Carver Creek Turbidity TMDL

June 2012

Submitted by:

Carver County Land and Water Services

and

Minnesota Pollution Control Agency

wq-iw7-34e

Table of Contents

Tables

Figures

TMDL Summary

Element	Summary	Page #
Waterbody ID	Carver Creek: Headwaters to Minnesota River 07020012-516	Page # 1
Location	The Carver Creek watershed is located entirely within Carver County. Carver County is located southwest of the Twin Cities and is one of the seven counties in the Twin Cities Metropolitan Area.	3
303(d) Listing Information	Carver Creek was listed on Minnesota's 303(d) Impaired Water List due to its high turbidity measurements in 2002.	1
Impairment/ TMDL pollutant of concern	Turbidity	1
Impaired Beneficial Use(s)	Aquatic Life	1
Applicable Water Quality Standards/ Numeric Targets	Carver 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. **See Table 4.1**	12

Municipal Separate Storm Sewer Systems (MS4s)	**See Table 4.1 and 4.3**	12, 13
Construction and Industrial Stormwater	**See Table 4.1**	12
Permitted Discharges from Wastewater Treatment and Industrial Facilities	**See Table 4.1 and 4.4**	12, 14
Total Wasteload Allocation	**See Table 4.1**	12
Load Allocation	**See Table 4.1**	12
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. **See Table 4.1**	12
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.	15
Reasonable Assurance	Carver County is the water management authority for Carver 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.	26
Monitoring	A general monitoring plan is included. A 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.	20
Implementation	Information about potential management measures is included in this TMDL report. More detailed information will be provided in the Final Implementation Plan.	21

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 2001. 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 ____ to ____was published in the State Register.	29

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 Carver 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 Carver Creek to meet the water quality standard for turbidity.

The Carver Creek watershed is located in Carver County, Minnesota, part of the Twin Cities Metropolitan Area. The watershed is one of the subwatersheds within the Lower Minnesota River Basin. The creek starts in Benton Township and winds through the Townships of Waconia, Laketown and Dahlgren before discharging into the Minnesota River. The watershed covers the entire city of Waconia and portions of the cities of Cologne and Carver. Land uses in the Carver Creek watershed are primarily agricultural (66.7 percent) with the remaining land cover divided between open water and wetlands (18.8 percent), forests (6.9 percent), and developed land (5 percent).

The TMDL process for Carver Creek began with the compilation of hydrology and water quality data collected from the Metropolitan Council Environmental Services (MCES) 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. In order to meet the target TSS goal (100 mg/L), the necessary TSS load reductions are estimated to be 86 percent at high flows, 77 percent at moist conditions, and 20 percent at mid-range flows. No reductions are needed at low flows and dry conditions.

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). 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 2002, Carver Creek (AUID 07020012-516) was listed on Minnesota's 303(d) list of impaired waters from its headwaters to the Minnesota River for an impairment of aquatic life due to turbidity levels in exceedence of the water quality target of 25 NTU for Class 2B waters. The objective of this TMDL 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 the Carver Creek watershed, there are only three small scale point source permit discharges and most of the area is not covered by a permitted MS4. Carver Creek receives minimal amounts of TSS loads from point sources and regulated MS4 stormwater. 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 the Carver Creek TMDL. The project was scheduled to begin in 2003 and be completed in 2007. 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 waterbody; 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. This guidance is based upon publications from 2002, from which the stream was listed. 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 Carver Creek watershed is located in Carver County, Minnesota (Figure 2.1). The watershed is one of the subwatersheds within the Lower Minnesota River Basin. The creek starts in Benton Township and winds through the Townships of Waconia, Laketown and Dahlgren before discharging into the Minnesota River. The watershed covers the entire city of Waconia and portions of the cities of Cologne and Carver.

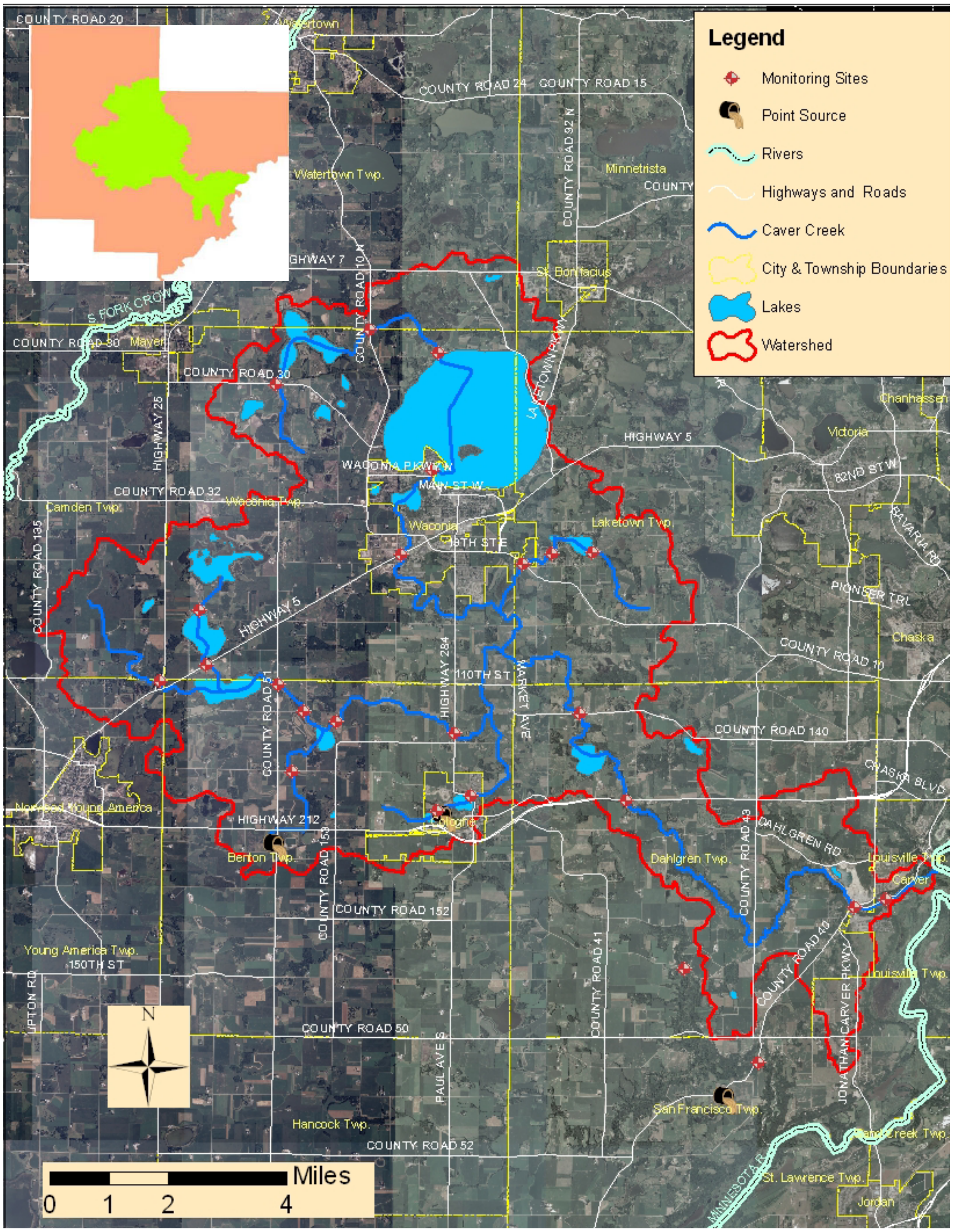

Figure 2.1 Carver Creek Watershed (inset shows watershed within Carver County)

The total area of the watershed is about 52,923 acres. Carver Creek flows through numerous lakes and wetlands prior to discharging into the Minnesota River. There are 15 lakes and approximately 89 miles of streams in the watershed. The stream, from its headwaters to the Minnesota River (AUID 07020012-516), was listed on Minnesota's 303(d) list of impaired waters for an impairment of aquatic life in 2002 due to turbidity levels in exceedence of the water quality target of 25 NTU for Class 2B waters.

Most of Carver County and all of the Carver Creek Watershed is in the North Central Hardwoods Forest (NCHF) ecoregion. The primary landscape features are circular, level topped hills with gentle, rolling slopes above a broad lower level. The lower level is interspersed with closed depressions containing lakes and some wetlands. The soils are dominated by loam, with textures ranging from loam to clayey loam. Soils are poor to well drained which formed medium textured calcareous glacial till. The annual precipitation ranges from 29-31 inches with a growing season of approximately 145-150 days.

2.2 Land Use and Cover

A detailed land use map of Carver Creek Watershed (Figure 2.3) was developed for the TMDL study in 2002 by the University of Minnesota and the Metropolitan Council (Yuan et al., 2005). The 15 land cover classifications used to develop the map are listed in Table 2.1. To create a more general distribution of land use for the Carver Creek Watershed, the land use classifications were lumped into 8 categories (Figure 2.2). Land uses in the Carver Creek watershed are primarily agricultural with the remaining land cover divided between open water and wetlands, forests, and developed land.

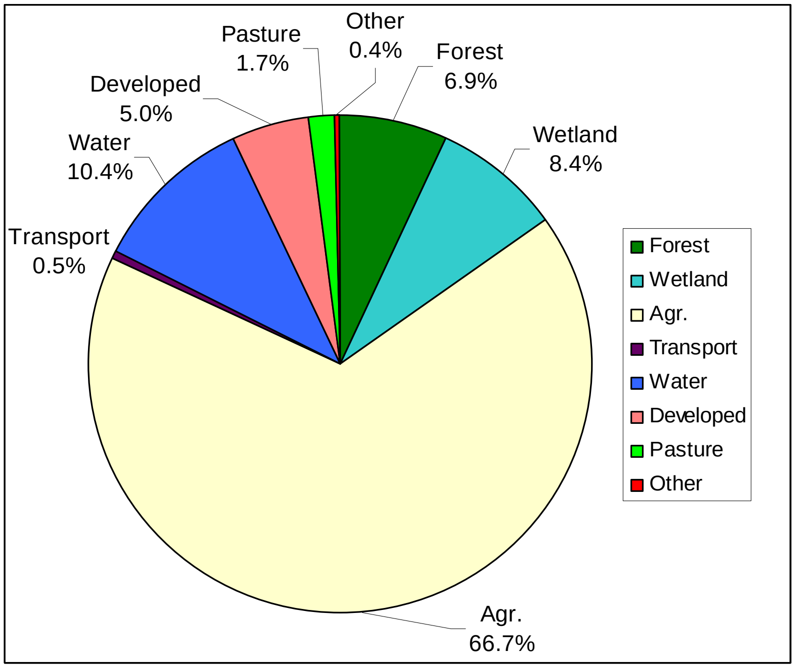

Figure 2.2 Land Uses in Carver Creek Watershed

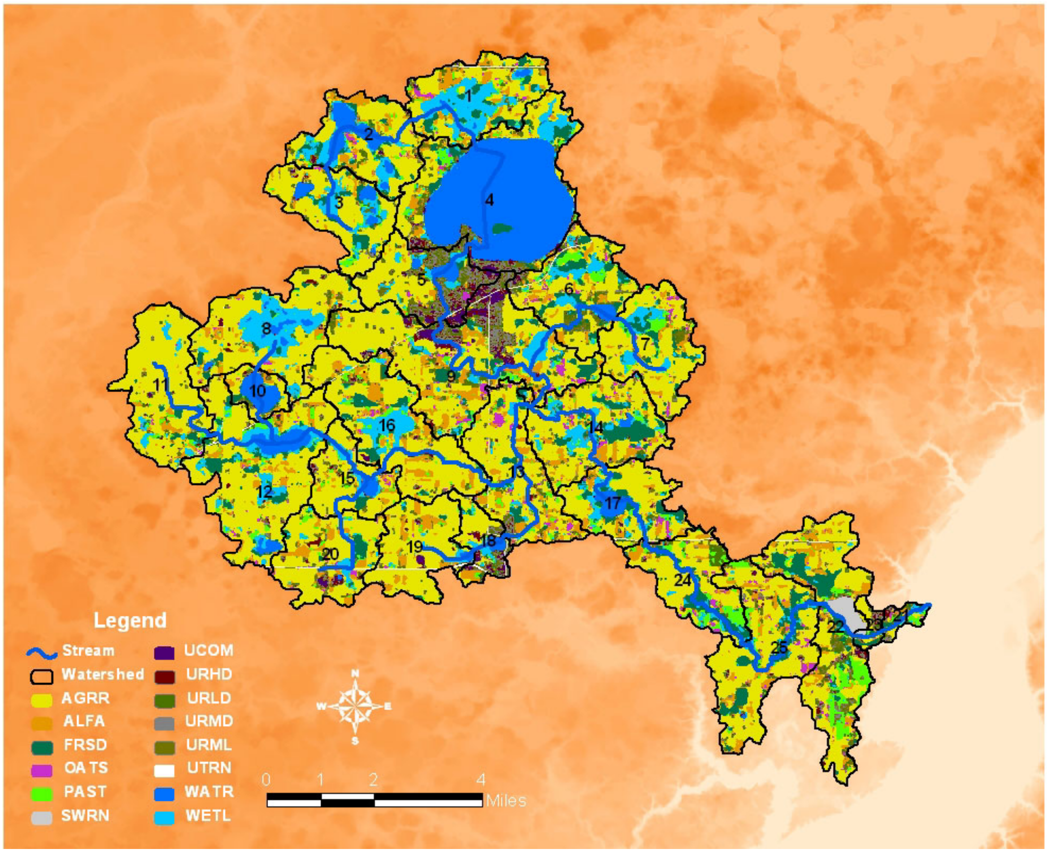

Figure 2.3 Carver Creek Watershed 2002 Land Use Map

Table 2.1 Definition of SWAT Land Use Legend

Land Use Category	Code
Low density residential	URLD
Medium-low density residential	URML
Medium density residential	URMD
High density residential	URHD
Commercial	UCOM
Forest – deciduous	FRSD
Pasture	PAST
Water	WATR
Wetlands – mixed	WETL
Alfalfa	ALFA
Row Crops: Corn, Soybean	AGRR
Oats	OATS
Pasture	PAST
Transportation (added)	UTRN

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 (Standard Methods 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. For Carver Creek, the turbidity standard is 25 NTU. Carver Creek is classified as 2B water. 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. 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 Carver Creek exceeded the listing criteria and in 2002 the MPCA placed Carver Creek on Minnesota's 303(d) list for turbidity impairment. The timing and magnitude of turbidity/TSS exceedences 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 Carver 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 seen in the following equation:

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

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 the National Pollution Discharge Elimination System (NPDES) permit program. In the Carver Creek Watershed the LA for the turbidity TMDL can be assigned to field and non-field erosion. In most TMDLs, including the TMDL for Carver 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 Carver 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 14025 County Road 40, Carver County, MN, which is about 1.7 miles upstream from the creek confluence with the Minnesota River (Figure 2.1). Carver County Environmental Services has three additional continuous monitoring stations established in 1997 (or after) located respectively at river miles 8.7 and 10.4 on Carver Creek and on Bent Creek near the outlet of Burandt Lake. 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 Carver Creek is shown in Figure 4.1. The curve uses average daily flow values monitored from 1990 through 2007 at the MCES monitoring station.

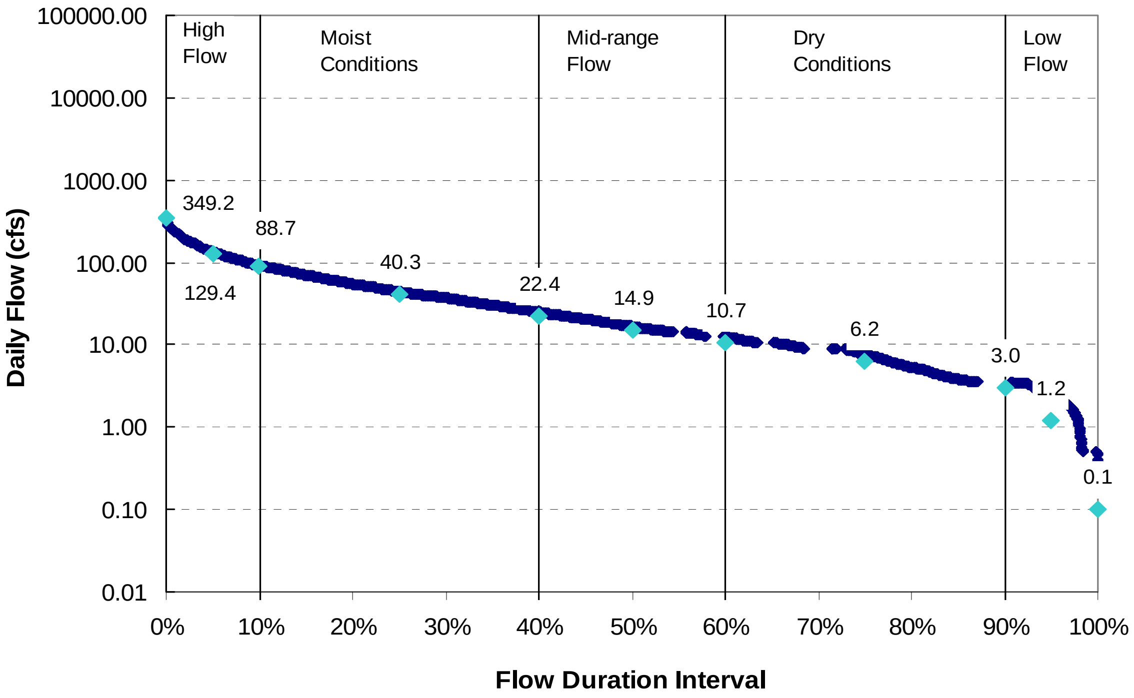

Figure 4.1 Flow Duration Curve for Carver Creek at MCES Monitoring Station.

4.4 Calculation of TSS Equivalent for Turbidity Standard

Minnesota has a water quality standard for turbidity in streams. For Carver 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 100 mg/L TSS is being used based on the correlation between turbidity and TSS loads.

MCES developed a statistical relationship between turbidity and TSS for the creeks in the metropolitan area (MCES, 2008). A simple linear regression equation was used to fit the monitoring data sets of TSS and turbidity. The regression analysis for Carver Creek is plotted in Figure 4.2 and the equation was:

$$\log(\mathrm{TSS}) = 0.2565 + 1.2472 * \log(\mathrm{NTU})$$

The equation was then used to estimate an average TSS value equal to 25 NTU. Based on this analysis, 100 mg/L was proposed as the surrogate of 25 NTU for Carver Creek. Therefore, 100 mg/L was used as the TSS concentration target.

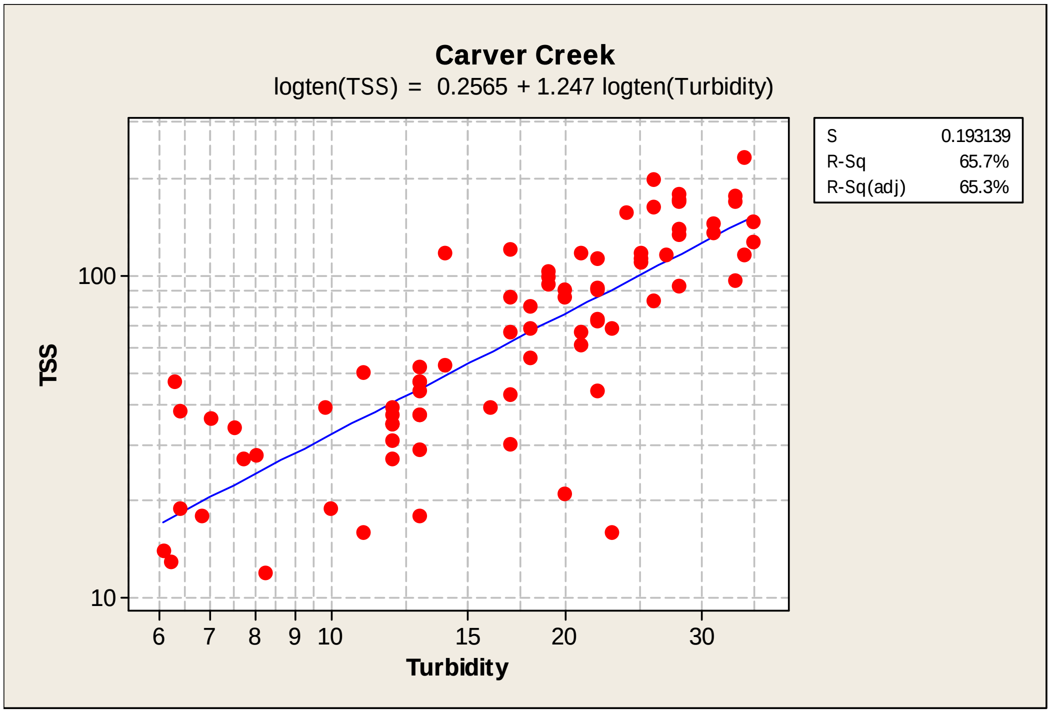

Figure 4.2 Regression Analysis of Turbidity and TSS for Carver Creek (MCES, 2008)

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 table of this report (Table 4.1) 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).
The TSS load duration curve for Carver Creek (Figure 4.3) was developed by multiplying stream flow with the numeric water quality target for TSS (100 mg/L). The curve is based on data from the MCES monitoring station, utilizing data from 1990 to 2007. The developed load duration curve displays the TSS loads that Carver Creek can carry and still be in attainment of the turbidity water quality standard based on using 100 mg TSS/L as a surrogate to the 25 NTU standard.

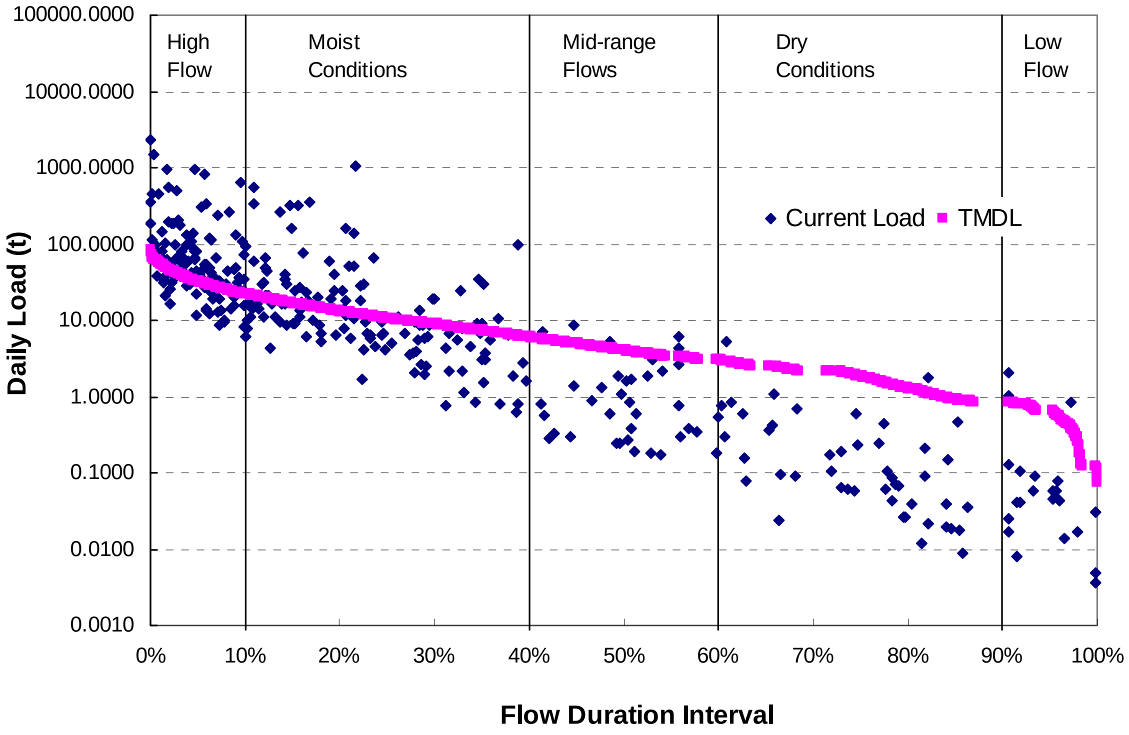

Figure 4.3 TSS Load Duration Curve for Carver Creek at MCES Monitoring Station.

