of year (n=1 for Jan 1), and φ is latitude. Note that for calculation purposes, 180°, 360°, and φ and δ in tan(φ)tan(δ) should be converted to radians and the output from arccos should be converted to degrees.

σ is the standard deviation of the Gaussian distribution consistent with the day length pattern and is shown by Baig et al. (1991) to be equal to:

$$\sigma = \frac{1}{r_{t=12}\sqrt{2\pi}}$$

Baig et al. (1991) do note that the slight and occasional misfit between experimental data and theoretical values in their work can be improved if one uses data averaged over many years instead of single day data. With this is mind, the calculation of σ was done for each individual day over the period of record and then averaged per day of year to capture longer term averages while maintaining seasonal differences. The "experimental" or observed data used to obtain $r_{t=12}$ and subsequently σ was NLDAS data at daily and disaggregated to hourly timescales.

Once r_t is calculated for each hour of the entire period of interest, those fractions are applied to a daily time series of cloudless solar radiation using the methods to calculate ($E_{surf}/E_{cloudless}$), which is then used to calculate cloud cover via Davis (1996) above.

1.1.6 Dew Point Temperature

NLDAS does not provide dew point temperature, but does provide specific humidity, air temperature, and air pressure, which can be used to estimate dew point temperature. Dew point temperature was calculated following the approach presented in Chapter 4 (Water Vapor) in Stull, R., 2017: *Practical Meteorology: An Algebra-based Survey of Atmospheric Science -version 1.02b*. Univ. of British Columbia. This book is freely available online under a Creative Commons license at https://www.eoas.ubc.ca/books/Practical_Meteorology/. The Stull, R., 2017 method was applied to derive dew point temperature for the full simulation period:

First, the mixing ratio (r) is calculated from specific humidity $(q; unitless)$:

$$r = \frac{q}{(1-q)}$$

Because specific humidity becomes extremely low under cold, dry conditions it is important to maintain full precision in this calculation. Then actual vapor pressure (e) is derived from atmospheric pressure $(P; in\ KPa)$:

$$e = \frac{r}{(0.622 + r)}P$$

Dew point temperature $(D; Kelvin)$ is then calculated with an assumed reference vapor pressure $(e_o = 0.6113; kPa)$:

$$D = \frac{1}{\left(\frac{1}{273.15} - 0.0001844\right)\ln(\frac{e}{e_o})}$$

Lastly, dew point temperature is converted to degrees Fahrenheit for HSPF. In general dew point temperature cannot exceed air temperature, except during transient supersaturated conditions; therefore, the dew point temperature is set equal to the air temperature when the calculated dew point temperature is higher than the air temperature, which is a reasonable approximation for use in a watershed model that doesn't explicitly consider fog.

1.1.7 Potential Evapotranspiration (PET)

NLDAS provides an estimate of potential evapotranspiration (as PEVAP) calculated by the modified Penman method of Mahrt and Ek (1984). However, this is not a focus of NLDAS because NLDAS is designed to run a variety of Land Surface Models (LSMs; such as the NOAH model), most of which generate their own energy-based ET estimates. PEVAP is provided only because one of the LSMs (SAC-SMA, the Sacramento soil moisture accounting model) does require it as an input (http://ldas.gsfc.nasa.gov/nldas/NLDAS2forcing.php; accessed 9/2/2015). On investigation it turns out that the PEVAP that NLDAS reports is the PEVAP calculated by the North American Regional Reanalysis (NARR) dataset (Mesinger, et al., 2006). NARR is documented to have a large positive bias in the estimation of shortwave radiation (Xia, et al., 2012). NLDAS corrects the NARR shortwave radiation estimates using satellite-based estimates, but the PEVAP estimate ported from NARR is not corrected. In addition, NARR is at a coarser spatial scale than NLDAS and the PET estimates may be off in areas with strong edge effects.

