Watershed

December 2022

# Cottonwood River Watershed Total Maximum Daily Load Report

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

MINNESOTA POLLUTION CONTROL AGENCY

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# Acronyms

| | |
|---|---|
| 1W1P | One Watershed, One Plan |
| AF | Anoxic factor |
| AFO | Animal Feeding Operation |
| AU | animal unit |
| BMP | best management practice |
| BWSR | Board of Water and Soil Resources |
| CAFO | Concentrated Animal Feeding Operation |
| cfu | colony-forming unit |
| chl-*a* | chlorophyll-a |
| CLP | curly-leaf pondweed |
| CREP | Conservation Reserve Enhancement Program |
| CRP | Conservation Reserve Program |
| DEM | Digital Elevation Model |
| DO | dissolved oxygen |
| DMR | discharge monitoring report |
| DNR | Minnesota Department of Natural Resources |
| *E. coli* | Escherichia coli |
| EPA | U.S. Environmental Protection Agency |
| FTPGW | fail to protect groundwater |
| HSPF | Hydrologic Simulation Program-Fortran |
| HUC | Hydrologic Unit Code |
| IBI | Index of Biotic Integrity |
| ITPHS | imminent threat to public health and safety |
| IWM | intensive watershed monitoring |
| km2 | square kilometer |
| LA | load allocation |
| Lb | pound |
| lb/yr | pounds per year |
| LDC | Load Duration Curve |
| LGU | Local Government Unit |

| | |
|---|---|
| LiDAR | Light Detection and Ranging |
| LWG | Local Work Group |
| m | meter |
| MAWQCP | Minnesota Agricultural Water Quality Certification Program |
| MDA | Minnesota Department of Agriculture |
| MDH | Minnesota Department of Health |
| mg/L | milligrams per liter |
| mL | milliliter |
| MMP | Manure Management Plan |
| MOS | Margin of Safety |
| MPCA | Minnesota Pollution Control Agency |
| MS4 | Municipal Separate Storm Sewer System |
| NLCD | National Land Cover Database |
| NMI | Nutrient Management Initiative |
| NPDES | National Pollutant Discharge Elimination System |
| NRCS | Natural Resources Conservation Service |
| NTU | nephelometric turbidity units |
| PFA | Public Facilities Authority |
| PWP | Permanent Wetland Preserve |
| RCRCA | Redwood Cottonwood River Control Area |
| RIM | Reinvest in Minnesota |
| RR | release rate |
| S-tube | Secchi tube |
| SAV | submerged aquatic vegetation |
| SDS | State Disposal System |
| SID | Stressor Identification |
| SONAR | Statement of Need and Reasonableness |
| SRO | surface runoff |
| SSTS | Subsurface Sewage Treatment Systems |
| SWCD | Soil and Water Conservation District |
| SWPPP | Stormwater Pollution Prevention Plan |

| | |
|---|---|
| TALU | tiered aquatic life uses |
| TMDL | total maximum daily load |
| TP | total phosphorus |
| TSS | total suspended solids |
| µg/L | microgram per liter |
| WASCOB | Water and Sediment Control Basin |
| WCBP | Western Cornbelt Plain |
| WLA | wasteload allocation |
| WRAPS | Watershed Restoration and Protection Strategy |
| WRP | Wetland Reserve Program |
| WWTP | wastewater treatment plant |

# Executive Summary

***Cottonwood River Watershed Approach***

Intensive watershed monitoring (IWM) and stressor identification (SID) were completed between 2017 and 2020 for the Cottonwood River Watershed, which is located in the Minnesota River Basin (MPCA 2020c). Seventy river/stream reaches were assessed for their ability to support aquatic life and/or aquatic recreation. Of the assessed river/stream reaches, 19 were fully supporting of aquatic life and none fully supported aquatic recreation due to high bacterial levels. Of the 25 lakes assessed in the Cottonwood River Watershed, 5 were determined to be impaired by nutrients (total phosphorus [TP]). In addition, Double and Rock Lakes were assessed for fish Index of Biotic Integrity (IBI) and were determined to not be meeting standards (DNR 2021). Based on previous and current monitoring assessment data, there are 11 turbidity (total suspended solids [TSS]) impaired river/stream reaches, 16 bacteria impaired river/stream reaches, 26 macroinvertebrates IBI impaired river/stream reaches, and 13 fish IBI impaired river/stream reaches within the Cottonwood River Watershed. For the remainder of this Total Maximum Daily Load (TMDL) report, the river/stream reach(es) will be referred to as just "reach(es)".

***Overview of this TMDL***

A TMDL represents the total mass of a pollutant that can be assimilated by the receiving water without causing that receiving water to violate water quality standards. This TMDL is a continuation of previously completed TMDLs in the Cottonwood River Watershed that have been approved by the U.S. Environmental Protection Agency (EPA) Region 5. The Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013) was approved in January 2014. Prior to the fecal coliform TMDL, the State of Minnesota submitted a state-wide TMDL to address mercury in fish, which included nine reaches in the Cottonwood River Watershed, which was approved in March 2007 (MPCA 2007a).

This TMDL addresses 11 turbidity/TSS impaired reaches, 8 bacteria impaired reaches, and 7 nutrient impaired lakes in the Cottonwood River Watershed. Twenty-six macroinvertebrate IBI impaired reaches and 13 fish IBI impaired reaches in the Cottonwood River Watershed are not addressed in this TMDL and will be deferred because the water quality chemistry data was insufficient or because multiple stressors that cannot be quantified were identified. However, these reaches will be addressed through implementation of the Cottonwood River Watershed Restoration and Protection Strategies (WRAPS) Report and local water planning efforts. Addressing multiple impairments in this TMDL is consistent with Minnesota's Water Quality Framework that seeks to develop watershed-wide protection and restoration strategies, rather than focusing on individual reach impairments.

***Turbidity/Total Suspended Solids Impairments***

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

Hydrologic Simulation Program – Fortran (HSPF) simulated flow and TSS output were used to establish load duration curves (LDCs) for the 11 turbidity/TSS impairments covered in this TMDL. The curve displays the Class 2B TSS standard of 65 mg/L. A TMDL, which includes the wasteload allocations (WLAs), load allocations (LAs), and margin of safety (MOS), was established for five flow zones along the flow duration curve: very high, high, mid, low, and very low flow conditions. Sediment sources were assessed for the turbidity/TSS impaired reaches which indicates loading is primarily driven by near-channel sources (i.e., bed, bank, ravine erosion) and upland erosion. Implementation activities will include upland best management practices (BMPs) to reduce soil erosion in highly erodible cropland areas, and restoring and increasing water storage opportunities throughout the watershed to decrease peak discharge rates.

***Bacteria (E. coli) Impairments***

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

***Lake Nutrient Impairments***

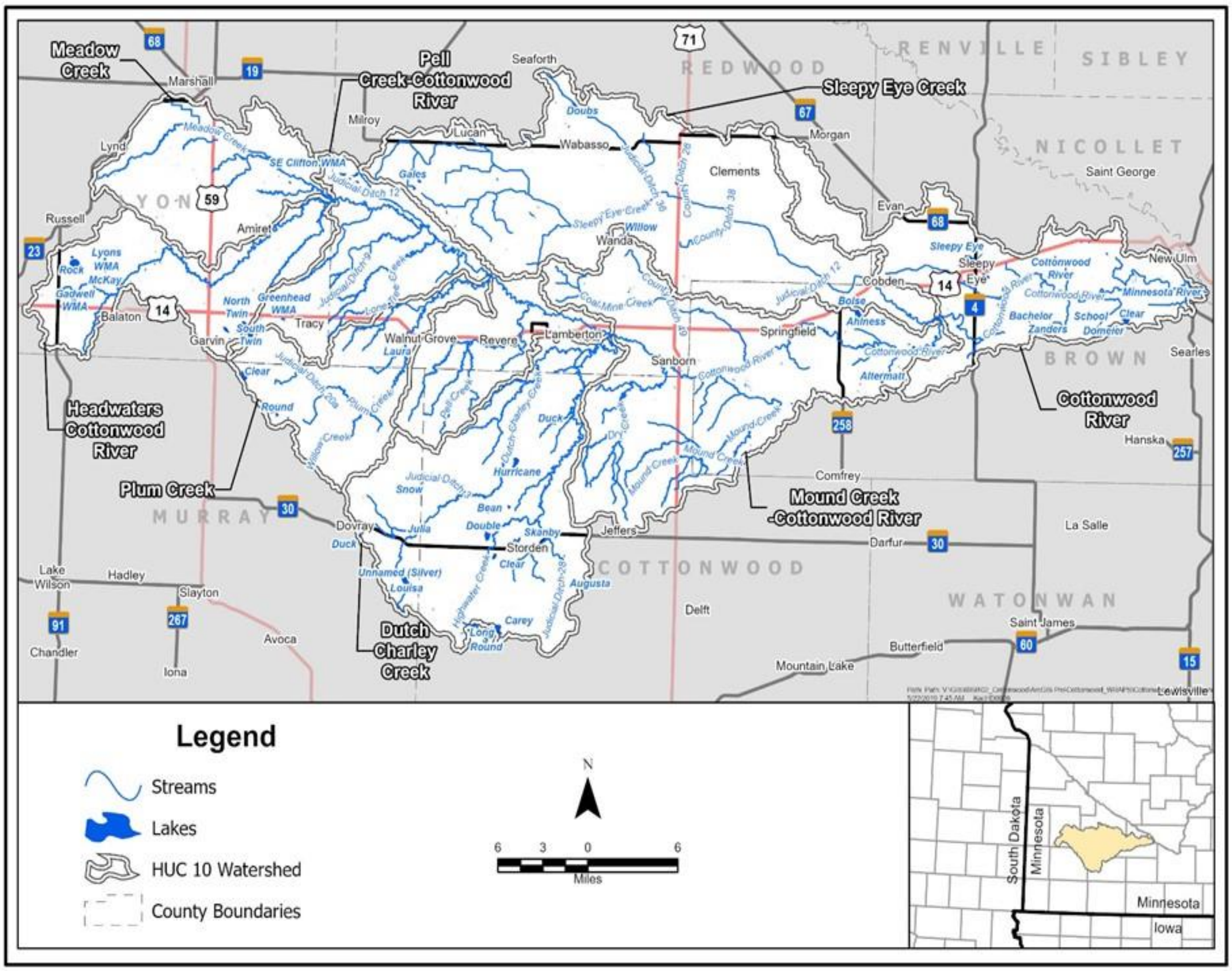
Nutrient budgets and lake response models were developed for the seven nutrient-impaired lakes in the Cottonwood River Watershed covered in this TMDL. The HSPF model was used along with in-lake monitoring data to develop nutrient budgets for each lake and set up the lake response models and TMDL equations. Pollutant source assessment for these lakes indicates all the lakes require phosphorus reductions from both internal and external (watershed) sources. For some of the lakes, internal load is a significant source of phosphorus and in-lake efforts will be important to achieve water quality standards. Watershed implementation activities will need to focus on upland BMPs to prevent phosphorus delivery to the lake. Internal load reductions will need to come from in-lake management activities such as rough fish management, alum treatment, and/or aquatic plant management. Sleepy Eye Lake (08-0045-00) was de-listed from the State’s 303(d) impaired waters list in 2020 due to improved water quality conditions since it was listed as impaired in 2002. Implementation efforts included septic upgrades, sediment control practices, education, and lake dredging. Since the de-listing occurred during the development of this TMDL study, this report does not include the results of the draft TMDL for Sleepy Eye Lake. However, the lake has been identified by local stakeholders as a high priority for protection in the Cottonwood River WRAPS Report. Additionally, some of the supporting items that were developed for the Sleepy Eye Lake draft TMDL prior to its de-listing can be found in Appendix B of this TMDL.

# 1. Project Overview

## 1.1 Purpose

This TMDL addresses 11 turbidity/TSS impairments, 8 bacteria (*E. coli*) impairments, and 7 lake nutrient (phosphorus) impairments in the Cottonwood River Watershed. The drainage areas of the impaired reaches and lakes presented in this TMDL cover portions of five counties in southwest Minnesota: Lyon, Murray, Redwood, Cottonwood, and Brown (Figure 1). The largest cities in the watershed include New Ulm (population 13,362), Marshall (population 12,432), Sleepy Eye (population 3,498), Tracy (population 2,110), and Springfield (population 1,193). Other cities/townships in the watershed include Lamberton, Walnut Grove, Westbrook, and others.

**Figure 1. Cottonwood River Watershed overview.**




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

**Table 1. List of stream and lake impairments addressed in Cottonwood River Watershed TMDL.**

| Affected use: Pollutant/ Stressor | Reach/Lake ID | Reach/Lake name | Reach/Lake description | Designated use class | Listing year | Target Start/ Completion |
|---|---|---|---|---|---|---|
| Aquatic Life: Turbidity/TSS | 07020008-502 | Cottonwood River | Headwaters to Meadow Creek | 2B | 2020 | 2019/2022 |
| | 07020008-504 | Cottonwood River | Plum Creek to Dutch Charley Creek | 2B | 2006 | |
| | 07020008-508 | Cottonwood River | Coal Mine Creek to Sleepy Eye Creek | 2B | 2006 | |
| | 07020008-509 | Cottonwood River | Sleepy Eye Creek to JD 30 | 2B | 2020 | |
| | 07020008-517 | Dutch Charley Creek | Highwater Creek to Cottonwood River | 2B | 2006 | |
| | 07020008-518 | Dutch Charley Creek | Headwaters to Highwater Creek | 2B | 2006 | |
| | 07020008-519 | Highwater Creek | Double Lake outlet to Dutch Charley Creek | 2B | 2020 | |
| | 07020008-535 | Pell Creek | Headwaters to T109 R38W S29, east line | 2B | 2010 | |
| | 07020008-599 | Sleepy Eye Creek | T109 R33W S5, west line to Cottonwood River | 2B | 2006 | |
| | 07020008-602 & 603 [1] | Plum Creek (JD 20A) | Headwaters to -95.576 44.177; -95.576 44.177 to Cottonwood River | 2B | 2006 | |
| Aquatic Recreation: *E. coli* | 07020008-502 | Cottonwood River | Headwaters to Meadow Creek | 2B | 2020 | 2019/2022 |
| | 07020008-511 | Judicial Ditch 30 | T110 R32W S31, west line to Cottonwood River | 7 | 2020 | |
| | 07020008-519 | Highwater Creek | Double Lk outlet to Dutch Charley Creek | 2B | 2020 | |
| | 07020008-520 | Dry Creek | T108 R36W S31, south line to Cottonwood River | 2B | 2020 | |
| | 07020008-521 | Mound Creek | Headwaters to Cottonwood River | 2B | 2020 | |
| | 07020008-523 | Pell Creek | T109 R37W S30, west line to Cottonwood River | 2B | 2020 | |
| | 07020008-604 | Coal Mine Creek | Headwaters to T109 R35W S22, south line | 2B | 2020 | |
| | 07020008-609 | Judicial Ditch 30 | T110 R33W S15, west line to T110 R33W S36, east line | 2B | 2020 | |
| Aquatic Recreation: Lake Nutrients | 17-0054-00 | Lake Bean | Sec. 14, T107 N., R38 W | 2B | 2010 | 2019/2022 |
| | 17-0056-01 | Double (North Portion) | Sec. 23, T107 N., R38 W | 2B | 2010 | |

| Affected use: Pollutant/ Stressor | Reach/Lake ID | Reach/Lake name | Reach/Lake description | Designated use class | Listing year | Target Start/ Completion |
|---|---|---|---|---|---|---|
| | 42-0052-00 | Rock Lake | Sec. 5 and 6, T. 109 N., R42 W | 2B | 2010 | |
| | 08-0011-00 | Clear Lake | Sec. 11, T109 N., R31 W | 2B | 2020 | |
| | 08-0054-00 | Altermatt Lake | Sec. 31, T109 N., R33 W | 2B | 2020 | |
| | 08-0096-00 | Boise Lake | Sec. 12, T109 N., R34 W | 2B | 2020 | |
| | 08-0029-00 | Bachelor Lake | Sec. 11, T109 N., R32 W | 2B | 2020 | |

[1] Plum Creek Reach 516 was split into two separate reaches, 602 and 603, during 2019 assessment process.

**Figure 2. Cottonwood River Watershed impairments covered in this TMDL.**

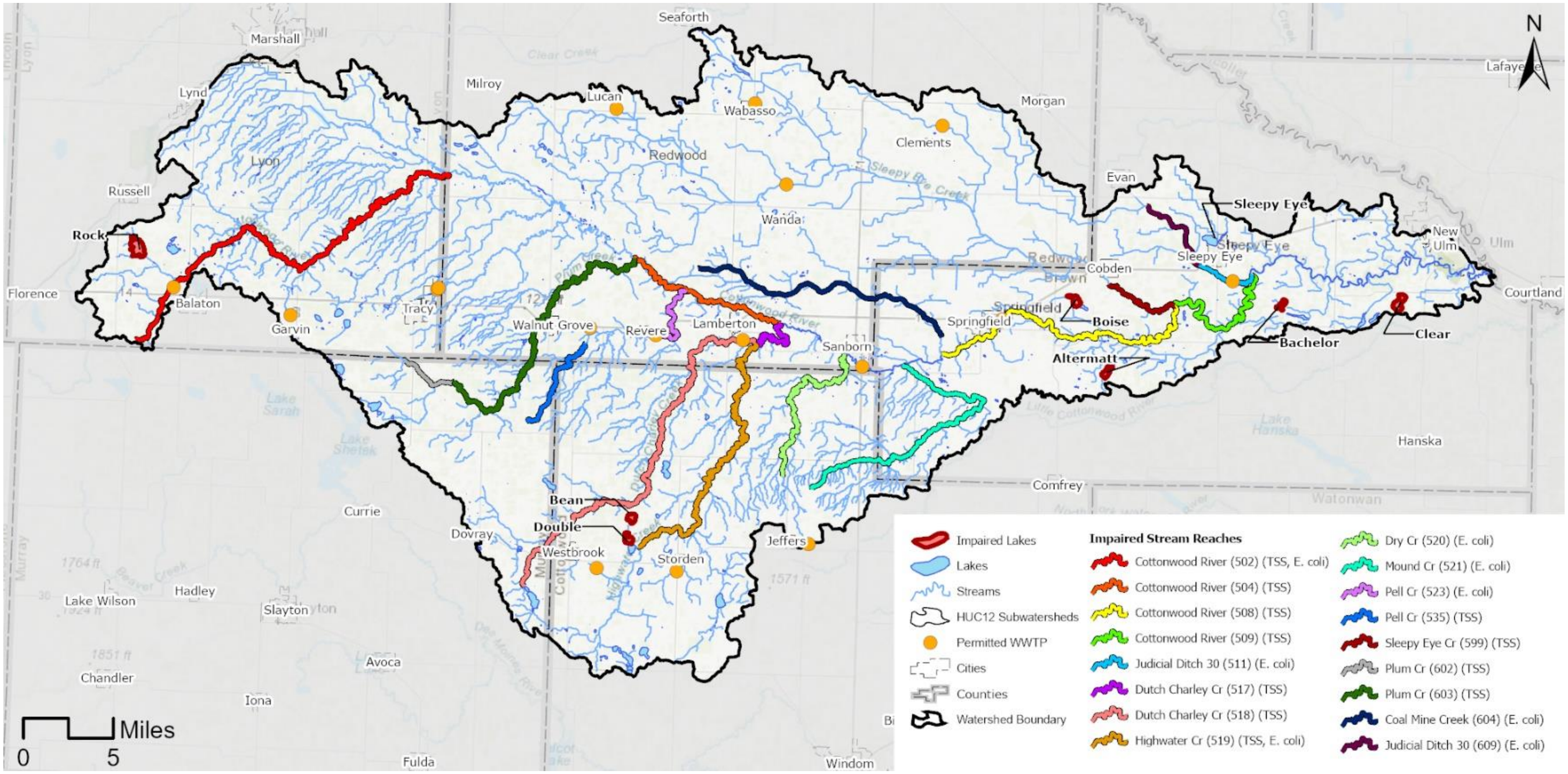


Table 2 provides a summary of the impaired stream reaches in the Cottonwood River Watershed with existing EPA-approved TMDL studies that were completed prior to this TMDL report.

**Table 2. Summary of TMDLs already completed within the Cottonwood River Watershed.**

| Stream or Lake Name | Reach AUID (Last 3 Digits) | Pollutant(s) | TMDL Report(s) |
|---|---|---|---|
| Cottonwood River (JD30 to Minnesota River) | 501 | Aquatic Recreation: Fecal coliform<br>Aquatic Life: TSS<br>Aquatic consumption: Mercury in fish | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013)<br>Minnesota River and Greater Blue Earth River Basin TSS TMDL Study (MPCA 2020b)<br>Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |
| Cottonwood River (Coal Mine Creek to Sleepy Eye Creek) | 508 | Aquatic Recreation: Fecal coliform<br>Aquatic consumption: Mercury in fish | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013)<br>Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |
| Sleepy Eye Creek (Headwaters to Cottonwood River) | 512 | Aquatic Recreation: Fecal coliform; | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013) |
| Cottonwood River (Plum Creek to Dutch Charley Creek) | 504 | Aquatic Recreation: Fecal coliform<br>Aquatic consumption: Mercury in fish | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013)<br>Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |
| Dutch Charley Creek (Highwood Creek to Cottonwood River) | 517 | Aquatic Recreation: Fecal coliform | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013) |
| Plum Creek (Headwaters to Cottonwood River) | 516 | Aquatic Recreation: Fecal coliform | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013) |
| Lone Tree Creek (T109 R39W S7 westline to Cottonwood River) | 524 | Aquatic Recreation: Fecal coliform | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013) |
| Meadow Creek (Headwaters to Cottonwood River) | 515 | Aquatic Recreation: Fecal coliform | Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013) |
| Cottonwood River (Headwaters to Meadow Creek) | 502 | Aquatic consumption: Mercury in fish | Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |
| Cottonwood River (Meadow Creek to Plum Creek) | 503 | Aquatic consumption: Mercury in fish | Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |

| Stream or Lake Name | Reach AUID (Last 3 Digits) | Pollutant(s) | TMDL Report(s) |
|---|---|---|---|
| Cottonwood River (Dutch Charley Creek to Dry Creek) | 505 | Aquatic consumption: Mercury in fish | Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |
| Cottonwood River (Dry Creek to Mound Creek) | 506 | Aquatic consumption: Mercury in fish | Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |
| Cottonwood River (Mound Creek to Coal Mine Creek) | 507 | Aquatic consumption: Mercury in fish | Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |
| Cottonwood River (Sleepy Eye Creek to Judicial Ditch 30) | 509 | Aquatic consumption: Mercury in fish | Minnesota Statewide Mercury Total Maximum Daily Load (MPCA 2007a) |

The IWM efforts for the Cottonwood River Watershed identified 13 stream reaches that currently do not meet fish IBI standards and 26 stream reaches that do not meet aquatic macroinvertebrate IBI standards. A SID report was developed for these reaches to determine the primary stressors to the biological communities (MPCA, available upon request). Nonpollutant stressors (e.g., habitat, connectivity) are not subject to load quantification and therefore do not require TMDLs. If a nonpollutant stressor is linked to a pollutant (e.g., habitat issues driven by TSS or low dissolved oxygen (DO) caused by excess phosphorus) a TMDL is required. However, in many cases habitat stressors are not linked to pollutants. Impairments where chemical pollutants from anthropogenic sources are not a primary stressor to the fish and aquatic macroinvertebrate communities will not be covered in this TMDL, and instead will be addressed through the implementation of the Cottonwood River WRAPS Report and local water planning efforts.

## 1.2 Identification of Water Bodies

The TSS-impaired reaches were placed on the Clean Water Act Section 303(d) impaired waters list in 2006, 2010, and 2020. The bacteria-impaired reaches were placed on the 303(d) list in 2020. The nutrient-impaired lakes were placed on the 303(d) list in 2010, and 2020. All of the impaired reaches addressed in this TMDL are Class 2B (warm water). TMDLs are developed for the most restrictive use class. Class 2B waters are the most stringent of the applicable standards.

Table 1 and the Cottonwood River Watershed Monitoring and Assessment Report (which includes notes regarding aquatic life impairments for which TMDLs are not computed) summarize Cottonwood River Watershed impairments and those addressed in this TMDL. There are two reaches of Plum Creek, reaches 602 and 603, which are covered under this TMDL. These reaches were previously combined as one contiguous reach, Plum Creek reach 516. During the 2019 assessment process, reach 516 was split into two separate reaches (602 and 603) due to new tiered aquatic life uses (TALU) standards for channelized streams. This impairment will be carried forward and one TMDL will be presented that covers both reaches in this report.

## 1.3 Priority Ranking

The Minnesota Pollution Control Agency (MPCA) schedule for TMDL completions, as indicated on the 2022 303(d) impaired waters list, reflects Minnesota’s priority ranking of this TMDL. The MPCA has aligned its TMDL priorities with the watershed approach and the WRAPS cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on a 10-year cycle. The MPCA developed a state plan (Minnesota’s TMDL Priority Framework Report) to meet the needs of EPA’s national measure (WQ-27) under EPA’s Long-Term Vision for Assessment, Restoration, and Protection under the Clean Water Act Section 303(d) Program. As part of these efforts, the MPCA identified water quality impaired segments that will be addressed by TMDLs by 2022. The Cottonwood River Watershed waters addressed by this TMDL are part of that MPCA prioritization plan to meet EPA’s national measure.

# 2. Applicable Water Quality Standards

## 2.1 Designated Uses

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

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

## 2.2 Turbidity/TSS

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

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

The 11 reaches of the Cottonwood River Watershed listed as impaired by turbidity/TSS are class 2B warm water streams. The class 2B TSS standard for streams and rivers in the Southern River Nutrient Region is 65 mg/L. This standard may not be exceeded more than 10% of the time from April through September over a multi-year data window (MPCA 2011).

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

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

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

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

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

## 2.3 Bacteria

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

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

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

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

It should also be noted that most analytical laboratories report *E. coli* in terms of colony forming units per 100 milliliters (cfu/100 mL), not organisms per 100 milliliters. This TMDL will present *E. coli* data in cfu/100 mL since all of the monitored data collected was reported in these units. Bacteria TMDLs were written to achieve the bacteria water quality standard of 126 orgs/100 mL as a monthly geometric mean. Geometric mean is used in place of arithmetic mean in order to measure the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. Geometric means are calculated using the following equation:

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

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

## 2.4 Lake Nutrients

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

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

**Table 3. Eutrophication standards for class 2B lakes, shallow lakes, and reservoirs in the Western Corn Belt Plains ecoregion.**

| Parameter | WCBP Ecoregion Standards (2B shallow lakes) |
|---|---|
| Total Phosphorus [µg/L]* | 90 |
| Chlorophyll-a [µg/L] | 30 |
| Secchi Disk Transparency [meters] | 0.7 |

* Microgram per liter or part per billion

# 3. Watershed and Water Body Characterization

The Cottonwood River Watershed is a major Hydrologic Unit Code (HUC)-8 watershed in the Minnesota River Basin, covering the central portion of the state. The Cottonwood River Watershed is approximately 1,314 square miles or 840,772 acres, split between five counties including: Redwood (35%), Brown (21%), Cottonwood (19%), Lyon (17%), and Murray (8%). There is no tribal land in the Cottonwood River Watershed and this TMDL does not allocate pollutant load to any federally recognized Indian tribe.

There are 36 individual HUC-12 subwatersheds in the Cottonwood River Watershed and 8 major HUC-10 subwatersheds: Headwaters –Cottonwood River, Meadow Creek, Plum Creek, Pell Creek – Cottonwood River, Dutch Charley Creek, Mound Creek – Cottonwood River, Sleepy Eye Creek, and Cottonwood River (see Figure 1). The streams and tributaries that make up these major subwatersheds flow to the Cottonwood River upstream of the confluence with the Minnesota River.

## 3.1 Lakes

Collectively lakes and open water areas in the Cottonwood River Watershed (07020008) account for approximately 1% of the watershed. There are seven assessed lakes impaired by excess nutrients in the watershed (see Figure 2). Lake morphometry and watershed information for each impaired lake covered in this TMDL is presented in Table 4. All seven lakes are considered shallow with average depths ranging from 1 to 11 feet. Residence time is generally short and watershed to surface area ratios vary widely from 3:1 to 15:1.

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

| Parameter | Rock | Bean | Double (North Portion) | Clear | Altermatt | Boise | Bachelor |
|---|---|---|---|---|---|---|---|
| County | Lyon | Cottonwood | Cottonwood | Brown | Brown | Brown | Brown |
| Lake ID | 42-0052-00 | 17-0054-00 | 17-0056-01 | 08-0011-00 | 08-0054-00 | 08-0096-00 | 08-0029-00 |
| Lake Type | Shallow | Shallow | Shallow | Shallow | Shallow | Shallow | Shallow |
| Lake Surface Area [acres] | 379 | 164 | 136 | 277 | 122 | 187 | 105 |
| Ave. Depth [ft] | 5.2 | 11.2 | 6.5 | 4.9 | 3.2 | 2.2 | 1.3 |
| Max Depth [ft] | 8 | 14 | 9 | 8 | 5 | 7 | 4 |
| Residence Time [yrs] | 0.9 | 3.2 | 1.2 | 0.8 | 0.4 | 0.4 | 0.4 |
| Littoral Area [%] | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Watershed Area[1] [acres] | 3,208 | 372 | 1,246 | 1,426 | 1,865 | 1,376 | 377 |
| Watershed Area: Surface Area | 8:1 | 3:1 | 9:1 | 5:1 | 15:1 | 7:1 | 4:1 |

[1] Does not include lake surface area.

## 3.2 Streams

The 17 impaired stream reaches in the Cottonwood River Watershed addressed in this TMDL cover approximately 280 stream miles and drain approximately 795,000 acres of land across the watershed (Figure 2, Table 5). Additional information for each impaired stream reach can be found in Appendix A. Eight bacteria-impaired reaches in the Cottonwood River Watershed were already addressed in the Cottonwood River Fecal Coliform TMDL Report (RCRCA 2013) as discussed in Section 1.1.

**Table 5. Impaired stream characteristics in the Cottonwood River Watershed.**

| Reach Name | Impaired Reach ID[1] | Imp. Parameter | Reach Length [miles] | Watershed Area [acres] | Upstream Impaired Reach(es) |
|---|---|---|---|---|---|
| Cottonwood River: Headwaters to Meadow Creek | 502 | TSS, *E. coli* | 42.4 | 64,218 | None |
| Cottonwood River: Plum Creek to Dutch Charley Creek | 504 | TSS | 13.4 | 285,997 | 502, 535, 602, 603 |
| Cottonwood River: Coal Mine Creek to Sleepy Eye Creek | 508 | TSS | 23.9 | 564,925 | 502, 504, 517, 518, 519, 520, 521, 523, 535, 602, 603, 604 |
| Cottonwood River: Sleepy Eye Creek to JD 30 | 509 | TSS | 12.0 | 759,705 | 502, 504, 508, 517, 518, 519, 520, 521, 523, 599, 602, 603, 604 |
| Judicial Ditch 30: T110 R32W S31, west line to Cottonwood River | 511 | *E. coli* | 4.2 | 37,473 | 609 |
| Dutch Charley Creek: Highwater Creek to Cottonwood River | 517 | TSS | 7.3 | 133,975 | 518, 519 |
| Dutch Charley Creek: Headwaters to Highwater Creek | 518 | TSS | 39.5 | 61,174 | None |
| Highwater Creek: Double Lake outlet to Dutch Charley Creek | 519 | TSS, *E. coli* | 33.1 | 69,375 | None |
| Dry Creek: T108 R36W S31, south line to Cottonwood River | 520 | *E. coli* | 17.8 | 26,262 | None |
| Mound Creek: Headwaters to Cottonwood River | 521 | *E. coli* | 24.9 | 35,259 | None |
| Pell Creek: T109 R37W S30, west line to Cottonwood River | 523 | *E. coli* | 6.6 | 33,171 | None |
| Pell Creek: Headwaters to T109 R38W S29, east line | 535 | TSS | 10.0 | 8,152 | None |
| Sleepy Eye Creek: T109 R33W S5, west line to Cottonwood River | 599 | TSS | 6.0 | 176,728 | None |
| Plum Creek: Headwaters to -95.576 44.177 (602); -95.576 44.177 to Cottonwood River (603) | 602 & 603[2] | TSS | 34.1 | 57,682 | None |
| Coal Mine Creek: Headwaters to T109 R35W S22, south line | 604 | *E. coli* | 17.33 | 29,413 | None |
| Judicial Ditch 30: T110 R33W S15, west line to T110 R33W S36, east line | 609 | *E. coli* | 5.8 | 28,452 | None |

[1] Only the last three digits of the impaired reach are shown in this table for the Cottonwood River (07020008) impairments.

[2] Plum Creek Reach 516 was split into two separate reaches, 602 and 603, during 2019 assessment process.

## 3.3 Subwatersheds

The drainage areas of the impaired water bodies (Figure 2) were developed using multiple data sources, starting with watershed delineations from the MPCA's HSPF model application for the Cottonwood River Watershed (Tetra Tech 2019). The model watershed boundaries are based on Minnesota Department of Natural Resources (DNR) Level 8 watershed boundaries and modified with a 30-meter digital elevation model (DEM). Where additional watershed breaks were needed to define the impairment watersheds, DNR Level 8 and Level 9 watershed boundaries and delineation were used based on contours derived from LiDAR. Maps showing specific watershed boundaries for each impaired stream reach and lake are included in Appendix A and Appendix C.

## 3.4 Land use

Uninterrupted prairie and wetlands originally covered a majority of the Cottonwood River Watershed. Like most areas across the Midwest, land throughout the watershed has been converted from a range of tallgrass prairie and a small number 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.

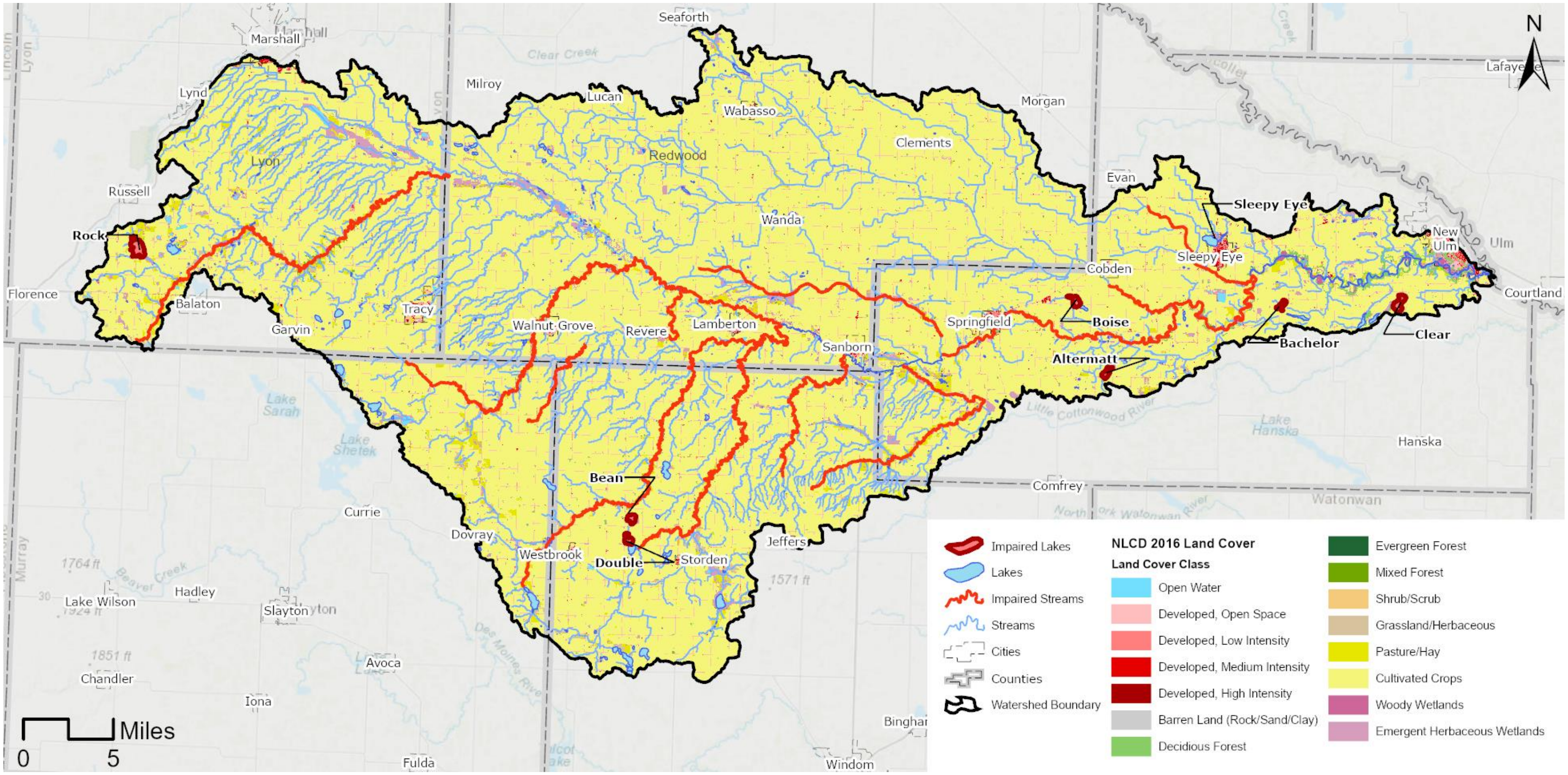
Land use within the Cottonwood River Watershed was analyzed using USGS's 2016 National Land Cover Database (NLCD). Current land use within the watershed is highly dominated by agriculture (mostly row crops,) followed by relatively small amounts of rangeland, developed land, wetlands, open water, and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

The city of New Ulm (MS400228) is the largest city in the Cottonwood River Watershed and is located at the confluence with the Minnesota River. A small portion (~671 acres) of the city of Marshall (MS400241) is also located within the Cottonwood River Watershed near the headwaters of the Meadow Creek Subwatershed. Both the cities of New Ulm and Marshall are subject to the MPCA's Municipal Separate Storm Sewer System (MS4) Permit program (see Section 4.2.2).

**Table 6. Summary of land use and watershed area for each impaired reach and lake in the Cottonwood River Watershed.**

| Impaired Water Body Name | Reach or Lake ID | Drainage Area [Acres] | Percent of Watershed [%] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Cropland | Rangeland | Developed | Forest/Shrub land | Open Water | Wetlands | Barren/Mining |
| Cottonwood River | 502 | 64,218 | 79% | 10% | 5% | 1% | 2% | 3% | <1% |
| Cottonwood River | 504 | 285,997 | 83% | 6% | 6% | <1% | <1% | 4% | <1% |
| Cottonwood River | 508 | 564,925 | 84% | 5% | 6% | < 1% | <1% | 4% | <1% |
| Cottonwood River | 509 | 759,705 | 85% | 4% | 5% | < 1% | <1% | 3% | <1% |
| Judicial Ditch 30 | 511 | 37,473 | 88% | 1% | 8% | <1% | <1% | 2% | <1% |
| Dutch Charley Creek | 517 | 133,975 | 85% | 5% | 5% | 1% | 1% | 2% | <1% |
| Dutch Charley Creek | 518 | 61,174 | 88% | 3% | 5% | 2% | <1% | 2% | <1% |
| Highwater Creek | 519 | 69,375 | 84% | 6% | 5% | 1% | 2% | 2% | <1% |
| Dry Creek | 520 | 26,262 | 88% | 4% | 5% | <1% | <1% | 2% | <1% |
| Mound Creek | 521 | 35,259 | 81% | 7% | 5% | <1% | <1% | 6% | <1% |
| Pell Creek | 523 | 33,171 | 88% | 2% | 7% | 1% | <1% | 2% | <1% |
| Pell Creek | 535 | 8,152 | 87% | 2% | 8% | < 1% | <1% | 2% | <1% |
| Sleepy Eye Creek | 599 | 176,728 | 91% | < 1% | 6% | < 1% | <1% | 2% | <1% |
| Plum Creek | 602 & 603 | 57,682 | 86% | 5% | 5% | 1% | 1% | 2% | <1% |
| Coal Mine Creek | 604 | 29,413 | 86% | 1% | 5% | <1% | <1% | 6% | <1% |
| Judicial Ditch 30 | 609 | 28,452 | 91% | 1% | 6% | <1% | <1% | 1% | <1% |
| Rock | 42-0052-00 | 3,208 | 74% | 7% | 5% | <1% | 13% | <1% | <1% |
| Bean | 17-0054-00 | 372 | 56% | <1% | 6% | 1% | 34% | 2% | <1% |
| Double | 17-0056-01 | 1,246 | 58% | 2% | 6% | 1% | 31% | 2% | <1% |
| Clear | 08-0011-00 | 1,426 | 57% | 2% | 4% | 5% | 22% | 10% | <1% |
| Altermatt | 08-0054-00 | 1,865 | 84% | < 1% | 4% | 2% | 7% | 2% | <1% |
| Boise | 08-0096-00 | 1,376 | 73% | < 1% | 11% | <1% | 12% | 4% | <1% |
| Bachelor | 08-0029-00 | 377 | 66% | <1% | 2% | <1% | 27% | 4% | <1% |
| Entire Watershed | 07020008 | 840,772 | 85% | 4% | 6% | 1% | 1% | 3% | <1% |

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



## 3.5 Current/Historical Water Quality

All data used in the development of this TMDL were collected between 2000 and 2018 by various agencies and local partners, including the MPCA, MDA, Redwood Cottonwood River Control Area (RCRCA), area Soil and Water Conservation Districts (SWCDs), and volunteer monitoring programs. Although data prior to 2000 exists in each of the major watersheds, the more recent data represent more current conditions.

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

### 3.5.1 TSS

TSS data were summarized by site for each TSS impaired reach in the Cottonwood River Watershed using data from 2000 to 2017 (Table 7). The TSS impairments presented in this TMDL are based upon the current TSS standard for the Southern River Nutrient Region of 65 mg/L. There is currently no TSS data available for Cottonwood River Reach 509 and Pell Creek Reach 535. However, S-tube (transparency) data were available for these reaches and were used by the MPCA to assess the TSS impairment for these reaches. The S-tube data for both reaches are presented in Table 8. As discussed in Section 2.2, 10cm represents the lower surrogate threshold for S-tube measurements while 15cm represents the upper surrogate threshold. Thus, any S-tube measurement less than 10cm is considered a violation of the TSS criterion for assessment purposes. Figure 8 through Figure 17 in Section 4.2.6 show the variability of TSS by flow condition over the most recent 10-year period (2008 through 2017) for each TSS impaired reach. The turbidity impairment listing for 07020008-535 is based on data collected between 2001 through 2004. The age of the data and relatively low exceedance rate suggest 07020008-535 should be prioritized for additional monitoring to determine candidacy for de-listing.

**Table 7. Summary of TSS data for impaired reaches from 2000-2017 in the Cottonwood River Watershed (April – October).**

| Parameter | Cottonwood River | Cottonwood River | Cottonwood River | Dutch Charley Creek | Dutch Charley Creek | Highwater Creek | Sleepy Eye Creek | Plum Creek Reach |
|---|---|---|---|---|---|---|---|---|
| Reach Id | 07020008-502 | 07020008-504 | 07020008-508 | 07020008-517 | 07020008-518 | 07020008-519 | 07020008-599 | 07020008-602 & 603 |
| Years of Data | 1 | 14 | 18 | 4 | 3 | 1 | 18 | 14 |
| Sample Count | 13 | 99 | 237 | 37 | 22 | 13 | 232 | 85 |
| $90^{th}$ Percentile [mg/L] | 156 | 108 | 234 | 107 | 65 | 110 | 114 | 166 |
| Mean [mg/L] | 75 | 71 | 100 | 51 | 33 | 54 | 50 | 101 |
| Maximum [mg/L] | 215 | 900 | 563 | 54 | 304 | 204 | 648 | 2,670 |
| Number of Exceedances | 7 | 31 | 126 | 8 | 3 | 3 | 45 | 31 |
| Frequency of Exceedances | 54% | 31% | 53% | 22% | 14% | 23% | 19% | 36% |

**Table 8. Summary of Secchi tube data for Cottonwood River Reach 509 and Pell Creek Reach 535 from 2000-2017 (April – October).**

| Parameter | Cottonwood River | Pell Creek |
|---|---|---|
| Reach Id | 07020008-509 | 07020008-535 |
| Years of Data | 3 | 4 |
| Sample Count | 107 | 97 |
| $10^{th}$ Percentile [cm] | 9 | 13.2 |
| Mean [cm] | 43.3 | 42.1 |
| Low [cm] | 1 | 5 |
| Number of Exceedances | 16 | 5 |
| Frequency of Exceedances | 15% | 5% |

### 3.5.2 Bacteria

Table 9 shows April through October monthly *E. coli* geometric means (2000 through 2017) for the bacteria-impaired reaches addressed in this TMDL. Older records for bacteria samples were analyzed for fecal coliform prior to switching to *E. coli* in 2006. All fecal coliform data collected prior to 2006 were converted to *E. coli* equivalents using the equation described in Section 2.3. Table 9 shows the individual chronic sample exceedances, acute exceedances, and monthly geometric means for each impaired reach. Results indicate monthly geometric means exceeded the chronic standard several times during the index period. Additionally, individual samples occasionally exceeded the acute standard for several reaches from April through October.

**Table 9. Summary of *E. coli* data for Cottonwood River Watershed impaired reaches from 2000-2017.**

| Monitored Month(s) | Parameter | Cottonwood River Reach 502 | Judicial Ditch 30 Reach 511 | Highwater Creek Reach 519 | Dry Creek Reach 520 | Mound Creek Reach 521 | Pell Creek Reach 523 | Coal Mine Creek Reach 604 | Judicial Ditch 30 Reach 609 |
|---|---|---|---|---|---|---|---|---|---|
| Apr-Oct | Years of data | 1 | 1 | 1 | 1 | 3 | 1 | 3 | 2 |
| Apr-Oct | Sample count | 9 | 9 | 9 | 9 | 24 | 9 | 24 | 15 |
| Apr-Oct | Maximum (MPN/100 mL) | 5,794 | 1,658 | 6,488 | 4,106 | 9,208 | 12,033 | 2,948 | 2,420 |
| Apr-Oct | Number of individual sample exceedances | 9 | 9 | 9 | 9 | 24 | 9 | 23 | 15 |
| Apr-Oct | Percent of individual sample exceedances | 100% | 100% | 100% | 100% | 100% | 100% | 96% | 100% |
| Apr-Oct | Geometric mean | **1,063** | **710** | **1,897** | **2,033** | **1,553** | **937** | **1,401** | **787** |
| Apr | Sample count | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Geometric mean | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| May | Sample count | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Geometric mean | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Jun | Sample count | 3 | 3 | 3 | 3 | 7 | 3 | 7 | 5 |
| | Geometric mean | **877*** | **704*** | **1,760*** | **3,248*** | **1,344** | **666*** | **1,156** | **303** |
| Jul | Sample count | 3 | 3 | 3 | 3 | 8 | 3 | 8 | 5 |
| | Geometric mean | **736*** | **551*** | **2,729*** | **2,683*** | **1,583** | **2,005*** | **1,740** | **780** |
| Aug | Sample count | 3 | 3 | 3 | 3 | 9 | 3 | 9 | 5 |
| | Geometric mean | **1,859*** | **921*** | **1,420*** | **964*** | **1,709** | **617*** | **1,343** | **2,064** |
| Sep | Sample count | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Geometric mean | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |
| Oct | Sample count | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Geometric mean | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A |

* Geometric means are calculated; however, there are fewer than the 5 required monthly samples for assessment.
Table notes:
-Red highlighted values indicate monthly geometric mean concentration exceeds the 126 organisms per 100 mL chronic standard.
-All geometric mean values presented in MPN/100 mL.

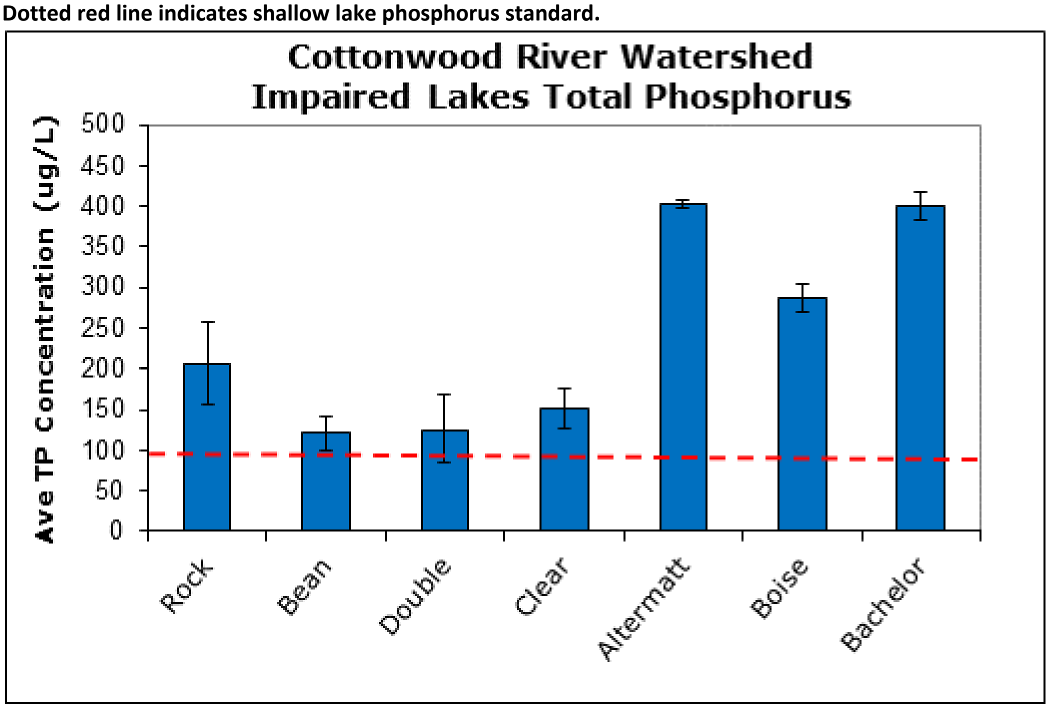
### 3.5.3 Lake Phosphorus and Response Variables

In general, historical in-lake water quality data collected from 2000 through 2018 was reviewed for use in this TMDL. Table 10 lists the June through September averages for TP, Chl-*a*, and Secchi depth for each impaired lake. The table also lists the data years which were used to calculate the average condition for this TMDL. All lakes indicate average summer TP, Chl-*a*, and/or Secchi depths are not meeting ecoregion-defined state standards. Figure 4 shows the average TP for each lake relative to the shallow lake standard.

**Table 10. Summer growing season averages for each water quality parameter in the Cottonwood River Watershed.**

| | | In-Lake Average Condition [Calculated June – September] | | |
|---|---|---|---|---|
| **Lake Name** | **"Average" Condition Calculation Years** | **TP Concentration [µg/L]** | **Chl-*a* Concentration [µg/L]** | **Secchi Depth [m]** |
| **WCBP Ecoregion 2B Shallow Lake Standards** | | **90** | **30** | **0.7** |
| Rock | 2002, 2007, 2017 | 202 (n=12) | 30 (n=12) | 0.5 (n=11) |
| Bean | 2007, 2008, 2017 | 122 (n=12) | 49 (n=12) | 1.0 (n=12) |
| Double | 2007, 2008, 2017, 2018 | 124 (n=15) | 52 (n=16) | 0.7 (n=16) |
| Clear | 2009, 2010, 2017 | 151 (n=15) | 78 (n=15) | 0.4 (n=19) |
| Altermatt | 2009, 2010 | 403 (n=14) | 138 (n=14) | 0.2 (n=12) |
| Boise | 2011, 2012 | 287 (n=11) | 141 (n=11) | -- |
| Bachelor | 2011, 2012 | 400 (n=11) | 183 (n=11) | -- |

**Figure 4. Average summer growing season TP concentrations for each impaired lake in the Cottonwood River Watershed. Dotted red line indicates shallow lake phosphorus standard.**



## 3.6 Pollutant Source Summary

The permitted sources discussed here are pollutant sources that require a National Pollutant Discharge Elimination System (NPDES) permit. Nonpermitted sources are pollutant sources that do not require an NPDES permit. All Minnesota NPDES permits are also state disposal system (SDS) permits, but some pollutant sources require SDS permit coverage alone without NPDES permit coverage (e.g., spray irrigation, large septic systems, land application of biosolids, and small feedlots).

***Overland Runoff/Erosion (Rural Areas)***

Nonpoint pollutant loads in rural areas can come from nonpermitted sources such as sediment erosion from upland fields, tile drainage, gully erosion, and livestock pastures in riparian zones (Schottler et al. 2013). Runoff from these sources can carry sediment, bacteria, phosphorus, and other nutrients to surface waters. For this TMDL, upland nonpoint sources of sediment and phosphorus were evaluated using the Cottonwood River Watershed HSPF Model (Tetra Tech 2019). HSPF is a comprehensive, mechanistic model of watershed hydrology and water quality that allows the integrated simulation of point sources, land and soil contaminant runoff processes, and in-stream hydraulic and sediment-chemical interactions. The results provide hourly runoff flow rates, sediment concentrations, and nutrient concentrations, along with other water quality constituents, at the outlet of any modeled subwatershed for the model time period 1996 through 2017. Model documentation contains additional details about model development and calibration (Tetra Tech 2019). Within each subwatershed, the upland areas are separated into multiple land use categories and are further parameterized based on hydrologic soil group. Simulated loads from upland areas represent the pollutant loads that are delivered to the modeled stream or lake; the loading rates do not represent field-scale soil loss estimates.

Overall, across the entire Cottonwood River HUC-8 Watershed, approximately 27% of the TSS load and 88% of the phosphorus load is from agricultural overland runoff (i.e., cultivated crops and hay/pasture lands identified in the 2016 NLCD land use layer, in addition to loading from feedlots) and other rural upland sources. Relative contributions by source vary widely between individual reaches. Sections 3.6.1 and 3.6.3 below contain more detailed discussion of the upland watershed source contributions for each impaired lake and stream reach.

***Animal Feeding Operations***

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

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

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

CAFO production areas need to be designed, constructed, operated, and maintained to contain all manure, manure-contaminated runoff, or process wastewater, and direct precipitation. CAFOs and AFOs with 1,000 or more AUs must be designed to contain all manure and manure contaminated runoff from precipitation events of less than a 25-year - 24-hour storm event. Having and complying with an NPDES permit allows some enforcement protection if a facility discharges due to a 25-year - 24-hour precipitation event (approximately 5.07" in 24 hours) and the discharge does not contribute to a water quality impairment. Large CAFOs permitted with an SDS permit or those not covered by a permit must contain all runoff, regardless of the precipitation event. Therefore, many large CAFOs in Minnesota have chosen to have an NPDES permit, even if discharges have not occurred in the past at the facility. A current manure management plan (MMP), which complies with Minn. R. 7020.2225, and the respective permit is required for all CAFOs and AFOs with 1,000 or more AUs. Additionally, MMP requirements for CAFOs are more stringent than for smaller feedlots. CAFOs are inspected by the MPCA in accordance with the MPCA NPDES Compliance Monitoring Strategy approved by the EPA. All CAFOs (NPDES permitted, SDS permitted, and not required to be permitted) are inspected by the MPCA on a routine basis with an appropriate mix of field inspections, offsite monitoring, and compliance assistance.

Feedlots under 1,000 AUs and those that are not federally defined large CAFOs do not operate with permits; however, the requirements under Minn. R. chs. 7020, 7050 and 7060 still apply. Manure may accumulate in these feedlots, and vegetative cover cannot be maintained due to the density of animals. 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. Registration also helps ensure that surface waters are not contaminated by the runoff from feeding facilities, manure storage or stockpiles, and cropland with improperly applied manure. 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.

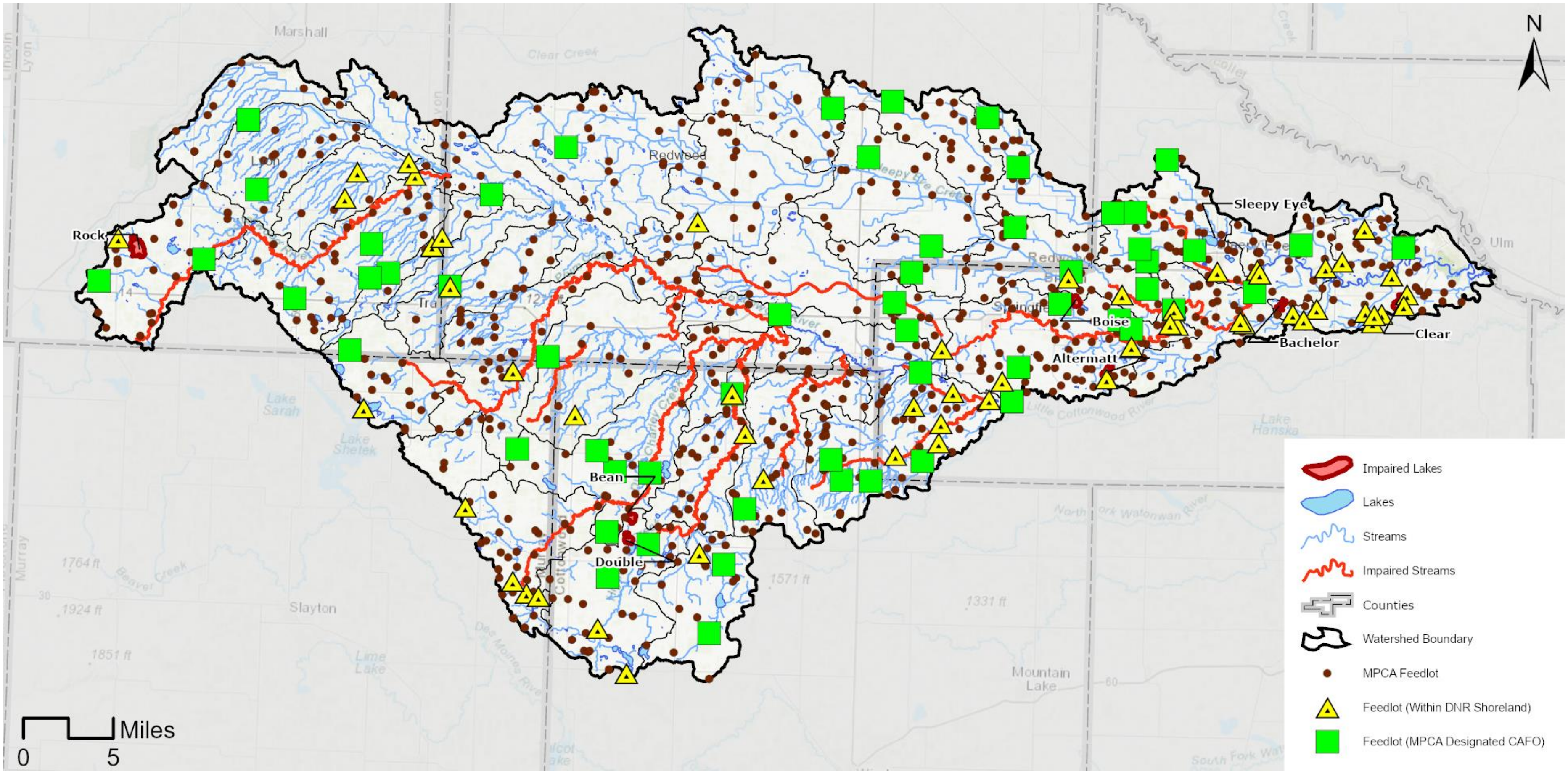
In the Cottonwood River Watershed, Redwood County is the only county that is not delegated to administer feedlot-related activities such as permitting, inspections, and compliance/enforcement. In Redwood County, the MPCA fulfills these responsibilities. Brown, Cottonwood, Lyon, and Murray Counties are 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 for CAFOs and registered feedlots that contains information such as feedlot locations, animal numbers, and types of animals. The database includes the maximum number of animals that each registered feedlot can hold; therefore, the actual number of livestock in registered facilities is likely lower. Livestock in nonregistered, smaller operations (e.g., hobby farms) likely contribute pollutant loads to surface waters through watershed runoff from fields and direct deposition in surface waters. The MPCA registered feedlot database indicates there were approximately 513 active feedlot facilities with over 228,065 livestock AUs throughout the Cottonwood River Watershed as of 2018 (Figure 5). Table 11summarizes facility type and livestock numbers for each impaired reach, lake, and the entire watershed. In the Cottonwood River Watershed, there are 46 feedlots located within 1,000 feet of a lake or 300 feet of a stream or river, an area generally defined as shoreland. Thirty-seven of these feedlots in shoreland 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 Appendices E for a list and summary of all CAFOs in the watershed.

**Table 11. MPCA active registered feedlots and feedlot type for each *E. coli* impaired reach and impaired lake in the Cottonwood River Watershed.**

| Impaired Reach/Lake | Impairment Type | Total Operations | | CAFOs | | Open Lots | | Shoreland | | Open Lots in Shoreland | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Count | AUs | Operations | AUs | Operations | AUs | Operations | AUs | Operations | AUs |
| Cottonwood River Reach 502 | *E. coli* | 47 | 19,325 | 3 | 3,768 | 31 | 7,597 | 1 | 651 | - | - |
| Judicial Ditch 30 Reach 511 | *E. coli* | 38 | 10,945 | 3 | 3,131 | 28 | 6,375 | 1 | 10 | - | - |
| Highwater Creek Reach 519 | *E. coli* | 59 | 16,618 | 2 | 6,195 | 20 | 6,553 | 5 | 5,515 | 3 | 633 |
| Dry Creek Reach 520 | *E. coli* | 29 | 5,933 | 1 | 900 | 19 | 4,087 | 1 | 84 | 1 | 84 |
| Mound Creek Reach 521 | *E. coli* | 40 | 14,146 | 3 | 1,860 | 23 | 6,769 | 5 | 781 | 4 | 691 |
| Pell Creek Reach 523 | *E. coli* | 12 | 1,799 | - | - | 9 | 1,724 | 1 | 15 | - | - |
| Coal Mine Creek Reach 604 | *E. coli* | 12 | 4,013 | 1 | 1,106 | 9 | 2,081 | - | - | - | - |
| Coal Mine Creek Reach 609 | *E. coli* | 29 | 9,557 | 3 | 3,131 | 21 | 5,741 | - | - | - | - |
| Bean Lake | Nutrients | - | - | - | - | - | - | - | - | - | - |
| Double Lake | Nutrients | 1 | 200 | - | - | - | - | - | - | - | - |
| Rock Lake | Nutrients | 6 | 1,631 | - | - | 4 | 560 | 1 | 651 | - | - |
| Clear Lake | Nutrients | 6 | 272 | - | - | 6 | 272 | 5 | 208 | 5 | 208 |
| Altermatt Lake | Nutrients | 4 | 1,486 | - | - | 4 | 1,486 | 1 | 549 | 1 | 549 |
| Boise Lake | Nutrients | 1 | 900 | - | - | - | - | - | - | - | - |
| Bachelor Lake | Nutrients | - | - | - | - | - | - | - | - | - | - |
| **Entire Cottonwood River Watershed** | **Multiple** | **513** | **228,065** | **64** | **91,155** | **322** | **98,170** | **46** | **13,108** | **37** | **5,555** |

**Figure 5. MPCA registered feedlots in the Cottonwood 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 stockpiled and then spread over agricultural fields to help fertilize the soil. When stored and applied properly, this beneficial re-use of manure provides a natural source for crop nutrition. Manure, however, can pose water quality concerns when it is not applied properly or leaks or spills from nearby fields, storage pits, lagoons, tanks, etc. Animal waste contains high amounts of fecal bacteria, phosphorus, and nitrogen, and therefore when delivered to surface and groundwater can cause high bacteria levels, eutrophication, and oxygen demand (i.e., low oxygen levels) that negatively impacts human health, aquatic organisms, and aquatic recreation.

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

Based on the MPCA feedlot staff analysis of feedlot demographics, knowledge, and actual observations, there is a significant amount of late winter solid manure application (before the ground thaws). During this time the manure can be a source of nutrients and pathogens in rivers and streams, especially during precipitation events. For feedlots with NPDES permits, surface applied solid manure is prohibited during the month of March. Winter application of manure (December through February) for permitted sites requires fields are approved in their MMP and the feedlot owner/operator must follow a standard list of setbacks and BMPs.

Short term stockpile sites are defined in Minn. R. ch. 7020 and are considered temporary. Any stockpile kept for longer than a year must be registered with the MPCA and would be identified as part of a feedlot facility. Because of the temporary status of the short-term stockpile sites, and the fact they are usually very near or at the land application area, they are included with the land applied manure.

Winter application of surface applied liquid manure is prohibited except for emergency manure application as defined by the NPDES permit. "Winter application" refers to application of manure to frozen or snow-covered soils, except below the soil surface. [Minn. R. 7001].

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 Cottonwood 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 active feedlot spatial dataset was extracted from the Minnesota Geospatial Commons. Feedlot data was intersected with impaired reach watersheds and queried to only include active feedlot registration. Table 12 provides a breakdown of AUs within each *E. coli* impaired reach and impaired lake by animal type: beef cattle, dairy cattle, swine, sheep, horses, and poultry. The "other" category encompasses AUs that do not fit into the category (i.e., llamas or alpaca). The MPCA feedlot dataset includes several subdivisions of beef cattle by age and weight; dairy cattle are similarly divided. The beef cattle animal count includes the following: steer, heifer, cow/calf pairs, and calves. Dairy cattle were summed from the following categories: cattle less than 1,000 lbs, heifers, calves, and cattle greater than 1,000 lbs. Poultry includes turkeys, chickens, and fowl produced for consumption.

**Table 12. MPCA registered livestock animal types within each *E. coli* impaired reach and impaired lake drainage area in the Cottonwood River Watershed.**

| Impaired Reach/Lake | Impairment Type | Active Operations | Total AUs | Animal Units (AUs) | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Beef Cattle | Dairy Cattle | Swine | Sheep | Horse | Poultry | Other |
| Cottonwood River Reach 502 | *E. coli* | 47 | 19,325 | 8,944 | 6 | 10,045 | 87 | - | 243 | - |
| Judicial Ditch 30 Reach 511 | *E. coli* | 38 | 10,945 | 3,530 | 1,159 | 6,224 | 20 | 12 | - | - |
| Highwater Creek Reach 519 | *E. coli* | 59 | 16,618 | 8,490 | 2,630 | 5,035 | 432 | 8 | 3 | 20 |
| Dry Creek Reach 520 | *E. coli* | 29 | 5,933 | 4,485 | 390 | 1,008 | 2 | 18 | 1 | 29 |
| Mound Creek Reach 521 | *E. coli* | 40 | 14,146 | 8,395 | 59 | 5,677 | 8 | 7 | - | - |
| Pell Creek Reach 523 | *E. coli* | 12 | 1,799 | 1,730 | - | 60 | 8 | 1 | - | - |
| Coal Mine Creek Reach 604 | *E. coli* | 12 | 4,013 | 1,051 | 190 | 1,665 | - | - | 1,107 | - |
| Coal Mine Creek Reach 609 | *E. coli* | 29 | 9,625 | 3,380 | 861 | 5,380 | - | 4 | - | - |
| Bean Lake | Nutrients | - | - | - | - | - | - | - | - | - |
| Double Lake | Nutrients | 1 | 200 | - | - | 200 | - | - | - | - |
| Rock Lake | Nutrients | 6 | 1,631 | 474 | - | 1,071 | 86 | - | - | - |
| Clear Lake | Nutrients | 6 | 272 | 85 | 140 | 30 | - | 17 | - | - |
| Altermatt Lake | Nutrients | 4 | 1,486 | 1,294 | - | 192 | - | - | - | - |
| Boise Lake | Nutrients | 1 | 900 | - | - | 900 | - | - | - | - |
| Bachelor Lake | Nutrients | - | - | - | - | - | - | - | - | - |
| **Entire Watershed** | All | 639 | 168,537 | 79,039 | 10,940 | 73,041 | 1,065 | 204 | 4,047 | 199 |

***Urban Stormwater***

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

Although land cover in the Cottonwood River Watershed is predominantly cultivated crops, there are a few medium sized cities located throughout the watershed. The city of New Ulm (MS400228; population 13,287) and a small portion of the city of Marshall (MS400241; population 13,608) are located in the eastern and western portion of the watershed, respectively. These cities are the only communities in the watershed that are subject to the MPCA's MS4 General Permit (MNR040000) program. MS4s are defined by the EPA as stormwater conveyance systems owned or operated by an entity such as a state, city, township, county, district, or other public body having jurisdiction over disposal of stormwater or other wastes. The municipal stormwater permit holds permittees responsible for stormwater discharging from the conveyance system they own and/or operate. The conveyance system includes ditches, roads, storm sewers, stormwater ponds, etc. Under the NPDES stormwater program, permitted MS4 entities are required to obtain a permit, then develop and implement an MS4 Stormwater Pollution Prevention Program (SWPPP), which outlines a plan to reduce pollutant discharges, protect water quality, and satisfy water quality requirements in the Clean Water Act. An annual report is submitted to the MPCA each year by the permittee documenting progress on implementation of the SWPPP.

In addition to New Ulm and Marshall, there are 26 smaller municipalities throughout the Cottonwood River Watershed that are not subject to MS4 permits (Table 13). Sediment and phosphorus loading from urban areas (both MS4 and non-MS4 communities) was estimated using the Cottonwood River Watershed HSPF model. The HSPF model estimates that urban areas account for approximately 8% of the TSS load and 3% of the TP load across the entire Cottonwood River Watershed. Sections 3.6.1 and 3.6.3 present urban TSS and TP source contributions for the individual reach and lake impairments covered in this TMDL.

**Table 13. Municipalities in the Cottonwood River Watershed.**

| City/Township | County | Downstream Impairment(s) | Area in Watershed [acres] | Population | Sewered (Sanitary) | MS4 |
|---|---|---|---|---|---|---|
| Amiret* | Lyon | 504, 508 | 84 | 235 | Individual | No |
| Balaton | Lyon | 502, 504, 508, 509 | 65 | 524 | Ponds | No |
| Clements | Redwood | 509, 599 | 243 | 185 | Ponds | No |
| Cobden | Brown | 599 | 635 | 23 | MSTS**** | No |
| Dotson* | Brown | 508 | 672 | 10** | Individual | No |
| Dovray | Murray | 518 | 74 | 69 | MSTS**** | No |
| Dudley* | Lyon | 504, 508 | 696 | 10** | Individual | No |
| Evan | Brown | -- | 2 | 51 | Ponds | No |
| Garvin | Lyon | 502, 504, 508, 509 | 170 | 120 | Ponds | No |
| Jeffers | Cottonwood | 508 | 80 | 419 | Ponds | No |
| Lamberton | Redwood | 504, 508, 509, 517, 518 | 474 | 844 | Ponds | No |
| Leavenworth* | Brown | 508 | 530 | 267 | Individual | No |
| Lucan | Redwood | 509, 599 | 195 | 175 | Ponds | No |
| Marshall*** | Lyon | 504, 508, 509 | 699 | 12,432 | Mechanical | Yes |
| New Ulm*** | Brown | -- | 2,878 | 13,362 | Mechanical | Yes |
| Revere | Redwood | 504, 508, 509, 523 | 368 | 100 | Ponds | No |
| Rowena* | Redwood | 599 | 780 | 20** | Individual | No |
| Sanborn | Redwood | 508, 509 | 1,356 | 337 | Ponds | No |
| Sleepy Eye | Brown | 511, | 1,340 | 3,498 | Ponds | No |
| Springfield | Brown | 508, 509 | 1,193 | 2,039 | Mechanical | No |
| Storden | Cottonwood | 508, 509, 517, 519 | 208 | 248 | Ponds | No |
| Tracy | Lyon | 504, 508, 509 | 1,434 | 2,110 | Ponds | No |
| Wabasso | Redwood | 509, 599 | 544 | 636 | Mechanical | No |
| Walnut Grove | Redwood | 504, 508, 509, 603, 523 | 685 | 821 | Mechanical | No |
| Wanda | Redwood | 509, 599 | 168 | 59 | Ponds | No |
| Westbrook | Cottonwood | 518, 508, 509, 517, 519 | 424 | 756 | Ponds | No |

*Unincorporated
**2010 Census Population
***Value from previous TMDL report (RCRCA 2013)
****Mid-size Subsurface Treatment System (MSTS)

### ***Near-Channel Sources***

Near-channel sources of sediment and nutrients are those in close proximity to the stream channel, including bluffs, banks, ravines, and the stream channel itself. Hydrologic changes in the landscape and altered precipitation patterns driven by climate change can lead to increased TSS and sediment-bound phosphorus in surface waters. Subsurface drainage tiling, channelization of waterways, land cover alteration, and increases in impervious surfaces all decrease detention time in the watershed and increase flow from fields and in streams. Draining and tiling wetland areas can decrease water storage on the landscape, which can lead to lower evapotranspiration and increased river flow (Schottler et al. 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, near-channel TSS and TP loading from ravines, bluffs, and streambanks were estimated using the Cottonwood 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 Cottonwood River Watershed. Model documentation (Tetra Tech 2016 and 2019) contains additional details about the model development and calibration. HSPF model output suggests approximately 65% of the TSS load and 4% of the TP load at the outlet of the Cottonwood River Watershed comes from near-channel sources. Sections 3.6.1 and 3.6.3 below contain more detailed discussion of the modeled near-channel source contributions for each impaired stream reach.

Additionally, the Cottonwood 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 Cottonwood River Watershed. This report includes the following components: characterization of the watershed, analysis of historical and existing hydrological data, assessment of geomorphic conditions and stream connectivity throughout the watershed.

***Internal Loading (Lakes)***

For many lakes, especially shallow lakes, internal loading can represent a significant portion of the annual TP load. Internal load can come from several sources including soluble phosphorus release from the sediment, rough fish (i.e., common carp), submerged aquatic vegetation (SAV), wind resuspension and physical disturbances such as motorized boat traffic.

Under anoxic conditions at the lake bottom, weak iron-phosphorus adsorption bonds on sediment particles break, releasing phosphorus into the water column. In shallow lakes that undergo intermittent mixing of the water column throughout the growing season, the released phosphorus can mix with surface waters throughout the summer and become available for algal growth. In deeper lakes with a more stable summer stratification period, the released phosphorus has the potential to remain in the bottom water layer throughout much of the growing season until stratification breaks down in late summer or fall. In many lakes, high sediment phosphorus release rates (RRs) are the result of a large pool of phosphorus in the lake bottom that has accumulated over several decades of watershed loading to the lake. Thus, even if significant watershed load reductions have been achieved through BMPs and other efforts, internal loading from the sediment can remain high and in-lake water quality may not improve.

Common carp and other rough fish uproot aquatic macrophytes during feeding and spawning and re-suspend bottom sediments, releasing phosphorus into the water column and decreasing water clarity.

Additionally, wind energy and motor boat traffic in shallow depths can disturb sediment that can be mixed into the water column and represent another potential source of internal load.

Certain SAV species such as invasive curly-leaf pondweed (CLP) can outcompete and suppress native vegetation species. CLP begins its growth cycle earlier in the season compared to other species and typically dies back in mid-summer. As a result, lakes with heavy CLP infestation can have little or no submerged vegetation by late summer. This can cause lower DO levels, increased sediment re-suspension, and phosphorus release from sediment. Eurasian watermilfoil, which is present in many lakes throughout Minnesota, is not considered a phosphorus source during the summer growing season, but is an invasive species that can out-compete native vegetation and negatively impact recreational activity.

***Septic and Unsewered Communities***

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

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

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

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

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

Currently, the exact number and status of SSTSs in the Cottonwood River Watershed is unknown. However, each year every county in the state reports estimated FTPGW and ITPHS compliance rate estimates to the MPCA. This TMDL report's bacteria source assessment (Section 3.6.2) and lake nutrient source assessment (Section 3.6.3) utilizes the most recent estimated rates reported by the county to the MPCA (Table 14; MPCA personal communication 2018). It should be noted that these rates are county-wide estimates and were developed using a wide range of methods and resources and are intended for planning purposes only.

**Table 14. Estimated SSTS compliance rates by county in the Cottonwood River Watershed (MPCA personal communication 2018).**

| County | FTPGW SSTS | ITPHS SSTS |
|---|---|---|
| Brown | 20% | 24% |
| Cottonwood | 40% | 39% |
| Lyon | 24% | 5% |
| Murray | 15% | 10% |
| Redwood | 30% | 5% |

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

***Municipal and Industrial Wastewater***

Domestic, commercial, and industrial wastewaters are collected and treated by municipalities before being discharged to water bodies as municipal wastewater effluent. Treated industrial wastewaters and cooling waters from industries, businesses, and other privately owned facilities may also be discharged to surface waters. Both municipal and industrial wastewater dischargers must obtain NPDES permits. There are no industrial wastewater dischargers in the watershed.

There are 16 active permitted municipal wastewater facilities that discharge to the impaired reaches covered in this TMDL (Table 15). Other permitted wastewater facilities that do not discharge pollutants of concern for this TMDL include Erickson Handi Mart (509) and Highwater Ethanol, LLC (517 and 518).

**Table 15. Municipal wastewater treatment facilities within the impaired reach watersheds in the Cottonwood River Watershed.**

| Facility Name | NPDES ID# | Facility Type | Impaired Reach(es) |
|---|---|---|---|
| Balaton WWTP | MN0020559 | Municipal | 502, 504, 508, 509 |
| Clements WWTP | MNG580094 | Municipal | 509, 599 |
| Garvin WWTP | MNG580101 | Municipal | 502, 504, 508, 509 |
| Jeffers WWTP* | MNG580111 | Municipal | |
| Lamberton WWTP | MNG580100 | Municipal | 508, 509, 517, 518 |
| Lucan WWTP | MNG580112 | Municipal | 509, 599 |
| Revere WWTP | MNG580114 | Municipal | 504, 508, 509, 523 |
| Sanborn WWTP | MNG580115 | Municipal | 508, 509 |
| Sleepy Eye WWTP | MNG580041 | Municipal | 511 |
| Springfield WWTP | MN0024953 | Municipal | 508, 509 |
| Storden WWTP | MNG580106 | Municipal | 517, 508, 509, 519 |
| Tracy WWTP | MN0021725 | Municipal | 504, 508, 509 |
| Wabasso WWTP | MN0025151 | Municipal | 509, 599 |

| Facility Name | NPDES ID# | Facility Type | Impaired Reach(es) |
|---|---|---|---|
| Walnut Grove WWTP | MN0021776 | Municipal | 504, 508, 509, 523 |
| Wanda WWTP | MNG580126 | Municipal | 509, 599 |
| Westbrook WWTP | MNG580127 | Municipal | 517, 508, 509, 519 |

*Jeffers WWTP is physically located in the Cottonwood River Watershed but discharges outside of the watershed via JD 9 to Little Cottonwood River (Minnesota River-Mankato Watershed)

***Construction and Industrial Stormwater***

Construction stormwater is regulated through an NPDES permit (MNR100001). Untreated stormwater that runs off construction sites often carries sediment to surface water bodies. Because phosphorus travels adsorbed to sediment, construction sites can also be a source of phosphorus to surface waters. Phase II of the stormwater rules adopted by the EPA requires an NPDES permit for a construction activity that disturbs one acre or more of soil; a permit is needed for smaller sites if the activity is either part of a larger development or if the MPCA determines that the activity poses a risk to water resources. Coverage under the construction stormwater general permit requires sediment and erosion control measures that reduce stormwater pollution during and after construction activities.

Industrial stormwater is regulated through an NPDES permit (MNR050000) or Nonmetallic Mining & Associated Activities general permit (MNG490000) when stormwater discharges have the potential to come into contact with materials and activities associated with the industrial activity. It is estimated that a small percent of the project area is permitted through the industrial stormwater permit, and industrial stormwater is not considered a significant source. On average, there is one permitted industrial stormwater site in every 53 square miles of the Cottonwood River Watershed.

On average, based on watershed-wide data, less than 0.2% of the watershed area is permitted under the construction and industrial stormwater permit in any given year. Thus, construction and industrial stormwater is not considered a significant source of sediment, and phosphorus throughout the Cottonwood River Watershed.

***Natural Bacterial Reproduction***

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

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

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

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

### 3.6.1 Stream TSS Source Summary

As discussed in the previous section, sediment loading to streams can come from both external and internal sources. External sources of TSS include sediment loading from permitted sources such as construction and industrial stormwater, runoff from urban areas, wastewater effluent; as well as nonpermitted sources such as overland erosion from cropland, hay/pasture, forest, and rangeland. Potential internal sources of sediment include bank erosion and in-channel algal production. This TMDL used the Cottonwood River Watershed HSPF model to evaluate sediment loading from various sources to each of the 11 TSS impaired reaches. Figure 6 and Table 15present HSPF predicted annual TSS loads to each impaired reach by major source category.

Chl-*a* data for each impaired reach was also reviewed to determine whether algae growth is a potential source of turbidity/TSS and poor water clarity. Six of the 11 impaired reaches have Chl-*a* data (Table 16). Chl-*a* concentrations in four of the six reaches with data have at least one exceedance of the State’s eutrophication criteria of 35 µg/L for streams in the South River Nutrient Region, suggesting algae may be a source of turbidity/TSS. Most of these exceedances occurred during late summer (August and September) low flow conditions. More data will need to be collected to fully assess algal turbidity in the TSS impaired reaches.

Figure 6. TSS contributions by source for each impaired reach estimated using the Cottonwood River Watershed HSPF model.

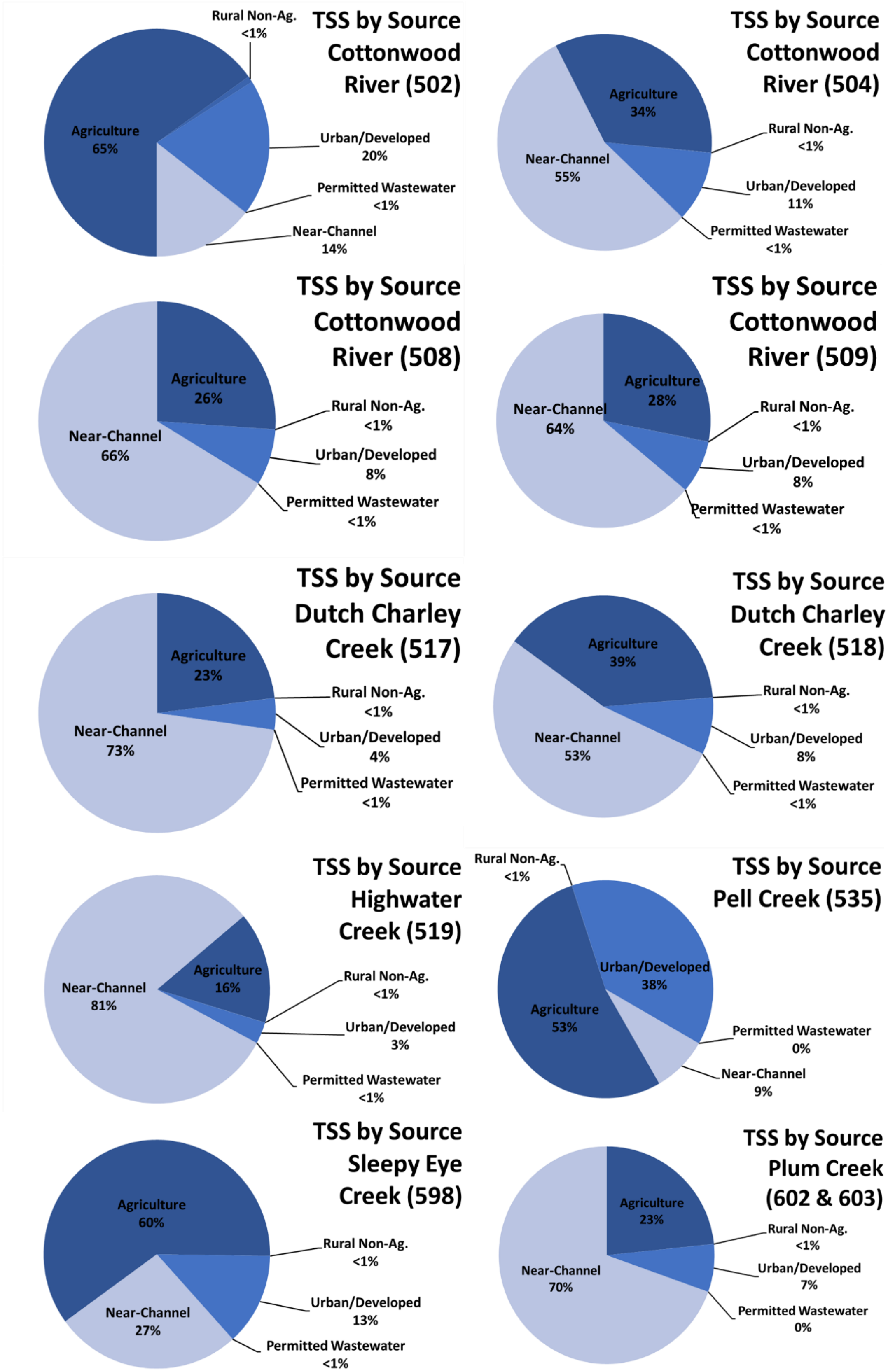


**Table 16. TSS source assessment by land use category in the Cottonwood River Watershed.**
Note: Numbers in this table are based on HSPF average annual TSS loads for model years 1996-2017.

| Impaired Reach Description | Reach ID | Units | HSPF Model Estimates | | | | | | Chl-*a* Data |
|---|---|---|---|---|---|---|---|---|---|
| | | | Agriculture[1] | Rural Non-Ag.[2] | Urban/Developed[3] | Permitted Wastewater | Near-Channel[4] | Total | |
| Cottonwood River: Headwaters to Meadow Creek | 502 | tons/yr | 1,578 | 21 | 472 | 2 | 349 | 2,423 | Of the 15 samples collected, none exceed 35 µg/L (average = 5 µ/L) |
| | | percent | 65% | <1% | 20% | <1% | 14% | 100% | |
| Cottonwood River: Plum Creek to Dutch Charley Creek | 504 | tons/yr | 9,020 | 15 | 2,799 | 27 | 14,660 | 26,521 | Of the 8 samples collected, none exceed 35 µg/L (average = 16 µg/L) |
| | | percent | 34% | <1% | 11% | <1% | 55% | 100% | |
| Cottonwood River: Coal Mine Creek to Sleep Eye Creek | 508 | tons/yr | 18,824 | 20 | 5,461 | 35 | 47,800 | 72,140 | Of the 8 samples collected, two exceed 35 µg/L (average = 24 µg/L) |
| | | percent | 26% | <1% | 8% | <1% | 66% | 100% | |
| Cottonwood River: Sleepy Eye Creek to JD 30 | 509 | tons/yr | 24,596 | 46 | 6,961 | 26 | 55,824 | 87,452 | No data has been collected |
| | | percent | 28% | <1% | 8% | <1% | 64% | 100% | |
| Dutch Charley Creek: Highwater Creek to Cottonwood River | 517 | tons/yr | 7,044 | 6 | 1 303 | 10 | 22,299 | 30,662 | Of the 8 samples collected, one exceeds 35 µg/L (average = 15 µg/L) |
| | | percent | 23% | <1% | 4% | <1% | 73% | 100% | |
| Dutch Charley Creek: Headwaters to Highwater Creek | 518 | tons/yr | 2,202 | 2 | 472 | 2 | 3,016 | 5,694 | No data has been collected |
| | | percent | 39% | <1% | 8% | <1% | 53% | 100% | |
| Highwater Creek: Double Lake outlet to Dutch Charley Creek | 519 | tons/yr | 3,898 | 16 | 751 | 3 | 20,025 | 24,693 | Of the 10 samples collected, one exceeds 35 µg/L (average = 10 µ/L) |
| | | percent | 16% | <1% | 3% | <1% | 81% | 100% | |
| Pell Creek: Headwaters to T109 R38W S29, east line | 535 | tons/yr | 208 | <1 | 149 | -- | 33 | 390 | No data has been collected |
| | | percent | 53% | <1% | 38% | 0% | 9% | 100% | |
| | 599 | tons/yr | 5,410 | 1 | 1,172 | 5 | 2,393 | 8,981 | |

| Impaired Reach Description | Reach ID | Units | HSPF Model Estimates | | | | | | Chl-*a* Data |
|---|---|---|---|---|---|---|---|---|---|
| | | | Agriculture[1] | Rural Non-Ag.[2] | Urban/Developed[3] | Permitted Wastewater | Near-Channel[4] | Total | |
| Sleepy Eye Creek: T109 R33W S5, west line to Cottonwood River | | percent | 60% | <1% | 13% | <1% | 27% | 100% | Of the 17 samples collected, two exceed 35 µg/L (average = 14 µg/L) |
| Plum Creek: Headwaters to Cottonwood River | 602, 603 | tons/yr | 1,942 | 2 | 592 | -- | 5,786 | 8,322 | No data has been collected |
| | | percent | 23% | <1% | 7% | 0% | 70% | 100% | |

[1] Includes cultivated cropland, grassland, hay/pasture
[2] Includes forest and shrubland, groundwater, wetlands and open water
[3] Includes MS4 and non-MS4 urban stormwater and city/county/state roadways
[4] Includes bluff and bed/bank erosion

### 3.6.2 Stream *E. coli* Source Summary

The primary *E. coli* sources considered for this TMDL include livestock, stormwater runoff from urban areas, wildlife, wastewater treatment plants (WWTPs), and ITPHS SSTS. Use of watershed models for estimating relative contributions of *E. coli* sources delivered to streams is difficult and generally has high uncertainty. Thus, a simpler desktop bacteria accounting exercise was conducted to provide a general estimate of the total amount of bacteria produced by each potential source within the impaired reach watersheds. This exercise was done using various GIS layers and other information, including: MPCA registered feedlot GIS layer, literature rates of livestock and domestic animals, 2010 census data for urban and rural areas, SSTS failure rates reported by county, and DNR wildlife population studies. Appendix A presents results of the desktop bacteria production exercise for each impaired reach watershed. Table 17below provides a general summary of the accounting exercise along with notes and discussion of local knowledge, data gaps, and additional information that would further refine our understanding of bacteria sources of the impaired reaches. It is important to point out that the desktop bacteria production exercise is not based on a quantitative assessment of *E. coli* loads delivered to surface waters. At this time, there is no microbial source tracking information (e.g., DNA fingerprinting) available to determine the exact source(s) of elevated bacteria observed within each impaired reach.