The load capacities of TSS for the five flow regimes were calculated for the midpoint values of their flow conditions. Due to the significant variations ranging from 129.4 cfs at high flow to 1.2 cfs at low flow, the load capacities are substantially different for the five flow regimes. The estimated load capacities vary from 32.4 t/day (32,400 kg/day) at high flow conditions to 0.6 t/day (600 kg/day) at low flow conditions. The load capacities at the moist conditions, mid-range flow and dry conditions are respectively 10.6 t/day (10,600 kg/day), 4.0 t/day (4,000 kg/day), and 1.8 t/day (1,800 kg/day).

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. Table 4.1 presents the allocated loads for total WLA, LA, and MOS as well as the individual allocations for WLA sources for the five flow regimes. Information about how the TSS loads were allocated is presented in the following sections.

Table 4.1 TMDL Allocations for Carver Creek (kg/day) (AUID: 07020012-516)

TMDL Allocation	High Flow	Moist Conditions	Mid-Range Flow	Dry Conditions	Low Flow
Total Loading Capacity	**32,360.0**	**10,580.0**	**4,030.0**	**1,840.0**	**650.0**
Total WLA	**2,343.0**	**1,043.4**	**652.6**	**521.9**	**466.0**
Permitted Discharges from Wastewater Treatment and Industrial Facilities					
- Bongards' Creamery	379.2	379.2	379.2	379.2	379.2
- Cologne WWTP	36.9	36.9	36.9	36.9	36.9
- Carver WWTP	41.5	41.5	41.5	41.5	41.5
MS4 NPDES Requirements					
- Laketown Township	534.6	166.1	55.3	18.2	2.4
- City of Waconia	1237.0	384.3	127.9	42.2	5.5
- City of Minnetrista	8.5	2.7	0.9	0.3	0.04
- City of Carver	39.8	12.4	4.1	1.4	0.2
- Carver County	14.2	4.4	1.5	0.5	0.1
Construction and Industrial Stormwater	25.6	8.0	2.6	0.9	0.1
Industrial Stormwater	25.6	8.0	2.6	0.9	0.1
Reserve Capacity	**228.8**	**228.8**	**228.8**	**228.8**	*****
- Bongards' Creamery	189.6	189.6	189.6	189.6	*
- Cologne WWTP	18.5	18.5	18.5	18.5	*
- Carver WWTP	20.8	20.8	20.8	20.8	*
Margin of Safety	**3,236.0**	**1,058.0**	**403.0**	**184.0**	**65.0**
Load Allocation	**26,552.2**	**8,249.8**	**2,745.6**	**905.3**	**119.0**

*See Section 4.8 for potential future use of reserve capacity

Table 4.2 Percent TMDL Allocations for Carver Creek (AUID: 07020012-516)

TMDL Allocation	High Flow	Moist Conditions	Mid-Range Flow	Dry Conditions	Low Flow
Total Loading Capacity	100.0%	100.0%	100.0%	100.0%	100.0%
WLA - Permitted Discharges	1.4%	4.3%	11.4%	24.9%	70.4%
WLA - MS4 NPDES	5.7%	5.4%	4.7%	3.4%	1.3%
WLA - Construction and Industrial Stormwater	0.2%	0.2%	0.1%	0.1%	0.04%
Reserve Capacity	0.7%	2.2%	5.7%	12.4%	*
Margin of Safety	10.0%	10.0%	10.0%	10.0%	10.0%
Load Allocation	82.1%	78.0%	68.1%	49.2%	18.3%

*See Section 4.8 for potential future use of reserve capacity

4.6.1 Determining Margin of Safety

Based on EPA guidance for preparing TMDLs, MOS is typically expressed either as unallocated assimilative capacity or as conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed controls). The MOS may be explicitly stated as an added, separate quantity in the TMDL calculation, or implicit, as in conservative assumptions.

The MOS for Carver Creek TMDL is ten percent of the total loading capacity at each of the flow zones. This is expected to provide an adequate accounting of uncertainty, especially since the wastewater treatment facilities within the study area have generally consistently met the TSS discharge limits (which is well below the TMDL TSS surrogate concentration). Also, the mechanisms for soil loss from agricultural sources and the factors that affect this have been extensively studied over the decades and are well understood. Therefore, the MOS for the Carver Creek TMDL is simply 10 percent of the total load capacity for each flow regime. See Table 4.1 for the allocated MOS values for Carver Creek.

4.6.2 Determining Wasteload Allocation

The 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 Carver Creek, thus point sources have little impact on turbidity.

The components of the Carver Creek WLA can be subdivided into three categories: permitted discharges from wastewater treatment plants (WWTP) and industrial facilities, publicly owned municipal separate storm sewer systems (MS4), and construction and industrial stormwater. MS4s are regulated through NPDES permits. Those systems include roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, and storm drains in the regulated community areas.

The WLA for this category was estimated based solely on the total area of urban land use for the MS4 communities. Table 4.3 lists the five MS4 NPDES permits and total percentage of land within that MS4 community classified as urban land (urban area includes area classified as roads within the urban area) based on 2030 land use maps. The assumption was made that using the 2030 land use map allows for future development. The WLA for each MS4 is calculated by taking the remaining loading capacity within each flow regime after wastewater WLA, MOS and reserve capacity is subtracted and multiplying that amount by the percent of the land area it makes up in the watershed (Table 4.3).

Table 4.3 MS4 NPDES Permits within the Carver Creek Watershed with Percent of 2030 Land Area Classified as Urban.

Name	NPDES Permits	Land Area	Note
Carver County	MS400070	0.05%	Mandatory MS4
Laketown Township	MS400142	1.88%	Mandatory MS4
City of Minnetrista	MS400106	0.03%	Mandatory MS4
City of Waconia	MS400232	4.35%	Designated MS4
City of Carver	MS400077	0.14%	Mandatory MS4

As development occurs within the watershed, the Census Bureau-defined Urban Area may expand. If this occurs, it may be necessary to transfer WLA from one MS4 to another. For example, a segment of state-owned highway may come under permit coverage as the Urban Area expands. In the event that additional stormwater discharges come under permit coverage within the watershed, WLA will be transferred to these new entities based on the process used to set WLAs in the TMDL. MS4s will be notified and will have an opportunity to comment on the reallocation. If and when areas within the watershed designated as LA are developed (urbanized) or become part of the Urban Area and thus fall under an NPDES regulated MS4 framework, the TMDL will be re-opened and load will be transferred from the LA to the WLA as appropriate.

There are three wastewater sources of permitted discharges in the Carver Creek watershed: Bongards' Creamery, the Cologne WWTP and the Carver WWTP. The Bongards' Creamery and Cologne WWTP discharge to one of the upstream tributaries of Carver Creek above the MCES monitoring station while the Carver WWTP discharge is located downstream of the MCES monitoring station. The TSS concentration limits for these facilities are well below the TSS goal for this TMDL. Their daily mass limits are used as their WLAs for this TMDL. Table 4.4 lists the TSS permits for the wastewater treatment facilities in the Carver Creek watershed. Among discharges in Bongards' Creamery facilities, SD-1 is not active, the designed flow for SD-2 is 2 million gallons and permitted to discharge periodically from April 1 to June 15 and September 1 to December 15, and the designed flow for SD-3 is 0.339 million gallons and discharge year around.

Table 4.4 Discharge Permits for TSS at Bongards' Creamery, Carver WWTP and Cologne WWTP.

Name	ID	Discharges	Limit (kg/day)	Concentration Limit (mg/L)	Note
Bongards' Creamery	MN0002135 (SD-1)	Non-contact Cooling water		30.0	Monthly average
				45.0	Daily max.
	MN0002135 (SD-2)	Pond effluents from process/sanitary wastes	341	45.0	Monthly average
			460	65.0	Monthly max.
	MN0002135 (SD-3)	Cooling water	38.5	30.0	Monthly average
				45.0	Daily max.
Cologne WWTP	MN0023108	Total facility discharge	36.9	kg/day	Monthly average
			55.3	kg/day	Weekly average
Carver WWTP	MN0053457	Total facility discharge	41.5	kg/day	Monthly average
			61.5	kg/day	Weekly average

The last category included in the WLA for Carver Creek is turbidity or TSS loads contributed from construction and industrial stormwater. Stormwater from construction sites and industrial facilities are subject to NPDES regulations. They were lumped together into a categorical WLA based on the approximate land use areas covered by those activities. According to MPCA records, there were a total of 263 applications for construction permits over the last four years in Carver County. The area of those construction sizes ranged from 0.25 to 4,958 acres. The total area covered by the applications was 9,998 acres, which is approximately 0.09 percent of the watershed area subject to NPDES construction permits on a yearly basis. The WLA for construction was then calculated by taking the remaining loading capacity after wastewater WLA, MOS and reserve capacity was subtracted and multiplying that amount by 0.09 percent. Since there is no comparable readily accessible information for NPDES industrial stormwater permits, we assumed that NPDES industrial stormwater permit areas were equal to NPDES construction permit areas in order to complete the TMDL allocation. The WLA for NPDES permitted industrial stormwater was made in addition to the WLA for permitted discharges from wastewater treatment and industrial facilities (see Table 4.1).

To meet the WLA for construction stormwater, construction stormwater 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 stormwater 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.

4.6.3 Determining Load Allocation

The LA is the remaining loading capacity after subtracting all WLA, MOS, and reserve capacity 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 exceedences 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

The potential impacts of growth on TMDL allocations were addressed for MS4s in the watershed by basing their allocations on future developed land use in year 2030 Comprehensive Plans. It should be noted that the expected land use changes in the watershed involve a slight decline in agricultural land uses, which contribute the highest TSS loads to the watershed, to increased urban land uses, which contribute high runoff but comparatively low TSS loads. To account for potential expansion of Bongards' Creamery and the WWTPs a small amount of reserve capacity (equivalent to 50 percent of their current daily mass loading) has been accounted for in the TMDL for all flow regimes, except low flow. 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 over most of the flow range 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. Regarding increased wastewater discharge at low flow, potential future allocations and permitting will take into account the added loading capacity the discharge provides (as well as other factors unrelated to turbidity). 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 the turbidity 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.

5 Turbidity Source and Load Reduction Evaluation

5.1 TSS Loading

The actual TSS loads for Carver 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 (100 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 100 mg/L occur in the high flow and moist conditions when flows are larger than 22.4 cfs. At dry and low flow conditions when the flows are smaller than 10.7 cfs, 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. To provide an estimate of field-derived sediment vs. bank-derived sediment 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 conclude that approximately 30 percent of the sediment is from field erosion and 70 percent is from non-field erosion. The majority of non-field erosion is assumed to be bank erosion.

To evaluate field erosion the SWAT (Soil and Water Assessment Tool) model developed by the U.S. Department of Agriculture Research Service and Texas A&M University was used. SWAT is a watershed scale model that is able to simulate natural, agricultural and urban ecological systems relevant to the hydrologic cycle, TSS yields and movements in the watershed. It 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 nonpoint 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 Carver Creek is included within Appendix A.

In the Carver Creek Watershed the majority of TSS loads are contributed from nonpoint sources. The developed SWAT model was used to identify the areas with relatively high surface runoff and TSS load contributions to Carver Creek. It was found that surface runoff from various land uses ranged from 0.30 to 220 millimeters (mm). The urban land use areas have significantly higher surface runoff, followed by soybean and corn fields. Forest has the lowest surface runoff (0.3 mm). Significantly high TSS loads are found from the soybean and corn fields (4.76 t/ha and 4.69 t/ha, respectively). While urban land uses have the highest runoff, the TSS exports from the urban land use are relatively low (0.16 t/ha). The surface runoff and TSS loads for the different land use types are compared in Figure 5.1.

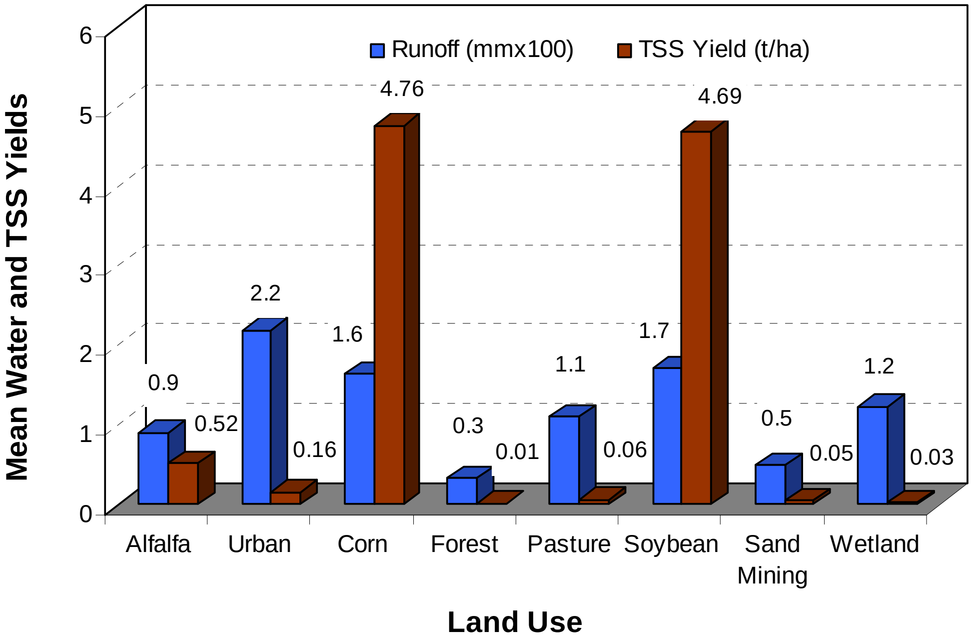

Figure 5.1 Simulated Water and TSS Export Rates by Land Use.

It is helpful to know what percentages of total TSS loads from field erosion are contributed by individual land use type. More than 99.5 percent of TSS loads from field erosion are from the agricultural activities, in which soybean production accounts for 60 percent, corn accounts for 38 percent and alfalfa accounts for 2 percent. The high TSS loadings from these land uses are due to the relatively large land areas and TSS export rates. The urban, forest, pasture and other land uses contribute less than 0.5 percent of the total TSS from field erosion. The percentage of TSS load by land use and the percentage of land area that land use accounts for are presented in Figure 5.2.

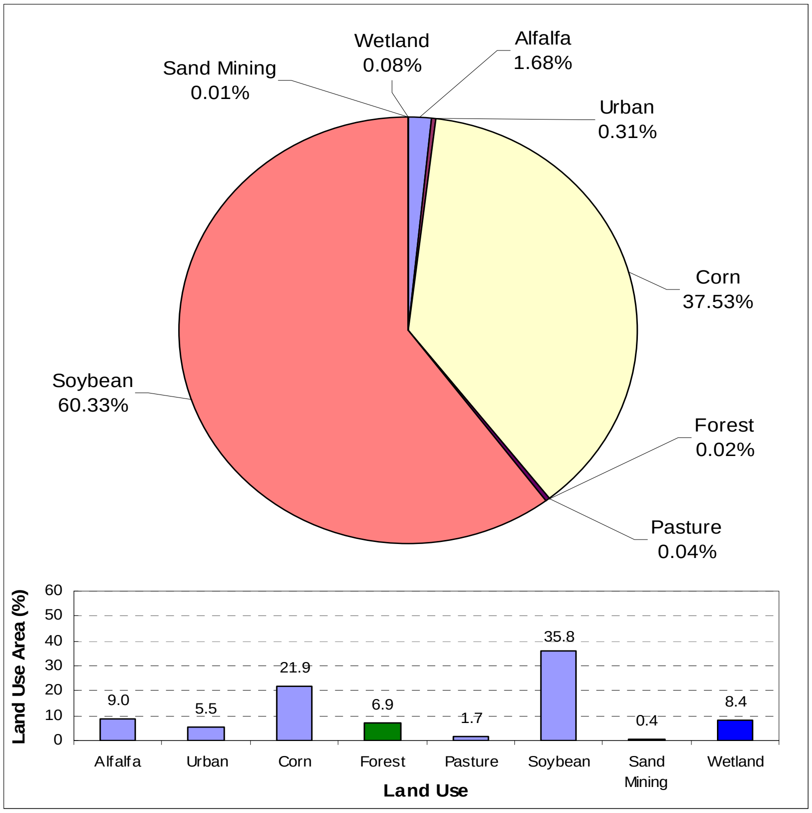

Figure 5.2 Simulated TSS Loadings from Field Erosion by Land Uses.

6 Monitoring Plan

Currently, a monitoring network of multiple stream locations is utilized by Carver County Staff to assess the overall water quality within the county, including the parameters TSS and turbidity. In addition to the base network of monitoring stations within Carver Creek, supplementary sites are used to assess E. coli bacteria levels within the Creek. This network will be used to determine if the goals of this TMDL are being met. The county has stable funding for water management and will continue its baseline-monitoring program. A more detailed monitoring plan will be included in the final Implementation Plan.

7 Implementation Activities

7.1 Introduction

Carver County, through their Water Management Plan, has embraced a basin wide goal for protecting water quality in the Carver Creek watershed. Currently, Carver County has developed detailed action strategies to address several of the issues identified in this TMDL. The Carver Soil and Water Conservation District (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. Further discussion on BMPs is presented in the Carver Creek SWAT Modeling Report included in the Appendix. 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. Costs to implement the TMDL range from $6,828,000 to $15,540,000.

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 Load Reduction Estimates

Estimates for the percent load reduction needed were made by comparing measured concentrations within each flow regime loads 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 loading target. Table 7.1 provides estimated percent reductions based on the load duration curve sampled TSS concentrations. 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 Flow Duration Curve and collected TSS samples.

	High Flows	Moist Conditions	Mid-Range	Dry Conditions	Low Flows
TSS Concentration Target (mg/L)	100	100	100	100	100
Measured TSS Concentration at 90th Percentile (mg/L)	706	440	125	32	99
Reduction Needed	86%	77%	20%	0%	0%

To determine if loading reductions are required for MS4s the current loads for these areas were estimated and compared to the WLAs. Current loadings from these areas were estimated using the SWAT Urban TSS loading estimate of 0.31 percent multiplied by the measured load at the 90th percentile (Table 5.1) for each flow regime. This result is then multiplied by the relative area of each MS4 (as a percent of the total MS4 area), with the City of Waconia at 67.4 percent, Laketown Township at 29.2 percent, City of Carver at 2.2 percent, City of Minnetrista at 0.5 percent, and Carver County at 0.8 percent. Table 5.2 provides current estimated loadings for MS4 areas. Comparing these to allowable loadings (Table 4.1) indicates that no reductions are needed for MS4 areas.

Table 7.2 Current MS4 TSS Loadings (kg/day).

MS4 NPDES Permits	High Flow	Moist Conditions	Mid-Range Flow	Dry Conditions	Low Flow
- Laketown Township	246.62	60.43	4.50	0.66	0.63
- City of Waconia	570.63	139.82	10.41	1.53	1.47
- City of Minnetrista	3.94	0.96	0.07	0.01	0.01
- City of Carver	18.37	4.50	0.34	0.05	0.05
- Carver County	6.57	1.61	0.12	0.02	0.02

7.4 Best Management Practices

The final implementation plan will be developed within a year of the final approval of the TMDL report by the EPA. It will list what and where BMPs will be applied in each 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 Carver Creek Watershed are highlighted below, but other BMPs will be considered as needed.

7.4.1 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 Carver 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 Carver Creek in areas deemed prudent.

1) Responsible Parties:	CCWMO, Carver SWCD
2) Timeline:	Long Term
3) Estimated Cost:	\$2,700,000 - \$8,250,000

7.4.2 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 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". Emphasis will be placed on subwatersheds that have the highest annual yield as predicted by SWAT Modeling. Evaluation will primarily be based upon a field assessment of farming practices utilized by farmers.

Task 1. Identify and prioritize key areas within the Carver Creek subwatersheds based upon areas not implementing conservation tillage and TSS loads modeled by 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

7.4.3 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. Infiltration can be one of the most important characteristics of ponds and wetlands to control runoff volume, reduce pollutant discharges, and mitigate downstream bank erosion.

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 Carver 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: $1,000,000 to $2,500,000

Task 4. Design and implement practices that will reduce volume within the stream, thus reducing in-stream erosion. Targeted wetland restoration projects have been identified in upper reaches of the Benton Lake watershed ($650,000), North Patterson Lake restoration ($780,000), Miller Lake northeast restoration ($310,000), and Winkler Lake restoration and re-meander ($300,000).

1) Responsible Parties: CCWMO, Carver SWCD, NRCS
2) Timeline: Long Term
3) Estimated Cost: $2,040,000

7.4.4 Bank Erosion Control

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 Carver 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 Carver Creek Watershed, some sub-basins are much more highly erodible than others. Simulated results using the SWAT model indicate that partially applying bank erosion BMPs to seven highly erodible sub-basins could remove up to 88% of TSS loads due to bank erosion. Applying BMPs to control bank erosion to the selected sub-basins rather than to the entire watershed can greatly reduce implementation costs.

Task 1. Identify and prioritize key areas within Carver 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 stream banks from erosion.

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

8 Reasonable Assurance

8.1 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.

8.2 Management of Carver Creek Watershed

Carver County is the water management authority for Carver Creek. 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 ground water.

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". 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% 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 CCWMO 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.

Within one year of the approval of the Turbidity TMDL by the EPA, 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 Carver Creek needed to reach the State Standard for turbidity.

8.3 Regulatory Approaches

8.3.1 Watershed Rules

Water Rules establish standards and specifications for the common elements relating to watershed resource management including: Water Quantity, Water Quality, 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.

8.4 Non-Regulatory and Incentive Based Approaches

8.4.1 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.

8.4.2 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 EPA 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.

9 Public Participation

9.1 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.

9.2 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 -
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 Watershed Research Station (SCWRS) on "Finger printing Sources of Suspended Sediment".

9.3 Public Meetings

Notice of the availability of a draft of this TMDL for review and comment for a 30 day period from ____ to ____was published in the State Register. During this time Carver County Staff plan to hold public meetings to present this TMDL to local stakeholders and the public.

10 Citations

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Appendices

Appendix A: SWAT Modeling for Carver Creek Turbidity TMDL

SWAT Modeling for Carver Creek Turbidity TMDL

Miller Lake at Carver Creek

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May 2009

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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.

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Questions about the contents of this study can be referred to Dr. Hong Wang at 651-602-1079.

Table of Contents

Tables

Figures

1. Introduction

In 2002, Carver Creek (AUID:07020012-516) in Carver County of the Twin Cities Metropolitan Area, MN, was listed as "impaired" on Minnesota's 303(d) Impaired Waters List due to its high turbidity measurements that surpassed the water quality standard of 25 Nephelometric Turbidity Units (NTUs). These higher measurements indicate that the creek does not meet beneficial uses for Class 2B water as designated by the MPCA.