Sensitivity analyses conducted by Tetra Tech in other Minnesota HSPF models concluded that the NLDAS/NARR reported PEVAP values were unreasonably high in some areas (due to the shortwave radiation bias) and exhibited too great a variation from the coastline to the interior (in part this is likely due to the downscaling of coarser-grid NARR data). Further, the PEVAP time series provided by NLDAS did not match the seasonal pattern of Penman Pan ET calculated at individual weather stations.

Based on these observations it is desirable to recalculate PET, rather than using the PEVAP reported by NLDAS/NARR. Therefore, Penman Pan PET was calculated for each model weather zone using inputs from NLDAS (including the corrected shortwave radiation) and applying the standard approach from BASINS that has been implemented in most other Minnesota HSPF models.
The PET time series requires dew point temperature as an input variable and because an alternative method was used to estimate dew point temperature for the full simulation period, PET was also updated for the full simulation period.

1.2 POINT SOURCES

Permitted point sources are present in the Cottonwood River and Redwood River watersheds and all were represented in the existing HSPF model (RESPEC 2012; 2014a; 2014b). A variety of municipal and industrial sources discharge to surface waters in the two watersheds (Table 2). All of the municipal dischargers are considered minor point sources, except for Marshall WWTP. ADM Corn Processing is an industrial facility, but its discharge is process wastewater and is assumed to behave like a Class A WWTP facility.

Inputs to the model include flow, heat content, and loads for DO, CBODu, nitrate, ammonia, refractory organic N, orthophosphate, refractory organic P, and sediment. Time series inputs to the model are represented on a daily basis, and conversion factors/statements are used within the model to convert daily rates to hourly rates, which match the model time-step.

To perform the time extension, point source data through 2017 were needed. MPCA provided data for Minnesota facilities from three different sources – a monthly Tempo database generally covering 1998 through 2017, a daily Tempo database generally beginning sometime in 2013 and ending in 2017, and the OnBase system to cover the remaining daily time period of 2012 - 2013.

In many cases, monitoring data were not available at a particular facility for a given parameter. This was frequently the case for nitrate and ammonia, and no data were available allowing for the calculation or estimation of refractory organic N and refractory organic P. When this occurred, a representative concentration was assumed. MPCA has developed a series of recommended surrogate values (Table 3), primarily from Weiss (2012), Helgen (1992), and a summary of wastewater effluent data provided in spreadsheet form by Dr. Ronald Jacobson (MPCA; provided in support of the 2002 updates to the Minnesota River models). Using the surrogate values requires knowing (or assuming) the type of facility. MPCA provided updated facility type information for Minnesota, which is shown in Table 2. The model input file was configured to calculate the product of the point source flow time series and the representative concentration (with appropriate conversion factor) to input pollutant load. The model was already configured this way prior to this time extension project. However, a review of the concentration assumptions in the original model found that in many cases the wrong facility type was assumed (likely due to facility type information not being available at the time of model development). When this occurred, the model input file was updated to reflect the revised concentration assumption.

As stated previously, a combination of daily and monthly point source monitoring data were available to specify the daily input time series to the models for the extension period, 2012 – 2017. Nearly all facilities had some months with complete daily flow records, and other months with only monthly flow volumes. This was the case for both continuous discharging facilities and intermittent discharging facilities (namely stabilization ponds). When daily flow data were available in a given calendar month, they were used directly in the model input time series. When daily flow data were not available, the monthly reported total flow volume was used, and distributed equally throughout the month (by dividing by the number of days in the month). Similarly, daily pollutant concentrations (and temperatures where monitored) were used when available; otherwise reported monthly average values were used. The product of flow and concentration was then used to calculate daily loads, with appropriate conversion factors.

Heat input time series were calculated in the original model using a daily varying water temperature obtained from a facility in the Sauk River Watershed, adjusted for differences between the Sauk and the Minnesota River (RESPEC, 2014a). Lacking recent monitoring data from the facility and details regarding the temperature adjustment, we instead calculated a mean monthly characteristic water temperature from the original model time series from 1995 – 2012 using temperature back-calculated from the BTU loads in the time series. We then used the product of flow and corresponding monthly temperature to calculate BTU load for the time extension period.

