Bevens Creek Turbidity TMDL

May 2012

Submitted by:

Carver County Land and Water Services

and

Minnesota Pollution Control Agency

Table of Contents

Tables

Figures

TMDL Summary Table

Element	Summary	Page #
Waterbody ID	Bevens Creek: AUID 07020012-717, AUID 07020012-718 and AUID 07020012-514; Silver Creek: AUID07020012-523	1
Location	The Bevens Creek watershed covers about 125 square miles and is located at the western edge of the Twin Cities Metropolitan Area. About 70 percent of the watershed is located in Carver County with the remaining 30 percent located outside the metropolitan area in Sibley County.	4
303(d) Listing Information	Bevens Creek was listed on Minnesota's 303(d) Impaired Water List due to its high turbidity measurements in 2002. Silver Creek was listed in 2006.	1
Impairment/ TMDL pollutant of concern	Turbidity	1
Impaired Beneficial Use(s)	Aquatic Life	1
Applicable Water Quality Standards/ Numeric Targets	Bevens Creek is designated as a Class 2B water. Class 2B refers to those State waters identified to support aquatic life (warm and cool water fisheries and associated biota) and recreation (all water recreation activities including bathing). The numeric target for turbidity for Class 2B waters is 25 NTU.	1
Loading Capacity (expressed as daily load)	Total load capacity was determined for high, moist, mid-range, dry, and low flow regimes. **Stream Reach** **Loading Capacity (kg/day)** 07020012-717 See Table 4.2 07020012-718 See Table 4.3 07020012-523 See Table 4.4 07020012-514 See Table 4.5	15 - 20
Total Wasteload Allocation	Wasteload Allocation (WLA) for Bevens Creek consists of permitted WWTPs and permitted construction and industrial stormwater. **Stream Reach** **WLA (kg/day)** 07020012-717 See Table 4.2 07020012-718 See Table 4.3 07020012-523 See Table 4.4 07020012-514 See Table 4.5	15 - 20
Permitted Discharges from Wastewater Treatment and Industrial Facilities	Norwood Young America WWTP ID: MN0024392 Hamburg WWTP ID: MN0025585 See Table 4.1 for info and Tables 4.2, 4.3 and 4.5 for WLAs	15 - 20
Industrial Stormwater	**Stream Reach** **WLA (kg/day)** 07020012-717 See Table 4.2 07020012-718 See Table 4.3	15 - 20

| | 07020012-523 | See Table 4.4 | |
| | 07020012-514 | See Table 4.5 | |

Construction Stormwater	**Stream Reach**	**WLA (kg/day)**	15 - 20
	07020012-717	See Table 4.2	
	07020012-718	See Table 4.3	
	07020012-523	See Table 4.4	
	07020012-514	See Table 4.5	

Margin of Safety (MOS)	Ten percent of the load capacity was used to calculate the MOS. This approach was applied to the high, moist, mid-range, dry, and low flow regimes and is expected to provide an adequate accounting of uncertainty.		15 - 20
	Stream Reach	**Margin of Safety (kg/day)**	
	07020012-717	See Table 4.2	
	07020012-718	See Table 4.3	
	07020012-523	See Table 4.4	
	07020012-514	See Table 4.5	

Load Allocation	The Load Allocation (LA) is the remaining load capacity after subtracting the WLA and MOS.		15 - 20
	Stream Reach	**LA (kg/day)**	
	07020012-717	See Table 4.2	
	07020012-718	See Table 4.3	
	07020012-523	See Table 4.4	
	07020012-514	See Table 4.5	

Seasonal Variation	By using a duration curve approach in this TMDL the full range of flow conditions occurring over the year are fully captured and accounted for.	13
Reasonable Assurance	Carver County is the water management authority for the majority of Bevens Creek and many of the goals outlined in the TMDL are consistent with the goals and objectives of the County Water Management Plan. The County is uniquely qualified through its zoning and land use powers to implement corrective actions to achieve TMDL goals. Carver County is committed to working with Sibley County to ensure the entire watershed is managed to meet the water quality target for turbidity.	29
Monitoring	A general monitoring plan is included. A more detailed monitoring plan will be included in the Final Implementation Plan. The county has stable funding for water management and will continue its baseline-monitoring program.	22
Implementation	Information about potential management measures is included in this TMDL report. More detailed information will be provided in the Final Implementation Plan.	23

Public Participation	The County has an excellent track record with inclusive participation of its citizens, as evidenced through the public participation in completion of the Carver County Water Management Plan, approved in 2010. The county has utilized stakeholder meetings, citizen surveys, workshops and permanent citizen advisory committees to gather input from the public and help guide implementation activities. Notice of the availability of a draft of this TMDL for review and comment for a 30 day period from November 14 to December 14, 2011, was published in the State Register.	32

Executive Summary

Section 303(d) of the Clean Water Act 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 "impaired." A total maximum daily load or TMDL must be developed for those impaired waters once they are placed on the list. The TMDL provides a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards.

The state agency responsible for listing waters in Minnesota is the Minnesota Pollution Control Agency (MPCA). In 2002, the MPCA added Bevens Creek to Minnesota's 303(d) list of impaired waters for an impairment of aquatic life due to turbidity levels in exceedance of the water quality target of 25 nephelometric turbidity units (NTUs) for Class 2B waters. Thus, the objective of this TMDL report is to estimate allowable pollutant loads and to allocate these loads to the known pollutant sources in the watershed so that the appropriate control measures can be implemented in order for Bevens Creek to meet the water quality standard for turbidity.

The Bevens Creek watershed covers about 125 square miles and is located at the western edge of the Twin Cities Metropolitan Area. About 70 percent of the watershed is in Carver County; the remainder is located outside the metropolitan area in Sibley County. The cities of Norwood Young America and Hamburg are located within the Carver County portion of the watershed and discharge treated wastewater to the creek. Land use in the watershed is mainly agricultural with 53 percent in row crops, 23 percent in hay, 16 percent wetlands, 7 percent forest, and about 1 percent commercial and residential.

The TMDL process for Bevens Creek began with the compilation of hydrology and water quality data collected from the Metropolitan Council Environmental Services (MCES) Mile 2 station since 1989. This data was used to construct Flow and Load Duration Curves and calculate a Total Suspended Solids (TSS) surrogate for the turbidity standard. With this information, the total loading capacity for the watershed at different flow levels and the corresponding load reduction needs were determined. In general, the turbidity standard was exceeded at high and medium flows with the majority of TSS loads contributed from field and bank erosion associated with agricultural activities. Depending on flow regime, it is estimated that TSS load reductions of 0 to 83 percent will be necessary to meet the TMDL limits.

The report describes applicable water quality standards for turbidity, TMDL development and allocations, future monitoring activities and suggested implementation strategies.

1   Introduction

1.1   Purpose

Section 303(d) of the Clean Water Act 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 "impaired." A total maximum daily load or TMDL must be developed for those impaired waters once they are placed on the list. 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 wasteload allocation (WLA), load allocation (LA), plus a margin of safety (MOS) and reserved capacity (RC). The TMDL can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard (USEPA, 1999). In 2006, new guidance was written by the EPA in response to a U.S. Court of Appeals decision stating that all TMDLs must be expressed as a daily load (USEPA, 2006).

In 2002, Bevens Creek (AUID 07020012-515 and 07020012-514) was listed on Minnesota's 303(d) list of impaired waters for an impairment of aquatic life due to turbidity levels in exceedance of the water quality target of 25 NTUs for Class 2B waters. In 2006, a portion of Silver Creek (AUID 07020012-523) was also listed as impaired for turbidity. On the draft 2010 303(d) list segment 07020012-515 of Bevens Creek was split into two reaches designated as AUID 07020012-717 and 07020012-718, with both impaired for turbidity. The objective of this TMDL is to estimate allowable pollutant loads and to allocate these loads to the known pollutant sources in the watershed for these reaches so that the appropriate control measures can be implemented.

Table 1.1 Bevens Creek Impaired Reaches.

Turbidity Impaired Reaches of Bevens Creek Watershed	
AUID 07020012-717	Bevens Creek-Washington Lake to unnamed creek
AUID 07020012-718	Bevens Creek-Unnamed creek to Silver Creek
AUID 07020012-514	Bevens Creek-Silver Creek to Minnesota River
AUID 07020012-523	Silver Creek-County Ditch 32 to Bevens Creek
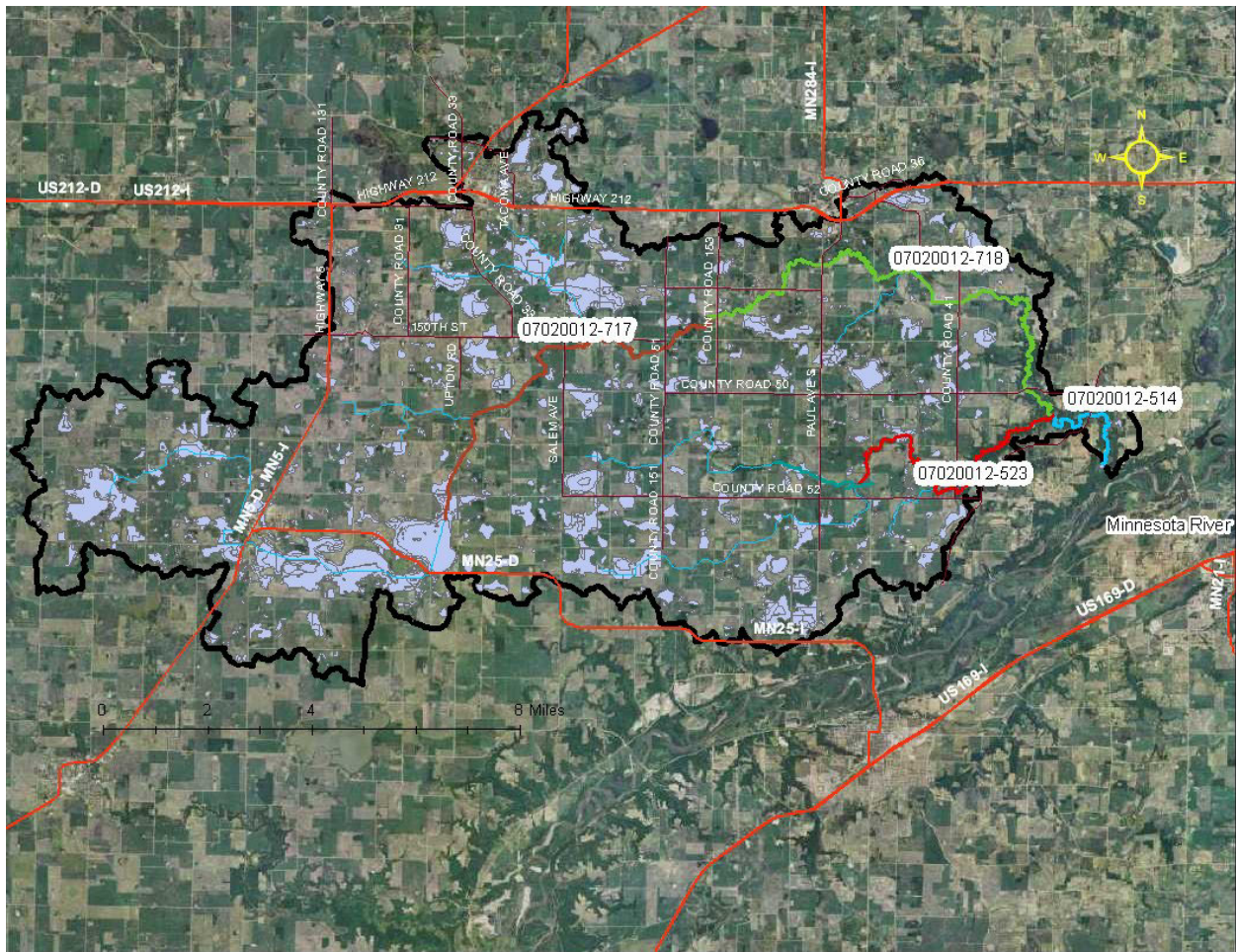
Figure 1.1 Bevens Creek Turbidity Impaired Reaches.

The Bevens Creek watershed receives minimal discharges from industrial and municipal sources. The most significant TSS loads in the watershed are from nonpoint sources. Determining the distribution and loading of the nonpoint sources in the watershed is critical in order to develop a detailed BMP implementation plan and achieve water quality targets.

1.2   Priority Ranking

The Minnesota Pollution Control Agency (MPCA) projected schedule for TMDL completions, as indicated on Minnesota's 303(d) impaired waters list, implicitly reflects Minnesota's priority ranking of this TMDL. The project for AUID 07020012-717 was scheduled to begin in 2003 and be completed in 2007. Projects for AUID 07020012-718, AUID 07020012-514, and AUID 07020012-523 were scheduled to begin in 2006 and be completed in 2010. Ranking criteria for scheduling TMDL projects include, but are not limited to: impairment impacts on public health and aquatic life; public value of the impaired water resource; likelihood of completing the TMDL in an expedient manner, including a strong base of existing data and restorability of the water body; technical capability and willingness locally to assist with the TMDL; and appropriate sequencing of TMDLs within a watershed or basin.

1.3   Criteria Used for Listing

The criteria used for determining stream reach impairments are outlined in the MPCA document, Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment – 305(b) Report and 303(d) List), January 2004. The applicable water body classifications and water quality standards are specified in Minnesota Rules Chapter 7050. Minnesota Rules Chapter 7050.0407 lists water body classifications and Chapter 7050.2222 subp. 5 lists applicable water quality standards for the impaired reaches.

Turbidity assessment for impairment listing involves pooling data over at least a ten-year period and requires a minimum of twenty samples. The surface water standard for turbidity is 25 NTUs. For assessment purposes, a stream is listed as impaired if at least three observations or 10 percent of observations exceed 25 NTUs. Transparency and total suspended solids samples may also be used as a surrogate for the turbidity standard.

2　Background Information

2.1　TMDL Study Area Overview

The Bevens Creek watershed covers about 125 square miles and is located at the western edge of the Twin Cities Metropolitan Area (Figure 2.1). About 70 percent of the watershed is in Carver County; the remainder is located outside the metropolitan area in Sibley County. As modeled, land use in the watershed is mainly agricultural with 53 percent in row crops, 23 percent in hay, 16 percent wetlands, 7 percent forest, and about 1 percent commercial and residential.
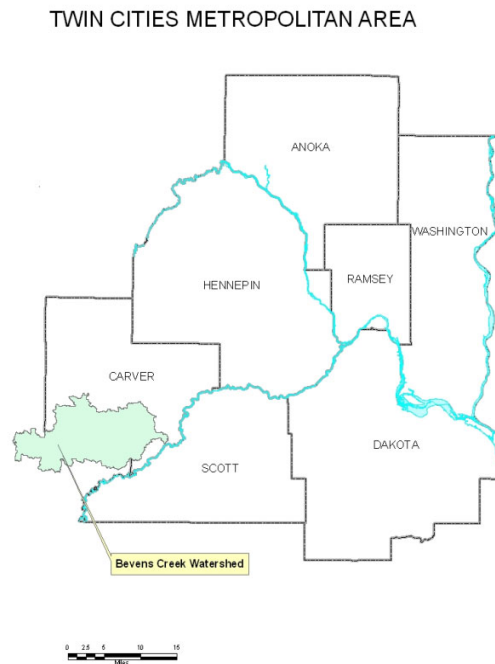
Figure 2.1　Location of Bevens Creek Watershed

The Sibley County portion of the watershed is very flat and ditched with several large shallow wetlands. The Carver County portion of the watershed is steeper with fewer wetlands, but also ditched. The cities of Norwood Young America and Hamburg (2010 estimated populations of 4,630 and 600, respectively) are located within the Carver County portion of the watershed and discharge treated wastewater to the creek (Figure 2.2).

MCES monitors Bevens Creek flow and water quality at mile 2.0 and mile 5.0. Additionally, Carver County has conducted some monitoring of the creek at various locations (Figure 2.3) including mile 9.0, mile 21.0, Bevens Creek at Tacoma Avenue, Bevens Creek near the Sibley County border, and Silver Creek Mile 2.0.
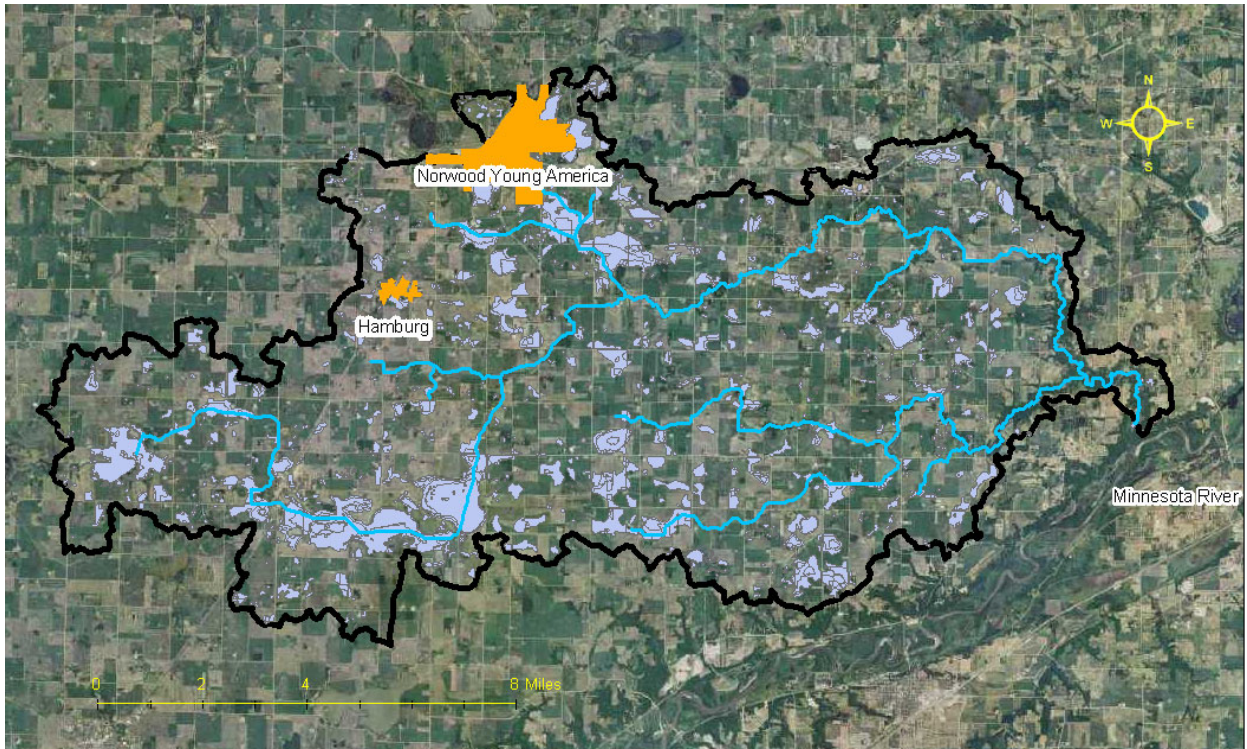
Figure 2.2 Cities of Norwood Young America and Hamburg
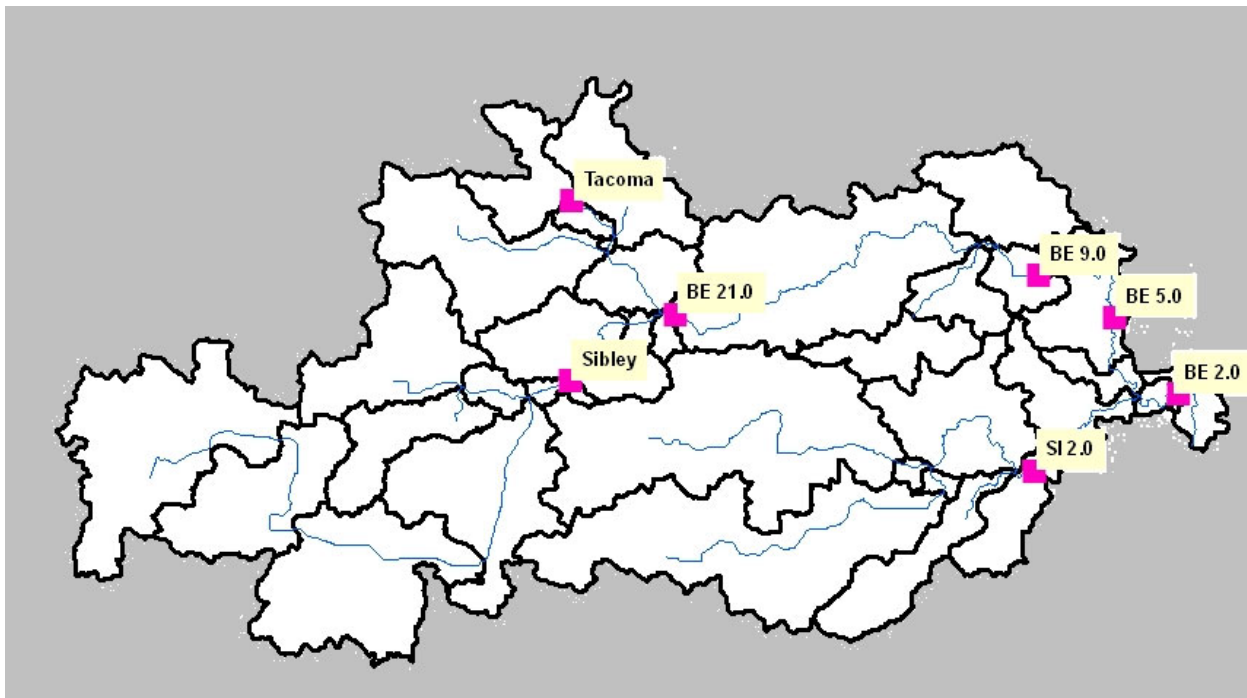
Figure 2.3 Bevens Creek Sampling Locations.

3 Turbidity Standards and Impairment Assessment

3.1 Description of Turbidity
Turbidity is an expression of the optical properties in a water sample that cause light to be scattered or absorbed. Turbidity may be caused by suspended matter, such as clay, silt, finely divided organic and inorganic matter, soluble colored organic compounds, and plankton and other microscopic organisms (USEPA, 1999). The scattering of light in the water column makes the water appear cloudy and the cloudiness increases with greater suspended loads. Turbidity limits light penetration which further inhibits healthy plant growth on the river bottom.

Turbidity is commonly measured in Nephelometric Turbidity Units (NTU). NTU is a unit of measurement quantifying the degree to which light traveling through a water column is scattered by the suspended particles.

3.2 Applicable Minnesota Water Quality Standards – Class 2B Waters
Minnesota has a water quality standard for turbidity in streams. Bevens Creek is classified as a 2B water and the turbidity standard is 25 NTU. This means the primary beneficial uses for the creek are aquatic life and recreation, and the creek must be protected for warm and cold water fisheries and swimming. However, turbidity cannot be expressed as a load as required by the TMDL regulations. To achieve a load-based value, a surrogate for turbidity is being used based on the correlation between turbidity and TSS loads.

3.3 Impairment Assessment: Turbidity
Measured turbidity of Bevens Creek exceeded the listing criteria and in 2002 the MPCA placed Bevens Creek on Minnesota's 303(d) list for turbidity impairment. In 2006, Silver Creek was also listed on Minnesota's 303(d) list for turbidity impairment due to exceedance of the turbidity standard. The timing and magnitude of turbidity/TSS exceedance is discussed in section 4.0. A TMDL study was required by the federal Clean Water Act for the creek.

4 Turbidity TMDL Development for Bevens Creek

4.1 Components of Turbidity TMDLs

A Total Maximum Daily Load (TMDL) provides a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The turbidity TMDL is the sum of four components as shown in the following equation:

$$TMDL = \Sigma\ WLA + \Sigma\ LA + MOS + RC$$

The Wasteload Allocation (WLA) typically refers to point sources and generally includes permitted wastewater and water treatment facilities, the MS4 permitted stormwater source category, and the permitted stormwater construction and industrial activities.

The Margin of Safety (MOS) may be explicitly stated as an added, separate quantity in the TMDL calculation, or implicit, as in conservative assumptions. The Reserve Capacity (RC) is reserve capacity for future growth.

The Load Allocation (LA) includes nonpoint pollution sources that are not subject to NPDES permit program. In the Bevens Creek Watershed the LA for the turbidity TMDL can be assigned to field and non-field erosion. In most TMDLs, including the TMDL for Bevens Creek, the LA accounts for the majority of the TSS loading contributing to turbidity and therefore is the critical piece for achieving the desired pollutant load reductions.

The objective of the TMDL is to estimate allowable pollutant loads and to allocate these loads to the known pollutant sources in the watershed so the appropriate control measures can be implemented.

4.2 Compilation of Flow Data

The stream flow and water quality data used for the TMDL and to develop and validate a SWAT model for this project were obtained from several sources. MCES and local partners initiated a monitoring program to record stream flow and water quality in the metropolitan area watersheds in the late 1980s. In Bevens Creek, continuous stream flow using automated stream monitoring equipment and water quality based on composite and grab samples have been monitored at the MCES station since 1989.

The MCES monitoring station is located at 16185 County Road 40, Carver County, MN, which is about 2.2 miles upstream from Bevens Creek confluence with the Minnesota River (Figure 2.3, BE 2.0). Carver County Environmental Services has six additional continuous monitoring stations established in 1997 (or after) located respectively at river miles 5.0 (BE 5.0), 9.0 (BE 9.0), 21.0 (BE 21.0), and 24.1 (Sibley) on Bevens Creek, mile 2.0 (SI 2.0) on Silver Creek near confluence Silver and Bevens Creek, and 2.2 miles (Tacoma) upstream on a tributary from BE 21. There are several additional upstream grab sample sites that were established by the County in 2003.