In general, livestock animals were by far the biggest bacteria producer within all the impaired reach drainage areas. Bacteria production for ITPHS AUs across the impaired reach drainage areas was significantly low compared to livestock production. The production exercise estimates that there are ~125 ITPHS SSTS systems throughout the eight impaired reach drainage areas. Although these numbers are relatively low, ITPHS systems that discharge near the impaired reach or a major tributary may be a critical source, particularly during low flow conditions.

Review of discharge monitoring data (Appendix B) from the seven point-source dischargers (see Section 4.3.2) located within the impaired reach watersheds suggest *E. coli* effluent concentrations are typically well below the *E. coli* standard. Thus, these point sources are not considered a source of concern. Since urban/developed land accounts for less than 10% (Table **6**) of the land use within the impaired reach drainage areas, urban sources (i.e., domestic pets) represent a very small portion of the total bacteria produced in the watersheds.

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

**Table 17. E. coli source summary for each impaired reach covered in this TMDL. Based on data collected between 2000 – 2017.**

| Impaired Reach | Cropland/Manure | Livestock/Pastures near Streams | Wildlife | Urban | WWTPs | SSTS | Upstream Reach(es) | In-stream (sediment) | Notes |
|---|---|---|---|---|---|---|---|---|---|
| Cottonwood River Reach 502 | ● | ○ | - | - | X | ●/○ | X | ? | • Exceedances occur during high (100%), mid (100%) and low (100%) flow conditions. No samples collected during very high or very low flow conditions.<br>• 3% of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |
| Judicial Ditch 30 Reach 511 | ● | - | - | - | - | ●/○ | ● | ? | • Exceedances occur during high (100%) and mid (100%) flow conditions. No samples collected during very high, low, or very low flow conditions.<br>• Less than 1% of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |
| Highwater Creek Reach 519 | ● | ● | - | - | - | ●/○ | X | ? | • Exceedances occur during very high (100%), high (100%) and mid (100%) flow conditions. No samples collected during low or very low flow conditions.<br>• 33% of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |
| Dry Creek Reach 520 | ● | ○ | - | - | X | ●/○ | X | ? | • Exceedances occur during very high (100%), high (100%) and mid (100%) flow conditions. No samples collected during low or very low flow conditions.<br>• 1% of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |
| Mound Creek Reach 521 | ● | ○ | - | - | X | ●/○ | X | ? | • Exceedances occur during very high (100%), high (100%), mid (100%) and low (100%) flow conditions. No samples collected during very low flow conditions.<br>• 6% of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |
| Pell Creek Reach 523 | ● | - | - | - | - | ●/○ | X | ? | • Exceedances occur during high (100%) and mid (100%) flow conditions. No samples collected during very high, low, or very low flow conditions.<br>• Less than 1% of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |
| Coal Mine Creek Reach 604 | ● | - | - | - | X | ●/○ | X | ? | • Exceedances occur during very high (100%), high (94%), mid (100%) and low (100%) flow conditions. No samples collected during very low flow conditions.<br>• None of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |
| Judicial Ditch 40 Reach 609 | ● | - | - | - | X | ●/○ | X | ? | • Exceedances occur during high (100%), mid (100%) and low (100%) flow conditions. No samples collected during very high or very low flow conditions.<br>• None of the MPCA registered livestock in the watershed are in close proximity to streams/waterways. |

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

### 3.6.3 Lake Phosphorus Source Summary

Lake response models were set up for each of the seven impaired lakes in the Cottonwood River Watershed to evaluate phosphorus sources and estimate annual phosphorus budgets. The lake response model selected for this exercise was the Canfield-Bachmann lake equation (Canfield and Bachmann, 1981). This equation estimates the lake phosphorus sedimentation rate, which is needed to predict the relationship between in-lake phosphorus concentrations and phosphorus load inputs. The phosphorus sedimentation rate is an estimate of net phosphorus loss from the water column through sedimentation to the lake bottom, and is used in concert with user supplied lake-specific characteristics such as annual phosphorus loading, mean depth, and hydraulic flushing rate to predict in-lake phosphorus concentrations. Model predictions are then compared to measured data to evaluate how well the model describes the lake system. If necessary, the model parameters are adjusted appropriately to achieve an approximate match to monitored data.

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

***Atmospheric Loads***

Atmospheric inputs of phosphorus from wet and dry deposition were estimated using published rates based on annual precipitation (Barr Engineering 2004). The atmospheric deposition values used for dry (<25 inches), average, and wet precipitation years (>38 inches) are 24.9, 26.8, and 29.0 kg/km2-year, respectively. These values are equivalent to 0.22, 0.24, and 0.26 lbs/acre/year for dry, average, and wet years, respectively.

***SSTS Loads***

Phosphorus loading from SSTSs to each impaired lake was estimated using methods similar to the Lower Minnesota River Watershed TMDL (MPCA 2020a). First, the total number of people in each lakeshed was estimated 1) for households in shoreland areas (i.e., near the lake); and 2) for households outside shoreland (i.e., farther from lakes). To estimate the number of people living immediately adjacent to each lake, aerial photos were used to count the number of homes/cabins. This number was then multiplied by number of people per household (assumed to be 2.55 on average for the Minnesota River Basin; Barr Engineering 2004) and an adjustment factor to account for the assumption that approximately half of homes/cabins adjacent to lakes are used only four months each year (adjustment factor was 2/3). To estimate the number of people living farther from lakes, 2010 U.S. Census data was used, and the estimated number of people adjacent to each lake was subtracted from Census-estimated lakeshed numbers. Phosphorus load from SSTSs was assumed to be 1.978 lbs of TP per person per year (Barr Engineering 2004) and was used in conjunction with the estimates above to obtain TP loading to SSTSs each year.

To determine the TP loading leaving SSTSs and entering each impaired lake, loads were calculated for each of the three types of SSTS: those labeled compliant, FTPGW, or ITPHS (see SSTS discussion in Section 3.6). Because the compliance status of SSTS in each lakeshed is not known at this time, 2018 county-wide estimated compliance rates were used for this calculation (Table 14; MPCA personal communication 2018). Phosphorus removal rates for SSTSs in each of these compliance groups were then applied: for SSTSs adjacent to lakes, 80% removal rates were assumed for compliant systems, while 57% removal rates were assumed for both failing and ITPHS SSTSs (Barr Engineering 2004). For SSTSs father from lakes, 90%, 70%, and 57% removal rates were assumed for compliant, failing, and ITPHS SSTSs, respectively (Barr Engineering 2004). The phosphorus removal and soil phosphorus attenuation percentages assumed for conforming and nonconforming SSTSs in this analysis are within the range of literature values (Viraraghavan and Warnock 1975; Reckhow and Simpson 1980; Kellogg et al. 1995; EPA 2002b; ENSR 2003) as reported by Barr Engineering in 2004. Finally, the sum was taken of phosphorus loading from all compliance groups and from households both adjacent to and farther from lakes to obtain TP loading to each impaired lake from SSTSs.

***Watershed Loads***

Watershed flow and phosphorus loads to each impaired lake were estimated using the Cottonwood River Watershed HSPF model (Appendix D). HSPF-predicted average annual watershed runoff depths and TP concentrations to each impaired lake in the Cottonwood River Watershed ranged from 5 to 18 inches/year and 211-429 µg/L, respectively. HSPF utilizes several individual subroutines/models and assumptions to model hydrology and pollutant loading rate and transport, and therefore the watershed load to each lake can be further analyzed and broken down by sub-categories such as feedlots, manure, groundwater, bluff erosion, bed/bank erosion, and individual land uses (i.e., developed, forest, cropland, grassland, etc.). Figure 7 shows the HSPF-predicted average annual watershed TP inputs to each impaired lake while Appendix C contains a more detailed description of the HSPF-predicted watershed load broken down by the sub-categories described above. As shown in Appendix C, an overwhelming majority of the watershed load to each lake comes from cropland. The HSPF results presented in Appendix C are also summarized in Table 18.

***Upstream Impaired Lake Loads***

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

***Internal Loads***

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

Although it is difficult and/or cost prohibitive to directly measure phosphorus inputs from sediment, fish, vegetation, and wind/boating, there are ways to evaluate whether these sources have significant potential to contribute to internal load. For example, internal loading from sediments can be estimated by combining sediment phosphorus RR estimates with an anoxic factor (AF) calculation (Nürnberg 2004).

Sediment phosphorus RRs were assessed as part of this TMDL for Double Lake by collecting intact sediment cores and incubating them in the laboratory under anoxic conditions. Results of this analysis (Table 18 and Appendix C) indicate that Double Lake (RR = 9.2 $mg/m^2/day$) has high potential for sediment phosphorus release under anoxic conditions. The AF estimates the period of anoxia over the lake sediments and is calculated using temperature-DO profiles. AFs are often difficult to measure in shallow lakes, such as Double Lake, since they can have intermittent anoxic periods that aren't measured with routine monitoring. Nonetheless, AF was estimated for Double Lake (<5 days/year) using available temperature-DO profile data and then multiplied by the laboratory measured phosphorus RR and total area of Double Lake to estimate gross internal load. Results indicate that sediment release of phosphorus may be accounting for approximately 12% of the internal load in Double Lake. Watershed inputs to the lake will need to be monitored and compared to HSPF predicted model output in order to validate the lake response model and the impact of internal loading.

In-lake water quality, particularly in shallow lakes, is closely linked to the health and structure of the lake's biological communities. Water quality degradation can occur when certain aquatic invasive species (i.e., common carp) are present in high densities or certain native species (i.e., black bullhead, fathead minnow) become over-abundant thus creating an imbalanced fishery. Common carp uproot vegetation and re-suspend sediment which, when there are high densities of carp in a lake, can lead to increased water turbidity, reduced vegetation coverage, and lower waterfowl populations. Recent research suggests that these impacts begin to occur at common carp densities of ~100 kg of carp biomass/hectare (89 lbs/acre) (Bajer et al. 2009). In 2018, Wenck Associates, Inc. conducted common carp population assessments for Double Lake using standard electroshocking methods described in (Bajer and Sorensen 2012). Results of the Double Lake assessment indicate the lake has a common carp density (208 lbs/acre) that is more than double the critical threshold (89 lbs/acre), suggesting that common carp (and possibly other fish) are contributing to poor water quality and habitat degradation. Appendix C contains a detailed discussion of the common carp assessments for Double Lake. Sleepy Eye Lake (delisted in 2020) is also included.

Double Lake was the only impaired lake in the Cottonwood River Watershed assessed for common carp densities; however, at least one DNR trap and gill net survey has been performed on four impaired lakes covered in this TMDL. Three impaired lakes did not have a DNR fisheries survey on record. Common carp along with certain native fishes (i.e., largemouth bass) avoid standard trap and gill nets used by the DNR, therefore, other techniques such as the electroshocking method described above are needed to accurately estimate population numbers and densities that can be used to inform management strategies. That said, the DNR trap and gill net surveys provide a good indicator of the presence/absence of common carp, black bullhead and other species that may impact water quality. Review of historic DNR trap and gill net surveys noted the presence of black bullhead and common carp in four of the seven lakes (Table 18 and Appendix C). In many of the lakes, black bullhead and/or common carp comprised a large percentage of the fish sampled in the trap and gill nets and therefore it is likely that these species are impacting water quality in these systems.

The final phosphorus source assessment results for each impaired lake are shown in Figure 6 (phosphorus lbs per year). Table 18 provides a summary of the source categories that are of most concern for each impaired lake, based on the quantitative lake response model results (Figure 7) as well as the sediment core and common carp survey results for Double Lake, the DNR fish surveys, and anecdotal information.

**Figure 7. Average annual TP contributions by source based on HSPF and lake response modeling results in the Cottonwood River Watershed.**

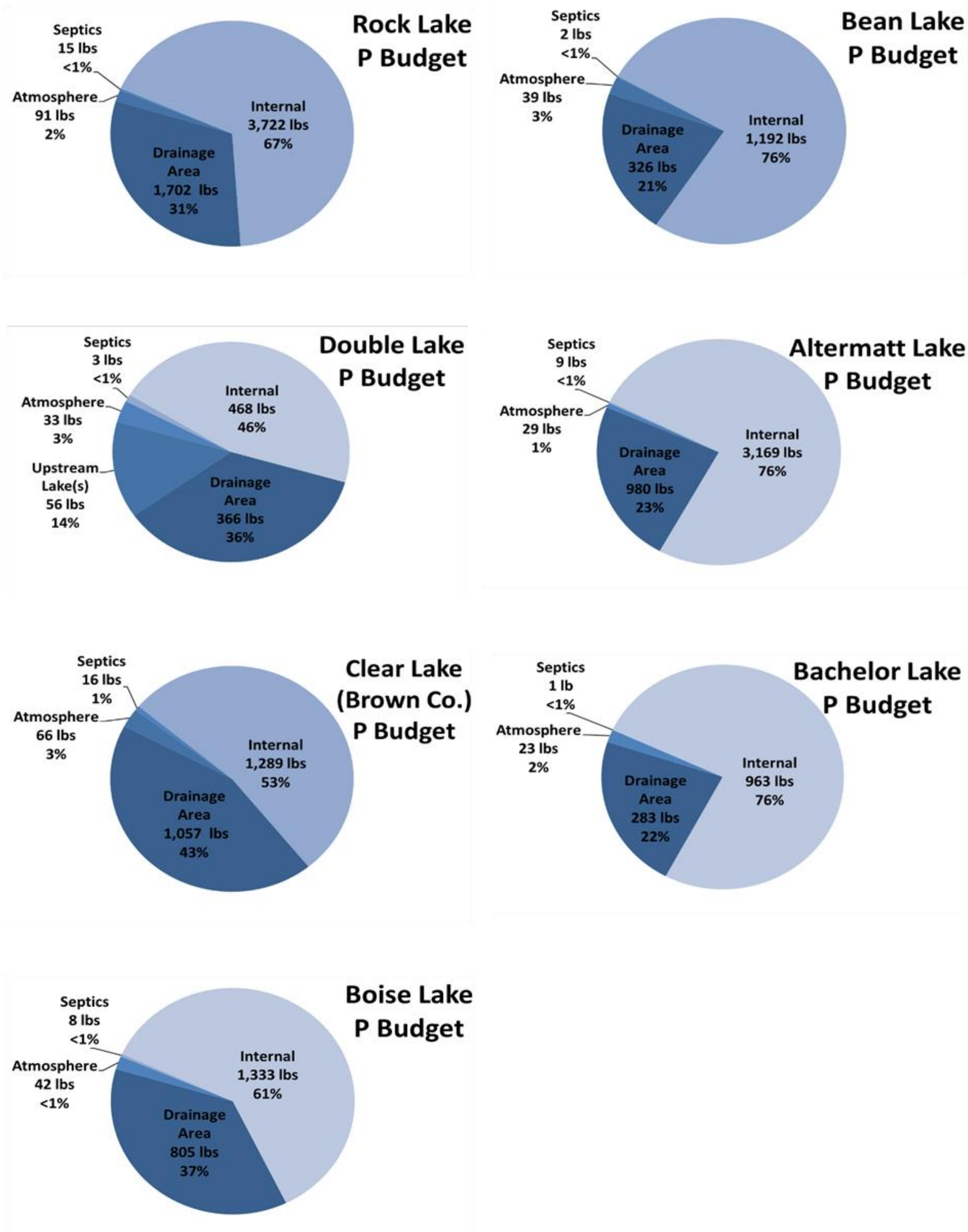


**Table 18. TP source summary for each impaired lake covered in this TMDL.**

| Lake Name | Watershed Sources | | | | | Internal Sources | | | Upstream Impaired Lake(s) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Agriculture[1] | Urban | SSTS | WWTPs | Upstream Lakes | Sediment Release | Aquatic Vegetation (i.e., (curly-leaf pondweed) | Rough Fish (i.e., common carp) | | |
| Rock | ● | x | ○ | x | x | Δ | Δ | Δ | NA | DNR fish surveys observed a large presence of black bullhead and moderate presence of common carp in 2014.<br>The internal loading rate (32.1 mg/m²/day) based on the model residual approach is extremely high.<br>The HSPF predicted average annual watershed TP concentration (286 µg/L) exceeds the 150 µg/L eutrophication standard. |
| Bean | ● | x | ○ | x | x | Δ | Δ | Δ | NA | DNR fish surveys observed a very large presence of black bullhead and relatively low presence of common carp in 2014.<br>The internal loading rate (17.9 mg/m²/day) based on the model residual approach is high.<br>The HSPF predicted average annual watershed TP concentration (211 µg/L) exceeds the 150 µg/L eutrophication standard. |
| Double (N. Potion) | ● | x | ○ | x | ○ | ○ | Δ | ● | Bean | DNR fish surveys observed a large presence of black bullhead and moderate presence of common carp in 2015.<br>A common carp population assessment conducted in 2018 suggested biomass density (~208 lbs/acres) was more than double the critical threshold (89 lbs/acre).<br>Lab measured sediment RR (9.2 mg/m²/day) is high compared to other lakes, however, DO profiles indicate low potential for anoxia (DO <2.0 mg/L) near the sediment/water interface.<br>The HSPF predicted average annual watershed TP concentration (429 µg/L; does not include Lake Benton contribution) exceeds the 150 µg/L eutrophication standard. |
| Clear (Brown Co.) | ● | x | ○ | x | x | Δ | Δ | Δ | NA | DNR fish surveys observed a large presence common carp and moderate presence of black bullhead in 2017.<br>The internal loading rate (40.6 mg/m²/day) based on the model residual approach is extremely high.<br>The HSPF predicted average annual watershed TP concentration (167 µg/L; does not include Lake Benton contribution) exceeds the 150 µg/L eutrophication standard. |
| Altermatt | ● | x | ○ | x | x | Δ | Δ | Δ | NA | No DNR fish surveys have been conducted on this lake.<br>The internal loading rate (35.7 mg/m²/day) based on the model residual approach is extremely high. |

| Lake Name | Watershed Sources | | | | | Internal Sources | | | Upstream Impaired Lake(s) | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Agriculture[1] | Urban | SSTS | WWTPs | Upstream Lakes | Sediment Release | Aquatic Vegetation (i.e., (curly-leaf pondweed) | Rough Fish (i.e., common carp) | | |
| | | | | | | | | | | The HSPF predicted average annual watershed TP concentration (356 µg/L) exceeds the 150 µg/L eutrophication standard. |
| Boise | ● | x | ○ | x | x | Δ | Δ | Δ | NA | No DNR fish surveys have been conducted on this lake.<br>The internal loading rate (10.7 mg/m²/day) based on the model residual approach is high.<br>The HSPF predicted average annual watershed TP concentration (329 µg/L) exceeds the 150 µg/L eutrophication standard. |
| Bachelor | ● | x | ○ | x | x | Δ | Δ | Δ | NA | No DNR fish surveys have been conducted on this lake.<br>The internal loading rate (12.7 mg/m²/day) based on the model residual approach is high.<br>The HSPF predicted average annual watershed TP concentration (349 µg/L) exceeds the 150 µg/L eutrophication standard. |

● Primary source ○ Secondary source x Not considered a primary or secondary source at this time Δ Potential source however not enough data/info available at this time to evaluate
Includes cropland, pasture/grassland, and feedlots. See Appendix C for more detail of each sub-category predicted by the HSPF model.

# 4. TMDL Development

## 4.1 TMDL Overview

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

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

Where:

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

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

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

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

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

Per Code of Federal Regulations (40 CFR 130.2(1)), TMDLs can be expressed in terms of mass per time, toxicity or other appropriate measures. For this TMDL, the TMDLs, allocations and margins of safety are expressed in mass/day. Each of the TMDL components is discussed in greater detail in the following sections.

### 4.1.1 Model Approach

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

HSPF models for the Cottonwood River Watershed were originally developed in 2012 and then updated in 2016 and 2019 to support this TMDL and other planning and management efforts in the watershed (Tetra Tech 2016 and 2019). The HSPF models predict the range of flows that have historically occurred in the modeled area, the load contributions from a variety of point and nonpoint sources in a watershed, and the source contributions when paired flow and concentration data are limited. Supporting documentation is available which discuss modeling methodologies, data used, and calibration results for the three major watershed HSPF models (Tetra Tech 2016 and 2019).

### 4.1.2 Load Duration Curve Approach

Pollutant loading capacity for the TSS and *E. coli* impaired stream reaches were developed using LDCs. LDCs incorporate flow and water quality across the reach flow zones, and provide loading capacities and a means of estimating load reductions necessary to meet water quality standards. To develop the LDCs, HSPF-simulated average daily flow values from 2008 through 2017 for each reach were multiplied by the appropriate water quality standard and converted to daily loads to create "continuous" LDCs. Because this method uses a long-term record of daily flows, virtually the full spectrum of allowable loading capacities is represented by the resulting curve.

In the TMDL equation tables of this TMDL, only five points on the entire loading capacity curve are depicted: very high flows (0% to 10%), high flows (10% to 40%), mid flows (40% to 60%), low flows (60% to 90%) and very low flows (90% to 100%). For simplicity, only the median (or midpoint) load of each flow zone is used to show the TMDL equation components in the TMDL tables. However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA. For the purposes of this TMDL, the baseline year for implementation will be 2012, which represents the mid-range year of the HSPF flow record used to construct the LDCs (See Section 8.2.3).

### 4.1.3 Natural Background Consideration

Natural background was given consideration in the development of LA in this TMDL. Natural background is the landscape condition that occurs outside of human influence. Minn. R. 7050.0150, subp. 4, defines the term "natural causes" as the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a water body in the absence of measurable impacts from human activity or influence. Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc. For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment and therefore natural background is accounted for and addressed through the MPCA's water body assessment process. Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this TMDL. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, wastewater treatment facilities, failing SSTSs, and other anthropogenic sources.

Based on the MPCA's water body assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of any of the impairments and/or affect the water bodies' ability to meet state water quality standards. For all impairments addressed in this TMDL study, natural background sources are implicitly included in the LA portion of the TMDL allocation tables and TMDL reductions should focus on the major anthropogenic sources identified in the source assessment. Federal law instructs an agency to distinguish between natural and nonpoint source loads "[w]herever possible." 40 CFR § 130.2(g). However, Minnesota law does not compel the MPCA to develop a separate LA for natural background sources. For more information, see Crystal Lake TMDL Court of Appeals Decision; Filed February 4, 2019.

## 4.2 TSS - Streams

### 4.2.1 Loading Capacity Methodology

LDCs were used to represent the loading capacity (LC) for each TSS impaired reach. The flow component of the LC curve is based on the HSPF-simulated daily average flows (2008 through 2017), and the concentration component is the TSS concentration criteria of 65 mg/L. TSS LDCs for each impaired reach are shown in Section 4.2.6. On these figures, the red curve represents the allowable TSS LC of the reach for each daily flow. The median (or midpoint) load of each flow zone is used to represent the total LC in the TMDL tables. Each reach's LC can be compared to current conditions by plotting the measured load during each water quality sampling event (black circles in Figure 8 through Figure 17). Each value that is above the curve represents an exceedance of the water quality standard, while those below the line are below the water quality standard.

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

### 4.2.2 Wasteload Allocation Methodology

The WLAs for TSS were divided into three categories: NPDES permitted wastewater dischargers, NPDES MS4 stormwater, and NPDES permitted construction and industrial stormwater. The following sections describe how each WLA category was determined. The NPDES permitted livestock CAFOs are zero discharge facilities and are given a WLA of zero and should not impact water quality in the watershed as a point source. Therefore, it is not necessary to put them in the TSS TMDL tables in Section 4.2.6. Also, straight pipe septic systems are illegal and receive a WLA of zero. Therefore, it is not necessary to put them in the TSS TMDL tables.

***NPDES Permitted Wastewater Dischargers***

There are 14 active regulated NPDES wastewater dischargers in the Cottonwood River TSS impaired reach drainage areas that have been assigned TSS effluent limits. Facility maximum daily effluent TSS loads were established and provided by the MPCA and are a function of the facility design flows and permitted TSS concentration limits (Table 19). WLAs for each facility were calculated by multiplying the TSS effluent concentration limit, permitted facility design flow, and a unit conversion factor. All dischargers have TSS effluent concentration limits less than the TSS standard of 65 mg/L. Therefore, facilities that discharge consistent with their WLAs are not a cause for in-stream exceedances of the TSS standard within their receiving water bodies and no permit modifications are needed at this time for the TSS impairments. WLAs for continuously discharging municipal WWTPs were calculated based on the average wet weather design flow, equivalent to the wettest 30-days of influent flow expected over the course of a year. Controlled municipal pond discharge WWTP WLAs were calculated based on the maximum daily volume that may be discharged in a 24-hour period.

**Table 19. TSS allocations for NPDES permitted wastewater dischargers in the Cottonwood River Watershed.**

| Impaired Reach | Facility Name and System Type | NPDES ID# | Flow used for WLA* (MGD) | Permitted Concentration (mg/L) | Wasteload Allocation (lbs/day) |
|---|---|---|---|---|---|
| 502, 504, 508, 509 | Balaton WWTP/Pond | MN0020559 | 0.816 | 45 | 306 |
| 509, 599 | Clements WWTP/Pond | MNG580094 | 0.163 | 45 | 61 |
| 502, 504, 508, 509 | Garvin WWTP/Pond | MNG580101 | 0.169 | 45 | 63 |
| 508, 509, 517, 518 | Lamberton WWTP/Pond | MNG580100 | 1.303 | 45 | 489 |
| 509, 599 | Lucan WWTP/Pond | MNG580112 | 0.684 | 45 | 257 |
| 504, 508, 509 | Revere WWTP/Pond | MNG580114 | 0.150 | 45 | 56 |
| 508, 509 | Sanborn WWTP/Pond | MNG580115 | 0.342 | 45 | 128 |
| 508, 509 | Springfield WWTP/Mechanical | MN0024953 | 0.780 | 30 | 195 |
| 517, 508, 509, 519 | Storden WWTP/Pond | MNG580106 | 0.264 | 45 | 99 |
| 504, 508, 509 | Tracy WWTP/Pond | MN0021725 | 3.495 | 45 | 1,312 |
| 509, 599 | Wabasso WWTP/Mechanical | MN0025151 | 0.113 | 30 | 28 |
| 504, 508, 509 | Walnut Grove WWTP/Mechanical | MN0021776 | 0.203 | 30 | 51 |
| 509, 599 | Wanda WWTP/Pond | MNG580126 | 0.179 | 45 | 67 |
| 509, 517, 508, 519 | Westbrook WWTP/Pond | MNG580127 | 1.629 | 45 | 611 |

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

***NPDES Permitted MS4 Stormwater***

The city of Marshall, which contributes to reaches 504, 508, and 509, is the only city subject to the NPDES/SDS MS4 General Permit (MNR040000), within the Cottonwood River TSS impaired reach watersheds covered by this TMDL. Figure 2 and Appendix A show the city of Marshall's municipal boundary and its location in the Cottonwood River Watershed. The city covers approximately 699 acres in the Cottonwood River Watershed, which is 0.2%, 0.1%, and 0.1% of the land area in the reach 504, 508, and 509 drainage areas, respectively. TSS allocations for the City of Marshall were calculated by multiplying each reach's MS4 percent drainage area coverage (percentages stated above) by the total watershed loading capacity (determined by LDCs). However, as there was a TSS unimpaired assessed reach (07020008-601) between the city of Marshall's outfall and the TSS impaired reaches, the City of Marshall isn't required to make any reductions to meet the assigned WLAs.

***NPDES Permitted Construction and Industrial Stormwater***

Construction stormwater is regulated by NPDES General Permit (MNR100001) 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 General Permit (MNR050000) or Nonmetallic Mining & Associated Activities General Permit (MNG490000) 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 a 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 Permits in the Cottonwood 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 0.15% of land in the Cottonwood River Watershed is currently under a Construction and Industrial Stormwater Permit. To determine the WLAs for these activities, total loading capacity in each flow zone was multiplied by the appropriate construction and industrial coverage percentage.

### 4.2.3 Load Allocation Methodology

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

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

### 4.2.4 Margin of Safety

The MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. The MOS can be either implicitly or explicitly defined as a set-aside amount. An explicit MOS was calculated as 5% of the loading capacity. Five percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty. The LDC calculations are based on TSS target concentrations and modeled flow data that has been calibrated to long-term monitored flow data. Most of the uncertainty with this calculation is therefore associated with the HSPF-modeled flow output for each reach. The Cottonwood River HSPF model was calibrated and validated using 21 years (1996 through 2017) of flow data from five gaging stations throughout the watershed (Tetra Tech 2019). Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. See Appendix D of this TMDL for the HSPF model calibration and validation results. The TSS stream LDCs were developed using HSPF-modeled daily flow data from April through September. The TSS TMDLs applied a MOS to each flow zone along the duration curves by subtracting 5% of the flow zones loading capacity.

### 4.2.5 Seasonal Variation and Critical Conditions

Both seasonal variation and critical conditions are accounted for in this TMDL through the application of LDCs. LDCs evaluate water quality conditions across all flow zones including high flow, runoff conditions where sediment transport tends to be greatest. Seasonality is accounted for by addressing all flow conditions in a given reach.

### 4.2.6 TSS TMDL Summary

The TMDL allocation tables (Table 20 through Table 29) present the total LC (Total Load (TMDL) in tables), the MOS, the WLAs (wasteload in tables) and the remaining watershed LAs (load in tables) for the TSS impaired reaches. Allocations for this TMDL were established using the 65 mg/L TSS standard. TMDL allocations for all reaches include the entire watershed draining to each impaired reach (See Figure 2 and Appendix A). For example, allocations for Cottonwood River reach 504 include the watersheds draining to Pell Creek reach 535 and Plum Creek reach 516, as well as the watersheds draining to all nonimpaired reaches upstream of these impairments.

The following rounding conventions were used in the TMDL tables:

- Values ≥1.0 reported in lbs/yr have been rounded to the nearest lb.
- Values <1.0 reported in lbs/yr have been rounded to one significant digit so that the value is greater than zero and a number is displayed in the table.

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

The bottom line of the table shows the estimated load reduction for all flow zones and is calculated based on the difference between the 90$^{th}$ percentile monitored TSS concentration (all available data April through September 2008 through 2017) and the 65 mg/L TSS standard. Since the TSS monitoring data is biased to higher flows (i.e., 50% to 72% of TSS samples collected during very high and high flow conditions), a flow zone correction was applied when calculating the percentile TSS concentration. This was done by multiplying each flow zone's 90$^{th}$ percentile monitored TSS concentration by the flow zone's frequency of occurrence. The following equation was used for this calculation:

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

At this time, there is not enough information or data available to estimate or calculate the existing (current conditions) load contribution from each of the WLA and LA sources presented in each table. Thus, the estimated load reduction for each flow zone applies to all sources. See Section 8 of this TMDL and the WRAPS report for further information on which sources and geographical locations within the impaired reach watersheds should be targeted for sediment reduction BMPs and restoration strategies. TSS LDCs (Figure 8 through Figure 17) for reaches in the Cottonwood River Watershed generally show TSS load exceedances during high and very high flows. TSS loading during high and very high flows is likely most related to near-channel (bank erosion) and agricultural sources (overland erosion from cropland, hay/pasture, and rangeland). Restoration and protection efforts should focus on these sources.

**Figure 8. Cottonwood River Reach 502 TSS load duration curve and monitored loads and exceedances.**

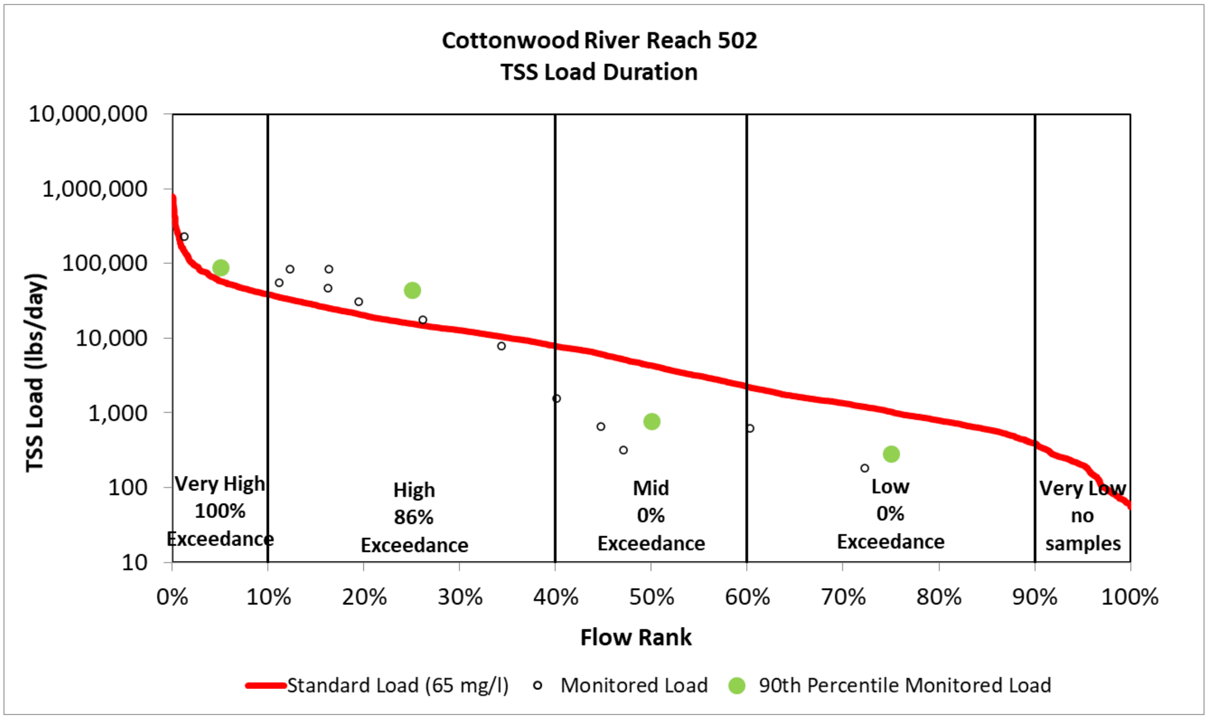



**Table 20. TSS TMDL summary for Cottonwood River Reach 502.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Garvin WWTP (MNG580101) | 63 | 63 | 63 | 63 | ** |
| | Balaton WWTP (MN0020559) | 306 | 306 | 306 | 306 | ** |
| | Construction/Industrial SW | 86 | 23 | 6 | 2 | ** |
| | **Total WLA** | **455** | **392** | **375** | **371** | ** |
| **Load** | **Total LA** | **54,513** | **14,430** | **3,708** | **608** | ** |
| **MOS** | | **2,893** | **780** | **215** | **52** | **10** |
| **Total load** | | **57,861** | **15,602** | **4,298** | **1,031** | **199** |
| **Existing 90th percentile concentration (mg/L)*** ** | | **75** | | | | |
| **Overall estimated percent reduction*** ** | | **13%** | | | | |

* Model simulated flow for HSPF reach 90 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
*** Water quality monitoring station(s) used to estimate reductions: S009-440.

**Figure 9. Cottonwood River Reach 504 TSS load duration curve and monitored loads and exceedances.**

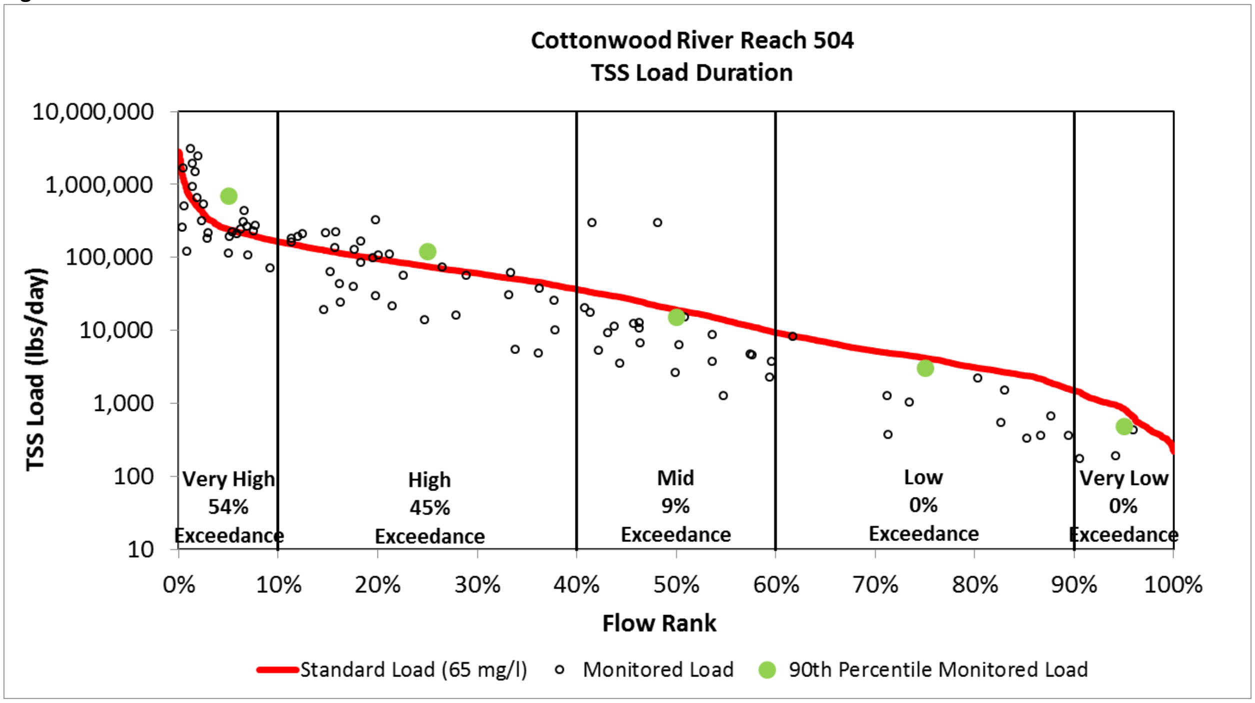



**Table 21. TSS TMDL summary for Cottonwood River Reach 504.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Garvin WWTP (MNG580101) | 63 | 63 | 63 | 63 | ** |
| | Revere WWTP (MNG580114) | 56 | 56 | 56 | 56 | ** |
| | Tracy WWTP (MN0021725) | 1,312 | 1,312 | 1,312 | 1,312 | ** |
| | Balaton WWTP (MN0020559) | 306 | 306 | 306 | 306 | ** |
| | Walnut Grove WWTP (MN0021776) | 51 | 51 | 51 | 51 | ** |
| | City of Marshall MS4 (MS400241)*** | 591 | 184 | 47 | 10 | ** |
| | Construction/Industrial SW | 360 | 112 | 29 | 6 | ** |
| | **Total WLA** | **2,739** | **2,084** | **1,864** | **1,804** | ** |
| **Load** | **Total LA** | **227,061** | **69,361** | **16,411** | **2,179** | ** |
| **MOS** | | **12,095** | **3,760** | **962** | **210** | **42** |
| **Total load** | | **241,895** | **75,205** | **19,237** | **4,193** | **836** |
| **Existing 90$^{th}$ percentile concentration (mg/L)******** | | **78** | | | | |
| **Overall estimated percent reduction******** | | **17%** | | | | |

* Model simulated flow for HSPF reach 250 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
*** Although a small portion of the city of Marshall falls within the drainage area for this reach, reductions are not required (see Section 4.2.2).
**** Water quality monitoring station(s) used to estimate reductions: S002-247.

**Figure 10. Cottonwood River Reach 508 TSS load duration curve and monitored loads and exceedances.**

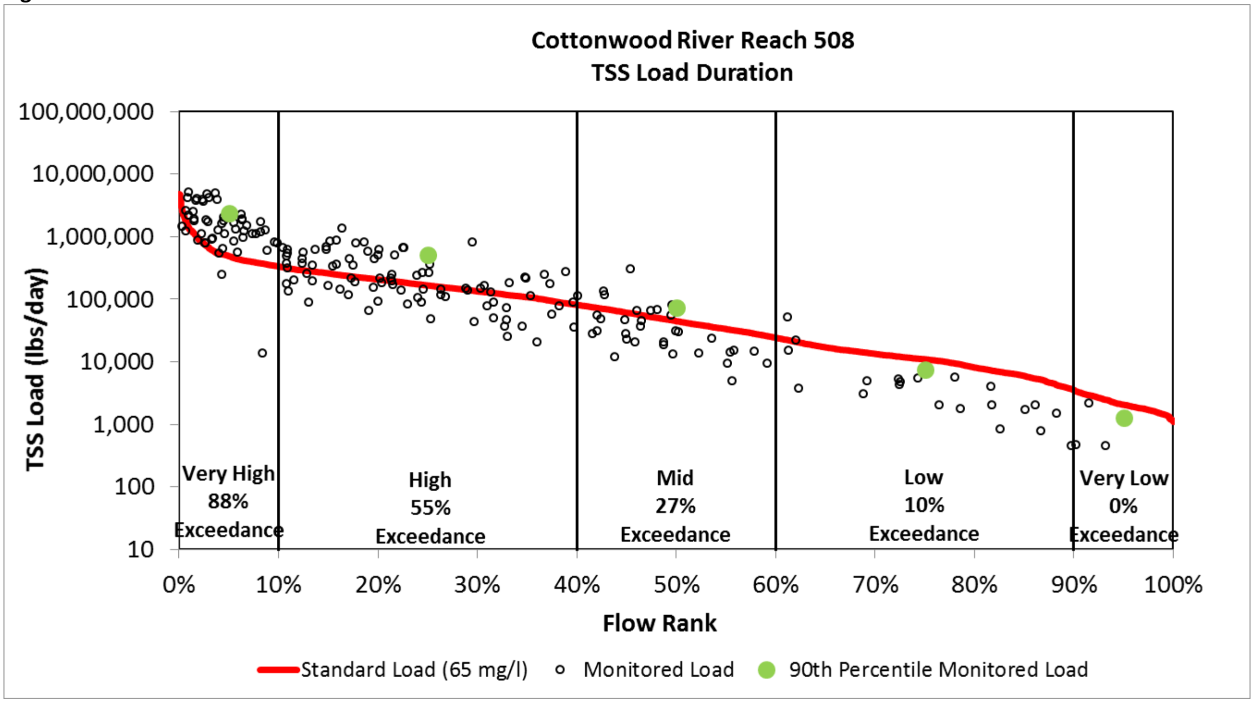



**Table 22. TSS TMDL summary for Cottonwood River Reach 508.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load lbs/day) | | | | |
| Wasteload | Sanborn WWTP (MNG580115) | 128 | 128 | 128 | 128 | ** |
| | Springfield WWTP (MN0024953) | 195 | 195 | 195 | 195 | ** |
| | Balaton WWTP (MN0020559) | 306 | 306 | 306 | 306 | ** |
| | Garvin WWTP (MNG580101) | 63 | 63 | 63 | 63 | ** |
| | Revere WWTP (MNG580114) | 56 | 56 | 56 | 56 | ** |
| | Tracy WWTP (MN0021725) | 1,312 | 1,312 | 1,312 | 1,312 | ** |
| | Walnut Grove WWTP (MN0021776) | 51 | 51 | 51 | 51 | ** |
| | Stordren WWTP (MNG580106) | 99 | 99 | 99 | 99 | ** |
| | Westbrook WWTP (MNG580127) | 611 | 611 | 611 | 611 | ** |
| | Lamberton WWTP (MNG580100) | 489 | 489 | 489 | 489 | ** |
| | City of Marshall MS4 (MS400241)*** | 591 | 184 | 47 | 10 | ** |
| | Construction/Industrial SW | 726 | 247 | 66 | 16 | ** |
| | **Total WLA** | **4,627** | **3,741** | **3,423** | **3,336** | ** |
| **Load** | **Total LA** | **458,470** | **153,751** | **38,880** | **7,114** | ** |
| **MOS** | | **24,374** | **8,289** | **2,226** | **550** | **103** |
| **Total load** | | **487,471** | **165,781** | **44,529** | **11,000** | **2,059** |
| **Existing 90th percentile concentration (mg/L)*** ** | | **130** | | | | |
| **Overall estimated percent reduction*** ** | | **50%** | | | | |

* Model simulated flow for HSPF reach 370 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
*** Although a small portion of the city of Marshall falls within the drainage area for this reach, reductions are not required (see Section 4.2.2).
**** Water quality monitoring station(s) used to estimate reductions: S001-920.

**Figure 11. Cottonwood River Reach 509 TSS load duration curve and HSPF simulated TSS loads and exceedances.**

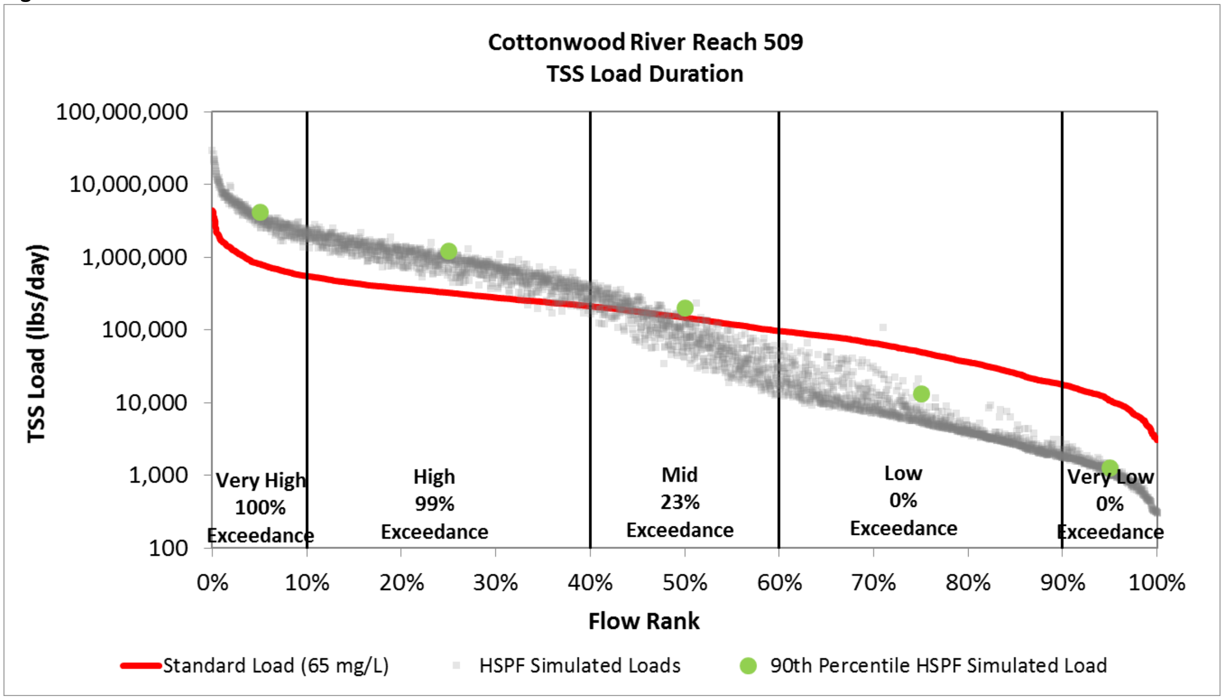



**Table 23. TSS TMDL summary for Cottonwood River Reach 509.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Sanborn WWTP (MNG580115) | 128 | 128 | 128 | 128 | ** |
| | Springfield WWTP (MN0024953) | 195 | 195 | 195 | 195 | ** |
| | Balaton WWTP (MN0020559) | 306 | 306 | 306 | 306 | ** |
| | Garvin WWTP (MNG580101) | 63 | 63 | 63 | 63 | ** |
| | Revere WWTP (MNG580114) | 56 | 56 | 56 | 56 | ** |
| | Tracy WWTP (MN0021725) | 1,312 | 1,312 | 1,312 | 1,312 | ** |
| | Walnut Grove WWTP (MN0021776) | 51 | 51 | 51 | 51 | ** |
| | Storden WWTP (MNG580106) | 99 | 99 | 99 | 99 | ** |
| | Westbrook WWTP (MNG580127) | 611 | 611 | 611 | 611 | ** |
| | Lamberton WWTP (MNG580100) | 489 | 489 | 489 | 489 | ** |
| | Lucan WWTP (MNG580112) | 257 | 257 | 257 | 257 | ** |
| | Wanda WWTP (MNG580126) | 67 | 67 | 67 | 67 | ** |
| | Clements WWTP (MNG580094) | 61 | 61 | 61 | 61 | ** |
| | Wabasso WWTP (MN0025151) | 28 | 28 | 28 | 28 | ** |
| | City of Marshall MS4 (MS400241)*** | 591 | 184 | 47 | 10 | ** |
| | Construction/Industrial SW | 968 | 339 | 91 | 23 | ** |
| | **Total WLA** | **5,282** | **4,246** | **3,861** | **3,756** | ** |
| **Load** | **Total LA** | **611,988** | **211,942** | **54,449** | **10,661** | ** |
| **MOS** | | **32,488** | **11,378** | **3,069** | **759** | **180** |
| **Total load** | | **649,758** | **227,566** | **61,379** | **15,176** | **3,598** |
| **Existing 90th percentile concentration (mg/L)**** | | **104** | | | | |
| **Overall estimated percent reduction**** | | **38%** | | | | |

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

*** Although a small portion of the city of Marshall falls within the drainage area for this reach, reductions are not required (see Section 4.2.2).
**** The impairment listing for this reach is based on Secchi Tube data (see Table 8) as no TSS data has been collected for this reach. Therefore, reductions are based on HSPF simulated TSS loads/concentrations.

**Figure 12. Dutch Charley Creek Reach 517 TSS load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

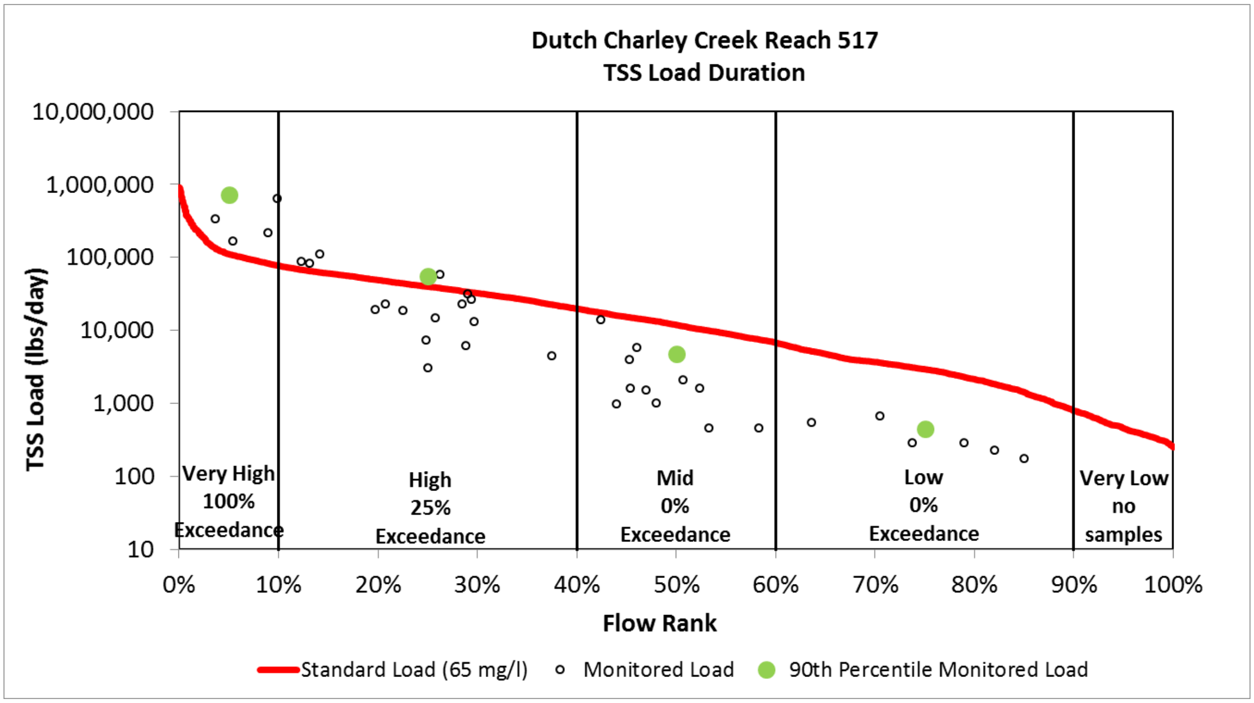



**Table 24. TSS TMDL summary for Dutch Charley Creek Reach 517.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Storden WWTP (MNG580106) | 99 | 99 | 99 | 99 | ** |
| | Westbrook WWTP (MNG580127) | 611 | 611 | 611 | 611 | ** |
| | Lamberton WWTP (MNG580100) | 489 | 489 | 489 | 489 | ** |
| | Construction/Industrial SW | 165 | 59 | 18 | 4 | ** |
| | **Total WLA** | **1,364** | **1,258** | **1,217** | **1,203** | ** |
| **Load** | **Total LA** | **104,035** | **36,612** | **10,094** | **1,589** | ** |
| **MOS** | | **5,547** | **1,993** | **595** | **147** | **23** |
| **Total load** | | **110,946** | **39,863** | **11,906** | **2,939** | **456** |
| **Existing 90th percentile concentration (mg/L)*** ** | | **79** | | | | |
| **Overall estimated percent reduction*** ** | | **18%** | | | | |

* Model simulated flow for HSPF reach 281 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.
*** Water quality monitoring station(s) used to estimate reductions: S001-915.

**Figure 13. Dutch Charley Creek Reach 518 TSS load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

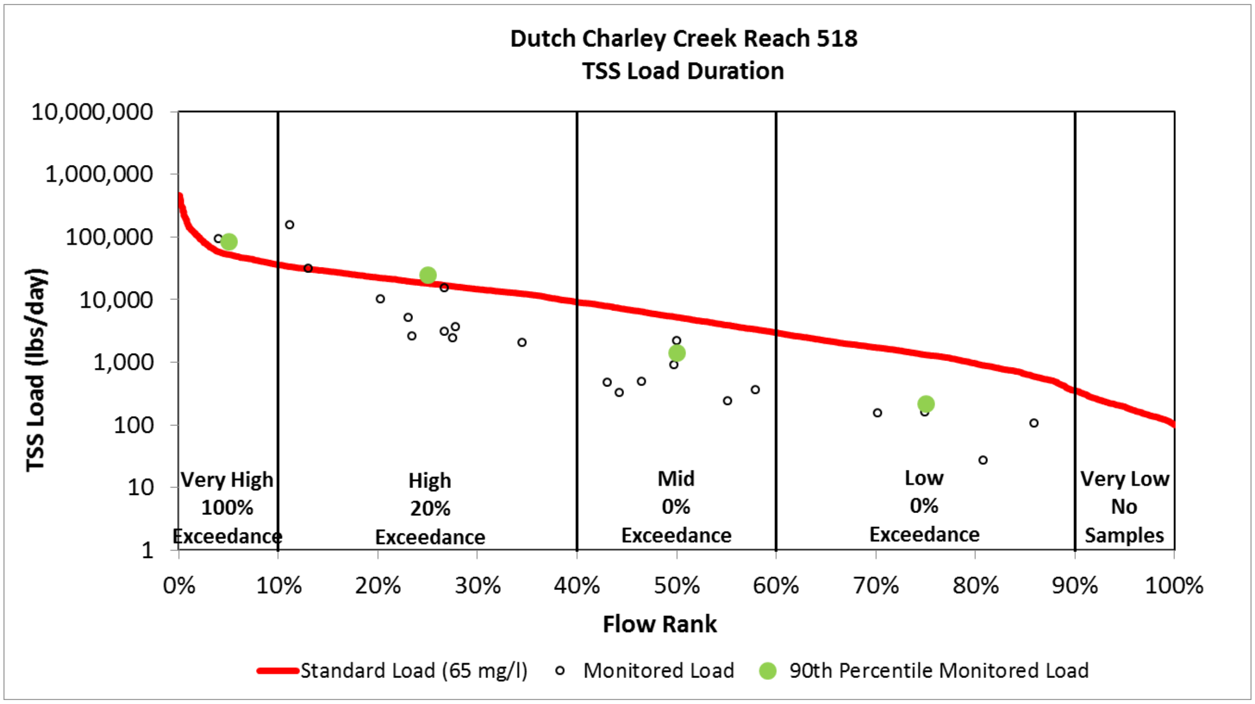



**Table 25. TSS TMDL summary for Dutch Charley Creek Reach 518.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Lamberton WWTP (MNG580100) | 489 | 489 | 489 | 489 | ** |
| | Construction/Industrial SW | 78 | 27 | 8 | 2 | ** |
| | **Total WLA** | **567** | **516** | **497** | **491** | ** |
| **Load** | **Total LA** | **49,303** | **16,749** | **4,468** | **756** | ** |
| **MOS** | | **2,625** | **909** | **261** | **66** | **10** |
| **Total load** | | **52,495** | **18,174** | **5,226** | **1,313** | **194** |
| **Existing 90th percentile concentration (mg/L)*** ** | | **** | | | | |
| **Overall estimated percent reduction*** ** | | **5%** | | | | |

* Model simulated flow for HSPF reach 267 (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors).
*** Water quality monitoring station(s) used to evaluate reductions: S004-879.
**** The 90th percentile flow-zone corrected monitored TSS concentration is at or below 65 mg/L and therefore a 5% load reduction is recommended to ensure the TSS standard is met. There were 22 TSS measurements collected in this reach from 2008-2017 and therefore more monitoring would help determine if reductions beyond 5% are needed.

**Figure 14. Highwater Creek Reach 519 TSS load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

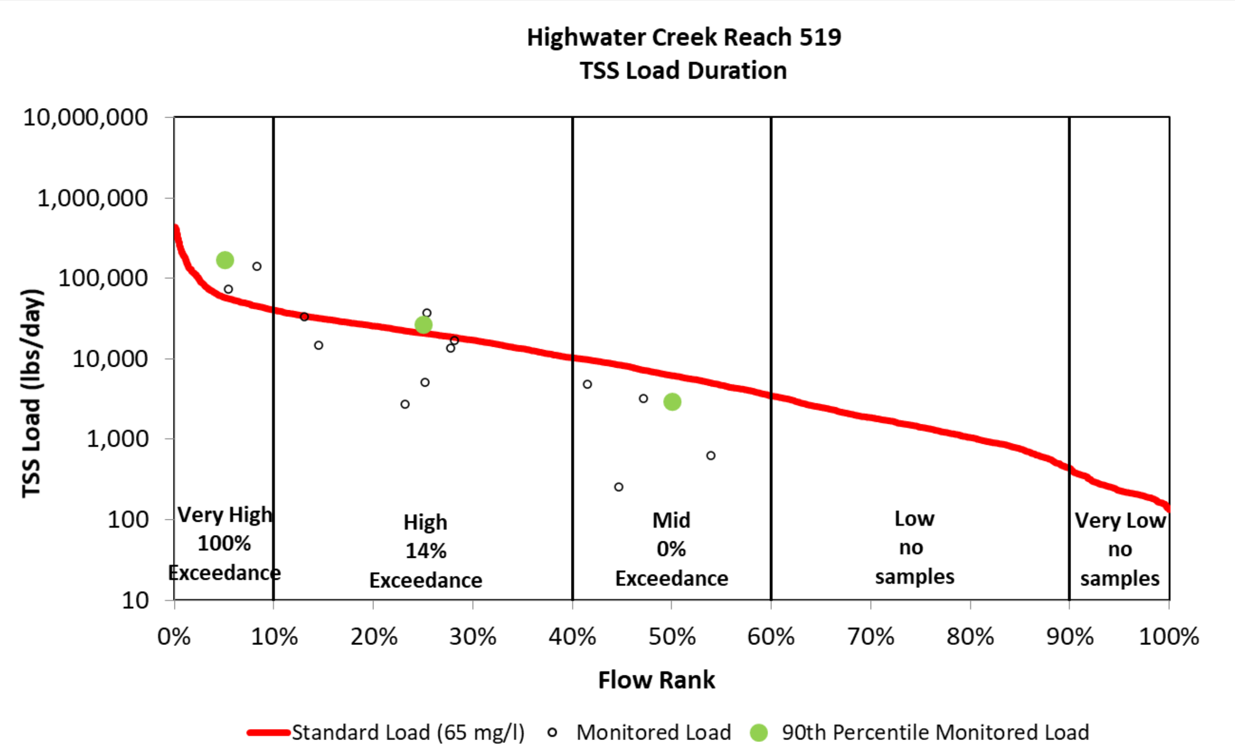



**Table 26. TSS TMDL summary for Highwater Creek Reach 519.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Storden WWTP (MNG580106) | 99 | 99 | 99 | 99 | ** |
| | Westbrook WWTP (MNG580127) | 611 | 611 | 611 | 611 | ** |
| | Construction/Industrial SW | 86 | 31 | 9 | 2 | ** |
| | **Total WLA** | **796** | **741** | **719** | **712** | ** |
| **Load** | **Total LA** | **53,847** | **18,990** | **5,136** | **622** | ** |
| **MOS** | | **2,876** | **1,038** | **308** | **70** | **11** |
| **Total load** | | **57,519** | **20,769** | **6,163** | **1,404** | **229** |
| **Existing 90th percentile concentration (mg/L)*** ** | | **** | | | | |
| **Overall estimated percent reduction*** ** | | **5%** | | | | |

* Model simulated flow for HSPF reach 279 (2008-2017) was used to develop the flow zones and LCs for this reach.

** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (65 mg/L or NPDES permit concentration) x (conversion factors). The LA is the remainder after the WLA is applied.

*** Water quality monitoring station(s) used to evaluate reductions: S009-443.

**** The 90th percentile flow-zone corrected monitored TSS concentration is at or below 65 mg/L and therefore a 5% load reduction is recommended to ensure the TSS standard is met. There were 22 TSS measurements collected in this reach from 2008-2017 and therefore more monitoring would help determine if reductions beyond 5% are needed.

**Figure 15. Pell Creek Reach 535 TSS load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

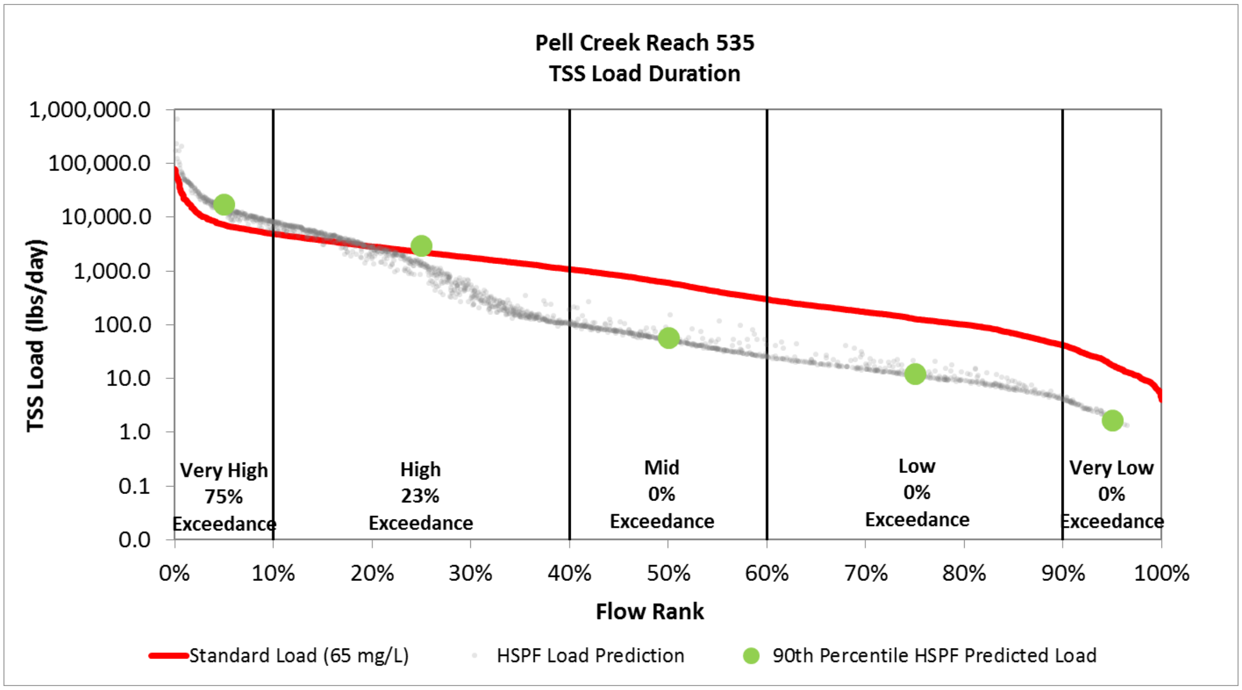



**Table 27. TSS TMDL summary for Pell Creek Reach 535.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Construction/Industrial SW | 11 | 3 | 0.9 | 0.2 | 0.03 |
| | **Total WLA** | **11** | **3** | **0.9** | **0.2** | **0.03** |
| Load | **Total LA** | **6,789** | **2,113** | **569** | **121** | **17** |
| **MOS** | | **358** | **111** | **30** | **6** | **0.9** |
| **Total load** | | **7,158** | **2,227** | **600** | **127** | **18** |
| **Existing 90th percentile concentration (mg/L)**** | | ***** | | | | |
| **Overall estimated percent reduction**** | | **5%** | | | | |

* Model simulated flow for HSPF reach 211 (2008-2017) was used to develop the flow zones and LCs for this reach.

** The impairment listing for this reach is based on Secchi Tube data (see Table 8) as no TSS data have been collected for this reach. Therefore, reductions were evaluated using HSPF simulated TSS loads/concentrations.

*** The 90th percentile flow-zone corrected HSPF simulated TSS concentration is at or below 65 mg/L and therefore a 5% load reduction is recommended to ensure the TSS standard is met. No TSS measurements have been collected in this reach. Future monitoring would help determine if reductions beyond 5% are needed.

**Figure 16. Sleepy Eye Creek Reach 599 TSS load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

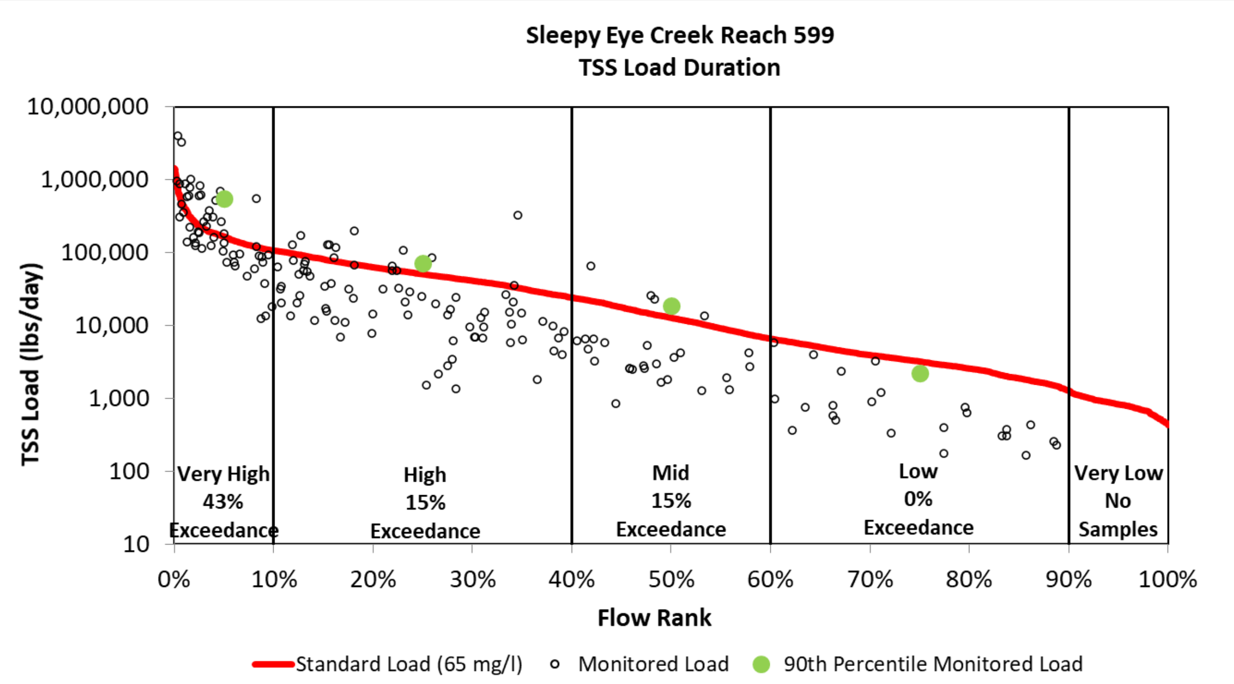



**Table 28. TSS TMDL summary for Sleepy Eye Creek Reach 599.**

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Clements WWTP (MNG580094) | 61 | 61 | 61 | 61 | 61 |
| | Lucan WWTP (MNG580112) | 257 | 257 | 257 | 257 | 257 |
| | Wabasso WWTP (MN0025151) | 28 | 28 | 28 | 28 | 28 |
| | Wanda WWTP (MNG580126) | 67 | 67 | 67 | 67 | 67 |
| | Construction/Industrial SW | 246 | 75 | 19 | 5 | 1 |
| | **Total WLA** | **659** | **488** | **432** | **418** | **414** |
| **Load** | **Total LA** | **156,318** | **47,368** | **11,601** | **2,619** | **366** |
| **MOS** | | **8,262** | **2,519** | **633** | **160** | **41** |
| **Total load** | | **165,239** | **50,375** | **12,666** | **3,197** | **821** |
| **Existing 90th percentile concentration (mg/L)**** | | **85** | | | | |
| **Overall estimated percent reduction**** | | **24%** | | | | |

* Model simulated flow for HSPF reach 407 (2008-2017) was used to develop the flow zones and LCs for this reach.

** Water quality monitoring station(s) used to estimate reductions: S001-919.

Figure 17. Plum Creek Reach 602 and 603 TSS load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.

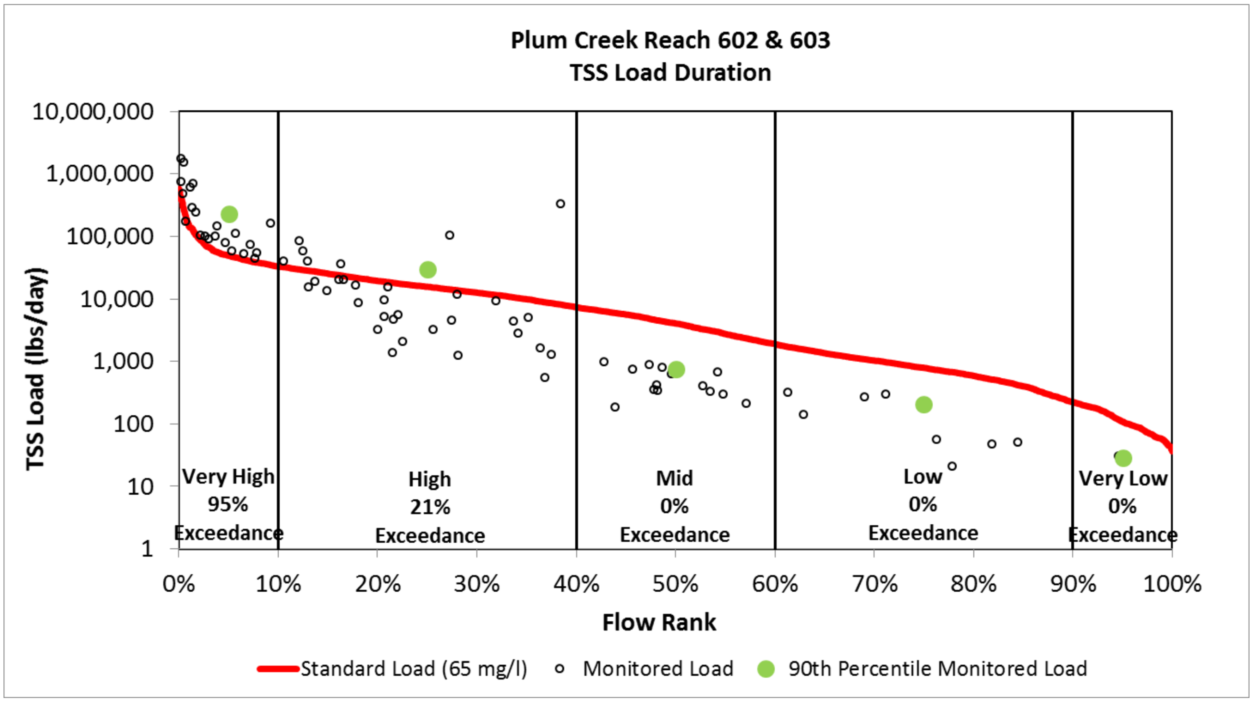



Table 29. TSS TMDL summary for Plum Creek Reach 602 and 603.

| Total Suspended Solids | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | TSS load (lbs/day) | | | | |
| Wasteload | Construction/Industrial SW | 73 | 23 | 6 | 1 | 0.2 |
| | Total WLA | **73** | **23** | **6** | **1** | **0.2** |
| Load | Total LA | **46,565** | **14,829** | **3,827** | **747** | **103** |
| | MOS | **2,455** | **782** | **202** | **39** | **5** |
| | Total load | **49,093** | **15,634** | **4,035** | **787** | **108** |
| Existing 90th percentile concentration (mg/L)** | | 77 | | | | |
| Overall estimated percent reduction** | | 16% | | | | |

* Model simulated flow for HSPF reach 191 (2008-2017) was used to develop the flow zones and LCs for this reach.
** Water quality monitoring station(s) used to estimate reductions: S001-913.

## 4.3 *E. coli* - Streams

### 4.3.1 Loading Capacity Methodology

LDCs were used to represent the LC for the *E. coli* impaired reaches (see Figure 2 and Appendix A) covered in this TMDL. The flow component of the LC curve is based on the HSPF-simulated average daily flows from April through October (2008 through 2017), and the concentration component is the *E. coli* concentration standard of 126 cfu/100 mL. *E. coli* LDCs for Cottonwood River Watershed impaired reaches are shown in Section 4.3.6. On these figures the red curve represents the allowable *E. coli* LC of the reach for each daily flow. The median (or midpoint) loads of each flow zone were used to represent the total LC in the TMDL tables. Each reach's LC can be compared to current conditions by plotting the measured load during each individual water quality sampling event (black circles). Each black circle that is above the curve exceeds the 126 cfu/100 mL water quality standard while those below the line are below the water quality standard. It is important to point out that the *E. coli* standard is not applied to individual sample points, but rather by aggregating the data by month and calculating the geometric mean. That said, plotting the individual sample points helps visualize how the individual data points relate to flow conditions and when elevated bacteria concentrations are more common.

The existing *E. coli* concentration for each impaired reach was calculated as the geometric mean of all monitoring data collected during the months that the standard applies (April through October). The loading capacity was calculated as flow multiplied by the *E. coli* geometric mean standard, 126 org/100 mL. It is assumed that practices that are implemented to meet the geometric mean standard will also address the individual sample standard (1,260 org/100 mL) and that the individual sample standard will also be met. The overall estimated concentration-based percent reduction needed to meet the TMDL was calculated by comparing the highest observed (monitored) monthly geometric mean from the months that the standard applies to the geometric mean standard. Also plotted on the LDC figure are the monitored *E. coli* geometric mean loads for each flow zone (solid green circles). Plotting these individual loads help determine what flow zones and practices should be targeted to achieve the overall reduction goal for each impaired reach.

### 4.3.2 Wasteload Allocation Methodology

The WLAs for the *E. coli* TMDLs were divided into three categories: NPDES permitted wastewater dischargers, NPDES permitted MS4 stormwater, and NPDES permitted construction and industrial stormwater. This section describes how each of these WLAs were assigned. The NPDES permitted livestock CAFOs are zero discharge facilities and are given a WLA of zero and should not impact water quality in the watershed as a point source. Therefore, it is not necessary to put them in the *E. coli* TMDL table. Straight pipe septic systems are illegal and receive a WLA of zero. Therefore, it is not necessary to put them in the *E. coli* TMDL table.

***NPDES Permitted Wastewater Dischargers***

There are seven active NPDES permitted surface wastewater dischargers in the Cottonwood River Watershed *E. coli* impaired reach drainage areas (Table 30, Appendix A). WLAs for each facility were calculated by multiplying the facility's wet weather design flow by the *E. coli* standard (126 cfu/100 mL). Discharge monitoring reports (DMRs) were downloaded to assess the typical monthly discharge values and bacteria concentrations at which each facility discharges. It should be noted that NPDES Wastewater Permit limits for bacteria are currently expressed in fecal coliform concentrations, not *E. coli*. However, the fecal coliform permit limit for each wastewater treatment facility (200 organisms/100 mL) is intended to demonstrate that the facility is effectively disinfecting its effluent and therefore does not contribute to *E. coli* standard violations in its receiving waters. No permit modifications are needed at this time for the *E. coli* impairments. The fecal coliform-*E. coli* relationship is documented extensively in the SONAR for the 2007 and 2008 revisions of Minn. R. ch. 7050. Results of DMRs are presented in Appendix B.

The WLA for permitted wastewater dischargers is based on facility design flow. For several of the reaches, however, the WLA exceeds the very low flow zone's daily loading capacity because the facilities in the reach typically discharge less than their design flows. To account for this, the WLA and nonpoint source LA for the very low flow zone are determined by the following formula:

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

**Table 30. *E. coli* allocations for NPDES permitted dischargers in the *E. coli* impaired reach drainage areas.**

| Impaired Reach | Facility Name and System Type | NPDES ID# | Flow Used for WLA* (MGD) | Chronic Standard (org./100 mL) | Wasteload Allocation (billions of org./day) |
|---|---|---|---|---|---|
| 502 | Balaton WWTP/ Pond | MN0020559 | 0.816 | 126 | 3.89 |
| 502 | Garvin WWTP/ Pond | MNG580101 | 0.169 | 126 | 0.81 |
| 523 | Revere WWTP/ Pond | MNG580114 | 0.150 | 126 | 0.71 |
| 511 | Sleepy Eye WWTP/ Pond | MNG580041 | 6.420 | 126 | 30.62 |
| 519 | Storden WWTP/ Pond | MNG580106 | 0.264 | 126 | 1.26 |
| 523 | Walnut Grove WWTP/ Mechanical | MN0021776 | 0.203 | 126 | 0.97 |
| 519 | Westbrook WWTP/ Pond | MNG580127 | 1.629 | 126 | 7.77 |

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

***<u>NPDES Permitted MS4 Stormwater</u>***

There are no permitted MS4s located in the drainage areas of the *E. coli* impaired reaches covered in this report.

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

WLAs for regulated construction stormwater permits (MNR100001) were not developed since *E. coli* is not a typical pollutant from construction sites. Industrial stormwater receives a WLA only if the pollutant is part of benchmark monitoring for an industrial site in the watershed of an impaired water body. There are no bacteria or *E. coli* benchmarks associated with any of the Industrial Stormwater permits (MNR050000) or Nonmetallic Mining & Associated Activities general permits (MNG490000) in the Cottonwood River Watershed *E. coli* impaired reach drainage areas, and therefore no industrial stormwater *E. coli* WLAs were assigned.

### 4.3.3 Load Allocation Methodology

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

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

### 4.3.4 Margin of Safety

The MOS is a portion of the TMDL that is set aside to account for the uncertainties associated with achieving water quality standards. The MOS can be either implicitly or explicitly defined as a set-aside amount. An explicit MOS was calculated as 5% of the loading capacity for the Cottonwood River Watershed *E. coli* impaired reaches. Five percent was considered an appropriate MOS since the LDC approach minimizes a great deal of uncertainty. The LDC calculations are based on *E. coli* target concentrations and modeled flow data that has been calibrated to long-term monitored flow data. Most of the uncertainty with this calculation is therefore associated with the HSPF modeled flow output for each reach. The Cottonwood River HSPF model was calibrated and validated using 21 years (1996 through 2017) of flow data from five gaging stations (Tetra Tech 2019). Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. See Appendix D of this TMDL for the HSPF model calibration and validation results. The *E. coli* LDCs were developed using HSPF modeled daily flow data from April through October (2008 through 2017). The *E. coli* TMDL applied a MOS to each flow zone along the duration curves by subtracting 5% of the flow zones loading capacity.

### 4.3.5 Seasonal Variation and Critical Conditions

*E. coli* monitoring data for the bacteria impaired reaches indicate all reaches had multiple exceedances of the monthly chronic standard (Table 9). Exceedances of the acute standard have also been recorded in each of the impaired reaches covered in this report. Fecal bacteria are most productive at temperatures similar to their origination environment in animal digestive tracts. Thus, these organisms are expected to be at their highest concentrations during warmer summer months when stream flow is low and water temperatures are high. High *E. coli* concentrations in many of the reaches continue into the fall, which may be attributed to constant sources of *E. coli* (such as failing SSTS and animal access to the stream) and less flow for dilution. However, some of the data may be skewed as more samples were collected in the summer months than in early spring and late fall. Seasonal and annual variations are accounted for by setting the TMDL across the entire flow record using the load duration method.

### 4.3.6 *E. coli* TMDL Summary

The TMDL summary tables (Table 31 through Table 38) for Cottonwood River Watershed *E. coli* impaired reaches present the existing load, the total LC (total load (TMDL) in tables, MOS, WLA (wasteload in tables), and LA (load in tables). Allocations for these TMDLs were established using the 126 cfu/100 mL *E. coli* standard. All LAs are reported in billions of organisms/day and were rounded to one significant figure to prevent zero load values. The last line of each table shows the estimated concentration-based percent load reductions to meet the TMDL for all flow zones. These reductions were calculated by comparing the highest observed (monitored) monthly geometric mean from the months that the standard applies to the geometric mean standard. At this time, there is not enough information or data available to estimate or calculate the existing (current conditions) load contribution from each of the WLA and LA sources presented in the TMDL tables. Thus, the estimated load reduction for each flow zone applies to the water body as a whole. *E. coli* LDCs (Figure 18 through– Figure 25) for reaches in the Cottonwood River Watershed generally show *E. coli* load exceedances during all flow conditions for which there is data. This suggests a variety of sources contribute to the impairments. For example, during high flow conditions, watershed runoff is likely the primary source of *E. coli* to the river reaches. During low flow conditions, other sources such as noncompliant SSTS and livestock in streams increase in relative importance. See Section 8 of this TMDL and the WRAPS report for further information on which sources and geographical locations within the impaired reach watershed should be targeted for bacteria BMPs and restoration strategies.

**Figure 18. Cottonwood River Reach 502 *E. coli* load duration curve and monitored loads and exceedances.**

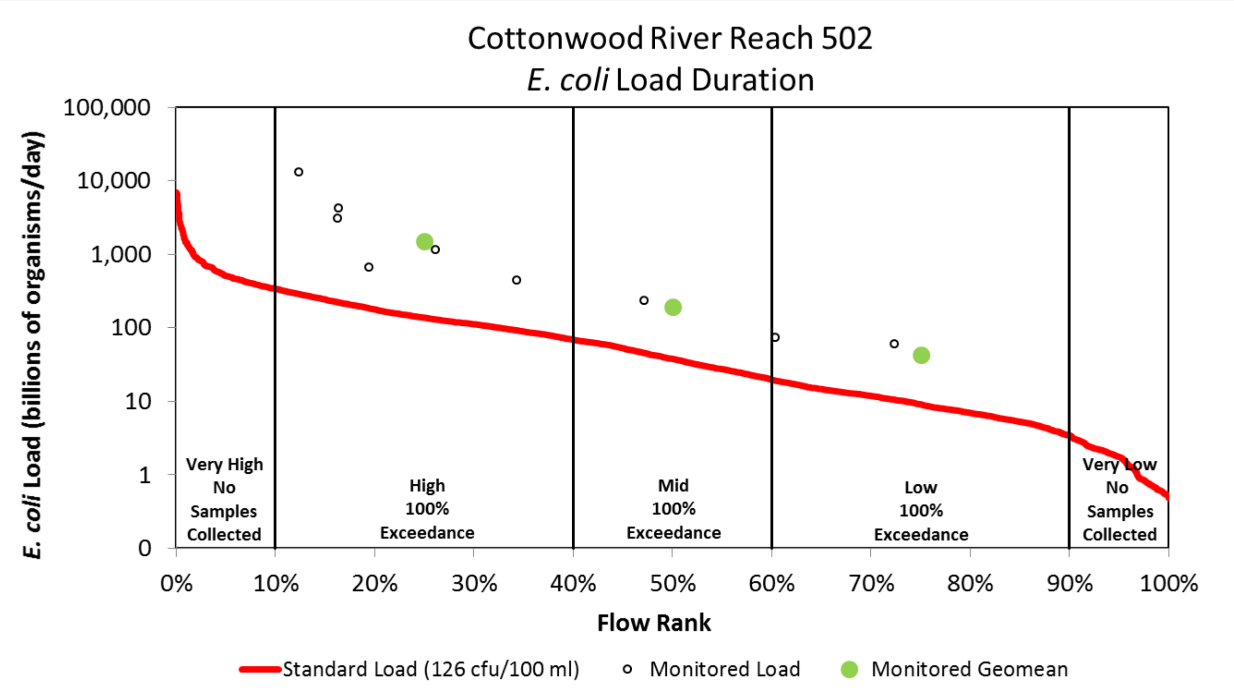



**Table 31. *E. coli* TMDL summary for Cottonwood River Reach 502.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| Wasteload | Balaton WWTP | 4 | 4 | 4 | 4 | ** |
| | Garvin WWTP | 0.8 | 0.8 | 0.8 | 0.8 | ** |
| | **Total WLA** | **5** | **5** | **5** | **5** | ** |
| **Load** | **Total LA** | **743** | **197** | **51** | **9** | ** |
| **MOS** | | **39** | **11** | **3** | **0.7** | **0.1** |
| **Total load** | | **787** | **213** | **59** | **15** | **3** |
| **Existing Concentration, Apr-Oct (org/100 mL)*** ** | | **1,063** | | | | |
| **Maximum Monthly Geometric Mean (org/100mL)*** ** | | **1,859** | | | | |
| **Overall Estimated Percent Reduction*** ** | | **93%** | | | | |

* Model simulated flow for HSPF reach 90 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (126 org per 100 mL) x conversion factors.

