Mustinka River Turbidity
Total Maximum Daily Load Report

(Impaired River Reaches AUIDs 09020102-518 and 09020102-503)

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Minnesota Pollution
Control Agency

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Public Participation	▪ Public Notice period: 5/18/2009 - 6/17/2009 ▪ Refer to Appendix D for Public Notice comments. ▪ In addition to the public comment period, four stakeholder meetings were held between August 2005 and April 2009.	27

Executive Summary

The Clean Water Act, Section 303(d), requires that every two years states publish a list of waters that do not meet water quality standards and do not support their designated uses. These waters are then considered to be "impaired." Once a water body is placed on the impaired waters list, a Total Maximum Daily Load (TMDL) must be developed. The TMDL provides a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. It is the sum of the individual waste load allocations (WLAs) for point sources, load allocations (LAs) for non-point sources and natural background, plus a margin of safety (MOS) and, a reserve capacity (RC).

In 2004 the Minnesota Pollution Control Agency (MPCA) listed two reaches on the Mustinka River as having impairments of aquatic life due to excessive turbidity. This report addresses those turbidity impairments for reaches of the Mustinka described as a reach running from the Grant/Traverse County line to Five Mile Creek (4.7 miles in length) and a reach starting at an unnamed creek running to Lake Traverse (8.28 miles in length). Other waters within the Mustinka River watershed listed as impaired will be addressed through subsequent TMDL reports.

The Mustinka River lies within the Mustinka River Watershed of the Red River Basin of the North. The Mustinka River watershed is comprised of portions of Otter Tail, Grant, Stevens, Big Stone and Traverse Counties and is approximately 825 square miles in area. Most of the Mustinka River located within Traverse County (from the Grant/Traverse County line to Lake Traverse) has been channelized. Land use in the watershed is dominated by agricultural crop production (2001 estimate of 84.18 percent). Much of the land is extensively drained for that purpose.

This TMDL report used a flow duration curve approach and the Soil and Water Assessment Tool (SWAT) to determine the pollutant loading capacity of the Mustinka River under various flow regimes. This approach was used to calculate the general allocations necessary to achieve water quality standards for the impaired stream reaches identified in this study. SWAT is a hydrologic model developed by the Agricultural Research Service (ARS) to predict the impact of land management practices in agricultural watersheds over long periods of time.

The primary contributing sources of the turbidity impairment for both impaired reaches appears to be agricultural land soil erosion and stream-bank erosion in part caused by the extensive hydrologic modification that has taken place across the watershed in the past. The degree of the turbidity impairment can be correlated with higher flows, with sediment reductions near 90 percent needed to achieve the turbidity water quality standard during moist and high flow conditions.

Introduction

Section 303(d) of the Clean Water Act provides the authority for completing TMDLs to achieve state water quality standards and/or designated uses.

A TMDL is a calculation of the maximum amount of pollutant that a water body can receive and still meet water quality standards and/or designated uses. A TMDL is the sum of the loads of a single pollutant from all contributing point and non-point sources. TMDLs are approved by the EPA based on the following elements: That they;

1. Are designed to implement applicable water quality criteria,
2. Include a total allowable load as well as individual waste load allocations,
3. Consider the impacts of background pollutant contributions,
4. Consider critical environmental conditions,
5. Consider seasonal environmental variations,
6. Include a margin of safety,
7. Provide opportunity for public participation; and
8. Have a reasonable assurance that the TMDL can be met.

In general, the TMDL is developed according to the following relationship:

TMDL = WLA + LA + MOS + RC

Where:

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

LA = load allocation, or the portion of the TMDL allocated to existing or future non-point sources of the relevant pollutant. The load allocation may also encompass "natural background" contributions;

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

RC = reserve capacity, an allocation for future growth. This is an MPCA-required element, if applicable, for TMDLs.

Background Information

Mustinka River Listing Information

The subject of this TMDL report is the impairment of aquatic life because of excessive turbidity in two separate reaches of the Mustinka River in the Mustinka River Watershed of the Red River Basin of the North. The Mustinka River flows into Lake Traverse which is considered the Headwaters of the Red River of the North.

The impaired reaches of the Mustinka River are both located entirely within Traverse County, Minnesota the first being a 4.7 mile reach (AUID 09020102-518) from the Grant/Traverse County line to Fiver Mile Creek (also known as Judicial Ditch 12), and the second being a 8.28 mile reach (AUID 09020102-503) running from an unnamed creek to Lake Traverse. The Mustinka River watershed encompasses approximately 825 square miles and is located in the Minnesota counties of Traverse, Ottertail, Stevens, Grant and Big Stone. The watershed lies within three ecoregions; the North Central hardwood Forests, the Red River Valley, and the Northern Glaciated Plains. The largest portion of the watershed lies within the Red River Valley eco-region and the two impaired reaches of the Mustinka River fall totally within the footprint of that eco-region.

The two impaired reaches of the Mustinka River were listed as being impaired for turbidity by the MPCA in Minnesota's 303(d) list of Impaired Waters in 2004. A summary of the information included in the List of Impaired Waters for each impaired reach is provided for in Table 1.

Table 1 - Mustinka River Impaired Reach Identification

REACH NAME ON 303(D) LIST / DESCRIPTION	ASSESSMENT UNIT ID	YEAR LISTED	POLLUTANT OR STRESSOR	AFFECTED USE	WATERSHED / HUC
Mustinka River: Grant/Traverse County Line to Five Mile Creek	09020102-518	2004	Turbidity	Aquatic life	09020102
Mustinka river: Unnamed Creek To Lake Traverse	09020102-503	2004	Turbidity	Aquatic life	09020102

The two impaired reaches were assessed as being impaired due to excessive turbidity by monitoring conducted by the MPCA for the monitoring stations listed in Table 2. These stations were monitored in 2001-2002. They are priority reaches in the Red River basin for addressing turbidity.

Essentially, listings for impairment can occur when greater than ten percent of samples collected within the previous ten-year period exceed the 25 nephelometric turbidity units (NTUs) standard. Impairment assessment procedures for turbidity are provided in The Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment (MPCA, 2007).

A summary of the information used to include the stream reach on the List of Impaired Waters is provided in Table 2. The entire listing dataset is included in Appendix A.

Table 2 –Mustinka River Assessment Summary

MONITORING STATIONS USED FOR ASSESSMENT ID #	MONITORING STATIONS USED FOR ASSESSMENT – LOCATION DESCRIPTION	PARAMETERS MEASURED	NUMBER OF SAMPLES	NUMBER OF EXCEEDENCES OF WATER QUALITY STANDARD	NUMBER OF YEARS OF DATA / DATA COLLECTION YEARS
518 S002-001	Mustinka R at SH-9 Bridge, 1.3 MI NW of Norcross	Turbidity	12	5	2
503 S000-062 S000-344	Mustinka R USH-75 at Wheaton Mustinka R SH-117 W of Wheaton	Turbidity	18	11	2

Figures 1 and 2- Mustinka River Watershed Reference Maps

Watershed Characteristics

Land cover for the Mustinka River Watershed is based on the National Land Cover Dataset (USGS, 2001). The land use in the watershed is predominantly agricultural in nature. Land under crop cultivation comprises over 84 percent of the land within the 562,099 acre watershed. The highest percentage of cultivated land lies in the Red River Valley portion of region. There are numerous small lakes and wetlands in the headwaters (northern) portion of the watershed.

Figure 3 – Mustinka River Turbidity Impairment

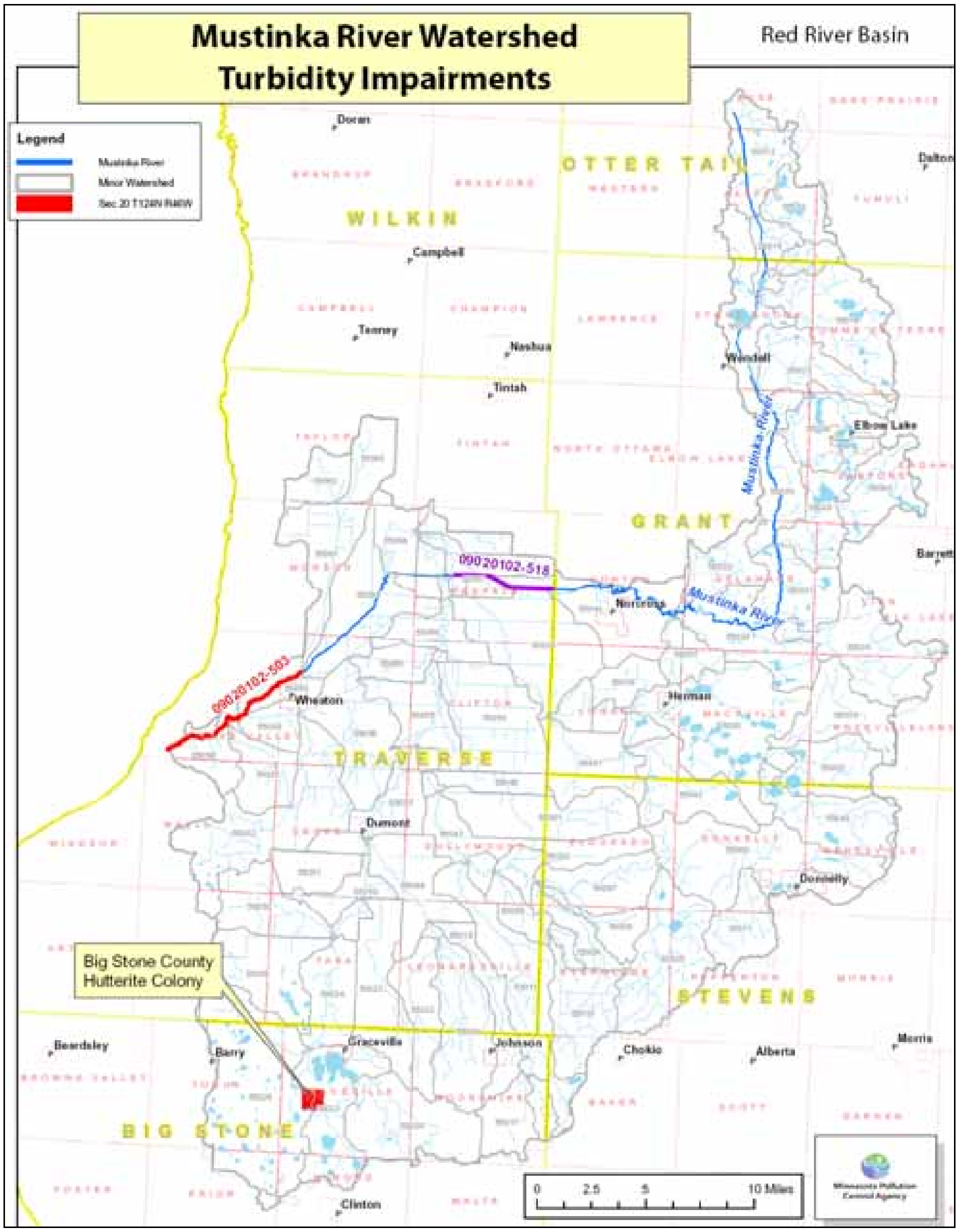


Table 3 –Land Cover Categories for the Mustinka River Watershed

Classification	Acres	%
Open Water	19211.802	3.42
Developed, Open Space	25388.82	4.52
Developed, Low Intensity	2519.067	0.45
Developed, Medium Intensity	611.141	0.11
Developed, High Intensity	129.211	0.02
Barren Land (Rock/Sand/Clay)	125.875	0.02
Deciduous Forest	4243.072	0.75
Evergreen Forest	158.79	0.03
Mixed Forest	60.047	0.01
Shrub/Scrub	33.582	0.01
Grassland/Herbaceous	2806.623	0.50
Pasture/Hay	8243.288	1.47
Cultivated Crops	473158.408	84.18
Woody Wetlands	587.567	0.10
Emergent Herbaceous Wetland	24821.268	4.42
Total	562098.561	

Geomorphology

The majority of the Mustinka River Watershed lies within the physiographic region known as the Glacial Lake Plain, which is a part of the historic Glacial Lake Agassiz. The region is characterized by flat extremely level deposits of lake sediment. The moraines of the northern and eastern portion of the watershed are located in the North Central Hardwood Forest Eco-region, and the southern portion of the watershed is located in the Northern Corn belt Plains.

Soils

The soils in the watershed are varied but are all based on glacial material. The predominant soil types in the lake plain portion of the watershed are poorly drained clays with low permeability. More coarse and sandier soil types are found in the remaining portions of the watershed.

Cropping

The cultivation of agricultural lands is the dominant land use practice in the watershed. The National Agricultural Statistics Service (2008) estimated that approximately 74 percent of the watershed `was planted in a variety of crops. Soybeans represented about 40.5 percent of that total and corn represented another 36 percent.

Drainage/Channelization

The lower (lake plain) portion of the Mustinka River watershed is extensively drained by legal drainage systems, ditches and tile drainage systems. The Mustinka River from the Grant/Traverse County line to Lake Traverse has been channelized and the reach from the county line to Five Mile Creek was naturally sinuous, but was straightened during the early part of the twentieth century and is also known as Judicial Ditch 14. The watershed's hydrology has also been significantly altered by drainage and ditching.

Water Quality Standards

Designated Beneficial Use of the Mustinka River

This TMDL addresses exceedences of the water quality standard for turbidity. According to Minn. R. 7050, the impaired reaches of the Mustinka River covered in this TMDL are classified as 2B and 3B waters. The designated beneficial use for 2B waters (the most protective use class) is as follows:

Class 2 waters, aquatic life and recreation. Aquatic life and recreation includes all waters of the state which do or may support fish, other aquatic life, bathing, boating, or other recreational purposes, and where quality control is or may be necessary to protect aquatic or terrestrial life or their habitats, or the public health, safety, or welfare.

Water Quality Standard for Turbidity

The turbidity water quality standard found in Minn. R. 7050.0222 for 2B and 3B water is 25 NTUs. This TMDL is written for Class 2 waters as this is the more protective class.

Turbidity in water is caused by suspended sediment, organic material, dissolved salts and stains that scatter light in the water column making the water appear cloudy. Excess turbidity can degrade aesthetic qualities of water bodies, increase the cost of treatment for drinking or food processing uses and can harm aquatic life. Aquatic organisms may have trouble finding food, gill function may be affected and spawning beds may be covered.

Total Suspended Solids (TSS) as the Surrogate Measure for Turbidity

Much of the Red River of the North basin, particularly in the portion known as the Red River Valley (the lake plain of Glacial Lake Agassiz), is cultivated cropland. Soil erosion from cropland contributes to the sediment loading of streams. It is widely accepted that sediment sources in streams in such settings are comprised of sediment that originates both from eroded soil and from erosion of stream-bank sediments (Colby, 1963). Utilizing the results from past work and current activities that are going on in the Mustinka River watershed, there is adequate flow and TSS data available to complete the necessary analysis for this TMDL.

The flow data has been derived from the SWAT modeling work that has been done by the Energy and Environmental Research Center (EERC 2008). While there are historic data records for four

United States Geological Survey (USGS) gaging stations within the watershed, the data do not extend beyond the 1950's and did not overlap with the simulation period of the SWAT model (January 1974 to August 2007). The model was calibrated using flow data measurements from the network of 26 gages maintained by the Bois de Sioux Watershed District (BDSWD).

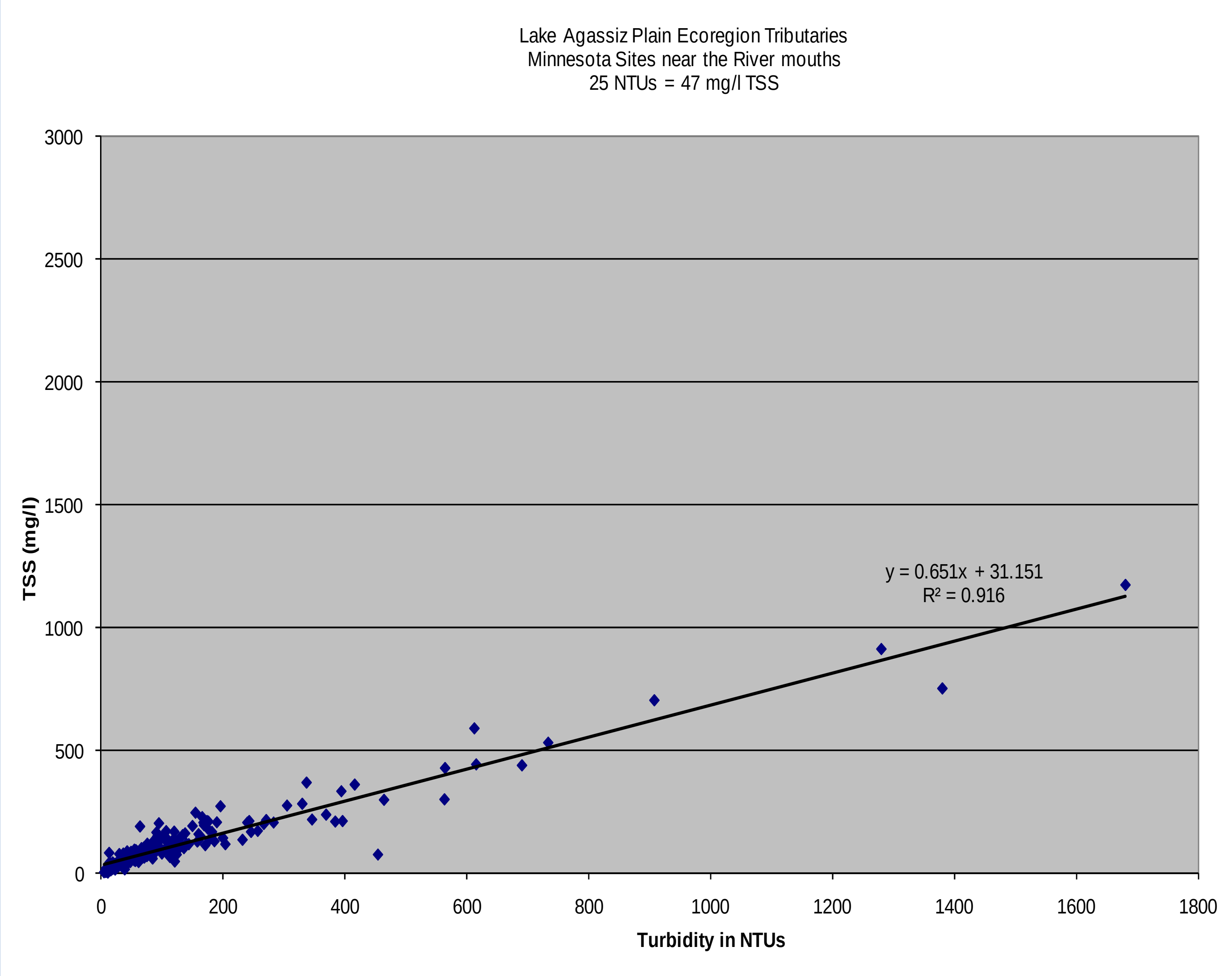
The TSS data utilized in this TMDL is from the MPCA water quality database and River Watch sampling. This data was collected by MPCA field staff and volunteers of the River Watch Program with lab analysis done by a certified laboratory.

Numeric Water Quality Target

The Mustinka River watershed is located within the Lake Agassiz Plain ecoregion. Glacial Lake Agassiz was the last in a series of glacial 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. These sediments include a relatively high percentage of clays, silts, and fine sands. The historic tallgrass prairie has been replaced by intensive row crop agriculture supported by an extensive surface drainage system throughout the ecoregion. The Lake Agassiz Plain ecoregion is defined by the natural features, environmental conditions, and ecology within its geographical boundary. Because of these natural features the area has also gone through similar land use pattern and vegetation changes as it has been transformed from prairie to crop production.

Turbidity cannot be converted into loads because it is a dimensionless unit. To use the 25 NTU turbidity standard in a load allocation scenario, a relationship between turbidity and TSS was developed. Using paired turbidity and TSS measurements for streams in the Lake Agassiz Plain ecoregion a multiple regression technique was used to predict TSS based on turbidity. Utilizing a regional or ecoregional target for turbidity/TSS TMDLs is the direction that the MPCA is going in for this type of work statewide. The turbidity in the streams was measured using an HF Scientific Model Micro 100 turbidity meter, with the appropriate reporting unit of an NTU. TSS results were reported in mg/l by the appropriate certified lab. The R^2 value indicates the strength of the correlation between the two variables. A very good correlation between TSS and turbidity is evidenced by a relatively high R^2 of 0.916 (Figure 4). This regression technique results in a value of **47 mg/L of TSS for the 25 NTU equivalent**. This target value was calculated using **230** paired samples from the ecoregion streams ranging from the Mustinka River in the south to the Two Rivers near the Canadian border. This ecoregion set of paired data represents a greater range of flow conditions and sampling dates than a dataset from only the Mustinka River. This TMDL will utilize the 47 mg/l TSS target that was calculated for the Lake Agassiz Plain ecoregion.

Figure 4 – Relationship of Turbidity to Total Suspended Solids (TSS)



Degree of Impairment

Based on the available TSS data (Appendix) the turbidity impairment in the watershed appears to be significant when viewed across the entire sampling season. Turbidity measurements were above the 25 NTU standard in all modeled flow regimes and substantial reductions in TSS are needed to achieve the water quality goal in all flow zones as well (Table 5).

Turbidity Sources

Point Sources

Point sources are the portion of the TMDL that make up the Waste Load Allocation (WLA). Point sources, for the purpose of this TMDL, are those facilities/entities that discharge or potentially discharge solids to surface water or otherwise may contribute to excess turbidity and require a National Pollutant Discharge Elimination System/State Disposal System (NPDES/SDS) permit (i.e., water quality permit from the MPCA). In the Mustinka River Watershed, the potential point sources include municipal wastewater treatment facilities, industrial facilities, concentrated animal feeding operations and construction activities. There are no communities subject to municipal separate storm sewer (MS4) NPDES/SDS permit requirements located within the watershed.

Municipal Wastewater Treatment Facilities

There are seven municipal wastewater treatment facilities (WWTFs) located within the Mustinka River watershed and include the cities of; Wendell, Dumont, Elbow Lake, Herman, Graceville, Wheaton and a Hutterite Colony in Big Stone County (SW1/4, Section 20,T124N, R46W). These WWTFs are all pond systems. The city of Donnelly is served by a community mound system which does not discharge to surface waters. Their NPDES/SDS permits include a discharge limit for Total Suspended Solids (TSS) expressed in kilograms per day. The permits allow for two discharge windows between April 1, and June 30 and between September 1 and December 15. In general, these windows coincide with high flow periods. The WWTFs are only allowed to discharge a limited volume of effluent from the pond system per day.

There are individual WLAs calculated for each of the seven WWTFs (Table 4). For the purpose of summarizing the load allocations and reserve capacity, the WWTFs will be lumped into one WWTF allocation. Ongoing efforts by the cities as well as continued regulatory oversight by MPCA should maintain the WWTFs as a minor contributor to the turbidity impairment.
Point sources are the portion of the TMDL that make up the WLA. Point sources, for the purpose of this TMDL, are those facilities/entities that discharge or potentially discharge solids to surface water or otherwise may contribute to excess turbidity and require a NPDES/SDS permit (i.e., water quality permit from the MPCA). The Wheaton WWTF discharges directly to the lower impairment (AUID 090200102-503) of the Mustinka River between the city and Lake Traverse. At the current time all facilities are in compliance with their NPDES/SDS permits.

Table 4 - Mustinka River Watershed Municipal Wastewater Treatment Facilities

City	NPDES	Design Flow (MGD)	TSS WLA lbs/day	TSS WLA tons/day
Wendell	MNG580153	0.0195	61.10	0.03055
Dumont	MN0064831	0.0149	45.76	0.02288
Elbow Lake	MNG580082	0.20792	590.04	0.29502
Herman	MN0023647	0.1015	256.08	0.12804
Wheaton	MN0047278	0.235	694.98	0.34749
Graceville	MNG580159	0.1256	279.4	0.1397
Hutterite Colony	MNG580168	0.0104	46.30	0.02315
Total		0.71482	1973.66	0.9868

Industrial Facilities

There are numerous sand and gravel operations located within the watershed. Industrial stormwater activities are considered in compliance with provisions of the TMDL if they obtain an industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all Best Management Practices (BMPs) required under the permit. The pollutant load from industrial stormwater activities such as these are estimated to be much less than one percent of the TMDL and are difficult to quantify. For the purposes of this TMDL, industrial stormwater and construction stormwater are lumped together into a categorical WLA based on an approximation of the land area covered by those activities.

Concentrated Animal Feeding Operations (CAFOs) and Feedlots

There are 98 registered feedlots located within the watershed. Six of those are Confined Animal Feeding Operations (CAFOs) and are listed below.

1) Big Stone County Hutterite Colony Feedlot (MNG440392)
2) Scott Andrews Farm (MNG440755)
3) Anthony Arens Farm (MNG440495)
4) Ryan and Lyle Pederson Farm (MNG440876)
5) Craig Lichtsinn Farm (MNG440304
6) Valley Pork LLP (MNG440400)

All the CAFO's have been issued NPDES/SDS permits under the State Of Minnesota General Livestock Production Permit. These facilities are assigned a zero waste load allocation. This is consistent with the conditions of the permit, which allows no discharge of pollutants from the production area of the CAFO.

Construction Activities

The pollutant load from construction stormwater is estimated to be much less than one percent of the TMDL and is difficult to quantify. Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all BMPs required under the permit, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit. These permits are issued for any construction activity disturbing: 1) one acre or more of soil; 2) less than one acre if that activity is part of a "larger development or sale" that is greater than one acre; and less than one acre of soil, but determined by the MPCA to pose a risk to water resources. For the purposes of this TMDL, construction stormwater and industrial stormwater are lumped together into a categorical WLA based on an approximation of the land area covered by those activities.

Non-point Sources

Non-point sources are the portion of the TMDL that make up the Load Allocation (LA). Non-point sources are not subject to NPDES/SDS permit requirements. They can include background sources, such as natural soil erosion from stream channels and upland areas. These source can also include runoff from agricultural lands and non-NPDES/SDS permitted stormwater runoff. In an agricultural watershed setting, such as the Mustinka watershed, non-point sources dominates the sediment load and are the primary areas designated for load reduction activities.

In the Mustinka River watershed, the sediment contributions from non-point sources are largely a result of soil erosion and stream-bank erosion.

Loading Capacity for the Mustinka River

General Methodology (Duration Curve Approach, EPA, 2007)

Due to the extreme seasonal variability that occurs with stream flows, hydrologists have long been interested in knowing seasonal patterns, as well as the percentage of days in a year when given flows occur. Seasonal flow patterns and the TMDL process are implicitly connected. A traditional load is typically a product of flow, concentration, and a conversion factor. Thus, the analysis of flow patterns plays a major role when considering seasonal variation for TMDL development.

One means of flow analysis is the use of flow duration curves. Duration curves describe the percentage of time during which specified flows are equaled or exceeded (Leopold, 1994). Flow duration analysis looks at the cumulative frequency of historic flow data over a specified period. Duration analysis results are illustrated by a curve, which correlates flow values to the percent of time those values have been met or exceeded. Thus, the full range of stream flows is considered. Low flows are exceeded a majority of the time, while high flows are exceeded less frequently. The flow records used for both reaches in this TMDL are derived from the SWAT model (EERC, 2008).

The initial flow duration curves plot flow values on the y-axis against the percent of time the flow is exceeded in the flow record. Flow duration curve development typically uses daily average discharge rates, which are described from the highest to the lowest value. Using this convention, flow duration intervals are expressed as percentage, with zero corresponding to the highest stream discharge in the record (i.e., flood conditions) and 100 to the lowest (i.e., drought conditions).

Flow duration curve intervals can be grouped into various zones. These zones provide additional insight regarding conditions and patterns associated with the impairment. For example, the duration curve in Figure 5 consists of five zones: one representing **high flows** **(0-10 percent),** another for **moist conditions** **(10-40 percent),** one covering **mid-range flows** **(40-60 percent),** another for **dry conditions** **(60-90 percent),** and one representing **low flows** **(90-100 percent).**

Figure 5 – Flow Duration Curve (AUID: 09020102-518)

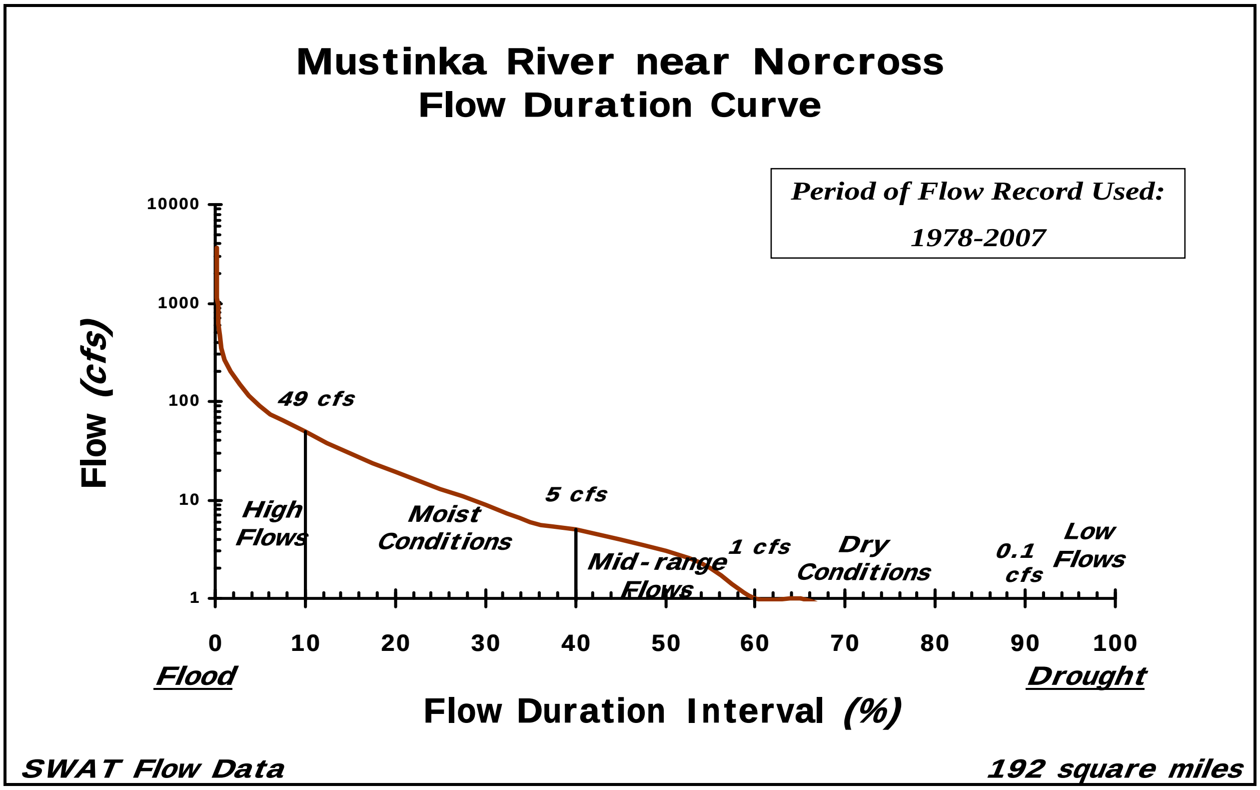
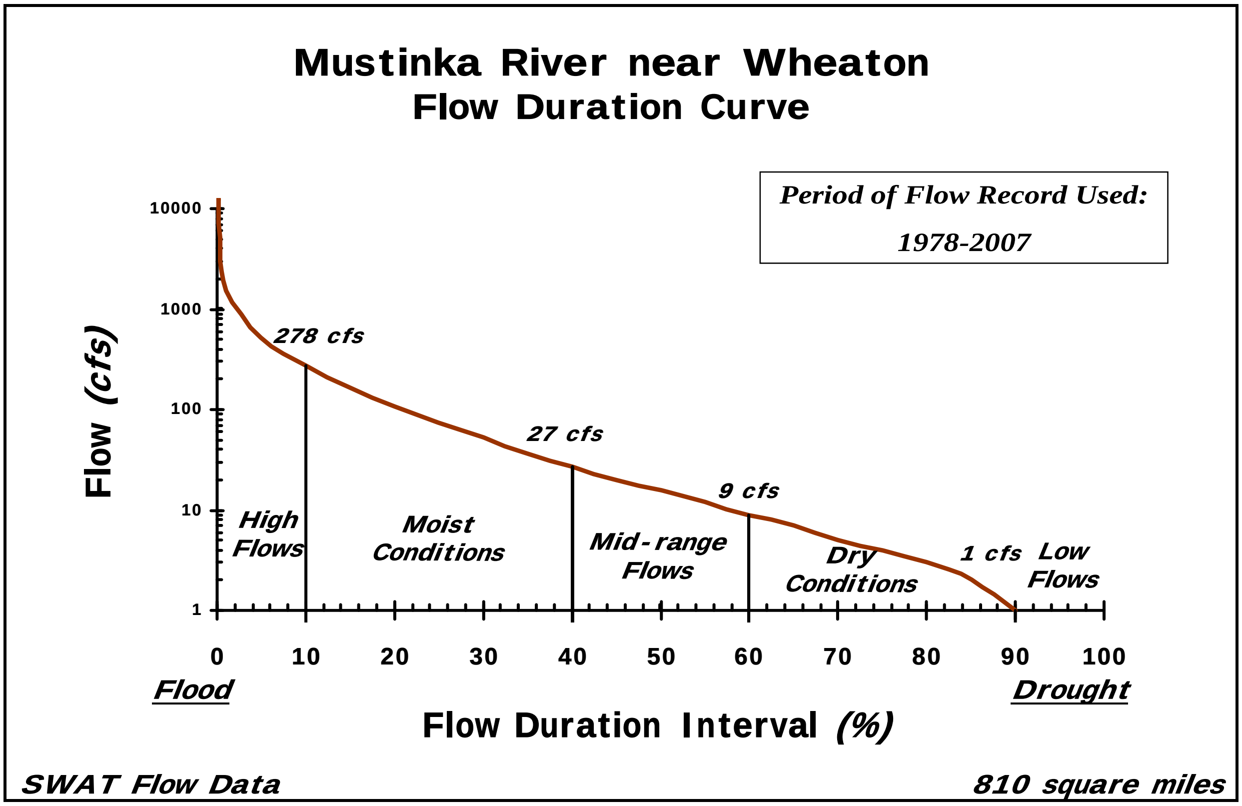


Figure 6– Flow Duration Curve (AUID: 09020102-503)



Given that the maximum load that can be carried in the river (i.e., the TMDL) at any given time is calculated as the target concentration times flow, the maximum load on any individual day is determined by the daily flow present. The TMDL is shown graphically as a load duration curve (Figures 7 and 8) where the flow values for each flow duration interval are multiplied by the target TSS concentration of 47 mg/l. Individual TSS samples are noted on the graphs with a blue diamond and correspond to the daily flow duration interval that they were taken on utilizing the SWAT derived flow duration interval.