The hydrology and quality of water in the watershed have been monitored at the MCES station since 1989. Continuous stream flow is measured from spring to fall using automated stream

monitoring equipment that records stream stage. Stream stage is converted into flow according to a stage-discharge relationship or "rating curve."

Water quality is measured from grab and storm composite samples. Grab samples are collected periodically during baseflow conditions. In the spring, summer and fall, baseflow samples are collected twice a month. Along with baseflow samples, event-based composite samples are collected using automatic samplers. Composite samples are collected on an equal-flow increment (EFI) basis. With EFI sampling, composite samples are collected throughout the event, with discrete sub-samples representing equal volumes of flow. Due to safety issues, no samples were collected during most of the winter season (December to February). Water quantity for winter was estimated by filling in the data using a straight line analysis of the data from the previous fall to the following spring. This approach assumes that the flows were only baseflow and that there were no runoff events during this time period. Water quality loads were calculated with the FLUX model developed by the United States Army Corps of Engineers. FLUX estimates missing water quality data using relationships between water quality parameters and flows in varying flow regimes.

4.3   Development of the Flow Duration Curve

The duration curve method depicts water quality data over the full range of expected flow conditions, and it is well suited to water quality impairments that are correlated with flow (USEPA, 2007). The flow duration curve serves as the foundation for development of the load duration curve, on which TMDLs can be based. It relates flow values to the percent of time those values have been met or exceeded. The use of "percent of time" provides a uniform scale ranging between 0 and 100. Thus, the full range of stream flows is considered. The curves generally use average daily flow values sorted from highest to lowest. The values are plotted, with zero corresponding to the highest flow value and 100 corresponding to the lowest value. Based on the flow duration curve method guide (USEPA, 2007) the flow duration curve can be divided into separate flow regimes represented by various percentiles. Typical divisions include high flow (<10 percent), moist conditions (10-40 percent), mid-range flow (40-60 percent), dry conditions (60-90 percent) and low flow (>90 percent). The flow duration curve for Bevens Creek is shown in Figure 4.1. The curve uses average daily flow values monitored from 1989 through 2007 at the MCES Mile 2.0 station.

Flow Duration Curve
Bevens Creek Mile 2.0 Daily Flows
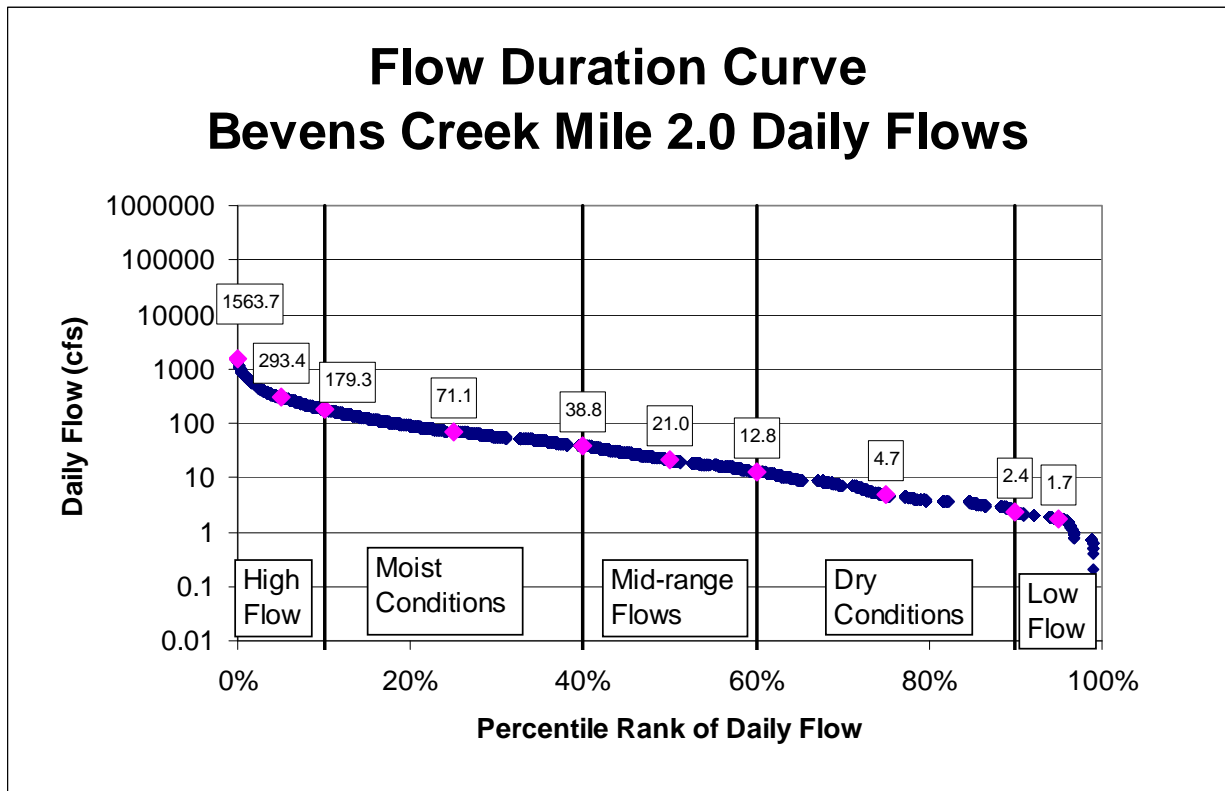
Figure 4.1 Bevens Creek Flow Duration Curve 1989 – 2007.

4.4   Calculation of TSS Equivalent for Turbidity Standard

Minnesota has a water quality standard for turbidity in streams. For Bevens Creek, the turbidity standard is 25 NTU. Turbidity cannot be expressed as a load as required by the TMDL regulations. To achieve a load based value, a surrogate of 110 mg/L TSS is being used based on the correlation between turbidity and TSS loads.

MCES performed a statistical analysis of the relationship between turbidity and TSS using monitoring data collected from streams in the Twin Cities Metropolitan Area. A simple linear regression equation was fit to turbidity and TSS data. The equation for Bevens Creek is:

$$\log(TSS) = 0.1260 + 1.368 * \log(NTU).$$

Using this relationship, it was determined that the TSS concentration corresponding to the 25 NTU turbidity standard was 110 milligrams per liter (mg/L). Therefore, the surrogate for the 25 NTU turbidity standard for Bevens Creek is 110 mg/L.
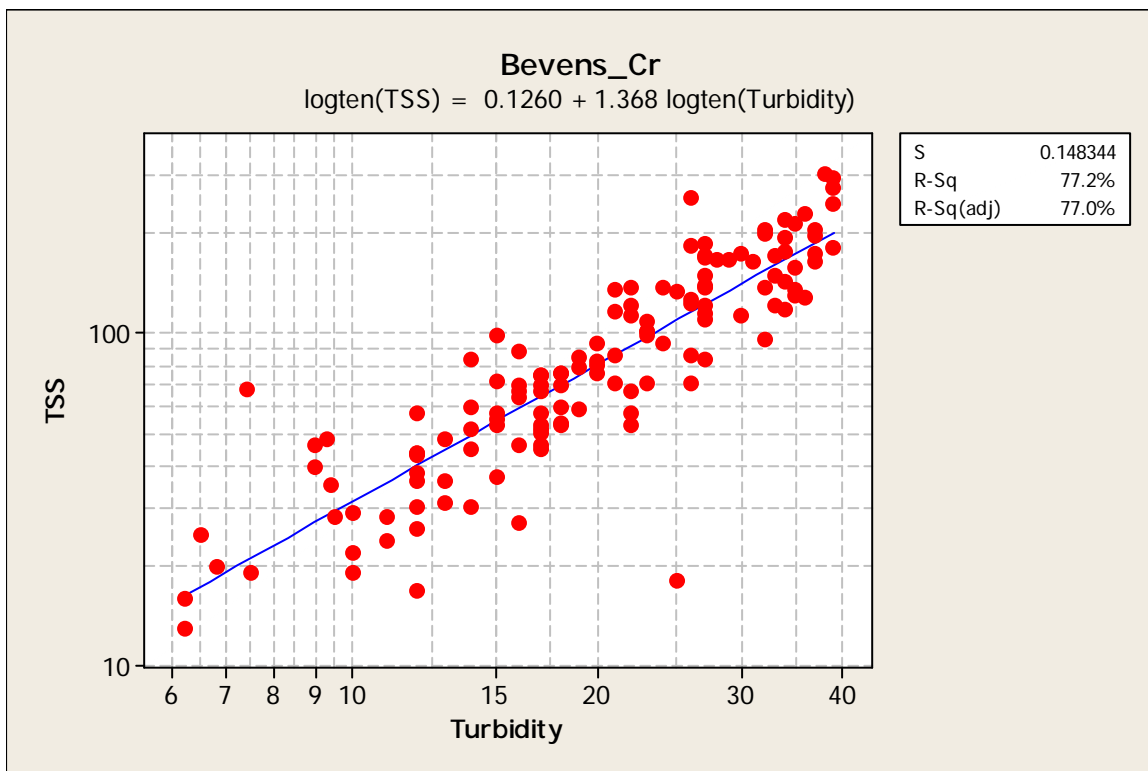
Figure 4.2 Bevens Creek TSS/Turbidity Relationship (MCES, 2009)

4.5   Determining Loading Capacity

There are several components to be estimated for TMDL allocations. They include loading capacity (TMDL), WLA, LA and MOS. Before the individual components of the TMDL can be allocated, the total loading capacity of the water body must be determined. The TSS load duration curve, which is estimated by multiplying stream flow and the target water quality standard, actually represents instantaneous loading capacities that vary as a function of flow (according to the guidance from the USEPA on using the duration curve method; USEPA, 2007). The load duration curve method is based on the flow duration curve analysis that looks at the cumulative frequency of historic flow data over a specified period. Because this method uses a long-term record of daily flow volumes virtually the full spectrum of allowable loading capacities is represented by the resulting curve. In the TMDL equation tables of this report (Tables 4.2 – 4.5) only five points on the entire loading capacity curve are depicted (the midpoints of the designated flow zones). However, it should be understood that the components of the TMDL equation could be illustrated for any point on the entire curve. The load duration curve method can be used to display collected TSS monitoring data and allows for estimation of load reductions necessary for attainment of the turbidity water quality standard (USEPA, 2007).

A load duration curve for Bevens Creek (Figure 4.3) was constructed from the flow duration curve by multiplying the stream flow by the numeric water quality target for TSS (110 mg/L) and a conversion factor. Plotting these values gives the loadings that correspond to the water quality target, or the loading capacity. Any of the monitored loads that are above the loading capacity line exceed the water quality standard, while those on or below it are in compliance with the standard. The load duration curve shows that the majority of the infractions occur at the high flow and moist conditions zones when flows are greater than 38.8 cubic feet per second (cfs). There are very few violations of the water quality standard at the lower flow regimes.
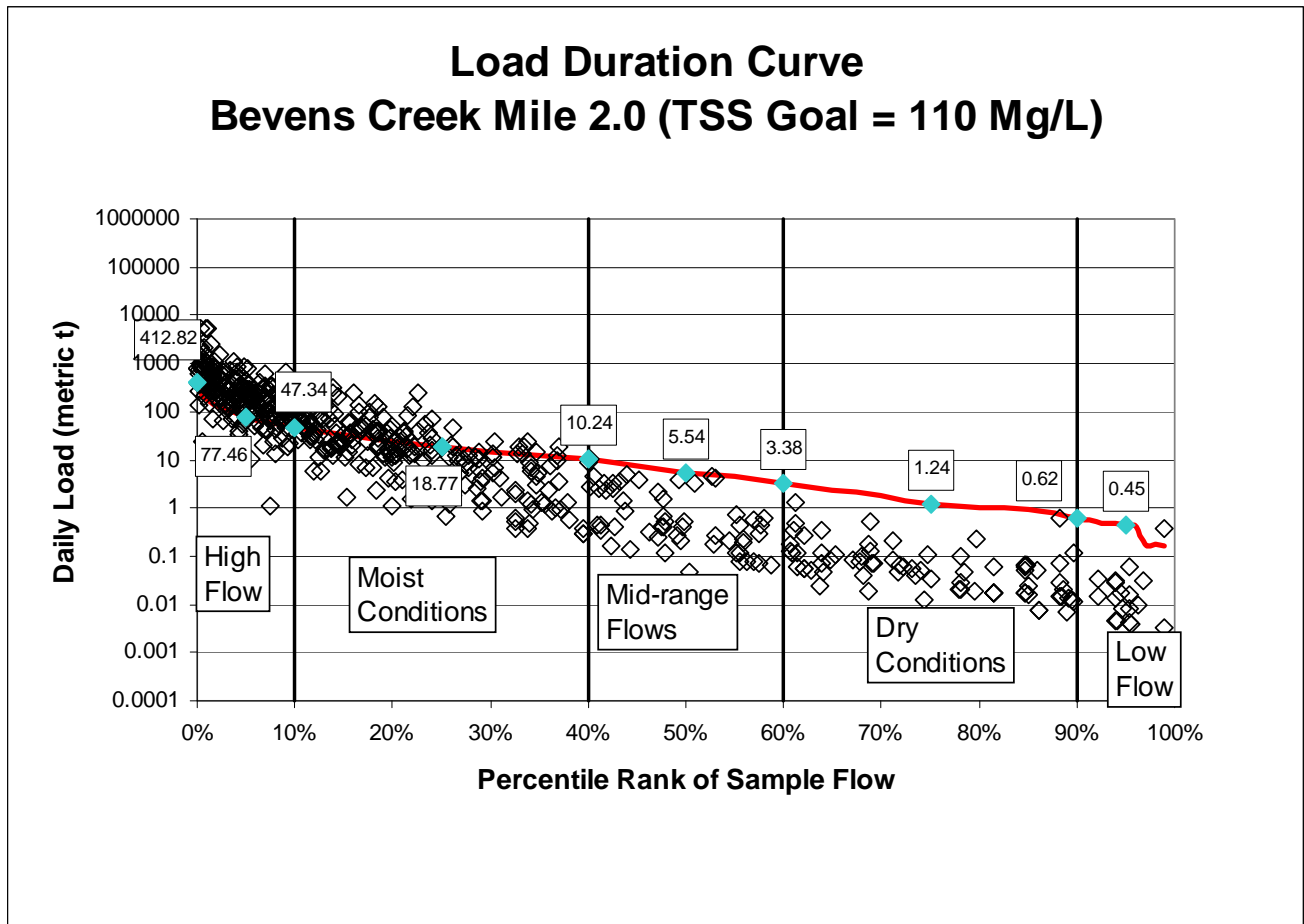
Figure 4.3 Bevens Creek TSS Load Duration Curve.

4.6 Allocation of TMDLs

Once the total loading capacity for TSS for the five flow regimes is determined, it is possible to allocate TSS loads to the different components of the TMDL. Information about how the TSS loads were allocated is presented in the following sections and the individual reach TMDLs for TSS.

4.6.1 Determining Margin of Safety (MOS)

The purpose of the MOS in the TMDL is to provide capacity to allow for uncertainty and future growth. The federal guidance for TMDLs states that the MOS may be implicit, that is incorporated into the calculations by using conservative assumptions, or explicit, expressed as loadings set aside for the MOS in the TMDL (MPCA, 2007).

The MOS for the Bevens Creek TMDL is ten percent of the total loading capacity at each of the flow zones. The MOS is expected to provide an adequate accounting of uncertainty, especially since point source discharges in the Bevens Creek watershed have generally been far lower than the permit limits (which is well below the TMDL TSS surrogate concentration). Also, the total loading capacity has limited error as it is a relatively simple calculation. It is basically the product of flow and the TSS surrogate concentration. Therefore, the MOS for the Bevens Creek

11

Turbidity TMDL is simply ten percent of the total load capacity for each flow regime. See Tables 4.2 to 4.5 for the allocated MOS values for each reach for Bevens Creek.

4.6.2   Determining Wasteload Allocation
WLA includes point-source contributions to turbidity or TSS to the total loading capacity for the given body of water. There is a limited amount of discharge from point sources to Bevens Creek, thus point sources have little impact on turbidity.

The WLA in this report consists of the permitted wastewater treatment facilities and permitted construction and industrial stormwater. Wastewater treatment plants (WWTPs) in the cities of Norwood Young America and Hamburg are located within the watershed, specifically in the reach designated as AUID 07020012-717 (and upstream of -514 and -718). The TSS concentration limits for these facilities are well below the TSS goal for this TMDL (Table 4.1). Their daily mass limits are used as their WLAs for this TMDL.

Table 4.1 WWTP NPDES TSS Discharge Permits in Bevens Creek Watershed.

Facility	ID	Discharges	Limit	Limit Concentration	Note
Norwood Young America WWTP	MN 0024392-SD 001 & SD 002	Effluent to surface water	103 kg/day	30 mg/L	Calendar Month Average
Hamburg WWTP	MN 0025585-SD 001	Effluent to surface water	96.5 kg/day	45 mg/L	Calendar Month Average

Stormwater from construction sites and industrial activities is covered by general NPDES permits. The values for construction are based on the fraction of area in Carver County that was under construction based on permit applications over the last 4.5 years. This area amounted to about 0.09 percent of the total county area. The WLA for construction was then calculated by taking the remaining loading capacity after other WLA, MOS and reserve capacity were subtracted and multiplying that amount by 0.09 percent. Consistent with other TMDL studies completed in Minnesota, industrial loads were set equal to those for construction.

To meet the WLA for construction stormwater, construction storm water activities are required to meet the conditions of the Construction General Permit under the NPDES program and properly select, install and maintain all 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.

To meet the WLA for industrial stormwater, industrial storm water activities are required to meet the conditions of the industrial stormwater general permit or General Sand and Gravel general permit (MNG49) under the NPDES program and properly select, install and maintain all BMPs required under the permit.

There are no municipal separate storm sewer (MS4) cities regulated under NPDES permits in the Bevens Creek watershed.

4.6.3   Determining Load Allocation

Load Allocation (LA) is determined by subtracting all WLA and MOS from the TMDL loading capacity. LA includes nonpoint pollution sources that are not subject to NPDES permit requirements, as well as "natural background" sources. The nonpoint pollution sources are largely related to wind and water erosion of upland soils, riparian area erosion, and streambank and channel erosion.

4.7   Seasonal Variation

As indicated in the load duration curve analysis, TSS loads vary significantly from high flow to low flow conditions. Most exceedance of the water quality standard for turbidity occur at the high- and moist-range flow conditions during the seasons with snow melt, rain and lack of a developed crop canopy. High-flow regimes are the critical condition for TMDL implementation. By using a duration curve approach in this TMDL the full range of flow conditions occurring over the year are fully captured and accounted for.

4.8   Impacts of Growth on Allocations

Currently, there are no permitted MS4 cities in the Bevens Creek watershed. The cities of Norwood Young America and Hamburg are not expected to be permitted by 2030. The Twin Cities Urban Area, as defined by the Census Bureau, appears unlikely to extend into the watershed in the foreseeable future. In the event the Urban Area expands into the watershed, the TMDL will be re-opened, if necessary, and WLA will be transferred from the LA category and will be assigned to regulated MS4s. To account for potential expansion of the two WWTPs a small amount of reserve capacity (equivalent to 50 percent of their current daily mass loading) has been accounted for in the TMDL. This additional potential future allocation accounts for a small fraction of the overall loading capacity because: 1) the actual volume of discharge relative to stream flow is very small and 2) the facilities discharge at a TSS concentration that is well below the TSS target for this TMDL so, in essence, the discharge provides a diluting effect. Nonetheless, should allocations for these facilities need to be increased or should new wastewater or cooling water dischargers come into the watershed, a streamlined process for updating TMDL WLAs to incorporate new or expanding discharges will be employed, which is summarized as follows:

> 1. A new or expanding discharger will file with the MPCA permit program a permit modification request or an application for a permit reissuance. The permit application information will include documentation of the current and proposed future flow volumes and TSS loads.
>
> 2. The MPCA permit program will notify the MPCA TMDL program upon receipt of the request/application, and provide the appropriate information, including the proposed discharge volumes and the TSS loads.
>
> 3. TMDL Program staff will provide the permit writer with information on the TMDL WLA to be published with the permit's public notice.
>
> 4. The supporting documentation (fact sheet, statement of basis, effluent limits summary sheet) for the proposed permit will include information about the TSS discharge requirements, noting that for TSS, the effluent limit is below the in-stream TSS target and the increased discharge will maintain the turbidity water quality standard. The public

will have the opportunity to provide comments on the new proposed permit, including the TSS discharge and its relationship to the TMDL.

5. The MPCA TMDL program will notify the EPA TMDL program of the proposed action at the start of the public comment period. The MPCA permit program will provide the permit language with attached fact sheet (or other appropriate supporting documentation) and new TSS information to the MPCA TMDL program and the US EPA TMDL program.

6. EPA will transmit any comments to the MPCA Permits and TMDL programs during the public comment period, typically via e-mail. MPCA will consider any comments provided by EPA and by the public on the proposed permit action and WLA and respond accordingly; conferring with EPA if necessary.

7. If, following the review of comments, MPCA determines that the new or expanded TSS discharge, with a concentration below the in-stream target, is consistent with applicable water quality standards and the above analysis, MPCA will issue the permit with these conditions and send a copy of the final TSS information to the USEPA TMDL program. MPCA's final permit action, which has been through a public notice period, will constitute an update of the WLA only.

8. EPA will document the update to the WLA in the administrative record for the TMDL. Through this process EPA will maintain an up-to-date record of the applicable WLA for permitted facilities in the watershed.

4.9   TMDL Allocations for Individual Impaired Reaches

The Bevens Creek watershed consists of two subwatersheds: Bevens Creek main stem and Silver Creek. The watershed has been listed for turbidity impairment as four contiguous reaches: AUID 07020012-717, AUID 07020012-718, AUID 07020012-523, and AUID 07020012-514. TMDLs were calculated to represent the specific reach and all upstream portions, representing the following portions of the upstream watershed area: 48 percent, 68 percent, 31 percent, and 100 percent, respectively. The data from the MCES mile 2.0 monitoring station is the most complete monitoring data for the Bevens Creek watershed. The loading capacity and load allocations for the designated reaches were estimated by assuming that the ungaged reaches are proportional to the gaged flow based on respective drainage areas. The loading capacities and allocations for these reaches are described in the following sections.

It should be noted that the total daily loading capacity in the low flow zone is very small due to the occurrence of very low flows in the long-term flow records. Consequently, the permitted wastewater treatment facility design flows exceed the stream flow at the low flow zone. Of course actual treatment facility flow can never exceed stream flow as it is a component of stream flow. To account for these unique situations 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 (*X* mg/L TSS), where *X* equals 45 for the Hamburg WWTP, 30 for Norwood Young America WWTP, and 110 for the LA sources

In essence, this assumption equates to assigning a concentration-based limit to the sources for the low flow zone.

4.9.1   AUID 07020012-717

AUID 07020012-717 extends from Washington Lake in northeastern Sibley County to an unnamed creek in Carver County (Figure 1.1). This reach accounts for 48 percent of the total watershed area, and contains the WWTP outfalls for the cities of Norwood Young America and Hamburg. The load duration curve for this reach is shown in Figure 4.4. The TMDL allocations for this reach are shown in Table 4.2.
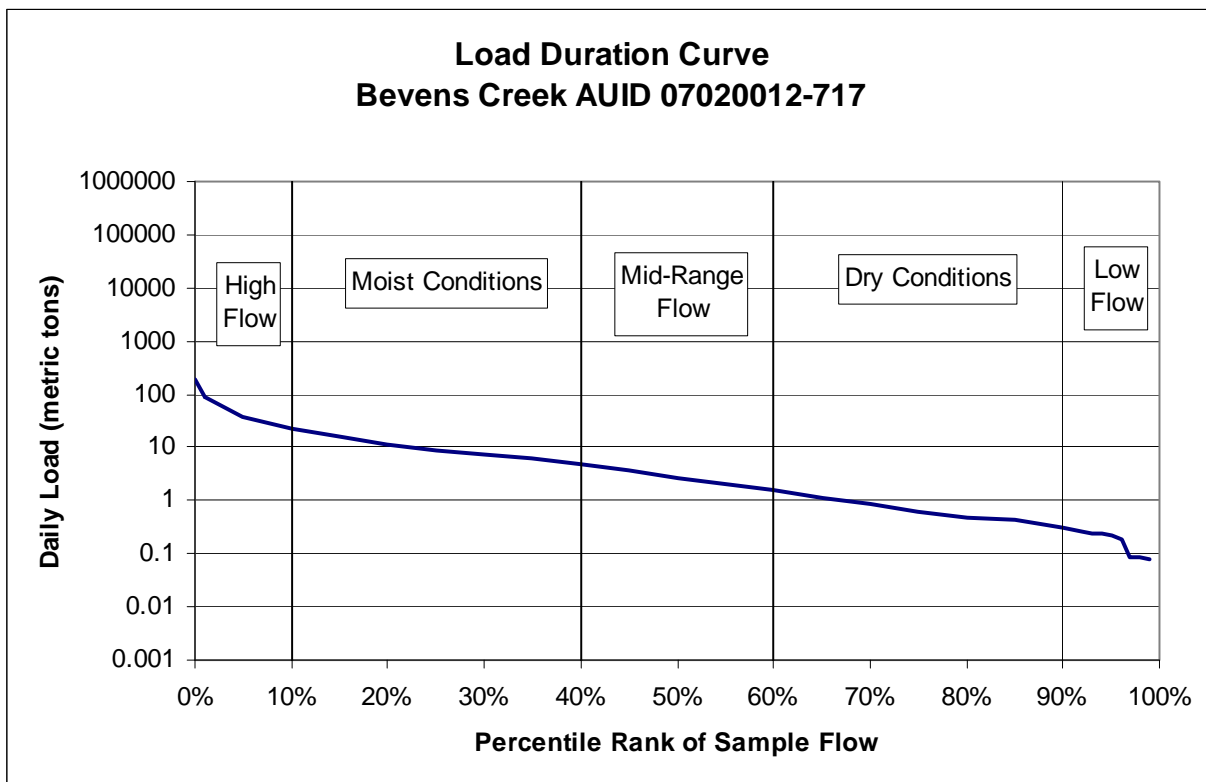

Figure 4.4 Load Duration Curve for Bevens Creek AUID 07020012-717.