Turbidity is commonly measured in NTU. NTU is a unit of measurement quantifying the degree to which light traveling through a water column is scattered by the suspended organic (including algae) and inorganic particles or total suspended solids (TSS). 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 may cause aquatic organisms to have trouble finding food, affect gill function and cause spawning beds to be covered. TSS also transports nutrients from lands to receiving waters aiding in eutrophication. Increased turbidity or suspended particles in a stream is associated with the alteration of the landscape and environmental conditions such as increased agricultural production and urbanization.

Section 303(d) of the Clean Water Act establishes a directive for developing Total Maximum Daily Loads (TMDLs) to achieve water quality standards established for designated uses of water bodies of the state. The Minnesota Pollution Control Agency (MPCA) has the responsibility to conduct TMDL studies for waters of the state if they are listed as impaired through assessments according to their designated uses and water quality standards. Under the directive, the MPCA has partnered with Carver County Environmental Services to develop a turbidity TMDL for Carver Creek. Following a public notice and review process, the MPCA will submit the TMDL to the United States Environmental Protection Agency (EPA) for approval.

The Metropolitan Council (Council) is the regional water quality-planning agency for the seven county Twin Cities Metropolitan Area under Section 208 of the Clean Water Act (33 U.S.C. 1288). The Council has responsibilities to assist the MPCA and local authorities with preparations of the assessments of waters of the state in the metropolitan area (M.S. 103F.721) and to prepare a water resources plan with target pollution loads for watersheds in the metropolitan area (M.S. 473.157). Furthermore, the Council has authority to engage in a continuous program of research and study of the control and prevention of water pollution in the metropolitan area (M.S. 473.244, Sub. 4) and to engage in activities to implement total watershed management (M.S. 473.505). The Council, under a Memorandum of Understanding signed with Carver County, is providing technical support in the preparation of the Carver Creek turbidity TMDL.

The Council is responsible for the following tasks:

- Conduct water quality monitoring including TSS, turbidity and associated hydrologic and water quality parameters
- Develop the TSS and turbidity relationship using monitoring data as a substitute for turbidity
- Develop, calibrate and validate a watershed model for flow and TSS loadings for TMDL allocation analyses
- Identify and quantify nonpoint source loadings by individual sources and locations for TMDL allocations
- Develop detailed allocations to individual sources including point-sources, bank erosion, specific land uses and areas
- Evaluate various best management practices (BMP) scenarios to help identify the potential BMPs and applications for TSS reductions

These tasks are addressed in the Council's report. Detailed background about the Carver Creek watershed, water quality assessment and impairment, public participation, future water quality monitoring and BMP implementation plans will be provided by a general TMDL report prepared by Carver County Environmental Services. Carver County's TMDL report will be submitted to the MPCA and consequently, EPA for approvals.

2. SWAT Model and Study Area

2.1 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 (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 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
- hydrology and water quality calibration/validation, parameter optimization
- model application and management scenarios

2.2 Watershed and Monitoring Descriptions

The Carver Creek watershed is located in Carver County, MN (Figure 1). The watershed is one of the sub-watersheds within the Lower Minnesota River Basin. The creek starts in Benton Township and winds through the Townships of Waconia, Laketown and Dahlgren before discharging into the Minnesota River. The watershed covers the entire city of Waconia and portions of the cities of Cologne and Carver.

The total area of the watershed is about 52,923 acres. Carver Creek flows through numerous lakes and wetlands prior to discharging into the Minnesota River. There are 15 lakes and approximately 89 miles of streams in the watershed.

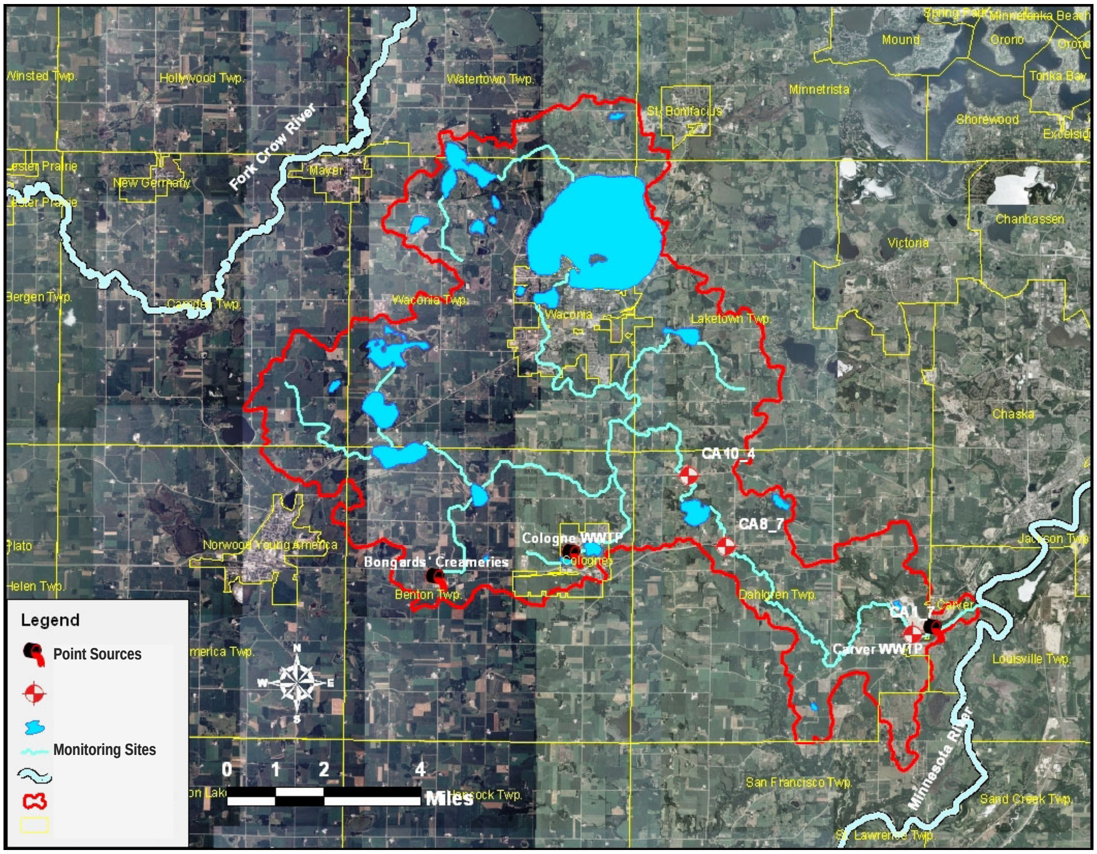

Figure 3 Carver Creek Watershed

Based on the 2002 land use map, Carver Creek watershed land uses are primarily agricultural, accounting for 66.7 percent (Figure 2); 18.8 percent are open water and wetland. Forest occupies 6.9 percent and just over 5 percent of the land in the watershed is developed.

The Metropolitan Council Environmental Services (MCES) monitoring station is located at 14025 County Road 40, Carver County, MN, which is about 1.7 miles upstream from the creek confluence with the Minnesota River (Figure 1). Carver County Environmental Services has three additional continuous monitoring stations established in 1997 (or after) located respectively at river miles 8.7 and 10.4 on Carver Creek and on Bent Creek near the outlet of Burandt Lake. 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.

Measured turbidities of Carver Creek exceeded the water quality standard of 25 NTUs. In 2002, Carver Creek was listed on Minnesota's 303(d) list of impaired waters for an impairment of aquatic life. A TMDL study was required by the federal Clean Water Act for the creek.

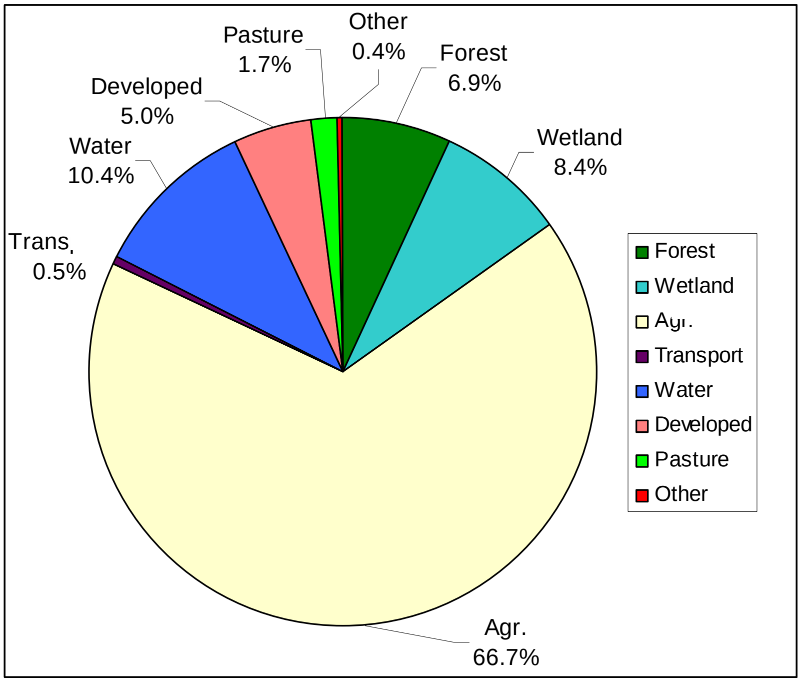

Figure 4 Land Uses in Carver Creek Watershed

3. Modeling Approach

3.1 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 hydrologic cycle, 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 3 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 Carver 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.

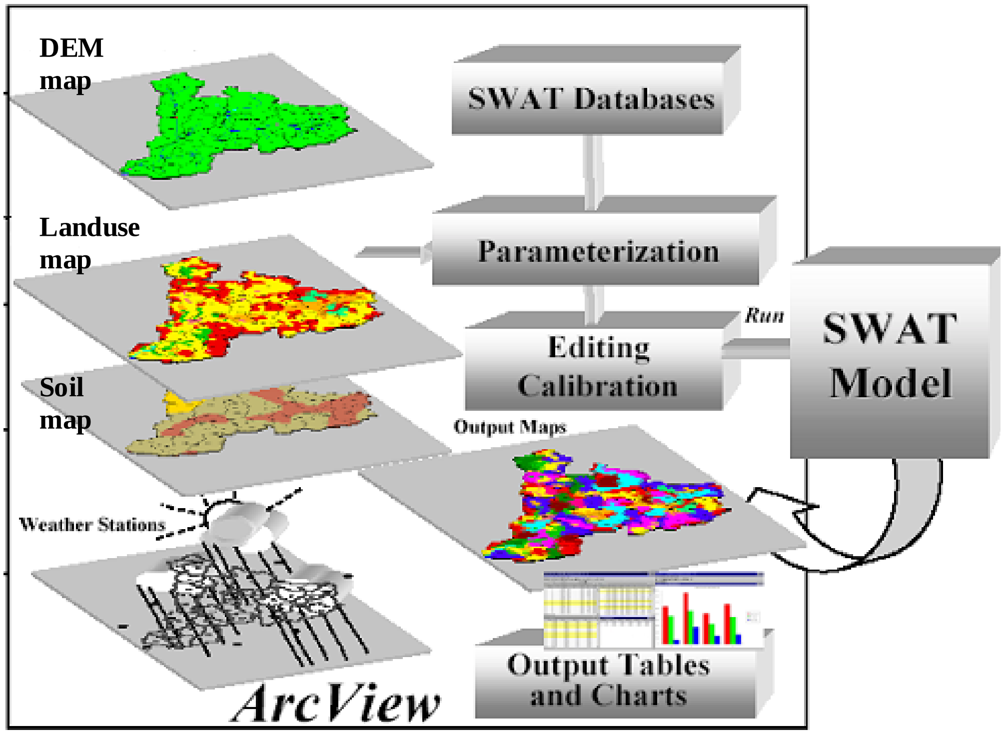

Figure 5 SWAT Model Components and Inputs (Modified from Neitsch et al., 2002)

3.2 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 describing physical and biogeochemical processes associated with hydrologic cycles and chemical behaviors in the watershed.

3.2.1 GIS Spatial Databases

Topography

The topographic map used in the Carver Creek watershed study was a 30-meter digital elevation model (DEM) consisting of the seven county metropolitan area. The map was developed by the Council's GIS department in 1980. The data represented an elevation surface of the region in a regular grid where each grid cell is a 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

Land use maps developed by the Council were used for model development. The databases were developed using 2002 multi-temporal Landsat Thematic Mapper data by the University of Minnesota and Council (Yuan et al., 2005). The various land uses were aggregated into 16 major categories in original maps for analysis, reflecting agricultural, urban and natural land covers (Table 2).

Table 4 Land Use Categories and Definitions

Definition in Original Land Use Map		Definition in SWAT Land Use Map		
Value	Land Use Category	Value	Land Use Category	Code
1	Low density urban	1	Low density residential	URLD
2	Medium-low density urban	2	Medium-low density residential	URML
3	Medium density urban	3	Medium density residential	URMD
4	Medium-high density urban	4	High density residential	URHD
5	High density urban	5	Commercial	UCOM
8	Mixed forest	8	Forest – deciduous	FRSD
9	Grass – lawns, sod	9	Pasture	PAST
10	Open water	10	Water	WATR
11	Wetland	11	Wetlands – mixed	WETL
12	Non-row crop: alfalfa, brome grass, pasture	12	Alfalfa	ALFA
13	Row crop: corn, soybean		Corn	CORN
			Soybean	SOYB
14	Grains: wheat, oats, rye	14	Oats	OATS
16	Herbaceous	9	Pasture	PAST
		17	Transportation (added)	UTRN

For agricultural land uses, alfalfa, brome grass and conservation reserve program were considered "non-row crop," corn and soybean as "row crop" and wheat, oat and rye as "grain." The SWAT model requires them to be broken down into individual categories. In order to match the SWAT designations, original "non-row crop" was, therefore, redefined to "alfalfa." The classification of "row crop" was split into "corn" and "soybean" using the SWAT split tool, which is based on the ratio calculated from the national agricultural statistic data for Carver County. "Grain" was redefined as "spring wheat." A new category of transportation (Value 17) was created based on the existing highway GIS data. The redefined land use categories and relevant SWAT land use codes are listed in Table 2. Figure 4 shows an example of the redefined 2002 land use GIS map for the Carver Creek watershed.

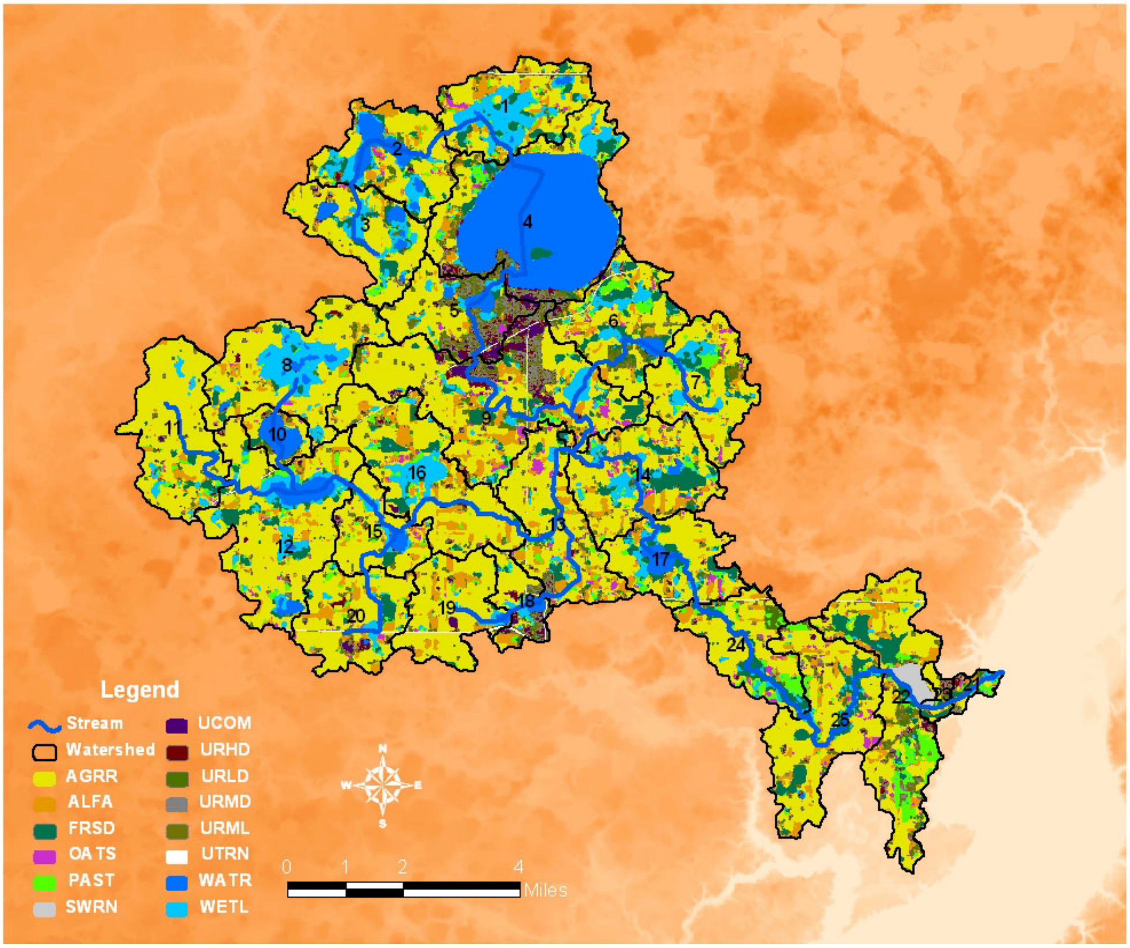

Figure 6 Carver Creek Watershed 2002 Land Use Map

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. A total of 50 categories of soils were identified in the region, represented by different color polygons (Figure 5). In the entire Carver Creek watershed there are only seven soil categories.

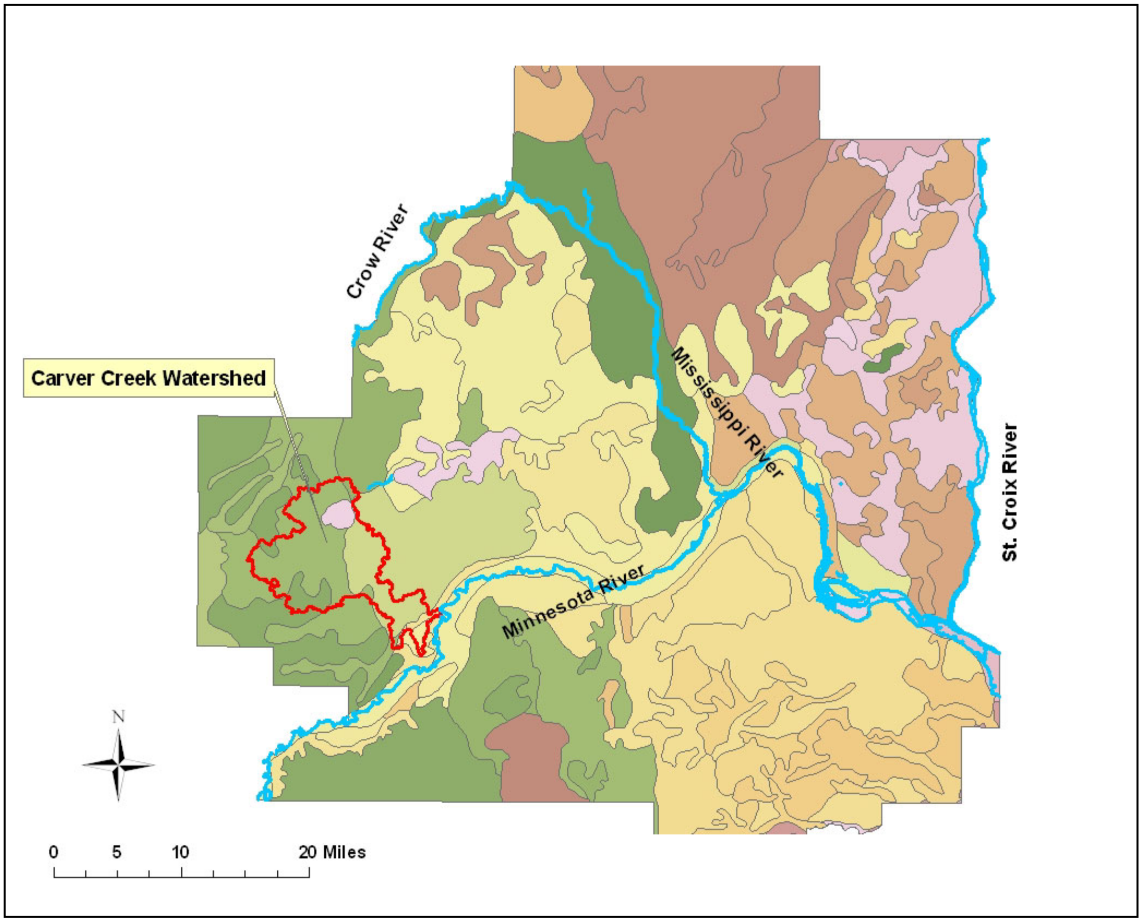

Figure 7 STATSGO Soil Map of the Twin Cities Metropolitan Area

3.2.2 Climate, Groundwater and Impoundment Data

Time-series climate data sets for the last 20 years were provided by the Minnesota Climatology Working Group. The data included daily precipitation, minimum and maximum temperature, solar radiation, humidity and wind speed. Time-series climate data is used in SWAT to simulate processes such as the hydrologic cycle, plant growth and potential evapotranspiration. Since there is no single national or local weather station with continuous climate records for the last 20 years close to the Carver Creek watershed, the precipitation and temperature data was obtained from the National Weather Service stations at Chaska and Chanhassen. Temperature, humidity and wind speed data was obtained from the national weather station at the Minneapolis-St Paul International Airport, which is located about 15 miles east of the watershed.

Baseflow and groundwater recharge information was obtained by analyzing stream hydrograph information using the separation method by Arnold and Allen (1999). Wetland and pond size and locations were obtained from GIS land use maps and databases. GIS information was used to estimate individual subbasin pond area at the principal water level. The surface water area at the emergency spillway water level was estimated as twenty percent larger than the area at the principal spillway water level.

The water depths used to estimate wetland water volumes at the principal and emergency water levels were 0.5 and 1.0 meter, respectively. Individual measurements for wetland depths were not readily available. The SWAT model delineated wetland areas were used for the surface areas of wetlands at the maximum water level. Twenty percent of the delineated wetland areas were used for the surface areas of wetlands at the normal water level.

3.2.3 Agriculture Management Practices

Agriculture management information used in the model includes crop types, planting dates, 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 technicians, farmers, Minnesota Extension Service documents (Rehm, et al., 1993a, 1993b, 1996) and Minnesota Agricultural Statistics (MASS, 1999; 2000 and 2003).

The most dominant crops planted in the metropolitan area are corn, soybean and alfalfa. Farmers typically use the crop rotation technique. Crop rotation is a crop production practice that promotes high production yields. Crop rotation usually involves the rotation of corn and soybean every year or two. Alfalfa is rotated partially with corn and soybean each year (about 20 percent) and killed every three to four years. The typical crop production practices in the region include:

- spring fertilizer application
- spring tillage (3-4 inch deep field cultivation)
- planting
- harvesting and kill
- fall plow (8-12 inches deep, applied following corn harvesting only)

A variety of fertilizers are applied on farmlands. The types of fertilizers used are dependent on factors such as crop types, farmer preferences, availability of fertilizer and time of year. For example, some farmers may use anhydrous ammonia while others may use urea or manure for nitrogen fertilizer. Others may use the composted manure produced from feedlot operations on their farms. For this study it was not feasible to identify where, what type and the fertilizer application rates for all farms in the watershed. The fertilizer application rates are, therefore, accounted for by using nitrogen and phosphorus as the inputs. According to general agricultural practices in the region, phosphorus is applied to corn, soybean and alfalfa; nitrogen is only applied to corn. Table 3 summarizes the fertilizer application rates and dates assumed for the region. The application rates are given in the ranges recommended to achieve various yields of crops at a median level condition of soil nutrient concentrations.