Figure 7– Load Duration Curve (AUID: 09020102-518)

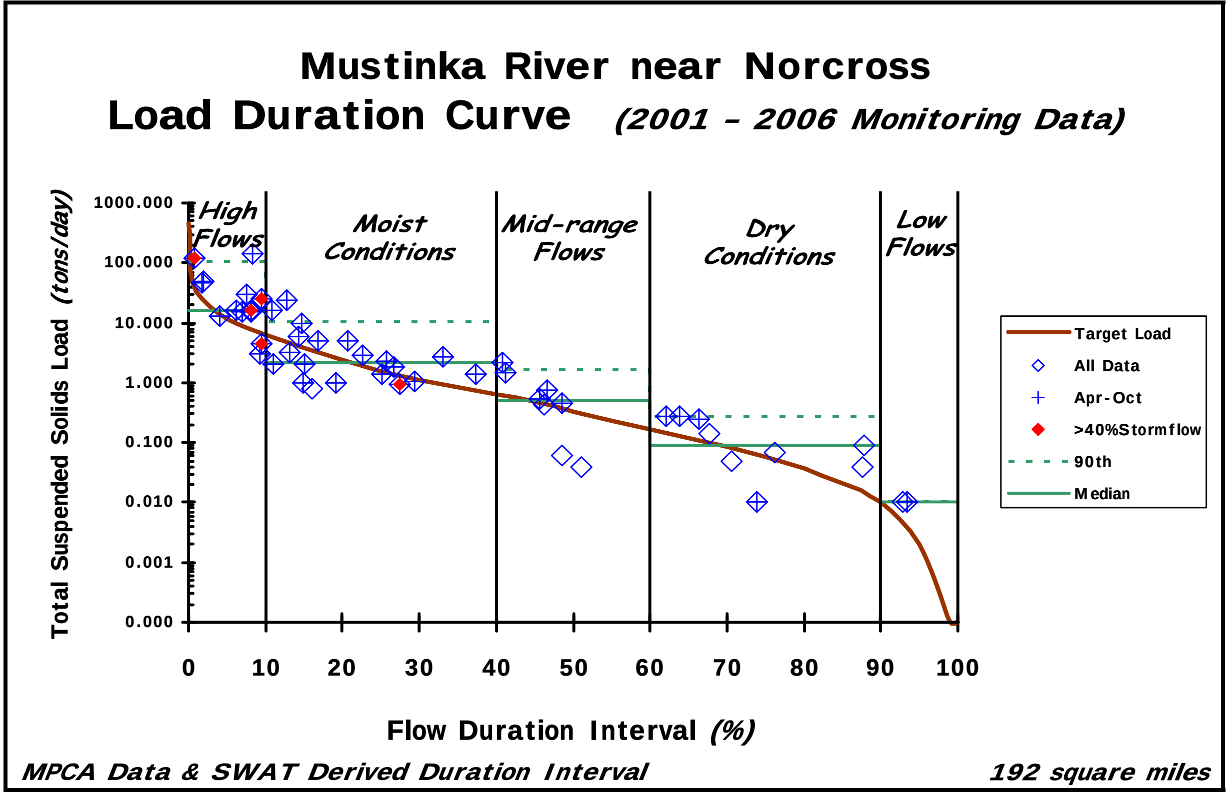
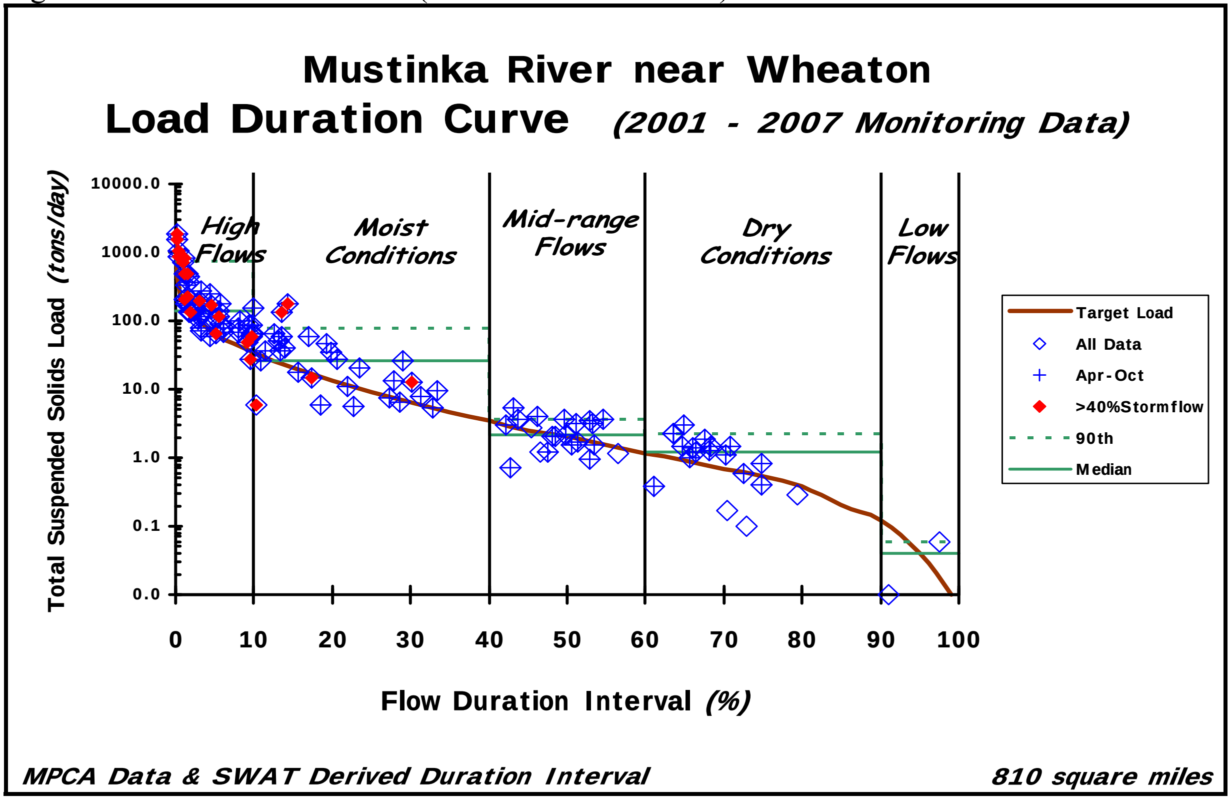


Figure 8– Load Duration Curve (AUID: 09020102-503)



Methodology for Waste load Allocation

- WLAs are calculated for each of the seven (7) WWTFs and can be found in Table 4 (page 14). For the purpose of summarizing the load allocations and reserve capacity, the WWTFs will be lumped into one WWTF allocation. The WLA was determined based on the permitted daily load of TSS. Although a daily WLA is assigned to these facilities, it is important to note that discharge occurs only during specified days during the year (March 1 through June 30 and September 15 through December 31).

  The total daily loading capacity in the low flow, dry, and mid-range (in one instance) zones are very small due to the occurrence of very low flows in the long-term flow estimates. Consequently, the WLA exceeds the total daily loading capacity of the stream in these flow zones. Of course, actual WWTF loads could never exceed the total load in the stream as it is a component of it. For the lower flow zones the calculated MOS would take up all of the remaining allocation capacity. To account for this unique situation only, the WLAs and LAs are expressed as an equation rather than an absolute number. That equation is simply:

  Allocation = (flow contribution from a given source) x (45 mg/L TSS, the permit limit)

  This equation assigns a concentration-based limit to the sources for the lower flow zones.

- The 45 mg/l TSS permitted effluent limit requirement for the WWTFs comes from the Minnesota Rules, Chapter 7050, which sets the standards of protection for water quality and purity in Minnesota. The permits allow for two discharge windows, between April 1st and June 30th and between September 1st and December 15th. In general, these windows coincide with high flow periods. The WWTFs are only allowed to discharge a limited volume of effluent from the pond systems per day.

- Construction stormwater and industrial stormwater are lumped together into a categorical WLA based on an approximation of the land area covered by those activities. MPCA construction stormwater permit application records over the last 4.5 years indicate approximately 0.02 percent of the acreage in the watershed is subject to construction on an annual basis. To account for industrial stormwater, for which the MPCA does not have readily accessible acreage data, this TMDL will estimate another 0.02 percent of the land area for a combined construction and industrial stormwater percentage of 0.04.

- There are no MS4 NPDES communities in the watershed and therefore this item will not be included in the WLA summary.

Necessary Load Reductions

Table 5 compares the 90th percentile TSS load for each of the flow zones to the loading capacity at the mid-point of each flow zone. The differences between these two sets of numbers produces the estimated percent reduction in the TSS load that will be necessary for the Mustinka River to be removed from the impaired waters list (i.e. fewer than 10 percent of the samples exceeding the 25

NTU standard). These reductions should not be confused with the target of the waste load and load allocations, which is to meet the 25 NTU standard on all days. Nevertheless, the percent reductions needed under each flow regime does describe a scenario under which the reaches in the Mustinka River would no longer be impaired.

Table 5 - Comparison of current 90th percentile daily load to capacity at the mid-point zone

• capacity is mid-point for flow zone • current load is 90th percentile value for flow zone		**Flow Zone**				
		High Flows	**Moist Conditions**	**Mid-Range Flows**	**Dry Conditions**	**Low Flows**
		values expressed as tons/day TSS				
Mustinka River near Norcross 09020102-518	**Capacity**	11.359	1.592	0.334	0.058	0.002
	Current Load	104.66	10.41	1.68	0.27	0.01
	% Red. Needed	89%	85%	80%	78%	80%
Mustinka River near Wheaton 09020102-503	**Capacity**	65.28	9.19	2.01	0.53	0.04
	Current Load	756.26	78.17	3.72	2.31	0.06
	% Red. Needed	91%	88%	46%	77%	33%

Methodology for Margin of Safety

The purpose of the Margin of Safety (MOS) is to account for any uncertainty that the allocations will result in attainment of water quality standards. For this TMDL an explicit ten percent (10 percent) MOS is applied. This is expected to provide an adequate accounting of uncertainty, especially given that the wastewater treatment facilities in the watershed have demonstrated consistently being well below their permitted TSS discharge limit. All of the wastewater treatment facilities in the watershed are also pond systems, which only discharge during spring and fall windows (i.e., before June 15th and after September 15th). It should also be noted that the mechanisms for soil loss from agricultural sources and the factors that affect this have been extensively studied over the years and are quite well understood. Much work has been done and continues to be done to target agricultural best management practices (BMPs) for soil loss prevention (see pages 25-26). Follow-up effectiveness monitoring will provide a means to evaluate installed BMPs in terms of compliance with WLAs and progress towards achievement of the TMDL.

For the impaired reaches in which the allocation for the low flow, dry, and mid-range flow zones required use of an alternative method of calculation, i.e., a concentration-based limit, an implicit MOS was used. An implicit MOS means that conservative assumptions were built into the TMDL and the allocations. In these instances, a key conservative assumption is that the reaches are expected to meet the TMDL requirements because the permitted point source dischargers are only allowed to discharge in the spring and fall, as noted above, meaning that during a significant portion of the year the discharge is zero. The WWTFs in the watershed have also consistently demonstrated discharging an effluent that is well below their permitted TSS limit of 45 mg/l, thereby providing additional capacity. Finally, during these lower flow conditions the stream itself is primarily being fed by ground water, this ground water typically conveys very little TSS.

Methodology for Load Allocations

Once the WLA and MOS were determined for a given reach and flow zone, the remaining loading capacity was considered. The LA includes non-point pollution sources that are not subject to NPDES permit requirements, as well as “natural background” sources. It is generally accepted that the non-point pollution sources for this TMDL originate from eroded soil and from erosion of stream-bank sediments.

TMDL Allocations for Mustinka River; Grant/Traverse County Line to Five Mile Creek (AUID: 09020102-518)

Table 6 provides the daily TSS loading capacities, as well as the WLA, LA and MOS. The loading capacities for the five flow zones were developed using the load duration curve approach. The drainage area to the downstream end of this impaired reach is approximately 192 square miles. There are two wastewater treatment facilities in the drainage area, Elbow Lake and Wendell.

Table 6 - Total suspended solids loading capacities and allocations (AUID: 09020102-518).

	Flow Zone				
	High	**Moist**	**Mid**	**Dry**	**Low**
	Tons/day				
TOTAL DAILY L0ADING CAPACITY	**11.359**	**1.592**	**.334**	**.058**	**.002**
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	**.325**	**.325**	**	**	**
Construction and Industrial Stormwater	**.004**	**<.001**	**<.001**	**<.001**	**<.001**
Load Allocation	**9.89**	**1.106**	**	**	**
Margin of Safety	**1.14**	**.16**	**Implicit**	**Implicit**	**Implicit**
	Percent of total daily loading capacity				
TOTAL DAILY L0ADING CAPACITY	**100%**	**100%**	**100%**	**100%**	**100%**
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	**2.86%**	**20.4%**	**	**	**
Construction and Industrial Stormwater	**0.04%**	**0.04%**	**0.04%**	**0.04%**	**0.04%**
Load Allocation	**87.1%**	**69.56%**	**	**	**
Margin of Safety	**10%**	**10%**	**Implicit**	**Implicit**	**Implicit**

*** Facilities are listed in Table 4, the results are in tons/day of TSS**

**** See the WLA Methodology Section above for the allocations in the lower flow zones (page 20).**

TMDL Allocations for Mustinka River; Unnamed Creek to Lake Traverse (AUID: 09020102-503)

Table 7 provides the daily TSS loading capacities, as well as the WLA, LA and MOS. The loading capacities for the five flow zones were developed using the load duration curve approach. The drainage area to the downstream end of this impaired reach is approximately 810 square miles. All seven of the wastewater treatment facilities are in the drainage area.

Table 7 - Total suspended solids loading capacities and allocations (AUID: 09020102-503).

	Flow Zone				
	High	Moist	Mid	Dry	Low
	Tons/day				
TOTAL DAILY L0ADING CAPACITY	65.28	9.19	2.01	0.53	0.04
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	0.986	0.986	0.986	**	**
Construction and Industrial Stormwater	.026	.003	<.01	<.01	<.01
Load Allocation	57.74	7.28	.82	**	**
Margin of Safety	6.53	.92	.2	Implicit	Implicit
	Percent of total daily loading capacity				
TOTAL DAILY L0ADING CAPACITY	100%	100%	100%	100%	100%
Wasteload Allocation					
Permitted Wastewater Treatment Facilities*	1.5%	10.7%	49.1%	**	**
Construction and Industrial Stormwater	0.04%	0.04%	0.04%	0.04%	0.04%
Load Allocation	88.46%	79.26%	40.86%	**	**
Margin of Safety	10%	10%	10%	Implicit	Implicit

*** Facilities are listed in Table 4, the results are in tons/day of TSS**

**** See the WLA Methodology Section above for the allocations in the lower flow zones (page 20).**

Critical Conditions and Seasonal Variation

The EPA states that the critical condition "…can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence" (USEPA, 1999). Turbidity levels are generally at their worst following significant storm events during the spring and summer months. Seasonal variations are somewhat more difficult to generalize given reach-specific differences. Regardless, such conditions and variation are fully captured in the duration curve methodology used in this TMDL.

Reserve Capacity

Population figures extrapolated for the watershed from the U.S. Census Bureau and the Minnesota State Demographic Center estimates that the watershed's population will decrease from a population of approximately 4,600 in 1990 to a population of approximately 3,900 people in the year 2010. Similarly, the six cities with WWTFs within the watershed whose combined population was 3,633 individuals in 1990 are expected to have a projected total population of 3,426 individuals by 2010.

In addition, a review of Discharge Monitoring Reports for each the seven facilities shows that over the course of the last several years daily discharges from the WWTFs are consistently below the design flow for the facilities. All seven of the facilities (including the Hutterite Colony) operate below the mass loading limits (WLA) assigned to them in their NPDES permits. However, the Wheaton and Dumont facilities currently do experience frequent by-passes of the systems. Wheaton's by-pass problem is due to high rates of inflow and infiltration into the system. The MPCA is instituting enforcement action to ensure that the collection system is repaired or upgraded. Dumont is by-passing due an inadequately sized collection system and the MPCA is working with the city to correct those deficiencies. According to MPCA municipal point source permitting staff none of these cities plans new or expanded wastewater discharges.

Because of these observations there will be no reserve capacity factored into the waste load allocation (WLA) of this TMDL. The key elements of this TMDL are non-point source reductions.

Reasonable Assurance of Implementation

The following should be considered as reasonable assurance that implementation will occur and result in sediment load reductions in the Mustinka River to meet the designated use over time.

There is a number of existing water management plans (e.g., Red River Basin Water Quality Plan, County Comprehensive Local Water Plans and the Bois de Sioux Watershed District Watershed Management Plan) that address water quality issues in the watershed. There are also a number of state and federal funding programs (e.g., Clean Water Legacy Act, EPA grants, Clean Water Partnership grants, Natural Resource Conservations Service programs, and Conservation Reserve Enhancement Program) that can address a variety of local water quality problems. These plans and programs have and will continue to play a major role in the protection and restoration of surface waters within the watershed. In addition, they demonstrate Minnesota's commitment to maintaining or improving water quality.

At the local level, county soil and water conservation districts (SWCDs), local water planners, and the Bois de Sioux Watershed Distinct have identified water quality related natural resource concerns and have developed plans to address surface and ground water issues. The watershed, through its Flood Damage Reduction process (FDR) will continue to play a major role (along with the State of Minnesota) in sponsoring flood control projects throughout the watershed that will result in reduced flows during high flow periods and consequently further reduce turbidity in the rivers and streams. The five SWCDs and the watershed district have identified BMPs and structural controls that they will support and promote which reduce sedimentation and erosion in critical areas of the watershed. Such practices and controls include: crop residue management, grass waterways, shelter belts, filter strips, buffer strips, side inlet control structures, sediment basin, grade control structures, stream bank stabilization practices, channel restoration activities, and so on. The Bois de Sioux Watershed District and local water planners have also consented to participate and support all future TMDL implementation efforts. The support of TMDL studies for all impaired waters and the development of TMDL implementation plans at the local level is a key element of the Bois de Sioux Watershed District Overall Plan and in each of the Local County Water Plans.

Monitoring of water quality changes will occur on an on-going basis by the MPCA, the Red River Water Management Board, River Watch and other local units of government in order to document changes in water quality as the various activities identified in the implementation plan are put into action. Watershed Districts and Soil and Water Conservation Districts will make routine observations with regard to the effectiveness of projects and conservations practices.

The principle of adaptive management will enable those involved with TMDL implementation to periodically access the effectiveness of implementation strategies and to make adjustments to those strategies to enhance their effectiveness.

The Soil and Water Assessment Tool (SWAT) was prepared for the Mustinka River Watershed by the Energy and Environmental Research Center (EERC), University of North Dakota in conjunction with the preparation of this TMDL report. One useful component of the SWAT modeling of the watershed was the evaluation of the effectiveness of changes in land management within the watershed to reduce sediment loading to surface waters. Hypothetical scenarios were created applying varying widths of field buffers on corn, soybean and wheat fields to simulate potential reductions in overland erosion and sediment loading within discrete basins within the watershed. During the implementation phase this tool can be used by resource managers to not only demonstrate the utility of Best Management Practices, but to also as a means for calculating reductions in erosion and sedimentation as management practices are instituted within the watershed.

Finally, continued funding of Minnesota’s Clean Water Legacy Act will ensure that there will be adequate future funding for TMDL Implementation Activities and water quality monitoring.

Monitoring Plan

There are several monitoring activities occurring in the Mustinka River Watershed and most will continue into the future. Some of these monitoring activities include the Red River Basin’s River Watch program, the Red River Water Management Board’s surface water quality monitoring program, United States Geological Survey flow monitoring, and the MPCA’s Milestone and condition monitoring programs. These existing monitoring activities and additional project specific monitoring will be used to track progress towards the achievement of the load allocation goals for the impaired reach on the Mustinka River as implementation of BMPs take place. The project specific monitoring (effectiveness monitoring) will require the development of a systematic monitoring program with standard operating procedures that monitor not only water chemistry, but where possible, flow in locations where implementation activities have occurred. A detailed monitoring plan will include additional monitoring site locations, sampling schedules and responsible parties, will be developed as part of the forthcoming implementation plan referenced in the next section of this report.

Monitoring will also include regular observations made by local resource managers as to the effectiveness of projects and installed BMPs in effectively reducing erosion and sedimentation.

Implementation Strategy

This is an overview of the implementation strategy for the Mustinka River. A detailed implementation plan will be developed by the Bois de Sioux Watershed District with the assistance of its Flood Damage Reduction Project Team and the various SWCDs within the watershed within one year of EPA approval of this TMDL report.

These local organizations will utilize existing water management plans to develop the implementation plan. The focus of the plan will be to spatially identify the sources of the sediment loading to the Mustinka River. The initial focus of the implementation plan will be on addressing the most critical contributions to sedimentation of the Mustinka River. The Bois de Sioux Watershed District and other local units of government will seek funding through existing state and federal programs for TMDL implementation activities. The SWAT model developed for the watershed will be a useful tool in aiding with the development and implementation of effective land management practices to reduce erosion and sedimentation within the watershed. The application of the principle of adaptive management throughout the process will insure that the effectiveness of these approaches will be periodically examined to determine their effective and that ongoing efforts will be made to identify new sources of sedimentation within the watershed.

Construction stormwater activities are considered in compliance with provisions of the TMDL if they obtain a Construction General Permit under the NPDES program and properly select, install and maintain all required Best Management Practices (BMPs) required under the permit, including any applicable additional BMPs required in Appendix A of the Construction General Permit for discharges to impaired waters, or meet local construction stormwater requirements if they are more restrictive than requirements of the State General Permit.

Public Participation

Public participation occurred in three phases. The first phase introduced the concept of impaired waters and TMDLs for the Red River Basin of the North. Meetings were held in strategic geographic locations within the basin and representatives of local units of government and the general public were invited to attended and participate. The second phase engaged a specific stakeholder group on the details of the TMDL for the Mustinka River. That stakeholder group was comprised of staff and appointed/elected officials from the various local units of government within the watershed. A number of state agency representatives also participated in that process. Further input regarding the TMDL was gleaned from participants at numerous FDR project team meetings and local water planning meetings that occurred within the watershed over an extended time frame. The third phase included a public meeting held at a location within the watershed and the formal public comment period required by federal and state regulations. Table 6 provides the location and dates of the meetings, in addition to the stakeholder groups that were represented.

Table 8 – Public meetings/Stakeholder Involvement

PHASE	MEETING LOCATION	MEETING DATE	STAKEHOLDER GROUPS
Phase I	Wheaton	7/27/2005	State and local governmental units and the general public
Phase II	Breckenridge	10/25/2006	Bois de Sioux Watershed Board, Staff, Soil and Water Conservation Districts, County Representatives
Phase II	Wheaton	12/6/2007	Bois de Sioux Watershed Project Team and local stakeholders
Phase II	Wheaton	3/24/08	Project Team and local stakeholders
Phase III	Wheaton	4/30/09	Public meeting/Project Team
Public III	Public Comment Period	3/8/2010-4/7/2010	state and local governmental units and citizens

References

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Appendices

List of monitoring sites used for the Mustinka River Turbidity TMDL:

S000-062	**Mustinka River at US Hwy-75, near Wheaton**
S000-344	**Mustinka River at SH-117, west of Wheaton**
S002-001	**Mustinka River at SH-9, northwest of Norcross**

Appendix A – Water Quality Data Used for Listing the Mustinka River as Impaired for Turbidity (AUID 09020102-503 and AUID 09020102-518).

AUID : 09020102-503

Date	Turbidity (FTU)	Site
9/24/2002	*24*	*S000-062*
8/6/2002	*61*	*S000-062*
7/23/2002	*32*	*S000-062*
7/9/2002	*102*	*S000-062*
6/25/2002	*38*	*S000-062*
6/4/2002	*51*	*S000-062*
5/14/2002	*58*	*S000-062*
4/16/2002	*48*	*S000-062*
3/19/2002	*5*	*S000-062*
2/12/2002	*4*	*S000-062*
1/15/2002	*13*	*S000-062*
12/11/2001	*7*	*S000-062*
9/13/2001	*11*	*S000-344*
8/16/2001	*20*	*S000-344*
7/31/2001	*34*	*S000-344*
7/16/2001	*29*	*S000-344*
6/27/2001	*40.5*	*S000-344*
6/13/2001	*45.2*	*S000-344*

AUID : 09020102-518

Date	Turbidity (FTU)	Site
9/24/2002	*22*	*S002-001*
8/6/2002	*91*	*S002-001*
7/23/2002	*19*	*S002-001*
7/9/2002	*120*	*S002-001*
6/25/2002	*98*	*S002-001*
6/4/2002	*100*	*S002-001*
5/14/2002	*60*	*S002-001*
3/19/2002	*4*	*S002-001*
2/12/2002	*8*	*S002-001*
1/15/2002	*13*	*S002-001*
12/11/2001	*0*	*S002-001*
11/5/2001	*18*	*S002-001*

Appendix B - Mustinka River Total Suspended Solids (TSS) Data Used for Load Duration Curve Analysis

AUID: 09020102-503 Site: S000-062

Sample date	TSS (mg/l)	Sample date	TSS (mg/l)	Sample date	TSS (mg/l)
04/01/2003	12	05/16/2005	42	03/26/2007	160
04/21/2003	150	05/24/2005	96	04/02/2007	166
04/28/2003	110	05/26/2005	90	04/11/2007	91
05/06/2003	54	06/01/2005	109	04/16/2007	67
05/12/2003	67	06/06/2005	122	04/23/2007	103
05/20/2003	78	06/09/2005	156	04/25/2007	52
06/03/2003	75	06/13/2005	67	04/30/2007	37
06/17/2003	81	06/20/2005	62		
06/24/2003	320	06/27/2005	162		
06/26/2003	77	07/05/2005	63		
06/30/2003	51	07/11/2005	137		
07/02/2003	40	07/18/2005	105		
07/07/2003	56	07/25/2005	116		
07/22/2003	80	08/08/2005	65		
08/04/2003	48	08/22/2005	42		
08/20/2003	50	09/06/2005	41		
03/29/2004	52	09/21/2005	60		
04/05/2004	26	10/18/2005	39		
05/12/2004	65	04/03/2006	60		
05/17/2004	74	04/10/2006	56		
05/24/2004	46	04/17/2006	81		
06/01/2004	270	04/24/2006	110		
06/07/2004	150	05/01/2006	84		
06/14/2004	170	05/08/2006	74		
07/12/2004	200	05/15/2006	111		
09/07/2004	34	05/23/2006	96		
09/23/2004	116	05/30/2006	122		
04/04/2005	43	06/05/2006	162		
04/11/2005	43	06/12/2006	18		
04/18/2005	79	06/19/2006	100		
04/25/2005	79	07/03/2006	87		
05/02/2005	25	07/17/2006	61		
05/09/2005	82	09/11/2006	40		
05/12/2005	37	10/16/2006	24		

Mustinka River Total Suspended Solids (TSS) Data

Used for Load Duration Curve Analysis

AUID: 09020102-518 Site: S002-001

Sample date	TSS (mg/l)	Sample date	TSS (mg/l)
9/24/2001	43	6/4/2003	112
10/9/2001	33	6/18/2003	110
11/5/2001	45	7/22/2003	134
12/11/2001	6	8/5/2003	89
1/15/2002	66	5/12/2005	54
2/12/2002	28	5/26/2005	116
3/19/2002	11	6/6/2005	122
4/16/2002	40	6/20/2005	86
5/14/2002	94	7/5/2005	93
5/20/2002	75	7/18/2005	161
6/4/2002	99	8/8/2005	78
6/20/2002	69	8/22/2005	12
6/25/2002	79	9/6/2005	17
7/9/2002	168	9/21/2005	20
7/23/2002	72	10/3/2005	18
8/6/2002	161	10/18/2005	34
8/20/2002	80	4/10/2006	44
9/10/2002	86	4/24/2006	68
9/24/2002	5	5/8/2006	90
10/8/2002	58	5/23/2006	840
11/5/2002	66	6/5/2006	133
12/10/2002	112	6/19/2006	119
1/14/2003	269	7/3/2006	245
2/11/2003	145	7/17/2006	62
3/26/2003	8	9/11/2006	30
4/16/2003	90	10/16/2006	26
5/20/2003	99		

Appendix C - Paired data used for the NTU-TSS Equivalent for the

Lake Agassiz Plain Ecoregion

Tributary	**Site**	**Tributary**	**Site**
Bois de Sioux River	BDS1	Sand Hill River	SH1
Mustinka River	MUS1	Grand Marais Creek	GM1
Rabbit River	RAB1	Red Lake River	RL1
Otter Tail River	OTT1	Snake River	SNA1
Buffalo River	BUF1	Tamarac River	TAM1
Wild Rice River	WR1	Two Rivers	TWO1
Marsh River	MAR1		

Site ID	Date	Lab Turbidity NTU	TSS mg/l			Site ID	Date	Lab Turbidity NTU	TSS mg/l
BUF1	3/26/2007	15.8	19			MAR1	5/29/2007	17.4	11
MAR1	3/26/2007	62.1	57			RL1	5/29/2007	28.7	34
OTT1	3/26/2007	71.4	103			OTT1	5/29/2007	34	52
MUS1	3/26/2007	139	160			MUS1	5/29/2007	49.2	60
BDS1	3/26/2007	241	204			WR1	5/29/2007	67.5	100
RAB1	3/26/2007	268	198			BUF1	5/29/2007	93.5	149
OTT1	4/2/2007	125	74			SNA1	5/29/2007	122	46
MAR1	4/2/2007	183	166			RAB1	5/29/2007	137	100
MUS1	4/2/2007	247	166			SH1	5/29/2007	170	193
RAB1	4/2/2007	258	170			GM1	5/29/2007	272	214
BDS1	4/2/2007	284	204			BDS1	5/29/2007	455	74
WR1	4/2/2007	613	586			TAM1	5/30/2007	306	273
RL1	4/2/2007	734	528			TWO1	5/30/2007	370	236
GM1	4/2/2007	908	700			GM1	6/4/2007	9.38	17
SH1	4/2/2007	1680	1168			MAR1	6/4/2007	48.5	56
BUF1	4/3/2007	417	358			RL1	6/4/2007	55.8	69
OTT1	4/11/2007	22.1	34			OTT1	6/4/2007	62.7	44
GM1	4/11/2007	23.9	34			MUS1	6/4/2007	75.9	90
SNA1	4/11/2007	24.3	13			WR1	6/4/2007	92	164
RL1	4/11/2007	28.7	28			BUF1	6/4/2007	108	169
BDS1	4/11/2007	35.8	46			RAB1	6/4/2007	113	85
MAR1	4/11/2007	36.1	43			BDS1	6/4/2007	125	88
TWO1	4/11/2007	40	14			SH1	6/4/2007	130	140
BUF1	4/11/2007	54	78			SNA1	6/5/2007	159	127
MUS1	4/11/2007	70.7	91			TWO1	6/5/2007	161	132

RAB1	4/11/2007	81.3	86			TAM1	6/5/2007	164	149
WR1	4/11/2007	169	204			OTT1	6/7/2007	29.9	38
SH1	4/11/2007	565	425			RAB1	6/7/2007	67.6	62
TWO1	4/16/2007	14.8	9			MUS1	6/7/2007	72.2	102
SNA1	4/16/2007	25.8	20			BDS1	6/7/2007	122	134
MAR1	4/16/2007	40	43			GM1	6/11/2007	17.1	12
GM1	4/16/2007	53.1	76			OTT1	6/11/2007	42.5	54
BUF1	4/16/2007	84.1	111			BUF1	6/11/2007	47.9	63
WR1	4/16/2007	151	190			RL1	6/11/2007	49.7	64
SH1	4/16/2007	161	157			MUS1	6/11/2007	77.4	104
TAM1	4/16/2007	172	112			RAB1	6/11/2007	80.4	83
RL1	4/16/2007	176	179			SH1	6/11/2007	114	117
GM1	4/22/2007	43	68			WR1	6/11/2007	121	135
RL1	4/22/2007	65	188			TWO1	6/11/2007	141	118
BUF1	4/22/2007	121	167			SNA1	6/11/2007	187	128
SH1	4/22/2007	395	331			BDS1	6/11/2007	191	205
WR1	4/22/2007	691	436			MAR1	6/11/2007	201	141
MAR1	4/22/2007	1380	748			TAM1	6/11/2007	616	440
OTT1	4/23/2007	22	34			OTT1	6/14/2007	35.1	47
TWO1	4/23/2007	76.4	68			BDS1	6/14/2007	37.6	78
TAM1	4/23/2007	92.8	95			RAB1	6/14/2007	81.1	89
SNA1	4/23/2007	113	95			MUS1	6/14/2007	109	139
MUS1	4/23/2007	117	103			BUF1	6/14/2007	114	112
BDS1	4/23/2007	133	111			WR1	6/14/2007	331	280
RAB1	4/23/2007	179	135			SH1	6/14/2007	338	366
OTT1	4/25/2007	15.2	42			MAR1	6/14/2007	564	298
BDS1	4/25/2007	17.8	32			TWO1	6/16/2007	17.4	11
MUS1	4/25/2007	37.5	52			SNA1	6/16/2007	23.5	17
RAB1	4/25/2007	46.5	49			TAM1	6/16/2007	114	85
MAR1	4/26/2007	55.5	51			SH1	6/18/2007	1280	908
RL1	4/26/2007	68	89			OTT1	6/18/2007	32.9	48
SH1	4/26/2007	109	125			BDS1	6/18/2007	35.2	60
BUF1	4/26/2007	167	226			RAB1	6/18/2007	57.4	48
WR1	4/26/2007	175	210			MUS1	6/18/2007	101	142
BDS1	4/30/2007	11.8	24			WR1	6/18/2007	114	64
OTT1	4/30/2007	12.8	32			BUF1	6/18/2007	117	94
MUS1	4/30/2007	25.6	37			MAR1	6/18/2007	465	296
MAR1	4/30/2007	26.8	28			TAM1	6/19/2007	85.6	58
RL1	4/30/2007	32.7	43			RL1	6/19/2007	125	111
TAM1	4/30/2007	34.6	34			OTT1	6/25/2007	32.2	48
GM1	4/30/2007	35.9	69			BDS1	6/25/2007	34.7	69
RAB1	4/30/2007	38.1	42			RAB1	6/25/2007	63.1	62
TWO1	4/30/2007	49.1	44			MUS1	6/25/2007	96.4	106

SNA1	4/30/2007	50.1	51			TWO1	6/26/2007	6.12	2
SH1	4/30/2007	65.2	69			MAR1	6/26/2007	12.1	9
BUF1	4/30/2007	77	118			RL1	6/26/2007	17.4	15
WR1	4/30/2007	90.7	128			GM1	6/26/2007	34.6	28
OTT1	5/7/2007	24	35			WR1	6/26/2007	43	58
RL1	5/7/2007	52	55			BUF1	6/26/2007	58.2	92
GM1	5/7/2007	82.9	103			WR1	6/26/2007	94.8	145
BDS1	5/7/2007	101	78			SH1	6/26/2007	177	208
SNA1	5/7/2007	110	107			SNA1	7/2/2007	8.54	4
TAM1	5/7/2007	128	97			TWO1	7/2/2007	12.4	1
RAB1	5/7/2007	233	134			MAR1	7/2/2007	26.6	28
TWO1	5/7/2007	244	210			TAM1	7/2/2007	37.6	21
MUS1	5/7/2007	347	216			OTT1	7/2/2007	39.3	70
BDS1	5/9/2007	12	23			GM1	7/2/2007	44.6	55
OTT1	5/9/2007	14.4	81			MUS1	7/2/2007	79.7	82
RAB1	5/9/2007	72.1	66			RAB1	7/2/2007	86.1	78
MUS1	5/9/2007	87.5	106			RL1	7/2/2007	86.4	91
RL1	5/14/2007	24.6	32			BUF1	7/2/2007	88.3	123
SNA1	5/14/2007	29.1	47			WR1	7/2/2007	103	151
MUS1	5/14/2007	36.8	47			SH1	7/2/2007	135	153
TWO1	5/14/2007	48.3	47			BDS1	7/2/2007	197	270
WR1	5/14/2007	54	79			MAR1	7/9/2007	19.8	20
BUF1	5/14/2007	55.9	79			OTT1	7/9/2007	31.1	76
SH1	5/14/2007	69.5	75			BDS1	7/9/2007	43.9	87
TAM1	5/14/2007	71.9	83			BUF1	7/9/2007	61	86
RAB1	5/14/2007	72.1	62			MUS1	7/9/2007	61.6	59
GM1	5/14/2007	156	244			RAB1	7/9/2007	87.5	76
MAR1	5/14/2007	16.1	10			WR1	7/9/2007	102	145
BDS1	5/14/2007	20.2	42			SH1	7/9/2007	117	117
OTT1	5/14/2007	20.2	32			OTT1	7/16/2007	50.3	85
BDS1	5/21/2007	15.6	33			MUS1	7/16/2007	67.4	70
OTT1	5/21/2007	20.6	41			BDS1	7/16/2007	96	201
MUS1	5/21/2007	39.4	49			MAR1	7/23/2007	12.1	13
RAB1	5/21/2007	69.3	62			BUF1	7/23/2007	49.8	71
GM1	5/22/2007	9.28	4			SH1	7/23/2007	78.1	73
RL1	5/22/2007	18.9	14			WR1	7/23/2007	119	133
TAM1	5/22/2007	56.3	61			OTT1	9/10/2007	22.8	31
SNA1	5/22/2007	61.1	51			BDS1	9/10/2007	28.2	32
TWO1	5/22/2007	145	116			MUS1	9/10/2007	29.9	27
MAR1	5/23/2007	16	17			SH1	9/10/2007	44.3	36
WR1	5/23/2007	55.8	94			BUF1	9/10/2007	48.8	48
SH1	5/23/2007	58.6	60			WR1	9/10/2007	49.1	47
BUF1	5/23/2007	88.1	131			MUS1	10/16/2007	15.6	14

MUS1	5/24/2007	66.6	82			WR1	10/16/2007	19.1	19
OTT1	5/24/2007	205	116			SH1	10/16/2007	20.8	17
BDS1	5/24/2007	385	208			OTT1	10/16/2007	24.3	36
RAB1	5/24/2007	397	210			BUF1	10/16/2007	26.1	29

DEVELOPMENT OF THE SOIL AND WATER ASSESSMENT TOOL (SWAT) TO ASSESS WATER QUALITY IN THE BOIS DE SIOUX AND MUSTINKA RIVER WATERSHEDS

Final Report

(*for the period of February 22, 2007, through January 31, 2008*)

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April 2008

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1.0 INTRODUCTION

Water quality issues in the Red River Basin (RRB) (Figure 1) are of great concern, especially with regard to sediment and nutrient (e.g., phosphorus) transport. The highly erodible soils of the region, coupled with intensive agriculture, extensively modified drainage, and loss of wetlands and their natural storage capacity, have resulted in a landscape that is especially prone to sediment erosion and nutrient transport. Excess quantities of sediment and nutrients in rivers and lakes can adversely affect aquatic life, drinking water, and recreation. Nutrients such as phosphorus can be especially problematic by exacerbating algal growth, sometimes to the point of widespread eutrophication such as is occurring within Lake Winnipeg and other water bodies of the region. Eutrophication can lower dissolved oxygen levels within waterways, which adversely affects aquatic life, such as fish.