Table 4.2 TSS TMDL Load Allocations for Bevens Creek AUID 07020012-717 in kg/day.

TMDL Allocation	High Flow	Moist Conditions	Mid-Range	Dry Conditions	Low Flow
Total Loading Capacity (TMDL)	37,181.0	9,010.0	2,659.0	595.0	216.0
Wasteload Allocation (WLA)	259.2	213.6	203.3	199.9	*
Norwood Young America WWTP	103.0	103.0	103.0	103.0	*
Hamburg WWTP	96.5	96.5	96.5	96.5	*
Construction WLA	29.8	7.0	1.9	0.2	*
Industrial WLA	29.8	7.0	1.9	0.2	*
Reserve Capacity (RC)	99.8	99.8	99.8	99.8	*
Norwood Young America WWTP	51.5	51.5	51.5	51.5	*
Hamburg WWTP	48.3	48.3	48.3	48.3	*
Margin of Safety (MOS)	3,718.1	901.0	265.9	59.5	21.6
Load Allocation (LA)	33,104.0	7,795.7	2,090.1	235.8	#
Percent of Total Loading Capacity					
Total Loading Capacity (TMDL)	100.0%	100.0%	100.0%	100.0%	100.0%
Wasteload Allocation (WLA)	0.70%	2.37%	7.64%	33.60%	*
Norwood Young America WWTP	0.28%	1.14%	3.87%	17.31%	*
Hamburg WWTP	0.26%	1.07%	3.63%	16.22%	*
Construction WLA	0.08%	0.08%	0.07%	0.04%	*
Industrial WLA	0.08%	0.08%	0.07%	0.04%	*
Reserve Capacity (RC)	0.27%	1.11%	3.75%	16.76%	*
Norwood Young America WWTP	0.14%	0.57%	1.94%	8.66%	*
Hamburg WWTP	0.13%	0.54%	1.81%	8.11%	*
Margin of Safety (MOS)	10.0%	10.0%	10.0%	10.0%	10.0%
Load Allocation (LA)	89.0%	86.5%	78.6%	39.6%	#

* see Section 4.9 for further discussion on WLA for WWTP loadings

\# see Section 4.9 for further discussion on LA

4.9.2   AUID 07020012-718

AUID 07020012-718 is contiguous with AUID 07020012-717 and extends from an unnamed creek in Carver County to the confluence of Bevens Creek and Silver Creek (Figure 1.1). This reach accounts for 68 percent of the total watershed area. The load duration curve for this reach is shown in Figure 4.5. The TMDL allocations for this reach are shown in Table 4.3.
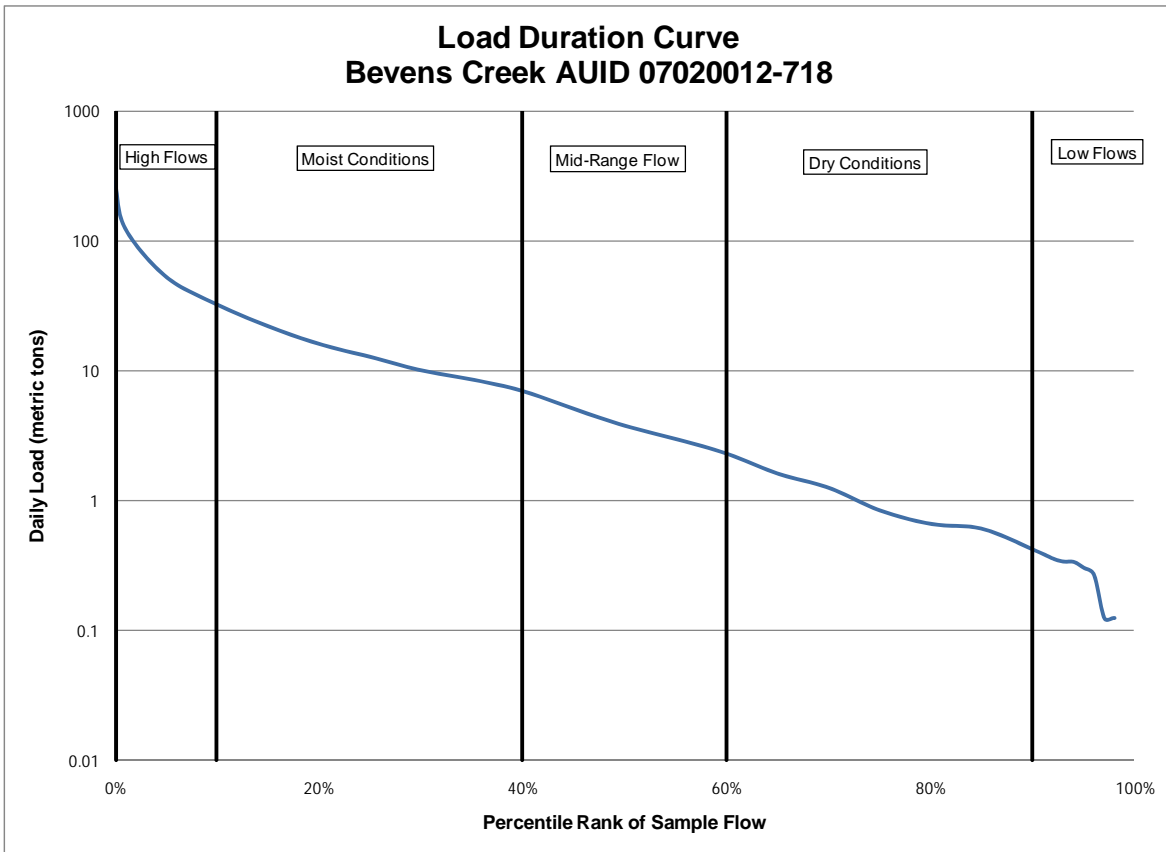
Figure 4.5 Load Duration Curve for Bevens Creek AUID 07020012-718.

Table 4.3 TSS TMDL Load Allocations for Bevens Creek AUID 07020012-718 in kg/day.

TMDL Allocation	High Flow	Moist Conditions	Mid-Range	Dry Conditions	Low Flow
Total Loading Capacity (TMDL)	52,673.0	12,764.0	3,767.0	843.0	306.0
Wasteload Allocation (WLA)	294.3	222.5	206.3	201.0	*
Norwood Young America WWTP	103.0	103.0	103.0	103.0	*
Hamburg WWTP	96.5	96.5	96.5	96.5	*
Construction WLA	42.4	10.1	2.8	0.4	*
Industrial WLA	42.4	10.1	2.8	0.4	*
Reserve Capacity (RC)	99.8	99.8	99.8	99.8	*
Norwood Young America WWTP	51.5	51.5	51.5	51.5	*
Hamburg WWTP	48.3	48.3	48.3	48.3	*
Margin of Safety (MOS)	5,267.3	1,276.4	376.7	84.3	30.6
Load Allocation (LA)	47,021.7	11,168.2	3,085.5	458.6	#
Percent of Total Loading Capacity					
Total Loading Capacity (TMDL)	100.0%	100.0%	100.0%	100.0%	100.0%
Wasteload Allocation (WLA)	0.56%	1.74%	5.48%	23.84%	*
Norwood Young America WWTP	0.20%	0.81%	2.73%	12.22%	*
Hamburg WWTP	0.18%	0.76%	2.56%	11.45%	*
Construction WLA	0.08%	0.08%	0.07%	0.05%	*
Industrial WLA	0.08%	0.08%	0.07%	0.05%	*
Reserve Capacity (RC)	0.19%	0.78%	2.65%	11.83%	*
Norwood Young America WWTP	0.10%	0.40%	1.37%	6.11%	*
Hamburg WWTP	0.09%	0.38%	1.28%	5.72%	*
Margin of Safety (MOS)	10.0%	10.0%	10.0%	10.0%	10.0%
Load Allocation (LA)	89.3%	87.5%	81.9%	54.4%	#

* see Section 4.9 for further discussion on WLA for WWTP loadings

\# see Section 4.9 for further discussion on LA

4.9.3   AUID 07020012-523

AUID 07020012-523 is a reach of Silver Creek that extends from County Ditch 32 to the confluence with the main stem of Bevens (Figure 1.1). This reach accounts for 31 percent of the total Bevens Creek watershed area. The load duration curve for this reach is shown in Figure 4.6. The TMDL allocations for this reach are shown in Table 4.4.
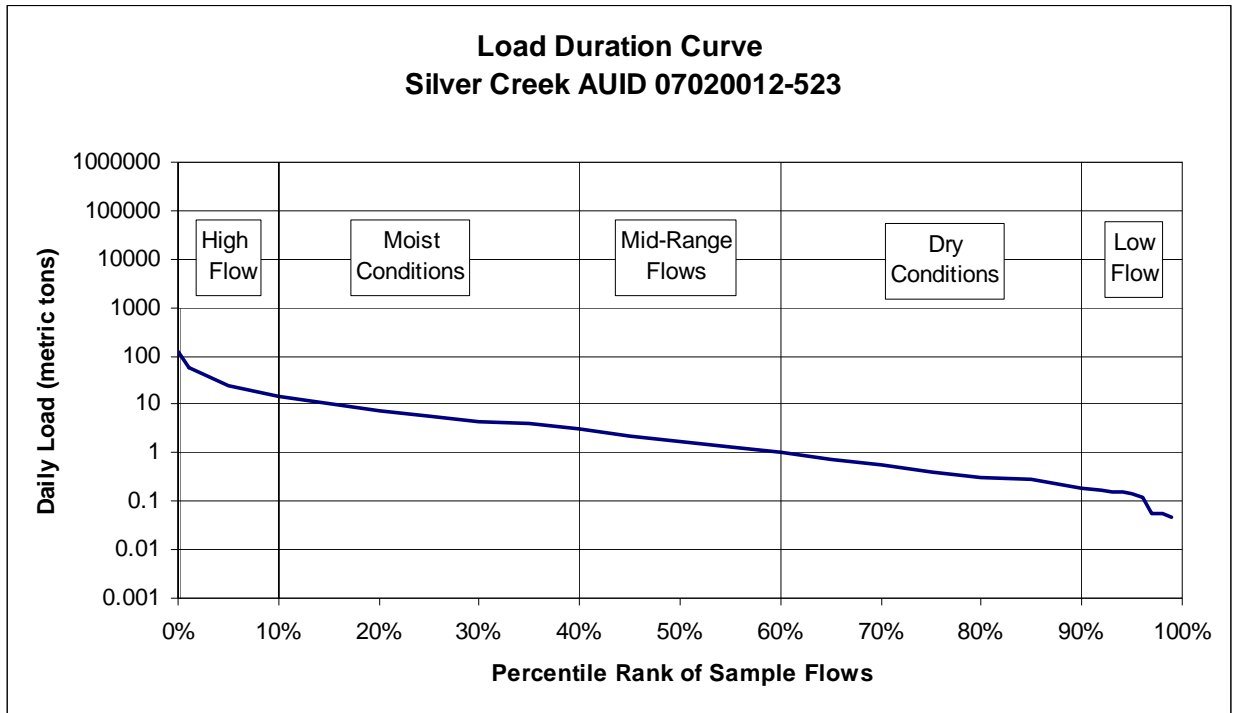
Figure 4.6 Load Duration Curve for Silver Creek AUID 07020012-523.

Table 4.4 TSS TMDL Load Allocations for Silver Creek AUID 07020012-523 in kg/day.

TMDL Allocation	High Flow	Moist Conditions	Mid-Range	Dry Conditions	Low Flow
Total Loading Capacity (TMDL)	24,013.0	5,819.0	1,717.0	384.0	140.0
Wasteload Allocation (WLA)	38.9	9.4	2.8	0.6	0.2
Construction WLA	19.5	4.7	1.4	0.3	0.1
Industrial WLA	19.5	4.7	1.4	0.3	0.1
Margin of Safety (MOS)	2,401.3	581.9	171.7	38.4	14.0
Load Allocation (LA)	21,572.8	5,227.7	1,542.5	345.0	125.8
Percent of Total Loading Capacity					
Total Loading Capacity (TMDL)	100.0%	100.0%	100.0%	100.0%	100.0%
Wasteload Allocation (WLA)	0.16%	0.16%	0.16%	0.16%	0.16%
Construction WLA	0.08%	0.08%	0.08%	0.08%	0.08%
Industrial WLA	0.08%	0.08%	0.08%	0.08%	0.08%
Margin of Safety (MOS)	10.0%	10.0%	10.0%	10.0%	10.0%
Load Allocation (LA)	89.8%	89.8%	89.8%	89.8%	89.8%

4.9.4   AUID 07020012-514

AUID 07020012-514 is a reach of Bevens Creek that extends from the confluence of Bevens and Silver Creek to the Minnesota River (Figure 1.1). This reach accounts for 100 percent of the total watershed area, and includes the MCES Mile 2.0 monitoring station. The load duration curve for this reach is shown in Figure 4.3. The TMDL allocations for this reach are shown in Table 4.5.

Table 4.5 TSS TMDL Load Allocations for Bevens Creek AUID 07020012-514 in kg/day.

TMDL Allocation	High Flow	Moist Conditions	Mid-Range	Dry Conditions	Low Flow
Total Loading Capacity (TMDL)	77,461.0	18,771.0	5,539.0	1,239.0	450.5
Wasteload Allocation (WLA)	324.4	229.4	207.9	201.0	199.7
Norwood Young America WWTP	103.0	103.0	103.0	103.0	103.0
Hamburg WWTP	96.5	96.5	96.5	96.5	96.5
Construction WLA	62.5	14.9	4.2	0.7	0.1
Industrial WLA	62.5	14.9	4.2	0.7	0.1
Reserve Capacity (RC)	99.8	99.8	99.8	99.8	99.8
Norwood Young America WWTP	51.5	51.5	51.5	51.5	51.5
Hamburg WWTP	48.3	48.3	48.3	48.3	48.3
Margin of Safety (MOS)	7,746.1	1,877.1	553.9	123.9	45.1
Load Allocation (LA)	69,290.7	16,564.8	4,677.4	814.4	106.0
Percent of Total Loading Capacity					
Total Loading Capacity (TMDL)	100.0%	100.0%	100.0%	100.0%	100.0%
Wasteload Allocation (WLA)	0.42%	1.22%	3.75%	16.22%	44.33%
Norwood Young America WWTP	0.13%	0.55%	1.86%	8.31%	22.86%
Hamburg WWTP	0.12%	0.51%	1.74%	7.79%	21.42%
Construction WLA	0.08%	0.08%	0.08%	0.06%	0.02%
Industrial WLA	0.08%	0.08%	0.08%	0.06%	0.02%
Reserve Capacity (RC)	0.13%	0.53%	1.80%	8.05%	22.14%
Norwood Young America WWTP	0.07%	0.27%	0.93%	4.16%	11.43%
Hamburg WWTP	0.06%	0.26%	0.87%	3.89%	10.71%
Margin of Safety (MOS)	10.0%	10.0%	10.0%	10.0%	10.0%
Load Allocation (LA)	89.5%	88.2%	84.4%	65.7%	23.5%

*see Section 4.9 for further discussion on WLA for WWTP loadings

see Section 4.9 for further discussion on LA

5 Turbidity Source Evaluation

5.1 TSS Loading

The actual TSS loads for Bevens Creek are plotted on the load duration curve in Figure 4.3. The load duration curve was developed by multiplying the numeric water quality target for TSS (110 mg/L) by daily stream flow. The individual points on the graph represent instantaneous TSS loads estimated using grab and composite TSS concentrations and the corresponding daily flows observed for the same days. The figure shows that most violations of the target water quality standard of 110 mg/L occur in the high flow and moist conditions when flows are larger than 38.8 cfs. At dry and low flow conditions, only a few samples surpassed the target TSS load.

5.2 Potential Sources of TSS

Based on observations by Carver County staff it is believed that bank erosion is a chief contributor to in-stream TSS load. Estimates made in studies by the St. Croix Watershed Research Station for nearby streams in the lower part of the Minnesota River basin using sediment isotope methodology were considered. These studies distinguished sediment derived from the surface (which they term "field") versus sediment derived from deeper than 12 inches (or "non-field"). The latter category is assumed to represent sediment from stream banks or gullies (SCWRS, 2009). These studies conclude that approximately 30 percent of the in-stream TSS load is from the surface and 70 percent is from subsurface-derived sediment. The majority of subsurface sediment erosion is assumed to be bank erosion in this watershed.

Objectives and tasks established for this study highlighted a need for a watershed scale model that was able to simulate natural, agricultural and urban ecological systems relevant to the hydrologic cycle, TSS yields and movements in the watershed. The SWAT (Soil and Water Assessment Tool) model developed by the U.S. Department of Agriculture Research Service and Texas A&M University was therefore chosen. SWAT is one of the advanced models recommended for TMDL studies by the USEPA. SWAT has been incorporated into the USEPA's BASINS modeling platform (USEPA, 2001). BASINS is a multipurpose environmental analysis system used by regional, state, and local agencies to perform watershed and water quality based studies.

SWAT was created initially for agricultural non-point source pollution studies in the early 1990s. Since then, it has undergone continued review and expansion of capabilities. An urban routine, which is an important feature for watersheds with mixed land uses, was incorporated into SWAT in 1999. The routine includes a set of United States Geological Survey (USGS) linear regression equations (Driver and Tasker, 1988) and build-up/wash-off equations (Huber and Dickinson, 1988) for estimating constituent loads. SWAT also includes models and databases about weather, soil properties, topography, vegetation and land management practices. These databases are necessary to simulate water and chemical yields and movements in the complex ecological systems of watersheds. A full modeling study for Bevens Creek is included within Appendix A. Use of the SWAT model in the TMDL report is not used to set allocations nor to conclude what sediment yields occur from the landscape. Rather its primary purpose is to evaluate relative differences in potential runoff of surface sediment among the subwatersheds within the larger Bevens Creek watershed (see Figure 20 of Appendix A) and to provide a tool for evaluating various BMP implementation scenarios to illustrate the potential magnitude of change that may be possible. This type of information helps to inform implementation planning.

6   Monitoring Plan

Carver County Staff currently monitors five automated stream sampling stations throughout Bevens Creek Watershed. These sites monitor discharge of the creek and tributaries, as well as taking composite samples during both storm and base events. Grab samples are also taken on a bi-weekly schedule. All samples are tested by certified labs for chemical composition, including, but not limited to, total phosphorus, total Kjedahl nitrogen, orthophosphate, dissolved phosphorus, alkalinity, ammonia nitrogen, nitrate, nitrite, total suspended solids and volatile suspended solids. A more detailed monitoring plan will be included in the final Implementation Plan.

7   Implementation Strategy

7.1   Introduction

Carver County, through their Water Management Plan, has embraced a basin wide goal for protecting water quality in the Bevens Creek watershed. Currently, Carver County has developed detailed action strategies to address several of the issues identified in this TMDL. The Carver SWCD is active in these watersheds and works with landowners to implement BMPs on their land.

This section broadly addresses the course that Carver County will take to incorporate actions and strategies to achieve the TMDL goals set forth within this document. An Implementation Plan that will lay out specific goals, actions and strategies will be published within one year of the final EPA approval of this TMDL. Any action items pertinent to this TMDL that are not included in the Carver County Water Plan will be identified and amended to the Implementation Plan.

7.2   The Carver County Water Management Plan

The Carver County Water Management Plan describes the set of issues requiring implementation action. MN Rule 8410 describes a list of required plan elements. Carver County has determined the following issues, bulleted below, to be of high priority. Items not covered in this plan will be addressed as necessary to accomplish the higher priority goals. Each issue is summarized in the Carver County Water Management Plan followed by background information, a specific goal, and implementation steps. The issues included in the plan which addresses the turbidity TMDL sources and reductions are:

- Construction Site Erosion and Sediment Control
- Stormwater Management
- Land Use Practices for Urban and Rural Areas
- Water Quality Assessment
- Wetland Management

7.3   The Sibley County Water Management Plan

Carver County will work closely with Sibley County to integrate the TMDL implementation plans into the Sibley County local management activities as well as the Sibley County Comprehensive Water Management Plan for the portions of the Bevens Creek watershed existing in Sibley County.

The Sibley County Comprehensive local water plan covers existing water and related land uses, water resource issues, problems and a plan of action to promote sound management of water and related land resources, effective environmental protection and efficient management. The plan was written in accordance with Minnesota Stature 103B. Items not covered in this plan will be addressed as necessary to accomplish the higher priority goals set forth by the TMDL results.

7.4   Load Reduction Estimates

Estimates for the percent load reduction needed were made by comparing measured TSS concentrations within each flow regime to the TSS surrogate concentration that is equivalent to the NTU standard (25 NTU). To make this estimate the listing/delisting criteria for turbidity was considered, which is based on whether or not 10 percent of the data points within a dataset exceed the turbidity standard. Therefore, this would mean reducing the 90th percentile value from

the dataset down to the TSS concentration target. Table 7.1 provides estimated percent reductions based on the flow duration curve and sampled TSS concentrations. The table is transferable to any of the four stream reaches within this TMDL. This serves to provide a starting point based on available water quality data for assessing the magnitude of the effort needed in the watershed to achieve the standard. These reduction percentages do not supersede the allocations provided in Table 4.1.

Table 7.1 Estimated Concentration Reductions Based on Sampled Data and Flow Duration Curve.

8	High Flows	Moist Conditions	Mid-Range	Dry Conditions	Low Flows
TSS Concentration Target (mg/L)	110	110	110	110	110
Measured TSS Concentration at 90th Percentile (mg/L)	638	401	61	12	7.5
Reduction Needed	83%	73%	0	0	0

8.1 Best Management Practices

The final Implementation Plan will be developed within a year of the final approval of the TMDL report by the USEPA. It will list what and where BMPs will be applied in the watershed and identify the cost and funding sources for their application. To reach the reduction goals Carver County will rely largely on its current Water Management Plan, which identifies the Carver SWCD as the local agency for implementing best management practices. Implementation goals not covered in the Water Management Plan will be identified and amended to the implementation plan.

BMPs under consideration include filter strip application, conservation tillage, wetland and pond infiltration, and bank erosion control. A short description of each BMP and its ability to reduce TSS loads in the Bevens Creek Watershed are highlighted below. Further discussion on these BMPs is presented in the Bevens Creek SWAT Modeling Report included in the Appendix.

Total costs to implement this TMDL, which encompasses multiple BMPs, has been estimated to be between $8,238,000 and $30,950,000. Individual strategies and costs are broken out in the following sections.

8.1.1 Filter Strip Application

Filter strips, sometimes referred to as buffer strips, are generally narrow and long areas of vegetation (mostly grasses). Filter strips are usually placed along watercourses, streams, ponds and lakes as part of a conservation system designed to conserve water, soil and protect receiving waters. They are one example of a BMP designed to slow the rate of runoff, and capture sediment, organic material, nutrients, and other chemicals conveyed by stormwater runoff. Filter strips are less effective in the control of soluble nutrients and pesticides in stormwater runoff. They also provide wildlife habitat and benefit the environment.

Task 1. Identify and prioritize key areas within the Bevens Creek subwatersheds not implementing conservation tillage and total TSS loads modeled within SWAT. Identification will be based on monitoring results and/or visual inspections of existing buffer strips, or lack of.

    1) Responsible Parties: CCWMO, Carver SWCD, NRCS
    2) Timeline: Short Term
    3) Estimated Cost: $5,500 - $15,000

Task 2. Identify and educate landowners through meetings, brochures, Carver County quarterly newspaper (The Citizen), Carver County Website, and various workshops.

    1) Responsible Parties: CCWMO, Carver SWCD
    2) Timeline: Long Term
    3) Estimated Cost: $5,000 - $10,000

Task 3. Offer incentives, cost share, easements, and acquisition of land for landowners to implement and construct buffer strips along agricultural ditches and main reaches of Bevens Creek in areas deemed prudent.

    1) Responsible Parties: CCWMO, Carver SWCD
    2) Timeline: Long Term
    3) Estimated Cost: $1,000,000 - $4,500,000

8.1.2   Conservation Tillage

Conventional tillage was probably the first and most important innovation that our ancestors developed in an attempt to increase crop productivity for food supply. Tillage was widely used on large areas with the invention of mechanical power, such as tractors, and the development of tillage technology. The major benefits of tillage include preparation of seed and root beds, weed control and establishment of surface soil conditions for water infiltration and soil erosion control. However, tillage destroys dense and perennial vegetation, buries biomass residues, compacts soil and accelerates the biomass decomposition. Conventional tillage practices result in more surface runoff, greater susceptibility of soils to wind and water erosion and greater nutrient and chemical exports to receiving waters.

Conservation tillage includes those agricultural practices and techniques that conserve both soils and water. These newer tillage practices and techniques may include: keeping biomass residues on the soil surface to minimize both water and wind erosion, reducing or eliminating tillage, delaying tillage until near the time to plant the next crops, and tilling in contour across sloping land. Technically, conservation tillage can be defined as any tillage or planting system in which at least 30 percent of the soil surface is covered by plant residue after planting in order to reduce erosion by water or wind (Scherts, 1988).

Conservation tillage prioritization will target "hot spots. Evaluation will primarily be based upon a field assessment of farming practices utilized by farmers.

> ***Task 1***. Identify and prioritize key areas within the Bevens Creek subwatersheds based upon areas not implementing conservation tillage and TSS loads modeled within SWAT.