Table 5 General Fertilizer Application Rates*

Fertilizer Type	Crop	Application Amount	Application Date
Nitrogen (N) (lb/acre)	Corn	100-180	Before spring tillage
	Soybean	-	
	Alfalfa	-	
Phosphorus (P_2O_5) (lb/acre)	Corn	20-50	
	Soybean	10-15	
	Alfalfa	20-50	

*Source: Rehm, et al., 1993a, 1993b, 1996

It is common practice in the region to till twice using field cultivators for corn, soybean and new alfalfa crops following the application of fertilizer and before planting in spring. The chisel plow method is often used for cornfields after fall harvesting. Irrigation is not commonly used in this watershed. The harvesting and kill operations are used in the model setup to terminate the growth of crops during fall before the lands are rotated to other crops. Table 4 summarizes the general information collected for crop types, planting, harvesting dates and rotations.

Table 6 General Agricultural Operation Practices

Plant Types	Planting Date	Harvesting Dates	Rotation
Corn	May 1-20	Sept. 30-Nov. 1	1-2 years
Soybean	May 10-June 15	Sept. 15-Oct. 1	1 year
Alfalfa	April 15-May 15	-	3-4 years

Nutrient concentrations in soils vary widely depending on region, land use, tillage, fertilizer application rates and previous crops planted. During model development, median concentrations were used, ranging from 8 to 15 ppm for phosphorus and 6 to 15 ppm for nitrogen. These ranges were based on documented fertilizer application rates for corn, soybean and alfalfa issued by Minnesota Extension Service (Rehm, et al., 1993a, 1993b, 1996).

Drainage tiles were historically used in the Carver Creek watershed to drain wetlands for use as crop lands. There was no data available on exactly where the drainage tiles were located. In the model setup, the drainage tiles were built into those corn and soybean fields with slopes equal to and less than five percent. Based on site inspections and aerial photography, it is apparent that most stream and drainage ditches in the watershed currently have some type of filter strip. However, the exact width of the filter strip varies throughout the watershed. Filter strips are applied to prevent soil loss. To reflect average existing conditions, one meter filter strips were built into the SWAT model for all agricultural and urban areas.

3.2.4 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 and local partners 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 is collected at 27 stations on 25 streams in the region. In Carver 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.

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 bedload sediment that is transported in the channel water column and in the bedload. Because bedload 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.

Total phosphorus (TP) was also calibrated for Carver County to use in its lake nutrient TMDL studies for the watershed. To calibrate phosphorus, a few assumptions were made. SWAT accounts for two forms of phosphorus in the channel processes: mineral phosphorus (MinP) and organic phosphorus (OrgP). The mineral phosphorus in natural water consists of dissolved and particulate inorganic phosphorus. The dissolved inorganic phosphorus is in a biologically available form for growth and called soluble reactive phosphorus. Particulate inorganic phosphorus is adsorbed and structurally bonded to particles, called active and stable pools in SWAT (Neitsch et al., 2002). As part of our modeling effort, it was assumed that the particulate mineral phosphorus transported with sediments from the landscape to streams was converted into dissolved phosphorus in streams. The remaining particulate mineral phosphorus was insignificant and therefore ignored. The assumption makes it possible to use the sum of OrgP and MinP as TP for calibration.

3.3 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 Carver 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 4 shows the delineated Carver 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 25 subbasins were delineated in which Subbasins 21 and 23 were located downstream of the MCES monitoring station. The extension of the modeling beyond the MCES monitoring station was made in order to include the city of Carver's wastewater treatment plant (WWTP), lower floodplains and wetlands. The use of subbasins is particularly beneficial when different areas of the watershed are dominated by various land uses or soils dissimilar enough to impact hydrology. By partitioning the watershed into subbasins, it becomes possible to spatially compare the different water and chemical yields of the subbasins.

Within each subbasin, the components of the watershed are further grouped or organized into HRUs. 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, ten percent for soil type and five percent for slopes. HRUs are areas with unique land uses, soils, slopes and management practices. A total of 367 HRUs were identified in the watershed. HRU construction increases the accuracy of load predictions and provides a better physical description of the water balance.

Three MPCA permitted point sources were included in the model delineation. They are discharges from Bongards' Creamery, the Cologne WWTP and the Carver WWTP. Bongards' Creamery and the Cologne WWTP discharge to one of the upstream tributaries of Carver Creek above the MCES monitoring station while the Carver WWTP discharges to a point downstream of the MCES station.

3.4 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 Carver Creek watershed, calibration was completed for parameters that characterized subbasin and channel roughness, groundwater flow, hydrology, soil erosion, snowfall and snow melt, 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 daily, monthly and annual flow, sediment, nitrate and phosphorus 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 $-\infty$ 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 5). 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.

Table 7 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

4. Model Performance

The SWAT model for the Carver Creek watershed was developed according to the general procedures as described in the SWAT user guide (Di Luzio et al., 2002). The guide contains procedures for database development, watershed delineation, segmentation, calibration and validation. The model parameterization began by performing calibration and validation of the hydrology of the watershed, followed by water quality calibration and validation for TSS and TP. The calibrations were based on field measurements from 1990 to 1998 and validations were checked against field measurements from 1999 to 2006, excluding 1993 and 2004 due to backflow and equipment failure at the monitoring station.

Most watershed modeling studies are calibrated and validated with a monthly or annual time-step (Dalzell, 2000; MPCA, 2003; OEPA, 2003). In this study, however, the hydrology calibration was performed on a daily basis to catch daily variations of flows in order to provide a more accurate basis for the TSS and TP calibration and predictions. Detailed daily calibration and validation can capture the flow magnitudes associated with individual flood events caused by rainfall and snowmelt events that were often not reflected in monthly or annual data. Flow magnitude information is critical for accurate modeling of runoff, flow-associated sediment and TP exports from agricultural fields and transport in channels. TSS and TP calibrations were computed on a monthly basis because no continuous daily measurements were available for TSS and TP calibrations. The model performance was analyzed statistically using monthly average as discussed previously.

4.1 Hydrology

Figure 6 gives an example of graphical comparisons between the predicted (simulated) and observed (measured) daily flows for the calibrated and validated period (1990 to 2006). The example years were used because of limited space to display all 17 years. The example is two consecutive years of the validation period (2000 to 2001). These years characterize low and high flows and represent typical and complex temporal variations of hydrology for Carver Creek. The predicted and observed monthly and annual flows (1990 to 2006) are shown in Figures 7 and 8. The results show that the developed SWAT model for Carver Creek adequately recreates daily flows with realistic conditions both for dry and flood years. Minnesota has a complex hydrograph pattern characterized by winter baseflow, snow-melt during spring, and low and high flows due to variable rainfalls. These characteristics were identified and used during the model development and calibration in order to ensure that the model can adequately and accurately predict the hydrology for Carver Creek in such a cold climate environment. The simulated monthly and annual flows are also consistent with observations both in magnitudes and seasonal variations.

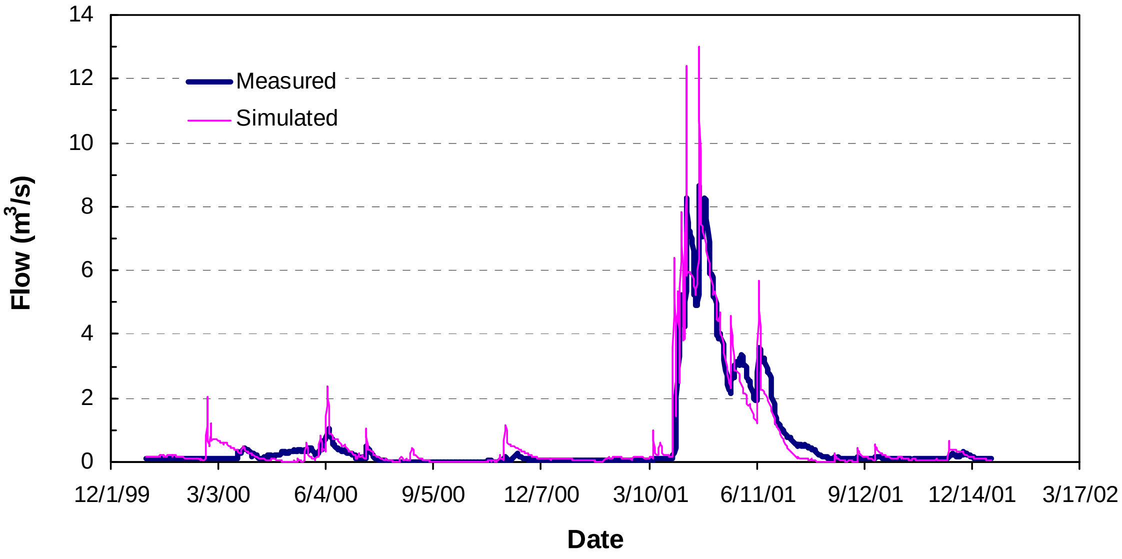

Figure 8 Calibrated Daily Flows in Carver Creek

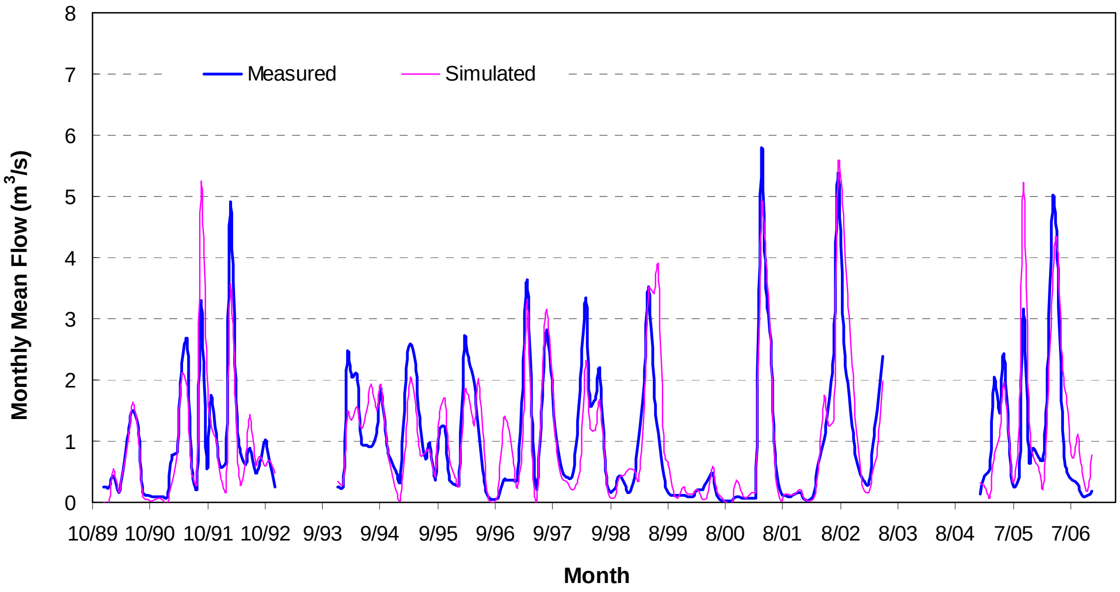

Figure 9 Calibrated Monthly Flows in Carver Creek

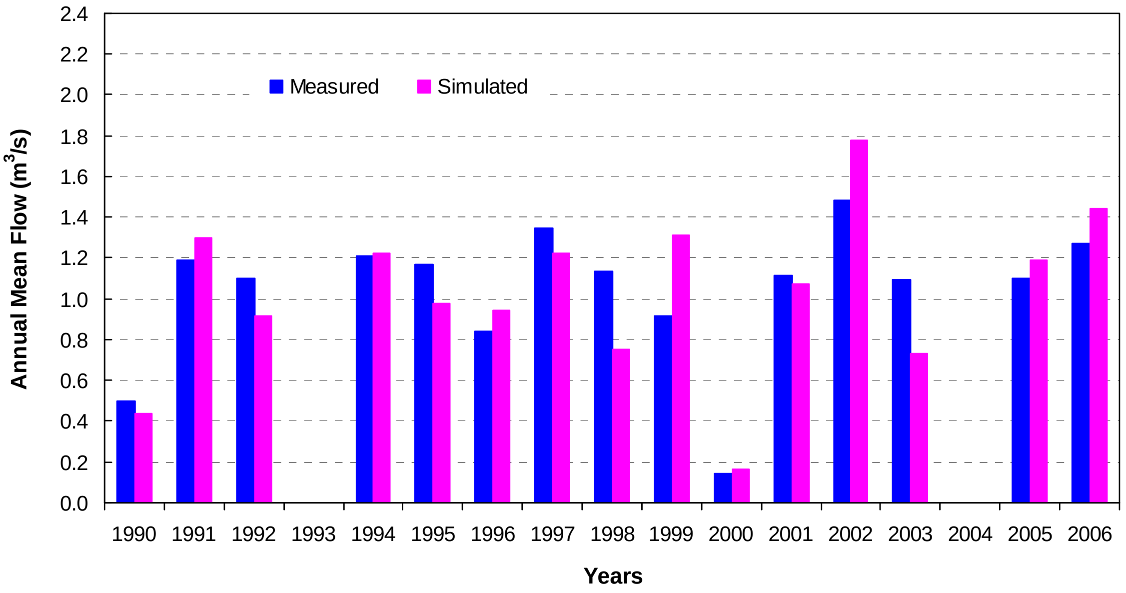

Figure 10 Calibrated Yearly Flow in Carver Creek

Table 6 lists the statistical analysis results of the hydrology calibration and validation for the Carver Creek watershed. The results indicate that the developed SWAT model for Carver Creek has an excellent performance for the hydrologic simulation. The overall relative deviation for the simulation period from 1991 to 2006 was as low as 0.34 percent, indicating that the model predictions were "very good" according to the recommended calibration and validation tolerance (<10%) (Table 5). In general, the calibrated model slightly under-predicts flow. The average RMSD of the simulated flows were 0.94, 0.94 and 0.21 m^3/s respectively for daily, monthly and annual averages from 1990 to 2006. The coefficients of determination (r^2) were 0.56, 0.75 and 0.65, the indexes of agreement (IA) were 0.88, 0.93 and 0.91, and the Nash-Sutcliffe Coefficients of Efficiency (NSCE) were 0.55, 0.71 and 0.57, respectively for daily, monthly and annual predictions.

Table 8 Statistical Analysis of SWAT Model Performance for Hydrology

Time Step	RMSD	r^2	IA	NSCE
Daily	0.94	0.56	0.88	0.55
Monthly	0.98	0.75	0.93	0.71
Annual	0.21	0.65	0.91	0.57

Compared with similar reported studies (King et al. 1996; Allred and Haan, 1996; Liu et al. 1998; Srinivasan et al., 1998; Dalzell, 2000; MPCA, 2003; Hummel et al., 2003; Tolson & Shoemaker, 2004) (Table 7), the model developed for the Carver Creek watershed is one of the high performance models with small deviation and high correlation between simulated and observed results. All these assessments (graphical comparisons, statistical analysis and reported studies) indicate that the developed SWAT model for the Carver Creek watershed is well calibrated and able to satisfactorily predict the hydrology in the watershed.

Table 9 Comparisons of Model Performance for Hydrology

Watershed	Deviation (%)	r^2	Model/Author
Carver Creek, MN	0.34	0.75	SWAT in this study
Bluff Creek, MN	21.0	0.47	ADAPT[a] by Dalzell (2000)
Long Prairie River, MN	1.9-20.0	–	SWAT by MPCA (2003)
Watersheds, GA	1.8-19.9	0.61-0.9	HSPF[b] by Hummel et al. (2003)
2 watersheds, TX	–	0.65-0.87	SWAT by Srinivasan et al. (1998)
15 watersheds, GA, TX, OH, MS	0-38.8	0.01-0.85	WEPP[c] by Liu et al. (1998)
6 watersheds, TX	6.6-37.0	0.74-0.82	EPIC[d] by King et al. (1996)
6 watersheds, GA, TX, Ok, NC, OH, ID	–	0.31-0.90	SWMHMS[e] by Allred & Haan (1996)
Cannonsville Basin, NY	1.0-15.7	0.59-0.80	SWAT by Tolson & Shoemaker (2004)

Notes:
a: ADAPT: Agricultural Drainage and Pesticide Transport model
b: HSPF: Hydrological Simulation Program Fortran model
c. WEPP: Watershed Erosion Prediction Project
d: EPIC: Erosion Productivity Impact Calculator
e: SWMHMS: Small Watershed Monthly Hydrological Modeling System

Because of high costs associated with the field measurements, most watershed studies usually have only one monitoring location available for model calibration. Therefore, no calibrations and assessments are made inside the watershed with regard to how the model performs spatially at various locations. In this study, there are a few other monitoring stations managed by Carver County Environmental Services in addition to the station by MCES that were used in the development and calibration of the Carver Creek watershed model. Carver County Environmental Services measured hydrology and water quality in these stations.

To verify spatial prediction abilities of the developed Carver Creek SWAT model, the model outputs were compared with the field observations at two stations, Ca_10_4 and Ca_8_7 located respectively above and below Miller Lake. The model was not calibrated at these two stations therefore the comparisons provided additional assessments of the model's ability related to spatial application. The comparisons were made with the flows at these two stations available during summer periods from 1996 to 2006 (Figures 9 and 10). The comparisons indicate that the model predictions at the two specified monitoring stations, located respectively upstream and downstream of Miller Lake, follow the observations both in magnitudes and seasonal variations. The average simulated flow at Station Ca_10_4 (upstream of Miller Lake) was 8.8 m^3/s, which was 19.3 percent larger than the observed mean, while at Station Ca_8_7 (downstream of the lake) the average simulated flow was 8.8 m^3/s, which was 3.9 percent larger than the observed mean.

While the model over-predicted the flow at the two stations, the results are considered as "fair" and "very good" according to Table 5. The results indicate the developed model is reliable for application not only at the calibrated watershed outlet, but also in other subbasins inside the watershed.

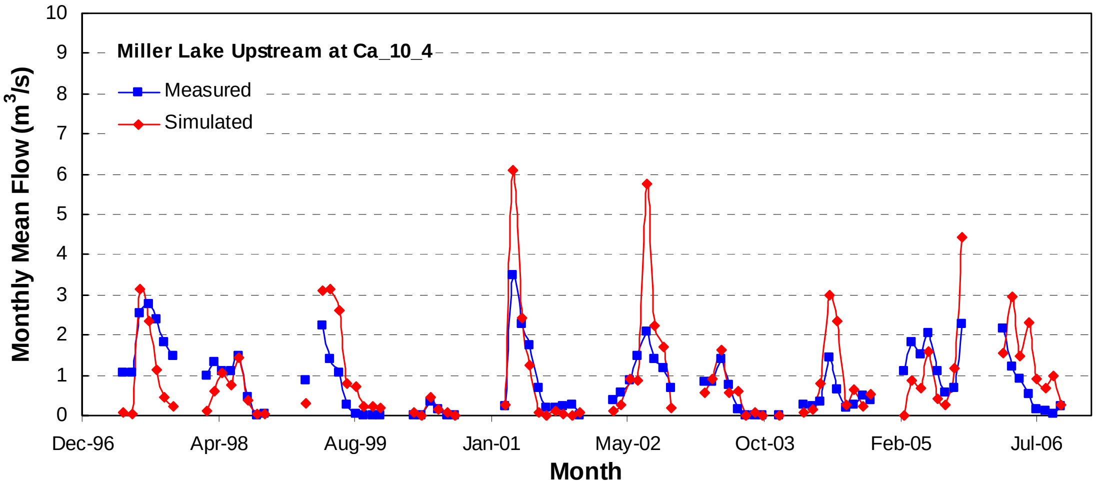

Figure 11 Predicted Monthly Flow in Comparison with Observations at Station Ca_10_4

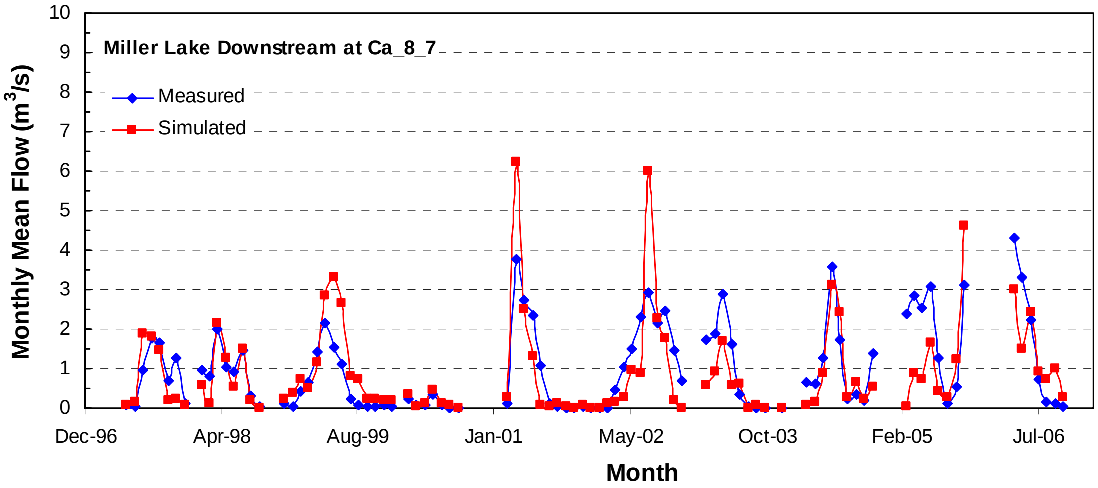

Figure 12 Predicted Monthly Flow in Comparison with Observations at Station Ca_8_7

4.2 Total Suspended Solids

Calibration of TSS is an important step for the Carver Creek watershed model because it will directly affect the TMDL allocations based on the model outputs and will also consequently affect the accuracy of nutrient predictions, particularly phosphorus. TSS is collected as composite or grab samples, therefore, TSS was calibrated on a monthly basis. The U.S. Army Corps of Engineers' FLUX model was used to estimate monthly and annual loads for model calibration.

FLUX estimates the loads based on regressions between observed TSS concentrations and flows. The FLUX estimations based on the composite and grab samples (hereafter referred to as observation) from 1990 to 1999 were used for calibration and the results from 2000 to 2006 were used for validation.

TSS calibrations are a complicated process because the calibration deals with field erosion, routing, and bank erosion. The routing may act as either a sink or a source for TSS. Personal communications with Shawn Schottler from Minnesota Science Museum St. Croix Watershed Research Station (SCWRS) about the preliminary results from the studies he is working on using isotope fingerprint techniques have indicated that a significant amount (50 to 90 percent) of TSS in the Lower Minnesota River Basin is from non-field erosion (bank, gully and ravine erosion). Generally non-field erosion includes soil and sediment that is not within the depth of the plow zone. Non field erosion which includes bank erosion is likely driven by altered hydrology due to land use. Since it is difficult to distinguish bank erosion from other non-field erosion sources for the SWAT modeling, the term bank erosion will be used interchangeably with non-field. For this study a mid-range value of 70 percent was assumed for TSS loads originating from bank erosion with the remaining portion from field erosion. There are no previous studies or references available on how to calibrate bank erosion for the SWAT model.