*** Water quality monitoring station(s) used to estimate reductions: S009-440; the maximum monthly geometric mean of 1,859 is from a month with fewer than 5 samples.

**Figure 19. Judicial Ditch 30 Reach 511 *E. coli* load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

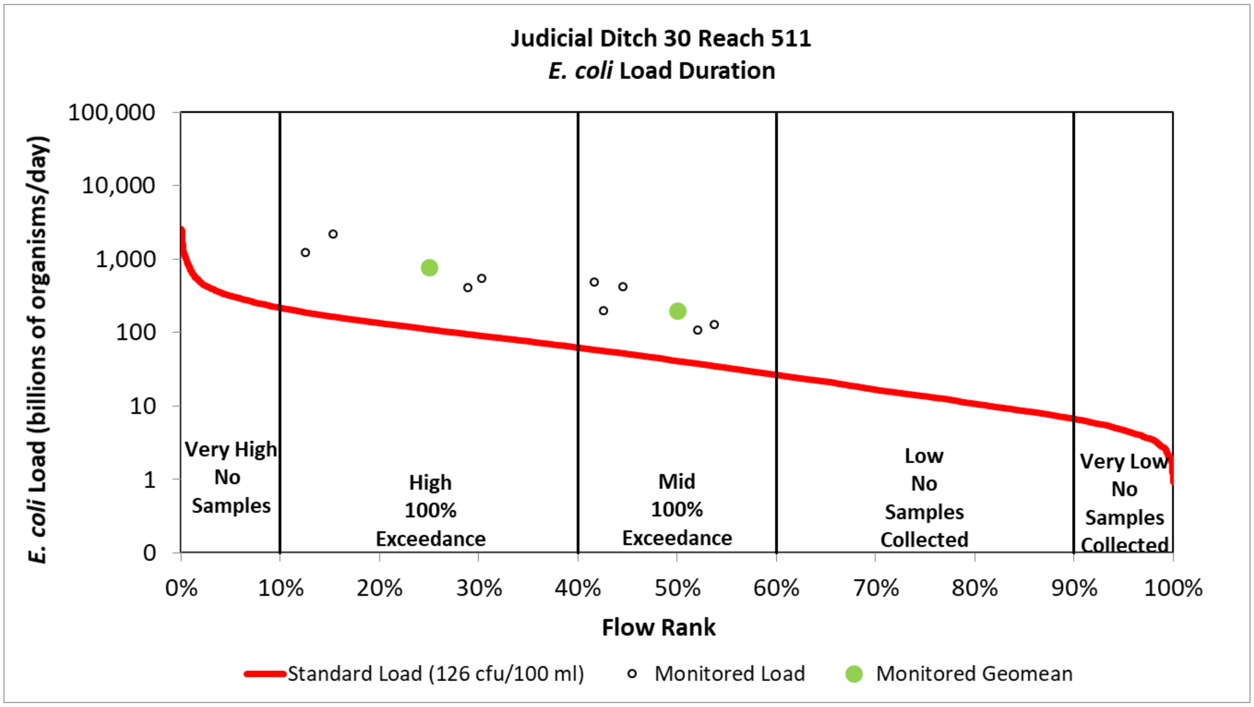



**Table 32. *E. coli* TMDL summary for Judicial Ditch 30 Reach 511.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| Wasteload | Sleepy Eye WWTP | 31 | 31 | 31 | ** | ** |
| | Total WLA | 31 | 31 | 31 | ** | ** |
| Load | Total LA | 451 | 149 | 30 | ** | ** |
| MOS | | 25 | 10 | 3 | 1 | 0.3 |
| Total load | | 507 | 190 | 64 | 20 | 7 |
| Existing Concentration, Apr-Oct (org/100 mL)*** | | 710 | | | | |
| Maximum Monthly Geometric Mean (org/100mL)*** | | 921 | | | | |
| Overall Estimated Percent Reduction*** | | 86% | | | | |

* Model simulated flow for HSPF reach 435 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (126 org per 100 mL) x conversion factors.

*** Water quality monitoring station(s) used to estimate reductions: S009-438; the maximum monthly geometric mean of 921 is from a month with fewer than 5 samples.

**Figure 20. Highwater Creek Reach 519 *E. coli* load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

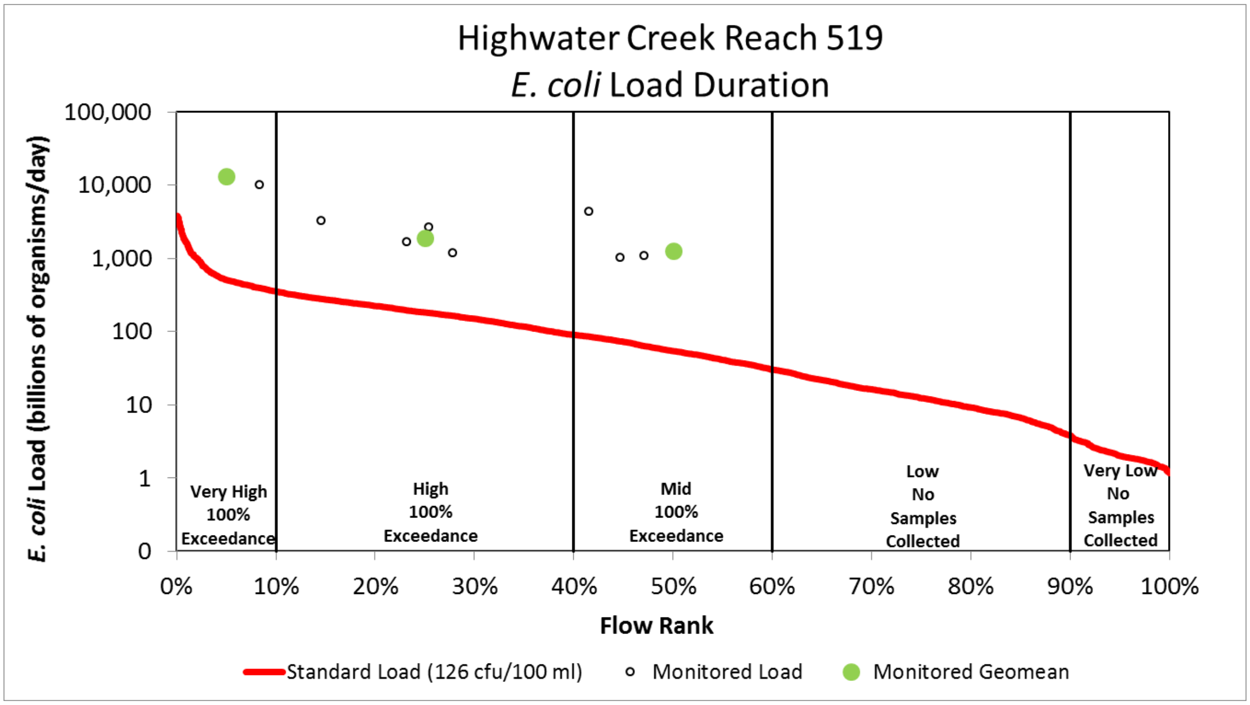



**Table 33. *E. coli* TMDL summary for Highwater Creek Reach 519.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| **Wasteload** | Storden WWTP | 1 | 1 | 1 | 1 | ** |
| | Westbrook WWTP | 8 | 8 | 8 | 8 | ** |
| | **Total WLA** | **9** | **9** | **9** | **9** | ** |
| **Load** | **Total LA** | **735** | **259** | **71** | **9** | ** |
| **MOS** | | **39** | **14** | **4** | **1** | **0.2** |
| **Total load** | | **783** | **282** | **84** | **19** | **3** |
| **Existing Concentration, Apr-Oct (org/100 mL)*** ** | | **1,897** | | | | |
| **Maximum Monthly Geometric Mean (org/100mL)*** ** | | **2,729** | | | | |
| **Overall Estimated Percent Reduction*** ** | | **95%** | | | | |

* Model simulated flow for HSPF reach 279 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (126 org per 100 mL) x conversion factors.

*** Water quality monitoring station(s) used to estimate reductions: S009-443; the maximum monthly geometric mean of 2,729 is from a month with fewer than 5 samples.

**Figure 21. Dry Creek Reach 520 *E. coli* load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

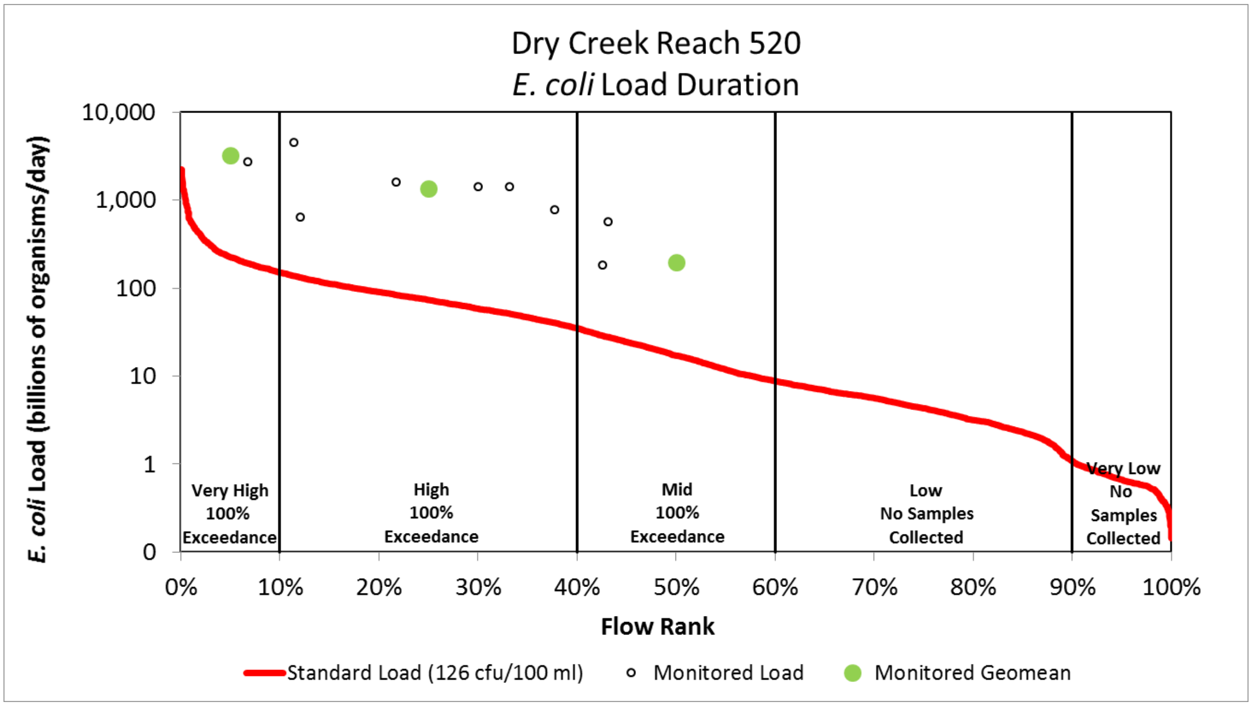



**Table 34. *E. coli* TMDL summary for Dry Creek Reach 520.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| Load | Total LA | 329 | 108 | 25 | 6 | 1 |
| | MOS | 17 | 6 | 1 | 0.3 | 0.1 |
| | Total load | 346 | 114 | 26 | 6 | 1 |
| | Existing Concentration, Apr-Oct (org/100 mL)** | 2,033 | | | | |
| | Maximum Monthly Geometric Mean (org/100mL)** | 3,248 | | | | |
| | Overall Estimated Percent Reduction** | 96% | | | | |

* Model simulated flow for HSPF reach 291 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** Water quality monitoring station(s) used to estimate reductions: S009-442; the maximum monthly geometric mean of 3,248 is from a month with fewer than 5 samples.

**Figure 22. Mound Creek Reach 521 *E. coli* load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

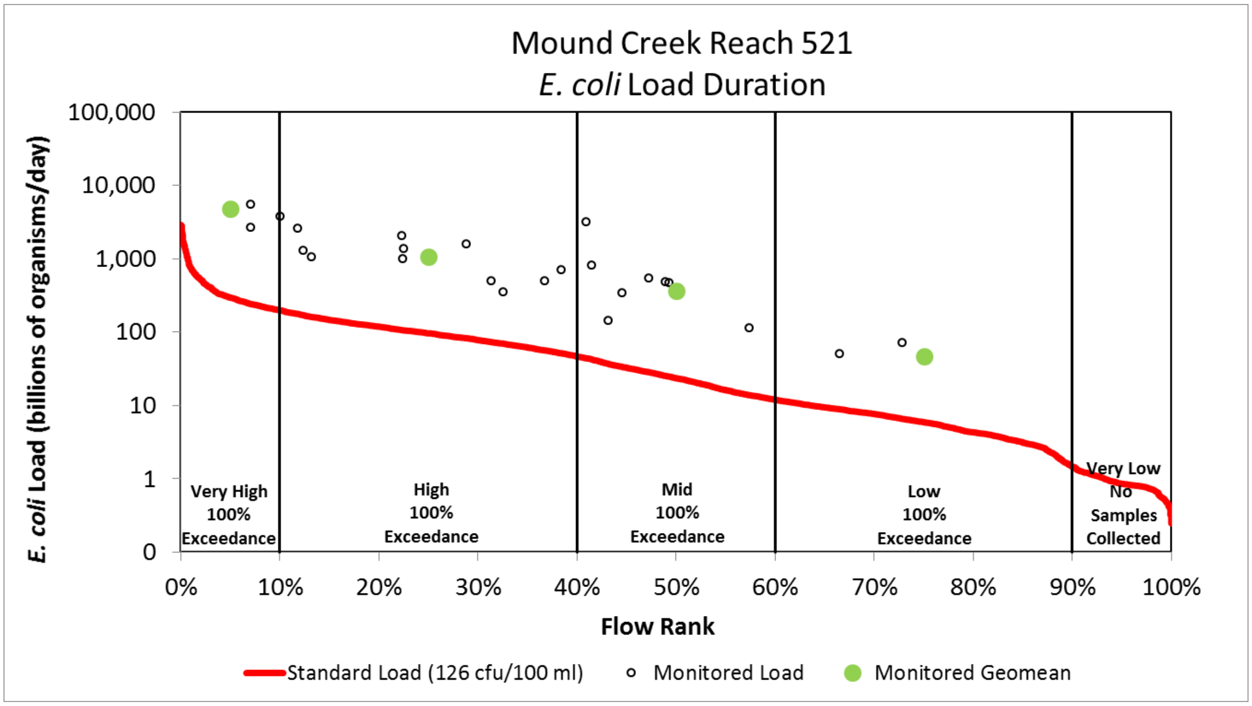



**Table 35. *E. coli* TMDL summary for Mound Creek Reach 521.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| Load | Total LA | 433 | 142 | 35 | 9 | 1 |
| | MOS | 23 | 7 | 2 | 0.5 | 0.1 |
| | Total load | 456 | 149 | 37 | 10 | 1 |
| | Existing Concentration, Apr-Oct (org/100 mL)** | 1,553 | | | | |
| | Maximum Monthly Geometric Mean (org/100mL)** | 1,709 | | | | |
| | Overall Estimated Percent Reduction** | 93% | | | | |

* Model simulated flow for HSPF reach 311 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** Water quality monitoring station(s) used to estimate reductions: S005-690.

**Figure 23. Pell Creek Reach 523 *E. coli* load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

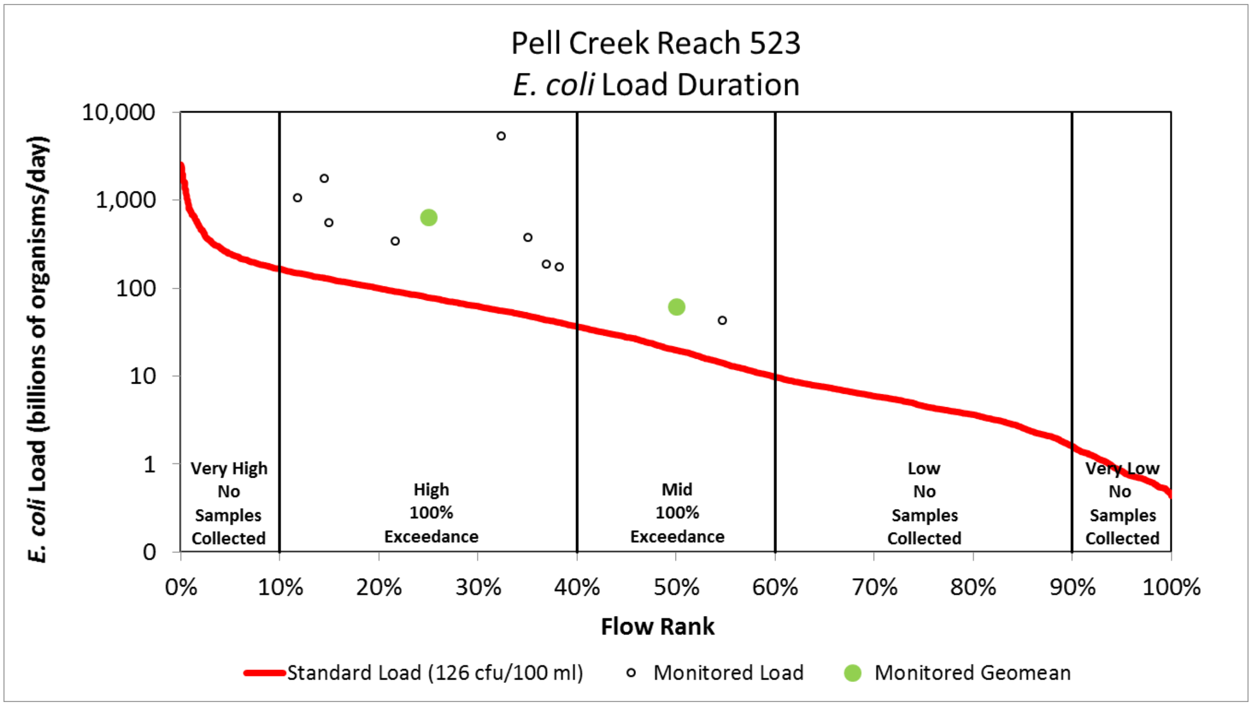



**Table 36. *E. coli* TMDL summary for Pell Creek Reach 523.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| **Wasteload** | Walnut Grove WWTP | 1 | 1 | 1 | 1 | ** |
| | Revere WWTP | 0.7 | 0.7 | 0.7 | 0.7 | ** |
| | **Total WLA** | **2** | **2** | **2** | **2** | ** |
| **Load** | **Total LA** | **358** | **113** | **27** | **5** | ** |
| **MOS** | | **19** | **6** | **2** | **0.4** | **0.1** |
| **Total load** | | **379** | **121** | **31** | **7** | **1** |
| **Existing Concentration, Apr-Oct (org/100 mL)***** | | **937** | | | | |
| **Maximum Monthly Geometric Mean (org/100mL)***** | | **2,005** | | | | |
| **Overall Estimated Percent Reduction***** | | **94%** | | | | |

* Model simulated flow for HSPF reach 215 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.
** The permitted wastewater design flows exceed the stream flow in the indicated flow zone(s). The allocations are expressed as an equation rather than an absolute number: allocation = (flow contribution from a given source) x (126 org per 100 mL) x conversion factors.
*** Water quality monitoring station(s) used to estimate reductions: S009-444; the maximum monthly geometric mean of 2,005 is from a month with fewer than 5 samples.

**Figure 24. Coal Mine Creek Reach 604 *E. coli* load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

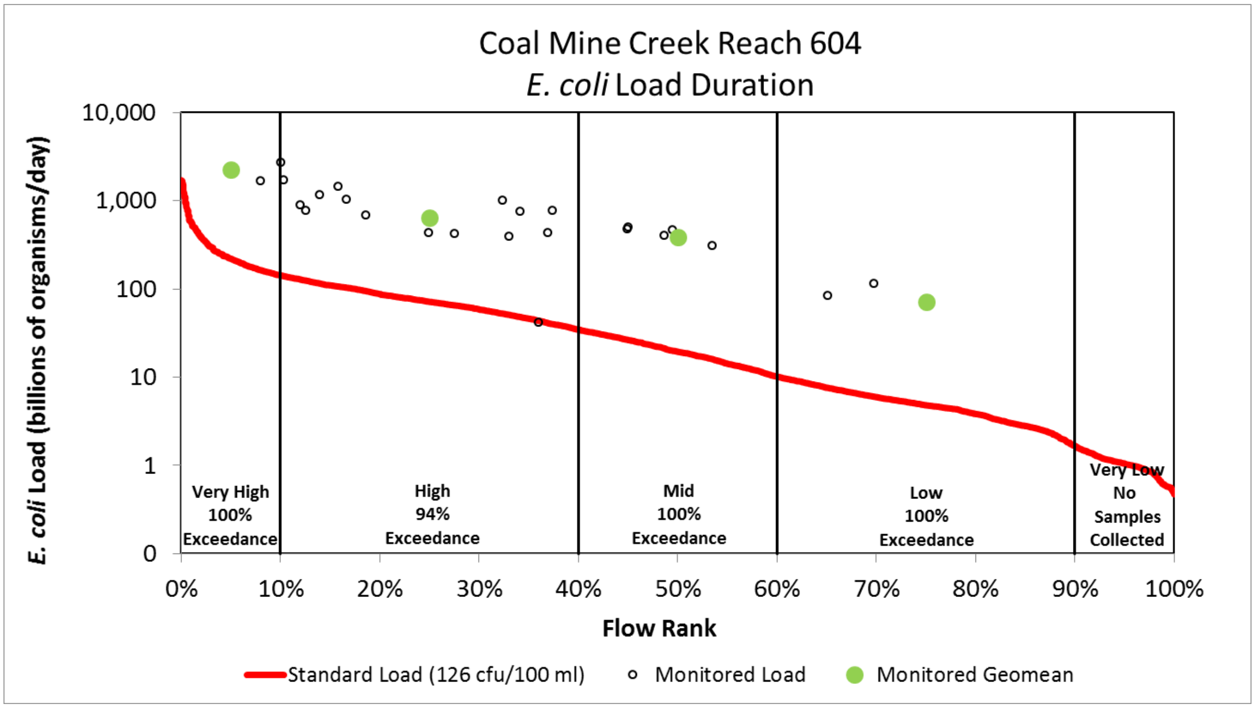



**Table 37. *E. coli* TMDL summary for Coal Mine Creek Reach 604.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| Load | Total LA | 321 | 105 | 29 | 7 | 2 |
| | MOS | 17 | 6 | 2 | 0.4 | 0.1 |
| | Total load | 338 | 111 | 31 | 7 | 2 |
| | Existing Concentration, Apr-Oct (org/100 mL)** | 1,401 | | | | |
| | Maximum Monthly Geometric Mean (org/100mL)** | 1,740 | | | | |
| | Overall Estimated Percent Reduction** | 93% | | | | |

* Model simulated flow for HSPF reach 335 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** Water quality monitoring station(s) used to estimate reductions: S005-691 and S009-439.

**Figure 25. Judicial Ditch 30 Reach 609 *E. coli* load duration curve and monitored loads and exceedances in the Cottonwood River Watershed.**

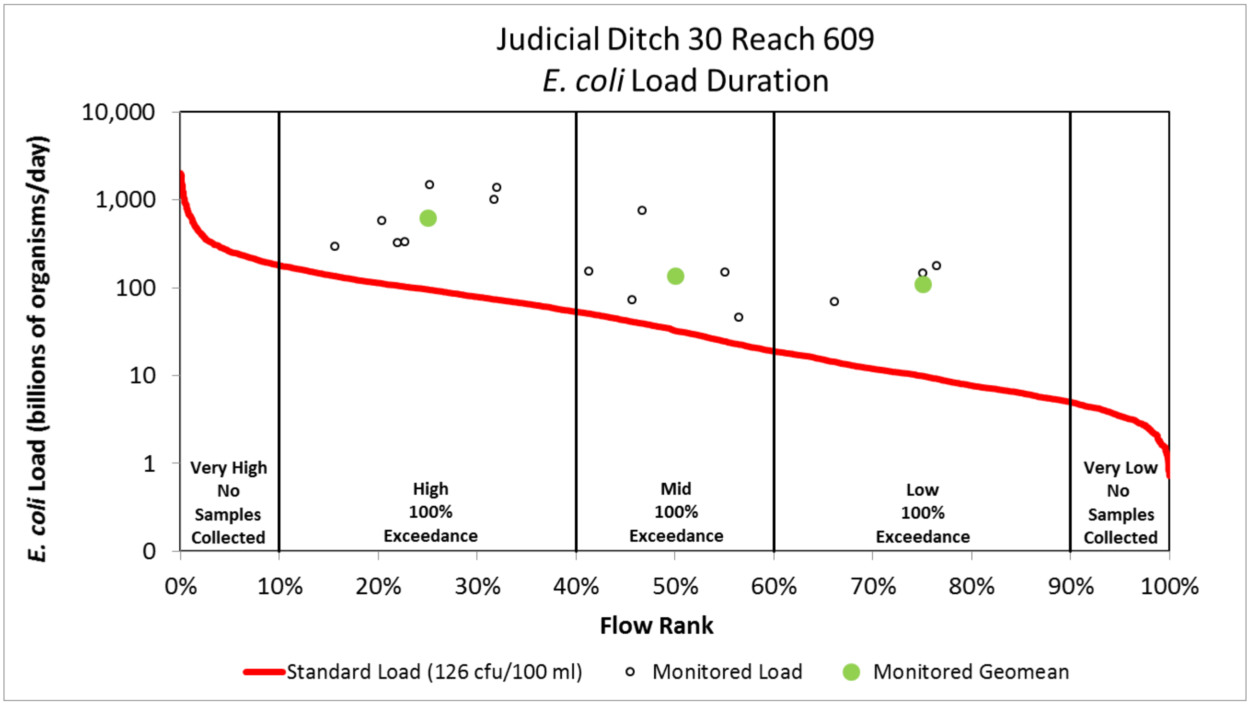



**Table 38. *E. coli* TMDL summary for Judicial Ditch 30 Reach 609.**

| *E. coli* | | Flow zones* | | | | |
|---|---|---|---|---|---|---|
| | | Very high | High | Mid-range | Low | Very low |
| Sources | | *E. coli* load (billions of orgs/day) | | | | |
| Load | Total LA | 378 | 140 | 48 | 15 | 5 |
| | MOS | 20 | 7 | 3 | 0.8 | 0.3 |
| | Total load | 398 | 147 | 51 | 16 | 5 |
| | Existing Concentration, Apr-Oct (org/100 mL)** | 787 | | | | |
| | Maximum Monthly Geometric Mean (org/100mL)** | 2,064 | | | | |
| | Overall Estimated Percent Reduction** | 94% | | | | |

* Model simulated flow for HSPF reach 435 from April-October (2008-2017) was used to develop the flow zones and LCs for this reach.

** Water quality monitoring station(s) used to estimate reductions: S005-688.

# 4.4 Phosphorus - Lakes

## 4.4.1 Loading Capacity Methodology

TP LCs for each impaired lake in the Cottonwood River Watershed (see Figure 2 and Appendix A) were developed using the Canfield-Bachmann Lake Response Model. Phosphorus loading from the atmosphere, SSTSs, watershed, upstream impaired lakes and internal load were the primary sources evaluated and incorporated into the Canfield-Bachmann Lake Response Models. Section 3.6.3 of this TMDL provides a detailed discussion of the phosphorus source assessment and lake response model methodology. Once each of the lake response models were calibrated, the resulting relationship between phosphorus load and in-lake water quality were used to determine the assimilative capacity.

To set the LC for each impaired lake, the nutrient inputs partitioned between sources in the lake response models were systematically reduced until the model predicted that each lake met their ecoregion TP standard. This process is discussed in more detail in Section 4.4.6.

### 4.4.2 Wasteload Allocation Methodology

The WLAs were divided into three primary categories: NPDES permitted wastewater dischargers, NPDES permitted MS4 stormwater, and NPDES-permitted construction and industrial stormwater. The NPDES permitted livestock CAFOs are zero discharge facilities and are given a WLA of zero and should not impact water quality in each lake's drainage area as a point source. Therefore, it is not necessary to put them in the lake phosphorus TMDL tables. Also, straight pipe septic systems are illegal and receive a WLA of zero. Therefore, it is not necessary to put them in the lake phosphorus TMDL tables.

***NPDES Permitted Wastewater Dischargers***

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

***NPDES Permitted MS4 Stormwater***

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

***NPDES Permitted Construction and Industrial Stormwater***

Construction and industrial stormwater WLAs were established based on estimated percentage of land in the Cottonwood River Watershed currently under construction or permitted for industrial use. A 2018 permit review across the watershed (see Section 4.2.2) showed minimal construction and industrial activities (~0.15% of the watershed).

### 4.4.3 Load Allocation Methodology

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

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

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

### 4.4.4 Margin of Safety

An explicit MOS was used for each of the impaired lake TMDLs in this TMDL. The purpose of the MOS is to account for uncertainty that the allocations will result in attainment of water quality standards. Section 303(d) of the CWA and EPA’s regulations in 40 CFR § 130.7 require that: TMDLs shall be established at levels necessary to attain and maintain the applicable narrative and numeric water quality standards with seasonal variations and a MOS, which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality. The MOS can either be implicitly incorporated into conservative assumptions used to develop the TMDL or be added as a separate explicit component of the TMDL (EPA 1991). Ten percent of the load was set aside in the TMDL for each impaired lake to account for uncertainty in the phosphorus source assessment and the lake response models. The use of an explicit MOS accounts for environmental variability in pollutant loading, variability in water quality monitoring data, calibration and validation processes of modeling efforts, uncertainty in modeling outputs, conservative assumptions made during the modeling efforts, and limitations associated with the drainage area-ratio method used to extrapolate flow data. This MOS is considered to be sufficient given the robust datasets used and high quality of modeling, as described below.

The Cottonwood River Basin HSPF model was calibrated and validated using 21 years (1996 through 2017) of flow data from five gaging stations. Calibration results indicate that the HSPF model is a valid representation of hydrological and chemical conditions in the watershed. The BATHTUB models used to develop the lake TMDLs show generally good agreement between the observed lake water quality and the water quality predicted by the lake response models. See Appendix D of this TMDL for the HSPF model calibration and validation results.

### 4.4.5 Seasonal Variation and Critical Conditions

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

### 4.4.6 Phosphorus Reduction Methodology

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

- No reductions to atmospheric load were assigned since these loads were generally a small portion of the total load to the lake and the sources are extremely difficult to define and control.
- Phosphorus loading from ITPHS SSTSs and SSTSs that fail to protect groundwater (FTPGW) were reduced to levels expected from properly functioning SSTSs. See Section 3.6.4 for more discussion on the methods used to estimate SSTS contributions and Reasonable Assurance SSTS Section 6.1.5.
- All upstream impaired lakes are expected to meet water quality standards, and the resultant reductions are applied to the lake being evaluated. If these reductions result in the lake meeting water quality standards, then the TMDL allocations are done. If more reductions are required, then the internal and external loads are evaluated simultaneously.
- Watershed loading will ideally be reduced until the lake response model indicates the lake is meeting lake water quality standards. Watershed loading was incrementally reduced until watershed TP concentrations met the river/stream eutrophication standard for the Southern River Nutrient Region (150 µg/L). If the lake model did not meet water quality standards after watershed phosphorus concentrations were set to the river/stream eutrophication standard, the remaining phosphorus reduction was taken from internal loading.
- For many of the lakes in the Cottonwood River Watershed, internal load is a significant source of phosphorus and in-lake efforts may be needed to achieve water quality standards. The general approach to internal load reductions is based on review of the potential internal loading sources (see discussion in Sections 3.6.4 and 8.3.5), the monitored/modeled sediment RRs and lake morphometry. This is accomplished by comparing the existing monitored/modeled RRs to literature values of “healthy lakes” (~1 $mg/m^2/day$) (Nürnberg 1997; Wenck 2011). If the estimated RR is high, then the rate is reduced systematically until either a minimum of 1 $mg/m^2/day$ is reached or the lake meets TMDL requirements.

### 4.4.7 Phosphorus TMDL Summary

The allowable TP load (TMDL) for each lake was divided among the WLA, LA, and the MOS as described in the preceding sections. The following tables summarize the existing and allowable TP loads (Total Load in tables), the TMDL allocations (Wasteload and Load in tables), and required reductions for each lake. In these tables the total load reduction is the sum of the required WLA reductions plus the required LA reductions; this is not the same as the net difference between the existing and allowable total loads, however, because the WLA and LA reductions must accommodate the MOS.

The following rounding conventions were used in the TMDL tables:

- Values ≥1.0 reported in lbs/yr have been rounded to the nearest lb.

- Values <1.0 reported in lbs/yr have been rounded to one significant digit so that the value is greater than zero and a number is displayed in the table.
- While some of the numbers in the tables show multiple digits, they are not intended to imply great precision; this is done primarily to make the arithmetic accurate.

Table 39 through Table 46 resent the allocations for the impaired lakes in the Cottonwood River Watershed and Figure 26 through Figure 32 show the estimated phosphorus sources for each of the lakes. Internal phosphorus load and watershed phosphorus load are the dominant sources for the lakes in this TMDL report. A focus on reducing internal phosphorus loads will be required to return these lakes to a nonimpaired state, however, long-term improvement to the lakes' trophic status will also require reductions from external load sources. See the Minnesota State and Regional Government Review of Internal Phosphorus Load Control (MPCA 2020d) for more information on internal phosphorus load control planning and practices.

**Table 39. Rock Lake (42-0052-00) phosphorus TMDL in the Cottonwood River Watershed.**

| Phosphorus Sources | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| **Wasteload** | Construction/Industrial SW | 3 | 0.01 | 3 | 0.01 | 0 | 0% |
| | **Total WLA** | **3** | **0.01** | **3** | **0.01** | **0** | **0%** |
| **Load** | Watershed runoff | 1,699 | 4.65 | 841 | 2.30 | 858 | 50% |
| | SSTS | 15 | 0.04 | 9 | 0.03 | 6 | 39% |
| | Atmospheric deposition | 91 | 0.25 | 91 | 0.25 | 0 | 0% |
| | Internal load | 3,722 | 10.19 | 496 | 1.36 | 3,226 | 87% |
| | **Total LA** | **5,527** | **15.13** | **1,437** | **3.94** | **4,090** | **74%** |
| **MOS** | | | | **160** | **0.44** | | |
| **Total load** | | **5,530** | **15.14** | **1,600** | **4.39** | **4,090** | **71%** |

* Model calibration year(s): 2002, 2007 & 2017.** Net reduction from current load to TMDL is 3,930 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 3,930 + 160 = 4,090 lbs/yr.

**Figure 26. Rock Lake phosphorus source reductions to meet TMDL in the Cottonwood River Watershed.**

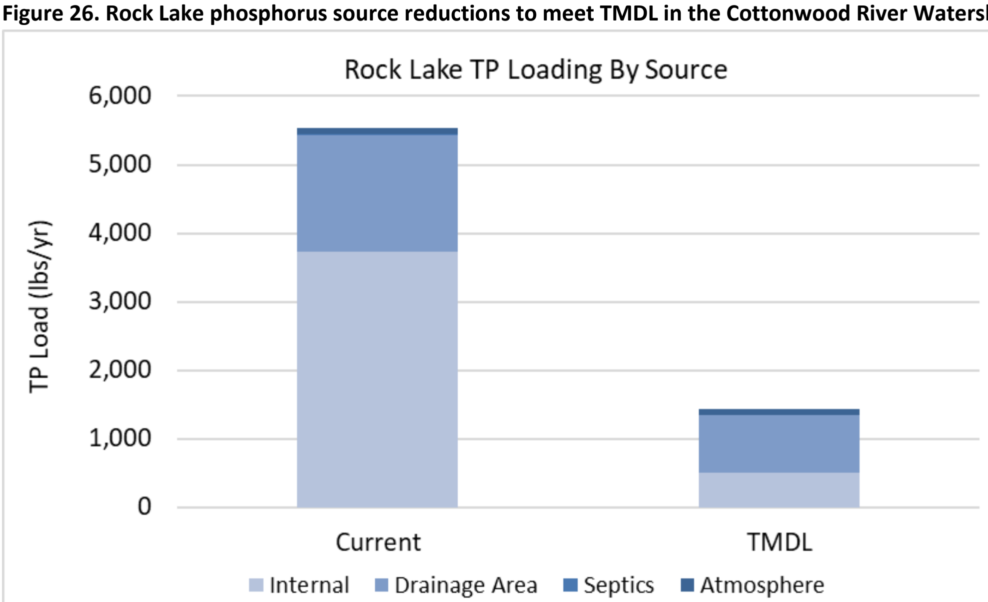


**Table 40. Bean Lake (08-0011-00) phosphorus TMDL in the Cottonwood River Watershed.**

| Phosphorus Sources | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| **Wasteload** | Construction/Industrial SW | 0.5 | 0.001 | 0.5 | 0.001 | 0.0 | 0% |
| | **Total WLA** | **0.5** | **0.001** | **0.5** | **0.001** | **0.0** | **0%** |
| **Load** | Watershed runoff | 326.0 | 0.893 | 211.6 | 0.579 | 114.4 | 35% |
| | SSTS | 2.5 | 0.007 | 1.2 | 0.003 | 1.3 | 54% |
| | Atmospheric deposition | 39.2 | 0.107 | 39.2 | 0.107 | 0.0 | 0% |
| | Internal load | 1,191.8 | 3.263 | 591.2 | 1.619 | 600.6 | 50% |
| | **Total LA** | **1,559.5** | **4.270** | **843.2** | **2.308** | **716.3** | **46%** |
| **MOS** | | | | **93.7** | **0.257** | | |
| **Total load** | | **1,560.0** | **4.271** | **937.4** | **2.566** | **716.3** | **40%** |

* Model calibration year(s): 2007, 2008 & 2017.

** Net reduction from current load to TMDL is 622.6 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 622.6 + 93.7 = 716.3 lbs/yr.

**Figure 27. Bean Lake phosphorus source reductions to meet TMDL in the Cottonwood River Watershed.**

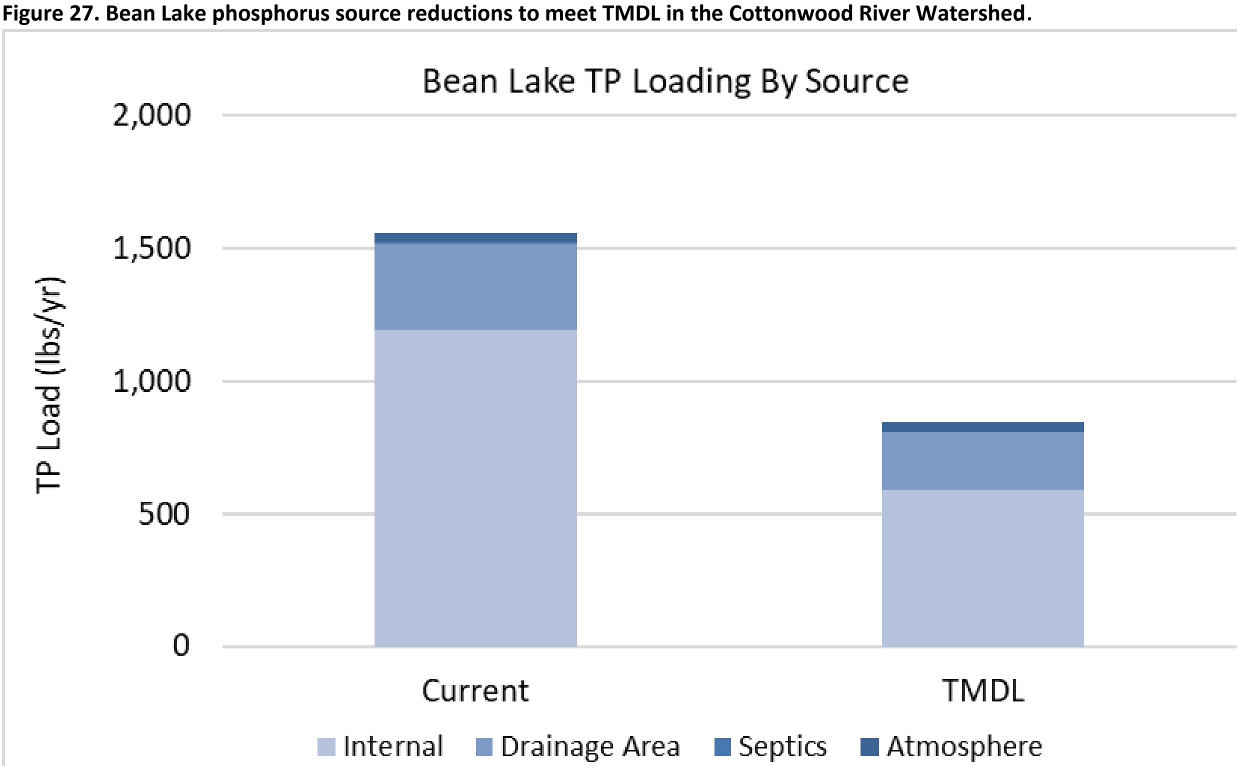


**Table 41. Double (North Portion) Lake (17-0056-01) phosphorus TMDL in the Cottonwood River Watershed.**

| Phosphorus Sources | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| **Wasteload** | Construction/Industrial SW | 0.5 | 0.001 | 0.5 | 0.001 | 0.0 | 0% |
| | **Total WLA** | **0.5** | **0.001** | **0.5** | **0.001** | **0.0** | **0%** |
| **Load** | Watershed runoff | 365.2 | 1.000 | 103.8 | 0.284 | 261.4 | 72% |
| | SSTS | 10.9 | 0.030 | 5.2 | 0.014 | 5.7 | 52% |
| | Upstream lake (Bean) | 145.8 | 0.399 | 97.8 | 0.268 | 48.0 | 33% |
| | Atmospheric deposition | 32.5 | 0.089 | 32.5 | 0.089 | 0.0 | 0% |
| | Internal load | 468.2 | 1.282 | 329.0 | 0.901 | 139.2 | 30% |
| | **Total LA** | **1,022.6** | **2.800** | **568.3** | **1.556** | **454.3** | **44%** |
| **MOS** | | | | **63.2** | **0.173** | | |
| **Total load** | | **1,023.1** | **2.801** | **632.0** | **1.730** | **454.3** | **38%** |

* Model calibration year(s): 2007, 2008, 2017 and 2018.

** Net reduction from current load to TMDL is 391.1 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 391.1 + 63.2 = 454.3 lbs/yr.

**Figure 28. Double (North Portion) Lake phosphorus source reductions to meet TMDL in the Cottonwood River Watershed.**

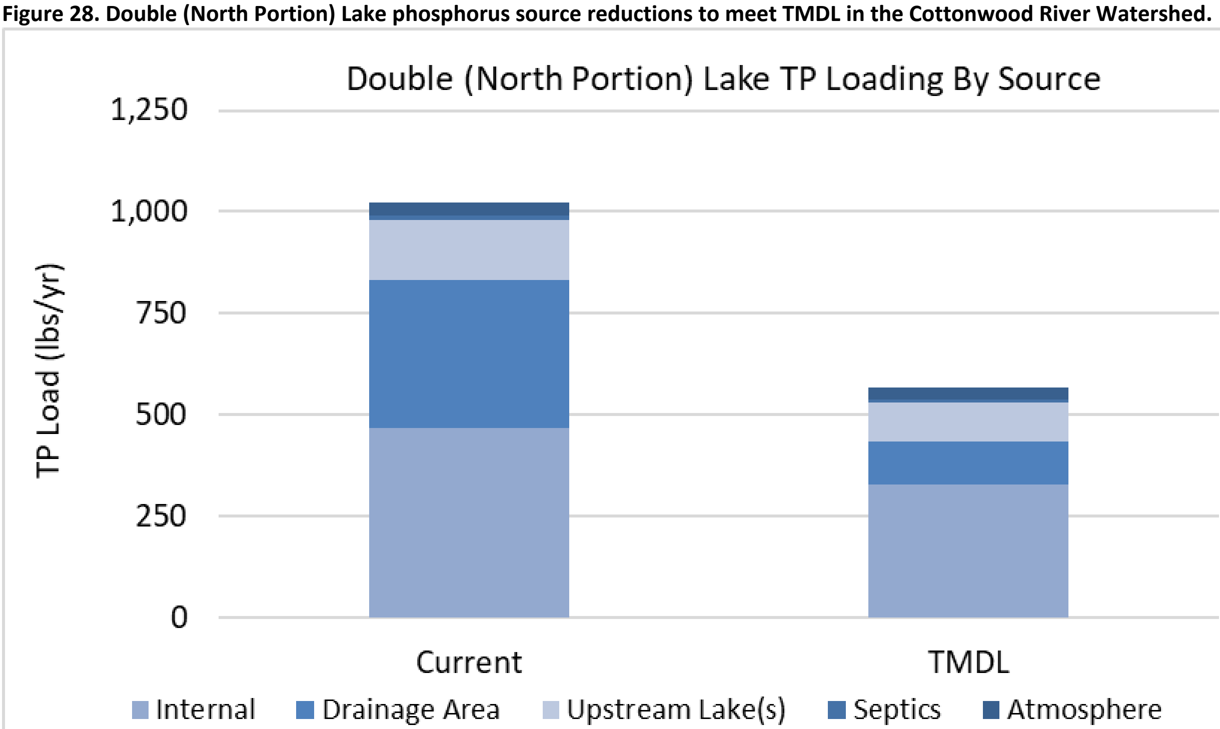


**Table 42. Clear Lake (08-0011-00) phosphorus TMDL in the Cottonwood River Watershed.**

| Phosphorus Sources | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| **Wasteload** | Construction/Industrial SW | 1.6 | 0.004 | 1.6 | 0.004 | 0.0 | 0% |
| | **Total WLA** | **1.6** | **0.004** | **1.6** | **0.004** | **0.0** | **0%** |
| **Load** | Watershed Runoff | 1,055.8 | 2.891 | 605.3 | 1.657 | 450.5 | 43% |
| | SSTS | 16.3 | 0.045 | 7.6 | 0.021 | 8.7 | 53% |
| | Atmospheric deposition | 66.2 | 0.181 | 66.2 | 0.181 | 0.0 | 0% |
| | Internal load | 1,289.0 | 3.529 | 344.6 | 0.943 | 944.4 | 73% |
| | **Total LA** | **2,427.3** | **6.646** | **1,023.7** | **2.802** | **1,403.6** | **58%** |
| **MOS** | | | | **113.9** | **0.312** | | |
| **Total load** | | **2,428.9** | **6.650** | **1,139.2** | **3.118** | **1,403.6** | **53%** |

* Model calibration year(s): 2009, 2010 and 2017.

** Net reduction from current load to TMDL is 1,289.7 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,289.7 + 113.9 = 1,403.6 lbs/yr.

**Figure 29. Clear Lake phosphorus source reductions to meet TMDL in the Cottonwood River Watershed.**

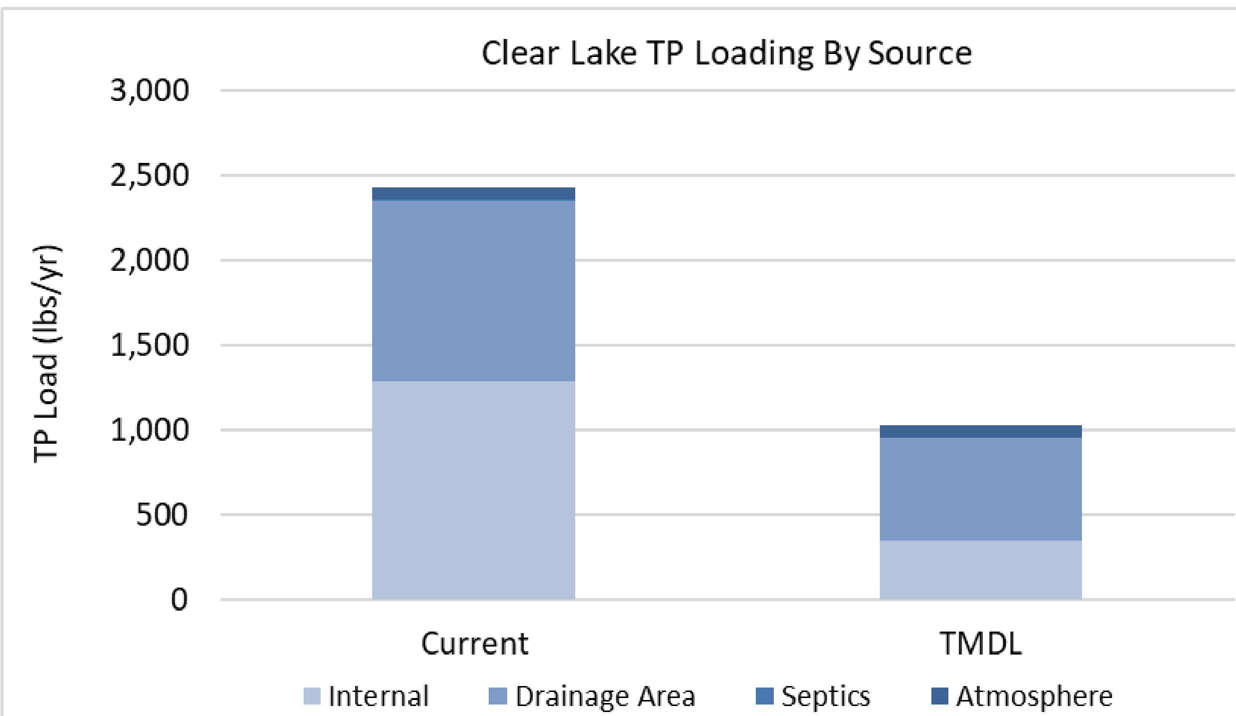


**Table 43. Altermatt Lake (08-0054-00) phosphorus TMDL in the Cottonwood River Watershed.**

| Phosphorus | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| Sources | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| **Wasteload** | Construction/Industrial SW | 1 | 0.004 | 1 | 0.004 | 0 | 0% |
| | **Total WLA** | **1** | **0.004** | **1** | **0.004** | **0** | **0%** |
| **Load** | Watershed runoff | 978 | 2.679 | 374 | 1.025 | 604 | 62% |
| | SSTS | 9 | 0.026 | 4 | 0.012 | 5 | 54% |
| | Atmospheric deposition | 29 | 0.080 | 29 | 0.080 | 0 | 0% |
| | Internal load | 3,169 | 8.677 | 50 | 0.136 | 3,119 | 98% |
| | **Total LA** | **4,185** | **11.462** | **457** | **1.253** | **3,728** | **89%** |
| **MOS** | | | | **51** | **0.140** | | |
| **Total load** | | **4,186** | **11.466** | **509** | **1.397** | **3,728** | **88%** |

* Model calibration year(s): 2009 and 2010.

** Net reduction from current load to TMDL is 3,677 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 3,677 + 51 = 3,728 lbs/yr.

**Figure 30. Altermatt Lake phosphorus source reductions to meet TMDL in the Cottonwood River Watershed.**

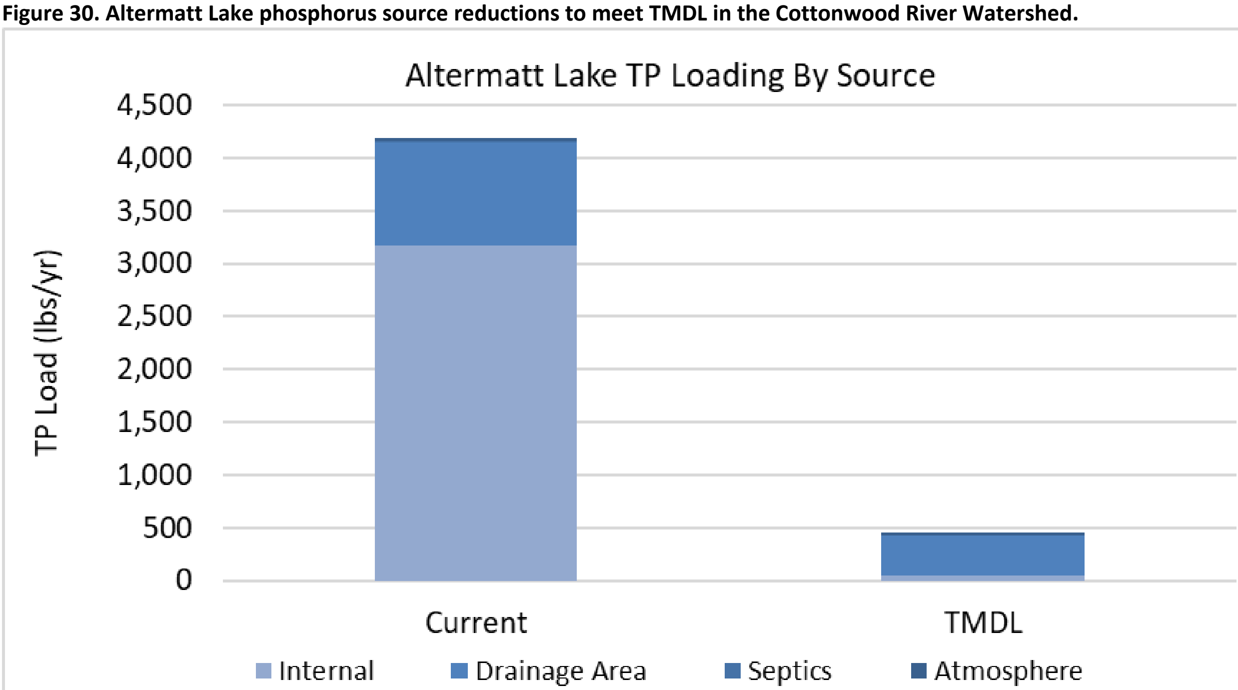


**Table 44. Boise Lake (08-0096-00) phosphorus TMDL in the Cottonwood River Watershed.**

| Phosphorus Sources | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| Wasteload | Construction/Industrial SW | 1 | 0.003 | 1 | 0.003 | 0 | 0% |
| | **Total WLA** | **1** | **0.003** | **1** | **0.003** | **0** | **0%** |
| Load | Watershed runoff | 804 | 2.202 | 258 | 0.706 | 546 | 68% |
| | SSTS | 8 | 0.023 | 4 | 0.010 | 4 | 50% |
| | Atmospheric deposition | 42 | 0.114 | 42 | 0.114 | 0 | 0% |
| | Internal load | 1,333 | 3.649 | 96 | 0.264 | 1,237 | 93% |
| | **Total LA** | **2,187** | **5.988** | **400** | **1.094** | **1,787** | **82%** |
| **MOS** | | | | **44** | **0.122** | | |
| **Total load** | | **2,188** | **5.991** | **445** | **1.219** | **1,787** | **80%** |

* Model calibration year(s): 2011 and 2012.
** Net reduction from current load to TMDL is 1,743 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,743 + 44 = 1,787 lbs/yr.

**Figure 31. Boise Lake phosphorus source reductions to meet TMDL in the Cottonwood River Watershed.**

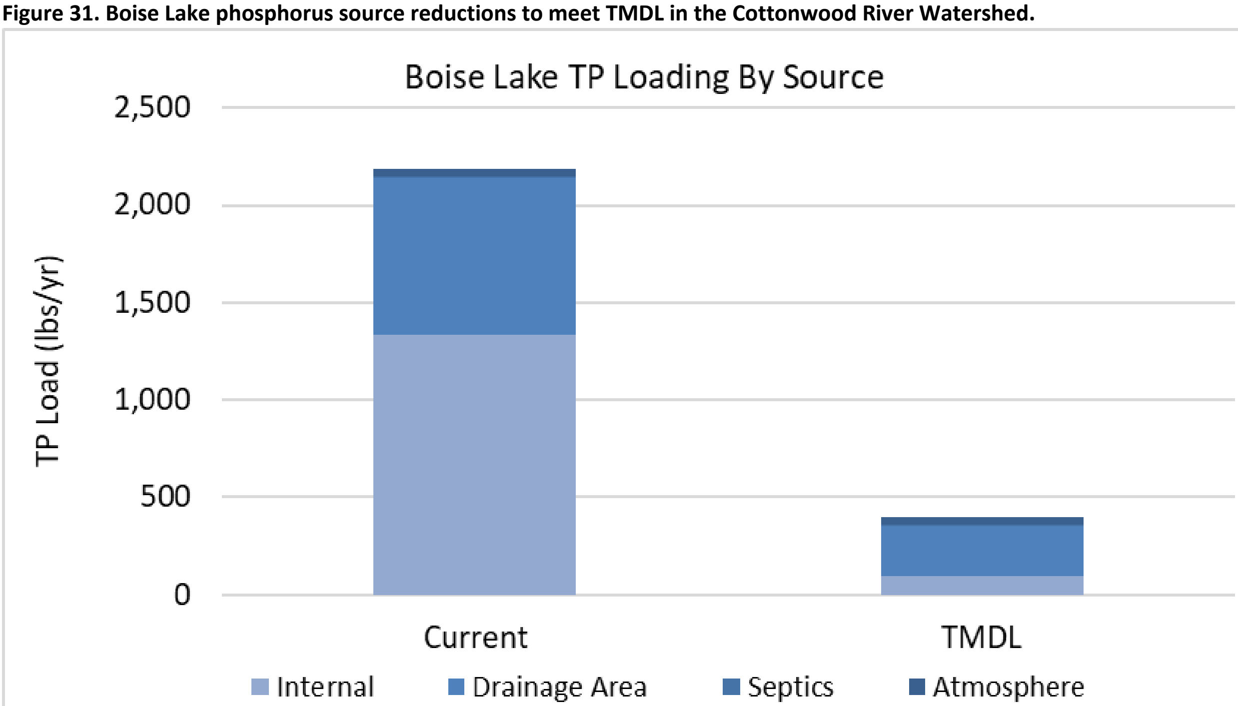
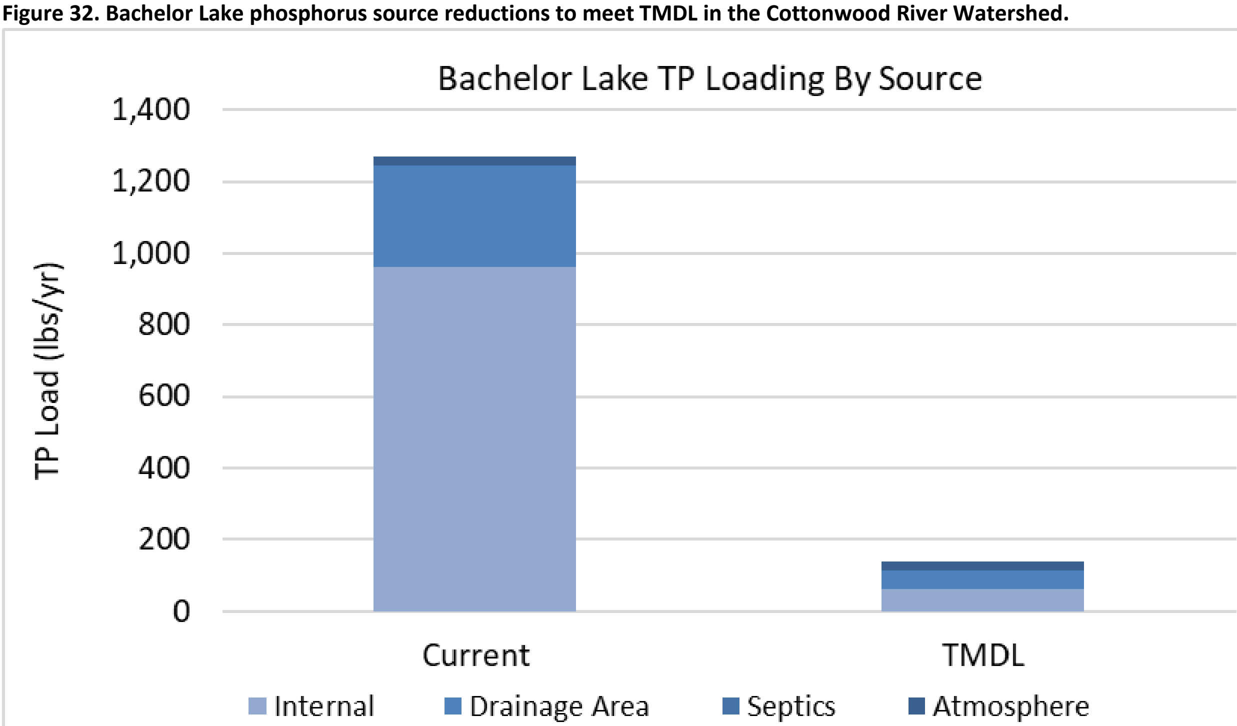


**Table 45. Bachelor Lake (08-0029-00) phosphorus TMDL in the Cottonwood River Watershed.**

| Phosphorus Sources | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| Wasteload | Construction/Industrial SW | 0.4 | 0.001 | 0.4 | 0.001 | 0.0 | 0% |
| | **Total WLA** | **0.4** | **0.001** | **0.4** | **0.001** | **0.0** | **0%** |
| Load | Watershed runoff | 282.2 | 0.773 | 50.5 | 0.138 | 231.7 | 82% |
| | SSTS | 0.6 | 0.002 | 0.4 | 0.001 | 0.2 | 33% |
| | Atmospheric deposition | 23.3 | 0.064 | 23.3 | 0.064 | 0.0 | 0% |
| | Internal load | 962.8 | 2.636 | 63.6 | 0.174 | 899.2 | 93% |
| | **Total LA** | **1,268.9** | **3.475** | **137.8** | **0.377** | **1,131.1** | **89%** |
| **MOS** | | | | **15.4** | **0.042** | | |
| **Total load** | | **1,269.3** | **3.476** | **153.6** | **0.420** | **1,131.1** | **88%** |

* Model calibration year(s): 2011 and 2012.
** Net reduction from current load to TMDL is 1,115.7 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 1,115.7 + 15.4 = 1,131.1 lbs/yr.

**Figure 32. Bachelor Lake phosphorus source reductions to meet TMDL in the Cottonwood River Watershed.**



# 5. Future Growth Considerations

According to the Minnesota State Demographic Center (Minnesota Department of Administration 2015) from 2015 to 2035, the populations of all five counties in the Cottonwood River Watershed are projected to decrease by 3% (Lyon County) to as much as 18% (Redwood County). The overall projection for all five counties is negative 8%. The MPCA does not anticipate significant population growth within the Cottonwood 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 (TSS and *E. coli* TMDLs only)

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

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

# 6. Reasonable Assurance

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

The MPCA will:

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

## 6.1 Regulatory

### 6.1.1 Construction Stormwater

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

### 6.1.2 Industrial Stormwater

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

### 6.1.3 MS4 Permits

The MPCA is responsible for applying federal and state regulations to protect and enhance water quality in Minnesota. The MPCA oversees stormwater management accounting activities for all MS4 entities listed in this TMDL report. The MS4 General Permit requires regulated municipalities to implement

BMPs that reduce pollutants in stormwater to the maximum extent practicable. A critical component of permit compliance is the requirement for the owners or operators of a permitted MS4 conveyance to develop a SWPPP. The SWPPP addresses all permit requirements, including the following six measures:

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

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

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 towards assigned WLAs. For WLAs being met at the time of permit application, the same level of treatment must be maintained in the future. This TMDL report assigns TSS WLAs to the City of Marshall, a permitted MS4. However, as there is an assessed unimpaired reach between the City's outfall and the TSS impaired reaches, no reductions are required for the city's MS4. Regardless of WLA attainment or required reductions, all permitted MS4s are still required to reduce pollutant loadings to the maximum extent practicable.

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

### 6.1.4 Wastewater NPDES and SDS Permits

The MPCA issues permits for WWTPs or industrial facilities that discharge into waters of the state. The permits have site specific limits on TSS and other parameters that are based on water quality standards. Permits regulate discharges with the goals of 1) protecting public health and aquatic life, and 2) assuring that every facility treats wastewater. In addition, NPDES and SDS Permits set limits and establish controls for land application of waste and byproducts. Permits issued under the NPDES program are required to have effluent limits consistent with the assumptions and requirements of the WLAs in this

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

***Bacteria, TSS, and Lake Phosphorus***

WWTPs discharging to the TSS and *E. coli* impaired reaches did not require any changes to their discharge permit limits due to the WLAs calculated in this TMDL report. No WWTPs discharge to the impaired lakes addressed in this TMDL report.

### 6.1.5 SSTS Program

SSTS, commonly known as septic systems, are regulated by Minn. Stat. §§ 115.55 and 115.56. Counties and other Local Government Unit (LGUs) that regulate SSTS must meet the requirements for local SSTS programs in Minn. R. ch. 7082. Counties and other LGUs must adopt and implement SSTS ordinances in compliance with Minn. R. chs. 7080 - 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 provisions in their ordinance above the minimum program requirements. The MPCA has worked with counties through the SSTS Implementation and Enforcement Task Force (SIETF) to identify the most beneficial ways to use these funds to accelerate SSTS compliance statewide:

- Compliance inspection for property transfer;
- Compliance inspection for any (all) permit-countywide;
- Plan to improve compliance, such as records catalog or inventory (past, ongoing or future); and
- 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 unsewered communities within the Cottonwood River Watershed are all addressing their wastewater treatment through SSTS upgrades regulated by county ordinances and funded by various sources, such as the Clean Water Fund (CWF) and Clean Water Partnership (CWP) State Revolving Fund (SRF) Loan Program.

### 6.1.6 Feedlot Program

All feedlots in Minnesota are regulated by Minn. R. ch. 7020. The MPCA has regulatory authority of feedlots but counties may choose to participate in a delegation of the feedlot regulatory authority to the 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 Cottonwood River Watershed, the counties of Lyon, Murray, Cottonwood, and Brown are the delegated feedlot regulatory authority. The only nondelegated county in the Cottonwood River Watershed is Redwood County. The Counties and MPCA will continue to implement the feedlot program and work with producers on MMPs.

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

There are two primary concerns about feedlots in protecting water:

- Ensuring that manure on a feedlot or manure storage area does not run into water.
- Ensuring that manure is applied to cropland at a rate, time and method that prevents bacteria and other possible contaminants from entering streams, lakes and ground water.

### 6.1.7 Buffers and Shoreland

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

Most of the private lands in the Cottonwood River Watershed contain well vegetated buffers along ditches, lakes, and streams. Reported rates of compliance for all four counties in the Cottonwood River Watershed are between 95% and 100% (Board of Water and Soil Resources; BWSR website).

Other nonpoint source statutes/rules include:

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

## 6.2 Nonregulatory

### 6.2.1 Pollutant Load Reduction

Reliable means of reducing nonpoint source pollutant loads are fully addressed in the WRAPS report (MPCA 2022), a document that is written to be a companion to this TMDL. In order for the impaired waters to meet water quality standards, the majority of pollutant reductions in the Cottonwood River Watershed will need to come from nonpoint sources. Agricultural drainage and surface runoff are major contributors of nutrients, bacteria, sediment, and increased flows throughout the watershed. As described in the WRAPS report, the BMPs identified for restoration have all been demonstrated to be effective in reducing transport of pollutants to surface water. The combinations of BMPs discussed throughout the WRAPS process were derived from Minnesota's Nutrient Reduction Strategy (NRS) (MPCA 2015a) and related tools. As such, they were vetted by a statewide engagement process prior to being applied in the Cottonwood River Watershed.

Selection of sites for BMPs will be led by LGUs, including SWCDs, watershed management organizations, and county planning and zoning, through the One Watershed, One Plan (1W1P) process, which was awarded planning funding for this watershed in August 2022, with support from state and federal agencies. These BMPs are supported by programs administered by the SWCDs and the Natural Resources 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 allowing waters to be in an impaired condition is not acceptable. Throughout the course of the WRAPS and TMDL meetings, local stakeholders endorsed the BMPs selected in the WRAPS report. These BMPs reduce pollutant loads from runoff (i.e., phosphorus, sediment and pathogens) and loads delivered through drainage tiles or groundwater flow (e.g., nitrates).

To help achieve nonpoint source reductions, a large emphasis has been placed on public participation, where the citizens and urban communities that hold the power to improve water quality conditions are involved in discussions and decision-making. The watershed's citizens and urban communities will need to voluntarily adopt the practices at the necessary scale and rates to achieve the 10-year targets presented in Implementation Table 14- through Table 22of the WRAPS report and the Minnesota Stormwater Manual. The WRAPS also presents the pollutant/stressor reduction goals and targets and the estimated years to meet the goal developed by the WRAPS Local Work Group (LWG). The strategies identified and relative adoption rates developed by the WRAPS LWG were used to calculate the adoption rates needed to meet the pollutant/stressor 10-year targets. In addition to public participation, several government programs are in place to support a political and social infrastructure that aims to increase the adoption of strategies that will improve watershed conditions and reduce loading from nonpoint sources.

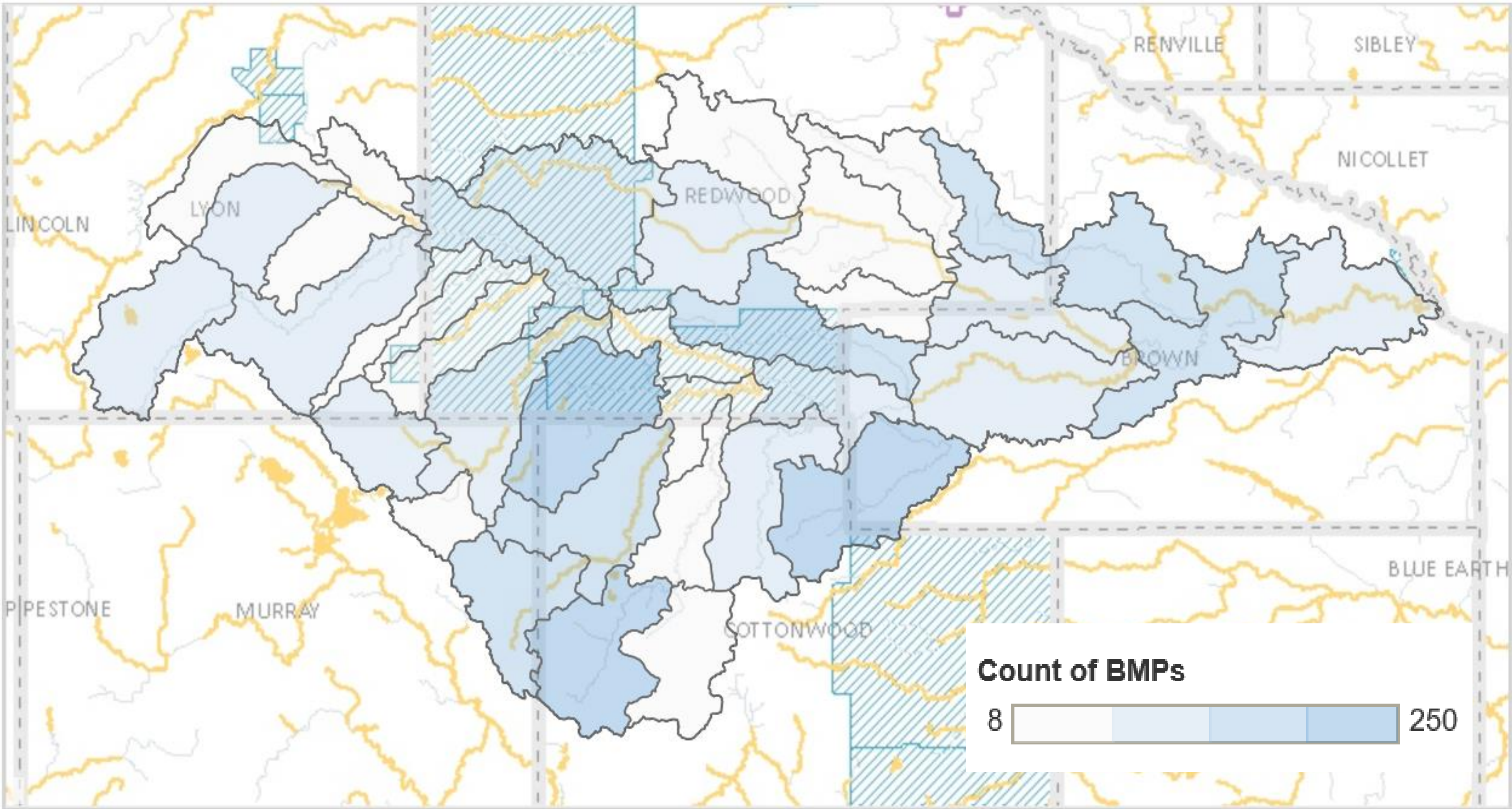
Several nonpermitted reduction programs exist to support implementation of nonpoint source reduction BMPs in the Cottonwood River Watershed. These programs identify BMPs, provide means of focusing BMPs, and support their implementation via state initiatives, ordinances, and/or dedicated funding.

From 2004 to 2019, over 3,500 BMPs were installed in the Cottonwood River Watershed by local partners. Table 46 summarizes the major types of BMPs that have been implemented throughout the watershed, while Figure 33 depicts the number of BMPs per subwatershed in the Cottonwood River Watershed. Additional information about the BMPs may be found on the MPCA's Healthier Watershed website.

**Table 46. Reported BMPs in the Cottonwood River Watershed by BMP type (2004-2021).**

| BMP Type | Total BMPs |
|---|---|
| Tile Inlet Improvements | 266 |
| Tillage/residue Management | 480 |
| Nutrient Management (Cropland) | 430 |
| Septic System Improvements | 48 |
| Designed Erosion Control | 271 |
| Converting Land to Perennials | 157 |
| Buffers and Filters | 59 |
| Living Cover to Crops in Fall/Spring | 135 |
| Stream Banks, Bluffs, and Ravines | 101 |
| Pasture Management | 63 |
| Tile Drainage Treatment/Storage | 11 |
| Habitat and Stream Connectivity | 9 |
| Crop Rotation | 19 |

**Figure 33. Numbers of BMPs installed in the Cottonwood River Watershed by subwatershed.**



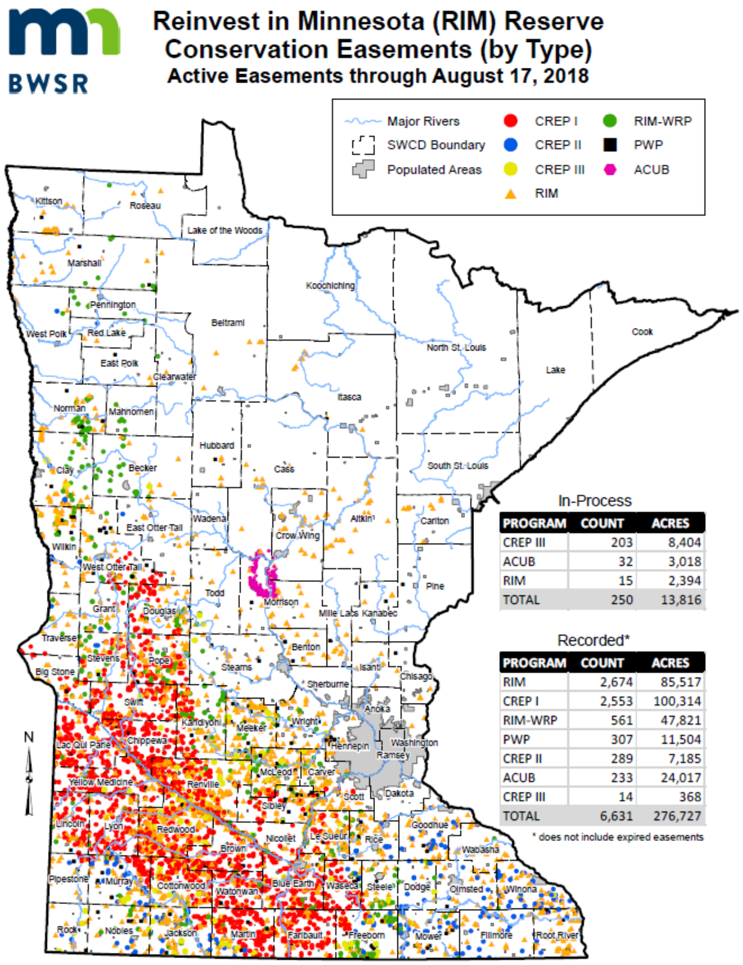
Further, two Minnesota Department of Agriculture (MDA) led initiatives - The Nutrient Management Initiative Program (NMI) and The Agricultural Water Quality Certification Program (MAWQCP) – have engaged farmers and increased agricultural BMP adoption in the Cottonwood River Watershed. The NMI Program has provided financial incentives for participants to conduct on-farm trials comparing related to nitrogen fertilizer rate management. A total of 31 nutrient trials took place in the Cottonwood and Redwood River Watersheds between 2006 and 2019. MAWQCP is a voluntary opportunity for farmers and agricultural landowners to take the lead in implementing conservation practices that protect water quality. Those who implement and maintain approved farm management practices are certified and in turn obtain regulatory certainty for a period of 10 years. In the Cottonwood River Watershed, there are 16 MAWQCP-certified producers that cover 12,239 acres. BMPs implemented to-date through this program include:

- 84 alternative/closed tile intakes
- 231 acres of pest management
- 19 sediment basins
- 4 acres of filter strips
- 1,431 acres of residue management
- 887 acres of nutrient management
- 946 acres nitrogen BMPs
- 313 acres cover crops
- 2,000 ft grassed waterway

**Conservation Easements**

Conservation easements are a critical component of the state's efforts to improve water quality by reducing soil erosion, phosphorus, and nitrogen loading, and improving wildlife habitat and flood attenuation on private lands. Easements protect the state's water and soil resources by permanently restoring wetlands, adjacent native grassland wildlife habitat complexes, and permanent riparian buffers. In cooperation with county SWCDs and the USDA NRCS, BWSR's programs compensate landowners for granting conservation easements and establishing native vegetation habitat on economically marginal, flood-prone, environmentally sensitive, or highly erodible lands. These easements vary in length of time from 10 years to permanent/perpetual easements. Types of conservation easements in Minnesota include: Conservation Reserve Program (CRP); Conservation Reserve Enhancement Program (CREP); Reinvest in Minnesota (RIM); and the Wetland Reserve Program (WRP) or Permanent Wetland Preserve (PWP) (Figure 34).

**Figure 34. Conservation easements in Minnesota.**




## 6.2.2 Prioritization

Water Quality Trends for Minnesota Rivers and Streams at Milestone Sites notes that sites across Minnesota, including the Cottonwood River, show long-term reductions in TSS, ammonia, and biochemical oxygen demand (MPCA 2014). The Minnesota NRS documented a 33% reduction of the phosphorus load leaving the state via the Mississippi River from the pre-2000 baseline to current (MPCA 2015). 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 Cottonwood River WRAPS and TMDL goals and strategies are reasonable and that long-term, enduring efforts to decrease erosion and nutrient loading to surface waters have the potential to reduce pollutant loads.

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

The State of Minnesota has provided tools to further the buffer initiative; they are being used in the implementation planning process to examine riparian land use in the Cottonwood 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 Cottonwood River Watershed. These data are being increasingly used by LGUs to examine landscapes, understand watershed hydrology, and prioritize BMP targeting.

### 6.2.3 Funding

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

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

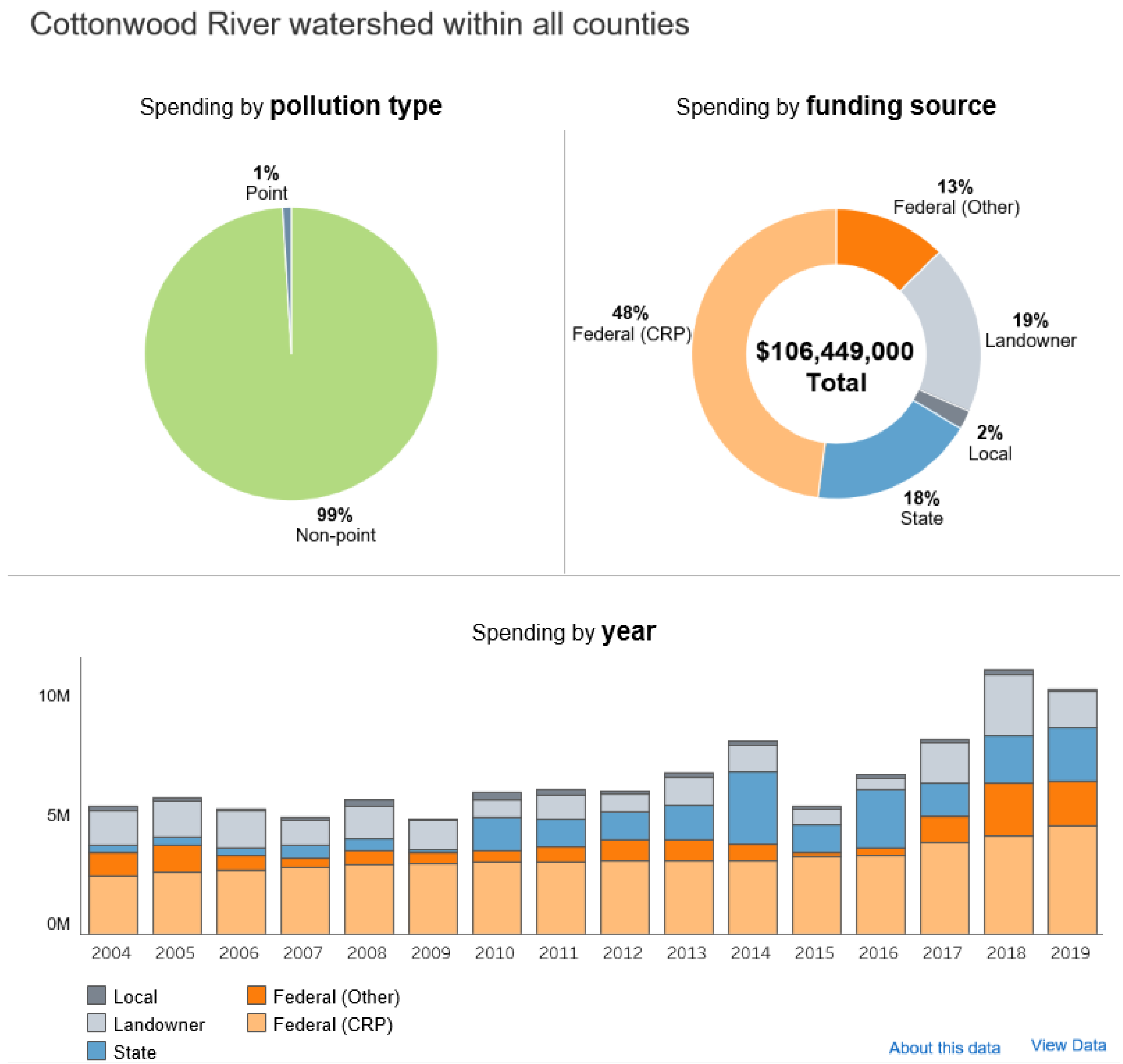
This is a secure funding mechanism with the explicit purpose of supporting water quality improvement projects.

Additionally, there are many other funding sources for nonpoint pollutant reduction work; they include but are not limited to Clean Water Act Section 319 grant programs, BWSR state CWF 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.

Minnesota was awarded $500 million to implement the 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 Cottonwood River Watershed strategies focused on converting marginal lands to perennials to reduce pollutant loading to surface and groundwater.

Since 2004, over $106 million have been spent addressing water quality issues in the Cottonwood River Watershed (Figure 35). Additional information about funding may be found on the MPCA’s Healthier Watersheds website.

**Figure 35. Spending addressing water quality issues in the Cottonwood River Watershed.**




## 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 comprehensive watershed management plan for the Cottonwood River Watershed awarded planning funding in August 2022, will draw on the goals, technical information, and tools to describe in detail strategies and actions 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. All counties in the Cottonwood River Watershed currently have approved, up-to-date water management 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. The 1W1P that will be developed for the watershed will be a cohesive, watershed-wide plan across all LGUs. TMDL and WRAPS goals will be incorporated in the process.

### 6.2.5 Tracking Progress

Water monitoring efforts within the Cottonwood 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 Cottonwood River Watershed. The MPCA's Healthier Watersheds web application tracks implementation efforts and funding for the watershed.

### 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 Cottonwood River Watershed.

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

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

# 7. Monitoring Plan

Several types of monitoring are necessary to track progress toward achieving the load reductions required for the TMDLs and the achievement of water quality standards. Water monitoring combined with tracking implementation of BMPs on the ground is critical in the adaptive management approach to implementing TMDLs. The LGUs will track the implementation of BMPs annually through BWSR's e-LINK system. This, and other data (e.g. USDA data) are readily available via the MPCA's Healthier Watersheds web application. 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 Cottonwood River Watershed as part of Minnesota's Water Quality Monitoring Strategy (MPCA 2021). Data needs are considered by each program and additional monitoring is implemented when deemed necessary and feasible. These monitoring programs are summarized as follows:

- Intensive Watershed Monitoring collects water quality and biological data for 2 years at established stream and lake monitoring stations across the Cottonwood River Watershed every 10 years. The MPCA, with assistance from LGUs, will re-visit and re-assess these monitoring stations, as well as have capacity to visit new sites in areas with BMP implementation activity, beginning in 2027. It is anticipated 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 Cottonwood River Watershed with data that vary by site.

- Volunteer Stream and Lake Monitoring Program data provide a continuous record of water body transparency throughout much of the basin. This program relies on a network of volunteers who make monthly stream and lake measurements annually. There is currently a limited number of volunteers doing monitoring within the Cottonwood River Watershed. The MPCA will seek more volunteer monitors to track trends of water quality transparency for impaired waters within the watershed.

- RCRCA has a long history of water quality monitoring in the Cottonwood River Watershed with a special focus on sediment and nutrient contributions from tributaries of the Cottonwood River. Water quality monitoring efforts have been based on a three-tier system. Primary, secondary, and tertiary monitoring stations have been developed to assess areas of the watershed delivering the greatest amount of sediment and nutrients to the Cottonwood River. This information has been used to select priority management areas and measure progress toward watershed goals.

