Sand Hill River Watershed Total Maximum Daily Load Study

Minnesota Pollution Control Agency

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<tr><td>Unnamed Lake (60-0236-00)</td><td>0.561</td></tr>
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TMDL Summary Table

EPA/MPCA Required Elements	Summary						TMDL Page #
	E. coli	**Very High**	**High**	**Mid**	**Low**	**Very Low**	
		Geometric Mean Standard (Billion organisms per day)					
	Sand Hill River (09020301-536)	1,595.7	346.1	133.5	63.0	29.9	75
	Sand Hill River (09020301-537)	2,371.3	475.5	209.6	104.8	55.5	
	Sand Hill River (09020301-542)	1,046.2	229.7	91.4	43.4	20.6	
	Sand Hill River (09020301-541)	678.45	140.34	56.27	27.35	13.81	
	TSS	**Very High**	**High**	**Mid**	**Low**	**Very Low**	81
		(Tons per day)					
	Sand Hill River (09020301-537)	156.7	30.3	13.7	6.5	3.16	
	Sand Hill River (09020301-541)	42.48	9.34	3.37	1.57	0.77	

EPA/MPCA Required Elements	Summary			TMDL Page #
Wasteload Allocation	Portion of the loading capacity allocated to existing and future point sources [40 CFR §130.2(h)].			
	Source (Permit #)	**Waterbody (AUID)**	**Individual WLA**	
	Phosphorus		**(lbs/day)**	71
	Construction Stormwater (MNR100001)	Ketchum Lake (44-0152-00)	0.0003	
		Kittleson Lake (60-0327-00)	0.0015	
		Uff Lake (60-0119-00)	0.0001	
		Unnamed Lake (60-0236-00)	0.0006	

EPA/MPCA Required Elements	Source (Permit #)	Waterbody (AUID)	Individual WLA	TMDL Page #
Wasteload Allocation	***E. coli***		(Billion organisms/day)	77
	Climax WWTF (MNG580169)	Sand Hill River (09020301-537)	1.3	
	Fertile WWTF (MNG580138)	Sand Hill River (09020301-536)	4.7	
		Sand Hill River (09020301-537)		
		Sand Hill River (09020301-542)		
	Winger WWTF (MN0046671)	Sand Hill River (09020301-536)	1.2	
		Sand Hill River (09020301-537)		
		Sand Hill River (09020301-542)		
		Sand Hill River (09020301-541)		

TMDL Summary Table

EPA/MPCA Required Elements	Summary						TMDL Page #
		Sand Hill River (09020301-541)					
	TSS		(Tons/day)				83
	Climax WWTF (MNG580169)	Sand Hill River (09020301-537)	0.05				
	Fertile WWTF (MNG580138)	Sand Hill River (09020301-537)	0.18				
	Winger WWTF (MN0046671)	Sand Hill River (09020301-537) Sand Hill River (09020301-541)	0.05				
	Construction Stormwater (MNR100001)	Sand Hill River (09020301-537) Sand Hill River (09020301-541)	1% of LA				
Load Allocation	The load allocation is for nonpoint source of a pollutant which does not require a NPDES permit. Load allocations are based on pollutant sources described in **Section 3.6.**						45
	Water Body (AUID)	**Loading Allocation**					
	Phosphorus	**(lbs/day)**					71
	Ketchum Lake (44-0152-00)	0.261					
	Kittleson Lake (60-0327-00)	1.328					
	Uff Lake (60-0119-00)	0.096					
	Unnamed Lake (60-0236-00)	0.505					
	E. coli	**Very High**	**High**	**Mid**	**Low**	**Very Low**	77
		Geometric Mean Standard (Billion organisms per day)					
	Sand Hill River (09020301-536)	1,430.2	305.6	114.3	50.8	21.0	
	Sand Hill River (09020301-537)	2127.00	420.80	181.40	87.10	42.80	
	Sand Hill River (09020301-542)	935.6	200.85	76.32	33.2	12.6	
	Sand Hill River (09020301-541)	609.41	125.11	49.44	23.42	11.23	

<table>
<tr><td rowspan="4"></td><td rowspan="2">TSS</td><td>Very High</td><td>High</td><td>Mid</td><td>Low</td><td>Very Low</td><td rowspan="4">83</td></tr>
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Streams: Critical conditions and seasonal variation are addressed in this TMDL through several mechanisms. The water quality analysis conducted on these data evaluated variability in flow through the use of five flow regimes: from high flows, such as flood events, to low flows, such as baseflow. Through the use of load duration curves and monthly summary figures, water quality was evaluated at actual flow conditions at the time of sampling and evaluated against precipitation and streamflow.</td><td>Lakes: 72
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Acronyms

AFO	Animal feedlot operations
AUID	Assessment Unit ID
BMP	Best Management Practice
BWSR	Minnesota Board of Water and Soil Resources
CAFO	Concentrated Animal Feeding Operation
CWLA	Clean Water Legacy Act
cfu	colony-forming unit
Chl-*a*	Chlorophyll-*a*
DO	Dissolved oxygen
DNR	Minnesota Department of Natural Resources
E. coli	Escherichia coli
EPA	Environmental Protection Agency
EQuIS	Environmental Quality Information System
FDC	flow duration curve
FSI	field-stream index
GIS	Geographical Information System
HUC	Hydrologic Unit Code
HSPF	Hydrologic Simulation Program – FORTRAN
IPHT	Imminent Public Health Threat
LA	Load Allocation
LAP	Lake Agassiz Plain
lb	pound
lb/ac/yr	pounds per acre per year
lb/yr	pounds per year
LC	Loading capacity
LDC	load duration curve
mg/L	milligrams per liter
m	meter
mL	milliliter
MOS	Margin of Safety
MPCA	Minnesota Pollution Control Agency
MS4	Municipal Separate Storm Sewer Systems
NASS	National Agricultural Statistics Service

NCHF	North Central Hardwood Forests
NLCD	National Land Cover Dataset
NLF	Northern Lakes and Forests
NPDES	National Pollutant Discharge Elimination System
NTU	Nephelometric Turbidity Unit
RR	Release rate
RRWMD	Red River Watershed Management Board
SDS	State Disposal System
SHRW	Sand Hill River Watershed
SHRWD	Sand Hill River Watershed District
SSTS	Subsurface Sewage Treatment Systems
SWCD	Soil and Water Conservation Districts
TDLC	Total Daily Loading Capacity
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TSS	Total suspended solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WMP	Watershed Management Plan
WLA	Wasteload Allocation
WRAPS	Watershed Restoration and Protection Strategies
WWTF	Wastewater Treatment Facility

Executive Summary

Section 303(d) of the Federal Clean Water Act (CWA) requires the Minnesota Pollution Control Agency (MPCA) to identify water bodies that do not meet water quality standards (Minn. R. 7050.022) and to develop total maximum daily pollutant loads for those water bodies. A total maximum daily load (TMDL) project results in an estimate of the amount of a pollutant that a water body can assimilate without exceeding the established water quality standard for that pollutant. Through a TMDL, pollutant loads are allocated to point and nonpoint sources within the watershed that discharge to the water body.

The Sand Hill River Watershed (SHRW) Hydrologic Unit Code (HUC) 09020301, located in northwest Minnesota, comprises over 486 square miles and includes portions of Polk, Norman, and Mahnomen Counties. Flow direction in the SHRW is generally east to west. Flow enters the Red River of the North and proceeds north to the U.S.–Canada border. Land use within the watershed is predominantly agricultural.

The MPCA has nine SHRW waterbodies listed on the United States Environment Protection Agency's (EPA) 303(d) list as having impaired water quality (i.e., not meeting the standards that have been set for them) and needing a TMDL. These waterbodies contain a total of 15 impairment listings: four for *E. coli*, two for turbidity, four for excess nutrients, two for aquatic macroinvertebrate bioassessment, two for fish bioassessment, and one for dissolved oxygen (DO). It should be noted, in the spring of 2015, Minnesota transitioned from turbidity to represent sediment to a total suspended solids (TSS) standard. Further discussion of this transition is discussed in **Sections 1.2** and **2**. This TMDL study addresses 10 of those impairments: four lakes impaired by excessive nutrients, two stream reaches impaired by TSS (formerly turbidity), and four stream reaches impaired by *E. coli*.

Information from multiple sources was used to evaluate the potential sources of pollutants and ultimate health of each waterbody, including (but not limited to): stressor identification studies, Hydrologic Simulation Program – FORTRAN (HSPF) modeling, lake modeling, analysis of the available water quality data for the last 10 years, and GIS (Geographical Information System) analysis. The following pollutant sources were evaluated for each lake or stream: watershed runoff, loading from upstream sources, atmospheric deposition, lake internal loading, point sources, feedlots, septic systems, wildlife and other natural sources, and hydrologic alterations. Pollutant source loadings were used to develop lake response models for each impaired lake. Load duration curves for each impaired stream reach were also used to determine the pollutant reduction needed to meet current water quality standards.

The Sand Hill River Watershed Restoration and Protection Strategy (WRAPS) process used the findings from this TMDL study to guide the development of its implementation strategies. The purpose of the WRAPS process is to support local working groups and jointly develop scientifically supported restoration and protection strategies. These implementation strategies are intended to meet the TMDL goals outlined in this document. Following completion of the WRAPS process, the WRAPS report, as well as numerous other technical reports referenced in this document, will be publically available on the MPCA SHRW website:

http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/red-river-of-the-north-sandhill-river.html

1. Project Overview

1.1 Purpose

The SHRW is located in northwest Minnesota and comprises approximately 495 square miles within Polk, Norman, and Mahnomen counties. The watershed is located in the Red River of the North Basin and the boundary spans two ecoregions: the Lake Agassiz Plain (LAP) and North Central Hardwood Forests (NCHF) ecoregions. Land use is predominantly agricultural with some pasture, grasslands, and forested areas in the central and far eastern portions of the SHRW. Municipalities located within the SHRW include Beltrami, Climax, Fertile, Fosston, Nielsville, and Winger, which account for two-thirds of the watershed's population.

The MPCA has nine SHRW waterbodies listed as having impaired water quality (i.e., not meeting water quality standards) and needing a TMDL. These waterbodies contain a total of 15 impairment listings: four for *E. coli*, two for turbidity, four for excess nutrients, two for aquatic macroinvertebrate bioassessment, two for fish bioassessment, and one for DO. A TMDL is defined as the maximum quantity of a pollutant that a water body can receive while meeting the (numeric) water quality standards for beneficial uses. The TMDL apportions the maximum load between point sources (i.e., a wasteload allocation (WLA)) to sources that are authorized by a permit under the Clean Water Act, nonpoint sources, (i.e., load allocation (LA) and a margin of safety (MOS)). The MOS is a portion of the maximum load reserved to account for uncertainty. The designated uses affected by these impairments are for aquatic life (turbidity) and aquatic recreation (*E. coli* and excess nutrients).

There are four biological impairments identified in the SHRW. Of those four, three of the biological impairments are caused by stressors that do not include conventional (e.g., lack of habitat, altered hydrology) pollutants and therefore lack a numeric standard. TMDLs for those biological impairments are not addressed by this TMDL. One of the four biological impairments has turbidity/sediment listed as a stressor (MPCA 2014b) and it is the only conventional pollutant stressor. The turbidity/sediment stressors are addressed through the TSS TMDLs. Assessment Unit ID (AUID) 0902031-541 (Sand Hill River headwaters to County Ditch 17; see **Table 1-1**) is impaired, among other impairments, by low DO. Due to the lack of sufficient data, the DO impairment is expected to be addressed in a future TMDL. Impairments as a result of mercury are also addressed elsewhere[1].

In 2006, Minnesota passed the Clean Water Legacy Act (CWLA) to protect, restore, and preserve the quality of Minnesota's surface waters. As a result, the MPCA established a watershed approach to restore and protect Minnesota's waters. One component of that approach is to complete TMDLs for the impaired waterbodies within each watershed and develop a watershed-wide TMDL study. This TMDL study is intended to fulfill the TMDL requirement for the SHRW.

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1 see http://www.pca.state.mn.us/index.php/view-document.html?gid=8507

1.2 Identification of Waterbodies

This TMDL study addresses 10 impairments in the SHRW (**Table 1-1, Figure 1-1)**; including four stream reaches with four *E. coli* impairments and two turbidity impairments, and four lakes with excess nutrient impairments. In the spring of 2015, Minnesota switched from a turbidity standard to represent sediment in a waterbody to a TSS standard. The stream reaches in the SHRW are listed as having impaired aquatic life due to elevated turbidity on the MPCA's 2014 Impaired Waters List[2]. The turbidity standard has been replaced by the TSS standard for the 2016 Impaired Waters list. For purposes of this TMDL document, the impairments will be listed as turbidity but the TMDLs will be for TSS.

Three of the four biological impairments in the watershed are not explicitly addressed in this report since their identified stressors (MPCA 2014) do not include conventional pollutants with numeric standards. For the remaining biological impairment in AUID 09020301-541, turbidity/sediment was identified as a stressor. The turbidity/sediment aspects of the biological impairments are addressed through the TSS TMDLs for this reach. The remaining stressors of the biological impairments (i.e. connectivity, altered hydrology, and habitat) are not conventional pollutants and are not addressed in this TMDL.

[2] http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/impaired-waters-list.html

Table 1-1: SHRW impairments addressed in this report.

AUID	Waterbody	Impairment / parameter	Beneficial Use	Year Listed	Addressed in this TMDL?
09020301-515	County Ditch 17-Garden Slough to Sand Hill River	Macroinvertebrate Bioassessments	Aquatic Life	2014	No
09020301-536	Sand Hill River-Kittleson Creek to Unnamed Creek	*E. coli*	Aquatic Recreation	2014	Yes
		Mercury in fish tissue	Aquatic consumption	2014	No
09020301-537	Sand Hill River-Unnamed Creek to Red River	*E. coli*	Aquatic Recreation	2014	Yes
		Turbidity	Aquatic Life	2010	Yes
		Mercury in fish tissue	Aquatic consumption	2014	No
09020301-541	Sand Hill River-Headwaters to CD 17	Macroinvertebrate Bioassessments	Aquatic Life	2014	No
		E. coli	Aquatic Recreation	2014	Yes
		Turbidity	Aquatic Life	2010	Yes
		Fish Bioassessments	Aquatic Life	2014	No
		Dissolved Oxygen	Aquatic Life	2008	No
09020301-542	Sand Hill River-CD 17 to Kittleson Creek	*E. coli*	Aquatic Recreation	2014	Yes
		Fish Bioassessments	Aquatic Life	2014	No
44-0152-00	Ketchum	Excess Nutrients	Aquatic Recreation	2014	Yes
60-0119-00	Uff	Excess Nutrients	Aquatic Recreation	2014	Yes
60-0236-00	Unnamed	Excess Nutrients	Aquatic Recreation	2014	Yes
60-0327-00	Kittleson	Excess Nutrients	Aquatic Recreation	2014	Yes

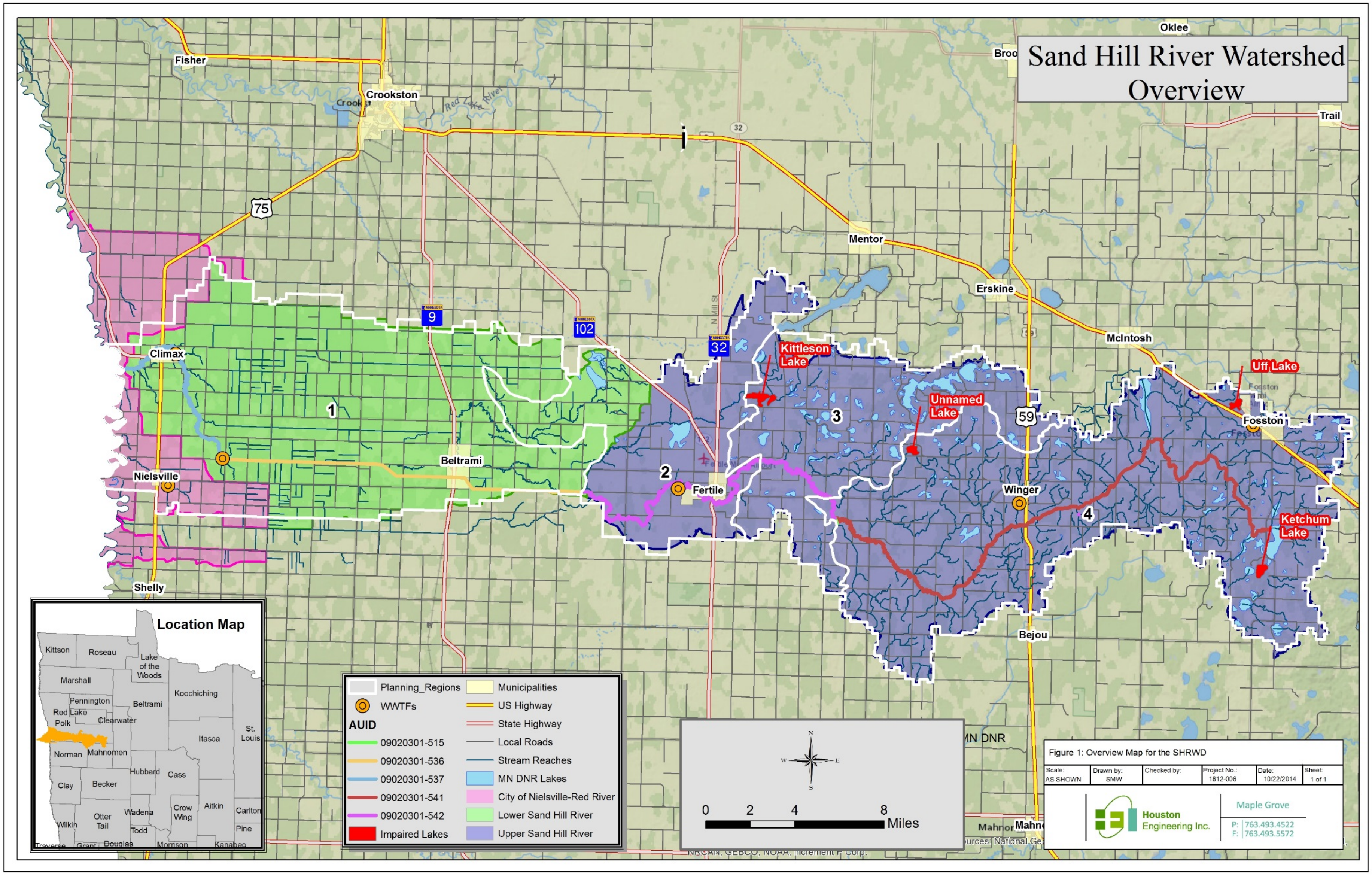

Figure 1-1: Impairments in the SHRW.

1.3 Priority Ranking

The MPCA's schedule for TMDL completions, as indicated on the 303(d) impaired waters list, reflects Minnesota's priority ranking of this TMDL. The MPCA has aligned our TMDL priorities with the watershed approach and our WRAPS cycle. The schedule for TMDL completion corresponds to the WRAPS report completion on the 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, which will be addressed by TMDLs by 2022. The SHRW waters addressed by this TMDL are part of that the MPCA prioritization plan to meet the EPA's national measure.

2. Applicable Water Quality Classification and Numeric Standards

Water quality standards are the fundamental benchmarks by which the quality of surface waters are measured and used to determine impairment. Use attainment status describes whether a waterbody is supporting its designated beneficial use as evaluated by the comparison of monitoring data to criteria specified in the *Minnesota Water Quality Standards* (Minn. R. ch. 7050 2008[2]). These standards can be numeric or narrative in nature and define the concentrations or conditions of surface waters that allow them to meet their designated beneficial uses, such as for fishing (aquatic life), swimming (aquatic recreation) or human consumption (aquatic consumption). All impaired waters addressed in this TMDL are classified as Class 2B or 2C waters.

> ***Class 2B waters*** - The quality of Class 2B surface waters shall be such as to permit the propagation and maintenance of a healthy community of cool or warm water sport or commercial fish and associated aquatic life, and their habitats. These waters shall be suitable for aquatic recreation of all kinds, including bathing, for which the waters may be usable. This class of surface water is not protected as a source of drinking water (Minn. R. 7050.0222, subp. 4).
>
> ***Class 2C waters*** - The quality of Class 2C surface waters shall be such as to permit the propagation and maintenance of a healthy community of indigenous fish and associated aquatic life, and their habitats. These waters shall be suitable for boating and other forms of aquatic recreation for which the waters may be usable (Minn. R. 7050.0222, subp. 5).

2.1 Lakes

Lake eutrophication standards are written to protect lakes as a function of their designated beneficial use. The lakes of the SHRW are considered Class 2B waters, which are protected for aquatic recreation. The numeric standards for aquatic recreation tend to be the most stringent. The MPCA considers a lake

2 https://www.revisor.leg.state.mn.us/rules/?id=7050

impaired when total phosphorus (TP) and a least one of the response variables (i.e., chlorophyll-*a* (Chl-*a*) or Secchi disk depth) do not meet the applicable standards (MPCA 2012).

In addition to meeting TP limits, Chl-*a* and Secchi transparency standards must also 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 phosphorus (P) target in each lake, the Chl-*a* and Secchi standards will likewise be met.

Minnesota developed lake water quality standards based upon depth classification and ecoregion. The lake water quality standards are listed in **Table 2-1.** Ecoregions in the SHRW include the NCHF, and the LAP. Currently, the MPCA does not have a specific numeric water quality standard for the LAP ecoregion. Lakes within the LAP ecoregion area are assessed on a case-by-case basis. In practice, when assessing a lake in the LAP ecoregion, the MPCA considers the land use within the lake's total contributing lakeshed and compares that land use to typical values seen in the other ecoregions (as summarized in Heiskary and Wilson (2005). The numeric criteria of whichever ecoregion's land use characteristics most closely match those of the lake in question are then applied for determining impairment. In the lakes of the SHRW, this analysis has typically resulted in the NCHF ecoregion's criteria being used for assessment purposes. The water quality standards for the NCHF are included in **Table 2-1**. Within the SHRW, all of the impaired lakes are classified as shallow.

Table 2-1: Lake water quality standards for SHRW lakes addressed in this report.

Ecoregion	TP (ug/L)	Chl-*a* (ug/L)	Secchi Disk Depth (m) [2]	Period of Time Standard Applies
North Central Hardwood Forest[1]				
- Deep lakes and reservoirs	40	14	1.4	June 1-Sept. 30
- Shallow Lakes	60	20	1	June 1-Sept. 30

[1]: Deep lakes are classified as having a maximum depth greater than 15 feet whereas shallow lakes have a maximum depth less than 15 feet or greater than 80% of the lake is part of the littoral zone.
[2]: Standard for Secchi disk depth is the minimum transparency value (i.e., values must be greater than the standard)

2.2 Streams

The Minnesota narrative water quality standard for all Class 2 waters (Minn. R. 7050.0150, subp. 3) states that:

> *The aquatic habitat, which includes the waters of the state and stream bed, shall not be degraded in any material manner, there shall be no material increase in undesirable slime growths or aquatic plants, including algae, nor shall there be any significant increase in harmful pesticide or other residues in the waters, sediments, and aquatic flora and fauna; the normal fishery and lower aquatic biota upon which it is dependent and the use thereof shall not be seriously impaired or endangered, the species composition shall not be altered materially, and the propagation or migration of the fish and other biota normally present shall not be prevented or hindered by the discharge of any sewage, industrial waste, or other wastes to the waters*.

Applicable water quality standards for the SHRW stream impairments in this report are shown in **Table 2-2**, while **Table 1-1** shows the specific water bodies affected.

Table 2-2: Surface water quality standards for SHRW stream reaches addressed in this report.

Parameter	Water Quality Standard	Units	Criteria	Period of Time Standard Applies
E. coli	Not to exceed 126	org/100 mL	Monthly geometric mean	April 1-October 31
	Not to exceed 1,260	org/100 mL	Upper 10th percentile	
Total suspended solids (TSS)-Southern Nutrient Region	Not to exceed 65	mg/L	Upper 10th percentile	April 1-September 30

The bacteria water quality standard change from fecal coliform to *E. coli* is supported by an EPA guidance document on bacteriological criteria (EPA 1986). As of 2013, Minn. R. ch. 7050.0222, water quality standards for *E. coli* states:

> *Escherichia (E.) coli - Not to exceed 126 organisms per 100 milliliters 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. The standard applies only between April 1 and October 31.*

Although surface water quality standards are now based on *E. coli*, wastewater treatment facilities (WWTFs) are permitted based on fecal coliform (not *E. coli*) concentrations. A conversion factor of 126 *E. coli* organisms per 100 mL for every 200 fecal coliform per 100 mL is used and discussed in **Section 4.1**.

Geometric mean is used in place of arithmetic mean in order to describe the central tendency of the data, dampening the effect that very high or very low values have on arithmetic means. The MPCA's *Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List* provides details regarding how waters are assessed for conformance to the *E. coli* standard (MPCA 2012).

In the spring of 2015, Minnesota replaced the turbidity standard of 25 Nephelometric Turbidity Units (NTUs) with a TSS water quality standard (see **Table 2-2**) in its streams. Streams in the SHRW are listed as having a turbidity impairment on MPCA's 2014 Impaired Waters List. The turbidity standard has been replaced by the TSS standard for the 2016 Impaired Waters list. Therefore, a TSS TMDL was completed for both streams with a turbidity impairment. Both turbidity-impaired streams in the SHRW lie in the South River Nutrient Region, which has a TSS standard of 65 mg/L. It should be noted for this document, the impairment will be referred to as turbidity but the TMDL will correspond to TSS.

3. Watershed and Waterbody Characterization

The drainage network in place today in the Red River Basin "has thousands of miles of principal drains and probably tens of thousands of miles of small laterals and on-farm channels." (Carlyle 1984). The Red River Valley is among the world's largest artificially drained landscapes.

Francis J. Marschner interpreted the notes from the General Land Office records to create a large state map showing how Minnesota looked at the time of European settlement. Marschner's map of "Minnesota Early Settlement Vegetation" can be found here: Marschner's map.

The SHRW (HUC 09020301), located in northwest Minnesota, comprises over 486 square miles and includes portions of Polk, Norman, and Mahnomen Counties. Flow direction in the SHRW is generally east to west. Flow enters the Red River of the North and proceeds north to the U.S.–Canada border. Land use within the watershed is predominantly agricultural with some pasture and grasslands found in the central and forested areas in the central and far eastern portions (see **Figure 3-13**). Municipalities located within the SHRW include Beltrami, Climax, Fertile, Fosston, Nielsville, and Winger, which account for two-thirds of the watershed's population. This TMDL covers only the stream reaches which ultimately drain to the outlet of the Sand Hill River. The SHRW 8-digit HUC covers additional areas that drain directly to the Red River of the North; those reaches are not covered in this TMDL and will be covered in future TMDLs addressing the Red River of the North. The SHRW includes portions of two Level III ecoregions as defined by the EPA: the LAP and the NCHF (see **Figure 3-1**). The vast majority of the watershed is located in the LAP (greater than 90%). The EPA defines an ecoregion as a relatively homogeneous ecological area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables. Much of the LAP has been drained for agricultural use. Since natural processes often vary by ecoregion, some water quality standards have taken these regions into account. Descriptions of the ecoregions in the SHRWD (Sand Hill River Watershed District) are given as follows (EPA 2013):

> "The Lake Agassiz Plain (LAP) was formed by Glacial Lake Agassiz, the last in a series of proglacial lakes to fill the Red River Valley in the three million years since the beginning of the Pleistocene. Thick beds of lake sediments on top of glacial till create the extremely flat floor of the Lake Agassiz Plain. The historic tall grass prairie has been replaced by intensive row crop agriculture. The preferred crops in the northern half of the region are potatoes, beans, sugar beets, and wheat; soybeans, sugar beets, and corn predominate in the south."

> "The NCHF ecoregion is transitional between the predominantly forested Northern Lakes and Forests (NLF) to the north and the agricultural ecoregions to the south. Land use/land cover in this ecoregion consists of a mosaic of forests, wetlands and lakes, cropland agriculture, pasture, and dairy operations. The growing season is generally longer and warmer than that of NLF and the soils are more arable and fertile, contributing to the greater agricultural component of land use. Lake trophic states tend to be higher in the NCHF than in the NLF, with higher percentages in eutrophic and hypereutrophic classes."

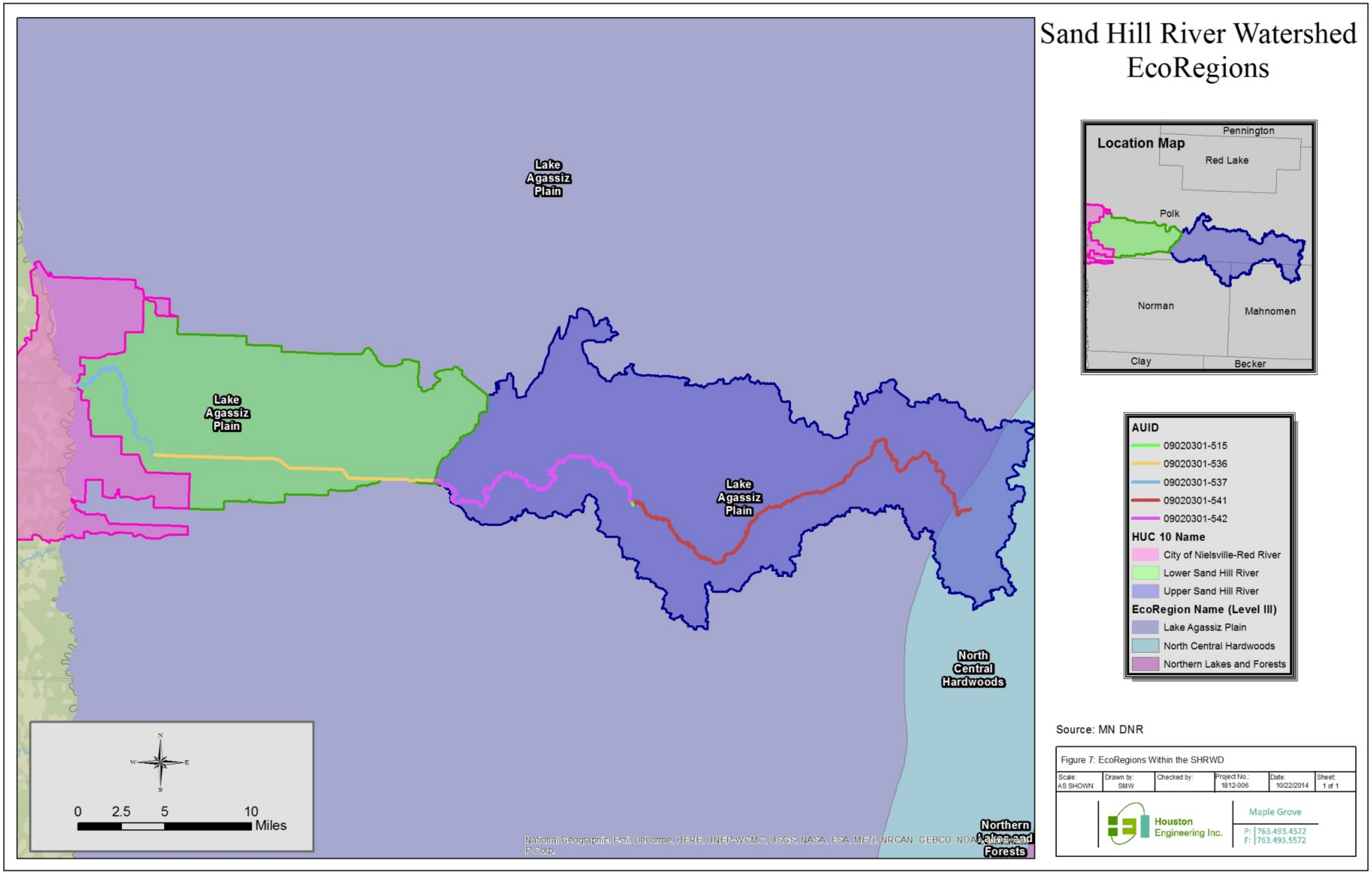

Figure 3-1: EPA Level 3 Eco-regions of the SHRW.

More information about the physical characteristics of the SHRW can be found in the SHRW Biotic Stressor Identification (MPCA 2014b) report, the SHRW Monitoring and Assessment Report (MPCA 2014a), and/or the Watershed Conditions Report (HEI 2011).

3.1 Lakes

The morphometry for the four impaired lakes in the SHRW is listed in **Table 3-1**. Each lake's surface area, average depth, maximum depth, and percent littoral area were taken from the MPCA reports (2014b) and confirmed using information reported at the Minnesota Department of Natural Resources (DNR) Lake Finder website[3]. Bathymetry information and lake volumes were not available for any impaired lakes and were estimated using the mean depth and surface area. The total drainage areas and watershed to surface area ratios were estimated using the DNR's lake catchment GIS data.

Table 3-1: Lake morphometry for impaired lakes in the SHRW.

AUID	Surface Area (ac)	Average Depth (feet)	Maximum Depth (feet)	Lake Volume (ac-ft)	Littoral Area (%)	Depth Class	Drainage Areas (ac)[1]	Watershed Area : Surface Area
44-0152-00 (Ketchum)	156	4.9	17.1	764	100	Shallow	1,897	12.2
60-0327-00 (Kittleson)	297.5	3.3	7.9	982	100	Shallow	14,035	47.1
60-0119-00 (Uff)	128	3.3	7.9	422	100	Shallow	699	5.5
60-0236-00 (Unnamed)	116	3.3	11.8	383	100	Shallow	2,126	18.3

[1]Includes each lake's surface area.

3.2 Streams

The direct drainage areas, total contributing drainage areas, any noncontributing areas, and any upstream waterbodies for impaired AUID stream reaches in the SHRW are listed in **Tables 3-2**. The direct drainage areas include only the areas draining to the impaired AUID downstream of any upstream assessed AUID. The direct drainage areas and total contributing drainage areas were delineated from the SHRW HSPF model subwatersheds (RESPEC 2013) and United States Geological Survey (USGS)

3 http://www.dnr.state.mn.us/lakefind/index.html

Table 3-2: Impaired stream reach direct and total drainage areas.

AUID (09020301-XXX)	Name	HUC 10 Subwatershed	Direct Drainage Area (acres)	Total Drainage Area (acres)	Noncontributing Area (acres)[1]	Upstream Waterbody
515	County Ditch 17-Garden Slough to Sand Hill R	Upper Sand Hill River	3,182	11,723	1,013	09020301-514 (Garden Slough)
536	Sand Hill River-Kittleson Creek to Unnamed Creek	Lower Sand Hill River	25,670	220,322	48,480	09020301-542 and 09020301-508 (Kittleson Creek)
537	Sand Hill River-Unnamed Creek to Red River	Lower Sand Hill River	84,021	304,343	48,591	09020301-536
541	Sand Hill River-Headwaters to CD 17	Upper Sand Hill River	100,098	103,116	31,834	Sand Hill Lake (60-0069-00)
542	Sand Hill River-CD 17 to Kittleson Creek	Upper Sand Hill River	40,500	155,339	7,595	09020301-541

[1]Noncotributing Areas based on 10-year, 24-hour storm event; area for total drainage area.

3.3 Subwatersheds

The SHRWD has subdivided the SHRW into four planning regions for the purposes of managing the water resources within its jurisdiction. These regions are shown on the map in **Figure 1-1**. For purposes of this TMDL study, the watershed is divided into two 10-digit HUC watersheds (**see Figure 1-1**) and used to organize components of this TMDL study throughout the document.

3.3.1 Upper Sand Hill River Subwatershed (HUC 0902030103)

The Upper Sand Hill River drainage area serves as the headwaters of the Sand Hill River, beginning at Sand Hill Lake and stretching westward to where Kittleson Creek flows into the Sand Hill River. It is located in the far eastern portion of the SHRW and comprised of the NCHF and the LAP ecoregions. Agricultural lands dominate the planning region with the majority of the area falling within the LAP ecoregion. The region contains three impaired stream reaches (AUIDs 09020301-515, -541, and -542) and all four impaired lakes.

The Upper Sand Hill River Subwatershed 10-digit HUC is shown in **Figure 3-2**. The drainage areas for each individual impaired reach are shown in **Figure 3-3** through **Figure 3-5**. The contributing surface water drainage areas (i.e., lakesheds) for each individual impaired lake are shown in **Figure 3-6** through **Figure 3-9**. Each figure includes the total drainage area, direct drainage areas, noncontributing drainage areas, any feedlots within the total drainage areas, water quality sites, 2006 National Land Cover Dataset (NLCD) land uses, and any point sources (e.g., WWTF) located in the total drainage areas.