While many water quality impairments have been identified in the streams and waterways of the RRB, identifying the source of a particular impairment can be problematic. The most reliable means of identifying problem areas is through long-term water quality monitoring; however, the repeated collection and analysis of water samples at multiple locations throughout the RRB is time-consuming and expensive. Another option is to use tools such as hydrologic models to gain a more comprehensive understanding of the various processes occurring in a watershed that can affect water quality. Hydrologic modeling is not a replacement for water quality monitoring; rather, it is a complementary effort that utilizes the flow and water quality data already collected for model calibration. This helps improve the accuracy of the model in predicting the impact of land management changes and/or climate on runoff, water quality, and nutrient and sediment transport. As the availability of monitoring data increases, models can be updated for improved accuracy.

The goal of this project was to assess the factors that contribute to the water quality impairments identified within two RRB tributaries, the Bois de Sioux and Mustinka Rivers, and to identify target areas for implementation of beneficial management practices (BMPs) using hydrologic models. Both, the Mustinka and Bois de Sioux Watersheds contain stream impairments that affect the designated aquatic life use. Three reaches of the Rabbit River within the Bois de Sioux Watershed are impaired as a result of high turbidity, low dissolved oxygen, and low fish counts based on the Index of Biotic Integrity (IBI). Two reaches of the Mustinka River are impaired as a result of high turbidity and low dissolved oxygen.

To better understand the source of the turbidity impairments within these two watersheds, hydrologic models developed with SWAT were utilized. Because SWAT models have already been developed and calibrated for each of the major RRB tributaries through the Energy & Environmental Research Center (EERC) Waffle® project, much of the base work related to model development was already done. However, the existing additional work

Figure 1. Locations and boundaries of the watersheds in the RRB.

was conducted to expand the Bois de Sioux and Mustinka models for use in water quality applications. In addition, since development of the initial SWAT models, new SWAT models developed by the EERC were used for water quantity applications, thus spatial data sets and updated versions of the SWAT program were available. These updates were incorporated into the models developed for this project.

The modeling conducted for this project focused on long-term (i.e., 20 to 30 year) simulations of water and sediment loading at multiple points of interest within the Bois de Sioux and Mustinka River Watersheds. The modeling results will be used to gain a better understanding of water quality issues within these watersheds and to aid the Minnesota Pollution Control Agency (MPCA) in development of total maximum daily loads (TMDLs) for the impaired reaches.

2.0 BACKGROUND

The Bois de Sioux and Mustinka River Watersheds are located in the upper most reaches of the RRB (Figures 1). The major tributaries of the Bois de Sioux Watershed include the Bois de Sioux and Rabbit Rivers as well as the south fork of the Rabbit River (Figure 2). The primary waterways of the Mustinka River Watershed include the Mustinka River, Five Mile Creek, Twelve Mile Creek, and the west and east branches of Twelve Mile Creek (Figure 2).

As defined by U.S. Geological Survey (USGS) 8-digit hydrologic unit codes (HUCs), the drainage area of the Bois de Sioux Watershed (HUC 09020101) is 1140 square miles and the drainage area of the Mustinka River Watershed (HUC 09020102) is 825 square miles. However, the actual watershed drainage area used in the Bois de Sioux SWAT model developed for this project was 589 square miles. This difference is because the Bois de Sioux Watershed area that drains into Lake Traverse was excluded from the model since the USGS gage just below White Rock Dam was considered the upstream starting point of the watershed. The flow data from this station were used to represent the upstream flow inputs into the watershed. Thus the portion of the Bois de Sioux Watershed area shown in Figure 2 represents only the portion that was included in the SWAT model.

The Bois de Sioux and Mustinka River Watersheds straddle the zone between the more humid climate of eastern Minnesota and Wisconsin and the arid to semiarid climate of western North Dakota. As a result, while precipitation averages about 22 inches a year, annual totals have ranged from below 15 inches (during extreme drought years) to greater than 25 inches. In addition to the occasional extreme swings in precipitation, the continental climate produces extreme annual temperature swings as a result of very cold winters and warm to hot summers.

The Bois de Sioux and Mustinka River Watersheds are contained within three ecological regions as defined by the U.S. Environmental Protection Agency (EPA) (http://www.epa.gov/naaujydh/pages/ecoregions/level_iii.htm)—the Lake Agassiz Plain, the Northern Glaciated Plains, and the North Central Hardwood Forests (Figure 2). An ecological region—or

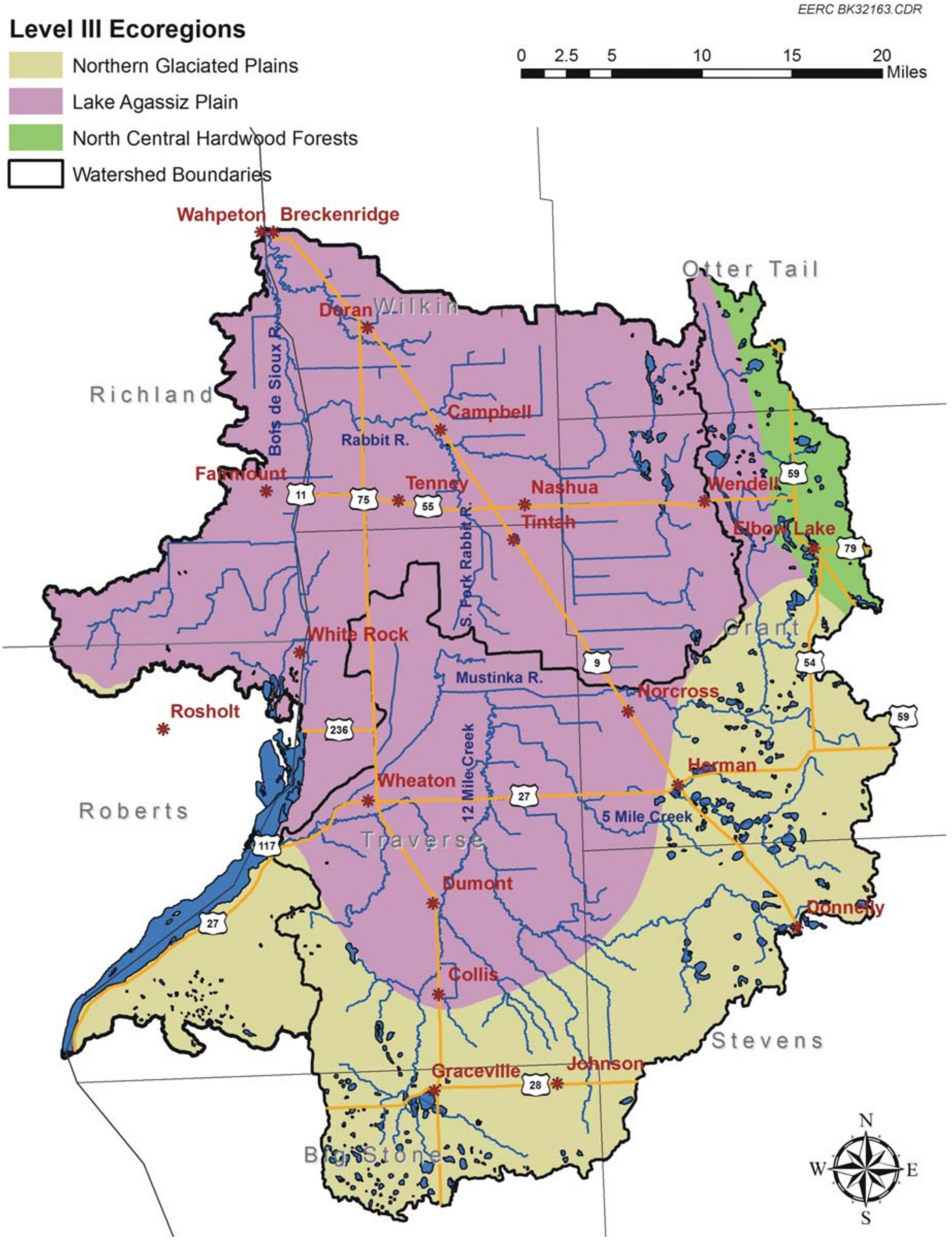

Figure 2. Location of the Bois de Sioux and Mustinka River Watersheds, major tributaries, towns, and ecological regions.

ecoregion—can be defined as a region that is characterized by a unique combination of geology, landforms, soils, vegetation, climate, wildlife, hydrology, and human factors (Commission for Environmental Cooperation [CEC], 1997). The portion of the Bois de Sioux Watershed modeled through this project is contained almost entirely within the Lake Agassiz Plain ecoregion, while the Mustinka Watershed is contained almost equally between the Lake Agassiz Plain and Northern Glaciated Plains ecoregion, and, to a small extent, within the North Central Hardwood Forests ecoregion.

The Lake Agassiz Plain ecoregion is characterized by thick beds of clay and silt which comprised the floor of former glacial Lake Agassiz approximately 10,000 years ago. Because of the environment in which it was formed, the Lake Agassiz Plain is extremely flat and, historically, was very poorly drained. The native tallgrass prairie of the region has been replaced by intensive row crop agriculture. The Northern Glaciated Plains ecoregion comprises glacial till, which forms a flat to gently rolling landscape interspersed with high concentrations of temporary and seasonal wetlands. The fertile soils of the region are highly conducive to agriculture. The native vegetation is transitional grassland containing tallgrass and shortgrass prairie. The North Central Hardwood Forests ecoregion can be characterized as a transition zone between the predominantly forested Northern Lakes and Forests ecoregion to the north and the agricultural ecoregions to the south. The vegetation and land use of the ecoregion is a mosaic of forests, wetlands and lakes, cropland agriculture, pasture, and dairy operations.

3.0 MATERIALS AND METHODS

3.1 Description of SWAT

SWAT is a hydrologic model developed by the U.S. Department of Agriculture's Agricultural Research Service (ARS) to predict the impact of land management practices on water, sediment, and agricultural chemical yields in watersheds over long periods of time. The model is increasingly being used in a variety of applications such as assessment of point and non-point sources of pollution, establishment of TMDLs, evaluation of climate change impacts on groundwater supplies and surface water flows, and watershed-scale investigations of flood and drought mitigation measures (Gassman et al., 2007, and references therein). The SWAT model can be used to determine the following:

1. How much runoff can be generated from a precipitation event
2. What is the loading of constituents at a particular location within a watershed
3. Where are the major contributors to sediment and nutrient loading located
4. What changes in flow or loading can be expected from adopting alternative land uses and watershed practices
5. How climate conditions affect loading

The SWAT model is physically based, meaning that it uses physically based data sets such as topography, vegetation, land management practices, soil type, and climate to predict water and sediment movement, crop growth, nutrient cycling, and a host of other processes associated with hydrology and water chemistry (Neitsch et al., 2002). The model can operate and produce output on a daily, monthly, or yearly time step for simulation periods up to 100 years.

SWAT is a compilation of several ARS models, some of which have been in development since the 1970s. It is a direct outgrowth of the SWRRB (Simulator for Water Resources in Rural Basins) model; however, it also incorporates components from CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems), GLEAMS (Groundwater-Loading Effects on Agricultural Management Systems), and EPIC (Erosion Productivity Impact Calculator) (Neitsch et al., 2002).

SWAT uses topography and the location of waterways to subdivide a watershed into a number of subbasins for modeling purposes. Each subbasin delineated within the model is simulated as a homogeneous area in terms of climatic conditions, but additional subdivisions are used within each subbasin to represent different land use, soils, and slope types. Each of these individual areas is referred to as a hydrologic response unit (HRU) and is assumed to be spatially uniform in terms of soils, land use, and topography.

The hydrologic cycle is the driving force in model simulations. The weather data input to the model (including precipitation, air temperature, wind speed, and humidity) is used to predict the interaction of precipitation (snowfall or rainfall) with the landscape and estimate the amount of runoff, infiltration, evaporation, transpiration, etc. (Figure 3), that occurs in each subbasin. Based on the estimated runoff and the physical characteristics of the landscape (such as soils, topography, and land use), SWAT calculates the amount of sediment, nutrient, and pesticide loading to the main channel in each subbasin. The model then predicts the movement of water, sediment, nutrients, and other water quality components through the channel network of the watershed to the outlet (Figure 4).

To help organize and track all of the various processes that are modeled, SWAT is subdivided into three major components, namely, subbasin, reservoir routing, and channel routing. Each of these components includes several subcomponents. For example, the subbasin component consists of eight subcomponents: hydrology, weather, sedimentation, soil moisture, crop growth, nutrients, agricultural management, and pesticides. The hydrology subcomponent, in turn, includes surface runoff, lateral subsurface flow, percolation, groundwater flow, snowmelt, evapotranspiration, transmission losses, and ponds. Thus there are many layers of data and detailed calculations that occur for each of the processes modeled by SWAT. Detailed descriptions of the methods used in modeling these components and subcomponents can be found in Arnold et al. (1998), Srinivasan et al. (1998), and Neitsch et al. (2002). Brief descriptions of the main components relevant to this project are provided herein for background information purposes.

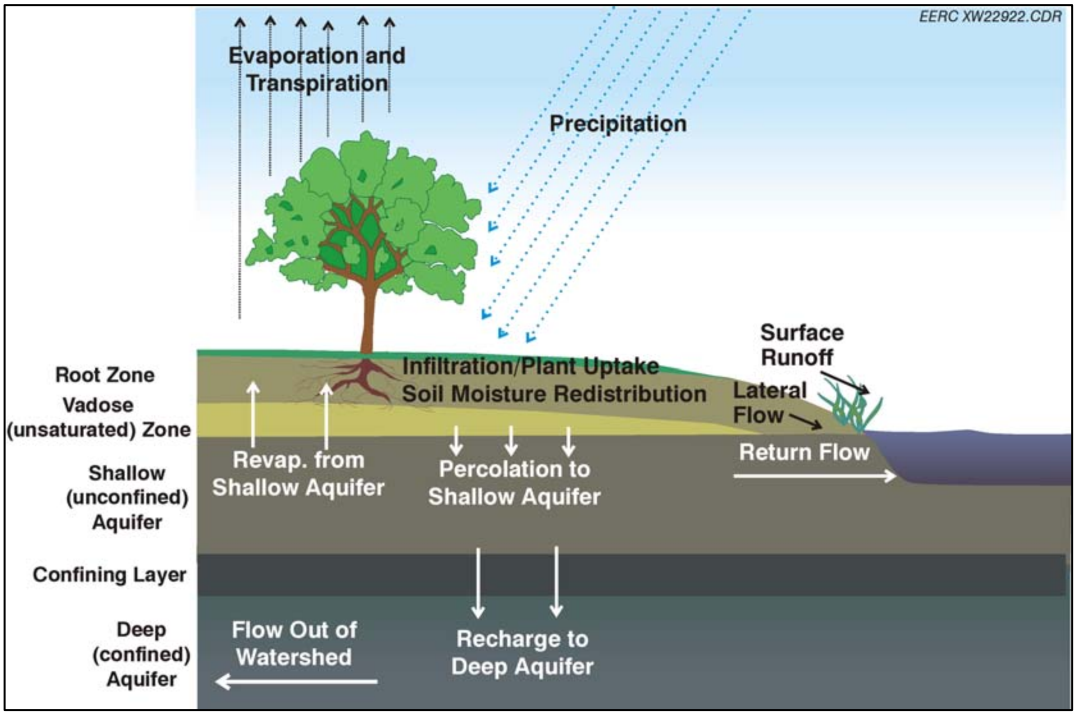

Figure 3. Hydrologic factors modeled within SWAT (modified from Neitsch et al., 2002, http://ftp.brc.tamus.edu/pub/swat/doc/swat2000theory.pdf).

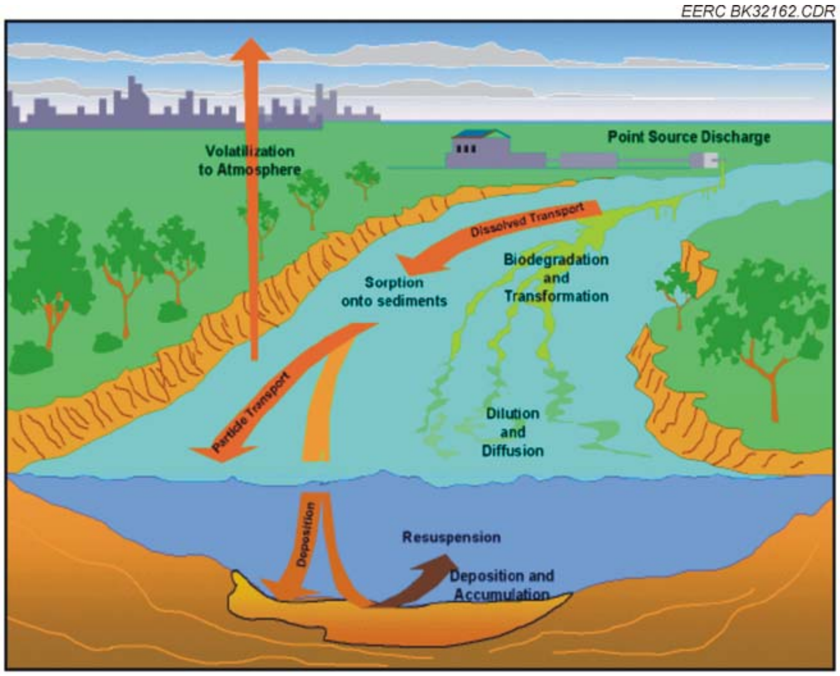

Figure 4. Routing phase of the SWAT model (Neitsch et al., 2002).

3.1.1 Rainfall Runoff Estimation

SWAT provides two methods for estimating surface runoff: 1) the Soil Conservation Service (SCS) runoff curve number method, with the SCS curve number adjusted according to soil moisture conditions, and 2) the Green–Ampt (GA) infiltration method. The SCS curve number method uses empirical equations to estimate the amounts of runoff under varying land use and soil types, whereas, the GA infiltration method is based on the principles of vadose zone hydrology. These two methods have distinct assumptions and data requirements. For example, the SCS curve number method assumes an infiltration excess rainfall runoff mechanism, but the GA method assumes a saturation excess mechanism. The GA method requires subdaily (e.g., hourly) weather data, but the SCS curve number method requires only daily data. In addition, SWAT provides three methods—Penman–Monteith, Priestley–Taylor, and Hargreaves—for estimating evapotranspiration. When available, observed evapotranspiration data can be used as model input as well. Further, SWAT uses a modified rational method to convert estimated surface runoff into corresponding flow rates.

Based on past modeling efforts by the EERC and others who have developed SWAT models in the upper Midwest, it is an appropriate choice to use the SCS runoff curve number method along with the Hargreaves method for rainfall runoff estimation. These two methods require a moderate amount of input data but are accurate enough for watershed-level studies.

3.1.2 Rainfall and Snowmelt

Because snowmelt accounts for a large percentage of the annual runoff in the study watersheds, it is imperative to appropriately model snow accumulation and melting processes. In this regard, SWAT is superior to other models.

SWAT classifies precipitation as either rain- or snow-based on the mean daily air temperature and a specified boundary temperature (i.e., snowfall temperature); the precipitation is classified as snow when the mean daily air temperature is less than the boundary temperature and as rain when the air temperature is greater. The water equivalent of the snow precipitation is then added to the snowpack. The snowpack will increase with additional snowfall and decrease with snowmelt and sublimation. Snowmelt is controlled by air and snowpack temperatures, melting rate, and areal coverage of snow. The snowpack temperature on a given day is estimated as the weighted average of that day's mean air temperature and the snowpack temperature on the previous day. The weighting includes a specified lag factor, which accounts for the snowpack density, snowpack depth, exposure, and other factors affecting the snowpack temperature. The snow-melting rate is allowed to have a seasonal variation, with the specified maximum and minimum values occurring on the summer and winter solstices, respectively.

The areal coverage of snow correlates well with the amount of snow present in a watershed of interest at a given time because other factors that contribute to variations in the snow coverage, such as drifting, shading, and topography, are usually similar from year to year (Anderson, 1976). This correlation is expressed in SWAT as an areal depletion curve, which is used to describe the seasonal growth and recession of the snowpack as a function of the amount of snow present in the watershed. The areal depletion curve requires a threshold depth of snow above which there will always be 100% cover. The threshold depth depends on factors such as vegetation distribution, wind loading and scouring of snow, interception, and aspect and is unique to the watershed. This snow accumulation and melt phenomenon is modeled using seven parameters in SWAT, which are discussed in detail by Neitsch et al. (2002).

3.1.3 Flow Routing

SWAT provides two methods to route flows through a channel reach: 1) the variable storage routing method and 2) the Muskingum routing method. The first method is based on the continuity equation for the reach and thus does not consider flow attenuation. On the other hand, the Muskingum routing method uses a continuity equation to consider flow translation and a momentum equation to consider attenuation. Hence, the Muskingum method may be more appropriate for the study watersheds.

In addition, SWAT provides three options—reservoirs, ponds, and wetlands—to model different types of storage. The reservoir function is intended to model storage that intercepts all runoff generated in its upstream drainage areas, whereas, the pond and wetland functions can be used to model storage (e.g., off-line detention ponds and lakes) that may intercept only a certain percentage of the runoff. The remaining runoff will be considered to bypass the storage feature. As with a channel reach, these storage features will attenuate the inflow hydrographs and thus reduce the peaks. Further, translation losses (e.g., seepage and evaporation) are considered for both channel and storage routings.

3.1.4 Erosion and Sediment Transport

SWAT uses the Modified Universal Soil Loss Equation (MUSLE) to compute the erosion caused by rainfall and runoff. When compared to the Universal Soil Loss Equation (USLE), MUSLE uses a runoff factor to improve the sediment yield prediction, eliminate the need for delivery ratios, and allow for application of the equation to individual storm events. The amount of sediment released into a stream reach is estimated based on the surface runoff transport capacity.

Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach. Deposition and degradation can be computed using the same channel dimensions for the entire simulation period. For alluvial channels, which are the type found in the proposed study watersheds, SWAT will simulate downcutting and widening of the stream channel and update channel dimensions throughout the simulation period. The maximum amount of sediment transported within a reach is a function of the peak channel velocity, defined by the peak flow rate divided by the cross-sectional area of flow. Deposition will occur when the sediment concentration is greater than the transport capacity, and degradation will occur otherwise. The amount of stream bank erosion is controlled by the channel erodibility factor, which is a function of the stream bank or bed materials. The amount of vegetative cover within each channel reach is also simulated using a channel cover factor.

3.1.5 Simulation of Other Parameters

Once a SWAT model is calibrated and validated in terms of hydrology, it can be expanded to simulate various chemical and biological constituents. In addition to the sediment transport functions discussed above, SWAT can also simulate nutrient (nitrogen and phosphorus) and pesticide loading and predict water quality parameters such as algae and dissolved oxygen. SWAT also allows for the simulation of crop growth and yield.

3.1.6 Simulating Effects of Watershed Management Practices

SWAT can simulate the effects of various agricultural and watershed management practices:

- Land use changes
- Agricultural conservation practices (e.g., no-till, reduced-till, and field buffers)
- Tile drainage
- Nutrient management
- Wetland restoration
- Stream restoration
- Riparian buffering (depending on the desired level of detail needed to evaluate this option, SWAT may need to be run in conjunction with the Riparian Ecosystem Management Model)

Because options for changing most of the above parameters are built into the model interface and relatively easy to adjust, the model is especially useful for evaluating options to achieve TMDLs.

3.2 Data Inputs

The following describes the primary data sets used to develop and calibrate the Bois de Sioux and Mustinka River SWAT models.

3.2.1 Topographic Data

A modified version of the 30-meter USGS National Elevation Dataset (NED) was used to represent the topography of both subbasins. NED is a raster product assembled and designed to provide national elevation data in a seamless form with a consistent datum, elevation unit, and projection (U.S. Geological Survey, 2006). The NED for the area encompassed by the Bois de Sioux and Mustinka Watersheds was modified by JOR Engineering of Alexandria, Minnesota, to better reflect the manmade roads and ditches (Mark Reineke, personal communication, July 2007).

3.2.2 Land Use Data

The 2006 National Agricultural Statistics Service (NASS) Cropland Data Layer was used to represent land use within both watersheds. This data set contains a variety of land use information, including crop-specific data, at a resolution of 56 meters. It was compiled using imagery from the Advanced Wide Field Sensor (AWIFS) equipped on India's ResourceSat-1 satellite.

3.2.3 Conservation Practice Data Layer

A geographic information system (GIS) shape file was obtained from the Minnesota Farm Service Agency (FSA) containing the location of conservation practices that have been implemented through FSA. The data set includes the location of 49 different practices, such as wetland restoration, field buffers, tree plantings, and land enrolled in the Conservation Reserve Program (CRP). This data set was used to update the 2006 Cropland Data Layer for incorporation into the SWAT models.

3.2.4 Soil Data

Soil data for both watersheds were incorporated using SSURGO (Soil SURvey GeOgraphic) data, a data set compiled and distributed by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). SSURGO is the most detailed geographic soil database available, containing digital data developed from detailed soil survey maps that are generally at scales of 1:12,000, 1:15,840, 1:20,000, 1:24,000, or 1:31,680.

3.2.5 Tillage Practice Data

County-level data summarizing tillage practices for various crop types as of 2004 were obtained from the Conservation Technology Information Center (CTIC), which compiled and published the results of the National Crop Residue Management Survey. The tillage practices included within the data set were conservation, reduced, and conventional till. This source only provided tillage data for Minnesota, and a similar data set for counties within North Dakota was not found.

3.2.6 Stream Flow Data

When available, daily flow data from local USGS gaging stations were used for model calibration. In addition to the USGS daily flow data, spot flow measurements and stage readings collected by the Bois de Sioux Watershed District (BDSWD) and JOR Engineering were used to aid in model calibration. If stage data were used, rating curves developed by JOR Engineering were used to estimate flows based on stage readings. Continuous stage data from stations maintained by the U.S. Army Corps of Engineers was also used to estimate flows at two locations within the Mustinka River Watershed.

3.2.7 Sediment and Water Quality Data

Water quality information, specifically total suspended solids (TSS) concentration data, was obtained from MPCA's Environmental Data Access Web site. This site contains water quality information collected and compiled by MPCA and other partner agencies, such as the Minnesota Department of Natural Resources.

4.0 DEVELOPMENT AND CALIBRATION OF THE BOIS DE SIOUX RIVER WATERSHED MODEL

The previously described data sets were used to develop and calibrate each model. This entailed delineation of each watershed into smaller subbasins and HRUs, incorporation of point source data (including any contributions from upstream watersheds), import of the climate data from each of the weather stations used, adjustment of various model parameters to best represent the physical characteristics of the region modeled, and model calibration using observed data. The following sections describe each of the steps taken to develop and calibrate the Bois de Sioux Watershed model.

4.1 Model Development

4.1.1 Watershed Delineation

The first step in model development is watershed delineation, which entails subdividing the watershed into smaller units called subbasin. The SWAT model predicts discharge, sediment and nutrient loading, and other water quality parameter output for each subbasin defined within the watershed. Thus, for studies such as this one which entail detailed water quality assessment, a higher number of subbasins is desirable.

Subbasins were defined based on the corrected NED and stream location data sets provided by JOR Engineering. A trial-and-error approach was used in this step to ensure that the subbasins were relatively similar in size and to ensure that the subbasin outlets were correlated to most USGS gaging and MPCA water quality station locations. The subbasin outlets were also designated to coincide with the outlets of the major reservoirs located throughout the watershed. A total of 126 subbasins with an average area of 12.1 square kilometers (4.7 square miles) were defined within the watershed. The location and number of each subbasin is shown in Figure 5. The total drainage area of the Bois de Sioux Watershed included in the SWAT model was 1526 square kilometers (589 square miles).

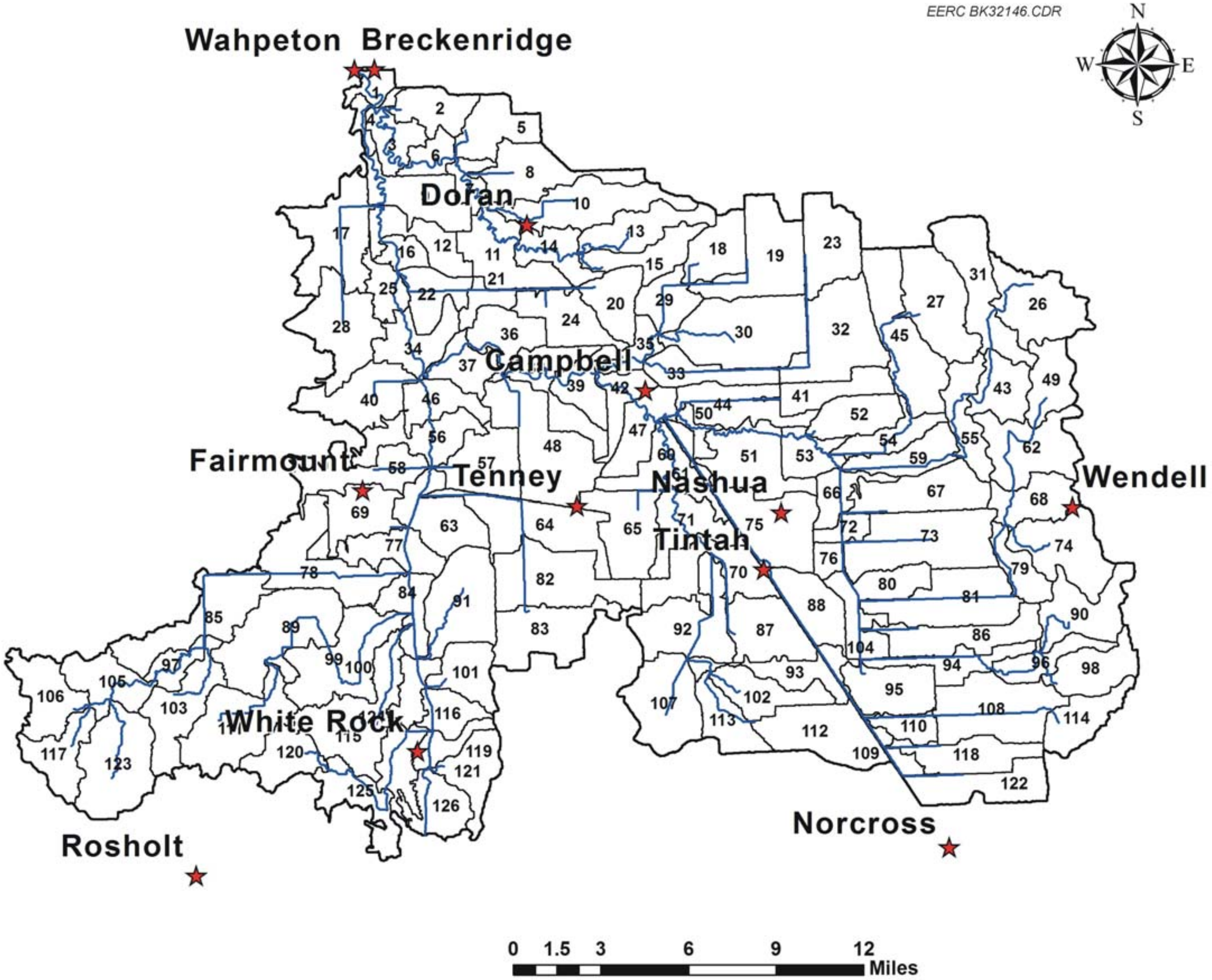

Figure 5. Location of the subbasins defined within the Bois de Sioux Watershed.

Once the subbasins were delineated, a total of six reservoirs were defined within the model (Table 1). SWAT only allows one reservoir to be designated per subbasin, thus the locations of the various reservoirs were taken into account during the subbasin delineation step to ensure that two major reservoirs would not be located within the boundaries of one subbasin.

The reservoirs were modeled using the targeted release rate which attempts to simulate the management of reservoirs during flood and nonflood seasons. The model assumes that during the nonflood season, no flood control storage is required, but during the flood season, flood control storage will be implemented based on the target storage volume and the soil water content. To use this approach, the following parameters were needed for each reservoir:

- Surface area of the reservoir when filled to the emergency spillway (RES_ESA)
- Surface area of the reservoir when filled to the principal spillway (RES_PSA)
- Volume of water held in the reservoir when filled to the emergency spillway (RES_EVOL)
- Volume of water held in the reservoir when filled to the principal spillway (RES_PVOL)
- Number of days required for the reservoir to reach the target storage volume (NDTARGR)

The above parameters for the Bois de Sioux reservoirs were provided by JOR Engineering.