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

The MDA completed 14 pesticide water quality sample collection events from seven lakes within the Cottonwood and Redwood River watersheds from 2012 through 2019. Double Lake was added to the 2020 303(d) Impaired Waters List for the insecticide chlorpyrifos due to one detection each in 2017 and 2018. No other lakes sampled in the Cottonwood River Watershed were above an applicable pesticide water quality reference value. The MDA will continue to monitor Double Lake until it can be delisted from the Impaired Waters List.

The MDA completed 517 pesticide and/or nutrient water quality sample collection events from 10 river and stream locations within the Cottonwood and Redwood River watersheds from 1992 through 2019. Sleepy Eye Creek at Cobden and the Cottonwood River at New Ulm were sampled within the Cottonwood River Watershed. Sleepy Eye Creek was designated on the 2018 Impaired Waters List for the insecticide chlorpyrifos due to detection in 2015 and 2016. No other river and stream pesticide impairments have been identified in the Cottonwood River Watershed. The MDA will continue to monitor the Cottonwood River and Sleepy Eye Creek into the future to allow for analysis of pesticide detections over time.

Finally, the MDA completed 10 pesticide water quality sample collection events from 5 wetlands within the Cottonwood and Redwood River watersheds in 2014. No pesticide detections in the wetlands in either watershed were above the applicable water quality reference values.

# 8. Implementation Strategy Summary

## 8.1 Implementation Framework

The strategies described in this section will be used in the 1W1P process to determine prioritized and targeted actions to reduce TSS, *E. coli*, and nutrient loads (TP) in the Cottonwood River Watershed. These actions are further developed in a separate, more detailed WRAPS report.

## 8.2 Permitted Sources

### 8.2.1 Construction Stormwater

The WLA for stormwater discharges from sites where there is construction activity reflects the number of construction sites greater than one acre expected to be active in the watershed at any one time, and the BMPs and other stormwater control measures that should be implemented at the sites to limit the discharge of pollutants of concern. The BMPs and other stormwater control measures that should be implemented at construction sites are defined in Minnesota's NPDES/SDS General Stormwater Permit for Construction Activity (MNR100001). If a construction site owner/operator obtains coverage under the NPDES/SDS General Stormwater Permit and properly selects, installs, and maintains all BMPs required under the permit, including those related to impaired waters discharges and any applicable additional requirements found in Section 23 of the Construction Stormwater General Permit, the stormwater discharges would be expected to be consistent with the WLA in this TMDL. Construction activity must also meet all local government construction stormwater requirements.

### 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

The City of Marshall should continue to treat its stormwater to the maximum extent practicable, even though no reductions are required to meet the assigned TSS WLAs. Information on stormwater BMPs can be found in the Minnesota Stormwater Manual. This resource includes links to specific urban BMP strategies, studies, calculators, special considerations for Minnesota, as well as links regarding industrial and stormwater programs. LGUs participated in the Cottonwood River WRAPS development and identified strategies that could be implemented.

For the purposes of this TMDL, the baseline year for implementation will be the mid-range year of the data years used for the lake response modeling (Table 46) and development of the TSS and *E. coli* LDCs. Since the TSS and *E. coli* LDCs were developed using the watershed HSPF models, the baseline year will coincide with the mid-range year of the HSPF model simulations. The rationale for developing a baseline year is that projects undertaken recently may take a few years to influence water quality. Any wasteload-reducing BMP implemented since the baseline year will be eligible to "count" toward an MS4's load reductions. If a BMP was implemented during or just prior to the baseline year, the MPCA is open to presentation of evidence by the MS4 Permit holder to demonstrate that it should be considered as a credit. The WRAPS report for the Cottonwood River Watershed was developed with input from the stakeholders to determine the appropriate BMPs and implementation strategies to meet the MS4 goals for all the TMDLs presented in this report.

**Table 47. Implementation baseline years in the Cottonwood River Watershed.**

| Impairment | Data Years Used for TMDL Development | Baseline Year |
|---|---|---|
| TSS Impairments (HSPF) | 2008 through 2017 | 2012 |
| *E. coli* Impairments (HSPF) | 2008 through 2017 | 2012 |
| Rock Lake | 2002, 2007, 2017 | 2007 |
| Bean Lake | 2007, 2008, 2017 | 2008 |
| Double Lake | 2007, 2008, 2017, 2018 | 2017 |
| Clear Lake | 2009, 2010, 2017 | 2010 |
| Altermatt Lake | 2009, 2010 | 2010 |
| Boise Lake | 2011, 2012 | 2012 |
| Bachelor Lake | 2011, 2012 | 2012 |

### 8.2.4 Wastewater

The MPCA issues permits for WWTPs that discharge into waters of the state. The permits have site specific limits that are based on water quality standards. Permits regulate discharges with the goals of protecting public health and aquatic life and assuring that every facility treats wastewater. In addition, SDS Permits set limits and establish controls for land application of sewage. For TSS and *E. coli*, WWTPs discharging into impaired reaches did not require any changes to their discharge permit limits due to the WLAs calculated in this TMDL. No WWTPs discharge to the impaired lakes addressed in this TMDL report.

## 8.3 Nonpermitted Sources

Implementation of the Cottonwood River Watershed TMDL will require BMPs that address the numerous pollutants in the watershed. This section provides an overview of example BMPs that may be used for implementation. The BMPs included in this section are not exhaustive, and the list may be amended after the development of future watershed plans and studies. Other reports and studies have evaluated implementation strategies in the Cottonwood River Watershed, such as the Cottonwood River Fecal Coliform TMDL (RCRCA 2013), and the draft Cottonwood River Watershed SID Report (MPCA, available upon request).

Agricultural sources such as livestock and runoff from cropland, human wastewater sources such as ITPHS septic systems, near-channel sources of sediment, and internal lake phosphorus loading were identified as high priority pollutant sources. Though developed areas within the Cottonwood River Watershed are small, urban stormwater runoff can contribute to localized pollutant loading. Urban runoff is a high priority pollutant source.

### 8.3.1 Agricultural Sources

Several different agricultural BMPs can be used to target priority sources and their associated pollutants. Table 47 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 48. Summary of agricultural BMPs for agricultural sources and their primary targeted pollutants.**

| BMP (NRCS standard) | Targeted pollutant(s) | | |
|---|---|---|---|
| | Phosphorus | TSS | *E. coli* |
| 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 |
| 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." (Lenhart et al. 2017). Riparian buffers are composed of a mix of grasses, forbs, sedges, and other vegetation that serve as an intermediate zone between upland and aquatic environments (Lenhart et al. 2017). The vegetation is tolerant of intermittent flooding and/or saturated soils that are prone to occur in intermediate zones.

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

***Clean Water Diversions (362)***

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

***Access Control/Fencing (472 and 382)***

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

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

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

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

Nonpermitted large dairies in the Cottonwood 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). 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***

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

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

***SSTS Upgrades/Replacement***

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

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

Many counties and SWCDs offer low interest loan programs for SSTS upgrades or replacement. The PFA Small Community Wastewater Program offers grant and loan packages of up to $2,000,000 for the construction of publicly owned community SSTS.

***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

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

***Direct Sediment Controls***

Direct controls for near channel sediment sources include practices such as limiting ravine erosion with a drop structure or energy dissipater, or controlling streambank or bluff erosion through streambank stabilization and restoration. Streambank stabilization and restoration should be implemented to address eroding banks and areas of instability in stream channels. Activities should be focused in priority areas as defined by the LGUs.

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

***Indirect Controls***

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

### 8.3.5 Internal Loading in Lakes

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

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

The MPCA recommends feasibility studies for any lakes in which water level drawdown or chemical treatment is considered. The Minnesota State and Regional Government Review of Internal Phosphorus Load Control (MPCA 2020d) paper provides more information on internal phosphorus load BMPs and considerations.

## 8.4 Education

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

## 8.5 Cost

TMDL reports are required to include an overall approximation of implementation costs (Minn. Stat. 2007, § 114D.25). It is estimated that the costs to implement the activities outlined in the strategy document are approximately $207 million dollars over the next 20 years. This value is considered a rough estimate at this time, as there is a level of uncertainty in the generalized cost estimate numbers used here as well as in the source assessment and TMDL allocations presented in this report. The individual cost estimate exercises include: BMPs commonly implemented to address upland TSS and TP sources, livestock BMPs, ITPHS system repairs/replacements, and lake internal load projects. Required buffer installation, replacement of FTPGW systems, and SSTS maintenance are not included in the cost estimate at this time. Below is a general discussion of cost considerations for the three pollutants (TSS, bacteria, and phosphorus (lakes)) covered in this TMDL.

***TSS***

Utilizing estimates developed by an interagency work group (BWSR, USDA, MPCA, Minnesota Association of SWCDs, Minnesota Association of Watershed Districts, NRCS) who assessed restoration costs for several TMDLs, it was determined that implementing the Cottonwood River Watershed TSS TMDLs will cost approximately $154 million over 20 years. This was based on total area of the watershed (1,314 square miles) multiplied by the cost estimate of $117,000/square mile for a watershed-based treatment approach.

***E. coli***

The cost estimate for bacteria load reduction is based on unit costs for the two major sources of bacteria: livestock and ITPHS SSTSs. The unit cost for bringing AUs under MMPs and feedlot lot runoff controls is $350/AU. This value is based on USDA EQIP payment history and includes buffers, livestock access control, MMPs, 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 165 ITPHS systems and 168,537 AUs in the Cottonwood River Watershed provides a total cost of approximately $62 million. However, the MPCA staff calculates that approximately 75% of these AUs currently have controls or management plans in place, thus reducing this estimate to approximately $18 million.

***Lake nutrients (phosphorus)***

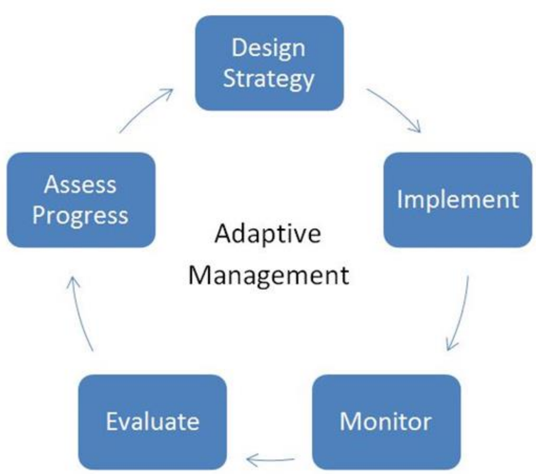
A detailed analysis of the cost to implement the nutrient TMDLs was not conducted. However, as a rough approximation one can use some general results from BMP cost studies across the United States. For example, an EPA summary of several studies showed a median life cycle cost of approximately $2,200 per lb TP removed for watershed BMPs (Foraste et al. 2012). Another recent review (Macbeth et al. 2018) of lake restoration projects performed throughout the State of Minnesota suggests a median life cycle cost of approximately $500 per lb of TP removed for internal load BMPs such as aluminum sulfate. Multiplying these rates by the needed watershed (3,196 lbs per year) and internal (10,165 lbs per year) TP reductions needed for the five lake basins included in this TMDL provides a total cost of approximately $12 million. This cost estimate assumes a 20-year life cycle for watershed and internal load BMPs.

## 8.6 Adaptive Management

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

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

**Figure 36. Adaptive management.**




A list of implementation strategies in the WRAPS report prepared in conjunction with this TMDL focuses on adaptive management (Figure 36). 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 water bodies.

# 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, RCRCA, MPCA, DNR, BWSR, MDA, Minnesota Department of Health (MDH) and other interested and affected agencies. The LWG, led by RCRCA and MPCA staff, convened multiple times to discuss and review TMDL results and provide input and feedback on the development of the Cottonwood River WRAPS. The entire public stakeholder process involved meetings and other forms of communication as described in Table 48.

**Table 49. Summary of stakeholder meetings/events held during the development of the Cottonwood 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 |
| 7/19/2018 | Public Informational Meeting at Sleepy Eye, MN |
| 7/24/2018 | Public Informational Meeting at Lake Benton, MN |
| 7/25/2018 | Public Informational Meeting at Marshall, MN |
| 7/26/2018 | Public Informational Meeting at Redwood Falls, MN |
| 8/16/2018 | Local Work Group Meeting at Lamberton, MN |
| 9/20/2008 | Local Work Group Meeting at Redwood Falls, MN |
| 11/15/2018 | Local Work Group Meeting at Marshall, MN |
| 1/16/2019 | 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 10, 2022 through November 9, 2022. There were no comments received as a result of the public comment period.

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# Appendices

# Appendix A - Stream Impairment Supporting Items

**Supporting Items for Cottonwood River TSS and *E. coli* Impaired Reach (07020008-502)**

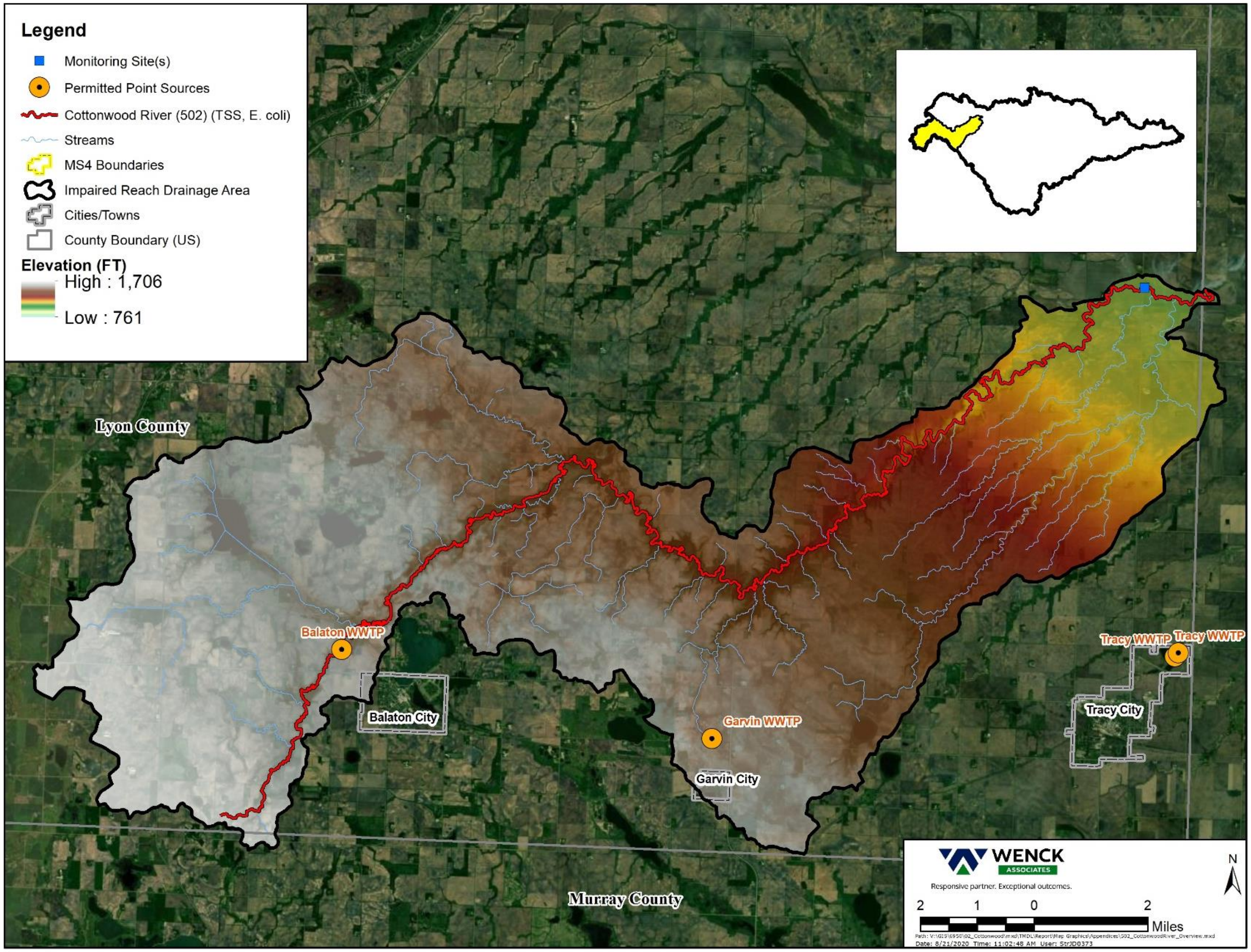



**Figure A-1. Cottonwood River Reach 502 Overview.**

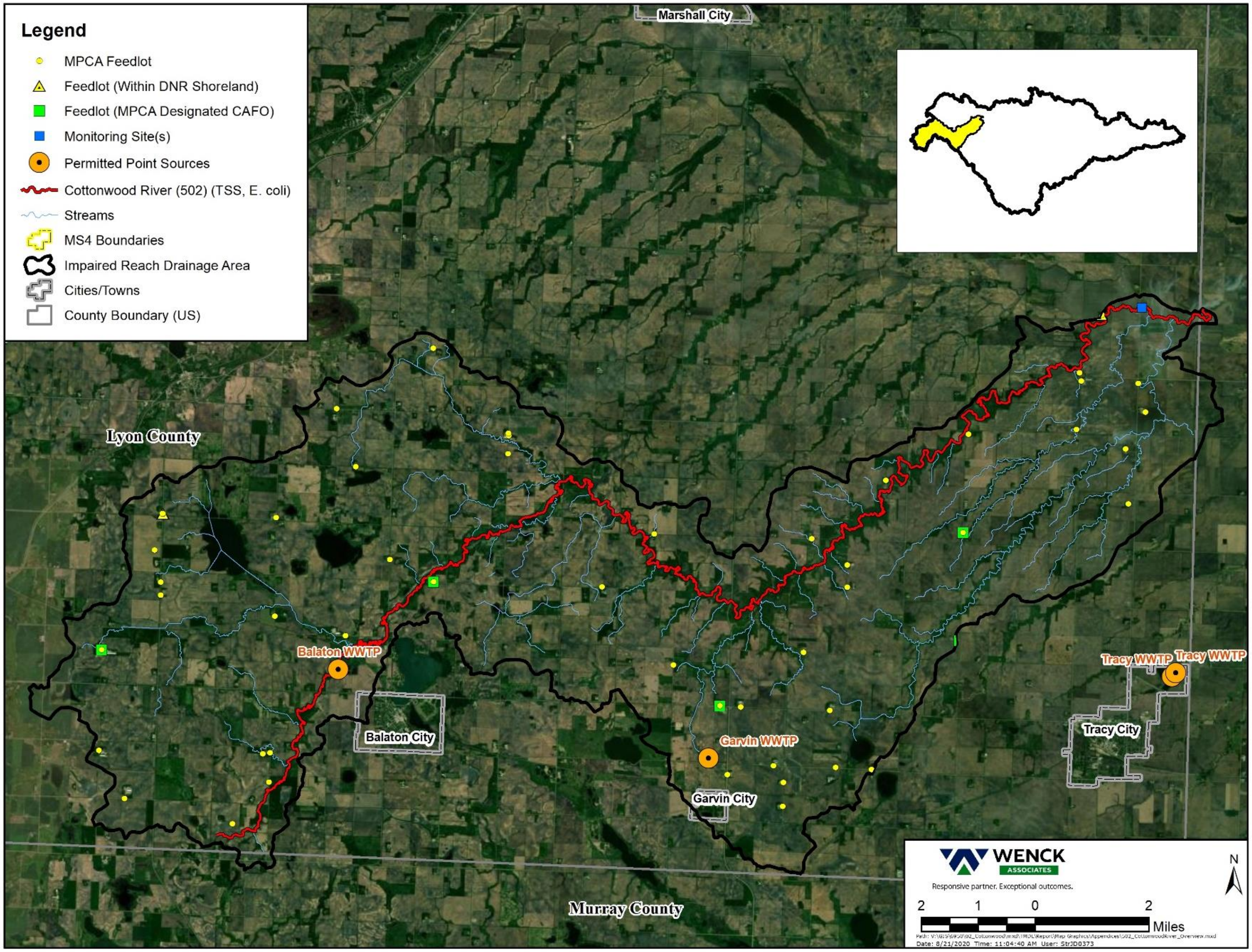



**Figure A-2. Cottonwood River Reach 502 Feedlots.**

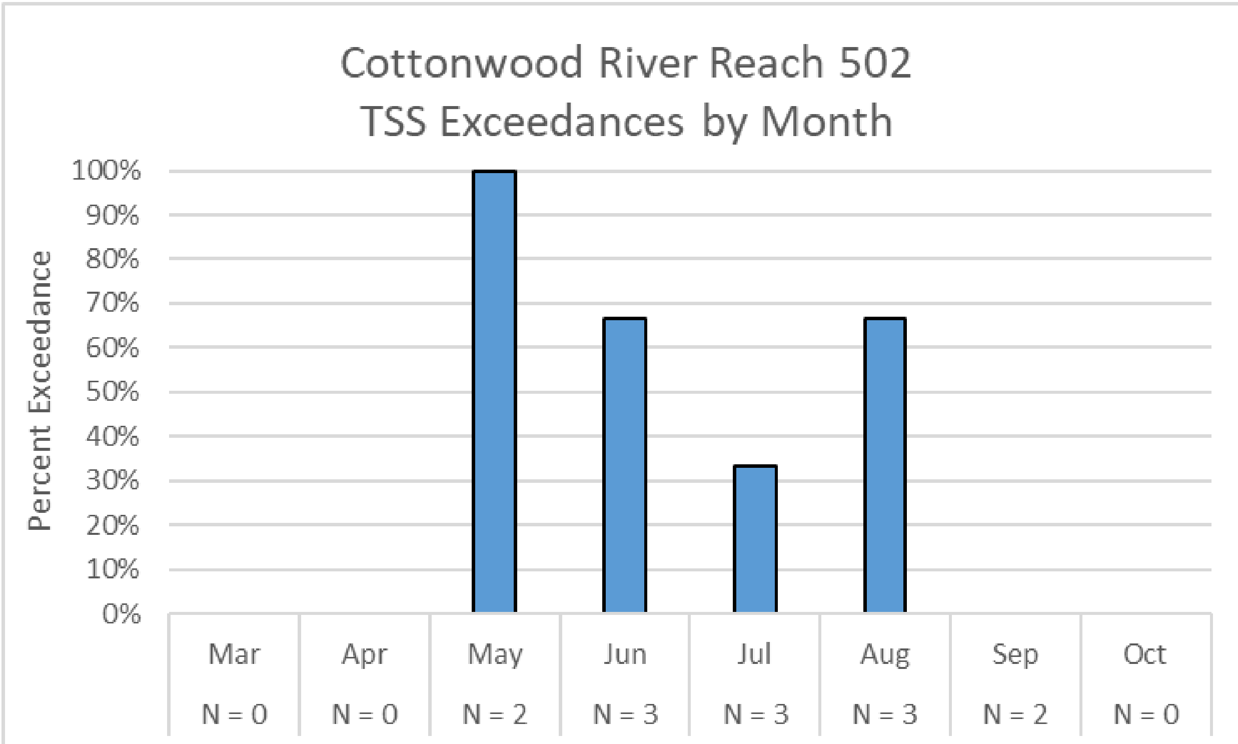



**Figure A-3. Cottonwood River Reach 502 TSS Exceedances by Month.**

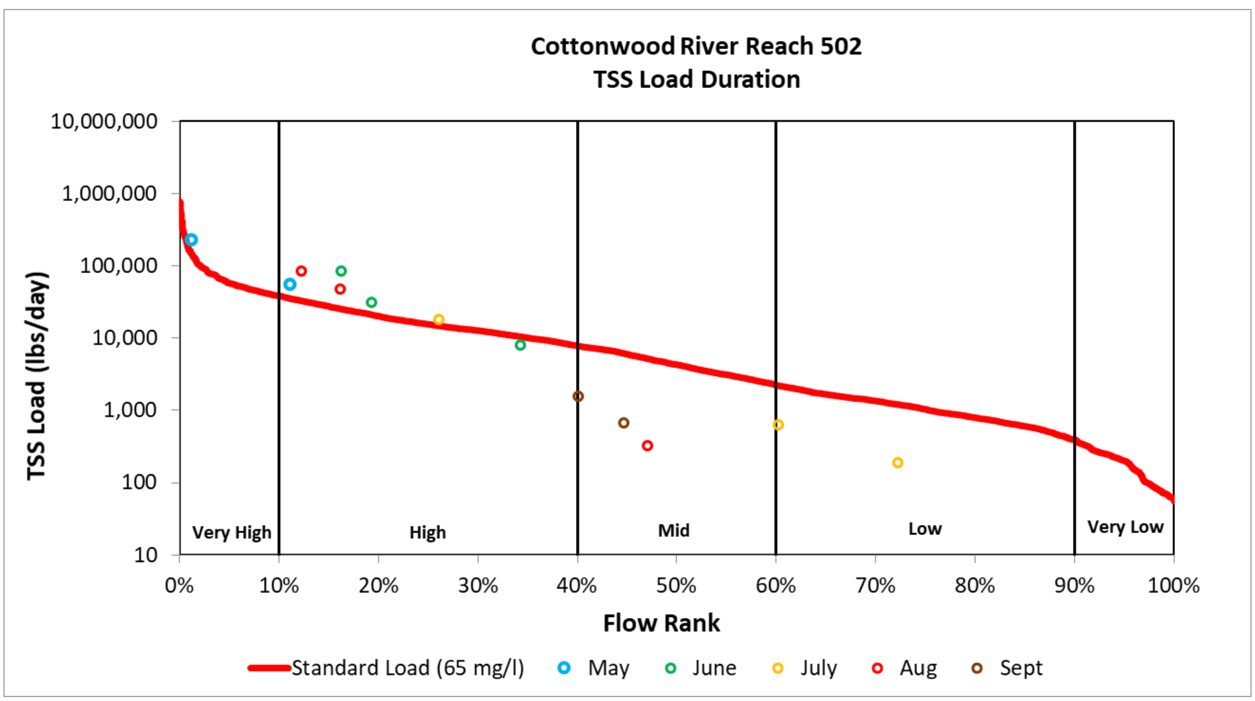



**Figure A-4. Cottonwood River Reach 502 TSS Load Duration Curve (by month).**

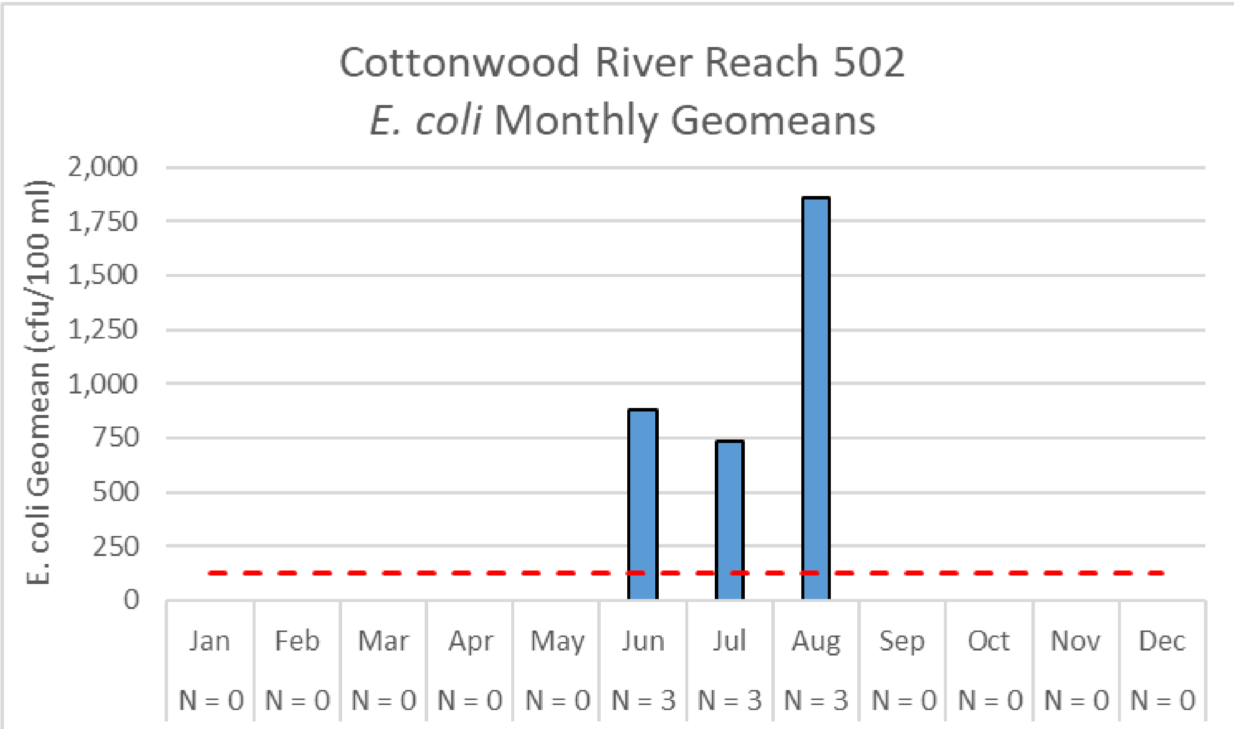



**Figure A-5. Cottonwood River Reach 502 *E. coli* Monthly Geomeans.**

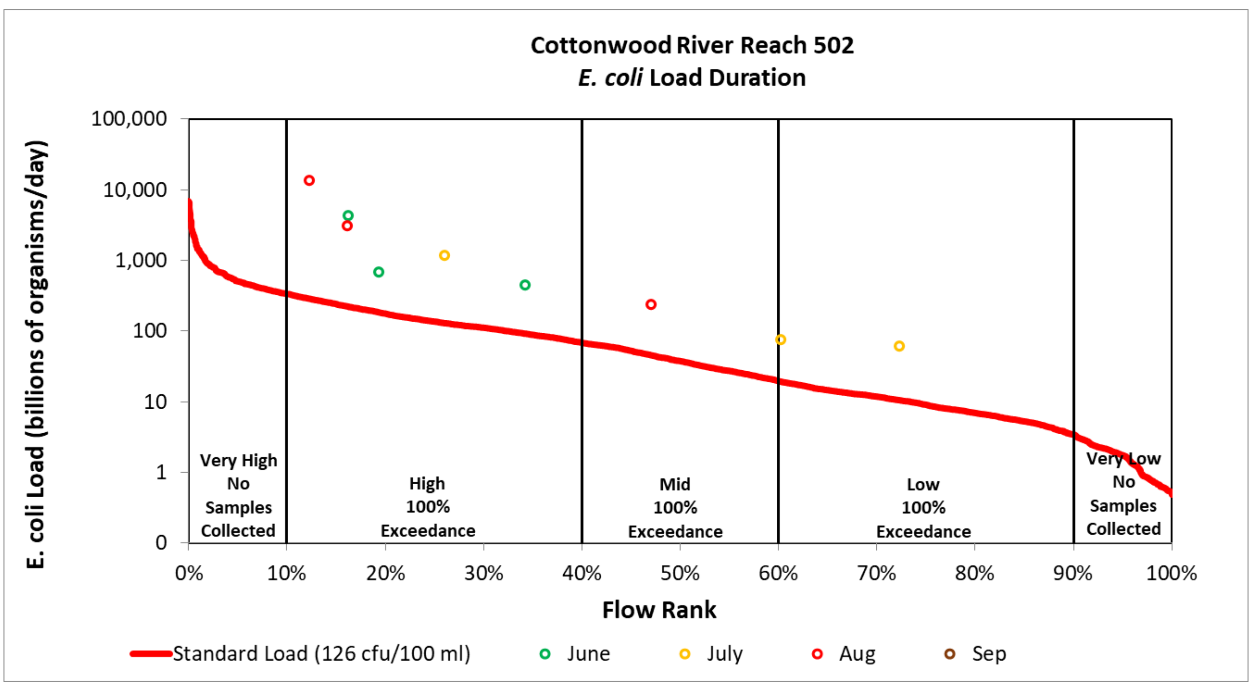



**Figure A-6. Cottonwood River Reach 502 E. coli Load Duration Curve (by month).**

**Table A-1. Cottonwood River Reach 502 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8] | Total Fecal Bacteria Produced Per Day [Billions of Org.] | Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.] | Percent by Category |
|---|---|---|---|---|---|---|
| Livestock (Surface Applied Manure) [1] | Horse* | - | - | - | 857,147 | 99.85% |
| | Swine* | 10,045 | 32.7 | 328,462 | | |
| | Bovine* | 8,949 | 58.2 | 520,849 | | |
| | Poultry* | 243.0 | 20.5 | 4,982 | | |
| | Other Livestock*,[9] | 87 | 32.7 | 2,855 | | |
| Wildlife | Deer [3] | 502 | 0.5 | 251 | 854 | 0.10% |
| | Waterfowl [4] | 1,506 | 0.4 | 603 | | |
| Human | Failing Septic Systems [5] | 9 | 5.7 | 53 | 53 | 0.01% |
| | WWTP effluent [6] | 2 | 0.1 | 0 | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 735 | 0.6 | 413 | 413 | 0.05% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

**Supporting Items for Cottonwood River TSS Impaired Reach (07020008-504)**

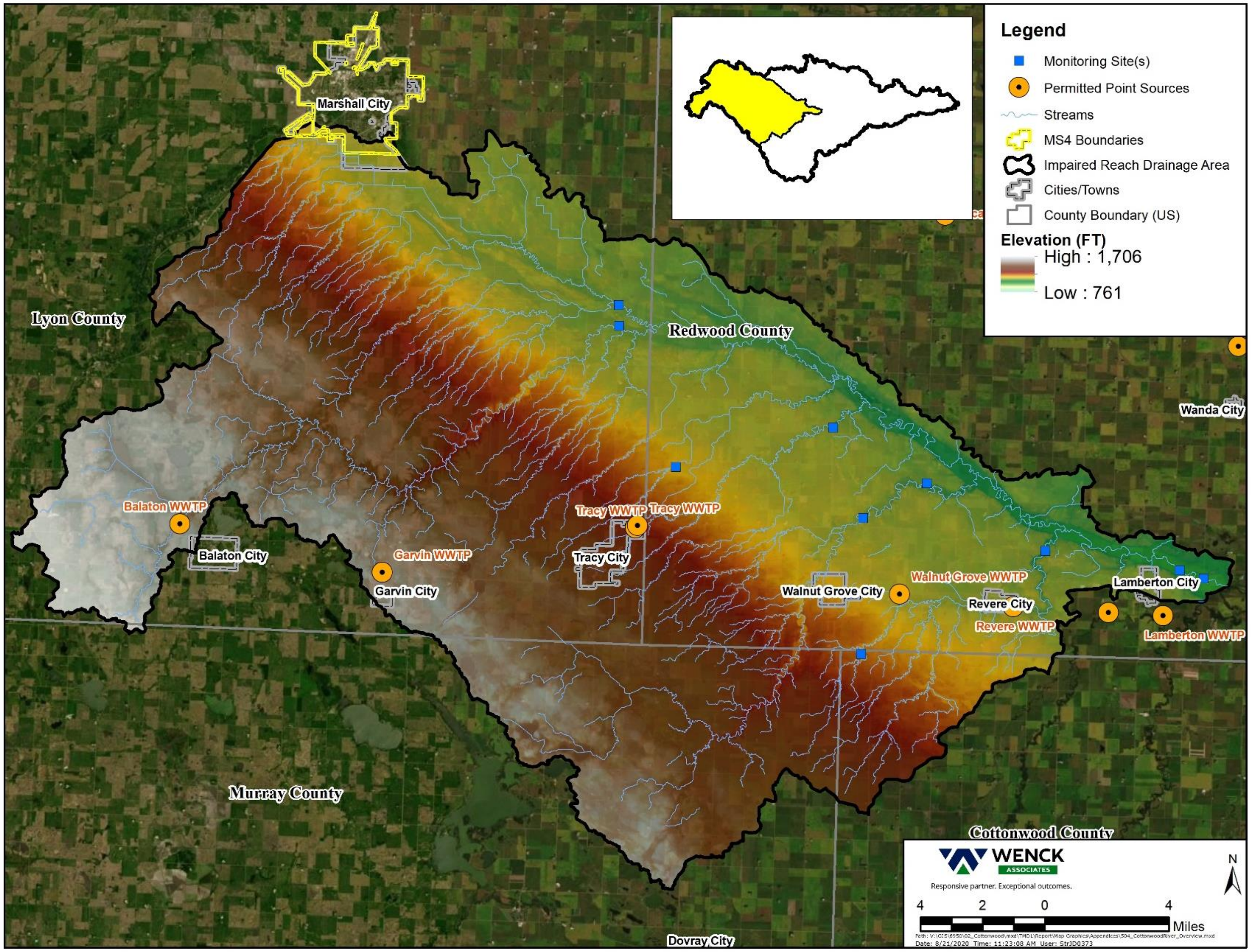



**Figure A-7. Cottonwood River Reach 504 Overview.**

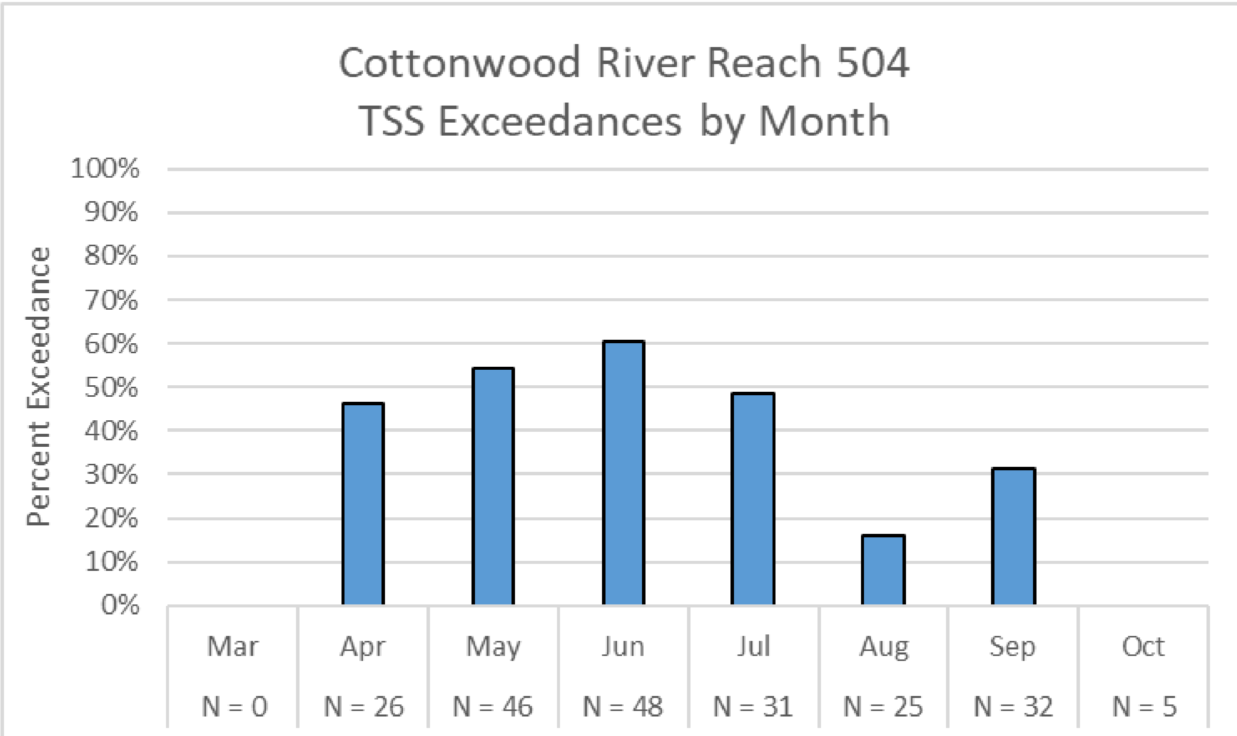



**Figure A-8. Cottonwood River Reach 504 TSS Exceedances by Month.**

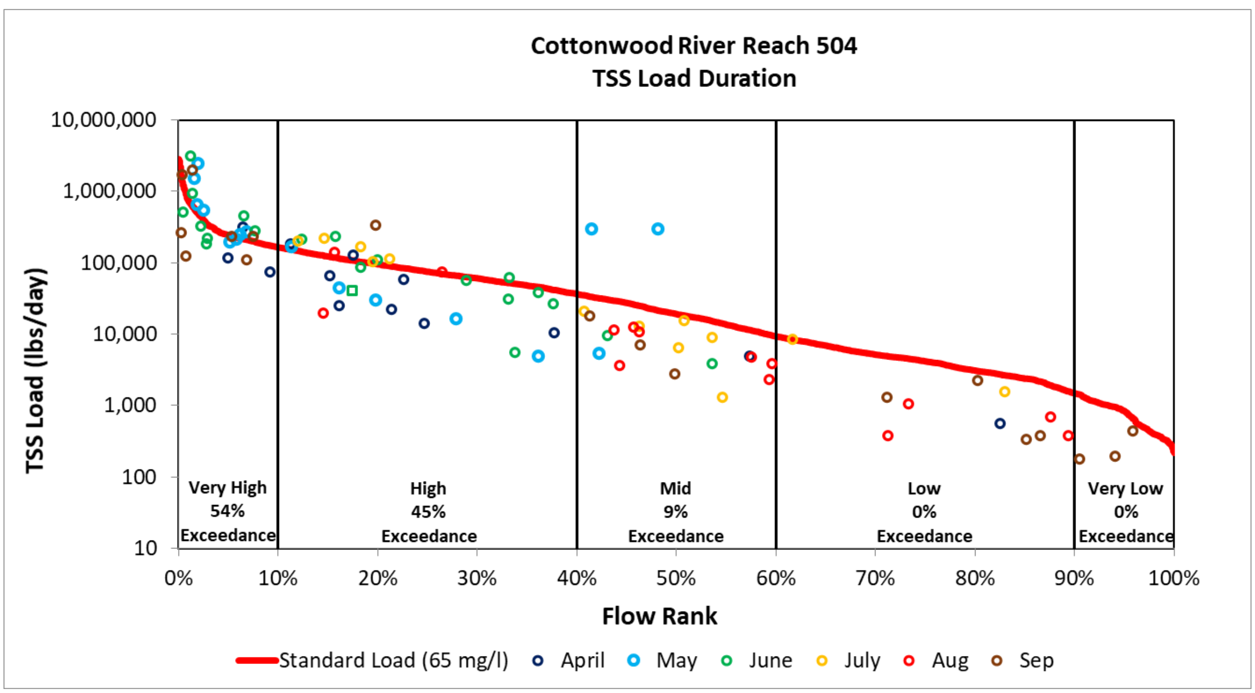



**Figure A-9. Cottonwood River Reach 504 TSS Load Duration Curve (by month).**

**Supporting Items for Cottonwood River TSS Impaired Reach (07020008-508)**

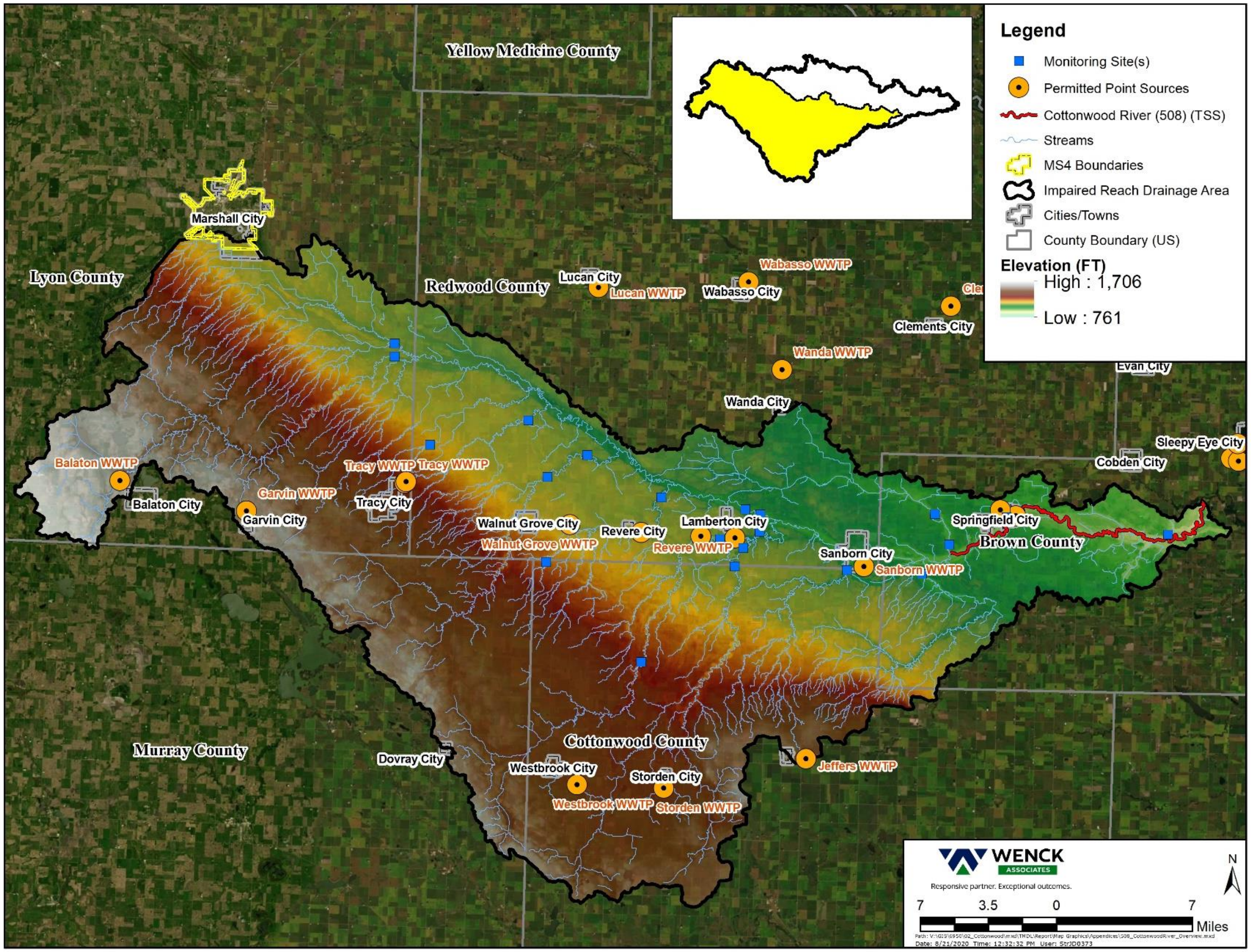



**Figure A-10. Cottonwood River Reach 508 Overview.**

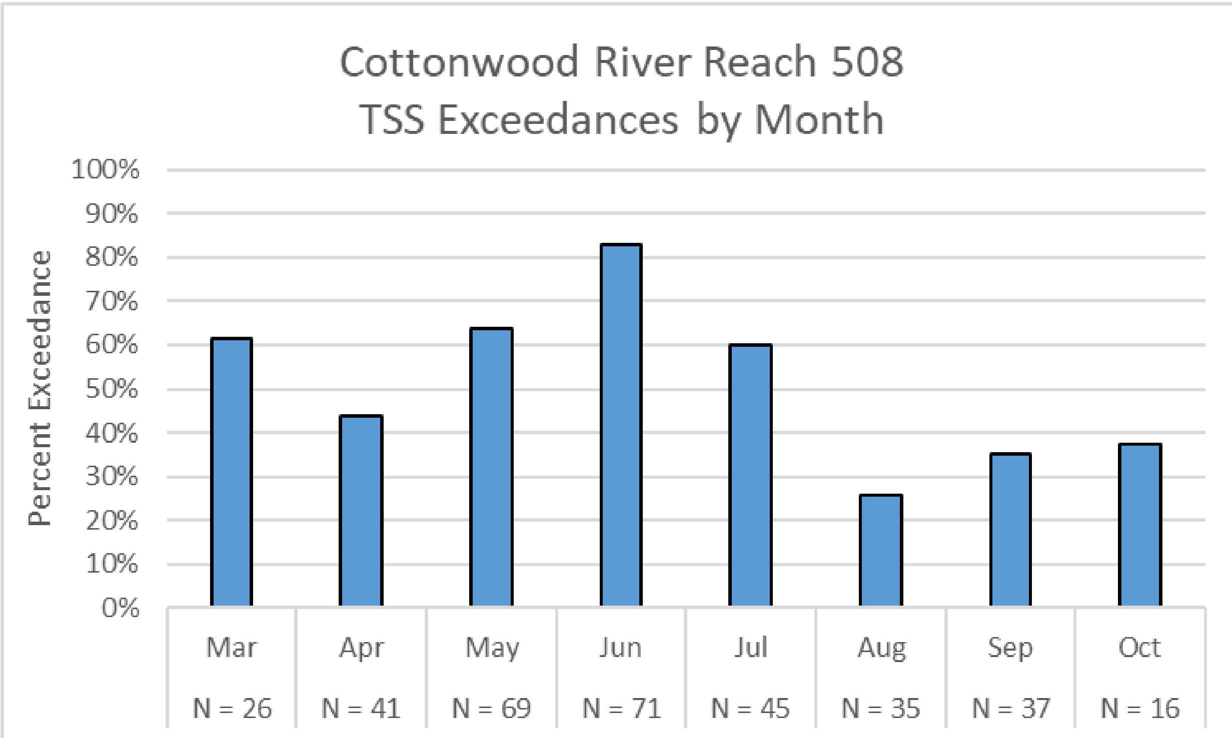



**Figure A-11. Cottonwood River Reach 508 TSS Exceedances by Month.**

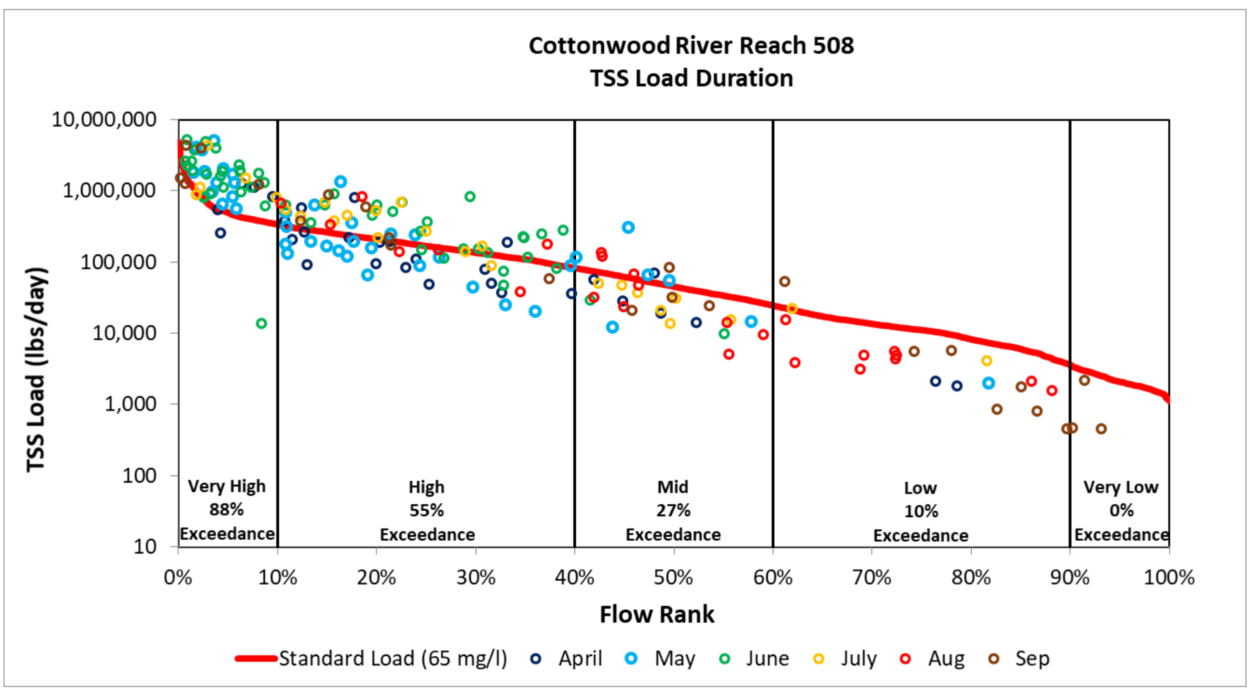



**Figure A-12. Cottonwood River Reach 508 TSS Load Duration Curve (by month).**

## Supporting Items for Cottonwood River TSS Impaired Reach (07020008-509)

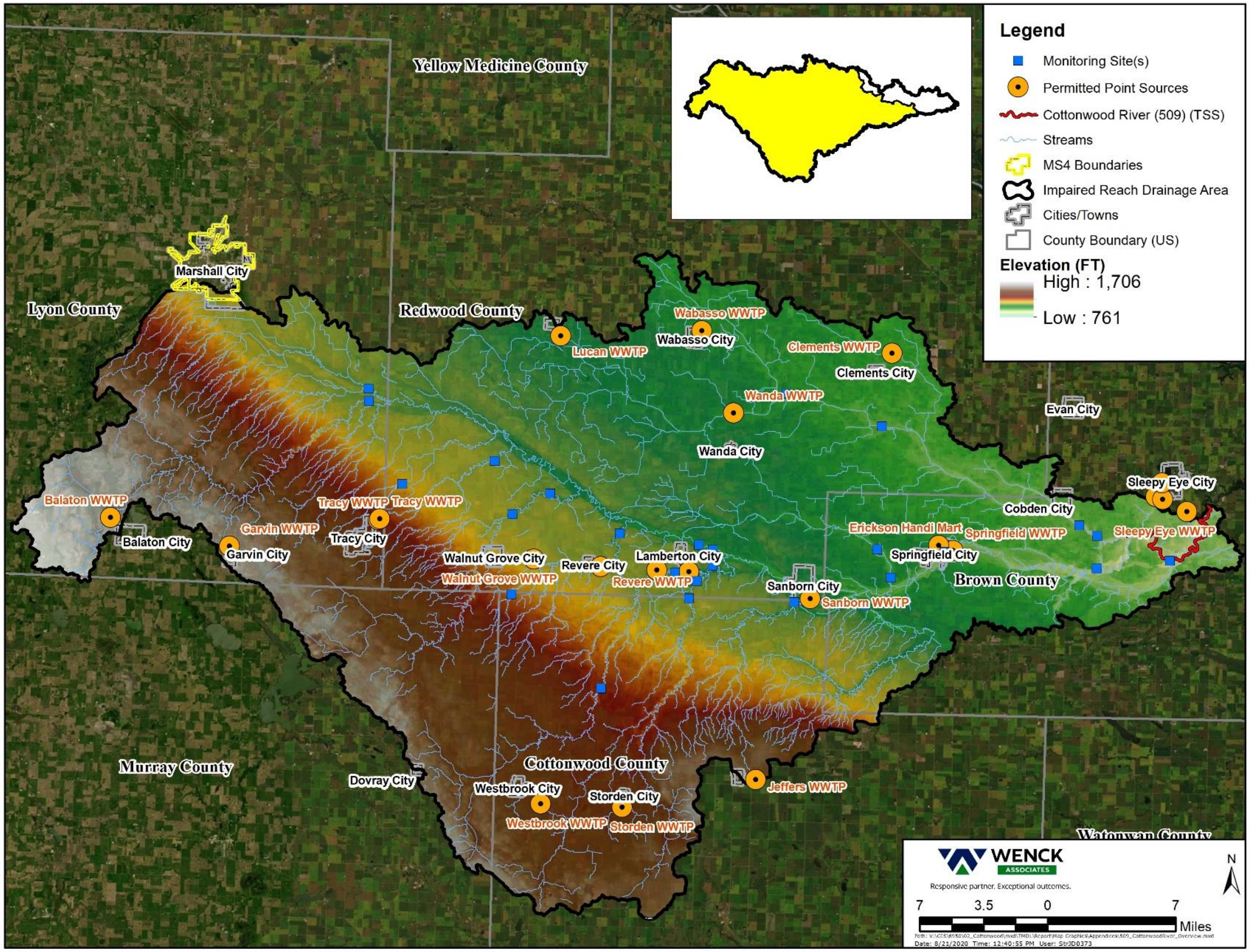



**Figure A-13. Cottonwood River Reach 509 Overview.**

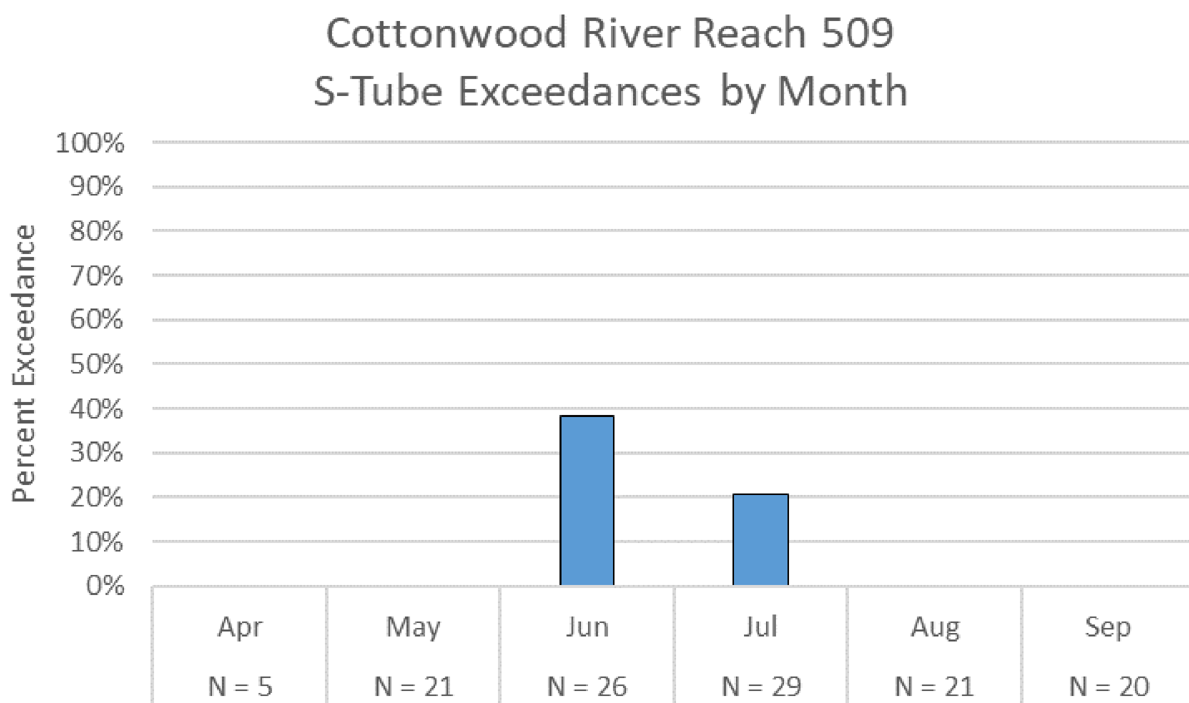



**Figure A-14. Cottonwood River Reach 509 S-tube Exceedances by Month.**

Note: No TSS data has been collected for this reach

**Supporting Items for Judicial Ditch 30 Bacteria Impaired Reach (07020008-511)**

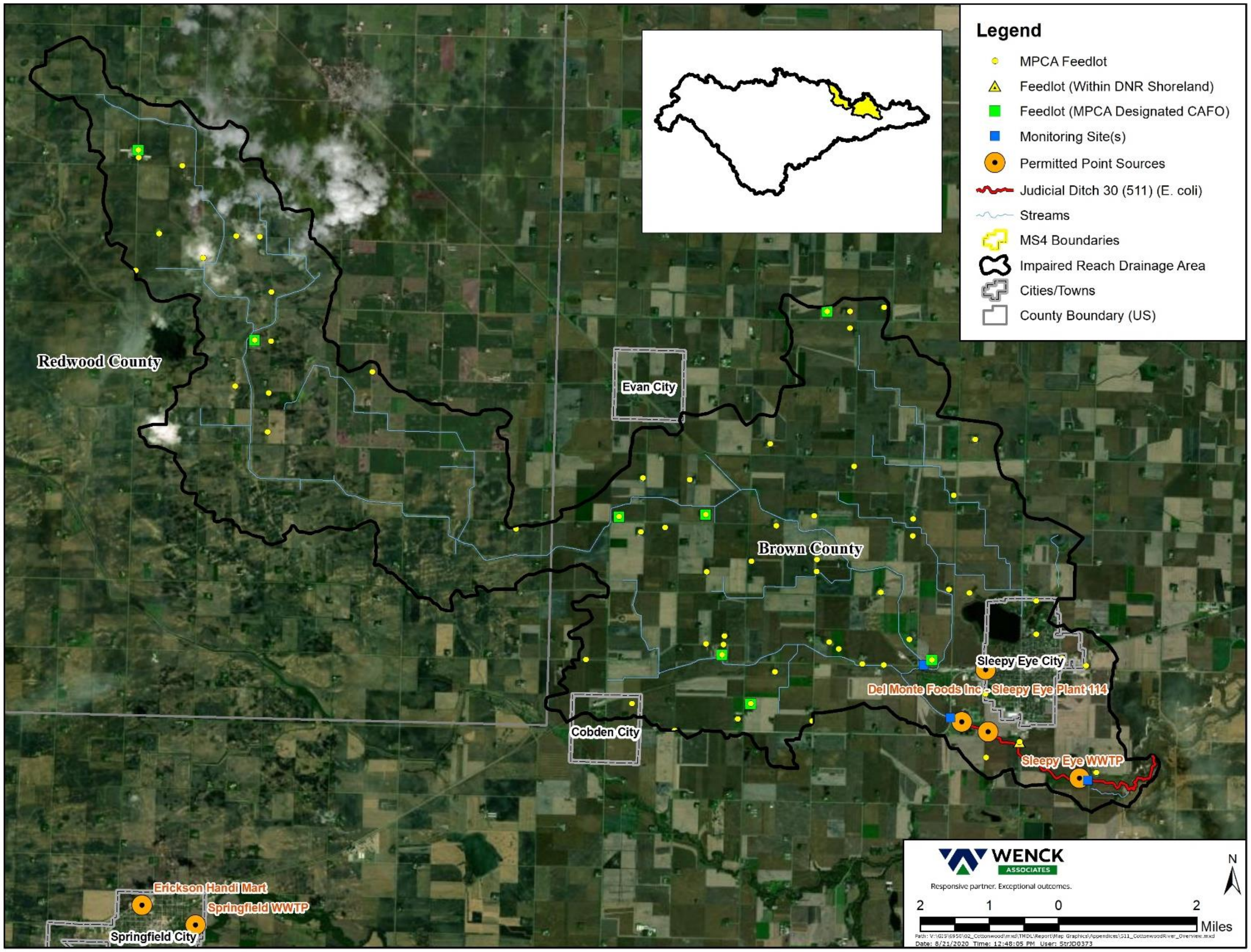



**Figure A-15. Judicial Ditch 30 Bacteria Impaired Reach 511 Overview.**

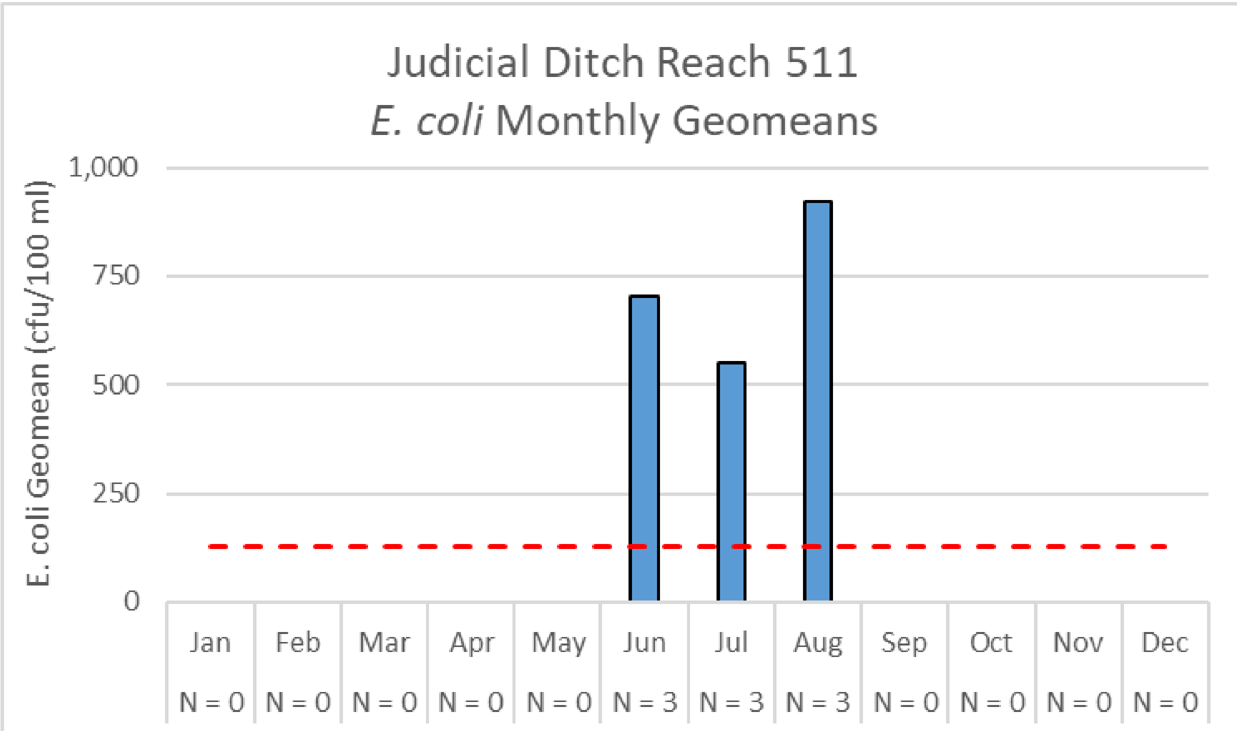



**Figure A-16. Judicial Ditch 30 Reach 511 *E. coli* Monthly Geomeans.**

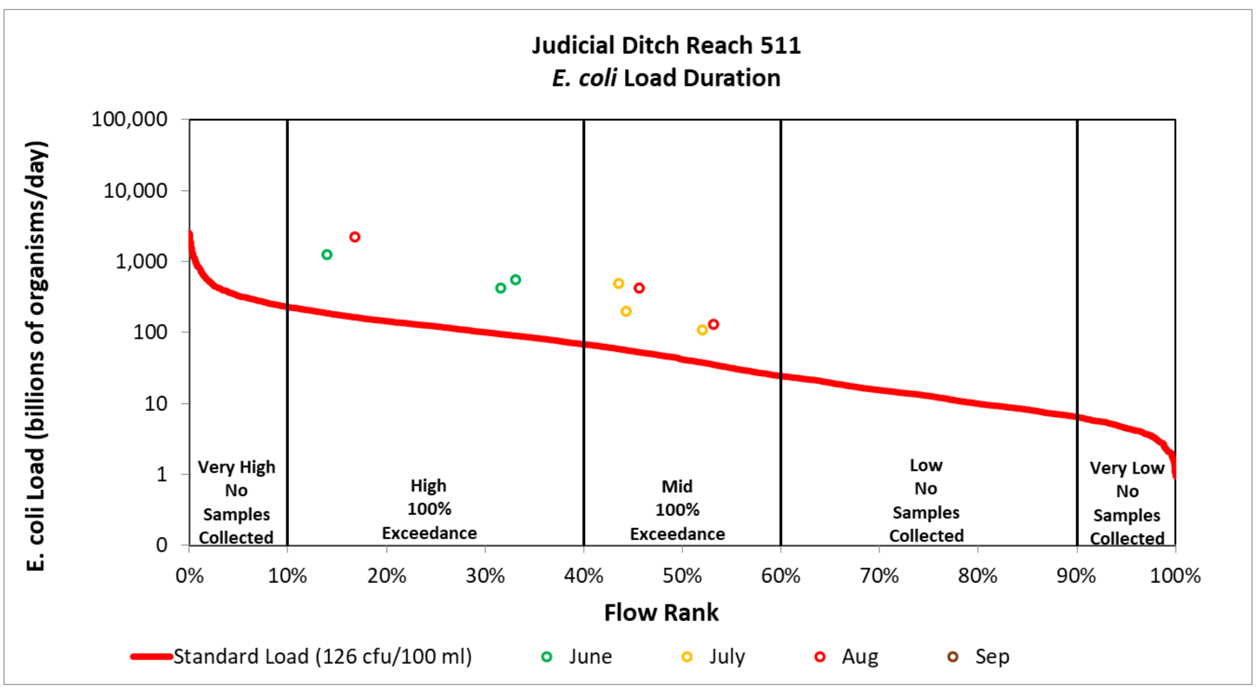



**Figure A-17. Judicial Ditch 30 Reach 511 *E. coli* Load Duration Curve (by month).**

**Table A-2. Judicial Ditch Reach 511 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8] | Total Fecal Bacteria Produced Per Day [Billions of Org.] | Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.] | Percent by Category |
|---|---|---|---|---|---|---|
| Livestock (Surface Applied Manure) [1] | Horse* | 12 | 58.2 | 698 | 477,767 | 99.79% |
| | Swine* | 6,224 | 32.7 | 203,515 | | |
| | Bovine* | 4,689 | 58.2 | 272,900 | | |
| | Poultry* | - | - | - | | |
| | Other Livestock*,[9] | 20 | 32.7 | 654 | | |
| Wildlife | Deer [3] | 293 | 0.5 | 147 | 498 | 0.10% |
| | Waterfowl [4] | 879 | 0.4 | 352 | | |
| Human | Failing Septic Systems [5] | 31 | 5.7 | 177 | 179 | 0.04% |
| | WWTP effluent [6] | 1 | 2.2 | 2 | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 601 | 0.6 | 338 | 338 | 0.07% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