The HSPF model represents a single form of carbonaceous biochemical oxygen demand (CBOD), which should correspond to the CBOD that decays over a representative residence time within a reach. This means that a long-term or ultimate value of CBOD (CBODu) should be used, and both models were already configured with CBODu as the time series input. The point source monitoring data, however, report only 5-day CBOD (CBOD5). BOD decay factors impact the ratio of CBODu to CBOD5, which is important because almost all available data for BOD is in the form of CBOD5 (at 20°C). Literature in this area suggests that a decay factor of 0.2 1/day is appropriate for treated effluent at 20 degrees Celsius, yielding a ratio of 1.58 (Table 6.5 in Thomann and Mueller, 1987). The use of the ratio of 1.58 is justified in the literature. Jayawardena (2014) states that 0.1 – 0.3 are typical decay rates for effluent that has gone through primary and secondary treatment. Lung (2001) states that 0.2 1/day is an appropriate value for BOD decay for wastewater effluent following secondary treatment, as does Sullivan et al. (2010). CBOD5 point source data was multiplied by this ratio prior to entry in the updated (2013 – 2017) model input time series. However, no changes were made to the CBODu time series prior to 2013. The ratio used in the original models to convert CBOD5 to CBODu is not documented in RESPEC 2014a, but comments in the model input file suggest that a ratio of 2.54 was used (corresponding to an assumed decay rate of 0.1 1/day).

HSPF considers both labile and refractory forms of organic nutrients. The refractory (non-decaying) portions are represented as separate state variables, but the labile portions are "hidden" with CBODu based on stoichiometric ratios for organic matter. The labile portions must be accounted for before calculating the refractory organic nutrient loads, which are model inputs. Refractory organic N is calculated as follows:

Refractory Organic N = max {Organic N – CVON x CBODu, 0}

where CVON is the assumed mass of labile organic N per mass of CBODu (equal to 0.052938 using default HSPF assumptions). A unique refractory organic N concentration was calculated for each facility using a) surrogate organic N concentrations by facility type from Table 3, and b) the mean of the monthly CBOD5 concentration reported in the Tempo database from 1999 – 2017, multiplied by the CBODu/CBOD5 ratio of 1.58. The refractory organic N concentrations were then used with a multiplier on the flow time series in the model input file to calculate load.

TP is reported by all the facilities in Cottonwood and Redwood, and orthophosphate is assumed to be 0.723 x TP (based on the MPCA default assumption). Organic P is assumed to be the remaining 0.277 of TP. Refractory organic P is calculated as follows:

Refractory Organic P = max {0.277 x Total P – CVOP x CBODu, 0}

where CVOP is the assumed mass of labile organic P per mass of CBODu (equal to 0.007326 using default HSPF assumptions). A unique refractory organic P concentration was calculated for each facility using a) the mean of the monthly TP concentration reported in the Tempo database from 1999 – 2017, multiplied by 0.277, and b) the mean of the monthly CBOD5 concentration reported in the Tempo database from 1999 – 2017, multiplied by the CBODu/CBOD5 ratio of 1.58. The refractory organic P concentrations were then used with a multiplier on the flow time series in the model input file to calculate load.

Two issues with the original point source time series were identified while performing the time extension update. First, we learned that the City of Storden operated a continuously discharging mechanical WWTP until October 2004, then a controlled discharge stabilization pond WWTP beginning in November 2004 through present. Prior to November 2004, daily influent flow was used as a proxy for effluent flow in the model point source time series. However, the change to operations was not accounted for, and thus daily influent flow was used through 2012 in the original model (rather than sporadic outflow from the stabilization pond). As a result, the model flow time series was updated to reflect the change in 2004 from continuous to occasional outflow per the point source monitoring data (note that heat is the only other model input time series used for Storden, and we updated it per the procedure discussed previously). Second, we determined that all the heat time series used in the original models were calculated incorrectly. The formula for BTU load (relative to freezing) is as follows:

Flow (MGD) x [Temperature (ºF) – 32] x 1.27×10^{-7} (BTU/lb/ºF) = BTU (1/day)

The original calculations failed to subtract 32 from the water temperature, resulting in BTU loads corresponding to water temperatures in the high 80ºF to low 90ºF range, rather than high 50ºF to low 60ºF range. We corrected all the heat model input time series for all the facilities for the entire period of record.