1) Responsible Parties: CCWMO, Carver SWCD, NRCS
2) Timeline: Short Term
3) Estimated Cost: $7,500 - $15,000

Task 2. Identify and educate landowners through meetings, brochures, Carver County quarterly newspaper (The Citizen), Carver County Website, and various workshops.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Long Term
3) Estimated Cost: $5,000 - $10,000

Task 3. Offer incentives and cost share to landowners for implementing conservation tillage practices on fields.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Long Term
3) Estimated Cost: $50,000 - $150,000

8.1.3   Wetland and Pond Infiltration

Impoundments such as wetlands and ponds are probably one of the most commonly used practices in watershed management to temporarily store excess water, reduce flood damage, stabilize drainage ways, reduce erosion, remove pollutants and provide habitat for wildlife. Sedimentation in combination with biogeochemical processes of adsorption, flocculation, decomposition, and biological uptake are the primary removal mechanisms for suspended solids and nutrients in wetlands, ponds and other water bodies.

Wetland restoration and enhancements will be prioritized through the Carver County Water Management Plan, consultant reports and staff recommendations. Areas that have been identified through this process will be confirmed through landowner consent and consultation.

Task 1. Identify and prioritize key areas within the Bevens Creek subwatersheds that have a high potential for wetland restoration. Identification will be based on mapping identification and ground truthing.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Short Term
3) Estimated Cost: $7,500 - $15,000

Task 2. Identify and educate landowners through meetings, brochures, Carver County quarterly newspaper (The Citizen), Carver County Website, and various workshops.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Long Term
3) Estimated Cost: $5,000 - $10,000

Task 3. Acquisition of lands deemed a high priority for wetland construction and completion of wetland projects.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Long Term
3) Estimated Cost: $2,500,000 - $10,000,000

Task 4. Design and implement practices that will reduce volume within the stream, thus reducing in-stream erosion.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Long Term
3) Estimated Cost: $1,000,000 - $2,500,000

8.1.4   Bank Erosion Control

Field studies by the St. Croix Watershed Research Station have indicated that non-field erosion contributes approximately 70 percent of the TSS loads in Bevens Creek. Significant efforts should be made to control field erosion in the watershed to reduce flow and TSS loads contributed from the landscapes to channels but also because reduced flows from the field erosion could also benefit downstream bank erosion. The non-field erosion, or bank erosion, directly contributes TSS to the channels and immediately impairs the water quality of the creek because the TSS from the non-field erosion is not assimilated by local water bodies such as wetlands and ponds. The non-field erosion control BMPs such as bank stabilization are, therefore, necessary in the Bevens Creek watershed in order to achieve the water quality standard for turbidity.

Bank erosion control measures are costly due to construction and maintenance requirements. In the Bevens Creek Watershed, some sub-basins are much more highly erodible than others. Thus, applying BMPs to control bank erosion to the selected sub-basins rather than to the entire watershed can greatly reduce implementation costs.

Bank stabilization prioritization will target "hot spots." Evaluation will primarily be based upon field assessment and GIS mapping software.

Task 1. Identify and prioritize key areas within the Bevens and Silver Creek reaches that have a high potential for bank erosion. Identification will be based on mapping identification and ground truthing.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Short Term
3) Estimated Cost: $7,500 - $15,000

Task 2. Identify and educate landowners through meetings, brochures, Carver County quarterly newspaper (The Citizen), Carver County Website, and various workshops.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Long Term
3) Estimated Cost: $5,000 - $10,000

Task 3. In stream projects to protect streambanks from erosion.

1) Responsible Parties: CCWMO, Carver SWCD
2) Timeline: Long Term
3) Estimated Cost: $2,640,000 - $13,200,000

9 Reasonable Assurance

9.1 Introduction

When establishing a TMDL, reasonable assurances must be provided demonstrating the ability to reach and maintain water quality endpoints. Several factors control reasonable assurances including a thorough knowledge of the ability to implement BMPs, the state and local authority to implement, as well as the overall effectiveness of the BMPs. Carver County is positioned to implement the TMDL and ultimately achieve water quality standards.

9.2 Management of Bevens Creek Watershed

Carver County is the water management authority for a large portion of Bevens Creek and it will continue to work with Sibley County to manage the portions of the watershed that lie outside its boundaries. The County is uniquely qualified through its zoning and land use powers to implement corrective actions to achieve TMDL goals. The County has stable funding for water management each year, and will continue its baseline-monitoring program. Carver County recognizes the importance of the natural resources within its boundaries, and seeks to manage those resources to attain the following goals:

1. Protect, preserve, and manage natural surface and groundwater storage and retention systems;
2. Effectively and efficiently manage public capital expenditures needed to correct flooding and water quality problems;
3. Identify and plan for means to effectively protect and improve surface and groundwater quality;
4. Establish more uniform local policies and official controls for surface and groundwater management;
5. Prevent erosion of soil into surface water systems;
6. Promote groundwater recharge;
7. Protect and enhance fish and wildlife habitat and water recreational facilities; and
8. Secure the other benefits associated with the proper management of surface and groundwater.

The Carver County Board of Commissioners (County Board), acting as the water management authority for the former Bevens Creek (includes Silver Creek), Carver Creek, East and West Chaska Creeks, and South Fork Crow River watershed management organization areas, has established the "Carver County Water Management Organization (CCWMO)". The purpose of establishing the CCWMO is to fulfill the County's water management responsibilities under Minnesota Statue and Rule. The County chose this structure because it will provide a framework for water resource management as follows:

- Provides a sufficient economic base to operate a viable program;
- Avoids duplication of effort by government agencies;
- Avoids creation of a new bureaucracy by integrating water management into existing County departments and related agencies;
- Establishes a framework for cooperation and coordination of water management efforts among all of the affected governments, agencies, and other interested parties; and
- Establishes consistent water resource management goals and standards for at

least 80 percent of the county.

The County Board is the "governing body" of the CCWMO for surface water and groundwater management. In function and responsibility the County Board is essentially equivalent to a joint powers board or a watershed district board of managers. Water management is an interdisciplinary effort and involves several County departments and associated County agencies including: Planning and Water Management, Environmental Services, County Extension and the Carver SWCD. The County Planning & Water Management Department is responsible for administration of the water plan and coordinating implementation. Other departments and agencies will be called upon to perform water management duties that fall within their area of responsibility. These responsibilities may change as the need arises. The key entities (Planning and Water Management, Environmental Services, County Extension and the SWCD) meet regularly as part of the Joint Agency Meeting (JAM) process to coordinate priorities, activities, and funding. Carver County has established a stable source of funding through a watershed levy in the CCWRMA taxing district (adopted 2001). This levy allows for consistent funding for staff, monitoring, engineering costs and also for on the ground projects. The County has also been very successful in obtaining grant funding from local, state and federal sources due to its organizational structure. Sibley County has been the recipient of several state and federal grants as well.

Within one year of the approval of the Turbidity TMDL by the USEPA, a Final Implementation Plan will be released. This Implementation Plan charts the course Carver County will take to incorporate TMDL results into local management activities as well as the Carver County Water Management Plan. The ultimate goal of the Implementation Plan is to achieve the identified load reductions in Bevens Creek needed to reach the State Standard for turbidity.

9.3   Regulatory Approaches

9.3.1   Watershed Rules
Water Rules establish standards and specifications for the common elements relating to watershed resource management including: Water Quantity, Water Quality, and Natural Resource
Protection, Erosion and Sediment Control, Wetland Protection, Shoreland Management, and Floodplain Management. The complete water management rules are contained in the Carver County Code, Section 153.

9.4   Non-Regulatory and Incentive Based Approaches

9.4.1   Education
The implementation of this plan relies on three overall categories of activities: 1) Regulation, 2) Incentives, and 3) Education. For most issues, all three means must be part of an implementation program. The County has taken the approach that regulation is only a supplement to a strong education and incentive based program to create an environment of low risk. Understanding the risk through education can go a long way in preventing problems. In addition, education, in many cases, can be a simpler, less costly and more community friendly way of achieving goals and policies. Education efforts can provide the framework for more of a "grass roots", community plan implementation, while regulation and incentives traditionally follow a more "top-down" approach. It is recognized however, that education by itself will not always meet

intended goals, has certain limitations, and is characteristically more of a long-term approach.

To this end, Carver County created the Environmental Education Coordinator position in 2000. This position has principal responsibility for development and implementation of the water education workplan.

9.4.2   Incentives

Many of the existing programs, on which the water management plan relies, are incentive-based programs offered through the County and the Carver and Sibley SWCDs.   Some examples include state and federal cost share funds directed at conservation tillage, crop nutrient management, rock inlets, and conservation buffers. Reducing sediment sources will need to rely on a similar strategy of incorporating incentives into implementing practices on the ground. After the approval of the TMDL by the USEPA and the County enters the implementation phase it is anticipated that we will apply for funds to assist landowners in the application of BMPs identified in the Implementation Plan.

10 Public Participation

10.1 Introduction
The County has an excellent track record with inclusive participation of its citizens, as evidenced through the public participation in completion of the Carver County Water Management Plan, approved in 2010. The county has utilized stakeholder meetings, citizen surveys, workshops and permanent citizen advisory committees to gather input from the public and help guide implementation activities. The use of this public participation structure will aid in the development of this and other TMDLs in the County.

10.2 Advisory Committees
The Water, Environment, & Natural Resource Committee (WENR) is established as a permanent advisory committee. The WENR is operated under the County's standard procedures for advisory committees. WENR works with staff to make recommendations to the County Board on matters relating to watershed planning.

The make-up of the Water, Environment, & Natural Resource Committee (WENR) is as follows:
> 1 County Board Member
> 1 Soil and Water Conservation District Member
> 5 citizens – (1 appointed from each commissioner district)
> 1 City of Chanhassen (appointed by city)
> 1 City of Chaska (appointed by city)
> 1 City of Waconia (appointed by city)
> 1 appointment from all other cities (County Board will appoint)
> 2 township appointments (County Board will appoint– must be on existing township board.)
> other County residents (1 from each physical watershed area – County)

The full WENR committee received updates on the TMDL process from its conception. As part of the WENR committee, two sub-committees are in place and have held specific discussions on the Turbidity TMDL. These are the Technical sub-committee and the policy/finance sub-committee. Carver County Land and Water Services also organizes an annual WENR tour for committee members and other interested members of the community. These tours visit implementation projects around the county. WENR committee meetings and other WENR related public events were held on:

> January 31st, 2007 – WENR Committee Meeting
> September 11th, 2007 – WENR Tour
> July 29th, 2008 – WENR Tour
> May 26th, 2009 – WENR Committee Meeting and presentation by Shawn Schottler from the St. Croix River Research Station (SCRRS) on "Fingerprinting Sources of Suspended Sediment."

10.3 Public Meetings
Notice of the availability of a draft of this TMDL for review and comment for a 30 day period from November 14 to December 14, 2011, was published in the State Register. On December 29, 2011, Carver County Staff held a public meeting to present this TMDL to local stakeholders and the public.

11 Citations

Carver County Water Management Plan.
http://www.co.carver.mn.us/departments/LWS/water_managment.asp

Huber, W.C., and R.E. Dickinson, 1988. Storm Water Management Model, Version 4, User's Manual, EPA-600/3-88-001a. United States Environmental Protection Agency, Athens, GA.

MCES, 2008. Spatial Analysis and Modeling of Stream Bank Erosion for Carver and Bevens Creeks, Minnesota (not yet published).

MCES, 2008. Project: Development of TSS/Turbidity Relationship. A Technical Report for Metropolitan Council's Impaired Water Studies.

MCES, 2009. SWAT Modeling for Bevens Creek Turbidity TMDL.

MPCA, 2008. West Fork Des Moines River Watershed Total Maximum Daily Load Final Report: Excess Nutrients (North and South Heron Lake), Turbidity, and Fecal Coliform Bacteria Impairments. Minnesota Pollution Control Agency (MPCA), St. Paul, Minnesota.

Schertz, D. L., 1988. Conservation tillage: an analysis of acreage projections in the United States. J. Soil Water Cons. 43:256-258.

SCRRS, 2009. "Fingerprinting Sources of Suspended Sediment". Presentation to Carver County WENR Committee.

Tasker, G.D., and N.E. Driver, 1988. Nationwide regression models for predicting urban runoff water quality at unmonitored sites. Water Resources Bulletin, 24(5): 1091-1101.

USEPA (U.S. Environmental Protection Agency). 1999. Protocol for Developing Sediment TMDLs, First Edition EPA 841-B-99-004. Washington, D.C

USEPA (U.S. Environmental Protection Agency). 2001. WDMUtil Version 2.0: A Tool for Managing Watershed Modeling Time-Series Data User's Manual. U.S. Environmental Protection Agency (USEPA)

USEPA (U.S. Environmental Protection Agency). 2006. Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in Friends of the Earth, Inc. v. EPA, et al.. No. 05-5015. Washington, D.C.

USEPA (U.S. Environmental Protection Agency). 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006. Washington, D.C.

Appendices

Appendix A: SWAT Modeling for Bevens Creek Turbidity TMDL

SWAT MODELING REPORT FOR BEVENS CREEK TURBIDITY TMDL

Metropolitan Council
390 N. Robert St. St. Paul, MN 55101

Metropolitan Council Members

Peter Bell	Chair
Roger Scherer	District 1
Tony Pistilli	District 2
Robert McFarlin	District 3
Craig Peterson	District 4
Polly Bowles	District 5
Peggy Leppik	District 6
Annette Meeks	District 7
Lynette Wittsack	District 8
Natalie Haas Steffen	District 9
Kris Sanda	District 10
Georgeanne Hilker	District 11
Sherry Broecker	District 12
Rick Aguilar	District 13
Kristin Sersland Beach	District 14
Daniel Wolter	District 15
Wendy Wulff	District 16

General Phone	651-602-1000
Data Center	651-602-1140
TTY	651-291-0904
Metro Info Line	651-602-1888
E-mail	*data.center@metc.state.mn.us*
Web site	*www.metrocouncil.org*

Printed on recycled paper with at least twenty percent post-consumer waste.

Version presented in this document has been modified by Carver County Staff in regards to remove duplication between this draft and Bevens Creek Turbidity TMDL. For original draft, please contact Metropolitan Council Data Center as noted below.

On request, this publication will be made available in alternative formats to people with disabilities. Call the Metropolitan Council Data Center at 651 602-1140 or
TTY 651-291-0904.

EXECUTIVE SUMMARY

The Bevens Creek watershed covers about 125 square miles and is located at the western edge of the Twin Cities Metropolitan Area. The Minnesota Pollution Control Agency (MPCA) placed Bevens Creek on the 303(d) list for turbidity impairment in 2002 (AUID 07020012515 and AUID 07020012514). Excessive turbidity can degrade the aesthetic qualities of waterbodies, affect the respiration, feeding, and reproduction of fish and other aquatic organisms, and increase water treatment costs.

A SWAT model for the Bevens Creek watershed was developed in accordance with instructions in the SWAT Users Guide. The model was calibrated on a monthly time step using MCES' Bevens Creek mile 2.0 field monitoring data from 1993 through 2004, and validated using data from 2005-2007.

The results of the flow validation at Bevens Creek Mile 5.0, Sibley, and Silver Creek Mile 2.0 sites indicate that the calibrated SWAT model is adequately predicting the watershed hydrology

The SWAT model was calibrated to 30% of the mean annual total sediment load at mile 2.0, using only the field erosion variables. The channel erosion parameters were then used to further calibrate the model for the total mean annual sediment load at mile 2.0.

Based on the model results, it appears that some bank erosion control, through flow reduction, bank protection, or some other means, will be necessary to achieve the required reduction in TSS loads for the watershed to meet the TMDL goal.

Project Team

This report was completed by the Environmental Quality Assurance Department (EQA) of MCES using the report template designed for the Carver Creek Turbidity TMDL (MCES, 2009).

The project team for the Bevens Creek turbidity Total Maximum Daily Load (TMDL) report includes:
- o Joe Mulcahy: lead author responsible for the model development, application, TMDL allocations and reporting
- o Dr. Hong Wang: technical report design, model method development, modeling methods and analysis
- o Karen Jensen: load duration curve creation and FLUX data processing
- o Dr. Ron Jacobson: development of TSS and turbidity relationship
- o Judy Sventek and Marcel Jouseau: overall project management and report review

Acknowledgements

Questions about the contents of this study can be referred to Joe Mulcahy at 651-602-1104.

Table of Contents

Tables

Figures

1. SWAT Model and Study Area

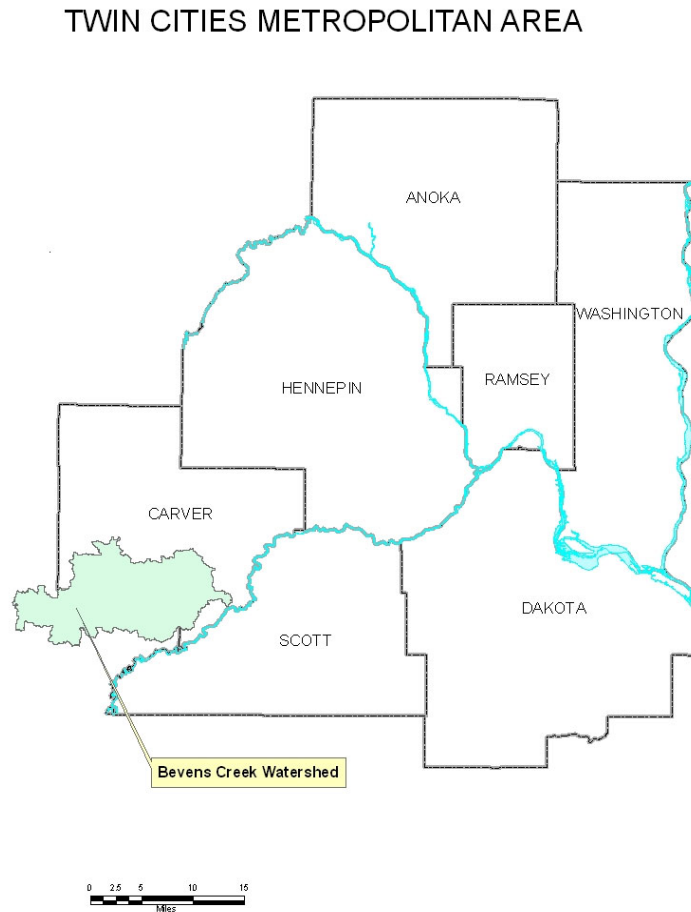TWIN CITIES METROPOLITAN AREA

Figure 1 Bevens Creek Watershed Location

1.1   Watershed and Monitoring Station Descriptions

The Bevens Creek watershed covers about 125 square miles and is located at the western edge of the Twin Cities Metropolitan Area. About 70% of the watershed is in Carver County; the remainder is located outside the metropolitan area in Sibley County (Figure 1). As modeled, land use in the watershed is mainly agricultural with 53% in row crops, 23% in hay or pasture, 16% wetlands, 7% forest, and about 1% commercial and residential (USGS, 2000).

The Sibley County portion of the watershed is very flat and ditched with several large shallow wetlands. The Carver County portion of the watershed is steeper with fewer wetlands, but also ditched. The cities of Norwood Young America and Hamburg are located within the Carver County portion of the watershed and discharge treated wastewater to Bevens Creek.

MCES monitors Bevens Creek flow and water quality at mile 2.0 and mile 5.0. Additionally, Carver County has conducted some monitoring of the creek at various locations (Figure 2) including mile 9.0, mile 21.0, Bevens Creek at Tacoma Avenue, Bevens Creek near the Sibley County border, and Silver Creek Mile 2.0.
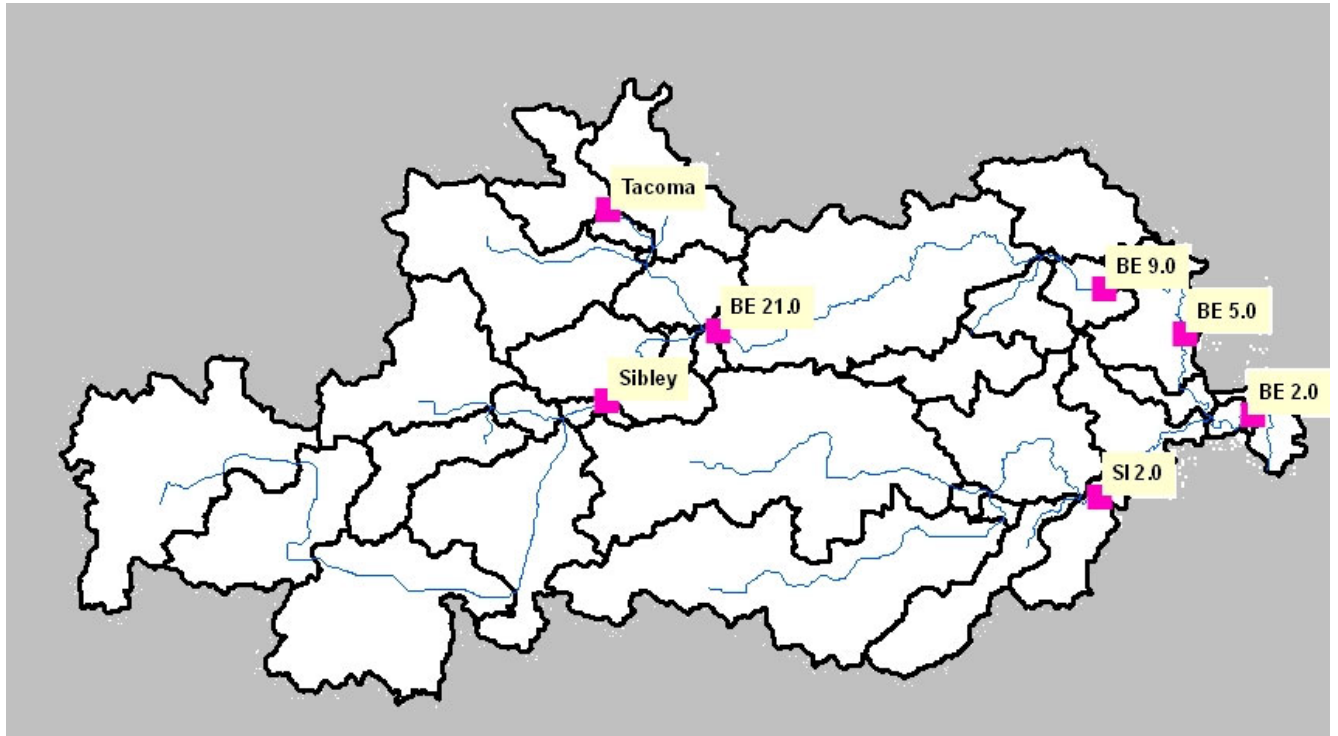
1

Figure 2 Bevens Creek Monitoring Locations

1.2   Model Selection

Based on the objectives and tasks established for this study, the model needed to be a watershed scale model that was able to simulate natural, agricultural, and urban ecological systems relevant to the hydrologic cycle, TSS yields and movements in the watershed. The SWAT model developed by the U.S. Department of Agriculture Research Service and Texas A&M University was therefore chosen. SWAT is one of the advanced models recommended for TMDL studies by the EPA. SWAT has been incorporated into the EPA's BASINS modeling platform (USEPA, 2001). BASINS is a multipurpose environmental analysis system used by regional, state, and local agencies to perform watershed and water quality based studies.

SWAT was created initially for agricultural non-point source pollution studies in the early 1990s. Since then, it has undergone continued review and expansion of capabilities. An urban routine, which is an important feature for watersheds with mixed land uses, was incorporated into SWAT in 1999. The routine includes a set of United States Geological Survey (USGS) linear regression equations (Driver and Tasker, 1988) and build-up/wash-off equations (Huber and Dickinson, 1988) for estimating constituent loads. SWAT also includes models and databases about weather, soil properties, topography, vegetation and land management practices. These databases are necessary to simulate water and chemical yields and movements in the complex ecological systems of watersheds.

The steps involved in the development and application of the SWAT model include:
-   watershed identification and site visit
-   modeling plan development
-   input database development
-   watershed delineation and segmentation

2

- hydrology and water quality calibration/validation, parameter optimization
- model application and management scenarios (MCES,2009).

2. Modeling Approach

2.1 SWAT Model Framework **and Process**

SWAT is a watershed scale model developed to predict the impact of land management practices on water, sediment, and chemical yields (nutrients, pesticides, conservative metals, bacteria) over long periods of time in large, complex watersheds that have varying soils, land use, and management conditions. The physical, chemical, and biological processes associated with water and sediment movement, crop growth and nutrient cycling are modeled by SWAT.

SWAT simulates the hydrology, pollutant yield, and transport in a watershed in two major steps. The first is to simulate the hydrologic cycle associated yields and movements of sediments, nutrients and pesticides, and their loadings to the channels in each subbasin. The second is to simulate the physical and biogeochemical processes of the sediments and chemicals during transport through the channel network and impoundment in the watershed. Table 1 summarizes the major processes involved in the subbasin and routing phases in SWAT.