**Supporting Items for Dutch Charley Creek TSS Impaired Reach (07020008-517)**

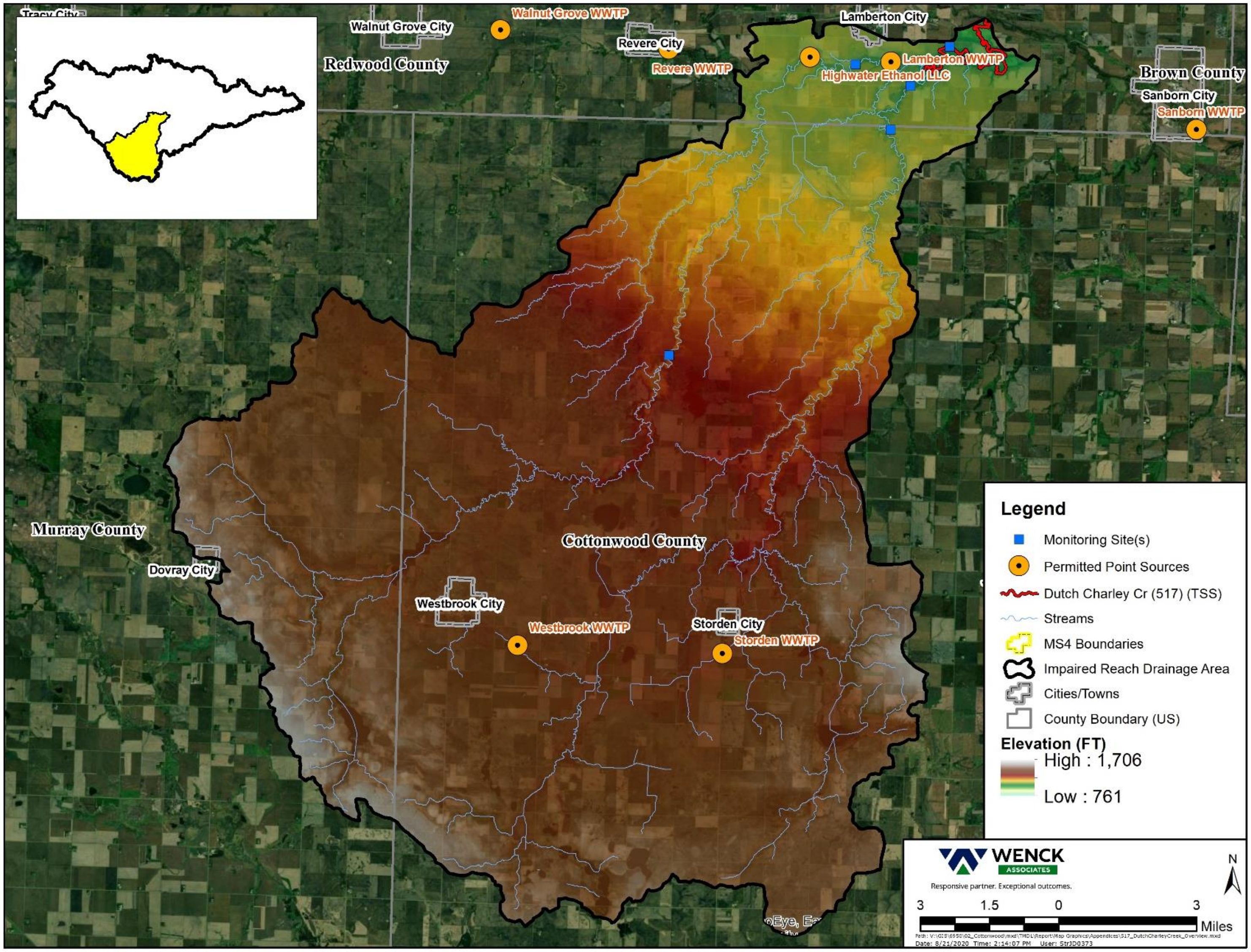



**Figure A-18. Dutch Charley Creek Reach 517 Overview.**

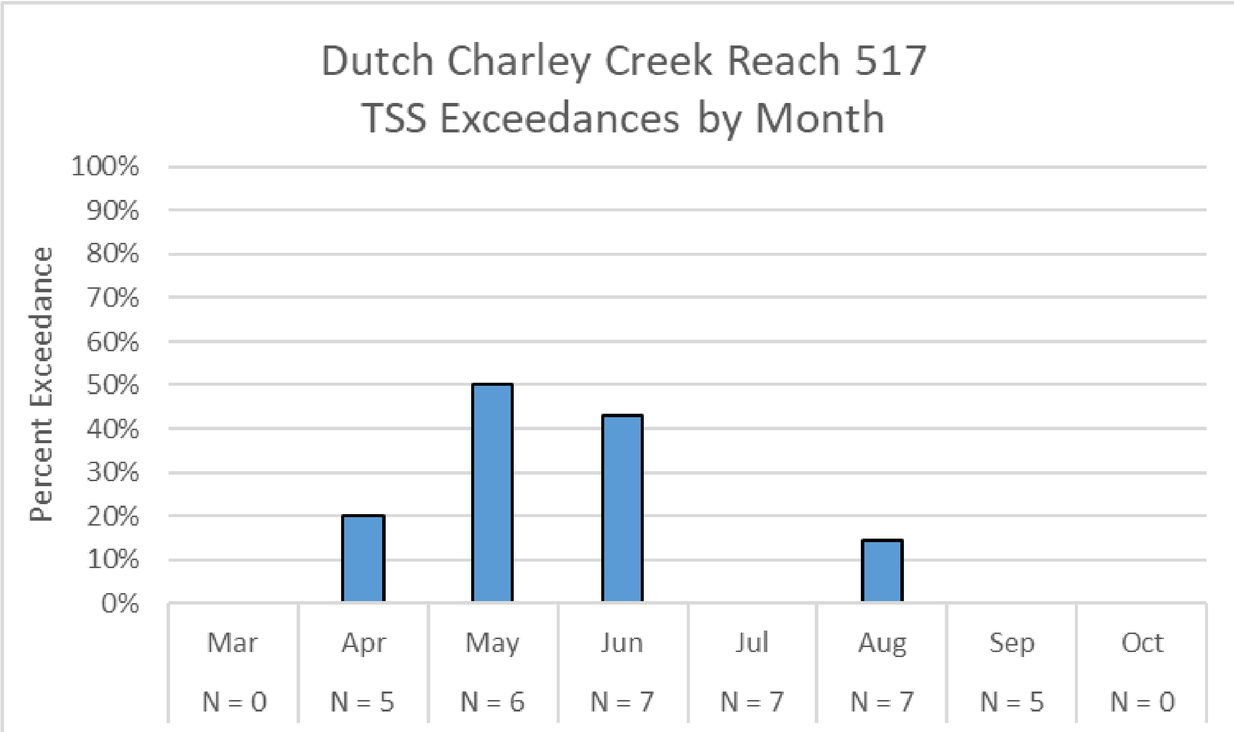



**Figure A-19. Dutch Charley Reach 517 TSS Exceedances by Month.**

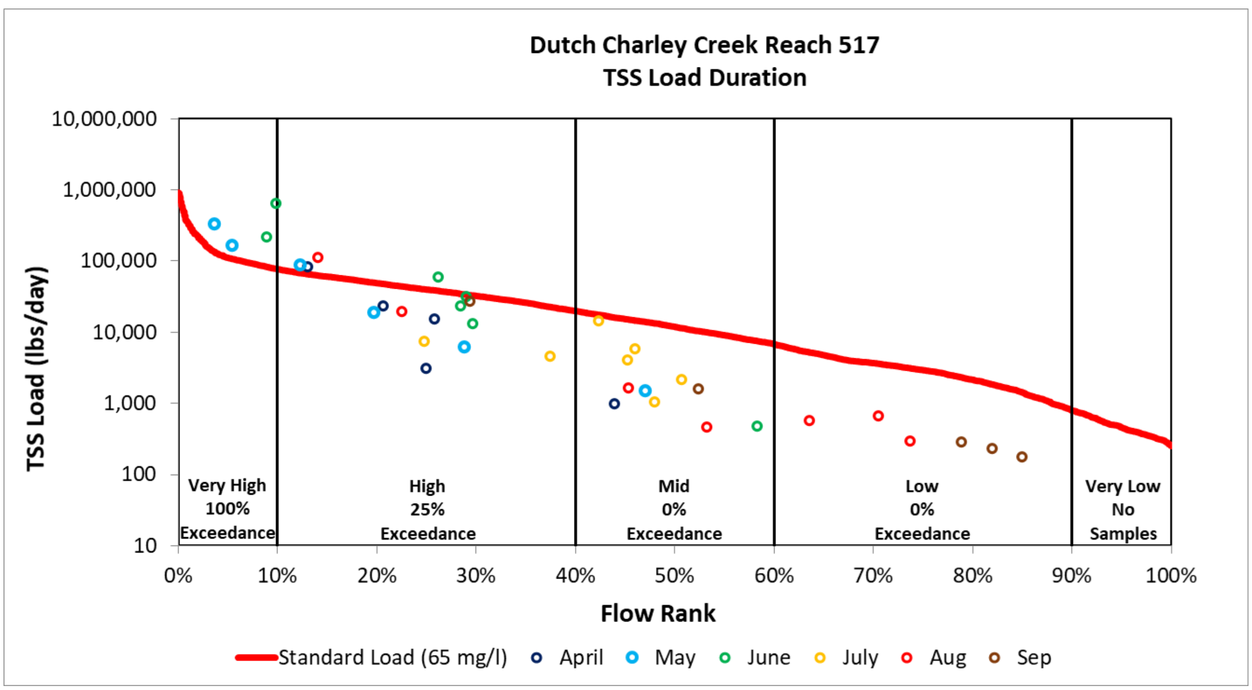



**Figure A-20. Dutch Charley Reach 517 TSS Load Duration Curve (by month).**

**Supporting Items for Dutch Charley Creek TSS Impaired Reach (07020008-518)**

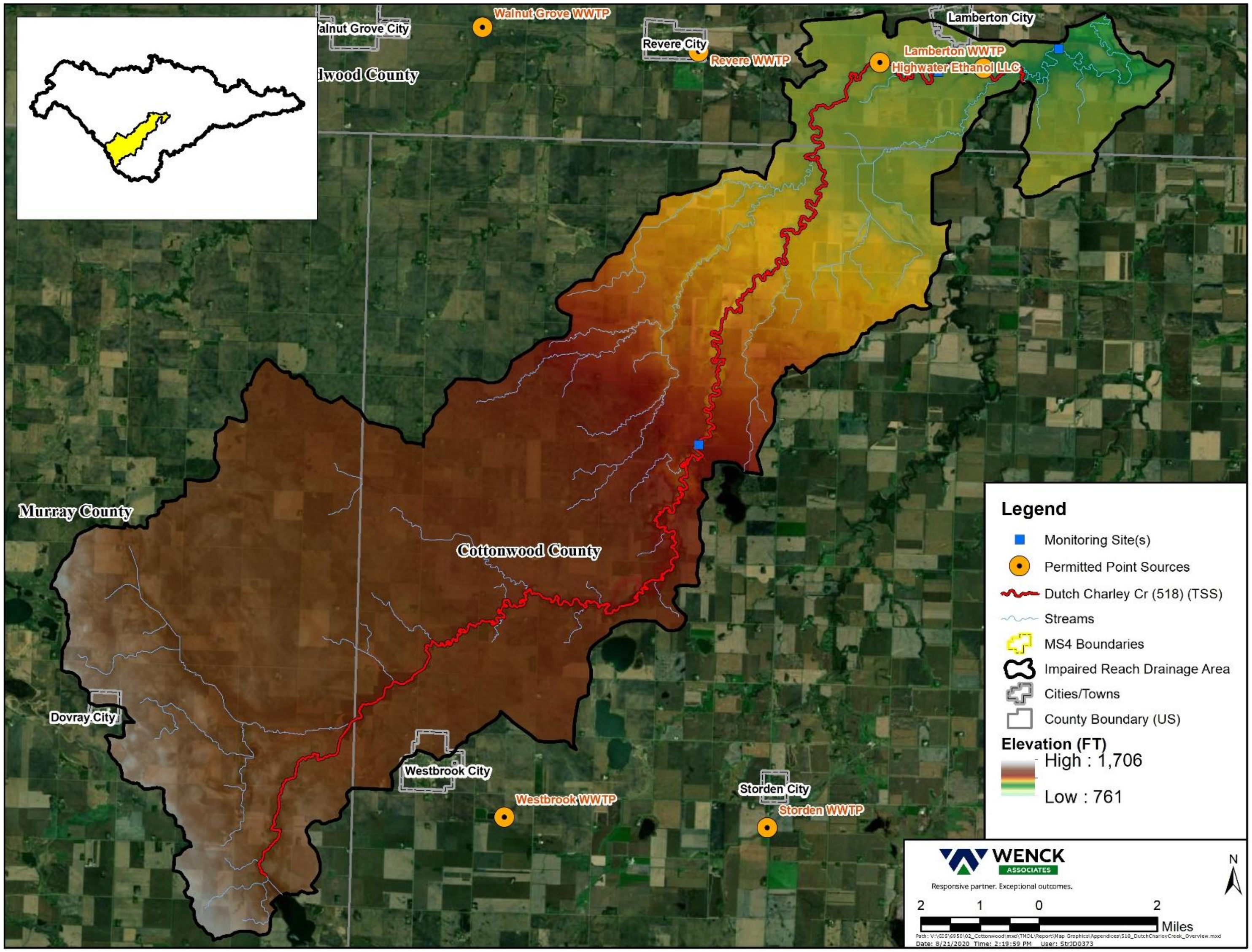



**Figure A-21. Dutch Charley Reach 518 Overview.**

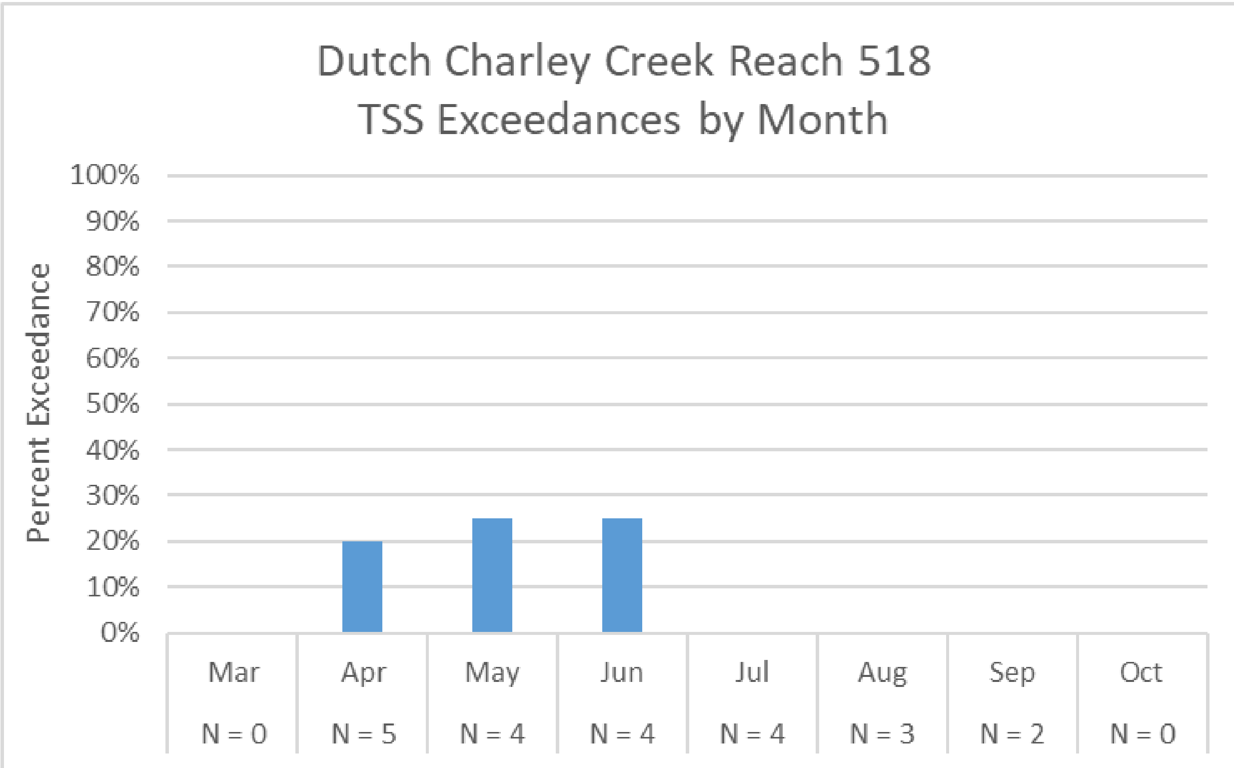



**Figure A-22. Dutch Charley Creek Reach 518 TSS Exceedances by Month.**

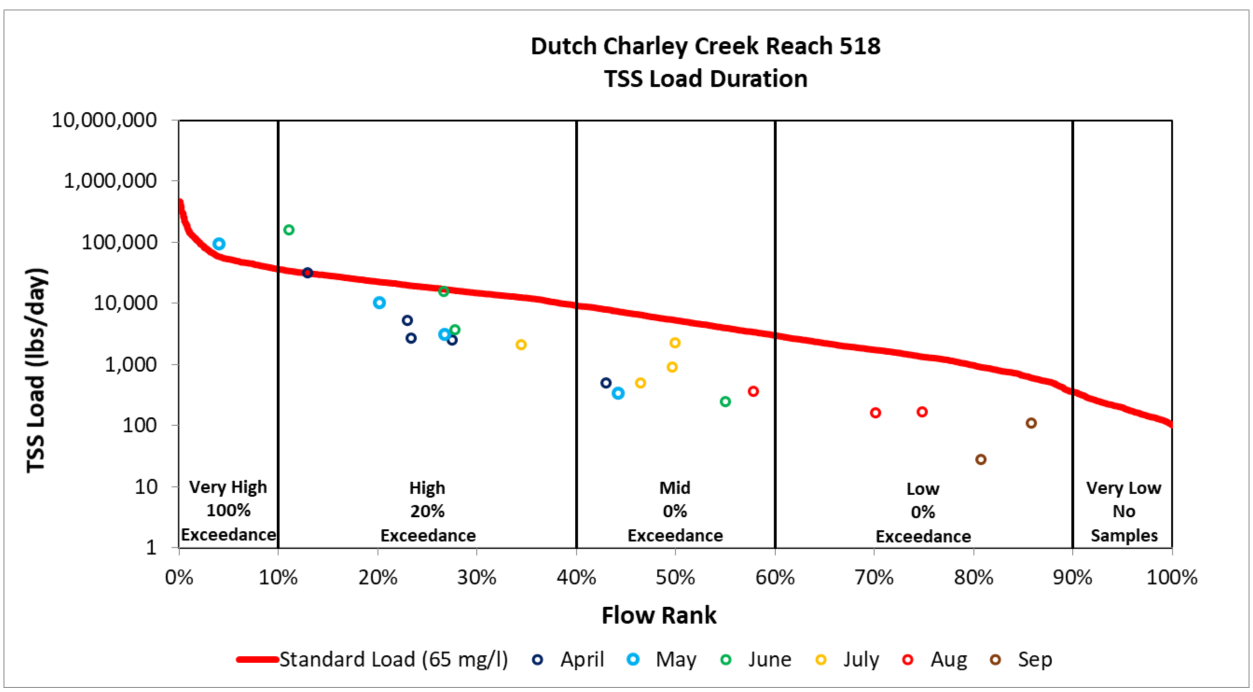



**Figure A-23. Dutch Charley Creek Reach 518 TSS Load Duration Curve (by month).**

**Supporting Items for Highwater Creek TSS and *E. coli* Impaired Reach (07020008-519)**

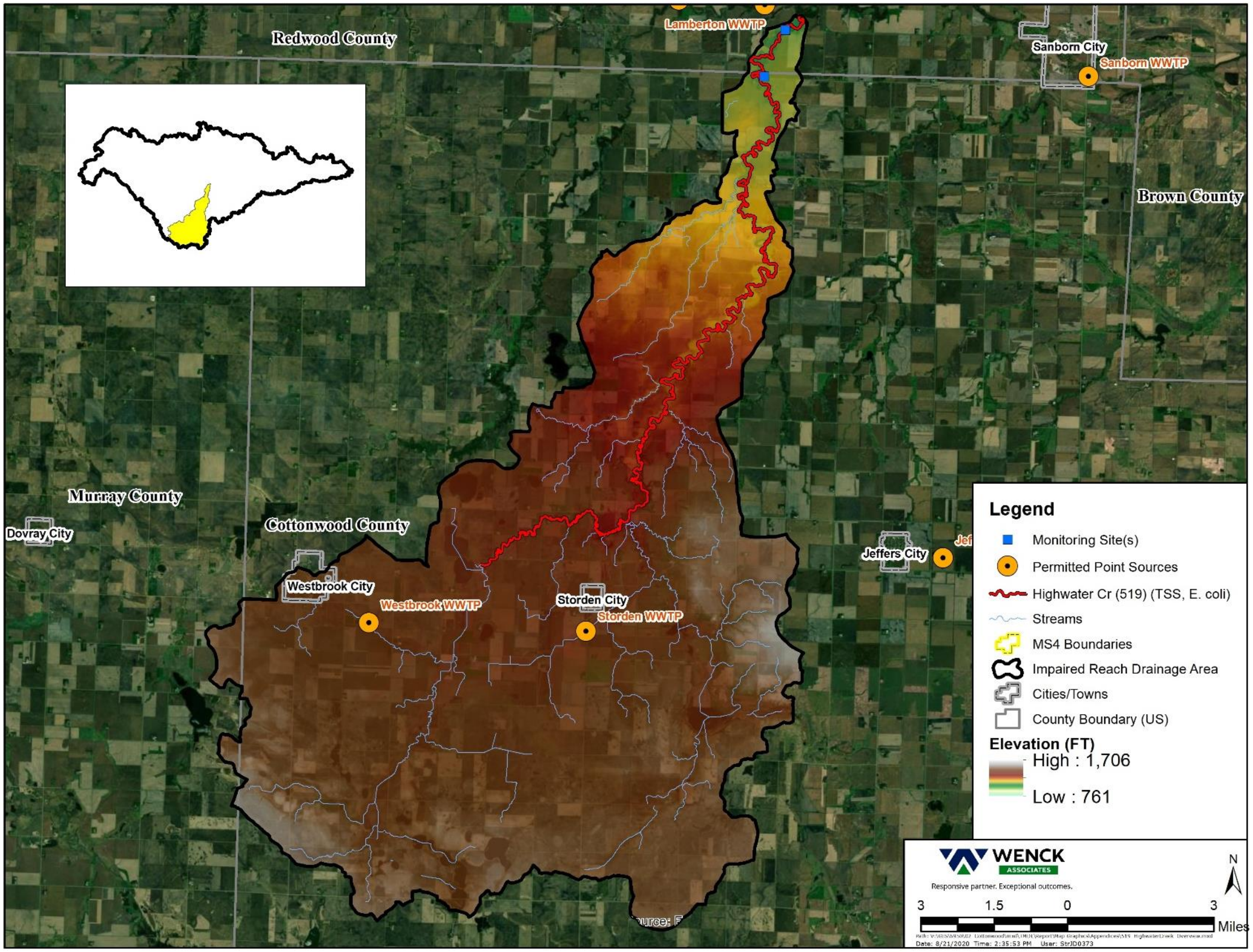



**Figure A-24. Highwater Creek Reach 519 Overview.**

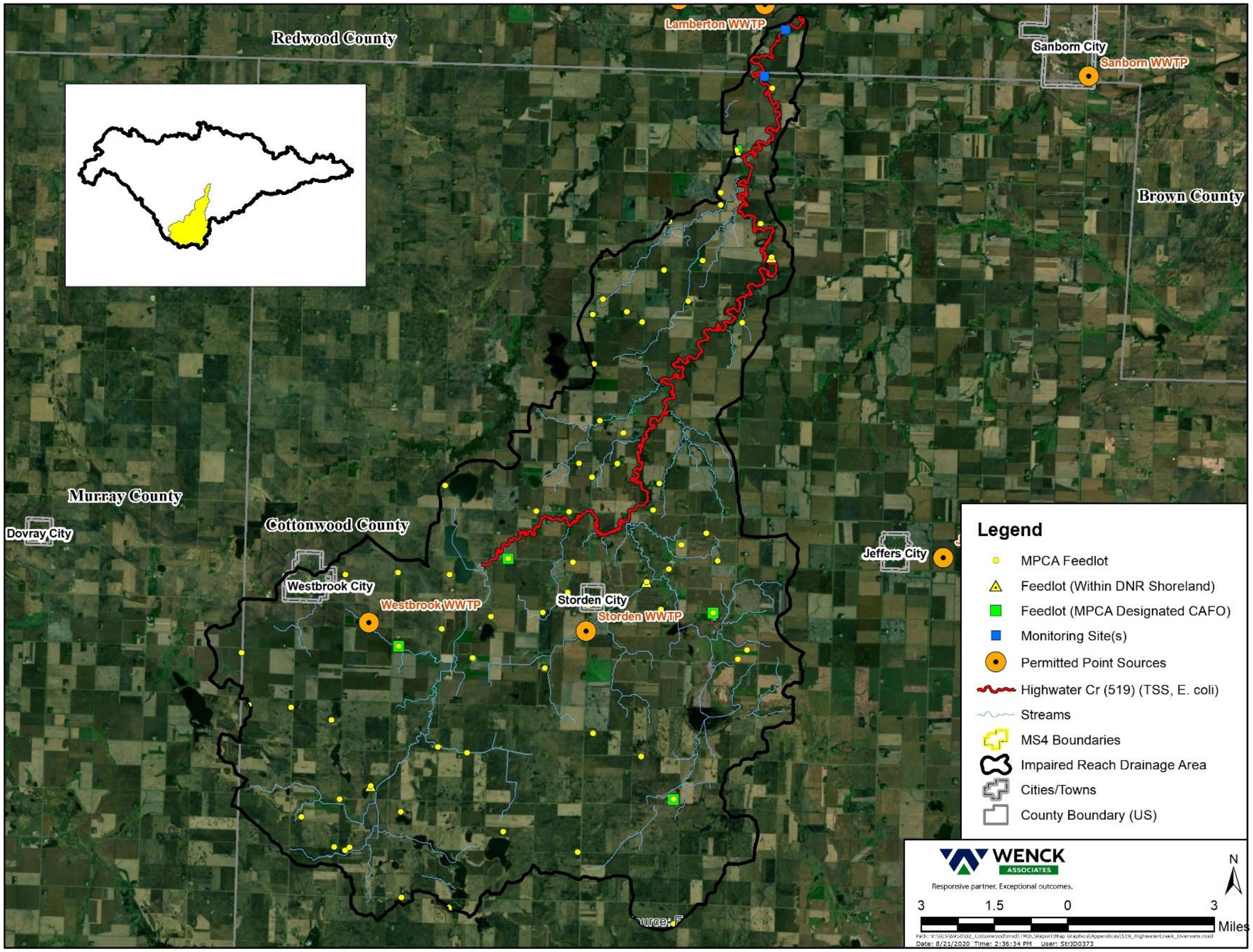



**Figure A-25. Highwater Creek Reach 519 Feedlots.**

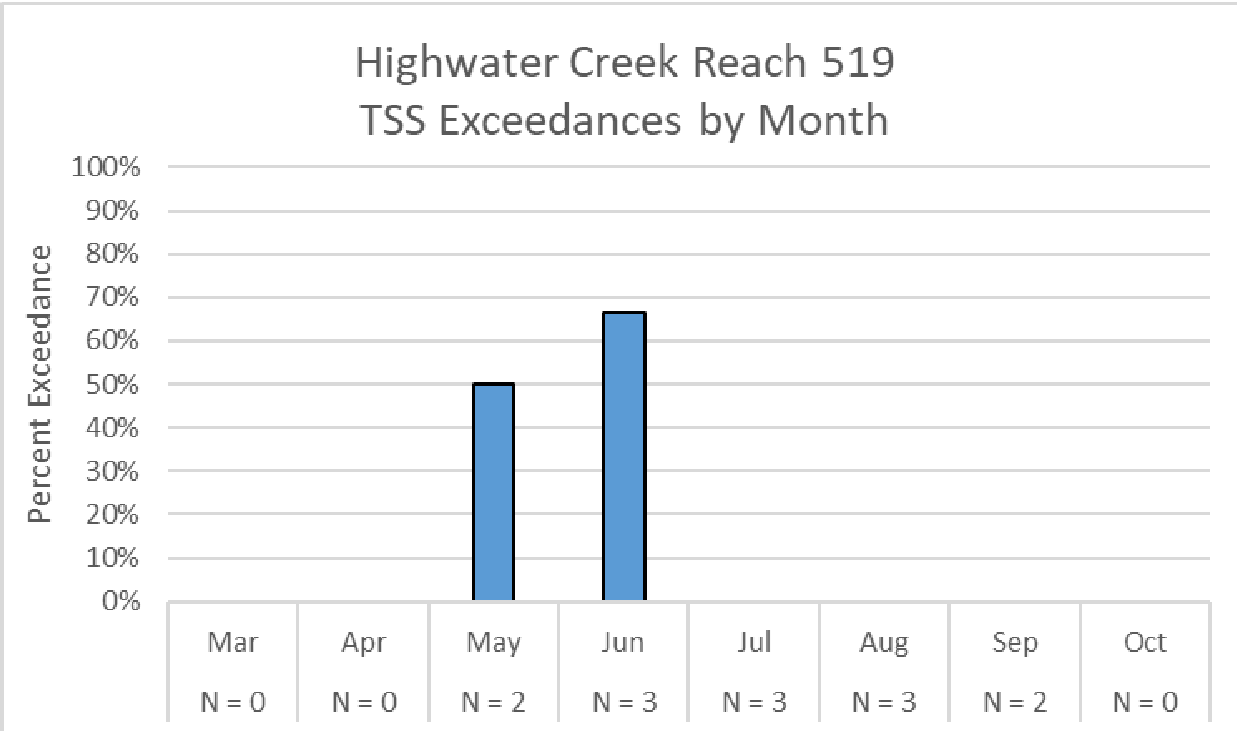



**Figure A-26. Highwater Creek Reach 519 TSS Exceedances by Month.**

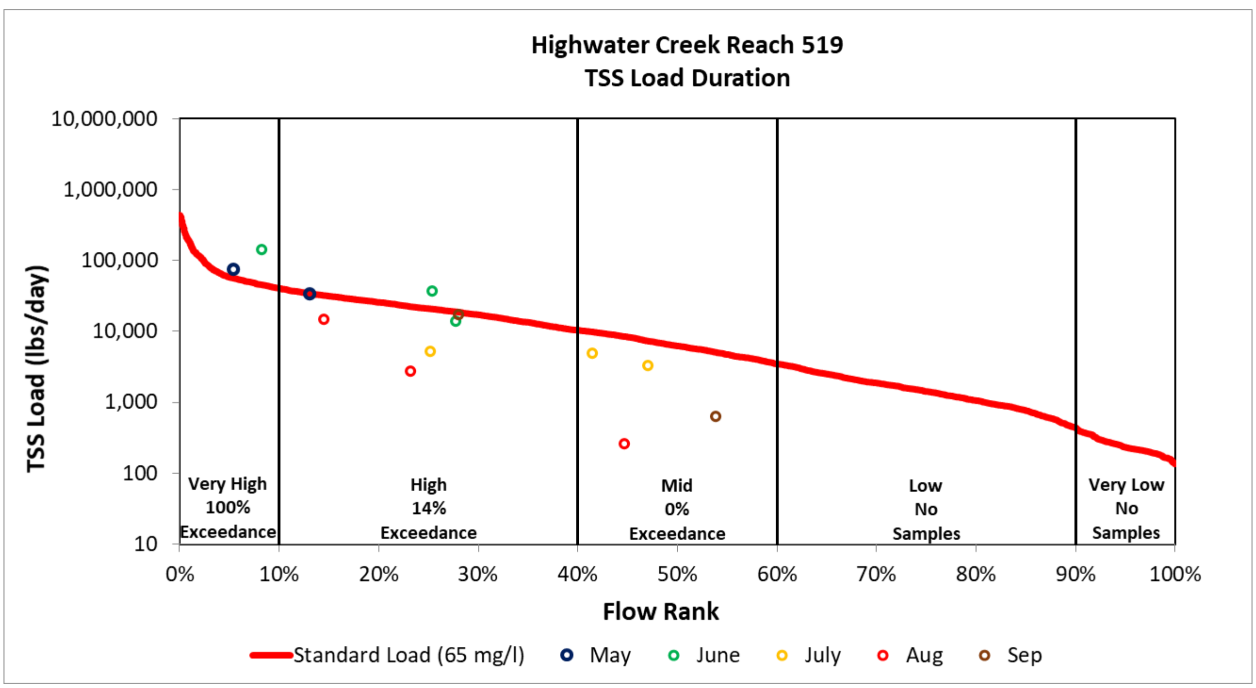



**Figure A-27. Highwater Creek Reach 519 TSS Load Duration Curve (by month).**

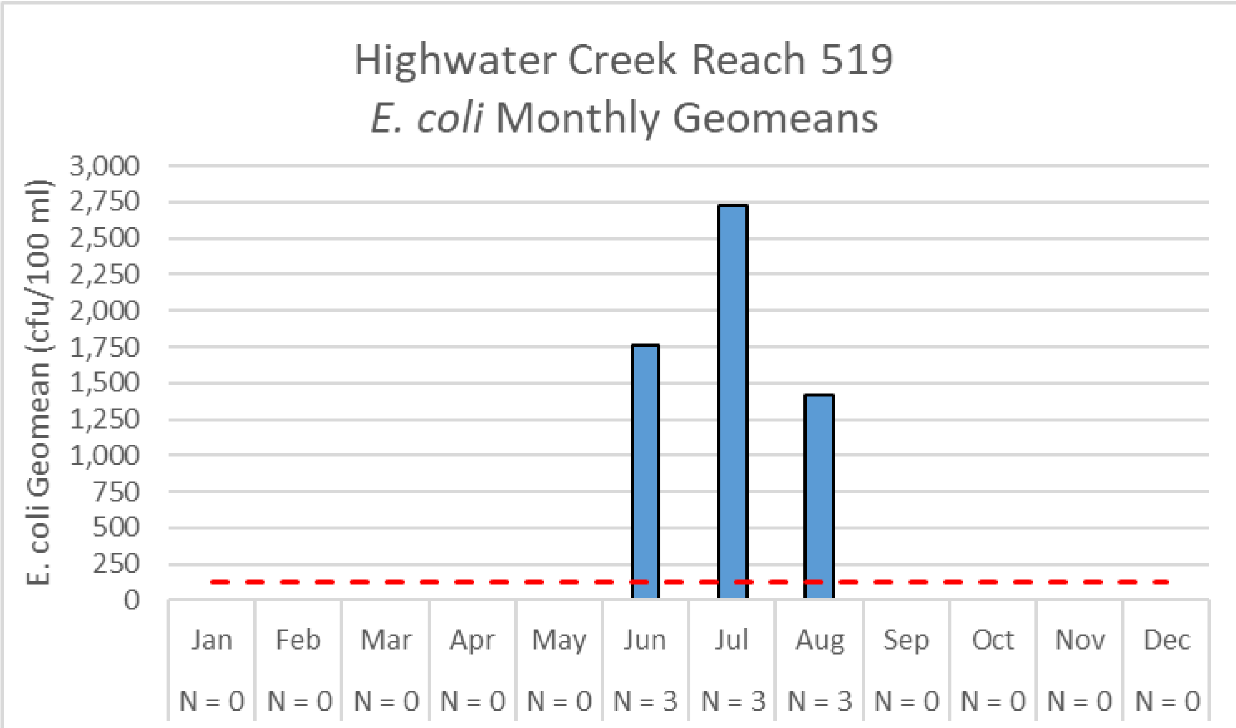



**Figure A-28. Highwater Creek Reach 519 *E. coli* Monthly Geomeans.**

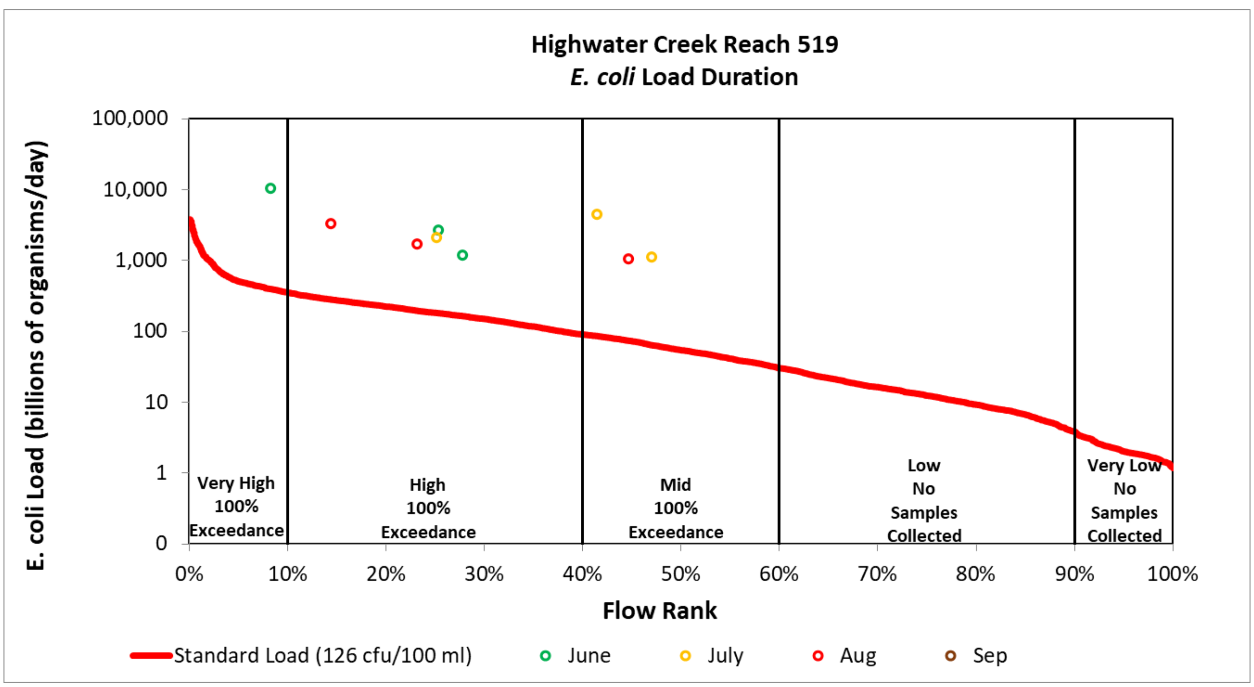



**Figure A-29. Highwater Creek Reach 519 E. coli Load Duration Curve (by month).**

**Table A-3. Highwater Creek Reach 519 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8] | Total Fecal Bacteria Produced Per Day [Billions of Org.] | Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.] | Percent by Category |
|---|---|---|---|---|---|---|
| Livestock (Surface Applied Manure) [1] | Horse* | 8 | 58.2 | 466 | 826,509 | 99.81% |
| | Swine* | 5,035 | 32.7 | 164,645 | | |
| | Bovine* | 11,120 | 58.2 | 647,201 | | |
| | Poultry* | 3.4 | 20.5 | 71 | | |
| | Other Livestock*,[9] | 452 | 31.3 | 14,126 | | |
| Wildlife | Deer [3] | 542 | 0.5 | 271 | 922 | 0.11% |
| | Waterfowl [4] | 1,627 | 0.4 | 651 | | |
| Human | Failing Septic Systems [5] | 35 | 5.7 | 200 | 227 | 0.03% |
| | WWTP effluent [6] | 2 | 13.4 | 27 | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 694 | 0.6 | 391 | 391 | 0.05% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

**Supporting Items for Dry Creek *E. coli* Impaired Reach (07020008-520)**

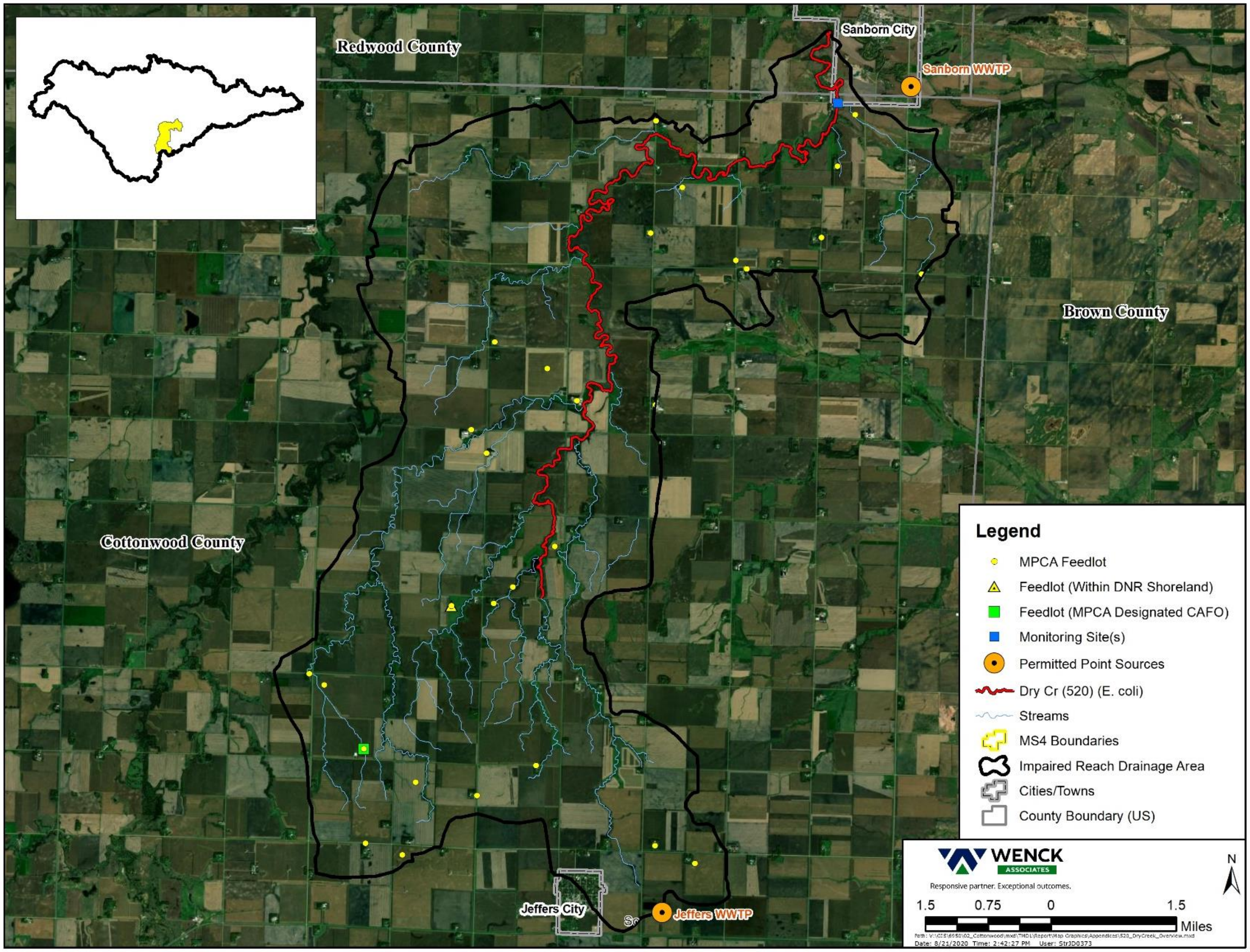



**Figure A-30. Dry Creek Reach 520 Feedlots.**

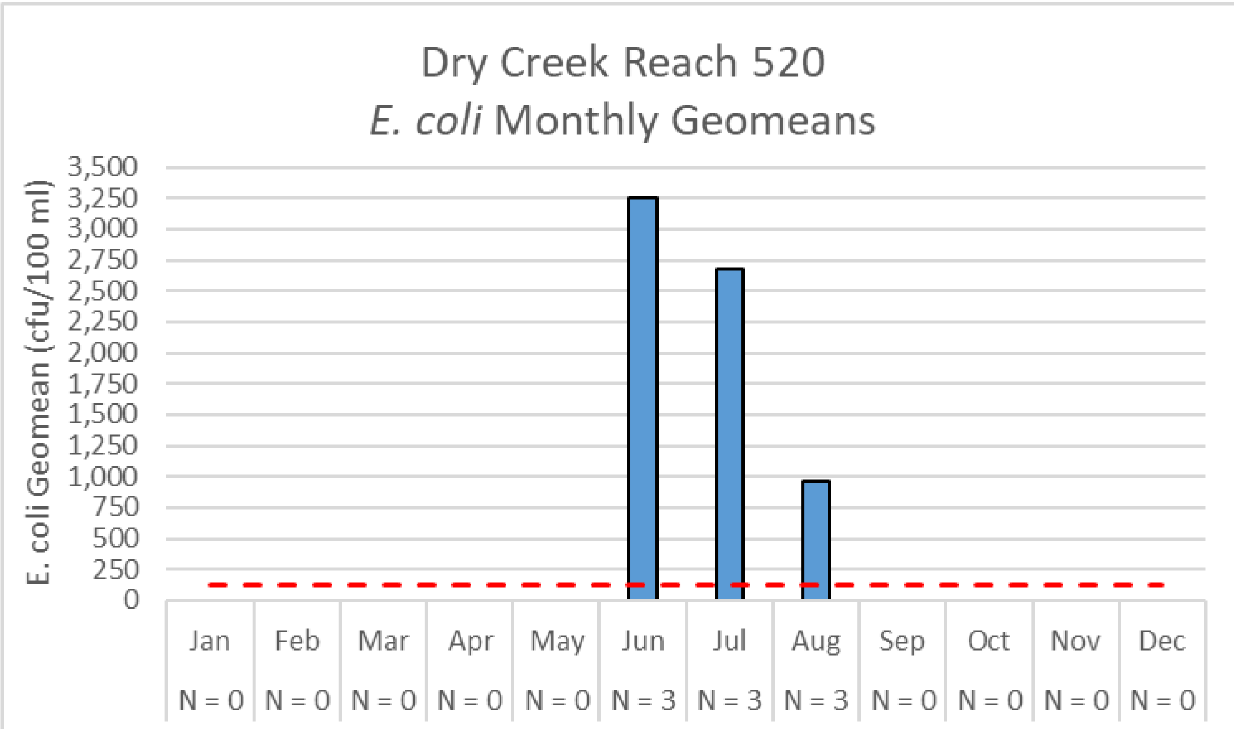



**Figure A-31. Dry Creek Reach 520 *E. coli* Monthly Geomeans.**

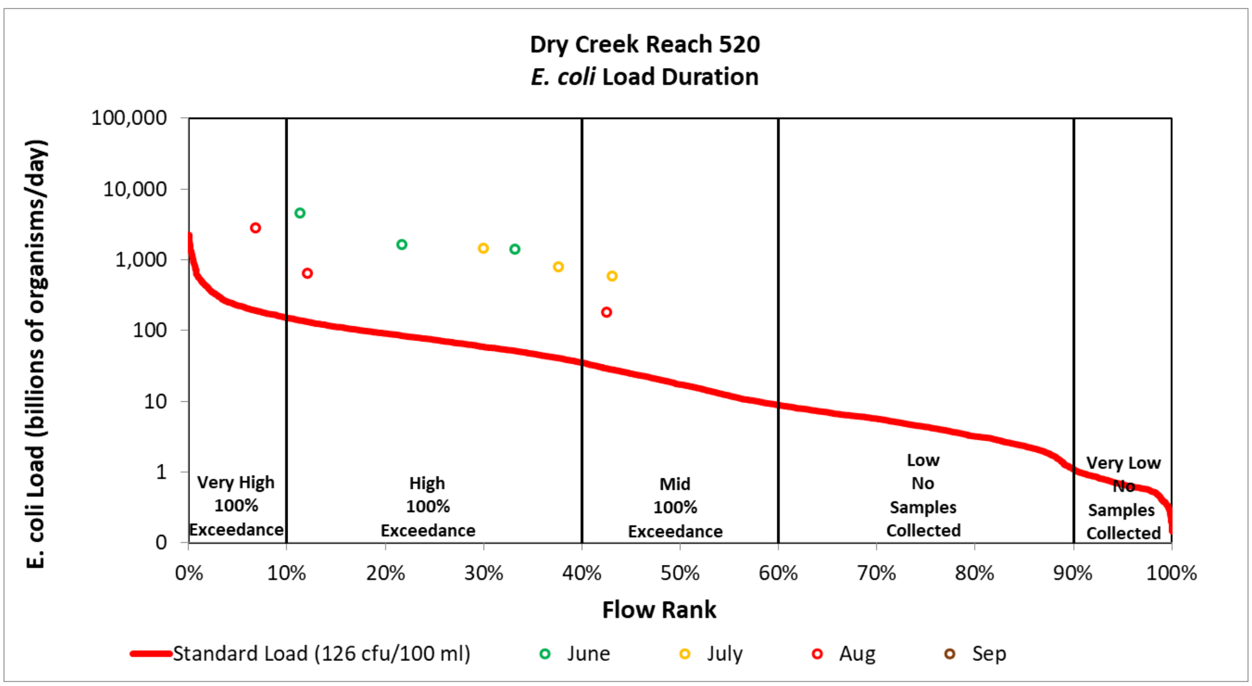



**Figure A-32. Dry Creek Reach 520 *E. coli* Load Duration Curve (by month).**

**Table A-4. Dry Creek Reach 520 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day | Total Fecal Bacteria Produced Per Day | Total Fecal Bacteria Produced Per Day by Major Category | Percent by Category |
|---|---|---|---|---|---|---|
| | | | [Billions of Org.] [8] | [Billions of Org.] | [Billions of Org.] | |
| Livestock (Surface Applied Manure) [1] | Horse* | 18 | 58.2 | 1,048 | 317,949 | 99.75% |
| | Swine* | 1,008 | 32.7 | 32,962 | | |
| | Bovine* | 4,875 | 58.2 | 283,719 | | |
| | Poultry* | 0.5 | 20.5 | 11 | | |
| | Other Livestock*,[9] | 32 | 6.6 | 209 | | |
| Wildlife | Deer [3] | 205 | 0.5 | 103 | 349 | 0.11% |
| | Waterfowl [4] | 616 | 0.4 | 246 | | |
| Human | Failing Septic Systems [5] | 26 | 5.7 | 145 | 145 | 0.05% |
| | WWTP effluent [6] | - | - | - | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 511 | 0.6 | 287 | 287 | 0.09% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

**Supporting Items for Mound Creek *E. coli* Impaired Reach (07020008-521)**

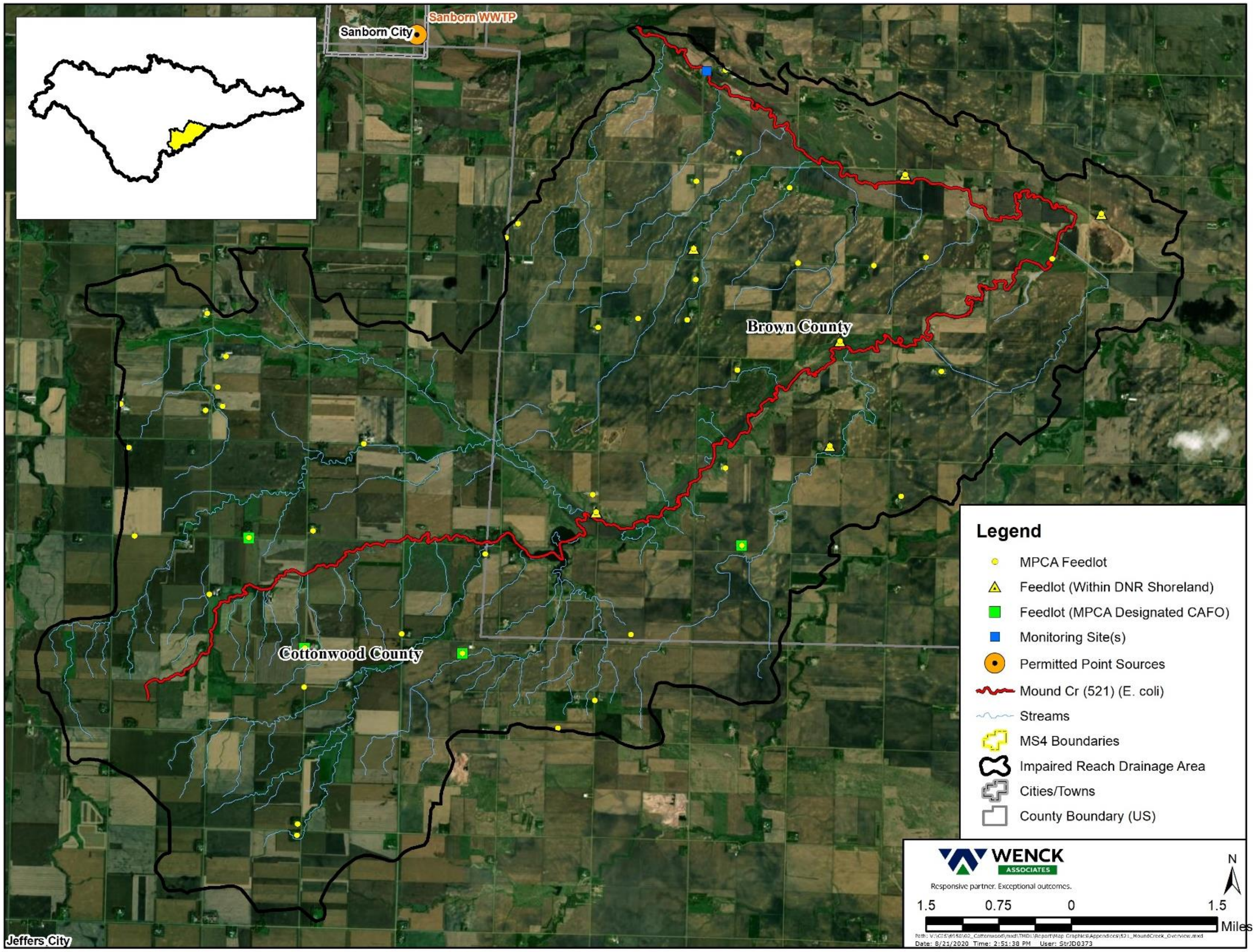



**Figure A-33. Mound Creek Reach 521 Feedlots.**

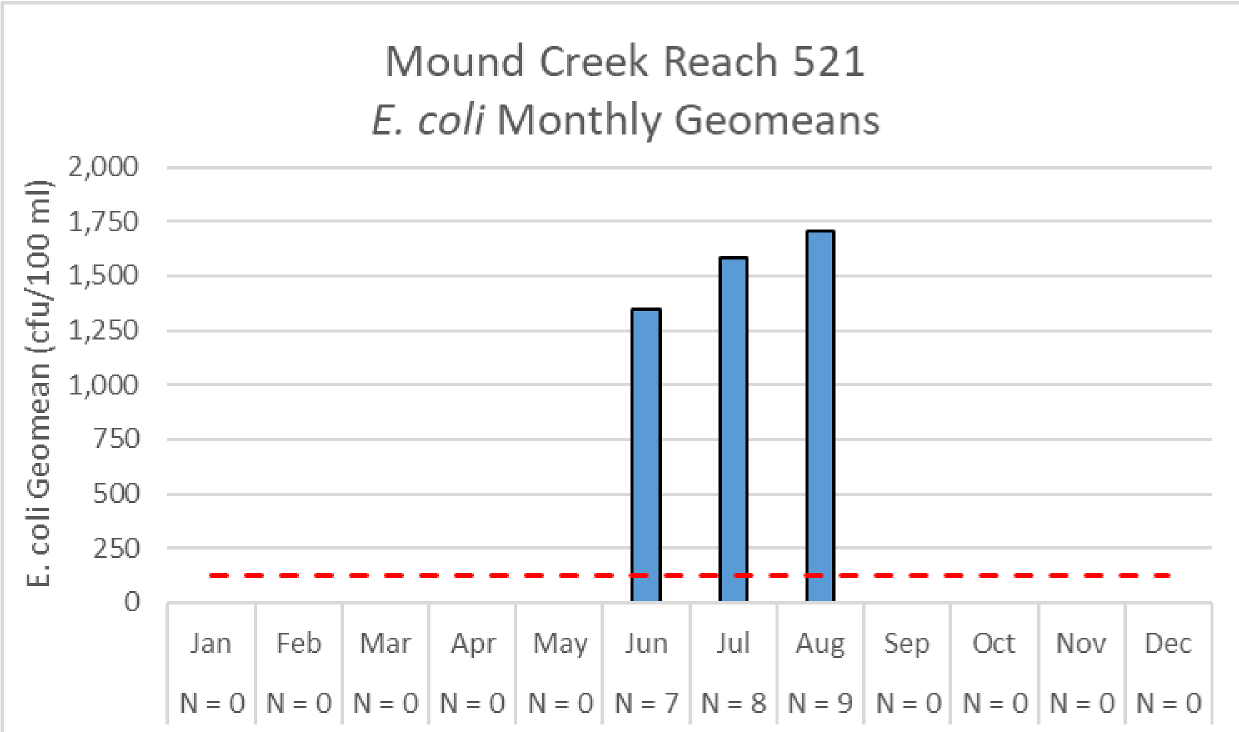



**Figure A-34. Mound Creek Reach 521 *E. coli* Monthly Geomeans.**

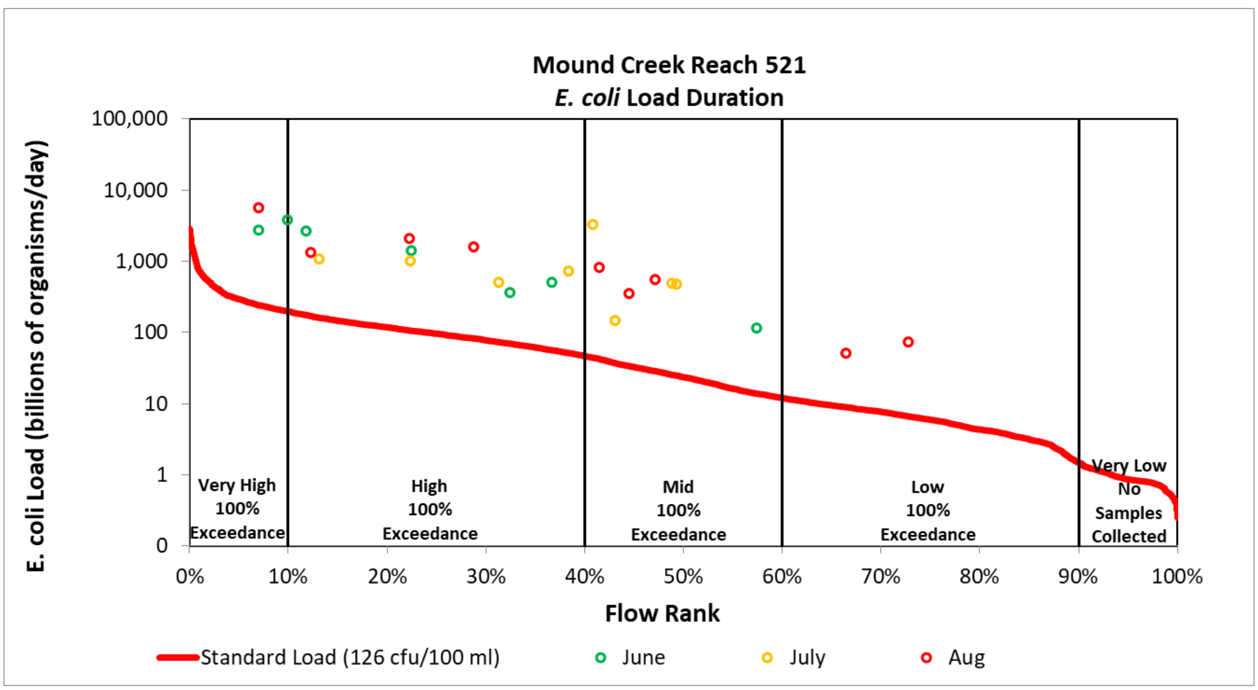



**Figure A-35. Mound Creek Reach 521 *E. coli* Load Duration Curve (by month).**

**Table A-5. Mound Creek Reach 521 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day | Total Fecal Bacteria Produced Per Day | Total Fecal Bacteria Produced Per Day by Major Category | Percent by Category |
|---|---|---|---|---|---|---|
| | | | [Billions of Org.] [8] | [Billions of Org.] | [Billions of Org.] | |
| Livestock (Surface Applied Manure) [1] | Horse* | 7 | 58.2 | 407 | 678,335 | 99.89% |
| | Swine* | 5,677 | 32.7 | 185,648 | | |
| | Bovine* | 8,454 | 58.2 | 492,017 | | |
| | Poultry* | 0.4 | 20.5 | 8 | | |
| | Other Livestock*,[9] | 8 | 32.7 | 255 | | |
| Wildlife | Deer [3] | 276 | 0.5 | 138 | 469 | 0.07% |
| | Waterfowl [4] | 827 | 0.4 | 331 | | |
| Human | Failing Septic Systems [5] | 20 | 5.7 | 114 | 114 | 0.02% |
| | WWTP effluent [6] | - | - | - | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 342 | 0.6 | 192 | 192 | 0.03% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

**Supporting Items for Pell Creek *E. coli* Impaired Reach (07020008-523)**

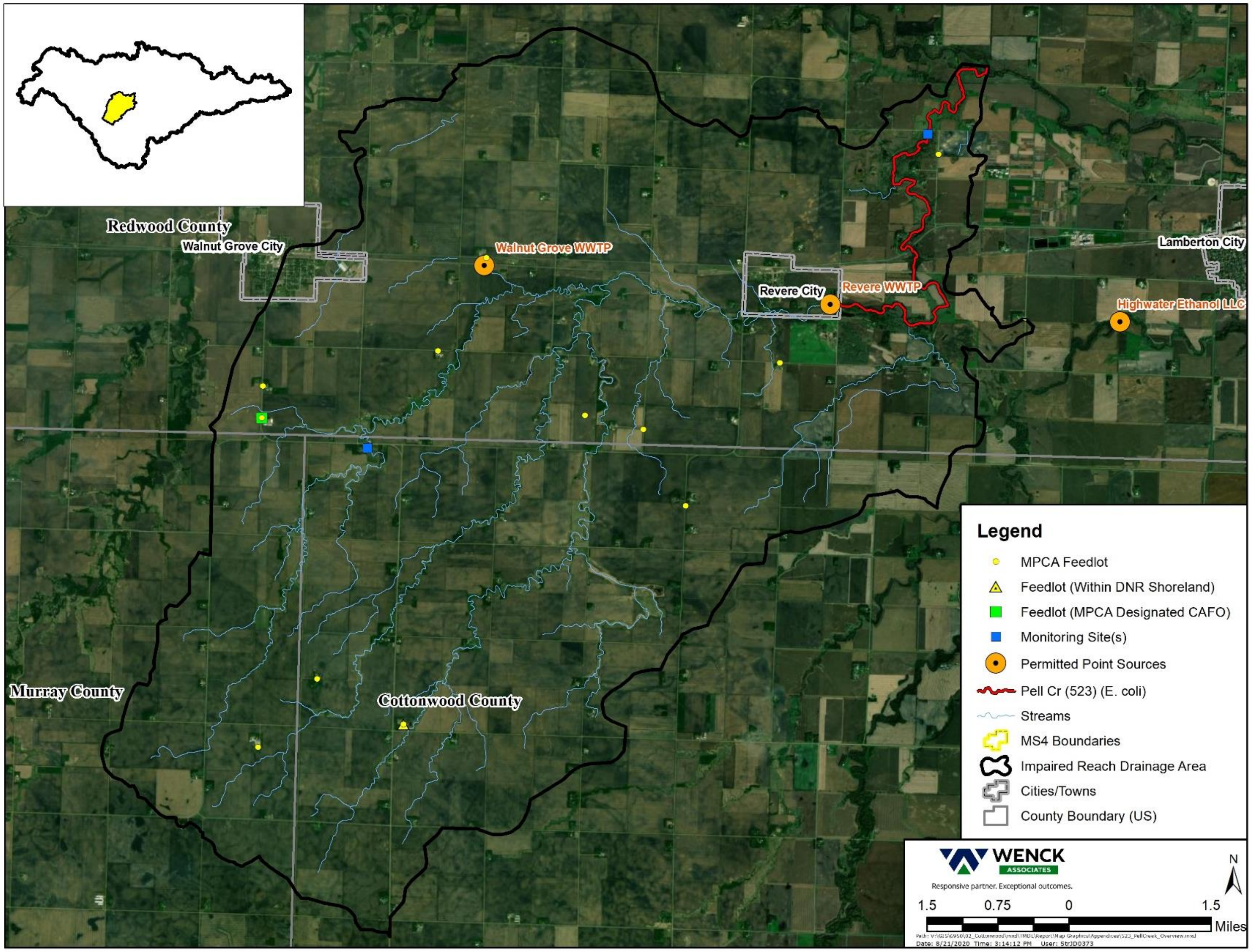



**Figure A-36. Pell Creek Reach 523 Feedlots.**

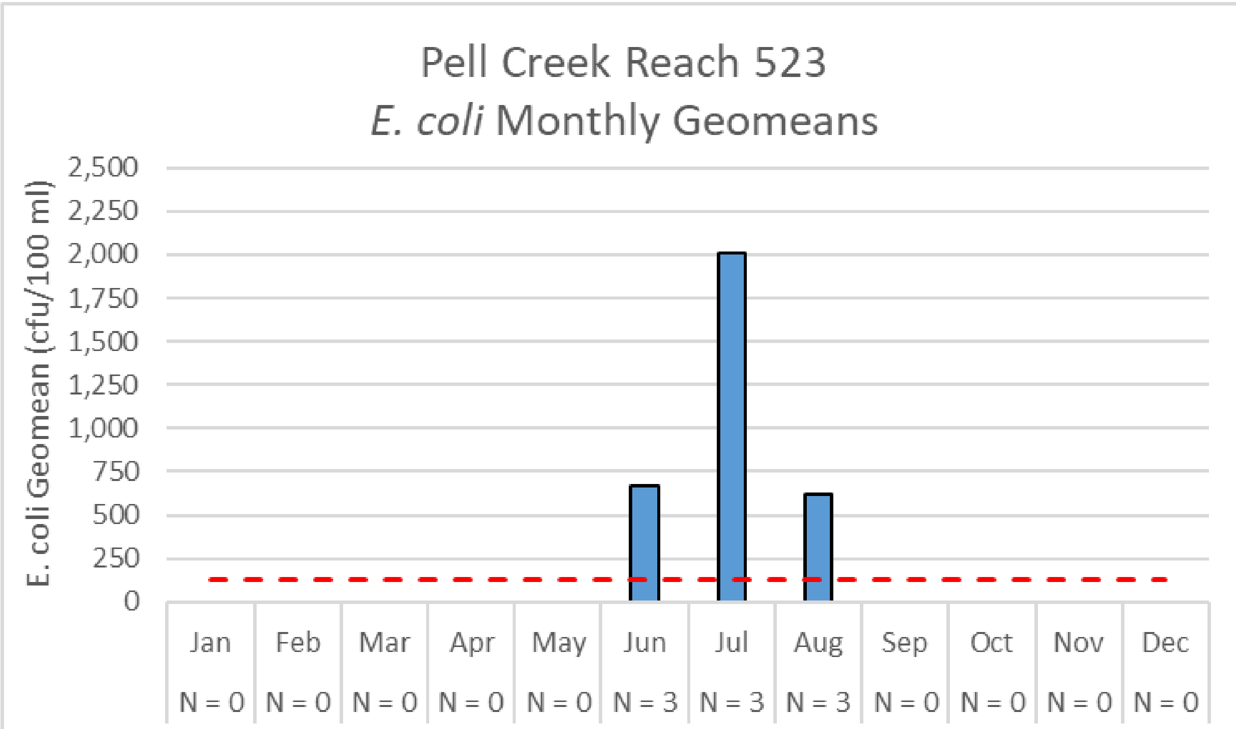



**Figure A-37. Pell Creek Reach 523 *E. coli* Monthly Geomeans.**

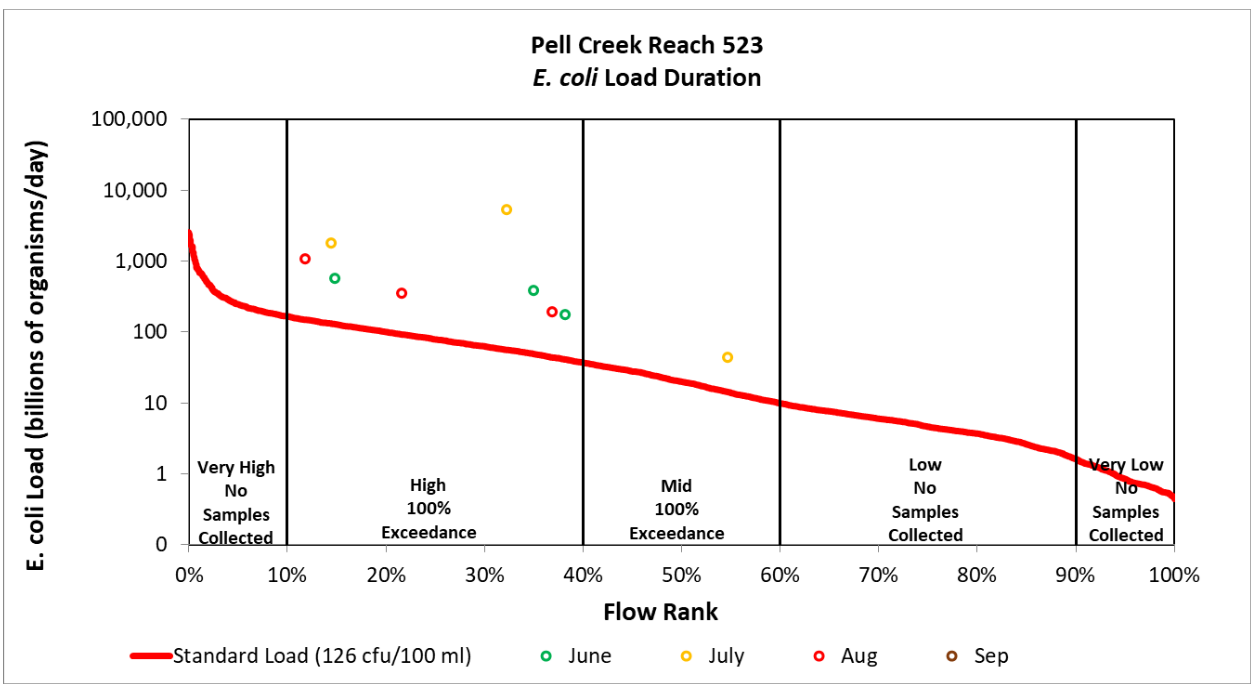



**Figure A-38. Pell Creek Reach 523 *E. coli* Load Duration Curve (by month).**

**Table A-6. Pell Creek Reach 523 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day | Total Fecal Bacteria Produced Per Day | Total Fecal Bacteria Produced Per Day by Major Category | Percent by Category |
|---|---|---|---|---|---|---|
| | | | [Billions of Org.] [8] | [Billions of Org.] | [Billions of Org.] | |
| Livestock (Surface Applied Manure) [1] | Horse* | 1 | 58.2 | 58 | 102,951 | 99.33% |
| | Swine* | 60 | 32.7 | 1,962 | | |
| | Bovine* | 1,730 | 58.2 | 100,686 | | |
| | Poultry* | - | - | - | | |
| | Other Livestock*,[9] | 8 | 32.7 | 245 | | |
| Wildlife | Deer [3] | 259 | 0.5 | 130 | 441 | 0.43% |
| | Waterfowl [4] | 777 | 0.4 | 311 | | |
| Human | Failing Septic Systems [5] | 12 | 5.7 | 65 | 66 | 0.06% |
| | WWTP effluent [6] | 2 | 0.1 | 0 | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 343 | 0.6 | 193 | 193 | 0.19% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

**Supporting Items for Pell Creek TSS Impaired Reach (07020008-535)**

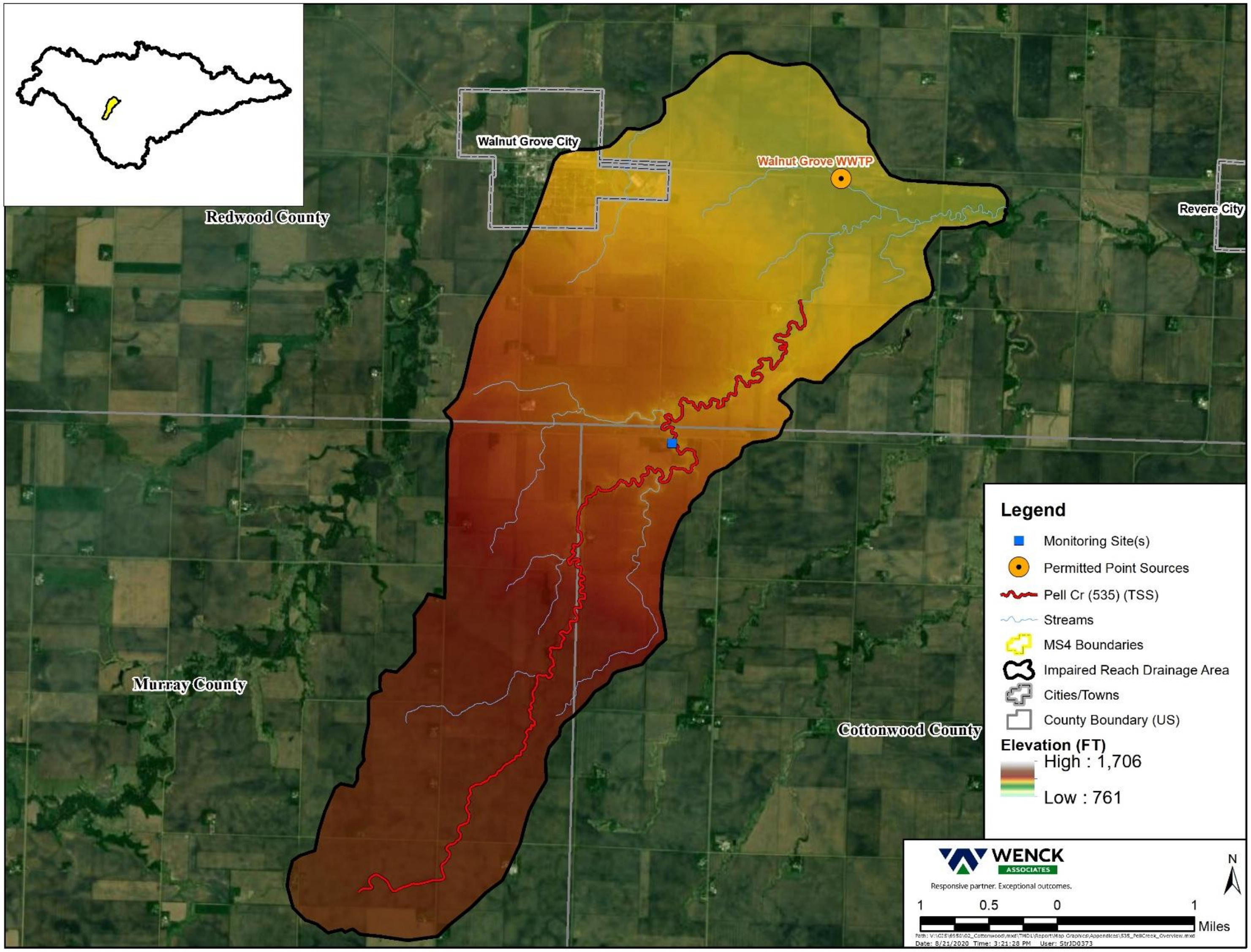



**Figure A-39. Pell Creek Reach 535 Overview.**

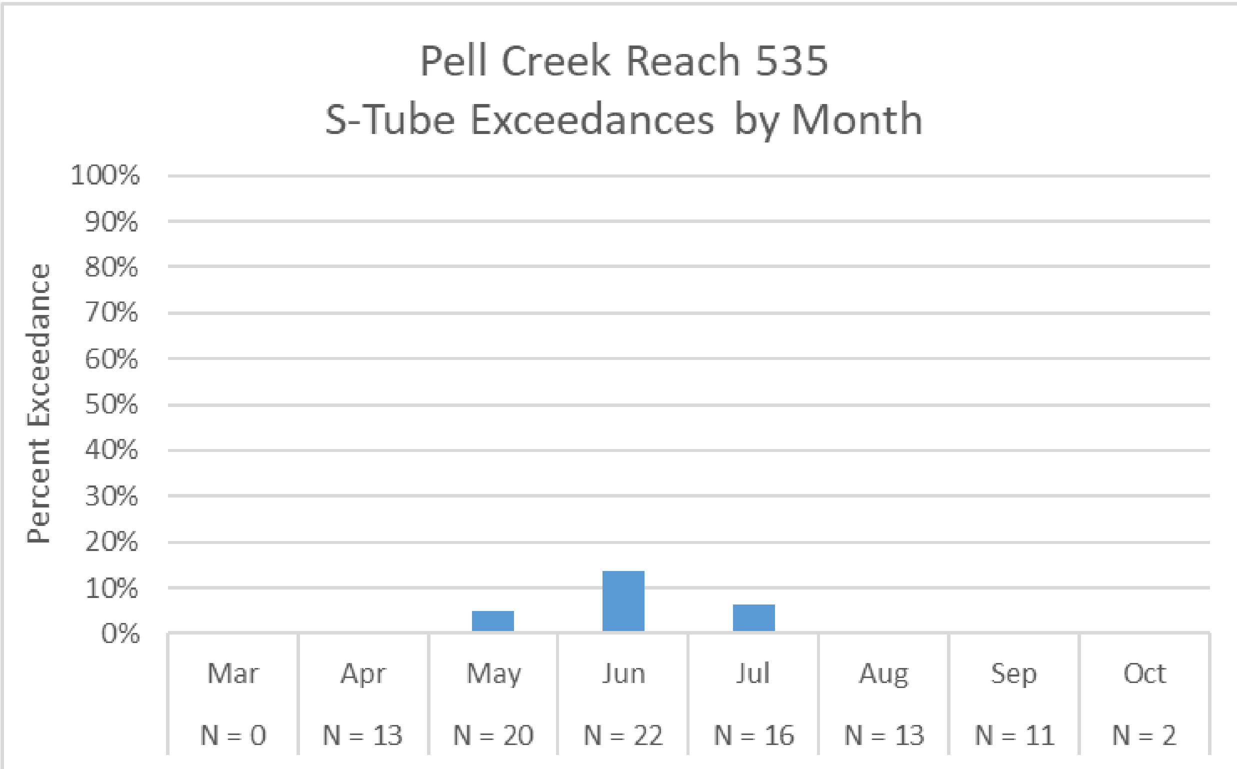



**Figure A-40. Pell Creek Reach 535 S-Tube Exceedances by Month.**

Note: No TSS samples have been collected for this reach

**Supporting Items for Sleepy Eye Creek TSS Impaired Reach (07020008-599)**

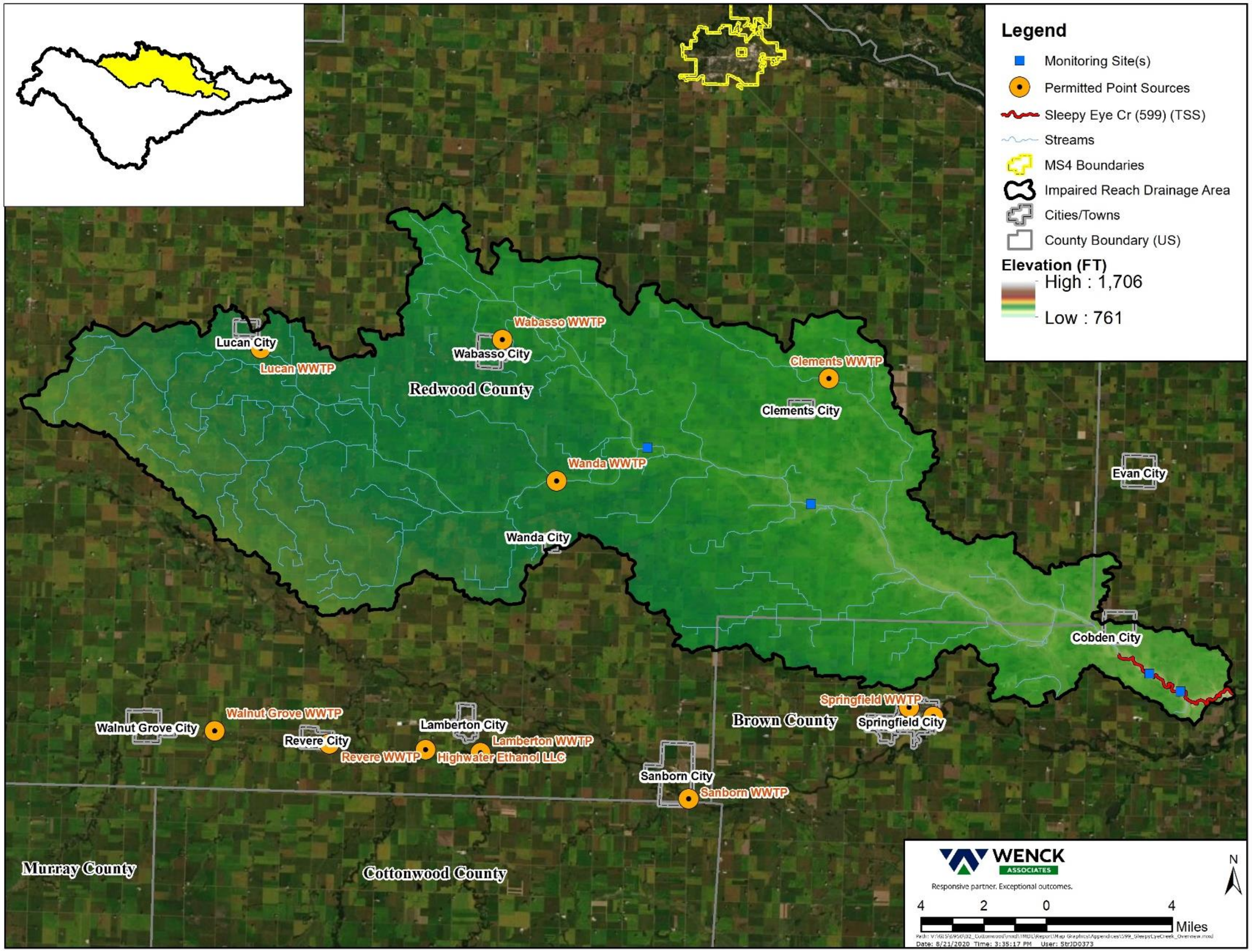



**Figure A-41. Sleepy Eye Creek Reach 599 Overview.**

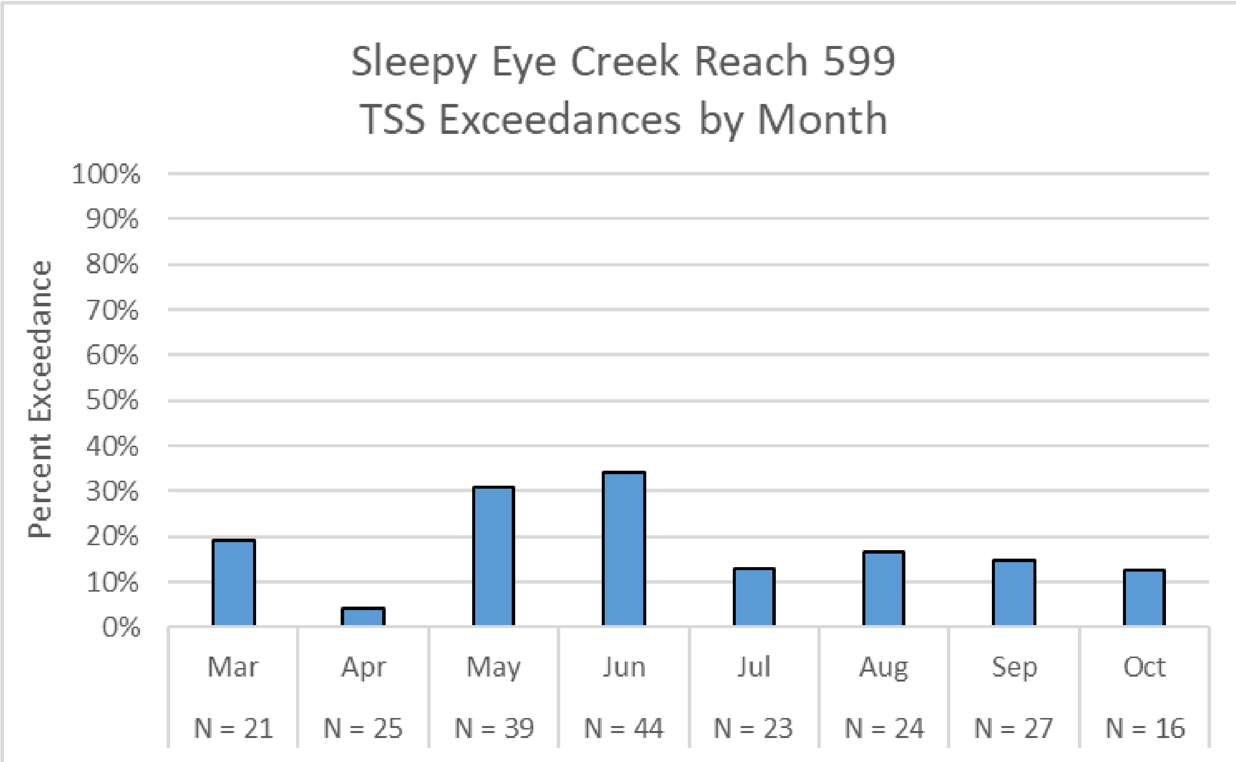



**Figure A-42. Sleepy Eye Creek Reach 599 TSS Exceedances by Month.**

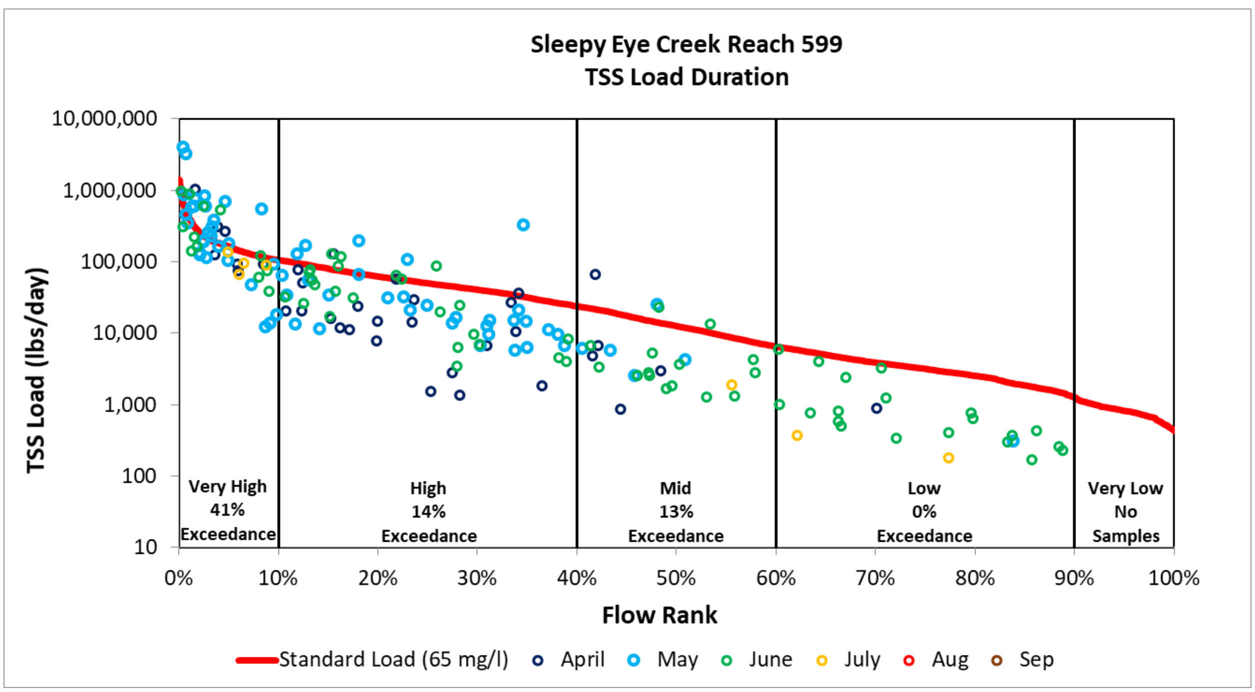



**Figure A-43. Sleepy Eye Creek Reach 599 TSS Load Duration Curve (by month).**

**Supporting Items for Plum Creek (JD 20A) TSS Impaired Reaches (07020008-602 & 603)**

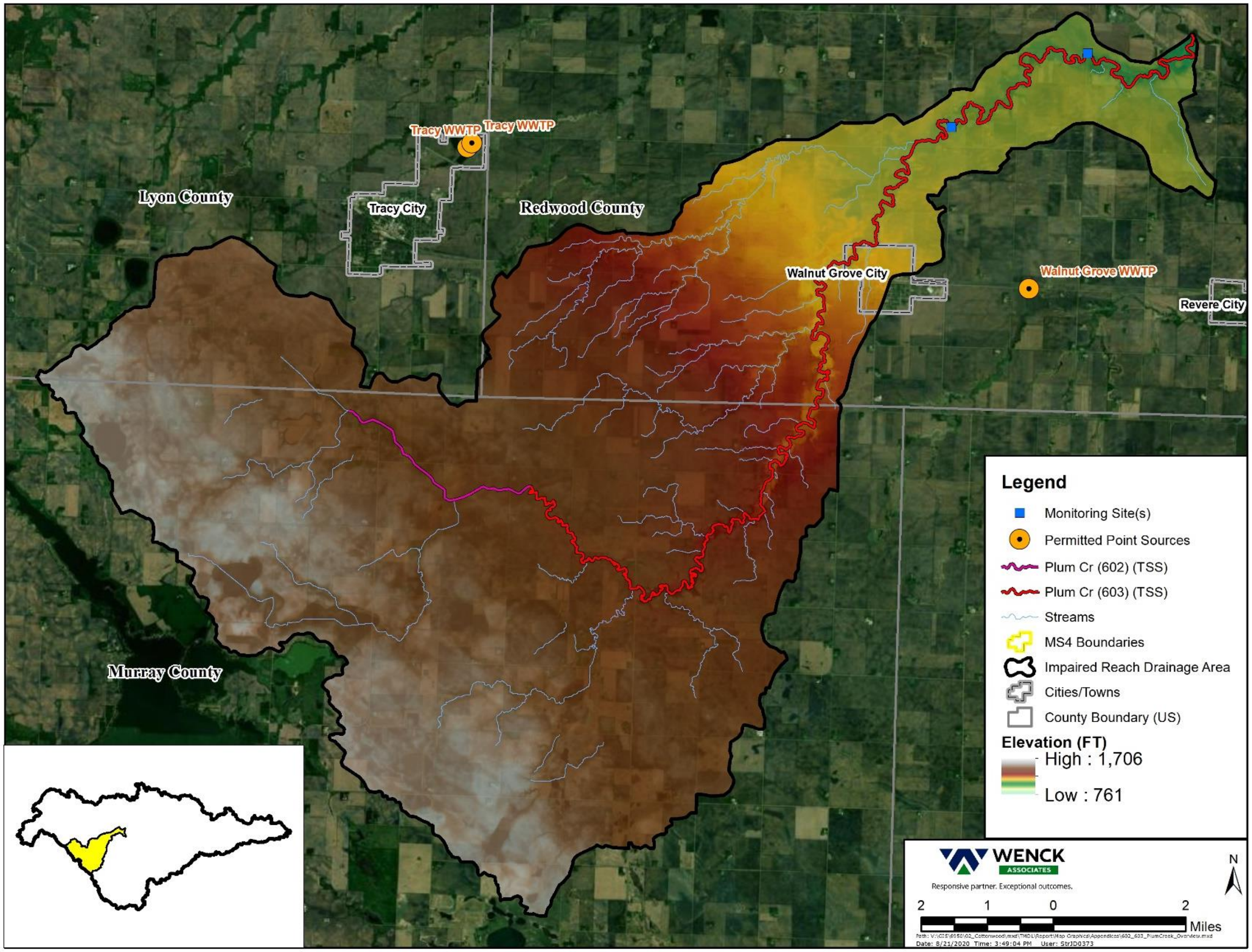



**Figure A-44. Plum Creek (JD 20A) Reach 602 & 603 Overview.**

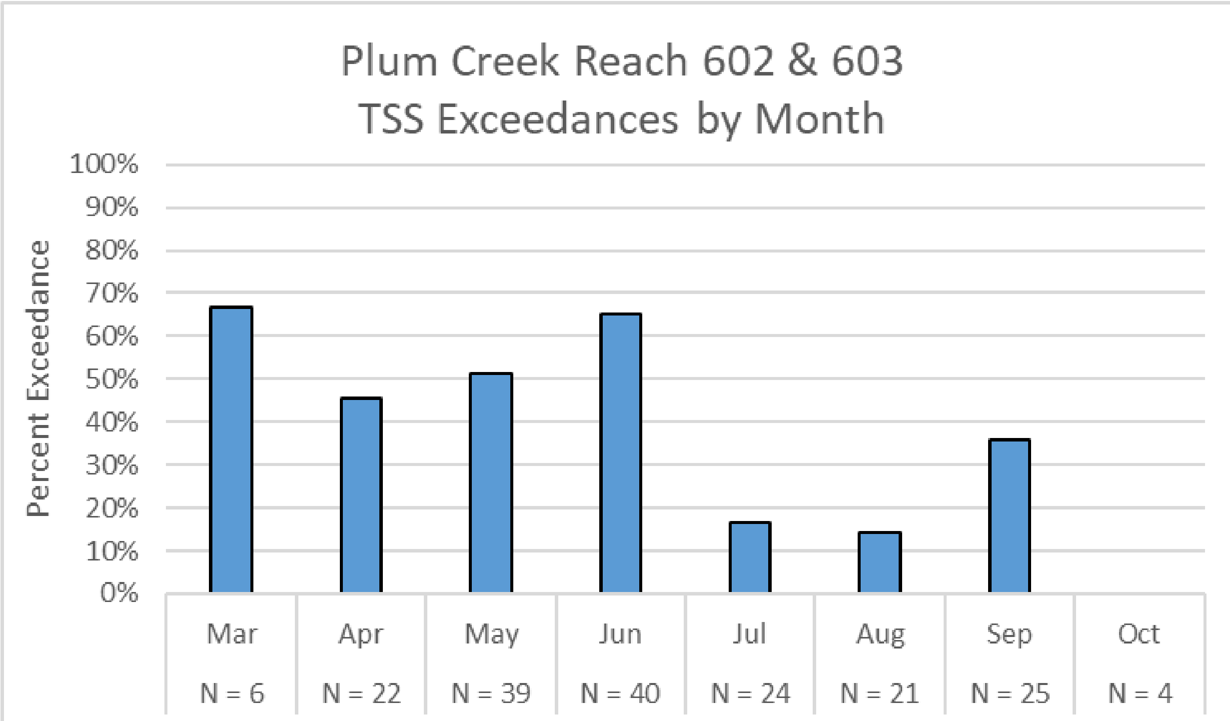



**Figure A-45. Plum Creek (JD 20A) Reach 602 & 603 TSS Exceedances by Month.**

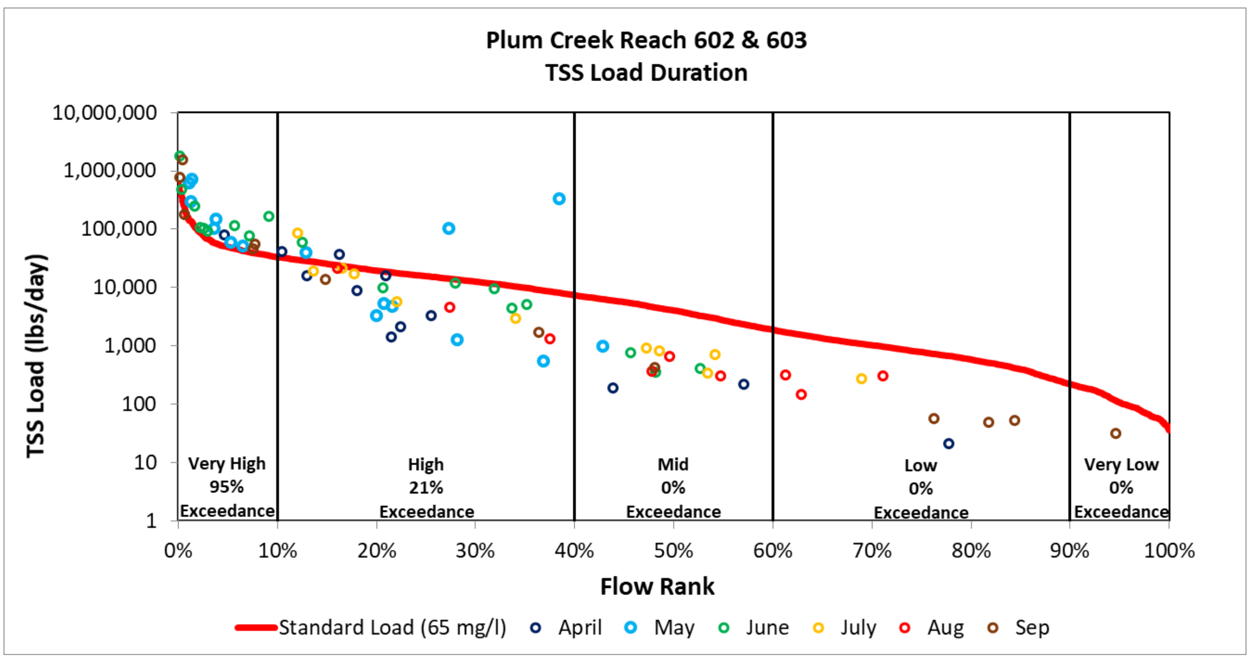



**Figure A-46. Plum Creek (JD 20A) Reach 602 & 603 TSS Load Duration Curve (by month).**

**Supporting Items for Coal Mine Creek *E. coli* Impaired Reach (07020008-604)**

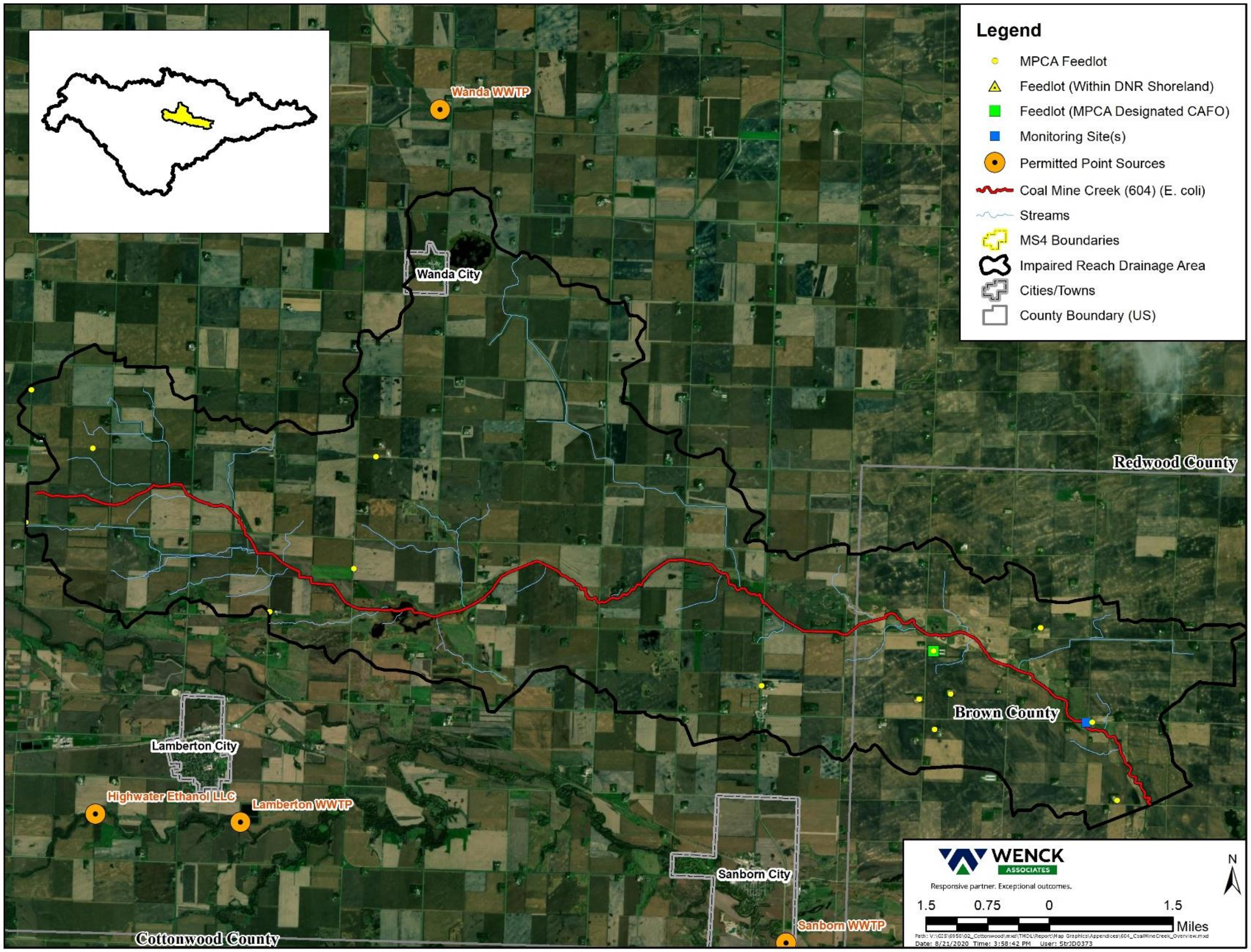



**Figure A-47. Coal Mine Creek Reach 604 Feedlots.**

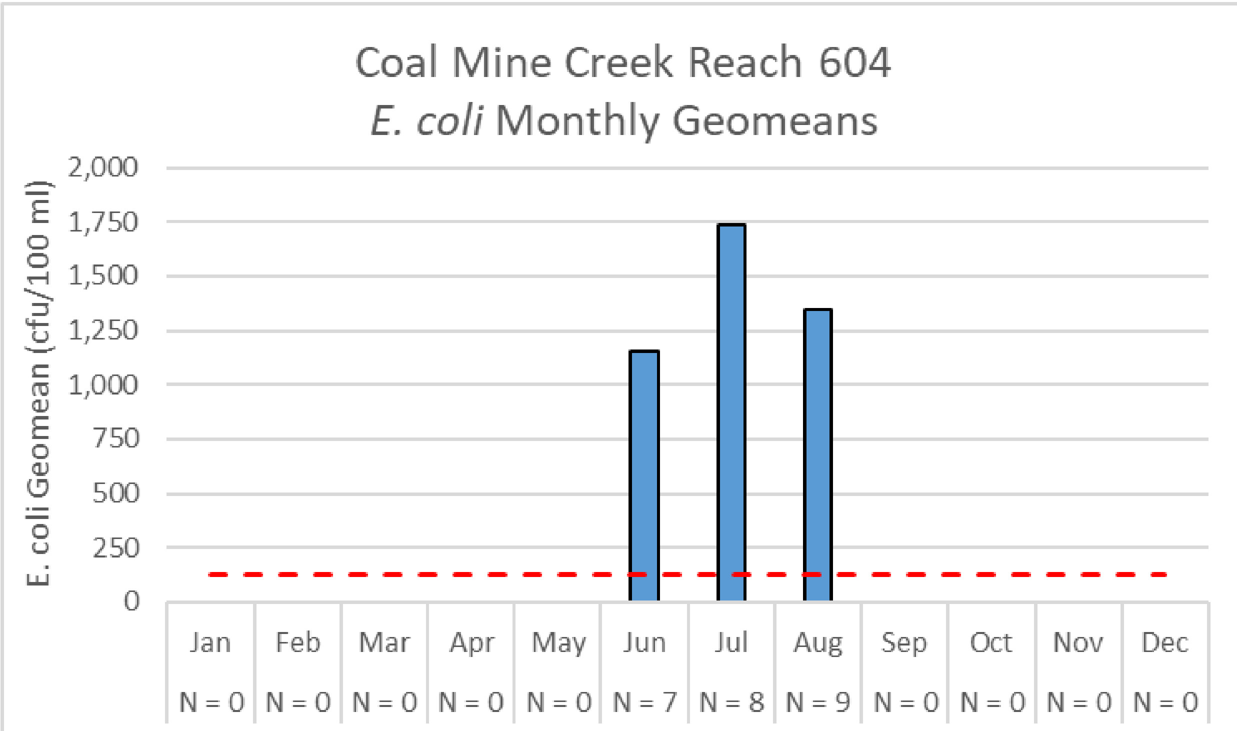



**Figure A-48. Coal Mine Creek Reach 604 *E. coli* Monthly Geomeans.**

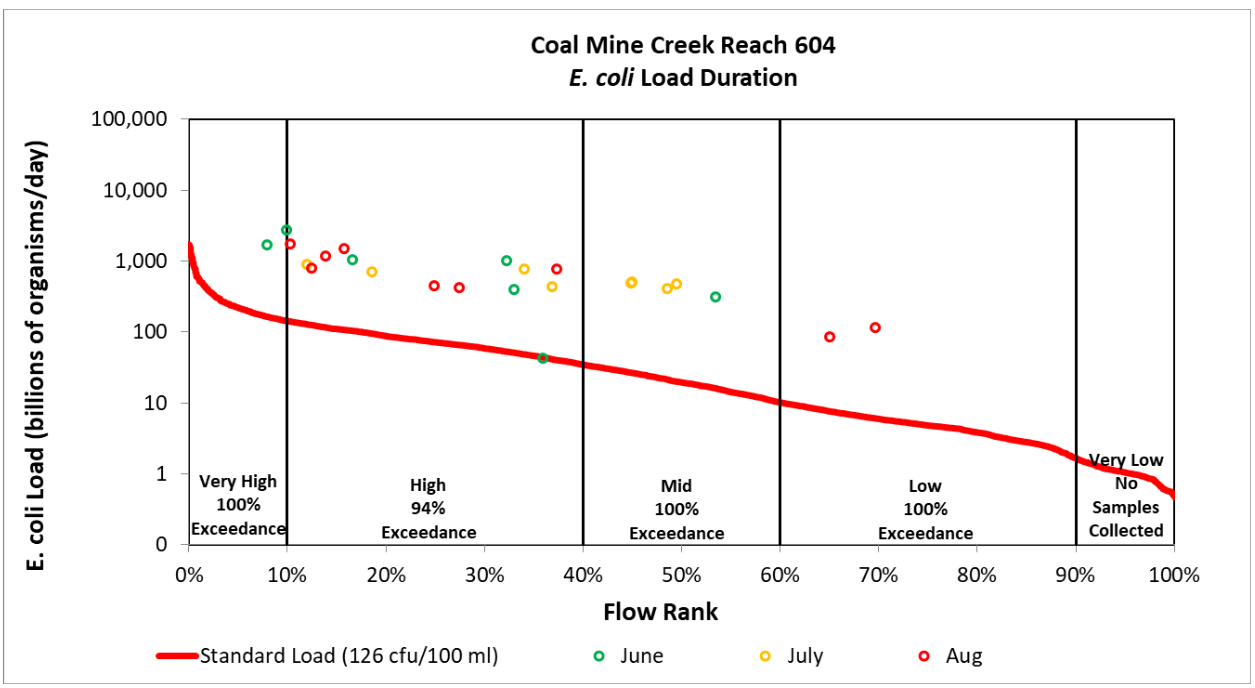



**Figure A-49. Coal Mine Creek Reach 523 *E. coli* Load Duration Curve (by month).**

**Table A-7. Coal Mine Creek Reach 604 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8] | Total Fecal Bacteria Produced Per Day [Billions of Org.] | Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.] | Percent by Category |
|---|---|---|---|---|---|---|
| Livestock (Surface Applied Manure) [1] | Horse* | - | - | - | 149,337 | 99.51% |
| | Swine* | 1,665 | 32.7 | 54,446 | | |
| | Bovine* | 1,241 | 58.2 | 72,203 | | |
| | Poultry* | 1,107 | 20.5 | 22,688 | | |
| | Other Livestock*,[9] | 0 | - | - | | |
| Wildlife | Deer [3] | 230 | 0.5 | 115 | 391 | 0.26% |
| | Waterfowl [4] | 689 | 0.4 | 276 | | |
| Human | Failing Septic Systems [5] | 12 | 5.7 | 71 | 71 | 0.05% |
| | WWTP effluent [6] | - | - | - | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 478 | 0.6 | 269 | 269 | 0.18% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