Table 2. Summary of Point Sources

Watershed	Facility Name	Permit ID	Facility Type	Average Flow (MG/year)
Cottonwood River	ACME Brick Great Lakes Plant	MN0061646	NCCW	41.3
	August Schell Brewing Co	MN0022284	NCCW	5.4
	Balaton WWTP	MN0020559	Class D	32.3
	Clements WWTP	MNG580094	Class D	4.2
	Del Monte Foods Inc - Sleepy Eye Plant 114 (SD001)	MN0001171	NCCW	49.9
	Del Monte Foods Inc - Sleepy Eye Plant 114 (SD006)	MN0001171	NCCW	2.4
	Garvin WWTP	MNG580101	Class D	5.0
	Lamberton WWTP	MNG580100	Class D	33.8
	Lucan WWTP	MNG580112	Class D	5.6
	Revere WWTP	MNG580114	Class D	3.3
	Sanborn WWTP	MNG580115	Class D	9.8
	Sleepy Eye WWTP	MNG580041	Class D	155.2
	Springfield WWTP	MN0024953	Class B	124.4
	Storden WWTP	MNG580106	Class D	8.1
	Tracy WWTP (SD001)	MN0021725	Class D	36.8
	Tracy WWTP (SD002)	MN0021725	Class D	38.4
	Wabasso WWTP	MN0025151	Class C	27.1
	Walnut Grove WWTP	MN0021776	Class B	39.4
	Wanda WWTP	MNG580126	Class D	9.2
	Westbrook WWTP	MNG580127	Class D	33.5

Watershed	Facility Name	Permit ID	Facility Type	Average Flow (MG/year)
Redwood River	ADM Corn Processing - Marshall	MN0057037	Class A	501.6
	Ghent WWTP	MNG580121	Class D	7.7
	Lynd WWTP	MNG580030	Class D	8.2
	Marshall WWTP	MN0022179	Class A	955.2
	Milroy WWTP	MNG580124	Class D	5.0
	Russell WWTP	MNG580062	Class D	19.3
	Ruthton WWTP	MNG580105	Class D	18.1
	Tyler WWTP	MNG580116	Class D	47.5
	Vesta WWTP	MNG580043	Class D	6.0

Facility type descriptions: Class A – municipal, large mechanical, Class B – municipal, medium mechanical, Class C – municipal, small mechanical/pond mix; Class D – municipal, mostly small ponds, NCCW – non-contact cooling water.

Table 3. Surrogate assumptions by facility type (mg/L)

Discharge Type	CBOD5	DO	NO_3-N	NH_4-N	Org-N
Class A municipal - large mechanical	3	5	15	3	1
Class B municipal - medium mechanical	12	5	10	4	3
Class C municipal- small mechanical/pond mix	6	5	7	1	2
Class D municipal - mostly small ponds	6	5	3	1	2
Non-contact cooling	0.5	7	1	2	1