Table 1 Major Processes in SWAT Land and Routing Phases

Water	Sediments	Nutrients	Pesticides
– Precipitation – Canopy storage – Infiltration – Soil re-distribution – Evapotranspiration – Lateral flow – Surface runoff – Crop rotation – Water use – Storage in impoundments – Base flow – Point sources	– Land cover and plant growth – Soil erosion – Settling – Resuspension – Point sources – Urban buildup and wash off	– Fertilization – Partitioning – Mineralization – Nitrification – Denitrification – Biological uptake – Volatilization – Settling – Resuspension – Leaching – Point sources – Urban buildup and wash off	– Degradation – Partitioning – Settling – Resuspension – Volatilization – Foliage wash-off – Leaching – Burial

The SWAT model has been developed to be run under ArcView and ArcGIS for the personal computer environment (Di Luzio *et al.*, 1998) called AVSWAT and ArcSWAT. ArcView and ArcGIS provide both the GIS computation engine and a common Windows-based user interface. With AVSWAT and ArcSWAT, the SWAT simulation is completed with a graphical user interface (Di Luzio *et al.*, 2002). Several sets of customized and user friendly tools are used by the SWAT model to complete the analytical analysis. These tools are designed to:
- generate specific parameters from user-specified GIS coverage
- create SWAT input data files
- establish agricultural management scenarios
- control and calibrate SWAT simulations
- extract and organize SWAT model output data for charting and display

The most relevant components of the SWAT simulation system include a complete and advanced watershed delineator and a tool for the definition of the Hydrologic Response Units (HRUs). SWAT has eight modules used to complete this simulation (Figure 3):
- watershed delineation
- HRU definition
- definition of the weather stations
- AVSWAT databases
- input parameterization, editing and scenario management
- model execution
- read and map-chart results
- calibration tool

These modules provide an easy and convenient procedure for model setup, simulation and application. For the Bevens Creek turbidity TMDL study, the latest version (1.0.7) of ArcSWAT, which was released in February 2008, was used. The model is run under ArcGIS Version 9.1 (MCES, 2009).
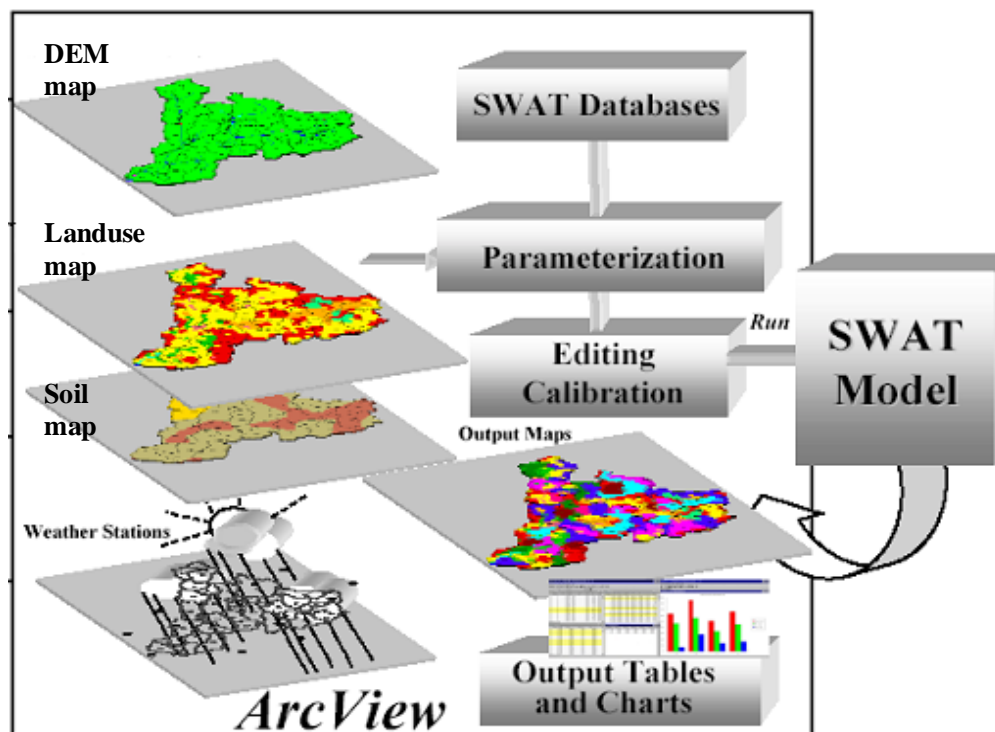
Figure 3 SWAT Model Components and Inputs (Modified from Neitsch et al., 2002)

2.2   Model Parameters and Inputs

Like other watershed models, SWAT requires a variety of spatial and temporal input data and constants to characterize the topographic condition, climate, and ecological systems of the watershed. The basic spatial inputs required for ArcSWAT include watershed digital elevation, soil, land use/cover maps, locations of weather stations, point sources, and watershed outlets. The temporal inputs include daily climate data, point source loads, inlet discharges, impoundment flows, irrigation, and other water usage. In addition, the interface requires land use designations, soil properties, groundwater parameters, plant growth, agricultural management information, impoundment and stream water quality data, as well as kinetic rates

4

describing physical and biogeochemical processes associated with hydrologic cycles and chemical behaviors in the watershed (MCES, 2009).

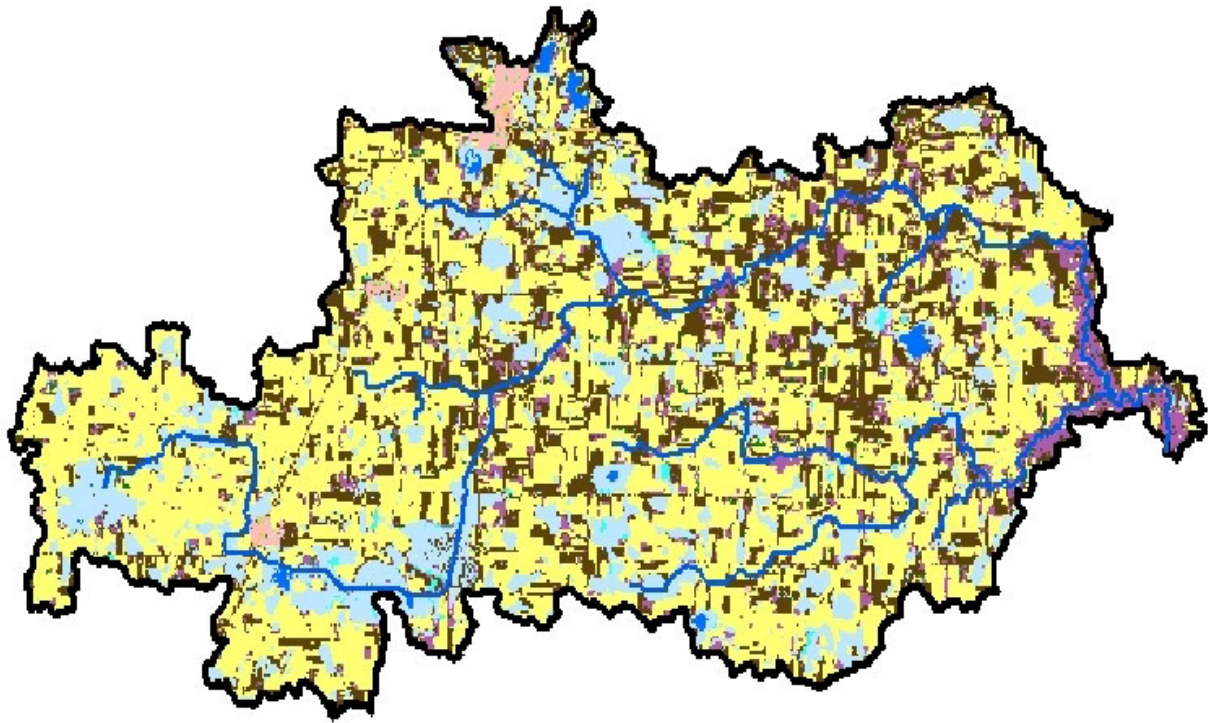## 2.2.1 GIS Spatial Databases
Topography
Because the Bevens Creek watershed is partially located outside the seven county Twin Cities Metropolitan Area, Council GIS products for the metropolitan area could not be used. Instead GIS data was clipped from USGS products that covered the entire state. The topographic map used in the Bevens Creek watershed study was a 30-meter digital elevation model (DEM). The data represented the surface elevation of the region in a regular grid where each grid cell is 30×30 square meters with a single elevation value for each cell given in feet above mean sea level. The DEM provided basic information for watershed delineation and segmenting to calculate relevant topographic parameters, such as lengths, slopes, boundaries, areas of watershed tributaries, main channel, HRUs and subwatersheds.

Land Use
The National Land Cover Dataset (NLCD 1992) was used for model development (USGS, 2000). The databases were developed using early to mid 1990's Landsat Thematic Mapper data by the Multi-Resolution Land Characteristics (MLRC) Consortium. Consortium members included the USEPA, USGS, the National Oceanic and Atmospheric Administration, the United States Forest Service, the National Aeronautic and Space Administration, and the Bureau of Land Management. The NLCD classifications and their SWAT counterparts are shown in Table 2. Several of these land use classes made up only a small area of the watershed, and essentially dropped out during the HRU definition process. Figure 4 shows the SWAT land use map for Bevens Creek.

Table 2 NLCD 1992 and SWAT Land Use Categories

1992 NLCD Land Use	SWAT Land Use	SWAT Code
11 - Open water	Water	WATR
21 - Low Intensity Residential	Low Density Residential	URLD
22 - High Intensity Residential	High Density Residential	URHD
23 - Commercial/Industrial/Transportation	Commercial	UCOM
71 Grassland/Herbaceous	Range	SWRN
41 - Deciduous Forest	Forest - Deciduous	FRSD
42 – Evergreen Forest	Forest – Evergreen	FRSE
43 – Mixed Forest	Forest – Mixed	FRST
51 – Shrubland	Range-Brush	RNGB
81 – Pasture/Hay	Hay	HAY
82 – Row Crops	Agricultural Row Crops	AGRR
83 – Small Grains	Wheat	WWHT
91 Woody Wetlands	Wetland - Forested	WETF
92 – Emergent Herbaceous Wetlands	Wetland – Non-Forested	WETN

Figure 4 Bevens Creek Land Use Map

Soil Properties

The State Soil GeOgraphic (STATSGO) data was used for the soil map. STATSGO is a digital soil association map developed by the National Cooperative Soil Survey. The maps were compiled by generalizing more detailed soil survey maps. This data set consists of geo-referenced digital map data and computerized attribute data, containing up to 21 different soil components. Soil map units are linked to attributes in the Map Unit Interpretations Record (MUIR) relational database which gives physical and chemical soil properties and interpretations for engineering uses. In the entire Bevens Creek watershed there are only seven STATSGO soil categories (MCES, 2009).

2.2.2   Climate and Impoundment Data

Time-series climate data sets for the last 20 years were obtained from the Minnesota Climatology Working Group. The daily minimum and maximum temperature, and daily precipitation were used for the model. The precipitation and temperature data was obtained from the "High Density" stations at Norwood Young America, and Jordan. Additional temperature, humidity

and wind speed data was generated by the model from the national weather station at the Minneapolis-St Paul International Airport, which is located about 20 miles northeast of the watershed (MCES, 2009).

In the SWAT model, impoundments may be modeled as reservoirs, ponds or wetlands. The model allows one reservoir, and two ponds or wetlands per subbasin. Ponds and wetlands receive water that originates in the subbasin in which the pond or wetland is located. Reservoirs receive water from all subbasins upstream of the water body. Seven large wetlands located on the main branch of Bevens Creek were modeled as reservoirs; the remaining water bodies were modeled as ponds or wetlands based on aerial photos (Figure 5). The principal difference between ponds and wetlands in the model is how the outflow is calculated. Wetlands drain whenever the volume exceeds the normal volume. Pond outflow is calculated as a function of season and soil water content.

The SWAT model requires a normal area and volume, and maximum area and volume for each water body modeled. Wetland and pond size and locations were obtained from GIS land use maps and databases. The SWAT model delineated wetland areas were used for the surface areas of impoundments at the maximum water level. The surface water area at the principal spillway (normal) water level was estimated as fifteen percent smaller than the area at the emergency spillway water level. An average water depth of one meter was used to estimate wetland water volume at the principal and emergency water levels. Individual measurements for wetland depths were not readily available.
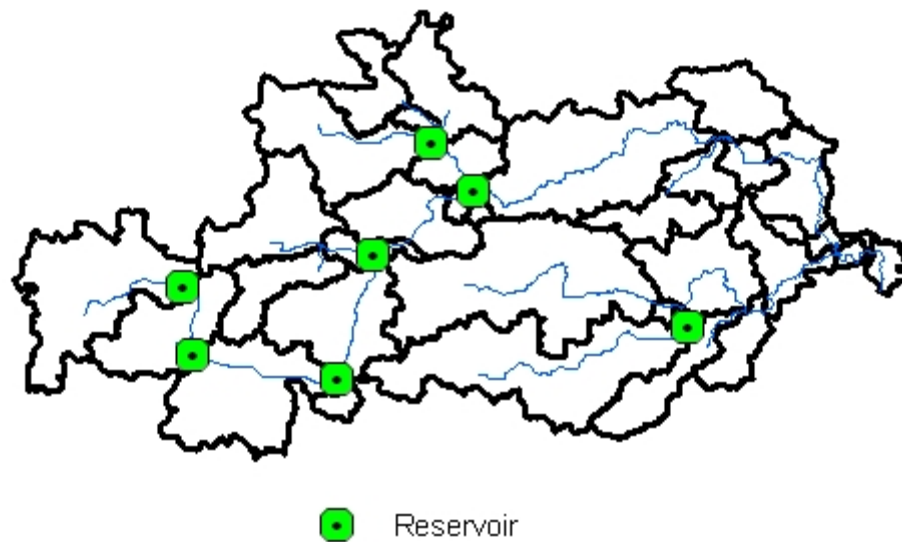
Figure 5 Bevens Creek Reservoirs

2.2.3 Agricultural Management Practices

Agriculture management information used in the model includes crop types, time of planting , fertilizer application rates, tillage, harvesting, rotation, water use and soil nutrient concentration. Agricultural management practices, particularly planting dates, fertilizer application rates, tillage types and timing often vary throughout the region or even watershed. It is difficult, expensive,

and time-consuming to determine the individual practice information for the entire watershed. Therefore, representative data and information were collected and generalized based on information gathered from interviews with local soil and water conservation district staff, and Minnesota Agricultural Statistics (MASS, 1999; 2000 and 2003), (MCES, 2009).

The NLCD 1992 dataset has a category of agricultural row crops. HRUs with this land use were split evenly into corn and soybean and rotated annually using the SWAT model's built in "Multiple Hydrologic Response Units" function and management options (MCES, 2009). The SWAT model option of auto fertilization was used for corn and soybeans. This option applies nitrogen whenever plant growth falls below a specified threshold due to nitrogen stress. All operations were scheduled using the model's heat unit approach. General operations used for corn and soybeans included:

- spring tillage
- planting
- auto fertilization initiation
- harvest and kill
- fall tillage

Tile drainage is common in the Bevens Creek watershed. All row crop land with a slope $\leq 5\%$ was assumed to be tiled. For these areas tile depth was set at 1 meter with an impervious layer at 1.8 meters, the time to drain soil to field capacity was set at 24 hours, and the time between transfer of water from the soil to the drain tile and release of the water to the reach was set at 48 hours (Du et al, 2005).

2.2.4 Field Measurements and Comparability with SWAT Parameters

Field measurements are an important component for watershed model development. They are needed to calibrate the model for parameter optimization and to validate the model for application. MCES initiated a monitoring program to record stream flow and water quality in the metropolitan area watersheds in the late 1980s. Currently, event-based and baseflow monitoring data are collected at 27 stations on 25 streams in the region (MCES, 2009). Continuous stream flow using automated stream monitoring equipment and water quality based on composite and grab samples have been monitored at MCES' Bevens Creek mile 2.0 station since 1989, and at the mile 5.0 station since 1992.

Water quality monitoring data for turbidity was available using a relationship of measured TSS and turbidity. TSS is composed of inorganic and organic matter transported in the water column. SWAT simulates total sediment loads from land, channel bed and bank erosions based on maximum flow velocity and sediment particle sizes. The loads include suspended solids and bed load sediment that is transported in the channel water column and in the bed load. Because bed load sediment usually occupies only a small portion (less than 10 percent) of total sediment load (Tolson & Shoemaker, 2004) and is usually transported a limited distance due to relatively large size, the measured TSS is assumed to be comparable with the total sediment loads simulated by SWAT. Therefore, measured TSS is directly used for sediment calibration (MCES, 2009).

2.3 Watershed Delineation and Segmentation

Watershed delineation and segmentation is the primary step in model development. It includes the following tasks:

− delineating the watershed boundaries and stream network

- defining the watershed outlet(s) and reservoirs
- segmenting the watershed into a number of subbasins
- defining HRUs
- calculating the topographic parameters

The Bevens Creek watershed was delineated and segmented according to the following data and information:
- DEM and GIS stream networks developed by the Council
- locations of MCES and Carver County Environmental Services monitoring stations
- locations of reservoirs
- locations of point source discharges
- channel and floodplain characteristics (e.g., slope, roughness)
- existing sub-watersheds provided by Carver County Environmental Services
- size and number of subbasins

Figure 6 shows the delineated Bevens Creek watershed, subbasins and stream networks. The watershed boundary, subbasins and stream channels delineated by SWAT were very close to the existing maps used for water quality monitoring and planning programs. A total of 36 subbasins were delineated in the watershed (MCES, 2009).

Within each subbasin, the components of the watershed are further grouped or organized into HRUs. HRUs are areas with unique land uses, soils, slopes and management practices. The HRUs were delineated using a combination of land uses, soil types and slopes that occurred within each subbasin, with threshold values of five percent for land uses, twenty percent for soil type, and twenty percent for slopes. A total of 299 HRUs were identified in the watershed. HRU construction increases the accuracy of load predictions and provides a better physical description of the water balance (MCES, 2009).

Two MPCA permitted point sources were included in the model delineation. They were the Norwood Young America WWTP, and the Hamburg WWTP. Discharge records from the WWTPs were used for model calibration.
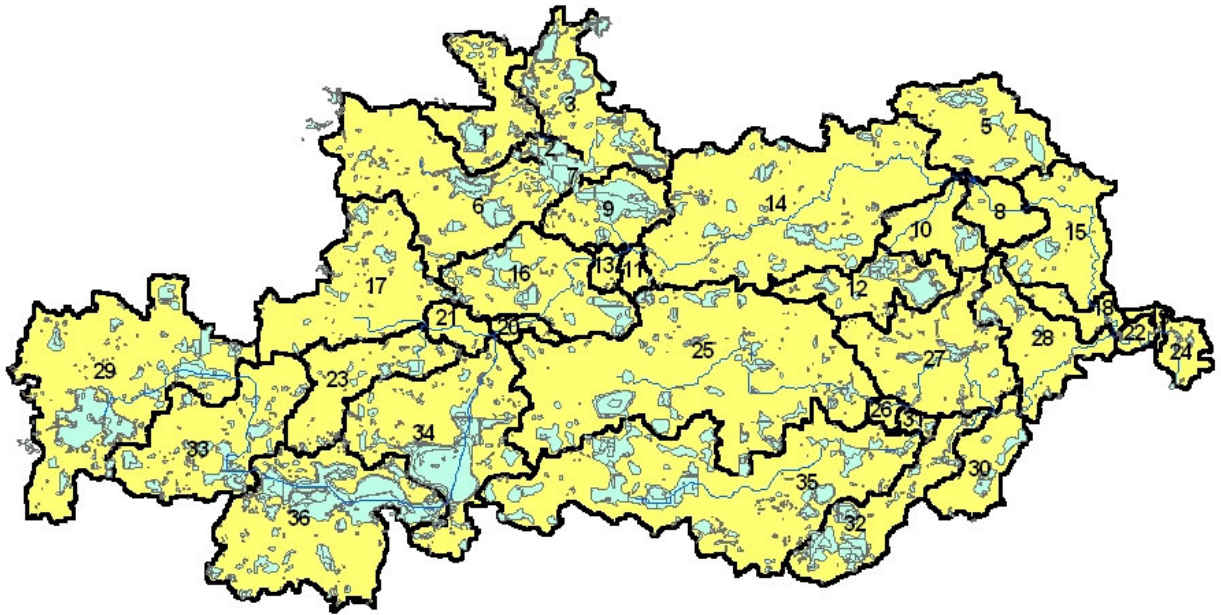
Figure 6 Bevens Creek Watershed as Modeled

2.4 Methodology for Model Calibration and Validation

Model calibration consists of optimizing model parameters in an attempt to match local conditions (e.g., daily, monthly or annual flows and mass loads) within reasonable scales and criteria. Model validation is a process of testing the performance of the calibrated model without further changing input parameters against an independent set of measured data. The data sets used for calibration and validation cover either different time periods or involve separate monitoring locations. Prior to calibration, the SWAT model uses the default built-in databases developed from literature and research results to characterize default values and define varying ranges for these parameters.

There are hundreds of physical, chemical and biological parameters in the model describing water and chemical yields, transformation and transportation in the watershed. It would be impractical and time-consuming to calibrate these parameters individually. For this study, the parameters that were calibrated were chosen based on their impacts on model outputs or sensitivities. Model parameter sensitivities may differ from watershed to watershed and will need to be analyzed for each watershed modeled. In the Bevens Creek watershed, calibration was completed for parameters that characterized groundwater flow, hydrology, tile drainage, wetland and reservoir outflow, soil erosion, snow fall and snow melt, and physical and biogeochemical processes regulating sediment, chemical yields, and fates.

The accuracy of the model results for the calibration and validation periods was evaluated using graphical comparisons and statistical tests. To evaluate model performance, predicted monthly and annual flow, and sediment loads were compared against field observations. The results were tested with a variety of statistical techniques, including:

- Observed, predicted means (OM and PM) and difference (relative deviation, RD)
- Root mean square deviation (RMSD)

$$RMSD = \sqrt{\sum_{i=1}^{N} \frac{1}{N}(P_i - O_i)^2}$$

where N is the number of data points, P_i and O_i are the predicted and observed values respectively.

- The coefficient of determination (r^2)

$$r^2 = \frac{\sum_{i=1}^{N}(O_i - OM)(P_i - PM)}{\left[\sum_{i=1}^{N}(O_i - OM)^2\right]^{0.5}\left[\sum_{i=1}^{N}(P_i - PM)^2\right]^{0.5}}$$

where OM and PM are the observed and predicted means, respectively.

- The index of agreement (IA)

$$IA = 1 - \frac{\sum_{i=1}^{N}(P_i - O_i)^2}{\sum_{i=1}^{N}(|P_i - OM| + |O_i - OM|)^2}$$

- The Nash-Sutcliffe Coefficient of Efficiency (NSCE)

$$NSCE = 1 - \frac{\sum_{i=1}^{N}(O_i - P_i)^2}{\sum_{i=1}^{N}(O_i - OM)^2}$$

Good model performance occurs when RD, RMSD and b approach zero, and a, r^2 and IA approach one, and NSCE is larger than 0 (NSCE varies from -∞ to 1).

There are no universally accepted "goodness-of-fit" criteria that apply in all cases. However, it is important that modelers make every attempt to minimize the difference between model simulations and measured field conditions. As a general guideline, a range of calibration and validation tolerances are recommended by Donigian (2000) for hydrology, sediment, nutrient, and pesticide predictions in watershed studies (Table 3). The ranges were initially used for the application of the Hydrological Simulation Program Fortran (HSPF) model, a watershed scale model similar to SWAT. Recommended tolerances were provided for monthly and annual simulations. Tolerance application is dependent on the quality and detail of input and calibration data, modeling purpose, capability of personnel, and availability of other resources such as time and budget (MCES, 2009).

Table 3 Recommended Calibration and Validation Tolerances

Parameters	Difference Between Simulated and Observed Means (%)

	Very Good	Good	Fair
Hydrology	<10	10-15	15-25
Sediments	<20	20-30	30-45
Nutrients	<15	15-25	25-35
Pesticides	<20	20-30	30-40

3.   Model Performance

The SWAT model for the Bevens Creek watershed was developed in accordance with instructions in the SWAT Users Guide. The model was calibrated on a monthly time step using MCES' Bevens Creek mile 2.0 field monitoring data from 1993 through 2007. Monthly data was used because it gave a far greater number of data points than an annual time step would have.