## Supporting Items for Judicial Ditch 30 *E. coli* Impaired Reach (07020008-609)

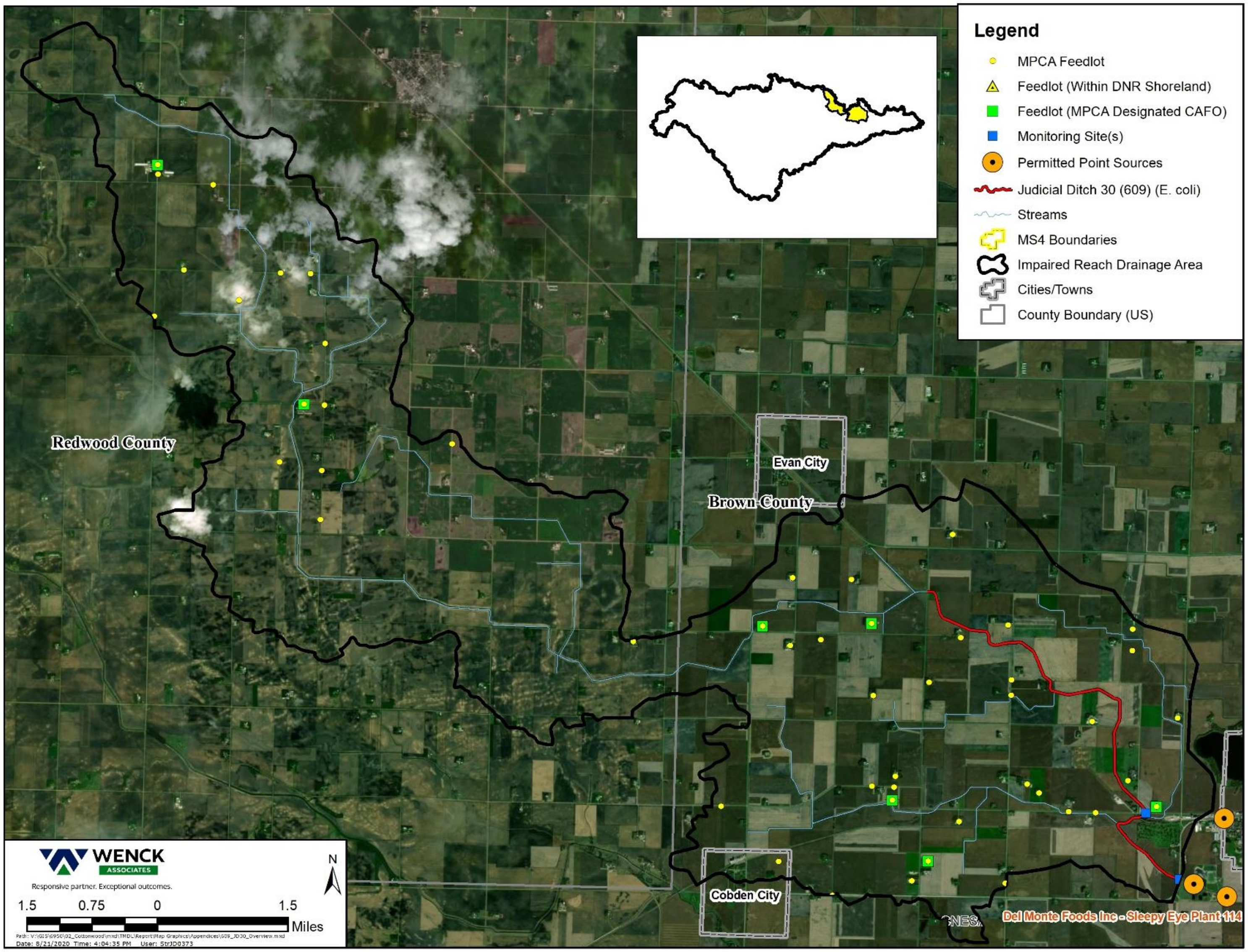



**Figure A-50. Judicial Ditch 30 Reach 609 Feedlots.**

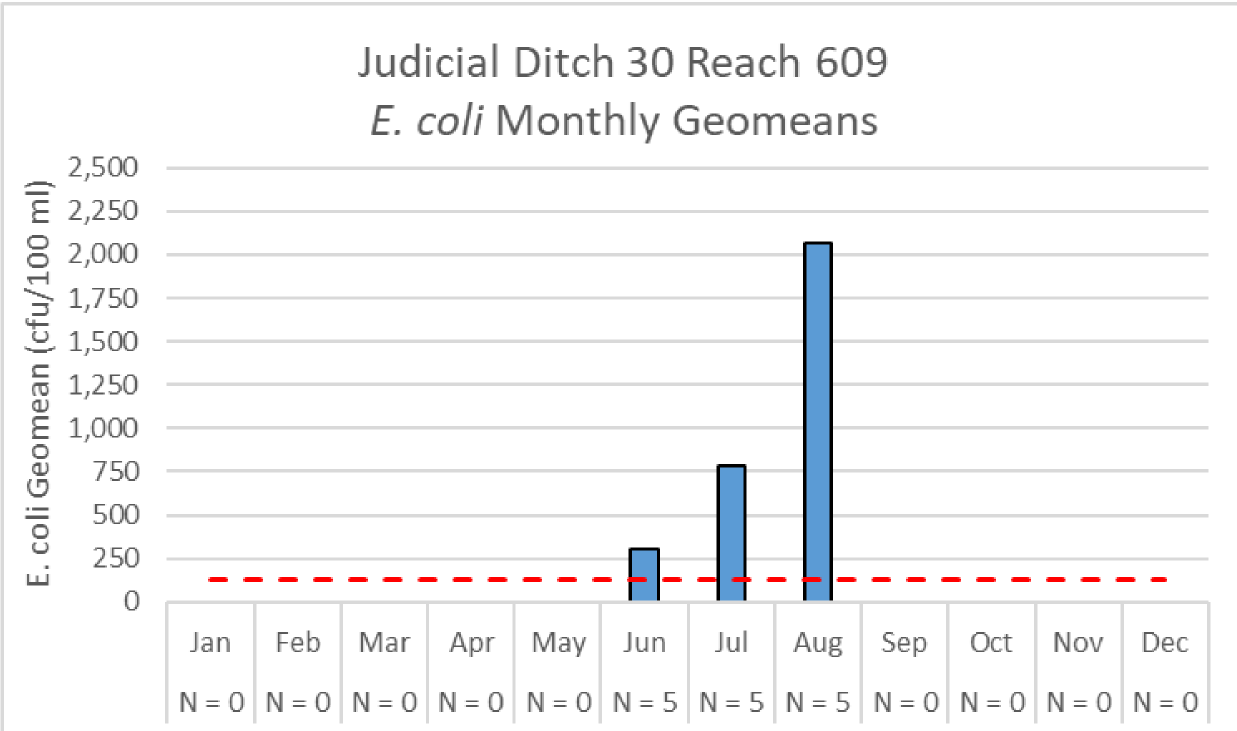



**Figure A-51. Judicial Ditch 30 Reach 609 *E. coli* Monthly Geomeans.**

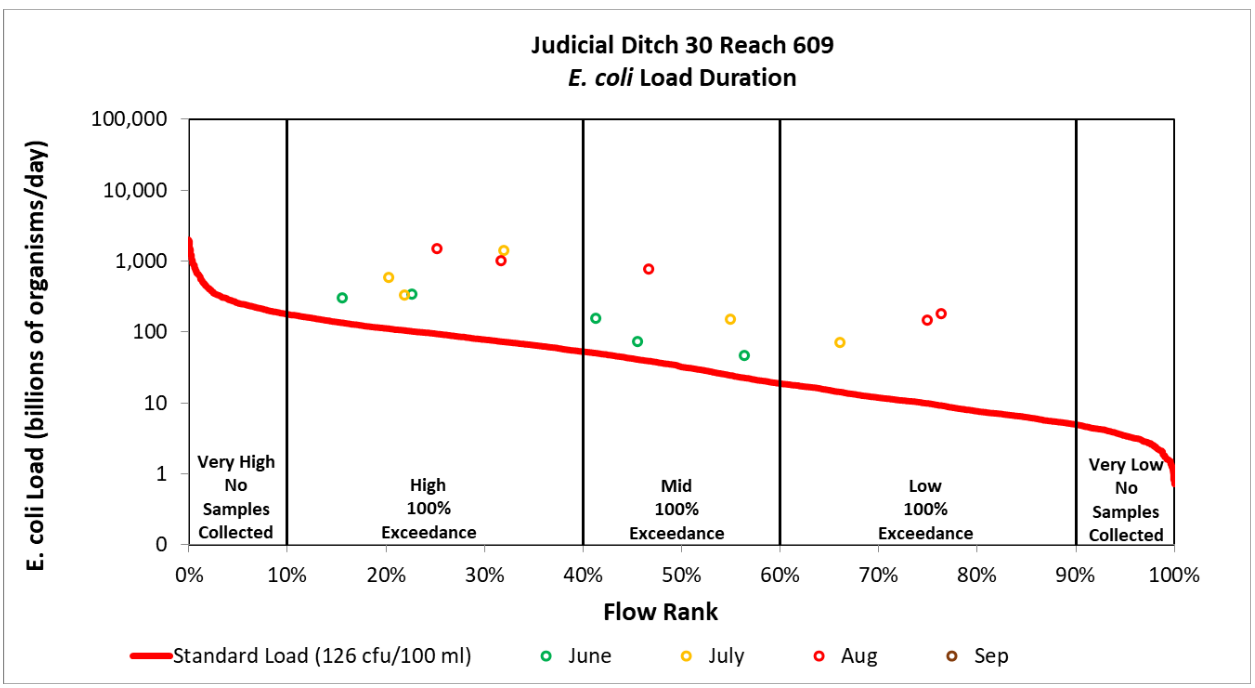



**Figure A-52. Judicial Ditch 30 Reach 609 *E. coli* Load Duration Curve (by month).**

**Table A-8. Judicial Ditch 30 Reach 609 Bacteria Production Exercise.**

| Major Category | Source | Animal Units* or Individuals in Subwatershed | Fecal Bacteria Organisms Produced Per Unit Per Day [Billions of Org.] [8] | Total Fecal Bacteria Produced Per Day [Billions of Org.] | Total Fecal Bacteria Produced Per Day by Major Category [Billions of Org.] | Percent by Category |
|---|---|---|---|---|---|---|
| Livestock (Surface Applied Manure) [1] | Horse* | 4 | 58.2 | 233 | 422,974 | 99.83% |
| | Swine* | 5,380 | 32.7 | 175,910 | | |
| | Bovine* | 4,241 | 58.2 | 246,832 | | |
| | Poultry* | - | - | - | | |
| | Other Livestock*,[9] | 0 | - | - | | |
| Wildlife | Deer [3] | 223 | 0.5 | 111 | 378 | 0.09% |
| | Waterfowl [4] | 668 | 0.4 | 267 | | |
| Human | Failing Septic Systems [5] | 19 | 5.7 | 110 | 110 | 0.03% |
| | WWTP effluent [6] | - | - | - | | |
| Domestic Animals [2] | Improperly Managed Pet Waste [7] | 262 | 0.9 | 239 | 239 | 0.06% |

* Values reported as Animal Units.

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

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

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

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

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

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

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

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

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

# Appendix B - Lake Impairment Supporting Items

## Supporting Items for Lake Bean (17005400)

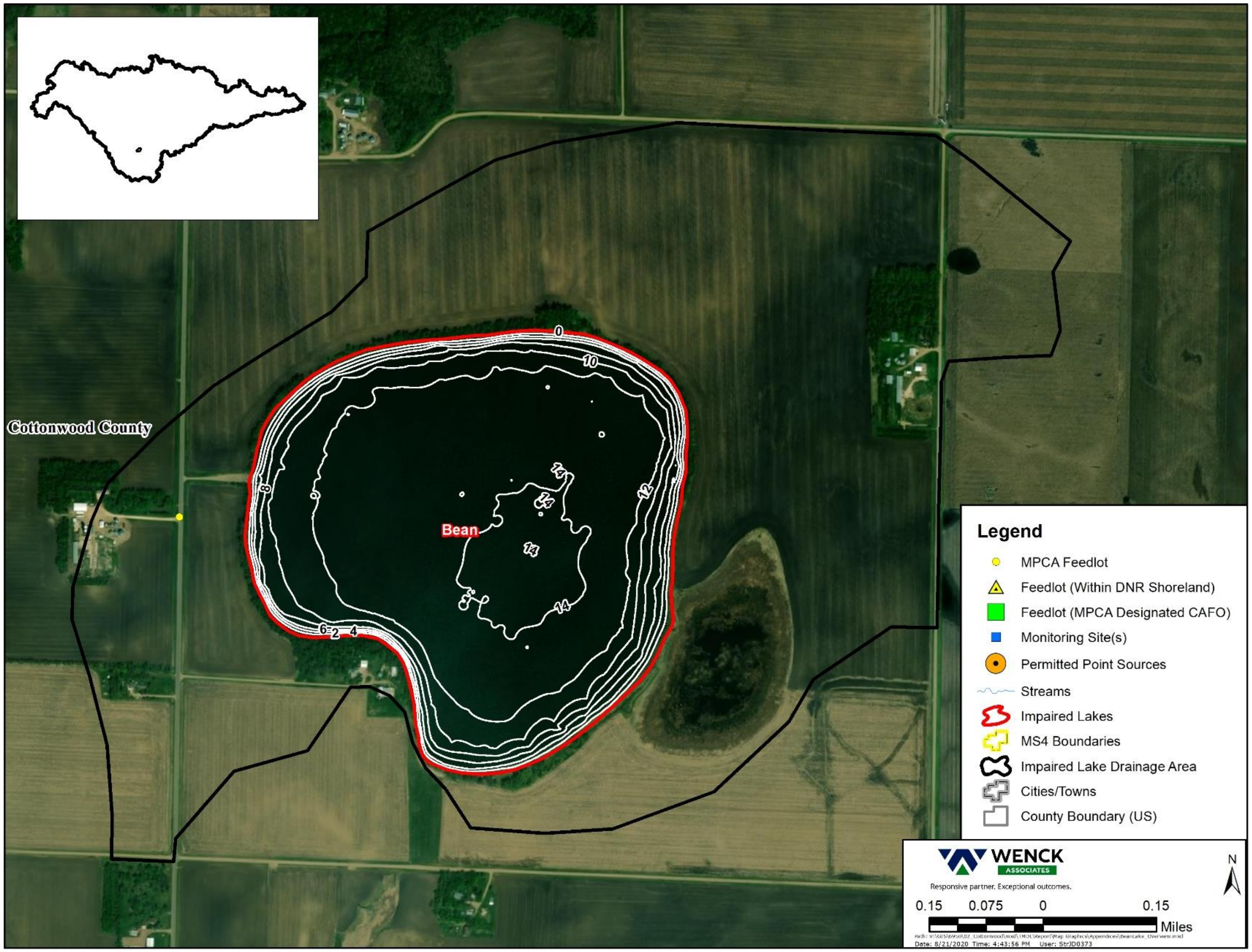



**Figure C-1. Lake Bean Overview.**

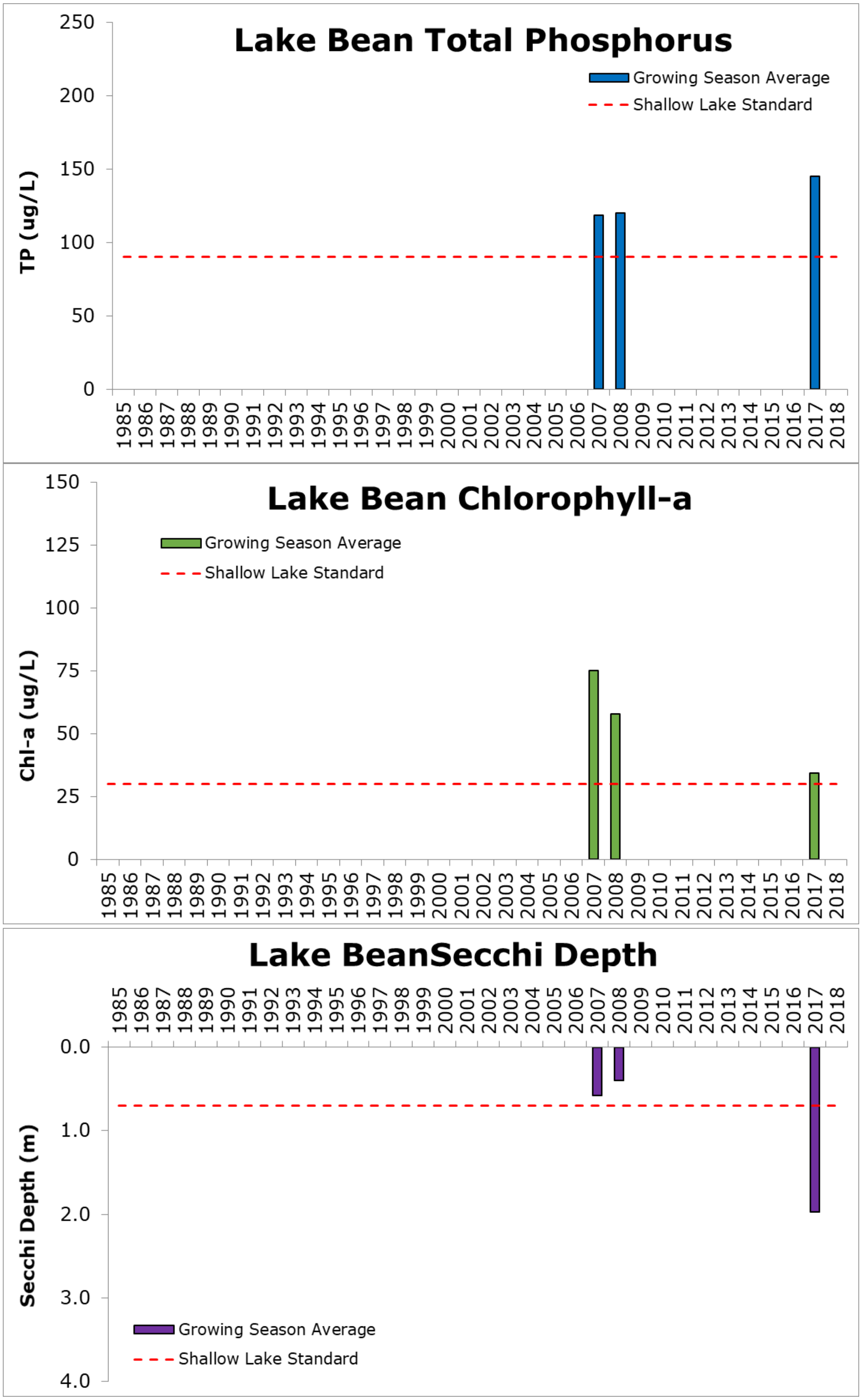



**Figure C-2. Lake Bean Historic Water Quality.**

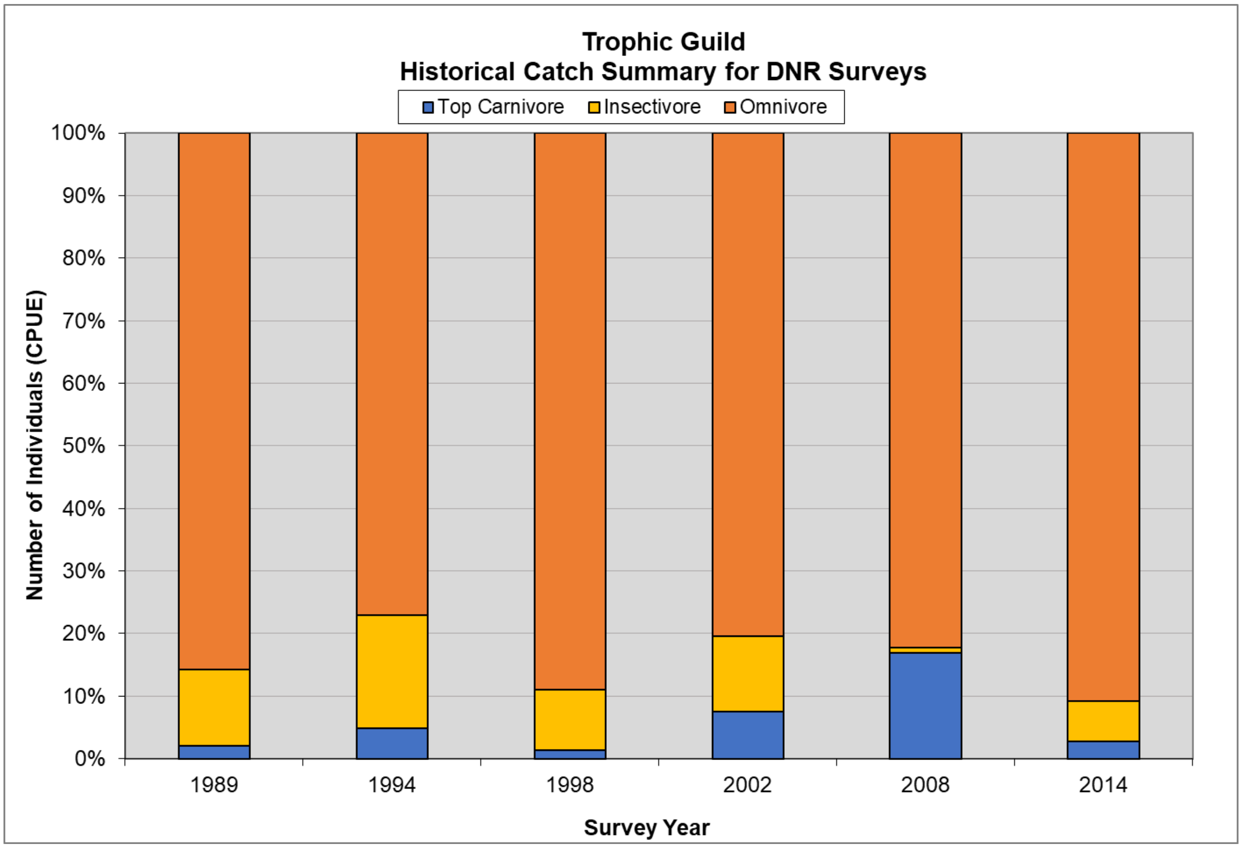



**Figure C-3. Lake Bean DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).**

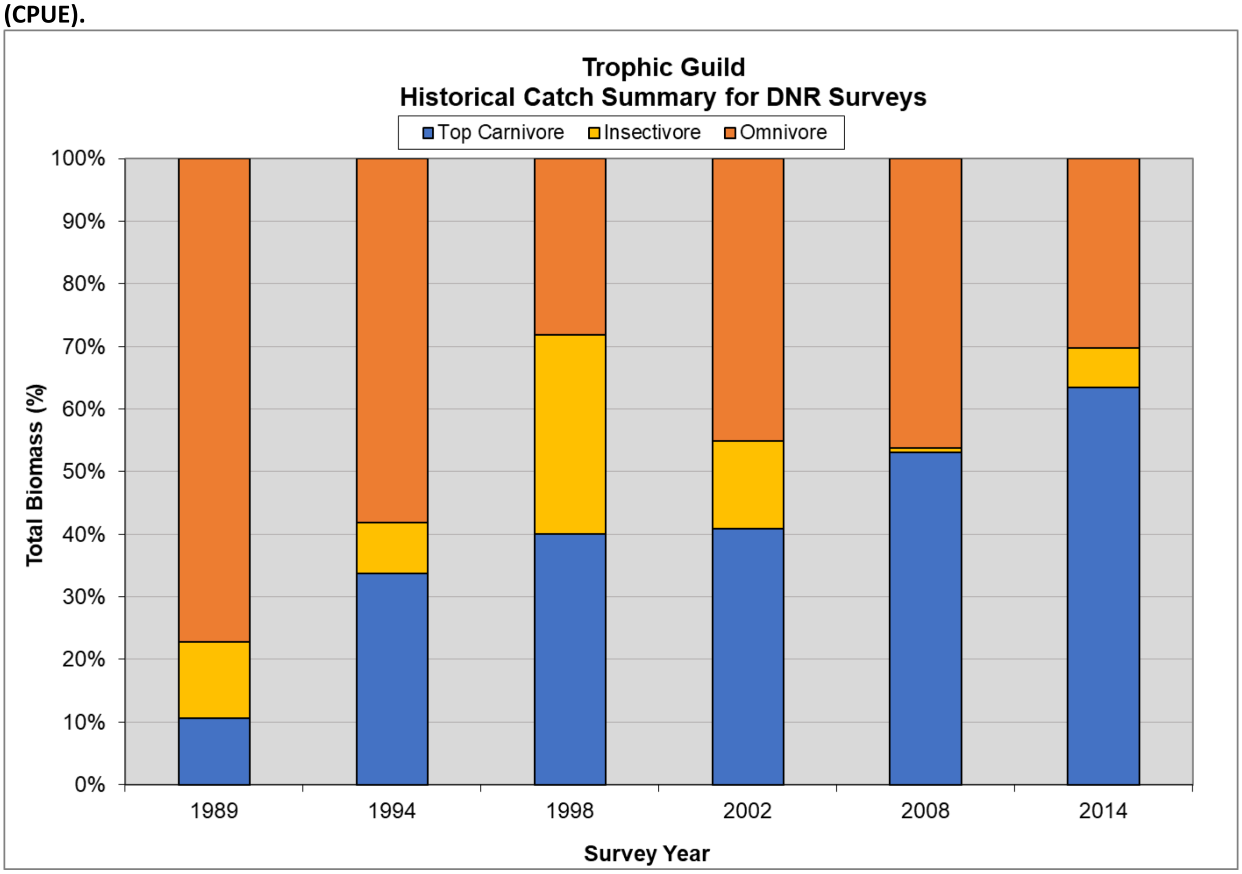



**Figure C-4. Lake Bean DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.**

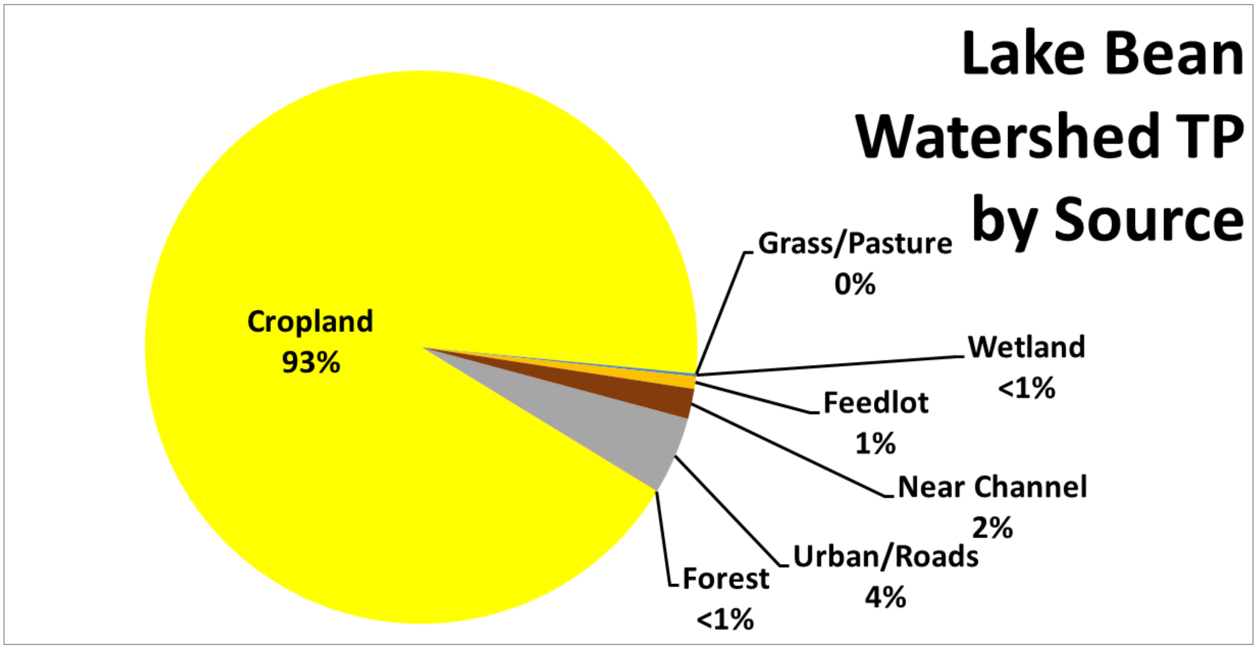



**Figure C-5. Lake Bean watershed TP load contribution by source predicted by HSPF.**

**Table C-1. Lake Bean Current Condition Lake Response Model.**

| | ***Average Loading Summary for Bean*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct watershed (HSPF 274) | 372 | 18.4 | 569 | 211 | 1.0 | 326 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *372* | *18* | *569.03* | | | *326* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | 0 | 2 | 0 | 0 | 0% | | 3 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *2* | *0* | *0.0* | 12% | | *3* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 164 | 26.7 | 26.7 | 0.00 | 0.24 | 1.0 | 39 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [km²] | [days] | | | [mg/m²-day] | [--] | [lb/yr] |
| | 0.66 | 0 | | Oxic | | 1.0 | 0 |
| | 0.66 | 45.6 | | Anoxic | | 1.0 | 1,192 |
| | *Summation* | | | | | | *1,192* |
| | | **Net Discharge [ac-ft/yr] =** | | **569** | **Net Load [lb/yr] =** | | **1,560** |

| ***Average Lake Response Modeling for Bean*** | | | |
|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value [Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | |
| $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 [--] |
| | | $C_{CB}$ = | 0.162 [--] |
| | | b = | 0.458 [--] |
| | | W (total P load = inflow + atm.) = | 708 [kg/yr] |
| | | Q (lake outflow) = | 0.7 [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 2.3 [$10^6$ $m^3$] |
| | | T = V/Q = | 3.21 [yr] |
| | | $P_i$ = W/Q = | 1008 [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **122.4 [ug/l]** |
| **Observed In-Lake [TP]** | | | **122.4 [ug/l]** |

**Table C-2. Lake Bean TMDL Condition Lake Response Model.**

| | ***TMDL Loading Summary for Bean*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct watershed (HSPF 274) | 372 | 18.4 | 569 | 150 | 0.7 | 232 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *372* | *18* | *569.03* | | | *232* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | 0 | 2 | 0 | 0 | 0% | | 1 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *2* | *0* | *0.0* | 0% | | *1* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 164 | 26.7 | 26.7 | 0.00 | 0.24 | 1.0 | 39 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [km$^2$] | [days] | | | [mg/m$^2$-day] | [--] | [lb/yr] |
| | 0.66 | 0 | | Oxic | | 1.0 | 0 |
| | 0.66 | 45.6 | | Anoxic | | 1.0 | 665 |
| | *Summation* | | | | | | *665* |
| | | **Net Discharge [ac-ft/yr] =** | | **569** | **Net Load [lb/yr] =** | | **937** |

| ***TMDL Lake Response Modeling for Bean*** | | | | |
|---|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 425 | [kg/yr] |
| | | Q (lake outflow) = | 0.7 | [$10^6$ m$^3$/yr] |
| | | V (modeled lake volume) = | 2.3 | [$10^6$ m$^3$] |
| | | T = V/Q = | 3.21 | [yr] |
| | | $P_i$ = W/Q = | 606 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **90.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **122.4** | **[ug/l]** |

## Supporting Items for Double (North Portion) Lake (17005601)

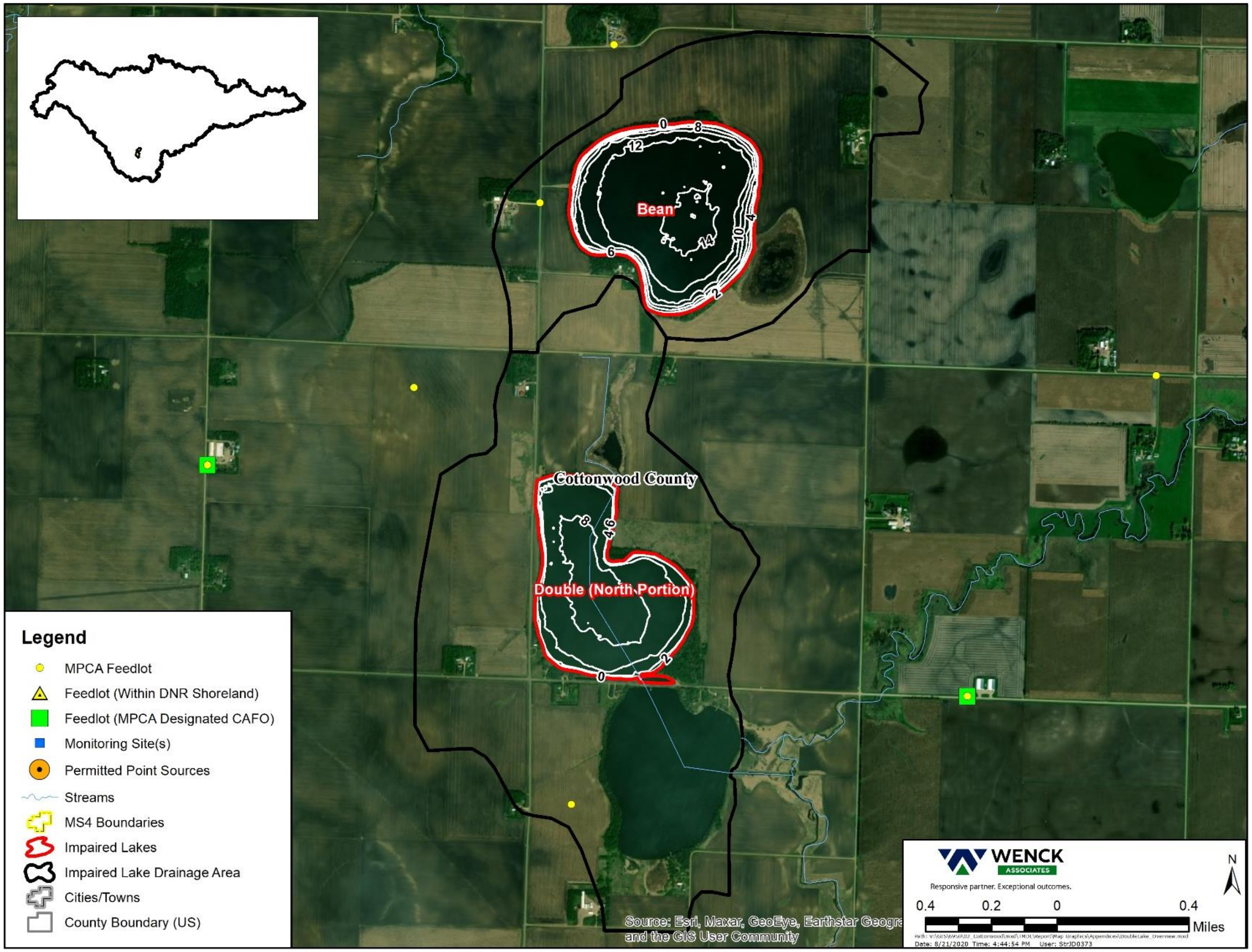



**Figure C-6. Double (North Portion) Lake Overview.**

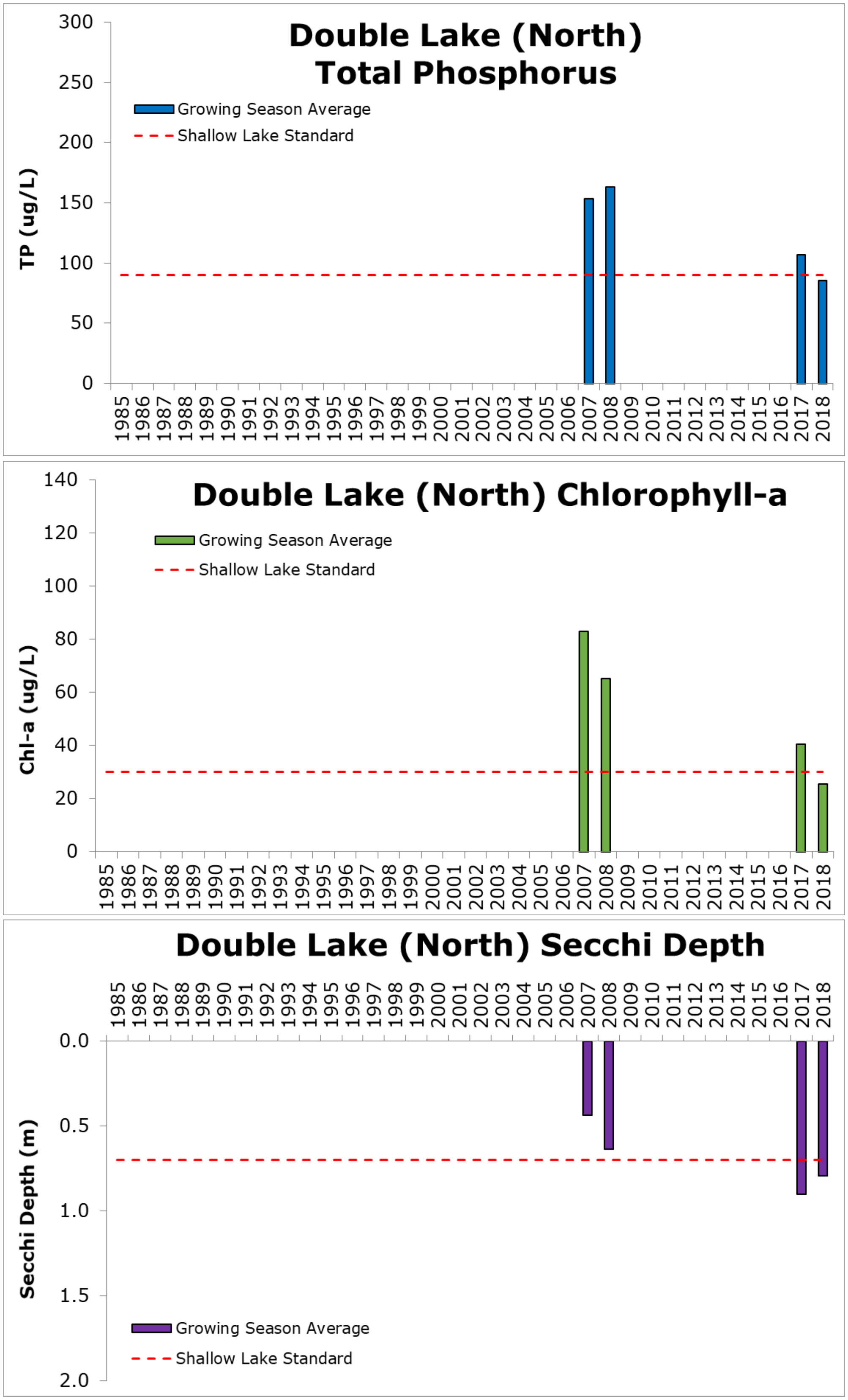



**Figure C-7. Double (North Portion) Lake Historic Water Quality.**

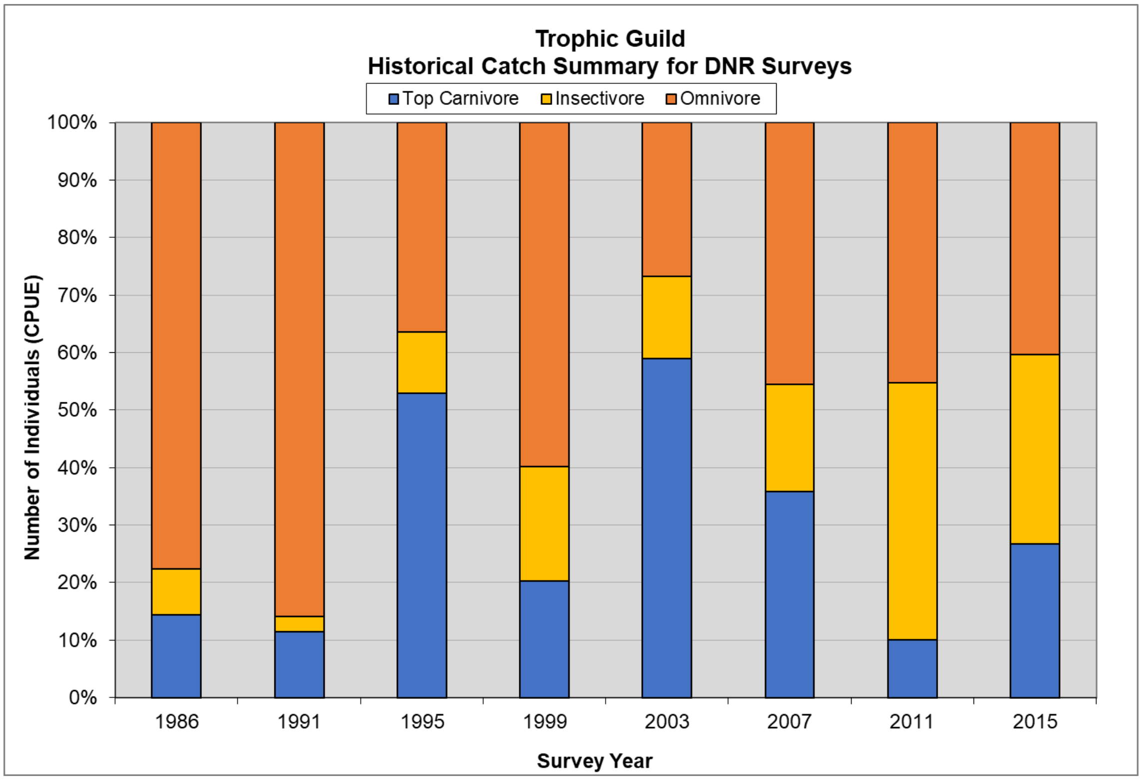



**Figure C-8. Double (North Portion) Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).**

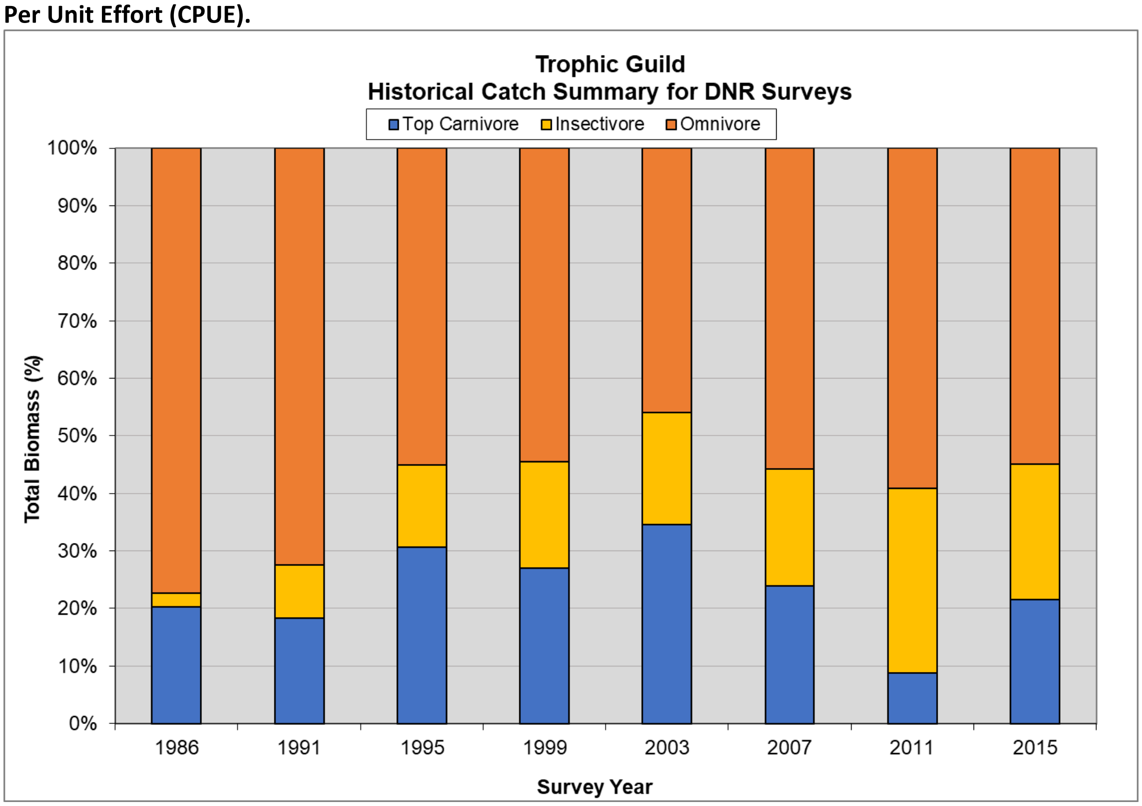



**Figure C-9. Double (North Portion) Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.**

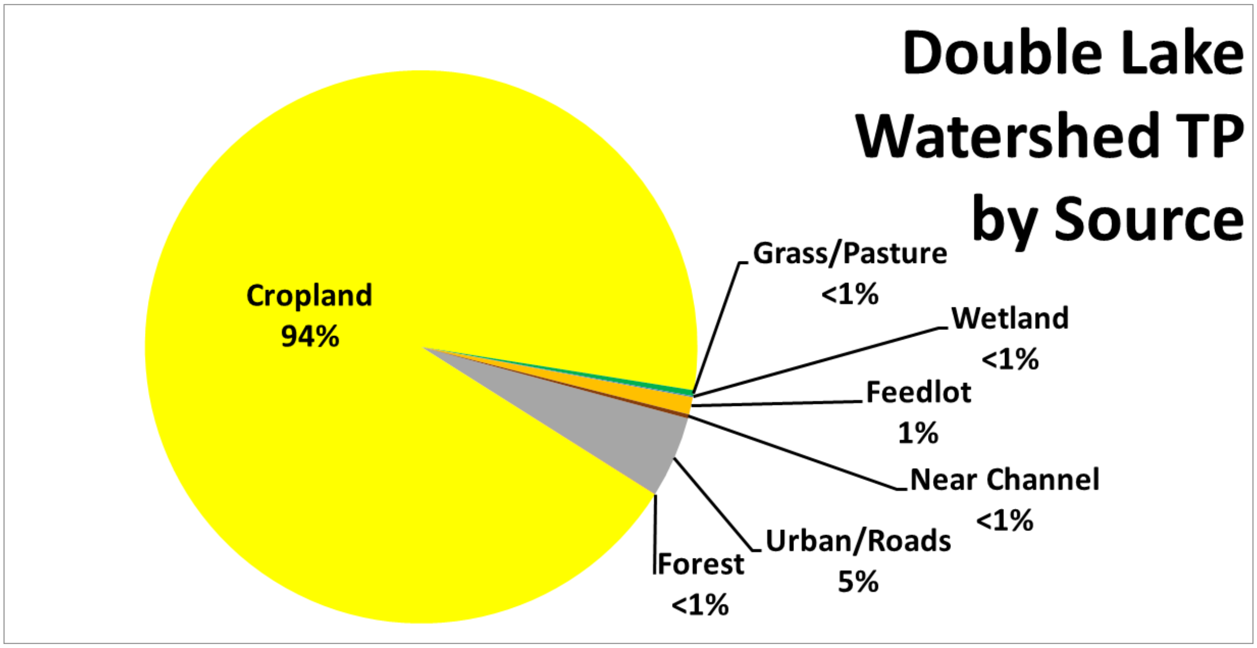



**Figure C-10. Double (North Portion) Lake watershed TP load contribution by source predicted by HSPF.**

**Table C-3. Double (North Portion) Lake Current Condition Lake Response Model.**

| | ***Average Loading Summary for*** | | | ***Double (North)*** | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | Name | Drainage Area [acre] | Runoff Depth [in/yr] | Discharge [ac-ft/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [lb/yr] |
| 1 | Direct Watershed (HSPF 276) | 710 | 5.3 | 313 | 429 | 1.0 | 366 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *710* | *5* | *313.35* | | | *366* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 9 | 1 | 0 | 12% | | 11 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *9* | *1* | *0.0* | 12% | | *11* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | Name | | | Discharge [ac-ft/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
| 1 | Bean | | | 438 | 122.4 | 1.0 | 146 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | | | *437.7* | *122.4* | | *146* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area [acre] | Precipitation [in/yr] | Evaporation [in/yr] | Net Inflow [ac-ft/yr] | Aerial Loading Rate [lb/ac-yr] | Calibration Factor [--] | Load [lb/yr] |
| | 136 | 30.1 | 30.1 | 0.00 | 0.24 | 1.0 | 33 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Model Residual Load*** | | | | | | | |
| | Name | | | | | Loading Calibration Factor (CF)[1] [--] | Load [lb/yr] |
| 1 | Model Residual Load | | | | | 1.0 | 412 |
| | *Summation* | | | | | | *412* |
| ***Internal*** | | | | | | | |
| | Lake Area [$km^2$] | Anoxic Factor [days] | | | Release Rate [$mg/m^2$-day] | Calibration Factor [--] | Load [lb/yr] |
| | 0.55 | 0 | | Oxic | | 1.0 | 0 |
| | 0.55 | 5.0 | | Anoxic | 9.2 | 1.0 | 56 |
| | *Summation* | | | | | | *56* |
| | | **Net Discharge [ac-ft/yr] =** | | **751** | **Net Load [lb/yr] =** | | **1,023** |

| ***Average Lake Response Modeling for*** | | ***Double (North)*** | | |
|---|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 464 | [kg/yr] |
| | | Q (lake outflow) = | 0.9 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 1.1 | [$10^6$ $m^3$] |
| | | T = V/Q = | 1.17 | [yr] |
| | | $P_i$ = W/Q = | 501 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **124.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **124.0** | **[ug/l]** |

**Table C-4. Double (North Portion) Lake TMDL Condition Lake Response Model.**

***TMDL Loading Summary for Double (North)***

| | Water Budgets | | | | Phosphorus Loading | | |
|---|---|---|---|---|---|---|---|
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct Watershed (HSPF 276) | 710 | 5.3 | 313 | 150 | 0.3 | 128 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *710* | *5* | *313.35* | | | *128* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 9 | 0 | 0 | 0% | | 5 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *9* | *0* | *0.0* | 0% | | *5* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Bean | | | 438 | 90.0 | 0.7 | 107 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | | | *437.7* | *90.0* | | *107* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 136 | 30.1 | 30.1 | 0.00 | 0.24 | 1.0 | 33 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Model Residual Load*** | | | | | | | |
| | | | | | | Loading Calibration Factor (CF)[1] | Load |
| | Name | | | | | [--] | [lb/yr] |
| 1 | Model Residual Load | | | | | 0.7 | 303 |
| | *Summation* | | | | | | *303* |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [km$^2$] | [days] | | | [mg/m$^2$-day] | [--] | [lb/yr] |
| | 0.55 | 0 | | Oxic | | 1.0 | 0 |
| | 0.55 | 5.0 | | Anoxic | 9.2 | 1.0 | 56 |
| | *Summation* | | | | | | *56* |
| | | **Net Discharge [ac-ft/yr] =** | | **751** | **Net Load [lb/yr] =** | | **632** |

***Average Lake Response Modeling for Double (North)***

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$ | | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 287 | [kg/yr] |
| | | Q (lake outflow) = | 0.9 | [$10^6$ m$^3$/yr] |
| | | V (modeled lake volume) = | 1.1 | [$10^6$ m$^3$] |
| | | T = V/Q = | 1.17 | [yr] |
| | | $P_i$ = W/Q = | 309 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **90.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **124.0** | **[ug/l]** |

**Supporting Items for Rock Lake (42005200)**

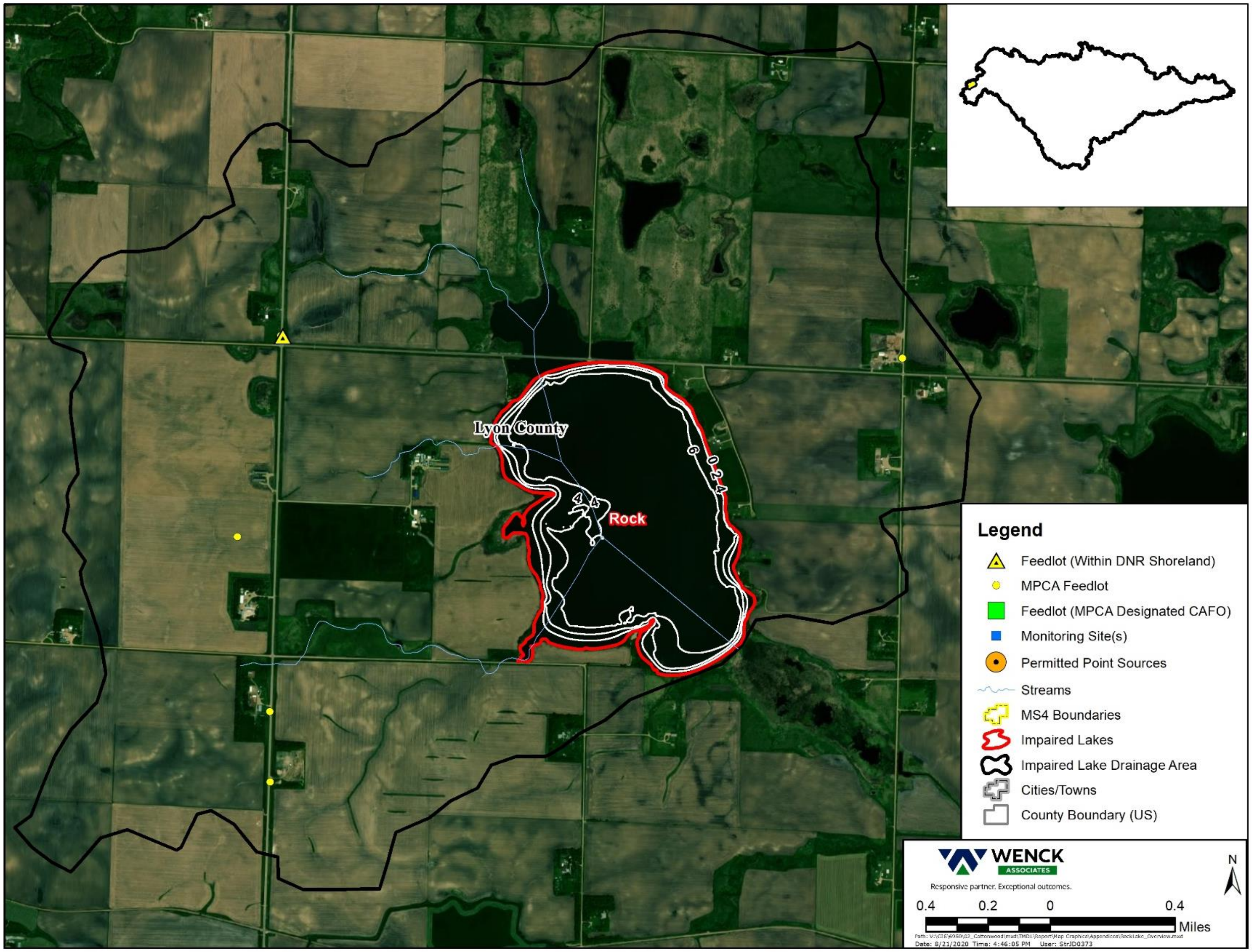
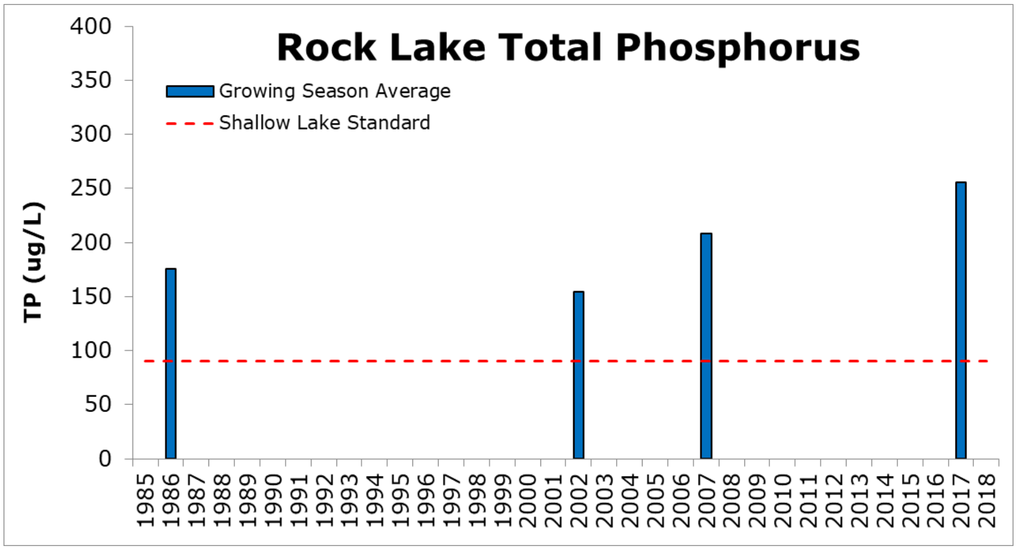
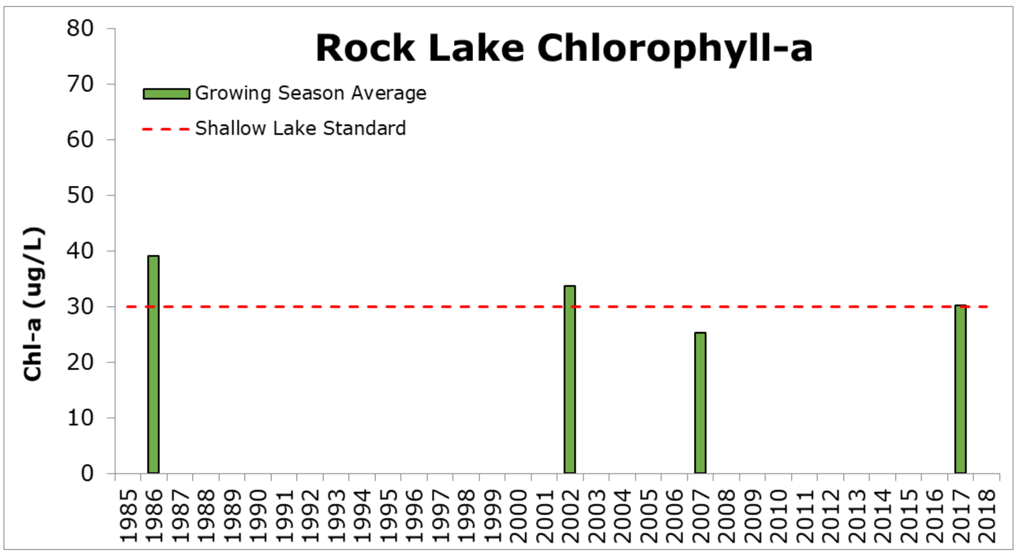



**Figure C-11. Rock Lake Overview.**



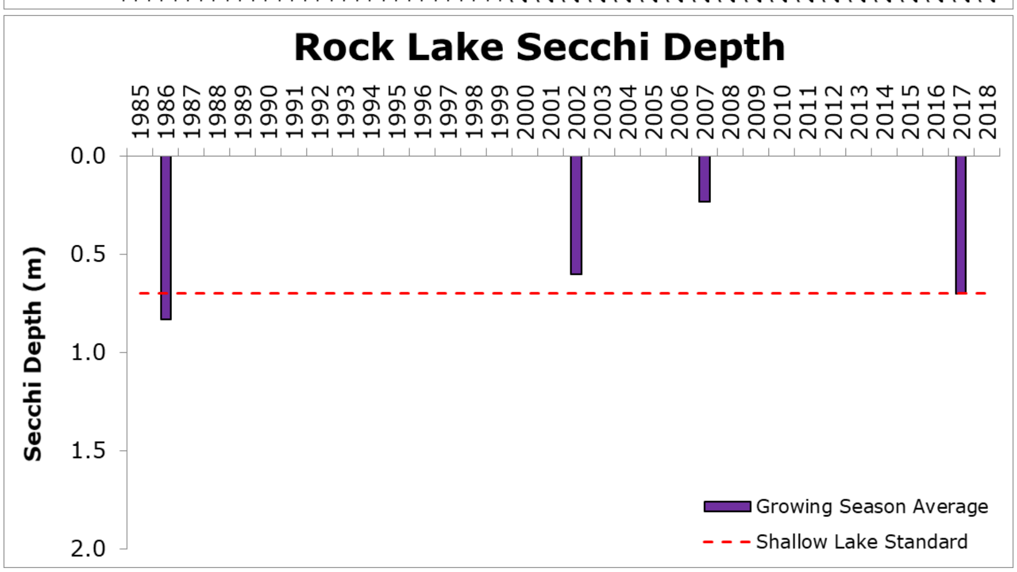




**Figure C-12. Rock Lake Historic Water Quality.**

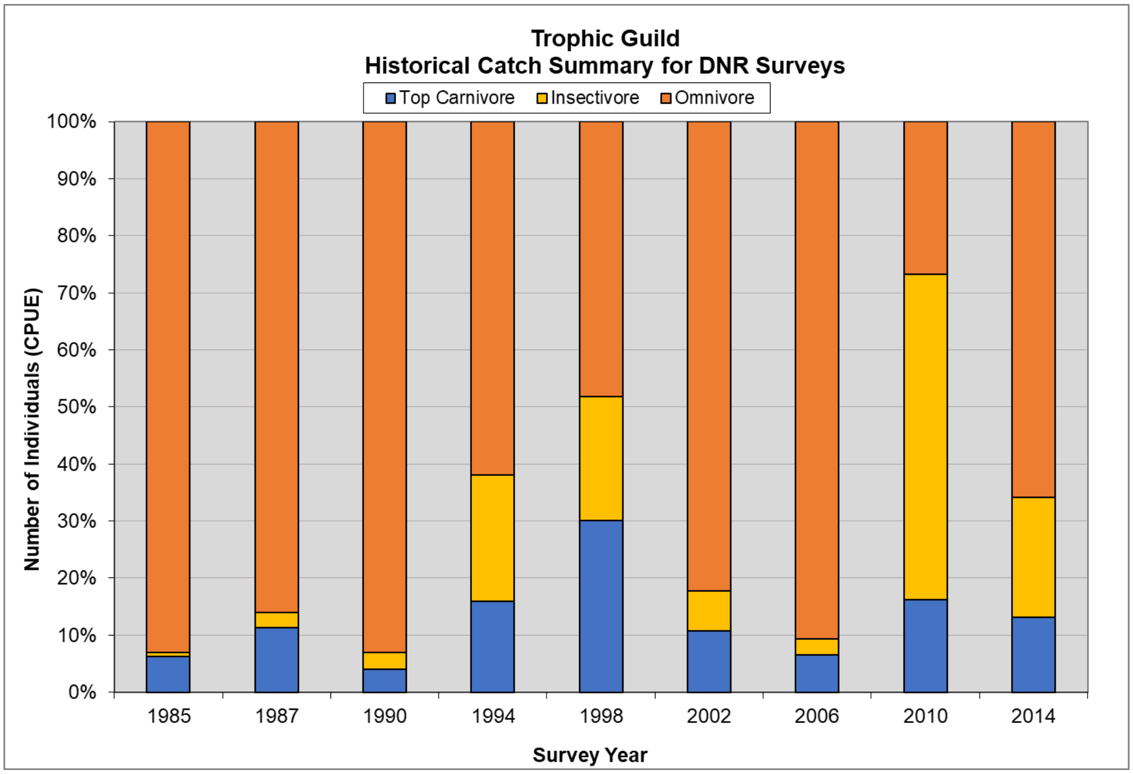



**Figure C-13. Rock Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).**

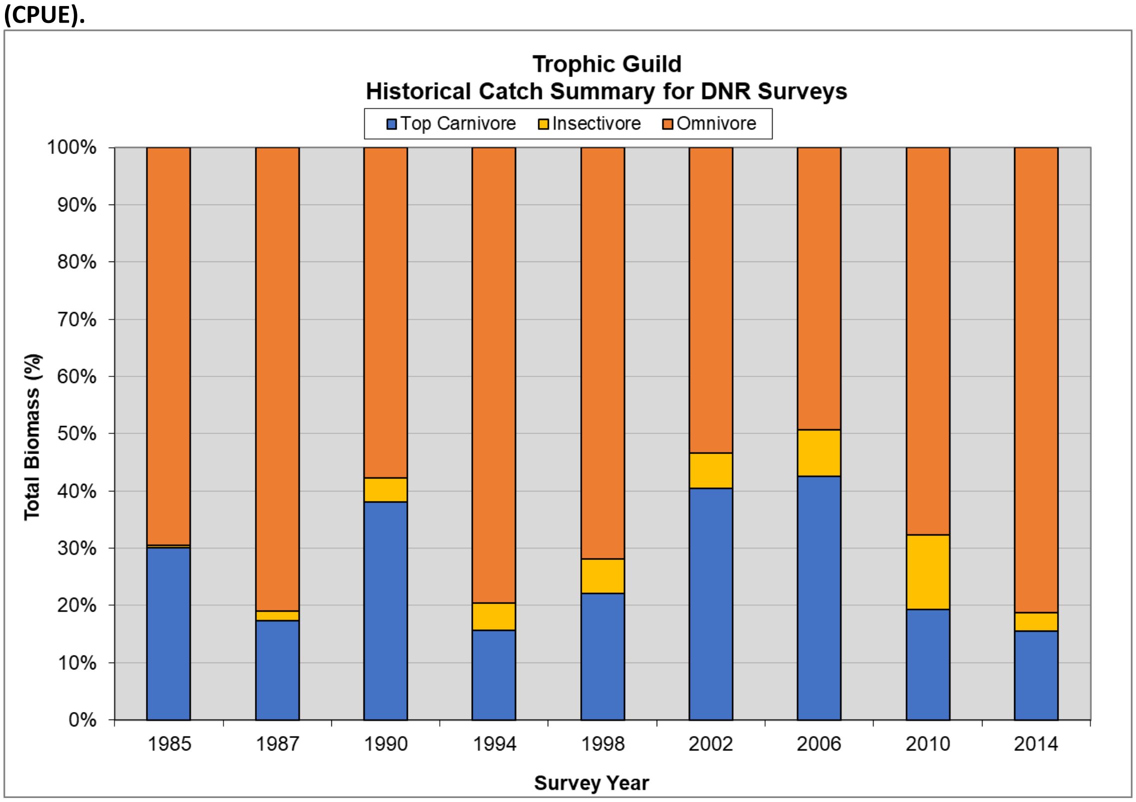



**Figure C-14. Rock Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.**

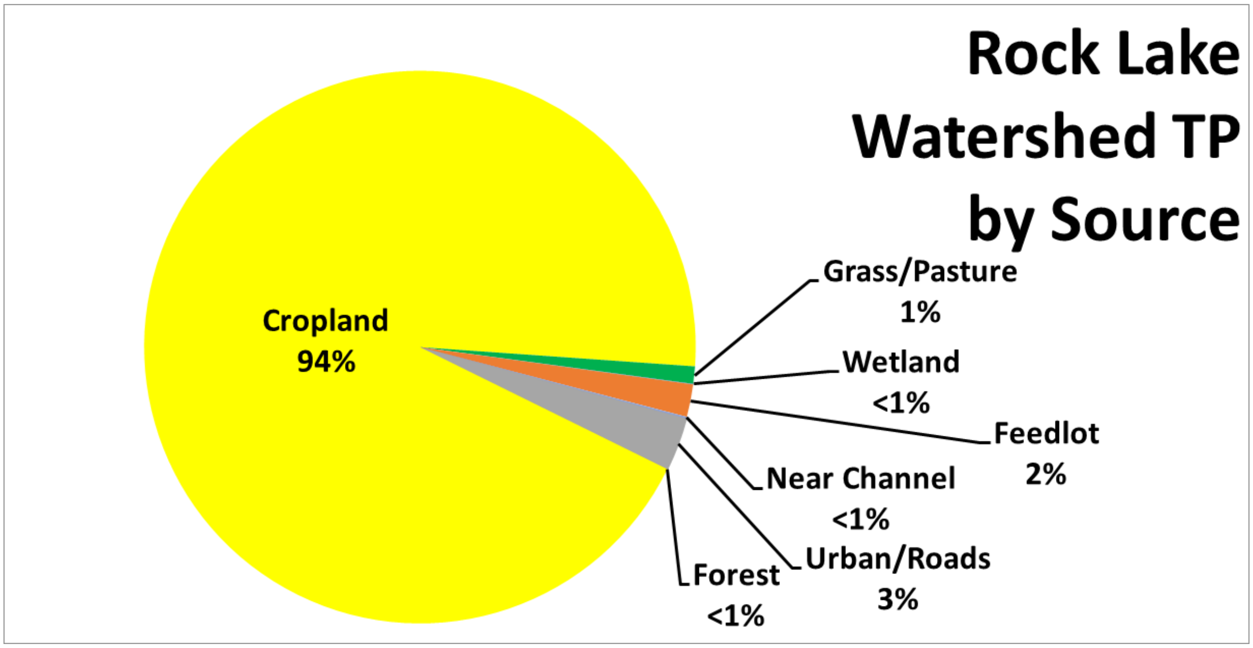



**Figure C-15. Rock Lake watershed TP load contribution by source predicted by HSPF.**

**Table C-5. Rock Lake Current Condition Lake Response Model.**

| | ***Average Loading Summary for*** | ***Rock*** | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | Name | Drainage Area [acre] | Runoff Depth [in/yr] | Discharge [ac-ft/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [lb/yr] |
| 1 | Direct Watershed (HSPF 12) | 3,208 | 8.2 | 2,190 | 286 | 1.0 | 1,702 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *3,208* | *8* | *2,190.18* | | | *1,702* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | 0 | 16 | 5 | 0 | 33% | | 15 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *16* | *5* | *0.0* | 33% | | *15* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | Name | | | Discharge [ac-ft/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area [acre] | Precipitation [in/yr] | Evaporation [in/yr] | Net Inflow [ac-ft/yr] | Aerial Loading Rate [lb/ac-yr] | Calibration Factor [--] | Load [lb/yr] |
| | 379 | 27.5 | 27.5 | 0.00 | 0.24 | 1.0 | 91 |
| | | | | Dry-year total P deposition = | 0.222 | | |
| | | | | Average-year total P deposition = | 0.239 | | |
| | | | | Wet-year total P deposition = | 0.259 | | |
| | | | | (Barr Engineering 2004) | | | |
| ***Internal*** | | | | | | | |
| | Lake Area [km$^2$] | Anoxic Factor [days] | | | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [lb/yr] |
| | 1.53 | 0 | | Oxic | | 1.0 | 0 |
| | 1.53 | 34.3 | | Anoxic | | 1.0 | 3,722 |
| | *Summation* | | | | | | *3,722* |
| | | | **Net Discharge [ac-ft/yr] =** | **2,190** | | **Net Load [lb/yr] =** | **5,529** |

| ***Average Lake Response Modeling for*** | | ***Rock*** | | |
|---|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 2,508 | [kg/yr] |
| | | Q (lake outflow) = | 2.7 | [$10^6$ m$^3$/yr] |
| | | V (modeled lake volume) = | 2.4 | [$10^6$ m$^3$] |
| | | T = V/Q = | 0.90 | [yr] |
| | | $P_i$ = W/Q = | 928 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **206.3** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **206.3** | **[ug/l]** |

**Table C-6. Rock Lake TMDL Condition Lake Response Model.**

| | ***TMDL Loading Summary for Rock*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct Watershed (HSPF 12) | 3,208 | 8.2 | 2,190 | 150 | 0.5 | 894 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *3,208* | *8* | *2,190.18* | | | *894* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | 0 | 16 | 0 | 0 | 0% | | 9 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *16* | *0* | *0.0* | 0% | | *9* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 379 | 27.5 | 27.5 | 0.00 | 0.24 | 1.0 | 91 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [$km^2$] | [days] | | | [$mg/m^2$-day] | [--] | [lb/yr] |
| | 1.53 | 0 | | Oxic | | 1.0 | 0 |
| | 1.53 | 34.3 | | Anoxic | | 1.0 | 605 |
| | *Summation* | | | | | | *605* |
| | | | **Net Discharge [ac-ft/yr] =** | **2,190** | | **Net Load [lb/yr] =** | **1,599** |

| ***TMDL Lake Response Modeling for Rock*** | | | |
|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value [Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | |
| $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 [--] |
| | | $C_{CB}$ = | 0.162 [--] |
| | | b = | 0.458 [--] |
| | | W (total P load = inflow + atm.) = | 725 [kg/yr] |
| | | Q (lake outflow) = | 2.7 [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 2.4 [$10^6$ $m^3$] |
| | | T = V/Q = | 0.90 [yr] |
| | | $P_i$ = W/Q = | 268 [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **90.0 [ug/l]** |
| **Observed In-Lake [TP]** | | | **206.3 [ug/l]** |

## Supporting Items for Sleepy Eye Lake (08004500)

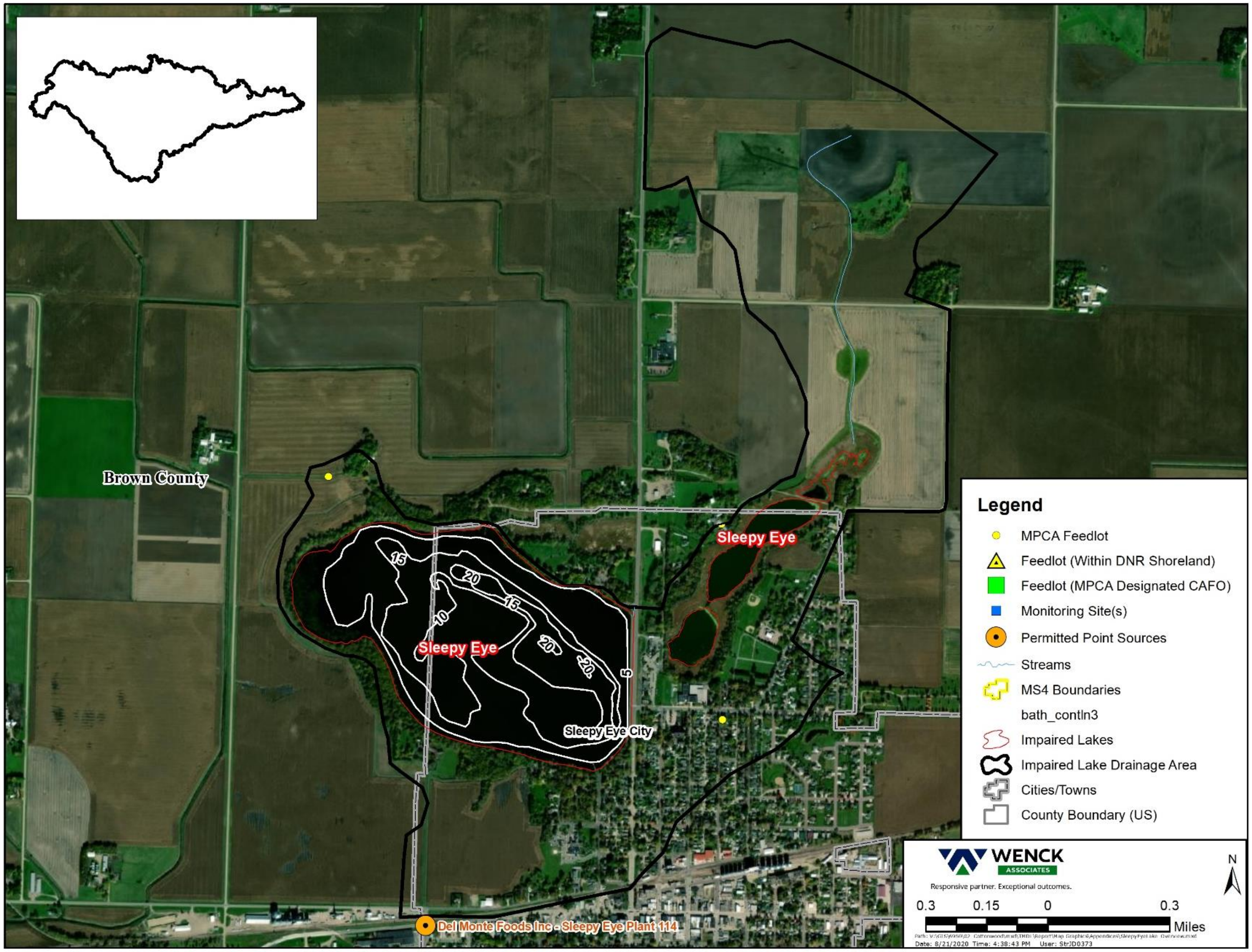



**Figure C-16. Sleepy Eye Lake Overview.**

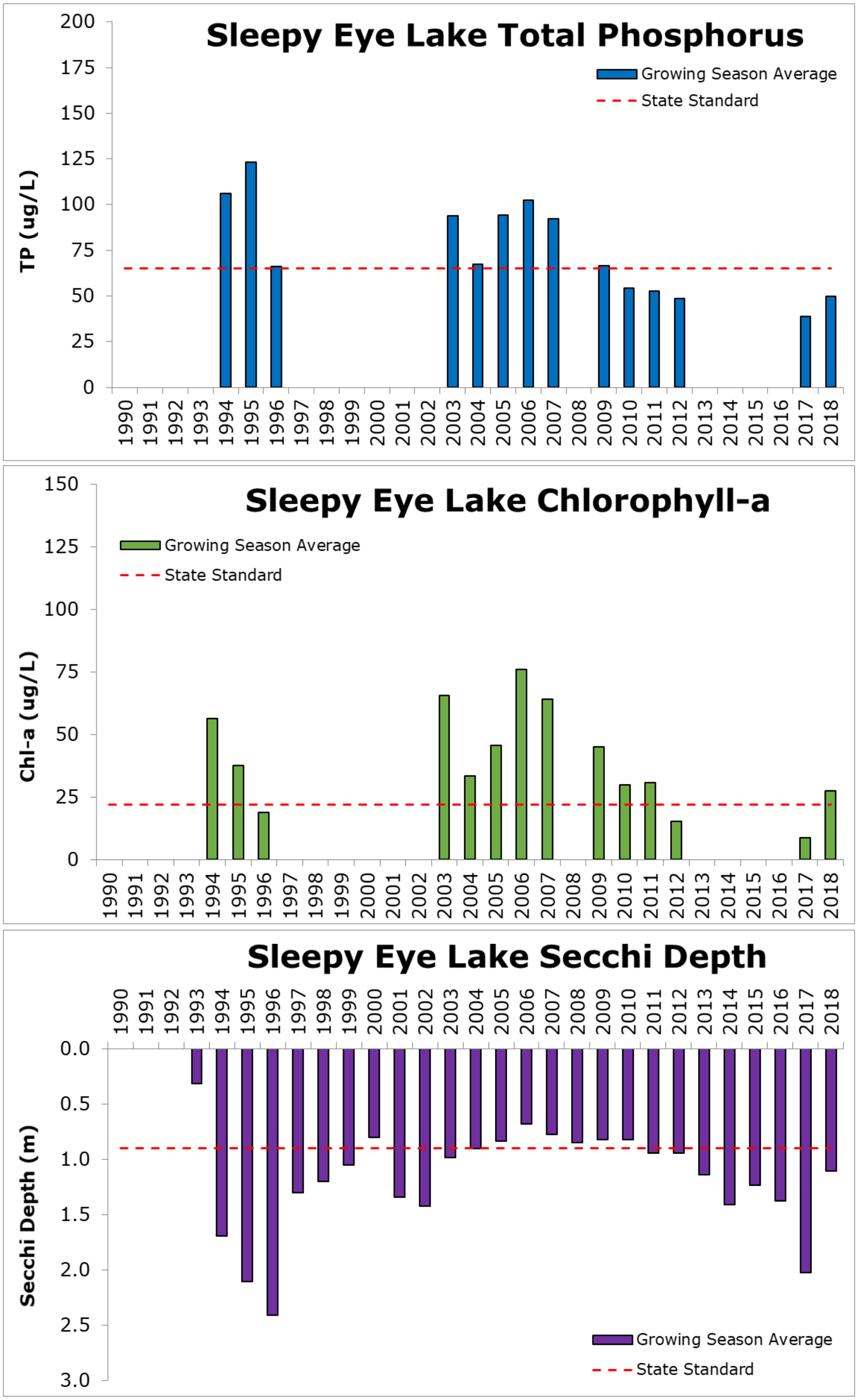



**Figure C-17. Sleepy Eye Lake Historic Water Quality.**

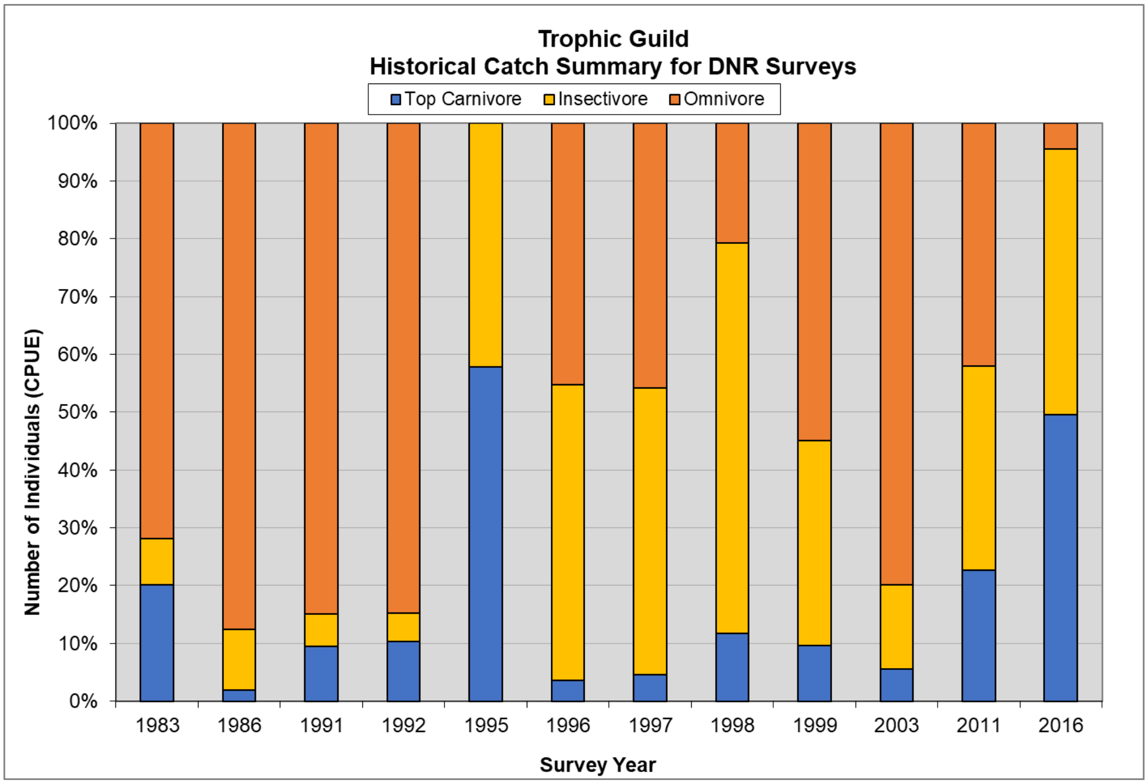



**Figure C-18. Sleepy Eye Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).**

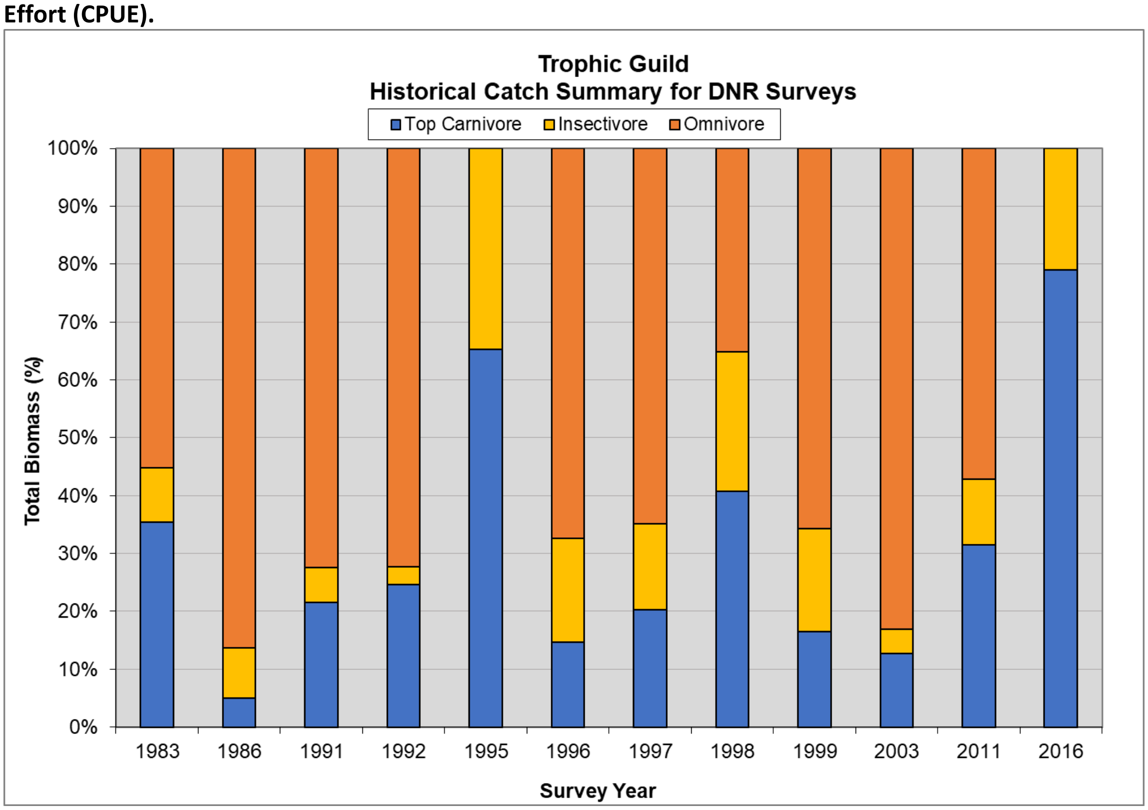



**Figure C-19. Sleepy Eye Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.**

**Table C-7. Sleepy Eye Lake summer growing season averages for each water quality parameter.**

| Lake Name | "Average" Condition Calculation Years | In-Lake Average Condition [Calculated June – September] TP Concentration [µg/L] | Chl-*a* Concentration [µg/L] | Secchi Depth [m] |
|---|---|---|---|---|
| **WCBP Ecoregion 2B Lake Standards** | | **65** | **22** | **0.9** |
| Sleepy Eye | 2003-2007*, 2009-2012*, 2017-2018 | 69 | 40 | 1.0 |

*Data from these years not currently available in EDA database. This data was collected by St. Mary's High School and was analyzed by MVTL Laboratories in New Ulm, MN.