3.3.2 Lower Sand Hill River Subwatershed (HUC 0902030104)

The Lower Sand Hill River Subwatershed drainage area is located in the western portion of the watershed downstream of the Upper Sand Hill River Subwatershed (see **Figure 3-1**). The Lower Sand Hill

River Subwatershed is located entirely in the LAP ecoregion. Most of the area is agricultural land. The Sand Hill River's mainstem travels east to west from the glacial moraines through the Agassiz beach ridges and into the lake plain, connecting with the Red River of the North on its western edge.

The Lower Sand Hill River Subwatershed 10-digit HUC is shown in **Figure 3-10**. The drainage areas for each individual impaired reach is shown in **Figure 3-11** and **Figure 3-12**. Each figure includes the total drainage area, direct drainage areas, noncontributing drainage areas, any feedlots within the total drainage areas, water quality sites, 2006 NLCD land uses, and any point sources (e.g., WWTFs) located in the total drainage areas.

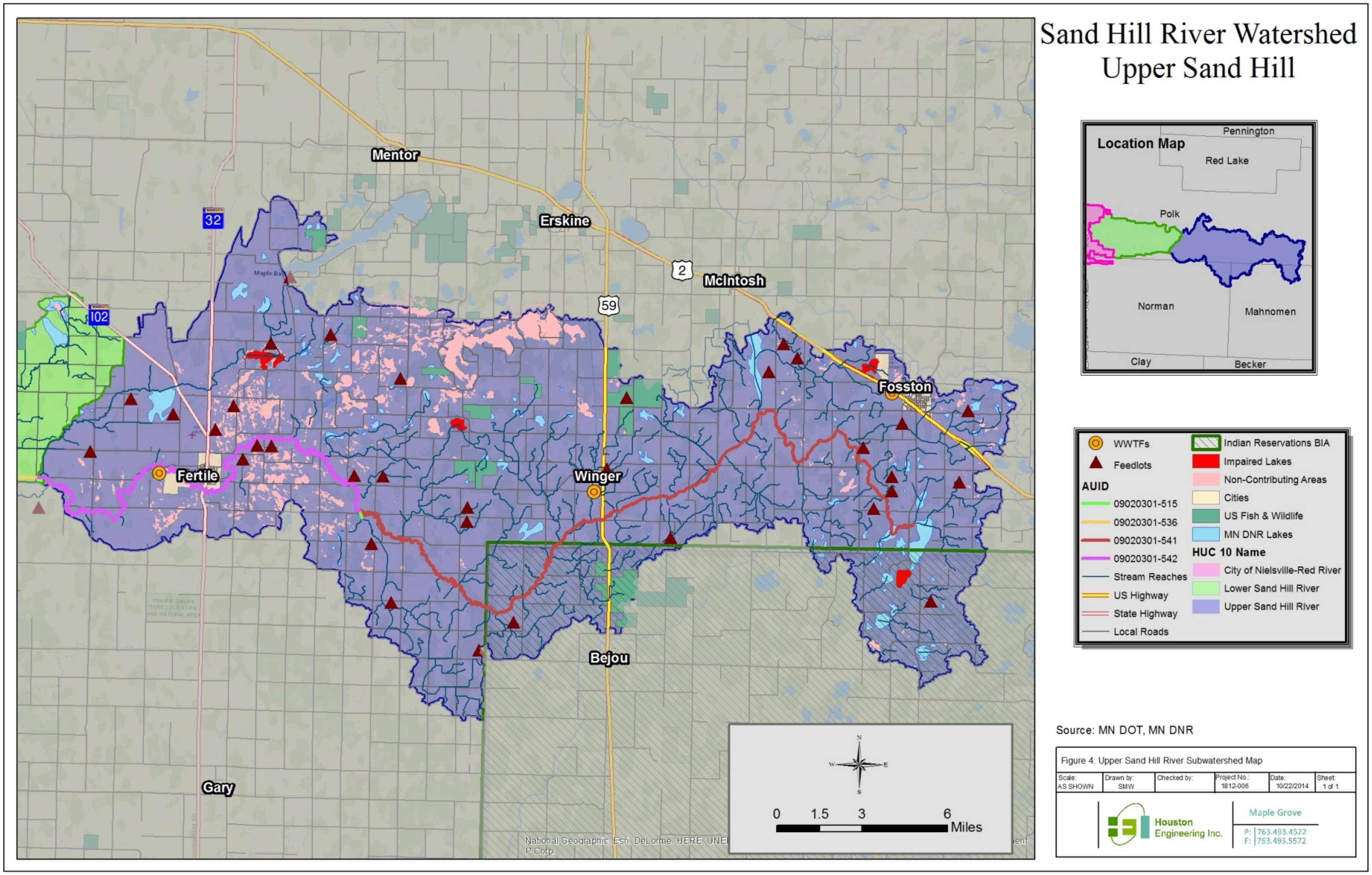

Figure 3-2: Upper Sand Hill River Subwatershed (HUC 0902030103).

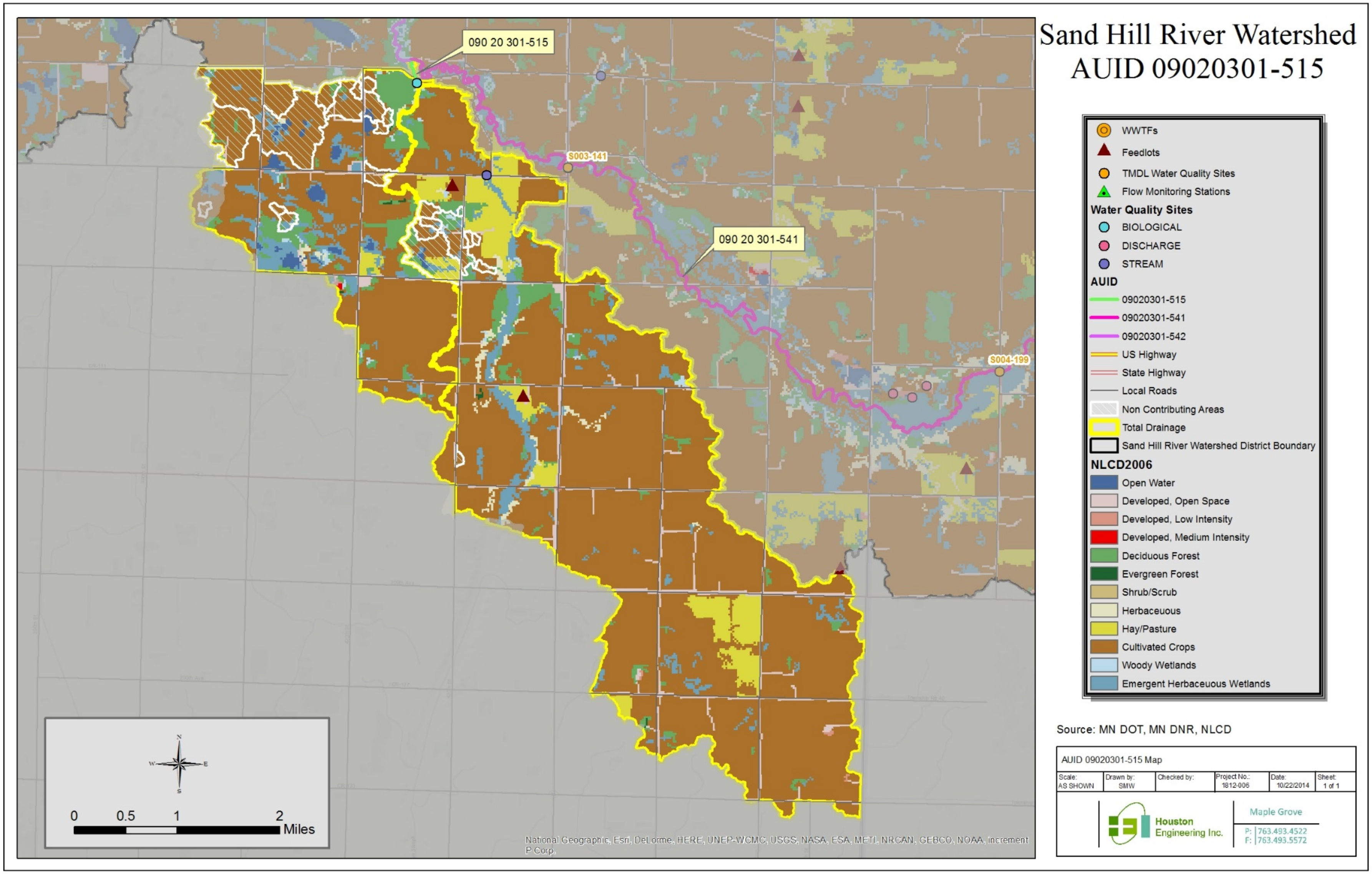

Figure 3-3: Drainage Area for AUID 09020301-515 in the SHRW.

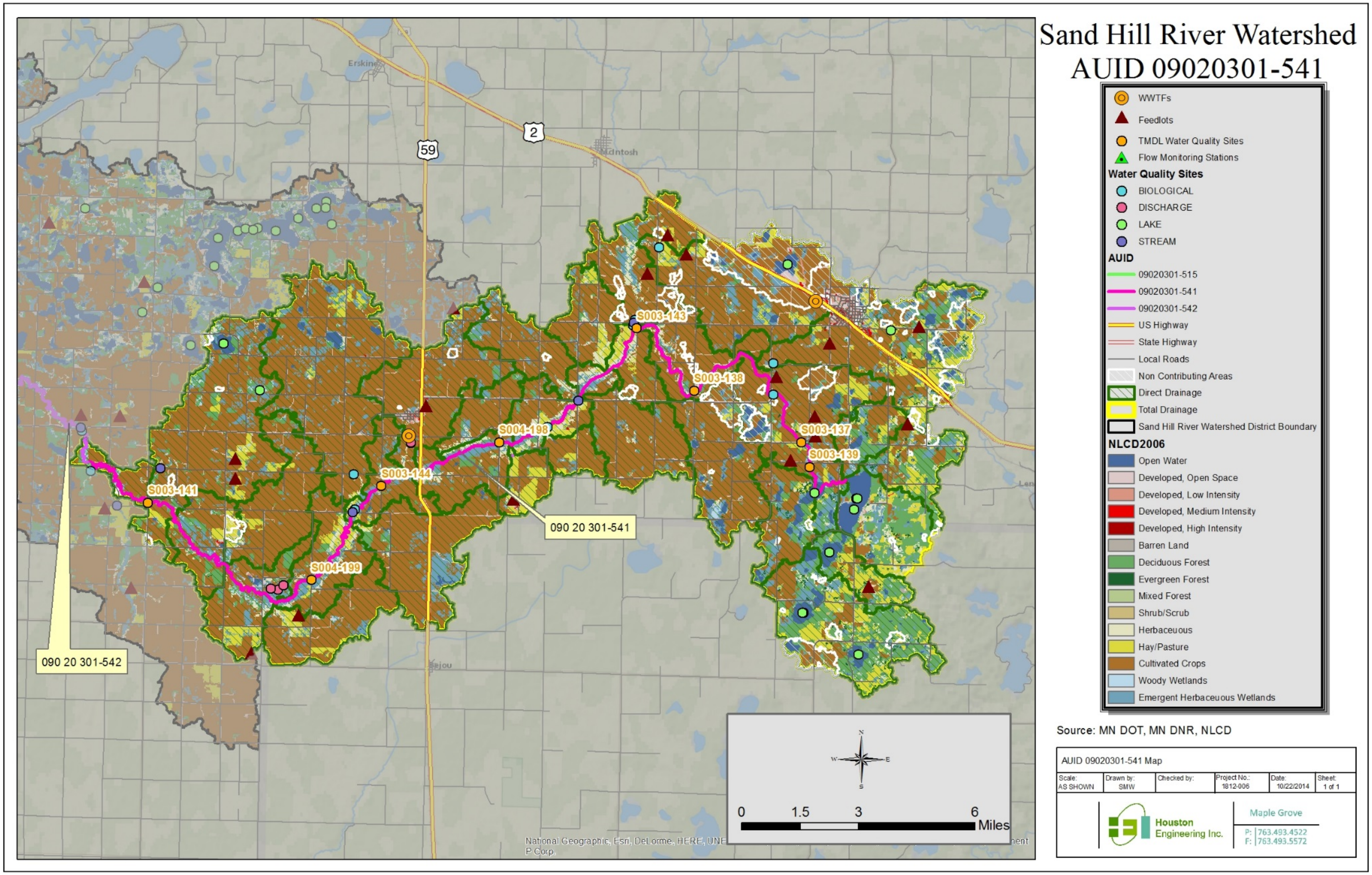

Figure 3-4: Drainage Area for AUID 09020301-541 in the SHRW.

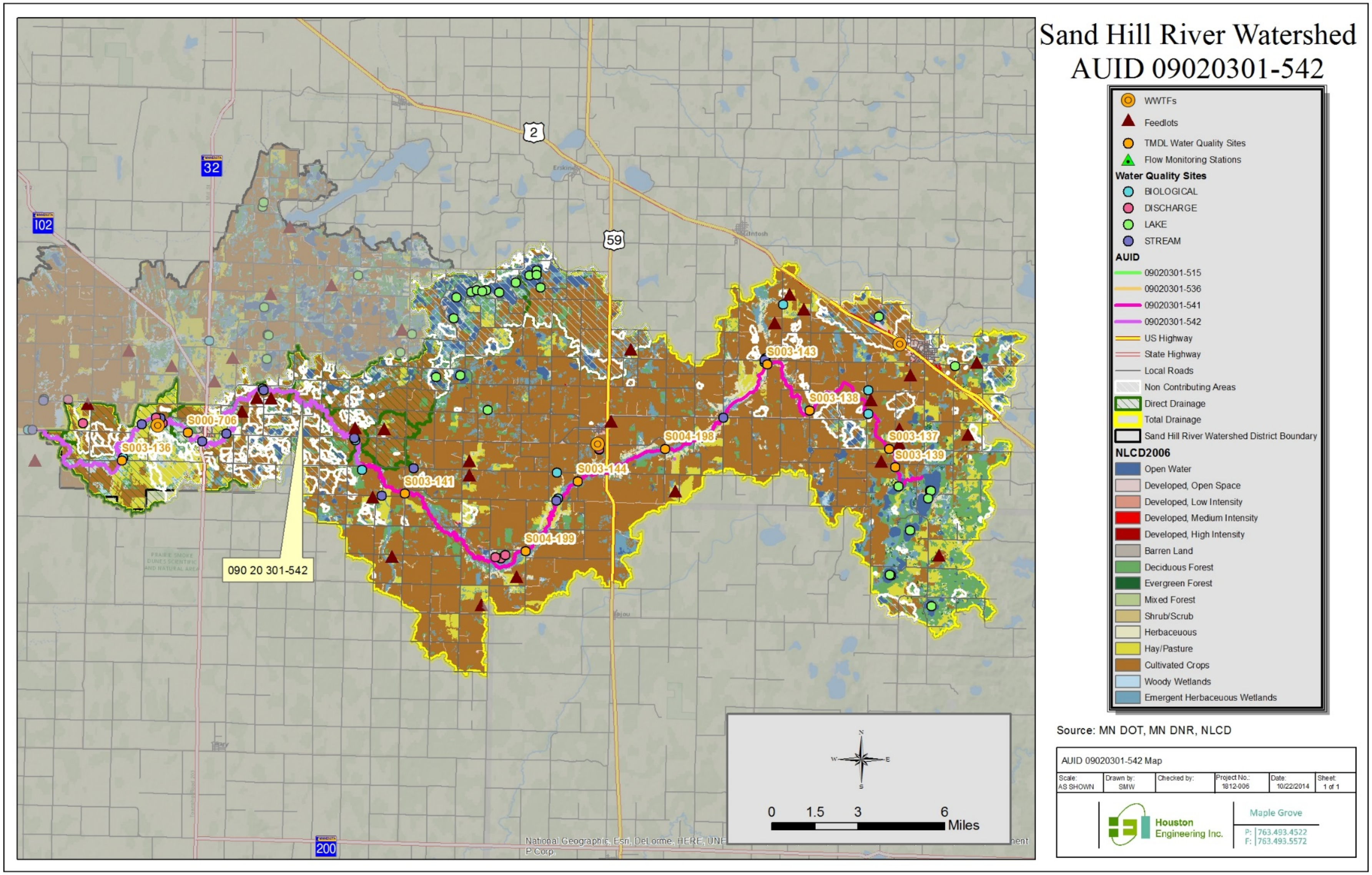

Figure 3-5: Drainage Area for AUID 09020301-542 in the SHRW.

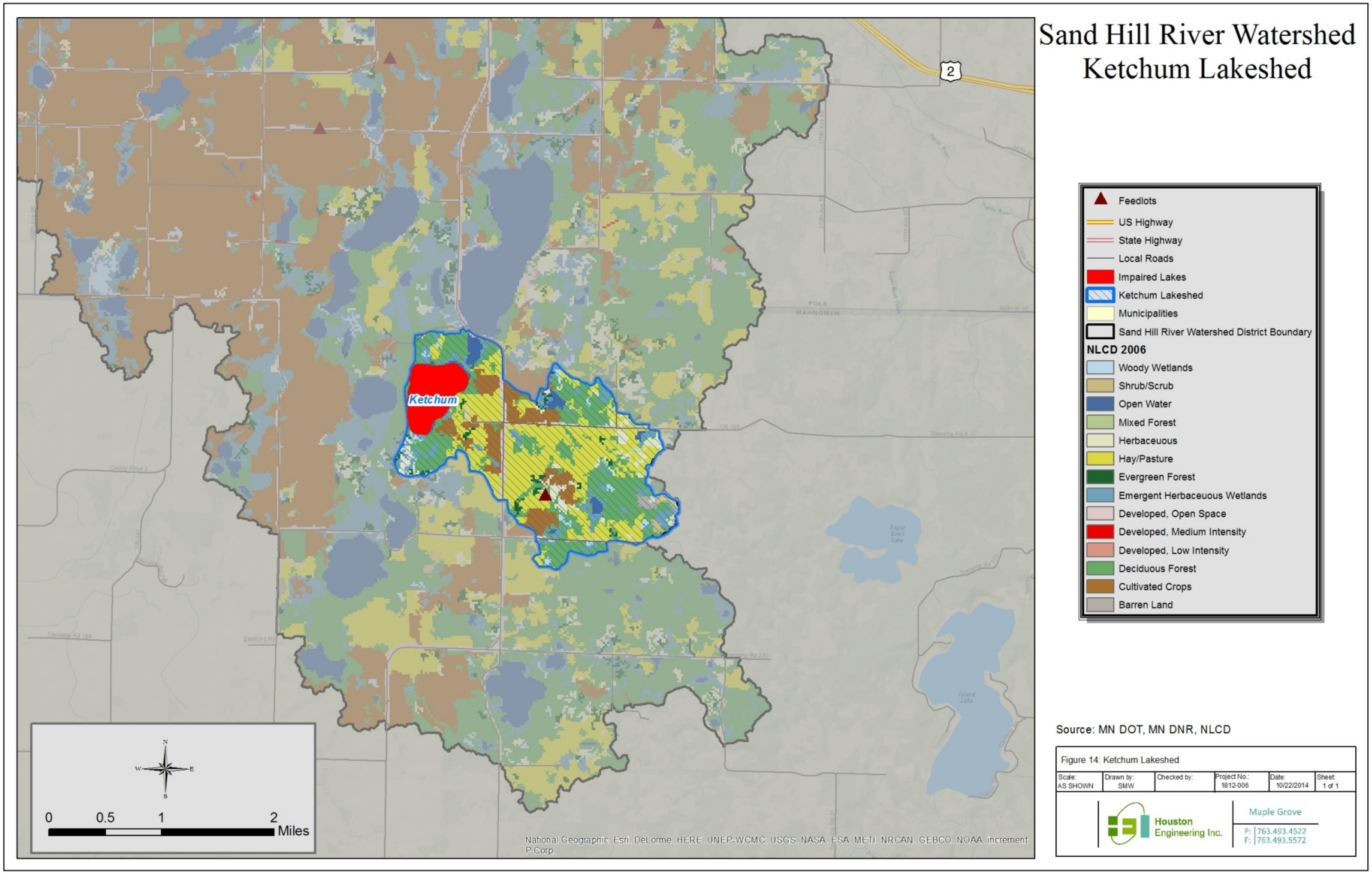

Figure 3-6: Ketchum Lake Lakeshed and Land Use.

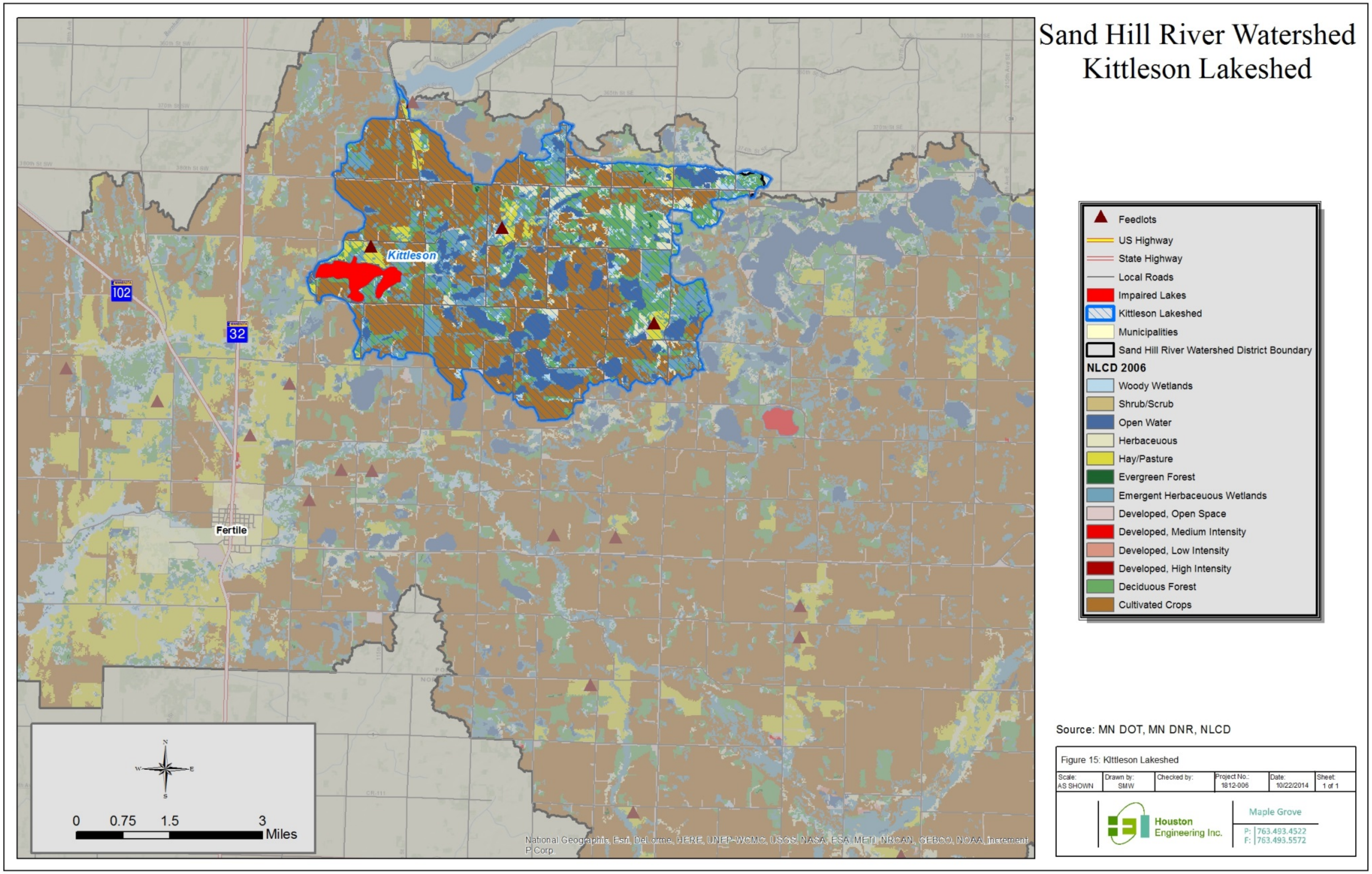

Figure 3-7: Kittleson Lake Lakeshed and Land Use.

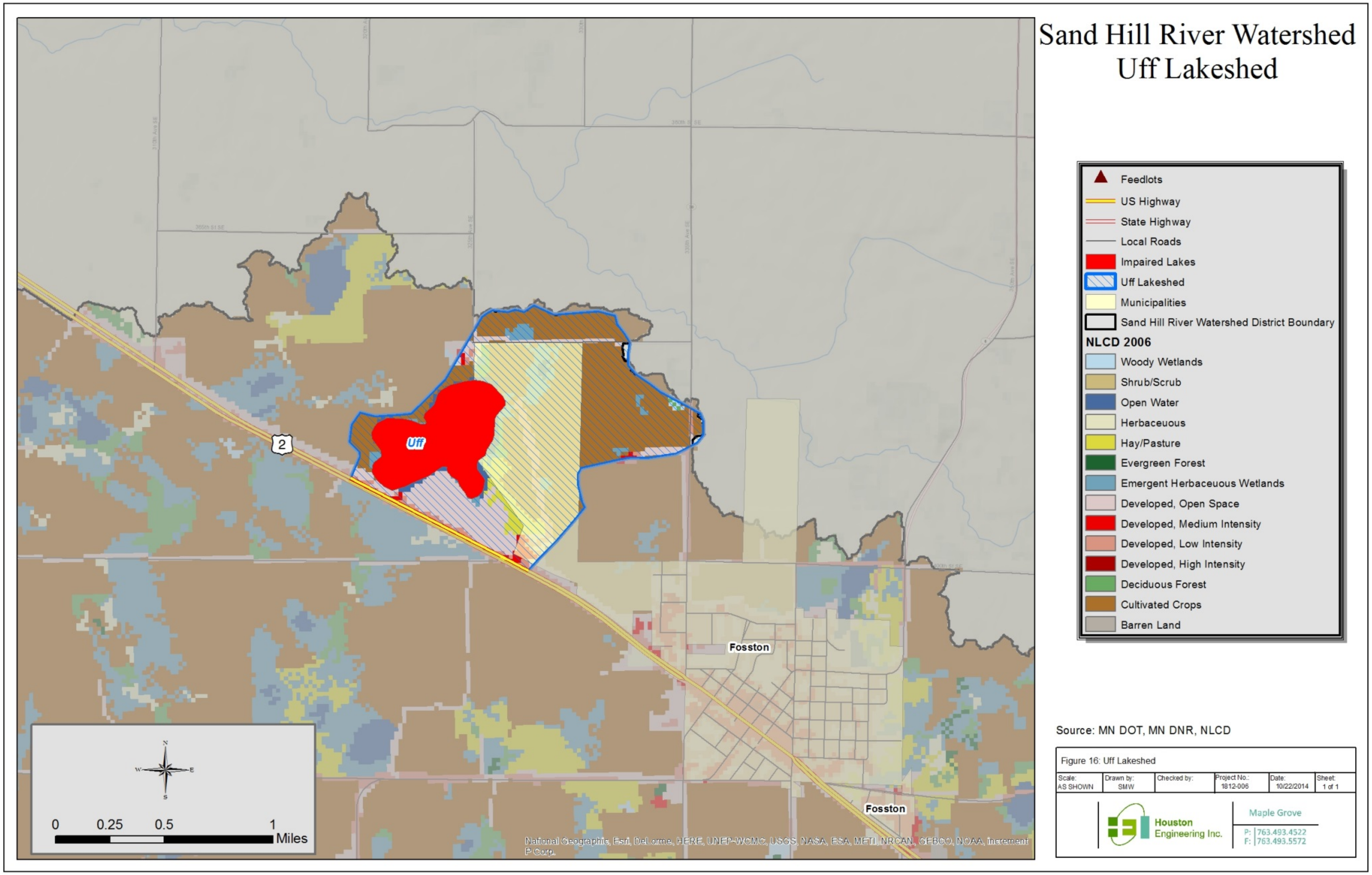

Figure 3-8: Uff Lake Lakeshed and Land Use.

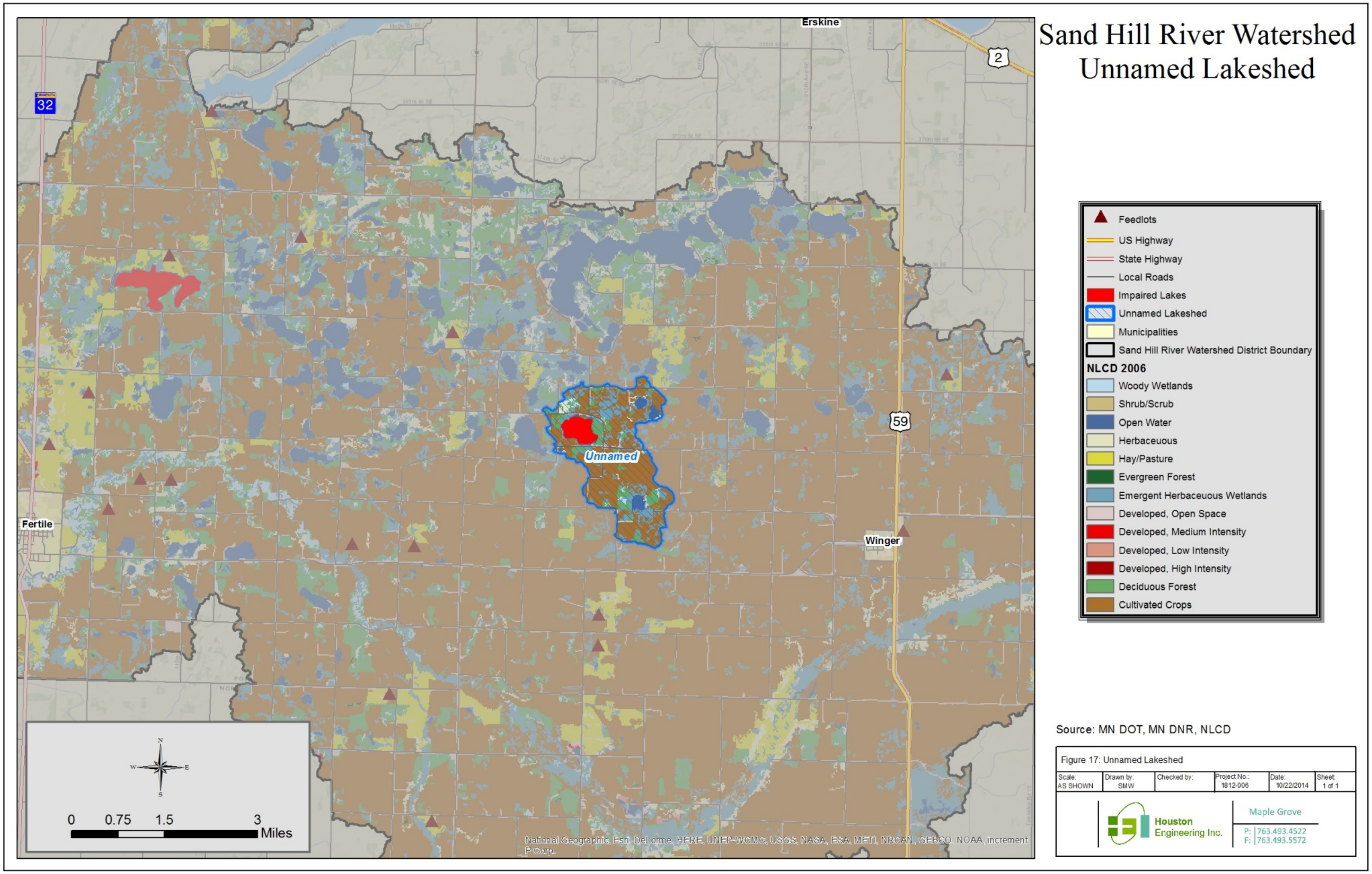

Figure 3-9: Unnamed Lake Lakeshed and Land Use.

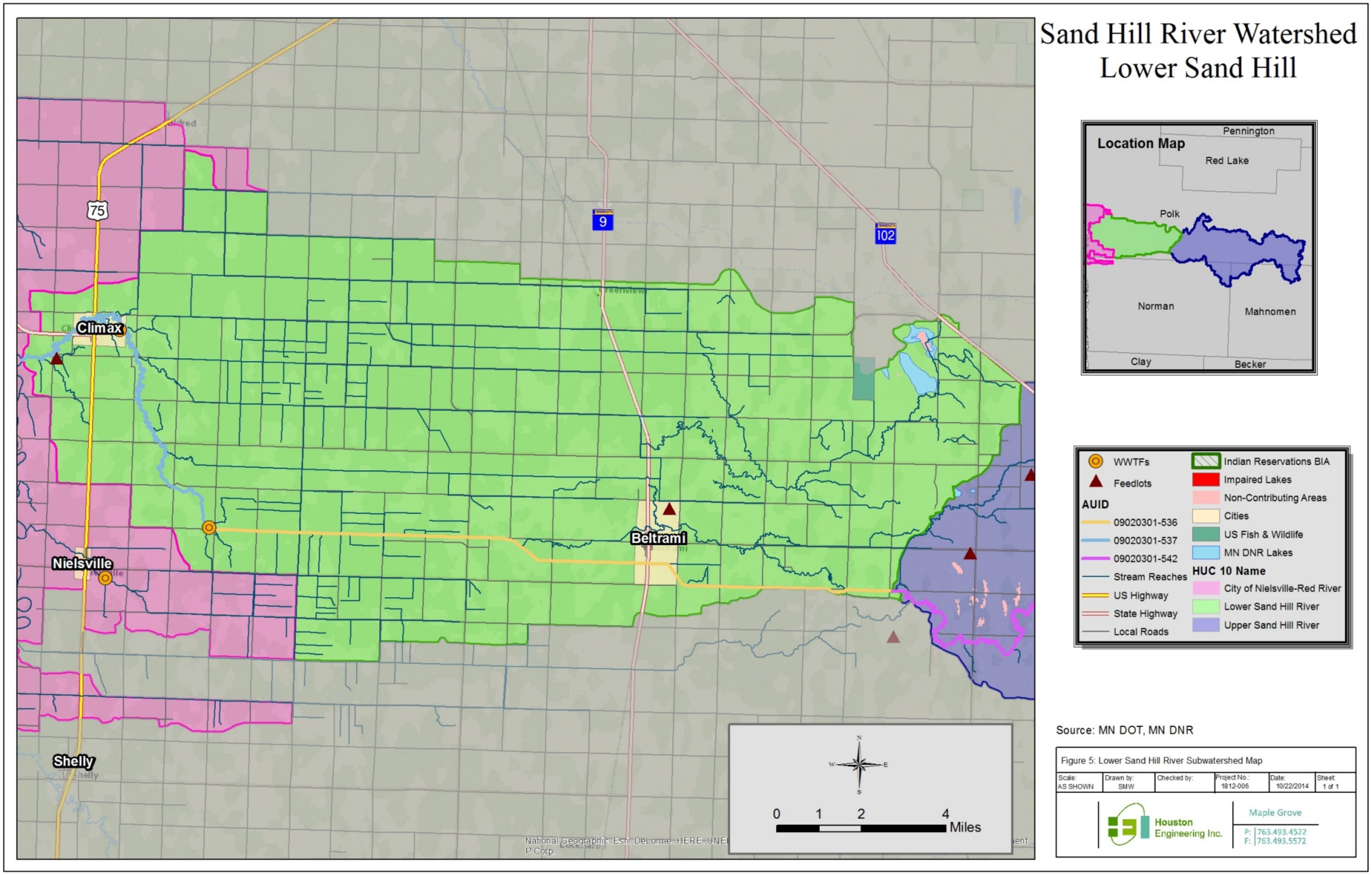

Figure 3-10: Lower Sand Hill River Subwatershed (HUC 0902030104).