In addition to including reservoirs, during the watershed delineation process, all point source flows and/or inputs from upstream watersheds must be defined. In this case, the only significant input to the model was the upstream flow coming from White Rock Dam. This was included by using the observed flows from the USGS gaging station located at White Rock.

Table 1. Reservoirs Included Within the Bois de Sioux Model

Reservoir Name	Subbasin Location	Township/Range/Section
Upper Lightning Lake	31	T: 131; R: 44, Section 36
Stony Lake	43	T: 130; R: 44; Section 12
Ash Lake	62	T: 130; R: 44; Section 25
Mud Lake	68	T: 130; R: 44; Section 36
Sections 7 and 8 of Stony Brook TWP	49	T: 130; R: 43; Section 07
Bailey Slough	114	T: 128; R: 43; Section 06

4.1.2 HRU Delineation

As previously described, a HRU is a smaller unit defined within each subbasin that is a unique combination of land use, soil type, and slope. Figures 6, 7, and 8 show the distribution of land use, soils, and slopes used to define the HRUs within the Bois de Sioux Watershed. Table 2 shows the percent distribution of land use within the watershed. Table 3 lists the soil types that comprise more than 0.5% of the watershed area.

Once the aforementioned data sets are loaded into the model, the user is able to define the number of HRUs within a watershed based on a specified threshold or degree of sensitivity to soil type, slope, and land use. For example, if a threshold value of 5% is designated for soil type, then any soils that comprise less than 5% of a subbasin area will not be included in the formation of HRUs.

Within the Bois de Sioux model, the following threshold values were used for each of the three categories:

- Land use: 5%
- Soil type: 10%
- Slope: 10%

This resulted in the formation of 3060 HRUs throughout the entire watershed or an average of 24 HRUs per subbasin. Typically, no more than 10 HRUs are needed per subbasin; however, given the more detailed land use and soil data sets used for this project, a larger number of HRUs was necessary to better capture the variability within each subbasin.

4.1.3 Climate Data

A total of five weather stations were used to provide precipitation and temperature data input to the model. The station name, number, and period of record is listed in Table 4, and the location of the stations within the watershed is shown in Figure 9. Missing values at individual stations were estimated based on data available at nearby stations using linear interpolation. The data from the Wahpeton and Breckenridge stations were combined because just as the period of record ended for Wahpeton, the Breckenridge station came online. Between the two stations, a record covering the desired time span was available.

Based on the above data sets, the period of record of climate data incorporated into the model ranges from January 1, 1970, to August 31, 2007. Given the long record of data available from each station, a significantly longer time period of data could have been incorporated into the model; however, a time period of 38 years seemed more than sufficient for the intended use of the model.

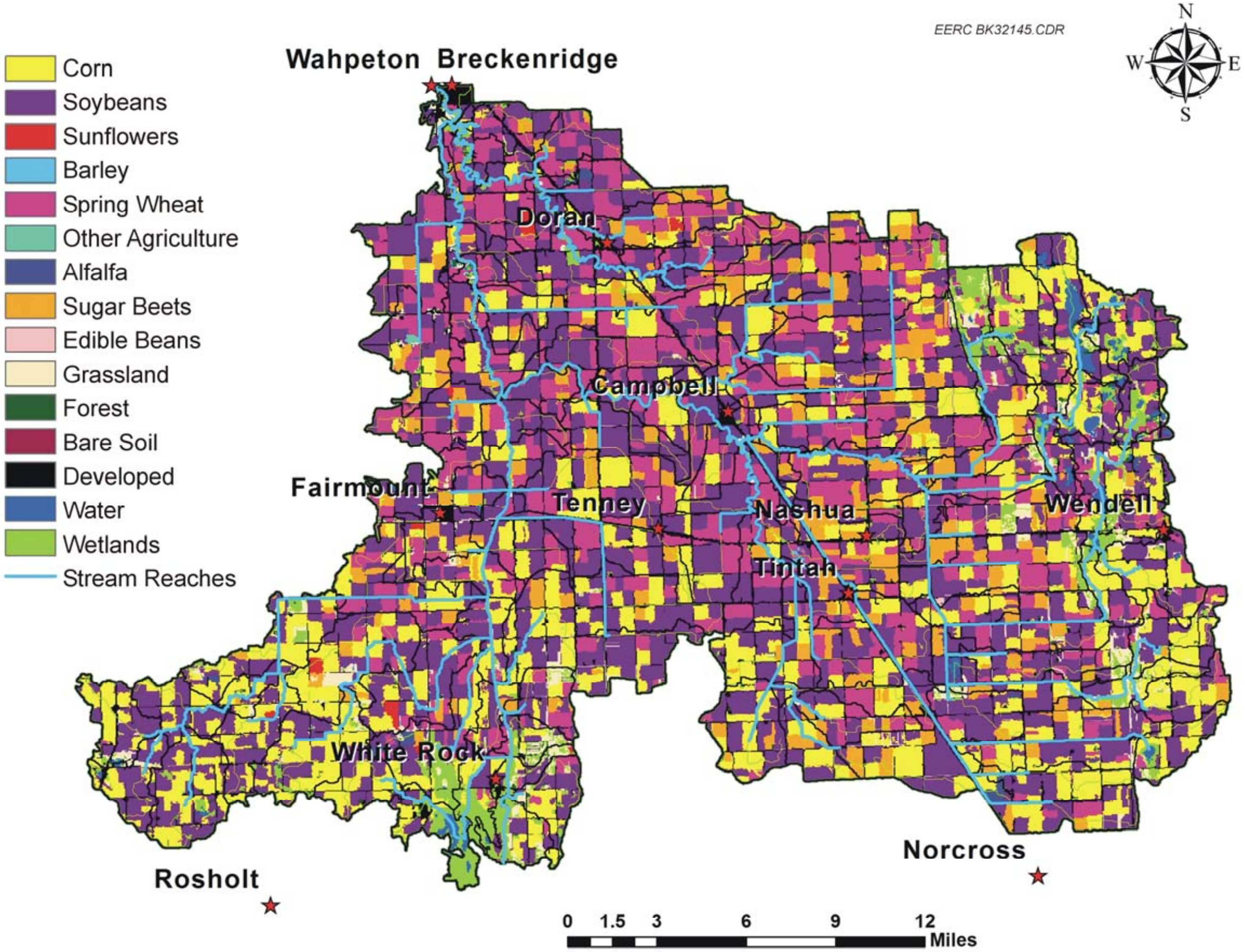

Figure 6. Distribution of land use within the Bois de Sioux River Watershed.

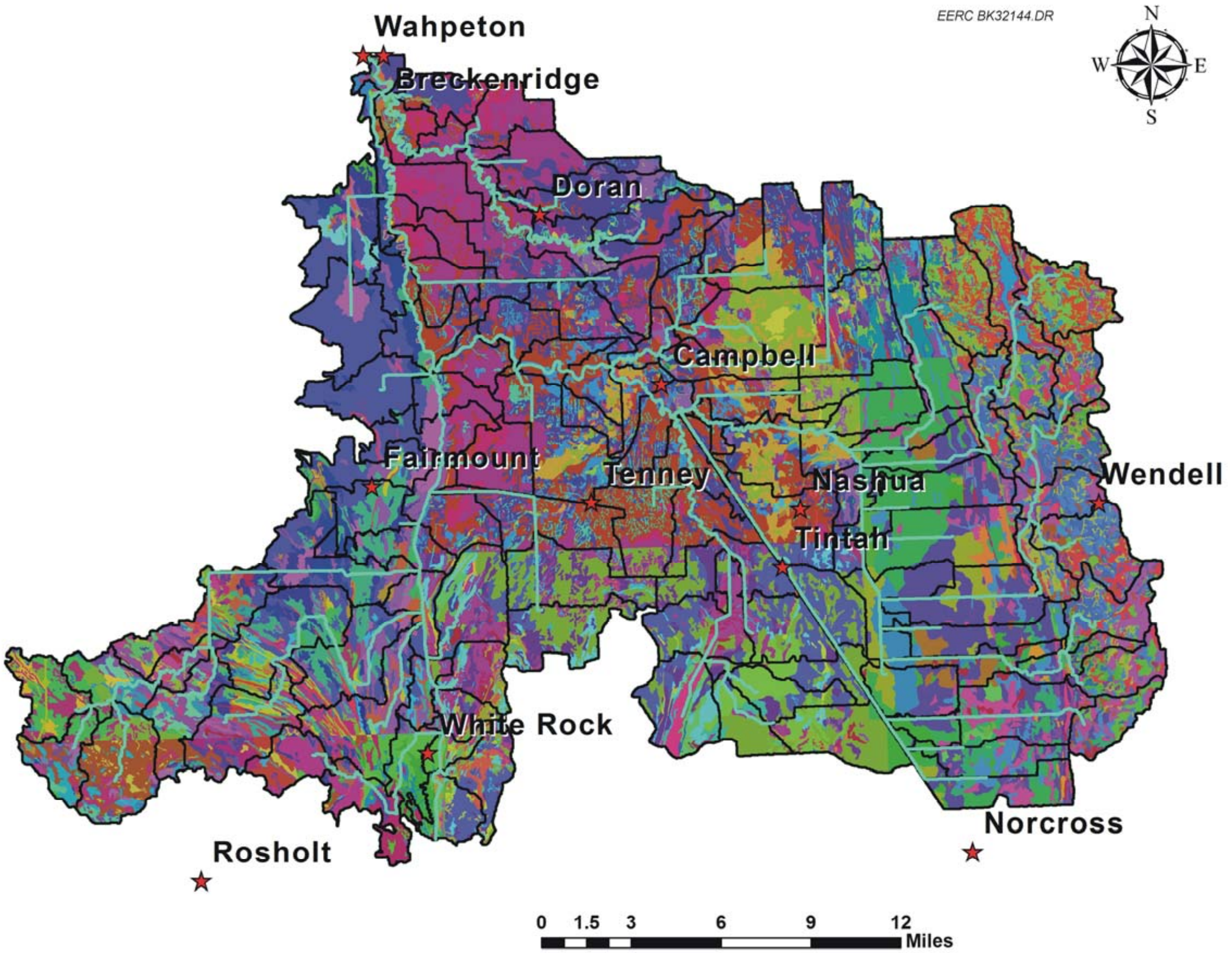

Figure 7. Distribution of soil types within the Bois de Sioux River Watershed.

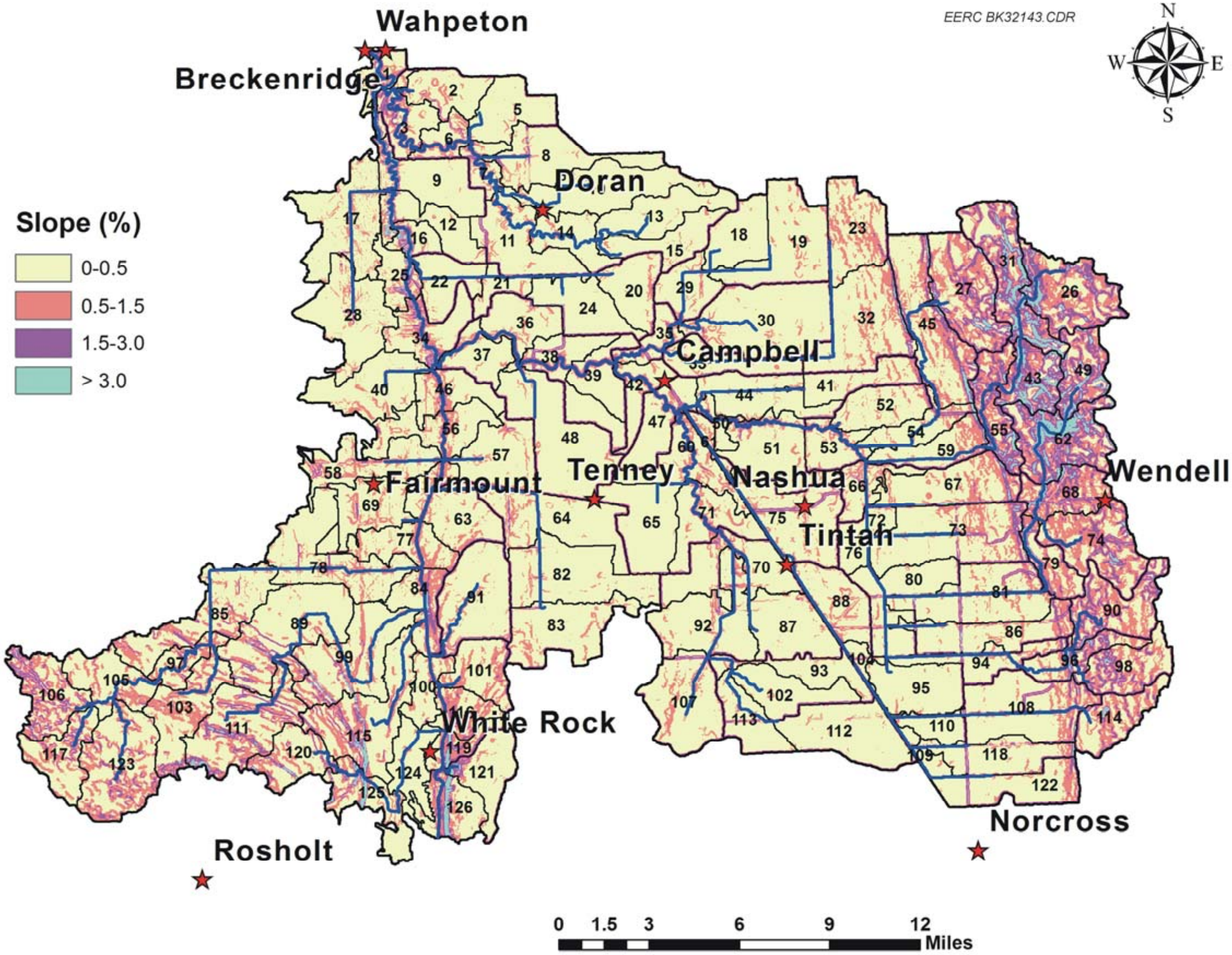

Figure 8. Distribution of slopes within the Bois de Sioux River Watershed.

Table 2. Distribution of Land Use Within the Bois de Sioux River Watershed

Land Use	Area, acres	% of Watershed Area
Soybeans	133,165	35.3
Corn	82,475	21.9
Spring Wheat	68,259	18.1
Sugar Beets	30,755	8.2
Sunflowers	989	0.3
Alfalfa	1093	0.3
Grassland	11,006	2.9
Wetlands	16,502	4.4
Forest	1823	0.5
Developed	26,657	7.1
Water	3878	1.0

Table 3. The Soil Types that Comprise More Than 0.5% of the Watershed Area

Soil Name	Area, acres	% of Watershed Area*
Hamerly	97,956	25.98
Doran	65,351	17.33
Roliss	30,518	8.09
Antler	24,349	6.46
Aazdahl	16,515	4.38
Formdale	11,233	2.98
Glyndon	9688	2.57
Wheatville	9316	2.47
Kittson	8190	2.17
Elmville	8029	2.13
Donaldson	7688	2.04
Lindaas	7080	1.88
Vallers	4949	1.31
Grimstad	4335	1.15
Clearwater	4185	1.11
Hecla	4111	1.09
Fargo	3925	1.04
Towner	3874	1.03
Bearden	3512	0.93
Lamoure	3440	0.91
Rockwell	3404	0.9
Flom	3359	0.89
Gardena	2373	0.63
Gilby	2292	0.61

Table 4. Location of the Stations Used to Provide Climate Data to the Model

Station Name	COOPID Number	Period of Record
Wahpeton, North Dakota–Breckenridge, Minnesota	329100	January 1893 – present
Wheaton, Minnesota	218907	May 1914 – present
Campbell, Minnesota	211245	January 1894 – January 2006
Victor, South Dakota	398652	June 1923 – present

For the purposes of this project, a 4-year warm-up period was used at the beginning of the model simulation. This allows the model to equilibrate and estimate the initial value of certain parameter, such as soil moisture, before it starts generating results. Thus the total simulation period of the model is January 1978 to August 2007.

4.1.4 Tillage Practices

The tillage practice data acquired by CTIC are shown in Table 5 for Grant, Otter Tail, Traverse, and Wilkin Counties, Minnesota. Unfortunately, similar data were not available for South Dakota or North Dakota. The data are listed as the percent tillage practice and total acreage per crop type for each county. Because the exact location of these practices was not given, the data were also incorporated into the model on a percentage basis. For each of the four counties, the various tillage practices for each specified crop type were implemented in the equivalent percentage of subbasins for that county. So, for example, if 3.0% of the corn acreage in Traverse County was no till, then this practice was implemented on the cornfields in 3.0% of the subbasins contained within Traverse County. The counties selected for implementation of each tillage practice were chosen randomly.

4.2 Flow Calibration

4.2.1 Calibration Parameters

The Bois de Sioux SWAT model was calibrated using the observed flow data from the USGS gaging station located on the Bois de Sioux River west of Doran, Minnesota (Station ID; USGS 05051300). There is a gage located along the Rabbit River near Campbell; however, USGS lists most of the data as “poor,” while the rest of the values are missing or listed as “fair.,” Since the Bois de Sioux gage near Doran captures most of the flow from the watershed, including all the flow from the Rabbit River, the Campbell gage was not used.

Flow data for the Doran station are available from October of 1989 to present. The calibration period of the Bois de Sioux SWAT model included 15 years, ranging from January 1, 1993, to August 31, 2007. While flow data were available beginning in October 1989, the early 1990s was a very dry period, and there was little to no flow in the Bois de Sioux River in 1990 and 1992. During extremely low-flow periods such as these, the reliability of the gage data can be questionable. Since 15 years of data past this period were available for calibration, it was decided to exclude them from the calibration period.

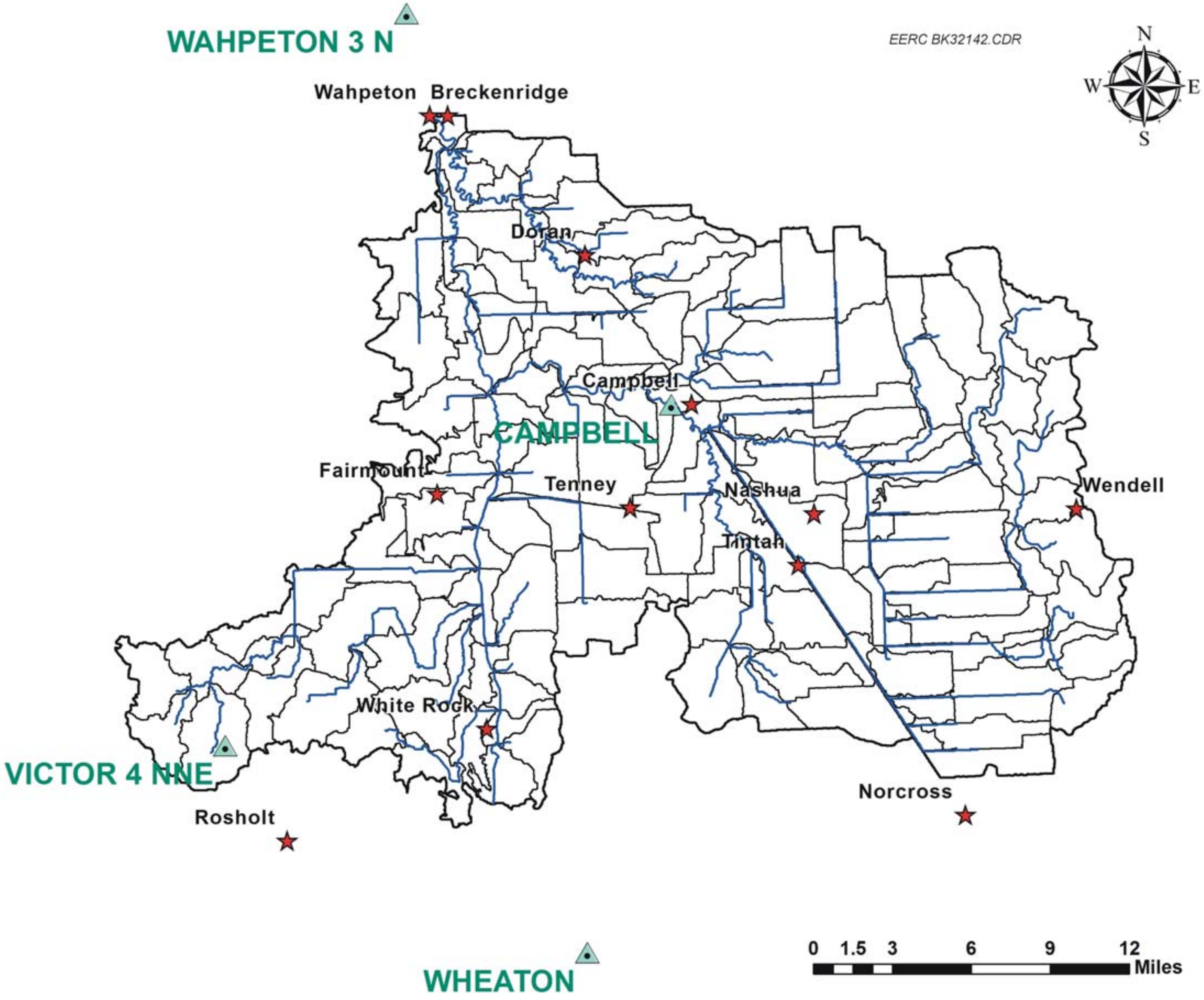

Figure 9. Location of the weather stations used to provide climate data for the model.

Table 5. Type of Tillage Practices Implemented in 2004 per Crop Type for Four Counties in Minnesota

Crop Type	Total Planted Acres	Acres in Conservation Tillage	% of Total Planted Acres	Acres in Reduced Tillage	% of Total Planted Acres	Acres in Conventional Tillage	% of Total Planted Acres
Wilkin County							
Corn	59,925	28,884	48.2	28,884	48.2	2157	3.6
Small Grains	138,361	21,971	15.9	63,860	46.2	52,530	38.0
Soybeans	143,214	359	0.3	39,398	27.5	103,098	72.0
Other Crops	45,954	0	0.0	0	0.0	45,954	100
Traverse County							
Corn	113,764	3413	3.0	37,542	33.0	72,809	64.0
Small Grains	37,917	0	0.0	37,917	100.0	0	0.0
Soybeans	138,860	62,819	45.2	48,848	35.2	27,193	19.6
Other Crops	7817	0	0.0	5237	67.0	2580	33.0
Otter Tail County							
Corn	141,109	12,700	9.0	39,087	27.7	89,322	63.3
Small Grains	80,059	3048	3.8	21,166	26.4	55,845	69.8
Soybeans	138,482	436,75	31.5	45,721	33.0	47,086	34.0
Other Crops	34,961	8587	24.6	5682	16.3	26,374	75.4
Grant County							
Corn	95,243	14,317	15.0	26,391	27.7	53,725	56.4
Small Grains	35,138	5973	17.0	11,596	33.0	17,569	50.0
Soybeans	109,358	76,551	70.0	17,497	16.0	15,310	14.0
Other Crops	12,914	1937	15.0	4132	32.0	6845	53.0

Table 6 lists the various model parameters that were adjusted to calibrate the model, including the default and calibrated parameter values. The calibration parameters were adjusted to reflect conditions most appropriate for the RRB and Bois de Sioux Watershed region. Appropriate ranges for most of the sensitive SWAT model parameters had been previously determined through extensive SWAT modeling work conducted by the EERC (Kurz et al., 2007; Wang et al., 2006; Wang and Melesse, 2006; Wang and Melesse, 2005). More information on each parameter, such as the assumptions and equations used to determine the parameter, can be found in the SWAT Input/Output File Documentation (Neitsch et al., 2005), available online at www.brc.tamus.edu/swat/doc.html.

Table 6. The Parameters Adjusted to Calibrate the Bois de Sioux River SWAT Model

Parameter	Default Value	Calibration Value	Description
SFTMP	1	1	Snowfall temperature, °C
SMTMP	0.5	0.5	Snowmelt base temperature, °C
SMFMX	4.5	6.9	Melt factor for snow on June 21 (mmH_2O/°C-day)
SMFMN	4.5	1.5	Melt factor for snow on December 21 (mmH_2O/°C-day)
TIMP	1	0.2	Snow pack temperature lag factor
SNOCOVMX	1	35	Minimum snow water content that corresponds to 100% snow cover (mmH_2O)
SNO50COV	0.5	0.3	Fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover
IPET	1	2	Potential evapotranspiration (PET) method: 0 – Priestley–Taylor method 1 – Penman–Monteith method 2 – Hargreaves method 3 – Manually input PET values
ESCO	0.95	0.86	Soil evaporation compensation factor
SURLAG	4	2	Surface runoff lag coefficient
SPCON	0.0001	0.0013	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing
SPEXP	1	1.3	Exponent parameter for calculating sediment reentrained in channel sediment routing
IRTE	0	1	Channel water-routing method: 0 = variable storage method; 1 = Muskingum routing method
MSK_CO1	0	0.9	Muskingum calibration coefficient used to for normal flow.

Continued . . .

Table 6. Parameters Adjusted to Calibrate the Bois de Sioux River Swat Model (continued)

Parameter	Default Value	Calibration Value	Description
MSK_CO2	3.5	1	Muskingum calibration coefficient used for low flow
MSK_X	0.2	0.2	Muskingum weighting factor used to control the relative importance of inflow and outflow in determining the storage in a reach
ALPHA_BF	0.048	0.04	Base flow alpha factor (days)
GWQMN	0	10	Threshold depth of water in the shallow aquifer required for return flow to occur (mmH_2O)
GW_REVAP	0.02	0.08	Groundwater reevaporation coefficient
REVAPMN	1	40	Threshold depth of water in the shallow aquifer for reevaporation or percolation to the deep aquifer to occur (mmH_2O)
RCHRG_DP	0.05	0.4	Deep aquifer percolation fraction
GWHT	1	6	Initial groundwater height (m)
CN2	Varies	+ 1	Initial SCS runoff curve number for moisture condition II
CH_K1	0.5	15	Effective hydraulic conductivity in tributary channel alluvium (mm/hr)
CH_N1	0.014	0.05	Manning's "n" value for the subbasin tributary channels
CH_N2	0.014	0.04	Manning's "n" value for the main channel in each subbasin
CH_K2	0	25	Effective hydraulic conductivity in main channel alluvium (mm/hr)
CH_EROD	0	0.15	Channel erodibility factor
CH_COV	0	0.7	Channel cover factor
ALPHA_BNK	0	0.35	Base flow alpha factor for bank storage (days)
OV_N	Varies	0.15 (for cropland)	Manning's "n" value for overland flow

4.2.2 Measures of Model Performance

The hydrograph of predicted versus observed flows for the Bois de Sioux River at Doran is shown in Figure 10. Overall, the predicted flows compare well to the measured flows. The peak timing matches well; however, for many of the high-flow events, SWAT slightly overpredicts the peak magnitude. The peak that occurred on June 5, 2007, is particularly problematic. The SWAT model highly overpredicts the peak flows for the event. An evaluation of the weather data shows that on June 2, 2007, 17.8 cm (7 inches) of rainfall was reported at the Wheaton

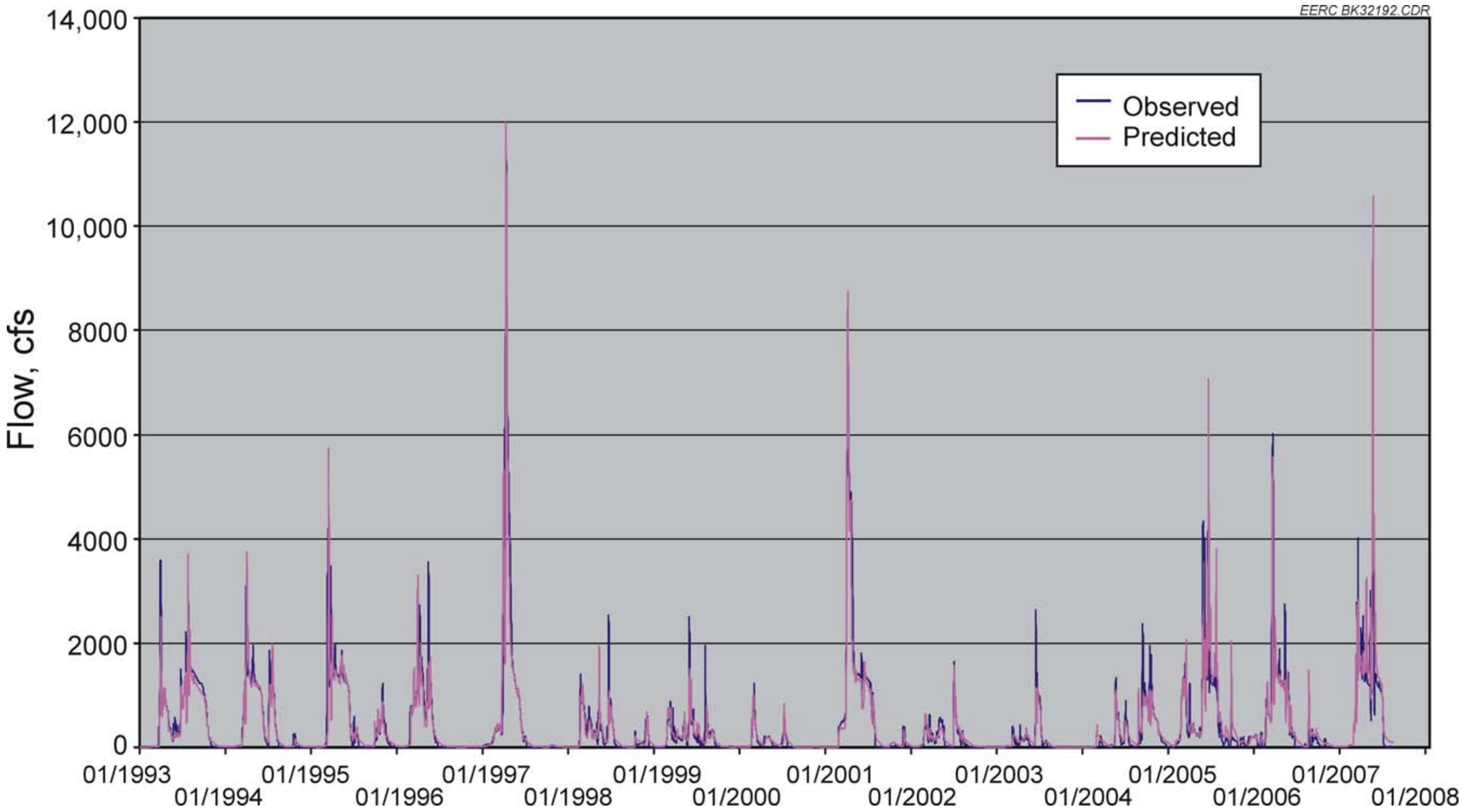

Figure 10. Comparison of the USGS-observed versus model-predicted flow at the Bois de Sioux River near Doran, Minnesota.

station, while a gage at White Rock located about 10 miles away reported 7.3 cm (2.8 inches) of rainfall. The Victor, South Dakota, station reported 6.6 cm (2.6 inches) of rainfall. Obviously, there were some localized areas of intense rainfall associated with this event that are not being accurately represented within the SWAT model.

While visually comparing the predicted versus observed peak shapes, volume, and timing is a good qualitative measure of model performance, a quantitative evaluation using statistics eliminates human subjectivity. Besides visualization, two statistics, the Nash–Sutcliffe efficiency coefficient (NSE) and volume deviation (Dvj) were also used to determine model performance in this study. These statistics can be applied for daily, monthly, seasonal, and annual evaluation time steps. In this project, the statistics were computed for the daily time step, which requires greater model accuracy to achieve acceptable statistical parameters.

The NSE measures the overall fit of the modeled hydrograph to that of an observed flow hydrograph (Nash and Sutcliffe, 1970). The NSE is computed as:

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n_j} (\mathrm{Q}_{\mathrm{obs}i}^{j} - \mathrm{Q}_{\mathrm{sim}i}^{j})^2}{\sum_{i=1}^{n_j} (\mathrm{Q}_{\mathrm{obs}i}^{j} - \mathrm{Q}_{\mathrm{mean}}^{j})^2}$$

Where $\mathrm{Q}_{\mathrm{sim}i}^{j}$ and $\mathrm{Q}_{\mathrm{obs}i}^{j}$ are the simulated and observed stream flows, respectively, on the *i*th time step for station *j*, and $\mathrm{Q}_{\mathrm{mean}}^{j}$ is the average of $\mathrm{Q}_{\mathrm{obs}i}^{j}$ across the n_j evaluation time steps. The NSE value can range from -∞ to 1.0. A value of 1 indicates that the predicted flows perfectly match measured flows, while negative values indicate that the annual average of the observed flow is more reliable than the model-predicted flow for any given day of the year. While there is no particular value above which a model's performance is considered acceptable, a review of values used within the literature suggests that values above 0.3 to 0.4 for daily-based calibrations generally indicate acceptable model performance (Gassman et al., 2007).

As seen in Table 7, the NSE values for the Bois de Sioux model range from 0.05 to 0.94, with an average value of 0.68 for the calibration period. If the 10-day period encompassing the problematic June 5, 2007, peak is removed from consideration, then the NSE values range from 0.50 to 0.94, and the average for the calibration period increases to 0.72.

While the Nash–Sutcliffe coefficient is an appropriate indicator of how closely the predicted hydrograph matches the shape of the observed hydrograph, it is not necessarily an appropriate measure for use in evaluating the accuracy of the volume predictions. To test whether the volume of an observed hydrograph is appropriately predicted, a statistical parameter referred to as the deviation in volume is used. This parameter is computed by integrating the flow hydrograph over the evaluation period.

Table 7. Calibration statistics for the Bois de Sioux Watershed SWAT Model (note that the 2007 Values Were Calculated with the Problematic Peak from June 5 and without)

Year	NSE	Dvj
1993	0.84	13.9
1994	0.80	1.5
1995	0.65	9.4
1996	0.71	12.8
1997	0.84	9.1
1998	0.60	7.7
1999	0.50	5.5
2000	0.82	−14.6
2001	0.94	11.0
2002	0.81	−11.3
2003	0.70	6.1
2004	0.69	7.7
2005	0.58	−10.1
2006	0.73	8.9
2007	0.05 (0.64)	−16.7 (−4.4)
Average	**0.68 (0.72)**	**2.7 (3.6)**

The Dvj is a measure of how the predicted annual discharge differs from the measured annual discharge. It is computed as:

$$D_{vj} = \frac{\sum_{i=1}^{n_j} Q_{\mathrm{sim}i}^{j} - \sum_{i=1}^{n_j} Q_{\mathrm{obs}i}^{j}}{\sum_{i=1}^{n_j} Q_{\mathrm{obs}i}^{j}} \times 100\%$$

Volume deviation is typically reported in % deviation, with a 0% deviation indicating that the volumes are perfectly matched, a negative deviation indicating that the model underpredicts the flow, and a positive deviation indicating that the model overpredicts the flow.

The average annual volume deviation for the Bois de Sioux SWAT model was 2.7% for the entire calibration period and 3.6% if the problematic June 5, 2007, peak is removed from consideration. Generally, values within ±15% are considered acceptable.

4.3 Sediment Comparison

As previously described, the SWAT model predicts the amount of sediment eroded from the landscape into the waterways of each subbasin, and it also predicts the amount of sediment transported within each subbasin reach. The sediment transported within each subbasin reach is reported by SWAT as the amount of sediment into and out of the reach (in metric tons) as well as the sediment concentration. Because the Bois de Sioux model was run on a daily time step, these values are reported for every day of the simulation period for each of the 126 stream reaches and can be used for comparison with measured water quality data.