For this study, bank erosion was calibrated by manipulating the model parameters associated with bank erosion according to several sources of data and information:

- field erosion of 5.46 t/ha based on a 1979 study
- impoundment sedimentation based on observations of TSS concentration in downstream streams
- non-field erosion based on the SCWRS fingerprint studies (70 percent of total TSS loads)
- TSS loads observed at MCES monitoring station

The calibrated bank erosion was then validated using spatial analysis of stream bank erosion conducted by MCES. The bank erosion assessments were based on remote sensing and GIS data (LiDAR high resolution digital aerial photography, soils and land cover maps) of streams in the Carver Creek watershed. Analysis used mean bank slopes, soil erodibilities, specific catchment areas, and sinuosity. The study provides an independent data set of the stream bank erosion in various subbasins of Carver Creek and can be used for validation of the SWAT model for its predictions of bank erosion.

The calibration processes were summarized in Figure 11. Based on the calibrations, TSS loadings by bank erosion from 25 subbasins were compared to the bank erosion risks obtained from the independent bank erosion assessments (Figure 12). In Figure 12, the simulated TSS loads were expressed in percentages of TSS contributions from each subbasin. The results show that the developed SWAT model has a high performance in bank erosion predictions. Simulated bank erosion potentials are highly correlated to the erosion risk factors from the independent study. The correlation coefficient is 0.86. The simulated bank erosions for each subbasin generally follow the results of the independent study in terms of spatial variation. Lower bank erosion risks occur in those relatively flat upland areas and higher erosion risks generally occur in downstream area with relatively larger slopes.

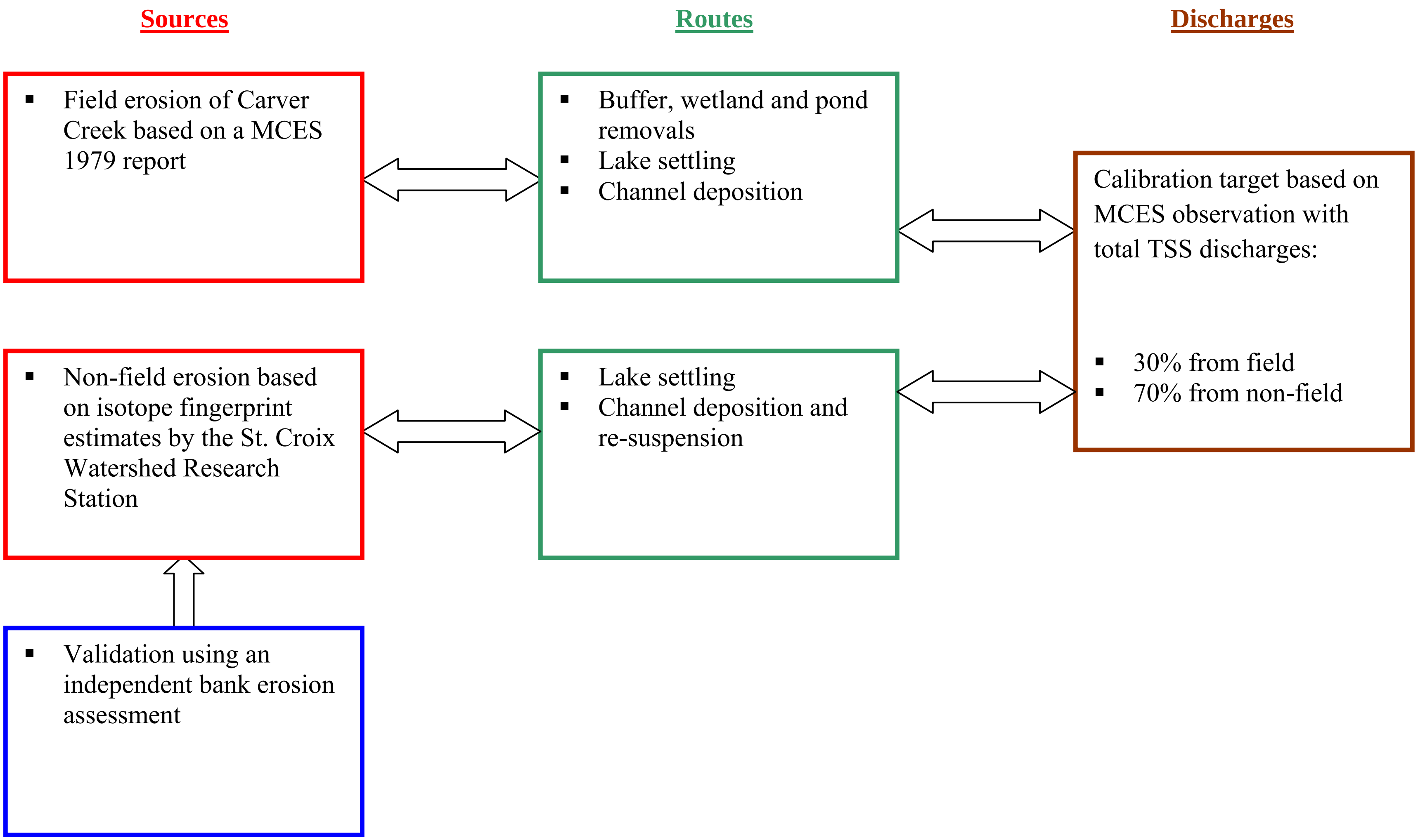

Figure 13 Flowchart of TSS Load and Bank Erosion Calibration and Validation for Carver Creek

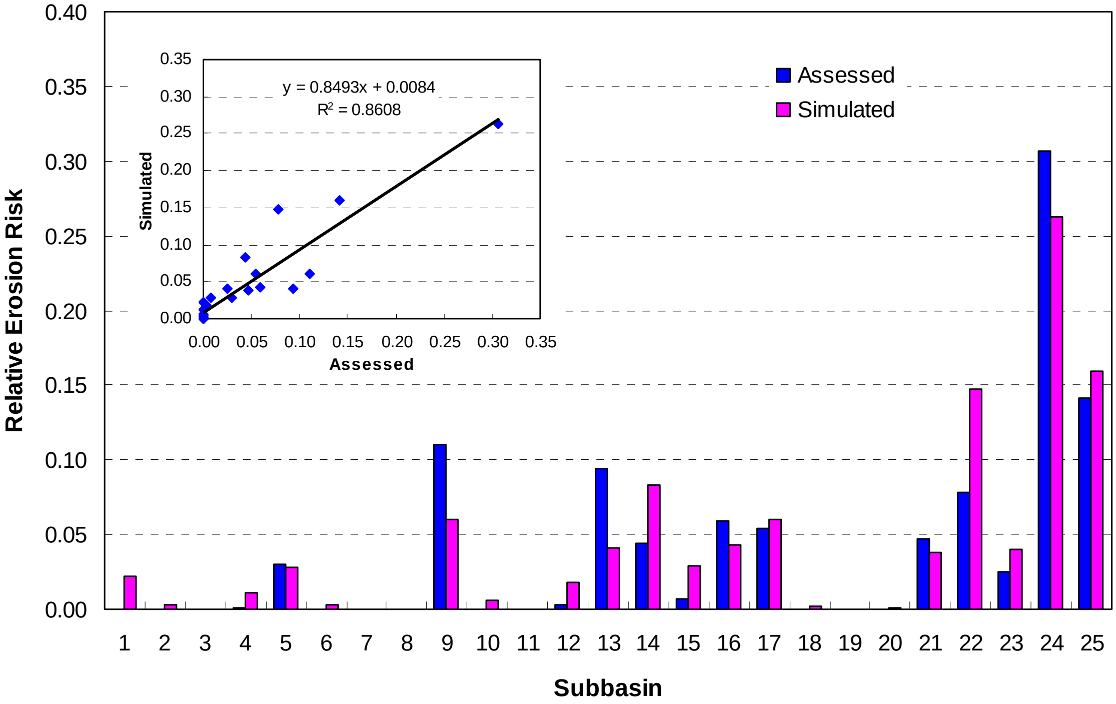

Figure 14 Simulated versus Assessed Bank Erosion Risks for Carver Creek Subbasins

After the field and bank (non-field) erosions were successfully calibrated, the TSS loads at the MCES station were outputted from the SWAT simulation for performance assessments. The results were plotted in Figures 13 and 14, including monthly and annual TSS loads compared to observations. The comparisons also include the TSS loads at the station contributed from field erosion. The final TSS load contributed from field erosion at the station was 29.5 percent of the observed load. The results are based on the simulated period (1990 to 2006) with some missing periods due to equipment failures at the monitoring station. In the figures, the observed loads are estimated from the measured composite, grab samples and daily flows using the FLUX model. As shown in the figures, the simulated TSS loads for Carver Creek generally follow observations.

Table 8 lists the statistical analysis results of the calibration and validation of the TSS loads. The results show that the developed SWAT model accurately predicts the TSS loads for Carver Creek. The predicted overall mean TSS load from 1990 to 2006 was 8,049 metric tons (t) per month, which is 1.1 percent larger than the observed value of 7,976 t per month. In general, the calibrated model slightly over-predicts the TSS load. The difference (relative deviation) is much less than the recommended modeling tolerance for “very good” model performance of 20 percent (Table 5). The RMSD for TSS loads were 954 t and 2,104 t respectively for monthly and annual averages for the 16-year simulation period.

The coefficients of determination (r^2) were 0.73 and 0.69, the indexes of agreement (IA) were 0.92 and 0.92, and the Nash-Sutcliffe Coefficients of Efficiency (NSCE) were 0.69 and 0.60, respectively for monthly and annual averages.

Table 10 Statistical Analysis of SWAT Model Performance for TSS

Time Step	RMSD	r^2	IA	NSCE
Monthly	953.7	0.73	0.92	0.69
Annual	2103.9	0.69	0.92	0.60

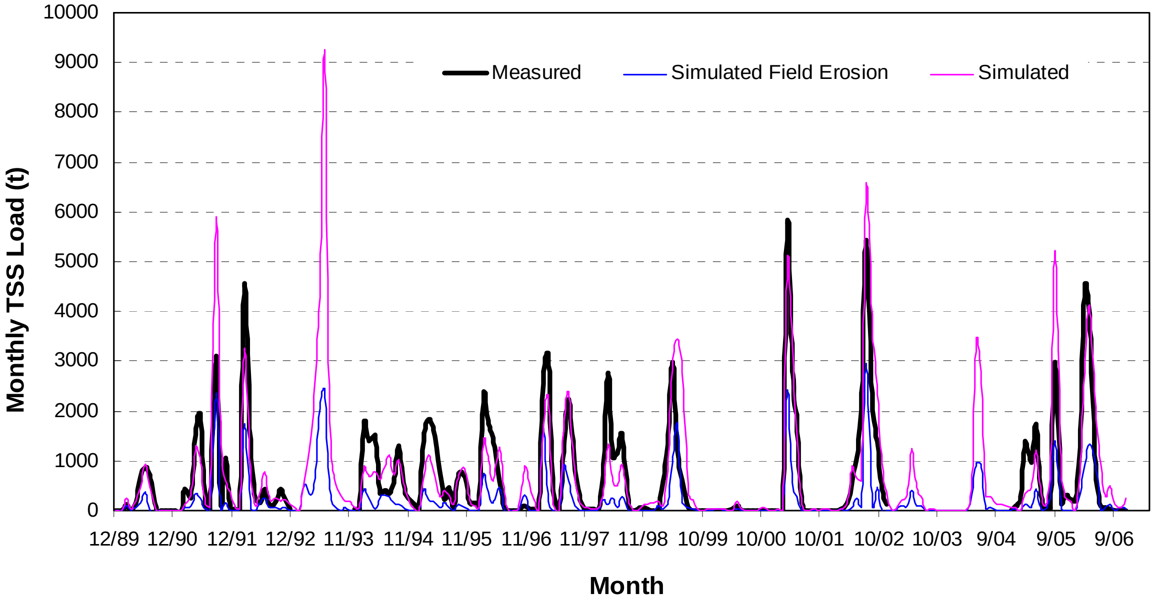

Figure 15 Calibrated Monthly TSS Load for Carver Creek

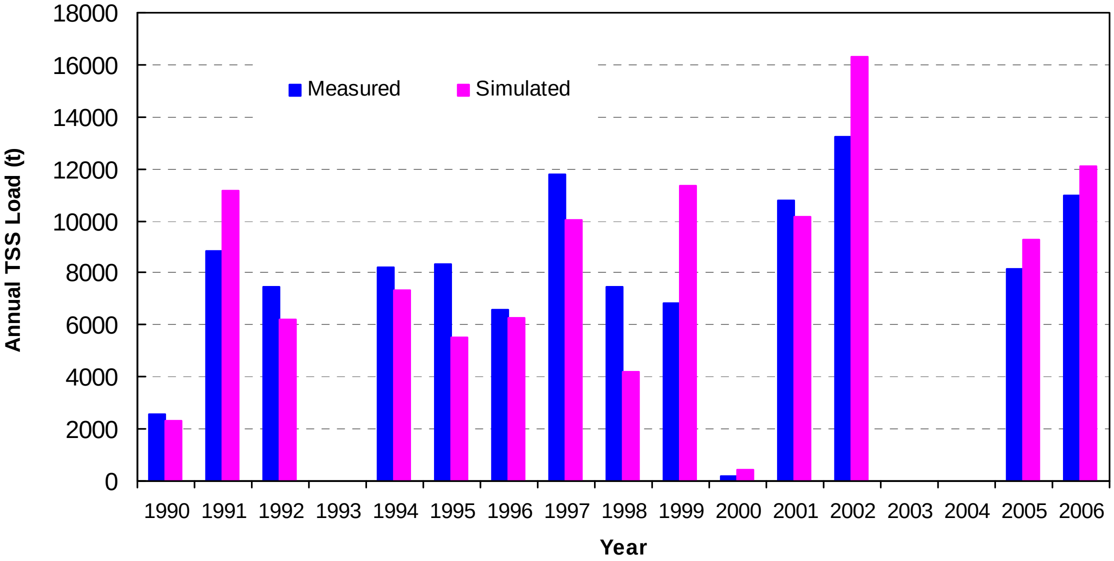

Figure 16 Calibrated Annual TSS Load for Carver Creek

Compared to similar reported studies (Dalzell, 2000, MPCA, 2000, Reyes et al., 1995, King et al., 1996, Liu et al., 1998 and Tolson & Shoemaker, 2004), the developed model for Carver Creek is able to predict TSS load more accurately. A study using the ADAPT model for Bluff Creek in Carver County, MN, Dalzell (2000) reported a mean difference of 9 percent between the simulated data and observed data (Table 9), the root mean square deviation was 156 percent of the observed mean, and the index of agreement was only 0.57. In conclusion, the SWAT model developed for Carver Creek is well calibrated and able to satisfactorily predict TSS loads in the watershed according to the performance assessments and compared with reported studies.

Table 11 Comparisons of Model Performance for TSS

Watershed	Deviation (%)	r^2	Model/Author
Carver Creek, MN	-1.1	0.72	SWAT in this study
Bluff Creek, MN	9.0	0.25	ADAPT by Dalzell (2000)
Long Prairie River, MN	9.3-37.1	–	SWAT by MPCA (2003)
Experimental fields, LA	51.0-400.0	0.46	GLEAMS* by Reyes et al. (1995)
6 watersheds, TX	4.8-43.6	0.15-0.72	EPIC by King et al. (1996)
15 watersheds, GA, TX, OH, MS	4.5-137.6	0.02-0.89	WEPP by Liu et al. (1998)
Cannonsville Basin, NY	2.2-52.2	0.42-0.71	SWAT by Tolson & Shoemaker (2004)

*GLEAMS: Groundwater Loading Effects of Agricultural Management System

4.3 Total Phosphorus

Modeling of phosphorus was not required for the Carver Creek turbidity TMDL. The SWAT model was calibrated and validated for TP to aid Carver County Environmental Services in their lake nutrient TMDL. TP calibration was performed on a monthly basis because daily TP observations were not available. The U.S. Army Corps of Engineers' FLUX model was used to estimate monthly and annual loads for the model calibration. The estimations were based on grab and composite samples and daily flows. The observations from 1990 to 1999 were used for calibration and those from 2000 to 2006 were used for validation.

Figures 15 and 16 display the monthly and annual TP loads calibrated at the MCES monitoring station compared to the observed results. The results are the simulated periods from 1990 to 2006 with some missing periods due to equipment failures at the monitoring station. As shown in the figures, the simulated TP loads for Carver Creek generally follow observations both in temporal and spatial variations. However, the model significantly over-predicted TP loads during the summers of 1991 and 1999, and under-predicted TP in 1994, 1995 and 1997.

One of the reasons the model over- and under-predicts TP may be due to the comparisons of the SWAT model results to the FLUX model estimates. The FLUX model may not be able to catch unusually high and low TP loads because it estimates monthly and annual

TP loads based on the co-relationships between composite and grab samples with daily flows, thus smoothing the variations of TP loads. This may particularly be an issue at extremely high and low flow conditions. On the other hand, SWAT calculates the TP loads based on daily precipitation which is dynamically variable, particularly in extreme wet and dry seasons.

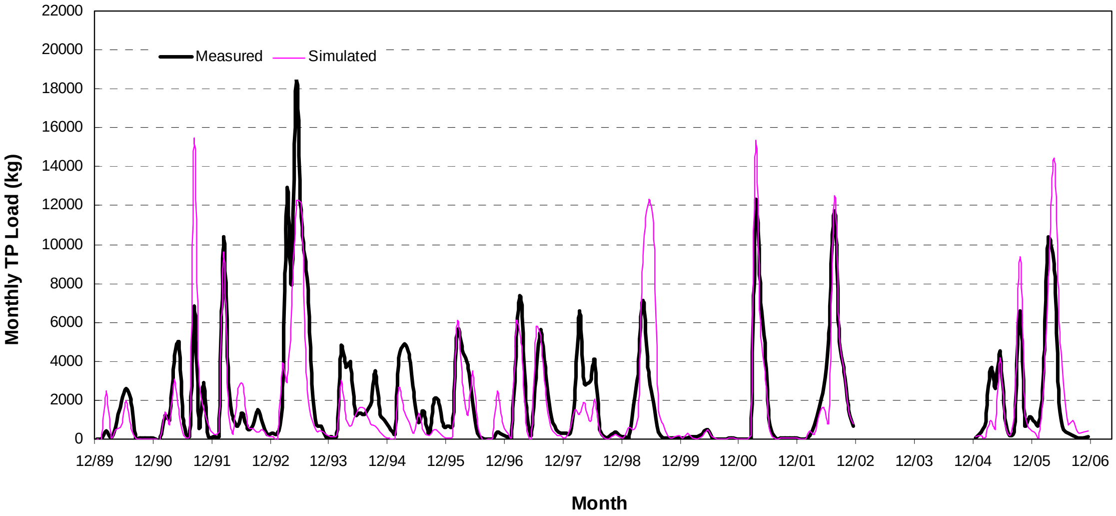

Figure 17 Calibrated Monthly TP Load for Carver Creek

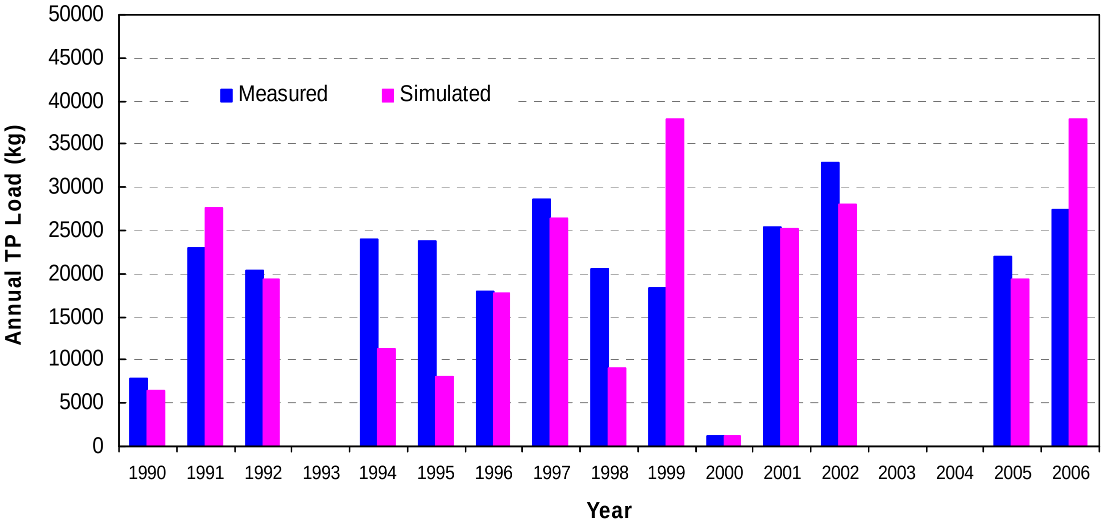

Figure 18 Calibrated Annual TP Load for Carver Creek

Table 10 lists the statistical analysis results for TP calibration and validation. The results show that the developed SWAT model for Carver Creek has relatively good performance compared to the observed TP loads.

The predicted overall mean TP load from 1990 to 1999 was 19,688 kg, which is 6 percent smaller than the observed value of 20,939 kg. The difference (relative deviation) is much less than the recommended modeling tolerance for "very good" model performance of 15 percent (Table 5). In general, the calibrated model slightly under-predicts the TP loads. The average RMSD for TP loads were 2,947 kg and 8,845 kg respectively for monthly and annual simulations. The coefficients of determination (r^2) were 0.70 and 0.41, the indexes of agreement (IA) were 0.88 and 0.76, and the Nash-Sutcliffe Coefficients of Efficiency (NSCE) were 0.44 and -0.27, respectively for monthly and annual predictions.

Table 12 Statistical Analysis of SWAT Model Performance for TP

Time Step	RMSD	r^2	IA	NSCE
Monthly	2947.0	0.70	0.88	0.44
Annual	8845.4	0.41	0.76	10.27

Table 11 shows the comparison of the developed Carver Creek SWAT model with other studies using SWAT for TP simulations. The model developed for Carver Creek has the highest performance in TP predictions among the studies listed. A TMDL study for the Long Prairie River watershed using SWAT conducted by the MPCA (MPCA, 2003) had relatively large prediction deviations ranging from 8 to 239 percent. Kirsch et al. (2002) used the SWAT model for the Rock River basin in Wisconsin and had simulation deviations varying from 8 to 63 percent for different monitoring stations. Tolson & Shoemaker (2004) used the SWAT model to study runoff, TSS and TP in Cannonsville Reservoir Basin, NY, with correlation coefficients (r^2) of predicted TP ranging from 0.46 to 0.72 and relative deviations ranging from 6.1 to 49 percent.

Table 13 Comparisons of SWAT Model Performance for TP

Watershed	Deviation (%)	r^2	Reference
Carver Creek, MN	6.0	0.70	This study
Long Prairie River, MN	8.0-239.0	–	MPCA (2003)
Rock River basin, WS	8.0-63.0	–	Kirsch et al. (2002)
Cannonsville Basin, NY	6.1-49.0	0.46-0.72	Tolson & Shoemaker (2004)

5. Non-Point source analysis using swat

5.1 Methodology for Non-Point Source Analysis

Calibration of watershed models is usually a black-box process for most reported studies. Due to high costs associated with sampling and measurements as well as limited available data, the calibration process examines the model performance only according to the observed flow and water quality at watershed outlets without considering processes occurring within the watersheds. This process may generate uncertainties in model applications, particularly when the model is used to analyze watershed non-point sources and to study the management scenarios. In this study, the model was not only calibrated at the watershed outlet and compared with two upstream locations, but the model was also calibrated with TSS sources from field and bank erosion using various data and study results. Therefore, the model for Carver Creek is a highly reliable tool to use for TSS loading analysis, TMDL implementation and BMP scenarios.