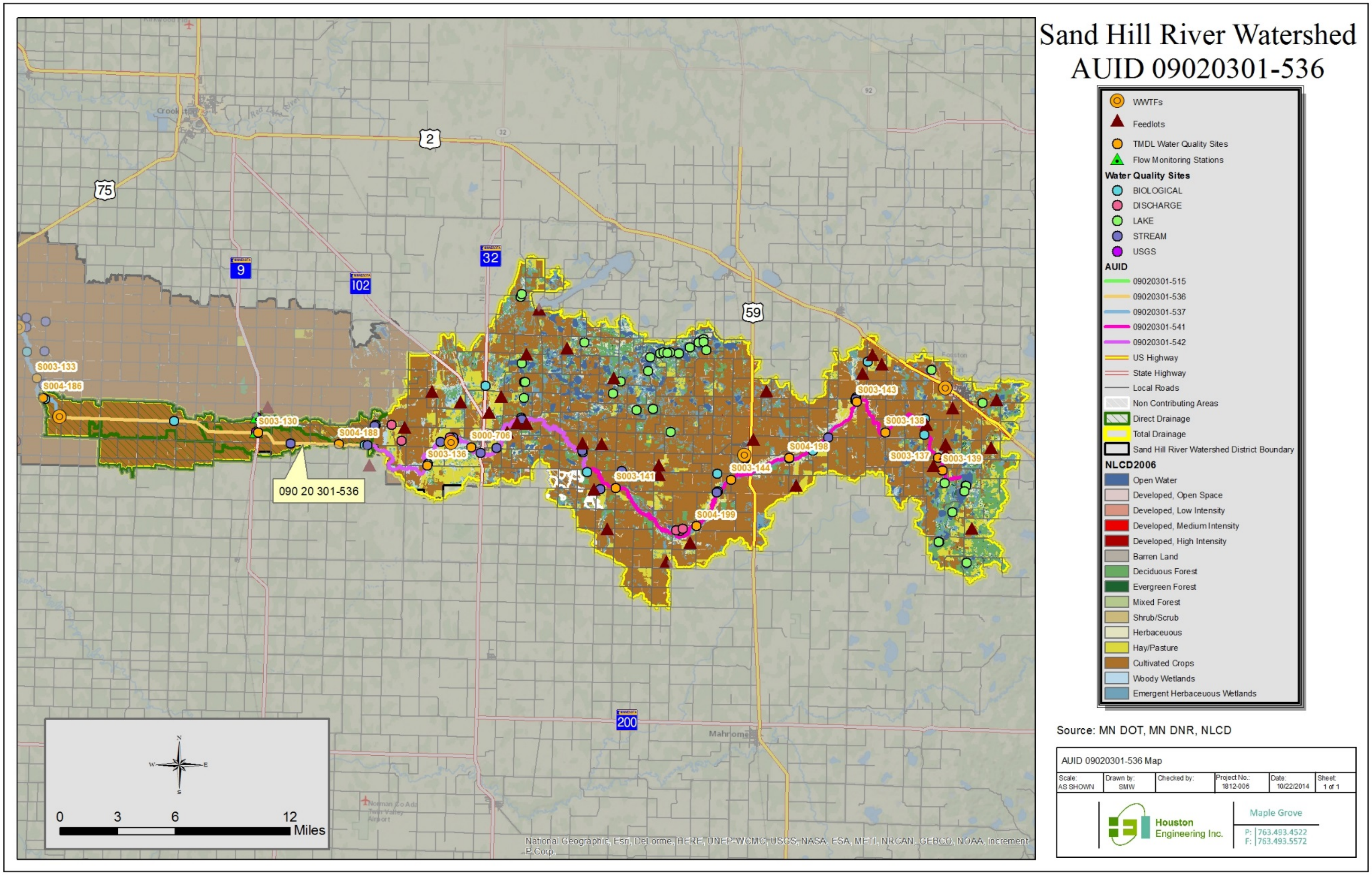

Figure 3-11: Drainage Area for AUID 09020301-536 in the SHRW.

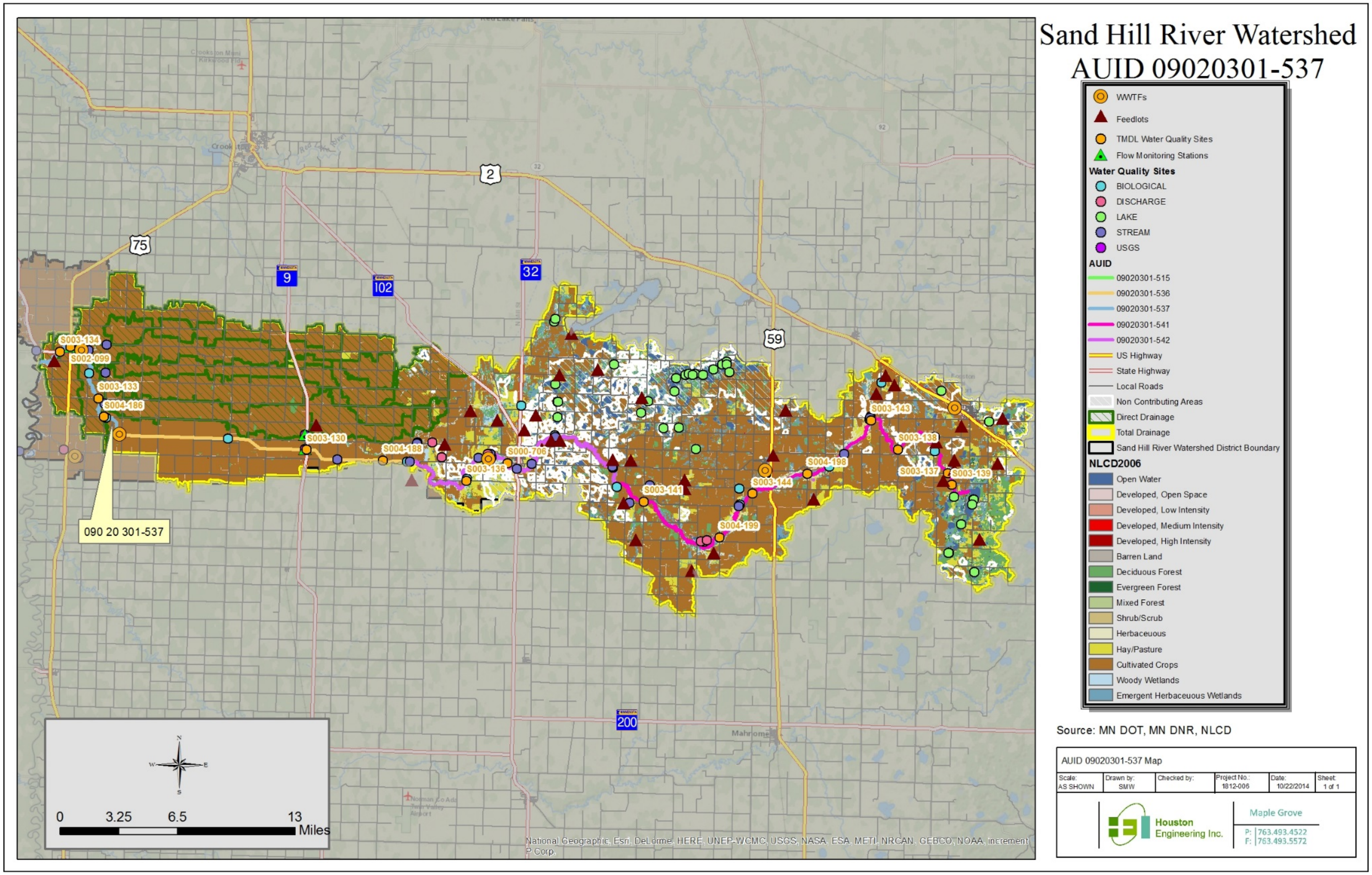

Figure 3-12: Drainage Area for AUID 09020301-537 in the SHRW.

3.4 Land Use

Land use within the SHRW can be described using the Multi-Resolution Land Characteristic Consortium (2006 NLCD)[4]. Agriculture is the primary land use in the SHRW. **Table 3-3** contains a summary of land uses in the SHRW, for the entire watershed as well as for each impaired water's drainage area. It should be noted, the 2006 NLCD distribution is provided instead of the current 2011 NLCD data (at this date of publication) since it better represents the time period and conditions for which the TMDLs were developed. In addition, land use in the SHRW has not seen significant changes in the last few generations of NLCD data (2001, 2006, and 2011).

Table 3-3: Land use percentages in the SHRW by drainage area. Land use statistics are based on 2006 NLCD and summarized for impaired AUIDs and Lakes.

Watershed/ Immediate Drainage Area	Open Water	Urban	Barren	Forest/ Shrub	Pasture/ Hay/ Grassland	Cropland	Wetland
Entire Watershed	3.0%	5.2%	0.0%	6.3%	7.3%	69.8%	8.3%
Upper Sand Hill River							
09020301-515	0.8%	5.1%	0.0%	5.8%	6.3%	75.9%	6.2%
09020301-541	2.9%	5.7%	0.0%	9.2%	10.0%	61.8%	10.4%
09020301-542							
Ketchum	10.3%	3.7%	1.0%	30.8%	35.7%	10.9%	7.6%
Kittleson	12.5%	5.1%	0.0%	14.2%	6.3%	44.6%	17.2%
Uff	19.2%	19.9%	0.0%	1.0%	3.2%	51.1%	5.5%
Unnamed	8.9%	4.6%	0.0%	10.6%	1.2%	57.0%	17.7%
Lower Sand Hill River							
09020301-536	4.0%	5.5%	0.0%	8.5%	9.9%	61.2%	11.0%
09020301-537	3.0%	5.2%	0.0%	6.3%	7.3%	69.8%	8.3%

[4] http://www.mrlc.gov/

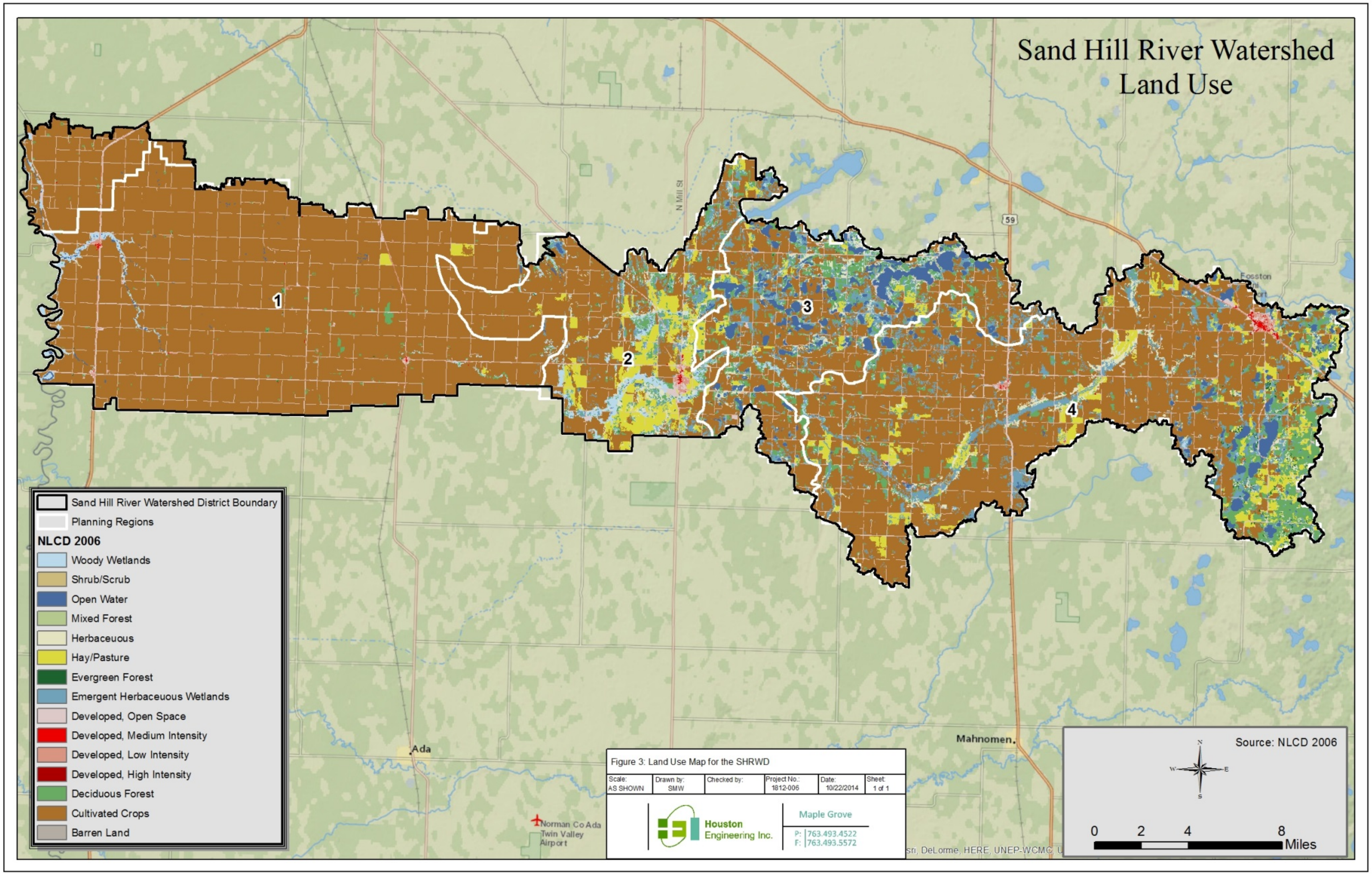

Figure 3-13: Land uses in the SHRW (2006 NLCD dataset).

3.5 Current/Historical Water Quality

The existing SHRW water quality conditions were described using data downloaded from the MPCA's Environmental Quality Information System (EQuIS) database[5]. EQuIS stores water quality data from more than 17,000 sampling locations across the state, containing information from Minnesota streams and lakes dating back to 1926. EQuIS stores data collected by the MPCA, partner agencies, grantees and citizen volunteers. All water quality sampling data utilized for assessments, modeling and data analysis, for this report and reference reports, are stored in this database and are accessible through the MPCA's Environmental Data Access (EDA) website[7].

According to EQuIS and the MPCA spatial datasets[6], there are 18 biological monitoring sites, 34 lake water quality monitoring sites, 37 stream water quality monitoring sites, 14 streamflow discharge sites, and 3 USGS gauging stations located in the SHRW (**Figure 3-14**). Not all sites were used in the development of the SHRW's TMDL study. Sites were excluded for various reasons including: 1) their period of record being outside of the assessment period (2002 through 2011); 2) the sites were not located in impaired stream reaches or lakes; or 3) a site did not have relevant observed data.

The MPCA conducts 2 years of intensive watershed monitoring in all 80 watersheds in Minnesota on a 10-year cycle (i.e., every major watershed is sampled for 2 years, once every 10 years). The SHRW intensive watershed monitoring occurred in 2011 and 2012.

Data from the current 10-year assessment period (2003 through 2012), consistent with the time period for the application of the water quality numeric standards, were used for development of this TMDL study. For turbidity, year round data were used. For *E. coli*, only data collected during the months of April through October were used. For the proposed TSS standard, data collected from April through September were used. Lake nutrient data are collected from May through September, but only June through September data were used for assessment and in development of the nutrient TMDLs to correspond to the period of application of the standard.

In instances where this TMDL study references "Natural Background Conditions", natural background conditions are considered the landscape condition that occurs outside of human influence. The Minn. R. 7050.0150, subp. 4, defines the term "Natural causes" as the multiplicity of factors that determine the physical, chemical, or biological conditions that would exist in a waterbody in the absence of measurable impacts from human activity or influence.

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5 http://www.pca.state.mn.us/index.php/data/environmental-data-access.html.

6 http://www.pca.state.mn.us/index.php/data/spatial-data.html

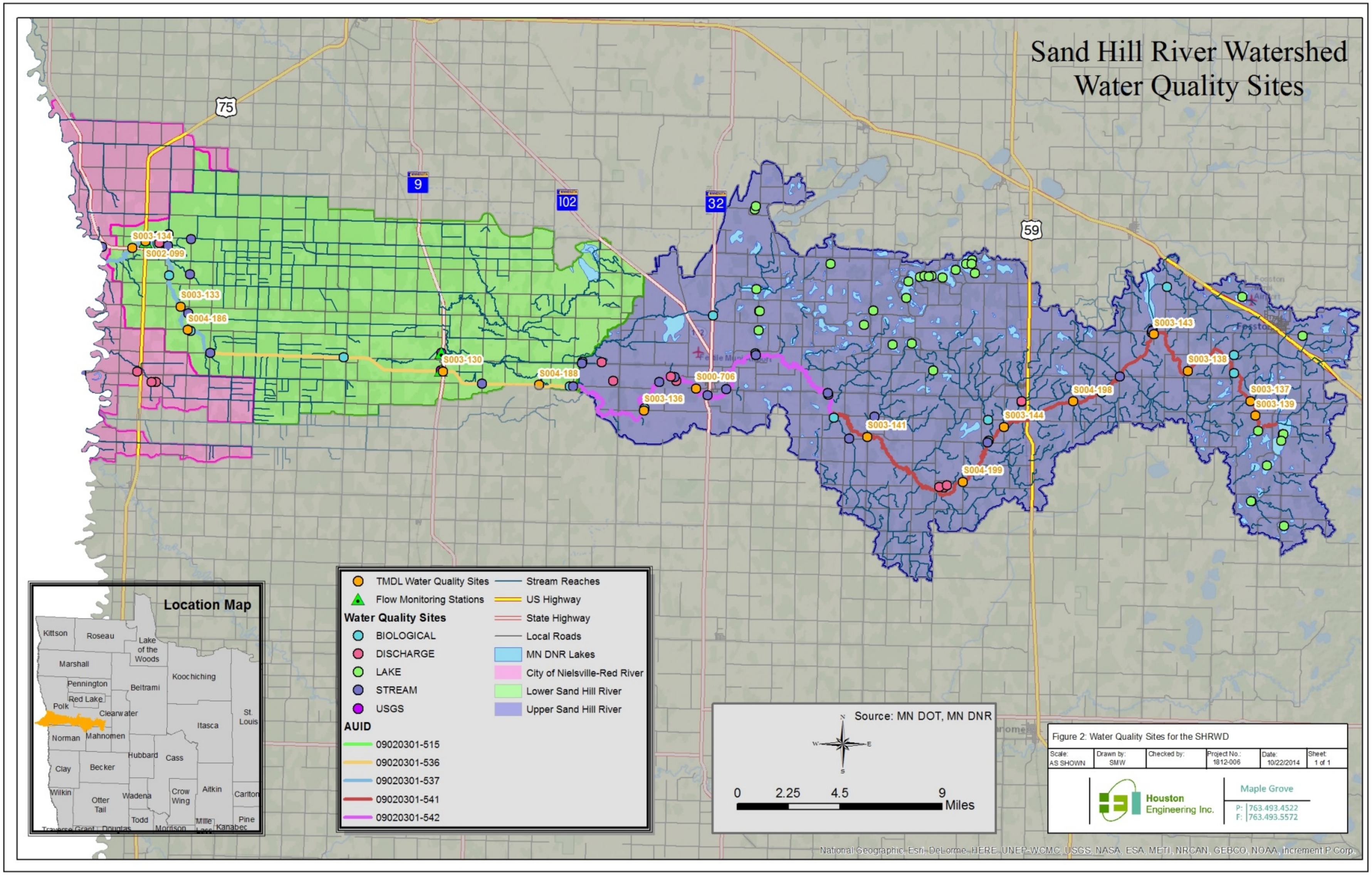

Figure 3-14: Water quality sites used to develop the TMDL study.

3.5.1 Lakes

Lake conditions were summarized, for each impaired lake, for the applicable numeric standard based on available in-lake water quality data. Only data collected during the watershed-wide intensive monitoring period (2011 and 2012) were available for impaired lakes in the SHRW. **Table 3-4** shows the average in-lake water quality conditions during the summer season (June through September) for impaired lakes in the SHRW. The water quality condition is quantified by TP concentrations, Chl-*a* concentrations, and Secchi Depth.

Table 3-4: Average water quality conditions for impaired lakes in the SHRW.

Lake Name	Observation Period	In-lake "Average" Water Quality Conditions (June-September)		
		TP (ug/L)	Chlorophyll-a (ug/L)	Secchi Depth (m)
Water Quality Standards for NCHF-Shallow Lakes		**<60**	**<20**	**>1.0**
Ketchum Lake	2011-2012	86.7	35.1	0.43
Kittleson Lake	2011-2012	87	67	0.43
Uff Lake	2011-2012	130.5	69.7	0.27
Unnamed Lake	2011-2012	68.7	45	0.5

3.5.2 Streams

3.5.2.1 Escherichia coli

A stream reach is listed as having impaired recreational use due to elevated *E. coli* if the geometric mean of the aggregated monthly *E. coli* concentrations for one or more months (with five or more samples) exceeds 126 organisms per 100 milliliters (mL), or if more than 10 % of the individual samples within a month (with five or more samples) exceeds 1,260 organisms per 100 mL.

Table 3-5 shows the number of samples for each month, the monthly geometric mean and the number of samples in each month exceeding 1,260 organisms per 100 mL, for April to October, for each of the four impaired stream reaches in the SHRW. The months where either standard is exceeded and have at least five samples, are highlighted in orange. Many more months showed standard exceedances but did not have the minimum five samples required to qualify for a standard exceedance. In general, *E. coli* concentrations were highest in June and July.

Table 3-5: Summary of *E. coli* in the SHRW for the Assessment Period 2003-2012 (Geo = geometric mean (no. per 100 mL); n=sample size).

			April			May			June			July			August			September			October		
AUID	Site ID	Sampling Years	n	Geo	% n>1260 org/100 mL	n	Geo	% n>1260 org/ 100mL	n	Geo	% n>1260 org/100 mL	n	Geo	% n>1260 org/100 mL	n	Geo	% n>1260 org/100 mL	n	Geo	% n>1260 org/100 mL	n	Geo	% n>1260 org/100 mL
-536	S003-130	2008-2009	0	NA	NA	2	40.4	0	5	134.4	0%	5	416.4	0%	5	68.5	0%	3	628.6	33%	0	NA	NA
-537	S002-099	2008-2012	0	NA	NA	0	NA	NA	10	93.4	0%	10	418.1	10%	10	145.6	0%	3	233.5	0%	0	NA	NA
	S004-186	2011-2012	3	12.5	0	3	101.4	0	5	224.3	0%	6	358.5	0%	5	91.1	0%	3	81.2	0%	3	44.2	0%
-541	S003-138	2008-2009	0	NA	NA	2	36.9	0	5	89.5	0%	5	46.1	0%	5	45.8	0%	3	262.4	33%	0	NA	NA
	S003-141	2008-2009	0	NA	NA	2	48.4	0	5	39.8	0%	5	46.8	0%	5	31.0	0%	3	214.3	33%	0	NA	NA
	S003-143	2011-2012	3	209.6	0	3	207.4	0	5	572.9	20%	5	535.1	20%	5	273.6	0%	3	183.3	0%	3	56.3	0%
	S006-559	2011-2012	0	NA	NA	0	NA	NA	5	563.5	20%	5	886.3	40%	5	434.6	20%	0	NA	NA	0	NA	NA
-542	S000-706	2008-2009	0	NA	NA	2	22.1	0	5	58.2	0%	5	78.4	0%	5	71.3	0%	3	341.7	0%	0	NA	NA
	S003-136	2006-2007, 2011-2012	0	NA	NA	0	NA	NA	4	63.8	0%	6	122.7	0%	10	84.7	0%	0	NA	NA	0	NA	NA
	S003-140	2001-2012	3	2.8	0	3	49.0	0	4	156.0	0%	4	402.1	0%	5	500.5	0%	3	190.3	0%	3	124.3	0%
	S006-560	2011-2012	0	NA	NA	0	NA	NA	5	155.7	0%	5	167.9	0%	5	82.8	0%	0	NA	NA	0	NA	NA

3.5.2.2 Total Suspended Solids

A stream reach is listed as having impaired aquatic life due to high TSS if more than 10 % of samples are above the numeric standard of 65 mg/L for the Southern Nutrient Region. The SHRW is considered to be part of the Southern Nutrient Region of Minnesota because of similar land use and topography.

Since Minnesota recently transitioned from a turbidity to a TSS standard to represent sediment in a stream, there are limited TSS samples at some sites in the SHRW, relative to the number of turbidity samples. Since there is typically a strong correlation between turbidity and TSS (see **Figure 3-15**), the TSS dataset was expanded using the available turbidity data, and converted to equivalent TSS using the relationship discussed below (**Figure 3-15** and **Equation 1**). **Table 3-6** lists all water quality sites within impaired reaches in the SHRW with turbidity and/or TSS observations during the assessment period.

Table 3-6: Summary of Sites with Turbidity and Total Suspended Solids Observations (n=sample size)

AUID	Site ID	Turbidity				Total Suspended Solids			
		Sampling Years	n	Average [NTU/NTRU]	# of Exceed.	Sampling Years	n	Average [mg/L]	# of Exceed.
-536	S003-130	2003-10	33	40	25	2008-10	21	62.3	7
-536	S004-358	2006	4	9	0				
-537	S002-099	2003-12	188	97	152	2003-12	252	118.6	148
-537	S003-134	2003-11	41	79	34				
-537	S004-186	2003-11	40	60	31	2011-12	16	54.4	2
-537	S004-188	2006-12	27	10	0				
-541	S003-138	2003-12	43	5	0	2008-09	16	4.8	0
-541	S003-139	2003-12	25	4	0				
-541	S003-141	2003-12	49	13	2	2008-09	16	2.3	0
-541	S003-143	2003-12	30	7	0	2011-12	16	10.2	0
-541	S003-144	2003-12	63	35	30				
-541	S004-198	2005-12	51	39	26				
-541	S004-199	2005-12	53	38	24				
-541	S006-559					2011-12	20	39.5	4
-542	S000-706	2003-12	51	7	1	2008-09	19	7.6	0
-542	S003-135	2003-05	14	13	2				
-542	S003-136	2003-12	30	8	1	2011-12	37	8.5	0
-542	S003-140	2003-12	56	8	2	2011-12	33	8.8	0
-542	S006-560					2011-12	20	7.1	0

A turbidity-TSS relationship was developed using all available paired turbidity and TSS data in the SHRW (**Figure 3-15**). The resultant equation was then used to compute the TSS-equivalent to the 25 NTU turbidity standard (i.e., the TSS surrogate standard). **Equation 1** shows the result of this analysis, with 25 NTU/NTRU turbidity approximately equal to 33.8 milligrams per liter (mg/L) of TSS. The R^2 value for this equation is 0.946. **Equation 1** was also used to convert turbidity observations into equivalent TSS estimates to extend the TSS dataset.

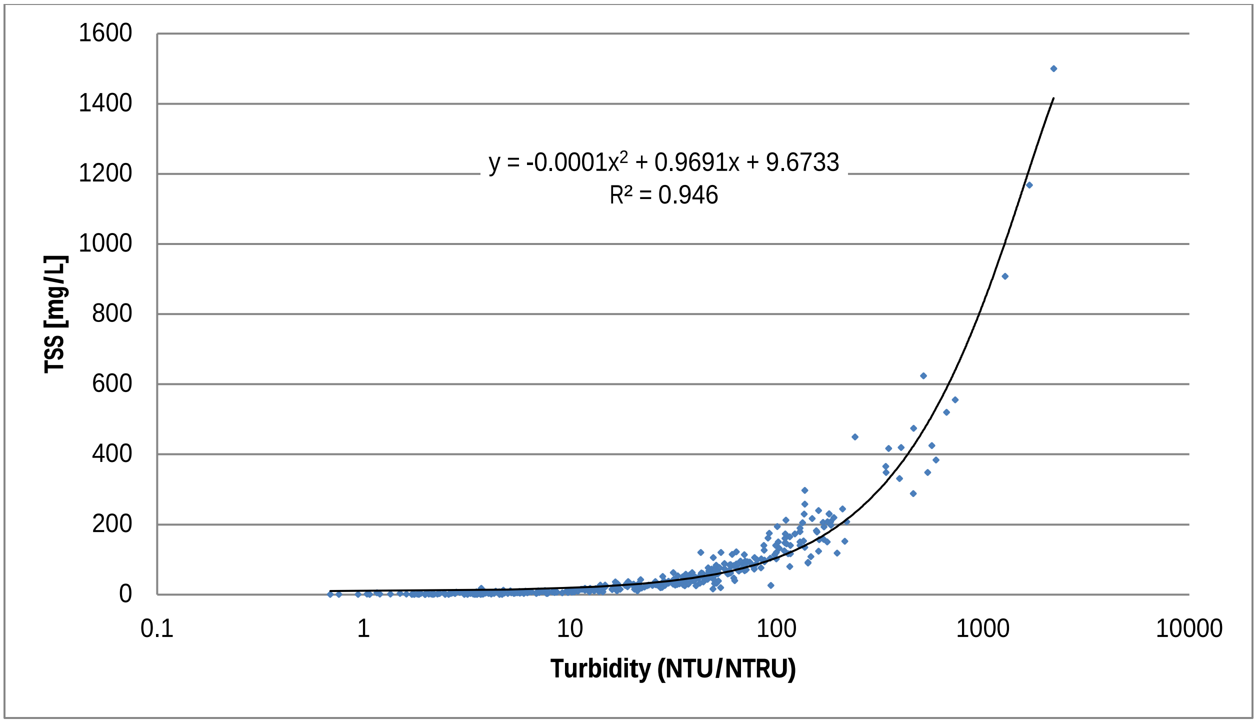

Figure 3-15: Relationship between TSS and Turbidity in the SHRW.

$$TSS = -0.0001 * Turbidity^2 + 0.9691 * Turbidity + 9.6733 \qquad \text{Equation [1]}$$

3.6 Pollutant Source Summary

A key component for developing TMDLs is understanding the sources contributing to the impairment(s). The SHRW is a complex system with considerable diversity in land use, topography, soils, and drainage intensity. This diversity results in a variety of conditions that support a broad spectrum of fish and other aquatic life. Several stressors in the SHRW play a role in influencing water quality in the system and limiting the health of these biological communities.

This section provides a brief description, by pollutant, of the sources in the watershed that potentially contribute to the listed impairments. A more in-depth discussion of the biological stressors, pollutant sources and causal pathways, excluding *E. coli*, can be found in the SHRW Biotic Stressor Identification report (MPCA 2014b). More discussion on the current conditions in the watershed can be found in the SHRW Monitoring and Assessment Report (MPCA 2014a).

3.6.1 Phosphorus

3.6.1.1 Permitted (Point) Sources

Potential sources of P within the SHRW, regulated through a National Pollutant Discharge Elimination System (NPDES) Permit (Permit), include effluent from WWTFs, construction sites, and industrial sites.

The only P (excessive nutrients) impairments are in lakes (see **Table 1-1**) and there are no NPDES permitted sites located in the drainage basins of any of the four impaired lakes. Therefore, no permitted sites were considered as potential sources of P in the lake TMDLs. This means the load is allocated completely to nonpoint sources.

3.6.1.2 Nonpoint Sources

The following potential sources of P from nonpoint sources (lacking the need for a permit) were considered in developing the nutrient budget for the lakes:

- Overland runoff;
- Livestock/Animals;
- Atmospheric deposition;
- Septic Systems;
- Internal loading from sediment in the lake;
- Natural background conditions.

Nonpoint Sources/ Overland Runoff

Figures 3-16 through **3-19** show the TP yields to the impaired lakes of the SHRW. TP yields were estimated using the SHRW HSPF (RESPEC 2014) model and are average annual yields in units of pounds per acre per year (lb/ac/yr). These yields can be generally related to various land uses. The following is a list of potential nonpoint sources of phosphorus, in the SHRW, by land use:

Forest/Shrub Land –Runoff from forested land can include decomposing vegetation and organic soils.

Cropland –Runoff from agricultural lands can include livestock wastes, fertilizers, soil particles, and organic material from agronomic crops.

Pasture/Hay/Grassland – This category combines several land uses including pasture, hay land, idle grasslands, Conservation Reserve Program (CRP) and any other state or federal program lands managed as grasslands. Surface runoff can deliver P from manure deposited by livestock and wildlife.

Developed (Urban) Land–Runoff from residences and impervious surfaces can include fertilizer, leaf and grass litter, pet waste, and numerous other sources of P.

Wetlands/Open Water –Wetlands and open water can export P through suspended solids as well as organic debris that flows through waterways.

Table 3-7 shows the average annual yields delivered to the lake as simulated by the SHRW HSPF for each land use type. It should be noted, HSPF does not distinguish between roads and urban areas and they are treated as the same unit. Therefore, the yields from the roads shown in Figures 3-16 through 3-19 and in Table 3-7 may be higher than the actually exists.

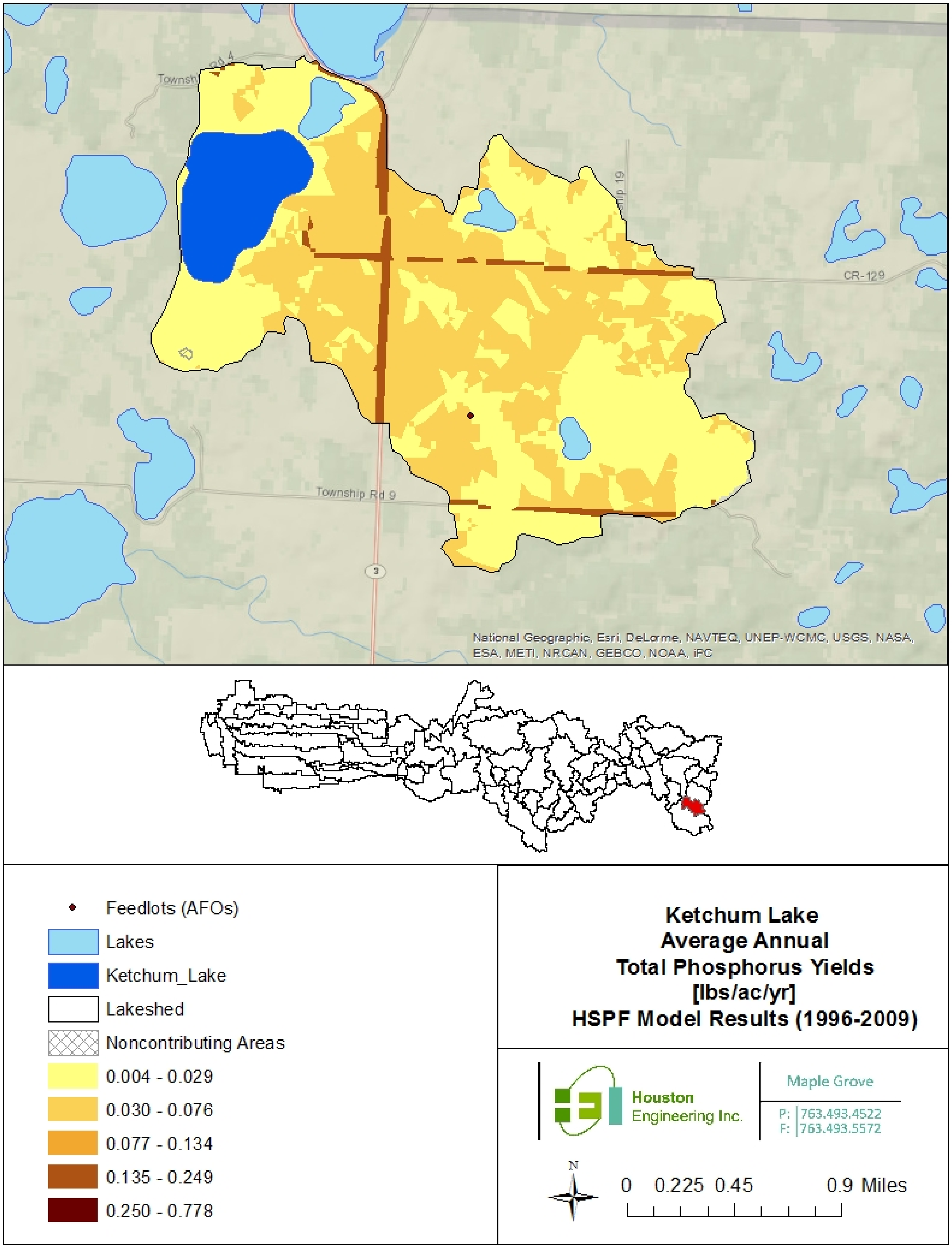

Figure 3-16: Distribution of TP Yields [lbs/acre/yr] in Ketchum Lake's Lakeshed.