1.3 ATMOSPHERIC DEPOSITION

The original Cottonwood and Redwood watersheds HSPF models included wet and dry deposition of ammonia-N and nitrate-N to pervious surfaces, impervious surfaces, and water bodies that were extended through 2017. Wet deposition concentrations of ammonia and nitrate N (as mg-N/L) from seasonal data recorded at NADP station MN27 (Lamberton), which is located southeast of the modeled watersheds, were applied for the extension period. Dry deposition rates of ammonia and nitrate N (as lb/ac) were taken from CASTNET monitoring. There are not CASTNET stations within or particularly close to the watersheds studied here, so data from the Perkinstown, WI (PRK134) station were applied. Reported data were converted from molar units to mass or mass-based concentration as nitrogen to generate the input time series. The entire time series for both wet and dry deposition of ammonia and nitrate N were updated and replaced (i.e., beginning in 1995), for a number of reasons. An examination of wet deposition values in the original model revealed that source monitoring stations changed during the modeling time period (i.e., the same station was not used from 1995 – 2012). For dry deposition, it appeared that the previous time series did not include the molar conversion to nitrogen mass. In addition, all the historic dry deposition values changed somewhat, likely due to advances in the modeling used to estimate dry deposition flux.

In addition to the extension and replacement of the wet and dry deposition series for N species, representation of both dry and wet deposition of phosphorus to surface water were maintained in the model. These are represented as constant monthly values through the MONTH-DATA block. The values were interpolated from Twaroski et al. (2007); for both Cottonwood and Redwood, the values were 0.27 kg/ha/yr for PO_4 dry deposition flux and 0.024 mg/L for PO_4 wet deposition concentration. Atmospheric deposition of phosphorus to the uplands is not included because it is assumed to be implicit in the sediment potency representation of pervious land loading and the buildup/washoff representation of impervious land loading of phosphorus.

2.0 HYDROLOGY PERFORMANCE REVIEW

The hydrology calibration was reviewed following the updates to the Cottonwood and Redwood HSPF models. The performance was evaluated based on relative flow volume error (assessed for annual, high, low, and seasonal flows), daily and monthly Nash-Sutcliffe Efficiency, and visual plots comparing simulated and observed flows (e.g., scatterplots of simulated versus observed monthly flow volumes). The updates to the meteorological time series (i.e., converting from time series derived from station-based data to time series derived from gridded weather data) did not significantly alter the performance of the models described in the previous hydrology recalibration report (Tetra Tech, 2015). However, a few coarse revisions to the hydrology parameters were implemented following the updates to the input time series. These adjustments included refining potential evapotranspiration factors, baseflow evapotranspiration, snow catch factors, infiltration rates, and upper soil zone nominal storage parameters.

Summary metrics are provided for the updated models in Table 4 and Table 5 and for the models prior to the updates following the 2015 hydrology recalibration in Table 6 and Table 7 (Tetra Tech, 2015). Errors in total streamflow volume were reduced at most sites in both watersheds following the input time series and parameter updates. The fraction of annual precipitation that evaporates or transpires remained about the same as the previous iterations of the models, about 79% for Cottonwood and 80% for Redwood. However, the representation of the 50% lowest flows were generally not improved and tend to be overestimated by the Cottonwood model; low flows tend to occur in the late fall and early winter when precipitation is often in the form of snow. Future recalibration efforts for both models should switch the snow accumulation and melt method from the degree-day method to the full energy balance method as recommended by MPCA and then the snow simulation should be recalibrated using gridded snow depth and/or snow water equivalent data. Daily and monthly NSEs were also improved at most tributary sites in the Cottonwood and Redwood watersheds. NSEs weren't improved at the most downstream gage in the Cottonwood watershed, although total, low and high flow volume errors were consistently reduced at that location (Cottonwood River near New Ulm).

Table 4. Summary Metrics for the Cottonwood HSPF Model Hydrology Performance, 1996-2012

Site	HSPF Reach	Error in Total Volume (%)	Error in 50% Low Flows (%)	Error in 10% High Flows (%)	Daily NSE	Monthly NSE
Plum Creek near Walnut Grove, CSAH10 (MN29048001)	189	-0.07	57.0	-10.5	0.808	0.858
Cottonwood River near Lamberton, US14 (MN29062002)	230	-10.6	34.4	-13.5	0.801	0.881
Cottonwood River near Springfield, CR2 (MN29015001)	330	5.03	42.0	2.61	0.833	0.821
Cottonwood River near Leavenworth, CR8 (MN29022001)	370	3.11	41.9	-3.55	0.857	0.875
Sleepy Eye Creek near Cobden, CR8 (MN29011001)	407	2.04	81.1	-9.93	0.825	0.874
Cottonwood River near New Ulm, MN (MN29001001)	490	-0.97	-3.19	-5.25	0.766	0.860