While there are several MPCA water quality stations located throughout the Bois de Sioux watershed (Figure 11), most have very limited sediment data, if at all. Two stations have more than 20 sediment data points – one located along the Bois de Sioux River southwest of Doran (Station MNPCA S000-553) and one located along the Rabbit River northwest of Campbell (Station MNPCA S001-029). These stations were used to calibrate the model as well as possible for sediment output.

There was one caveat to using the data from these stations for model calibration. The sites were sampled for TSS, while the SWAT model predicts suspended sediment. TSS accounts for any physical material entrained in the water column such as sediment, bits of detritus (i.e., leaves, vegetation), and algae, while SWAT is only able to predict sediment. Thus the sediment values predicted by SWAT may be lower than the TSS values, particularly during the later summer months when algae content in the waterways may be elevated.

With that said, the suspended sediment concentrations predicted by SWAT versus the measured TSS concentrations for the two evaluation locations are shown in Figures 12 and 13. At the Rabbit River station near Campbell, the low- to mid-range values predicted by SWAT compare well to the measured TSS values. Some of the higher measured values are underpredicted by SWAT. Since the predicted sediment concentrations are highly correlated to flow, if SWAT under- or over-predicts the flow for a storm event, this will also affect the predicted sediment.

A similar trend is seen at the Bois de Sioux River station west of Doran. Again, the midrange values are predicted fairly well, while some of the higher measured TSS values are underpredicted by SWAT, especially during the summer of 2005. This may be a result of storm runoff events that were underestimated by the model, as is shown in the flow calibration hydrograph for this location (Figure 10).

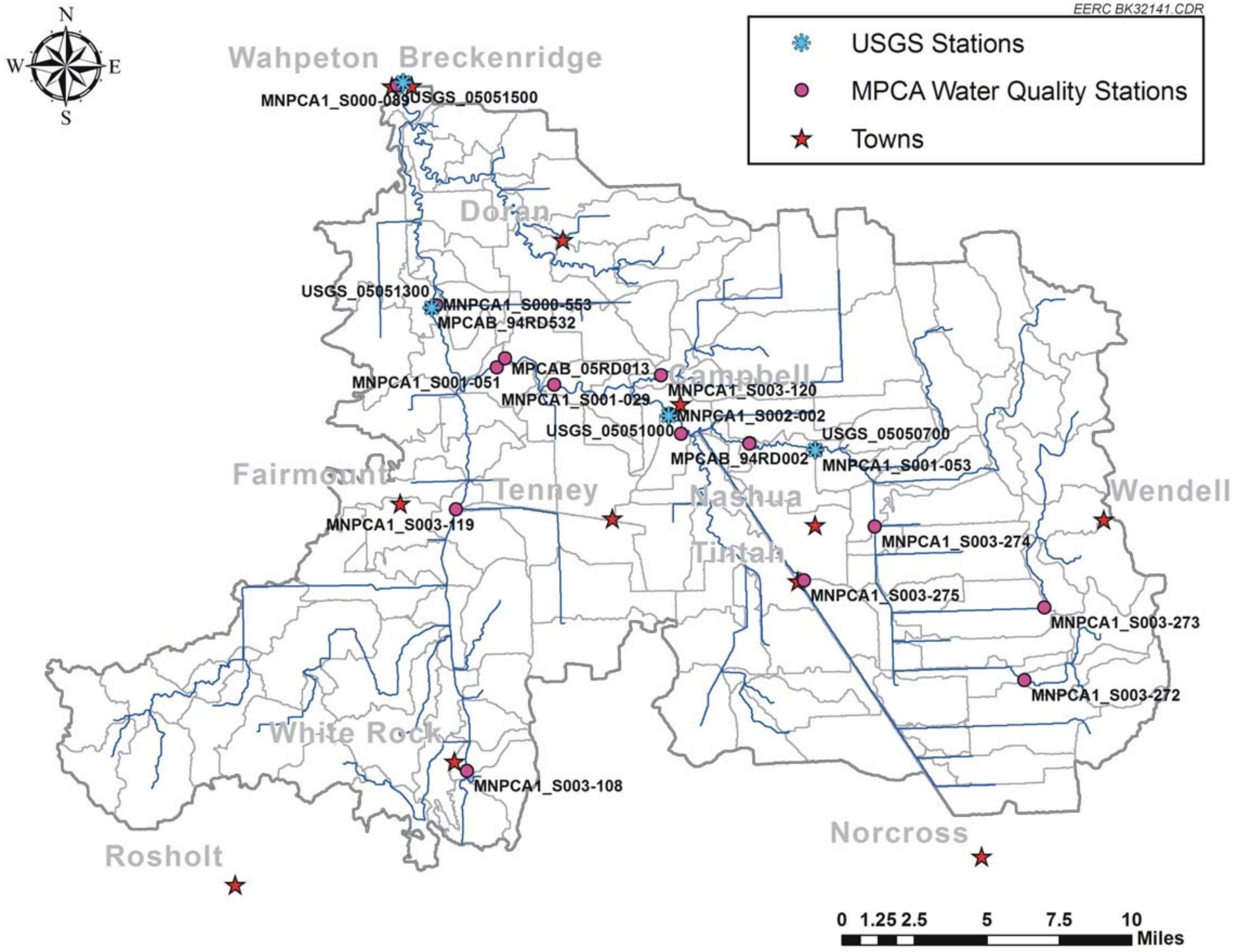

Figure 11. Location of MPCA water quality stations and USGS flow gaging stations.

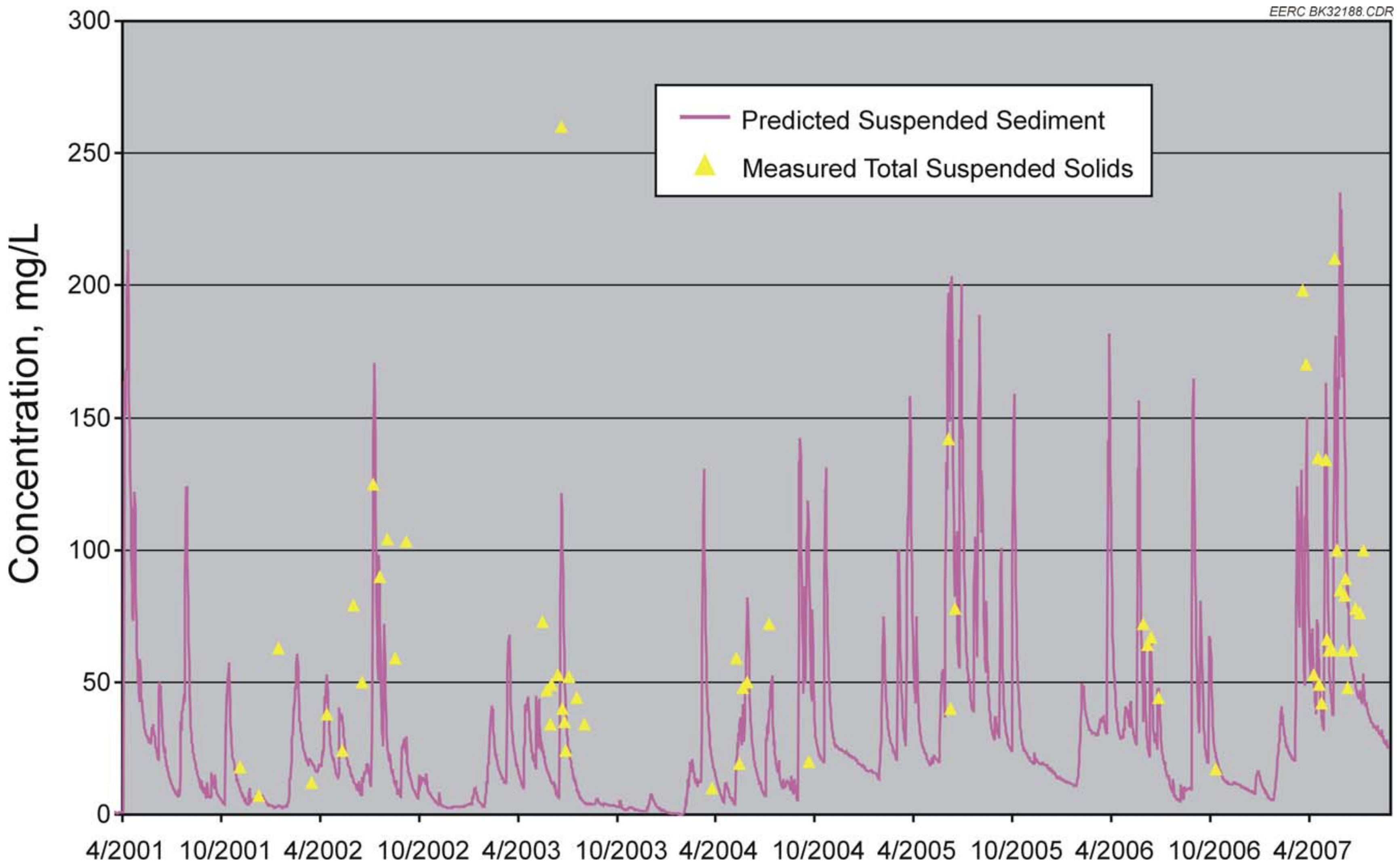

Figure 12. Comparison of SWAT-predicted suspended sediment versus measured TSS concentrations along the Rabbit River.

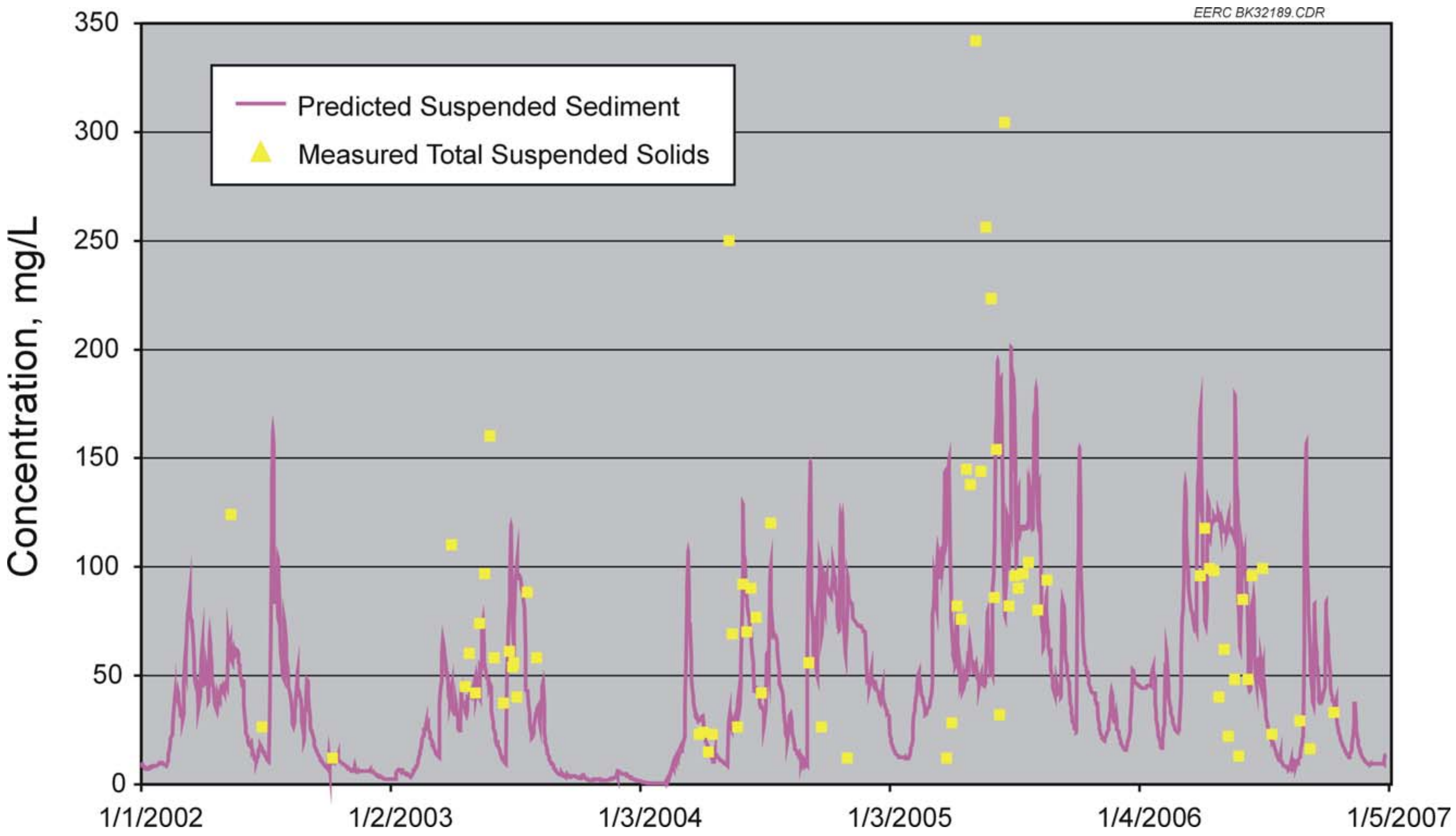

Figure 13. Comparison of SWAT-predicted suspended sediment versus measured TSS concentrations along the Bois de Sioux River.

A comparison of predicted annual sediment loads to estimates published in a report by Paakh et al. (2006) is possible for the Bois de Sioux site near Doran. The load estimates reported by Paakh et al. (2006) were compiled using measured TSS concentrations for the 2003, 2004, and 2005 monitoring seasons, coupled with USGS flow data and the FLUX model. Table 8 shows the annual loads listed in the report versus the loads predicted by the SWAT model. The 2003 loads predicted by SWAT are much lower than the reported values, and the predicted 2004 loads are quite a bit higher. The 2005 loads are quite close in value. Based on comparison with this limited data set, there does not appear to be any trends in the data (i.e., consistent under- or over-prediction).

5.0 DEVELOPMENT AND CALIBRATION OF THE MUSTINKA RIVER WATERSHED MODEL

5.1 Model Development

5.1.1 Watershed Delineation

The Mustinka River watershed subbasins were defined based on the corrected NED and stream location data sets provided by JOR Engineering. A trial-and-error approach was used during this step to ensure that the subbasins were relatively similar in size and to ensure that the subbasin outlets were correlated to most USGS gaging and MPCA water quality station locations. The subbasin outlets were also designated to coincide with the outlets of the major reservoirs located throughout the watershed. A total of 128 subbasins with an average area of 17.0 square kilometers (6.6 square miles) were defined within the watershed. The location and number of each subbasin, as well as the location of USGS and MPCA water quality stations are shown in Figure 14. The total area of the Mustinka River Watershed included in the SWAT model was 2174.6 square kilometers (839.6 square miles).

Once the subbasins were delineated, a total of 22 reservoirs were defined within the model (Table 9). SWAT only allows one reservoir to be designated per subbasin, thus the locations of the various reservoirs were taken into account during the subbasin delineation step to ensure that two major reservoirs would not be located within the boundaries of one subbasin. Just as with the Bois de Sioux Watershed model, the reservoirs were modeled using a targeted release rate. The reservoir parameters needed for input to the model were determined using reservoir data provided by JOR Engineering.

Table 8. Comparison of Sediment Loads Estimated at the Bois de Sioux River Site Near Doran, Minnesota

	2003	2004	2005
Estimated Sediment Loads Reported by Paakh et al. (2006)	14,449	9164	63,333
SWAT Estimated Sediment Loads	6577	15,236	60,284

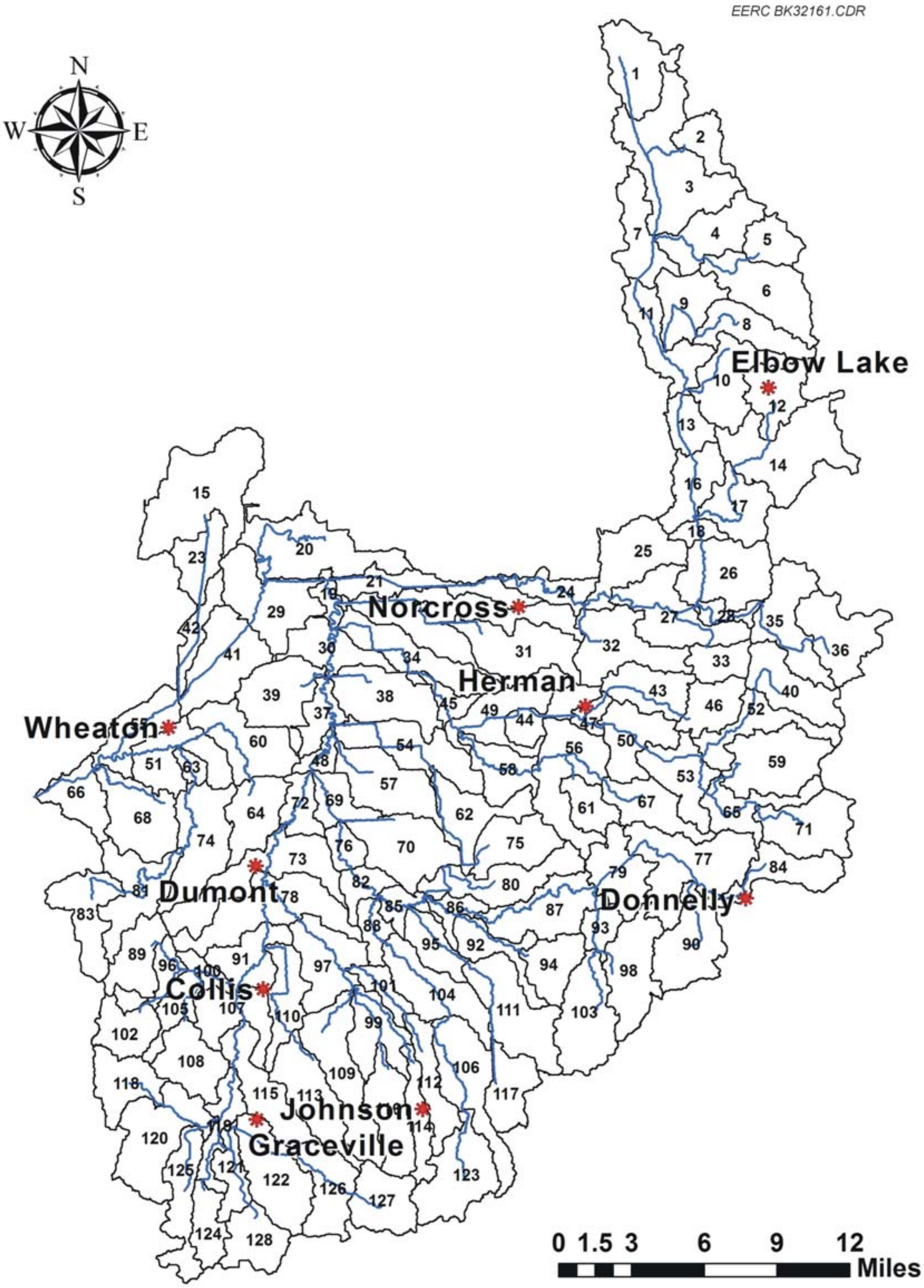

Figure 14. Location of the subbasins delineated within the Mustinka River Watershed.

Table 9. Reservoirs Included Within the Mustinka River Watershed Model

Reservoir Name	Subbasin Location	Township/Range/Section
Stony Brook Lake	3	T: 130; R: 43; Section 10
Lightning Lake	7	T: 130; R: 43; Section 21
Island Lake	12	T: 129; R: 42; Section 20
Round Lake	14	T: 129; R: 42; Section 31
Pine Ridge Park	27	T: 128, R: 43; Section 30
Burr Lake	33	T: 127; R: 43; Section 02
Big Lake	43	T: 127; R: 43; Section 18
Ohlsrud Lake	46	T: 127; R: 43; Section 22
Pullman Lake	47	T: 127; R: 44; Section 23
Nelson Lake	50	T: 127; R: 43; Section 19
Niemakl Lakes	53	T: 127; R: 43; Section 29
Cottonwood Lake	59	T: 127; R: 43; Section 36
Cheney Trust WPA	61	T: 127; R: 44; Section 35
Sherstad Slough	65	T: 126; R: 43; Section 02
Lundberg Lake	84	T: 126; R: 43; Section 26
Mud Lake	93	T: 126; R: 44; Section 36
Fish Lake	98	T: 125; R: 44; Section 01
Saint Mary's Lake	108	T: 125; R: 46; Section 19
West Toqua Lake	121	T: 124; R: 46; Section 08
East Toqua Lake	122	T: 124; R: 46; Section 09
Moonshine Lake	127	T: 124; R: 45; Section 30
North Rothwell	128	T: 124; R: 46; Section 28

5.1.2 HRU Delineation

Figures 15, 16, and 17 show the distribution of land use, soils, and slopes used to define the HRUs within the Mustinka River Watershed. Table 10 shows the percent distribution of land use within the watershed. Table 11 lists the soil types that comprise more than 0.5% of the watershed area. A total of 3013 HRUs were defined using the following threshold criteria:

- Land use: 5%
- Soil type: 15%
- Slope: 5%

The selected thresholds resulted in an average of 23.5 HRUs per subbasin. Similar to the Bois de Sioux model, a larger number of HRUs was necessary to capture the variability within each subbasin given the more detailed land use and soil data sets used for this project.

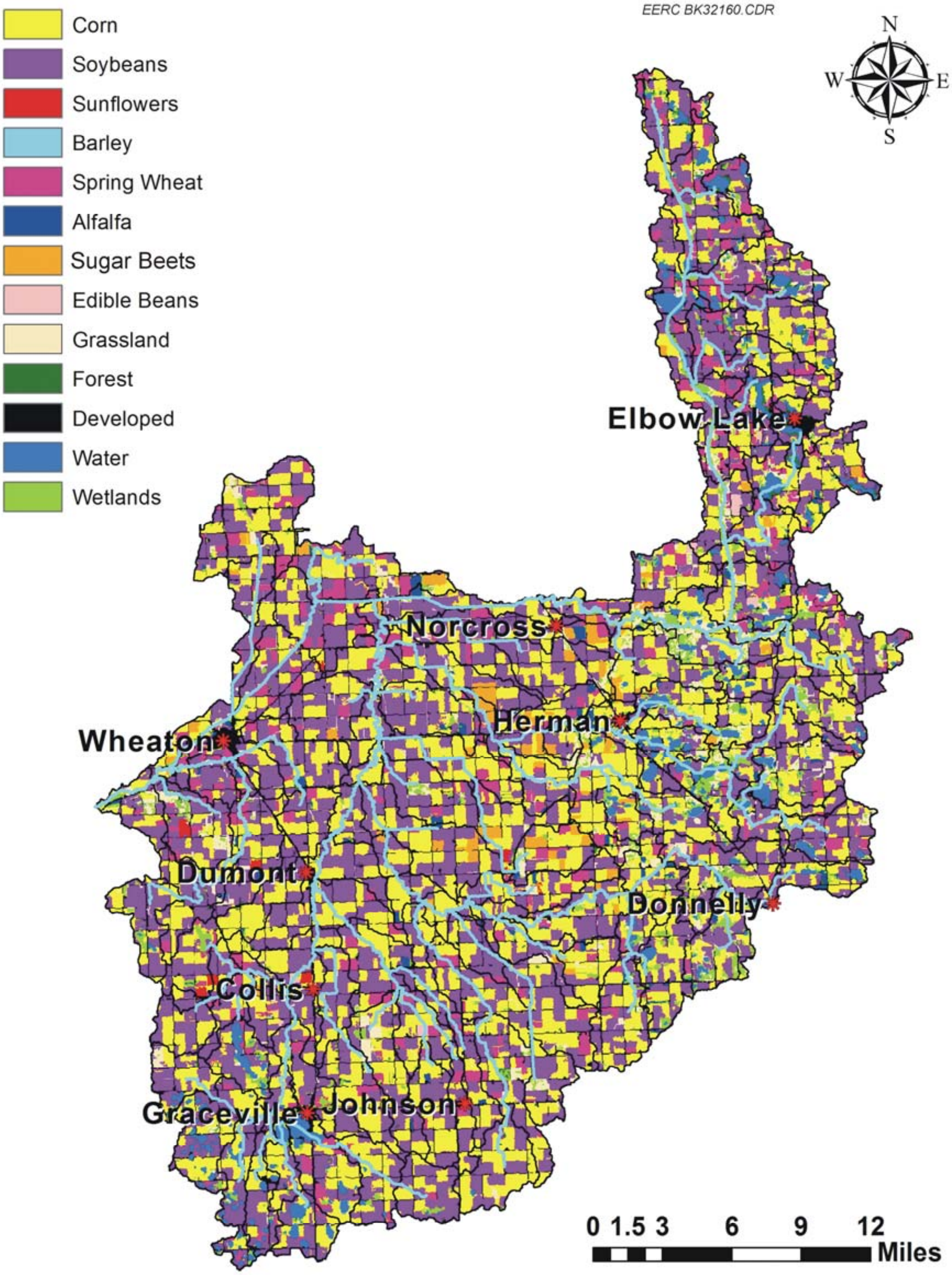

Figure 15. Distribution of land use within the Mustinka River Watershed.

Figure 16. Distribution of soil types within the Mustinka River Watershed.

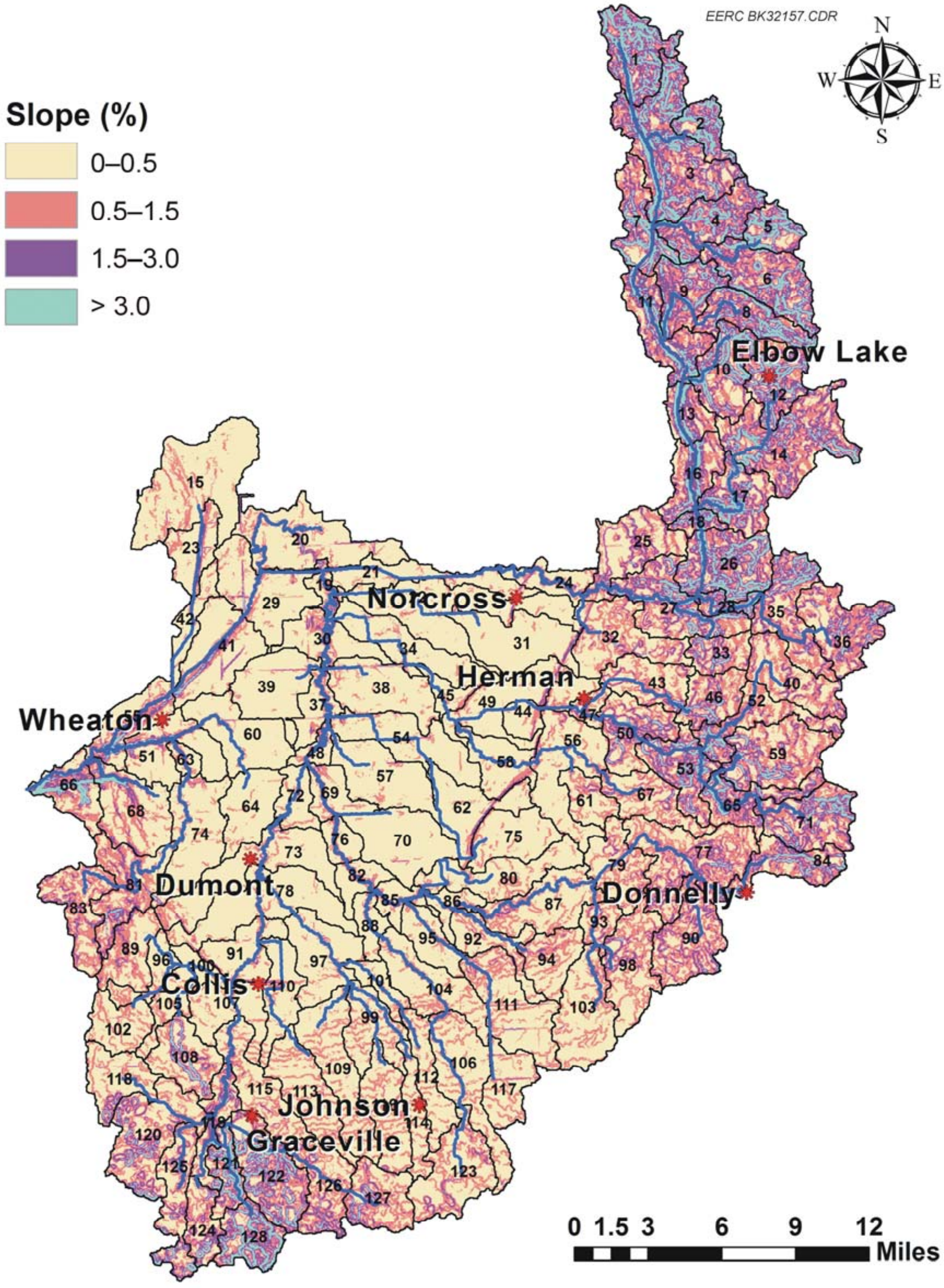

Figure 17. Distribution of slopes within the Mustinka River Watershed.

Table 10. Distribution of Land Use Within the Mustinka River Watershed

Land Use	Area, acres	% of Watershed Area
Soybeans	217,334	40.45
Corn	193,272	35.97
Spring Wheat	29,356	5.46
Sugar Beets	6181	1.15
Edible Beans	349	0.06
Sunflowers	196	0.04
Alfalfa	174	0.03
Grassland	18,220	3.39
Wetlands	18,141	3.38
Forest	334	0.06
Developed	37,456	6.97
Water	16,340	3.04

Table 11. Soil Types that Comprise more than 0.5% of the Watershed Area

Soil Name	Area, acres	% of Watershed Area*
Hamerly	198,456	36.93
Doran	74,355	13.84
Formdale	48,051	8.94
Glyndon	33,283	6.19
Aazdahl	30,448	5.67
McIntosh	22,515	4.19
Bearden	19,732	3.67
Fargo	17,584	3.27
Roliss	13,722	2.55
Water	9977	1.86
Forman	8161	1.52
Barnes	7447	1.39
Wheatville	7078	1.32
Buse	6884	1.28
Grimstad	6437	1.20
Langhei	5786	1.08
Vallers	4434	0.83
Kittson	4116	0.77

5.1.3 Climate Data

Two weather stations were used to provide precipitation and temperature data input to the model. The station name, number, and period of record is listed in Table 12, and the location of the stations within the watershed is shown in Figure 18. Missing values at individual stations were estimated based on data available at nearby stations using linear interpolation.

Based on the above data sets, the period of record of climate data incorporated into the model ranged from January 1, 1974, to August 31, 2007. Given the 4-year warm-up period used at the beginning of each model simulation, the total maximum simulation period of the model is January 1978 to August 2007.

5.1.4 Tillage Practices

The tillage practices within the Mustinka River Watershed were implemented just as described for the Bois de Sioux model. The types of tillage practices implemented in 2004 for Grant, Otter Tail, Traverse, and Wilkin Counties is shown in Table 3.

5.2 Flow Calibration

Unlike the Bois de Sioux SWAT model, there were no continuous flow data available for calibration of the Mustinka model. While there are historic data records for four USGS gaging stations located within the watershed, the data do not extend beyond the 1950s and did not overlap with the simulation period of the model (January 1974 to August 2007).

While no continuous flow data exist, spot flow measurements and stage data are collected at 26 gages throughout the Mustinka Watershed (Table 13 and Figure 19). These stations are maintained by the Bois de Sioux Watershed District. Stage readings are taken at 20 of the gages by a network of volunteers who submit readings to the BDSWD office on an annual basis. The remaining stations are automated and provide real-time measurements that are available through JOR Engineering. Four of these stations, Gages 5, 23, 34, and 53, have continuous-stage data beginning in 2003 provided by the U.S. Army Corps of Engineers, St. Paul District.

In addition to collection of stage data, BDSWD also collects occasional stream flow measurements at many sites. These data have been used by JOR Engineering to construct rating curves that can be used to estimate stream flows based on stage readings for several of the

Table 12. Location of the Weather Stations Used to Provide Climate Data Input to the SWAT Model

Station Name	COOPID Number	Period of Record
Brown’s Valley	211063	December 1973 – Present
Wheaton, Minnesota	218907	May 1914 – Present

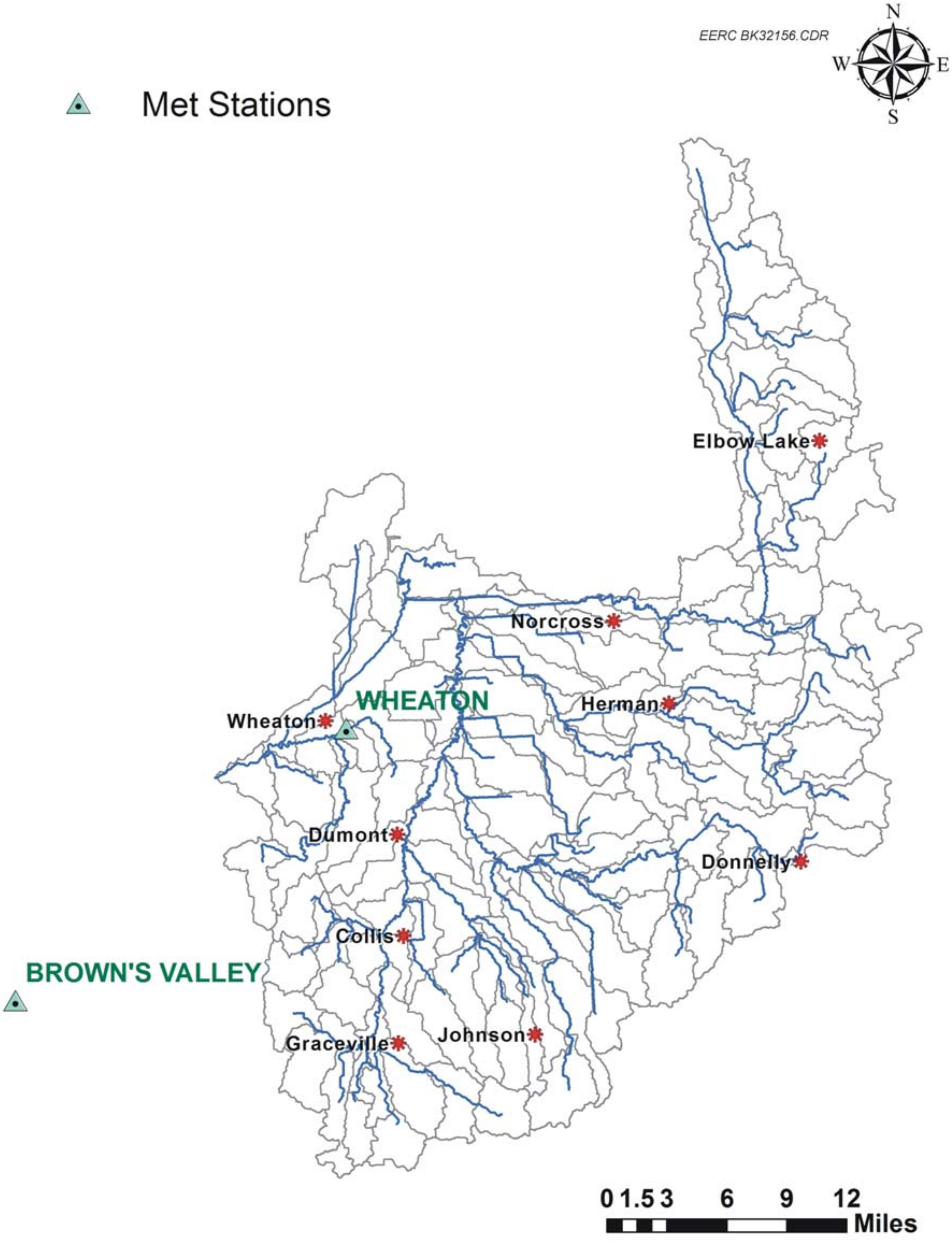

Figure 18. Location of the weather stations used to provide climate data for the model.