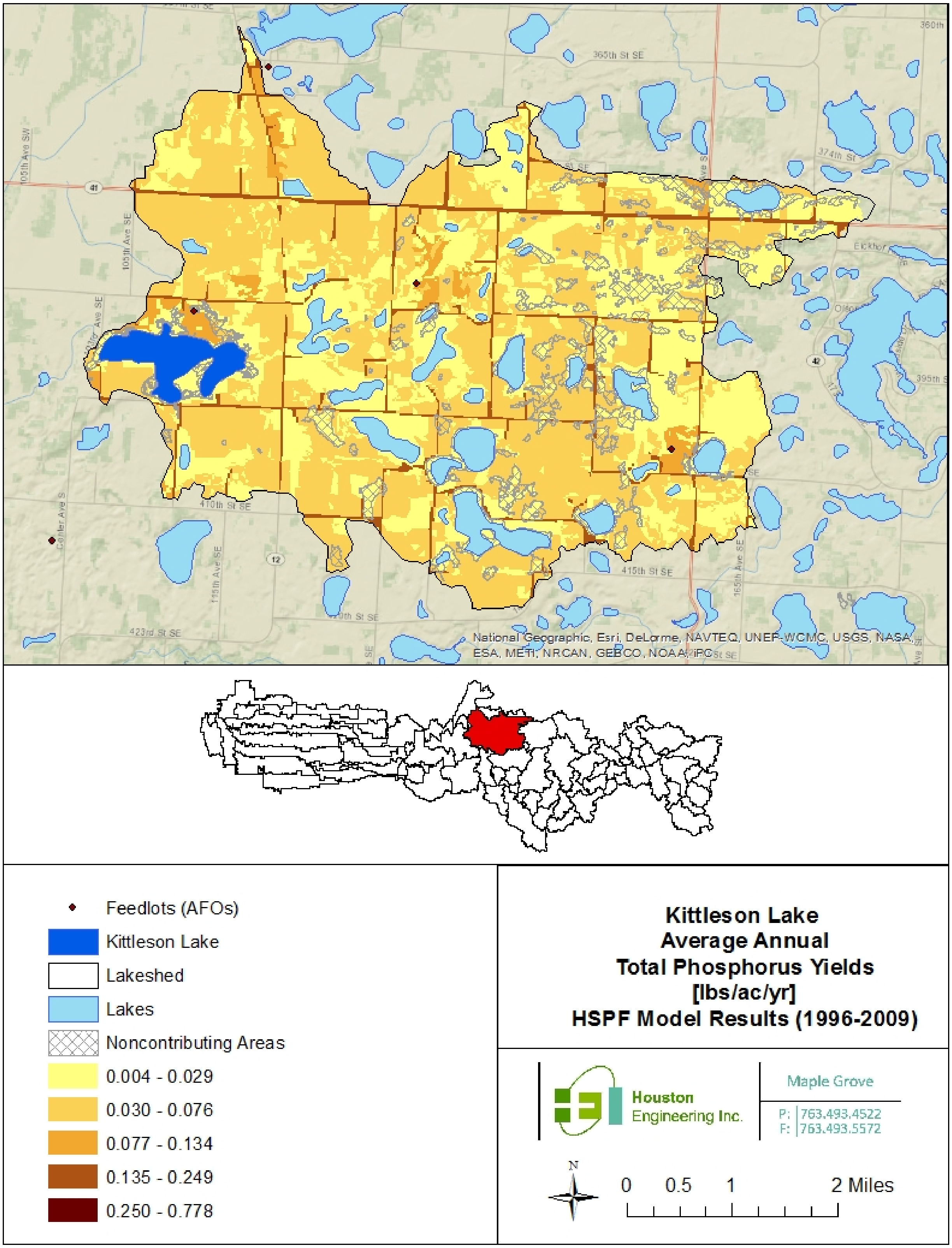

Figure 3-17: Distribution of TP Yields [lbs/acre/yr] in Kittleson Lake's Lakeshed.

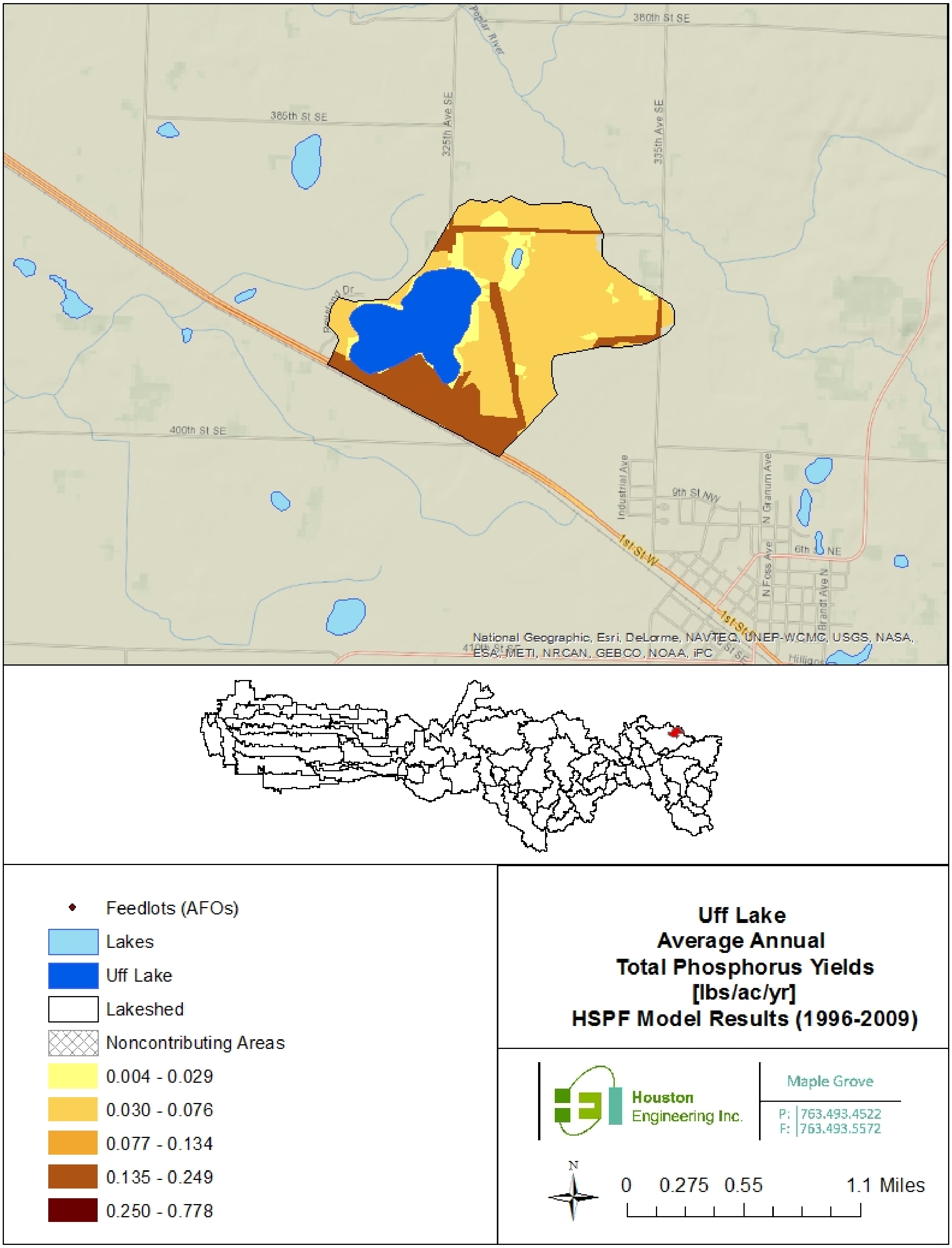

Figure 3-18: Distribution of TP Yields [lbs/acre/yr] in Uff Lake's Lakeshed.

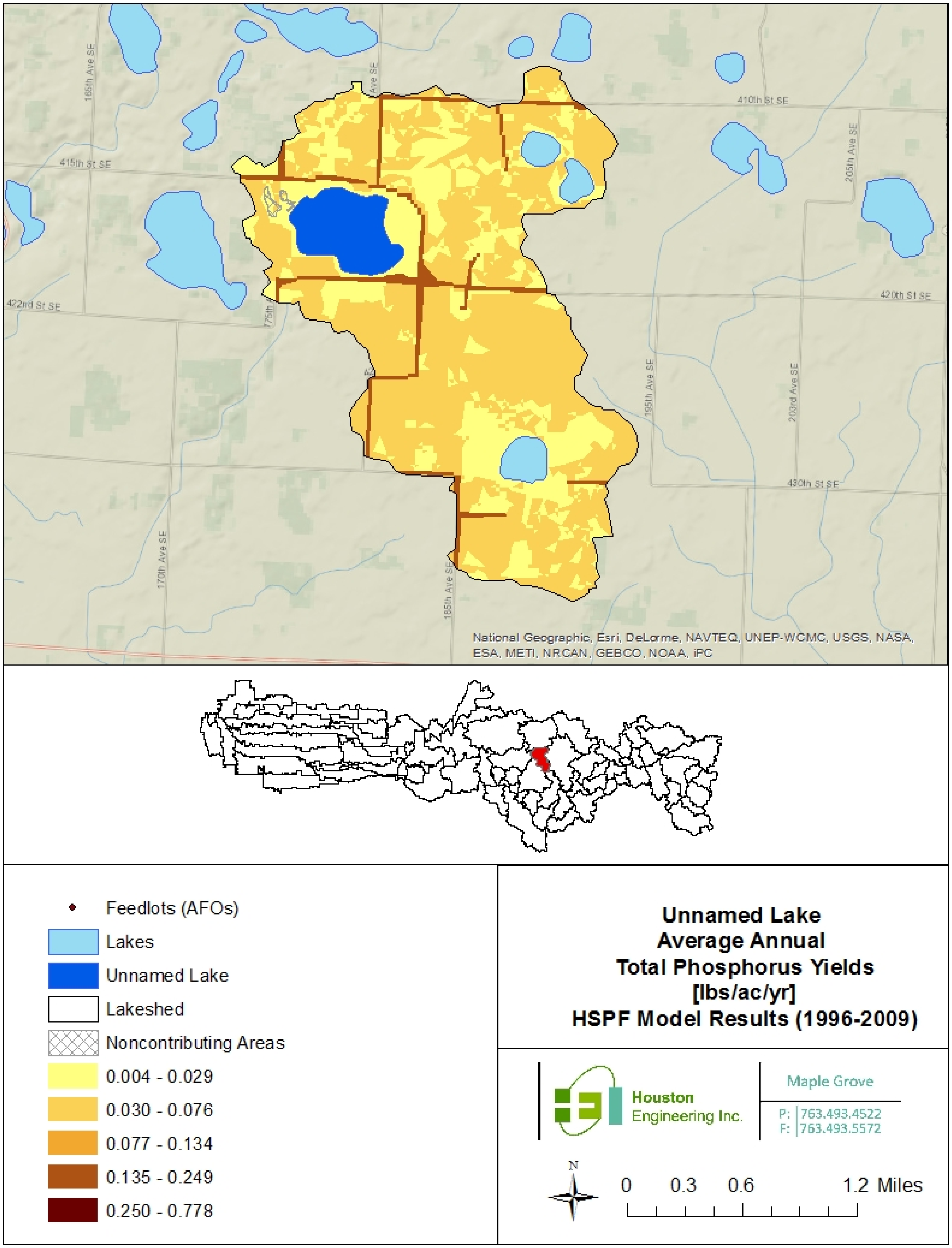

Figure 3-19: Distribution of TP Yields [lbs/acre/yr] in Unnamed Lake's Lakeshed.

Table 3-7: Annual Average Total Phosphorus Yields [lbs/ac/yr] by Land Use.

Land Use	Ketchum Lake	Kittleson Lake	Uff Lake	Unnamed Lake
	[lbs/ac/yr]	[lbs/ac/yr]	[lbs/ac/yr]	[lbs/ac/yr]
Urban	0.235	0.205	0.235	0.196
Forest	0.0017	0.0034	0.0017	0.0046
Cropland	0.055	0.054	0.055	0.069
Grassland	0.019	0.029	0.019	0.034
Pasture	0.054	0.078	0.054	0.09
Wetland	0.0009	0.0028	0.0009	0.002

Livestock/Wildlife

Livestock can contribute P to the watershed through runoff at feeding, holding, and manure storage areas as well as direct loading if allowed access to streams or lakes. Additional runoff can occur through manure applications. The P loading from livestock/manure was not explicitly included but was implicitly accounted for in the calibration of the HSPF model. More discussion on the livestock and wildlife is provided in **Section 3.6.2**.

Atmospheric Load

Direct atmospheric deposition to the surface of the lakes was based on regional values. Sources of particulate P in the atmosphere may include pollen, soil erosion, oil and coal combustion and fertilizers. The atmospheric export coefficient used in the model was 0.3 kilograms per hectare year (kg/ha-yr) (Barr 2007).

Inadequate Sub-Surface Sewage Treatment Systems

Without individual inspections, it is difficult to know for certain the rate of compliance for septic systems in the lake catchment areas. Individual county estimates range from 84% to 86% compliance (see **Section 3.6.2.2, Table 3-11**). Increasing septic compliance should be a focus of the lake restoration strategy, especially in shoreline areas. The P loading from failing sub-surface sewage treatment systems (SSTS) was not explicitly included but was implicitly accounted for in the calibration of the HSPF model.

Internal Load

Internal loading of P can come from a wide variety of sources including re-suspension of sediments due to wave action, rough fish, wildlife activity, boating and bio-chemical processes that release P. The nutrient retention models within the BATHTUB/CNET framework already account for nutrient recycling, so it is generally not advisable to add internal load without independent estimates or measurements (Walker 1999).

No information on internal loading rates on lakes in the SHRW is available at this time. Internal loading in the SHRW lakes was estimated using a mass balance approach developed by Nurnberg (1984, 1995, and 2009).

Internal loading is estimated by adding an internal loading term to the current models based on external loading and predicted retention (Nurnberg 1984):

$$TP = {L_{ext}}/{q_s}\left(1 - R_{pred}\right) + {L_{int}}/{q_s} \qquad \text{[Equation 2]}$$

where TP is the in-lake TP concentration (ug/L); L_{ext} is the external load (kg/yr), q_s is the lake outflow (hm^3/yr), R_{pred} is the predicted retention coefficient, and L_{int} is the internal loading (kg/yr).

Solving **Equation 2** for internal loading and using average annual TP loads from the HSPF model and observed average annual in-lake TP concentrations, average annual internal loading rates of TP can be found. For the impaired lakes in the SHRW, only Kittleson Lake and Unnamed Lake were shown to have internal loading (i.e. a positive value of internal loading from **Equation 2**) (see **Table 3-8**).

Natural Background Conditions

Natural background conditions refer to inputs that would be expected under natural, undisturbed conditions. Natural background sources can include inputs from natural geologic processes such as soil loss from upland erosion and stream development, atmospheric deposition, and loading from forested land, wildlife, etc. For each impairment, natural background levels are implicitly incorporated in the water quality standards used by the MPCA to determine/assess impairment and therefore natural background is accounted for and addressed through the MPCA's waterbody assessment process. Natural background conditions were also evaluated, where possible, within the modeling and source assessment portion of this study. These source assessment exercises indicate natural background inputs are generally low compared to livestock, cropland, streambank, WWTFs, failing SSTSs and other anthropogenic sources.

Based on the MPCA's waterbody assessment process and the TMDL source assessment exercises, there is no evidence at this time to suggest that natural background sources are a major driver of any of the impairments and/or affect the waterbodies' 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.

Total Phosphorus Loading

Estimated annual P loading rates into the lakes of the SHRW were taken from the SHRW HSPF model, including surface water runoff unit loadings and tributary TP loads. The HSPF model accounts (both explicitly and implicitly) for most of the above listed potential sources of P (excluding direct atmospheric deposition and internal loading) and simulates transport of them overland and, eventually, into the nearest waterbody; in this case, the nearest lake. Internal loading was estimated by solving **Equation 2** for internal loading and using average annual loading rates and observed average annual in-lake concentrations to estimate internal loading rates. Atmospheric deposition was estimated by using the 0.3 kilograms per hectare year (kg/ha-yr) (Barr 2007) times the surface area of the lake. **Table 3-8** shows the total average annual TP loading used to model the impaired lakes.

Table 3-8: Annual Average Total Phosphorus Loading to Impaired Lakes in the SHRW.

Lake Name	Gains (kg/yr)			Losses (kg/yr)	
	Atmospheric Deposition	Direct Drainage Area Load	Internal Loading	Sedimentation	Outflow Load
Ketchum Lake	19	65	0	63	21
Kittleson Lake	36	283	529	488	360
Uff Lake	16	32	0	45	3
Unnamed Lake	14	55	61	79	52

Assumes net groundwater = 0.

3.6.2 *Escherichia* coli

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. Despite the complexity of the relationship between sources and in-stream bacterial concentrations, the following can be considered major sources in rural areas: livestock facilities, livestock manure, wildlife, malfunctioning SSTSs and WWTFs. The following section will discuss the major sources and methods used to estimate the magnitude of each source relative to the bacteria load in an impaired waterbody.

To evaluate the potential sources of bacteria delivered to the impaired waterbody, a bacteria source investigation was conducted based on population production estimates and potential delivery to the waterway. The bacteria source investigation includes the following steps:

1. Identify and estimate potential populations that may contribute *E. coli* in the watershed. These populations may include humans, companion animals (cats and dogs), livestock (cows, chickens, goats, hogs, horses, sheep, and turkeys), and wildlife (deer, ducks, geese, and others). Once the bacteria-contributing populations have been identified, population estimates are obtained from the various sources provided in the following sections.
2. Each population type is assigned a bacteria production rate (see **Table 3-9**), based on literature values. These bacteria yields are then applied to the relevant areas, described in the following sections.
3. A delivery factor based on die-off and travel time is then estimated and applied to the watershed. This delivery factor accounts for the fate and transport of bacteria from the source to the impaired waterbody.
4. Finally, the total bacteria load is estimated by summing the bacteria production with the delivery factor applied to estimate the relative loads for each identified source. A ranking is applied based on percentage of total bacteria load.

Production Rates

The EPA's *Protocols for Developing Pathogen TMDLs* provides estimates for bacteria production rates for most animals. The estimates are shown in **Table 3-9** (EPA 2001 p. 5-6 to 5-8). Bacteria production rates are based on estimated bacteria content in feces and average excretion rate, expressed as units of colony-forming units (cfu) per day per head (individual). Production rates are usually provided as fecal coliform; therefore, a conversion factor of 0.63 was used to convert fecal coliform to *E. coli*. The conversion factor is based on the ratio of the previous fecal coliform standard (200 org/100 mL) to the current *E. coli* standard (126 org/100 mL).

Table 3-9: Bacteria production rates by source

Source	Producer	Fecal Coliform Production Rate [billion (10^9) org/day-head]	*E. coli* Production Rate [billion (10^9) org/day-head][1]	Reference[1]
Humans	Humans	2	1.3	Metcalf and Eddy 1991
	Domestic Animals	5	3.2	Horsley and Witten 1996
Livestock	Cattle	5.4	3.4	Metcalf and Eddy 1991
	Hogs	8.9	5.6	Metcalf and Eddy 1991
	Sheep and Goats	18	11.3	Metcalf and Eddy 1991
	Poultry	0.24	0.15	Metcalf and Eddy 1991
	Horses	4.2	2.6	ASAE 1998
Wildlife	Deer	0.36	0.2	Zeckoski et al 2005
	Geese	4.9	3.1	LIRPB 1978
	Ducks	11	6.9	Metcalf and Eddy 1991
	Other (feral cats, raccoons, etc.)	5	3.2	Yaggow 1991

[1]Literature rates are provided as fecal coliform, estimates for *E. coli* rates are based on fecal coliform estimates and conversion factor of 0.63, based on the conversion of the fecal coliform standard and *E. coli* standard.

3.6.2.1 Permitted (Point) Sources

Wastewater Treatment Facilities (WWTF)

All permitted WWTF in the state of Minnesota are required to monitor their effluent to ensure that concentrations of specific pollutants remain within levels specified in their NPDES discharge permit. Although water quality standards in Minnesota for fecal bacteria are now based on *E. coli*, WWTF are permitted based on fecal coliform, not *E. coli*. Effluent limits require that fecal coliform concentrations remain below 200 organisms/100 mL (MPCA 2002; page 2). Based on the previous fecal standard and the current *E. coli* standard (**Table 1-1**), a ratio of 200:126 (0.63) is used to convert fecal coliform to *E. coli*. Therefore, the effluent limit for *E. coli* concentrations remains below 126 organisms/100 mL.

The SHRW contains three “minor” (as defined by the MPCA) WWTFs that drain into impaired streams. These facilities are all pond-type treatment plants with primary and secondary treatment lagoons. The general operation of these facilities is to discharge their treated waste into the surface water system in the spring/early summer and again in the late fall of each year. The most typical windows for releases are in April through June and then again in September through November. **Table 3-10** identifies the four permitted WWTF in the SHRW. In addition, **Table 3-10** provides their permitted daily discharge flow and permitted daily bacteria load.

Table 3-10: WWTF, permitted flows and bacteria loads in the SHRW.

Facility	Permit Number	12-Digit HUC (09020301-XXXX)	Discharge to AUID	City / Township	System Type	Secondary Pond size [acres]	Permitted Daily Flow [mgd]	Equivalent Bacteria Load as *E. coli*: 126 org/100mL [billion org/day]
Climax	MNG580169	0306	537	Climax	Pond	1.7	0.277	1.32
Fertile	MNG580138	0208	542	Fertile	Pond	6	0.978	4.66
Winger	MN0046671	0203	510 (to 541)	Winger	Pond	1.5	0.245	1.17

NPDES Permitted Concentrated Animal Feeding Operation

The MPCA regulates the collection, transportation, storage, processing, and disposal of animal manure and other livestock operation wastes (MPCA 2011). The MPCA currently uses the federal definition of a Concentrated Animal Feeding Operation (CAFO) in its regulation of animal facilities. In Minnesota, the following types of livestock facilities are issued, and must operate under, a NPDES Permit: (a) all federally defined CAFOs; and (b) all CAFOs and non-CAFOs that have 1,000 or more animal units (AUs) (MPCA 2010). There are no CAFOs requiring NPDES Permits in the SHRW.

3.6.2.2 Nonpoint Sources

Humans

Subsurface Sewage Treatment Systems

Malfunctioning SSTSs can be an important source of fecal contamination to surface waters, especially during dry periods when these sources continue to discharge and surface water runoff is minimal. According to the MPCA (MPCA 2011b; Page 6), these malfunctioning SSTSs fall into two categories: Imminent Public Health Threat (IPHTs) or failing to protect groundwater (i.e., failing). IPHT indicates the system has a sewage discharge to surface water; sewage discharge to ground surface; sewage backup; or any other situation with the potential to immediately and adversely affect or threaten public health or safety. Failing to protect groundwater indicates the bottom of the system does not have the required separation to groundwater or bedrock.

Of the rural population in the SHRW, an estimated 8201 people - or 14.2% - have inadequate treatment of their household wastewater. This includes individual residences and any unsewered communities. A MPCA document (MPCA 2011) reports numbers from 2000 through 2009 on the total number of SSTSs by county, along with the average estimated percent of SSTSs that are failing versus the percent that are considered IPHTs. The total numbers of SSTSs per county were multiplied by the estimated percent IPHT and percent failing within each area (MPCA 2011) to compute the number of potential IPHTs and potentially failing SSTSs per county and in the SHRW overall. **Table 3-11** summarizes the results. It should be noted that no data were available for Mahnomen County. Estimates for Mahnomen Count were taken from Norman County, which has similar populations and demographics.

Table 3-11: SSTS compliance status in the SHRW, by County.

	Polk	Norman	Mahnomen[1]	Watershed Total
Identified # of SSTSs	6000	1161	1040	8201
Estimated % Failing	15%	12%	12%	14.2%
Estimated % IPHT	3%	4%	4%	3.3%
# of potentially failing SSTSs	900	139	125	1164
# of potential IPHTs	180	46	42	268

[1]No data was available for Mahnomen County. Percentages of failing and IPHT SSTSs were taken from Norman County due to similarities in population and demographics.

Companion Animals

Companion animals, such as dogs and cats, can contribute bacteria to a watershed when their waste is not disposed of properly. Dog waste can be a significant source of bacteria to water resources (Geldreich 1996) at a local level when in the immediate vicinity of a waterbody. However, it is generally thought these sources may be minor on the watershed scale, especially in agricultural areas. It was estimated that 34.3% of households own dogs and each of these households has 1.4 dogs (AVMA 2007). Waste from domestic cats is usually collected by owners in the form of litter boxes. Therefore, it is assumed that domestic cats do not supply significant amounts of bacteria on the watershed scale. Feral cats may supply a significant source of bacteria and are accounted for under wildlife.

Population estimates of domestic dogs was taken from the 2010 Census. Distribution of bacteria from companion animals is applied to all land uses in the NLCD land cover layer except open water.

Data Sources and Assumptions for Humans

Bacteria sources, assumptions and distribution used to estimate the potential source of bacteria, related to humans, are listed in **Table 3-12**.

Table 3-12: Data sources, assumptions, and distribution of bacteria attributed to humans.

Bacteria Source	Distribution
Unsewered Communities-Failing and IPHT SSTS Population in unsewered communities based on 2010 Census Block information. Number of failing and IPHT SSTS from County estimates (MPCA 2011b).	The population of unsewered communities were estimated based on 2010 Census Block data. Production rates of 1.3 x 10^9 cfu/day/person were used. Total bacteria was applied to developed land use classes in the 2006 NLCD dataset.
Companion Animals (Dogs only) 34.3% of households own dogs, 1.4 dogs in households with dogs. Populations of dogs were based on the 2010 Census Block data.	An estimated 38% of dog owners do not depose of waste properly (TBEP 2012). Population distributions are based on 2010 Census Blocks. Production rates of 3.2 x 10^9 cfu/day/dog was used. Total bacteria was distributed among all land use classes in the 2006 NLCD dataset except open water.

Livestock

Livestock Populations

The Census of Agriculture is a complete count of U.S. farms and ranches. The Census of Agriculture defines a farm as *any place from which $1,000 or more of agricultural products were produced and sold,* *or normally would have been sold, during the census year* (USDA 2009). The census looks at data in many areas, including animal ownership and sales. The authority for the census comes from federal law under the *Census of Agriculture Act of 1997* (Public Law 105-113, Title 7, United States Code, Section 2204g). The census is taken every fifth year, covering the prior year and the most recent census was completed for the year 2012.

The United States Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) provides livestock numbers, by county, for the number of cattle, hogs, horses, sheep, goats and poultry (chicken and turkey). County livestock populations were distributed across the watershed in an area-weighted basis. For example, if County A is 100 square miles and has 100 head of cattle, the population density of cattle is one head per square mile. If 60 square miles of County A is located in the watershed, then an estimated 60 head of cattle would be in the watershed. County-wide livestock populations were estimated for cattle, chickens, goats, horses, and sheep and are provided in **Table 3-13**. If the number of farms with a certain type of livestock (e.g., pullets) exists in a small number where numbers at an individual farm can be known, the census lists the number of farms and not the livestock numbers to protect the farmer. Therefore, for some types of livestock (pullets), the number of farms is listed in **Table 3-13** instead of livestock populations.

Although the MPCA's geographic feedlot database developed for registered and NPDES permitting provides location and allowable populations of animals, these populations are the maximum allowable populations under the permits and are not the actual populations at these sites. Therefore, the USDA census data was used to estimate livestock populations.

Table 3-13: Livestock Population Estimates in the SHRW.

Animal	Type	Mahnomen	Norman	Polk
Cattle	All	6,881	6,855	12,174
	Beef	2,356	1,793	5,702
	Dairy	823	417	1,084
	Cattle on Feed	3,702	4,645	5,388
Pigs	--	550	7,070	17,637
Sheep	--	497	493	432
Goats	--	57	57	144
Horses	--	119	175	524
Poultry	Layers	291	443	998
	Pullets	100	0	1 farm
	Boilers	0	420	205

Livestock waste is distributed throughout the watershed in three main categories: grazing animals, animal feedlot operations (AFOs), and land application of manure. Discussion of each of these categories follows.

Grazing

Grazing occurs on pastured areas where concentrations of animals maintain grasses or other vegetative cover during the growing season. Grazing pastures are neither permitted nor registered in the state of Minnesota. Agricultural areas adjacent to lakes, rivers, and streams require a buffer strip of permanent vegetation that is 50 feet wide unless the areas are part of a resource management system plan (Minn. R. 6120.330, subp. 7). It should be noted, that it is commonly believed that these rules have limited enforcement statewide. Grazing cattle were assumed to be the total cattle population from the Census of Agriculture (see *Livestock Populations*) minus the cattle on feed.

Animal Feedlot Operations

AFOs with less than 1,000 but more than 50 AUs (and that are outside of shoreland areas) are regulated by the MPCA under a registration program. AFOs with more than 10 AUs and that are inside shoreland areas are also regulated under this program. Shoreland is defined in Minn. Stat. § 103F.205, to include: land within 1,000 feet of the normal high-watermark of lakes, ponds or flowages; land within 300 feet of a river or stream; and designated floodplains (MPCA 2009). These smaller facilities are subject to state feedlot rules, which include provisions for registration, inspection, permitting and upgrading. There are 36 active registered AFOs[7] in the SHRW.

Land Application of Manure

Manure is often surface applied or incorporated into fields as a fertilizer and soil amendment. This land application of manure has the potential to be a substantial source of fecal bacteria, transported to waterbodies from surface runoff and drain tile intakes. Minn. R. ch. 7020 contains manure application setbacks based on research related to nutrient transport, but the effectiveness of these setbacks on bacteria transport to surface waters are unknown.

A portion of the livestock population is assumed to supply manure for land application (see **Table 3-14**). The bacteria production (see **Table 3-14**) from these livestock will be applied across 2006 NLCD *cropland* land cover.

Small Livestock Operations

Small-scale animal operations do not require registration and not included in the MPCA's geographic feedlots (AFOs) database but should be included in the Census of Agriculture (see *Livestock Populations*). All cattle, goats, horses, sheep, and poultry were treated as partially housed or open lot operations without runoff controls. The geographic areas for stockpiling or spreading of manure from these small, partially housed or open lot operations is based on 2006 NLCD *Pasture/Hay* and *Grassland/Herbaceous* land covers. Bacteria production estimates are based on the values cited in **Table 3-13**.

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[7] Data source: http://www.pca.state.mn.us/index.php/data/spatial-data.html (Feedlots Layer, Accessed June 2014)

Table 3-14: Data sources, assumptions, and watershed distribution of bacteria from livestock.

<table>
<tr><th colspan="2">Bacteria Sources</th><th>Distribution</th></tr>
<tr><td colspan="2">Grazing
Grazing populations estimates for cattle, horses, goats, and sheep were based on USDA 2007 Census of Agriculture (USDA NASS 2009).</td><td>Bacteria form grazing animals was applied to grasslands and pasture classes in the 2006 NLCD dataset.</td></tr>
<tr><td rowspan="2">Animal Feeding Operation (AFO)
AFO populations for cattle, goats, hogs, horses, poultry, and sheep are based on the 2012 Census of Agriculture (USDA NASS 2009).</td><td>Partially Housed or Open Lot without Runoff Controls[8]
The proportion of AFO animals that are partially housed or in open lots without runoff controls:
- Cattle 50%
- Poultry 8%
- Goats 42%
- Sheep 42%
- Hogs 15%</td><td>Bacteria from Open Lot AFOs were applied to barren, scrub/shrub, grassland, and pasture classes of the 2006 NLCD dataset.</td></tr>
<tr><td>Land Application of Manure
- Cattle 50%
- Poultry 92%
- Goats 58%
- Sheep 58%
- Hogs 85%</td><td>Land application of manure was distributed across the cropland class of the 2006 NLCD dataset.</td></tr>
</table>

Wildlife

Wildlife, especially waterfowl, contributes bacteria to the watershed by directly defecating into waterbodies and through runoff from wetlands and fields adjacent to waterbodies, which are used as feeding grounds. In the SHRW, land cover which could potentially attract wildlife includes: herbaceous wetlands and row crops adjacent to streams and lakes, wildlife management areas, and open water. Wildlife contribute bacteria to surface waters by living in waterbodies, living near conveyances to waterbodies or when their waste is delivered to waterbodies during storm runoff events. Areas such as DNR designated wildlife management areas, state parks, national parks, national wildlife refuges, golf courses, state forest and other conservation areas provide habitat for wildlife and are potential sources of bacteria due to high densities of animals. Additionally, many other areas within the watershed have the potential to be a source of bacteria from wildlife sources.

Fate and transport mechanisms differ between wildlife that live in surface waters (e.g., ducks, geese, and beavers) where bacteria are directly delivered to waters and wildlife that live in upland areas (e.g., deer) where bacteria delivery is primarily driven by washoff and surface runoff.

The wildlife considered as potential sources of bacteria include deer, ducks, geese and others. Data sources and assumptions for wildlife populations are shown in **Table 3-15**. In addition, a category called

[8] Estimates based on Mulla et al. 2001.

"other wildlife" was added to the source summary. These other animals include all other wildlife that may dwell in the watershed, such as beaver, raccoons, coyote, foxes, squirrels, etc.

Table 3-15: Data Sources and Assumption for Wildlife Population and Bacteria Delivery.

Bacteria Source	Delivery
Deer The DNR report "Status of Wildlife populations, Fall 2009" includes a collection of studies that estimate wildlife populations of various species (Dexter, 2009). Pre-fawn deer densities (in deer/ sq. mi.) were reported by DNR deer permit area.	Bacteria from deer were applied to all land use classes in the 2006 NLCD dataset except for open water and developed land use classes.
Ducks Populations of breeding ducks was taken from the U.S. Fish and Wildlife "Thunderstorm" Maps for the Prairie Pothole Region of Minnesota and Iowa.[9]	The USFW "Thunder Maps" are spatially distributed and were used once a bacteria production was applied.
Geese Population estimates were taken from the state-wide DNR's Minnesota Spring Canada Goose Survey, 2009 (Rave, 2009). Counts were reported by Level 1 Ecoregion. An area-weighted estimate was taken from the state-wide data, resulting in an estimate of 1,568 geese in the SHRW.	Bacteria from geese were distributed to areas within a 100 ft buffer of and including wetlands and open water classes in the 2006 NLCD dataset.
Other Wildlife Other wildlife in the SHRW includes such animals as beaver, raccoons, coyote, foxes, and squirrels. Instead of estimating individual populations of each type of wildlife within the SHRW. The bacteria production was assumed to be the same as the bacteria production from deer. Therefore, the bacteria production from deer was doubled to account for all other wildlife in the watershed that are not accounted for explicitly.	Same as deer.

Natural/Background Sources

Two Minnesota studies described the potential for the presence of "naturalized" or "indigenous" *E. coli* in watershed soils (Ishii et al. 2006), ditch sediment and water (Sadowsky et al. 2010). Sadowsky et al. (2010) by conducting DNA fingerprinting of *E. coli* in sediment and water samples from Seven Mile Creek, located in south-central Minnesota. The studies concluded that roughly 63.5% of the *E. coli* was represented by a single isolate, suggesting new or transient sources of *E. coli*. The remaining 36.5% of 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 but results might not be transferable to other locations without further study. Although the result may not be transferable to other locations, they do suggest the presence of natural background *E. coli* and a fraction of *E. coli* may be present regardless of the control measures taken by traditional implementation strategies.

Ishii et al. (2006) concluded that *E. coli* can persist over long periods in soils, including winter freeze/thaw cycles and through multiple years. The *E. coli* strains based on DNA fingerprint analysis within soils are somewhat unique to the specific soil type and landscape location and based upon laboratory analysis are capable of growth in natural soils. The soil *E. coli* strains are believed to become

9 http://www.fws.gov/midwest/hapet/thunderstormmaps.html

naturalized, autochthonous members of the soil microbial community and are unlikely to be deposited by animal feces in water, and based on DNA fingerprint. Soils *E. coli* strains differ from those from wildlife commonly found in river environments.

Fate and Delivery Mechanisms of Bacteria

A delivery factor was developed to account for the transportation of bacteria from the landscape to the impaired waterbody. The delivery factors account for fate and transport factors such as proximity to surface waters, landscape slope, imperviousness, and bacteria die-off. The bacteria deliver factor assumes the delivery of bacteria to the waterbody is dependent on travel time and a bacteria die-off rate.

The EPA's *Protocols for Developing Pathogen TMDLs* provides a methodology for estimating bacteria die-off and lists coefficients for die-off calculations (EPA 2001 p. 6-6 to 6-7). The die-off equation is given as:

$$C = C_0 exp(-KT_t) \qquad \text{[Equation 3]}$$

Where C is the concentration of bacteria (cfu/day), C_0 is the initial concentration of bacteria (cfu/day), K is the decay (die-off) coefficient (1/day), and T_t is travel time (days). The die-off coefficient for natural surface water used in the SHRW was 0.202 $days^{-1}$ (EPA 2001).