For non-point source analysis, watershed flows and TSS loadings from surface runoff, field and bank erosions were quantified in terms of land uses and subbasins. The annual average surface runoff and TSS loadings during the period of the simulation (1990 to 2006) were analyzed and summarized based on simulation results from the calibrated SWAT model. In the surface runoff and field erosion analysis for land uses, it was found that the export rates of water and TSS loads from the same category of land uses may be substantially different if they are in different subbasins. The export rates were spatially related to a certain location in a watershed due to various soil types and other properties that affect infiltration and soil erosion. Therefore, an area-weighted statistical method was used to obtain the mean flow and TSS export rates from an HRU or a subbasin:

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

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.

5.2 Surface Runoff and TSS Loading by Land Uses

The annual flow and TSS loading per unit area summarized from the SWAT model simulations were used to identify the lands with relatively high surface runoff and TSS loads. The land uses with high TSS loads should be looked at first when implementing BMPs for TSS load minimization. Figure 17 displays the export rates of surface runoff and TSS by land use. The results show that surface runoff from various land uses ranged from 0.30 mm to 220 mm. The urban areas export the highest surface runoff, followed by soybean and corn fields. Forest has the lowest surface runoff contribution of 0.3 mm. However, significantly high TSS loads are found where the dominant land uses are soybean or corn. The TSS loads from these two land uses are 4.8 t/ha and 4.7 t/ha respectively. While the urban land use has the highest runoff, the TSS export from the land is relatively low (0.2 t/ha).

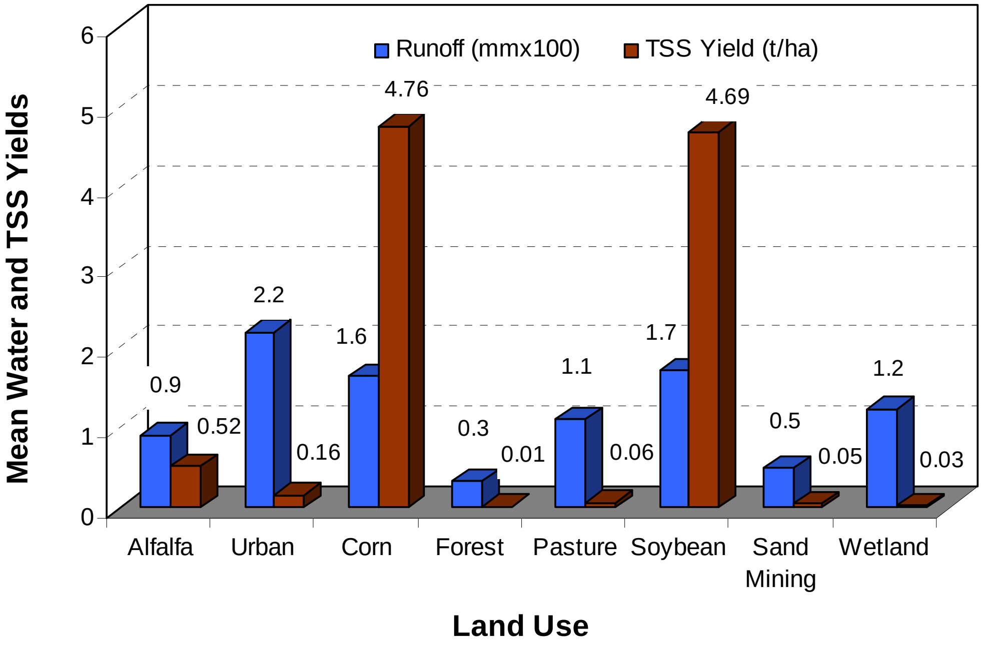

Figure 19 Simulated Water and TSS Export Rates by Land Use

Impact of land use on watershed flow and water quality is dependent not only on its unit runoff and pollutant export rates but also on its area. TMDL studies require an identified and quantified annual or daily loading in order to perform a detailed TMDL allocation to individual sources. The total TSS loadings of individual land uses, which were calculated using both their unit export rates and the land use areas, are plotted in Figure 18. The land use areas for each land use categories are also included in the figure for comparisons. The results indicate that more than 99 percent of the TSS loads from field erosion in the Carver Creek watershed are from agricultural land uses, particularly from soybean and corn production, accounting for 60 percent and 38 percent respectively. Urban, forest, pasture and land uses other than agriculture contribute less than 1 percent of the total TSS loadings from field erosion (60,100 t/year).

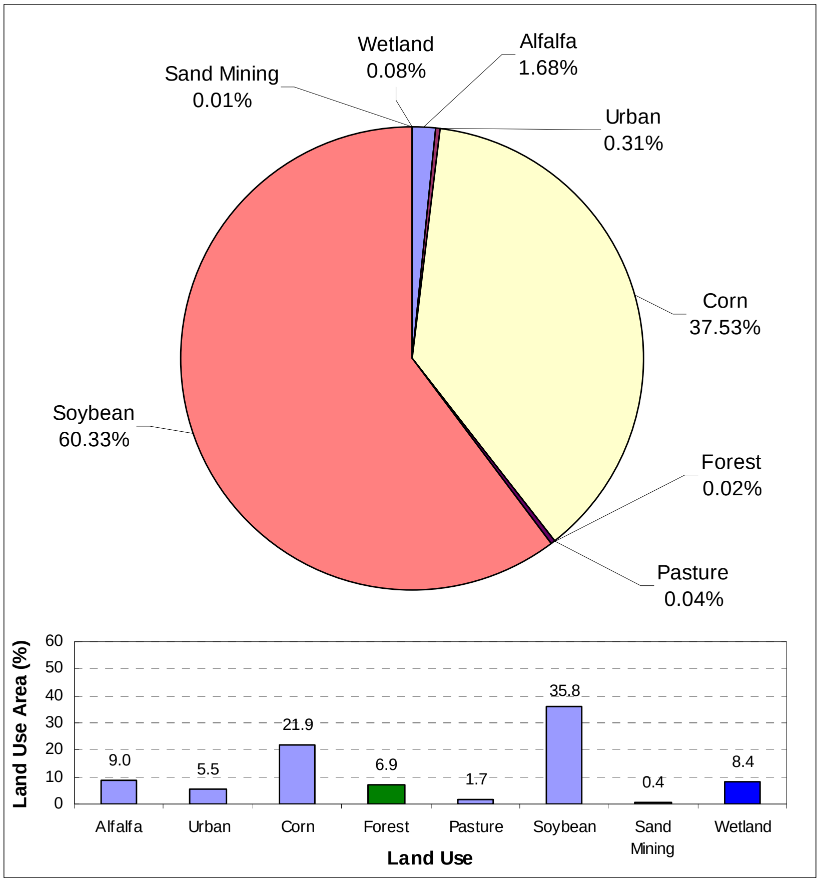

Figure 20 Simulated TSS Loadings from Field Erosion by Land Uses

5.3 Spatial Distributions of Water and TSS Loads in the Watershed

Spatial distributions of the surface runoff volumes and TSS loads are analyzed to further identify the areas that contribute major flow and TSS to Carver Creek and where BMP implementation for TSS control would be a priority. Twenty-five subbasins have been delineated in the watershed by the developed model, numbered roughly from upstream to downstream as shown in Figure 21. Annual average flow and TSS exports per unit area from each subbasin were analyzed based on the modeled results of the subbasins for the period of 1990 to 2006 (Figure 19). Because there is no field erosion from lakes, and the TSS load export rate is zero as calculated by the SWAT model, lake areas were excluded in the analysis.

The results show that there are differences in surface runoff from the 25 subbasins (Figure 19) in the watershed. The runoff rates ranged from 60.7 mm from Subbasin 23 to 123.8 mm/ha from Subbasin 25. Subbasin 21 has an average runoff of 38.8 mm. Subbasin 21 is a small subbasin located in the Minnesota River floodplain below the MCES monitoring station and just before the confluence with the river. The subbasin consists primarily of wetland and therefore, has a limited impact on the water quality of Carver Creek.

The unit TSS loads from the Carver Creek subbasins vary significantly. Based on the simulated results, the lowest TSS loads (less than 1 t/ha) are found mostly from the upstream subbasins, subbasins 1, 8, 11, 14, 16 and 19. The highest TSS loads are found mostly from the downstream subbasins, subbasins 7, 10, 13, 17, 24 and 25. The TSS export rates from these downstream subbasins are larger than 5 t/ha. Subbasin 1 has the lowest unit TSS load of 0.007 t/ha and Subbasin 25 has the highest load of 9.3 t/ha.

Among parameters affecting field erosion, slopes and land uses seem to be the two primary factors regulating the TSS loads in the subbasins. The subbasins exporting less flow volumes and TSS loads have statistically smaller slopes and less agricultural areas, while those having larger flow volume and TSS exports have relatively greater slopes and corn and soybean land uses. For subbasins that have similar corn and soybean areas, the lower flow and TSS exporting subbasins are usually located upstream in the watershed, while those with higher surface runoff and field erosion are usually located in the watershed valley or downstream in subbasins with relatively large slopes.

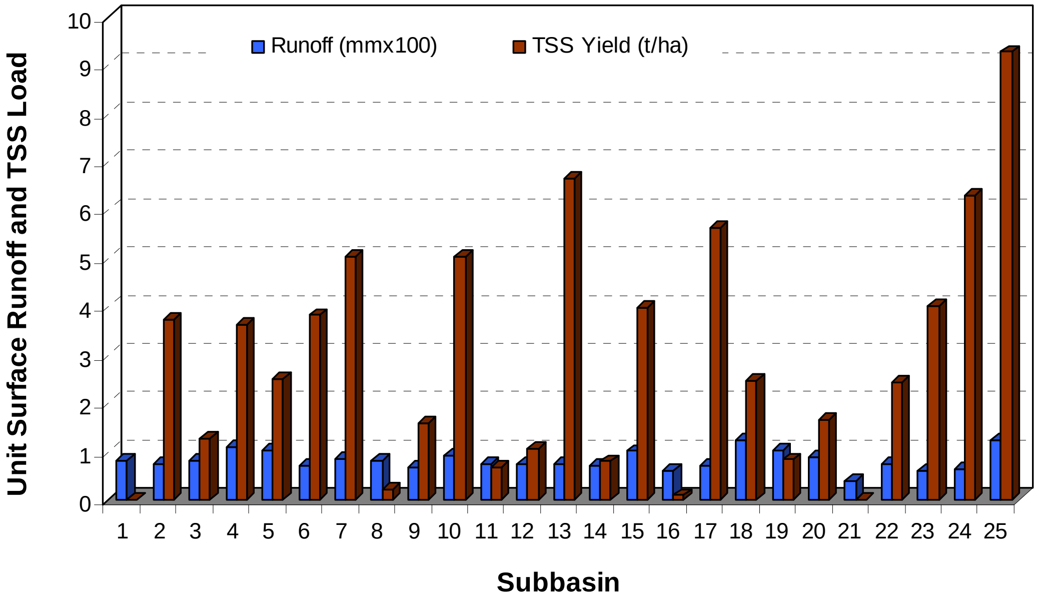

Figure 21 Simulated Unit Surface Runoff and TSS Loads by Subbasins

To spatially allocate loads into individual subbasins, annual or daily TSS inputs are necessary to understand existing non-point sources of TSS loads in the watershed. Since the SWAT model assumes no field erosion from lakes, the open water areas of lakes were excluded in the load calculations. Figure 20 displays the annual TSS loadings calculated by subbasins. The SWAT model estimates that Subbasins 25, 4 and 13 provide significantly high TSS loads. The TSS loads from these subbasins are 10,380, 7,046 and 6,121 t/year respectively. Generally, a subbasin will have a larger TSS export if it has a greater slope and large agricultural area. It is not clear; however, why Subbasin 4 is one of the subbasins with significant TSS exports. The subbasins located in uplands generally have relatively low TSS loads due to the relatively small subbasin slopes. The SWAT model predicts small TSS loads from Subbasins 1 (6 t/year), 16 (116 t/year) and 8 (244 t/year). Subbasin 21, which is located in the Minnesota River floodplain below the MCES monitoring station, also has a very small TSS load (less than 1 t/year) even though it has a relatively large runoff volume. The spatial distributions of non-point source TSS loads are displayed in Figure 21.

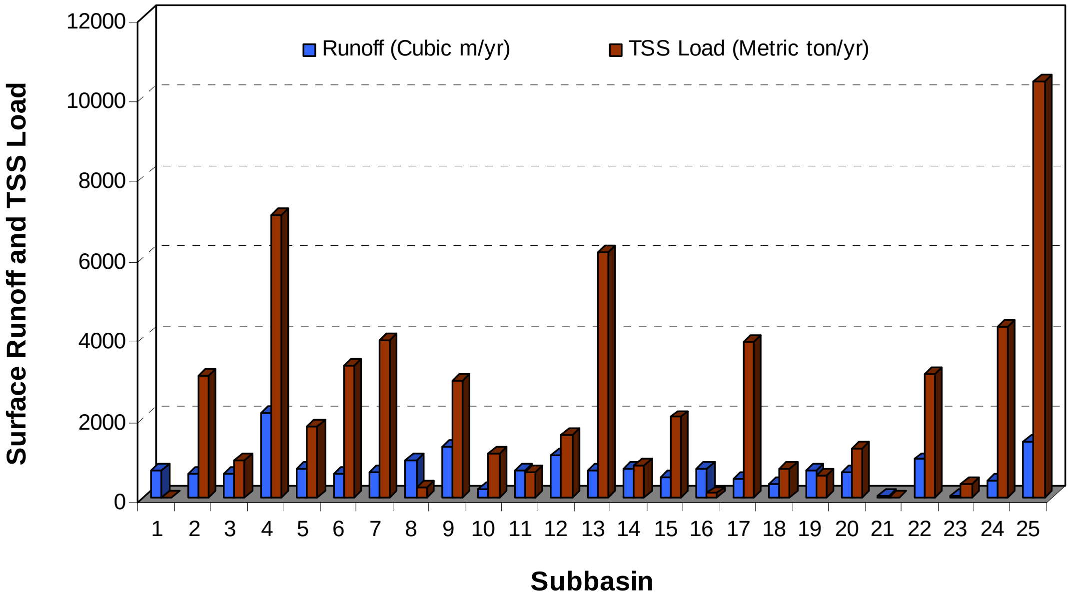

Figure 22 Simulated Total Surface Runoff and TSS loads by Subbasins

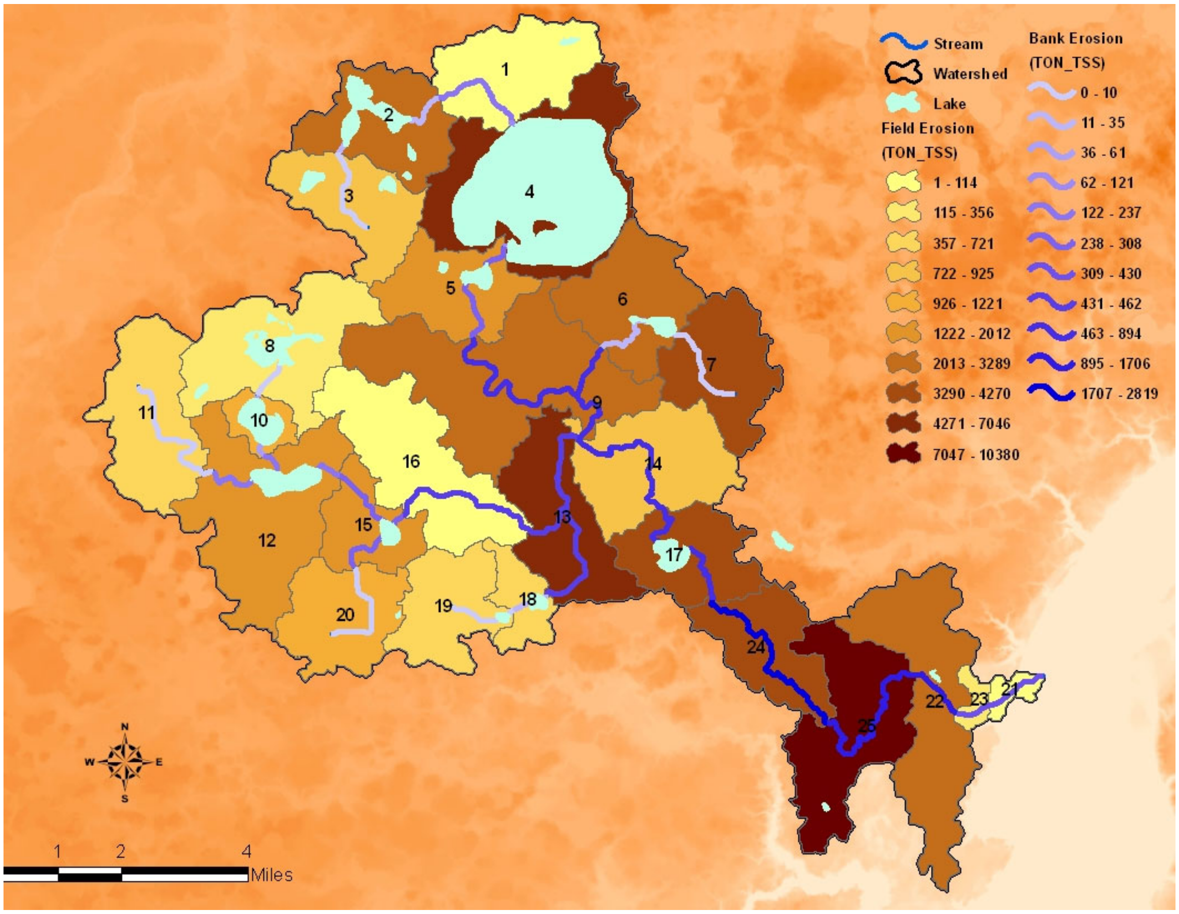

Figure 23 Spatial Distributions of Predicted Annual Non-Point Source TSS Loads in the Carver Creek Watershed

5.4 Bank Erosion TSS by Subbasins

Bank erosion is a significant source of TSS in the Carver Creek watershed. The SWAT model was calibrated to reflect that 30 percent of TSS loads were from field erosion and 70 percent were from non-field erosion based on the preliminary findings of the isotope fingerprint studies being done by the Minnesota Science Museum St. Croix Watershed Research Station. Annual average bank erosion in the channel of each subbasin was analyzed using the developed SWAT model which was run for the period of 1990 to 2006 (Figure 22). The results indicate that a large amount of bank erosion happens in Subbasins 22, 24 and 25, which contribute TSS loads ranging from 2,819 to 1,586 t/year. The three sub-basins contribute up to 54 percent of the total TSS load from bank erosion. The subbasins located in uplands (Subbasins 2, 3, 6, 7, 8, 10, 11, 18, 19 and 20) have low erosion potential with low TSS exports from bank erosion. The contribution from these subbasins only accounts for less than 2 percent of the total bank erosion. The remaining 44 percent of the TSS loads from bank erosion are from those subbasins mostly located in the middle section areas of the Carver Creek watershed. These subbasins have medium bank erosion potentials with TSS loads ranging from 894 to 121 t/year. The spatial distribution of TSS loadings from bank erosion is displayed in Figure 21.

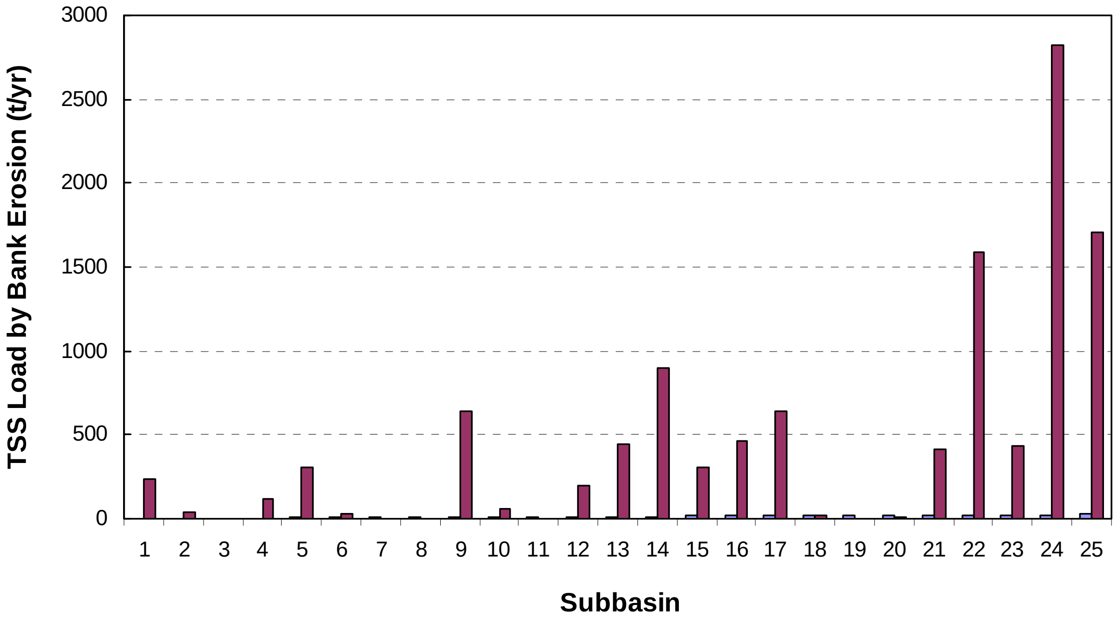

Figure 24 Simulated TSS Loads from Bank Erosion by Subbasins

5.5 Summary of Non-Point Source Loadings in the Watershed

On average, there are 60,100 t of TSS eroded each year from fields in the Carver Creek watershed, accounting for 84 percent of the total nonpoint source loads. However, watershed-wide 96 percent of the TSS load from field erosion is removed by existing buffer strips, wetlands, ponds, lakes and channels as flow is routed towards the watershed outlets. Only 2,400 t or 4 percent of the TSS load from field erosion reaches the watershed outlet and ultimately discharges to the Minnesota River. This accounts for 30 percent of the total TSS loads observed at the outlet.

There are 11,400 t of TSS contributed from bank erosion or non-field erosion each year in the Carver Creek watershed, accounting for 16 percent of the total nonpoint source TSS loads in the watershed. However, 50 percent of the TSS loads due to bank erosion are settled out in lakes and channels during routing towards the watershed outlet. 5,700 t or 50 percent of the total TSS loads from bank erosion reaches the outlet and discharges to the Minnesota River. This accounts for 70 percent of the total TSS loads observed at the outlet. Figure 23 displays the mass balance of the non-point source TSS loads in the Carver Creek watershed.