Table 13. Locations of the BDSWD Gage Sites Located Within the Mustinka River Watershed

Gage Number	Station Type	Stream
1	Staff	Mustinka River
2	Staff	Mustinka River
3	Staff	Mustinka River
4	Staff	Mustinka River
5	Remote	Twelve Mile Creek
11	Staff	Grant County Ditch 8
12	Staff	Twelve Mile Creek
13	Staff	Twelve Mile Creek
15	Staff	West Fork Twelve Mile Creek
16	Remote	Twelve Mile Creek
17	Staff	West Branch Twelve Mile Creek
18	Staff	East Fork West Branch Twelve Mile Creek
19	Staff	West Branch Twelve Mile Creek
20	Staff	West Branch Twelve Mile Creek
21	Staff	West Branch Eighteen Mile Creek
22	Staff	Eighteen Mile Creek
23	Remote	Five Mile Creek
32	Remote	Mustinka River
33	Staff	Mustinka River
34	Remote	West Branch Twelve Mile Creek
41	Staff	Fish Lake Outlet
42	Staff	Mud Lake Outlet
52	Staff	Twelve Mile Creek
53	Remote	Mustinka River
54	Staff	Five Mile Creek
55	Staff	Big Stone County Ditch 8

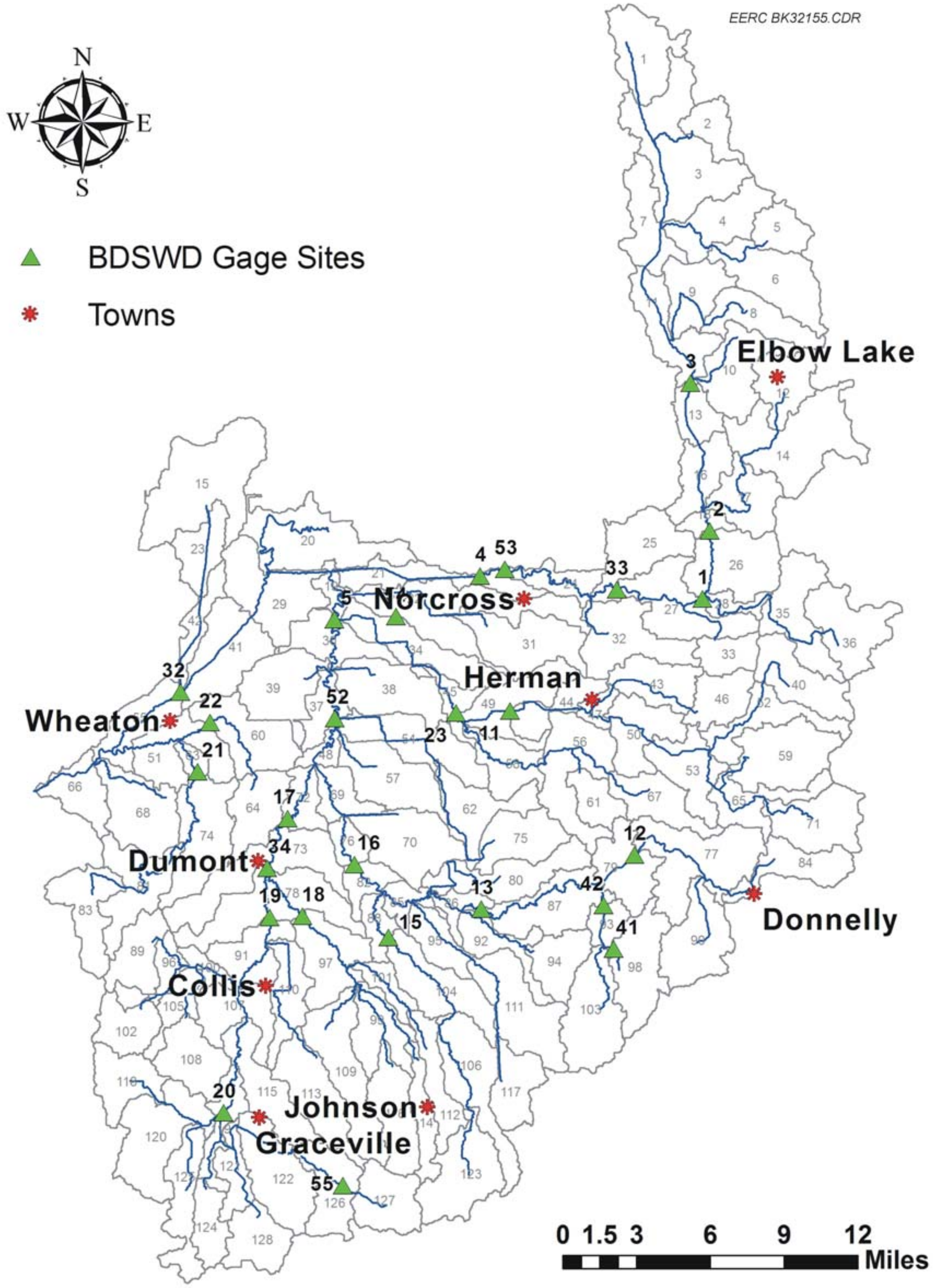

Figure 19. Location of the BDSWD gage sites within the Mustinka River Watershed.

gaging sites. While caution must be exercised when using the flows estimated from this approach, these data still provide a valuable resource for model calibration when continuous flow readings are not available.

The rating curves developed by JOR Engineering were used to estimate flows for several of the gage sites. These "observed" flow data were then used for comparison with model-predicted flows. The data from four gages, 5, 23, 32, and 34, were selected for model calibration. While Gage 53 has continuous-stage readings, several of the stage values were lower than the stage readings used to develop the rating curve and, therefore, could not be used to estimate flow values. After removal of the missing values and stage readings that were outside the rating curve, few data points were left.

The predicted versus stage-derived flows for each of the four calibration gages are shown in Figures 20–23. Missing data values in the observed data are plotted as zero so, in most cases, it is not possible to compare the shapes of the peaks – only the magnitude. Also, because many of the observed data points are missing, in most of the cases where the model predicts a peak but none is reflected by the observed data, it is because the observed data are absent. Overall, the peak timing appears to match quite well, while a comparison of peak magnitudes at all stations indicates that the peak magnitudes appear equally over- and under-estimated (in cases where they do not match).

It should be noted that while the stage-derived flows provide a range of values to use for calibration, the accuracy of the data is not absolute, and caution should be exercised. For example, a comparison of stage-derived flows versus spot flow measurements collected by BDSWD at Gage 5 reveals that it is not uncommon for the stage-derived flows to be off as much as 30% or more (Table 14). Given the questionable and discontinuous nature of the stage-derived flow data available for this watershed, calibration statistics were not calculated for the Mustinka River SWAT model.

Table 15 lists the various model parameters that were adjusted to calibrate the model, including the default and calibrated parameter values. The calibration parameters were adjusted to reflect conditions most appropriate for the RRB and Mustinka River Watershed region.

5.3 Sediment Comparison

There are several MPCA water quality stations located throughout the Mustinka River Watershed (Figure 24); however, most have very limited sediment data, if at all. Two stations have more than 20 sediment data points – one located along the Mustinka River at Wheaton (Station MNPCA S000-062) and one located along the Mustinka River near Norcross (Station MNPCA S002-001). These stations were used to calibrate the model as well as possible for sediment output given the limited data. As previously mentioned, the assumption used here is that the measured TSS concentrations are close enough in value to suspended sediment concentrations to be used for comparison.

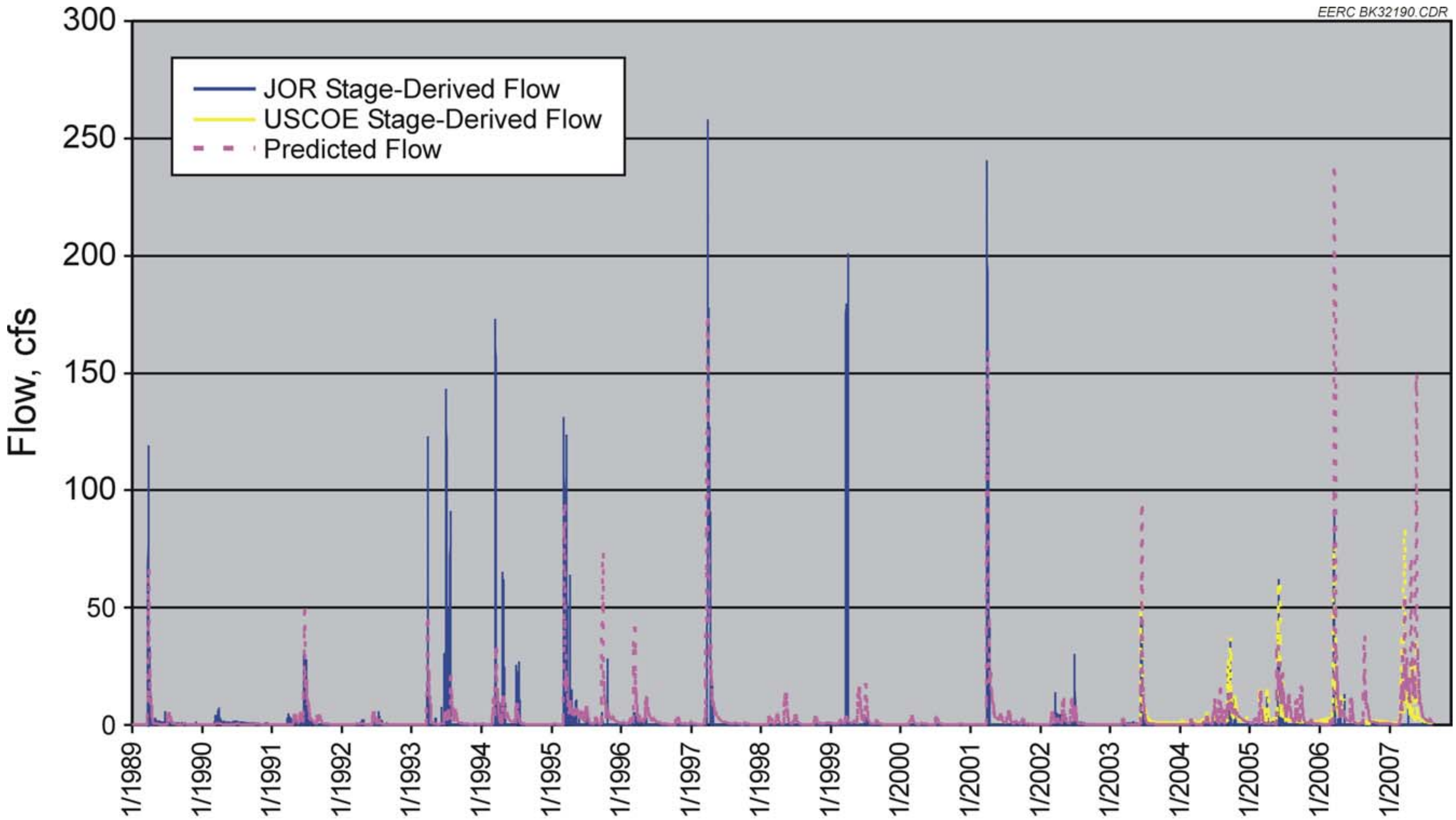

Figure 20. Comparison of stage-derived and model-predicted flows for Twelve Mile Creek west of Norcross, Minnesota.

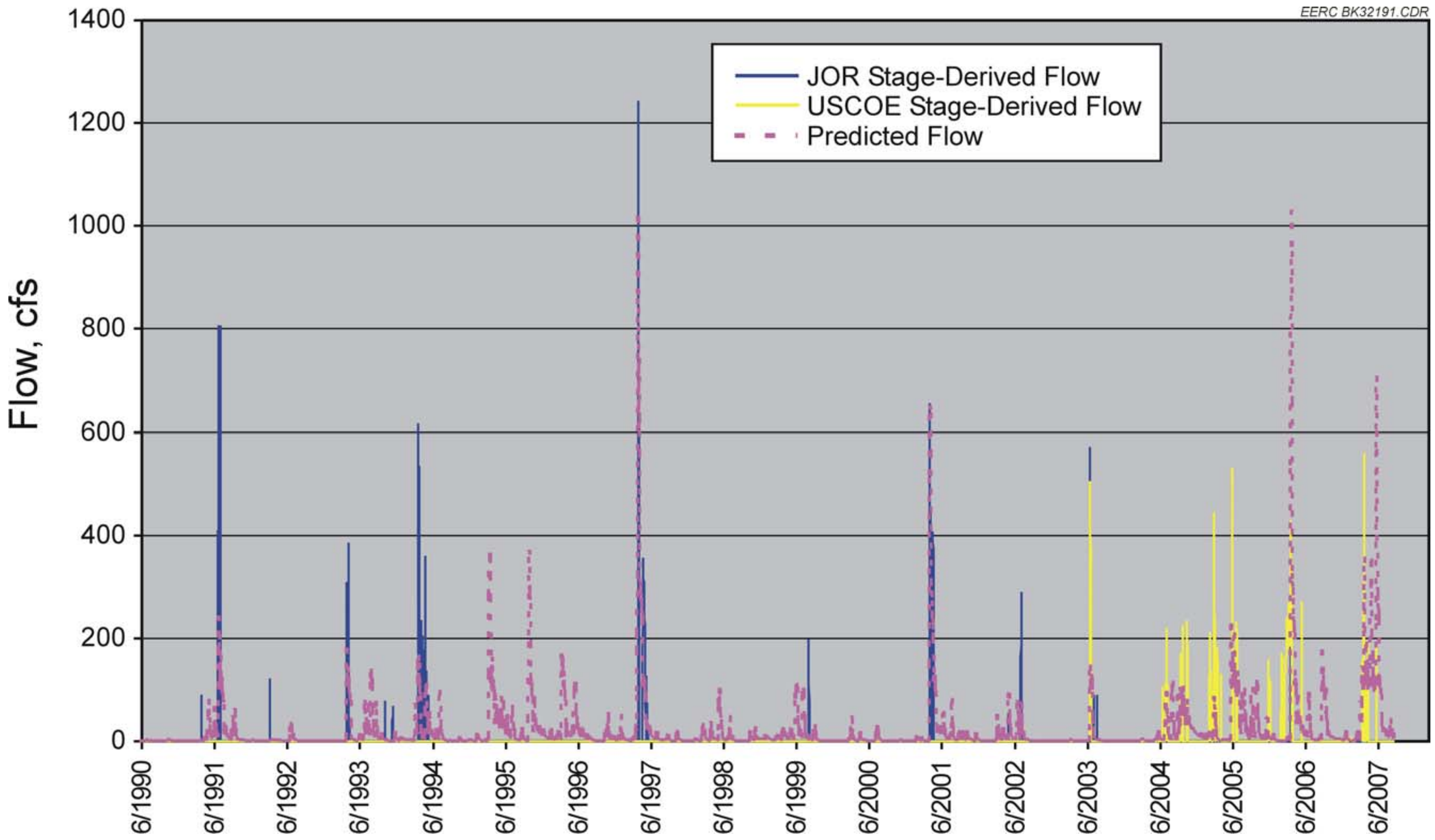

Figure 21. Comparison of stage-derived and model-predicted flows for Five Mile Creek near Norman, Minnesota.

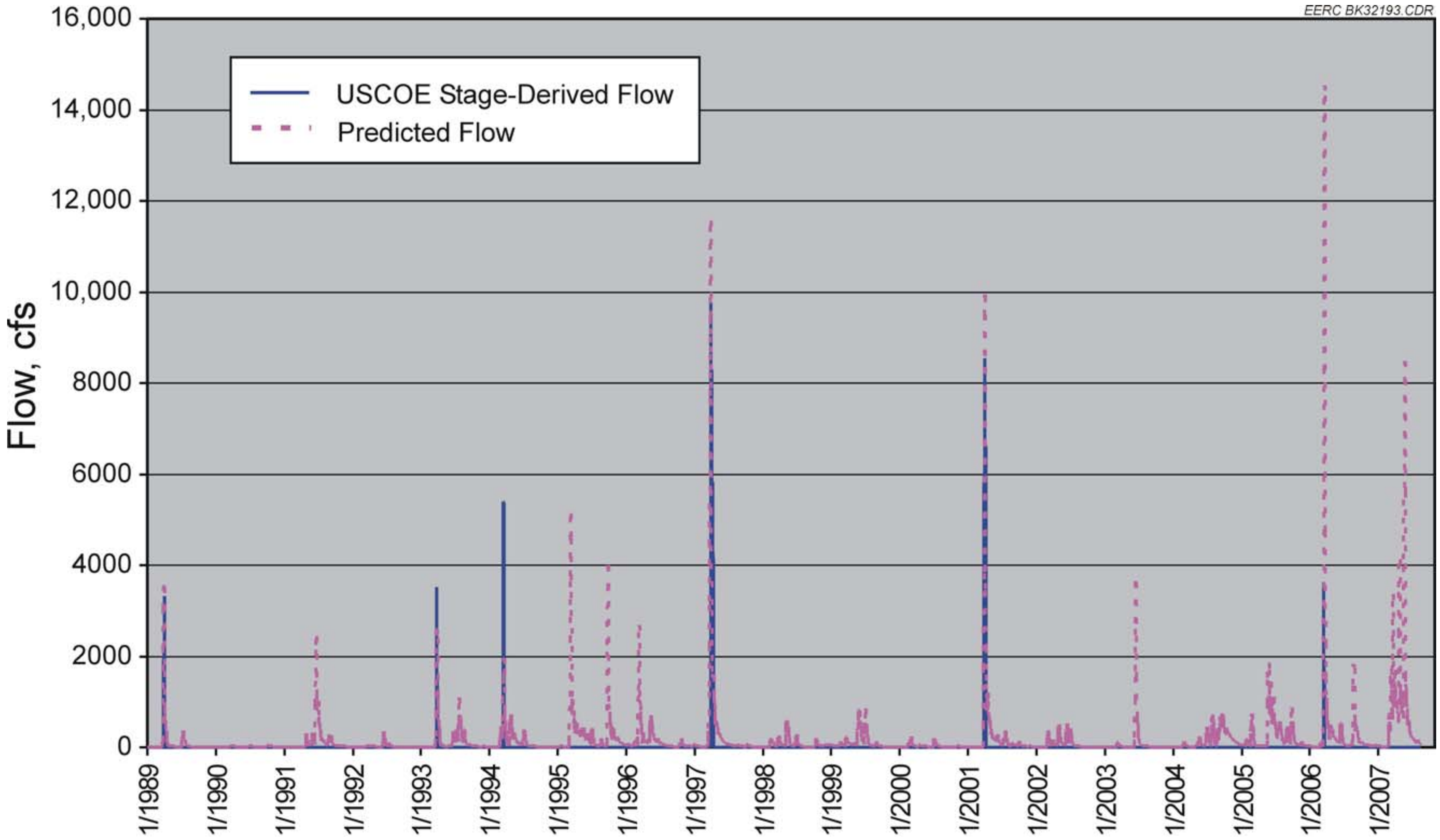

Figure 22. Comparison of stage-derived and model-predicted flows for the Mustinka River near Wheaton, Minnesota.

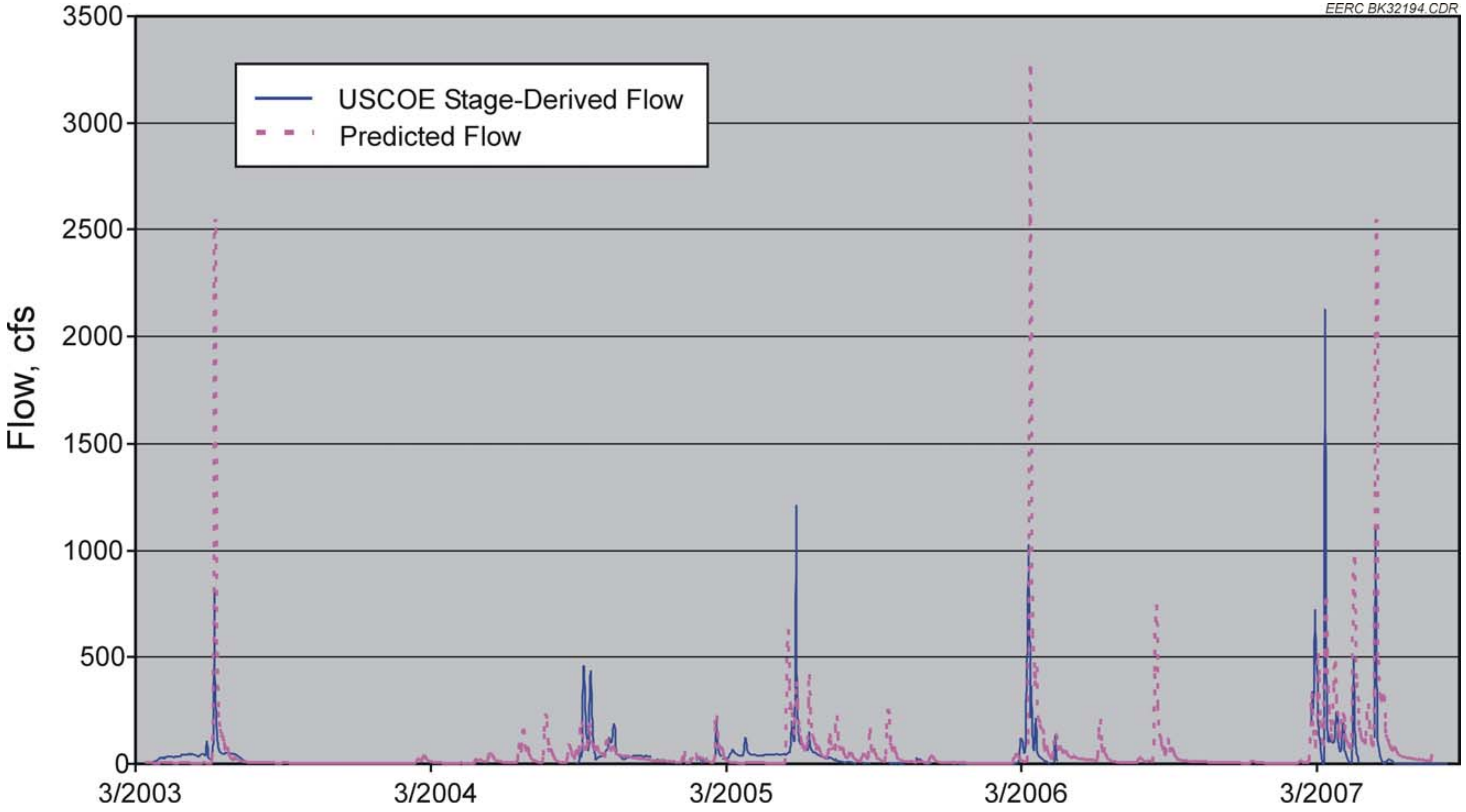

Figure 23. Comparison of stage-derived and model-predicted flows for Twelve Mile Creek at Dumont, Minnesota.

Table 14. Comparison of Stage-Derived and Measured Flows for Twelve Mile Creek West of Norcross, Minnesota (Gage 5)

Date	Stage-Derived Flow, cfs	Measured Flow, cfs	% Error
3/29/1989	2437	1087	−124.2
4/3/1989	1164	448	−159.7
3/31/1993	1883	2063	8.7
6/23/1993	583	728	19.9
3/21/1994	6087	4510	−35.0
3/22/1994	3839	682	−463.2
4/25/1994	274	1518	82.0
5/7/1994	873	539	−62.0
3/15/1995	2168	2009	−7.9
3/17/1995	1024	967	−5.8
3/28/1995	4341	4241	−2.4
3/29/1995	2290	2114	−8.3
3/30/1995	1542	1229	−25.5
4/13/1995	284	425	33.1
4/14/1995	416	491	15.2
4/10/1996	204	220	7.4
4/3/1997	5551	3754	−47.9
4/4/1997	7664	11,022	30.5
4/5/1997	7319	12,072	39.4
4/13/1997	3097	3191	3.0
4/14/1997	4341	4325	−0.4
4/15/1997	4083	4363	6.4
4/16/1997	2824	2666	−5.9
3/30/2006	3253	2964	−9.7
4/24/2007	635	588	−8.0
7/11/2007	44	28	−58.0

Table 15. Parameters Adjusted to Calibrate the Mustinka River SWAT Model

Parameter	Default Value	Calibration Value	Description
SFTMP	1	1	Snowfall temperature, °C
SMTMP	0.5	2	Snowmelt base temperature, °C
SMFMX	4.5	6.5	Melt factor for snow on June 21 (mmH_2O/°C-day)
SMFMN	4.5	1.5	Melt factor for snow on December 21 (mmH_2O/°C-day)
TIMP	1	0.5	Snow pack temperature lag factor
SNOCOVMX	1	50	Minimum snow water content that corresponds to 100% snow cover (mm H_2O)
SNO50COV	0.5	0.3	Fraction of snow volume represented by SNOCOVMX that corresponds to 50% snow cover
IPET	1	2	PET method: 0 – Priestley–Taylor method 1 – Penman–Monteith method 2 – Hargreaves method 3 – Manually input PET values
ESCO	0.95	0.9	Soil evaporation compensation factor
SURLAG	4	1.5	Surface runoff lag coefficient
SPCON	0.0001	0.0006	Linear parameter for calculating the maximum amount of sediment that can be reentrained during channel sediment routing
SPEXP	1	1.5	Exponent parameter for calculating sediment reentrained in channel sediment routing
IRTE	0	1	Channel water routing method: 0 = variable storage method; 1 = Muskingum routing method
MSK_CO1	0	0.8	Muskingum calibration coefficient used to for normal flow
MSK_CO2	3.5	1	Muskingum calibration coefficient used to for low flow
MSK_X	0.2	0.2	Muskingum weighting factor used to control the relative importance of inflow and outflow in determining the storage in a reach
ALPHA_BF	0.048	0.1	Baseflow alpha factor (days)
GW_REVAP	0.02	0.1	Groundwater reevaporation coefficient
REVAPMN	1	200	Threshold depth of water in the shallow aquifer for reevaporation or percolation to the deep aquifer to occur (mmH_2O)

Continued . . .

Table 15. Parameters Adjusted to Calibrate the Mustinka River SWAT Model (continued)

RCHRG_DP	0.05	0.4	Deep aquifer percolation fraction
GWHT	1	6	Initial groundwater height (m)
CN2	Varies	+ 6.10%	Initial SCS runoff curve number for moisture condition II
CH_K1	0.5	15	Effective hydraulic conductivity in tributary channel alluvium (mm/hr).
CH_N1	0.014	0.045	Manning's "n" value for the subbasin tributary channels
CH_N2	0.014	0.04	Manning's "n" value for the main channel in each subbasin
CH_K2	0	25	Effective hydraulic conductivity in main channel alluvium (mm/hr)
CH_EROD	0	0.1	Channel erodibility factor
CH_COV	0	0.65	Channel cover factor
ALPHA_BNK	0	0.5	Baseflow alpha factor for bank storage (days)
SOL_AWC	Varies	+ 20%	Available water capacity of the soil layer (mmH_2O/mm soil)
OV_N	Varies	0.13 (for cropland)	Manning's "n" value for overland flow

The suspended sediment concentrations predicted by SWAT versus the measured TSS concentrations for the two evaluation locations are shown in Figures 25 and 26. At the Mustinka River station near Campbell, most of the low- to mid-range values predicted by SWAT compare well to the measured TSS values. There are some points that do not compare well during the spring and early summer of 2003 and 2007. The 2007 values can be explained because of the overprediction of the peak flows by SWAT. The underprediction of the 2003 values may be a result of flows that are under-predicted by SWAT, but without reliable flow data, it is difficult to tell.

The measured TSS concentrations versus predicted sediment concentrations match well in most cases at the Mustinka River near Norcross. Again, there are values that are under- or over-predicted by the model. Without better flow data, it is difficult to tell if this is an issue related to inaccurate prediction of flows or if it is a reflection of the differences between TSS and suspended sediment at these times.

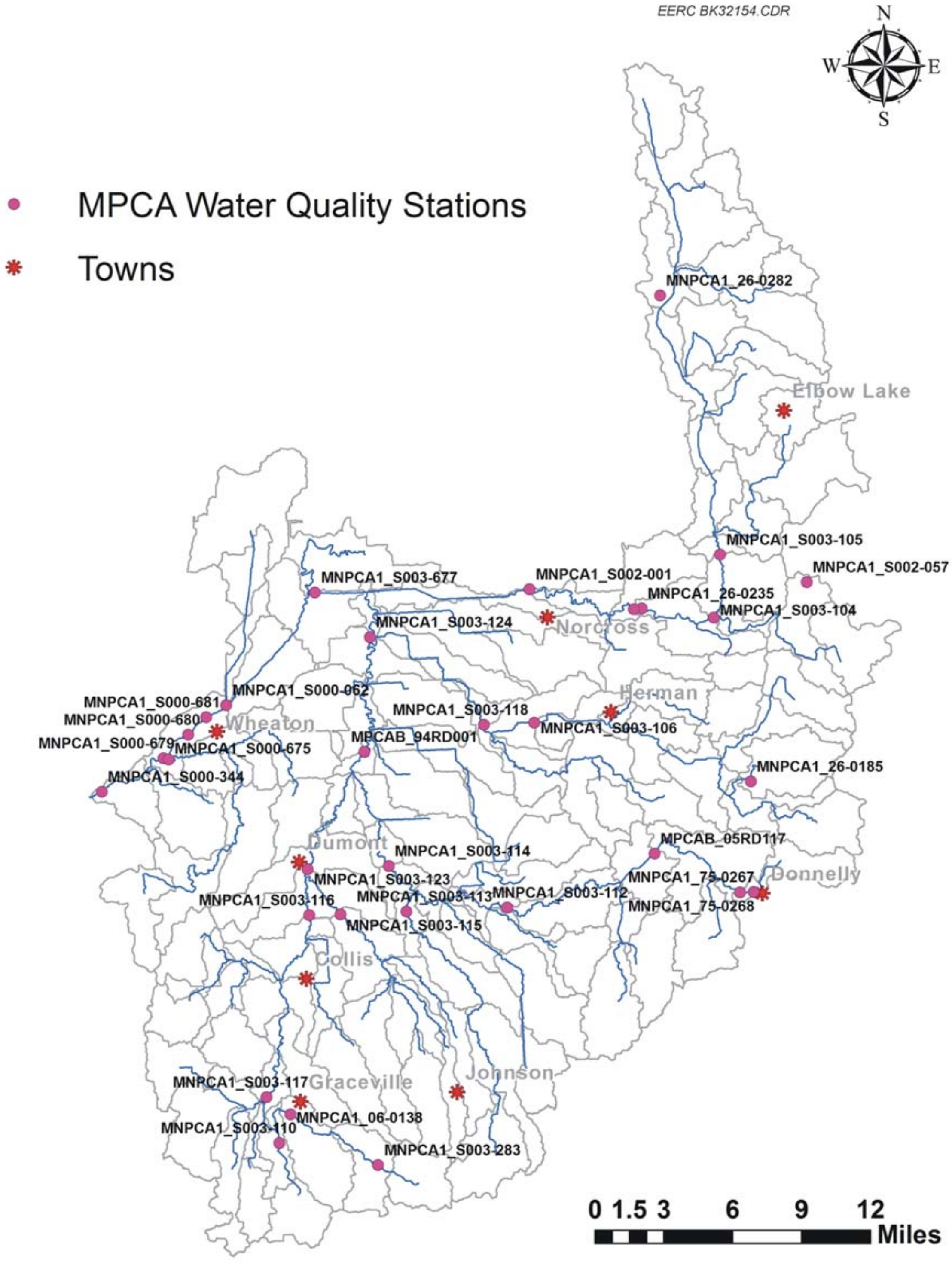

Figure 24. Location of MPCA water quality stations throughout the Mustinka River Watershed.

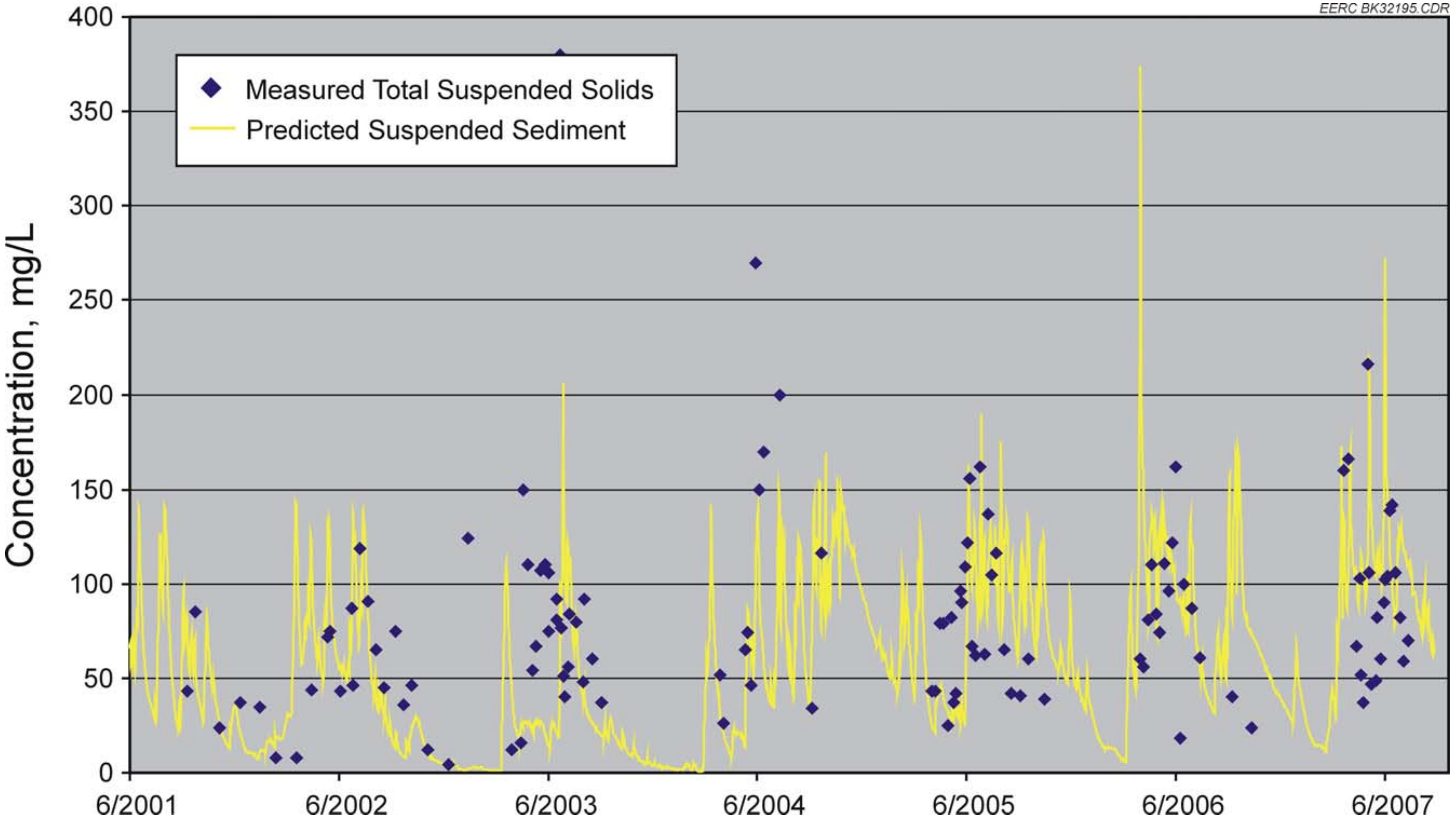

Figure 25. Comparison of measured TSS versus model-predicted suspended sediment at the Mustinka River near Wheaton, Minnesota.