The die-off equation [3] was applied to a travel-time grid for the watershed as a whole and each impaired reach to get delivery factor.

E. coli Source Summary

After the delivery factor was estimated, it was applied to each bacteria source to find the magnitude of bacteria reaching the end of the stream reach or outlet. Then, each source was summed and compared to the total bacteria load. Results from this source summary are shown in **Table 3-16**. **Table 3-16** shows the level of each identified bacteria source in the direct drainage area and the percentage of loading coming from upstream sources.

The levels of bacteria sources were broken into three categories: low, medium and high. The rankings are based the percentage of total bacteria load and what would be expected. There are 10 types of bacteria sources listed in **Table 3-16**, so each source's expected value, if all were equal, would be 10% of the total load. This would be ranked as medium. We assigned a range to the medium value of 5% to 20%, or half to twice the expected value. If the source of bacteria was less than 5% of the total load, the rank would be low and if greater than 20% the rank would be high.

Table 3-16: *E. coli* Relative Source Summaries.

AUID	Humans				Livestock				Wildlife					Upstream Sources	
	All	WWTF Effluent	Septic Systems	Domestic Animals	All	Grazing	Manure	AFO Open Lots	All	Deer	Ducks	Geese	Other	Level	Estimated Percentage
Watershed	™	™	™	™	˜	›	˜	›	™	™	™	™	™	NA	NA
536	™	™	™	™	˜	™	˜	™	™	™	›	™	™	˜	83.7%
537	™	™	™	™	˜	™	˜	™	™	™	™	™	™	›	63.0%
541	™	™	™	™	˜	›	˜	›	™	™	›	™	™	NA	NA
542	™	™	™	™	˜	›	˜	˜	™	™	›	™	™	˜	77.5%

Key: ˜ = high risk, › = medium risk, ™ = low risk

3.6.3 Total Suspended Solids

The SHRW Biotic Stressor Identification Report (MPCA 2014) describes the sources and causal pathways for turbidity and TSS. Elevated TSS/Turbidity is somewhat inherent to SHRW due to the very fine sediment size of clays and silts. TSS/Turbidity levels in the glacial moraine and beach ridge zones are in a large part tied to two factors. First, many of the headwater streams in the subwatershed are farmed through and/or have been channelized for agricultural drainage-related purposes. These modified streams have lost many of their inherent functions and rapidly convey agricultural runoff (including sediment and nutrients) to receiving waters. Soil erosion from this concentrated flow moves downstream into the next receiving stream and contributes sediment/turbidity to the system. Second, the geology and topography of the Sand Hill River contribute to soil and bank erosion. As stated in the SHRW Biotic Stressor Identification Report (MPCA 2014), “the SHRW is divided into three distinct physiographic regions. These regions, oriented from east to west, include the till plain/moraine, beach ridges, and lake plain. The till plain/moraine region encompasses the eastern half of the SHRW, extending from the eastern boundary of the watershed, to approximately one mile east of Fertile. This area is characterized by a rolling topography, interspersed with small lakes and wetlands. The soils of this region vary in texture and were formed from glacial till deposited during the last glaciation approximately 12,000 years ago. The beach ridges region follows a north-south corridor approximately 10 miles wide through the center of the watershed and is located on the western boundary of the till plain/moraine region. This region represents the ancient shorelines of Glacial Lake Agassiz. The Sand Hill River drops approximately 176 feet in elevation from the highest beach ridge to the base of the lake plain. The soils of this region are coarse textured and derived from sand and gravel deposits. Soil and bank erosion is a significant concern in this area.”

3.6.3.1 Permitted (Point) Sources

The SHRW contains three "minor" (as defined by the MPCA) WWTFs that drain into impaired streams. These facilities are all pond-type plants with primary and secondary treatment ponds. Per their permits, these facilities are allowed to discharge only during certain time periods during the year: March 1 through June 30 and September 1 through December 31. The WWTF are listed in **Table 3-17**.

Table 3-17: Relevant WWTF permits in the TMDL.

Facility	Permit Number	12-Digit HUC	City / Township	System Type	Secondary Pond size (acres)
Climax	MNG580169	Sand Hill River	Climax	Pond	1.7
Fertile	MNG580138	City of Fertile-Sand Hill River	Fertile	Pond	6
Winger	MN0046671	City of Winger – Sand Hill river	Winger	Pond	1.5

3.6.3.2 Nonpoint Sources

Within the SHRW, there are two major sources of nonpoint sediment that contribute to turbidity impairments; upland field erosion and in-channel stream bank and bluff erosion. Upland field erosion occurs primarily when the soil is unprotected (e.g., row crop agriculture, ditch maintenance/repair, construction, mining, insufficiently vegetated pastures or livestock access to stream banks). Since 69.8% of the SHRW is comprised of cultivated agricultural lands, the soils can, at times, be insufficiently protected (without a crop canopy for eight to nine months) making cultivated fields a potential source of sediment to rivers. Another potentially significant source of soil loss and high stream turbidity levels is altered stream processes (often referred to as stream channel instability or streambank erosion) where sediment/soil is eroded from the stream banks, bluffs, and stream bed. This destabilization can be caused by perturbations in the landscape such as channelization of waterways, riparian land cover alteration, increases in impervious surfaces resulting in more runoff, and livestock access to the stream channel.

The Sand Hill River has few remaining natural tributaries, one being Kittleson Creek, which outlets into the Sand Hill River in the beach ridge area. Hydrology in the SHRW has been altered, primarily for agricultural purposes. Examples of alterations include ditching, subsurface tiling, and the channelization of natural streams. While much of the surface drainage occurred 50 or more years ago, subsurface tiling is a relatively new practice in the region and is increasing in extent. Since the early 1900s, there have been numerous public and private drainage systems specifically constructed to provide agricultural drainage in the eastern portion of the SHRW. These ditch networks have hydrologically connected previously unconnected areas. The western region of the SHRW also contains public and private drainage systems; however, unlike the ditch systems in the eastern region, these systems follow natural water courses that existed prior to their construction (HEI 2012).

According to the *Sand Hill River Biotic Watershed SID Report* (MPCA 2014b), being developed as part of the *SHRW Monitoring and Assessment Report* (MPCA 2014a), gradient is an important factor in stream stability within the SHRW. Digital elevation models show the river maintains a gradient of 5.6 feet per mile (ft/mi) between the Sand Hill Lake outlet and monitoring site S003-138. Thereafter, the gradient increases substantially to 11.6 ft/mi for the next 3 miles. The increase in gradient, coupled with the extensive amount of channelization and ditching upstream and presence of fine sediment makes this segment of the river especially vulnerable to degradation. Over the next 34 miles, the river essentially plateaus and the mean gradient decreases to 2.3 ft/mi. However, near monitoring site S006-559 the gradient drops even further down to 1.2 ft/mi. Aggradation of sediment is a concern along this portion of the river. From monitoring site S006-560 and continuing to the confluence with Kittleson Creek, the river meanders through the beach ridge region of the watershed and drops 176 feet in elevation. The mean gradient (9.0 ft/mi) and presence of loose, unconsolidated materials makes this region prone to degradation. Finally, the river flows through the glacial lake plain for the next 32 miles, eventually reaching its confluence with the Red River of the North. The mean gradient of the river on the lake plain is 4.1 ft/mi (MPCA 2014b).

Figure 3-20 shows the sediment yields from the landscape, by land use in the SHRW, as estimated by the HSPF model. **Figure 3-20** shows that the largest source of sediment is from agricultural lands, especially in the Lake Agassiz lake plain in the western half of the watershed.

To show the relative magnitude of field sources of sediment to in-stream sources, a field-stream index (FSI) was developed using results from the HSPF model. The FSI is the total field load from a subwatershed, divided by the in-stream flux (positive values indicating a source of sediment and negative values indicating a sediment sink) in a stream reach. The FSI highlights areas, within the watershed, where in-stream processes are dominant and areas where field processes are more important. If the FSI is between -1 and 1, in-stream processes are more important than field sources. If the FSI is less than -1 or greater than 1, the field sources are larger in magnitude. The FSI for sediment, in the SHRW, is shown in **Figure 3-21**. In **Figure 3-21**, the grey-green colors represent subwatersheds with stream reaches that are, on an annual average, sediment sources. The yellowish green colors represent subwatersheds with stream reaches that are sediment sinks.

Figures 3-22 and **3-23** show subwatershed prioritization for TSS based on sediment yields from the SHRW HSPF model. **Figures 3-22** and **3-23** highlight the subwatersheds that contribute the highest yields of sediment within the drainage areas of the impaired AUID.

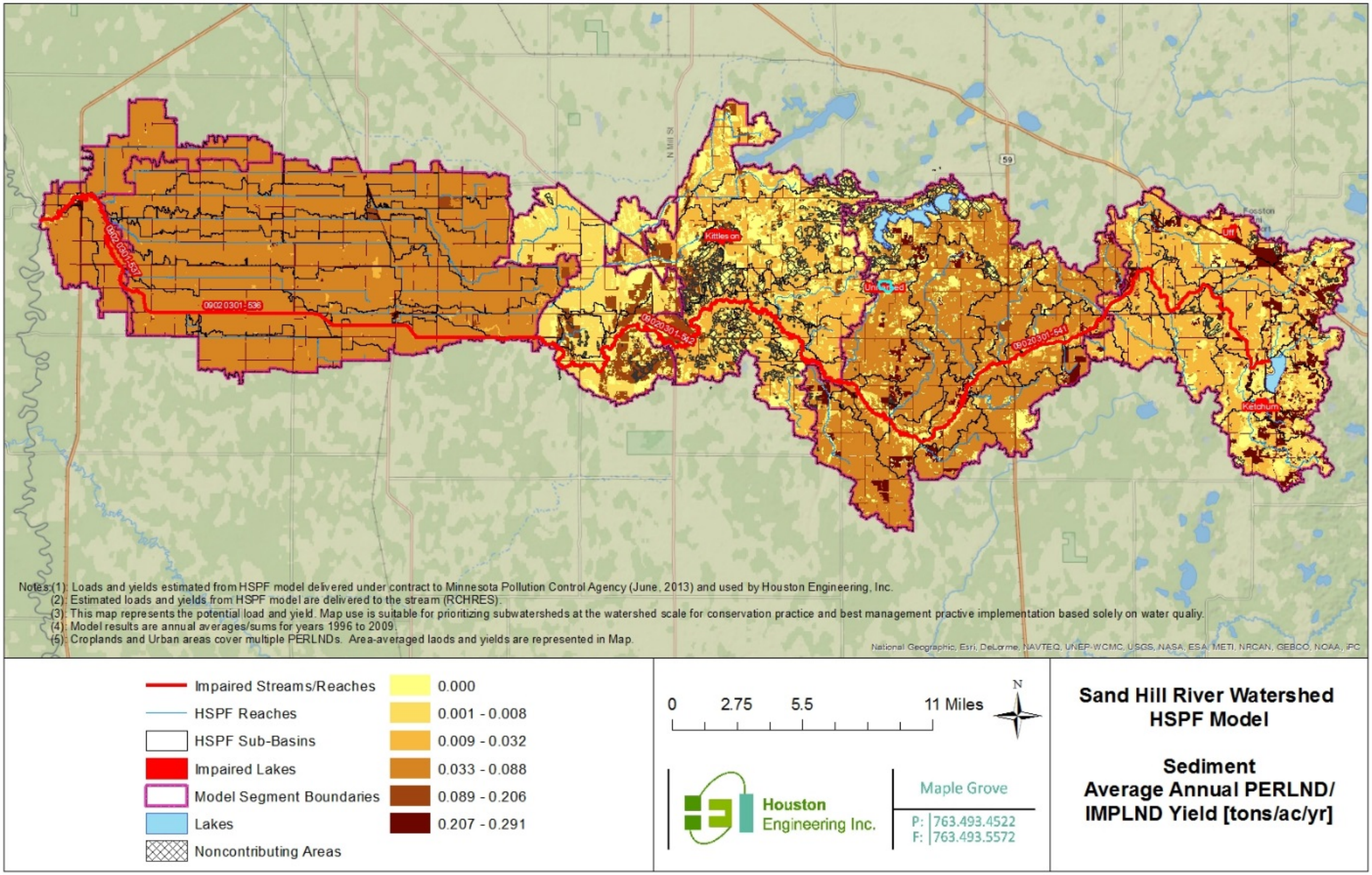

Figure 3-20: Total Sediment Yields from the landscape as estimated by the SHRW HSPF model.

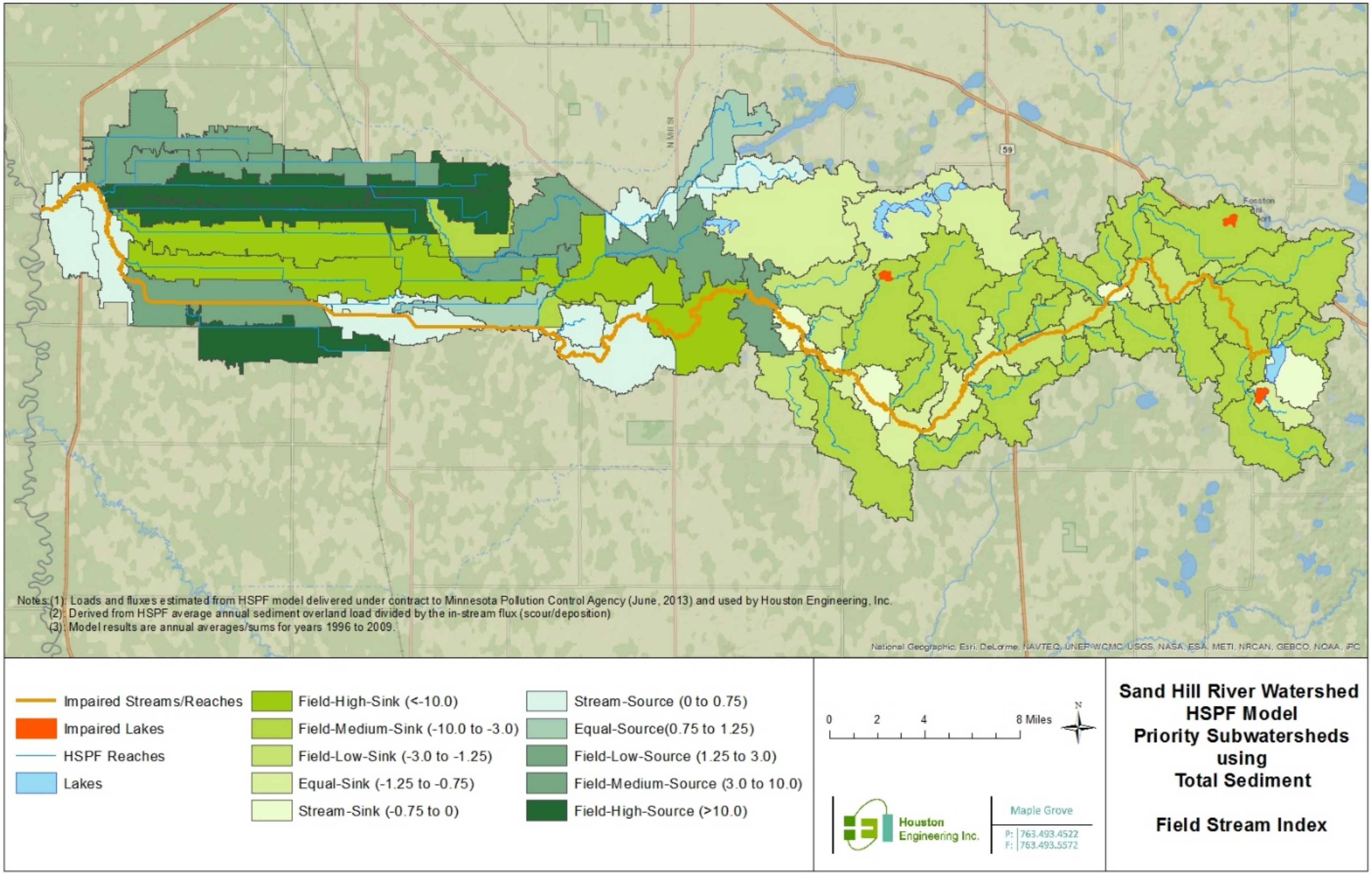

Figure 3-21: Total Sediment Field Stream Index using HSPF model results.

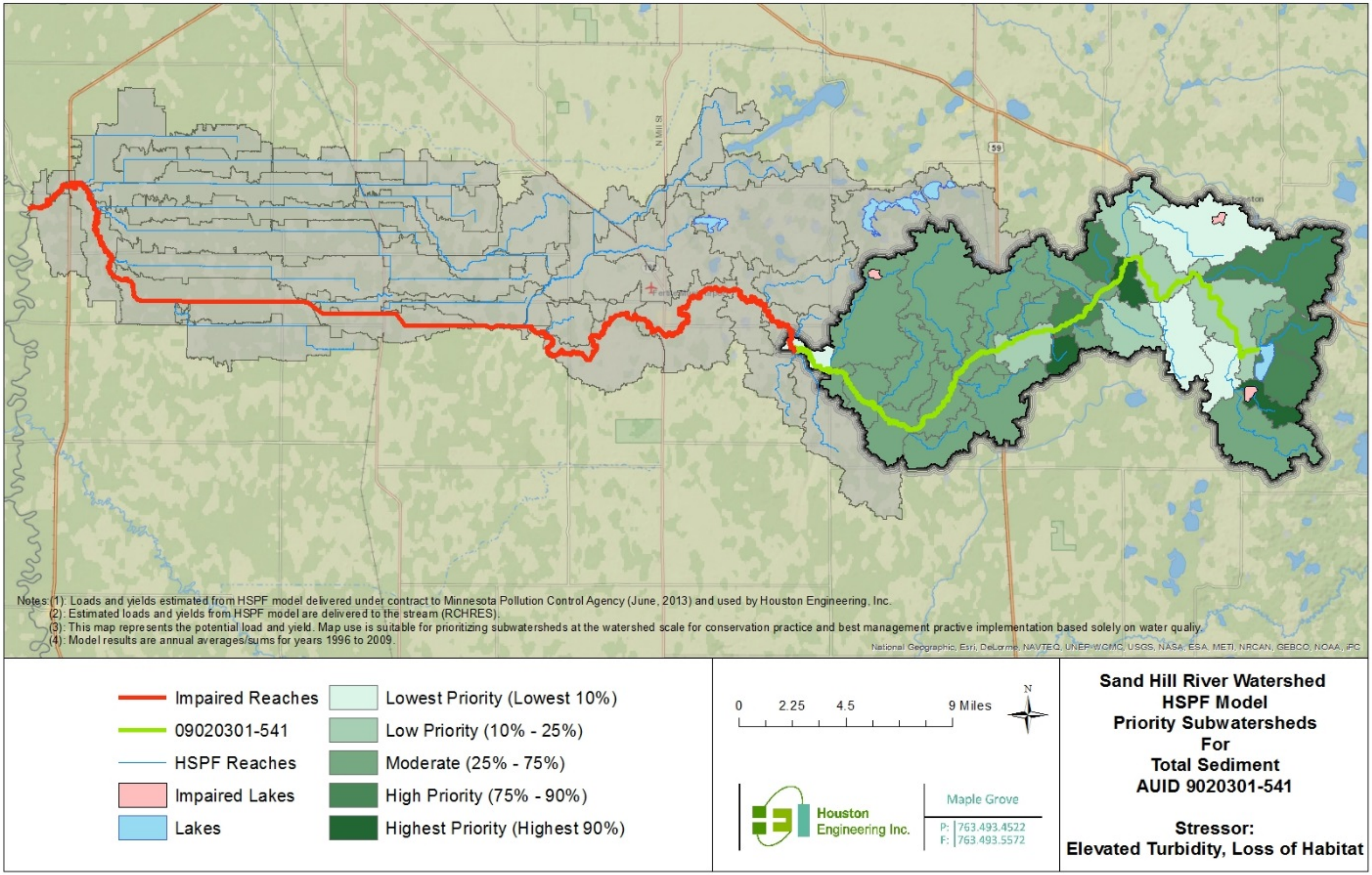

Figure 3-22: Subwatershed priority of TSS yields for AUID 09020301-541 drainage area based on HSPF model results.

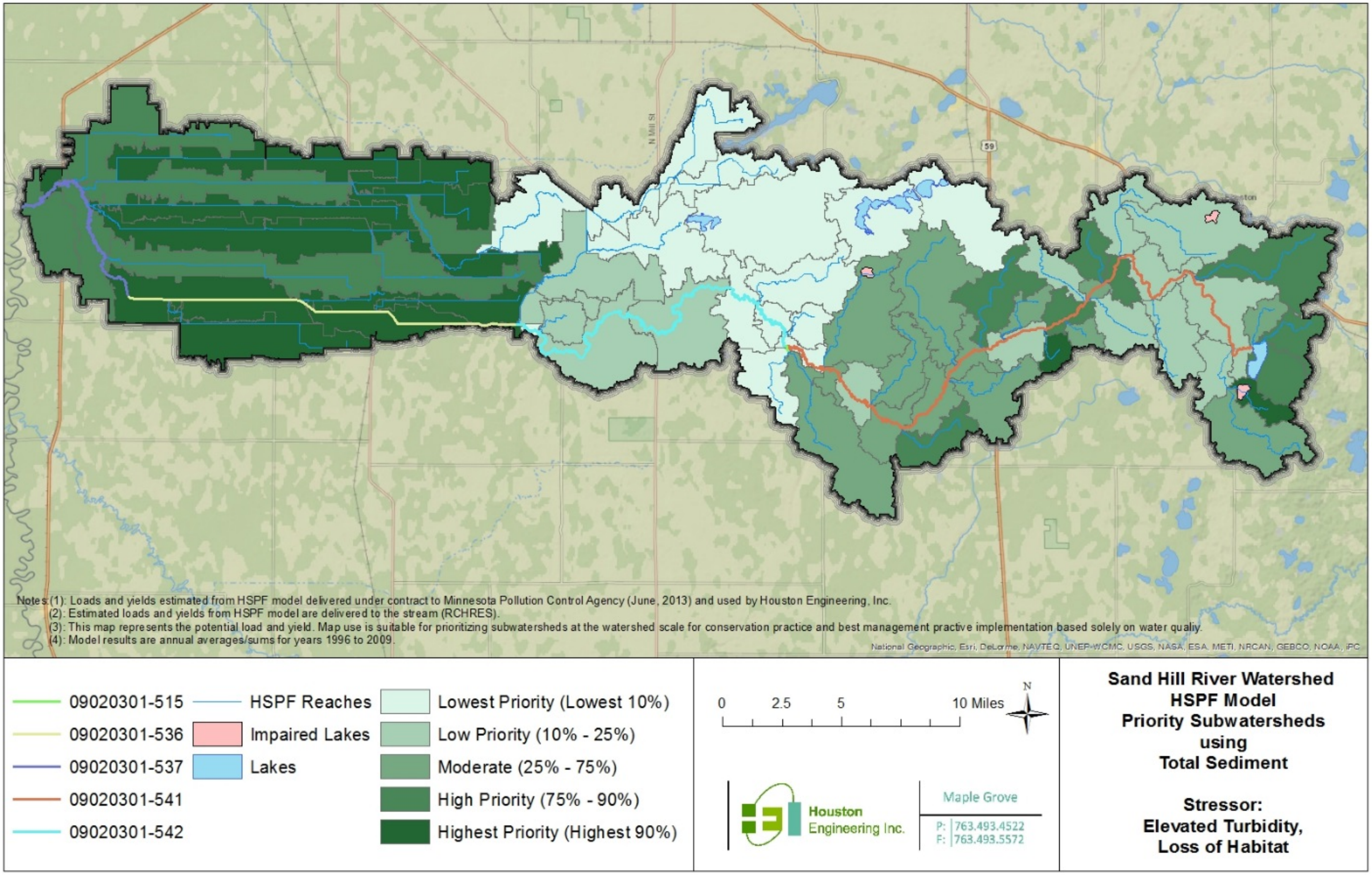

Figure 3-23: Subwatershed priority of TSS yields for AUID 09020301-537 drainage area based on HSPF model results

4 TMDL Development

TMDLs are developed based on the following equation:

$$\mathbf{TMDL = LC = \sum WLA + \sum LA + MOS + RC}$$

Where:

LC = Loading capacity, or the greatest amount of a pollutant a waterbody can receive and still meet water quality standards (see **Section 4.1.1**);

WLA = Wasteload allocation, or the portion of the loading capacity allocated to existing or future permitted point sources (see **Section 3.2**);

LA = Load allocation, or the portion of the loading capacity allocated for existing or future nonpoint sources (see **Section 3.3**);

MOS = Margin of safety, or accounting for any uncertainty associated with attaining the water quality standard. The MOS may be explicitly stated as an added, separate quantity in the TMDL calculation or maybe implicit, as in a conservative assumption (EPA 2007) (see **Section 3.4**);

RC = Reserve capacity, or the portion of the TMDL that accommodates for future loads;

The following sections discuss each component of the SHRW TMDLs in greater detail.

4.1 Phosphorus

4.1.1 Loading Capacity Methodology

The loading capacity is the greatest amount of a pollutant a waterbody can receive and still meet the water quality standard. For the lake TMDLs in the SHRW, individual lake models were developed using the in-lake water quality model CNET. CNET is a modified, spreadsheet version of the United States Army Core of Engineers (USACE) BATHTUB model. The lake modeling used a Monte Carlo approach. With a Monte Carlo approach, selected modeling inputs are allowed to vary within typical ranges based upon known or assumed statistical distributions. The approach results in a statistical distribution of in-lake eutrophication conditions based on the distributions of the input parameters. The approach is powerful because the results reflect the variability in model parameters inherent in natural systems (e.g., climate) and allows for a more realistic prediction of long-term water quality condition. Crystal Ball[10] was used to perform the Monte Carlo simulations. The lake models were used to estimate the TP load reductions necessary to meet current water quality lake eutrophication standards in each lake.

Lake modeling requires information about lake morphometric characteristics (mean depth, surface area), the contributing drainage area, climate and the sources and losses of water for the lake (a water budget), and the sources and losses of TP (a TP mass balance). The primary data sources used for the

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10 A proprietary software developed by Oracle;http://www.oracle.com/us/products/applications/crystalball/overview/index.html?msgid=3-4114203260

lake morphometric characteristics and drainage area were the DNR LakeFinder website[11], the DNR GIS online data deli[12], and the Sand Hill Monitoring and Assessment Report (2014b).

Loading estimates (both for water and P) into the lake were extracted from the watershed model HSPF. The loadings extracted from HSPF for each lake includes: annual precipitation depths, evaporation depths, surface runoff flows and loadings, and tributary flows and loadings. Data were extracted for the period 1996 through 2009. The HSPF model does explicitly models some larger lakes (Kittleson and Ketchum) but does not represent the in-lake processes well enough to use for TMDL development, hence the use of an in-lake water quality model (CNET version of BATHTUB). For lakes that were explicitly modeled in the HSPF, loads and flows entering the lakes were extracted, with units of acre-feet and pounds per year (lb/yr). For lakes that were not explicitly modeled, yields by land use were extracted from the model and total loads were estimated by taking an area-weighted summation by land use within the contributing drainage area. A more in-depth discussion on the HSPF is provided in **Section 4.2.1** or can be found in RESPEC (2013). The average annual loads used to develop the lakes models are provided in **Table 3-8** in **Section 3.6.1**.

The CNET lakes models were calibrated to the average TP, Chl-*a*, and Secchi disk depths of the observed data (from the EQuIS database) in the most recent assessment period (2003 through 2012). All of the impaired lakes had only two years of monthly observations during the summer months in 2011 and 2012. Since the overland loading estimates from HSPF model is for 1995 through 2009, calibration of the lake models had to be made between the average in-lake condition and the average loading of years with similar precipitation. The HSPF simulation period tended to be wetter than the in-lake water quality period (average precipitation for 1996 to 2009 was 25.9 inches/year versus 19.4 for 2011 to 2012). Therefore, data from years of the HSPF simulation period with similar hydrology as the observed in-lake water quality were averaged and used to calibrate the CNET models. These years included 1996, 2001, 2003, and 2006 and are assumed to be representative of the hydrologic and TP loading conditions represented in the average in-lake water quality condition. Because the data sources do not allow for actual comparisons between in-lake water quality and overland loading, no validation period was used. **Table 4-1** shows the calibration statistics for the lake models developed for this TMDL. A complete in-depth discussion on the data sources and observed water quality data used in the lake modeling (CNET) can be found in the *SHRW Lakes Eutrophication Modeling Report* (HEI 2014a).

Table 4-1: Calibration statistics for lake models (CNET-BATHTUB) of impaired lakes (June through September).

Lake Name	TP (ug/L)		Chl-*a* (ug/L)		Secchi Disk (m)	
	Observed	Modeled	Observed	Modeled	Observed	Modeled
Ketchum	87.0	87.1	67.0	67.2	0.43	0.43
Kittleson	86.8	86.5	35.1	34.9	0.43	0.43
Uff	130.5	130.8	69.7	69.6	0.27	0.27
Unnamed	68.7	68.7	45.0	45.1	0.50	0.50

11 http://www.dnr.state.mn.us/lakefind/index.html
12 http://deli.dnr.state.mn.us

4.1.2 Load Allocation Methodology

The LA represent the portion of the loading capacity designated for nonpoint sources of P. The LA includes all sources of P that do not require NPDES Permit coverage, including unregulated watershed runoff, internal loading, groundwater, and atmospheric deposition and a consideration for natural background conditions. These nonpoint sources include surface runoff, internal loading, atmospheric deposition, and any other identified loads described in **Section 3.6.1**. The LA is calculated as the remaining portion of the LC once the WLA and MOS is subtracted.

4.1.3 Wasteload Allocation Methodology

The WLA represents the regulated portion of the loading capacity, requiring a NPDES Permit. Regulated sources may include construction stormwater, industrial stormwater, Municipal Separate Storm Sewer Systems (MS4) permitted areas, NPDES permitted feedlots, and WWTFs. The only regulated sources with a WLA for the SHRW's impaired lakes are construction and industrial stormwater discharges. There are no MS4s, NPDES permitted feedlots, or WWTFs in the drainage areas of any impaired lake.

WLAs for construction and industrial stormwater discharges were combined and addressed through a categorical allocation. This TMDL study assumes that 0.1% of the SHRW's land use contributes construction and/or industrial stormwater runoff at any given time. Historical permits and land use in the watershed support this assumption.

Stormwater runoff from construction sites that disturb: a) one acre of soil or more, b) less than one acre of soil and are part of a "larger common plan of development or sale" that is greater than one acre, or c) less than one acre, but determined to pose a risk to water quality are regulated under the state's NPDES/State Disposal System (SDS) General Stormwater Permits for Construction Activity (MNR1000001). This permit requires and identifies best management practices (BMPs) to be implemented to protect water resources from mobilized sediment and other pollutants of concern. If the owner/operators of impacted construction sites within the SHRW obtain and abide by the NPDES/SDS General Construction Stormwater Permit, the stormwater discharges associated with those sites are expected to meet the WLAs set in this TMDL study.

Similar to construction activities, industrial sites are regulated under general permits, in this case either the NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or the NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying, and Hot Mix Asphalt Production facilities (MNG490000). Like the NPDES/SDS General Construction Stormwater Permit, these permits identify BMPs to be implemented to protect water resources from pollutant discharges at the site. If the owner/operators of industrial sites within the SHRW obtain and abide by the necessary NPDES/SDS General Stormwater Permits, the discharges associated with those sites are expected to meet the WLAs set in this TMDL study.

Due to the transient nature of construction and industrial activities, it is assumed 0.1% of the drainage area is under construction and industrial activities at any given time. Therefore, to calculate the WLA for construction and industrial stormwater, 0.1% of the LA for the lake was assumed and assigned to construction/industrial stormwater WLA. It should be noted, the construction/industrial stormwater WLA is dependent on the LA.

4.1.4 Margin of Safety

The MOS accounts for the uncertainty with attaining water quality standards. Uncertainty can be associated with data collection, lab analysis, data analysis, modeling error, and implementation activities. An explicit 10% MOS was applied to all P TMDLs and is considered to be adequate given the stochastic nature of the lake models.

4.1.5 Critical Conditions and Seasonal Variation

Water quality monitoring for the SHRW suggests the in-lake TP concentrations vary over the course of the summer growing season (June through September), generally peaking in mid to late summer. The MPCA eutrophication water quality guideline for assessing TP is defined as the June through September mean concentration. TP loadings were calculated to meet the water quality standards during the summer growing season; the most critical period of the year. Calibration to this critical period will provide adequate protection during other times of the year with reduced loading.

In addition, the lake modeling performed for this study was completed using stochastic simulations in the CNET models. Use of the stochastic approach allows for the representation of naturally-occurring variability in the systems due to changing hydrology, weather patterns and other considerations. Basing the load reduction scenarios on these results explicitly incorporates seasonal variation and critical conditions into the analysis.

4.1.6 Future Growth/Reserve Capacity

Potential changes in population and land use over time in the SHRW could result in changing sources of P. Possible changes and how they may or may not impact TMDL allocations are discussed below. The following is applicable to all TMDLs in this document.

4.1.6.1 New or Expanding Permitted MS4 WLA Transfer Process

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

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

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

4.1.6.2 New or Expanding Wastewater (TSS and *E. coli* TMDLs only)

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

4.1.7 TMDL Summary

The TMDLs are established for the four impaired lakes within the SHRW (**Tables 4-2** through **4-5**). All of the lakes are considered shallow, and the TMDL is established based on achieving a TP numeric water quality standard of 60 ug/L average concentration for the June through September period. The required TP load reductions are considerable ranging up to 71% for Kittleson Lake. Because of the general absence of point sources, these reduction need to come from nonpoint sources.

Table 4-2: Ketchum Lake TP TMDL and Allocations.

		Existing Annual TP Load		Maximum Allowable TP Load		Estimated Load Reduction Needed	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD CAPACITY		**187**	**0.51**	**106**	**0.29**	**81**	**43%**
Wasteload Allocation	**Total WLA**	**0.106**	**0.0003**	**0.106**	**0.0003**	**0**	**0**
	Construction/Industrial Stormwater	*0.106*	*0.0003*	*0.106*	*0.0003*	*0*	*0*
Load Allocation	**Total LA**	**186.9**	**0.51**	**95.4**	**0.26**	**91.5**	**49%**
	Direct runoff	*144.9*	*0.40*	*53.4*	*0.15*	*91.5*	*63%*
	Failing SSTS	*0*	*0*	*0*	*0*	*0*	*NA*
	Upstream lakes	*0*	*0*	*0*	*0*	*0*	*NA*
	Atmospheric deposition	*42*	*0.11*	*42*	*0.11*	*0*	*0*
	Groundwater	*0*	*0*	*0*	*0*	*0*	*NA*
	Internal load	*0*	*0*	*0*	*0*	*0*	*NA*
MOS				**10.6**	**0.03**		

Table 4-3: Kittleson Lake TP TMDL and Allocations.

		Existing TP Load		Maximum Allowable TP Load		Estimated Load Reduction Needed	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD CAPACITY		**1863**	**5.10**	**540**	**1.48**	**1324**	**71%**
Wasteload Allocations	**Total WLA**	**0.539**	**0.0015**	**0.539**	**0.0015**	**0**	**0**
	Construction/Industrial Stormwater	*0.539*	*0.0015*	*0.539*	*0.0015*	*0*	*0*
Load Allocations	**Total LA**	**1862**	**5.11**	**485.1**	**1.33**	**1377**	**74%**
	Direct runoff	*623*	*1.71*	*31.1*	*0.09*	*592*	*95%*
	Failing SSTS	*0*	*0*	*0*	*0*	*0*	*NA*
	Upstream lakes	*0*	*0*	*0*	*0*	*0*	*NA*
	Atmospheric deposition	*79*	*0.22*	*79*	*0.21*	*0*	*0*
	Groundwater	*0*	*0*	*0*	*0*	*0*	*NA*
	Internal load	*1160*	*3.18*	*375*	*1.03*	*785*	*68%*
MOS				**53.9**	**0.15**		

Table 4-4: Uff Lake TP TMDL and Allocations.