3.1   Hydrology

Figure 7 shows the predicted and measured mean monthly flow results for the entire 1993-2007 period at mile 2.0. Figure 8 shows the predicted and observed annual flows for the same time period. Table 4 lists the statistical analysis results for the hydrologic calibration.
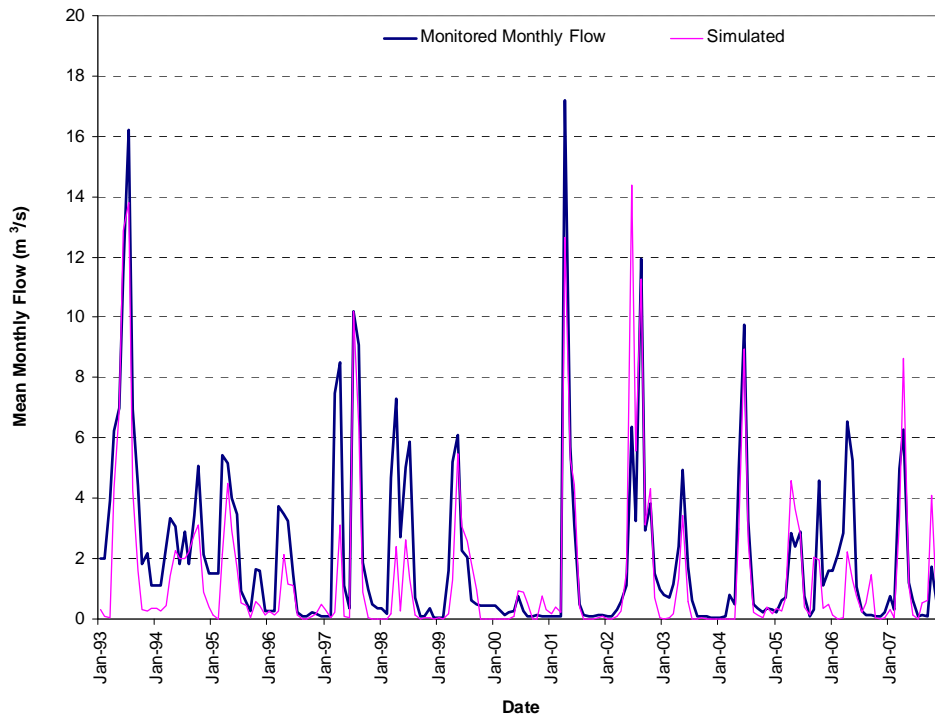

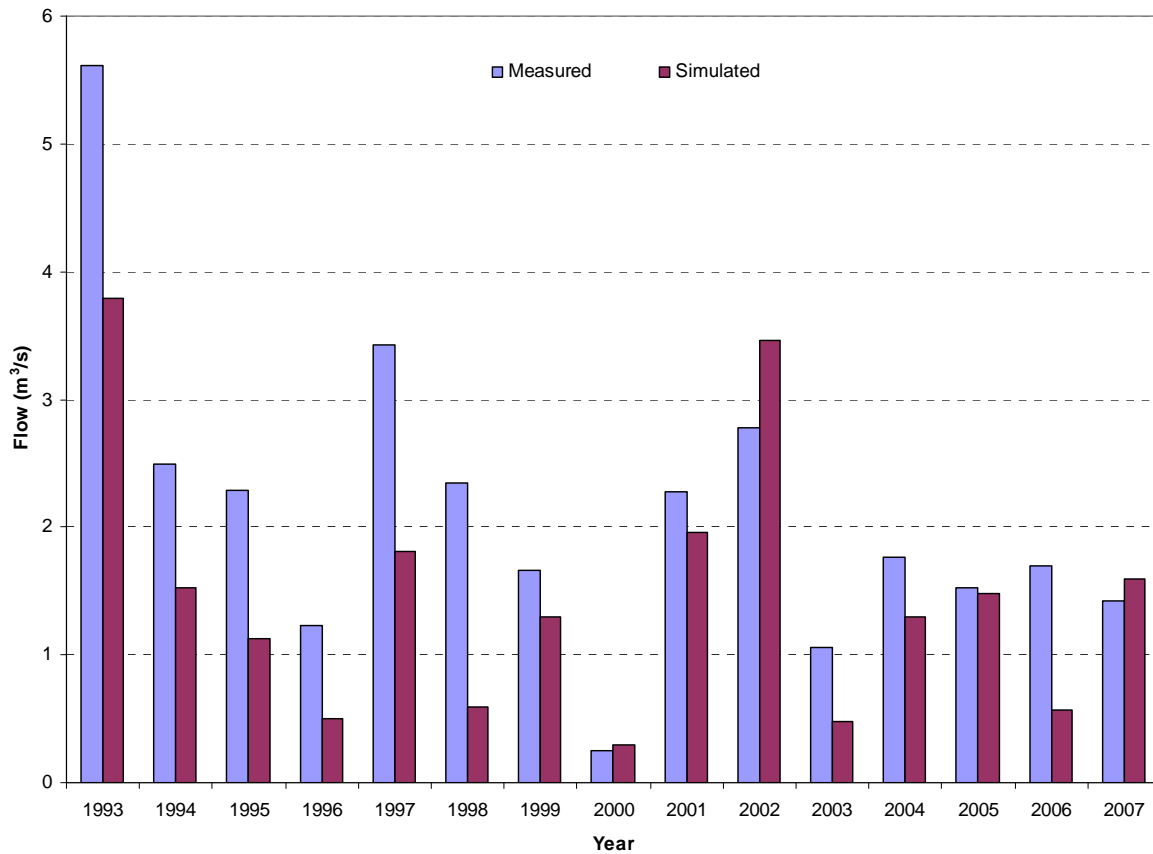**Figure 7 Bevens Creek Calibrated Monthly Flow at Mile 2.0 - 1993-2007**

Figure 8 Bevens Creek Calibrated Annual Flow at Mile 2.0 - 1993-2007

Table 4 Statistical Analysis of Hydrology Calibration at Bevens Creek Mile 2.0

Time Step	%RD	r^2	IA	NSE
Monthly	30.7	0.72	0.91	0.67
Annual	31.6	0.64	0.81	0.32

A coefficient of determination greater than 0.5 is generally considered acceptable model performance, though this measure is oversensitive to high extreme values. The index of agreement (IA) varies between 0 and 1, with a value of 1 indicating perfect agreement between measured and predicted values, and a value of 0 indicating no agreement at all. The Nash-Sutcliffe Efficiency (NSE) ranges between $-\infty$ and 1.0. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance. Values equal or less than 0 indicate that the observed mean is a better predictor than the simulated value, signifying unacceptable model performance (Moriasi et al.,2007). By these measures, the values in Table 4 show the Bevens Creek SWAT model is adequately predicting the watershed hydrology at mile 2.0.

3.2   Hydrology Validation

The calibrated model can be validated by using it, without alteration, to predict flow for a different time period or at a different monitoring location than that used for calibration.

In addition to the monitoring station at mile 2.0, MCES also monitors Bevens Creek at mile 5.0. This data provides an additional check of model hydrologic performance. Figure 9 shows the

predicted and observed monthly flow at mile 5.0 from 1998 through 2007. Table 5 lists the statistical analysis for this site.
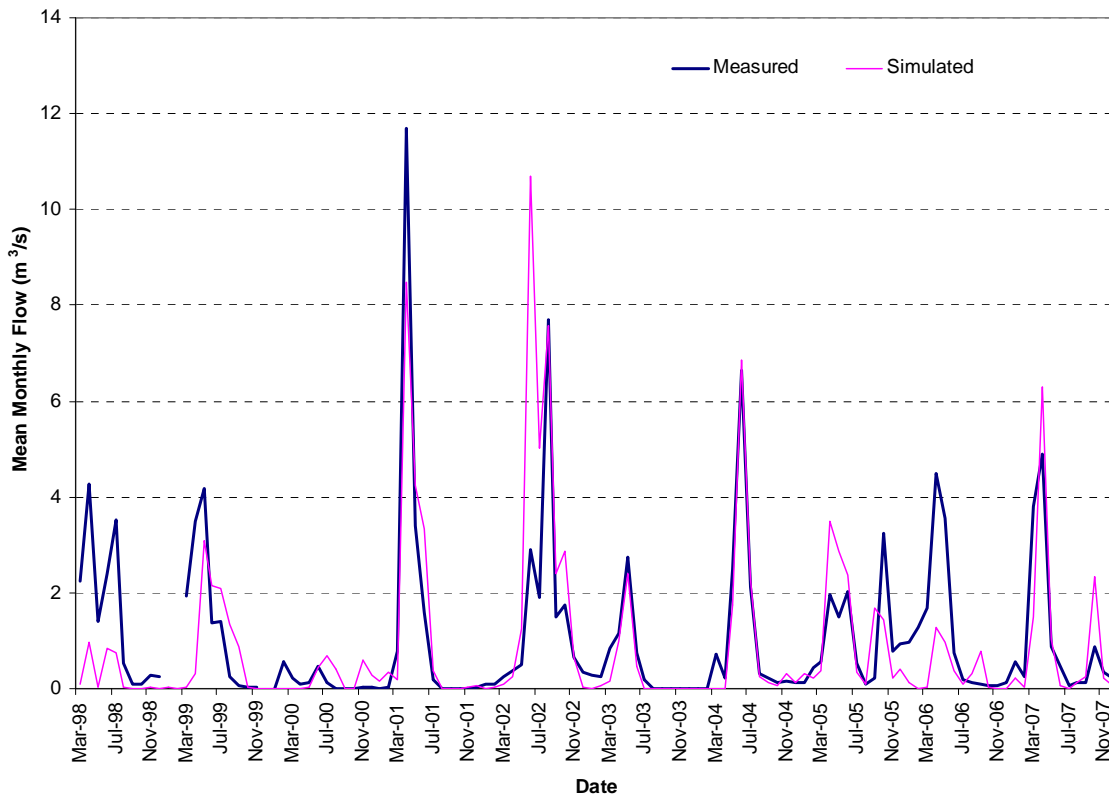

Figure 9 Measured and Simulated Mean Monthly Flow at Bevens Creek Mile 5.0 - 1998-2007

Table 5 Statistical Analysis of Hydrology Calibration at Bevens Creek Mile 5.0

Time Step	%RD	r^2	IA	NSE
Monthly	11.3	0.58	0.86	0.49

In Table 5, the coefficient of determination is above 0.5, the Index of Agreement is closer to 1 than to 0, and the Nash-Sutcliffe Efficiency is greater than 0. These results indicate that the model is adequately predicting flow at mile 5.0, despite being calibrated using the mile 2.0 mean monthly flow data. It also indicates that the model is adequately simulating the flow from Silver Creek, which is the main tributary input to the main stem between mile 5.0 and mile 2.0.

Carver County has also collected flow data at several other locations in the watershed. The data collection and rating curves at these sites were done by a consultant. The SWAT model was calibrated using data collected at mile 2.0 and a rating curve developed by MCES. Comparisons of the measured flows and those simulated by the model at two of these Carver County sites are presented in Figures 10 & 11. The Sibley site is near the Sibley County/Carver County border, and the Silver Creek Mile 2.0 site is just before Silver Creek joins the main stem of Bevens Creek (Figure 2, page 10).
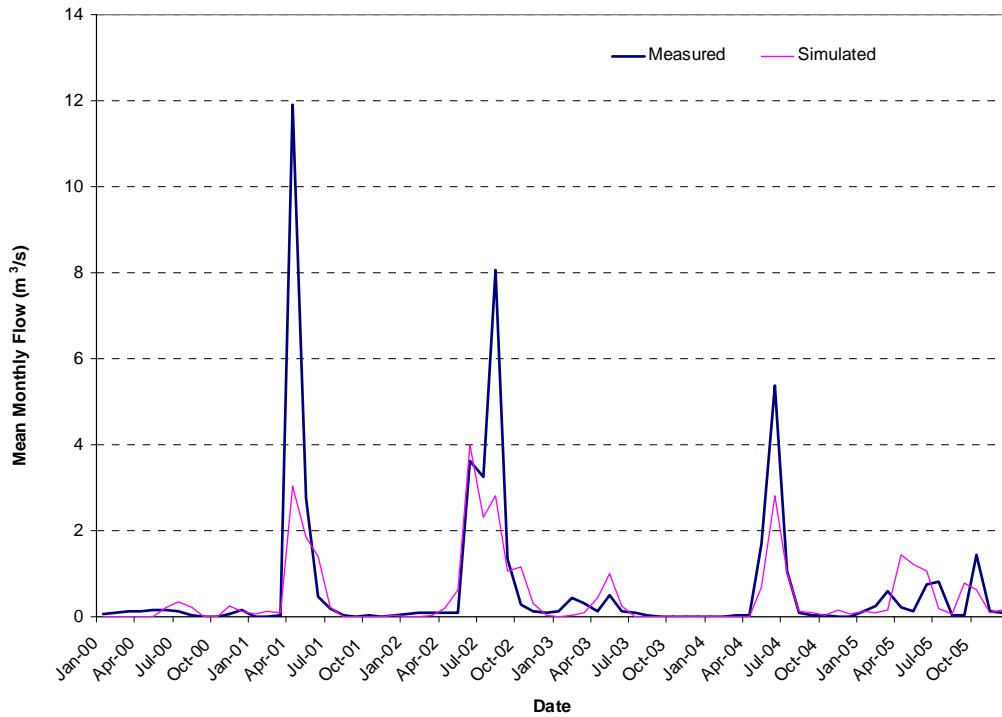
15

Figure 10 Measured and Simulated Monthly Flow at Sibley Site, 2000-2005
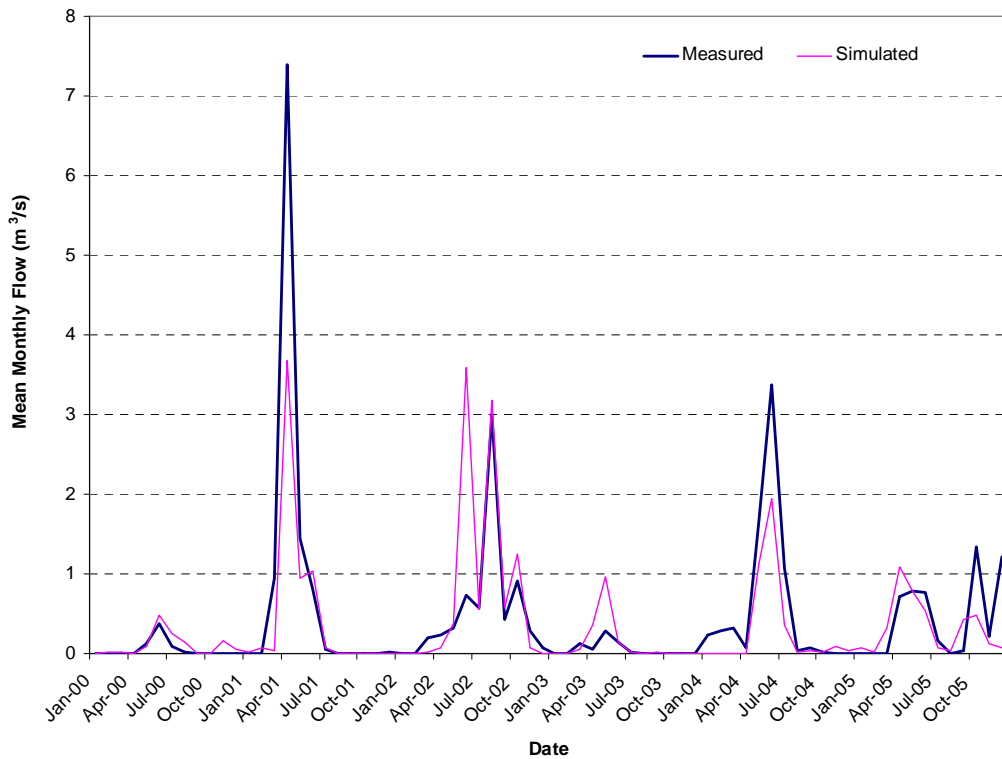

Figure 11 Measured and Simulated Monthly Flow at Silver Creek Mile 2.0 Site, 2000-2005

Table 6 Statistical Analysis for Carver County Monitoring Sites.

	%RD	r^2	IA	NSE
Sibley	31	0.64	0.74	0.5
Silver 2.0	16.3	0.62	0.86	0.61

16

Table 6 presents the statistics for the flow validation at these sites. While no attempt was made to calibrate the model at these locations, the statistics show that the model is predicting flow at the Sibley and Silver Creek mile 2.0 sites fairly well.

The results of the flow validation at Bevens Creek Mile 5.0, Sibley, and Silver Creek Mile 2.0 sites further demonstrate that the calibrated SWAT model is adequately predicting the watershed hydrology.

3.3   Total Suspended Solids

Research at the Science Museum of Minnesota's St. Croix Watershed Research Station has indicated a substantial portion (50 to 90 percent) of the TSS load in the Minnesota River watershed is from non-field sources (Meeting/Personal Communication).

The research station has performed isotope analysis on sediment cores to determine sedimentation rates, and to determine the sources of the sediments. They have divided the sediment into field and non-field sources. Sediment from field sources has eroded from about the top 20 centimeters of the soil profile, and has been exposed to rain and the atmosphere. Non-field sediments are those that eroded from deeper soil layers unexposed to the atmosphere. The sources of these non-field sediments could include stream bank, ravine, and gully erosion.

In discussions with staff at Carver County and the MPCA, it was agreed that the source ratio should be set at 30% field erosion and 70% non-field erosion. The SWAT model has been designed to roughly model stream bank erosion, but it has no provision for simulating gully erosion. In this project, all non-field erosion was modeled as bank erosion and in this report the terms "non-field erosion" and "bank erosion" are used interchangeably.

The SWAT model was calibrated to 30% of the mean annual total sediment load at mile 2.0, using only the field erosion variables. The channel erosion parameters were then used to further calibrate the model for the total mean annual sediment load at mile 2.0.

Figures 12 and 13 show the mean monthly and annual observed and simulated TSS loads. Table 7 lists the results of the statistical analysis of the total TSS loads.
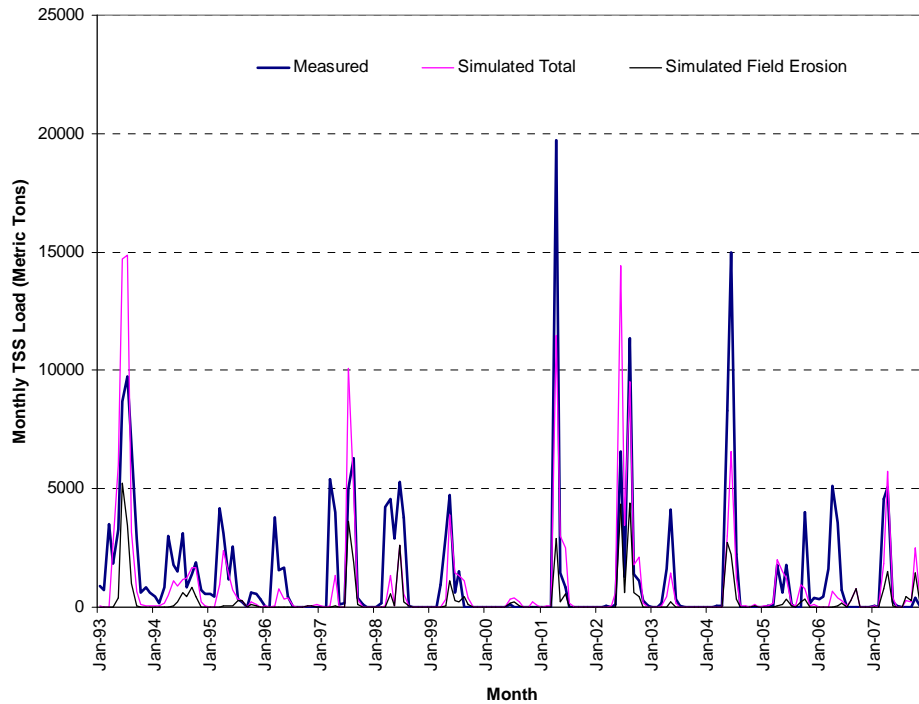
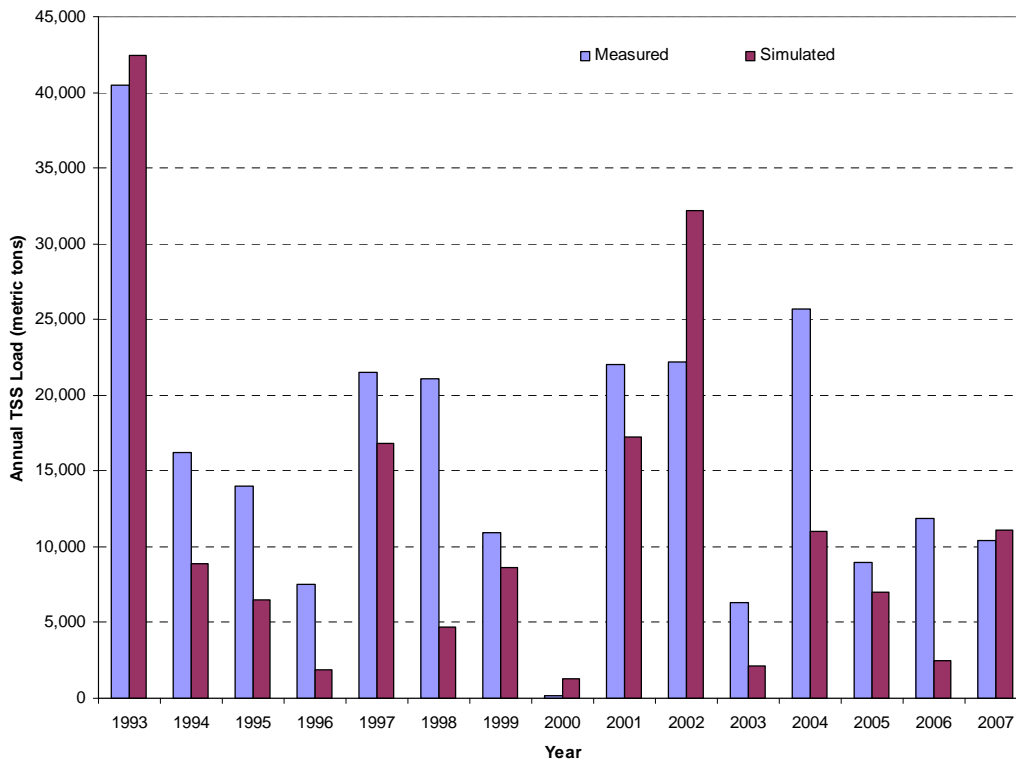**Figure 12 Bevens Creek Mean Monthly TSS load at Mile 2.0**

Figure 13 Bevens Creek Mean Annual Total TSS Load at Mile 2.0

Table 7 Statistical Analysis of Total TSS Load Calibration

Time Step	%RD	r²	IA	NSE
Monthly	27.2	0.58	0.86	0.53
Annual	27.3	0.68	0.87	0.35

Again, the statistics in Table 7 show that the model is adequately predicting TSS Loading at Mile 2.0.

4. Non-point Source Analysis

The calibrated SWAT model can be used to gain insight regarding the sources of surface runoff and non-point source pollution in the watershed. Average annual surface runoff and field erosion rates from the same land use varied by subbasin (position in the watershed). Therefore, an area-weighted statistical method was used to obtain the mean flow and TSS export rates from an HRU or a subbasin:

$$ R = \frac{a_1 r_1 + a_2 r_2 + a_3 r_3 + ... + a_i r_i}{a_1 + a_2 + a + ... + a_i} $$

where R is the water or TSS export rate for land use i; a_i is the area of HRU or subbasin i, and r_i are the water or pollutant export rates corresponding to individual HRU or subbasin i (MCES, 2009).

4.1 Surface Runoff and TSS Loading by Land Use

The SWAT model annual simulations were used to identify land uses with high field erosion and runoff rates. Figure 14 shows the average annual export rates of runoff and TSS by land use.
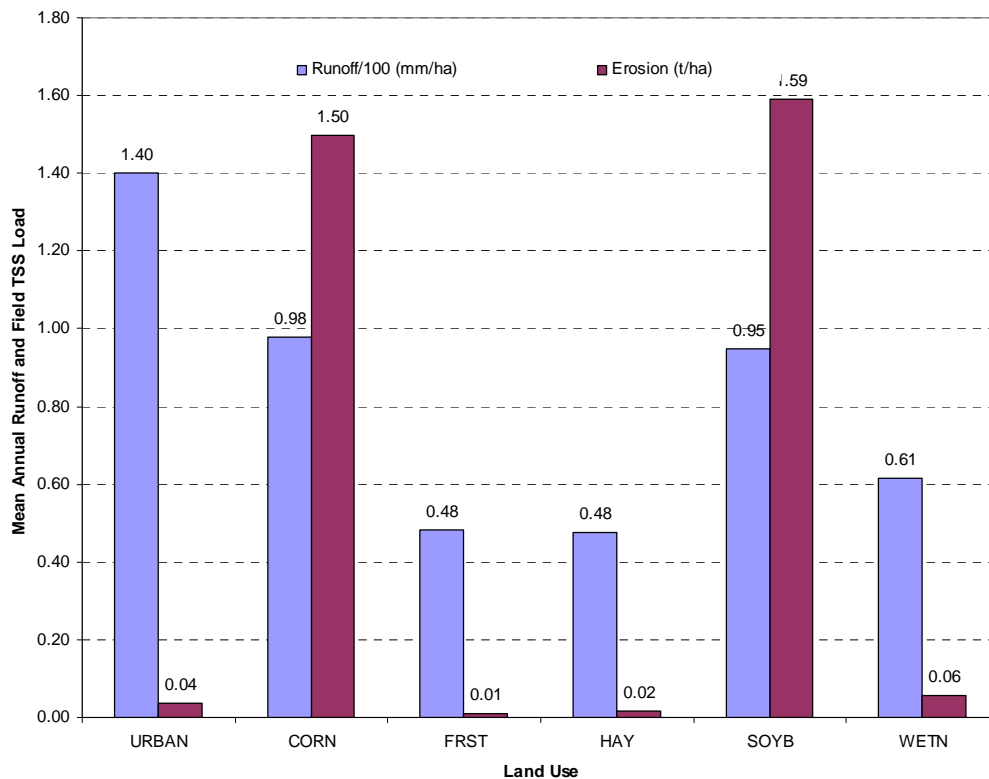

Figure 14 Simulated Water and TSS Export Rates by Land Use

The highest surface runoff comes from urban areas, followed in order by corn, soybeans, wetlands, forest, and hay. The highest field erosion is from soybeans followed by corn and wetlands. So, although urban areas exhibit the highest rate of runoff, soybeans and corn export by far the highest amounts of sediment.

20

The total TSS loading from field erosion is dependent on the unit export rate and the total area of the individual land use in the watershed. Figure 15 shows the percentage of total TSS loading from field erosion by land use. Figure 16 shows the percentage of each land use in the watershed.

Corn and soybeans together comprise 54% of the land use in the watershed, but these land uses account for 98% of the field erosion in the watershed. All other land uses in the watershed account for 46% of the land use in the watershed, but only about 2% of the TSS loading from field erosion in the watershed.