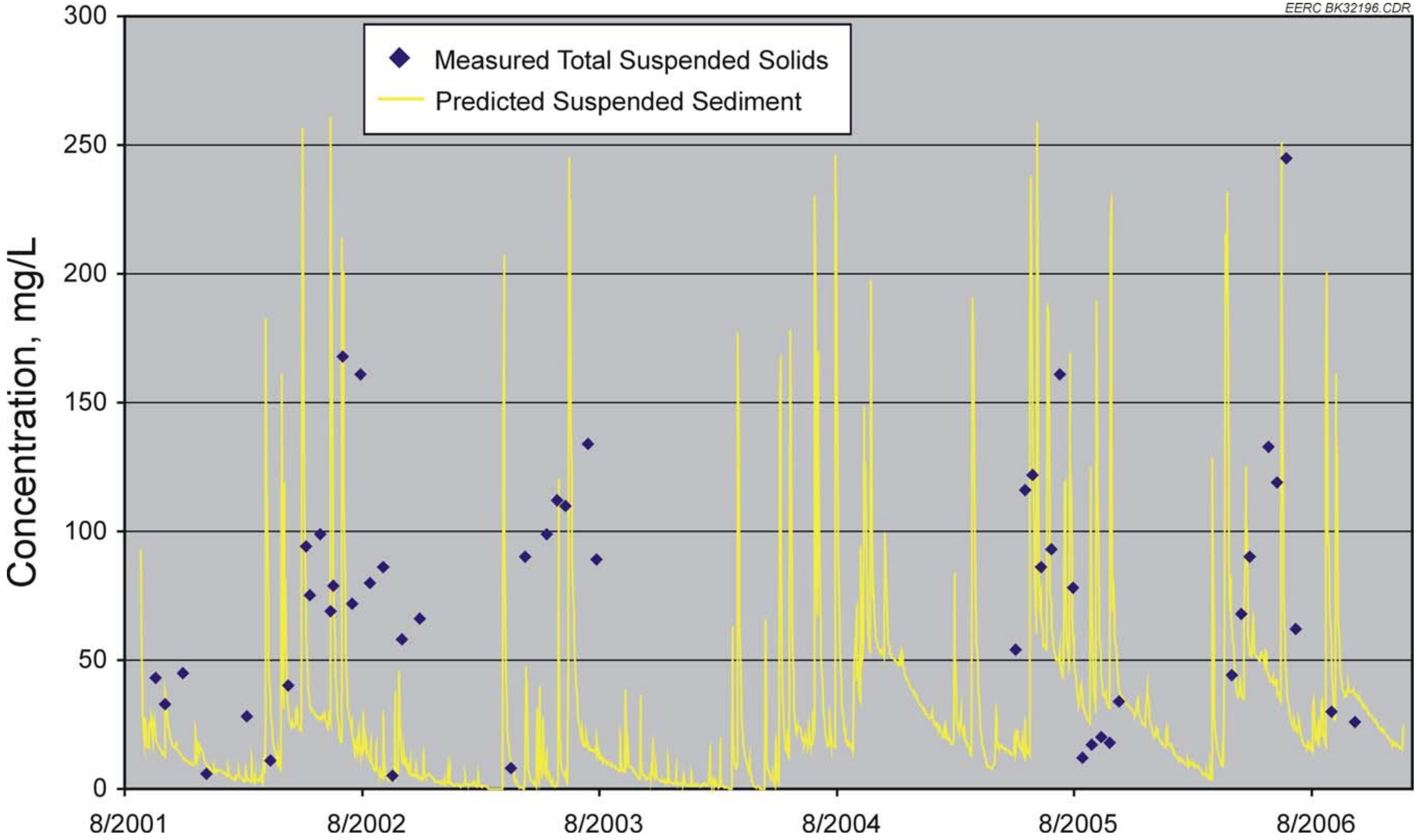

Figure 26. Comparison of measured TSS versus model-predicted suspended sediment at the Mustinka River near Norcross, Minnesota.

6.0 SEDIMENT-LOADING ASSESSMENT AND EVALUATION OF HYPOTHETICAL BMPs

In addition to predicting the amount of sediment loading in each subbasin reach, the SWAT model also predicts the amount of sediment eroded from the landscape within each subbasin. While this can be used to target subbasins for implementation of BMPs, careful attention must also be paid to the amount of sediment eroded from or deposited within individual stream reaches. The following section describes the sediment erosion and loading results from both watersheds as well as an evaluation of BMP implementation to help reduce sediment loading in the impaired waterways.

6.1 Bois de Sioux Results

The predicted overland erosion from the subbasins within the Bois de Sioux Watershed is shown in Figure 27. In general, there appears to be a correlation between slope and higher rates of sediment erosion; however, there are occasional subbasins that do not seem to fit this correlation. It is important to note that the subbasins with the highest overland sediment erosion rates do not necessarily contain stream reaches with the highest sediment-loading rates. Figure 28 shows the predicted sediment output, or loading, from the respective stream reach. This figure illustrates that many of the subbasins with high rates of overland erosion have relatively low sediment-loading rates (such as Subbasins 26, 27, 74, and 90). In some subbasins, the sediment eroding from the landscape and transported within the stream reach is retained by a reservoir, displayed as pink dots in Figure 28. In these instances, the sediment loading (or sediment output) of the subbasin in which the reservoir is located, as well as in downstream subbasins, will be relatively low even though the subbasin may exhibit high overland erosion rates. Good examples of this are seen with the reservoirs located in Subbasins 62 and 74. This is also supported by the SWAT model output, which lists the predicted sediment loading into and out of each reservoir. In all cases, the reservoirs intercept a large percentage of sediment from upstream sources.

Not all of the sediment that is eroded from the landscape and into the subbasin reaches is transported out of the subbasin. Figure 29 shows the predicted net sediment output from each of the subbasin reaches. It is calculated by subtracting the upstream inputs to the subbasin by the amount of sediment leaving the subbasin. Positive values indicate that more sediment is leaving the subbasin reach than is coming in. The source of this sediment can be from stream bank or bed erosion or from overland erosion. In subbasin reaches with high positive values (net output) but low overland erosion rates, a higher percentage of the sediment is probably coming from stream bank erosion. Negative values indicate that more sediment is coming in than is leaving, suggesting that, on average, sediment is being deposited into the reach. Most of the reaches within the watershed appear to be dominated by deposition. Because sediment transport or deposition within the stream reaches is controlled by flow volume and velocity, during major flood events much of the deposited sediment can be transported out of the stream reaches and eventually out of the watershed.

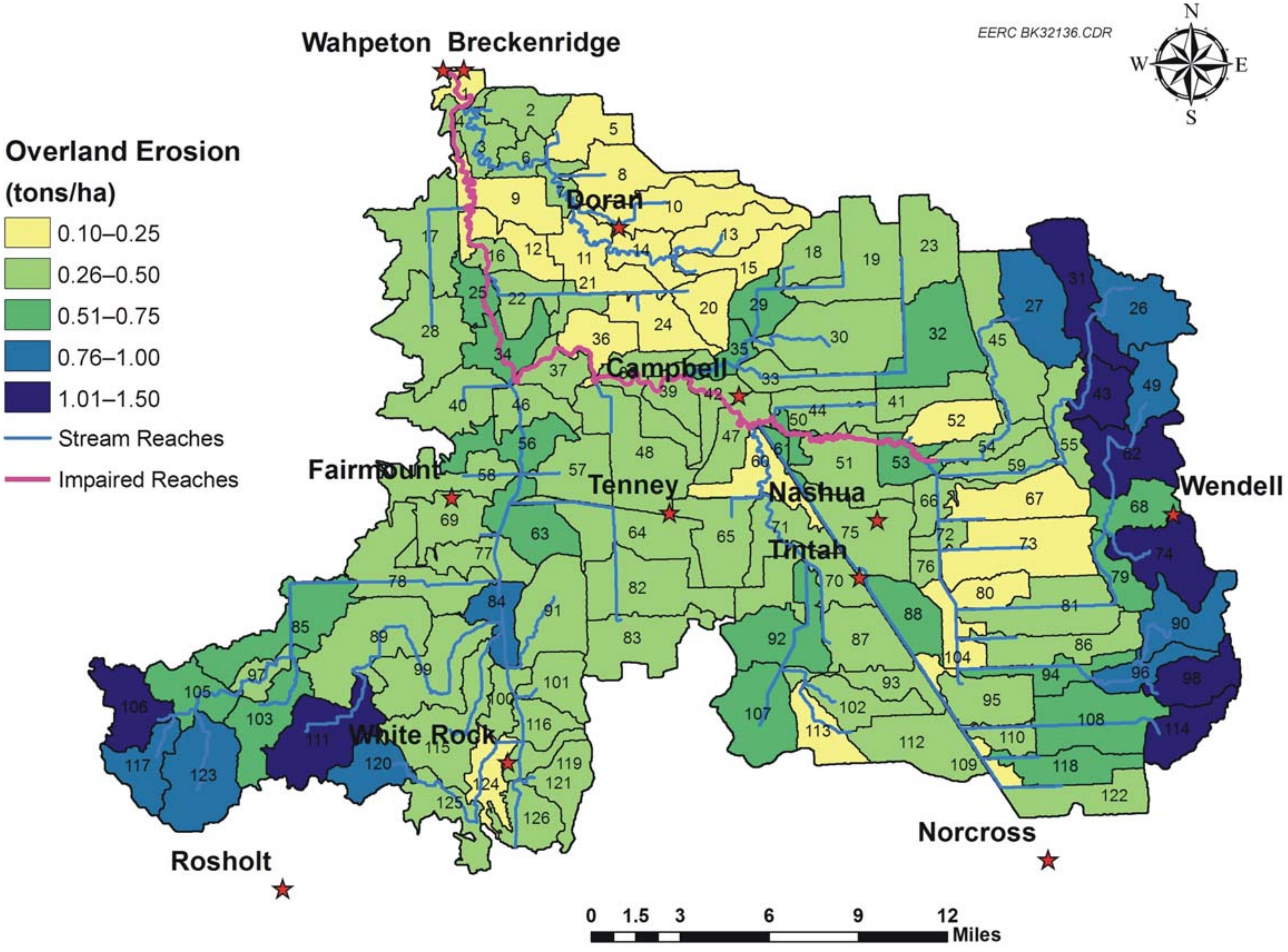

Figure 27. Estimated average annual sediment erosion from the landscape of the Bois de Sioux River Watershed.

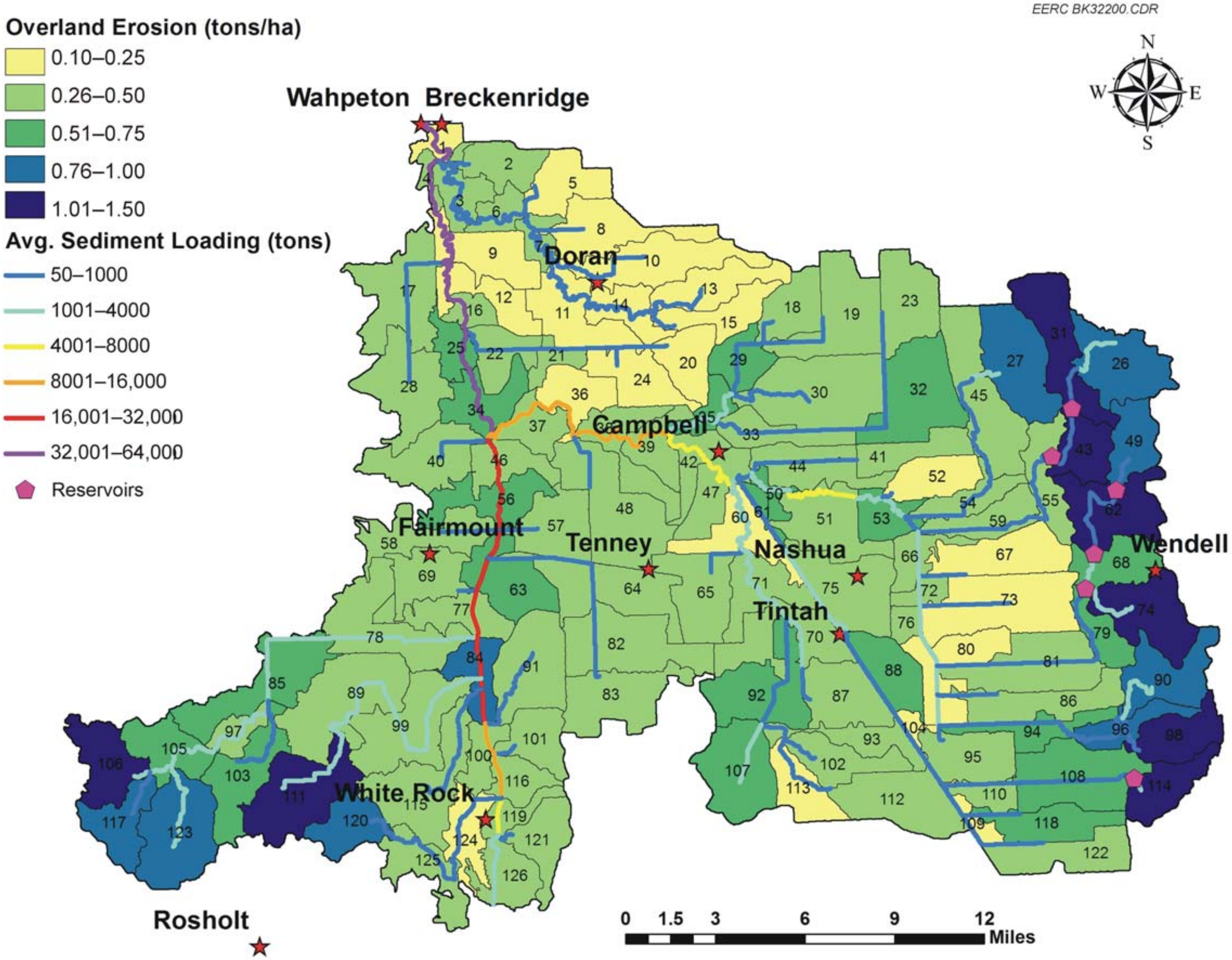

Figure 28. Estimated average annual sediment erosion from the landscape and sediment loading within the waterways of the Bois de Sioux River Watershed.

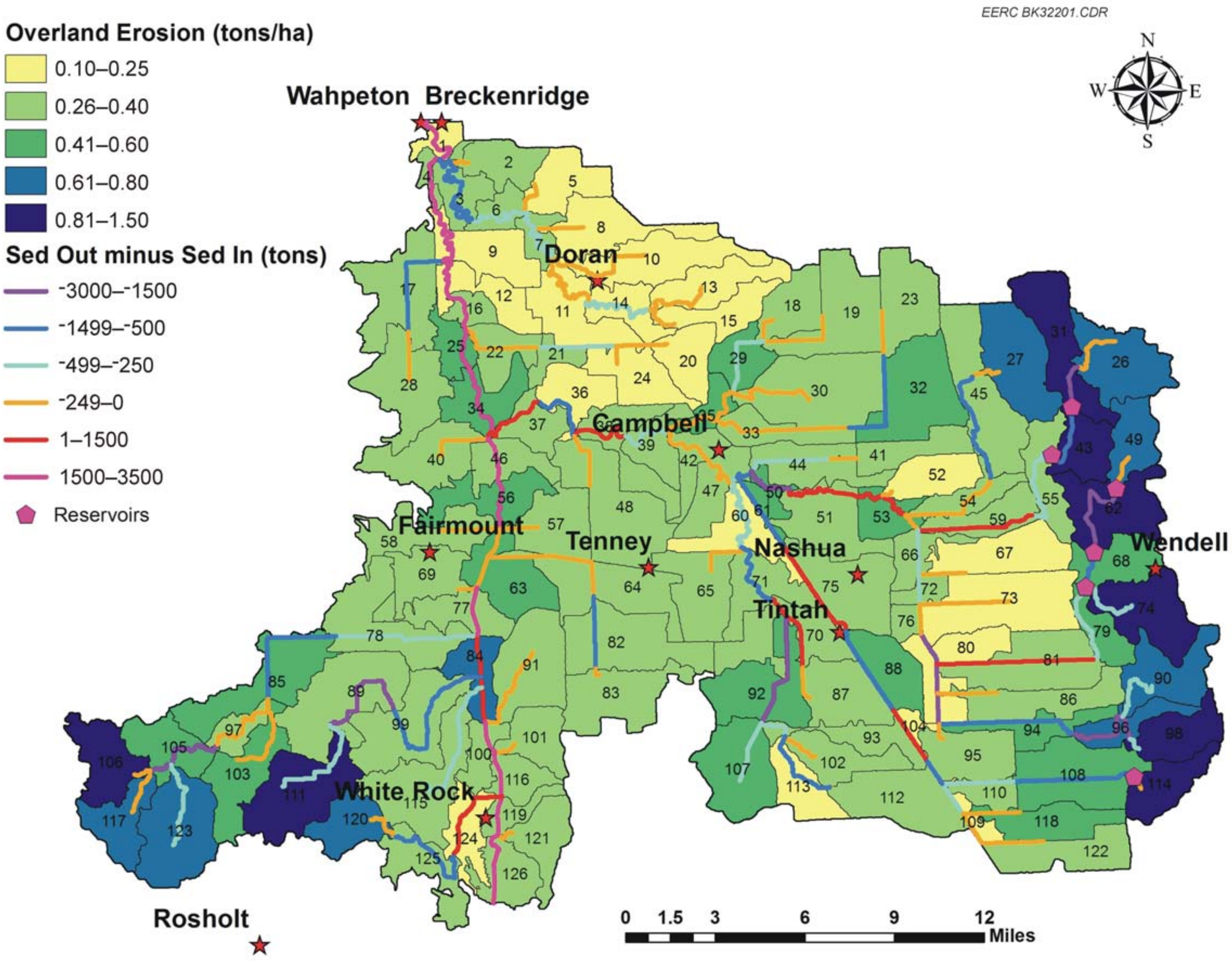

Figure 29. Estimated average annual sediment erosion from the landscape and net sediment loading (upstream inputs minus subbasin outputs) within the waterways of the Bois de Sioux River Watershed.

Overall, the average amount of sediment eroded from the Bois de Sioux Watershed landscape per year is 75,065 tons, and the predicted sediment loading at the watershed outlet is 63,316 tons. While deposition seems to be occurring in many of the subbasin, the high total loading rate at the outlet would indicate that either much of the overland sediment is being transported out of the water or stream bank erosion is contributing significantly to the overall loading rate. Again, since sediment transport is a function of stream discharge, those years and/or months with increased discharge will also have increased sediment transport. This is shown in Figure 30, which illustrated the correlation between average annual sediment loading and discharge at the Bois de Sioux River outlet.

6.2 Mustinka Sediment Results

The results from the Mustinka River Watershed are similar to the Bois de Sioux Watershed results. The predicted overland erosion from the subbasins within the Mustinka River Watershed is shown in Figure 31. In this watershed, there also appears to be a correlation between slope and overland sediment erosion and, again, there are occasional subbasins that do not fit this pattern. Just as with the Bois de Sioux Watershed, the subbasins with the highest overland sediment erosion rates do not necessarily contain stream reaches with the highest sediment-loading rates. Figure 32 shows the predicted sediment output, or loading, from the respective stream reach. This figure illustrates that many of the subbasins with high rates of overland erosion have relatively low sediment-loading rates (such as Subbasins 5, 8, 35, and 84). Many of the reservoirs in this watershed also retain sediment from overland and upstream sources, as seen by the low sediment-loading rates in the reservoir reach and downstream stream reaches. Good examples of this are seen with the reservoirs located in Subbasins 14, 84, and 121.

Similar to the Bois de Sioux Watershed results, not all of the sediment that is eroded from the landscape and into the subbasin reaches is transported out of the subbasin. Figure 33 shows the predicted net sediment output from each of the subbasin reaches. Positive values indicate that more sediment is leaving the subbasin reach than is coming in. Negative values indicate that more sediment is coming into the reach (from overland erosion and/or upstream inputs) than is leaving, suggesting that, on average, sediment is being deposited into the reach. Overall, this watershed appears to have less stream bank erosion than the Bois de Sioux Watershed.

Overall, the average amount of sediment eroded from the Mustinka River Watershed landscape per year is 87,853 tons and the average annual sediment loading at the outlet is 19,655 tons. This represents a delivery ratio of 22.4%, indicating that much of the sediment eroded from the landscape is being deposited in the streams and rivers of the watershed. The correlation between average annual sediment loading and discharge at the Mustinka River outlet is shown in Figure 34.

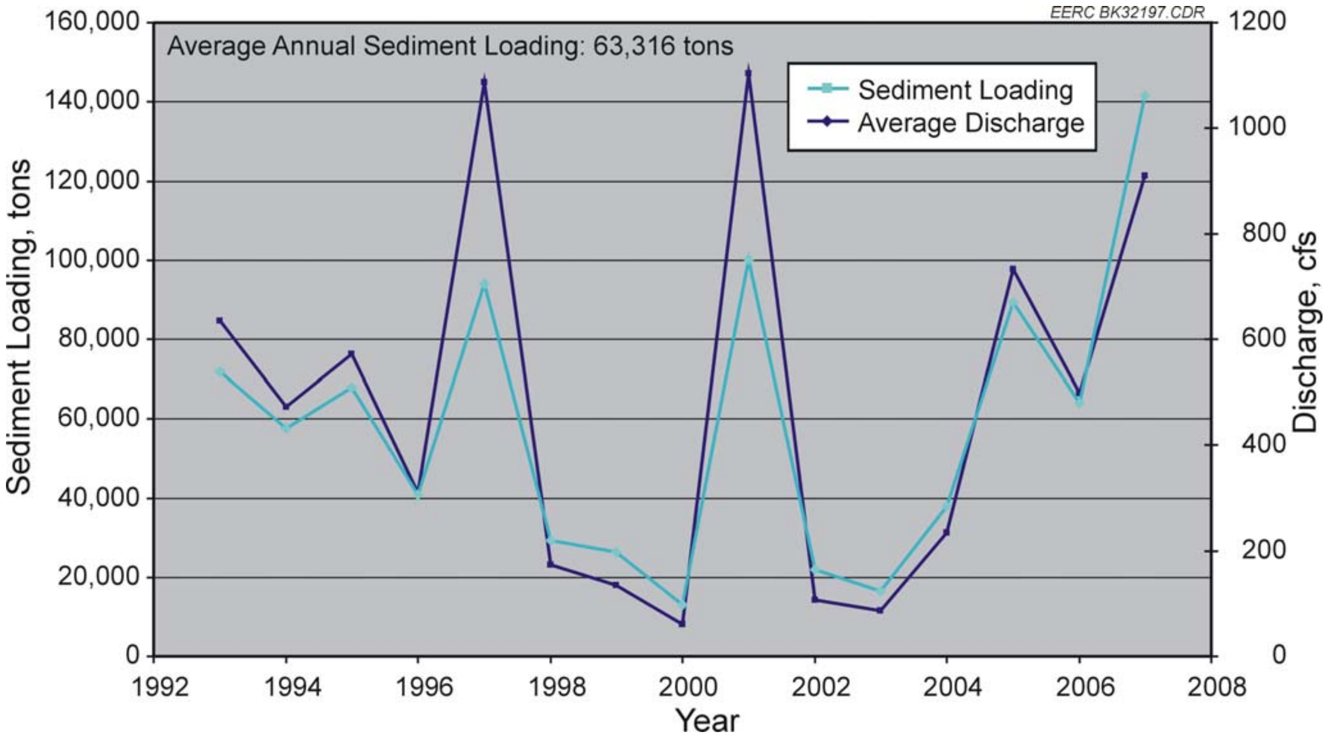

Figure 30. The correlation between sediment loading and flow within the Bois de Sioux River SWAT model.

6.3 Evaluation of Changes in Land Management

To evaluate how improvements in sediment loading might be achieved within the impaired reaches of the Bois de Sioux and Mustinka River Watersheds, a hypothetical evaluation of field buffer implementation was evaluated. All of the simulations were conducted for the calibration period of the models (Bois de Sioux – 1993 to 2007; Mustinka – 1989 to 2007). Initially, an evaluation of 120-foot, 80-foot, and 40-foot field buffers within the subbasins directly adjacent to or upstream of the impaired reaches of both watersheds was conducted. Within the Bois de Sioux River Watershed, field buffers were applied to all corn, soybean, and wheat fields larger than
70 acres in the subbasins shown in Figure 35. Within the Mustinka River Watershed, field buffers were applied to all corn and soybean fields larger than 70 acres in the selected subbasins shown in Figure 36 (since there was so much less wheat in this watershed, filter strips were not considered for this crop type).

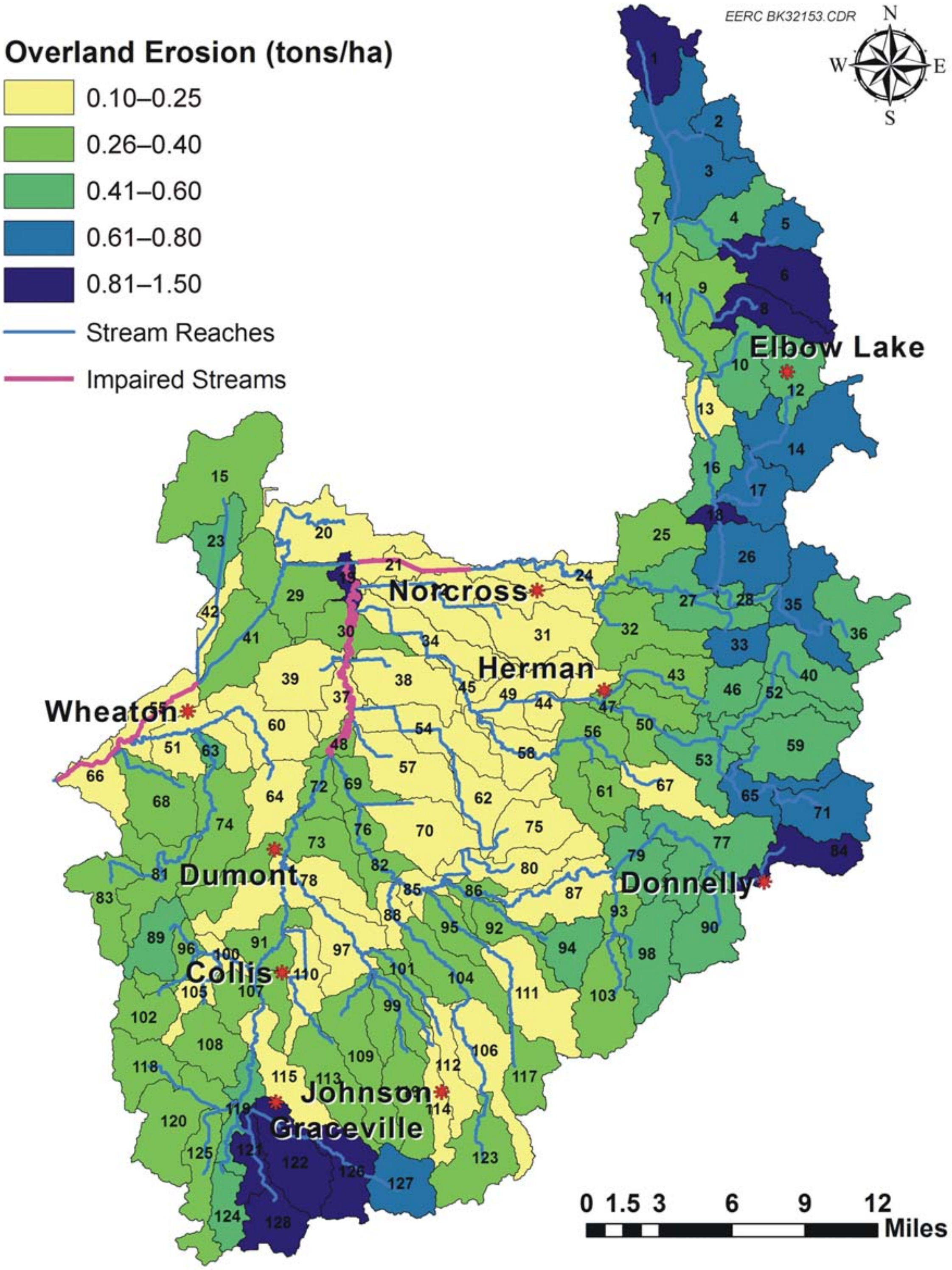

Figure 31. Estimated average annual sediment erosion from the landscape of the Mustinka River Watershed.

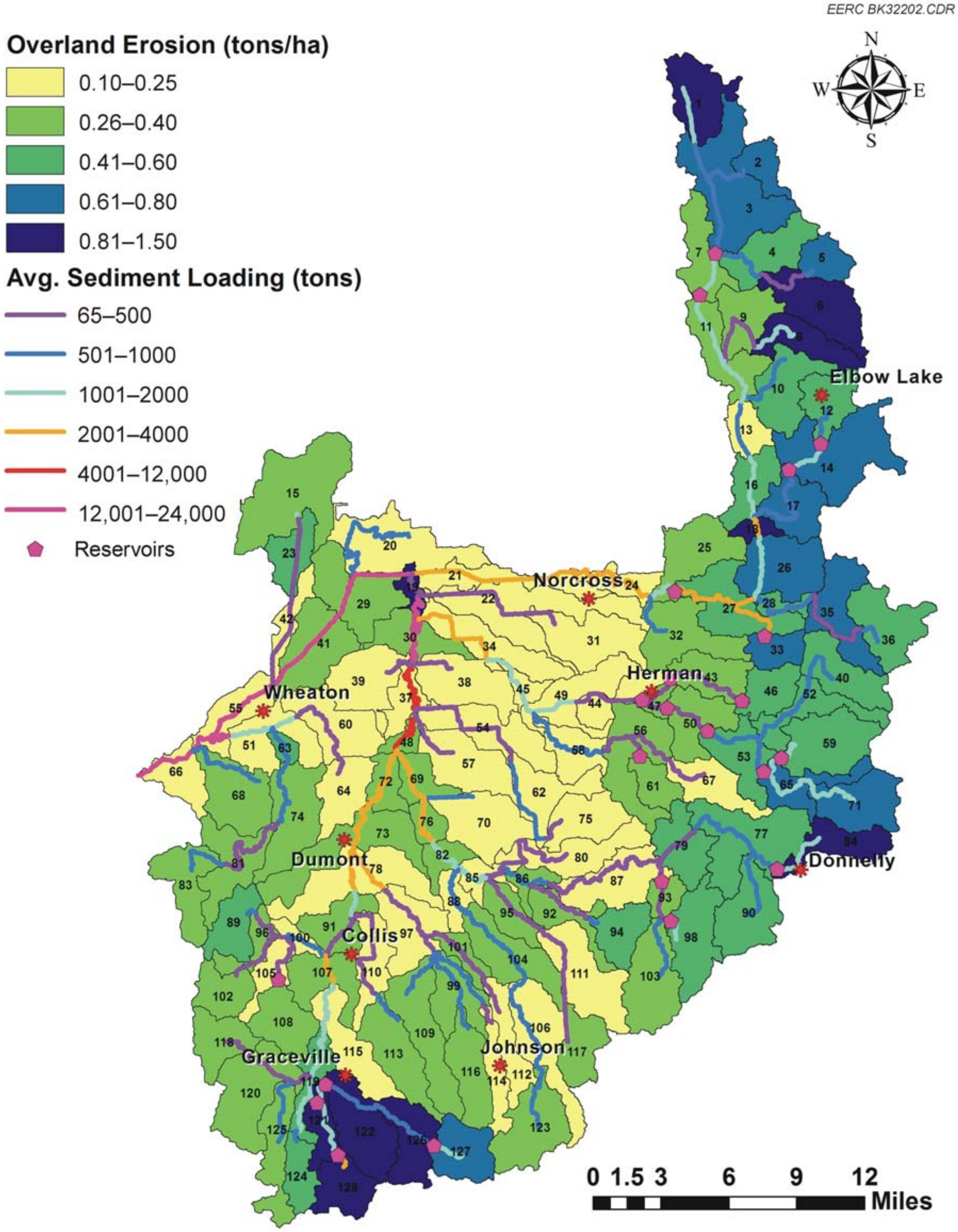

Figure 32. Estimated average annual sediment erosion from the landscape and sediment loading within the waterways of the Mustinka River Watershed.

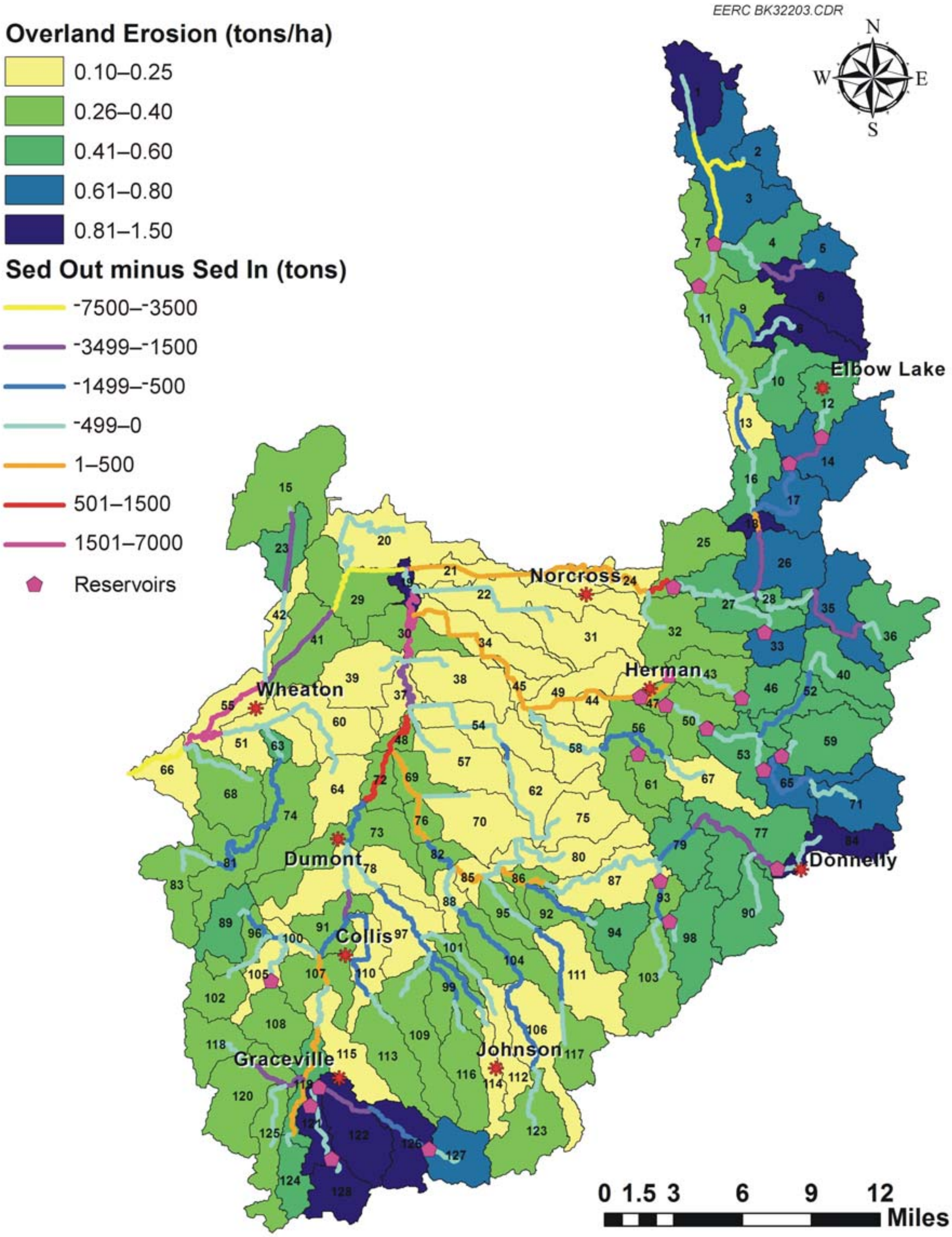

Figure 33. Estimated average annual sediment erosion from the landscape and net sediment loading (upstream inputs minus subbasin outputs) within the waterways of the Mustinka River Watershed.