		Existing TP Load		Maximum Allowable TP Load		Estimated Load Reduction Needed	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD CAPACITY		**105**	**0.287**	**40**	**0.101**	**65**	**62%**
Wasteload Allocations	**Total WLA**	**0.037**	**0.0001**	**0.037**	**0.0001**	**0**	**0**
	Construction/Industrial Stormwater	*0.037*	*0.0001*	*0.037*	*0.0001*	*0*	*0*
Load Allocations	**Total LA**	**105**	**0.29**	**38**	**0.10**	**67**	**67%**
	Non-MS4 runoff	*70*	*0.20*	*3*	*0.01*	*67*	*96%*
	Failing SSTS	*0*	*0*	*0*	*0*	*0*	*NA*
	Upstream lakes	*0*	*0*	*0*	*0*	*0*	*NA*
	Atmospheric deposition	*35*	*0.09*	*35*	*0.09*	*0*	*0*
	Groundwater	*0*	*0*	*0*	*0*	*0*	*NA*
	Internal load	*0*	*0*	*0*	*0*	*0*	*NA*
MOS				**2**	**0.005**		

Table 4-5: Unnamed Lake TP TMDL and Allocations.

		Existing TP Load		Maximum Allowable TP Load		Estimated Load Reduction Needed	
		lbs/yr	lbs/day	lbs/yr	lbs/day	lbs/yr	%
TOTAL LOAD CAPACITY		287	0.79	205	0.56	82	29%
Wasteload Allocations	Total WLA	0.205	0.0006	0.205	0.0006	0	0
	Construction/Industrial Stormwater	*0.205*	*0.0006*	*0.205*	*0.0006*	*0*	*0*
Load Allocations	Total LA	287	0.79	184.5	0.51	102.3	36%
	Non-MS4 runoff	*135*	*0.37*	*77*	*0.21*	*58.3*	*43%*
	Failing SSTS	*0*	*0*	*0*	*0*	*0*	*0*
	Upstream lakes	*0*	*0*	*0*	*0*	*0*	*NA*
	Atmospheric deposition	*31*	*0.09*	*31*	*0.09*	*0*	*0*
	Groundwater	*0*	*0*	*0*	*0*	*0*	*NA*
	Internal load	*121*	*0.33*	*77*	*0.21*	*44.0*	*36%*
MOS				20.5	0.06		

4.2 *Escherichia coli*

4.2.1 Loading Capacity Methodology

The loading capacity for stream reaches with *E. coli* impairments and receiving a TMDL were determined using the load duration curve (LDC) approach. A LDC is developed by applying a particular pollutant load standard or criteria to a stream's flow duration curve (FDC) and expressing it as a pollutant load per day. The FDC analysis looks at the cumulative frequency of historical flows and plots flows over the exceedance probability scale. The probability of exceedance scale ranges from 0% to 100% with high flows near 0% and low flows being near 100% exceedance (e.g., the maximum flow during the time period will be near 0% exceedance). The LDC analysis is the same but applies the water standard to the flows to obtain a load for a given flow frequency. Methods detailed in the EPA document *An Approach for Using Load Duration Curves in the Development of TMDLs* were used in creating the curves (EPA 2007).

To adequately capture different types of flow events and pollutant loading during these events, five flow regimes were identified per EPA guidance (EPA 2007; page 2): High flow (0% to 10%), Moist Conditions (10% to 40%), Mid-range Flows (40% to 60%), Dry Conditions (60% to 90%), and Low Flow (90% to 100%).

The LDC method is based on an analysis that encompasses the cumulative frequency of historical flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report (Tables 4.10 – 4.19), only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA.

Benefits of LDC analysis include: (1) the loading capacities are calculated for multiple flow regimes, not just a single point; (2) use of the method helps identify specific flow regimes and hydrologic processes/patterns where loading maybe a concern; and (3) ensuring that the applicable water quality standards are protective across all flow regimes. Some limitations with the LDC approach exist: (1) the approach is limited in the ability to track individual loadings or relative source contributions; and (2) is appropriate when a correlation between flow and water quality exists and flow is the driving force behind pollutant delivery mechanics.

For *E. coli*, the loading capacity was calculated using both the instantaneous standard of 1260 organisms/100 mL and the geometric mean (i.e., geomean) standard of 126 organisms/100 mL. Given that all bacteria impairments in the SHRW occur under the geomean standard, the load reductions computed under the geomean scenario were used to set the TMDLs. Conversions for computing bacterial loads are shown in **Table 4-6.**

Table 4-6: Converting flow and concentration into bacterial load.

Load (org/day) = Concentration (organisms/100mL) * Flow (cfs) * Factor			
Multiply by **28.316** to convert	ft^3 per second	→	L/sec
Multiply by **1000** to convert	Liters per second	→	mL/sec
Divide by **100** to convert	mLs per second	→	organisms/sec
Multiply by **86,400** to convert	organisms per second	→	organisms/day

Observed daily flow data are limited within the SHRW. Only one USGS station located on the Sand Hill River at Climax, Minnesota (USGS Station #05069000) has continuous flow data (AUID 09020301-537). Therefore, simulated daily mean flows from the SHRW HSPF model (RESPEC 2013) were used to create the LDCs for the remaining AUIDs. The HSPF model simulates flows from 1995 through 2009. In order to best capture the flow regimes of each AUID, the period 1996 through 2009 was used in development of the LDCs. The year 1995 was used in the model as a warm-up period and simulated flows might not be valid (RESPEC 2013). Although continuous, observed flow data for AUID 09020301-537 extends beyond 2009, the period 1996 through 2009 for all AUIDs is used for consistency among all locations.

The water quality data used to develop the LDCs were obtained from the MPCA through their EQuIS database (see **Section 3.5.2** for water quality sites). For the purposes of creating the LDCs, only water quality data from the most recent completed assessment period (2003 through 2012) were used. While data exists for bacteria spanning from 2006 through 2013, the HSPF model only estimates flows for 1996 through 2009. Therefore, the LDCs are based on bacteria from the overlapping time period of 2002 through 2009. The year 2002 was added to the assessment period to include numerous water quality sites and expand the dataset. **Table 4-7** provides a list of water quality stations used to develop the LDCs. To match the time period when the water quality standard is applicable, the bacterial LDCs were created using flow and *E. coli* water quality data from April through October only. Individual loading estimates were calculated by combining the observed *E. coli* concentration and simulated mean daily flow value on each sampling date. The load estimates were separated by month and by station, mainly for purposes of display on the curve. "Allowable" loading curves were created for both the instantaneous (1260 organisms/100mL) and monthly geometric mean (i.e., geomean, 126 organisms/100mL) criteria by multiplying each "allowable" concentration by the simulated mean daily flow values and ranking the flows.

Table 4-7: Water quality sites used to develop load duration curves by AUID.

AUID	Water Quality Monitoring Site	*E. coli*	
		Sampling Period	# of Samples
09020301-536	S003-130	2008-2009	20
09020301-537	S002-099	2008-2009	17
09020301-541	S003-138	2008-2009	20
	S003-141	2008-2009	20
09020301-542	S000-706	2008-2009	20
	S003-136	2006-2007	8

4.2.2 Load Allocation Methodology

LAs represent the portion of the loading capacity designated for nonpoint sources of *E. coli*. The LA is the remaining load once the WLA, reserve capacity, and MOS are determined and subtracted from the loading capacity. LAs are associated with loads that are not regulated by NPDES Permits, including nonpoint sources of pollutants and “natural background” contributions. “Natural background” can be described as physical, chemical, or biological conditions that would exist in a waterbody that are not a result of human activity. Nonpoint sources of *E. coli* in the SHRW were previously discussed in **Section 3.6.2**.

4.2.3 Wasteload Allocation Methodology

All SHRW WWTFs are limited to discharging from a single surface secondary treatment cell. All WWTFs are permitted to discharge only during specified discharge windows in the spring and fall. The discharge windows are March 1 through June 30 and September 1 through December 31 with no discharge to ice covered waters.

Maximum daily permitted WLAs were calculated for each WWTF based on a maximum discharge of six inches per day, per the MPCA guidance. WLAs were computed for TSS and bacteria based on the maximum permitted daily flow rate from each facility.

The maximum daily permitted bacteria WLAs were converted to maximum annual loads by reviewing Discharge Monitoring Reports to determine the average number of days that each WWTF discharged each year (over the past 10 years) and multiplying that value by the allowable daily loads. Maximum permitted daily and annual bacteria WLAs for the SHRW WWTFs are shown in **Table 4-8**. The WLAs for straight pipe septic systems and NPDES-permitted livestock operations remain at zero.

Table 4-8: Annual and daily *E. coli* WLAs for SHRW WWTFs.

	A	B	C	D	E	F	G
Facility	Permitted Max Daily Discharge (liters/day)[1]	Average # of Days Discharging per Year	Permitted Fecal Coliform Conc. (org/100 mL)	WLA-Fecal Coliform (10^9org/day) (A*C/10^6/100)	*E. coli* Colonies per Fecal Coliform Colony[2]	WLA-*E. coli* (10^9org/day) (D*E)	WLA-*E. coli* (10^9/yr) (B*F)
Climax	1,048,938	21	200	2.1	0.63	1.3	28
Fertile	3,702,133	27	200	7.4	0.63	4.7	125
Winger	925,533	37	200	1.85	0.63	1.2	43

[1] Computed based on the average surface area of the secondary treatment pond size and an assumed maximum daily discharge of six inches per day.

[2] Based on the MPCA recommended *E. coli* to fecal coliform ratio of 126:200

4.2.4 Margin of Safety

The purpose of the MOS is to account for uncertainty with attaining water quality standards. Uncertainty can be associated with data collection, lab analysis, data analysis, modeling error, and implementation activities. An explicit 10% of the loading capacity MOS was applied to each flow regime for all LDCs developed for this TMDL. The explicit 10% MOS accounts for:

- Uncertainty in the observed daily flow record;
- Uncertainty in the observed water quality data;
- Uncertainty with regrowth in the sediment, die-off, and natural background levels of *E. coli*.
- Allocations and loading capacities are based on flow, which varies from high to low. This variability is accounted for using the five flow regimes and the LDCs.

4.2.5 Critical Conditions and Seasonal Variation

The water quality standard for *E. coli* applies to April through October, coinciding with the time period when aquatic recreation occurs including portions of, or all of the spring, summer, and fall season. Spring is usually associated with the spring snowmelt and flood flows, the summer with low flows and rapid-rising flows for storm events, fall with increases in precipitation and rapidly changing landscape, especially in agricultural landscapes. The summer months tend to be the time when the water quality standards for *E. coli* are exceeded the most. This is partly due to the fact that the required five samples needed to assess a stream reach as impaired is met most often, partly due to the build-up and wash-off of bacteria associated with summer hydrology, and partly due to warmer water temperatures.

A summary of the bacteria load reduction results and critical flow regimes can be found in **Table 4-9**. Results are summarized by indicating the maximum required percent load reduction for each curve and the flow regime and water quality criteria under which this maximum reduction occurred (i.e., the critical flow regime and criteria). The critical flow regime for bacteria loading ranges from low flows to high flows.

Table 4-9: Maximum required bacterial and turbidity load reductions for the SHRW.

AUID	Bacteria		
	Max. % Load Reduction	**Critical Flow Regime**	**Critical Criterion**
09020301-536	53%	High	Geometric Mean
09020301-537	50%	Low	Geometric Mean
09020301-541	40%	Mid	Geometric Mean
09020301-542	35%	Mid	Geometric Mean

4.2.6 Future Growth/Reserve Capacity

No additional reserve capacity was included for the point sources in the SHRW, given the nature of assumptions used to create the WLAs. Similarly, no reserve capacity was included for nonpoint sources in the watershed (LAs), given that the land use in the SHRW is dominated by agriculture and is unlikely to substantially change in the future. For more information on future growth and reserve capacity, see **Section 4.1.6**.

4.2.7 TMDL Summary

Tables 4-10 through **4-13** show the computed loading capacities and allocations for the stream *E. coli* impairments in the SHRW. The various components of these allocations were developed as described in **Sections 4.2.1 – 4.2.4**. All *E. coli* TMDLs apply to the geometric mean standard. In addition to the TMDL components, the existing load, the unallocated load (if applicable), and the estimated load reduction as a percentage are given for each flow regime. The existing load is based on existing water quality data, the unallocated load is the potential load available if the existing load is lower than the loading capacity for a given flow regime (i.e. the loading capacity minus the existing load). An unallocated load is only provided if the existing load is lower than the loading capacity. The estimated load reduction is required load reduction, as a percentage of existing load, to meet the loading capacity. A load reduction is only provided if the loading capacity is less than the existing load.

The LDC method is based on an analysis that encompasses the cumulative frequency of historical flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report (**Tables 4-10 – 4-13**), only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA. The LDCs used to develop the loading capacities and allocations are provided in **Appendix A**.

Table 4-10: Bacteria loading capacities and allocations for AUID 09020301-541.

E. coli		Flow Condition				
		Very High	High	Mid	Low	Very Low
		Geometric Mean (Billion organisms per day)				
Loading Capacity		**678.45**	**140.34**	**56.27**	**27.35**	**13.81**
Wasteload Allocations	**Total WLA**	**1.2**	**1.2**	**1.2**	**1.2**	**1.2**
	Winger WWTF	1.2	1.2	1.2	1.2	1.2
Load Allocations	**Total LA**	**609.41**	**125.11**	**49.44**	**23.42**	**11.23**
MOS		**67.84**	**14.03**	**5.63**	**2.73**	**1.38**
Existing Load		**797.76**	**75.57**	**84.12**	**9.16**	**3.52**
Unallocated Load		**0.00**	**50.74**	**0.00**	**15.46**	**8.91**
Estimated Load Reduction		**23%**	**0%**	**40%**	**0%**	**0%**

Table 4-11: Bacteria loading capacities and allocations for AUID 09020301-542.

E. coli		Flow Condition				
		Very High	High	Mid	Low	Very Low
		Geometric Mean (Billion organisms per day)				
Loading Capacity		**1,046.2**	**229.7**	**91.4**	**43.4**	**20.6**
Wasteload Allocations	**Total WLA**	**5.9**	**5.9**	**5.9**	**5.9**	**5.9**
	Fertile WWTF	4.7	4.7	4.7	4.7	4.7
	Winger WWTF	1.2	1.2	1.2	1.2	1.2
Load Allocations	**Total LA**	**935.6**	**200.85**	**76.32**	**33.2**	**12.6**
MOS		**104.6**	**22.97**	**9.14**	**4.34**	**2.06**
Existing Load		---	**158.00**	**126.17**	**24.66**	**15.47**
Unallocated Load		---	**48.75**	**0.00**	**14.44**	**3.05**
Estimated Load Reduction		---	**0%**	**35%**	**0%**	**0%**

Table 4-12: Bacteria loading capacities and allocations for AUID 09020301-536.

E. coli		Flow Condition (Geomean Standard)				
		Very High	High	Mid	Low	Very Low
		Geometric Mean (Billion organisms per day)				
Loading Capacity		**1,595.7**	**346.1**	**133.5**	**63.0**	**29.9**
Wasteload Allocations	**Total WLA**	**5.9**	**5.9**	**5.9**	**5.9**	**5.9**
	Fertile WWTF	4.7	4.7	4.7	4.7	4.7
	Winger WWTF	1.2	1.2	1.2	1.2	1.2
Load Allocations	**Total LA**	**1,430.2**	**305.6**	**114.3**	**50.8**	**21.0**
MOS		**159.6**	**34.6**	**13.3**	**6.3**	**3.0**
Existing Load		**--**	**659.6**	**240.7**	**72.3**	**23.1**
Unallocated Load		**--**	**0.0**	**0.0**	**0.0**	**3.8**
Estimated Load Reduction		**--**	**53%**	**50%**	**22%**	**0%**

Table 4-13: Bacteria loading capacities and allocations for AUID 09020301-537.

E. coli		Flow Condition				
		Very High	High	Mid	Low	Very Low
		Geometric Mean (Billion organisms per day)				
Loading Capacity		**2,371.3**	**475.5**	**209.6**	**104.8**	**55.5**
Wasteload Allocations	**Total WLA**	**7.2**	**7.2**	**7.2**	**7.2**	**7.2**
	Climax WWTF	1.3	1.3	1.3	1.3	1.3
	Fertile WWTF	4.7	4.7	4.7	4.7	4.7
	Winger WWTF	1.2	1.2	1.2	1.2	1.2
Load Allocations	**Total LA**	**2127.00**	**420.80**	**181.40**	**87.10**	**42.80**
MOS		**237.1**	**47.5**	**21.0**	**10.5**	**5.5**
Existing Load		**--**	**121.9**	**282.4**	**159.3**	**100.5**
Unallocated Load		**--**	**306.1**	**0.0**	**0.0**	**0.0**
Estimated Load Reduction		**--**	**0%**	**33%**	**41%**	**50%**

4.3 Total Suspended Solids

In the spring of 2015, Minnesota transitioned from a turbidity standard to a TSS standard to represent sediment in a stream reach. Therefore, TSS TMDLs were developed for all turbidity impairments in the SHRW.

4.3.1 Loading Capacity

Sediment load reductions were computed using the LDC approach. To adequately capture different types of flow events and pollutant loading during these events, five flow regimes were identified per EPA guidance: Very High (0% to 1%), High (10% to 40%), Mid (40% to 60%), Low (60% to 90%), and Very Low Flow (90% to 100%). Development of the LDCs is discussed in other sections (see **Section 4.2.1** and **Appendix A**).

The TSS standard-based LDCs were created using the Southern Region TSS standard of 65 mg/L. The TSS standard-based LDCs were calculated using a combination of TSS data and converted turbidity data (see **Section 3.5.2**) collected during the assessment period. The TSS standard only applies during the months of April through September. A 10% MOS was applied. Conversion factors for this work are shown in **Table 4-15**.

Table 4-14: Converting flow and concentration to sediment load.

Load (tons/day) = TSS standard (mg/L) * Flow (cfs) * Conversion Factor			
For each flow regime			
Multiply **flow** (cfs) by **28.31** (L/ft^3) and **86,400** (sec/day) to convert	cfs	→	L/day
Multiply **TSS surrogate** (32 mg/L) by **L/day** to convert	L/day	→	mg/day
Divide **mg/day** by **907,184,740** (mg/ton) to convert	mg/day	→	tons/day

The water quality sites used to develop the TSS LDCs are provided in **Table 4-16**. It should be noted, only unique data points of turbidity and TSS were used to develop the LDCs; in other words, if both turbidity and TSS were sampled at the same time and at the same site, the TSS sample was used. This accounts for the number of combined turbidity and TSS samples (in **Table 4-16**) being less than the sum of the number of turbidity samples and the number of TSS samples.

Table 4-15: Water Quality Sites used to Develop TSS LDCs.

AUID (0902030 1-XXX)	Water Quality Monitoring Site	TSS		Turbidity		Combined Turbidity/TSS	
		Sampling Period	# of Samples	Sampling Period	# of Samples	Sampling Period	# of Samples
537	S002-099	2002-09	140	2002-09	89	2002-09	168
	S003-133	2002	5	2002	5	2002	5
	S003-134	2002	3	2002-09	34	2002-09	34
	S004-186	NA	0	2003-09	28	2003-09	28
	S004-188	NA	0	2006-09	8	2006-09	8
541	S003-137	2002	2	2002	5	2002	5
	S003-138	2002, 2008-09	18	2002-09	38	2002-09	42
	S003-139	2002	4	2002-09	23	2002-09	23
	S003-141	2002, 2008-09	17	2002-09	33	2002-09	37
	S003-143	2002	5	2002-09	26	2002-09	26
	S003-144	2002	5	2002-09	41	2002-09	41
	S004-198	NA	0	2005-09	25	2005-09	25
	S004-199	NA	0	2005-09	27	2005-09	27

4.3.2 Load Allocation Methodology

The LA is considered the remaining loading capacity once WLAs, reserve capacities, and MOSs are determined. LAs are associated with loads that are not regulated by NPDES Permits, including nonpoint sources of pollutants and "natural background" contributions. "Natural background" can be described as physical, chemical, or biological conditions that would exist in a waterbody that are not a result of human activity. Nonpoint sources of pollution in the SHRW were discussed previously and include overland erosion, channel degradation, wildlife, and other sources.

4.3.3 Wasteload Allocation Methodology

The WLA represents the regulated portion of the loading capacity, requiring a NPDES Permit. Regulated sources may include construction stormwater, industrial stormwater, MS4 permitted areas, NPDES permitted feedlots, and WWTFs. The only regulated sources of TSS are construction and industrial stormwater discharges and WWTFs. There are no MS4s or NPDES permitted feedlots in the drainage basins of any impaired streams.

WLAs for construction and industrial stormwater discharges were combined and addressed through a categorical allocation. This TMDL study assumes that 0.1% of the SHRW's land use contributes construction and/or industrial stormwater runoff at any given time. Historical permits and land use in the watershed support this assumption. Stormwater runoff from construction sites that disturb: (a) one acre of soil or more, (b) less than one acre of soil and are part of a "larger common plan of development or sale" that is greater than one acre, or (c) less than one acre, but determined to pose a risk to water quality are regulated under the state's NPDES/SDS General Stormwater Permits for Construction Activity (MNR1000001). This permit requires and identifies BMPs to be implemented to protect water resources from mobilized sediment and other pollutants of concern. If the owner/operators of impacted construction sites within the SHRW obtain and abide by the NPDES/SDS General Construction Stormwater Permit, the stormwater discharges associated with those sites are expected to meet the WLAs set in this TMDL study.

Similar to construction activities, industrial sites are regulated under general permits, in this case either the NPDES/SDS Industrial Stormwater Multi-Sector General Permit (MNR050000) or the NPDES/SDS General Permit for Construction Sand & Gravel, Rock Quarrying, and Hot Mix Asphalt Production facilities (MNG490000). Like the NPDES/SDS General Construction Stormwater Permit, these permits identify BMPs to be implemented to protect water resources from pollutant discharges at the site. If the owner/operators of industrial sites within the SHRW obtain and abide by the necessary NPDES/SDS General Stormwater Permits, the discharges associated with those sites are expected to meet the WLAs set in this TMDL study.

Due to the transient nature of construction and industrial activities, it is assumed 0.1% of the drainage area is under construction and industrial activities at any given time. Therefore, to calculate the WLA for construction and industrial stormwater, 0.1% of the LA for the lake was assumed and assigned to construction/industrial stormwater WLA. It should be noted, the construction/industrial stormwater WLA is dependent on the LA.

All SHRW WWTFs are limited to discharging from a single surface secondary treatment cell. All WWTFs are permitted to discharge only during specified discharge windows in the spring and fall. The discharge windows are March 1 through June 30 and September 1 through December 31 with no discharge to ice covered waters.

Maximum daily permitted WLAs were calculated for each WWTF based on a maximum discharge of six inches per day, per the MPCA guidance. WLAs were computed for TSS based on the maximum permitted daily flow rate from each facility.

The maximum daily permitted TSS WLAs were converted to maximum annual loads by reviewing Discharge Monitoring Reports to determine the average number of days that each WWTF discharged each year (over the past 10 years) and multiplying that value by the allowable daily loads. Maximum permitted daily and annual TSS WLAs for the SHRW WWTFs are shown in **Table 4-17**.

Table 4-16: Annual and daily TSS WLAs for SHRW WWTFs.

	A	B	C	D	E	F	G	H	I	J
Facility	Secondary Pond Size (acres)	Permitted Max Daily Discharge (gpd)[1] ($A*0.163*10^6$)	Liters per Gallon	Permitted Max Daily Discharge (liters/day)[1] (B*C)	Average # of Days Discharging per Year	Permitted TSS Conc. (mg/L)	WLA-TSS (kg/day) (D*F/106)	Kg per Ton	WLA-TSS (tons/ day)	WLA-TSS (tons/yr)
Climax	1.7	277,100	3.785	1,048,938	21	45	47	907.2	0.05	1.11
Fertile	6	978,000	3.785	3,702,133	27	45	167	907.2	0.18	4.94
Winger	1.5	244,500	3.785	925,533	37	45	42	907.2	0.05	1.70

4.3.4 Margin of Safety

The purpose of the MOS is to account for any uncertainty with attaining water quality standards. Uncertainty can be associated with data collection, lab analysis, data analysis, modeling error, and implementation activities. An explicit 10% of the loading capacity MOS was applied to each flow regime for all LDCs developed for this TMDL. The explicit 10% MOS accounts for:

- Uncertainty in the observed daily flow record;
- Uncertainty in the observed water quality data, including uncertainty associated with the transformation of turbidity data to a TSS surrogate to expand the observed record;
- Allocations and loading capacities are based on flow, which varies from high to low. This variability is accounted for using the five flow regimes and the LDCs.

4.3.5 Critical Conditions and Seasonal Variation

A summary of the TSS load reduction results can be found in **Table 4-17**. Results are summarized by indicating the maximum required percent load reduction for each curve and the flow regime and water quality criteria under which this maximum reduction occurred (i.e., the critical flow regime and criteria). The critical flow regimes for TSS loading were low flows for AUID 09020301-541 and high flows for AUID 09020301-537.

Table 4-17: Maximum required total suspended load reductions for the SHRW.

AUID	TSS	
	Max. % Load Reduction	Critical Flow Regime
09020301-537	92%	High
09020301-541	16%	Low

4.3.6 Future Growth Consideration/Reserve Capacity

No additional reserve capacity was included for the point sources in the SHRW, given the nature of assumptions used to create the WLAs. Similarly, no reserve capacity was included for nonpoint sources in the watershed (LAs), given that the land use in the SHRW is dominated by agriculture and is unlikely to substantially change in the future. For more information on how future growth and reserve capacity, see **Section 4.1.6**.

4.3.7 TMDL Summary

Table 4-24 and **Table 4-25** show the computed loading capacities and allocations for the SHRW streams, which are currently impaired by turbidity, using the proposed TSS standard. The various components of these allocations were developed as described in **Sections 4.4.1** to **4.3.4**. The LDCs used to develop the loading capacities and allocations are provided in **Appendix A**. It should be noted that the sum of some of the TMDL calculations may not equal the loading capacity of the AUID; this is due to rounding errors.

In addition to the TMDL components, the existing load, the unallocated load (if applicable), and the estimated load reduction as a percentage are given for each flow regime. The existing load is based on existing water quality data, the unallocated load is the potential load available if the existing load is lower than the loading capacity for a given flow regime (i.e. the loading capacity minus the existing load). An unallocated load is only provided if the existing load is lower than the loading capacity. The estimated load reduction is required load reduction, as a percentage of existing load, to meet the loading capacity. A load reduction is only provided if the loading capacity is less than the existing load.

The LDC method is based on an analysis that encompasses the cumulative frequency of historical flow data over a specified period. Because this method uses a long-term record of daily flow volumes, virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report (**Tables 4-18 & 4-19**), only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the entire curve represents the TMDL and is what is ultimately approved by the EPA. The LDCs used to develop the loading capacities and allocations are provided in **Appendix A**.

Table 4-18: TSS loading capacities and allocations for AUID 09020301-537.

TSS		Flow Condition				
		Very High	High	Mid	Low	Very Low
		Tons per day				
Loading Capacity		**156.7**	**30.3**	**13.7**	**6.5**	**3.16**
Wasteload Allocations	**Total WLA**	**0.42**	**0.31**	**0.29**	**0.29**	**0.28**
	Climax WWTF	0.05	0.05	0.05	0.05	0.05
	Fertile WWTF	0.18	0.18	0.18	0.18	0.18
	Winger WWTF	0.05	0.05	0.05	0.05	0.05
	Construction/Industrial Stormwater	0.14	0.03	0.01	0.006	0.003
Load Allocations	**Total LA**	**140.61**	**26.96**	**12.04**	**5.56**	**2.55**
MOS		**15.7**	**3.0**	**1.4**	**0.7**	**0.3**
Existing Load		**1,680**	**181**	**30**	**9.0**	**4.2**
Unallocated Load		**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Estimated Load Reduction		**92%**	**85%**	**59%**	**35%**	**32%**

Table 4-19: TSS loading capacities and allocations for AUID 09020301-541.

TSS		Flow Condition				
		Very High	High	Mid	Low	Very Low
		Tons per day				
Loading Capacity		**42.48**	**9.34**	**3.37**	**1.57**	**0.77**
Wasteload Allocations	**Total WLA**	**0.08**	**0.06**	**0.05**	**0.05**	**0.05**
	Winger WWTF	0.05	0.05	0.05	0.05	0.05
	Construction/Industrial Stormwater	0.03	0.008	0.002	0.0015	0.0007
Load Allocations	**Total LA**	**38.15**	**8.35**	**2.98**	**1.36**	**0.64**
MOS		**4.25**	**0.93**	**0.34**	**0.16**	**0.08**
Existing Load		**29.0**	**7.6**	**1.5**	**1.7**	**0.6**
Unallocated Load		**9.2**	**0.8**	**1.5**	**0.0**	**0.1**
Estimated Load Reduction		**0%**	**0%**	**0%**	**16%**	**0%**

5 Reasonable Assurance

Reasonable assurance of the load reductions and strategies developed under this TMDL study comes from multiple sources. WLAs are assured through the issuance and regulation of NPDES Permits. LAs and their associated nonpoint source implementation strategies are reasonably assured by historical and ongoing collaborations in the watershed. Several agencies and local governmental units have been and continue to work toward the goal of reducing pollutant loads in the SHRW. Strong partnerships between the SHRWD, counties, and soil and water conservation districts (SWCDs) have led to the implementation of conservation practices in the past and will continue to do so into the future. As discussed in the Monitoring Plan section (**Section 6**) and the Implementation Strategy Summary (**Section 7**), the SHRWD as a long history of stream monitoring and implementing BMPs. The SHRWD has been actively involved in volunteer water quality monitoring since 1993 through the Sand Hill River Watch Program and has been involved in an ongoing citizen river monitoring project with the Red River Watershed Management Board (RRWMD), Agassiz Environmental Learning Center, and public schools in the SHRWD. Since 2011, the SHRWD in partnership with the East Polk SWCD has applied for and received several Clean Water Fund Grants to install numerous water and sediment control basins and riffle structures in the watershed to improve water quality. The SHRWD, East Polk SWCD, and West Polk SWCD plan to continue their partnerships to proactively seek funding and implement BMPs to address water quality issues within the watershed. Further discussion on the monitoring and implementation strategies can be found in **Section 6** and **Section 7**, respectively.

Upon approval of the TMDL study by the EPA, the SHRWD will incorporate the various implementation activities described by this TMDL study into their Watershed Management Plan (WMP). The SHRWD is committed to taking a lead role during the implementation of this TMDL study and has the ability to generate revenue and receive grants to finance the implementation items.

In addition to commitment from local agencies, the state of Minnesota has also made a commitment to protect and restore the quality of its waters. In 2008, Minnesota voters approved the Clean Water, Land, and Legacy Amendment to increase the state sales tax to fund water quality improvements. The interagency Minnesota Water Quality Framework (**Figure 5-1**) illustrates the cycle of assessment, watershed planning, and implementation to which the state is committed. Funding to support implementation activities under this framework is made available through Minnesota's Board of Water and Soil Resources (BWSR), an agency that the SHRWD has received grants from in the past.

The SHRWD has the ability to provide funding for projects consistent with those identified within the WMP. The WMP is required to be updated following a 10-year cycle and future revisions will include projects and methods to make progress toward implementing the TMDLs.

Figure 5-1: Minnesota Water Quality Framework.

6 Monitoring Plan

Continued stream monitoring within the SHRW will continue primarily through the efforts of the SHRWD. As outlined in the Section 7 of the SHRWD WMP (HEI 2011), the SHRWD has been actively involved in volunteer water quality monitoring since 1993 through the Sand Hill River Watch Program and has been involved in an ongoing citizen river monitoring project with the RRWMD, Agassiz Environmental Learning Center, and public schools in the SHRWD. These include Fosston, Win-E-Mac (Winter, Erskine, and McIntosh), Fertile-Beltrami, and Climax schools. The goals of this project are to develop baseline water quality data on the Sand Hill River, provide hands-on "real world" science opportunities for students and promote greater citizen awareness and understanding of the watershed and the role of the watershed district. The River Watch Program collects samples at 25 sites in the SHRWD.

To supplement data collection between intensive monitoring cycles, the MPCA coordinates two programs aimed at encouraging citizen surface water monitoring; the Citizen Lake Monitoring Program (CLMP) and the Citizen Stream Monitoring Program (CSMP). Sustained citizen monitoring can provide the long-term picture needed to help evaluate current water quality status and trends. The advance identification of lake and stream sites that will be sampled by agency staff provides an opportunity to actively recruit volunteers to monitor those sites, so that water quality data collected by volunteers are available for the years before and after the intensive monitoring effort by the MPCA staff (MPCA 2012a; page 14).

In addition to the stream monitoring sponsored by the SHRWD and River Watch, the MPCA also has ongoing monitoring in the watershed. The MPCA's major watershed outlet monitoring will continue to provide a long-term ongoing record of water quality at the SHRW outlet. The lakes of the SHRW are not being routinely monitored at this time. The MPCA will return to the watershed and monitor lakes under their 10-year cycle Intensive Watershed Monitoring program in 2021 and 2022.

7 Implementation Strategy Summary

Water quality restoration and implementation strategies within the SHRW were identified through collaboration with state and local partners. Due to the homogeneous nature of the watershed, most of the suggested strategies are applicable throughout the watershed. Exceptions include residue management, which is not practical for implementation in the Lake Plain region. Similarly, side inlet controls are effective in the Lake Plain, and water and sediment control basins are appropriate in the central and eastern portions of the watershed.

The identified implementation strategies and priorities are discussed in the SHRW WRAPS Report (HEI 2014b) and the SHRW Biotic SID Report (MPCA 2014b). Below are examples of the suggested strategies needed to achieve restoration goals in the SHRW. For more in-depth discussion, see the Sand Hill WRAPS Report.

- Modify the grade control structures to restore fish passage and streambank erosion along the Sand Hill River;
- Prevent or mitigate activities that will further alter the hydrology of the watershed, improve storage capacity within the watershed;
- Consider opportunities and options to attenuate peak flows and augment base flows in streams throughout the watershed;
- Re-establish natural functioning stream channels wherever possible using natural channel design principles;
- Increase the quantity and quality of instream habitat throughout the watershed;
- Establish and/or protect riparian corridors along all waterways, including ditches, using native vegetation whenever possible;
- Implement agricultural BMPs to reduce soil erosion and sedimentation;
- Ensure all septic systems are compliant to current standards and address all failing and IPHT systems;
- Ensure all NPDES-permitted sources comply with conditions of their permits; and
- Limit or exclude the access of livestock to waterways and develop manure management plans.

7.1 Permitted Sources

7.1.1 MS4

There are no MS4s in the SHRW. Therefore, no implementation strategies were developed for MS4s in the SHRW.

7.1.2 Construction Stormwater

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

7.1.3 Industrial Stormwater

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

7.1.4 Wastewater

The requirements of the WWTFs' NPDES Permits, along with the WLAs and reserve capacity (for turbidity only), should be sufficient implementation strategies for the WWTFs in the watershed. If a WWTF follows all requirements under the NPDES Wastewater Permit, the wastewater would be expected to be consistent with the WLA in this TMDL.

7.2 Non-Permitted Sources

The SHRWD, the East Polk SWCD and West Polk SWCD have a long history of improving water quality. Addressing sediment movement in the watershed has been a priority of all three and they have been seeking grants to improve local water quality since the passage of the Clean Water, Land and Legacy Amendment.

In 2010, the SHRWD and East Polk SWCD received funds to assist landowners with flood related projects. Some of the projects were for water and sediment basins on cropland with slopes greater than 10%. A water and sediment basin is an earthen embankment built so that sediment-laden runoff is temporarily detained, allowing sediment to settle out before runoff is discharged. These are installed on agricultural cropland where erosion exceeds the allowable soil rate. Minimum detention time to store water is 36 hours for a 10-year, 24-hour runoff event. The average water/sediment basin costs $6,000 and averages 19.31 tons/yr of sediment reduction, 20.66 lbs/yr of P reduction and 33.16 tons/yr of soil saved.

The success of these BMPs had landowners requesting more funding than the SWCD had available. In 2011, the SHRW received a $255,142 grant to install 70 water and sediment basins. In 2012, the SHRW received a $251,680 grant to install 67 water and sediment basins. In 2014, the SHRW received a grant for more water and sediment basins and in-channel riffle structures. According to preliminary field reviews and landowner interest, the 2014 money will all be used and encumbered to install an additional 80 water and sediment basins. There is still a huge backlog of landowners requesting assistance. Because of this popular conservation practice, the SHRWD has landowners on a waiting list. Water and sediment basins are a practical practice landowners can install while at the same time addressing the impairments of the Sand Hill River. In 2015, The SHRWD submitted a request for a Targeted Watershed Program Grant to fund 60 sediment control basins and a coulee stabilization project in the watershed that contributes to AUID 09020301-541.