**Table C-8. Sleepy Eye Lake (08-0045-00) phosphorus TMDL.**

| Phosphorus Sources | | Existing TP load* | | Allowable TP load | | Estimated load reduction | |
|---|---|---|---|---|---|---|---|
| | | lbs/year | lbs/day | lbs/year | lbs/day | lbs/year** | % |
| **Wasteload** | Construction/Industrial SW | 0.8 | 0.002 | 0.8 | 0.002 | 0.0 | 0% |
| | **Total WLA** | **0.8** | **0.002** | **0.8** | **0.002** | **0.0** | **0%** |
| **Load** | Watershed runoff | 537.3 | 1.471 | 407.2 | 1.115 | 130.1 | 24% |
| | SSTS | 0.0 | 0.000 | 0.0 | 0.000 | 0.0 | 0% |
| | Atmospheric deposition | 50.7 | 0.139 | 50.7 | 0.139 | 0.0 | 0% |
| | Internal load | 117.7 | 0.322 | 117.7 | 0.322 | 0.0 | 0% |
| | **Total LA** | **705.7** | **1.932** | **575.6** | **1.576** | **130.1** | **18%** |
| **MOS** | | | | **64.0** | **0.175** | | |
| **Total load** | | **706.5** | **1.934** | **640.4** | **1.753** | **130.1** | **9%** |

* Model calibration year(s): 2003-2007, 2009-2012 and 2017-2018

** Net reduction from current load to TMDL is 66.1 lbs/yr; but the gross load reduction from all sources must accommodate the MOS as well, and hence is 66.1 + 64.0 = 130.1 lbs/yr.

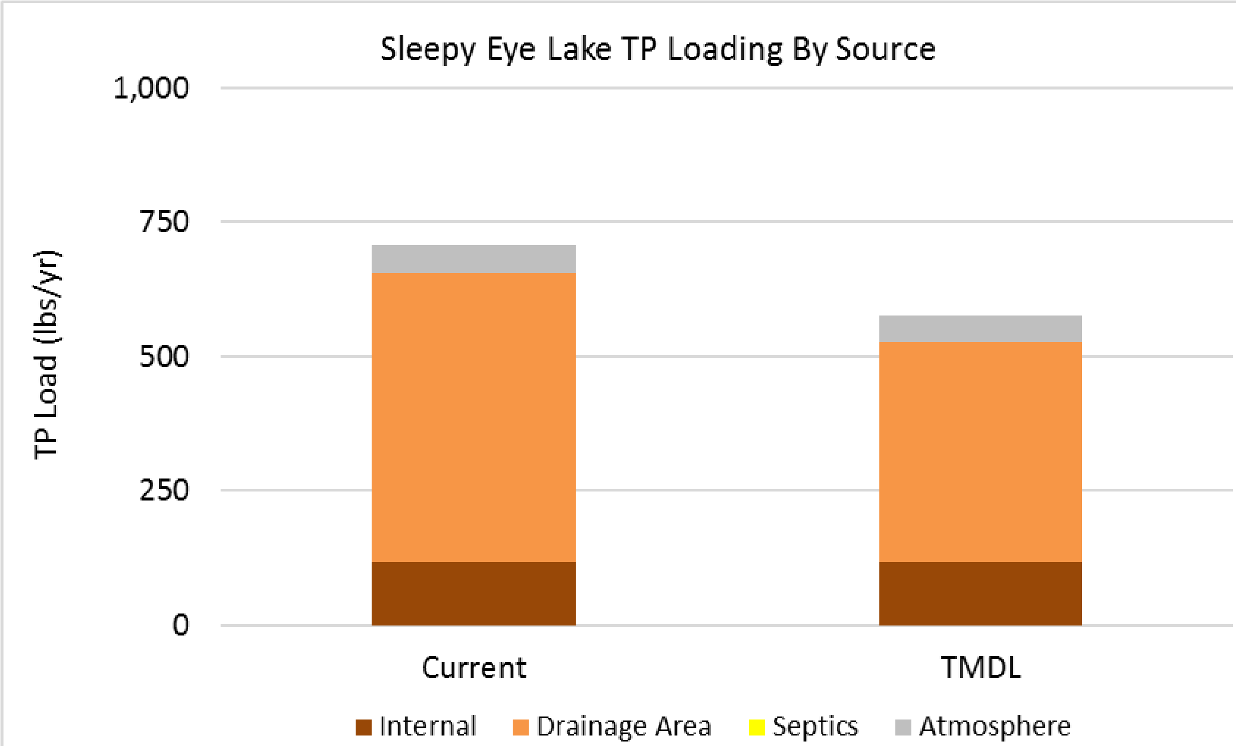


Figure C-20. Sleepy Eye Lake phosphorus source reductions to meet TMDL.

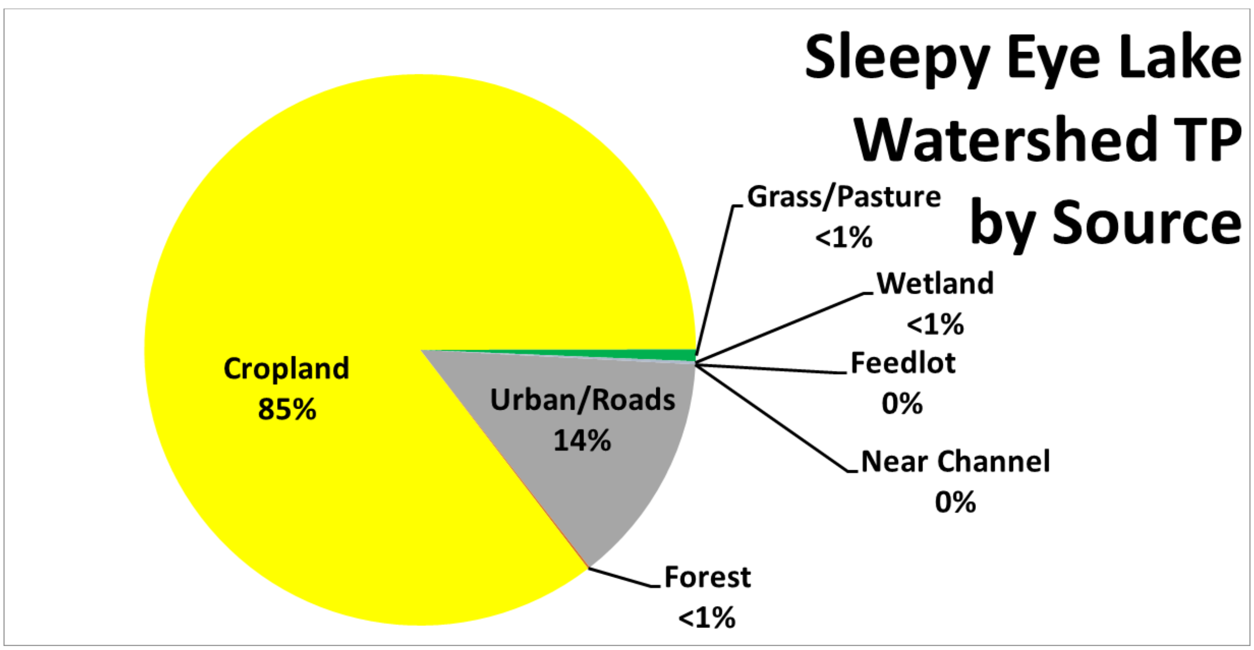



Figure C-21. Sleepy Eye Lake watershed TP load contribution by source predicted by HSPF.

**Table C-9. Sleepy Eye Lake Current Condition Lake Response Model.**

| | ***Average Loading Summary for Sleepy Eye*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct Watershed (434) | 747 | 10.4 | 650 | 304 | 1.0 | 538 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *747* | *10* | *649.88* | | | *538* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | 0 | 0 | 0 | 0 | 0% | | 0 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *0* | *0* | *0.0* | #DIV/0! | | *0.0* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 212 | 29.8 | 29.8 | 0.00 | 0.24 | 1.0 | 51 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [$km^2$] | [days] | | | [$mg/m^2$-day] | [--] | [lb/yr] |
| | 0.86 | 0 | | Oxic | | 1.0 | 0 |
| | 0.86 | 14.4 | | Anoxic | 4.3 | 1.0 | 118 |
| | *Summation* | | | | | | *118* |
| | | **Net Discharge [ac-ft/yr] =** | | **650** | **Net Load [lb/yr] =** | | **706** |

| ***Average Lake Response Modeling for Sleepy Eye*** | | | | |
|---|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.05 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 320 | [kg/yr] |
| | | Q (lake outflow) = | 0.8 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 2.4 | [$10^6$ $m^3$] |
| | | T = V/Q = | 2.99 | [yr] |
| | | $P_i$ = W/Q = | 400 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **69.1** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **69.1** | **[ug/l]** |

Table C-10. Sleepy Eye Lake TMDL Condition Lake Response Model.

| | ***TMDL Loading Summary for*** | | | ***Sleepy Eye*** | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct Watershed (434) | 747 | 10.4 | 650 | 267 | 0.9 | 472 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *747* | *10* | *649.88* | | | *472* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | 0 | 0 | 0 | 0 | 0% | | 0 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *0* | *0* | *0.0* | #DIV/0! | | *0.0* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 212 | 29.8 | 29.8 | 0.00 | 0.24 | 1.0 | 51 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [$km^2$] | [days] | | | [$mg/m^2$-day] | [--] | [lb/yr] |
| | 0.86 | 0 | | Oxic | | 1.0 | 0 |
| | 0.86 | 14.4 | | Anoxic | 4.3 | 1.0 | 118 |
| | *Summation* | | | | | | *118* |
| | | **Net Discharge [ac-ft/yr] =** | | **650** | **Net Load [lb/yr] =** | | **640** |

| ***TMDL Lake Response Modeling for*** | | ***Sleepy Eye*** | | |
|---|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $$P = P_i \Big/ \left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)$$ | | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.05 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 290 | [kg/yr] |
| | | Q (lake outflow) = | 0.8 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 2.4 | [$10^6$ $m^3$] |
| | | T = V/Q = | 2.99 | [yr] |
| | | $P_i$ = W/Q = | 362 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **65.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **69.1** | **[ug/l]** |

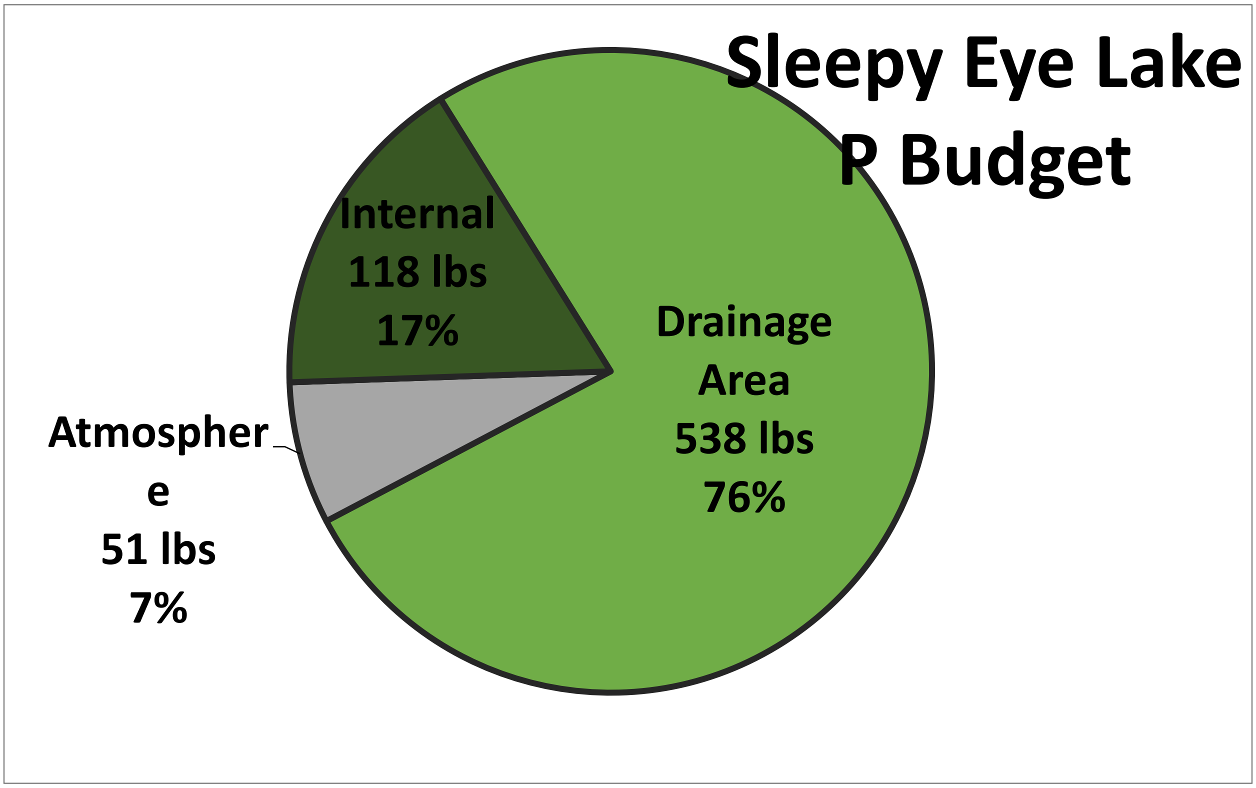



**Table C-11. Sleepy Eye Lake average annual TP contributions by source based on HSPF and lake response modeling results.**

## Supporting Items for Clear Lake (08001100)

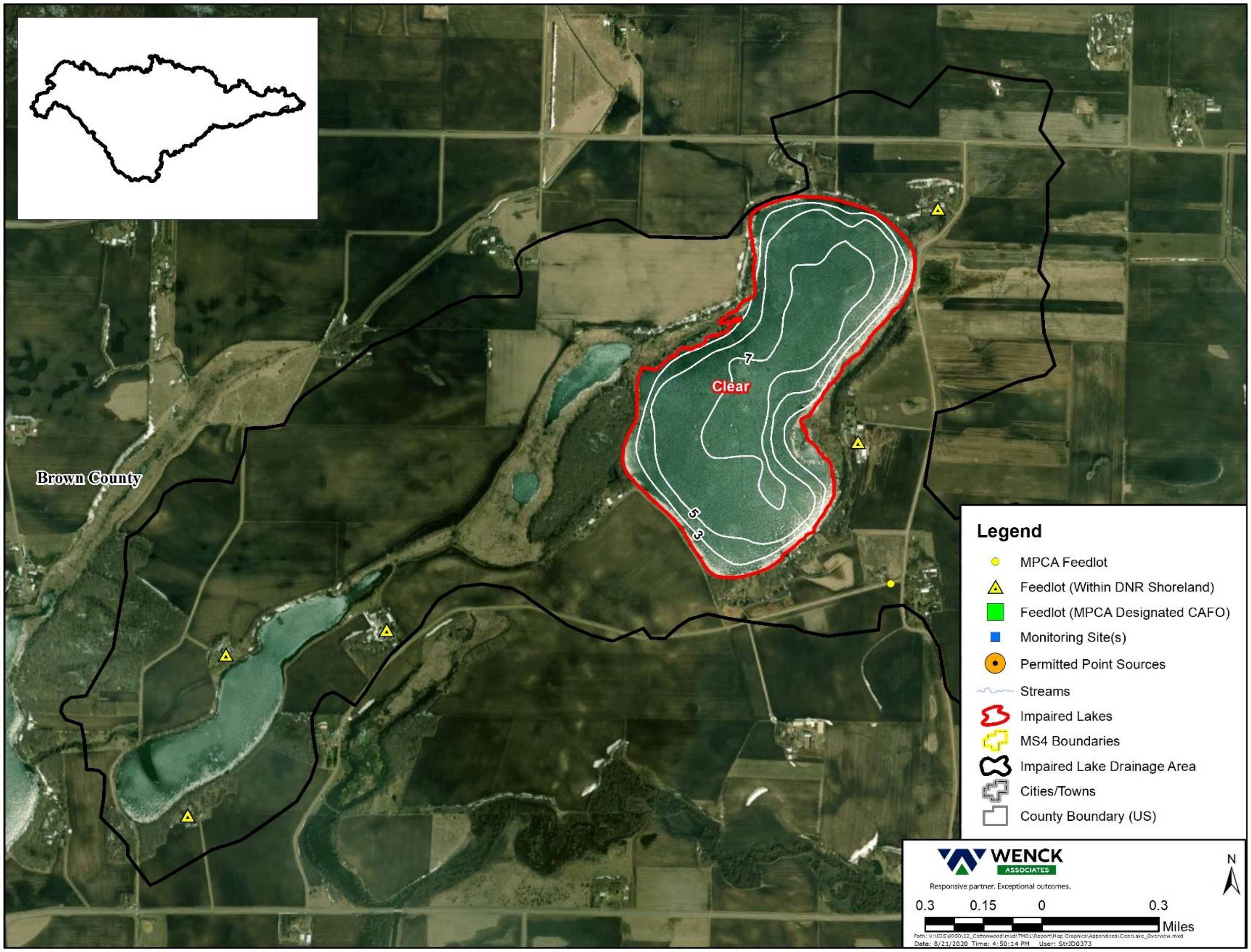



**Figure C-22. Clear Lake Overview.**

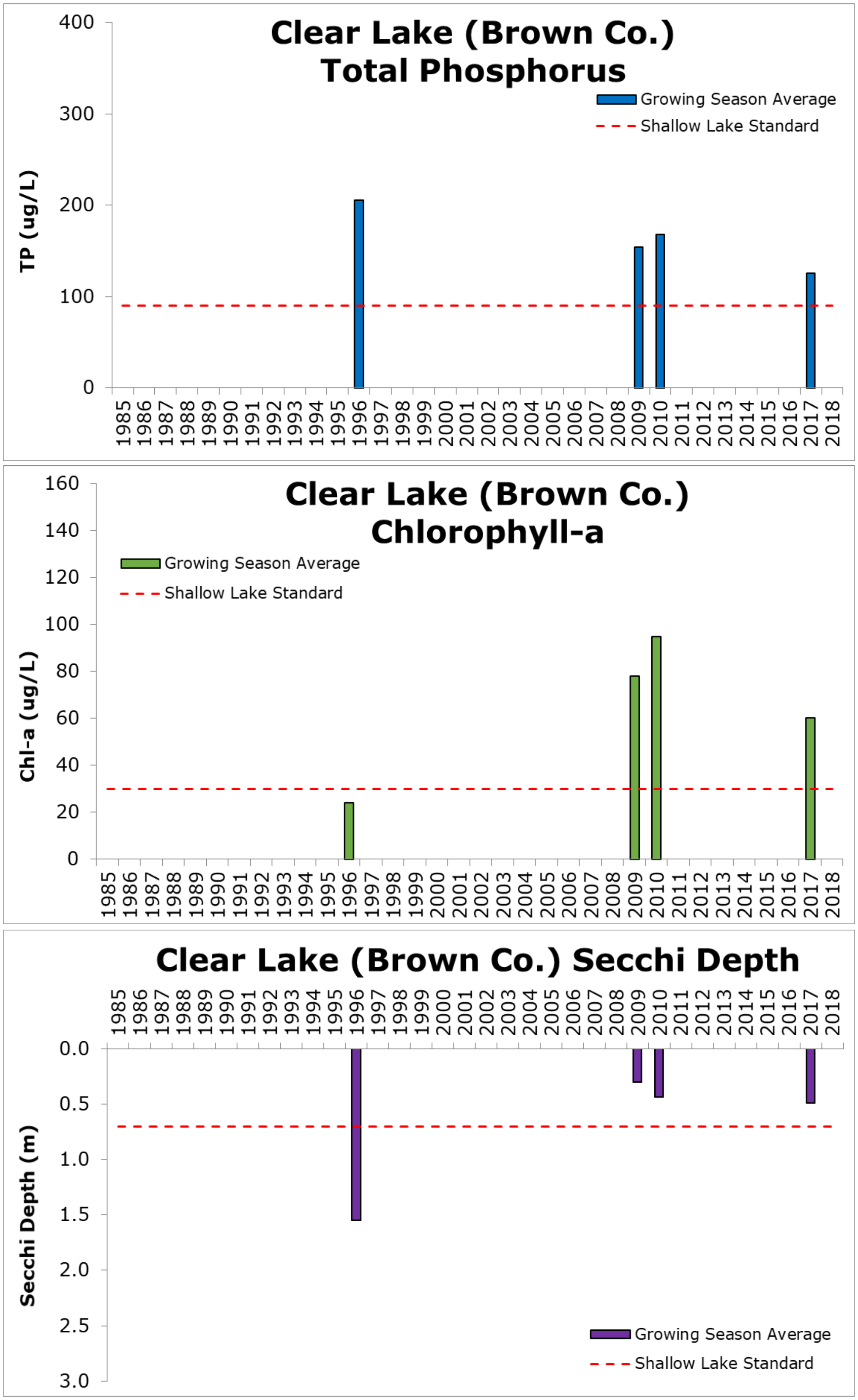



**Figure C-23. Clear Lake Historic Water Quality.**

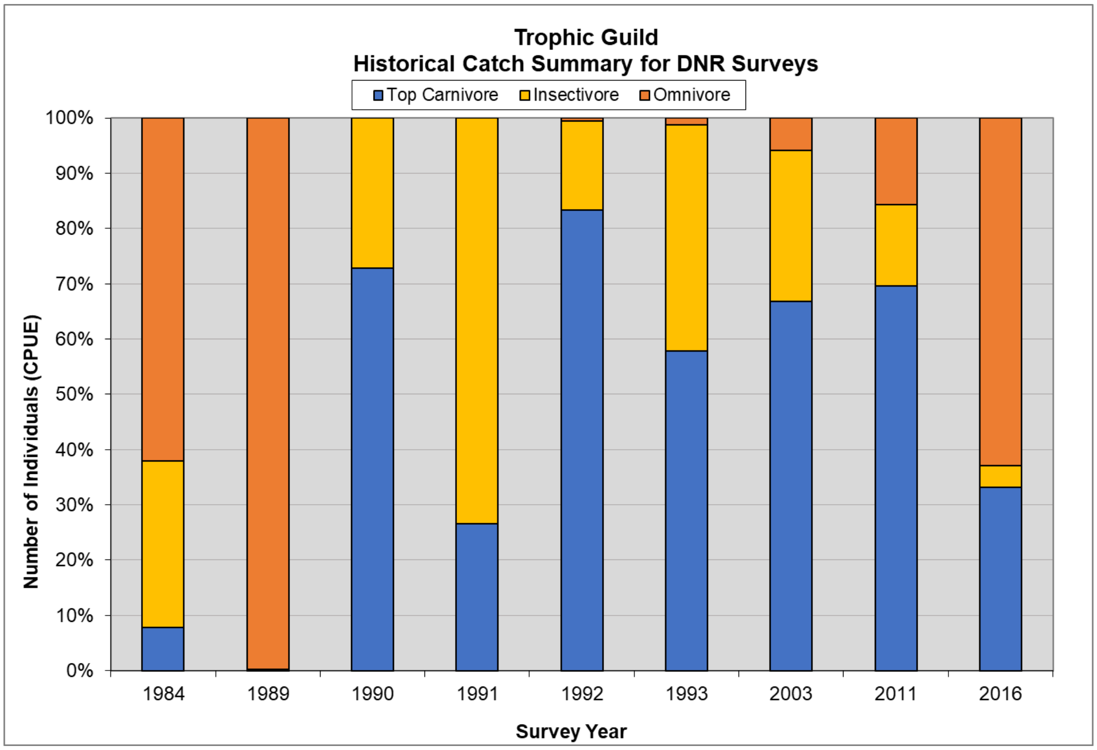



**Figure C-24. Clear Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Catch Per Unit Effort (CPUE).**

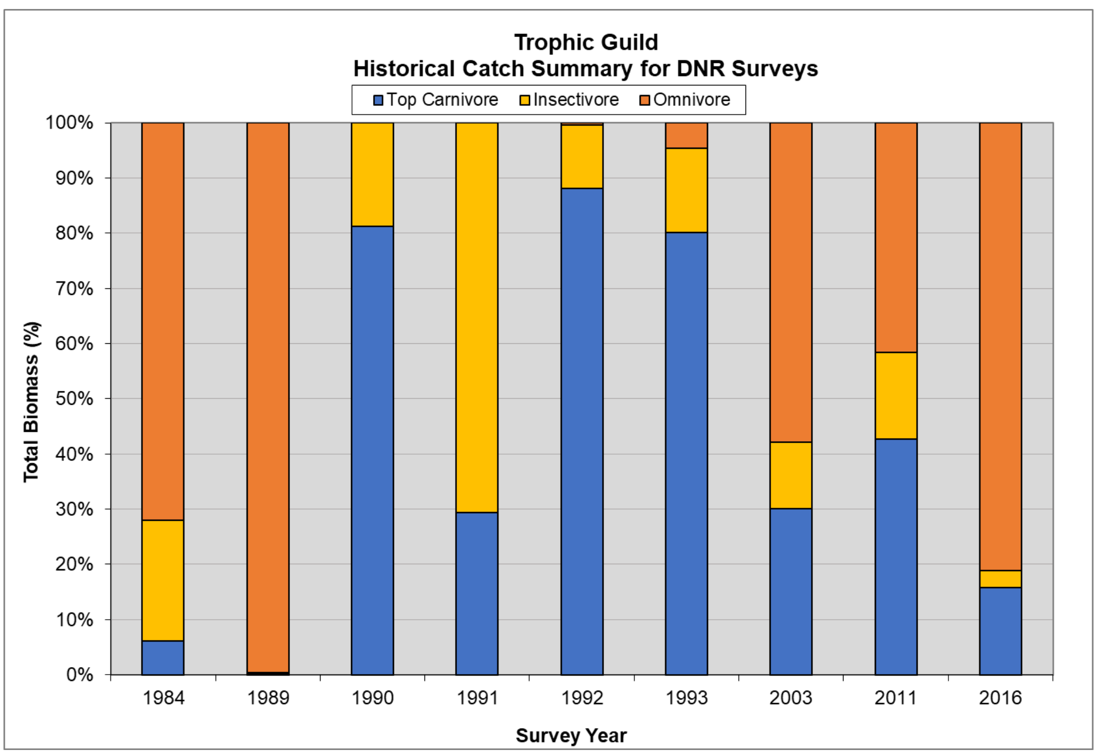



**Figure C-25. Clear Lake DNR Fish Survey Historic Catch Summarized by Trophic Guild and Total Biomass.**

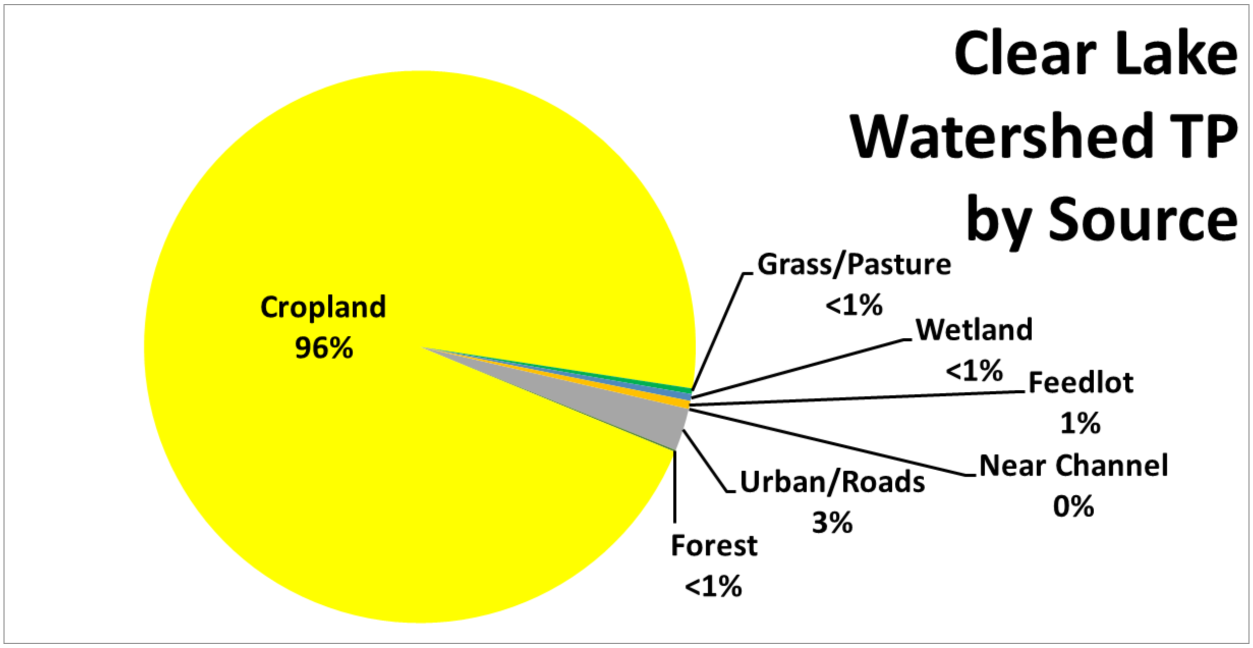



**Figure C-26. Clear Lake watershed TP load contribution by source predicted by HSPF.**

**Table C-12. Clear Lake Current Condition Lake Response Model.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***Average Loading Summary for*** | | | ***Clear (Brown Co.)*** | | | |
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct Watershed (HSPF 452) | 1,426 | 13.6 | 1,613 | 241 | 1.0 | 1,057 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *1,426* | *14* | *1,612.95* | | | *1,057* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | Calibration Factor | Load [lb/yr] |
| 1 | | 13 | 1.74 | 0 | 13% | | 16 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *13* | *2* | *0.0* | 13% | | *16* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 277 | 32.0 | 32.0 | 0.00 | 0.24 | 1.0 | 66 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [km²] | [days] | | | [mg/m²-day] | [--] | [lb/yr] |
| | 1.12 | 0 | | Oxic | | 1.0 | 0 |
| | 1.12 | 37.0 | | Anoxic | | 1.0 | 1,289 |
| | *Summation* | | | | | | *1,289* |
| | | **Net Discharge [ac-ft/yr] =** | | **1,613** | **Net Load [lb/yr] =** | | **2,429** |

| | | | |
|---|---|---|---|
| ***Average Lake Response Modeling for*** | | ***Clear (Brown Co.)*** | |
| **Modeled Parameter** | **Equation** | **Parameters** | **Value [Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | |
| $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 [--] |
| | | $C_{CB}$ = | 0.162 [--] |
| | | b = | 0.458 [--] |
| | | W (total P load = inflow + atm.) = | 1,102 [kg/yr] |
| | | Q (lake outflow) = | 2.0 [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 1.7 [$10^6$ $m^3$] |
| | | T = V/Q = | 0.84 [yr] |
| | | $P_i$ = W/Q = | 554 [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **151.0 [ug/l]** |
| **Observed In-Lake [TP]** | | | **151.0 [ug/l]** |

**Table C-13. Clear Lake TMDL Condition Lake Response Model.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***TMDL Loading Summary for Clear (Brown Co.)*** | | | | | | |
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | Direct Watershed (HSPF 452) | 1,426 | 13.6 | 1,613 | 150 | 0.6 | 658 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *1,426* | *14* | *1,612.95* | | | *658* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | Calibration Factor | Load [lb/yr] |
| 1 | 0 | 13 | 0 | 0 | 0% | | 8 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *13* | *0* | *0.0* | 0% | | *8* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 277 | 32.0 | 32.0 | 0.00 | 0.24 | 1.0 | 66 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [km$^2$] | [days] | | | [mg/m$^2$-day] | [--] | [lb/yr] |
| | 1.12 | 0 | | Oxic | | 1.0 | 0 |
| | 1.12 | 37.0 | | Anoxic | | 1.0 | 407 |
| | *Summation* | | | | | | *407* |
| | | **Net Discharge [ac-ft/yr] =** | | **1,613** | **Net Load [lb/yr] =** | | **1,139** |

| | | | | |
|---|---|---|---|---|
| ***TMDL Lake Response Modeling for Clear (Brown Co.)*** | | | | |
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 517 | [kg/yr] |
| | | Q (lake outflow) = | 2.0 | [$10^6$ m$^3$/yr] |
| | | V (modeled lake volume) = | 1.7 | [$10^6$ m$^3$] |
| | | T = V/Q = | 0.84 | [yr] |
| | | $P_i$ = W/Q = | 260 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **90.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **151.0** | **[ug/l]** |

## Supporting Items for Altermatt Lake (08005400)

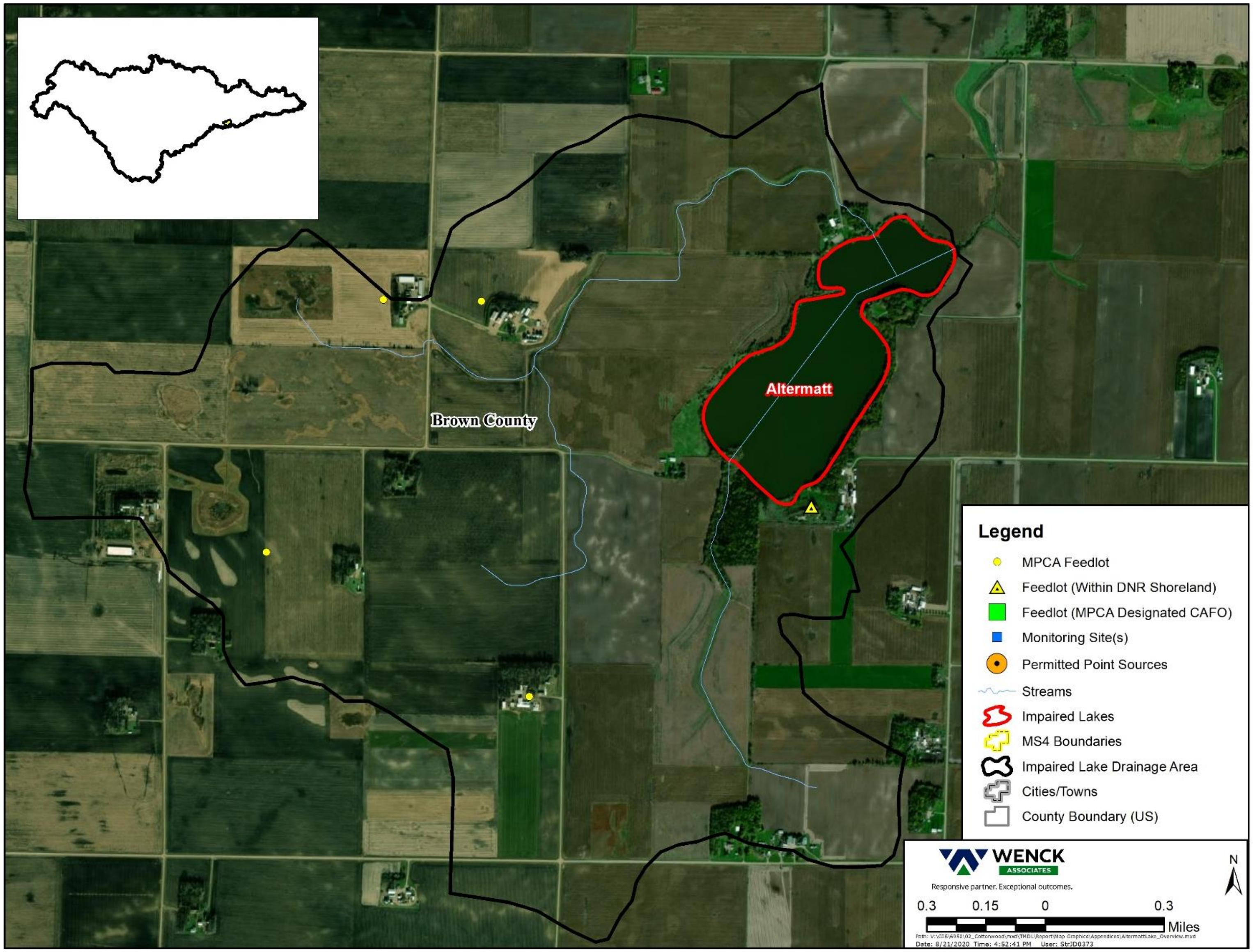



**Figure C-27. Altermatt Lake Overview.**

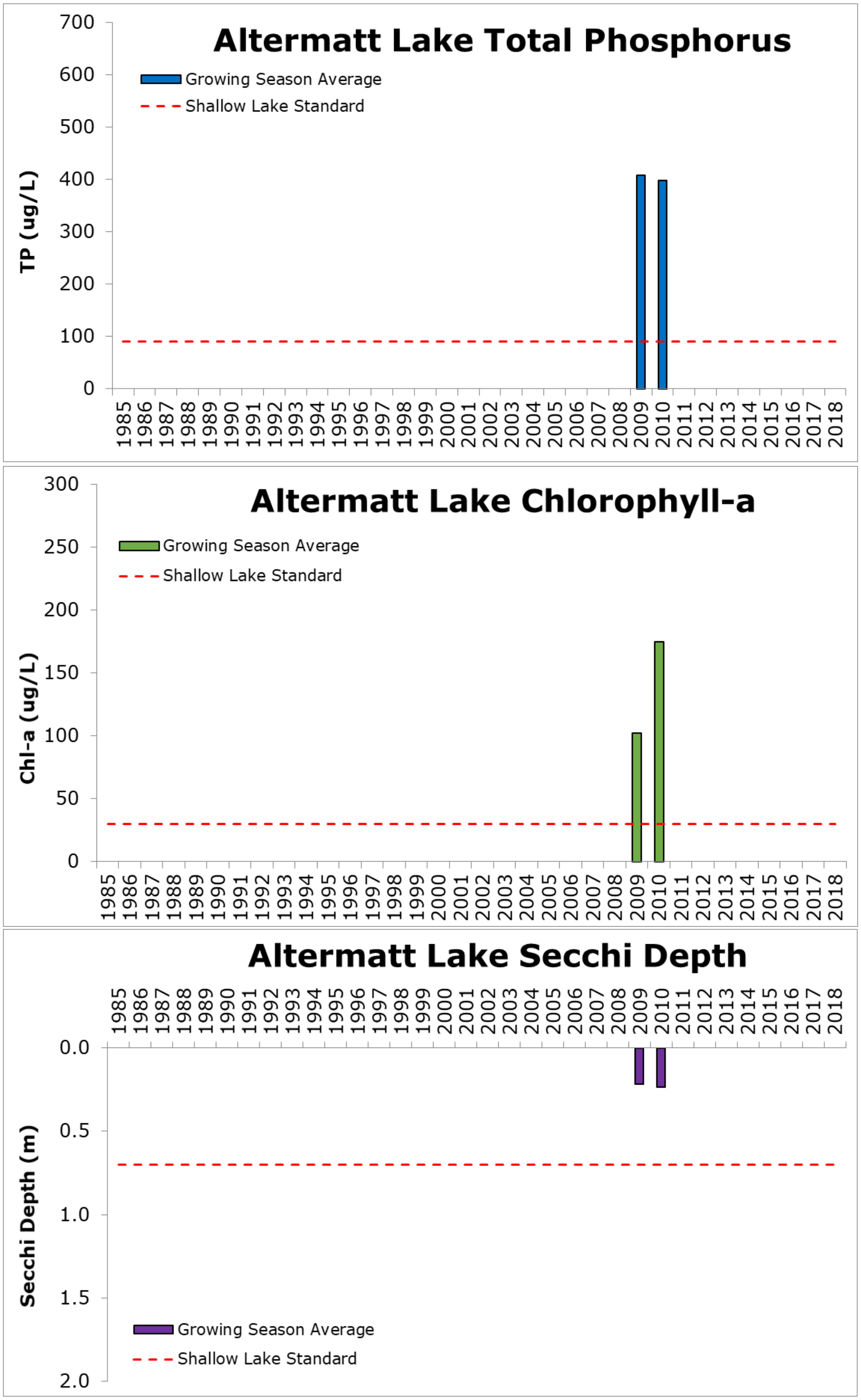



**Figure C-28. Altermatt Lake Historic Water Quality.**

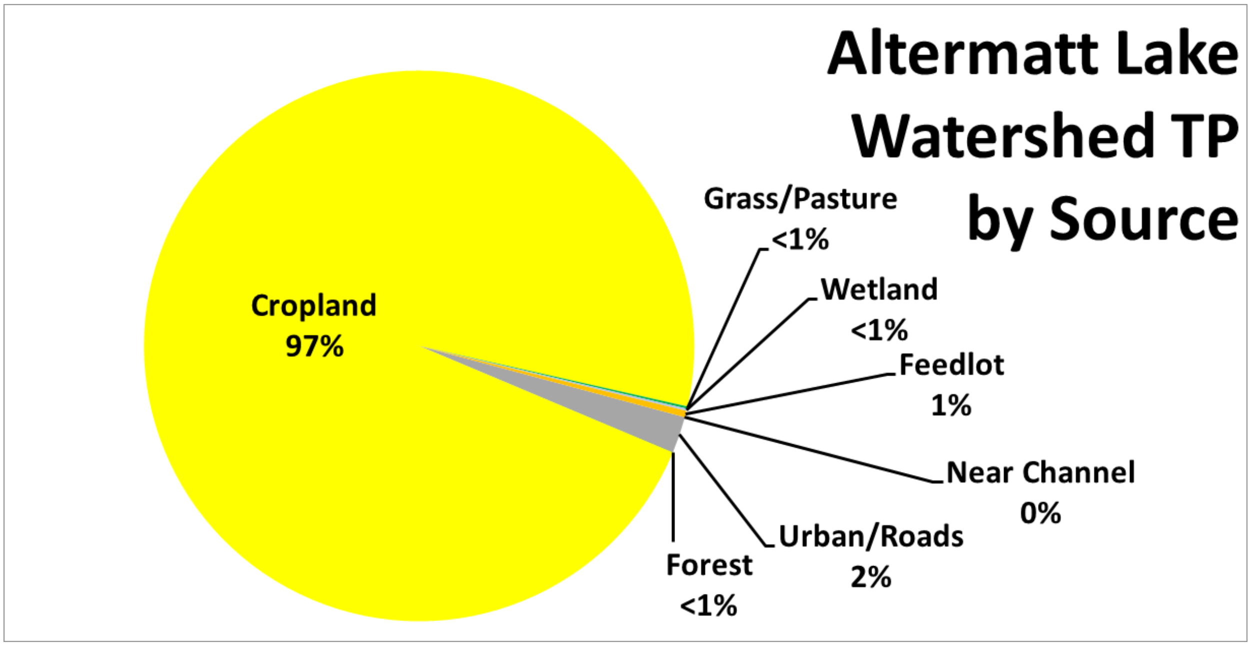



**Figure C-29. Altermatt Lake watershed TP load contribution by source predicted by HSPF.**

**Table C-14. Altermatt Lake Current Condition Lake Response Model.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***Average Loading Summary for Altermatt*** | | | | | | |
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | All | 1,865 | 6.5 | 1,012 | 356 | 1.0 | 980 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *1,865* | *7* | *1,012.10* | | | *980* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 9 | 2 | | 25% | | 9 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *9* | *2* | *0.0* | 25% | | *9* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 122 | 34.6 | 34.6 | 0.00 | 0.24 | 1.0 | 29 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [$km^2$] | [days] | | | [$mg/m^2$-day] | [--] | [lb/yr] |
| | 0.49 | 0 | | Oxic | | 1.0 | 0 |
| | 0.49 | 81.5 | | Anoxic | 35.7 | 1.0 | 3,169 |
| | *Summation* | | | | | | *3,169* |
| | | | **Net Discharge [ac-ft/yr] =** | **1,012** | | **Net Load [lb/yr] =** | **4,188** |

## *Average Lake Response Modeling for Altermatt*

| Modeled Parameter | Equation | Parameters | Value | [Units] |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 1,900 | [kg/yr] |
| | | Q (lake outflow) = | 1.2 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.5 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.39 | [yr] |
| | | $P_i$ = W/Q = | 1521 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **402.8** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **402.8** | **[ug/l]** |

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

**Table C-15. Altermatt Lake TMDL Condition Lake Response Model.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***TMDL Loading Summary for Altermatt*** | | | | | | |
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | All | 1,865 | 6.5 | 1,012 | 141 | 0.4 | 388 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *1,865* | *7* | *1,012.10* | | | *388* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 9 | 2.25 | 0 | 25% | | 4 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | *9* | *2* | *0.0* | 25% | | *4* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 122 | 34.6 | 34.6 | 0.00 | 0.24 | 1.0 | 29.2 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [$km^2$] | [days] | | | [$mg/m^2$-day] | [--] | [lb/yr] |
| | 0.49 | 0 | | Oxic | | 1.0 | 0 |
| | 0.49 | 81.5 | | Anoxic | 35.7 | 1.0 | 89 |
| | *Summation* | | | | | | *89* |
| | | | **Net Discharge [ac-ft/yr] =** | **1,012** | | **Net Load [lb/yr] =** | **510** |

| | | | |
|---|---|---|---|
| ***TMDL Lake Response Modeling for Altermatt*** | | | |
| **Modeled Parameter** | **Equation** | **Parameters** | **Value [Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | |
| | $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | |
| | | $C_P$ = | 1.00 [--] |
| | | $C_{CB}$ = | 0.162 [--] |
| | | b = | 0.458 [--] |
| | | W (total P load = inflow + atm.) = | 231 [kg/yr] |
| | | Q (lake outflow) = | 1.2 [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.5 [$10^6$ $m^3$] |
| | | T = V/Q = | 0.39 [yr] |
| | | $P_i$ = W/Q = | 185 [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **90.0 [ug/l]** |
| **Observed In-Lake [TP]** | | | **402.8 [ug/l]** |

## Supporting Items for Boise Lake (08009600)

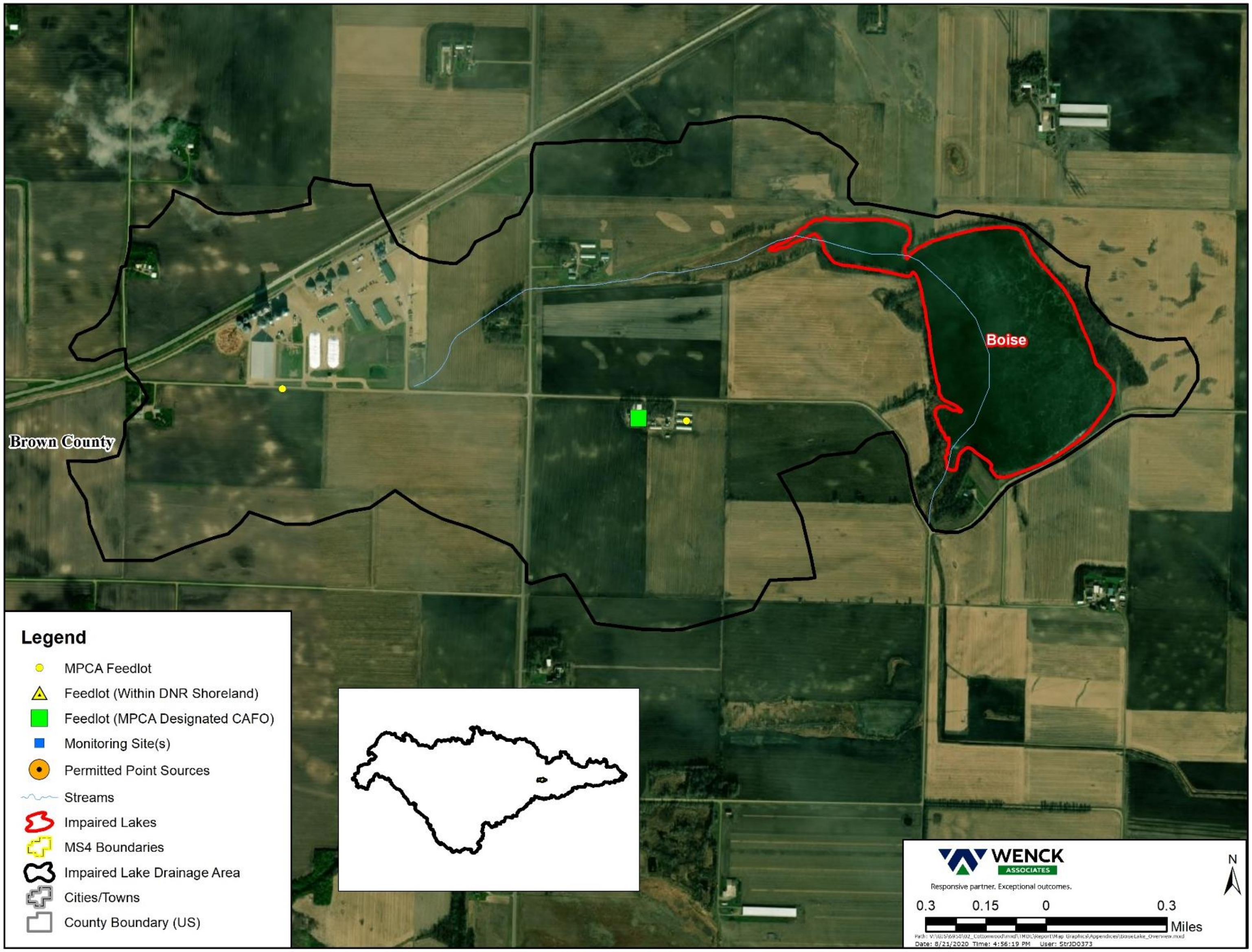



**Figure C-30. Boise Lake Overview.**

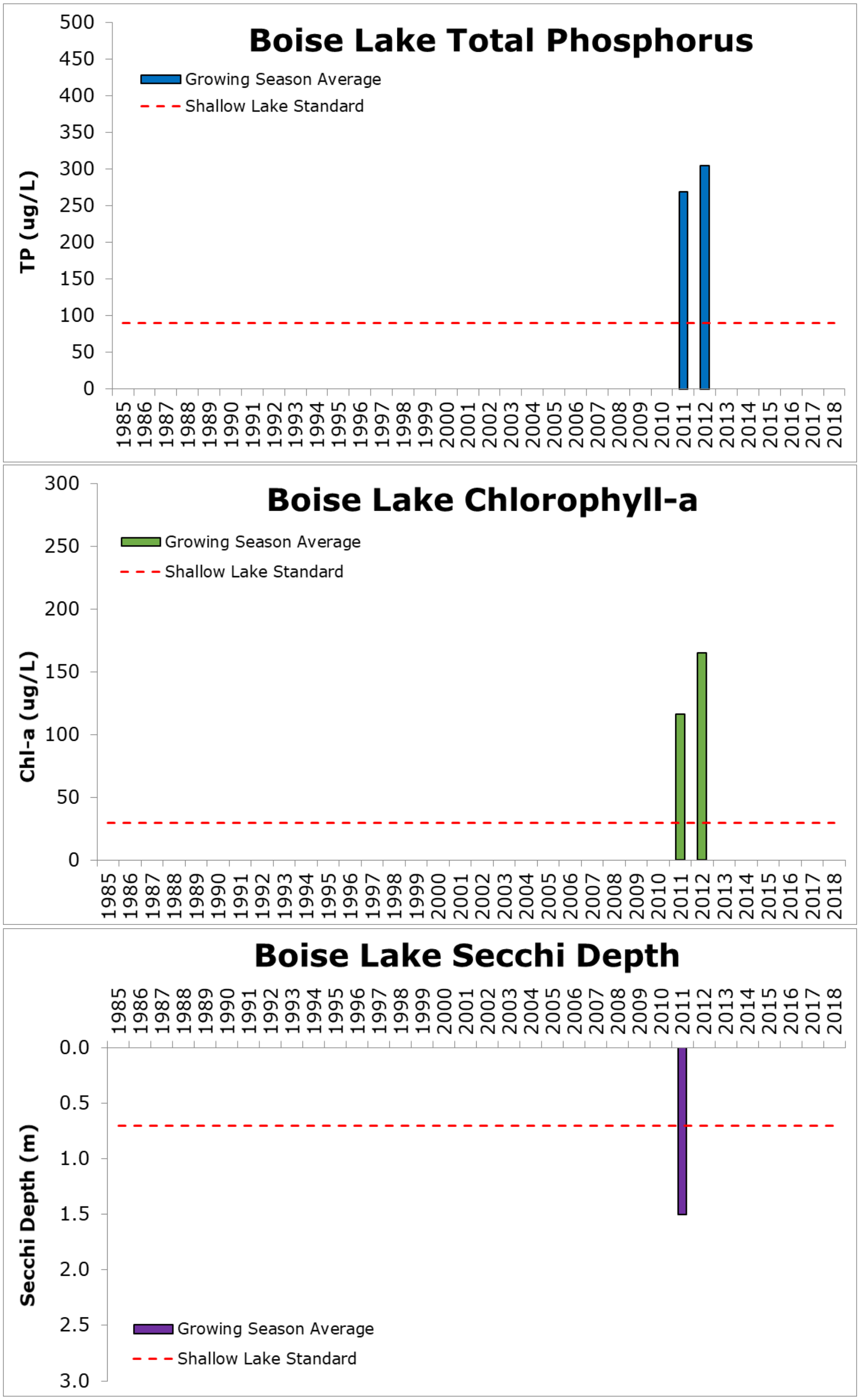



**Figure C-31. Boise Lake Historic Water Quality.**

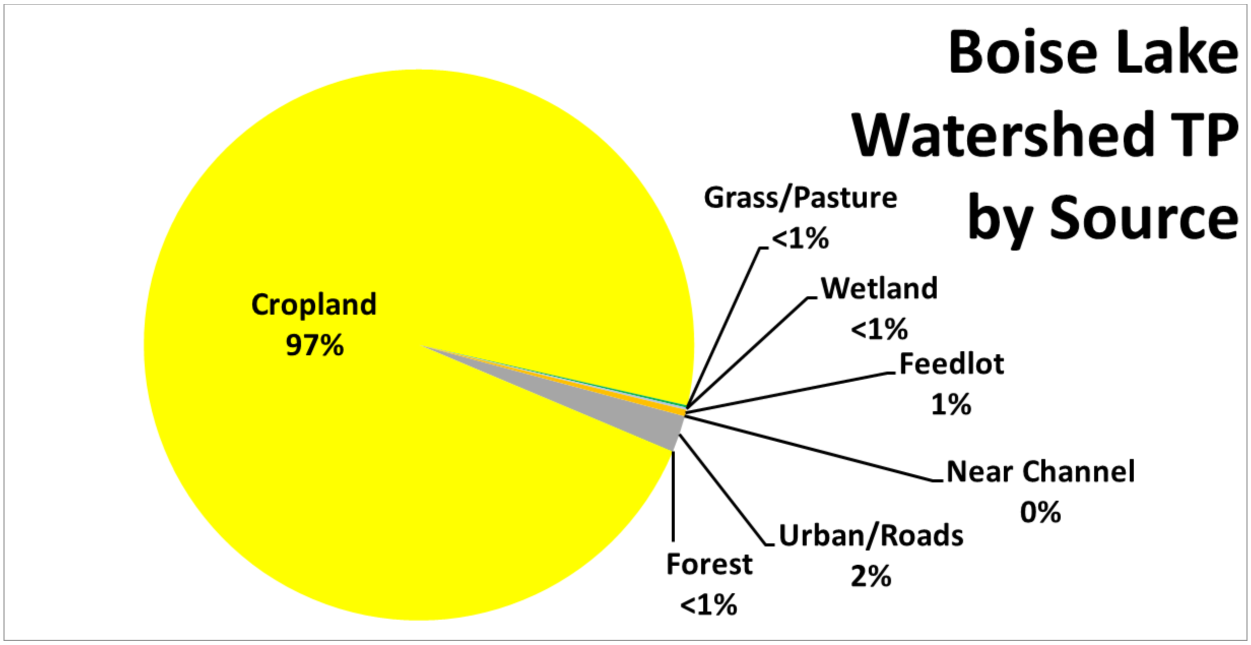



**Figure C-32. Boise Lake watershed TP load contribution by source predicted by HSPF.**

**Table C-16. Boise Lake Current Condition Lake Response Model.**

| | ***Average Loading Summary for Boise*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| | ***Inflow from Drainage Areas*** | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | All | 1,376 | 7.9 | 901 | 329 | 1.0 | 805 |
| 2 | | | | 0 | 0 | | 0 |
| 3 | | | | 0 | 0 | | 0 |
| 4 | | | | 0 | 0 | | 0 |
| 5 | | | | 0 | 0 | | 0 |
| 6 | | | | 0 | 0 | | 0 |
| | *Summation* | *1,376* | *8* | *900.61* | | | *805* |
| | ***Failing Septic Systems*** | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 7 | 1.75 | | 25% | | 8 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | | | *0.0* | | | *8* |
| | ***Inflow from Upstream Lakes*** | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| | ***Atmosphere*** | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 187 | 23.9 | 23.9 | 0.00 | 0.22 | 1.0 | 42 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| | ***Internal*** | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [$km^2$] | [days] | | | [$mg/m^2$-day] | [--] | [lb/yr] |
| | 0.76 | 0 | | Oxic | | 1.0 | 0 |
| | 0.76 | 74.4 | | Anoxic | 10.7 | 1.0 | 1,333 |
| | *Summation* | | | | | | *1,333* |
| | | | **Net Discharge [ac-ft/yr] =** | **901** | | **Net Load [lb/yr] =** | **2,188** |

| ***Average Lake Response Modeling for Boise*** | | | | |
|---|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| | $P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 992 | [kg/yr] |
| | | Q (lake outflow) = | 1.1 | [$10^6$ $m^3$/yr] |
| | | V (modeled lake volume) = | 0.4 | [$10^6$ $m^3$] |
| | | T = V/Q = | 0.37 | [yr] |
| | | $P_i$ = W/Q = | 893 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **287.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **287.0** | **[ug/l]** |

**Table C-17. Boise Lake TMDL Condition Lake Response Model.**

| | ***TMDL Loading Summary for Boise*** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | All | 1,376 | 7.9 | 901 | 113 | 0.3 | 276 |
| 2 | | | | 0 | 0 | | 0 |
| 3 | | | | 0 | 0 | | 0 |
| 4 | | | | 0 | 0 | | 0 |
| 5 | | | | 0 | 0 | | 0 |
| 6 | | | | 0 | 0 | | 0 |
| | *Summation* | *1,376* | *8* | *900.61* | | | *276* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 7 | 0 | | 0% | | 4 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | | | *0.0* | | | *4* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 187 | 23.9 | 23.9 | 0.00 | 0.22 | 1.0 | 42 |
| | | | | Dry-year total P deposition = | 0.222 | | |
| | | | | Average-year total P deposition = | 0.239 | | |
| | | | | Wet-year total P deposition = | 0.259 | | |
| | | | | (Barr Engineering 2004) | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [km²] | [days] | | | [mg/m²-day] | [--] | [lb/yr] |
| | 0.76 | 0 | | Oxic | | 1.0 | 0 |
| | 0.76 | 74.4 | | Anoxic | 10.7 | 1.0 | 124 |
| | *Summation* | | | | | | *124* |
| | | | | **Net Discharge [ac-ft/yr] =** **901** | | **Net Load [lb/yr] =** | **445** |

| ***TMDL Lake Response Modeling for Boise*** | | | | |
|---|---|---|---|---|
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $P = \dfrac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\dfrac{W_P}{V}\right)^b \times T\right)}$ | | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 202 | [kg/yr] |
| | | Q (lake outflow) = | 1.1 | [$10^6$ m³/yr] |
| | | V (modeled lake volume) = | 0.4 | [$10^6$ m³] |
| | | T = V/Q = | 0.37 | [yr] |
| | | $P_i$ = W/Q = | 182 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **90.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **287.0** | **[ug/l]** |

**Supporting Items for Bachelor Lake (08002900)**

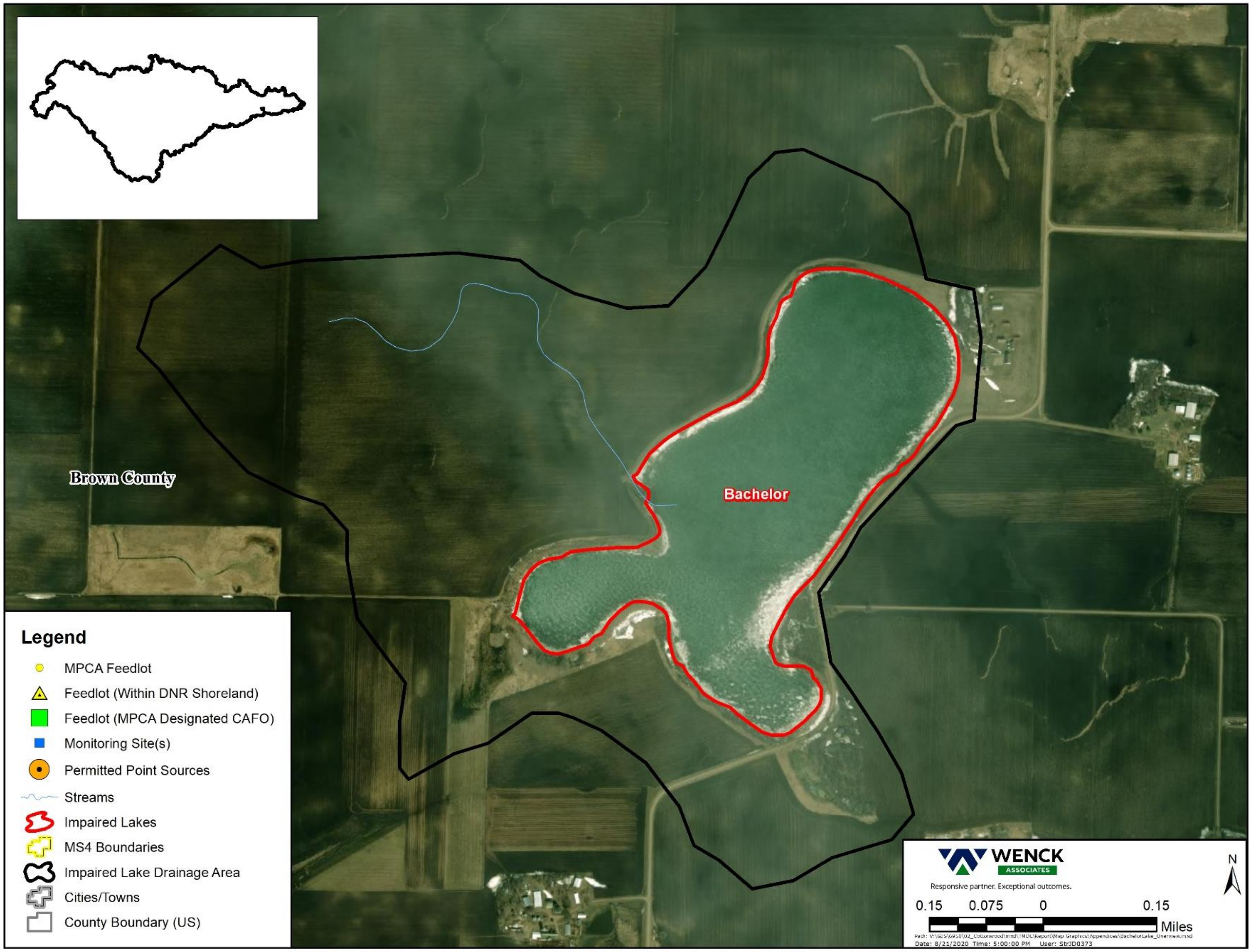



**Figure C-33. Bachelor Lake Overview.**

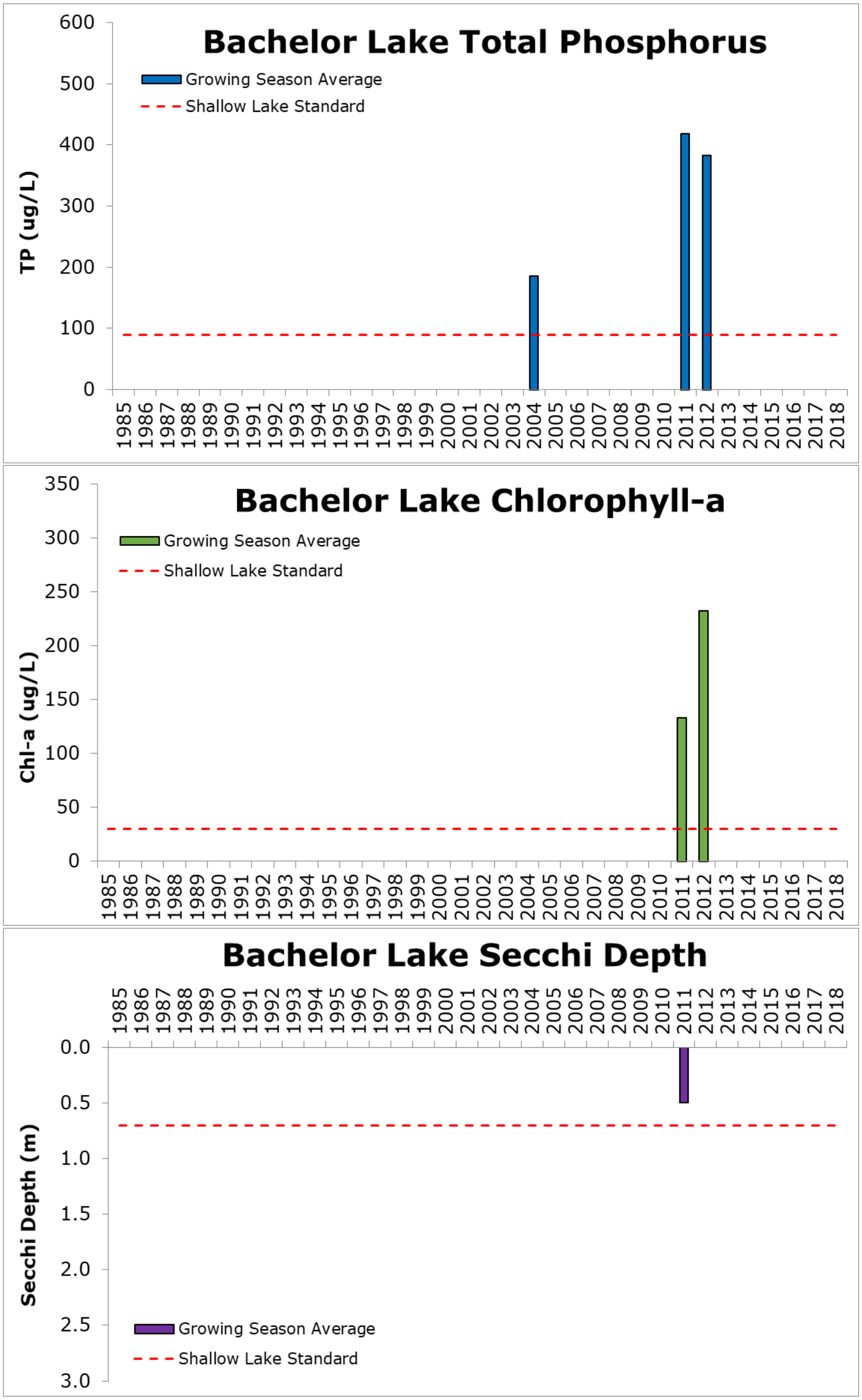



**Figure C-34. Bachelor Lake Historic Water Quality.**

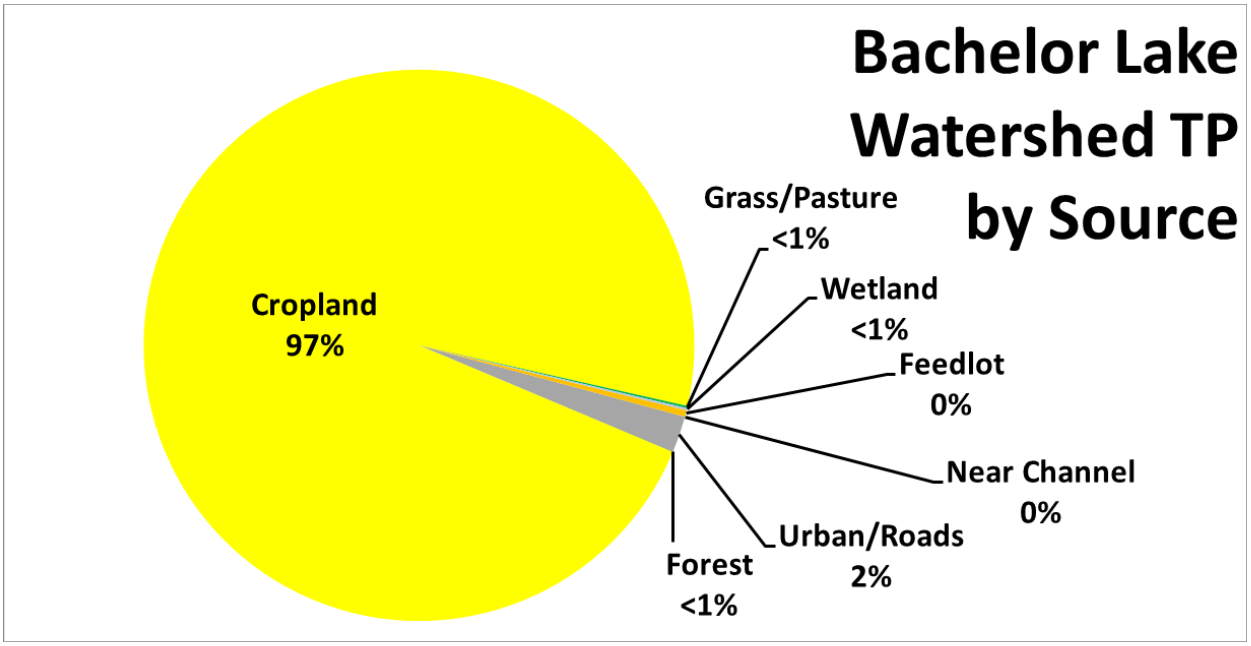



**Figure C-35. Bachelor Lake watershed TP load contribution by source predicted by HSPF.**

## Table C-18. Bachelor Lake Current Condition Lake Response Model.

| | *Average Loading Summary for* | *Bachelor* | | | | | |
|---|---|---|---|---|---|---|---|
| | **Water Budgets** | | | | **Phosphorus Loading** | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | | Drainage Area | Runoff Depth | Discharge | Phosphorus Concentration | Loading Calibration Factor (CF)[1] | Load |
| | Name | [acre] | [in/yr] | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | All | 377 | 9.5 | 297 | 349 | 1.0 | 283 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *377* | *9* | *297.48* | | | *283* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 1 | 0 | | 49% | | 1 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | | | *0.0* | | | *1* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | | | | Discharge | Estimated P Concentration | Calibration Factor | Load |
| | Name | | | [ac-ft/yr] | [ug/L] | [--] | [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area | Precipitation | Evaporation | Net Inflow | Aerial Loading Rate | Calibration Factor | Load |
| | [acre] | [in/yr] | [in/yr] | [ac-ft/yr] | [lb/ac-yr] | [--] | [lb/yr] |
| | 105 | 23.9 | 23.9 | 0.00 | 0.22 | 1.0 | 23.3 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area | Anoxic Factor | | | Release Rate | Calibration Factor | Load |
| | [km$^2$] | [days] | | | [mg/m$^2$-day] | [--] | [lb/yr] |
| | 0.42 | 0 | | Oxic | | 1.0 | 0 |
| | 0.42 | 80.6 | | Anoxic | 12.7 | 1.0 | 963 |
| | *Summation* | | | | | | *963* |
| | | **Net Discharge [ac-ft/yr] =** | | **297** | **Net Load [lb/yr] =** | | **1,269** |

## *Average Lake Response Modeling for Bachelor*

| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
|---|---|---|---|---|
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | | as f(W,Q,V) from Canfield & Bachmann (1981) | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 576 | [kg/yr] |
| | | Q (lake outflow) = | 0.4 | [$10^6$ m$^3$/yr] |
| | | V (modeled lake volume) = | 0.2 | [$10^6$ m$^3$] |
| | | T = V/Q = | 0.41 | [yr] |
| | | $P_i$ = W/Q = | 1568 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **400.4** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **400.4** | **[ug/l]** |

**Table C-19. Bachelor Lake TMDL Condition Lake Response Model.**

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | ***TMDL Loading Summary for*** | | | ***Bachelor*** | | | |
| **Water Budgets** | | | | **Phosphorus Loading** | | | |
| ***Inflow from Drainage Areas*** | | | | | | | |
| | Name | Drainage Area [acre] | Runoff Depth [in/yr] | Discharge [ac-ft/yr] | Phosphorus Concentration [ug/L] | Loading Calibration Factor (CF)[1] [--] | Load [lb/yr] |
| 1 | All | 377 | 9.5 | 297 | 67 | 0.2 | 54 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| 6 | | | | | | | |
| | *Summation* | *377* | *9* | *297.48* | | | *54* |
| ***Failing Septic Systems*** | | | | | | | |
| | Name | Total Systems | Failing Systems | Discharge [ac-ft/yr] | Failure [%] | | Load [lb/yr] |
| 1 | | 1 | 0 | | 0% | | 0 |
| 2 | | | | | | | |
| 3 | | | | | | | |
| 4 | | | | | | | |
| 5 | | | | | | | |
| | *Summation* | | | *0.0* | | | *0* |
| ***Inflow from Upstream Lakes*** | | | | | | | |
| | Name | | | Discharge [ac-ft/yr] | Estimated P Concentration [ug/L] | Calibration Factor [--] | Load [lb/yr] |
| 1 | | | | | - | 1.0 | |
| 2 | | | | | - | 1.0 | |
| 3 | | | | | - | 1.0 | |
| 4 | | | | | - | 1.0 | |
| 5 | | | | | - | 1.0 | |
| | *Summation* | | | *0.0* | - | | *0.0* |
| ***Atmosphere*** | | | | | | | |
| | Lake Area [acre] | Precipitation [in/yr] | Evaporation [in/yr] | Net Inflow [ac-ft/yr] | Aerial Loading Rate [lb/ac-yr] | Calibration Factor [--] | Load [lb/yr] |
| | 105 | 23.9 | 23.9 | 0.00 | 0.22 | 1.0 | 23 |
| | | Dry-year total P deposition = | | | 0.222 | | |
| | | Average-year total P deposition = | | | 0.239 | | |
| | | Wet-year total P deposition = | | | 0.259 | | |
| | | (Barr Engineering 2004) | | | | | |
| ***Internal*** | | | | | | | |
| | Lake Area [km$^2$] | Anoxic Factor [days] | | | Release Rate [mg/m$^2$-day] | Calibration Factor [--] | Load [lb/yr] |
| | 0.42 | 0 | | Oxic | | 1.0 | 0 |
| | 0.42 | 80.6 | | Anoxic | 12.7 | 1.0 | 76 |
| | *Summation* | | | | | | *76* |
| | | | **Net Discharge [ac-ft/yr] =** | **297** | | **Net Load [lb/yr] =** | **154** |

| | | | |
|---|---|---|---|
| ***TMDL Lake Response Modeling for*** | ***Bachelor*** | | |
| **Modeled Parameter** | **Equation** | **Parameters** | **Value** | **[Units]** |
| **TOTAL IN-LAKE PHOSPHORUS CONCENTRATION** | | | | |
| $$P = \frac{P_i}{\left(1 + C_P \times C_{CB} \times \left(\frac{W_P}{V}\right)^b \times T\right)}$$ | as f(W,Q,V) from Canfield & Bachmann (1981) | | | |
| | | $C_P$ = | 1.00 | [--] |
| | | $C_{CB}$ = | 0.162 | [--] |
| | | b = | 0.458 | [--] |
| | | W (total P load = inflow + atm.) = | 70 | [kg/yr] |
| | | Q (lake outflow) = | 0.4 | [$10^6$ m$^3$/yr] |
| | | V (modeled lake volume) = | 0.2 | [$10^6$ m$^3$] |
| | | T = V/Q = | 0.41 | [yr] |
| | | $P_i$ = W/Q = | 190 | [µg/l] |
| **Model Predicted In-Lake [TP]** | | | **90.0** | **[ug/l]** |
| **Observed In-Lake [TP]** | | | **400.4** | **[ug/l]** |

**Additional Supporting Items for Impaired Lakes**

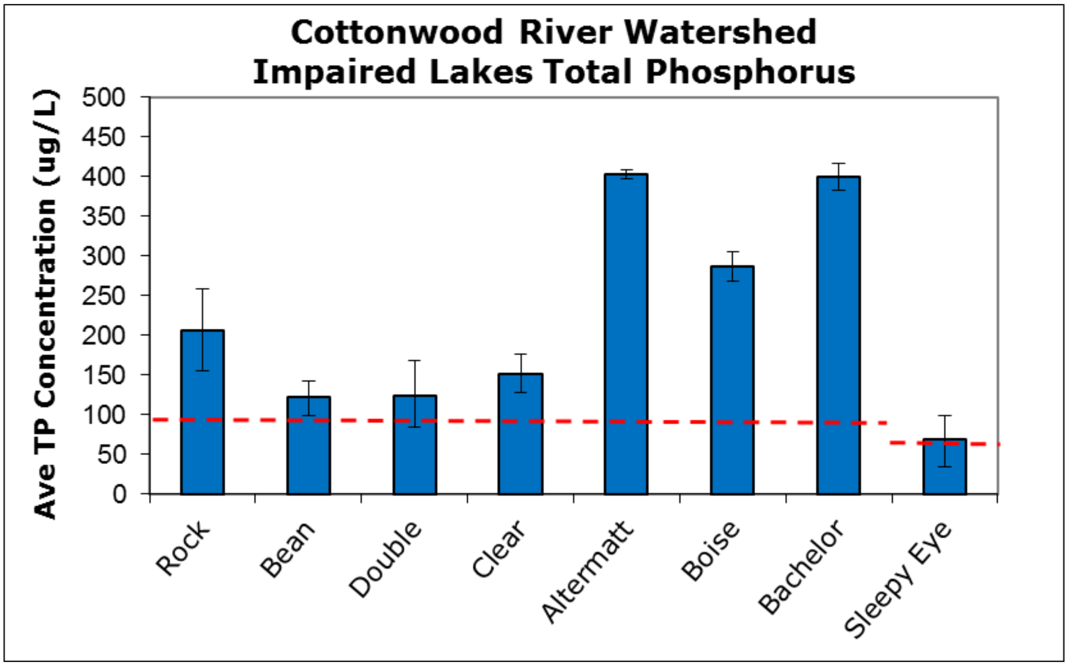



**Figure C-36. Average summer growing season TP concentrations for each impaired lake, including Sleepy Eye (delisted 2020).**

**To:** Redwood Cottonwood Rivers Control Area

Minnesota Pollution Control Agency

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

**Date:** February 4, 2019

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

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

## Methods

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

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

## Results

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

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

**Table 1: Summary of common carp assessments.**

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

## Discussion

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

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

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

## References


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

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


## Photos

**Photo 1: Common carp.**

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

**To:** Redwood Cottonwood Rivers Control Area
Minnesota Pollution Control Agency

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

**Date:** February 5, 2019

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

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

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

## Water Column Profile Results

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

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

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

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

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

## Anoxic Factor Estimates

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

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

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

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

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

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

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

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

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

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

## Sediment Core Results

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

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

**Table 3**. Anaerobic phosphorus release rates.

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

## References


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

# Appendix C – WWTF DMR Data Summary

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

| Facility | Number of Samples | TSS (ave; mg/L) | TSS (min; mg/L) | TSS (max; mg/L) | Samples exceeding 65mg/L | Facility Monthly Limit |
|---|---|---|---|---|---|---|
| ACME Brick Great Lakes Plant | 24 | 8 | 2 | 19 | 0 | 45 |
| August Schell Brewing Co | 34 | 3 | 1 | 9 | 0 | 30 |
| Balaton WWTP | 45 | 15 | 2 | 68 | 1 | 45 |
| Clements WWTP | 25 | 12 | 2 | 50 | 0 | 45 |
| Del Monte Foods Inc - Sleepy Eye Plant 114 | 88 | 23 | 2 | 170 | 3 | 30; 45 |
| Garvin WWTP | 43 | 8 | 1 | 24 | 0 | 45 |
| Highwater Ethanol LLC | 4 | 9 | 7 | 10 | 0 | 30 |
| Lamberton WWTP | 29 | 14 | 4 | 45 | 0 | 45 |
| Lucan WWTP | 47 | 32 | 6 | 89 | 4 | 45 |
| New Ulm WWTP | 5 | 4 | 3 | 6 | 0 | 30 |
| Revere WWTP | 25 | 41 | 7 | 124 | 3 | 45 |
| Sanborn WWTP | 24 | 12 | 3 | 51 | 0 | 45 |
| Sleepy Eye WWTP | 49 | 8 | 0 | 22 | 0 | 45 |
| Springfield WWTP | 120 | 5 | 2 | 11 | 0 | 30 |
| Storden WWTP | 32 | 30 | 2 | 97 | 1 | 45 |
| Tracy WWTP | 104 | 14 | 2 | 54 | 0 | 45 |
| Wabasso WWTP | 120 | 9 | 1 | 21 | 0 | 30 |
| Walnut Grove WWTP | 120 | 9 | 1 | 26 | 0 | 30 |
| Wanda WWTP | 28 | 7 | 2 | 18 | 0 | 45 |
| Westbrook WWTP | 40 | 24 | 3 | 309 | 2 | 45 |

Note: Samples refer to single monthly reported value

**Table C-2. WWTF Effluent Fecal Coliform Summary (2005-2019).**

| Facility | count | min | max | Geomean (#/100ml) | samples >200/ml | % >200/ml |
|---|---|---|---|---|---|---|
| Sleepy Eye WWTP | 44 | 10 | 464 | 33 | 6 | 14% |
| Westbrook WWTP | 41 | 10 | 530,000 | 36 | 5 | 12% |
| Balaton WWTP | 47 | 1 | 292 | 5 | 1 | 2% |
| Garvin WWTP | 45 | 1 | 2,420 | 5 | 2 | 4% |
| Walnut Grove WWTP | 89 | 1 | 630 | 13 | 2 | 2% |
| Revere WWTP | 21 | 1 | 2,420 | 22 | 2 | 10% |
| Storden WWTP | 37 | 1 | 2,420 | 5 | 1 | 3% |