Table 5. Summary Metrics for the Redwood HSPF Model Hydrology Performance, 1996-2012

Site	HSPF Reach	Error in Total Volume (%)	Error in 50% Low Flows (%)	Error in 10% High Flows (%)	Daily NSE	Monthly NSE
Redwood River at Russell, CR15 (MN27043001)	190	-1.74	20.9	-10.9	0.802	0.863
Redwood River near Marshall, MN (MN27043002)	210	-2.36	-24.8	-3.77	0.801	0.880
Threemile Creek near Green Valley, CR67 (MN27039001)	313	8.81	10.1	-2.52	0.690	0.753
Clear Creek near Seaforth, CR56 (MN27030001)	443	-2.78	24.4	-11.7	0.791	0.836
Redwood River near Redwood Falls, MN (MN27035001)	450	3.98	-9.63	5.36	0.769	0.863

Table 6. Summary Metrics for the Cottonwood HSPF Model Hydrology Performance – Previously Recalibrated Model, 1996-2012 (Tetra Tech, 2015)

Site	HSPF Reach	Error in Total Volume (%)	Error in 50% Low Flows (%)	Error in 10% High Flows (%)	Daily NSE	Monthly NSE
Plum Creek near Walnut Grove, CSAH10 (MN29048001)	189	3.79	86.1	-9.11	0.866	0.904
Cottonwood River near Lamberton, US14 (MN29062002)	230	-15.9	45.7	-18.1	0.719	0.848
Cottonwood River near Springfield, CR2 (MN29015001)	330	-0.39	42.1	0.38	0.752	0.671
Cottonwood River near Leavenworth, CR8 (MN29022001)	370	-7.34	38.6	-11.4	0.839	0.838
Sleepy Eye Creek near Cobden, CR8 (MN29011001)	407	-8.41	58.9	-14.5	0.757	0.788
Cottonwood River near New Ulm, MN (MN29001001)	490	-4.15	7.77	-7.76	0.815	0.888

Table 7. Summary Metrics for the Redwood HSPF Model Hydrology Performance – Previously Recalibrated Model, 1996-2012 (Tetra Tech, 2015)

Site	HSPF Reach	Error in Total Volume (%)	Error in 50% Low Flows (%)	Error in 10% High Flows (%)	Daily NSE	Monthly NSE
Redwood River at Russell, CR15 (MN27043001)	190	-5.99	7.54	-10.0	0.714	0.851
Redwood River near Marshall, MN (MN27043002)	210	-4.19	-8.45	-5.96	0.772	0.876
Threemile Creek near Green Valley, CR67 (MN27039001)	313	5.56	28.3	-6.41	0.533	0.664
Clear Creek near Seaforth, CR56 (MN27030001)	443	-9.86	8.16	-9.39	0.623	0.568
Redwood River near Redwood Falls, MN (MN27035001)	450	1.75	9.63	-0.89	0.789	0.860

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Appendix D – Redwood River Watershed Impairments Covered by other TMDLs Supporting

Table D-1. Impaired waterbodies in the Redwood River Watershed addressed in previous TMDL reports.