23% of the land use in the watershed is hay and pasture, but this land use is responsible for less than 1% of the TSS load from field erosion. Forest is 7% of the watershed land use but accounts for only 0.1% of the field erosion sediment load.
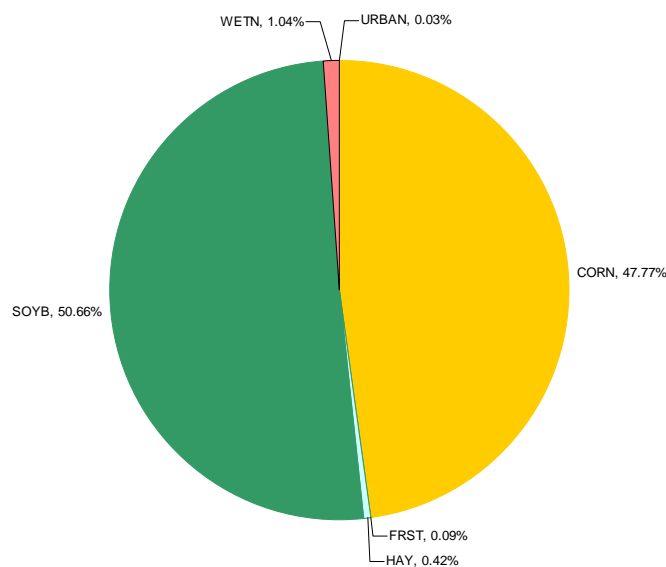

Figure 15 Simulated TSS Loadings from Field Erosion by Land Use
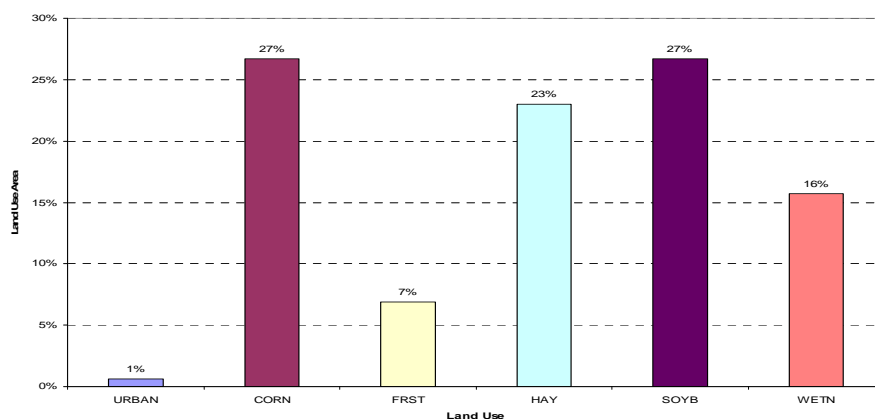

Figure 16 Land Use in Bevens Creek Watershed

4.2   Spatial Distributions of Water and TSS Loads in the Watershed

The SWAT model output shows that identical land uses can have different runoff and erosion rates depending on their slope, soil type, management, and location in the watershed. Identifying

the subbasins that contribute the greatest amounts of water and sediment to the creek can provide a guide for implementation of Best Management Practices (BMPs) to control TSS loading.

In the SWAT model, the Bevens Creek watershed was divided into 36 subbasins. Each of these subbasins contains varying amounts of the different land uses. Each subbasin also has different slopes and occupies a unique spatial position in the watershed.

Figure 17 shows the mean annual unit runoff and sediment generated in each subbasin. Figure 18 shows the total mean annual surface runoff and TSS load from field erosion generated in each subbasin.
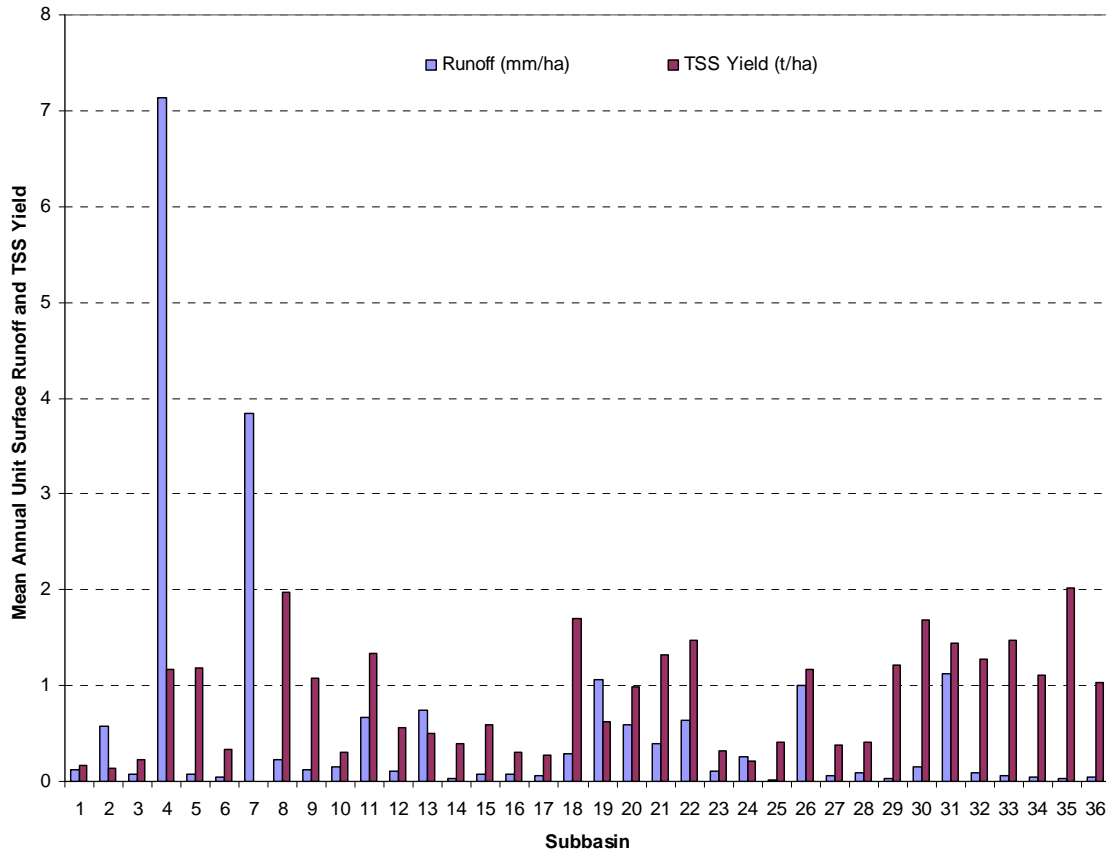

Figure 17 Simulated Mean Annual Unit Runoff and Sediment Yield by Subbasin

Subbasins 4 and 7 show by far the highest unit runoff at 7.1 and 3.8 mm/ha respectively. However these two subbasins do not have the highest sediment yields. Subbasins 35, 8, and 18, have the highest sediment yield at 2.02, 1.97, and 1.70 t/ha, respectively.
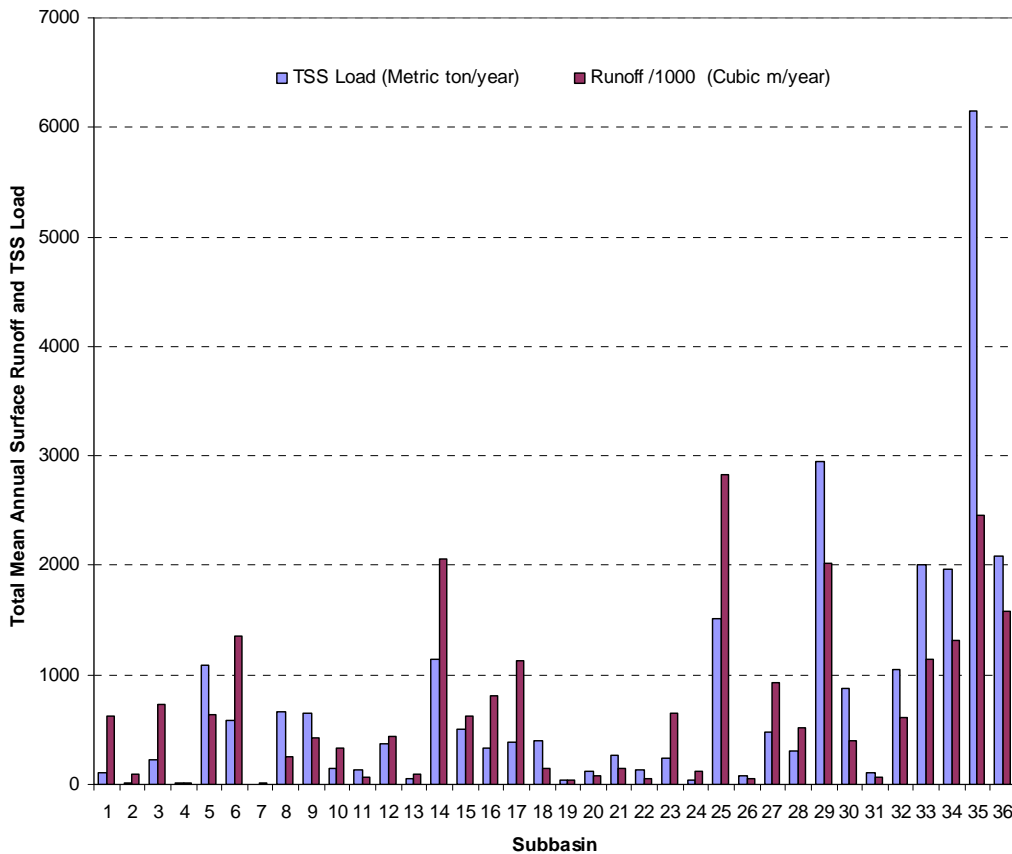
Figure 18 Simulated Total Field Erosion TSS Load and Surface Runoff by Subbasin

Figure 19 shows that the subbasins with the highest unit rates of runoff and sediment yield are not necessarily those that contribute the highest total loading to the creek. Subbasins 35, 29, 36, 33, and 34, contribute the highest average annual amounts of TSS, while subbasins 35, 8, 18, 30, and 33, have the highest unit sediment yields. BMPs should be targeted at the subbasins with the greatest total contribution to the main stem of Bevens Creek, not those with the greatest unit yield.

A significant fraction of the total TSS load in the watershed is from non-field sources. The primary source of this fraction in the model is bank erosion. The average annual bank erosion for each subbasin was analyzed using the calibrated SWAT model, run from 1993 through 2007. This data, sorted in descending order for clarity, is shown in Figure 20. The highest loads are contributed by subbasins 15, 14, 18 and 24, which contribute TSS loads from 1,170 to 746 metric tons/year. These four reaches account for 38.3% of the total TSS load from bank erosion. Ten subbasins, mostly located in the upstream areas or at the edges of the watershed, show an average annual bank erosion load of zero.

It is interesting to note that 3 of the 4 subbasins with the highest total field erosion loads, (35, 29, and 33) contribute an average annual bank erosion load of zero, while the fourth (subbasin 36) only contributes 1.8% of the total bank erosion load.
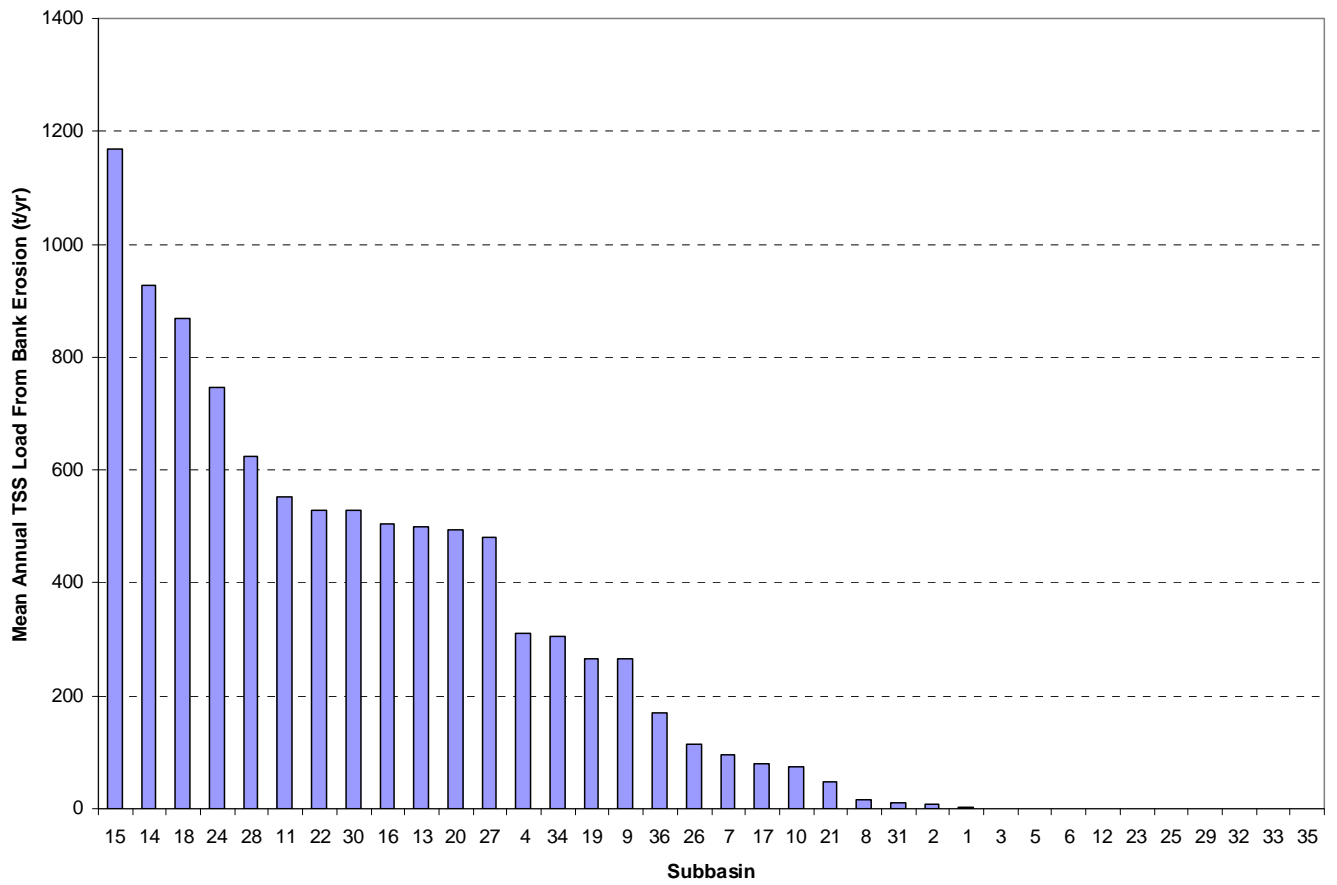
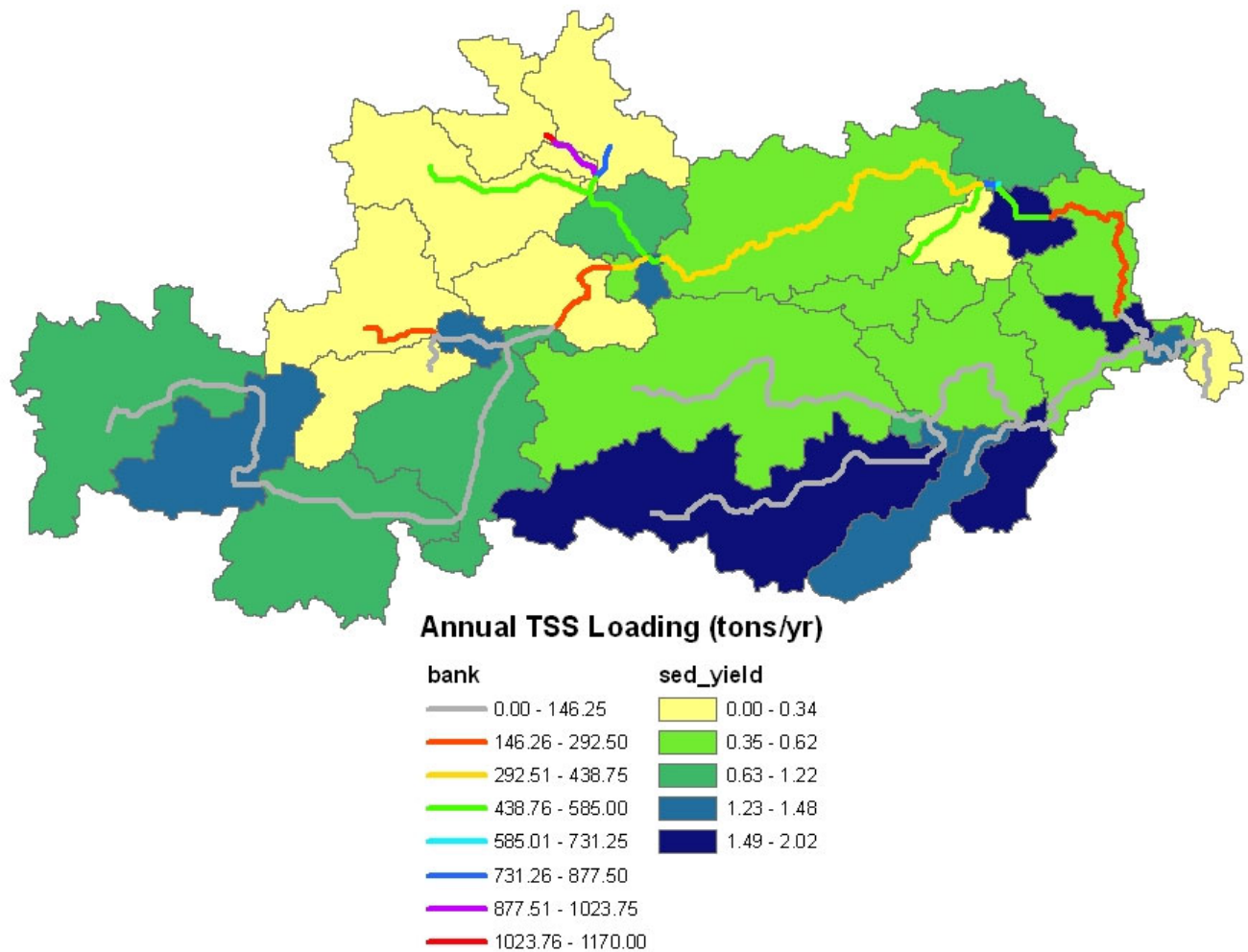**Figure 19 Simulated Bank Erosion TSS Loads, Sorted in Descending Order**

Annual TSS Loading (tons/yr)

bank		sed_yield	
	0.00 - 146.25		0.00 - 0.34
	146.26 - 292.50		0.35 - 0.62
	292.51 - 438.75		0.63 - 1.22
	438.76 - 585.00		1.23 - 1.48
	585.01 - 731.25		1.49 - 2.02
	731.26 - 877.50		
	877.51 - 1023.75		
	1023.76 - 1170.00		

Figure 20 Spatial Distributions of Simulated Annual Non-Point Source TSS Loads in Bevens Creek Watershed

4.3   Summary of TSS Loadings from Non-point Sources in the Watershed

Based on the output of the calibrated SWAT model run for the time period 1993-2007, a total of 27,230 metric tons of sediment was generated annually from field erosion in the watershed. Of this total, 3,502 metric tons made it to the outlet of the watershed. Similarly, a mean total of 9,691 metric tons of bank erosion was generated annually in the watershed, and 8,108 metric tons made it to the outlet of the watershed.

All sediment eroded from fields does not necessarily make it to a tributary or the main channel. Some of the sediment that does make it to the channel system settles out and is deposited in ponds, wetlands, or the channel itself, during transport.

Thus, on a source basis, 74% of the TSS load is from field erosion and 26% is from non-field erosion. However, at the <u>outlet</u> these percentages are nearly reversed (due to losses from settling and deposition during transport), with 70% of the total load from non-field erosion and 30% from field erosion.

5.   BMP Implementation Scenarios

5.1   Filter Strip Application

Filter or buffer strips are linear areas of vegetation planted alongside streams, ditches, or wetlands to attenuate overland flow and pollutants from stormwater runoff before they reach a water body. The SWAT model uses empirical equations to estimate the sediment trapping efficiency of filter strips based on width. The model applies the strips directly to the HRU rather than along the stream or tributary. The filter strip function in SWAT does not represent an edge of field effect, but rather a sediment trapping practice for the entire HRU. For this report, filter strips were applied to all corn, soybean, hay, and urban HRUs.

Figure 21 shows the simulated reduction in field erosion and TSS at the watershed outlet versus filter strip width. A width of 5 meters would reduce field erosion about 58%, 15 meters would remove 81%, and a width of 30 meters would reduce field erosion by almost 99%. However, the reductions in watershed outlet TSS load are much smaller. A 30 meter wide filter strip would only reduce the total TSS load at the outlet by about 20%. This is because field erosion only represents about 30% of the total erosion load at the outlet in the calibrated SWAT model.
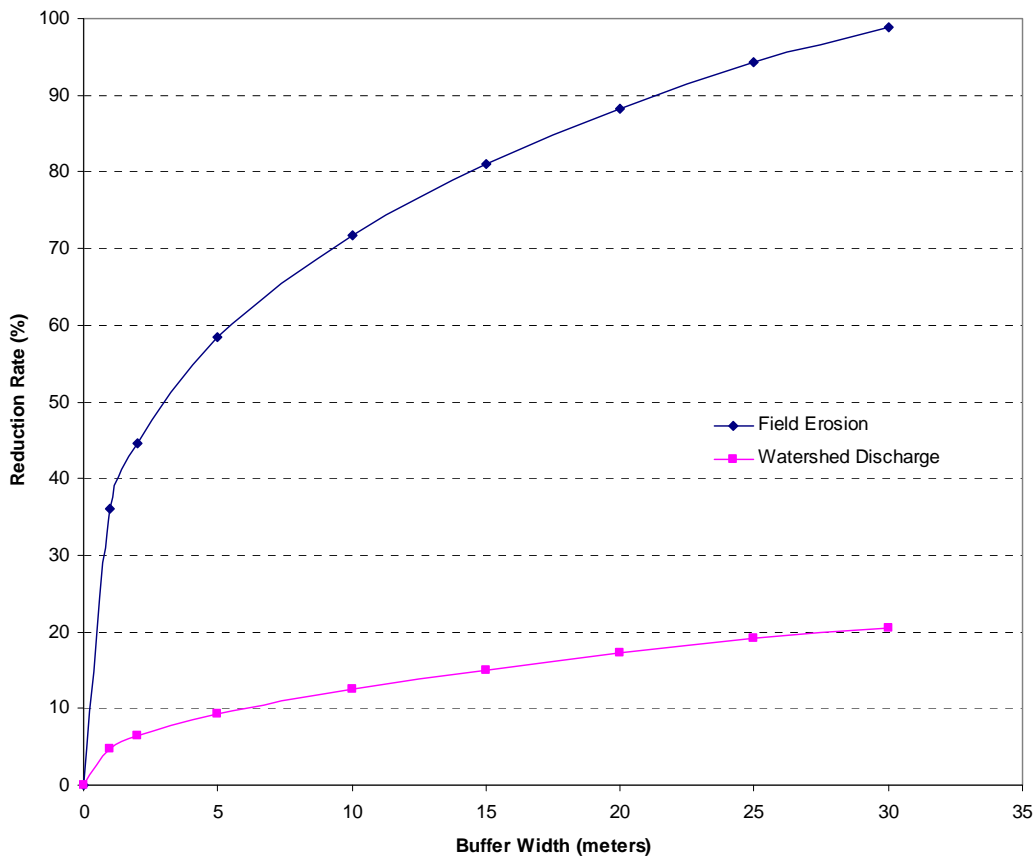

Figure 21 Simulated Reductions in Field Erosion and Total TSS Loads by Filter Strips

5.2   Conservation Tillage

Conservation tillage is defined as any tillage system that leaves at least 30% residue on the soil surface after planting. Conservation tillage was applied to all corn and soybean HRUs by

reducing the curve number by two units and increasing Manning's Roughness Coefficient for overland flow as described in Arabi et al, 2008.

Figure 22 shows that application of conservation tillage reduces the field erosion TSS load from corn, and soybeans by about 7%. However, the total TSS load at the watershed outlet is only reduced by 0.3%, due to the small portion of field erosion in the total outlet load.

The relatively small reductions in field erosion from conservation tillage may be due to the low relief of the cropland in the watershed. About 91% of the cropland in the watershed has a slope of 5% or less.
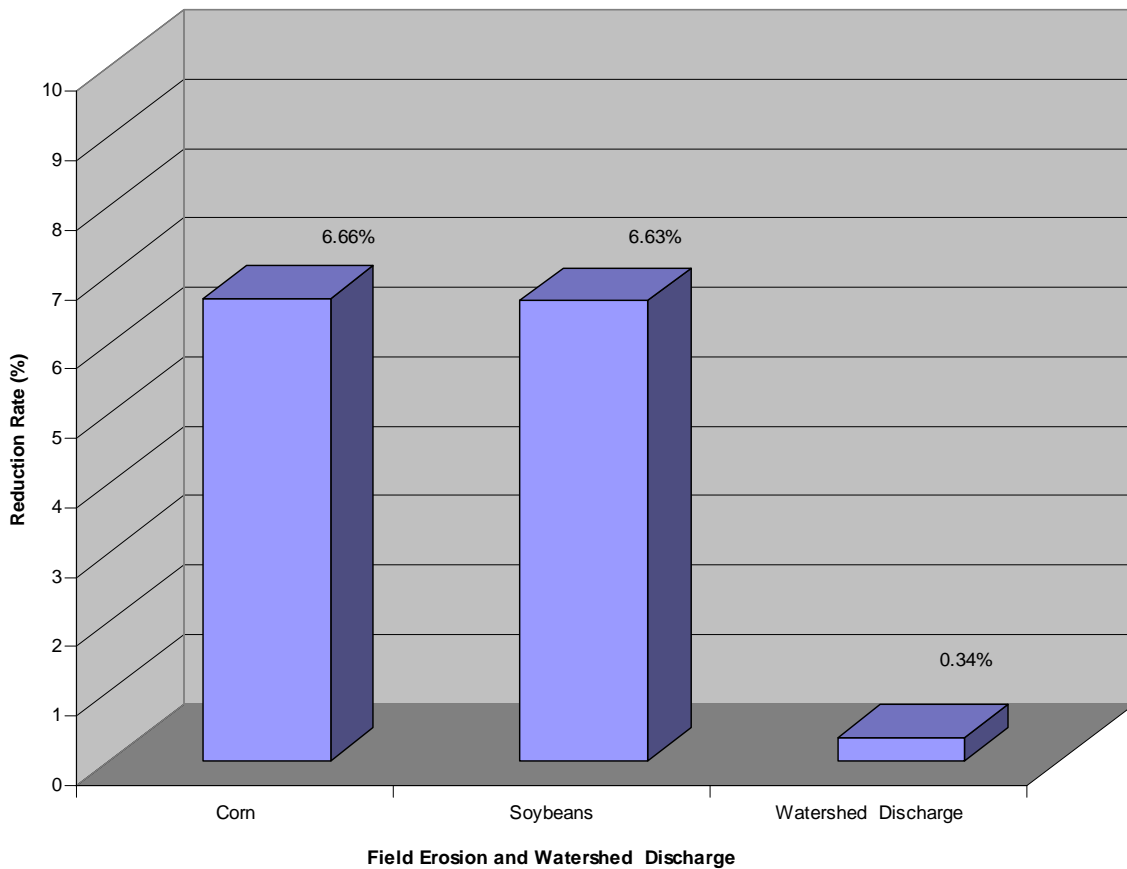

Figure 22 Simulated TSS Loading Reductions Using Conservation Tillage

5.3   Wetland and Pond Infiltration

The Bevens Creek watershed has experienced much agricultural drainage. There has been continuing interest in increasing storage in the watershed as a best management practice to improve water quality. Increasing the area of existing wetlands in the model resulted in an increase in runoff and TSS loading. This was due to the condition where wetland areas were increased but the original adjacent land uses were not reduced to reflect the change of land use to wetlands, thus these areas were "double counted," resulting in more runoff and TSS loading. To actually change the land use to reflect the increase in wetland area would require building and calibrating an entirely new model, as the land use layer cannot be changed once the model is

built. Efforts to increase only the depth of the existing ponds and wetlands encountered similar difficulties with outflow rates and timing.