# Appendix E – CAFO List and Watershed Summary

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

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| Headwaters – Cottonwood River | 083-50002 | 973 | N |
| | 083-50003 | 1440 | N |
| | 083-50015 | 300 | N |
| | 083-60847 | 140 | N |
| | 083-62344 | 400 | N |
| | 083-62428 | 473.5 | N |
| | 083-62444 | 650 | N |
| | 083-62543 | 285 | N |
| | 083-62553 | 693 | N |
| | 083-62704 | 57.8 | N |
| | 083-62734 | 150 | N |
| | 083-62825 | 1080 | N |
| | 083-62848 | 602.5 | Y |
| | 083-62856 | 490 | N |
| | 083-62862 | 386 | N |
| | 083-62863 | 300 | N |
| | 083-62926 | 999 | N |
| | 083-62928 | 660 | N |
| | 083-63509 | 138 | N |
| | 083-63783 | 169 | N |
| | 083-65527 | 297.5 | N |
| | 083-80220 | 980 | N |
| | 083-83840 | 711 | N |
| | 083-89079 | 600 | N |
| | 083-98301 | 1248 | N |
| | 083-100060 | 600 | N |
| | 083-104800 | 210 | N |
| | 083-105640 | 66 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 083-109880 | 2700 | N |
| | 083-113093 | 980 | N |
| | 083-113278 | 720 | N |
| | 083-119803 | 820 | N |
| | 083-121082 | 720 | N |
| | 083-121083 | 60 | N |
| | 083-124355 | 600 | N |
| | 083-125550 | 299 | N |
| Meadow Creek | 083-50012 | 700 | N |
| | 083-50014 | 840 | N |
| | 083-50024 | 1248 | N |
| | 083-60844 | 500 | N |
| | 083-61769 | 88 | N |
| | 083-61770 | 540 | Y |
| | 083-61803 | 373 | N |
| | 083-62112 | 177 | N |
| | 083-62170 | 500 | N |
| | 083-62425 | 395 | N |
| | 083-62427 | 500 | N |
| | 083-62441 | 165 | N |
| | 083-62541 | 210 | Y |
| | 083-62542 | 210 | Y |
| | 083-62563 | 525 | N |
| | 083-62691 | 200 | N |
| | 083-62709 | 720 | N |
| | 083-62737 | 238.6 | N |
| | 083-62842 | 880 | N |
| | 083-65081 | 397 | N |
| | 083-68166 | 485 | N |
| | 083-87104 | 4500 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 083-106440 | 72 | N |
| | 083-111440 | 285 | N |
| | 083-121434 | 202.5 | N |
| | 083-121438 | 190 | N |
| | 083-125701 | 720 | |
| | 083-125800 | 1440 | |
| | 083-125999 | 720 | |
| | 083-126540 | 720 | N |
| Plum Creek | 083-50007 | 2520 | |
| | 101-68937 | 590 | N |
| | 101-68950 | 54 | N |
| | 101-77051 | 50 | N |
| | 101-77080 | 270 | N |
| | 101-77154 | 160.2 | N |
| | 101-77185 | 74 | N |
| | 101-77400 | 231 | N |
| | 101-88975 | 171 | N |
| | 101-88981 | 660 | N |
| | 101-88985 | 120 | N |
| | 101-88990 | 133 | N |
| | 101-89012 | 132 | Y |
| | 101-89021 | 420 | N |
| | 101-89037 | 340 | N |
| | 101-107508 | 85 | N |
| | 101-107847 | 110 | N |
| | 101-107848 | 30 | Y |
| | 101-107849 | 56 | N |
| | 101-107853 | 75.9 | N |
| | 101-119167 | 150 | N |
| | 101-121921 | 200 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 101-126420 | 720 | N |
| | 127-50083 | 240 | N |
| | 127-50084 | 845 | N |
| | 127-50085 | 620 | N |
| | 127-62486 | 95 | N |
| | 127-62506 | 60 | N |
| | 127-62745 | 158 | N |
| | 127-62750 | 222 | N |
| | 127-63074 | 999 | N |
| | 127-63123 | 84 | N |
| | 127-63790 | 268 | N |
| | 127-105560 | 390 | N |
| | 127-114503 | 97.5 | N |
| Pell Creek – Cottonwood River | 033-97854 | 23.5 | Y |
| | 033-97989 | 60 | N |
| | 083-50010 | 20 | Y |
| | 083-50011 | 48 | Y |
| | 083-50029 | 1200 | N |
| | 083-50030 | 750 | N |
| | 083-62706 | 195 | N |
| | 083-62836 | 20.6 | Y |
| | 083-63796 | 50 | N |
| | 083-65618 | 71 | N |
| | 083-119884 | 1440 | N |
| | 101-107850 | 1470.5 | N |
| | 127-50031 | 888.5 | N |
| | 127-50056 | 295 | N |
| | 127-50061 | 698.4 | N |
| | 127-50063 | 1728 | Y |
| | 127-50066 | 166 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-50080 | 632.5 | N |
| | 127-50097 | 90 | N |
| | 127-60086 | 95 | N |
| | 127-62328 | 141 | N |
| | 127-62472 | 180 | N |
| | 127-62507 | 321.5 | N |
| | 127-62694 | 350 | N |
| | 127-62954 | 154 | N |
| | 127-62959 | 62 | N |
| | 127-62969 | 162 | N |
| | 127-65083 | 346 | N |
| | 127-65084 | 142.5 | N |
| | 127-65520 | 270 | N |
| | 127-80028 | 131 | N |
| | 127-80102 | 1200 | N |
| | 127-98160 | 990 | N |
| | 127-99980 | 936 | N |
| | 127-105720 | 600 | N |
| | 127-117681 | 735 | N |
| | 127-125907 | 375 | |
| Dutch Charley Creek | 033-50001 | 1177 | N |
| | 033-50006 | 4480 | Y |
| | 033-60187 | 1715 | N |
| | 033-97860 | 720 | N |
| | 033-97879 | 265 | N |
| | 033-97881 | 845 | N |
| | 033-97882 | 210 | N |
| | 033-97908 | 600 | N |
| | 033-97910 | 291 | Y |
| | 033-97912 | 80 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-97914 | 200 | N |
| | 033-97915 | 140 | N |
| | 033-97918 | 82 | N |
| | 033-97919 | 80 | N |
| | 033-97929 | 139 | N |
| | 033-97935 | 60 | N |
| | 033-97938 | 60 | N |
| | 033-97939 | 135 | N |
| | 033-97940 | 90 | N |
| | 033-97965 | 42 | Y |
| | 033-97970 | 150 | N |
| | 033-97974 | 980 | N |
| | 033-97976 | 220 | N |
| | 033-97978 | 122.765 | N |
| | 033-97981 | 290.5 | N |
| | 033-97992 | 139.25 | N |
| | 033-97993 | 150 | N |
| | 033-97997 | 990 | N |
| | 033-97999 | 150 | N |
| | 033-98002 | 38 | Y |
| | 033-98005 | 280 | N |
| | 033-98032 | 705 | N |
| | 033-98033 | 570 | N |
| | 033-98035 | 310.5 | N |
| | 033-98047 | 183 | N |
| | 033-98061 | 89 | N |
| | 033-98063 | 150 | N |
| | 033-98065 | 84 | N |
| | 033-98078 | 150 | N |
| | 033-98080 | 150 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-98081 | 990 | N |
| | 033-98088 | 200 | N |
| | 033-98095 | 588 | N |
| | 033-98102 | 141 | N |
| | 033-98107 | 90 | N |
| | 033-102342 | 990 | N |
| | 033-102566 | 250.3 | N |
| | 033-102577 | 530 | N |
| | 033-103543 | 60 | N |
| | 033-103552 | 960 | N |
| | 033-104200 | 1342.5 | |
| | 033-104201 | 990 | N |
| | 033-107458 | 56 | N |
| | 033-108225 | 250 | N |
| | 033-108322 | 120 | N |
| | 033-110360 | 1342.5 | N |
| | 033-117658 | 930 | N |
| | 033-120691 | 750 | N |
| | 033-125533 | 60 | N |
| | 033-125751 | 1290 | N |
| | 033-125896 | 360 | N |
| | 033-126396 | 720 | |
| | 101-50005 | 2126.4 | |
| | 101-68939 | 50 | Y |
| | 101-77068 | 399 | N |
| | 101-77069 | 119 | N |
| | 101-77135 | 120 | N |
| | 101-77141 | 16.3 | Y |
| | 101-77169 | 95 | N |
| | 101-77170 | 53.5 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 101-77388 | 180 | N |
| | 101-77389 | 100 | N |
| | 101-88997 | 50 | N |
| | 101-89033 | 193 | Y |
| | 101-108062 | 128 | N |
| | 101-108064 | 325 | N |
| | 101-108066 | 16 | Y |
| | 101-108076 | 60 | |
| | 101-114832 | 480 | N |
| | 127-50034 | 180.7 | N |
| | 127-62710 | 110 | N |
| | 127-122138 | 100 | N |
| Mound Creek – Cottonwood River | 015-50005 | 1872 | N |
| | 015-71652 | 33 | Y |
| | 015-71655 | 450 | N |
| | 015-71671 | 1125 | N |
| | 015-71702 | 497.4 | Y |
| | 015-71716 | 350 | N |
| | 015-71727 | 2936.3 | N |
| | 015-71740 | 171 | N |
| | 015-71744 | 160 | N |
| | 015-71757 | 120 | N |
| | 015-71787 | 90 | N |
| | 015-71794 | 195 | N |
| | 015-71810 | 195 | N |
| | 015-71824 | 192.5 | N |
| | 015-71856 | 285 | N |
| | 015-71872 | 160 | N |
| | 015-71876 | 78 | N |
| | 015-71889 | 90 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-71921 | 295 | N |
| | 015-71933 | 590 | N |
| | 015-71966 | 125.5 | N |
| | 015-72003 | 216 | N |
| | 015-72024 | 115 | N |
| | 015-72032 | 160 | N |
| | 015-72035 | 182 | Y |
| | 015-72041 | 900 | N |
| | 015-72075 | 624 | N |
| | 015-72094 | 91 | N |
| | 015-72098 | 735 | N |
| | 015-72107 | 900 | N |
| | 015-72127 | 163 | N |
| | 015-72138 | 225 | N |
| | 015-72147 | 400 | N |
| | 015-72162 | 990 | N |
| | 015-72168 | 242 | N |
| | 015-72171 | 55 | Y |
| | 015-72178 | 110 | N |
| | 015-72200 | 325 | N |
| | 015-72204 | 300 | N |
| | 015-72210 | 138.07 | Y |
| | 015-72217 | 112 | Y |
| | 015-72218 | 180 | Y |
| | 015-72223 | 315 | N |
| | 015-72233 | 50 | N |
| | 015-72244 | 840 | N |
| | 015-72246 | 90 | Y |
| | 015-72273 | 992 | N |
| | 015-72285 | 96.12 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-72315 | 213.6 | N |
| | 015-72317 | 500 | N |
| | 015-72324 | 50 | N |
| | 015-72328 | 1106 | |
| | 015-72332 | 160 | N |
| | 015-80242 | 258 | N |
| | 015-82445 | 85 | N |
| | 015-82469 | 102 | Y |
| | 015-82477 | 300 | N |
| | 015-93741 | 360 | N |
| | 015-95050 | 144 | N |
| | 015-95133 | 84 | Y |
| | 015-95136 | 125 | N |
| | 015-95141 | 300 | N |
| | 015-95145 | 565.5 | Y |
| | 015-95148 | 1106 | |
| | 015-105820 | 900 | N |
| | 015-105961 | 900 | N |
| | 015-107460 | 1600 | N |
| | 015-107461 | 295 | N |
| | 015-108312 | 620 | N |
| | 015-109414 | 810 | N |
| | 015-115876 | 595 | N |
| | 015-117075 | 421 | N |
| | 015-119172 | 250 | Y |
| | 015-125529 | 900 | |
| | 015-126342 | 748.5 | N |
| | 015-127146 | 270 | N |
| | 015-127195 | 990 | N |
| | 033-50011 | 1682 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-97856 | 480 | N |
| | 033-97885 | 73.126 | N |
| | 033-97894 | 100 | N |
| | 033-97909 | 210 | N |
| | 033-97922 | 94 | N |
| | 033-97925 | 56 | N |
| | 033-97926 | 60 | N |
| | 033-97932 | 217 | N |
| | 033-97933 | 789 | N |
| | 033-97934 | 60.3 | N |
| | 033-97944 | 72 | N |
| | 033-97948 | 250 | N |
| | 033-97952 | 343.5 | N |
| | 033-97954 | 265.4 | N |
| | 033-97959 | 211 | N |
| | 033-97962 | 133 | N |
| | 033-97968 | 950 | N |
| | 033-97975 | 180 | N |
| | 033-97998 | 300 | N |
| | 033-98016 | 900 | N |
| | 033-98024 | 55.725 | N |
| | 033-98025 | 209 | N |
| | 033-98038 | 450 | N |
| | 033-98048 | 482.5 | N |
| | 033-98051 | 61.4 | N |
| | 033-98068 | 780 | N |
| | 033-98069 | 75 | N |
| | 033-98076 | 930 | N |
| | 033-98089 | 117 | N |
| | 033-98098 | 998.9 | Y |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-98099 | 900 | N |
| | 033-98103 | 999 | N |
| | 033-103542 | 50 | N |
| | 033-103546 | 240 | N |
| | 033-103548 | 500 | N |
| | 033-105840 | 900 | N |
| | 033-108226 | 57.7 | N |
| | 033-110813 | 600 | N |
| | 033-112558 | 900 | N |
| | 033-121655 | 84 | Y |
| | 127-50079 | 128 | N |
| | 127-62535 | 78.53 | N |
| | 127-62536 | 102 | N |
| | 127-63134 | 225 | N |
| | 127-98660 | 900 | N |
| | 127-111220 | 750 | N |
| | 127-125865 | 720 | |
| | 127-126355 | 990 | N |
| Sleepy Eye Creek | 015-50009 | 2092 | N |
| | 015-50013 | 1200 | N |
| | 015-60703 | 1640 | N |
| | 015-71726 | 900 | N |
| | 015-71769 | 390 | N |
| | 015-71982 | 325 | N |
| | 015-72159 | 315 | N |
| | 015-72207 | 290 | N |
| | 015-72278 | 65.3 | N |
| | 015-82450 | 70 | N |
| | 015-82459 | 608 | N |
| | 015-82459 | 608 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-82460 | 750 | N |
| | 015-82476 | 750 | N |
| | 015-82840 | 612 | N |
| | 015-125789 | 744 | N |
| | 015-126350 | 30.66 | Y |
| | 127-50001 | 576 | N |
| | 127-50009 | 120 | N |
| | 127-50010 | 77 | N |
| | 127-50014 | 427 | N |
| | 127-50023 | 150 | N |
| | 127-50027 | 1420 | N |
| | 127-50029 | 500 | N |
| | 127-50032 | 600 | N |
| | 127-50033 | 54.08 | N |
| | 127-50036 | 198 | N |
| | 127-50042 | 902.5 | N |
| | 127-50046 | 499 | N |
| | 127-50047 | 912.5 | N |
| | 127-50049 | 80 | N |
| | 127-50051 | 1872 | N |
| | 127-50058 | 553 | N |
| | 127-50059 | 420.1 | N |
| | 127-50060 | 52 | N |
| | 127-50074 | 290 | N |
| | 127-50086 | 173.5 | N |
| | 127-60040 | 110.4 | N |
| | 127-60085 | 120.5 | N |
| | 127-60520 | 104 | N |
| | 127-60564 | 57.5 | N |
| | 127-60848 | 350 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-61729 | 177.5 | N |
| | 127-61738 | 660 | N |
| | 127-61742 | 180 | N |
| | 127-61761 | 54 | N |
| | 127-62182 | 97.5 | N |
| | 127-62466 | 200 | N |
| | 127-62475 | 226.5 | N |
| | 127-62523 | 92.5 | N |
| | 127-62695 | 480 | N |
| | 127-62697 | 165 | N |
| | 127-62699 | 390 | N |
| | 127-62872 | 272.8 | N |
| | 127-62875 | 14.4 | Y |
| | 127-62886 | 312.5 | N |
| | 127-62891 | 150 | N |
| | 127-62899 | 50 | N |
| | 127-62904 | 268 | N |
| | 127-63122 | 480 | N |
| | 127-63124 | 83 | N |
| | 127-63151 | 87.5 | N |
| | 127-63155 | 60 | N |
| | 127-63190 | 96.7 | N |
| | 127-63529 | 299 | N |
| | 127-63758 | 401.4 | N |
| | 127-63781 | 515 | N |
| | 127-64986 | 90 | N |
| | 127-65613 | 135 | N |
| | 127-65616 | 660 | N |
| | 127-101040 | 624 | N |
| | 127-105900 | 900 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-106300 | 936 | N |
| | 127-106840 | 177.1 | N |
| | 127-107260 | 760 | N |
| | 127-109480 | 270 | N |
| | 127-109820 | 432 | N |
| | 127-110620 | 936 | N |
| | 127-112698 | 360 | N |
| | 127-120771 | 720 | N |
| | 127-124541 | 1440 | N |
| | 127-125564 | 840 | N |
| | 127-125590 | 744 | N |
| | 127-125731 | 720 | N |
| | 127-126807 | 133.9 | N |
| | 127-127020 | 990 | N |
| Cottonwood River | 015-50002 | 1575 | N |
| | 015-50008 | 1200 | |
| | 015-71647 | 600 | N |
| | 015-71650 | 93.5 | Y |
| | 015-71654 | 153 | N |
| | 015-71673 | 70.6 | N |
| | 015-71675 | 624 | N |
| | 015-71678 | 41 | Y |
| | 015-71698 | 78.1 | N |
| | 015-71703 | 495.5 | N |
| | 015-71720 | 306 | N |
| | 015-71737 | 125 | N |
| | 015-71745 | 59.5 | N |
| | 015-71816 | 120 | N |
| | 015-71852 | 97.9 | Y |
| | 015-71853 | 17 | Y |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-71857 | 295 | N |
| | 015-71866 | 101.5 | N |
| | 015-71880 | 68.6 | N |
| | 015-71890 | 147 | N |
| | 015-71892 | 36 | Y |
| | 015-71905 | 311.8 | Y |
| | 015-71919 | 510 | N |
| | 015-71948 | 108 | N |
| | 015-71949 | 129.6 | N |
| | 015-71964 | 50 | Y |
| | 015-71968 | 70 | N |
| | 015-71973 | 57.425 | N |
| | 015-71987 | 98.2 | N |
| | 015-71999 | 60 | N |
| | 015-72029 | 194 | N |
| | 015-72049 | 108 | N |
| | 015-72059 | 465 | N |
| | 015-72066 | 163.9 | N |
| | 015-72068 | 80 | N |
| | 015-72074 | 645 | N |
| | 015-72139 | 1690 | N |
| | 015-72155 | 294 | N |
| | 015-72165 | 832 | N |
| | 015-72175 | 60 | N |
| | 015-72197 | 247.9 | Y |
| | 015-72226 | 61.075 | N |
| | 015-72236 | 75 | N |
| | 015-72238 | 675 | N |
| | 015-72282 | 75 | N |
| | 015-72283 | 60 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-72304 | 50.05 | N |
| | 015-72331 | 149 | N |
| | 015-72336 | 10.2 | Y |
| | 015-72353 | 95 | N |
| | 015-72357 | 81 | N |
| | 015-72369 | 128.6 | N |
| | 015-72375 | 196 | N |
| | 015-72395 | 62 | N |
| | 015-95056 | 318.5 | N |
| | 015-95134 | 72 | Y |
| | 015-95138 | 22.8 | Y |
| | 015-95147 | 247.1 | N |
| | 015-100000 | 1440 | N |
| | 015-107462 | 1200 | N |
| | 015-107843 | 170 | N |
| | 015-107846 | 123 | N |
| | 015-109481 | 936 | N |
| | 015-115641 | 80 | N |
| | 015-120278 | 97 | N |
| | 015-126352 | 102 | N |
| | 015-126800 | 100 | N |
| | 015--126427 | 85 | N |
| | 127-50088 | 2053 | N |
| | 127-50092 | 180 | N |
| | 127-50093 | 576 | N |
| | 127-60702 | 70 | N |
| | 127-61745 | 350 | N |
| | 127-61762 | 1895 | |
| | 127-62180 | 330 | N |
| | 127-63144 | 735 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-65511<br>127-112251<br>127-112801<br>127-117156<br>127-124992 | 660<br>800<br>720<br>945<br>412 | N<br>N<br>N<br>N |

**Table E- 2. Cottonwood River Watershed CAFO Summary.**

| **General** | |
|---|---|
| Total Feedlots | 513 |
| Total Permitted CAFO's | 64 |
| Total Animal Units (AUs) | 228,065 |
| Primary Animal Type[1] | Swine (53%) |
| | Cattle (45%) |
| **Sensitive Areas** | |
| Open Lot Feedlots | 322 |
| Feedlots in Shoreland | 46 |
| Open Lot Feedlots in Shoreland | 37 |

[1]Percentages are based on animal units.

# Appendix D – 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 |

# 1 Introduction

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

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

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

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

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

# 2 Approach

## 2.1 Goals and Objectives for Recalibration

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

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

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

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

**Table 1. Sediment Apportionment Calibration Targets**

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

## 2.2 Sediment Performance Metrics

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

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

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

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

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

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

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

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

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

## 2.3 Calibration and Validation/Corroboration

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

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

## 2.4 Components not Adjusted

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

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

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

Also significant to the sediment recalibration are the following:

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

# 3 Calibration Gage Sites

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

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

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

### Table 3. Sediment Calibration and Corroboration Stations

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

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

* Name truncated in RESPEC database

# 4 Model Updates

## 4.1 Model Structural Reconfiguration

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

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

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

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

## 4.2 Upland Sediment Simulation

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

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

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

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

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

### Table 4. KRER Values Used for Updated Models

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

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

### Table 5. KSER Values Used for Updated Models

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

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

**Table 6. KEIM Values Used for Updated Models**

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

**Table 7. Typical Monthly Cover Values Used for Updated Models**

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

## 4.3 INSTREAM SEDIMENT SIMULATION

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

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

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

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

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

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

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

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

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

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

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

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

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

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

## 4.4 Sediment Source Apportionment

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

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

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

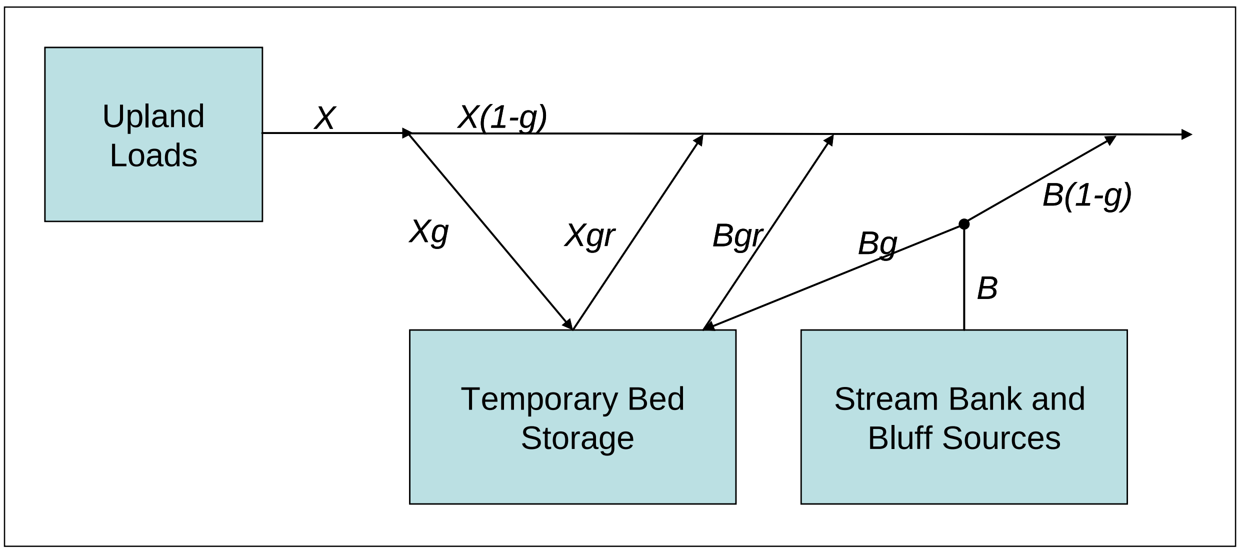



**Figure 1. Conceptual Representation of Stream Sediment Processing**

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

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

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

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

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

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

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

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

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

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

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

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

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

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

# 5 Results

## 5.1 Upland Unit Area Loads

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

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

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

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

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

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

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

## 5.2 Instream Calibration and Validation

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

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

### 5.2.1 Calibration Stations

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

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

**Table 11. Summary Statistics for Calibration Stations**

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

**(Table 11. Continued)**

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

**(Table 11. Continued)**

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

**(Table 11. Continued)**

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

**(Table 11. Continued)**

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

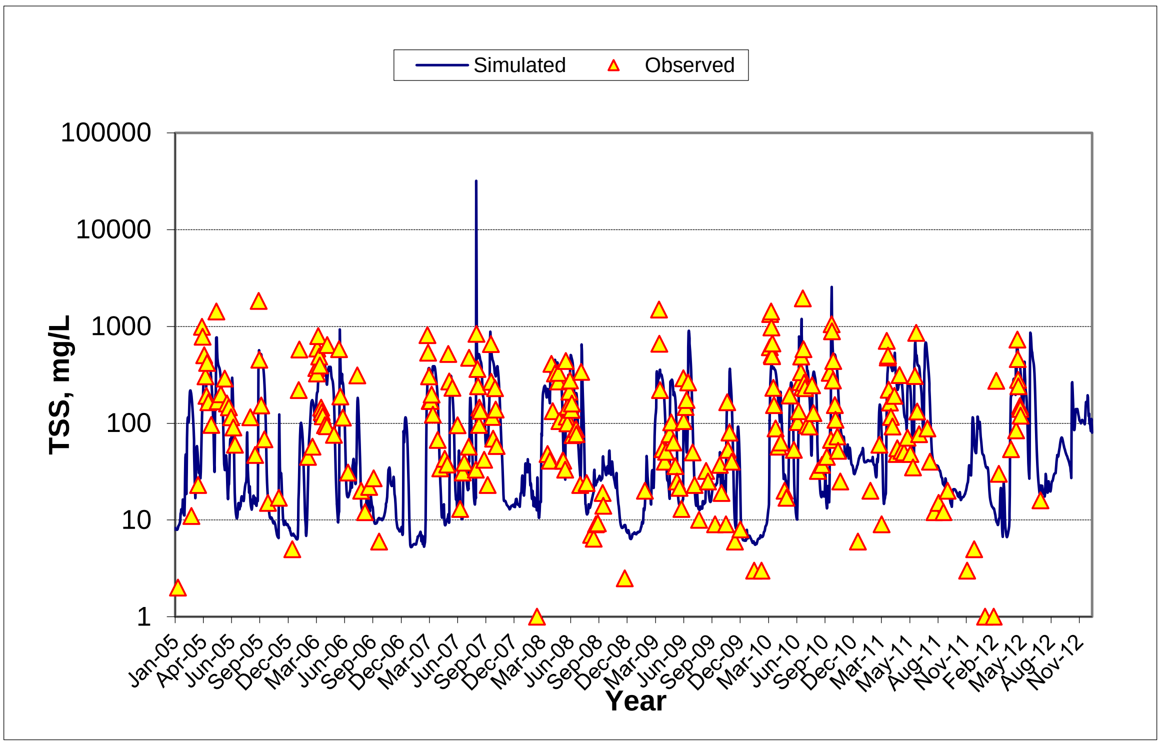



**Figure 2. Timeseries Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012**

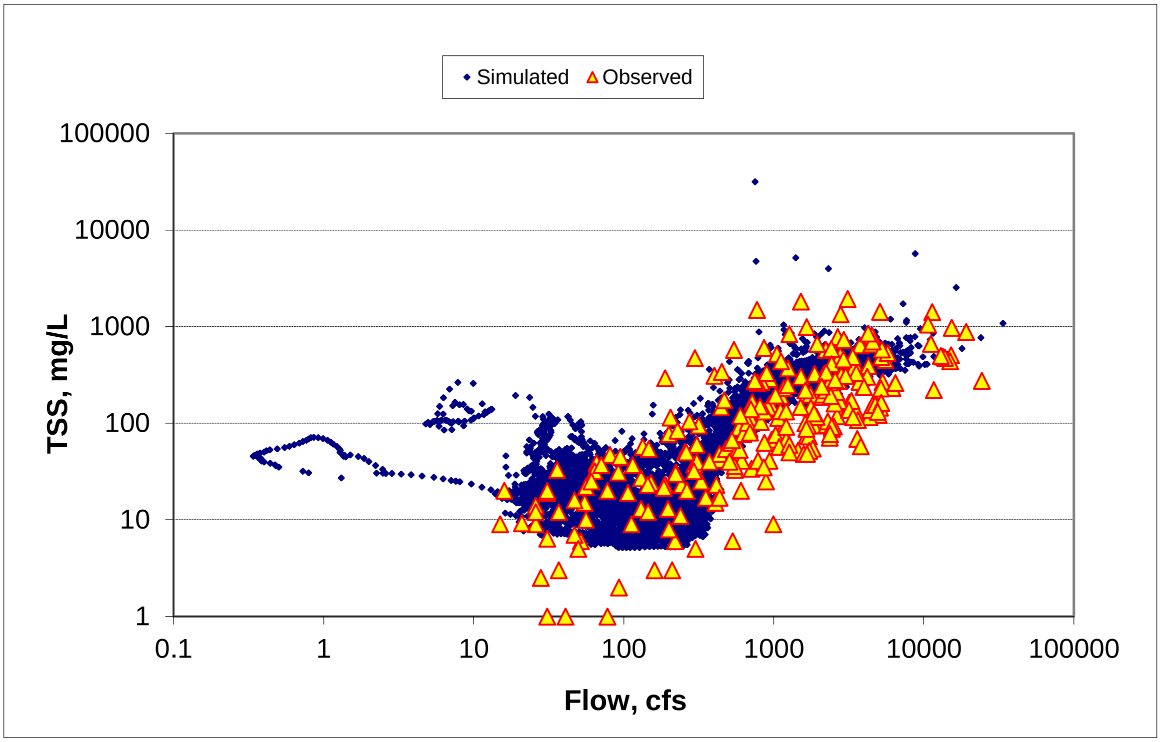



**Figure 3. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012**

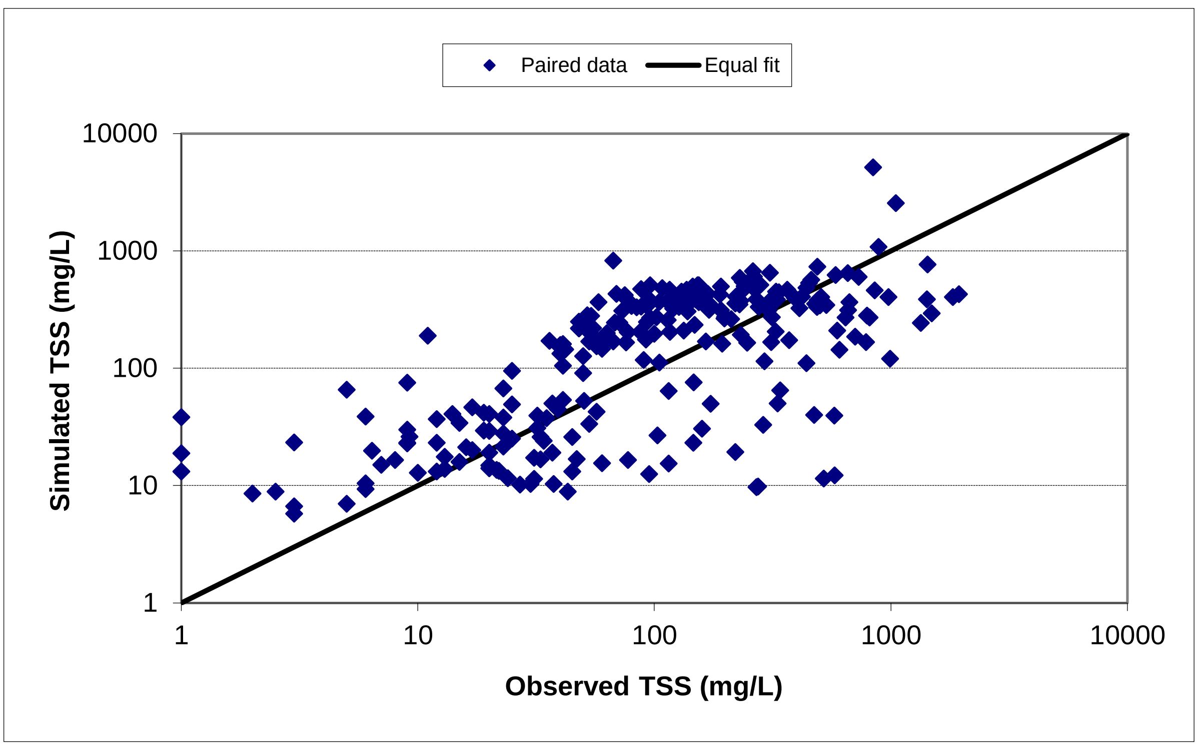



**Figure 4. Simulated and Observed TSS Concentration Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012**

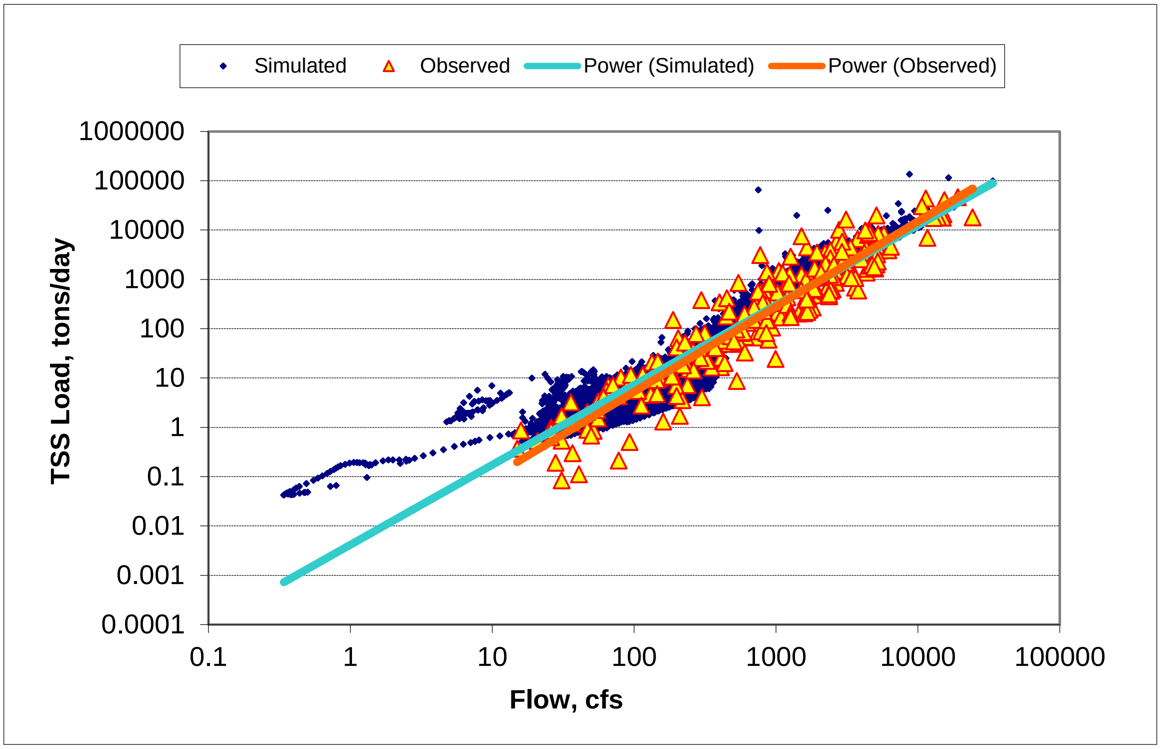



**Figure 5. Load vs Flow Plot of Simulated and Observed TSS Load for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012**

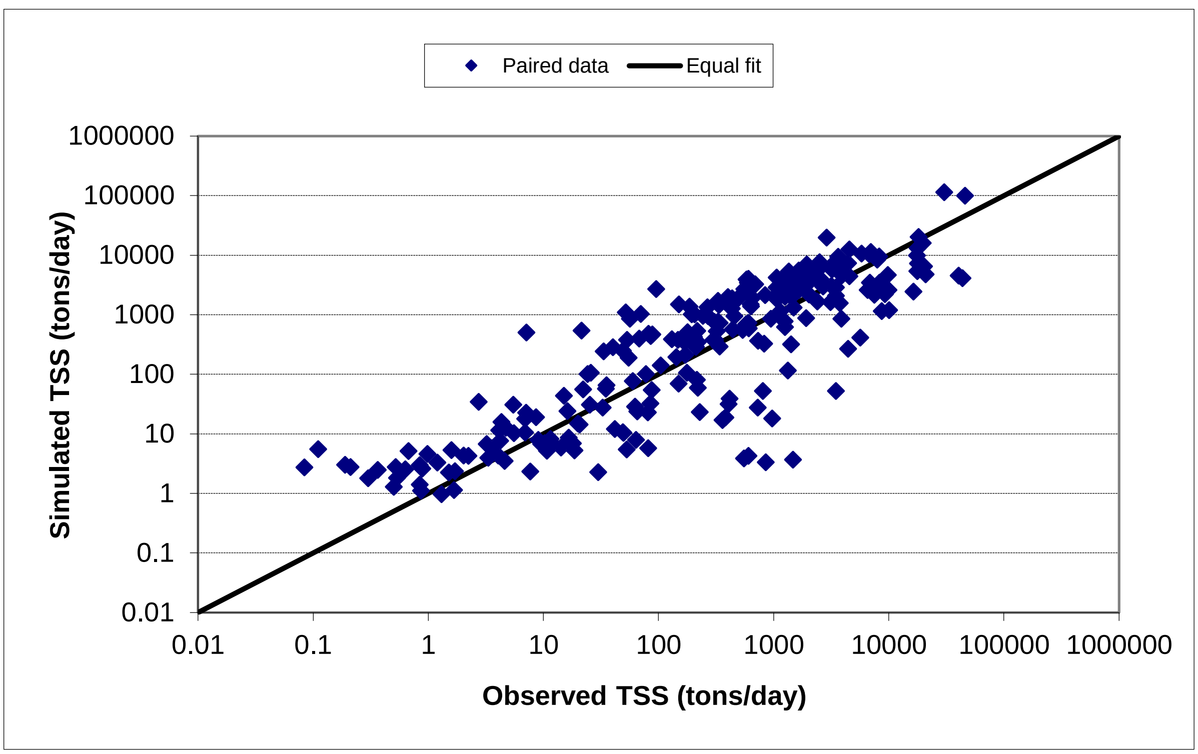



**Figure 6. Simulated and Observed TSS Load Paired Regression Plot for Le Sueur River at MN-66 1.5 miles NE of Rapidan for 2005-2012**

## 5.2.2 Validation Stations

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

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

**Table 12. Summary Statistics for Validation Stations**

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

**(Table 12. Continued)**

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

**(Table 12. Continued)**

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

**(Table 12. Continued)**

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

**(Table 12. Continued)**

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

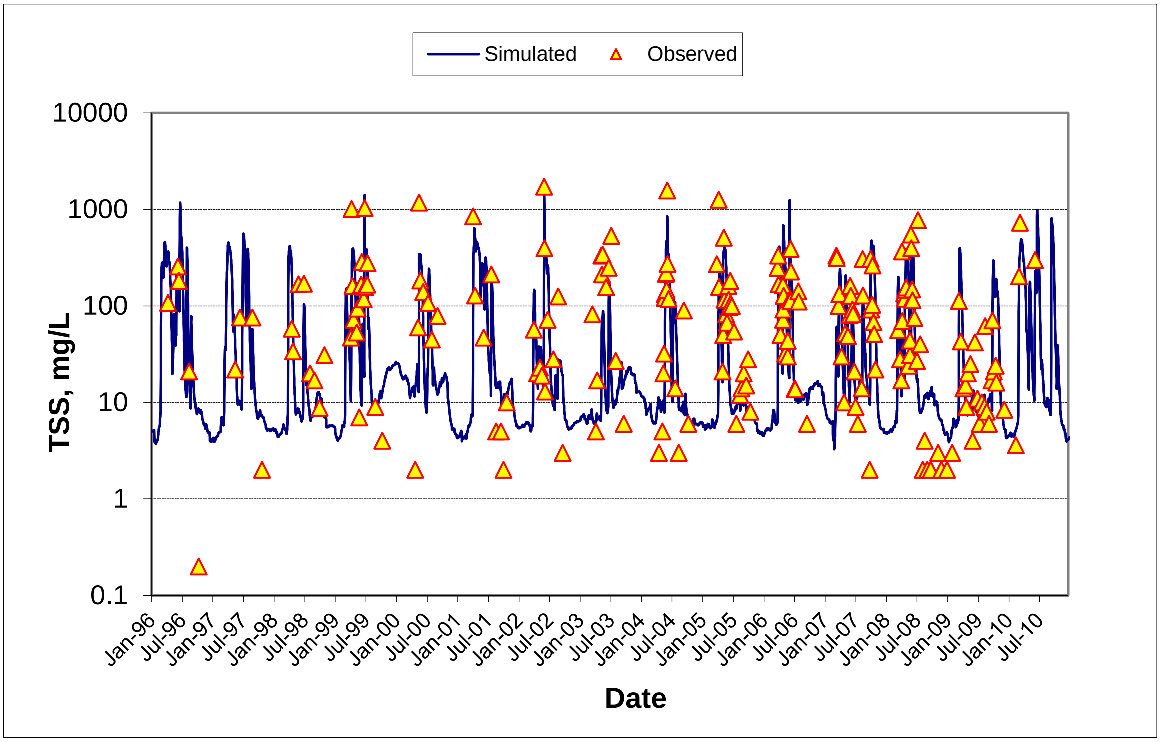



**Figure 7. Timeseries Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010**

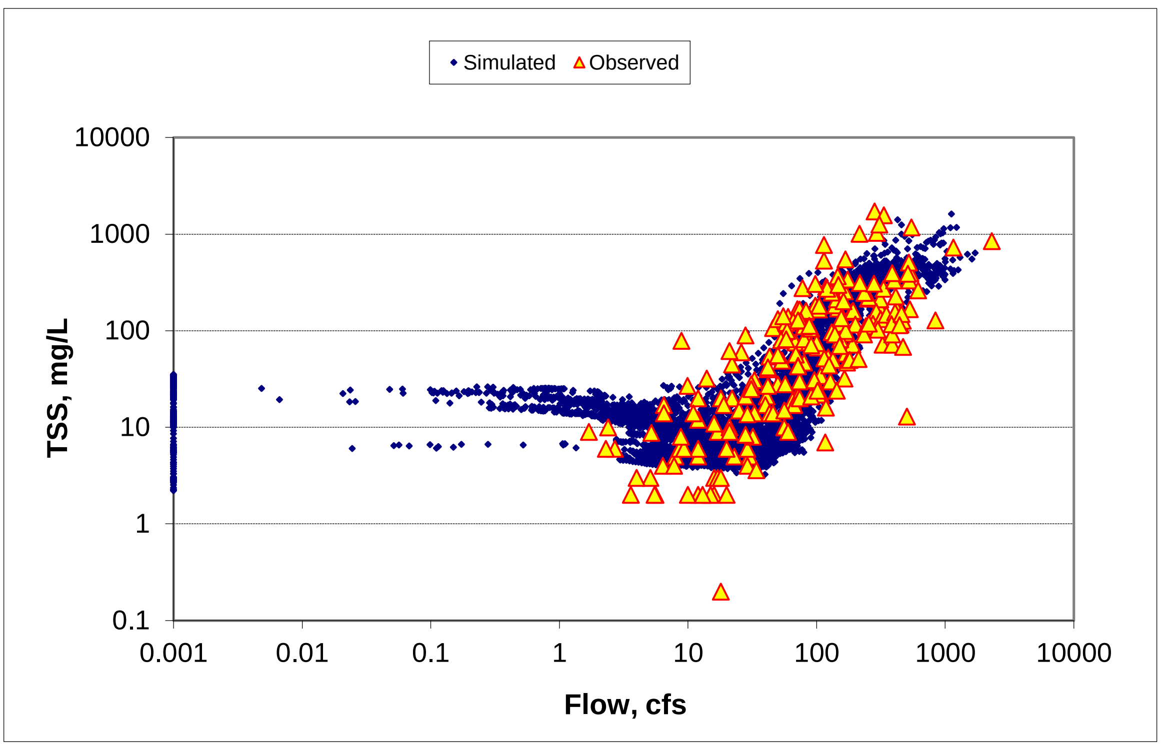



**Figure 8. Concentration vs Flow Plot of Simulated and Observed TSS Concentration for Little Cottonwood River at Apple Road for 1996-2010**

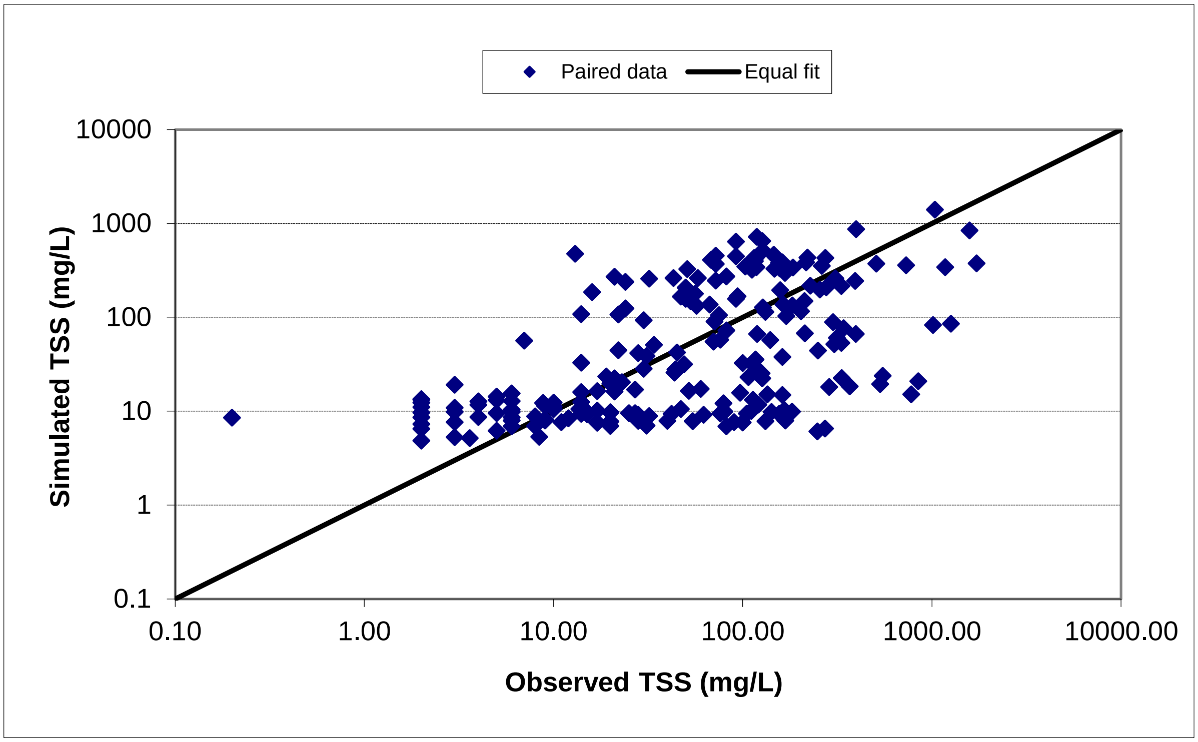



**Figure 9. Simulated and Observed TSS Concentration Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010**

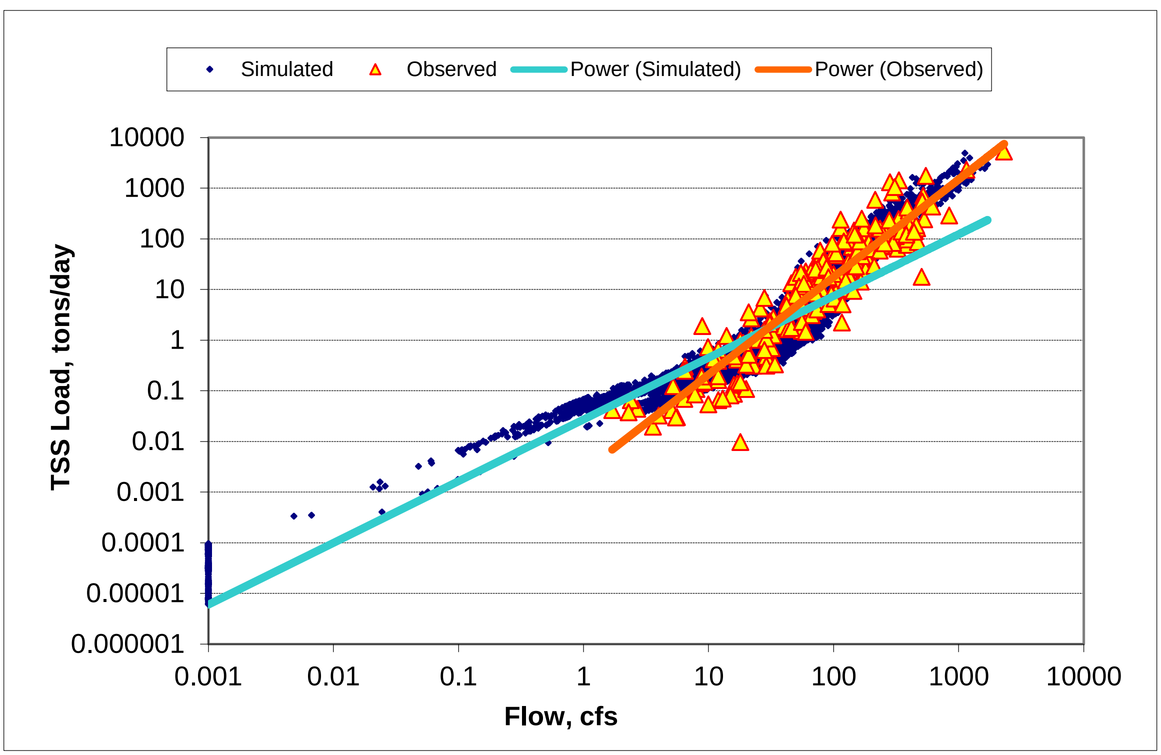



**Figure 10. Load vs Flow Plot of Simulated and Observed TSS Load for Little Cottonwood River at Apple Road for 1996-2010**

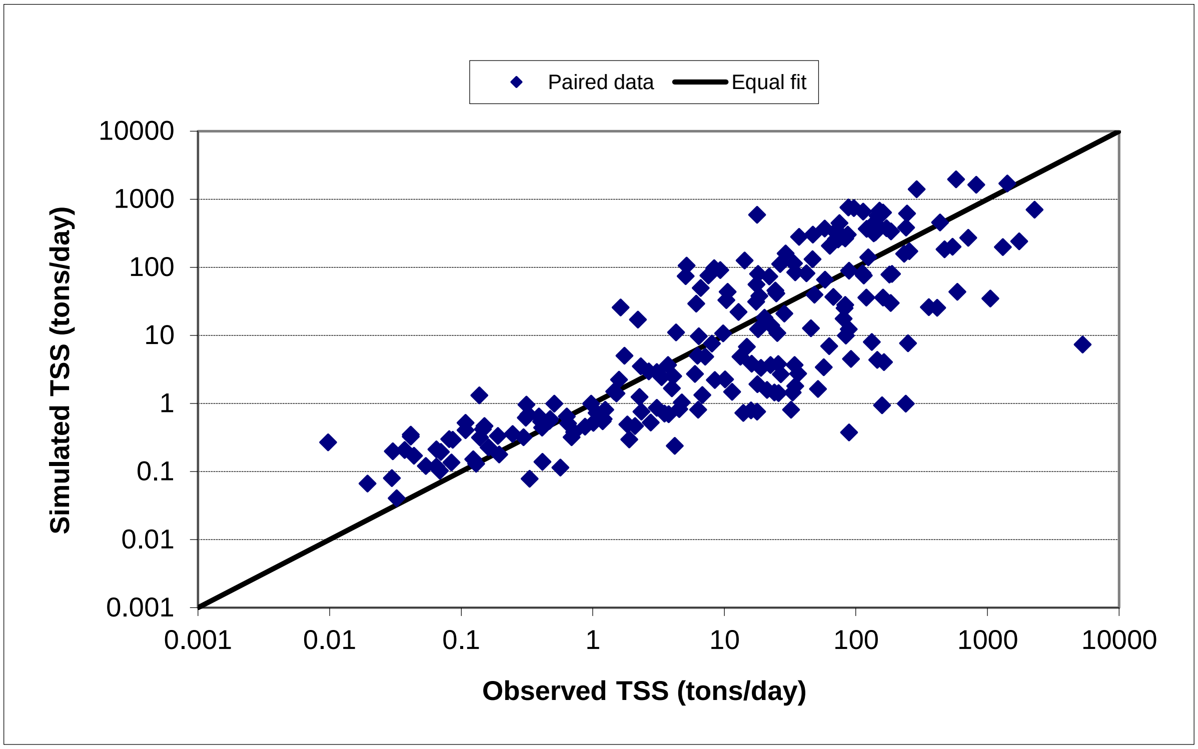



**Figure 11. Simulated and Observed TSS Load Paired Regression Plot for Little Cottonwood River at Apple Road for 1996-2010**

## 5.3 Comparison to FLUX Loads

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

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


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

## 5.4 SEDIMENT SOURCE APPORTIONMENT

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

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

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

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

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

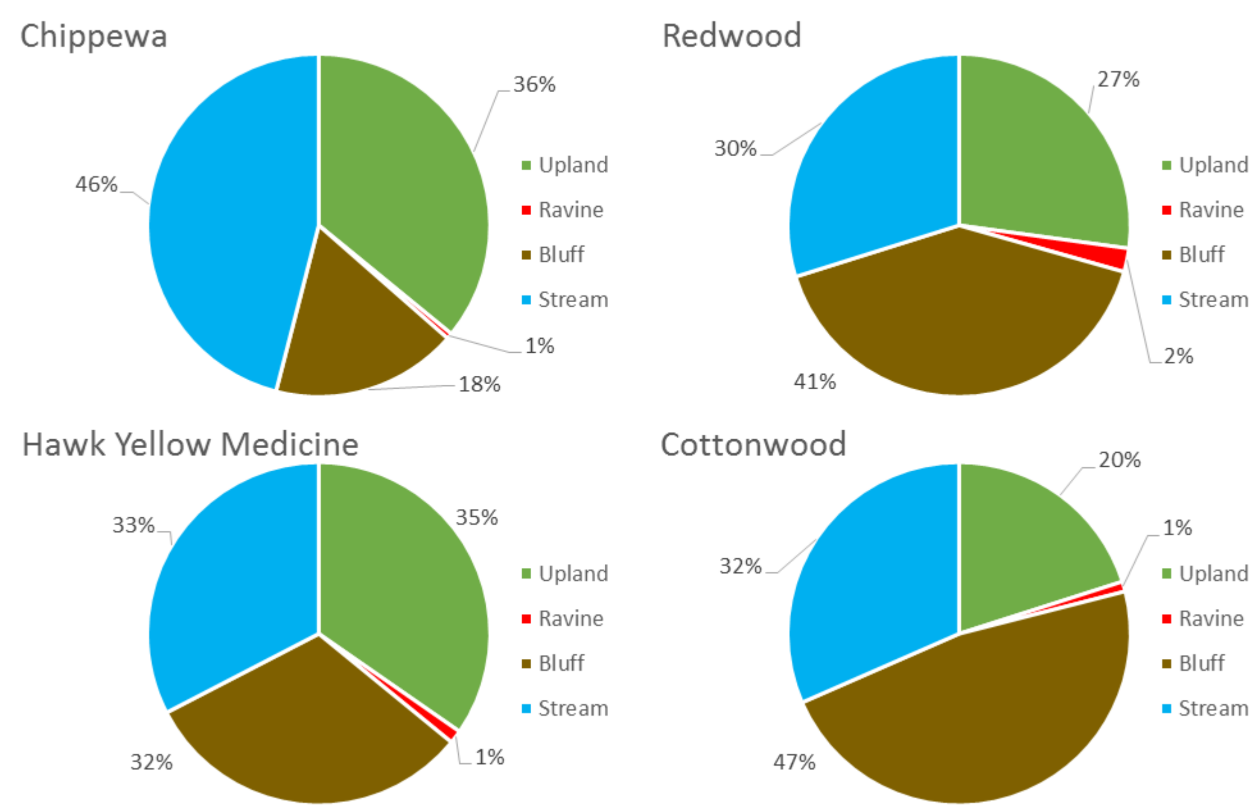
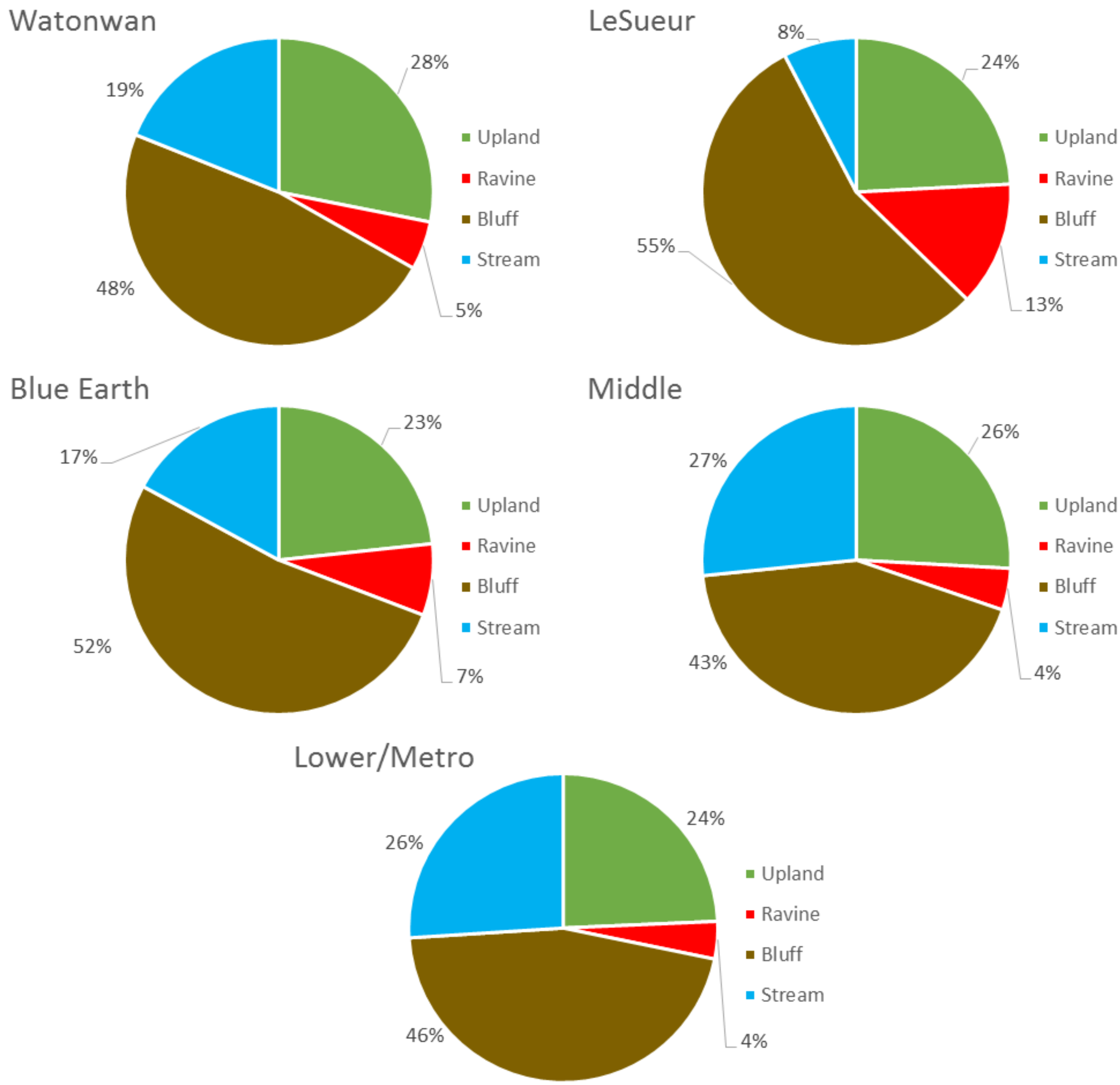



**Figure 13. Instream Sediment Source Apportionment at HUC8 Outlets**




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

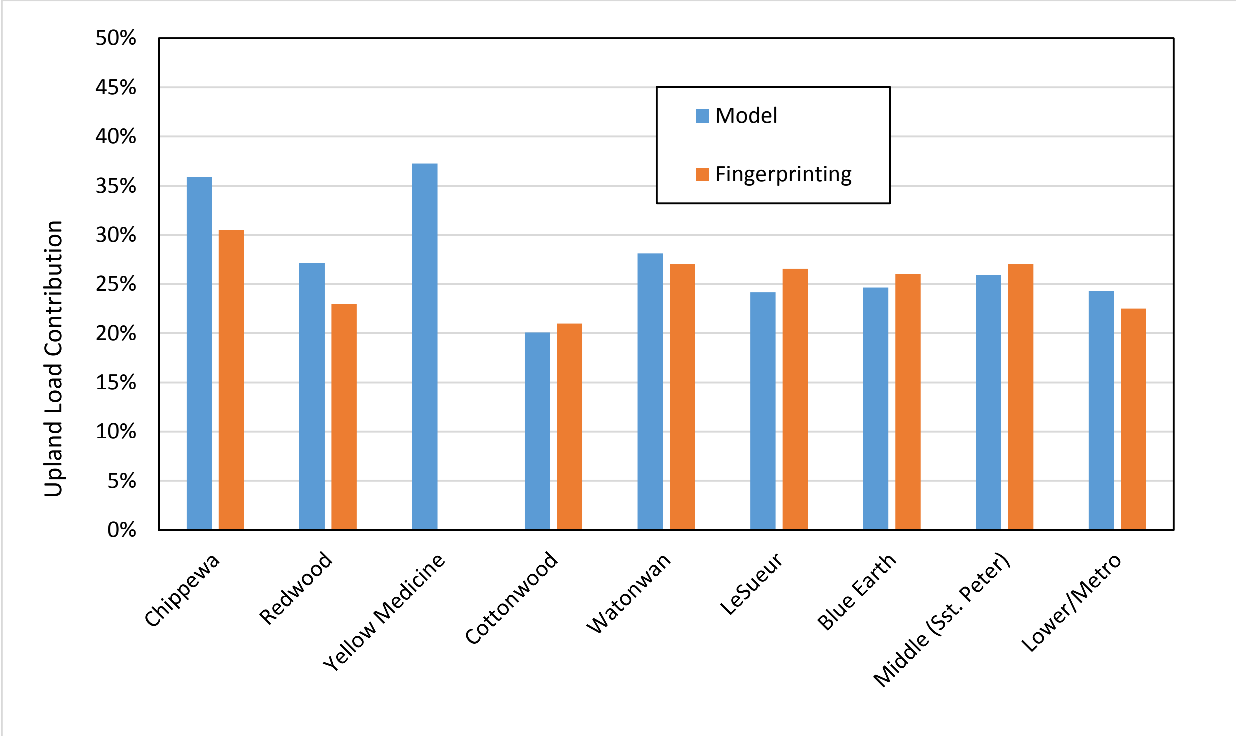



**Figure 14. Comparison of Simulated Surface Washoff Loading to Surface Source Fraction from Sediment Fingerprinting Analysis**

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

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

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

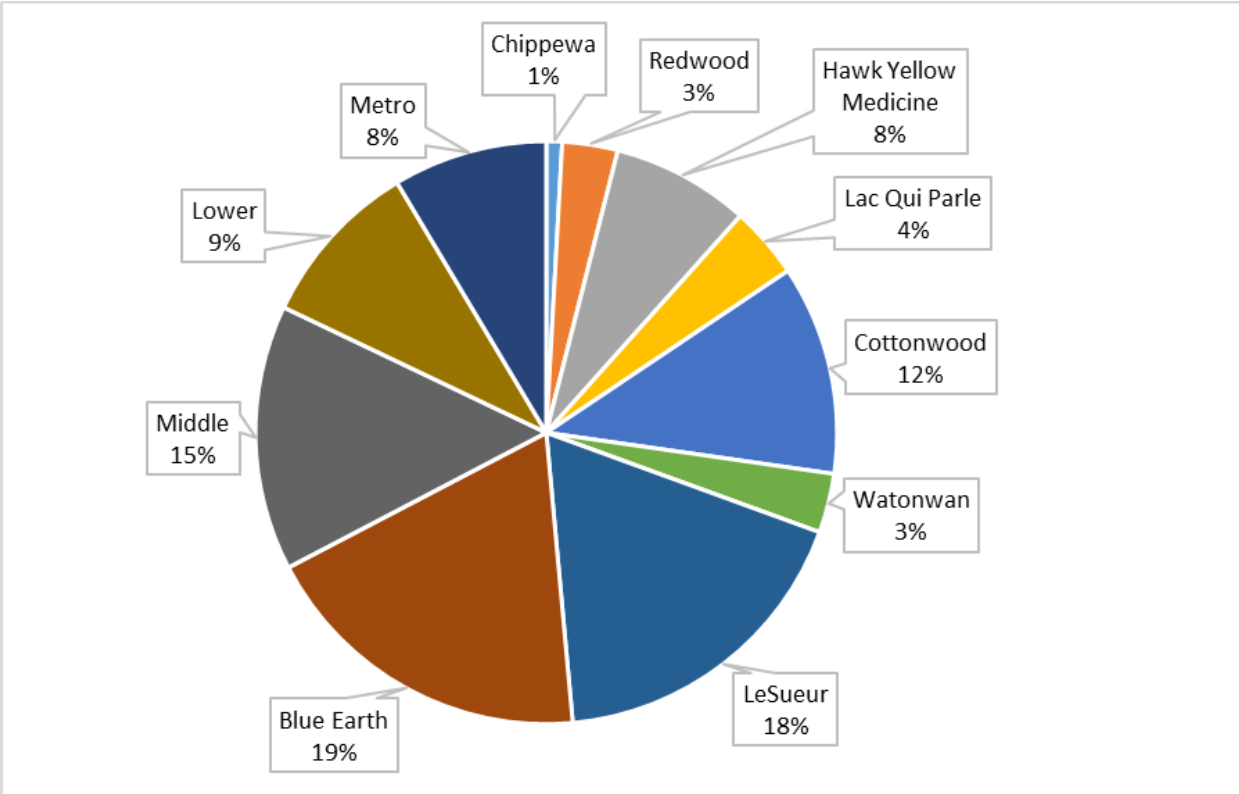



**Figure 15. HUC8 Contributions to Sediment Load at the Mouth of the Metro Model**

# 6 Summary and Potential Enhancements

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

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

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

3. **Ravine and Bluff Areas**: At the start of this work assignment it was anticipated that new information on the extent of ravine and bluff land use areas would be provided for each HUC8 watershed. Those coverages have not been finalized (and the current bluff coverage based on LiDAR appears to delineate features such as ditch banks as "bluffs," which is not particularly useful to basin-scale modeling). When these delineation efforts are completed the models should be updated to incorporate the information.

4. **Parameters for Manured Land**: It required a considerable amount of time to reach an agreement with MPCA on the appropriate approach to determine the land area that received manure applications. Manure applications have impacts on nutrient loading, but also change the soil structure in somewhat subtle ways that can change runoff and sediment loading impacts. Due to the delay in resolving the manured land area representation, the definition of manured area was not finalized until after the hydrologic recalibration had been completed. To avoid disturbing the hydrologic calibration, the manure application areas were specified (and area shifted from) as equal to existing conventional tillage on A/B soils. In fact, evidence (summarized in Tetra Tech, 2008) suggests that land receiving manure application should have somewhat greater upper zone storage capacity (UZSN), which in turn affects runoff sediment transport capacity. This refinement should be incorporated into any revised models.

5. **Tile Drain Sediment**: RESPEC (2014) adopted a modified approach to the simulation of sediment transport through surface tile inlets that was much simpler and more efficient than the SPECIAL ACTIONS approach implemented by Tetra Tech (2008). The revised approach gives a similar estimate of total sediment load transported by this pathway, but the pollutograph is very different, with the load transmitted to the stream much more quickly. At this point it is not clear which representation is correct, although the approach earlier use by Tetra Tech did result in a good match between observed and simulated sediment concentrations. This topic appears worthy of further investigation.

# 7 References

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# MEMORANDUM

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

## 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 i[th] interval after n level of subdivision is shown as $\Delta_n^i$ (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 $\lambda_n$ 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" $\Delta_n^i$ (or i[th] interval in the n[th] 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:

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

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, $\delta$ 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 $1.27 \times 10^{-7}$ (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 E – CAFO List and Watershed Summary

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

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| Headwaters – Cottonwood River | 083-50002 | 973 | N |
| | 083-50003 | 1440 | N |
| | 083-50015 | 300 | N |
| | 083-60847 | 140 | N |
| | 083-62344 | 400 | N |
| | 083-62428 | 473.5 | N |
| | 083-62444 | 650 | N |
| | 083-62543 | 285 | N |
| | 083-62553 | 693 | N |
| | 083-62704 | 57.8 | N |
| | 083-62734 | 150 | N |
| | 083-62825 | 1080 | N |
| | 083-62848 | 602.5 | Y |
| | 083-62856 | 490 | N |
| | 083-62862 | 386 | N |
| | 083-62863 | 300 | N |
| | 083-62926 | 999 | N |
| | 083-62928 | 660 | N |
| | 083-63509 | 138 | N |
| | 083-63783 | 169 | N |
| | 083-65527 | 297.5 | N |
| | 083-80220 | 980 | N |
| | 083-83840 | 711 | N |
| | 083-89079 | 600 | N |
| | 083-98301 | 1248 | N |
| | 083-100060 | 600 | N |
| | 083-104800 | 210 | N |
| | 083-105640 | 66 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 083-109880 | 2700 | N |
| | 083-113093 | 980 | N |
| | 083-113278 | 720 | N |
| | 083-119803 | 820 | N |
| | 083-121082 | 720 | N |
| | 083-121083 | 60 | N |
| | 083-124355 | 600 | N |
| | 083-125550 | 299 | N |
| Meadow Creek | 083-50012 | 700 | N |
| | 083-50014 | 840 | N |
| | 083-50024 | 1248 | N |
| | 083-60844 | 500 | N |
| | 083-61769 | 88 | N |
| | 083-61770 | 540 | Y |
| | 083-61803 | 373 | N |
| | 083-62112 | 177 | N |
| | 083-62170 | 500 | N |
| | 083-62425 | 395 | N |
| | 083-62427 | 500 | N |
| | 083-62441 | 165 | N |
| | 083-62541 | 210 | Y |
| | 083-62542 | 210 | Y |
| | 083-62563 | 525 | N |
| | 083-62691 | 200 | N |
| | 083-62709 | 720 | N |
| | 083-62737 | 238.6 | N |
| | 083-62842 | 880 | N |
| | 083-65081 | 397 | N |
| | 083-68166 | 485 | N |
| | 083-87104 | 4500 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 083-106440 | 72 | N |
| | 083-111440 | 285 | N |
| | 083-121434 | 202.5 | N |
| | 083-121438 | 190 | N |
| | 083-125701 | 720 | |
| | 083-125800 | 1440 | |
| | 083-125999 | 720 | |
| | 083-126540 | 720 | N |
| Plum Creek | 083-50007 | 2520 | |
| | 101-68937 | 590 | N |
| | 101-68950 | 54 | N |
| | 101-77051 | 50 | N |
| | 101-77080 | 270 | N |
| | 101-77154 | 160.2 | N |
| | 101-77185 | 74 | N |
| | 101-77400 | 231 | N |
| | 101-88975 | 171 | N |
| | 101-88981 | 660 | N |
| | 101-88985 | 120 | N |
| | 101-88990 | 133 | N |
| | 101-89012 | 132 | Y |
| | 101-89021 | 420 | N |
| | 101-89037 | 340 | N |
| | 101-107508 | 85 | N |
| | 101-107847 | 110 | N |
| | 101-107848 | 30 | Y |
| | 101-107849 | 56 | N |
| | 101-107853 | 75.9 | N |
| | 101-119167 | 150 | N |
| | 101-121921 | 200 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 101-126420 | 720 | N |
| | 127-50083 | 240 | N |
| | 127-50084 | 845 | N |
| | 127-50085 | 620 | N |
| | 127-62486 | 95 | N |
| | 127-62506 | 60 | N |
| | 127-62745 | 158 | N |
| | 127-62750 | 222 | N |
| | 127-63074 | 999 | N |
| | 127-63123 | 84 | N |
| | 127-63790 | 268 | N |
| | 127-105560 | 390 | N |
| | 127-114503 | 97.5 | N |
| Pell Creek – Cottonwood River | 033-97854 | 23.5 | Y |
| | 033-97989 | 60 | N |
| | 083-50010 | 20 | Y |
| | 083-50011 | 48 | Y |
| | 083-50029 | 1200 | N |
| | 083-50030 | 750 | N |
| | 083-62706 | 195 | N |
| | 083-62836 | 20.6 | Y |
| | 083-63796 | 50 | N |
| | 083-65618 | 71 | N |
| | 083-119884 | 1440 | N |
| | 101-107850 | 1470.5 | N |
| | 127-50031 | 888.5 | N |
| | 127-50056 | 295 | N |
| | 127-50061 | 698.4 | N |
| | 127-50063 | 1728 | Y |
| | 127-50066 | 166 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-50080 | 632.5 | N |
| | 127-50097 | 90 | N |
| | 127-60086 | 95 | N |
| | 127-62328 | 141 | N |
| | 127-62472 | 180 | N |
| | 127-62507 | 321.5 | N |
| | 127-62694 | 350 | N |
| | 127-62954 | 154 | N |
| | 127-62959 | 62 | N |
| | 127-62969 | 162 | N |
| | 127-65083 | 346 | N |
| | 127-65084 | 142.5 | N |
| | 127-65520 | 270 | N |
| | 127-80028 | 131 | N |
| | 127-80102 | 1200 | N |
| | 127-98160 | 990 | N |
| | 127-99980 | 936 | N |
| | 127-105720 | 600 | N |
| | 127-117681 | 735 | N |
| | 127-125907 | 375 | |
| Dutch Charley Creek | 033-50001 | 1177 | N |
| | 033-50006 | 4480 | Y |
| | 033-60187 | 1715 | N |
| | 033-97860 | 720 | N |
| | 033-97879 | 265 | N |
| | 033-97881 | 845 | N |
| | 033-97882 | 210 | N |
| | 033-97908 | 600 | N |
| | 033-97910 | 291 | Y |
| | 033-97912 | 80 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-97914 | 200 | N |
| | 033-97915 | 140 | N |
| | 033-97918 | 82 | N |
| | 033-97919 | 80 | N |
| | 033-97929 | 139 | N |
| | 033-97935 | 60 | N |
| | 033-97938 | 60 | N |
| | 033-97939 | 135 | N |
| | 033-97940 | 90 | N |
| | 033-97965 | 42 | Y |
| | 033-97970 | 150 | N |
| | 033-97974 | 980 | N |
| | 033-97976 | 220 | N |
| | 033-97978 | 122.765 | N |
| | 033-97981 | 290.5 | N |
| | 033-97992 | 139.25 | N |
| | 033-97993 | 150 | N |
| | 033-97997 | 990 | N |
| | 033-97999 | 150 | N |
| | 033-98002 | 38 | Y |
| | 033-98005 | 280 | N |
| | 033-98032 | 705 | N |
| | 033-98033 | 570 | N |
| | 033-98035 | 310.5 | N |
| | 033-98047 | 183 | N |
| | 033-98061 | 89 | N |
| | 033-98063 | 150 | N |
| | 033-98065 | 84 | N |
| | 033-98078 | 150 | N |
| | 033-98080 | 150 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-98081 | 990 | N |
| | 033-98088 | 200 | N |
| | 033-98095 | 588 | N |
| | 033-98102 | 141 | N |
| | 033-98107 | 90 | N |
| | 033-102342 | 990 | N |
| | 033-102566 | 250.3 | N |
| | 033-102577 | 530 | N |
| | 033-103543 | 60 | N |
| | 033-103552 | 960 | N |
| | 033-104200 | 1342.5 | |
| | 033-104201 | 990 | N |
| | 033-107458 | 56 | N |
| | 033-108225 | 250 | N |
| | 033-108322 | 120 | N |
| | 033-110360 | 1342.5 | N |
| | 033-117658 | 930 | N |
| | 033-120691 | 750 | N |
| | 033-125533 | 60 | N |
| | 033-125751 | 1290 | N |
| | 033-125896 | 360 | N |
| | 033-126396 | 720 | |
| | 101-50005 | 2126.4 | |
| | 101-68939 | 50 | Y |
| | 101-77068 | 399 | N |
| | 101-77069 | 119 | N |
| | 101-77135 | 120 | N |
| | 101-77141 | 16.3 | Y |
| | 101-77169 | 95 | N |
| | 101-77170 | 53.5 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 101-77388 | 180 | N |
| | 101-77389 | 100 | N |
| | 101-88997 | 50 | N |
| | 101-89033 | 193 | Y |
| | 101-108062 | 128 | N |
| | 101-108064 | 325 | N |
| | 101-108066 | 16 | Y |
| | 101-108076 | 60 | |
| | 101-114832 | 480 | N |
| | 127-50034 | 180.7 | N |
| | 127-62710 | 110 | N |
| | 127-122138 | 100 | N |
| Mound Creek – Cottonwood River | 015-50005 | 1872 | N |
| | 015-71652 | 33 | Y |
| | 015-71655 | 450 | N |
| | 015-71671 | 1125 | N |
| | 015-71702 | 497.4 | Y |
| | 015-71716 | 350 | N |
| | 015-71727 | 2936.3 | N |
| | 015-71740 | 171 | N |
| | 015-71744 | 160 | N |
| | 015-71757 | 120 | N |
| | 015-71787 | 90 | N |
| | 015-71794 | 195 | N |
| | 015-71810 | 195 | N |
| | 015-71824 | 192.5 | N |
| | 015-71856 | 285 | N |
| | 015-71872 | 160 | N |
| | 015-71876 | 78 | N |
| | 015-71889 | 90 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-71921 | 295 | N |
| | 015-71933 | 590 | N |
| | 015-71966 | 125.5 | N |
| | 015-72003 | 216 | N |
| | 015-72024 | 115 | N |
| | 015-72032 | 160 | N |
| | 015-72035 | 182 | Y |
| | 015-72041 | 900 | N |
| | 015-72075 | 624 | N |
| | 015-72094 | 91 | N |
| | 015-72098 | 735 | N |
| | 015-72107 | 900 | N |
| | 015-72127 | 163 | N |
| | 015-72138 | 225 | N |
| | 015-72147 | 400 | N |
| | 015-72162 | 990 | N |
| | 015-72168 | 242 | N |
| | 015-72171 | 55 | Y |
| | 015-72178 | 110 | N |
| | 015-72200 | 325 | N |
| | 015-72204 | 300 | N |
| | 015-72210 | 138.07 | Y |
| | 015-72217 | 112 | Y |
| | 015-72218 | 180 | Y |
| | 015-72223 | 315 | N |
| | 015-72233 | 50 | N |
| | 015-72244 | 840 | N |
| | 015-72246 | 90 | Y |
| | 015-72273 | 992 | N |
| | 015-72285 | 96.12 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-72315 | 213.6 | N |
| | 015-72317 | 500 | N |
| | 015-72324 | 50 | N |
| | 015-72328 | 1106 | |
| | 015-72332 | 160 | N |
| | 015-80242 | 258 | N |
| | 015-82445 | 85 | N |
| | 015-82469 | 102 | Y |
| | 015-82477 | 300 | N |
| | 015-93741 | 360 | N |
| | 015-95050 | 144 | N |
| | 015-95133 | 84 | Y |
| | 015-95136 | 125 | N |
| | 015-95141 | 300 | N |
| | 015-95145 | 565.5 | Y |
| | 015-95148 | 1106 | |
| | 015-105820 | 900 | N |
| | 015-105961 | 900 | N |
| | 015-107460 | 1600 | N |
| | 015-107461 | 295 | N |
| | 015-108312 | 620 | N |
| | 015-109414 | 810 | N |
| | 015-115876 | 595 | N |
| | 015-117075 | 421 | N |
| | 015-119172 | 250 | Y |
| | 015-125529 | 900 | |
| | 015-126342 | 748.5 | N |
| | 015-127146 | 270 | N |
| | 015-127195 | 990 | N |
| | 033-50011 | 1682 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-97856 | 480 | N |
| | 033-97885 | 73.126 | N |
| | 033-97894 | 100 | N |
| | 033-97909 | 210 | N |
| | 033-97922 | 94 | N |
| | 033-97925 | 56 | N |
| | 033-97926 | 60 | N |
| | 033-97932 | 217 | N |
| | 033-97933 | 789 | N |
| | 033-97934 | 60.3 | N |
| | 033-97944 | 72 | N |
| | 033-97948 | 250 | N |
| | 033-97952 | 343.5 | N |
| | 033-97954 | 265.4 | N |
| | 033-97959 | 211 | N |
| | 033-97962 | 133 | N |
| | 033-97968 | 950 | N |
| | 033-97975 | 180 | N |
| | 033-97998 | 300 | N |
| | 033-98016 | 900 | N |
| | 033-98024 | 55.725 | N |
| | 033-98025 | 209 | N |
| | 033-98038 | 450 | N |
| | 033-98048 | 482.5 | N |
| | 033-98051 | 61.4 | N |
| | 033-98068 | 780 | N |
| | 033-98069 | 75 | N |
| | 033-98076 | 930 | N |
| | 033-98089 | 117 | N |
| | 033-98098 | 998.9 | Y |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 033-98099 | 900 | N |
| | 033-98103 | 999 | N |
| | 033-103542 | 50 | N |
| | 033-103546 | 240 | N |
| | 033-103548 | 500 | N |
| | 033-105840 | 900 | N |
| | 033-108226 | 57.7 | N |
| | 033-110813 | 600 | N |
| | 033-112558 | 900 | N |
| | 033-121655 | 84 | Y |
| | 127-50079 | 128 | N |
| | 127-62535 | 78.53 | N |
| | 127-62536 | 102 | N |
| | 127-63134 | 225 | N |
| | 127-98660 | 900 | N |
| | 127-111220 | 750 | N |
| | 127-125865 | 720 | |
| | 127-126355 | 990 | N |
| Sleepy Eye Creek | 015-50009 | 2092 | N |
| | 015-50013 | 1200 | N |
| | 015-60703 | 1640 | N |
| | 015-71726 | 900 | N |
| | 015-71769 | 390 | N |
| | 015-71982 | 325 | N |
| | 015-72159 | 315 | N |
| | 015-72207 | 290 | N |
| | 015-72278 | 65.3 | N |
| | 015-82450 | 70 | N |
| | 015-82459 | 608 | N |
| | 015-82459 | 608 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-82460 | 750 | N |
| | 015-82476 | 750 | N |
| | 015-82840 | 612 | N |
| | 015-125789 | 744 | N |
| | 015-126350 | 30.66 | Y |
| | 127-50001 | 576 | N |
| | 127-50009 | 120 | N |
| | 127-50010 | 77 | N |
| | 127-50014 | 427 | N |
| | 127-50023 | 150 | N |
| | 127-50027 | 1420 | N |
| | 127-50029 | 500 | N |
| | 127-50032 | 600 | N |
| | 127-50033 | 54.08 | N |
| | 127-50036 | 198 | N |
| | 127-50042 | 902.5 | N |
| | 127-50046 | 499 | N |
| | 127-50047 | 912.5 | N |
| | 127-50049 | 80 | N |
| | 127-50051 | 1872 | N |
| | 127-50058 | 553 | N |
| | 127-50059 | 420.1 | N |
| | 127-50060 | 52 | N |
| | 127-50074 | 290 | N |
| | 127-50086 | 173.5 | N |
| | 127-60040 | 110.4 | N |
| | 127-60085 | 120.5 | N |
| | 127-60520 | 104 | N |
| | 127-60564 | 57.5 | N |
| | 127-60848 | 350 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-61729 | 177.5 | N |
| | 127-61738 | 660 | N |
| | 127-61742 | 180 | N |
| | 127-61761 | 54 | N |
| | 127-62182 | 97.5 | N |
| | 127-62466 | 200 | N |
| | 127-62475 | 226.5 | N |
| | 127-62523 | 92.5 | N |
| | 127-62695 | 480 | N |
| | 127-62697 | 165 | N |
| | 127-62699 | 390 | N |
| | 127-62872 | 272.8 | N |
| | 127-62875 | 14.4 | Y |
| | 127-62886 | 312.5 | N |
| | 127-62891 | 150 | N |
| | 127-62899 | 50 | N |
| | 127-62904 | 268 | N |
| | 127-63122 | 480 | N |
| | 127-63124 | 83 | N |
| | 127-63151 | 87.5 | N |
| | 127-63155 | 60 | N |
| | 127-63190 | 96.7 | N |
| | 127-63529 | 299 | N |
| | 127-63758 | 401.4 | N |
| | 127-63781 | 515 | N |
| | 127-64986 | 90 | N |
| | 127-65613 | 135 | N |
| | 127-65616 | 660 | N |
| | 127-101040 | 624 | N |
| | 127-105900 | 900 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-106300 | 936 | N |
| | 127-106840 | 177.1 | N |
| | 127-107260 | 760 | N |
| | 127-109480 | 270 | N |
| | 127-109820 | 432 | N |
| | 127-110620 | 936 | N |
| | 127-112698 | 360 | N |
| | 127-120771 | 720 | N |
| | 127-124541 | 1440 | N |
| | 127-125564 | 840 | N |
| | 127-125590 | 744 | N |
| | 127-125731 | 720 | N |
| | 127-126807 | 133.9 | N |
| | 127-127020 | 990 | N |
| Cottonwood River | 015-50002 | 1575 | N |
| | 015-50008 | 1200 | |
| | 015-71647 | 600 | N |
| | 015-71650 | 93.5 | Y |
| | 015-71654 | 153 | N |
| | 015-71673 | 70.6 | N |
| | 015-71675 | 624 | N |
| | 015-71678 | 41 | Y |
| | 015-71698 | 78.1 | N |
| | 015-71703 | 495.5 | N |
| | 015-71720 | 306 | N |
| | 015-71737 | 125 | N |
| | 015-71745 | 59.5 | N |
| | 015-71816 | 120 | N |
| | 015-71852 | 97.9 | Y |
| | 015-71853 | 17 | Y |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-71857 | 295 | N |
| | 015-71866 | 101.5 | N |
| | 015-71880 | 68.6 | N |
| | 015-71890 | 147 | N |
| | 015-71892 | 36 | Y |
| | 015-71905 | 311.8 | Y |
| | 015-71919 | 510 | N |
| | 015-71948 | 108 | N |
| | 015-71949 | 129.6 | N |
| | 015-71964 | 50 | Y |
| | 015-71968 | 70 | N |
| | 015-71973 | 57.425 | N |
| | 015-71987 | 98.2 | N |
| | 015-71999 | 60 | N |
| | 015-72029 | 194 | N |
| | 015-72049 | 108 | N |
| | 015-72059 | 465 | N |
| | 015-72066 | 163.9 | N |
| | 015-72068 | 80 | N |
| | 015-72074 | 645 | N |
| | 015-72139 | 1690 | N |
| | 015-72155 | 294 | N |
| | 015-72165 | 832 | N |
| | 015-72175 | 60 | N |
| | 015-72197 | 247.9 | Y |
| | 015-72226 | 61.075 | N |
| | 015-72236 | 75 | N |
| | 015-72238 | 675 | N |
| | 015-72282 | 75 | N |
| | 015-72283 | 60 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 015-72304 | 50.05 | N |
| | 015-72331 | 149 | N |
| | 015-72336 | 10.2 | Y |
| | 015-72353 | 95 | N |
| | 015-72357 | 81 | N |
| | 015-72369 | 128.6 | N |
| | 015-72375 | 196 | N |
| | 015-72395 | 62 | N |
| | 015-95056 | 318.5 | N |
| | 015-95134 | 72 | Y |
| | 015-95138 | 22.8 | Y |
| | 015-95147 | 247.1 | N |
| | 015-100000 | 1440 | N |
| | 015-107462 | 1200 | N |
| | 015-107843 | 170 | N |
| | 015-107846 | 123 | N |
| | 015-109481 | 936 | N |
| | 015-115641 | 80 | N |
| | 015-120278 | 97 | N |
| | 015-126352 | 102 | N |
| | 015-126800 | 100 | N |
| | 015--126427 | 85 | N |
| | 127-50088 | 2053 | N |
| | 127-50092 | 180 | N |
| | 127-50093 | 576 | N |
| | 127-60702 | 70 | N |
| | 127-61745 | 350 | N |
| | 127-61762 | 1895 | |
| | 127-62180 | 330 | N |
| | 127-63144 | 735 | N |

| HUC10 Watershed | Reg Number | Animal Unit (AU) Count | Within Shoreland |
|---|---|---|---|
| | 127-65511 | 660 | N |
| | 127-112251 | 800 | N |
| | 127-112801 | 720 | N |
| | 127-117156 | 945 | N |
| | 127-124992 | 412 | |

**Table E- 2. Cottonwood River Watershed CAFO Summary.**

| **General** | |
|---|---|
| Total Feedlots | 513 |
| Total Permitted CAFO's | 64 |
| Total Animal Units (AUs) | 228,065 |
| Primary Animal Type[1] | Swine (53%) |
| | Cattle (45%) |
| **Sensitive Areas** | |
| Open Lot Feedlots | 322 |
| Feedlots in Shoreland | 46 |
| Open Lot Feedlots in Shoreland | 37 |

[1]Percentages are based on animal units.