Affected use: Pollutant/ Stressor	Reach ID 07020006 -	Reach/Lake name	Reach description	TMDL Report
Aquatic Life: Turbidity/TSS	502	Redwood River	T111 R42W S33, west line to Three Mile Creek	*Redwood River Watershed TMDL Report* (MPCA 2023)
	503	Redwood River	Three Mile Creek to Clear Creek	
	509	Redwood River	Clear Creek to Redwood Lake	
	510	Redwood River	Coon Creek to T110 R42W S20, north line	
	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)	
	567 & 568	Clear Creek	-95.323 44.466 to Redwood River	
Aquatic Life: TSS	501	Redwood River	Ramsey Creek to Minnesota River	*Minnesota River and Greater Blue Earth River Basin TSS TMDL Study* (MPCA 2020)
	506	Clear Creek	Headwaters to Redwood River	
Aquatic Recreation: Fecal Coliform	501	Redwood River	Ramsey Creek to MN River	*Redwood River Fecal Coliform TMDL Report* (RCRCA 2013)
	509	Redwood River	Clear Creek to Redwood Lake	*Redwood River Watershed TMDL Report* (MPCA 2023)
Aquatic Recreation: Bacteria (Fecal Coliform, *E. coli*)	510	Redwood River	Coon Creek to T110 R42W S20, north line	
	521	Ramsey Creek	T113 R36W S35, west line to Redwood River	
Aquatic Recreation: Fecal Coliform Aquatic Consumption: Mercury in Fish Tissue	502A	Redwood River	T111 R42W S33 west line to Three Mile Creek	*Redwood River Fecal Coliform TMDL Report* (RCRCA 2013) *Minnesota Statewide Mercury TMDL* (MPCA 2007)

Affected use: Pollutant/ Stressor	Reach ID 07020006 -	Reach/Lake name	Reach description	TMDL Report
Aquatic Recreation: Fecal Coliform Aquatic Consumption: Mercury in Fish Tissue Aquatic Consumption: Mercury in Fish Tissue	502B	Redwood River	T111 R42W S33 west line to Three Mile Creek (excluding and above the city of Marshall)	*Redwood River Fecal Coliform TMDL Report* (RCRCA 2013) *Minnesota Statewide Mercury TMDL* (MPCA 2007) *Minnesota Statewide Mercury TMDL* (MPCA 2007)
	504	Three Mile Creek	Headwaters to Redwood River	
	505	Redwood River	Headwaters to Coon Creek	
	512	Tyler Creek	Headwaters to Redwood River, a limited resource value water	
	511	Coon Creek	Lake Benton to Redwood River	
	505	Redwood River	Headwaters to Coon Creek	
	510	Redwood River	Coon Creek to T110 R42W S32 east line	
	513	Redwood River	T110 R42W S17, south link to T111 R42W S32 east line	
	503	Redwood River	Three Mile Creek to Clear Creek	
Aquatic Consumption: Mercury in Fish Tissue	509	Redwood River	Clear Creek to Redwood Lake	*Minnesota Statewide Mercury TMDL* (MPCA 2007)
	501	Redwood River	Ramsey Creek to Minnesota River	
Aquatic Consumption, Life and Recreation: Chloride	502	Redwood River	T111 R42W S33, west line to Three Mile Creek	*Redwood River Watershed TMDL Report* (MPCA 2023)
Aquatic Recreation: Lake Nutrients	41-0043-00	Benton	T110 N. R45 W.	*Redwood River Watershed TMDL Report* (MPCA 2023)
	41-0021-01	Dead Coon (Main Lake)	T110 N. R44 W.	
	42-0093-00	Goose	Sec. 32, T111 N., R43 W.	
	42-0002-00	School Grove	Sec. 36, T 113 N., R36 W.	
	42-0055-00	Clear	T 110 N. R 42 W.	
	42-0096-00	Island	Sec. 34, T111 N., R43 W.	

[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 proces

Appendix E – CAFO List and Watershed Summary

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

HUC-10 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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	081-87446	17	Y
	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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	101-108020	120	N
	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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	081-87313	290	N
	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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	083-63768	82	N
	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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	083-61751	990	N
	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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	083-106760	650	N
	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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	127-115816	190	N
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

HUC-10 Watershed	Reg Number	Animal Unit (AU) Count	Within Shoreland
	127-50004	800	N
	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.