These sediment basins reduce the amount of sediment loading reaching the Sand Hill River and will help address the turbidity/TSS impairments throughout the watershed and reduce the elevated turbidity stressors on biological impairments. In addition, the sediment basins detain surface runoff up to 36 hours, helping reduce the altered hydrology stressors identified in the SID Report (MPCA 2014b).

In addition to the sediment basins, multiple channel and grade stabilization projects, including improved fish passage, are planned or proposed. The SHRWD, along with the West Polk SWCD, received a $475,000 grant in Clean Water Funds (CWF) and $100,000 from Enbridge., Inc. to install 16 rock riffles to assist with grade stabilization and facilitate fish passage for 3.5 miles of the channelized reach of the Sand Hill River (AUID 09020301-536), which contributes thousands of tons of sediment downstream. The total project length is five miles of channel located between the cities of Fertile and Beltrami in western Polk County. It has been estimated that the channelized reach bed and banks lose 2,270 tons of sediment, per mile, each year. Channelization of a watercourse decreases the stream length, increases the channel grade/slope and increases flow velocities, resulting in incision of the channel bed and destabilization of the banks. The Sand Hill River channelized reach has been experiencing channel bed incision, destabilized banks, and increased turbidity/sedimentation, which has led to the water quality impairment. To address this, several projects are planned to reduce in-channel sediment load and resulting turbidity in the Sand Hill River and will address the turbidity/TSS impairments in AUID 9020301-536 and any identified elevated turbidity stressor.

In addition, the SHRWD wants to install grade control measures in a 2.75 mile reach of the Polk County Ditch 122 and will complete as funds become available. The SHRWD is also providing stabilization to head-cutting that is occurring along a tributary (Carlson Coulee) to the Sand Hill River. Carlson Coulee is also located within the Targeted Watershed Program area. If successful, the Targeted Watershed Program could fund the Carlson Coulee. The SHRWD also plans to install grade stabilization measures along an abandoned ditch near Winger (formerly known as County Ditch 133).

The SHRWD is also installing gully stabilization measures around the perimeter of Union Lake that will reduce sediment loading into the lake. This is expected to improve water quality by reducing TP and turbidity. Although not listed as impaired, Union Lake is a popular recreational lake in the district, and is a high priority for protection.

The SHRWD has secured funding for retrofitting the US Army Corps of Engineers drop structures, located in the upper reaches of the Sand Hill River (AUID 9020301-541 and -542), with riprap to allow fish passage. This project is a high priority for the DNR, is federally funded with a 75% match, and is currently in the design and contracting stages (as of April 2016) and will have a total estimated cost of $6.7 million. This will help address the loss of connectivity stressors identified in the SID Report (MPCA 2014b).

The SHRWD is also implementing a regional detention facility and strategy to reduce the magnitude of downstream flooding and restore the natural hydrology in the watershed. The strategy will include Natural Resource Enhancement features, where applicable, to meet multiple goals and objectives for SHRWD Planning Region No. 4 (see **Figure 1-1**). The SHRWD will use required easement areas to restore natural vegetation to land required to implement runoff detention in Region 4 of the SHRWD for enhanced habitat, reduced contaminant loading and reduced rate of runoff. The anticipated completion is 2016 and 2017 at a cost of $3 Million. This project will reduce sediment loading and address the turbidity/TSS impairment in AUID 9020301-541 and address the elevated turbidity and altered hydrology stressors indicated in the Stressor Identification Report (MPCA 2014b).

The SHRWD will continue existing programs to install side water inlets and establish vegetated buffer strips adjacent to the Sand Hill Drainage System. These will reduce sediment and P loading from agricultural sources to the channel. These programs are ongoing with an estimated cost of $4 million and will address the turbidity and excessive nutrient impairments, as well as the elevated turbidity and excessive nutrients stressors.

7.3 Cost

The CWLA requires that a TMDL study include an overall approximation of implementation costs (Minn. Stat. 2007, § 114D.25). Based on cost estimates from current, planned and proposed work (listed above) in the SHRW and the level of effort required to address the water quality issues, a reasonable estimate to continue efforts for reducing sediment and P in the impaired reaches, addressed in this study, would be $10 to $20 million dollars over 10 years. These dollars would be spent primarily on practices such as regional water retention projects, riparian vegetative buffers, sediment BMPs (water and sediment control basins and side inlets), pasture management, conservation tillage, vegetative practices, wetland restorations, rain gardens, urban BMPs and structural practices.

P and bacteria reductions are also needed to meet the targets of this TMDL study. Residential practices would include those that reduce runoff from lakeshore homes and residences within the watershed. These practices could include shoreland buffers, rain gardens, lawn fertilizer reductions, vegetation management and permeable pavement. Continued residential development of shoreland through construction and increased runoff, has the potential to add P to the system. Low impact practices and shoreland BMPs should be utilized for any new development. Practices on the homeowner scale often vary widely in cost (i.e., $500 for a small rain garden to $5,000 for permeable pavement).

7.4 Adaptive Management

Adaptive management is an iterative implementation process that makes progress toward achieving water quality goals while using any new data and information to reduce uncertainty and adjust implementation activities. It is an ongoing process of evaluating and adjusting the strategies and activities that will be developed to implement the TMDL. The implementation of practicable controls should take place even while additional data collection and analysis are conducted to guide future implementation actions. 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.

The SHRW WRAPS Report (HEI 2014b) provides details of the management strategies and activities listed in Section 7 (and HEI 2013e). The WRAPS report focuses on adaptive management (**Figure 7-1**) to evaluate project progress as well as to determine if the implementation plan should be amended. Implementation of TMDL related activities can take many years, and water quality benefits associated with these activities can also take many years. As the pollutant source dynamics within the watershed are better understood, implementation strategies and activities will be adjusted and refined to efficiently meet the TMDLs and lay the groundwork for de-listing the impaired reaches. The follow up water monitoring program outlined in **Section 6** will be integral to the adaptive management approach, providing assurance that implementation measures are succeeding in attaining water quality standards.

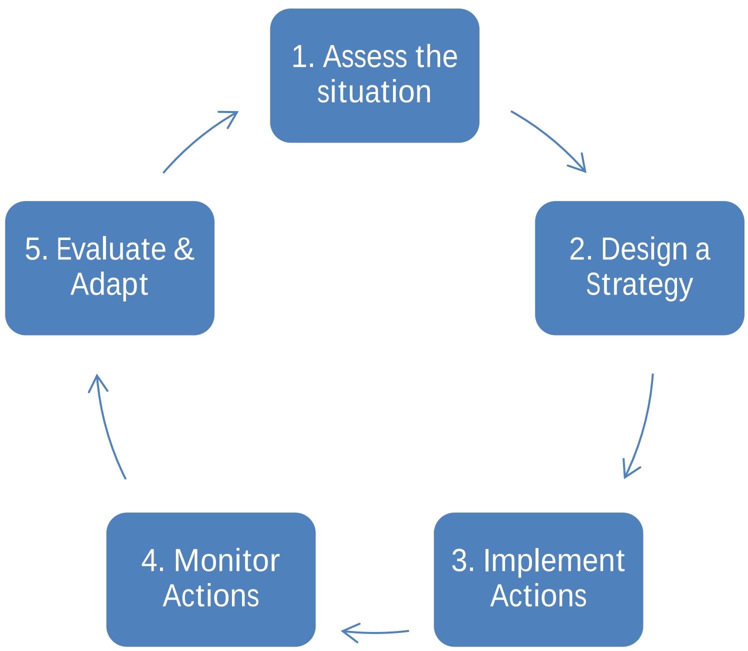

Figure 7-1: Adaptive management cycle.

8 Public Participation

Public participation (i.e., civic engagement) during this TMDL study process was led by the SHRWD. On March 22, 2012, a public kick-off meeting was held to provide background information on the TMDL and WRAPS process. A TMDL study stakeholder group was identified early in the TMDL study process and kept up to date of actions as the project proceeded. Members of the group included area landowners, representatives from the area SWCDs, counties and townships, representatives from state agencies (MPCA, DNR, BWSR), and board members of the SHWD. On March 28, 2014, a public stakeholders meeting was held at the Fertile Community Center to showcase the WRAPS process and discuss the technical work being performed as part of the WRAPS process. TMDL study updates were regularly presented through open houses and public meetings in the watershed. In addition, the SHRWD developed a project webpage[13] where updates and select reports were posted. The MPCA also developed a project webpage[14] to keep the public informed of progress.

The SHRW TMDL went through its 30-day public noticed review and comment period from May 31, 2016, through June 29, 2016. The MPCA received two comments regarding the TMDL, all of which were submitted by the USDA. All comments have been addressed in this final TMDL.

Since water quality is among the ongoing priorities of the SHRWD's management activities, future civic engagement will continue to go through the District. The SHRWD will update, educate, and engage stakeholders on water quality issues through the normal District communications, including plan update events and on their website. As one of most trusted authorities on water issues in the area the SHRWD is uniquely suited to provide information and leadership on this topic.

13 http://www.sandhillwatershed.org/tmdl.html

14 http://www.pca.state.mn.us/index.php/water/water-types-and-programs/watersheds/red-river-of-the-north-sandhill-river.html

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Appendix

MEMO

(External Correspondence)

To: Cary Hernandez

Date: June 16, 2014

File: 1812-006

From: Timothy Erickson, PE
Mark R. Deutschman, Ph.D., P.E.

Subject: Sand Hill River Watershed Load Duration Curves

INTRODUCTION

This memorandum summarizes the methods used and results for creating load duration curves (LDCs) for four impaired stream segments (delineated by assessment unit identification (AUID) numbers) in the Sand Hill River Watershed (SHRW). Each of the segments are impaired for aquatic recreation due to elevated *E. coli* levels and two of the reaches are also impaired relative to aquatic life due to high turbidity and/or do not meet criterion for the proposed total suspended solids (TSS) standards. Preparation of the LDCs includes computing necessary load reductions within each flow regime of the curve, which will be used to develop total maximum daily loads (TMDLs) for impaired reaches. A dual endpoint TMDL will be performed for the SHRW for both turbidity and TSS impairments. This means LDCs were developed for both the current turbidity standard, as well as the proposed TSS standard. These efforts were performed under Objective 2 of Phase II of the Sand Hill River Watershed Restoration and Protection Strategy (WRAPS) project.

A list of the AUIDs addressed in this memorandum is included in **Table 1**. Also included is an indication of the impairments that LDCs will be used to address, a list of water quality monitoring stations located within each AUID and the associated HSPF (Hydrologic Simulation Program Frotran) model sub-basin or U.S. Geological Survey (USGS) gaging site which was used to represent flows for creating the curves. In addition, the AUIDs, monitoring locations and HSPF subbasins are shown in

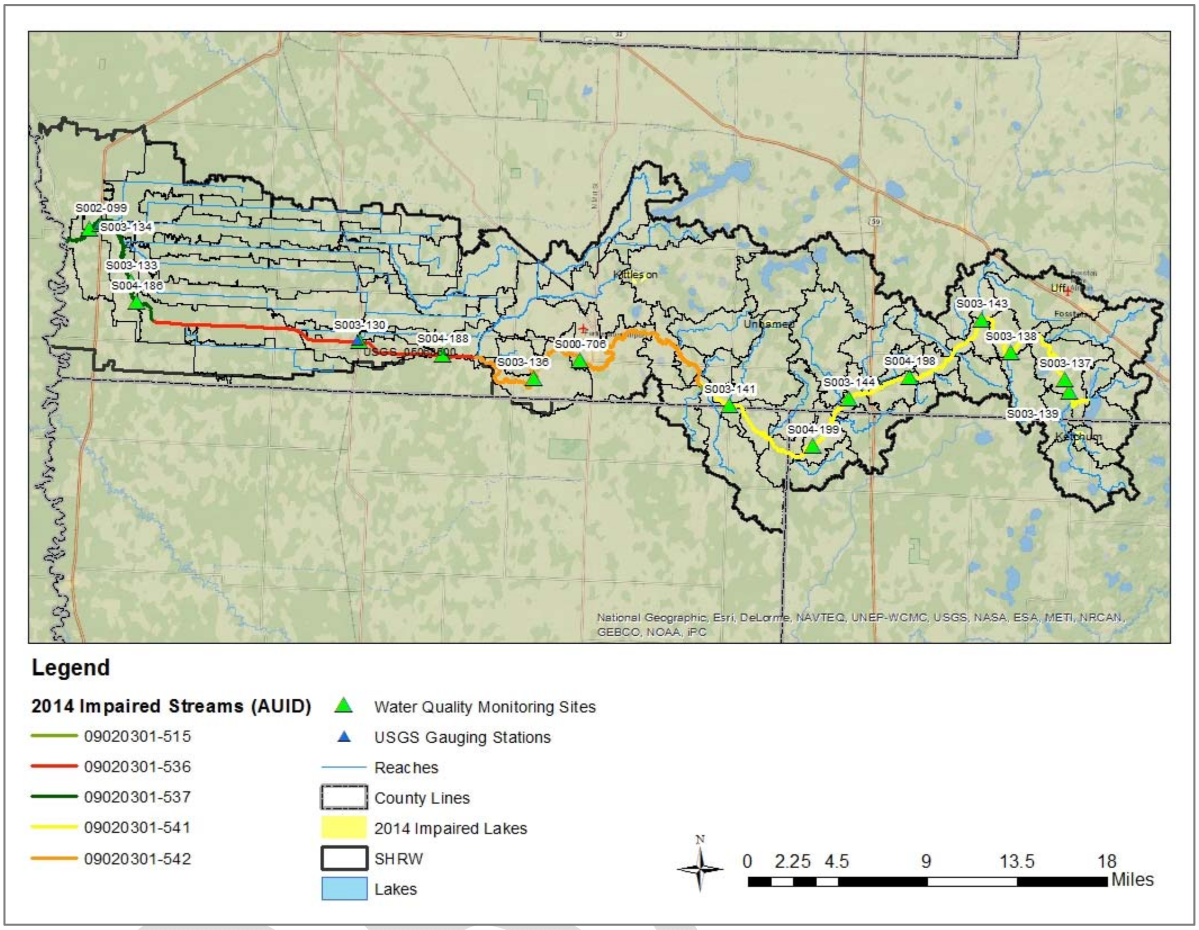

Figure 1.

Table 1. AUIDs associated with LDCs, stressors and data used.

AUID (09020301-XXX)	Reach Name	Stressors	Water Quality Stations	USGS Site or HSPF Flow RCHRES ID
536	Sand Hill River-Kittleson Crk to Unnamed Crk	*E. coli*	S003-130	RCHRES 390
537	Sand Hill River-Unnamed Crk to Red R	*E. coli*, Turbidity	S002-099, S003-133, S003-134, S004-186, S004-188	USGS # 05069000
541	Sand Hill River-Headwaters to CD 17	*E. coli,*Turbidity	S003-137, S003-138, S003-139, S003-141, S003-143, S003-144, S004-198, S004-199	RCHRES 250
542	Sand Hill River-CD 17 to Kittleson Cr	*E. coli*	S000-706, S003-136	RCHRES 350

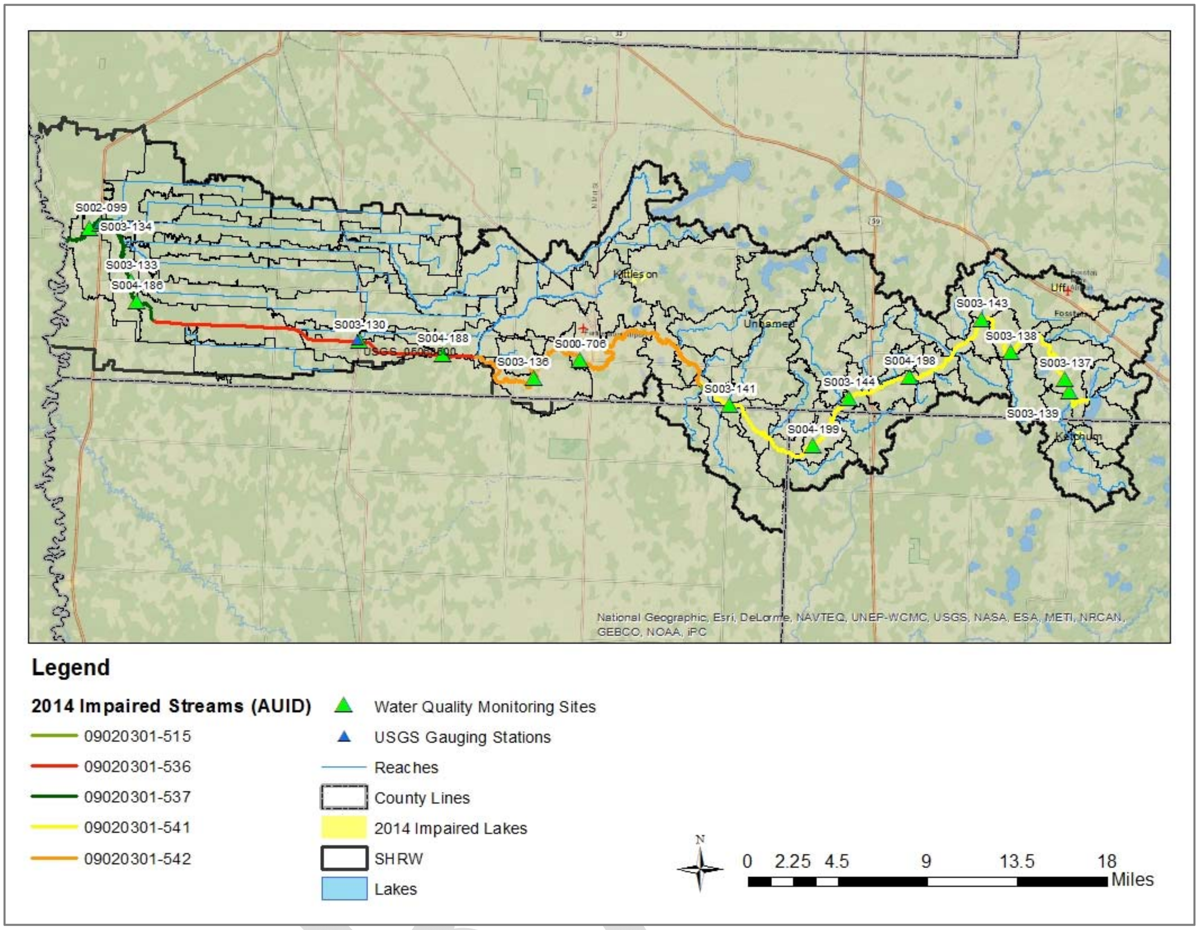

Figure 1. AUIDs, water quality monitoring locations used for LDCs in the SHRW.

METHODOLOGY

LDCs were developed for each of the 4 AUIDs listed in **Table 1**. Each LDC was developed by combining the (simulated or observed) river/stream flow at the downstream end of the AUID with the measured concentrations available within the segment. Methods detailed in the US Environmental Protection Agency (USEPA) document *An Approach for Using Load Duration Curves in the Development of TMDLs* were used in creating the curves (USEPA, 2007). A summary of this methodology, as applied in the SHRW, is provided below. Full details on LDC methods can be found in the USEPA guidance (USEPA, 2007).

Data

Observed daily flow data is limited within the SHRW, only one USGS station, Sand Hill River at Climax, MN (USGS Station #05069000), has continuous flow data (AUID 09020301-537). Therefore simulated daily mean flows from the SHRW HSPF model (RESPEC, 2013) were used to create the LDCs for the remaining AUIDs. The HSPF model simulates flows from 1995-2009. In order to best capture the flow regimes of each AUID, the period 1996 – 2009 was used in development of the LDCs, 1995 was used as a warm-up period of the model and simulated flows might not be valid (RESPEC, 2013). Although continuous, observed flow data for AUID 09020301-537 extends beyond 2009, the period 1996-2009 for all AUIDs is used for consistency.

The water quality data used in this work was obtained from the Minnesota Pollution Control Agency (MPCA) through their EQuIS (Environmental Quality Information System) database. For the purposes of creating the curves (which will inform TMDL development), only water quality data from the most recent completed assessment period (2003-2012) was used. While data exists for bacteria, turbidity, and TSS, spanning from 2003-2010, the HSPF model only estimates flows for 1995-2009; therefore the LDCs are based on bacteria and TSS data from the overlapping time period of 2003-2009.

Table 2 summarizes the water quality data used in the bacteria and TSS LDCs for each AUID in the SHRW.

Table 2. Water quality data used for each LDC.

AUID (09020301-XXX)	Water Quality Monitoring Locations	*E. coli* Data	Turbidity/ TSS Data
536	S003-130	2008-2009	2001, 2003-2009
537	S002-099, S003-133, S003-134, S004-186, S004-188	2008-2012	2005-2007, 2009
541	S003-137, S003-138, S003-139, S003-141, S003-143, S003-144, S003-499, S004-198, S004-199, S005-559	2008-2012	2006-2009
542	S000-706, S003-136, S003-140, S006-560	2006-2012	2006-2009

Bacterial LDCs

To match the time period when the water quality standard is applicable, the bacterial LDCs were created using flow and *E. coli* water quality data from April through October only. Individual loading estimates were calculated by combining the observed *E. coli* concentration and simulated mean daily flow value on each sampling date. The load estimates were separated by month and by station, mainly for purposes of display on the curve. “Allowable” loading curves were created for both the instantaneous (1260 organisms/100mL) and monthly geometric mean, i.e., geomean, (126 organisms/100mL) criteria by multiplying each “allowable” concentration by the simulated mean daily flow values and ranking the flows. A 10% margin of safety (MOS) was applied to each of the “allowable” loading curves.

Turbidity using TSS Surrogate LDCs

To match the time period when the water quality standard is applicable, the turbidity LDCs were created using flow and turbidity/TSS water quality data throughout the year. Following common practice, TSS LDCs were used as a surrogate to represent and address turbidity impairments in the turbidity-impaired SHRW AUIDs. Turbidity using TSS surrogate LDCs were calculated using a combination of TSS and turbidity data. When available, TSS was used as the preferred value for calculating solids loading. However, since turbidity data are more prevalent in the SHRW, turbidity was used to estimate TSS values at sites where insufficient TSS data was available. This is consistent with MPCA guidance (MPCA, 2012). TSS and turbidity data were paired for the SHRW and a regression was applied to test the relationship. The resulting regression equation for converting turbidity values (in NTU) in the SHRW to TSS (in mg/L) during the 2002-2012 time-period is:

$$TSS = -0.0001 * Turbidity^2 + 0.9691 * Turbidity + 9.6733$$

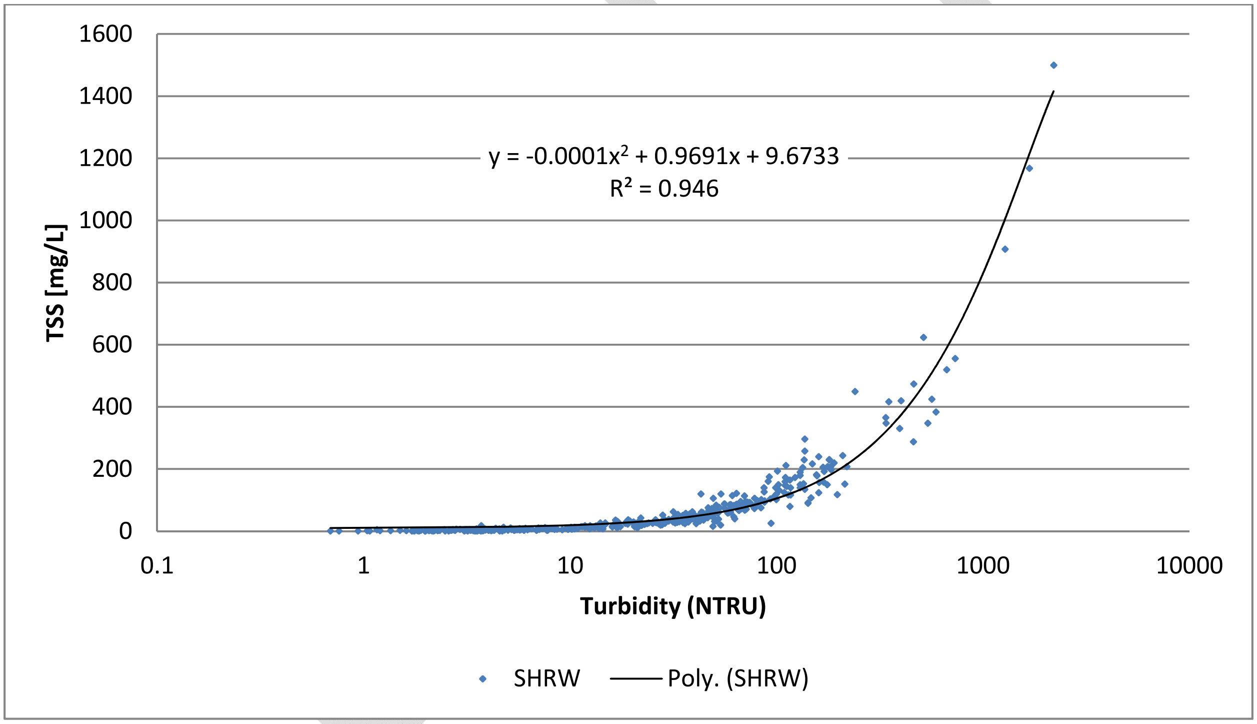

Figure 2: Relationship between Turbidity and Total Suspended Solids in the SHRW.

Application of this regression equation to Minnesota's Class 2B stream turbidity water quality standard of 25 NTU (Nephelometric Turbidity Units) yields an "allowable" TSS value of 33.8 mg/L. As such, it is expected that a stream in the SHRW with TSS concentrations of less than or equal to 33.8 mg/L would meet the turbidity water quality standard.

The turbidity using TSS surrogate LDCs represent one of the two dual endpoint TMDLs. Because the turbidity standard is applied over the entire year, the turbidity using TSS surrogates were created using turbidity/TSS data from the entire year during the assessment period. Again, a 10% MOS was applied.

Proposed TSS Standard LDCs

Additionally, as part of the dual endpoint TMDL, proposed TSS standard LDCs were created using the proposed Southern Region TSS standard of 65 mg/L. The proposed TSS standard LDCs were calculated using the turbidity/TSS data collected during the assessment period, overlapping the period of available flow information. Like the turbidity LDCs, turbidity data was converted to TSS to expand the dataset. The proposed standard only applies during the months of April through September. Therefore the proposed TSS standard LDCs were created using turbidity/TSS data and flow data from this period. As with the other LDCs, a 10% MOS was applied.

RESULTS

A system's water quality often varies based on flow regime, with elevated pollutant loadings sometimes occurring more frequently under one regime or another. Loading dynamics during certain flow conditions can be indicative of the type of pollutant source causing an exceedance (e.g., point sources contributing more loading under low flow conditions). The LDC approach identifies these flow regimes and presents the observed and "allowable" loading within each regime, to compute necessary load reductions. To represent different types of flow events, and pollutant loading during these events, five flow regimes were identified in the SHRW LDCs based on percent exceedance: High Flows (0%-10%), Moist Conditions (10%-40%), Mid-range Flows (40%-60%), Dry Conditions (60%-90%), and Low Flows (90%-100%). An example *E. coli* LDC (for AUID 09020301-537) is shown in **Figure 2**, identifying the flow regimes.

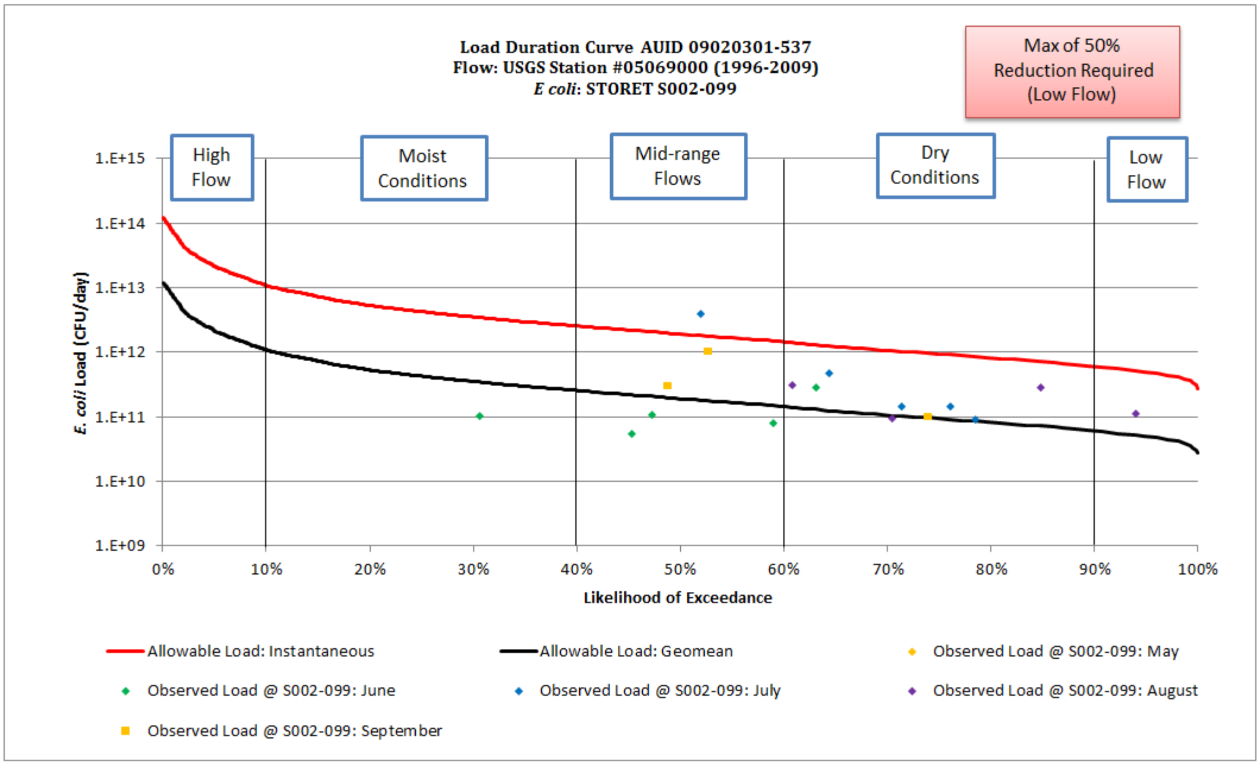

Figure 2. Example bacterial LDC (AUID 09020301-537)

The example bacterial LDC in **Figure 2** was created with flow and water quality data from April through October. The percent likelihood of flow exceedance is shown on the x-axis, while the computed bacterial loading is shown on the y-axis. “Allowable” loadings under each flow condition, based on the instantaneous and geomean standards, are shown with the red and black lines, respectively. Observed loads are also shown, indicated by points on the plot. Observed loads are broken out by station as well as month, allowing for a detailed examination of when and where loading exceedances have occurred. The bacterial LDCs for all of the AUIDs indicating bacterial impairment in **Table 1** are included in **Appendix A**.

The SHRW turbidity using TSS surrogate LDCs were created using similar methods to the bacterial curves. However, the entire annual flow record was used and the empirical loading data was not broken out by month. These modifications are due to the nature by which turbidity impairments are assessed. An example turbidity using TSS surrogate LDC is shown in **Figure 3**.

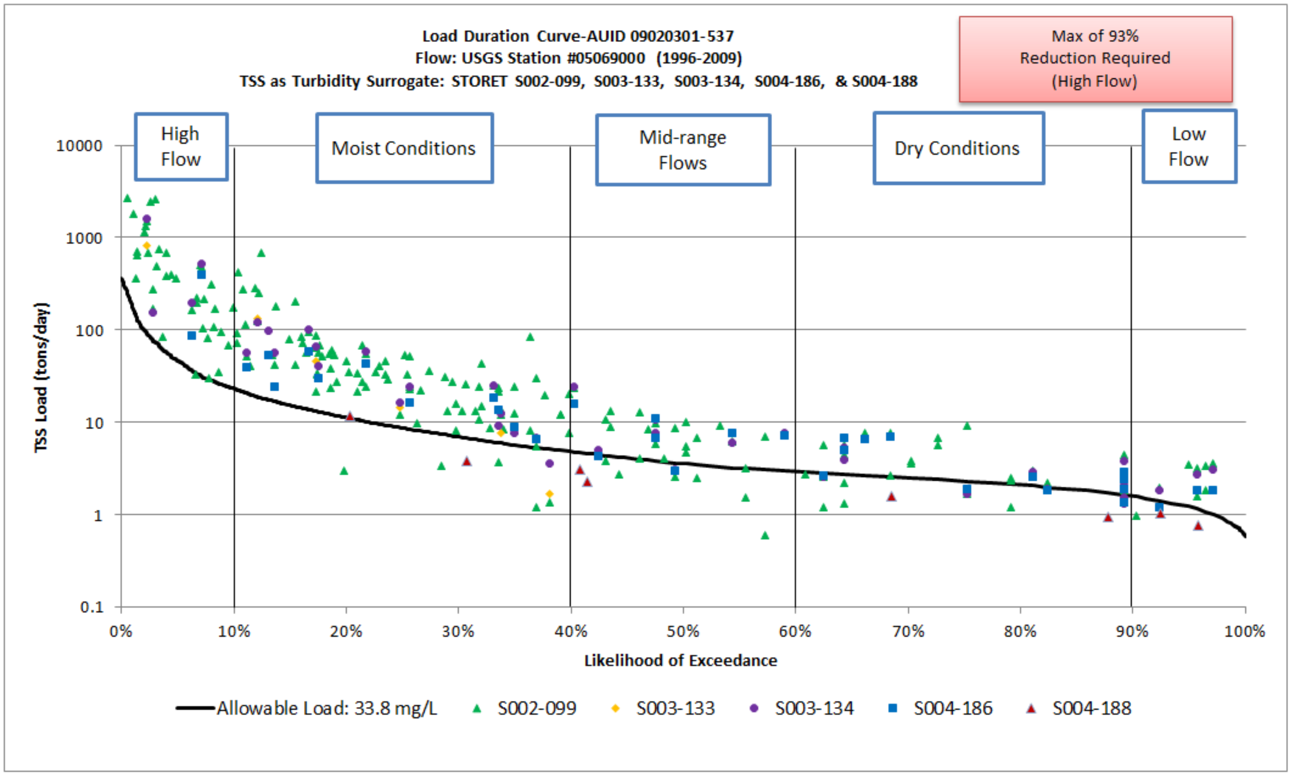

Figure 3. Example turbidity using TSS surrogate LDC (AUID 09020301-537).

The black line in the turbidity using TSS surrogate LDC represents the "allowable" load based on the SHRW turbidity/TSS relationship of 25 NTU to 33.8 mg/L. The turbidity using TSS surrogate LDCs for all of the AUIDs indicating turbidity impairment in **Table 1** are included in **Appendix B**.

The proposed TSS standard LDCs were created using similar methods to the turbidity, using TSS surrogate LDCs. However, only the seasonal (April through September) flow record was used. An example proposed TSS standard LDC is shown in **Figure 4**.