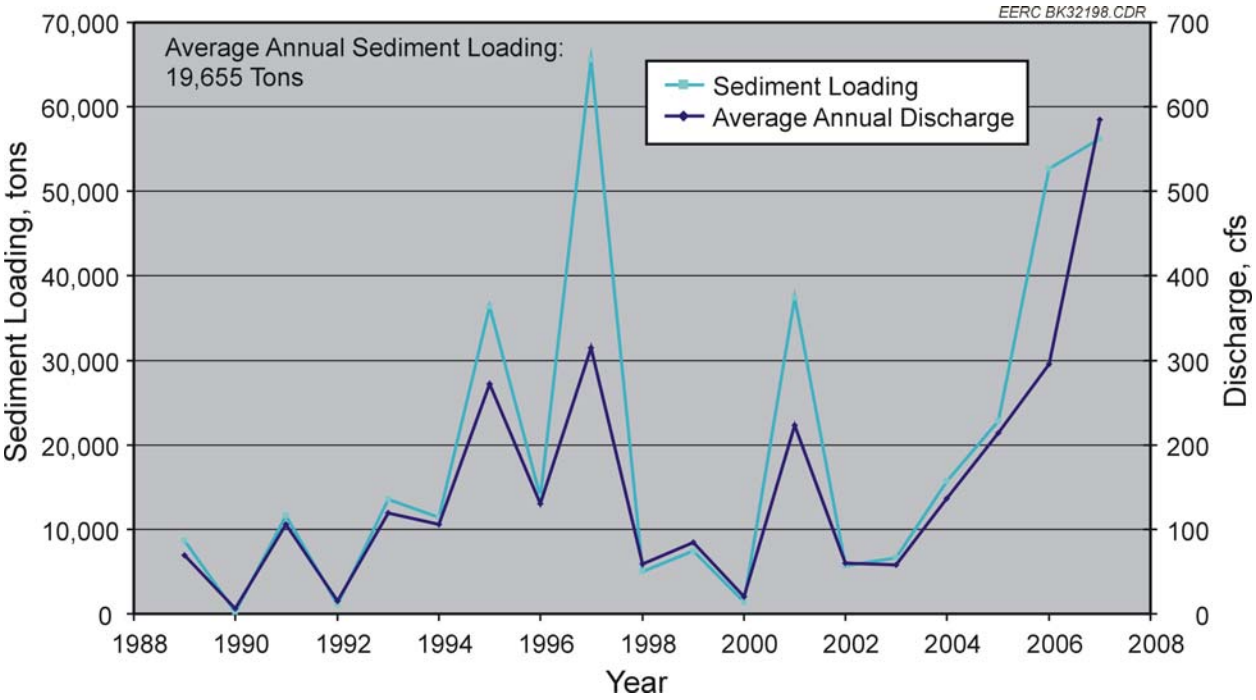

Figure 34. Correlation between sediment loading and flow within the Mustinka River SWAT model.

The average reduction in overland erosion and sediment loading within the watershed subbasins and reaches as a result of implementing 80-foot buffers is shown in Table 16. While there was a significant reduction in overland erosion, there was a significantly lower reduction in stream loading, indicating that sediment from upstream sources plays a major role in turbidity impairments the larger load reductions in Subbasins 17 and 22 of the Bois de Sioux Watershed and in Subbasin 68 of the Mustinka Watershed are because those reaches have much smaller drainage areas than the main stream reaches). It should be noted that no field buffers were applied to the subbasins highlighted in blue (Bois de Sioux Subbasins 36, 9, 12, 4, 50, and 1). The predicted sediment load reductions in these subbasin reaches were a result of upstream implementation of field buffers.

The next evaluation focused on implementing buffers only within the upstream subbasins that exhibited high sediment erosion and/or loading rates, such as Subbasins 1–10 within the Mustinka River Watershed. The results indicated very high reductions in sediment erosion within individual subbasins, as well as high reductions in sediment loading within the stream reaches, but the sediment load reduction effects did not extend very far downstream. For example, within the Mustinka River Watershed the average reduction in sediment erosion as a result of implementing 120-ft buffers in corn and soybean fields (larger than 70 acres) in Subbasins 1–10 was 64.3%, and the average sediment load reduction was 39.9%. However, by Reach 18, the reduction in sediment loading was reduced to 1.0%.

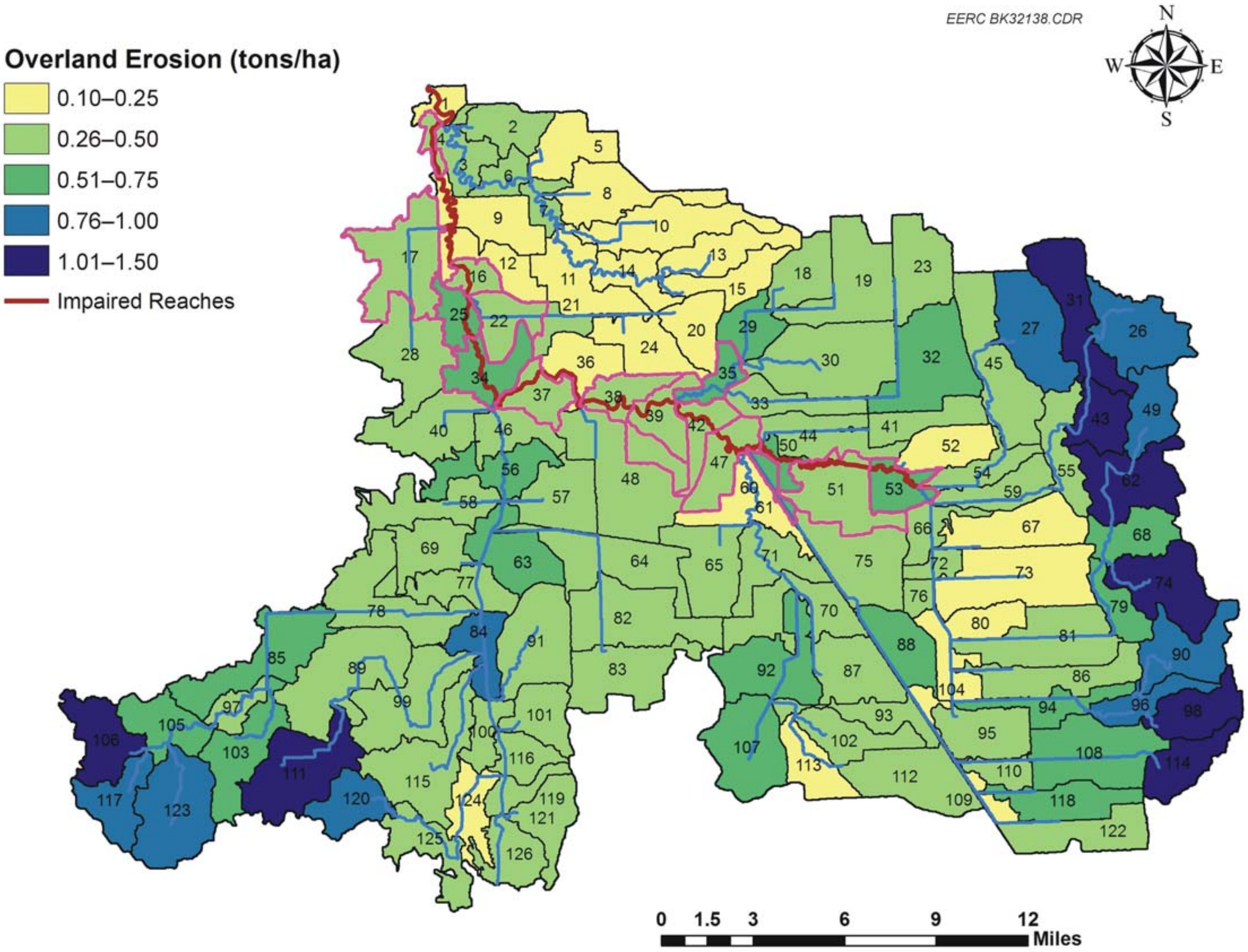

Figure 35. Initial subbasins selected for implementation of field buffers (outlined in pink) in the Bois de Sioux River Watershed.

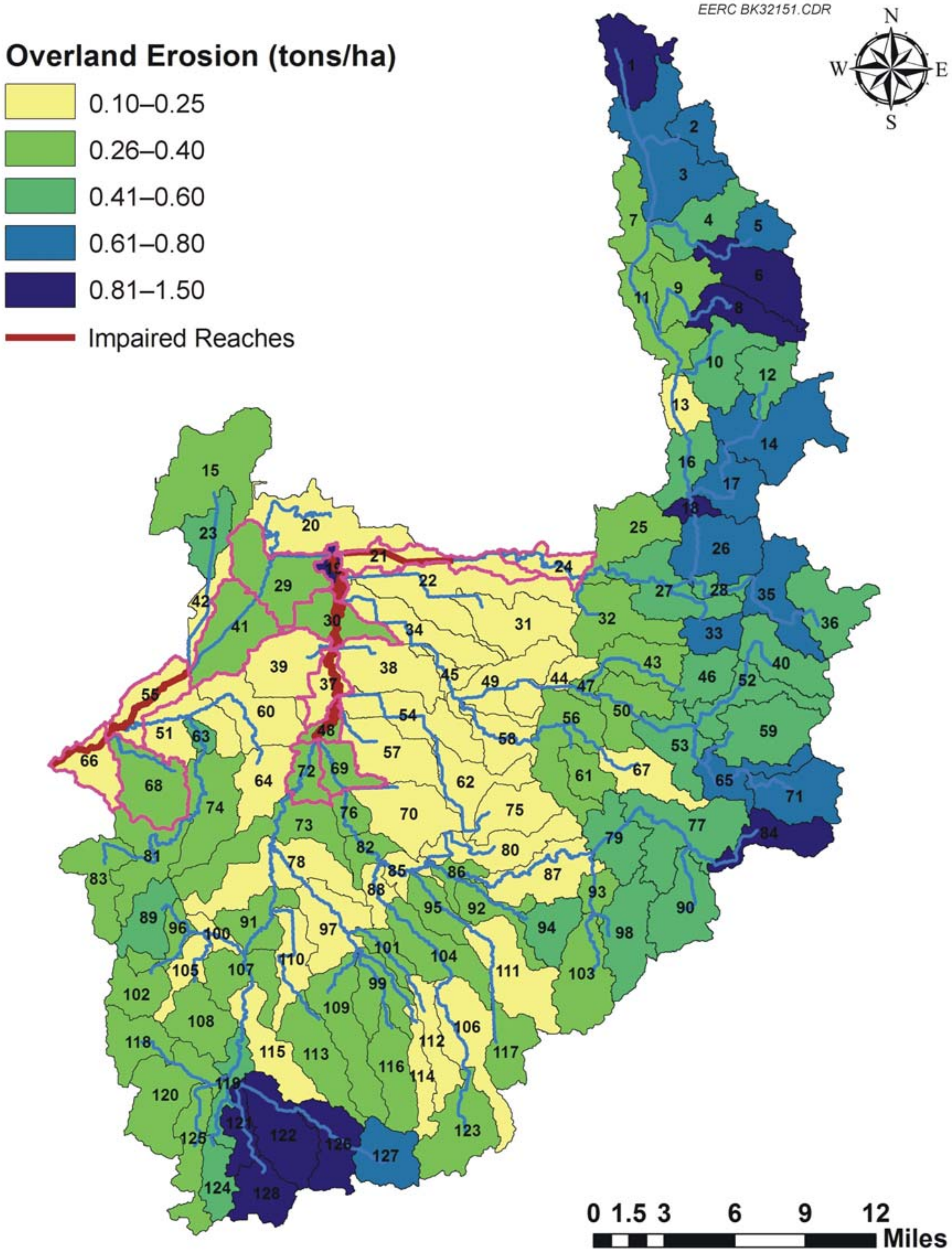

Figure 36. Initial subbasins selected for implementation of field buffers (outlined in pink) in the Mustinka River Watershed.

Table 16. Results of Implementing 80-Foot Field Buffers in Selected Subbasins

Bois de Sioux River Watershed			Mustinka River Watershed		
Subbasin and/or Reach	% Reduction in Overland Erosion	% Reduction in Sediment Loading	Subbasin and/or Reach	% Reduction in Overland Erosion	% Reduction in Sediment Loading
34	84.53	1.07	72	95.29	5.87
17	77.10	26.63	68	90.36	89.62
22	75.47	40.67	30	89.86	3.81
38	67.48	3.93	69	88.56	5.62
39	67.41	2.53	29	83.80	1.73
37	59.33	2.36	21	82.71	3.78
16	54.20	1.04	41	79.71	2.86
25	47.76	0.99	55	77.71	2.70
47	46.70	2.12	37	70.79	2.18
42	43.68	2.71	66	70.52	2.81
51	43.67	6.05	48	61.67	4.84
53	40.39	3.36	24	49.80	1.19
61	36.45	0.05	19	5.67	2.45
35	3.20	0.27			
36	0.00	2.05			
9	0.00	0.85			
12	0.00	0.80			
4	0.00	0.68			
50	0.00	0.56			
1	0.00	0.54			

The results of these evaluations indicated that buffers were needed both in the upstream subbasins with high rates of sediment erosion and/or loading as well as in the subbasins adjacent to the impaired waterways. Thus the next evaluation that was conducted focused on implementation of 80-foot buffers in both upstream and downstream subbasins. Again, the field buffers were only applied to corn and soybean fields larger than 70 acres within the Mustinka Watershed and to corn, soybean, and wheat fields larger than 70 acres within the Bois de Sioux Watershed. This resulted in buffers being applied to the equivalent of 299 fields in the Bois de Sioux Watershed and 273 fields in the Mustinka Watershed. The locations of subbasins where buffers were implemented are shown in Figures 37 and 38.

The results of this evaluation are shown in Table 17 and indicate that significant reductions in sediment erosion and stream loading can be achieved by implementing field buffers (note that only subbasins or stream reaches that experienced a reduction are shown). The average reduction in stream loading was 25.1% for the affected Bois de Sioux Watershed reaches and 28.6% for the affected Mustinka Watershed reaches. The reduction in overland erosion rates was higher, at an average of 62.8% for the Bois de Sioux Watershed and 82.4% in the Mustinka Watershed.

Within Table 17, the stream reaches that are impaired are in bold text. The predicted reductions in sediment loading are probably not high enough to address the impairments in all

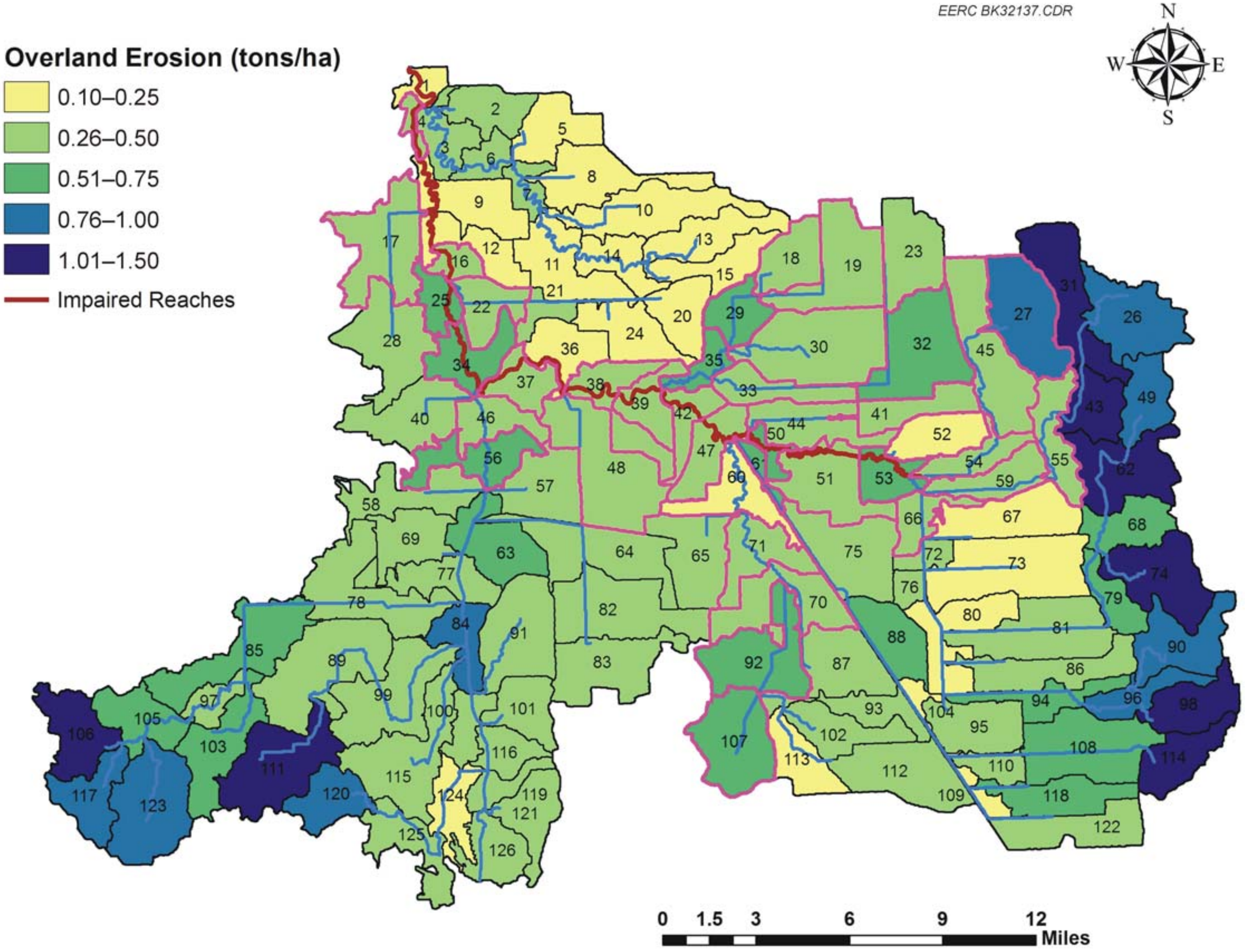

Figure 37. Location of the upstream and downstream subbasins in which field buffers were implemented.

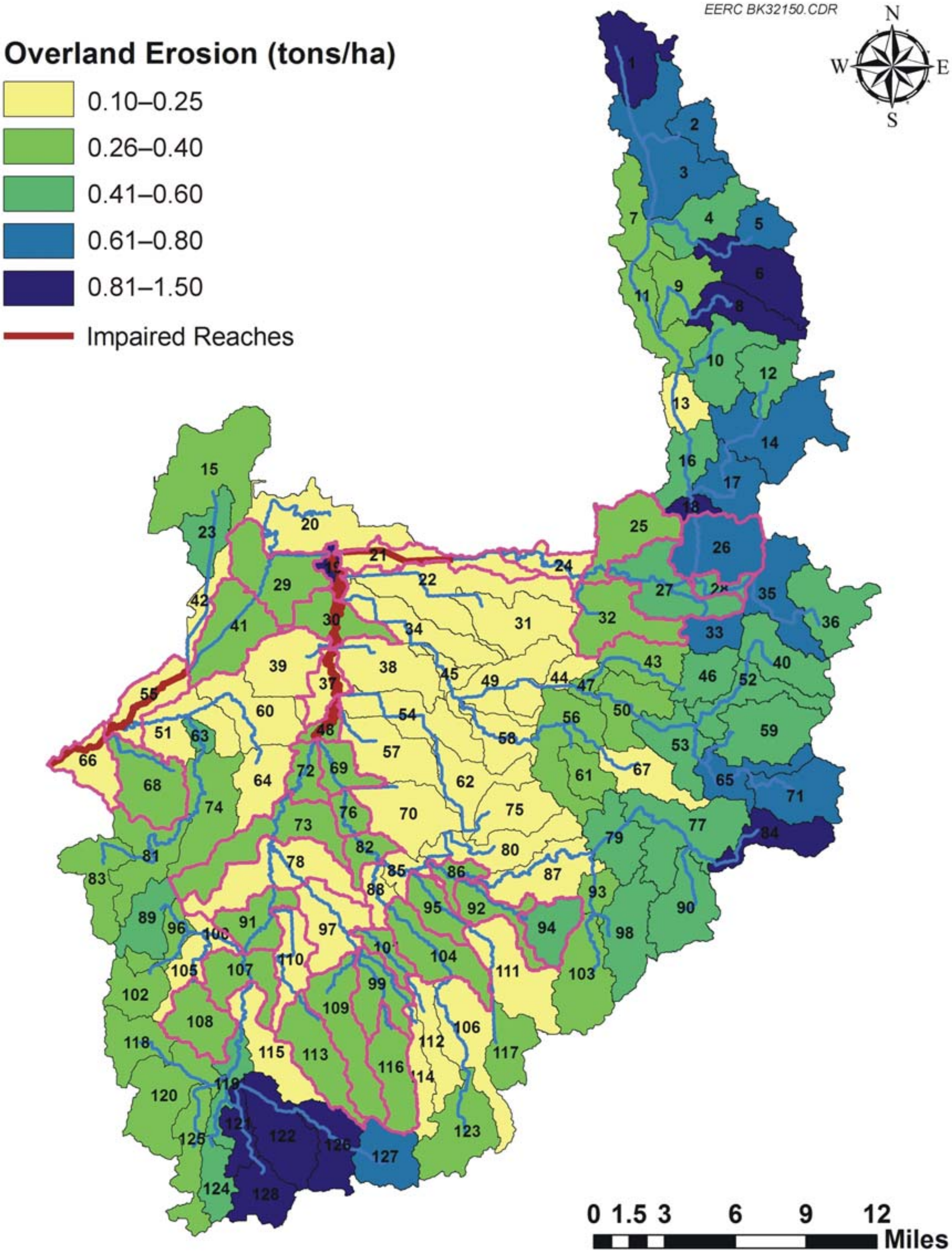

Figure 38. Location of the upstream and downstream subbasins in which field buffers were implemented.

Table 17. Predicted Reductions in Sediment Erosion and Loading as a Result of Implementing 80-Foot Buffers in Upstream and Downstream Subbasin (impaired reaches are in bold text)

Bois de Sioux River Watershed			Mustinka River Watershed		
Subbasin and/or Reach	% Reduction in Sediment Loading	% Reduction in Overland Erosion	Subbasin and/or Reach	% Reduction in Sediment Loading	% Reduction in Overland Erosion
48	83.16	83.70	94	94.50	95.05
107	82.79	82.02	113	94.37	95.29
27	82.48	82.70	116	94.37	95.19
41	78.97	78.87	15	93.27	94.12
30	73.54	73.25	108	92.07	92.91
18	66.48	66.54	109	91.53	92.27
19	62.59	62.74	68	89.62	90.36
44	49.02	71.54	92	66.96	95.20
45	46.24	74.38	99	48.27	90.59
29	42.16	63.49	42	38.12	66.17
22	40.67	75.47	25	36.59	88.16
59	39.37	70.97	110	33.35	89.35
54	33.80	44.11	23	29.91	78.26
35	32.12	3.20	73	26.42	93.43
55	30.17	76.94	72	23.19	95.29
92	29.28	89.68	86	22.08	70.83
17	26.63	77.10	27	20.08	85.44
70	25.96	73.45	107	17.90	93.24
49	22.14	22.13	78	17.08	95.40
33	14.87	41.76	104	16.65	92.66
53	**12.19**	**40.39**	24	15.55	49.80
71	11.97	55.78	97	13.71	92.62
51	**11.85**	**43.67**	**21**	**13.04**	**82.71**
60	10.86	95.30	**48**	**12.28**	**61.67**
39	**10.06**	**67.41**	85	10.58	0.00
38	**9.30**	**67.48**	88	10.30	0.00
36	**9.26**	**0.00**	69	9.74	88.56
37	**7.65**	**59.33**	105	8.45	0.00
47	**6.43**	**46.70**	95	7.92	79.73
42	**6.04**	**43.68**	101	7.48	88.81
32	4.25	67.24	76	7.43	75.32
34	**2.73**	**84.53**	**37**	**6.51**	**70.79**
25	**2.24**	**47.76**	**30**	**6.01**	**89.86**
16	**1.99**	**54.20**	**19**	**4.70**	**5.67**
66	1.86	57.46	41	4.59	79.71
50	**1.61**	**0.00**	**55**	**3.79**	**77.71**
12	**1.54**	**0.00**	**66**	**3.69**	**70.52**
9	**1.42**	**0.00**	29	3.21	83.80
46	1.41	76.45	82	2.55	74.12
4	**1.15**	**0.00**	100	1.93	0.00
1	**0.92**	**0.00**	91	0.95	84.87
56	0.91	65.57	26	0.50	87.20
61	0.04	36.45			
Average	25.1	54.0	Average	28.6	74.6

reaches; however, this illustrates an example of how reductions may be achieved. Ultimately, the evaluation of BMP implementation scenarios needs to be a balance between what can realistically be implemented and what is needed to achieve the desired load reductions. In this case, if implementation of further buffer strips is not realistic, then implementation of sediment retention ponds within some of the impaired reaches is an option that will likely yield measurable results.

One last scenario was evaluated to predict the effects that conservation tillage and residue management has had on reducing sediment erosion and loading within these two watersheds. All of the previously implemented conservation tillage and residue management practices were removed from both watersheds, and the models were rerun. Table 18 lists the predicted increases in sediment erosion and loading in each of the subbasin and respective subbasin reaches. The average increase in sediment loading was 6.3% within the Bois de Sioux Watershed and 8.8% within the Mustinka Watershed. The average increase in sediment eroded from the landscape was 12.7% in the Bois de Sioux Watershed and 19.7% in the Mustinka Watershed. This evaluation indicates the implementation of conservation, and reduced tillage has had a major impact on sediment erosion in these watersheds.

Table 18. Predicted Increases in Sediment Loading and Overland Erosion as a Result of Removing Conservation Tillage and Residue Management

Mustinka River Watershed			Bois de Sioux River Watershed		
Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion	Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion
1	6.44	6.65	1	0.49	12.65
2	5.85	6.25	2	19.28	20.48
3	1.30	6.37	3	2.96	15.76
4	2.14	7.12	4	0.57	25.75
5	5.13	5.70	5	20.19	22.29
6	1.37	8.36	6	5.03	17.99
7	2.31	7.60	7	6.17	16.83
8	7.98	9.40	8	20.52	23.25
9	1.64	7.72	9	0.80	22.14
10	6.91	8.66	10	23.90	28.41
11	2.01	9.26	11	6.11	20.98
12	7.35	9.31	12	0.64	22.54
13	1.44	10.39	13	24.54	27.76
14	2.66	10.06	14	6.08	27.79
15	11.11	12.13	15	21.29	24.03
16	1.85	11.56	16	0.74	16.10
17	1.21	9.27	17	7.67	19.47
18	1.73	8.54	18	17.42	23.20
19	3.01	5.08	19	12.42	19.37
20	11.81	12.83	20	17.71	23.26
21	3.64	19.46	21	6.13	18.57
22	8.70	18.91	22	8.71	20.86

Continued . . .

Table 18. Predicted Increases in Sediment Loading and Overland Erosion as a Result of Removing Conservation Tillage and Residue Management (continued)

Mustinka River Watershed			Bois de Sioux River Watershed		
Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion	Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion
23	2.54	11.58	23	8.57	15.06
24	4.45	20.52	24	28.12	31.70
25	5.23	13.77	25	0.88	13.37
26	1.35	8.06	26	9.61	11.16
27	1.91	9.55	27	11.27	11.88
28	1.66	8.61	28	20.98	23.87
29	2.13	12.64	29	5.63	17.82
30	3.18	10.45	30	17.45	20.89
31	19.76	21.63	31	3.01	9.03
32	12.46	13.57	32	3.58	16.44
33	11.36	11.92	33	5.29	18.67
34	4.59	16.84	34	1.02	16.47
35	2.15	10.95	35	6.63	14.61
36	7.70	11.12	36	3.12	20.07
37	2.75	10.85	37	2.23	18.57
38	12.94	14.20	38	3.10	17.39
39	13.70	14.70	39	3.30	19.91
40	9.77	13.55	40	21.98	24.73
41	2.09	13.68	41	16.01	18.58
42	5.65	15.64	42	2.58	15.36
43	2.14	14.19	43	-3.37	9.05
44	5.41	15.85	44	6.18	21.95
45	4.80	16.05	45	0.52	16.83
46	12.10	12.60	46	0.88	17.79
47	5.89	14.32	47	2.84	19.03
48	3.76	9.09	48	19.25	23.17
49	5.60	18.67	49	7.31	8.74
50	2.06	12.98	50	2.09	14.11
51	5.15	15.59	51	3.82	19.04
52	2.52	13.12	52	21.95	22.69
53	2.53	10.78	53	3.36	15.80
54	7.79	14.52	54	2.23	19.12
55	2.07	15.07	55	1.27	13.74
56	6.03	15.79	56	0.96	19.53
57	16.13	17.89	57	16.33	18.38
58	5.25	17.50	58	16.93	19.77
59	11.11	12.41	59	7.02	18.08
60	6.56	13.65	60	4.39	17.82
61	11.98	12.75	61	2.75	13.94
62	5.53	17.90	62	-1.08	9.22
63	2.93	10.82	63	0.64	17.24
64	14.23	15.69	64	11.65	23.95
65	2.35	8.47	65	19.83	22.60

Continued . . .

Table 18. Predicted Increases in Sediment Loading and Overland Erosion as a Result of Removing Conservation Tillage and Residue Management (continued)

Mustinka River Watershed			Bois de Sioux River Watershed		
Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion	Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion
66	1.89	7.30	66	2.37	17.83
67	11.21	13.05	67	15.84	19.57
68	10.65	13.33	68	0.48	13.12
69	4.06	12.99	69	16.03	16.62
72	3.59	11.29	72	2.90	17.54
73	3.60	14.72	73	16.06	20.02
74	2.55	14.36	74	13.25	16.08
75	13.05	15.99	75	5.89	18.50
76	3.37	15.91	76	2.99	22.38
77	2.42	9.76	77	0.99	19.14
78	3.78	18.00	78	3.54	26.46
79	1.93	9.78	79	-1.16	18.29
80	14.06	14.89	80	2.00	23.33
81	1.27	11.70	81	7.73	23.59
82	2.64	15.08	82	5.89	20.73
83	8.59	12.02	83	16.77	17.38
84	5.39	7.93	84	0.94	16.09
85	4.45	14.40	85	1.82	21.24
86	3.45	14.82	86	22.62	25.77
87	2.79	13.71	87	17.70	23.84
88	5.21	19.21	88	2.55	19.39
89	9.36	11.42	89	4.01	22.98
90	7.33	10.08	90	11.73	15.04
91	3.04	15.18	91	15.36	18.46
92	1.03	12.06	92	3.83	18.70
93	3.52	12.10	93	7.03	28.70
94	8.60	10.22	94	-0.40	23.33
95	3.65	14.23	95	19.41	23.71
96	3.05	14.52	96	0.61	15.57
97	4.09	15.56	97	3.51	21.56
98	9.42	10.90	98	12.77	17.25
99	5.70	13.14	99	5.16	22.67
100	5.24	15.56	100	0.68	18.08
101	6.22	16.08	101	16.97	18.21
102	11.97	12.66	102	22.03	28.20
103	11.31	13.23	103	16.51	21.23
104	4.19	13.06	104	3.98	17.51
105	9.96	17.46	105	0.65	19.29
106	6.18	15.10	106	13.97	15.48
107	6.27	14.54	107	12.34	17.16
108	12.67	13.00	108	3.26	21.22
109	13.88	16.06	109	3.43	25.63
110	3.41	17.09	110	6.41	26.57

Continued . . .

Table 18. Predicted Increases in Sediment Loading and Overland Erosion as a Result of Removing Conservation Tillage and Residue Management (continued)

Mustinka River Watershed			Bois de Sioux River Watershed		
Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion	Subbasin and/or Reach	% Increase in Sediment Loading	% Increase in Overland Erosion
111	4.91	15.23	111	13.93	16.48
112	14.62	15.45	112	23.86	24.29
113	11.81	13.13	113	5.98	23.25
114	15.14	16.23	114	17.23	18.03
115	5.53	14.35	115	15.26	22.61
116	13.22	13.99	116	0.72	18.27
122	2.44	6.92	122	21.12	24.30
123	10.22	11.46	123	14.99	18.42
124	9.68	10.61	124	9.97	25.18
125	10.11	12.31	125	0.92	20.38
126	2.58	10.15	126	1.06	18.19
127	7.68	9.36			
128	5.16	5.92			
Average	6.3	12.7	Average	8.8	19.7

7.0 CONCLUSIONS

Through this project, water quality models of the Bois de Sioux and Mustinka River Watersheds were developed and calibrated using the best available data. The results of the study indicate that the waterways of the region are characterized by a net accumulation of sediment. The average annual overland sediment erosion was predicted as 0.492 tons/ha within the Bois de Sioux Watershed and 0.404 tons/ha within the Mustinka River Watershed. This is equivalent to 75,065 and 87,853 tons of sediment, eroding from each watershed, respectively. The estimated average annual loading at the outlets of the Bois de Sioux and Mustinka River Watersheds was 63,316 and 19,655 tons, respectively. This represents a delivery ratio of 84.3% and 22.4% within the watersheds, indicating that much less deposition is occurring within the Bois de Sioux waterways than in the Mustinka River Watershed. Because sediment delivery is highly correlated to stream discharge, increased rates of sediment erosion and loading were exhibited during periods of high flow.

An evaluation of field buffer implementation for select crop types revealed that dramatic reductions in sediment erosion are possible. Implementing buffers around every field in a subbasin could yield sediment erosion reductions greater than 95%. Even field buffers applied only to a portion of the fields within a subbasin could yield reductions greater than 40%. These values are comparable to the sediment retention percentages reported in the literature (Grismer et al, 2006; U.S. Environmental Protection Agency, 2002). The model results indicated that significant reductions in sediment loading (over 80%) could also be achieved by implementing upstream filter strips; however, the most drastic reductions were seen in smaller tributaries with small drainage areas. Less dramatic reductions were exhibited in the larger tributaries. The results of this evaluation indicated that a combination of buffers located in areas adjacent to water quality impairments as well as in areas located upstream of impaired waterways is probably needed to achieve significant sediment load reductions.

The effects of conservation tillage implementation and residue management were also evaluated by the models. A scenario was run where all conservation and reduced tillage practices as well as residue management were removed from the models. The results indicated an average sediment loading increase of 6.3% in the Bois de Sioux Watershed and 8.8% in the Mustinka River Watershed. Overland sediment erosion increased 12.7% in the Bois de Sioux Watershed and 19.7% in the Mustinka River Watershed. These results indicate that conservation tillage practices and residue management have had a significant positive impact in these watersheds.

The work described here and the models developed through this project will hopefully serve as a base upon which future research and implementation efforts can build. There are many more scenarios that can be evaluated using these models, especially as target BMPs are identified as a function of implementation likelihood and/or as new federal programs and policies arise to support BMP implementation. In addition, the accuracy of these models can be improved as new data become available and as updates are made to the model programming.

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