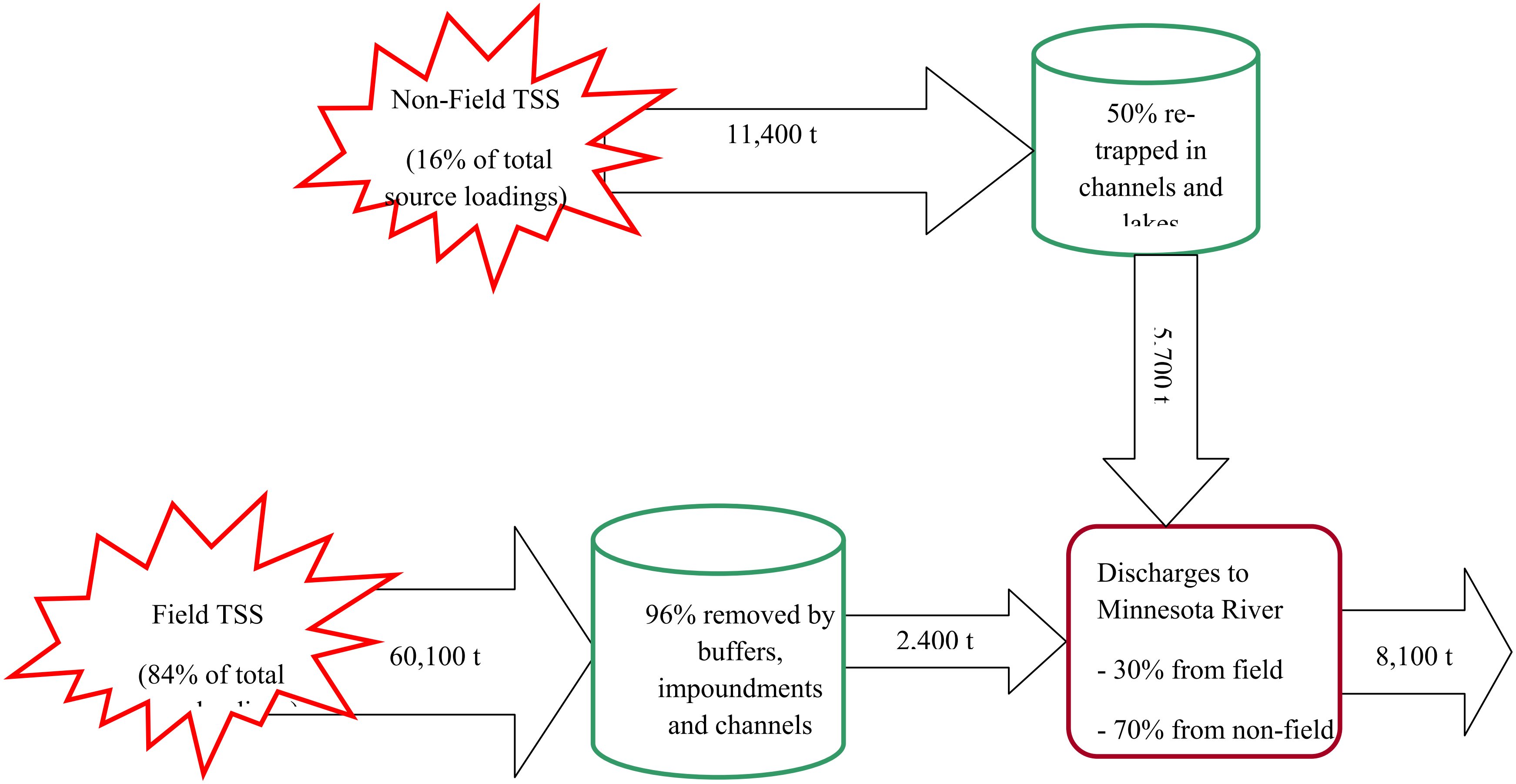

Figure 25 Mass Balance of Non-Point TSS Loads in Carver Creek Watershed

6. BMP Implementation Scenarios

6.1 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 (Figure 24). 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 storm water runoff. Filter strips are less effective in the control of soluble nutrients and pesticides in storm water runoff. They also provide wildlife habitat and benefit the environment.

Figure 26 Grass Filter Strip Along a Stream Course (Photo by BERBI)

The Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture has developed general guidelines for minimum widths for filter strips related to field slopes (US-NRCS, 1988). These guidelines (Table 12) were developed for a drainage area to filter strip ratio of 30:1, or no more than 30 acres of field draining to one acre of filter. Filter strip effectiveness is substantially dependent on soil characteristics, topographic conditions of the land, type and quality of vegetation, drainage areas, pollutant loads, filter strip widths, installation quality and maintenance. The SWAT model was used to study the relationship between TSS reductions and filter strip widths to evaluate the efficiency of filter strip implementation.

To estimate the trapped fractions of TSS loads, SWAT simulates the use of filter strips with empirical equations that are a function of the strip width. SWAT does not take into account the areas to be used for the filter strip. In addition, because SWAT does not consider the spatial relationship among the different land areas in a subbasin, it applies the filter strip directly to HRUs instead of along the receiving waters. SWAT also does not simulate infiltration and evapotranspiration occurring within strip zones. Therefore, the model cannot predict runoff reductions as the runoff passes through the filter strips. The assessment of the efficiency of filter strips for reducing TSS loads in Carver Creek watershed was based on the assumption that the filter strips would be applied to all agricultural and urban HRUs in the watershed.

Table 14 Minimum Filter Strip Widths for Maximum Field to Filter Area Ratio of 30:1 (USDA-NRCS, 1988)

Field Slope (%)	Minimum Width (ft)
<1	10
1-10	15
10-20	20
20-30	25

Figure 25 displays the simulated average reduction rates of field erosion TSS loadings in response to various filter strip widths compared to results from published studies. Simulated storm water runoff is not reduced by filter strips, which is consistent with the earlier discussion that SWAT does not simulate infiltration and evaporation occurring in the filter strips. Contributions of TSS loads from fields to streams are reduced non-linearly in proportion to the filter strip widths. Reduction rates are found to increase sharply when the filter strip width increases to 5 m, which could remove as much as 60 percent of the TSS loads from field erosion.

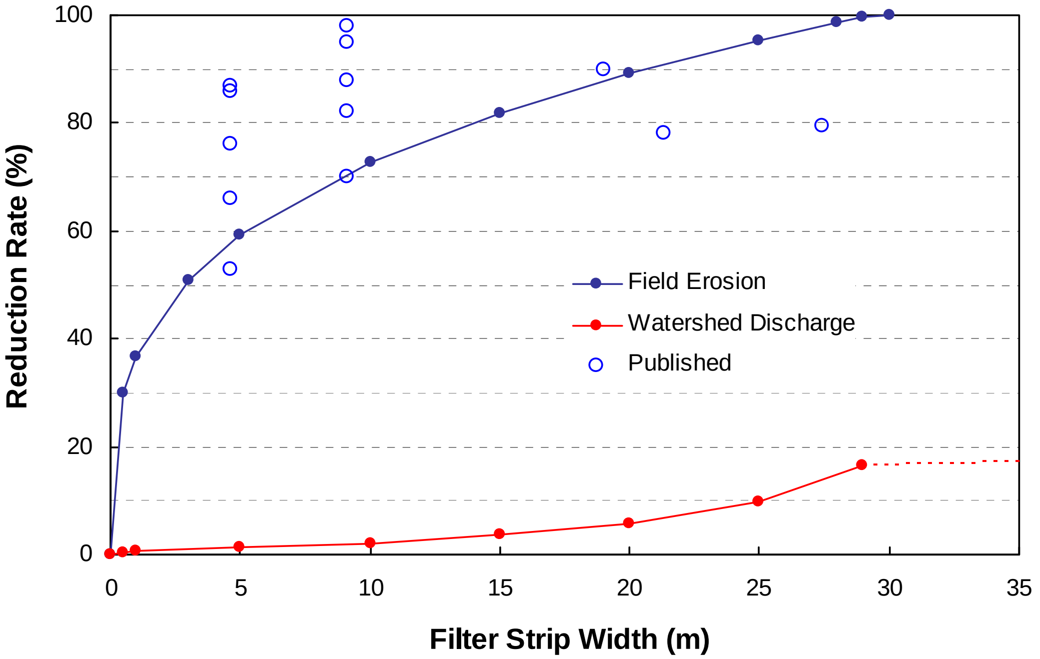

Figure 27 Simulated and Published Field Erosion TSS Reductions by Filter Strips

As filter strip widths increase, the reduction rates of TSS loads slow down. The results show that if the width of a filter strip increases to 30 m, it can remove approximately 99 percent of the TSS loads from field erosion. The filter strips are highly efficient in removing sediment particles transported from the fields to the channels. But the filter strips are not efficient in reducing flow. Generally, wider filter strips are more efficient in sediment and nutrient (such as phosphorus) control. Based on the simulated relationship between filter strips width and pollutant reduction rates (Figure 36), a minimum filter strip width of 3–5 m is suggested for the Carver Creek watershed.

Figure 35 also includes the reported effectiveness of the filter strips in removal of TSS (Young et al. 1980, Jacobs & Gilliam 1985, Peterjohn & Correll, 1985, Dillaha 1988 and 1989, Magette 1987 and 1989, Vought et al 1994 and Mander et al. 1997). The slopes of the reported study fields vary from 4 to 16 percent while the average subbasin slopes of the Carver Creek watershed range from 2 to 8 percent. Wenger (1999) reviewed over 140 relevant articles and concluded that a filter strip width as narrow as 4.6 m would be fairly effective in short-term sediment control, although wider filter strips would provide greater efficiency. For long-term sediment control, a 30 m wide filter strip is recommended by Wenger (1999) to trap sediments under most circumstances. This width may have been enlarged to account for factors such as landscape slopes, land uses, sediment sizes and vegetation used. The absolute minimum filter strip width recommended was 9 m. A similar literature review by EOR (2001) also concluded that on average a 15 m (50 ft) filter strip could reduce about 70 percent of the sediment load if the slopes were less than 5 percent. A 30 m filter strip with slopes varying from 5 to 15 percent could achieve a reduction of sediment loads up to about 80 to 100 percent. The modeled TSS reduction rates for Carver Creek watershed fall within the reduction rates found in the literature reviews.

The total reduction rates of TSS loads where there are filter strips are also shown in Figure 35. SWAT model results show that although substantial TSS loadings can be removed by the filter strips, the general reduction of TSS loads discharged from the watershed is marginal, with the maximum reduction less than 20 percent. The result is not unexpected because the TSS loads from the field erosion only contribute about 30 percent of the overall TSS loads. There are several factors contributing to the low response of total TSS load reduction where there filter strips are applied in the field. First, watershed wetlands, ponds and lakes could have a significant impact on the removal of TSS loads during transport even without field erosion controls. Second, less field erosion may result in less deposition of TSS in the lower section of the channels and more channel beds being exposed to greater flow energy, thus resulting in more bank erosion TSS outputs. The field erosion control can protect the local water bodies but is found to have limited efficiency in total load reduction at the mouth of the stream.

6.2 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
- 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).

The SWAT model was used to assess the efficiency of TSS load reduction when conservation tillage was applied in the Carver Creek watershed. For the SWAT simulation, it was assumed that conservation and contour tillage techniques were applied to corn and soybean fields over the entire Carver Creek watershed during the studied period (1990 to 2006). Comparisons of runoff volume and TSS loads with and without implementation of conservation and contour tillage were performed. The simulation was run using the built-in database of conservation and contour tillage with contour tillage settings that have lower curve numbers for row crops as shown in the SWAT user manual. The assumptions used for curve number reduction may consist of 3 unit reductions for contour farming and two units for biomass residue management (Arabi, et. al., 2007).

Figure 26 shows the simulated reductions of water volumes and TSS loads exported from fields to local tributaries and ultimately discharged from the Carver Creek watershed to the Minnesota River after conservation tillage is applied. The results indicate that both runoff volumes and TSS loads from corn and soybean fields to the local channels could be significantly reduced if conservation tillage is applied. The surface runoff and TSS loads could be reduced respectively by 30 percent and 41 percent from corn fields, and 30 percent and 40 percent from soybean fields. On average, conservation tillage could reduce 14 percent of the runoff volume and remove 38 percent of the field erosion from TSS loads.

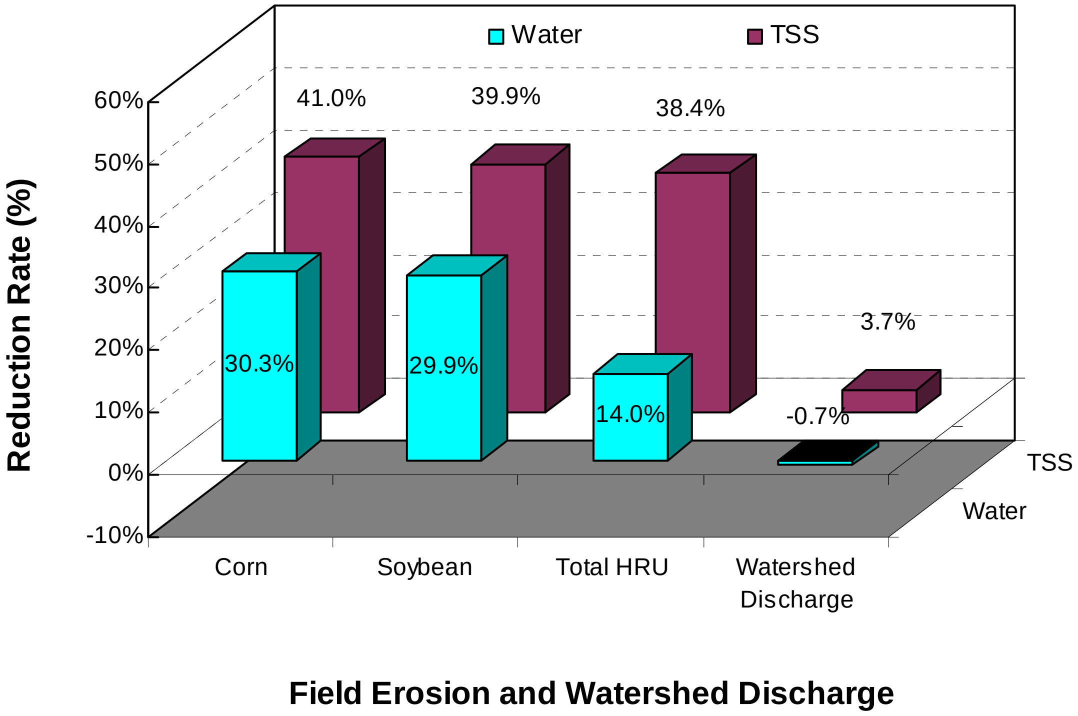

Figure 28 Simulated Flow and TSS Reductions using Conservation Tillage

However, total runoff volume and TSS loads discharged from the watershed would have a limited reduction. This is due to the following facts. First, the field erosion only contributes 30 percent of the total watershed TSS loads. Second, the conservation tillage already reduces surface runoff by increasing infiltration in crop lands, which will eventually transport to downstream channels through subsurface flows, therefore overall runoff volume reduction is limited as well. But conservation tillage will be a benefit to bank erosion control because it minimizes the peak flow during flood events by transferring surface runoff to baseflow.

6.3 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. Infiltration can be one of the most important characteristics of ponds and wetlands to control runoff volume, reduce pollutant discharges and mitigate downstream bank erosion. Impacts of wetland and pond infiltration on runoff volume and TSS loads were assessed using the developed SWAT model.

To simulate the potential benefits of infiltration, the infiltration coefficients of the ponds and wetlands that are built in the SWAT model are increased in various intervals to test the reduction in water volumes, bank erosion and total TSS loads in watershed discharges. The reduction rates of watershed flow and TSS loads in response to the various increases in infiltration coefficients are plotted in Figure 27. As shown in the figure, pond and wetland infiltration is highly effective in watershed flow and TSS control. They not only reduce field runoff and TSS loads, but also greatly reduce downstream bank erosion due to the reduction of flow speeds and volumes.

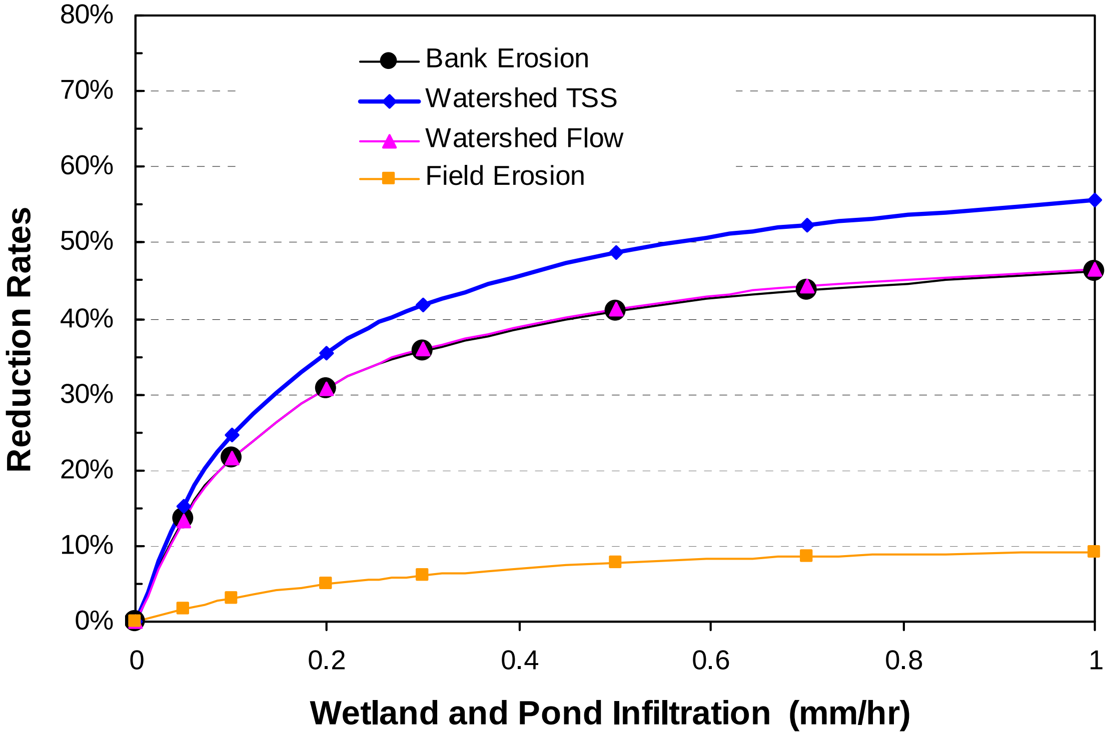

Figure 29 Simulated Reductions of Surface Runoff and TSS Loads in Response to Increases in Pond and Wetland Infiltration

Greater flow reductions and TSS load reductions are found when the infiltration rates in the ponds and wetlands increase from 0 to 0.3 mm/hr. When the infiltration rates increase to 0.3 mm/hr, the TSS from field erosion can be reduced by 6 percent, TSS from bank erosion up to 36 percent, total watershed flow up to 36 percent and total TSS loads up to 42 percent. Rate of change in flow and TSS reductions become lower when infiltration rates increase to above 0.3 mm/hr.

When pond and wetland infiltration rates increase up to 1 mm/hr, the TSS from field erosion can be reduced by 9 percent, TSS from bank erosion by 46 percent, total watershed flow by 47 percent and TSS load by 56 percent. The calibrated SWAT model successfully simulated the bank erosion in response to watershed flow reduction. Figure 28 displays the relationship between the reduction of flow volumes and bank erosion. As shown in the figure, the reduction of the bank erosion is linearly proportional to the reduction in flow volumes.

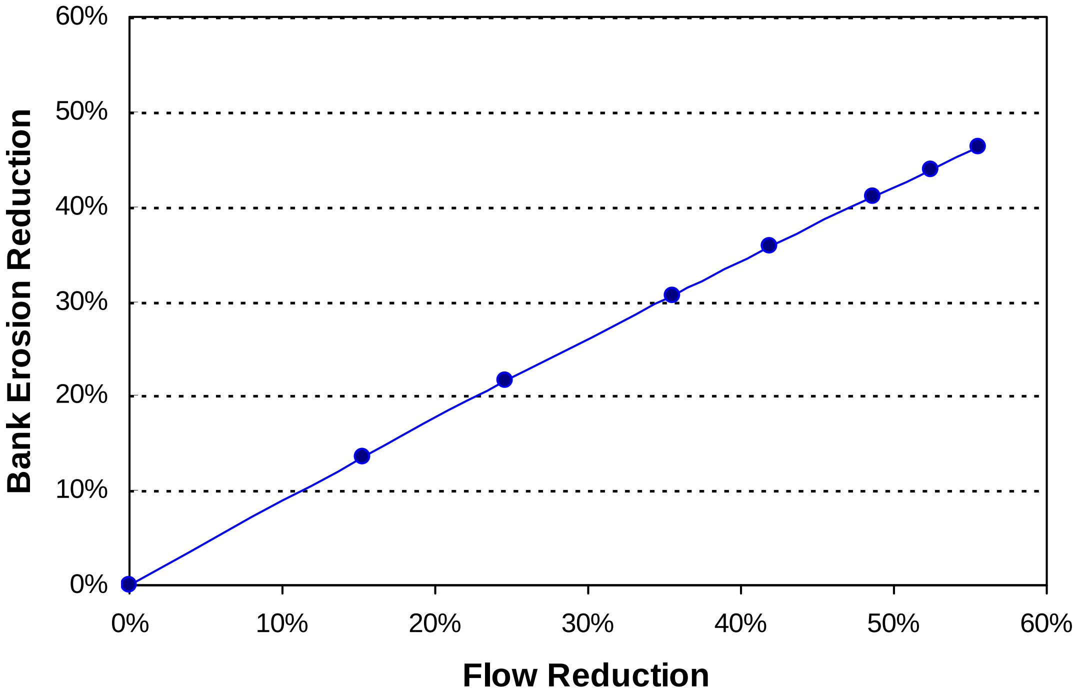

Figure 30 Simulated Bank Erosion Reductions in Response to Flows

6.4 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 Carver Creek. Similar loadings were simulated by the developed SWAT model. Significant efforts should be made to control field erosion in the watershed to reduce flow and TSS loads contributed from the landscapes to channels. Reduced flows from the field erosion could also benefit downstream bank erosion. However, field erosion control BMPs can only remove limited amounts of total TSS loads in Carver Creek due to the significant contributions of TSS from bank (non-field) erosion. The non-field erosion directly contributes 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 Carver Creek watershed in order to achieve the water quality standard for turbidity.

The SWAT model is used to simulate bank erosion control scenarios and to understand their impacts on water quality improvements if they are implemented in the watershed. Bank erosion control measures are costly due to construction and maintenance requirements. Therefore, two scenarios were studied: (1) bank erosion control BMPs are applied to the entire watershed and, (2) the BMPs are only applied to a few subbasins with high bank erosion potentials.

The bank erosion potential of a channel is dependent on its slope, soil property, vegetation coverage, sinuosity and other factors. In the Carver Creek subbasins those characteristics vary substantially, resulting in some subbasin channels being highly erodible while others are relatively less susceptible to erosion. To select sub-basins for the second scenario, those subbasins with bank erosion TSS load contributions larger than 4 percent are chosen. There are only eight subbasins among 23 that meet the criteria. Based on the model results, these eight subbasins contribute 87 percent of the TSS loads from bank erosion in the watershed. The selected subbasins were 9, 13, 14, 16, 17, 22, 24 and 25.

Figure 29 represents the simulated results of two bank erosion control scenarios that are applied to the entire Carver Creek watershed (E) and to the selected subbasins (S). The results are based on the existing bank erosion condition where the SWAT bank erosion erodibility parameter was 0.32 and the simulated bank erosion accounts for 71 percent of the total TSS loads in the watershed. As expected, the application of bank erosion control BMPs to the entire watershed could remove more TSS loads from bank erosion than the application to the selected subbasins. For example, by reducing the bank erodibility parameter to 0, the model could remove 100 percent of the TSS loads due to bank erosion if BMPs used to control bank erosion are applied to the entire watershed. However, the scenario could only remove up to 88 percent if the BMPs are partially applied to the selected subbasins (9, 13, 14, 16, 17, 22, 24 and 25).