The SWAT model has built in coefficients for pond and wetland infiltration. These coefficients are generally set at zero, leaving run out, overflow, and evaporation as the only way water leaves a pond or wetland. Increases in pond and wetland storage capacity were simulated by increasing these infiltration coefficients in a step-wise manner. These increases in infiltration were applied only to the ponds and wetlands, not to the large reservoirs on the main stem of the creek. Figure 23 shows the results of this scenario.
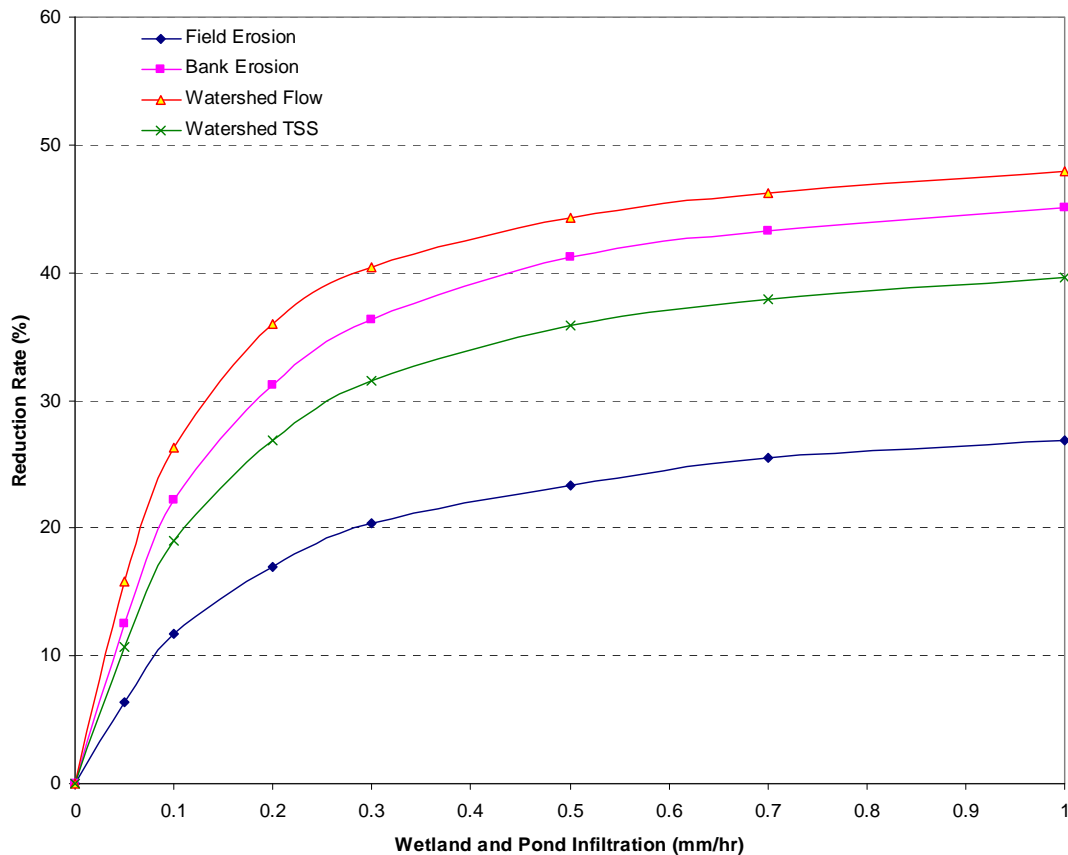

Figure 23 Simulated Reductions in Flow and TSS Loads in Response to Increases in Pond and Wetland Infiltration

As shown in the figure, increasing pond and wetland infiltration reduces both field erosion and bank erosion, and also decreases the total TSS load and flow at the watershed outlet. The reductions increase quickly as infiltration goes from 0 to 0.3 mm/hour and then increase more gradually as infiltration increases to 1 mm/hour.

Bank erosion and flow reduction data from this same exercise are plotted in Figure 24. The figure shows that there is a nearly linear relationship between flow reduction and bank erosion reduction. Thus a decrease in flow should result in a direct reduction in bank erosion.
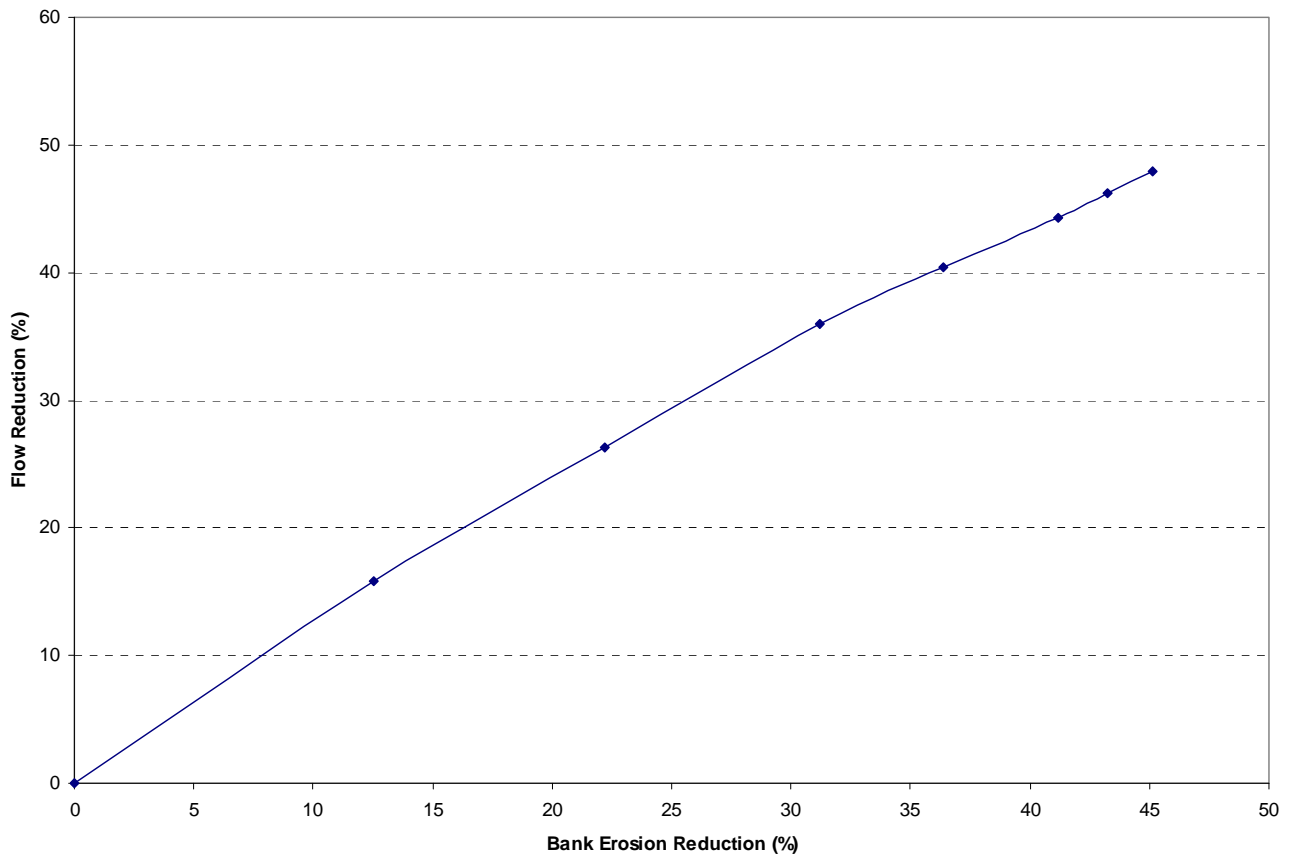
29

Figure 24 Simulated Bank Erosion Reduction in Response to Flow Reduction

5.4   Bank Erosion Control

Due to the high proportion of non-field (bank) erosion in the total erosion load at the watershed outlet, BMPs addressing bank erosion control will probably be needed to achieve the load reductions necessary to be in compliance with water quality standards at the higher flow regimes.

The SWAT model has a channel erodabilty parameter that can be adjusted from zero, (which corresponds to complete channel protection), to 1.0 (no protection at all). Two scenarios were run where this parameter was varied from its calibrated value to zero. One scenario was to reduce the parameter for every reach in the watershed, and the other was to reduce it only for selected reaches. For the selected reach scenario, the bank erosion parameter was reduced in 12 of the 36 subbasins (11, 13, 14, 15, 16, 18, 20, 22, 24, 27, 28, and 30). These subbasins were those that contributed 4% or more to the total bank erosion load at the watershed outlet.
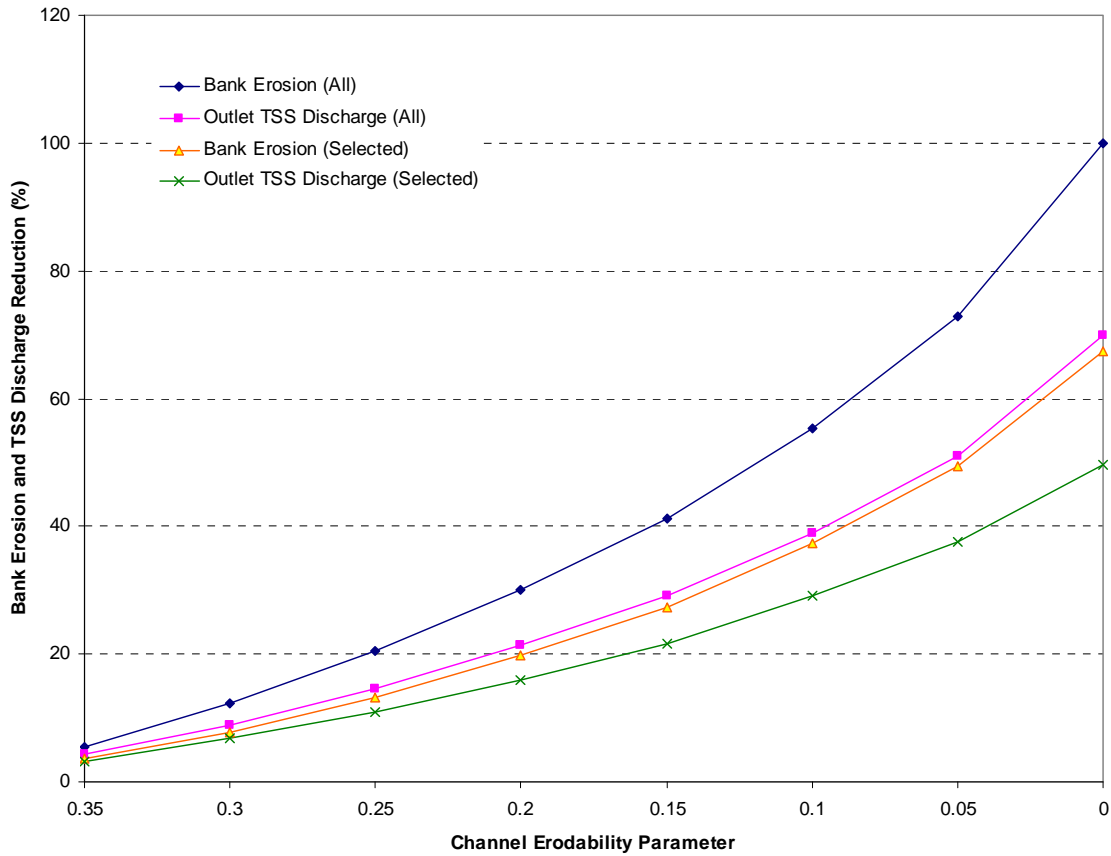
Figure 25 Bank Erosion and Watershed TSS Reduction by Reduced Channel Erodability

Figure 25 shows that reducing the parameter for all subbasins reduced bank erosion and total TSS load at the watershed outlet more than reducing the parameter the same amount for selected subbasins.

Figure 26 shows the percent reduction in watershed outlet TSS load compared to reduction in bank erosion and field erosion. From the figure, a 60% reduction in bank erosion would result in approximately 45% reduction in watershed TSS load, while a 100% reduction in bank erosion would result in a 70% reduction in TSS load at the watershed outlet. In contrast, even a 100% reduction in field erosion would result in only about a 20% reduction in the watershed TSS load.
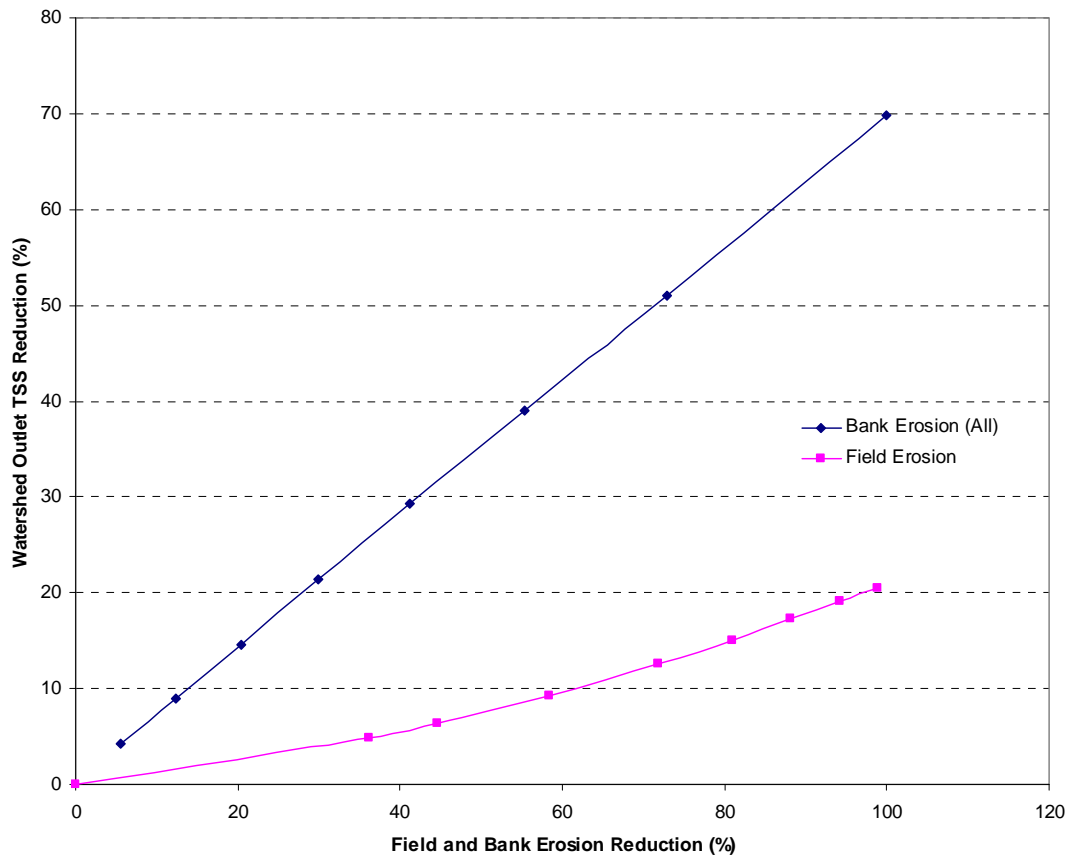
Figure 26 Watershed Discharge TSS Reduction in Response to Field and Bank Erosion Reduction

5.5   Combined BMPs

In the Bevens Creek watershed reductions in both field erosion and bank erosion are needed in order to be in compliance with water quality standards at all flow regimes.

To evaluate combined BMPs in the watershed, the following BMP scenarios for field erosion were applied to the calibrated model:

1.) A five meter vegetated buffer was applied to all agricultural and urban HRUs
2.) Conservation tillage was applied to all row crop HRUs.

The channel erodabilty parameter was then adjusted downward in all subbasins to simulate increased bank protection.

Figure 27 shows the results of this exercise. The uppermost dotted horizontal line in the chart shows the current average annual watershed TSS load of 11,610 metric tons. The middle horizontal line shows the reduction in watershed TSS load to 10,490 metric tons when both of the above field erosion BMP scenarios are applied. The lowest dotted horizontal line is the TMDL goal load of 7,240 metric tons. The downward curving line shows the further decreases in average annual watershed TSS load as bank erosion is reduced. A reduction in non-field erosion of 30 to 35% is necessary to reduce the average annual watershed TSS load to the goal of 7,240 metric tons.
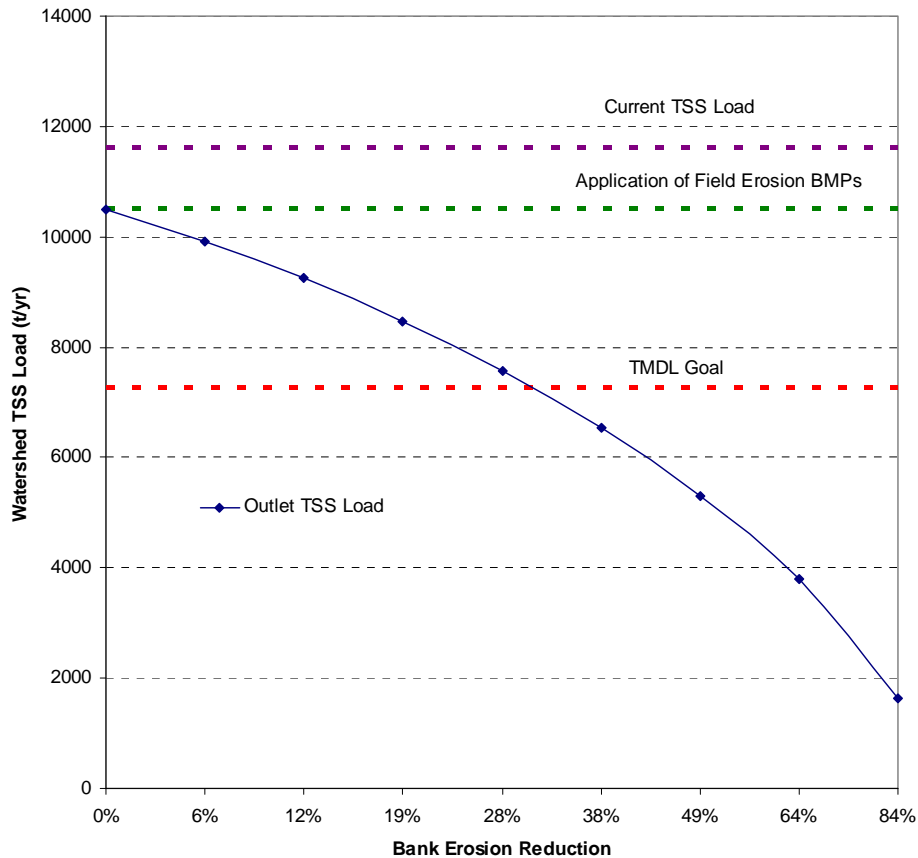
Figure 27 Simulated Watershed TSS Reductions in Response to Field and Bank Erosion Control BMPs

5.6 BMP Summary

A 37.6% reduction in the mean annual TSS load measured at mile 2.0 will be necessary to meet the turbidity TMDL goal. The SWAT modeling has shown that while field erosion is the largest source of TSS loading on a source basis, it only comprises 30% of the total watershed TSS load.

Table 8 Reductions in Watershed TSS Load by Management Practice

Management Practice	Watershed TSS Load Reduction
Conservation Tillage	0.3%
Filter Strip (5 meters)	9.2%
Filter Strip (10 meters)	12.6%
Filter Strip (15 meters)	15.1%
Wetland Infiltration (0.2 mm/hr)	26.9%
Channel Erodability (0.15)	29.3%
TMDL Goal	37.6%

Table 8 shows that application of conservation tillage will result in only a small (0.3%) reduction in the watershed TSS load. Application of 5 meter, 10 meter, and 15 meter wide filter strips will result in TSS load reductions of 9.2%, 12.6%, and 15.1%, respectively. These strips would need to be applied to all ditches, tributaries, and the main stem of Bevens Creek. However, even with

the application of filter strips, additional reductions would still be required. Wetland infiltration and reduction in channel erodability were modeled as scenarios to represent bank erosion control. Actual wetland infiltration would be difficult to accomplish in the watershed.

Based on these results, it appears that some bank erosion control, through flow reduction, bank protection, or some other means, will be necessary to achieve the required reduction in TSS loads for the watershed.

Implementation of the turbidity TMDL should begin with a careful inspection of the stream itself. The entire length of the stream should be walked and inspected for obvious erosion sources. Special attention should be given to gullies, areas where banks have obviously failed, areas of sediment accumulation, places where concentrated flow goes over the banks, and sites where tile lines discharge to the stream. Areas should be prioritized as to their severity and difficulty to remedy, and a long term effort to gradually address the worst sites should be undertaken.

Over time, any opportunities to restore or expand wetlands should be pursued. However, it is unlikely that adding additional storage by itself will reduce flow and TSS loading enough to meet the TMDL goals.

6.   References

Arabi, M., J. Frankenberger, B. Engel, and J. Arnold. 2008. Representation of Agricultural Conservation Practices with SWAT. *Hydrol. Process. 22, 3042-3055.*

Di Luzio,M., R. Srinivasan, J. G. Arnold, and S. L. Neitsch. 2002. ArcView Interface for SWAT2000 User's Guide. USDA Agricultural Research Service.

Donigian, Jr., A.S., 2000. HSPF Training Workshop Handbook and CD. Lecture #19. Calibration and Verification Issues, Slide #L19-22. EPA Headquarters, Washington Information Center, 10-14 January, 2000. Presented and prepared for U.S. EPA, Office of Water, Office of Science and Technology, Washington, D.C.

Driver, N.E. and G.D. Tasker. 1988. Techniques for estimation of storm-runoff loads, volumes, and selected constituent concentrations in urban watersheds in the United States. U.S. Dept. of the Interior, U.S. Geological Survey: Books and Open-File Reports Section 88-191

Du, B., J. G. Arnold, A. Saleh, and D. B. Jaynes. 2005. Development and Application of SWAT to Landscapes with Tiles and Potholes. *Transactions of the ASAE* 48(3) 1121-1133

Green, C.H., M.D. Tomer, M. Di Luzio, and J. G. Arnold. 2006. Hydrologic Evaluation of the Soil and Water Assessment Tool for a Large Tile-Drained Watershed in Iowa. *Transactions of the ASABE* 49(2) 413-422.

Huber, W.C. and R.E. Dickinson. 1988. Storm water management model, version 4: user's manual. U.S. Environmental Protection Agency, Athens, GA.

MASS, 1999. Minnesota Agricultural Statistics. Minnesota Agricultural Statistics Service (MASS), St. Paul, Minnesota.

MCES, 2008. Metropolitan Council's Impaired Waters Project: Development of TSS/Turbidity Relationship.

MCES, 2009. Swat Modeling for Carver Creek Turbidity TMDL.

Minnesota Pollution Control Agency, 2006. TMDL Work Plan Guidance.

Moriasi, D. N., J. G. Arnold, M.W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *Transactions of the ASABE* 50(3) 885-900.

MPCA, 2007. Turbidity TMDL Protocols and Submittal Requirements

Neitsch, S. L., J. G. Arnold, J. R. Kiniry, R. Srinivasan, and J. R. Williams. 2002. Soil and Water Assessment Tool User's Manual Version 2000. USDA Agricultural Research Service.

Neitsch, S. L., J. G. Arnold, J. R. Kiniry, and J. R. Williams. 2005. Soil and Water Assessment Tool Theoretical Documentation Version 2005. USDA Agricultural Research Service.

Tolson B. A and Shoemaker C. A. 2004. Watershed Modeling of the Cannonsville Basin using SWAT 2000. Technical report prepared for Delaware County Board of Supervisors, New York. Dept. of Civil and Environ. Engr, Cornell University.

USGS, 2000. 1992 National Land Cover Dataset. United States Geological Survey EROS Data Center.
Tolson B. A and Shoemaker C. A. 2004. Watershed Modeling of the Cannonsville Basin using SWAT 2000. Technical report prepared for Delaware County Board of Supervisors, New York. Dept. of Civil and Environ. Engr, Cornell University.

USEPA, 2007. An Approach for Using Load Duration Curves in the Devlopment of TMDLs. EPA 841-B-07-006.

Winchell, M., R. Srinivasan, M. Di Luzio, and J. Arnold. 2007. ArcSWAT Interface For SWAT2005 User's Guide. USDA Agricultural Research Service.