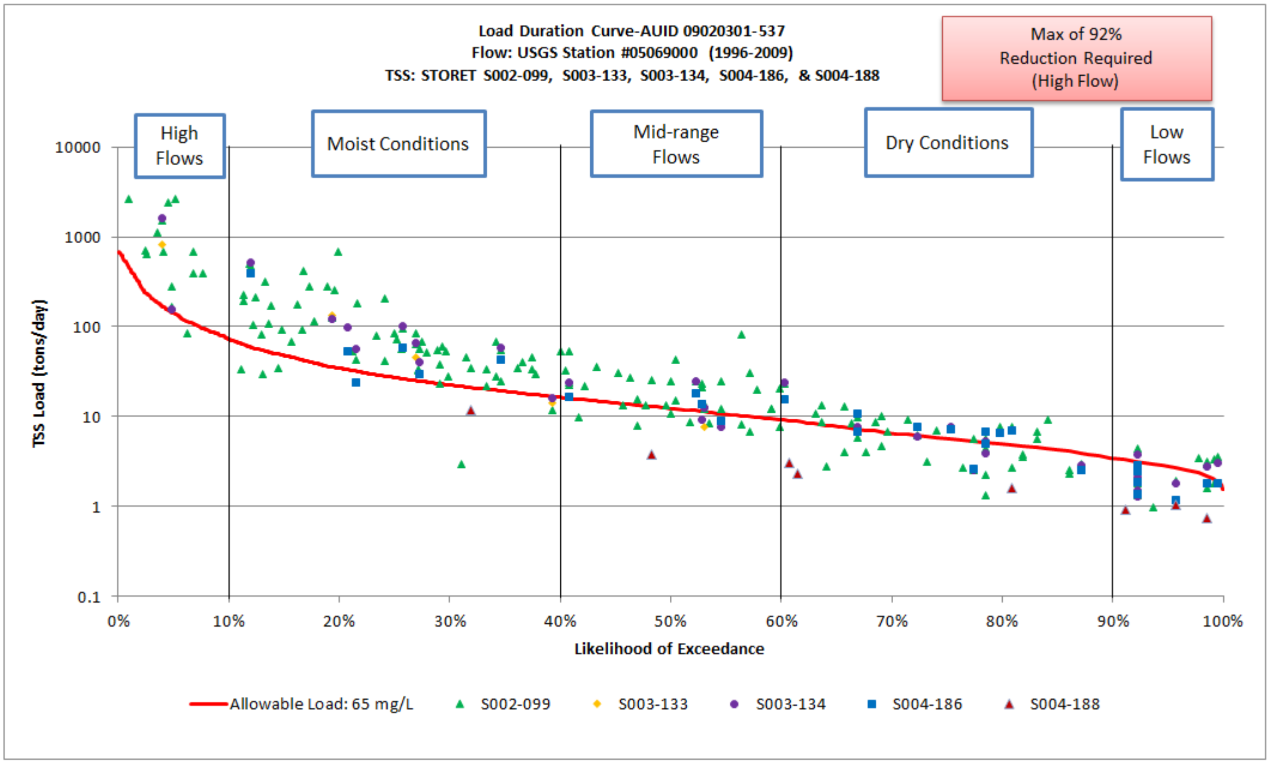

Figure 4. Example proposed TSS standard LDC (AUID 09020301-537).

The red line in the proposed TSS standard LDC represents the "allowable" load based on the proposed Southern Region TSS standard of 65 mg/L. The proposed TSS standard LDCs for all of the AUIDs indicating turbidity impairments in **Table 1** are included in **Appendix C**.

LOAD REDUCTIONS

Bacteria

Total required bacterial load reductions (in organisms/day) and percent load reductions were calculated for each curve, using both the geomean and instantaneous criteria. Methods outlined in the USEPA guidance document (USEPA, 2007) were followed, computing observed and "allowable" loads for each flow regime by combining the median flow in each regime with the applicable water quality criteria and/or representative observed *E. coli* concentration. An example of this process is shown in **Table 3**. The reduction for each criterion (in each flow regime) is determined using the difference between the observed and "allowable" values.

Table 3. Example bacterial load reduction table (AUID 09020301-537)

Flow Regimes	Median Observed Flow (cfs)	Geomean Standard						Instantaneous Standard					
		Observed *E. coli* Geomean (#/100 mL)	Observed *E. coli* Geomean Loading (#/day)	Allowable Load (#/day)	Allowable Load w/10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction	*E. coli* Value that 90% are less than (#/100mL)	Observed *E. coli* 90th Percentile Loading (#/day)	Allowable Load (#/day)	Allowable Load w/ 10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction
0-10%	769	---	---	2.37E+12	2.13E+12	---	---	---	---	2.37E+13	2.13E+13	-2.13E+13	---
10-40%	154	32	1.22E+11	4.75E+11	4.28E+11	-3.06E+11	NR	32.3	1.22E+11	4.75E+12	4.28E+12	-4.16E+12	NR
40-60%	68	170	2.82E+11	2.10E+11	1.89E+11	9.38E+10	33%	2419.6	2.55E+12	2.10E+12	1.89E+12	6.66E+11	26%
60-90%	34	191	1.59E+11	1.05E+11	9.43E+10	6.49E+10	41%	435.2	3.46E+11	1.05E+12	9.43E+11	-5.98E+11	NR
90-100%	18	228	1.00E+11	5.55E+10	4.99E+10	5.06E+10	50%	228.2	1.00E+11	5.55E+11	4.99E+11	-3.99E+11	NR

--- insufficient data

NR – no reduction required

Table 4. Example turbidity using TSS surrogate LDC load reduction table (AUID 09020301-537)

Flow Regime	Observed Data			"Allowable" Based on Turbidity/TSS Conversion			
	Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	Required % Load Reduction
0%-10%	561	436.0	660	51.2	46.1	614.04	93%
10%-40%	106	190	54	9.7	8.7	45.62	84%
40%-60%	44	78	9	4.0	3.6	5.60	61%
60%-90%	29	76	6	2.6	2.4	3.57	60%
90%-100%	15	82.5	3	1.4	1.2	2.11	63%

Table 5. Example proposed TSS standard LDC load reduction table (AUID 09020301-537)

Flow Regime	Observed Data			Proposed TSS Standard (65 mg/L)			
	Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	% Load Reduction
0%-10%	894	696.8	1680	156.7	141.0	1538.74	92%
10%-40%	173	388	181	30.3	27.3	153.90	85%
40%-60%	78	144	30	13.7	12.3	17.90	59%
60%-90%	37	89	9	6.5	5.8	3.08	35%
90%-100%	18	86.1	4	3.2	2.8	1.34	32%

Turbidity using TSS Surrogate and Proposed TSS Standard

Similar methods were used to compute the total required TSS load reductions (tons/day) and percent reductions for both turbidity using TSS surrogate and the proposed TSS standard. These load reduction were also calculated using the median flow of each of the five flow regimes. Examples of this process are shown in **Table 4** for turbidity using TSS surrogate and

Flow Regime	Observed Data			"Allowable" Based on Turbidity/TSS Conversion			
	Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	Required % Load Reduction
0%-10%	561	436.0	660	51.2	46.1	614.04	93%
10%-40%	106	190	54	9.7	8.7	45.62	84%
40%-60%	44	78	9	4.0	3.6	5.60	61%
60%-90%	29	76	6	2.6	2.4	3.57	60%
90%-100%	15	82.5	3	1.4	1.2	2.11	63%

Table 5 for the proposed TSS standard. Again, the reduction for each criterion is determined using the difference between the observed and “allowable” loads. It should be noted, there is a large difference between the average loading rates between the turbidity using TSS surrogate and proposed TSS standard. This is mostly due to the differing time periods used to develop the LDCs (turbidity suing annual data and TSS using April-September data). For the most part, the percentage of required load reductions are similar, especially for the higher flow regimes.

Critical Condition

A summary of the bacterial, turbidity using TSS surrogate, and proposed TSS standard load reduction results can be found in **Table 6**. Results are summarized by indicating the maximum required percent load reduction for each curve and the flow regime and water quality criteria under which this maximum reduction occurred (i.e., the critical flow regime and criteria). The critical criterion for each of the bacterial LDCs is consistently the geomean criterion, indicating a watershed wide bacterial water quality problem. The critical condition for turbidity using TSS surrogate and proposed TSS standard is low flows in the upper reaches and high flows near the outlet of the watershed. The critical flow regime for bacteria, turbidity using TSS surrogate, and proposed TSS standard loading is most often under mid-range to high flow conditions.

Table 6. Maximum required bacterial and sediment load reductions for the SHRW.

AUID (09020301 -XXX)	Bacterial			Turbidity using TSS Surrogate		Proposed TSS Standard	
	Max. % Load Reduction	Critical Flow Regime	Critical Standard	Max. % Load Reduction	Critical Flow Regime	Max. % Load Reduction	Critical Flow Regime
536	53%	Moist	Geomean	---	---	---	---
537	50%	Low	Geomean	93%	High	92%	High
541	40%	Mid-range	Geomean	53%	Dry	16%	Dry
542	35%	Mid-range	Geomean	---	---	---	---

--- Not impaired for turbidity/TSS

NRR No reduction required

CONCLUSION

Bacteria, turbidity using TSS surrogate, and proposed TSS standard LDCs were developed for four AUIDs in the SHRW based on impairment status. The curves were developed following the methods in the USEPA guidance document, *An Approach for Using Load Duration Curves in the Development of TMDLs* (USEPA, 2007).Results of this analysis showed maximum required bacterial load reductions ranging from 35-53%, all based on the geomean *E. coli* criterion, and occurring during low to moist flow conditions. Maximum turbidity using TSS surrogate load reductions range from 53-93%, based on the turbidity/TSS conversion criterion of 33.8 mg/L, and occurring during high and dry flow conditions. Maximum proposed TSS standard load reductions range from 16-92%, based on the proposed Southern Region TSS criterion of 65 mg/L, occurring during high and dry flow conditions. Results of the LDC analysis will be used to compute TMDLs for these stream segments under future tasks of the SHRW WRAPS project.

REFERENCES

Minnesota Pollution Control Agency (MPCA). 2012. Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List. Minnesota Pollution Control Agency. St. Paul, MN

RESPEC. 2013. Hydrological and Water Quality Calibration and Validation of Sand Hill River HSPF Watershed Model. Memorandum to Minnesota Pollution Control Agency, Detroit Lakes, MN.

United States Environmental Protection Agency (USEPA). 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. August 2007.

APPENDIX A: BACTERIAL LOAD DURATION CURVES AND TABLES

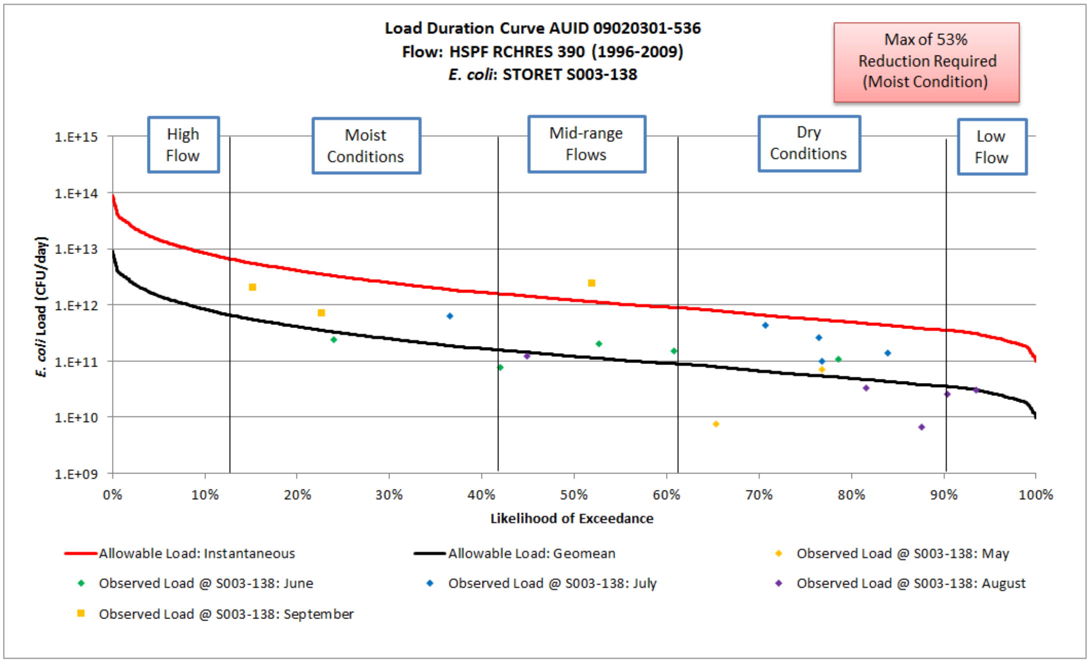

Figure A1. AUID 09020301-536 bacterial LDC.

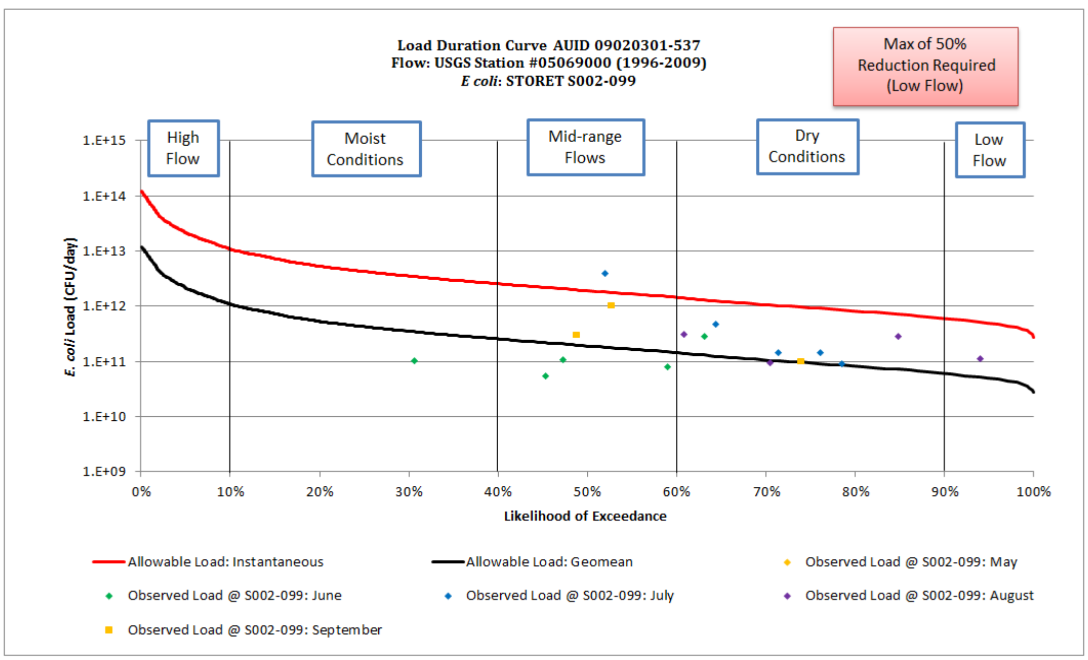

Figure A2. AUID 09020301-537 bacterial LDC.

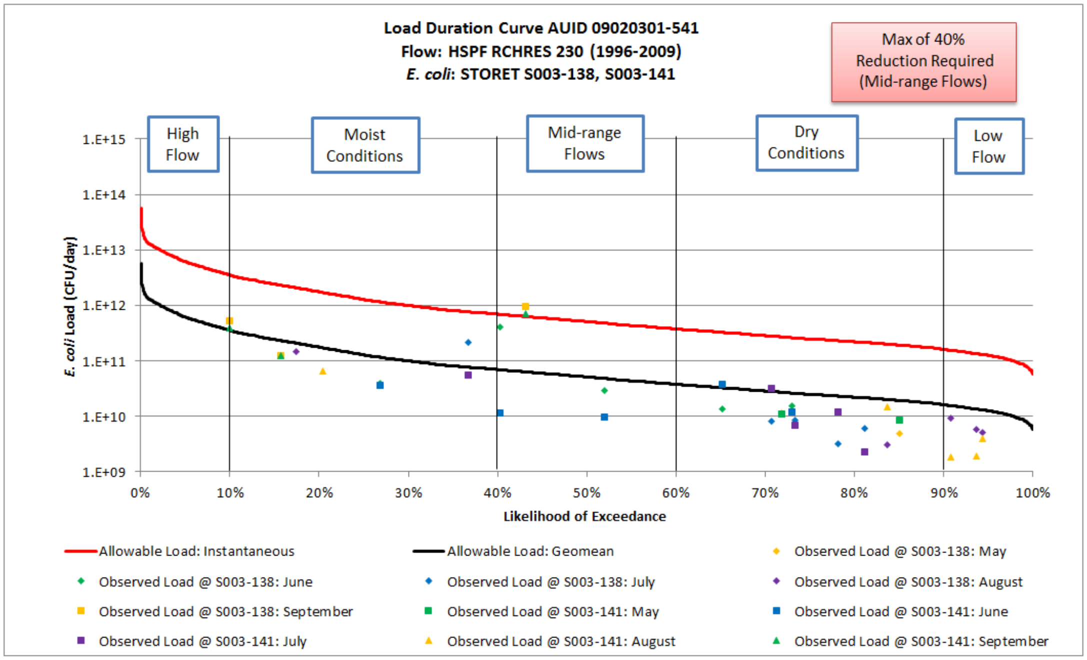

Figure A3. AUID 09020301-541 bacterial LDC

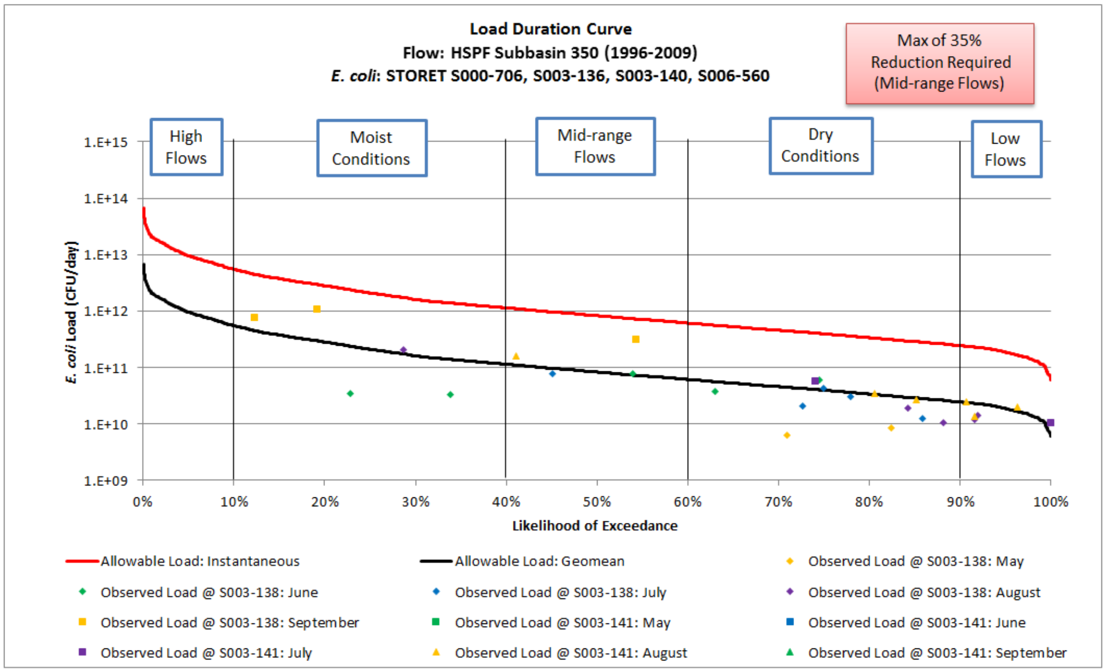

Figure A4. AUID 09020301-542 bacterial LDC

Table A.1. Bacterial load reduction table for AUID 09020301-536.

Flow Regimes	Median Observed Flow (cfs)	Geomean Standard						Instantaneous Standard					
		Observed *E. coli* Geomean (#/100 mL)	Observed *E. coli* Geomean Loading (#/day)	Allowable Load (#/day)	Allowable Load w/10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction	*E. coli* Value that 90% are less than (#/100mL)	Observed *E. coli* 90th Percentile Loading (#/day)	Allowable Load (#/day)	Allowable Load w/ 10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction
0-10%	518	--	--	1.60E+12	1.44E+12	--	--	--	--	1.60E+13	1.44E+13	--	--
10-40%	112	240	6.60E+11	3.46E+11	3.12E+11	3.48E+11	53%	435.2	1.16E+12	3.46E+12	3.12E+12	-1.96E+12	NR
40-60%	43	227	2.41E+11	1.33E+11	1.20E+11	1.21E+11	50%	2419.6	1.86E+12	1.33E+12	1.20E+12	6.58E+11	35%
60-90%	20	145	7.23E+10	6.30E+10	5.67E+10	1.56E+10	22%	770.1	2.85E+11	6.30E+11	5.67E+11	-2.82E+11	NR
90-100%	10	97	2.31E+10	2.99E+10	2.69E+10	-3.81E+09	NR	113.7	2.62E+10	2.99E+11	2.69E+11	-2.43E+11	NR

"---" insufficient data, NR – no reduction required

Table A.2. Bacterial load reduction table for AUID 09020301-537.

Flow Regimes	Median Observed Flow (cfs)	Geomean Standard						Instantaneous Standard					
		Observed *E. coli* Geomean (#/100 mL)	Observed *E. coli* Geomean Loading (#/day)	Allowable Load (#/day)	Allowable Load w/10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction	*E. coli* Value that 90% are less than (#/100mL)	Observed *E. coli* 90th Percentile Loading (#/day)	Allowable Load (#/day)	Allowable Load w/ 10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction
0-10%	769	---	---	2.37E+12	2.13E+12	---	---	---	---	2.37E+13	2.13E+13	-2.13E+13	---
10-40%	154	32	1.22E+11	4.75E+11	4.28E+11	-3.06E+11	NR	32.3	1.22E+11	4.75E+12	4.28E+12	-4.16E+12	NR
40-60%	68	170	2.82E+11	2.10E+11	1.89E+11	9.38E+10	33%	2419.6	2.55E+12	2.10E+12	1.89E+12	6.66E+11	26%
60-90%	34	191	1.59E+11	1.05E+11	9.43E+10	6.49E+10	41%	435.2	3.46E+11	1.05E+12	9.43E+11	-5.98E+11	NR
90-100%	18	228	1.00E+11	5.55E+10	4.99E+10	5.06E+10	50%	228.2	1.00E+11	5.55E+11	4.99E+11	-3.99E+11	NR

"---" insufficient data, NR – no reduction required

Table A.3. Bacterial load reduction table for AUID 09020301-541.

Flow Regimes	Median Observed Flow (cfs)	Geomean Standard						Instantaneous Standard					
		Observed *E. coli* Geomean (#/100 mL)	Observed *E. coli* Geomean Loading (#/day)	Allowable Load (#/day)	Allowable Load w/10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction	*E. coli* Value that 90% are less than (#/100mL)	Observed *E. coli* 90th Percentile Loading (#/day)	Allowable Load (#/day)	Allowable Load w/ 10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction
0-10%	339	---	---	1.05E+12	9.42E+11	---	---	---	---	1.05E+13	9.42E+12	---	---
10-40%	75	87	1.58E+11	2.30E+11	2.07E+11	-4.87E+10	NR	411	5.94E+11	2.30E+12	2.07E+12	-1.47E+12	NR
40-60%	30	174	1.26E+11	9.14E+10	8.22E+10	4.39E+10	35%	488	2.84E+11	9.14E+11	8.22E+11	-5.38E+11	NR
60-90%	14	72	2.47E+10	4.34E+10	3.91E+10	-1.44E+10	NR	119	5.26E+10	4.34E+11	3.91E+11	-3.38E+11	NR
90-100%	7	95	1.55E+10	2.06E+10	1.85E+10	-3.05E+09	NR	168	2.58E+10	2.06E+11	1.85E+11	-1.59E+11	NR

"---" insufficient data, NR – no reduction required

Table A.4. Bacterial load reduction table for AUID 09020301-542.

Flow Regimes	Median Observed Flow (cfs)	Geomean Standard						Instantaneous Standard					
		Observed *E. coli* Geomean (#/100 mL)	Observed *E. coli* Geomean Loading (#/day)	Allowable Load (#/day)	Allowable Load w/10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction	*E. coli* Value that 90% are less than (#/100mL)	Observed *E. coli* 90th Percentile Loading (#/day)	Allowable Load (#/day)	Allowable Load w/ 10% MOS (#/day)	Required Load Reduction (#/day)	Required % Load Reduction
0-10%	220	148	7.98E+11	6.78E+11	6.11E+11	1.87E+11	23%	172	9.04E+11	6.78E+12	6.11E+12	-5.20E+12	NR
10-40%	46	68	7.56E+10	1.40E+11	1.26E+11	-5.07E+10	NR	326	1.72E+11	1.40E+12	1.26E+12	-1.09E+12	NR
40-60%	18	188	8.41E+10	5.63E+10	5.06E+10	3.35E+10	40%	1733	6.77E+11	5.63E+11	5.06E+11	1.71E+11	25%
60-90%	9	42	9.16E+09	2.73E+10	2.46E+10	-1.55E+10	NR	127	2.13E+10	2.73E+11	2.46E+11	-2.25E+11	NR
90-100%	4	32	3.52E+09	1.38E+10	1.24E+10	-8.90E+09	NR	67	6.77E+09	1.38E+11	1.24E+11	-1.17E+11	NR

"---" insufficient data, NR – no reduction required

APPENDIX B: TURBIDITY LOAD DURATION CURVES

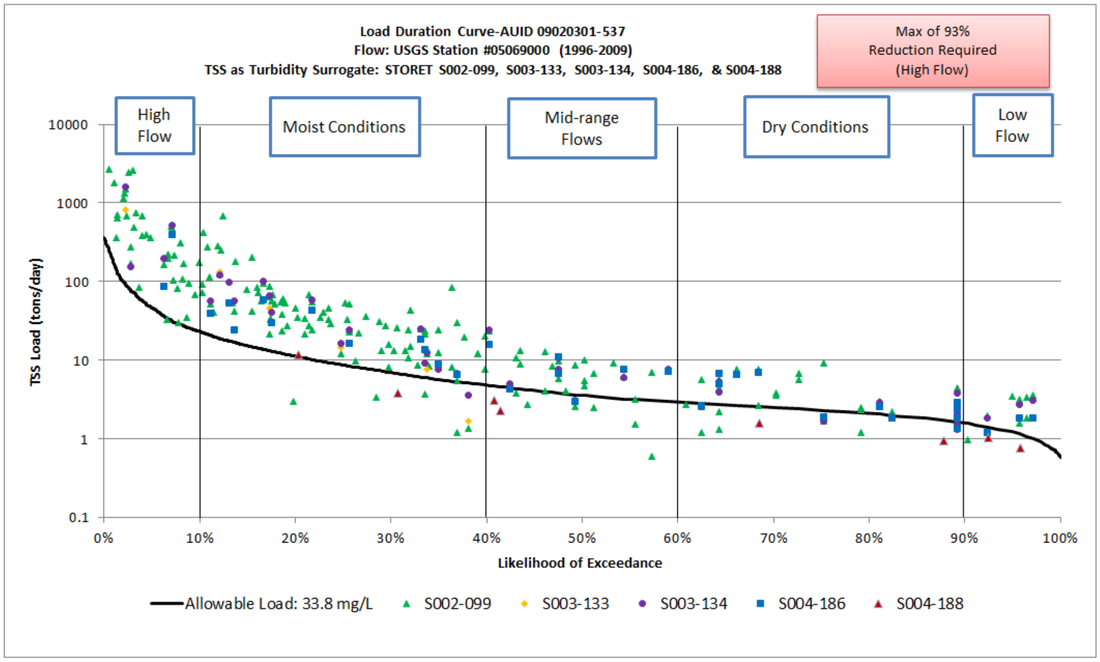

Figure B1: AUID 09020301-537 turbidity LDC.

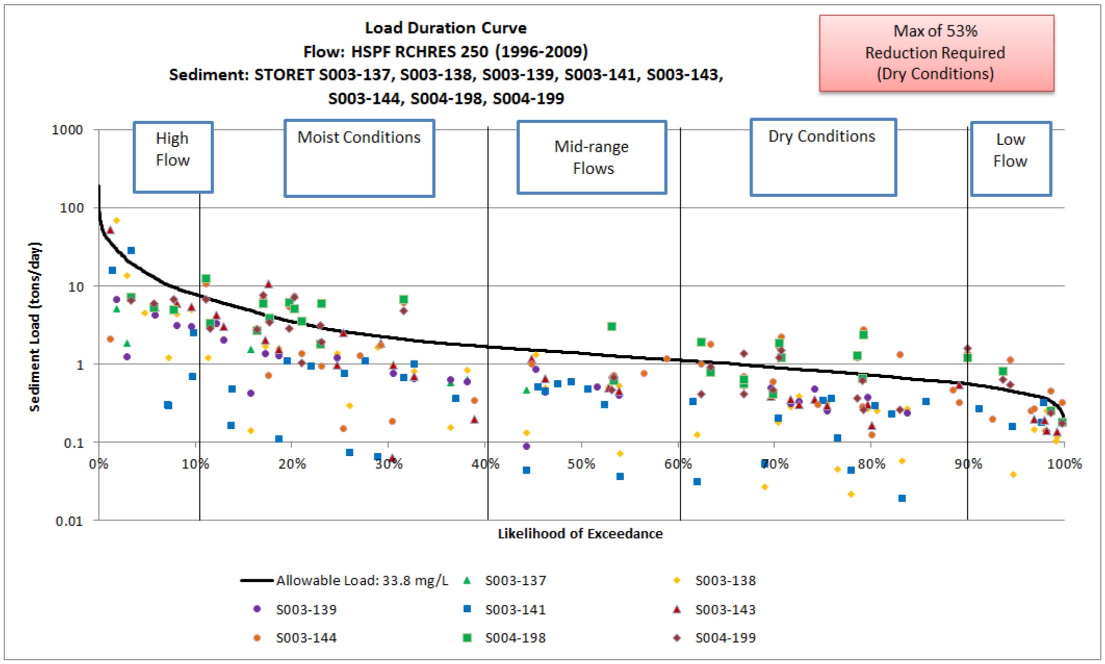

Figure B2: AUID 09020301-541 turbidity LDC.

Table B.1 Turbidity using TSS surrogate LDC load reduction table (AUID 09020301-537)

Flow Regime	Observed Data			"Allowable" Based on Turbidity/TSS Conversion			
	Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	Required % Load Reduction
0%-10%	561	436.0	660	51.2	46.1	614.04	93%
10%-40%	106	190	54	9.7	8.7	45.62	84%
40%-60%	44	78	9	4.0	3.6	5.60	61%
60%-90%	29	76	6	2.6	2.4	3.57	60%
90%-100%	15	82.5	3	1.4	1.2	2.11	63%

Table B.2 Turbidity using TSS surrogate LDC load reduction table (AUID 09020301-541)

Flow Regime	Observed Data			"Allowable" Based on Turbidity/TSS Conversion			
	Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	Required % Load Reduction
0%-10%	156	39.8	17	14.3	12.8	3.92	23%
10%-40%	28	60	5	2.6	2.3	2.28	49%
40%-60%	15	26	1.0	1.4	1.2	-0.18	NR
60%-90%	9	65	1.5	0.8	0.7	0.81	53%
90%-100%	5	50.8	0.6	0.4	0.4	0.26	40%

NR – no reduction required

APPENDIX C: TSS LOAD DURATION CURVES

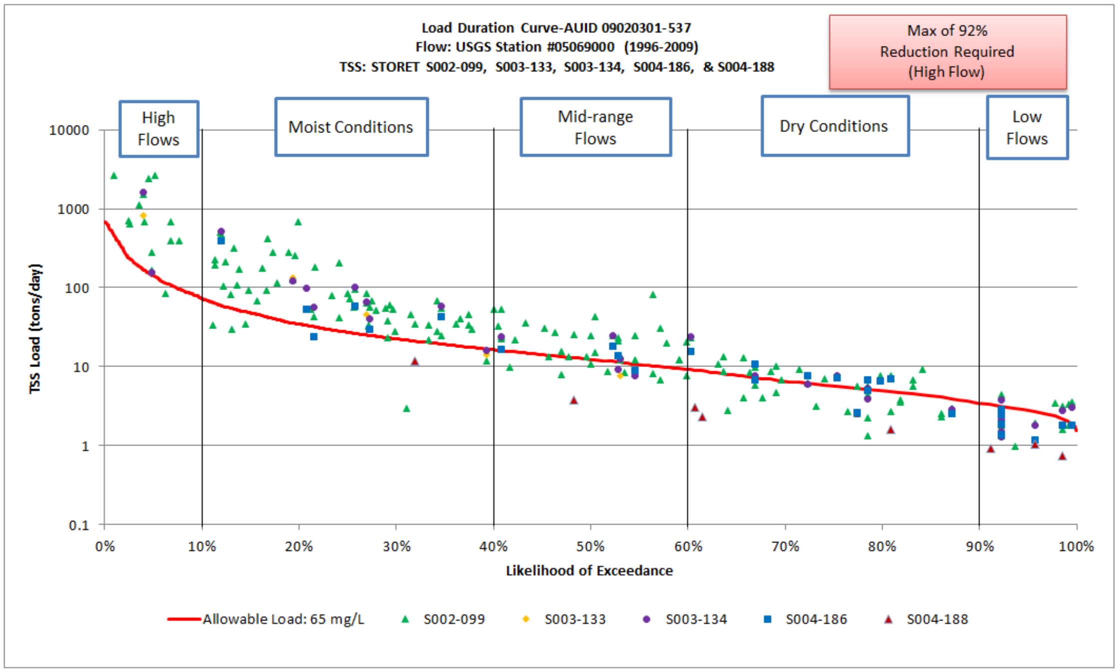

Figure C1. AUID 09020301-537 TSS LDC

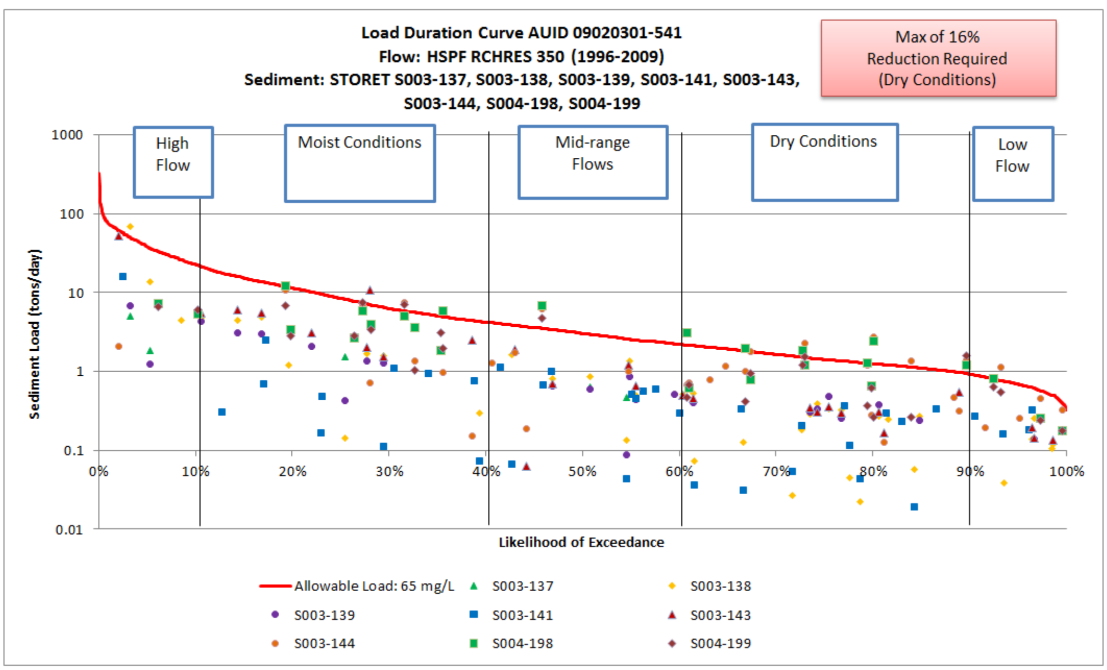

Figure C2. AUID 09020301-541 TSS LDC

Table C.1: Proposed TSS standard LDC load reduction table for AUID 09020301-537.

Flow Regime	Observed Data			Proposed TSS Standard (65 mg/L)			
	Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	% Load Reduction
0%-10%	894	696.8	1680	156.7	141.0	1538.74	92%
10%-40%	173	388	181	30.3	27.3	153.90	85%
40%-60%	78	144	30	13.7	12.3	17.90	59%
60%-90%	37	89	9	6.5	5.8	3.08	35%
90%-100%	18	86.1	4	3.2	2.8	1.34	32%

Table C.2: Proposed TSS standard LDC load reduction table for AUID 09020301-541.

Flow Regime	Observed Data			Proposed TSS Standard (65 mg/L)			
	Median Observed Flow (cfs)	90th % Observed TSS (mg/L)	Average Observed TSS Loading (tons/day)	Allowable TSS Load (tons/day)	Allowable Load w/ 10% MOS (tons/day)	Required Load Reduction (tons/day)	% Load Reduction
0%-10%	242	44.4	29	42.5	38.2	-9.21	NR
10%-40%	53	53	8	9.3	8.4	-0.80	NR
40%-60%	19	30	1.5	3.4	3.0	-1.49	NR
60%-90%	9	70	1.7	1.6	1.4	0.27	16%
90%-100%	4	53.8	0.6	0.8	0.7	-0.06	NR

NR – no reduction required