In terms of total watershed TSS reduction, however, partially applying BMPS to control bank erosion could achieve similar TSS reduction rates due to the fact that deposition of TSS from upstream field and bank erosion is being settled out in Miller Lake, ponds, and channels. Scenario Two provides an equivalent reduction in TSS with less investment in the erosion control practices (Figure 29). This scenario only applies BMPS to control bank erosion to seven of the 23 subbasins, which have relatively high bank erosion potentials. Applying BMPS to control bank erosion to the selected subbasins can greatly reduce the BMP implementation costs in comparison to Scenario One that applies BMPs to control bank erosion to the entire watershed. Therefore, it appears that Scenario Two is more efficient and cost effective. However, it should be noted that Miller Lake is listed on the impaired waters list and that the use of lakes as settling basins is not being proposed or encouraged in this study.

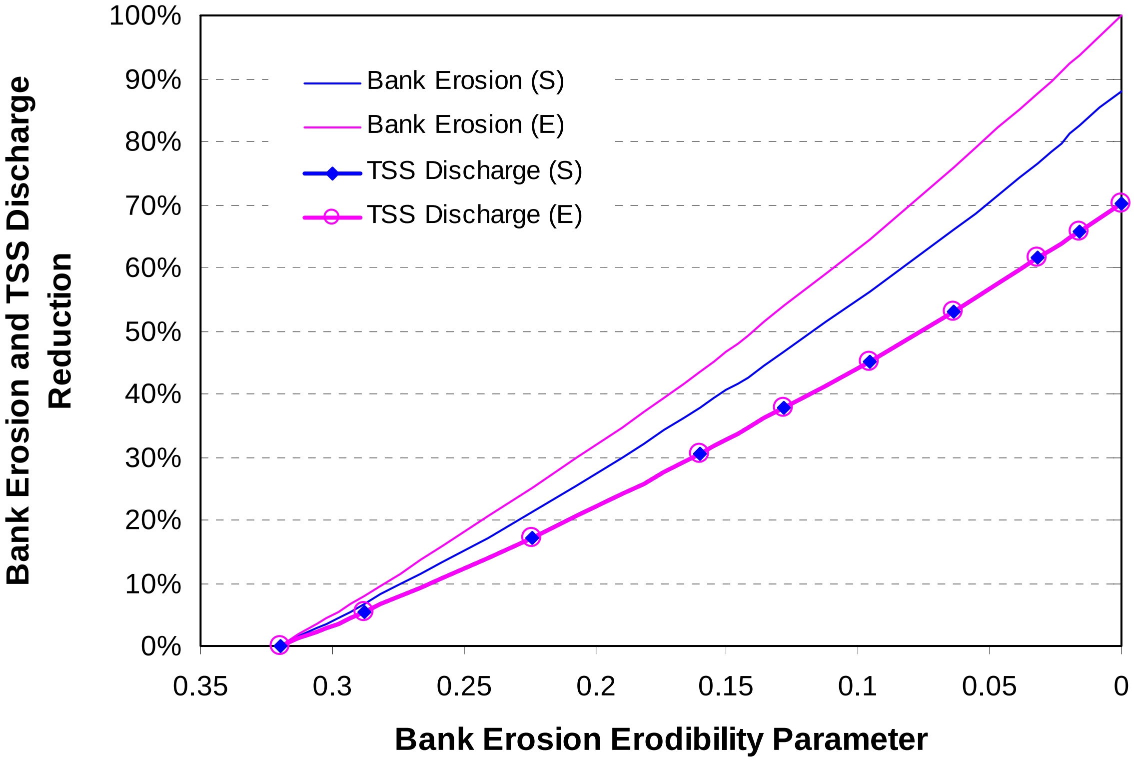

Figure 31 Simulated Bank Erosion and Watershed TSS Reduction in Response to Various Scenarios for Bank Erosion Control

Figure 30 shows comparisons of total watershed TSS reductions by BMPs used to control field and bank erosion. The figure shows that the impact of BMPs used to control field erosion on the TSS reduction at the MCES monitoring station is limited. The TSS reduction rate from BMPs used to control field erosion is significantly lower than the reduction rate from BMPs used to control bank erosion. This is because most of the TSS from field erosion is being removed by settling in the local water bodies and channels and therefore less TSS is reaching the watershed outlet. The benefits of BMPs used to control field erosion on the reduction of TSS at the outlet are marginal. However, BMPS used to control field erosion are critical for the protection of local water bodies and improvements of their water quality.

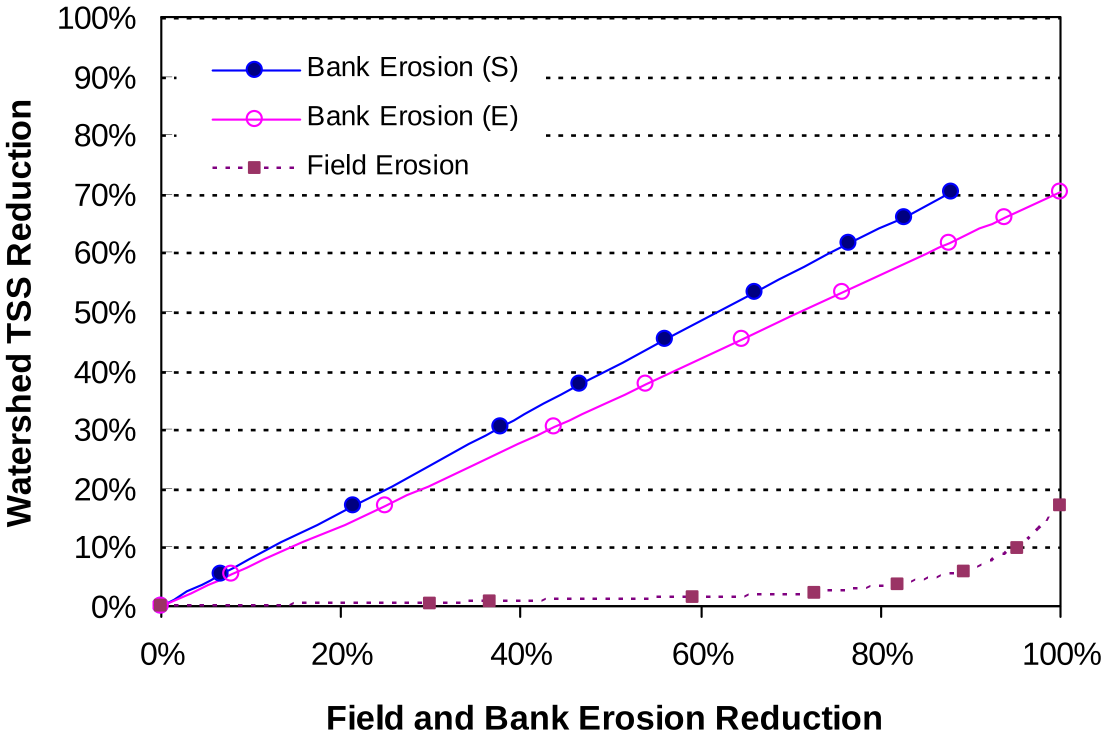

Figure 32 Watershed TSS Discharges in Response to Bank Erosion Reduction

6.5 Combined BMPs

TMDL allocations and turbidity reduction needs for the Carver Creek watershed indicate that significant reductions in TSS loads are needed from both field and non-field erosion sources in order to meet the water quality standard. Application of a single BMP to address either field or non-field erosion alone is unable to reduce enough TSS in the watershed to reach the goal. The next step was to use the calibrated SWAT model to run scenarios that combine various BMPs.

The four BMPs studied in the previous sections were combined. The application is based on the obtained optimum conditions of the individual BMPs studied in terms of TSS reduction efficiency. The BMPs and their optimum conditions selected are:

- Five meter filter strips applied to agriculture and urban HRUs
- Conservation tillage applied to corn and soybean fields
- Pond/wetland infiltration with infiltration rate of 0.3 mm/hr
- Bank erosion control with various TSS removal potentials

Figure 31 plots the simulated results of the combined BMPs used for TSS load reduction. The figure presents the simulated existing conditions of Carver Creek with average TSS loads of 8,291.0 t/yr or 22.7 t/day, the allocated average TMDL of 3,311.5 t/yr or 9.07 t/day and simulated watershed TSS loads in response to various BMP application scenarios. As shown in the figure, the watershed TSS loads could be reduced from the current 8,291.0 t/yr to 4,449.0 t/yr or 46 percent if only BMPs used to control field erosion are applied in Carver Creek watershed. The BMPs used to control field erosion include conservation tillage, 5 m filter strips, and ponds and wetlands with infiltration rates increased to 0.3 mm/hr.

The simulated results indicate that application of field erosion control alone is not enough to improve the water quality in Carver Creek in order to meet the allocated TSS TMDL and to achieve the reduction goal (average 60.1 percent of total watershed TSS). Additional field erosion control BMPs, such as increases in filter strip width and pond/wetland infiltration abilities, may be an option to increase TSS removal rates. However, it may not be an optimum option because field erosion only contributes 30 percent of the TSS loads in the watershed while 70 percent of the TSS loads are from bank erosion. In addition, increases in BMPs such as applying filter strips wider than 5 m and pond/wetland infiltration larger than 0.3 mm/hr may be too costly for the benefit received. Therefore, increases in investments to control field erosion may still not be able to achieve the TSS removal goal without significantly increased implementation costs. Therefore, additional efforts at implementing additional BMPs to control field erosion beyond the recommended optimum conditions are not recommended for the Carver Creek watershed.

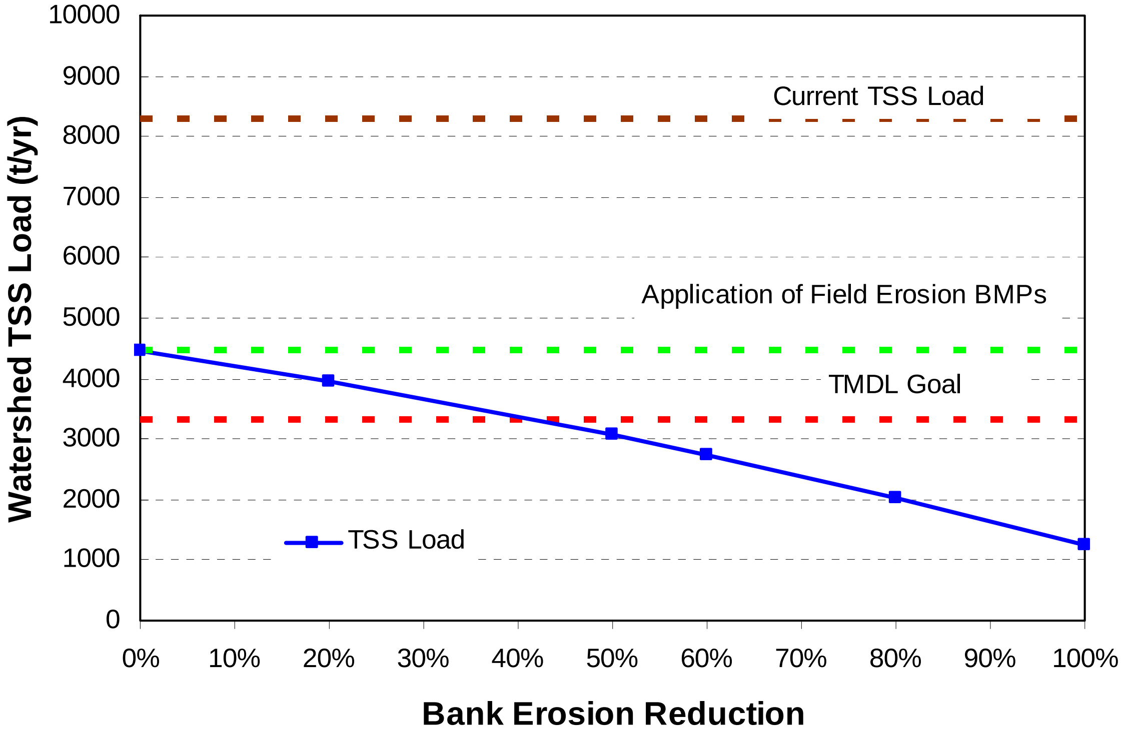

Figure 33 Simulated Watershed TSS Reductions in Response to Various Combinations of Field and Bank Erosion Control BMPs

In order to achieve the TMDL goal of 3,311.5 t/yr (9.07 t/day), bank erosion control measures such as BMPS used for bank stabilization are recommended in combination with BMPs used to control field erosion. Because application of bank erosion control measures to the selected subbasins can achieve similar TSS removal efficiencies at a reduced cost, partial application of bank erosion control to the selected subbasins in addition to the recommended field erosion BMPs was studied. It was found that when BMPs used to control bank erosion are applied in addition to BMPs used to control field erosion, water quality continues to improve (Figure 41).

Additional TSS loads in the watershed could be removed by BMPs used to control bank erosion. The TSS load removal rate in the watershed is linearly proportional to the TSS removal rate from bank erosion. According to the results from the SWAT modeling, to achieve the TMDL goal of 3,311.5 t/yr (9.07 t/day) or reduce 60 percent of current TSS loads at least 50 percent of the existing bank erosion should be controlled. If bank erosion is completely controlled, the TSS loads could be reduced to as low as 1,253.5 t/yr. It should be noted, however, that the studies are based on an average load. To achieve daily load compliance, further studies should be conducted.

7. Conclusions and recommendations

7.1 Model Development and Calibration

SWAT is a dynamic model developed to predict the impact of land management practices on flow, sediment, and agricultural chemical yields in watersheds with varying soils, land use, and management conditions over long periods of time. Data sets for topography, land use, soils, weather and agriculture management have been developed to construct a watershed model for Carver Creek. The model segmented the watershed into 25 subbasins and 367 HRUs.

The model was calibrated with 9 years of monitoring data (1990 to 1998) and validated with data from 1999 to 2006. The calibration parameters included flow, TSS and TP. Statistical tests of the model performance and comparisons of the model results with reported similar studies indicate that the developed model can satisfactorily predict spatial and temporal variations of flow and target pollutant yields in the watershed. The tests also show that the model can satisfactorily predict flow and transport of target pollutants in the watershed channels and loads.

When calibrating TSS, bank erosion was also calibrated using the field erosion study, impoundment sedimentation based on stream TSS concentrations, isotope fingerprint results and independent bank erosion assessment study in addition to using observed TSS at the MCES monitoring station. The results show that the calibrated SWAT model performs well at predicting bank erosion in Carver Creek. Simulated bank erosion potentials consistently follow the spatial variations of analyzed results in subbasins: lower bank erosion risks in those upland areas where the fields are relatively flat and higher erosion risks in downstream areas where the subbasins have relatively greater slopes. The simulated bank erosion risks using the calibrated SWAT model are highly correlated (0.86) with results of an independent study.

7.2 Non-Point Source Analysis in the Watershed

7.2.1 Surface Runoff and Field Erosion

The developed SWAT model was used to identify the areas with relatively high surface runoff and TSS load contributions to Carver Creek. To minimize the TSS loads, the sources and areas identified with high TSS export should be looked at first for BMP implementation.

It was found that surface runoff from various land uses ranged from 0.30 mm to 220 mm. The urban land use areas have significantly higher surface runoff, followed by soybean and corn fields. Forest has the lowest surface runoff (0.3 mm). Significantly high TSS loads are found from the soybean and corn fields (4.76 t/ha and 4.69 t/ha respectively). While urban land uses have the highest runoff, the TSS exports from the urban land use are relatively low (0.16 t/ha).

More than 99.5 percent of TSS loads from field erosion are from the agricultural activities, in which soybean production accounts for 60 percent, corn accounts for 38 percent and alfalfa accounts for 2 percent. The high TSS loadings from these land uses are due to the relatively large land areas and TSS export rates. The urban, forest, pasture and other land uses contribute less than 0.5 percent of the total TSS from field erosion.

7.2.2 Spatial Distributions of Flow and TSS Loads in the Watershed

Spatial analysis of flow and pollutant yields determined the areas with relatively high flow and TSS export rates and areas where BMP implementation for pollutant load reduction should be a priority. It was found that surface runoff from the twenty five subbasins in Carver Creek ranged from 60.7 mm/ha (Subbasin 23) to 123.8 mm/ha (Subbasin 25).

The unit TSS loads from the subbasins vary significantly. The lowest TSS loads are found mostly from the upstream subbasins that export less than 1 t/ha of TSS. They include Subbasins 1, 8, 11, 14, 16 and 19. Subbasin 1 has the lowest TSS unit load (0.007 t/ha). The highest TSS loads are found mostly in the downstream subbasins, including Subbasins 7, 10, 13, 17, 23 and 24. The TSS export rates from these subbasins are larger than 5 t/ha. Subbasin 25 has the highest TSS load (9.3 t/ha).

The highest total TSS loads are found in Subbasins 4, 13 and 25. The TSS loads from these subbasins are 10,380, 7,046 and 6,121 t/year, respectively. The smallest TSS loads are found in Subbasins 1, 8 and 16, ranging from 6, 114 and 244 t/year respectively. Subbasin 21, which is located in the Minnesota River floodplain below the MCES monitoring station, also has a very small TSS load (0.6 t/year) even though it has a relatively large runoff volume. Subbasin slopes, areas and land use conditions are the primary factors dictating the amount of TSS loads exporting from the subbasins.

7.2.3 Bank Erosion by Subbasins

Bank erosion is a significant source of TSS in the Carver Creek watershed. Analysis using the calibrated SWAT model indicates that Subbasins 22, 24 and 25 have high bank erosion risks that contribute TSS loads ranging from 2,819 to 1,586 t/year. These three subbasins contribute up to 54 percent of the total TSS bank erosion load. The upland subbasins have low erosion potentials, contributing less than 2 percent of the total TSS bank erosion load. They include Subbasins 2, 3, 6, 7, 8, 10, 11, 18, 19 and 20. The remaining 44 percent of TSS bank erosion load is from those subbasins mostly located in middle sections of the watershed. They have medium bank erosion potentials with TSS loads ranging from 121 to 894 t/year.

7.2.4 TSS Load Balance in the Watershed

There are over 60,000 t of TSS eroded from fields each year in the Carver Creek watershed, accounting for 84 percent of the total non-point source loads. However, 96 percent of the TSS loads from field erosion are removed by existing buffer strips, wetlands, ponds, lakes and channels during their routing towards the watershed outlet. Only 2,400 t or 4 percent of the TSS loads from field erosion reach the watershed outlet defined at the MCES monitoring station. This accounts for 30 percent of the total TSS loads observed at the outlet.

There are 11,400 t of TSS contributed each year from bank erosion or non-field erosion in the Carver Creek watershed, accounting for 16 percent of the total non-point source TSS loads in the watershed. However, 50 percent of the TSS loads from bank erosion are settled in lakes and channels during the routing towards the watershed outlets. 5,700 t or 50 percent of the total TSS loads from bank erosion reaches the outlet, which account for 70 percent of the total TSS loads observed at the outlet.

7.3 BMP Implementation Scenarios

7.3.1 Filter Strip Application

The SWAT model was used to study the relationship between TSS reductions and filter strip widths to evaluate the efficiency of filter strip implementation. The filter strips were assumed to apply to all agricultural and urban HRUs in the Carver Creek watershed. Simulated storm water runoff is not reduced by filter strips. TSS loads from fields to streams are reduced non-linearly in proportion to the filter strip widths. Reduction rates are found to increase sharply when the filter strip width increases to 5 m, which could remove as much as 60 percent of the TSS loads from field erosion. If the filter strip width increased to 30 m, the filter strip can remove approximately 99 percent of the TSS loads from field erosion. A minimum filter strip width of 3-5 meters is suggested for the Carver Creek watershed.

Filter strips are highly efficient for controlling field erosion and protecting the local water bodies but are also limited in their ability to reduce total TSS load due to the fact that bank erosion contributes substantial TSS loads directly to the channels.

7.3.2 Conservation Tillage

Efficiency of TSS load reduction using conservation tillage was assessed using SWAT. The scenario includes implementation of conservation and contour tillage to corn and soybean fields over the entire Carver Creek watershed. The results indicate that both runoff volumes and TSS loads from the corn and soybean fields could be significantly reduced by conservation tillage practices. The surface runoff and TSS loads could be reduced respectively by 30 percent and 41 percent from corn fields and 30 percent and 40 percent from soybean fields. On average, conservation tillage could reduce 14 percent of the flow and 38 percent of the TSS loads from field erosion to the water bodies and channels.

7.3.3 Wetland and Pond Infiltration

Based on the SWAT model simulations, pond and wetland infiltration is highly effective in reducing watershed flow and consequently reducing TSS loads as well as in reducing downstream bank erosion due to their ability to reduce flow speeds and water volumes. Greater flow and TSS load reductions are found when the infiltration rates in the ponds and wetlands increase from 0 to 0.3 mm/hr. At 0.3 mm/hr, the TSS from field erosion is reduced by up to 6 percent, TSS from bank erosion up to 36 percent, total watershed flow volumes up to 36 percent and total TSS loads up to 42 percent. The rate of change in flow and TSS load reductions decrease when infiltration rates increase to above 0.3 mm/hr. When pond/wetland infiltration rates increase up to 1 mm/hr, TSS from field erosion can be reduced by 9 percent, TSS from bank erosion by 46 percent, total watershed flow by 47 percent and TSS load by 56 percent.

7.3.4 TSS from Bank Erosion Control

Two scenarios for bank erosion control were studied using the SWAT model. BMPs for controlling bank erosion were applied (1) to the entire watershed and (2) to a few selected subbasins with high bank erosion potentials. Results indicate that Scenario (1) could remove more TSS loads from bank erosion than Scenario (2). For example, by reducing the bank erodibility parameter to 0, the TSS loads from bank erosion could remove 100 percent of the erosion, if BMPS to control bank erosion are applied to the entire watershed, but only remove up to 88 percent if the BMPs are partially applied to the selected subbasins (9, 13, 14, 16, 17, 22, 24 and 25).

In terms of total watershed TSS reduction, however, partial application of bank erosion control BMPs to the selected subbasins could achieve similar TSS reduction rates as Scenario (1). Partial application of the BMPs to control bank erosion could be used to improve water quality at reduced implementation costs. However, it should be noted that Miller Lake is listed on the impaired waters list and that the use of lakes as settling basins is not being proposed or encouraged in this study.

7.3.5 Combined BMPs for TMDL Compliance

The SWAT modeling showed that more than one BMP is needed to reduce enough TSS load in the watershed to meet the water quality standard. A combination of field erosion and non-field erosion control BMPs were studied using the SWAT model. The scenarios were based on the optimum conditions of the studied individual BMPs in terms of TSS reduction efficiency and cost considerations. They include:

1) Five meter filter strips applied to agriculture and urban HRUs
2) Conservation tillage applied to corn and soybean fields
3) Pond/wetland infiltrations with infiltration rates of 0.3 mm/hr
4) Bank erosion control with various TSS removal potentials

The results indicate that a combination of the BMPs to control field erosion at their optimum conditions could reduce the watershed TSS loads from the current 8,291.0 t/yr to 4,449.0 t/yr or 46 percent. In order to meet the allocated TSS limit of 3,311.5 t/yr (60 percent reduction) needed to met the water quality standard for this TMDL , bank erosion control measures such as bank stabilization BMPs are recommended in combination with field erosion BMPs. It is found that when BMPS used to control bank erosion are partially applied to the selected Subbasins 9, 13, 14, 16, 17, 22, 24 and 25 in addition to field erosion BMPs as defined above, the watershed TSS load could continue to be removed in linear proportion to the bank erosion TSS removal rates. The TMDL can be met if TSS loads from bank erosion remove at least 50 percent of the existing bank erosion. If bank erosion is completely controlled, the TSS loads in Carver Creek could be reduced to as low as 1,253.5 t/yr.

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